A GENERALIZED SOLUTION FOR TIME-DEPENDENT RESPONSE AND STRENGTH OF NONCOMPOSITE AND COMPOSITE PRESTRESSED CONCRETE BEAMS

APPROVED BY SUPERVISORY COMMITTEE:

[illegible]

Richard W. Furlong

John E. Breen

C. Philip Johnson

[illegible]

A GENERALIZED SOLUTION FOR TIME-DEPENDENT RESPONSE AND STRENGTH OF NONCOMPOSITE AND COMPOSITE PRESTRESSED CONCRETE BEAMS

by

CHAICHAN SUTTIKAN, B. Eng., M.S.

DISSERTATION

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS AT AUSTIN

August, 1978

ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to Dr. Ned H. Burns, who was the chairman of the supervisory committee, for his patience, constructive criticism, and continuous guidance throughout this entire study. It has been a most rewarding experience to work with Dr. Burns in developing and reporting this research. Special appreciation is also expressed to Dr. John E. Breen, Dr. Richard W. Furlong, Dr. David W. Fowler, and Dr. C. Philip Johnson for their assistance while serving on the committee.

The encouragement, understanding, and support of my parents are gratefully acknowledged and deeply appreciated.

Chaichan Suttikan

The University of Texas at Austin
August, 1978

A GENERALIZED SOLUTION FOR TIME-DEPENDENT RESPONSE AND STRENGTH OF NONCOMPOSITE AND COMPOSITE PRESTRESSED CONCRETE BEAMS

Publication No.______

Chaichan Suttikan, Ph.D.
The University of Texas at Austin, 1978

Supervisong Professor: Ned H. Burns

A computer program is developed for the analysis of initial and time-dependent responses and strength in simple bending of partially or fully prestressed concrete members. The program is capable of analyzing members of any cross-sectional shape having one axis of symmetry, noncomposite or composite, subjected to various sequences of loading and construction. It accounts for the effects of nonlinearity of stress-strain responses of materials, variations with time of strength, creep, and shrinkage of concrete, and relaxation of bonded prestressing steel in different parts of cross-sections. The nonlinearity of rotational and translational supports can also be accounted for in the analysis.

A step-by-step method divides the time interval of interest into several smaller time increments in which the

responses are determined as if they are independent of time as a part of the time-dependent response analysis. An iterative procedure where structures are modeled using a discrete element method is used to analyze instantaneous responses.

The changes in strength and shrinkage of concrete are considered to be functions of time only. Creep of concrete is considered proportional to applied strains and is a function of time and age of concrete when the strains are applied. Relaxation of prestressing steel is a function of time and stress level. Both the rate of creep method and the superposition method are used in predicting creep strains of concrete under variable stresses. A method equivalent to the rate of creep method is used in estimating relaxation stresses of prestressing steel under variable stresses.

The program is capable of analyzing instantaneous load-deflection response up to failure of a prestressed concrete beam in addition to time-dependent response analysis. The beam may be pre-tensioned or post-tensioned providing that the prestressing tendons are perfectly bonded to the surrounding materials. The program may be used equally well in analyzing beams of other materials.

Five example problems are presented to demonstrate the validity and the application of the program. The solutions are compared with field and laboratory measurements and previous analytical results, if available.

TABLE OF CONTENTS

		Page
CHAPTER I.	INTRODUCTION	1
1.1	Review of Available Analytical Procedures	3
1.2	Objectives and Scope	9
1.3	Outline of the Following Chapters	12
CHAPTER II.	MATERIAL PROPERTIES	13
2.1	Strain Components of Concrete	13
2.2	Instantaneous Stress-Strain Relationship of Concrete	14
2.2.1	Compressive Stress-Strain Relationship	14
2.2.2	Tensile Stress-Strain Relationship	28
2.2.3	Age-Strength Relationship	33
2.3	Time-Dependent Properties of Concrete	37
2.3.1	Creep of Concrete under Constant Sustained Stress	37
2.3.2	Creep of Concrete under Variable Stress	58
2.3.3	Shrinkage of Concrete	65
2.4	Stress-Strain Relationship of Steel	76
2.4.1	Instantaneous Stress-Strain Relationship of Steel	77
2.4.2	Relaxation of Steel under Constant Strain	77
2.4.3	Relaxation of Steel under Variable Strain	83

Page

CHAPTER III. DERIVATION OF ANALYSIS.................... 84

3.1 Assumptions and Limitations................ 84

3.2 Discrete Element Model..................... 85

3.3 Tangent Stiffness Method................... 87

3.4 Instantaneous Response Analysis............ 90

3.5 Prestressing Forces........................ 94

3.6 Convergence of Solution.................... 100

3.7 Time-Dependent Response Analysis........... 101

3.8 Composite Beam Action...................... 108

3.9 Program PBEAM.............................. 110

CHAPTER IV. EXAMPLE PROBLEMS.......................... 113

4.1 Example Problem 1 - Instantaneous Response of a Continuous Pre-tensioned Beam with Draped Tendons.................. 114

4.2 Example Problem 2 - Instantaneous Response of a Simply Supported Composite Pre-tensioned Beam with Draped Tendons.............................. 125

4.3 Example Problem 3 - Time-Dependent Responses of Simply Supported Pre-Tensioned Beams...................... 131

4.4 Example Problem 4 - Failure Load Responses of Grouted Post-Tensioned Concrete Beams after 12 Years of Sustained Loads............................... 142

4.5 Example Problem 5 - Time-Dependent and Failure Load Responses of a Two-Span Composite Beam.................. 168

4.6 Summary of the Comparisons of Analytical Results with Test Results............ 184

	Page
CHAPTER V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS..	191
5.1 Summary..................................	191
5.2 Conclusions..............................	193
5.3 Recommendations for Further Research......	199
REFERENCES....................................	200
APPENDICES....................................	210
Appendix A. Input and Output Details..........	210
Appendix B. Data Input Guide..................	223
Appendix C. Listing of Program PBEAM..........	261
Appendix D. Sample Input......................	304
Appendix E. Sample Output.....................	311
Appendix F. Branson's Method for Calculating Time-Dependent Responses of Prestressed Beams..................................	377

LIST OF TABLES

TABLE		Page
1.1	Summary of the Capabilities of Some of the Available Methods for Estimating Time-Dependent Responses of Prestressed Concrete Beams	11
2.1	Coefficients for Estimating Creep and Shrinkage by the C.E.B.	54
3.1	Friction Coefficients for Post-Tensioned Tendons	97
4.1	Time Variations of Change in Camber at Midspan for BEAM I Series, Camber Specimens, at Some Calculated Points	138
4.2	Time Variations of Change in Midspan Deflection for BEAM I Series, Deflection Specimens, at Some Calculated Points	141
4.3	Instantaneous Midspan Deflections Due to Prestressing Force and Applied Loads	154
4.4	Time Variations of Change in Camber at Midspan for Beam in Example Problem 4, Unloaded Beam, at Some Calculated Points	156
4.5	Time Variations of Change in Midspan Deflection for Beams in Example Problem 4, Loaded Beams, at Some Calculated Points	160
4.6	Time Variations of Change in Interior Support Reaction after Removal of Deck Slab Formwork of Girder 3/4 at Some Calculated Points	178
4.7	Time Variations of Change in Midspan Deflection after Removal of Deck Slab Formwork of Girder 3/4 at Some Calculated Points	181

TABLE | | Page

4.8 Comparison of Analytical and Experimental Ultimate Applied Loads for Beams in the Example Problems.............................. 186

4.9 Summary of the Time-Dependent Response Analysis of the Example Problems............. 188

LIST OF FIGURES

FIGURE Page

2.1 Soliman-Yu Stress-Strain Diagram for Confined Concrete.......................... 20

2.2 Kent-Park Stress-Strain Diagram for Confined and Unconfined Concrete............ 20

2.3 Comparison of the Proposed Stress-Strain Relationship, the Hognestad Stress-Strain Relationship, and the Test Data for Unconfined Concrete from Flexural Test, Ref. 42.............................. 29

2.4 Modulus of Rupture for Normal Weight Concrete as Function of Cylinder Strength by Various Investigators.................. 32

2.5 Concrete Stress-Strain Relationship Used in This Study............................. 34

2.6 Concrete Stress-Strain Curves at Different Ages, Using the A.C.I. Committee 209 Recommendation for Type I Cement, Moist Cured Concrete............................. 38

2.7 The P.C.I.'s Creep Prediction Curves........ 49

2.8 The C.E.B.'s Creep Prediction Curves........ 55

2.9 The P.C.I.'s Shrinkage Prediction Curves.... 72

2.10 The C.E.B.'s Shrinkage Prediction Curves.... 74

2.11 Typical Reinforcing Steel Stress-Strain Curve.................................... 78

2.12 Typical Prestressing Steel Stress-Strain Curves.................................... 79

3.1 Discrete Element Representation of a Prestressed Concrete Member................. 86

3.2 Tangent Stiffness Method.................... 89

3.3 Tangent Stiffness Iteration Procedure for One Load Level............................ 91

FIGURE

FIGURE		Page
3.4	Strain and Stress Distributions in a Discrete Element	93
3.5	Prestressing Force in a Post-Tensioned Tendon Resulting from Sequences of Jacking Forces P_1 and P_2 and Release Forces P_3 and P_4	98
3.6	Linear and Parabolic Segments That Can Be Generated by the Program	99
3.7	Flow Diagram for Crack Freezing Iterative Cycles to Ensure Convergence of the Solution	102
3.8	Sequence of Construction of a Two-Span Composite Beam	109
3.9	Flow Diagram for the Program PBEAM	111
4.1	Details of Loading Arrangement, Tendon Profile, and Cross-Section of Beam BW.10.072	115
4.2	Modeled Boundary Conditions, Loading Arrangement, and Cross-Section for Beam BW.10.072	117
4.3	Instantaneous Stress-Strain Relationship in Tension of Prestressing Wires for Beam BW.10.072	119
4.4	Comparison of the Measured Load-Deflection Response and the Analytical Results of Beam BW.10.072	120
4.5	Effects of Number of Elements on the Predicted Load-Deflection Response for Beam BW.10.072	122
4.6	Relationship between Number of Fibers in the Member and Time Consumed (TM Time) per Iteration	124
4.7	The 8 DT 12+2 Composite Section from the Report by Lo	126
4.8	Instantaneous Stress-Strain Relationship of Prestressing Strands for the 8 DT 12+2 Composite Section	128

FIGURE

Page

4.9 Comparison of Load-Deflection Responses of the 8 DT 12+2 Composite Section from the Program PBEAM, Lo's Analysis, and Hand Calculation at Low Load Level......... 129

4.10 Comparison of Load-Deflection Responses of the 8 DT 12+2 Composite Section from the Program PBEAM, Lo's Analysis, and Hand Calculation.......................... 130

4.11 Effects of Number of Elements on the Predicted Load-Deflection Response for the 8 DT 12+2 Composite Section............ 132

4.12 BEAM I from the Report by Zundelevich, et al.................................... 134

4.13 Comparison of Time Variations of Midspan Deflection as Predicted by Various Methods with Experimental Data for Beams in Example Problem 3................ 135

4.14 Comparison of Time Variations of Change in Camber at Midspan after Prestressing of Camber Specimen, Example Problem 3, as Predicted by Various Methods with Experimental Data......................... 137

4.15 Comparison of Time Variations of Change in Midspan Deflection after Loading of Deflection Specimen, Example Problem 3, as Predicted by Various Methods with Experimental Data......................... 140

4.16 Time Consumed per Time Increment for BEAM I Using the Rate of Creep Method and the Superposition Method............... 143

4.17 Prestressing Bar Layout and Cross-Section for Beams in Example Problem 4............. 145

4.18 Loading Arrangement, Boundary Conditions, and Modeled Cross-Section for Beams in Example Problem 4........................ 146

4.19 Instantaneous Stress-Strain Relationship in Tension of Stressteel Bars for Beams in Example Problem 4...................... 148

FIGURE Page

4.20 Age-Strength Relationships of Concrete for Beams in Example Problem 4............. 149

4.21 Time-Variations of Modulus of Elasticity of Concrete for Beams in Example Problem 4. The Modulus of Elasticity Is Based on the Axial Strain Induced by Raising the Compressive Stress from 350 psi. to 1000 psi.............................. 150

4.22 Comparison of Time Variations of Mid-span Deflection of Beams in Example Problem 4 from Various Methods and Experiment................................ 153

4.23 Comparison of Time Variations of Change in Midspan Camber after Prestressing of Beam with No Sustained Load Predicted by Various Methods with Experimental Data.................................... 155

4.24 Comparison of Time Variations of Change in Midspan Deflection after Loading of Beam with Sustained Load of 0.5 Design Live Load by Various Methods with Experimental Data......................... 157

4.25 Comparison of Time Variations of Change in Midspan Deflection after Loading of Beam with Sustained Load of 1.0 Design Live Load by Various Methods with Experimental Data......................... 158

4.26 Comparison of Time Variations of Change in Midspan Deflection after Loading of Beam with Sustained Load of 1.5 Design Live Load by Various Methods with Experimental Data......................... 159

4.27 Load-Deflection Responses of Beam with No Sustained Load, at the Age of Concrete of 4740 days, Predicted by Various Methods and from Experiment........ 163

FIGURE | Page

4.28 Load-Deflection Responses of Beam with Sustained Load of 1.0 Design Live Load, at the Age of Concrete of 4692 days, Predicted by Various Methods and from Experiment.................................. 164

4.29 Load-Deflection Responses of Beam with Sustained Load of 1.5 Design Live Load, at the Age of Concrete of 4674 days, Predicted by Various Methods and From Experiment.................................. 165

4.30 Details of Cross-Section and Continuity Reinforcement for Girder 3/4.............. 169

4.31 Longitudinal Section and Loading Arrangements for Girder 3/4...................... 171

4.32 Modeled Cross-Section at Midspan for Girder 3/4................................ 172

4.33 Instantaneous Stress-Strain Relationship in Tension of Prestressing Strands for Girder 3/4................................ 173

4.34 Time Variations of Interior Support Reaction, Girder 3/4...................... 176

4.35 Time Variations of Change in Interior Support Reaction after Removal of Deck Slab Formwork, Girder 3/4................. 177

4.36 Time Variations of Midspan Deflection, Girder 3/4................................ 179

4.37 Time Variations of Change in Midspan Deflection after Removal of Deck Slab Formwork, Girder 3/4..................... 180

4.38 Failure Load-Deflection Responses at the Age of Girder of 680 days, Girder 3/4...................................... 182

B.1 Linear and Parabolic Segments That Can Be Generated by the Program............... 249

LIST OF SYMBOLS*

Symbol	Typical Units	Definition
a, a_i, a_{ij}	--	Empirical constants
A	%	Air content
A_b	in^2	Area of confined concrete under compression
A_c	in^2	Area of concrete under compression
A_i	in^2	Cross-sectional area of fiber i
A_s	in^2	Area of steel
A'_s	in^2	Area of compressive steel effective in binding
A''_s	in^2	Area of one leg of lateral reinforcement
b	in	Width of compression face of member
b, b_i	--	Empirical constants
b''	in	Width of confined core
B	--	Number of 94 lb. sacks of cement per cubic yard
B	in	Width or 0.7 depth of confined concrete, whichever is greater

* See Appendix C for additional information.

Symbol	Typical Units	Definition
B_H	--	Coefficient depending on surrounding medium
B_S	--	Coefficient depending on speed of setting of cement
$(c)_t$	--	Creep coefficient, ratio of creep strain to initial strain, at time t
$(c)_{t,t'}$	--	$= \{(\varepsilon)_t - (\varepsilon_s)_t - (\varepsilon_e)_{t'}\}/(\varepsilon)_{t'}$, creep coefficient at time t due to sustained load applied at time t'
$(c_\varepsilon)_t$	in/in/psi	Specific creep, creep strain per unit sustained stress, at time t
$(c_\varepsilon)_{t,t'}$	in/in/psi	$= \{(\varepsilon)_t - (\varepsilon_s)_t - (\varepsilon_e)_{t'}\}/(f_c)_{t'}$, specific creep at time t due to sustained load applied at time t'
$(\Delta c_\varepsilon)_i$	in/in/psi	$= (c_\varepsilon)_{t_i} - (c_\varepsilon)_{t_{i-1}}$, specific creep increment in time interval i
$(c_{\varepsilon de})_t$	in/in/psi	Specific delay elastic strain, delay elastic strain per unit sustained stress, at time t

Symbol	Typical Units	Definition
$(c_{\varepsilon dej})_\infty$	in/in/psi	j term of ultimate specific delay elastic strain
$(c_{\varepsilon f})_t$	in/in/psi	Specific flow at time t
$(\Delta c_{\varepsilon f})_i$	in/in/psi	$= (c_{\varepsilon f})_{t_i} - (c_{\varepsilon f})_{t_{i-1}}$, specific flow increment in time interval i
CC_A	--	Creep correction factor for air content of concrete
CC_D	--	Deferred coefficient of elasticity
CC_F	--	Creep correction factor for fine aggregate content of concrete
CC_{FO}	--	$= CC_{F1}CC_{F2}$, deferred coefficient of flow
CC_{F1}	--	Coefficient taking into account consistency of concrete
CC_{F2}	--	Coefficient depending on the theoretical thickness of member, h_{th}
CC_H	--	Creep correction factor for ambient humidity

Symbol	Typical Units	Definition
CC_{LA}	--	Creep correction factor for age of concrete at loading
$(CC_{LA})_{t'}$	--	Value of CC_{LA} estimated at age of concrete at loading t'
CC_S	--	Creep correction factor for consistency of concrete
CC_T	--	Creep correction factor for member thickness
CS_A	--	Shrinkage correction factor for air content of concrete
CS_B	--	Shrinkage correction factor for cement content of concrete
CS_F	--	Shrinkage correction factor for fine aggregate content of concrete
$CS_{h_{th}}$	--	Coefficient depending on theoretical thickness of member, h_{th}
CS_H	--	Shrinkage correction factor for ambient humidity
CS_S	--	Shrinkage correction factor for consistency of concrete

Symbol	Typical Units	Definition
CS_T	--	Shrinkage correction factor for member thickness
CUR1, CUR2	rad	Curvatures at location of first and second rotational springs in discrete element model
d	in	Distance from extreme compression fiber to centroid of tension reinforcement
d'	days	Number of days from January 1
d"	in	Depth of confined core
d_{sp}	in	Spalling depth
e	--	= 2.71828, base of Napierian logarithms
E_c	lb/in^2	Modulus of elasticity of concrete
$(E_c)_t$	lb/in^2	Modulus of elasticity of concrete at age of concrete t
E_{ci}	lb/in^2	Initial modulus of elasticity of concrete
$(E_{cs})_t$	lb/in^2	Basic value for secant modulus of longitudinal deformation of concrete at age t

Symbol	Typical Units	Definition
$(E_{eff})_t$	lb/in^2	Effective modulus of elasticity of concrete at age t
$(E_{eff})_{t,t'}$	lb/in^2	Effective modulus of elasticity of concrete at age t subjected to sustained load applied at time t'
EP	in/in	Strain at member axis
f	lb/in^2	Stress. Positive stress is tension and negative stress is compression
f_c	lb/in^2	Stress in concrete
$(f_c)_{iave}$	lb/in^2	Average value of f_c in time interval i
$(f_c)_t$	lb/in^2	Stress applied to concrete at time t or at age of concrete t
f'_c	lb/in^2	Concrete cylinder strength
$(f'_c)_m$	lb/in^2	Concrete cylinder strength at age m or at maturity m
f''_c	lb/in^2	Maximum compressive stress in concrete stress-strain curve
f_r	lb/in^2	Modulus of rupture of concrete

Symbol	Typical Units	Definition
f_s	lb/in^2	Steel stress
$(f_s)_t$	lb/in^2	Stress in steel at time t
f_{sh}	lb/in^2	Magnitude of sustained stress which will give creep strain equal to shrinkage strain of concrete at given relative humidity
f_{si}	lb/in^2	Initial stress in steel
$(f_{sr})_t$	lb/in^2	Steel relaxation stress at time t
f_{sy}	lb/in^2	Specific yield strength of steel
$f_{sy0.2\%}$	lb/in^2	Prestressing steel stress at 0.2% offset
f_{su}	lb/in^2	Ultimate strength of steel
f_t	lb/in^2	Concrete tensile stress
f_u	lb/in^2	Concrete compressive stress at ε_u
f_1--f_6	lb and lb-in	End forces on discrete element
F	lb	Axial thrust
F	%	Fine aggregate content in percent

Symbol	Typical Units	Definition
$(g)_t$	--	Magnitude of function g evaluated at t
g_c	--	Function representing development with time of creep
g_d	--	Function representing development with time of deferred elastic deformation
g_f	--	Function representing development with time of deferred flow
g_s	--	Function representing development with time of shrinkage
g_u	lb and lb/in	Load or force as function of displacement u
g_u'	lb/in and lb-in/rad	Derivative of g_u (tangent stiffness)
$g_u'^{-1}$	in/lb and rad/lb-in	Reciprocal or inverse of g_u'
G	--	$= (1 - V_a - V_{uc})^2/V_{hc}$, gel compliance

Symbol	Typical Units	Definition
h	in	Distance between concentrated rotational springs in discrete element model, one-half of element's length
Δh	in	Elongation of axial deformable bar in discrete element
h_{th}	cm	Theoretical thickness
H	%	Ambient relative humidity
k	--	Function of f'_c
k_3	--	$= 1.0 - 0.1(\lvert f'_c \rvert - 4000) \leq 1.0$, function of f'_c
k_4	--	$= 1.72(d_{sp}/l_{cr}) + 1.0$, function of d_{sp} and l_{cr}
K	--	Wobble friction coefficient
K_1--K_6	--	Concrete grades based on consistencies of concrete
K_{lc}	--	Creep reduction coefficient for lightweight concrete
ℓ	in	Length along prestressing tendon from jacking end
l_{cr}	in	Crushing length
M	°F-hr	Maturity of concrete

Symbol	Typical Units	Definition
M_1, M_2	lb-in	Bending moments at location of first and second rotational springs in discrete element model
n	--	Number of load increments of time increments
n	--	$= f''_c/(E_c \varepsilon_0 - f''_c)$, function of f''_c, E_c, and ε_0
P	lb and lb-in	Load or force
P_i	lb and lb-in	P at end of i^{th} load increment
$\overline{P}_{i,j}$	lb and lb-in	Estimated value of P_i at end of j^{th} iteration
ΔP_j	lb and lb-in	Equilibrium error, i.e. load not absorbed by structure, at end of j^{th} iteration
P_s	lb	Steel force at jacking end
P_x	lb	Steel force at point x along tendon
q	--	$= -1.3 + \{(\log t)/3\}(f_{si}/f_{sy} - 0.55)$, function of time t and initial stress/strength ratio

Symbol	Typical Units	Definition
q''	--	Parameter referring to effectiveness of transverse reinforcement
Q	--	Empirical constant
R	--	Ratio of specific creep recovery response to specific creep
$(R)_{t,t'}$	--	Ratio of specific creep recovery response to specific creep at age of concrete t due to removal of load at age of concrete t'
S	in	Longitudinal spacing of lateral reinforcement
S	in	Slump of concrete
S	in^2	Surface of specimen exposed to atmosphere
S_0	in	Longitudinal spacing at which lateral reinforcement is not effective in confining concrete
t	days	Time or age of concrete
t'	days	Loading time or age of concrete when load is applied

Symbol	Typical Units	Definition
T	^{o}F	Surrounding temperature
T	in	Thickness of specimen
TH	in	Length of element
u	in and rad	Displacement
u_i	in and rad	Displacement corresponding to i^{th} load increment
$\bar{u}_{i,j}$	in and rad	Estimated value of u_i at end of j^{th} iteration
Δu_j	in and rad	Increment of displacement corresponding to ΔP_j
V	in^3	Volume
V_a	--	Ratio of volume of aggregate to volume of concrete
V_{hc}	--	Ratio of volume of hydrated cement including gel pores to volume of concrete
V_p	--	Ratio of volume of cement paste to volume of concrete
V_s	--	$= V_a + V_{uc}$, ratio of volume of solids to volume of concrete

Symbol	Typical Units	Definition
V_{uc}	--	Ratio of volume of unhydrated cement to volume of concrete
w	lb/in^3	Unit weight
w_1--w_6	in and rad	End displacements of discrete element
x	--	$= \varepsilon/\varepsilon_0$, ratio of concrete strain to concrete strain at maximum stress
$(X)_{t,t'}$	--	Aging coefficient at age of concrete t for concrete loaded at age of concrete t'
y_i	in	Distance from centroidal axis of fiber i to centroid of cross-section
Z	--	Slope of descending branch of stress-strain relationship for concrete
α	rad	Total angular change of prestressing tendon profile from jacking end
$\alpha_{x,s}$	rad	Total angular change of tendon profile from s to x

Symbol	Typical Units	Definition
ε	in/in	Strain. Positive strain is tensile strain and negative strain is compressive strain
$(\varepsilon)_t$	in/in	Total strain at time t
$(\varepsilon_c)_t$	in/in	Concrete creep strain at age of concrete t or at time t after loading
$(\varepsilon_c)_{t,t'}$	in/in	Concrete creep strain at age of concrete t due to sustained load applied at age of concrete t'
$(\varepsilon_{c,f_0})_{t,t_0}$	in/in	Concrete creep strain at age of concrete t due to sustained load f_0 applied at age of concrete t_0
$(\Delta\varepsilon_{c,f})_{t_j-t_i,t_0}$	in/in	$= (\varepsilon_{c,f})_{t_j,t_0} - (\varepsilon_{c,f})_{t_i,t_0}$, creep strain increment in time interval t_i to t_j due to sustained load f applied at age of concrete t_0
$(\varepsilon_{cb})_t$	in/in	Basic creep strain of concrete at time t after loading

Symbol	Typical Units	Definition
$(\varepsilon_{cd})_t$	in/in	Drying creep strain of concrete at time t after loading
ε_{ce}, ε_{cs}, ε_{cf}	in/in	Characteristics of idealized stress-strain relationship of concrete
$\varepsilon_{com,i}$	in/in	Offset strain due to composite action at centroidal axis of fiber i
$(\varepsilon_{de})_t$	in/in	Delayed elastic strain of concrete at time t after loading
$(\varepsilon_{dej})_t$	in/in	j^{th} term of $(\varepsilon_{de})_t$
$(\varepsilon_e)_t$	in/in	Instantaneous strain at time t
$(\Delta\varepsilon_e)_t$	in/in	Instantaneous strain increment at time t
$(\varepsilon_e)_{t,t'}$	in/in	Instantaneous strain at time t due to load applied at time t'
$(\varepsilon_{e,f})_t$	in/in	Instantaneous strain at time t due to load f
$(\varepsilon_f)_t$	in/in	Flow of concrete at time t after loading

Symbol	Typical Units	Definition
$(\varepsilon_s)_t$	in/in	Free drying shrinkage train of concrete at age of concrete t
$(\varepsilon_s)_\infty$	in/in	Ultimate free drying shrinkage strain of concrete
ε_{sH}	in/in	Free drying shrinkage strain of concrete stored in relative humidity H
$\varepsilon_{si,i}$	in/in	Initial strain at centroidal axis of fiber i
$(\varepsilon_{ss})_\infty$	in/in	Ultimate free drying shrinkage strain of concrete at standard conditions
$(\varepsilon_{s1})_\infty$	in/in	Basic value of ultimate free drying shrinkage strain of concrete, depending on surrounding medium and consistency of concrete
$\varepsilon_{time,i}$	in/in	Time-dependent strain at centroidal axis of fiber i

Symbol	Typical Units	Definition
$\varepsilon_{tot,i}$	in/in	Total strain at centroidal axis of fiber i
$(\varepsilon_t)_{t,t'}$	in/in	Total strain in concrete, in excess of shrinkage strain, at time t due to sustained load applied at time t'
ε_u	in/in	Ultimate strain of concrete
ε_0	in/in	Concrete strain at f''_c
ε_{50c}	in/in	Strain at 0.5 f'_c on descending branch of stress-strain relationship for confined concrete
ε_{50h}	in/in	$= \varepsilon_{50c} - \varepsilon_{50u}$
ε_{50u}	in/in	Strain at 0.5 f'_c on descending branch of stress-strain relationship for unconfined concrete
μ	--	Curvature friction coefficient

Symbol	Typical Units	Definition
ρ''	--	Volumetric ratio of lateral reinforcement to bounded concrete
σ	lb/in^2	Stress. Positive stress is tension and negative stress is compression
σ_i	lb/in^2	Stress at centroidal axis of fiber i
Ψ_1, Ψ_2	rad	Discrete angle changes which occur at rotational springs in discrete element model

CHAPTER I

INTRODUCTION

Concrete appeals to many engineers as a good construction material because of its relatively high strength/cost ratio. Since concrete possesses low tensile strength compared to its compressive strength, steel which has both high compressive and tensile strengths, is usually used in conjunction with concrete to carry tensile stresses that may occur in a member or to precompress the concrete so that the additional service loads do not produce tensile stresses in the concrete in excess of acceptable levels. The fundamental concepts in designing ordinary reinforced concrete structures and prestressed concrete structures have been recognized.

Concrete "ages", i.e. it gains strength with time. It also undergoes, however small, time-dependent volumetric change. Concrete "creeps" under loads, "shrinks" when aged, and "shrinks" or "swells" as its moisture content changes. Steel under a constant strain "relaxes" with time. Since a prestressed concrete member depends upon prestressing force in order that the materials can be used effectively, the time variation properties of the materials influence the effective prestressing force and hence both instantaneous and long-term load responses of the member.

The problem of the time-dependent response of a prestressed concrete member is very complex. It depends not only upon the time-dependent properties of the materials, geometry of the structure, and loading arrangements, but also upon the amounts of prestressing, methods and sequences of prestressing and construction, and type of structure. Usually, under prestressing forces, a prestressed concrete member is deflected upward. "Creep" of concrete produces additional camber with time while "shrinkage" of concrete and "relaxation" of prestressing steel reduce the effective prestressing forces and thus the camber. Applied loads make the member deflect downward and creep and shrinkage of concrete and relaxation of prestressing steel give additional downward deflection with time. The instantaneous load-deflection response of the member is also affected by the "aging" effect of concrete and the effective prestressing forces which regulate the cracking moment of the section. "Differential shrinkage" and "differential creep" of composite sections and the continuity of continuous structures further complicate the problem of analysis for time-dependent deflections.

Although the creep and shrinkage of concrete and relaxation of prestressing steel do not affect the flexural capacity of a bonded prestressed concrete member (where final stress after losses of prestressing steel is greater than 0.5 of its ultimate strength (67)), they may greatly affect the servicibility characteristics of the member such as camber, deflection, and cracking which are very important in many cases. The excessive deflection of a structure housing a very delicate instrument may be undesirable. Uneven highway bridge riding surfaces may result from both the underestimating or overestimating of cambers and deflections of the supporting girders. Ponding problems of long-span roof structure may arise from too much deflection. The possibility of cracking under service loads amplifies the problem, since the stiffness of a cracked section is lower than that of an uncracked one.

1.1 Review of Available Analytical Procedures.

Corley, Sozen, and Siess (20) developed a numerical step-by-step method based on the "rate of creep" and the "superposition" methods to predict the long-term behavior of simply supported pre-tensioned prestressed concrete beams. The method included the effects of creep and shrinkage of concrete and relaxation of prestressing steel. It was assumed that instantaneous stress-strain relationships of concrete and prestressing steel were linear and creep of concrete was proportional to the applied stress under the stress level of interest. The aging effect of concrete was taken into account in the creep-time relationship. By dividing the time interval of interest into several small time steps, stress conditions and curvatures at any sections of the beam at the ends of each time step were found based on the stress conditions and curvatures of those sections up to the beginning of the corresponding time steps. Deflection of the beam was found by numerical integration along the span. The time-dependent response of the beam over the whole range of interest was estimated by marching along with the divided time steps.

Sinno and Furr (81) developed a computer program to predict the time-dependent responses of noncomposite and composite simply supported pre-tensioned prestressed beams. The step-by-step procedure together with the rate of creep theory similar to that proposed by Corley, et al., (20) was used in estimating prestress losses and camber of noncomposite prestressed beams. For composite sections, the procedure utilized the step-by-step method together with a revised rate of creep method in which creep and shrinkage functions for the beam concrete and the slab concrete were different. The separation method of predicting responses of composite sections as proposed by Branson (12) was used in estimating the effects of the differential shrinkage and the differential creep. For a composite section, a complete compatibility between the precast beam and the deck slab was assured in the differential shrinkage analysis, but only the strain compatibility between the interface of the beam and the deck slab was considered in the differential creep analysis. In the differential creep analysis, the curvatures of the beam and the deck slab might not be compatible. The method also assumed linear stress-strain relationships for both concrete and prestressing steel. It did not take into account the effects of the aging of concrete and the relaxation of steel. No provision was made for the analysis of the effects, both instantaneous and time-dependent, of external applied loads.

Mossiossian and Gamble (64) developed a computer program based on a step-by-step procedure which iteratively estimates the time-dependent responses of both noncomposite and composite continuous pre-tensioned prestressed concrete beams. The superposition method and a revised rate of creep method taking into account the relationship of creep and the age of concrete at loading were used in estimating creep strains. In the composite section analysis, the separation method was used allowing the compatibilities of strains at the interface and the curvatures of the beam and the deck slab to be preserved. A simple single step procedure, based on the superposition method and several additional assumptions, for calculating loss of prestress, change in camber and deflection, and redistribution of stresses and strains in noncomposite and composite prestressed structures was also developed. In developing the computer program, linear stress-strain relationships for both concrete and steel were assumed. The aging effects, creep, and shrinkage of concrete were considered, but the relaxation of prestressing steel was neglected. The program also contained an error in the method of taking into account the elastic recovery of concrete, with the result that the force equilibrium in a cross-section did not quite exist, especially after casting of the deck concrete (39). The error was corrected and the effect of the relaxation of prestressing steel was included in the updated program by Hernandez and Gamble (39). A program similar to those developed by Mossiossian and Gamble (64) and Hernandez and Gamble (39), using the revised rate of creep method, was also developed by Fadl and Gamble (27) to predict time-dependent responses of noncomposite and composite post-tensioned concrete beams.

Based on the step function approach as derived by Branson and Ozell (15) and the work by Branson, Meyers, and Kripanarayanan (14), Branson (11) advanced a modified step function method for calculating prestress losses, cambers, and deflections of noncomposite and composite prestressed beams. Formulas were given to estimate prestress losses and cambers or deflections for different types of structures. The formulas were the summations of the contributions of each factor that affects prestress losses or cambers and deflections. The procedure is summerized in Appendix F. The method of analysis, both instantaneous and time-dependent, was also presented in detail in the book by Branson (10). It included the effects of aging, creep, and shrinkage of concrete and relaxation of prestressing steel. The effects of nonprestressing steel, cracking of the section, and continuity of the structure were also taken into account. The method was developed mainly for hand calculation, with tables and charts provided for many cases, but it can also be adapted for computer analysis.

A rational method of analysis called "the varying stiffness method" was proposed by Rao and Dilger (72) to predict time-dependent responses of simply supported pretensioned members, both noncomposite and composite. The method took into account aging, creep, and shrinkage of concrete and the relaxation of prestressing steel. In estimating creep strains, the method used a modified version of the superposition principle. It was also assumed that creep was proportional to stress and instantaneous stress-strain relationships of concrete and prestressing steel were linear in the range of stress level of interest.

Several procedures for estimating prestress losses were advanced. Grouni (32) developed a set of expressions and monograms to predict the prestress losses of noncomposite prestressed concrete beams taking into account creep and shrinkage of concrete and relaxation of prestressing steel. The effects of ordinary reinforcement were neglected in the procedure. Huang (43) proposed a direct method for estimating prestress losses in pre-tensioned noncomposite members avoiding a step-by-step method. Several expressions were introduced to take into account the effects of creep and shrinkage of concrete and relaxation of steel. Tadros, Ghali, and Dilger (85) suggested a procedure for predicting prestress losses taking into consideration the effects of continuous reduction of prestressing stress due to creep and shrinkage of concrete and relaxation of steel by a recovery parameter and a relaxation reduction factor. The recovery parameter and the relaxation factor were derived by a step-by-step procedure and were given for different material properties and cross-sections. The P.C.I. Committee on Prestress Losses (67) also recommended a step-by-step method of estimating prestress losses in both pre-tensioned and post-tensioned concrete members. Total prestress losses could also be computed using a simplified method where several equations were given by the Committee for different types of materials and methods of tensioning.

The methods for estimating prestress losses mentioned are very useful for noncomposite, simply supported beams where bending moments at any sections are independent of stiffnesses of the members. For composite sections, the effects of differential shrinkage and differential creep between deck slabs and precast beams are difficult to obtain. The change in stiffnesses of structures due to time-dependent properties of materials may change the bending moments caused by external loads in any sections in indeterminate beams. These effects are not considered in the above mentioned prestress loss methods.

Adapting the step-by-step method, the time-dependent response problem of prestressed members is reduced to a series of instantaneous response problems. The instantaneous load responses of a general prestressed beam can be best estimated numerically through the use of a digital computer. Various versions of the direct stiffness method of structural analysis in which structural elements are modeled using either the finite element method of the discrete element method are widely used to iteratively solve nonlinear structural problems.

The discrete element method and the recursive form of solution were developed by Lytton and Matlock (60) for determining the deflected shape of elastic beams or beam-columns. The method was extended to analyze elastic or inelastic prestressed concrete members by Atkins (7), elastic or inelastic prestressed concrete members with unbonded tendons by Pierce (68), composite prestressed concrete members by Chang (19) and Lo (57), and by Matlock and colleagues to analyze beam-column structures, plates, and planar frames, linear or nonlinear, under various loading conditions, static or moving loads. According to Hays and Matlock (38), structures with widely varying and discontinuous loadings, stiffnesses, and support conditions may be more economically modeled using a discrete element model method than a finite element model method. It was decided to extent the discrete element method to analyze the problem of time-dependent response of prestressed concrete structures.

It should be noted that all of the time-dependent response analysis procedures mentioned assumed that stress-strain relationships of concrete and prestressing steel were linear. The use of the nonlinear discrete element method offers an advantage in flexural strength analysis in addition to the time-dependent response analysis and the long-term load response analysis of a cracked section, since the method could be used with instantaneous stress-strain relationships of any reasonable shapes.

1.2 Objectives and Scope.

The main objective of this study is to develop a rational analytical procedure, based on the discrete element technique developed by Hays and Matlock (37,38), capable of predicting both strength and long-term load responses of prestressed concrete beams, providing that uniaxial load-deformation properties, both instantaneous and time-dependent, of the materials that comprise the beams are available. The analytical computer program which is developed to perform this analysis should be capable of utilizing known material properties, when complete data are available, and projecting reasonable values from minimal experimental data. A further objective is to show the validity of the proposed method by comparing the analytical results with the existing observed values from actual beam tests or previous analytical results.

The scope of this study is limited to prestressed beams, noncomposite or composite, which are originally straight, of any cross-sectional shape having one axis of symmetry. The beams may be supported, linearly or non-linearly, in any of the three directions, i.e. the member axis direction, the transverse direction, and the rotational direction. Reinforcing steel is assumed to be perfectly bonded to the surrounding materials. Prestressing steel may be pre-tensioned or post-tensioned. A pre-tensioned tendon is bonded to the surrounding materials before the transferring of the prestressing force but a post-tensioned tendon is bonded to the surrounding materials just after the transferring of the prestressing force. It is assumed that no slipping between the deck slab and the precast girder occurs after the composite beam action starts.

Materials that comprise the beams, i.e. concrete, reinforcing steel, and prestressing steel, may be treated as elastic or inelastic materials. The time-dependent properties of the materials included in the study are aging, creep, and shrinkage of concrete, and relaxation of prestressing steel.

External loads under consideration are axial loads, loads perpendicular to the beam axes, and moments, in the planes of the symmetrical axes of the cross-sections of the beams. Loads may be applied at any time after the beams gain enough strength to carry the loads, but only statically applied loads are considered; dynamically applied loads, e.g. impact or fatigue, are not taken into account. Final failures of the beams are assumed to be in the flexural mode, which may occur either by crushing of concrete or rupture of reinforcing steel; no provision is made for other modes of failure, such as shear, bond, and anchorage failures.

The broad capabilities of the proposed method compared with some other methods for analyzing time-dependent responses of prestressed concrete beams are noted from the summary in Table 1.1.

Table 1.1

Summary of the Capabilities of Some of the Available Methods for Estimating Time-Dependent Responses of Prestressed Concrete Beams

Reference	Corley, et al. (20)	Sinno and Furr (81)	Hernandez and Gamble (39) #	Fadl and Gamble (27)	Branson (10)	Rao and Dilger (72)	Proposed Method
Number of Spans	1	1	1+	1+	1+	1+	1+
Nonlinear Supports	No	No	No	No	No	No	Yes
Distributed Supports	No	No	No	No	No	No	Yes
Time-Dependent Supports	No	No	No	No	No	No	No
Composite Section	No	Yes	Yes	Yes	Yes	Yes	Yes
Cracked Section	No	No	No	No	Yes	No	Yes
Pre-tensioning	Yes	Yes	Yes	No	Yes	Yes	Yes
Post-tensioning (Grouted)	No	No	No	Yes	Yes	No	Yes
Unbonded Reinforcement	No	No	No	No	No	No	No
Nonlinear σ-ϵ Curves	No	No	No	No	*	No	Yes
Aging of Concrete	Yes	No	Yes	Yes	Yes	Yes	Yes
Creep of Concrete	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shrinkage of Concrete	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Relaxation of Steel	Yes	Yes	Yes	Yes	Yes	Yes	Yes
External Applied Loads	Yes	No	Yes	Yes	Yes	Yes	Yes
Ultimate Load Computation	No	No	No	No	No	No	Yes

Updated Version of Mossiossian's and Gamble's Program (64)

* Indirectly

1.3 Outline of the Following Chapters.

In the next chapter, mechanical properties of materials used in this study are discussed. Methods used in estimating instantaneous uniaxial load-responses of concrete and different types of reinforcing steel and time-dependent responses, i.e. aging, creep under constant and variable loads, and shrinkage of concrete and relaxation of steel are presented. Chapter III reviews the fundamental concepts which are used as the basis for the development of the proposed method. Example problems illustrating the capability and the validity of the proposed numerical method are presented in Chapter IV. Chapter V concludes and summarizes the study. Appendices show the input details and listings of example of input data, output, and the program.

CHAPTER II

MATERIAL PROPERTIES

A prestressed beam is generally composed of concrete, prestressing steel, and some additional reinforcing steel. In order to accurately predict the behavior of the beam under any loading condition, constitutive relations, i.e. stress-strain-time relationships for the materials that comprise the beam, must be available. In the following chapter, the expressions representing the uniaxial constitutive laws typical of concrete, prestressing steel, and reinforcing steel will be reviewed. This is by no means complete information about the mechanical properties of the materials, but the presentation will be helpful in determining the material properties for estimating the responses of the structure when minimum experimental data are available.

2.1 Strain Components of Concrete.

Total strain in concrete under sustained load at any time may be considered as consisting of two components: instantaneous strain and time-dependent strain. Different definitions of the strain components have been used by different investigators. In this study, the following definitions will be used.

Instantaneous Strain is the strain that occurs during the changing of load. The stress-strain relationship follows a previously defined stress-strain curve. In case of the changing of stress-strain curve with time, the stress-strain curve at the time of consideration will be used.

Time-Dependent Strain is the strain which occurs in excess of the instantaneous strain. It can be further subdivided into two components: creep or creep recovery, the increase or decrease in strain with time under sustained load or removal of load, and shrinkage or swelling, the change in strain with time due to the change in moisture content of concrete. Creep or creep recovery and shrinkage or swelling occur simultaneously and are not independent of one another thereby not allowing the principle of superposition to be applied. Shrinkage tends to increase the magnitude of creep (65). However, for convenience, they are usually assumed to be independent and additive as:

Shrinkage or Swelling is the portion of time-dependent strain occurring in a specimen due to the change of moisture content if the specimen is not loaded.

Creep or Creep Recovery is the portion of time-dependent strain in excess of shrinkage or swelling caused by sustained load or removal of load.

The following is a review of expressions representing stress and time relationships for each of the components of strain.

2.2 Instantaneous Stress-Strain Relationship of Concrete.

2.2.1 Compressive Stress-Strain Relationship.

The instantaneous compressive stress-strain relationship of concrete depends on so many factors that it is difficult to accurately estimate the relationship for a particular concrete from its constituents, curing conditions, and ambient conditions. The most common method for determining the relationship is to perform a series of compression tests on cylinders taken from the same mix and stored in the same ambient conditions as the structure. But a complete stress-strain curve of concrete in compression is not easily obtained. Concrete cylinders under uniaxial compression fail suddenly when loaded beyond their ultimate strength. Especially designed equipment is needed in order to obtain the descending branch of the stress-strain curve, i.e. the portion of stress-strain curve exceeding the ultimate strength, which is an essential component of stress-strain behavior in the analysis of the responses of concrete structures loaded near their capacity.

Several empirical expressions representing complete compressive concrete stress-strain curves have been proposed. Using one of the expressions, the curve can be accurately determined based on only the ultimate strength of the concrete or a few points on the ascending branch of the curve including the ultimate strength point. Some of the available expressions will be listed. More extensive references may be found in the reports by Sargin (78) and by Popovics (71). Note that the expressions will be changed such that they are consistent with the sign convention used in this study, i.e. compressive stress and strain are negative and tensile stress and strain are positive.

Hognestad (41), after extensive tests of reinforced concrete columns subjected to combined bending and axial loads, proposed a stress-strain relationship composed of a parabolic ascending branch and a straight descending branch as:

for $0 \geq \varepsilon \geq \varepsilon_0$

$$f_c = f''_c \, [2\varepsilon/\varepsilon_0 - (\varepsilon/\varepsilon_0)^2]$$

for $\varepsilon_0 > \varepsilon \geq \varepsilon_u$

$$f_c = f''_c \, (\varepsilon_u - 0.85\varepsilon_0 - 0.15\varepsilon)/(\varepsilon_u - \varepsilon_0)$$

where:

ε = Concrete compressive strain

f_c = Concrete compressive stress at strain ε

f''_c = Maximum compressive stress in concrete stress-strain curve

= $0.85 \, f'_c$

f'_c = Concrete cylinder strength (negative value)

ε_0 = Concrete strain at maximum compressive stress f''_c

= $2 \, f''_c/E_{ci}$ in./in.

E_{ci} = Initial modulus of elasticity of concrete

= $1{,}800{,}000 + 480|f'_c|$ psi., f'_c is in psi.

ε_u = Ultimate compressive strain of concrete

= -0.0038 in./in.

Lee (55), in his study of inelastic behavior of reinforced concrete members, assumed that both ascending and descending branches of the curve could be represented by a single parabolic curve as:

$$f_c = f''_c \, [2\varepsilon/\varepsilon_0 - (\varepsilon/\varepsilon_0)^2] \qquad 0 \leq \varepsilon/\varepsilon_0 \leq 2$$

Kriz and Lee (54) represented the relationship by a quadratic equation:

$$f_c + a\varepsilon^2 + a_1 f_c \varepsilon + a_2 f_c + a_3 \varepsilon = 0$$

where a, a_1, a_2, and a_3 are empirical constants.

The empirical constants were estimated from uniaxial compression test data by solving four simultaneous equations obtained from substituting the values of stress corresponding to the strains of -0.0006, -0.0012, -0.0018, and -0.0024 in./in., respectively.

Young (93) used the following expressions to describe the stress-strain curve of concrete. Each of the expressions represented the curve up to the ultimate strain of concrete.

$$f_c = (E_{ci}\varepsilon_0 - 2f'_c)(\varepsilon/\varepsilon_0)^3 - (2E_{ci}\varepsilon_0 - 3f'_c)(\varepsilon/\varepsilon_0)^2 + E_{ci}\varepsilon$$

$$f_c = f'_c\,(\varepsilon/\varepsilon_0)\,e^{[1 - (\varepsilon/\varepsilon_0)]}$$

or

$$f_c = f'_c \sin\,(\pi\varepsilon/2\varepsilon_0)$$

Liebenberg (56) proposed a relationship consisting of an elastic part and an inelastic part as:

$$f_c = E_{ci}\,\varepsilon[1 - (\varepsilon/\varepsilon_0)^n]$$

where:

n = Function of f''_c, E_{ci}, and ε_0

$= f''_c/(E_{ci}\,\varepsilon_0 - f''_c)$

$E_{ci} = 67000\sqrt{|f'_c|}$ psi.

$f''_c = 0.9\, f'_c$

and $\varepsilon_0 = -0.002$ in./in.

The ultimate strain ε_u used was assumed to be equal to $-0.004 + |f'_c|\,/(6.5 \times 10^6)$ in./in.

Desayi and Krishnan (22) proposed that the stress-strain relationship of concrete up to the ultimate strain could be represented by a simple equation:

$$f_c = E_{ci}\varepsilon / [1 + (\varepsilon/\varepsilon_0)^2]$$

where $E_{ci} = 2\, f'_c/\varepsilon_0$

Strain at the ultimate stress, ε_0, would be obtained from the values of stress and strain at the ultimate strain.

Saenz (76), in the discussion of Desayi's and Krishnan's paper, proposed a more general equation:

$$f_c = \varepsilon/(a + a_1\varepsilon + a_2\varepsilon^2 + a_3\varepsilon^3)$$

The empirical constants, a, a_1, a_2, and a_3 were estimated by satisfying the boundary conditions of the curve:

$$f_c = f'_c \quad \text{at} \quad \varepsilon = \varepsilon_0$$

$$f_c = f_u \quad \text{at} \quad \varepsilon = \varepsilon_u$$

$$df_c/d\varepsilon = E_{ci} \quad \text{at} \quad \varepsilon = 0$$

$$df_c/d\varepsilon = 0 \quad \text{at} \quad \varepsilon = \varepsilon_0.$$

Tulin and Gerstle (88) also suggested another general form of Desayi's and Krishnan's expression:

$$f_c = E_c\varepsilon / [a + (\varepsilon/\varepsilon_0)^b]$$

where E_c = modulus of elasticity of concrete

and a and b are empirical constants.

Kabaila (47) proposed a fourth order polinomial expression to describe the stress-strain relationship for concrete:

$$f_c/f'_c = 2.0\,x - 1.189\,x^2 + 0.1763\,x^3 + 0.0027\,x^4$$

where $x = \varepsilon/\varepsilon_0$, ratio of concrete strain to concrete strain at maximum stress.

The expression is valid from zero strain to the strain of $3\varepsilon_0$.

Drysdale (23) used a fourth order polynomial concrete stress-strain relationship in his study:

$$f_c = a + a_1\varepsilon + a_2\varepsilon^2 + a_3\varepsilon^3 + a_4\varepsilon^4$$

The empirical constants, a, a_1, a_2, a_3 and a_4, were estimated by a least square fitting of experimental data, assuming that the curve slopes off to a stress of 80% of f'_c at a strain of -0.004 in./in..

Wu (92) also used the same polynomial expression. A set of boundary conditions was imposed in estimating the constants. The boundary conditions are:

$$f_c = 0 \quad \text{at} \quad \varepsilon = 0$$

$$df_c/d\varepsilon = E_{ci} \quad \text{at} \quad \varepsilon = 0$$

$$f_c = f'_c \quad \text{at} \quad \varepsilon = \varepsilon_0$$

$$df_c/d\varepsilon = 0 \quad \text{at} \quad \varepsilon = \varepsilon_0$$

and

$$f_c = 0.85f'_c \quad \text{at} \quad \varepsilon = \varepsilon_u,\ \varepsilon_u = 2\varepsilon_0.$$

Soliman and Yu (82) tested 16 eccentrically loaded specimens, rectangular in cross-section, with varying cross-sectional area and amount of transverse reinforcement. Based on the test results, a stress-strain relationship, as shown in Fig. 2.1, was developed for confined concrete in flexure. The relationship consists of a parabolic ascending branch, a straight horizontal part, and a straight descending branch with the following values at control points for the normal range of concrete strength used in practice:

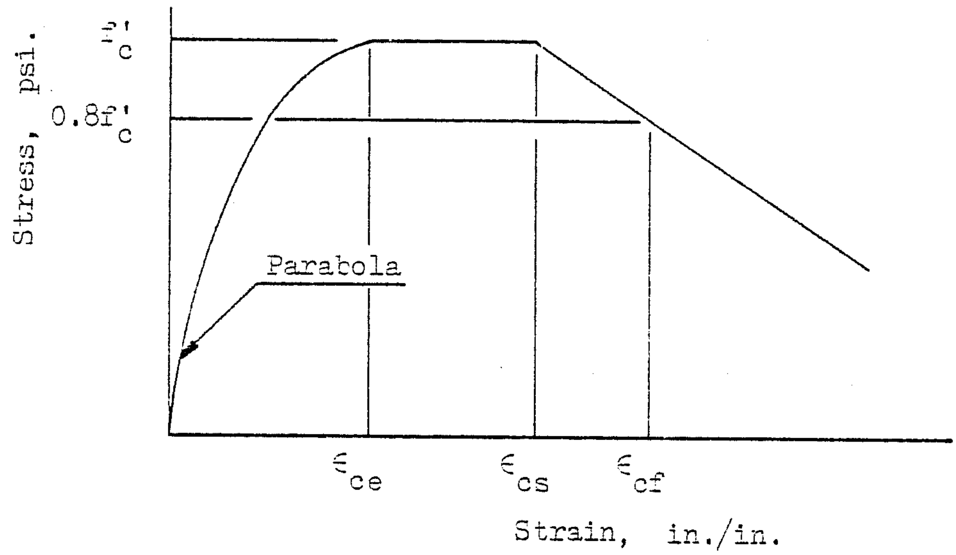


Fig. 2.1 Soliman-Yu Stress-Strain Diagram for Confined Concrete.

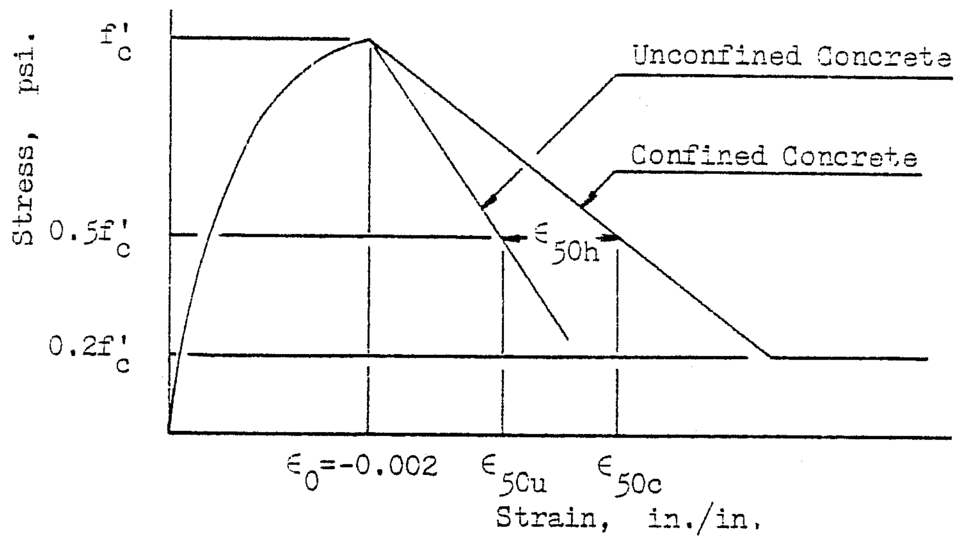


Fig. 2.2 Kent-Park Stress-Strain Diagram for Confined and Unconfined Concrete.

$$f''_c = 0.9\, f'_c(1 + 0.05\, q'')$$

$$\varepsilon_{ce} = 0.55\, f''_c \times 10^{-6} \text{ in./in.}$$

$$\varepsilon_{cs} = -0.0025(1 + q'') \text{ in./in.}$$

$$\varepsilon_{cf} = -0.0045(1 + 0.85\, q'') \text{ in./in.}$$

$$q'' = (1.4\, A_b/A_c - 0.45)\; A''_s\, (S_0 - S)/(A''_s S + 0.0028\, B\, S^2)$$

where A_b = area of confined concrete under compression

A_c = area of concrete under compression

A''_s = cross-sectional area of one leg of lateral reinforcement

S = longitudinal spacing of lateral reinforcement

S_0 = longitudinal spacing at which lateral reinforcement is not effective in confining the concrete (approximately equal to 10 in.)

and B = width or 0.7 depth of confined concrete, whichever is the greater

ε_{ce}, ε_{cs}, and ε_{cf} are characteristics of the idealized stress-strain relationship.

Sargin (78) proposed a concrete stress-strain relationship:

$$f_c = af'_c\; [a_1 x + (a_2 - 1)x^2] \;/\; [1 + (a_1 - 2)x + a_2 x^2]$$

The empirical constants, a, a_1, and a_2, depended on various factors. The method for estimating the constants was illustrated in detail in his book and will not be reproduced herein.

Kent and Park (51) proposed a stress-strain relationship for unconfined or confined concrete as shown in Fig. 2.2. The relationship can be represented by the following expressions:

for $0 \geq \varepsilon \geq \varepsilon_0$

$$f_c = f'_c \, [2\varepsilon/\varepsilon_0 - (\varepsilon/\varepsilon_0)^2]$$

for $\varepsilon_0 > \varepsilon$

$$f_c = f'_c \, [1 - Z(\varepsilon - \varepsilon_0)] \geq 0.2 \, f'_c$$

where Z = slope of the descending branch of the stress-strain relationship

= $0.5/(\varepsilon_{50u} - \varepsilon_0)$ for unconfined concrete

= $0.5/(\varepsilon_{50c} - \varepsilon_0)$ for confined concrete

ε_{50u} = strain at 0.5 f'_c on the descending branch of the stress-strain relationship for unconfined concrete

and ε_{50c} = strain at 0.5 f'_c on the descending branch of the stress-strain relationship for confined concrete

= $\varepsilon_{50u} + \varepsilon_{50h}$

ε_0 was assumed to be equal to -0.002 in./in.. ε_{50u} and ε_{50h} were found from the analysis of the test results from various investigators, e.g. Hognestad, et al.(42), Soliman and Yu (82), Bertero and Felippa (9), to be as follows:

$$\varepsilon_{50u} = -(3 + 0.002|f'_c|)/(|f'_c| - 1000) \quad \text{in./in.}$$

(where f'_c is in psi.)

$$\varepsilon_{50h} = -0.75 \, \rho'' \sqrt{b''/S} \quad \text{in./in.}$$

where ρ'' = volumetric ratio of lateral reinforcement to bound concrete

= $2(b'' + d'') A''_s / (b''d''S)$

b'' = width of confined core

d'' = depth of confined core

A''_s = cross sectional area of one leg of lateral reinforcement

and S = longitudinal spacing of lateral reinforcement

Chang (18) proposed a stress-strain relationship for confined concrete in beam-column structures as follows:

for $0 \geq \varepsilon \geq \varepsilon_0$

$$f_c = f'_c \, [2\varepsilon/\varepsilon_0 - (\varepsilon/\varepsilon_0)^2]$$

for $\varepsilon_0 > \varepsilon$

$$f_c = f'_c \, [1 - Z(\varepsilon - \varepsilon_0)] \geq 0.2 \, f'_c$$

and $\varepsilon_0 = 2f'_c/E_c$ in./in.

$$Z = 0.5/(\varepsilon_{50u} + \varepsilon_{50h} - \varepsilon_0)$$

$$\varepsilon_{50u} = -(3 + 0.002|f'_c|)/(|f'_c| - 1000) \text{ in./in.}$$

(where f'_c is in psi.)

$$\varepsilon_{50h} = -0.75 \, \rho'' \sqrt{b''/S} \text{ in./in.}$$

$$\rho'' = 2(b'' + d'') A''_s / (b''d''S) + A'_s / (b''d'')$$

where b'' = width of confined core

d'' = depth of confined core

S = spacing of lateral reinforcement

A''_s = cross sectional area of one leg of lateral reinforcement perpendicular to longitudinal reinforcement

A'_s = area of compressive steel effective in binding

$\leq$ 0.02 bd

b = width of compression face of member

d = distance from extreme compression fiber to centroid of tension reinforcement

Chang compared the analytical thrust-moment-curvature curves using the above stress-strain curve, the stress-strain curves proposed by Hognestad (41), Soliman and Yu (82), and Kent and Park (51) with experimental data. Chang's stress-strain curve (18) gave the best results in both the rotation and moment capacity and the values of extreme compression fiber strain.

The C.E.B. (84) recommended an expression representing the compressive stress-strain relationship of normal weight concrete as:

$$f_c/f'_c = [kx - x^2] / [1 + (k - 2)\,x]$$

$$k = E_{ci}\varepsilon_0/f'_c$$

where $x = \varepsilon/\varepsilon_0$

ε_0 = strain at maximum stress, f'_c, on the stress-strain curve

and E_{ci} = initial modulus of elasticity of concrete

$= 10450\sqrt{(|f'_c| + 8)}$, E_{ci} and f'_c are in MPa.

The values of ε_0 are found to range from -0.0020 in./in. to -0.0025 in./in.. The value of ε_0 of -0.0022 in./in. is recommended for the stress-strain curve. The values of the ultimate strain, ε_u, are found to range from -0.0035 in./in. to -0.0070 in./in. and the values of the stress at the ultimate strain to range from 0.75 f'_c to 0.25 f'_c.

From the existing experimental data and the stress-strain relationships proposed by various investigators previously mentioned, the following characteristics of stress-strain relationship for a normal weight concrete specimen in compression are observed:

1) Compressive stress increases as compressive strain increases, at a decreasing rate, up to the maximum compressive stress, f''_c, of the concrete, where slope of the stress-strain curve is equal to 0.

2) Most investigators gave the strain at the maximum compressive stress, ε_0, independent of the strength and the modulus of elasticity of concrete. ε_0 ranges from -0.0020 in./in. to -0.0025 in./in..

3) For compressive strain greater than ε_0, compressive stress decreases as compressive strain increases. The descending part of the stress-strain relationship can be adequately represented by a straight line until the stress drops to a certain level. The concrete can sustain that stress level (usually assumed as $0.2f''_c$) at relatively large strain. The slope of the descending branch depends on the strength of the concrete and the degree of lateral confinement.

Based on the observed properties above, the following expressions are proposed for the stress-strain relationship of concrete in compression:

for $0 \geq \varepsilon \geq \varepsilon_0$

$$f_c/f''_c = [kx - x^2]/\ [1 + (k - 2)x]$$

$$k = E_{ci}\varepsilon_0/f''_c$$

where $x = \varepsilon/\varepsilon_0$ and $\varepsilon_0 = -0.0022$ in./in.

for $\varepsilon_0 > \varepsilon$

$$f_c/f''_c = 1 - Z(\varepsilon - \varepsilon_0) \geq 0.2$$

$$Z = 0.5\ /\ (\varepsilon_{50u} + \varepsilon_{50h} - \varepsilon_0)$$

$$\varepsilon_{50u} = -(3 + 0.002|f''_c|)/(|f''_c| - 1000)$$

in./in. (where f''_c is in psi.)

$$\varepsilon_{50h} = -0.75\ \rho''\ \sqrt{b''/S} \text{ in./in.}$$

$$\rho'' = 2(b'' + d'')\ A''_s\ /\ (b''d''S) + A'_s\ /\ (b''d'')$$

where b'' = width of confined core

d'' = depth of confined core

S = spacing of lateral reinforcement

A''_s = cross sectional area of one leg of lateral reinforcement perpendicular to longitudinal reinforcement

A_s' = area of compressive steel effective in binding $\leq$ 0.02 bd

b = width of compression face of member

and d = distance from extreme compression fiber to centroid of tension reinforcement.

Using the proposed relationship, the stress-strain curve can then be determined as a function of the maximum stress, f_c'', the initial modulus, E_{ci}, or the modulus of elasticity, E_c, and the amount of lateral reinforcement. The maximum stress, f_c'', and the modulus of elasticity, E_c, may be expressed in terms of the cylinder compressive strength, f_c', as described below.

The maximum stress, f_c'', is usually taken as a portion of f_c', ranging from 0.85 f_c' to f_c'. Hognestad (41) suggested that the value depended on the geometry of the cross-section and the position of specimens during casting. He used the value of 0.85 f_c' for vertically cast columns in his report. Liebenberg (56), although employing a different expression for the stress-strain relationship, stated that the maximum stress, f_c'', usually exceeded 0.9 f_c'. Iqbal and Hatcher (46), also employing a different expression for the stress-strain relationship, suggested that each compressive fiber of a beam in the crushing length had a unique stress-strain relationship. They proposed that f_c'' for each of the fibers could be estimated as:

$$f_c'' = k_3 k_4 f_c'$$

$$k_3 = 1.0 - 0.1(|f_c'| - 4000) \leq 1.0$$

$$k_4 = 1.72(d_{sp}/1_{cr}) + 1.0$$

where d_{sp} = spalling depth,

and l_{cr} = crushing length.

Most of the investigators used a constant f''_c equal to f'_c for a particular concrete in the structure under consideration in estimating its behavior with satisfactory results. In the present study, f''_c will also be used equal to f'_c.

Several expressions had been proposed to estimate the modulus of elasticity for concrete, E_c. Sargin (78) listed the following expressions:

Graf: $E_c = 4.92\ |f'_c| \times 10^6/(1970 + |f'_c|)$

Ros: $E_c = 7.82\ |f'_c| \times 10^6/(2133 + |f'_c|)$

Jensen: $E_c = 6.00\ |f'_c| \times 10^6/(2000 + |f'_c|)$

Hognestad: $E_c = 180000 + 460|f'_c|$

Walker: $E_c = 66000\sqrt{|f'_c|}$

Pauw: $E_c = 33\ w^{1.5}\ \sqrt{|f'_c|}$

where E_c and f'_c are in psi. and w is in pcf.

The investigators who proposed the expressions are listed preceding the expressions.

Saenz (76) also suggested an expression:

$$E_c = \sqrt{|f'_c|} \times 10^5/(1 + 0.006\sqrt{|f'_c|})$$

Pauw's expression for E_c (66) is somewhat more general than the others and was adopted by the A.C.I. (3). In the absence of the experimental data, Pauw's expression for E_c will be used in this study.

The Hognestad stress-strain relationship (a parabolic ascending part and a straight line descending part with the stress at the strain of -0.0038 in./in. equal to 0.85 f''_c) has been adopted by a number of investigators (7, 19, 68) with the results of analysis in fairly good agreement with experimental data. It should be noted that the concrete used in the studies were of the strength of not more than 6500 psi.. The Hognestad stress-strain relationship and the proposed stress-strain relationship are compared with the stress-strain curves obtained from flexural test of unconfined concrete at the age of 28 days reported by Hognestad, et al., (42) in Fig. 2.3. The relationships are used with f''_c equal to f'_c and E_c equal to $57000\sqrt{|f'_c|}$ psi., the value suggested by the A.C.I. Code 318-71 (3) for normal weight concrete. The comparison shows the similar stress-strain curves by both expressions and the test data for the concrete of the strength up to 5000 psi. For concrete at the higher strength, the Hognestad relationship gives more strain at the maximum stress and does not reflect a steeper slope for the descending branch. The proposed relationship gives a representation of the stress-strain curve for concrete of the strength in that range better than the Hognestad relationship. The use of either stress-strain relationship for concrete in structural analysis should give about the same responses for the concrete of the strength up to 5000 psi.. The difference will be shown in the concrete at a higher strength. In Chapter 4, further comparison will be made regarding the two stress-strain relationships.

2.2.2 Tensile Stress-Strain Relationship.

Tensile strength of concrete is usually neglected in conventional reinforced concrete theory. It is of a magnitude so small that the stress induced by shrinkage in a reinforced concrete member may exceed the tensile strength and cracks may develop even before the member is loaded in flexure. It would be unconservative to take it into account. However, in a prestressed concrete member, stress can be controlled in such a way that under service load it rarely exceeds the

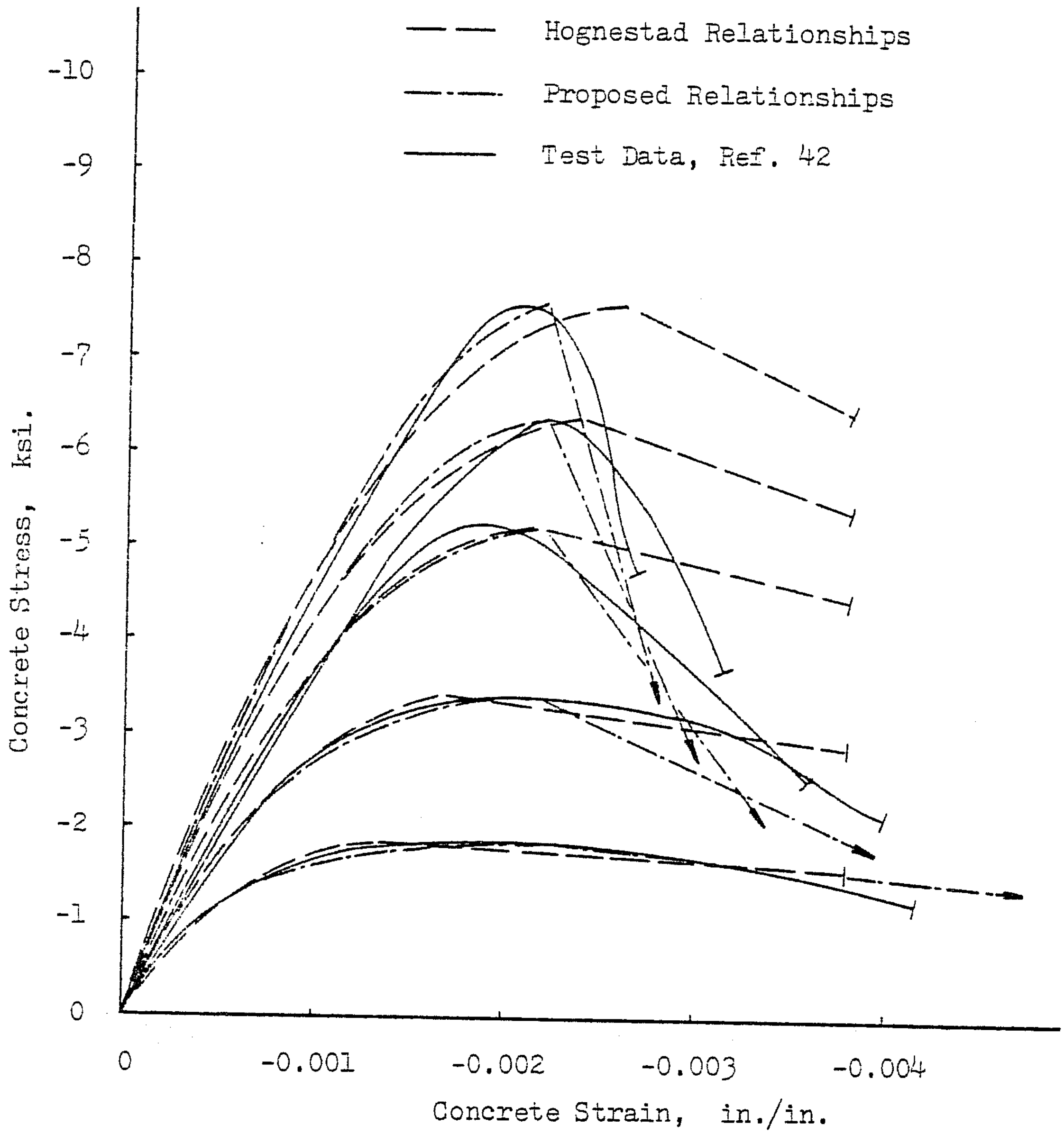


Fig. 2.3 Comparison of the Proposed Stress-Strain Relationship, the Hognestad Stress-Strain Relationship, and the Test Data for Unconfined Concrete from Flexural Test, Ref. 42.

tensile strength. Because the stiffness of the member after it is cracked is greatly reduced, the neglect of the tensile strength of concrete will greatly affect the prediction of the response of a prestressed beam.

Since the tensile strength of concrete is relatively small, compared to the compressive strength, and stress in a prestressed concrete member is mostly in compression, the tensile stress-strain relationship for the member may be adequately represented as a straight line at a slope equal to the initial modulus of elasticity for concrete, E_{ci}, up to the modulus of rupture, f_r, as:

$$f_t = E_{ci}\varepsilon \qquad \text{for} \quad \varepsilon \leq f_r/E_{ci}$$

$$f_t = 0 \qquad \text{for} \quad \varepsilon > f_r/E_{ci}$$

where f_t = tensile stress of concrete at tensile strain of ε .

The accuracy of the estimation of the modulus of rupture is of importance for it influences directly the cracking moment of a section.

Warwaruck, et al., (91) based on an extensive study of strength and behavior of prestressed beams, suggested that the modulus of rupture of concrete, f_r, may be related to f'_c by the following expression:

$$f_r = 3000/(3 + 12000/|f'_c|)$$

The current trend is to express f_r as a power function of f'_c as:

$$f_r = a\, f'^{\,b}_c$$

The A.C.I. (3) recommended the values of a of 7.5 for normal weight concrete, 0.85 x 7.5 for sand-lightweight concrete, and 0.75 x 7.5 for all-lightweight concrete, and the value of b of 1/2. However, tensile stress ranging from $6.0\sqrt{|f'_c|}$ to $12.0\sqrt{|f'_c|}$ is allowed at service load in a flexural prestressed concrete member depending on loading conditions. The deflection must be checked by a rational analysis for those higher stress levels which may produce cracking.

The C.E.B. (84) recommended the value of a of 0.56 and the value of b of 2/3 for the mean value of f_r for normal wieght concrete. A correction factor of 0.30 + 0.7 w/2400 is needed for lightweight concrete. Note that w is in kg./m.^{3} and the function is in MPa units. The factors of 0.6 and 1.4 are applied for f_r at 5 % fractile and 95 % fractile, respectively.

Sargin (78), after an analysis of available experimental data, suggested that the value of a of between 2 and 2.3 along with the value of b of 2/3 are more appropriate. He recommended the value of a as 2.3 and the value of b as 2/3.

Fadl, et al., (28) based on the tests on post-tensioned composite bridge girders, stated that the use of f_r equal to $7.5\sqrt{|f'_c|}$ gave a good indication of the positive moment cracking potential and $6\sqrt{|f'_c|}$ worked well for the negative moment cracking and cracking at the junctions between the precast girders and the cast-in-place splice concrete.

The values of f_r for normal weight concrete as estimated by the listed expressions are compared in Fig. 2.4. The values recommended by Wararuck, et al., the A.C.I. and the C.E.B. are about the same in the range of f'_c between 1000 psi. to 9000 psi.. The A.C.I values for f_r seem to be good averages of the three expressions. So in the absence of the experimental data, for normal weight concrete, it was decided to use the A.C.I. expression for the modulus of rupture of concrete as:

$$f_r = 7.5\sqrt{|f'_c|}$$

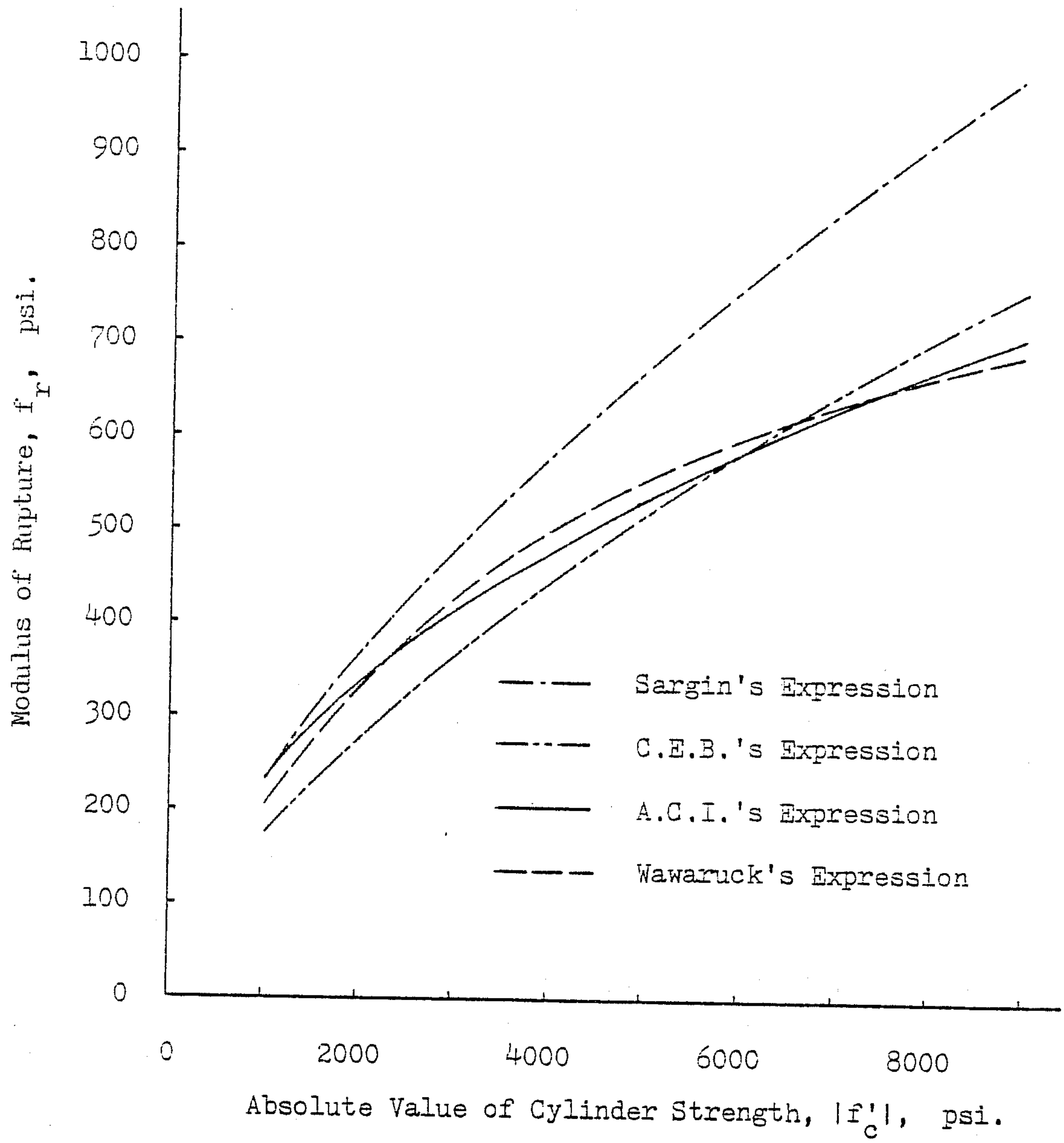


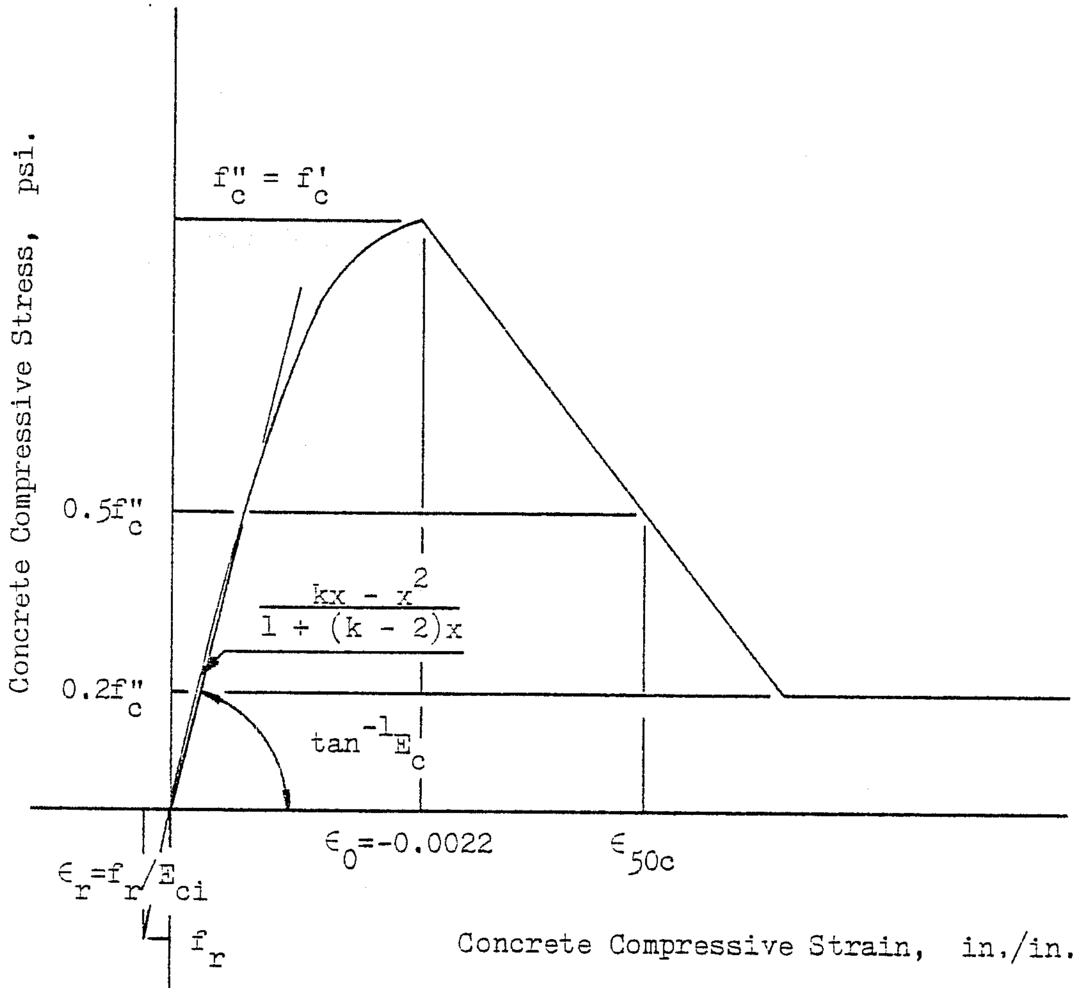
Fig. 2.4 Modulus of Rupture for Normal Weight Concrete as Function of Cylinder Strength by Various Investigators.

The complete stress-strain curve of concrete as a function of the compressive cylinder strength, f'_c, which will be used in the present study, is shown in Fig. 2.5.

2.2.3 Age-Strength Relationship.

Concrete under ordinary ambient conditions gains strength with age because of further hydration of the cement. A study of fifty year properties of concrete by Washa and Wendt (90) showed the increase in strength of concrete to reach a peak value at the age of about 10 to 50 years, depending on the storage condition and the types of cement, and showed strength retrogressions thereafter. Average increase in compressive strength at the age of 50 years is about 10 to 40 percent of the strength of the comparable specimens at the age of 28 days. Although the increase in strength is usually neglected in design, for more accuracy, the effect will be included in the present study.

Compressive strength tests of concrete cylinders are usually made at the age of 7 days or 28 days. Several investigators have attempted, almost all of them with experimental data, to relate the strength of concrete at a later age to the strength at a standard age. The relationship depends on many factors, such as water-cement ratio, mix proportion, admixture, qualities of cement, curing condition, ambient condition, and cross-sectional shape. For a particular mix, age-strength relationship of concrete may be expressed as a function of age of concrete and curing condition. Empirical expressions were proposed, some of which will be discussed below.



$$k = E_{ci}\epsilon_0/f''_c$$

$$E_c = w^{1.5} 33 \sqrt{|f''_c|}$$

$$E_{ci} = E_c \left[1 + \{f''_c/(E_c\epsilon_0) - 1\}^2\right]$$

$$f_r = 7.5 \sqrt{|f''_c|}$$

Fig. 2.5 Concrete Stress-Strain Relationship Used in This Study.

Plowman (69) indicated that concrete kept at a relative humidity of 90 percent or more gained strength as a function of maturity M as:

$$(f'_c)_M/(f'_c)_{35600} = a + a_1 \log M - a_2$$

where a, a_1, and a_2 are empirical constants, a_2 applies only with rapid hardening cement for maturities greater than 40000 ^oF-hours.

M is the summation of the integrals of time and temperature of concrete above 11 ^oF, negative values being disregarded. M is in ^oF-hours.

Khalifa (52) proposed a logarithmic function of the same form as Plowman's. But instead of maturity, he expressed the relation as a function of age of concrete as:

$$(f'_c)_t/(f'_c)_{28} = a + a_1 \log t$$

where t = age of concrete in days.

Based on the observation that the strength gain with time has an asymptotic character and the strength is zero at zero time, Goral (31) proposed a hyperbolic function to represent strength-age curve of concrete.

$$(f'_c)_t/(f'_c)_{28} = t/(a + a_1 t)$$

The A.C.I Committee 209 (2), based on the extensive study by Branson and Christiason, recommended a function of the same form as Goral's. From the measurements of some 88 specimens of normal weight, sand-lightweight and all lightweight concrete, using both moist curing and steam curing and Type I and Type III cement, the values of a are found to range from 0.50 to 9.25 and the values of a_1 from 0.67 to 0.98. The following values have been suggested for different types of cement and curing conditions.

Moist cured concrete, Type I cement:

$$(f'_c)_t/(f'_c)_{28} = t/(4.00 + 0.85t)$$

Moist cured concrete, Type III cement:

$$(f'_c)_t/(f'_c)_{28} = t/(2.30 + 0.92t)$$

Steam cured concrete, Type I cement:

$$(f'_c)_t/(f'_c)_{28} = t/(1.00 + 0.95t)$$

Steam cured concrete, Type III cement:

$$(f'_c)_t/(f'_c)_{28} = t/(0.70 + 0.98t)$$

Each of the proposed relations seem to represent the age-strength of the concrete well, at least for the data and the range of limitations in the corresponding studies. Since there are many factors involved and each relationship takes into account only some of them, for a set of data, one relationship may prove to be better than the others. In the present study, if long term data are available, a best fitting curve can be used directly. In the absence of the experimental data, the A.C.I. Committee 209 recommendation seems to be better than the others since it takes into account all major variables.

The stress-strain curve of concrete, as previously discussed, can be expressed as a function of the cylinder compressive strength of concrete, f'_c. For consistency, each key variable should be estimated from the strength of concrete at the time of consideration. Without redetermining the general shape of the curve, a stress at any strain at different ages may be found from modified curves taking into account the aging effects. As will be seen later, a nonlinear stress-strain curve is specified at points along the curve. The curve will be generated when needed by linearly connecting consecutive points on the curve. Each modified curve then will be obtained by applying a stress age factor and a strain age factor for that age to the points on the corresponding standard age curve. The factors are applied in such a way that the initial modulus and the maximum compressive strength of the modified curve will be the same as those of the actual curve at that age. The cut-off points, i.e. the maximum and minimum strain limits, for the modified curves will not be adjusted. The procedure used is illustrated, using the A.C.I. Committee 209 recommendation for the age function, in Fig. 2.6. The figure shows a stress-strain curve for concrete at the standard age of 28 days and a modified stress-strain curve for concrete at the age of t days. The stress-strain relationship along the modified curves will not be strictly correct, but the error which arises will be minimal.

2.3 Time-Dependent Properties of Concrete.

2.3.1 Creep of Concrete Under Constant Sustained Stress.

Creep of concrete under constant stress follows a specific pattern. Creep is proportional to the applied stress up to some limiting stress level. The limiting values suggested, as listed in the report by Hamada, et al., (33) range from $0.225f'_c$ to $0.9f'_c$. Rate of creep decreases with time providing that stress is not high enough to cause progressive internal cracking which leads to time failure. Creep tends to approach a finite limiting value. Although tests (87) show creep deformations continue over a period of as long as 28 years, the rate of creep at the later age was so small that it would not cause any significant deformation.

Attempts have been made to represent the time-creep response of concrete with creep functions so that the amount of creep under sustained load may be estimated without performing long term creep measurements. Extensive references may be found in the report by Ali and Kesler (5), A.C.I. Annotated Bibliography No. 7 (1), and the book by Neville (65).

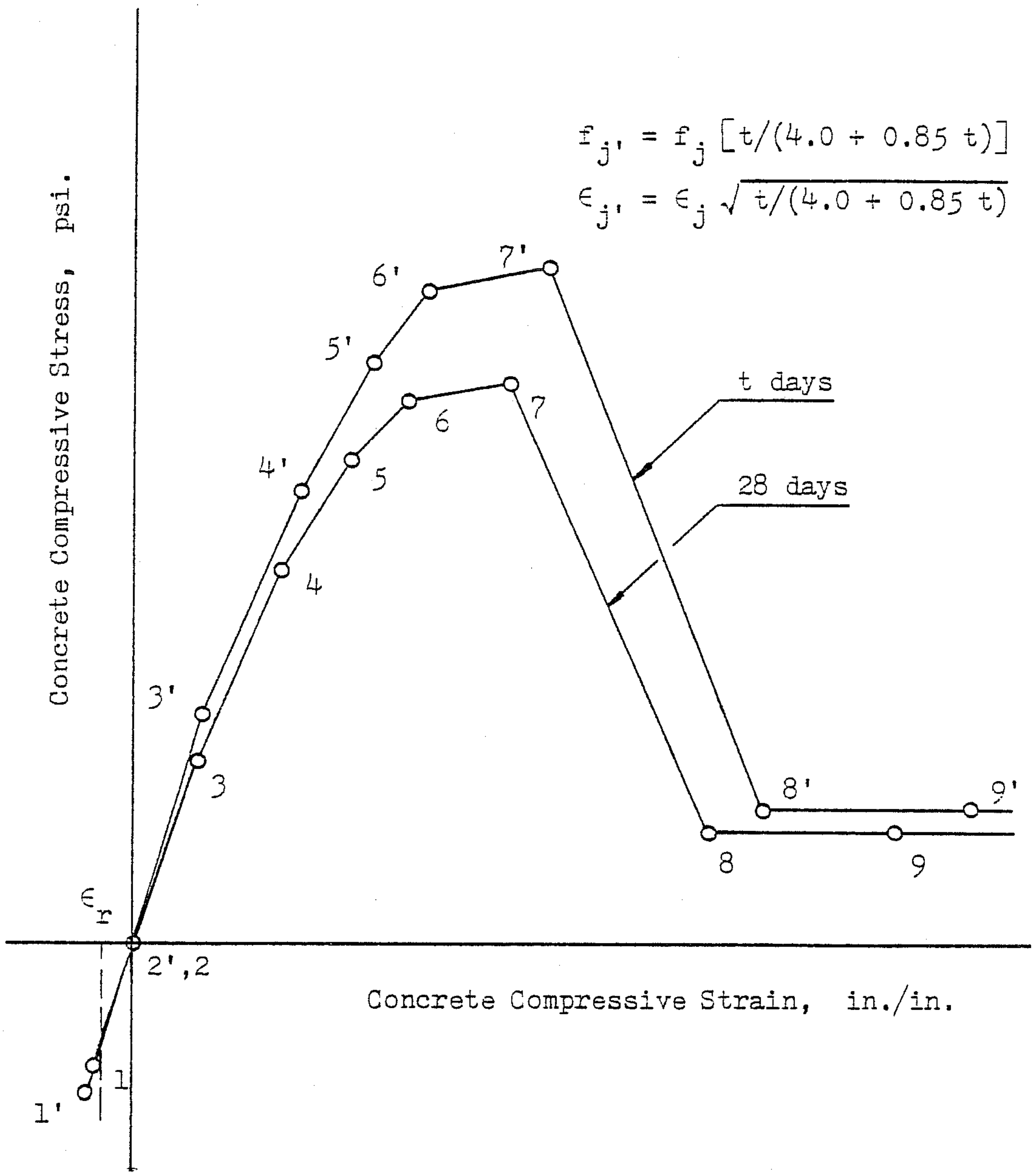


Fig. 2.6 Concrete Stress-Strain Curves at Different Ages, Using the A.C.I. Committee 209 Recommendation for Type I Cement, Moist Cured Concrete.

Four broad types of creep functions were proposed: power function, logarithmic function, exponential function, and hyperbolic function. Some of them will be listed below.

Power Functions.

Straub (83) proposed an expression in the form of:

$$(\varepsilon_c)_t = a f_c^{b1} t^{b2}$$

where $(\varepsilon_c)_t$ = concrete creep strain at time t after loading under sustained compressive strain f_c,

and a, b_1, and b_2 = empirical constants.

Creep is a power function of both stress level and time after loading.

Shank (80), based on the expression proposed by Straub and the observation that for ordinary Portland cement concrete under ordinary conditions, creep was proportional to stress, suggested the following expression:

$$(c_\varepsilon)_t = a\ t^{1/b}$$

where $(c_\varepsilon)_t$ = specific creep, creep strain per unit sustained stress, at time t days after loading,

and a and b = empirical constants.

The empirical constants, a and b, were found to depend on qualities of concrete, age at loading, and surrounding atmospheric conditions. For cylinder of Type I cement concrete loaded at 28 days and stored in air, a was found to be 0.13×10^{-6} and b was found to be 3. Because the equation has no limiting value, it fits the experimental data well for the period of one day to one year. Shank suggested a method to scale down the values calculated by the proposed equation for better accuracy.

Saliger (77) proposed another power function to represent creep-time relationship.

$$(\varepsilon_c)_t = a(g)_t f_c$$

where g = function of time.

The empirical constant, a, was found to be 0.422×10^{-6}, the function g was equal to $t^{1/3}$. Saliger also assumed that there was no further creep after load had been sustained for 30 months.

Friedrich (29) suggested an expression similar to Shank's to predict creep.

$$(\varepsilon_c)_t = a(t/1400)^{1/4}$$

Creep was assumed to stop at the end of 1400 days.

Logarithmic Functions.

The U.S. Bureau of Reclamation (45), based on the assumption that the rate of specific creep was inversely proportional to time after loading, derived the following expression:

$$(c_\varepsilon)_t = a \ln(t/a_1 + 1)$$

where a is a parameter obtained experimentally, representing the rate of creep with time. If no time distortion element is desired, the constant a_1 may be taken equal to 1 and the expression is reduced to:

$$(c_\varepsilon)_t = a \ln(t + 1)$$

Troxell, et al., (87) observed a relation between creep and logarithm of time. Despite the variety of mixes, water-cement ratio, consistency, rock types, storage, load intensity, and age at loading, the plot between creep and logarithm of time fell in a narrow band. Without losing much accuracy, the data may be represented by two straight lines as:

For 10 days $\leq t < 730$ days

$$(\varepsilon_c)_t = [0.149 \ln(t + 1) - 0.123]\,(\varepsilon_c)_{7300}$$

For 730 days $\leq t$

$$(\varepsilon_c)_t = [0.0665 \ln(t/730) + 0.86]\,(\varepsilon_c)_{7300}$$

Bazant (8) also used the following expression in his study.

$$(c)_{t,t'} = (c)_{\infty,t'} 0.113 \ln(1 + t - t')$$

$$(c)_{\infty,t'} = (c)_{\infty,7} 1.25\, t'^{-0.118}$$

where $(c)_{t,t'}$ = creep coefficient, ratio of creep strain to instantaneous strain, at time t days due to sustained load applied at time t' days.

Exponential Functions.

Thomas (86) assumed that creep of cement paste was proportional to the applied stress and creep of hydrated cement paste was restrained by the aggregate with the load being gradually transferred from the cement paste to the aggregate. He developed the following expression for creep in concrete:

$$(c)_t = (c)_\infty \{1 - e^{[-a_1 \{(t + a_2)^b - a_2{}^b\}]}\}$$

where $(c)_t$ = creep coefficient, ratio of creep strain to initial strain, at time t days.

McHenry (63) assumed that, under constant stress, the rate of creep was at all times proportional to the amount of potential creep remaining. And he also assumed that during the period before the properties stabilized a transient creep property existed, disappearing at a rate proportional to itself. The two types of creep are additive. Various combinations of functions may satisfy the assumptions. The following expression was chosen:

$$(c_\varepsilon)_{t,t'} = a(1 - e^{b_1 t}) + be^{-b_2 t'}(1 - e^{-b_3 t})$$

For sealed concrete, loading at the age of 7 days to 90 days, the constants were found to be:

$$10^6(c_\varepsilon)_{t,t'} = 0.04(1 - e^{-0.6t}) + 0.398e^{-0.025t'}(1-e^{-0.06t})$$

If the age at loading is less than 5 days, the expression conforms to the experimental data better if a third term

$$1.55e^{-0.726t'}(1 - e^{-0.122t})$$

is added.

Lyse (59), based on the assumption that shrinkage was proportional to the cement paste content, and upon the observation of the similarity between creep-time relationship and shrinkage-time relationship, proposed an expression for creep of concrete:

$$(\varepsilon_c)_t = (\varepsilon_s)_\infty (1 - e^{-bt}) V_p f_c / f_{sh}$$

where $(\varepsilon_s)_\infty$ = ultimate free drying shrinkage strain of concrete,

V_p = ratio of volume of cement paste to volume of concrete,

and

f_{sh} = magnitude of sustained stress which will give creep strain equal to shrinkage strain of concrete at given relative humidity.

The expression was based on Arutyunyan's shrinkage curve.

Kingham, et al., (53) used a modified exponential expression to predict creep and shrinkage of concrete and relaxation of steel. Taking into account the dependence of creep on the stress-strength ratio, they represented the creep-time relation as:

$$(\varepsilon_c)_t = a[f_c/(f'_c)_{t'}]^{b_1}(1 - e^{-t/b_2})^{b_3}$$

From a regression analysis of data from the tests of 24 concrete cylinders with more than three yers of outdoor exposure, the following values of constants were obtained:

$$(\varepsilon_c)_t = -0.00356\ [f_c/(f'_c)_{t'}]^{0.96}(1 - e^{-t/500})^{0.73}$$

Arutyunyan (6) noted the following properties for a creep function:

a) $(c_\varepsilon)_{t,t'} > 0$ for all values of $t > t'$,
$(c_\varepsilon)_{t,t'} = 0$ and $t = t'$,

b) $\lim_{t \to \infty} \partial(c_\varepsilon)_{t,t'}/\partial t = 0$ for all values of $0 < t' \leq t$,

c) $(c_\varepsilon)_{t,t'}$ decreases uniformly in relation with age of material so that the function approaches a final value,

and d) there is a dependence, however little, of the creep on the age of the material at loading.

Based on these properties, he suggested a creep function in the form of:

$$(c_\varepsilon)_{t,t'} = [(c_\varepsilon)_{\infty,t'} + \sum_{k=1}^{m} a_{1k}/t'^{k}]\ (\sum_{k=0}^{n} a_{2k}e^{-b_k(t - t')})$$

Since the terms in the series decrease their values very rapidly, only the first two terms might be sufficient. The creep function is then reduced to:

$$(c_\varepsilon)_{t,t'} = [(c_\varepsilon)_{\infty,t'} + a_1/t']\ (1 - a_2e^{-b(t - t')})$$

Erzen (26) proposed the following formula to estimate total strain in excess of shrinkage strain:

$$(\varepsilon_t)_{t,t'} = (\varepsilon_e)_{t,t'}e^{a[1 - (t'/t)^b]}$$

where $(\varepsilon_t)_{t,t'}$ = total strain in concrete under sustained load applied at time t' days, in excess of shrinkage, at time t days,

and $(\varepsilon_e)_{t,t'}$ = instantaneous strain at time t days due to load applied at time t' days.

Creep strain then may be written as:

$$(\varepsilon_c)_{t,t'} = (\varepsilon_e)_{t,t'} \{e^{a\,[1 - (t'/t)^b]} - 1\}$$

From the Shasta Dam concrete data, Erzen found both constants, a and b, to be equal to 0.75.

Hyperbolic Functions.

Ross (74) proposed a hyperbolic function to predict creep:

$$(c_\varepsilon)_t = t/(a_1 + a_2 t)$$

Hansen and Nielsen (35) made a study on the influence of size and shape of member on the shrinkage and creep of concrete. The specimens were stored at the temperature of 70°F and in 50 percent relative humidity. Creep specimens were loaded in compression at a uniform stress of about $0.25f'_c$. The data were represented by a hyperbolic function of the form:

$$(\varepsilon_c)_t = (\varepsilon_c)_\infty t/(a + t)$$

where the constant, a, is a function of volume-surface ratio, V/S, as:

$$a = 26.0\ e^{0.36(V/S)}$$

The curve fit closely to the data except at the early age of less than 100 days where it overestimated the data.

The A.C.I. Committee 209 (2), based on the work by Branson and Christiason (13), represented the creep-time relationship by a function:

$$(c)_t = (c)_\infty t^b/(a + t^b)$$

The empirical constants, a and b, and the ultimate creep coefficient, $(c)_\infty$, are the functions of material properties, geometry, ambient atmosphere, and the time at loading. The values of a are found to range from 6 to 30, b ranges from 0.40 to 0.80, and $(c)_\infty$ ranges from 1.3 to 4.15. To estimate creep, a standard creep curve is recommended.

$$(c)_{t,t'} = (c)_\infty (t - t')^{0.60} / [10 + (t - t)^{0.60}]$$

The curve is for 4 in. or less slump, 40 percent ambient relative humidity, minimum thickness of member 6 in. or less, loading age 7 days for moist cured or 1 to 3 days for steam cured concrete. The average suggested value of $(c)_\infty$ is 2.35. Correction factors are suggested for concrete under different conditions. They are listed below:

Loading ages later than 7 days for moist cured concrete and later than 1 to 3 days for steam cured concrete:

For moist cured concrete

$$CC_{LA} = 1.25t'^{-0.118}$$

For steam cured concrete

$$CC_{LA} = 1.13t'^{-0.095}$$

where CC_{LA} = creep correction factor for age of concrete at loading t' days.

Ambient relative humidity greater than 40 percent

$$CC_H = 1.27 - 0.0067\ H \qquad H > 40\%$$

where CC_H = creep correction factor for ambient relative humidity H percent.

Minimum thickness of member, T is the minimum thickness in in.

$$CC_T = 1.14 - 0.023\ T \qquad \text{for} \leq 1 \text{ yr. loading}$$

$$CC_T = 1.10 - 0.017\ T \qquad \text{for ultimate value}$$

where CC_T = creep correction factor for member thickness T in..

Slump, S is the slump in in.

$$CC_S = 0.82 + 0.067\ S$$

where CC_S = creep correction factor for consistency of concrete.

Percent fine, F is the percent of fine aggregate by weight

$$CC_F = 0.88 + 0.24\ F$$

where CC_F = creep correction factor for percent fine F of concrete.

Air content, A is the air content in percent

$$CC_A = 1.0 \qquad A \leq 6\%$$

$$CC_A = 0.46 + 0.090\ A \qquad A > 6\%$$

where CC_A = creep correction factor for air content A of concrete.

A combination of hyperbolic and exponential expressions was recommended by Wallo and Kesler (89). The total creep was assumed to be a summation of two components, basic creep and drying creep. Basic creep was considered to be the part of creep which could occur independent of the moisture loss or gain and drying creep is the additional creep due to the change of moisture content. A rheological model was developed conforming to the viscoelastic nature of the basic creep. The following expression was obtained for the basic creep:

$$(\varepsilon_{cb})_t = f_c\, G\, [a_1(1 - e^{-t/b_1}) + a_2(1 - e^{-t/b_2}) + a_3 t]$$

$$G = (1 - V_a - V_{uc})^2/V_{hc}$$

where $(\varepsilon_{cb})_t$ = basic creep strain of concrete at time t after loading,

G = gel compliance, ratio of deformation of gel component of concrete to deformation of hypothetical specimen of pure gel subjected to same stress as concrete,

V_a = ratio of volume of aggregate to volume of concrete,

V_{uc} = ratio of volume of cement paste to volume of concrete,

and V_{hc} = ratio of volume of hydrated cement including gel pores to volume of concrete.

For concrete stored at 70°F temperature and in the relative humidity of 100 percent, the following values of constants were found:

a_1 = 225×10^{-9}
a_2 = 115×10^{-9}
a_3 = 0.3×10^{-9}
b_1 = 35
and b_2 = 2

As for drying creep, the following hyperbolic function was recommended:

$$(\varepsilon_{cd})_t = f_c G \left| (\varepsilon_s)_t \right| (a + a_1/t)/V_{hc}$$

where $(\varepsilon_{cd})_t$ = drying creep strain of concrete at time t after loading,

and $(\varepsilon_s)_t$ = free drying shrinkage strain of concrete at time t after loading.

The free drying shrinkage at time t days, $(\varepsilon_s)_t$, may be estimated as:

$$(\varepsilon_s)_t = -\ (2400 - 2100V_{hc})(1 - V_s)(0.96 \log \{(105 - H)/5\}\ (1 - e^{-0.1(S/V)t^{0.65}}) \times 10^{-6} \text{ in./in.}$$

where V_s = $Va + V_{uc}$, ratio of volume of solids to volume of concrete, Form the data measured at 70°F and 50 percent relative humidity, the constants, a and a_1, were found to be 2.99 x 10^{-4} and 7.73 x 10^{-4}, respectively.

The creep function is also presented as curves instead of mathematical expressions by some investigators. The P.C.I. Committee on Prestress Losses (67) recommended a method in determining prestress losses using a series of curves. The prestress losses due to creep may be converted to the equivalent creep strain by dividing the loss by the modulus of elasticity of the prestressing steel (27.5 x 10^6 psi.). Creep may then be written as follows:

$$(\varepsilon_c)_{t,t'} = (c_\varepsilon)_\infty CC_T CC_{LA} (g_c)_t f_c$$

where CC_T = correction factor for size and shape of member. It is a function of volume to exposed surface ratio.

CC_{LA} = correction factor for age at loading and length of cure. The factor does not apply to accelerated cured concrete.

and $(g_c)_t$ = function representing of creep with time evaluated at time t.

The correlation factors, CC_T, CC_{LA}, and g_c are shown in Fig. 2.7. The ultimate creep strain per unit stress, $(c_\varepsilon)_\infty$, may be estimated as follows:

Normal weight concrete, moist cure not exceeding 7 days

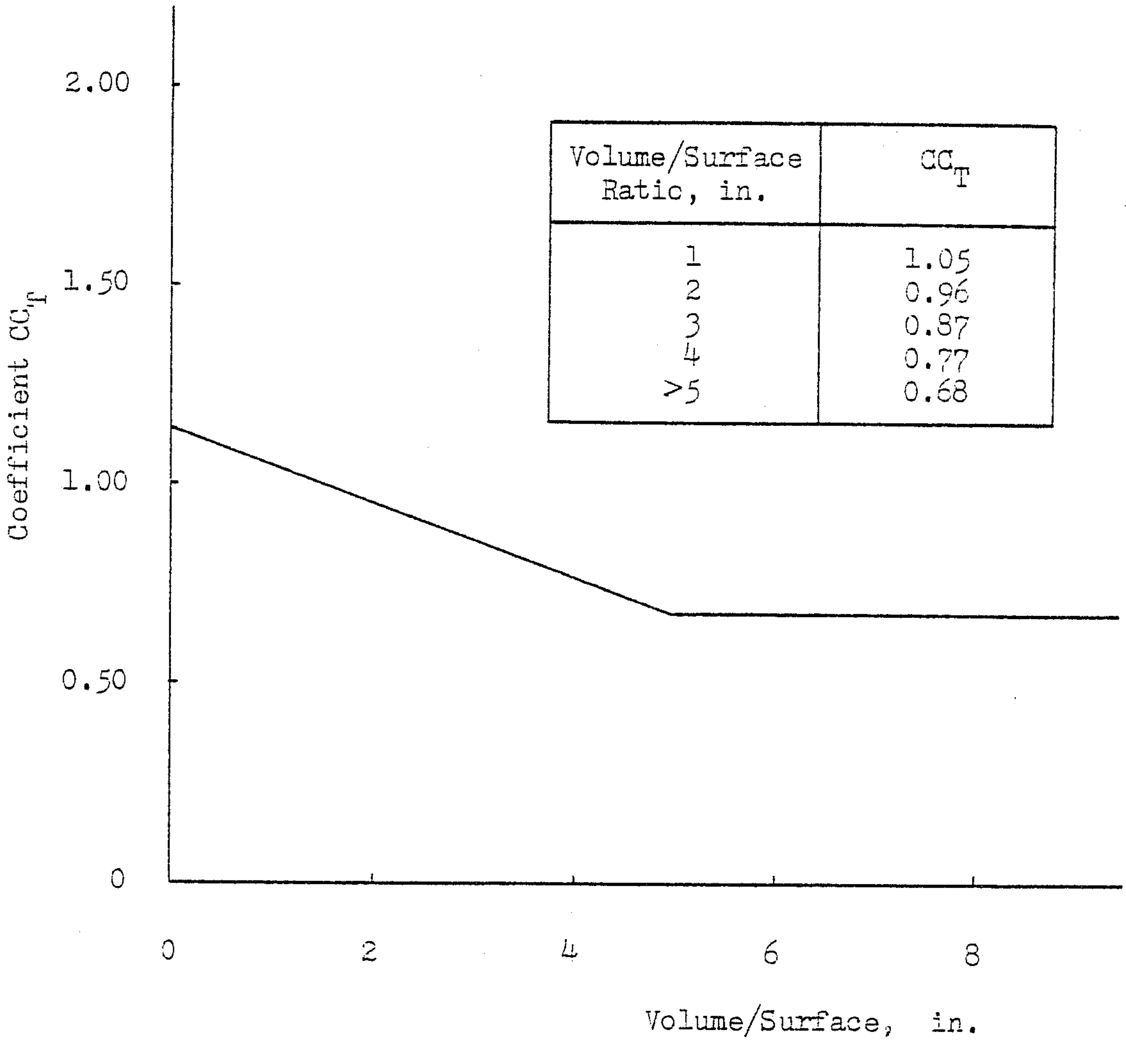
$$(c_\varepsilon)_\infty = 3.455 \times 10^{-6} - 7.273 \times 10^{-13} E_c \geq 4.00 \times 10^{-6}$$

Normal weight concrete, accelerated cure

$$(c_\varepsilon)_\infty = 2.291 \times 10^{-6} - 7.273 \times 10^{-13} E_c \geq 4.00 \times 10^{-6}$$

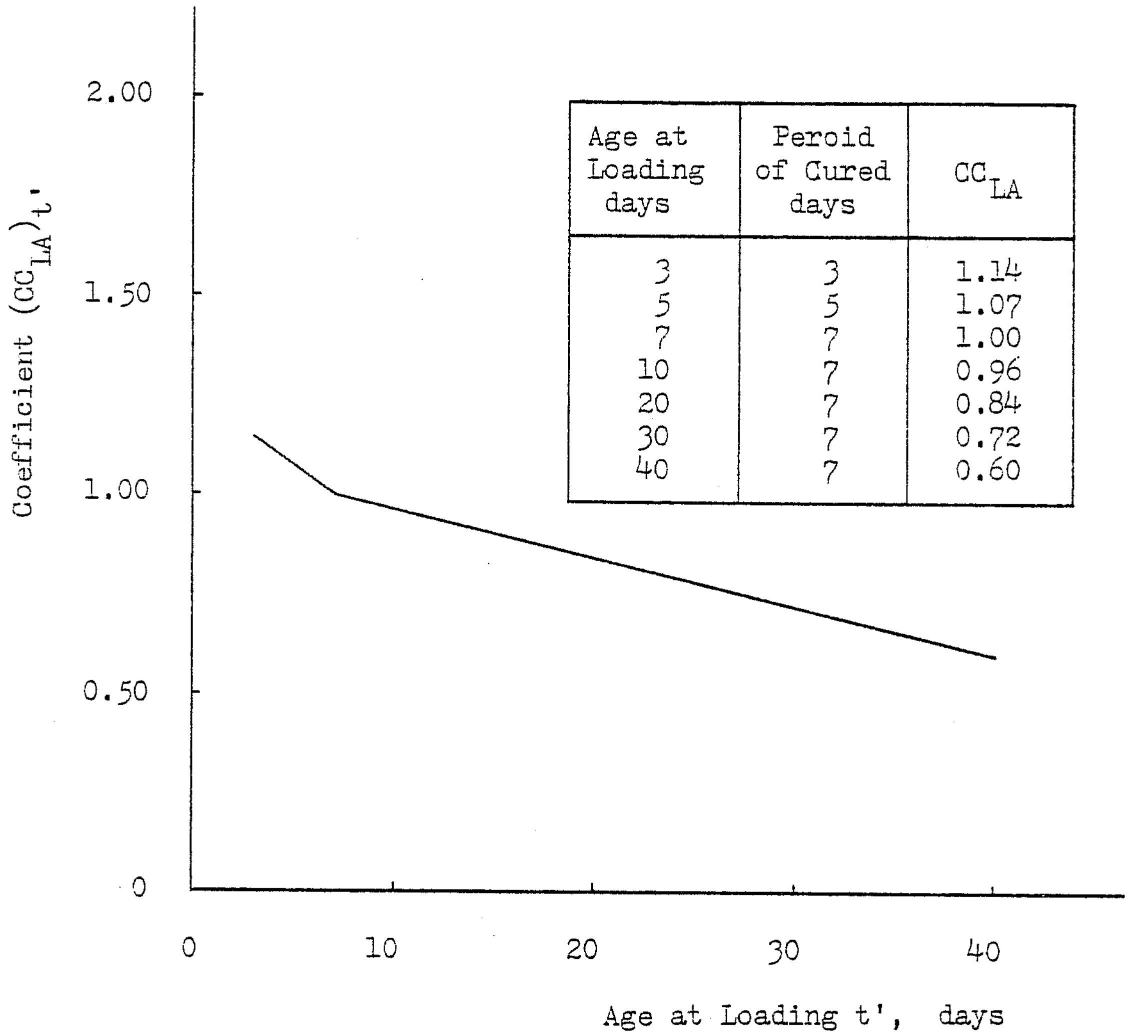
Lightweight concrete, moist cure not exceeding 7 days

$$(c_\varepsilon)_\infty = 2.764 \times 10^{-6} - 7.273 \times 10^{-13} E_c \geq 4.00 \times 10^{-6}$$



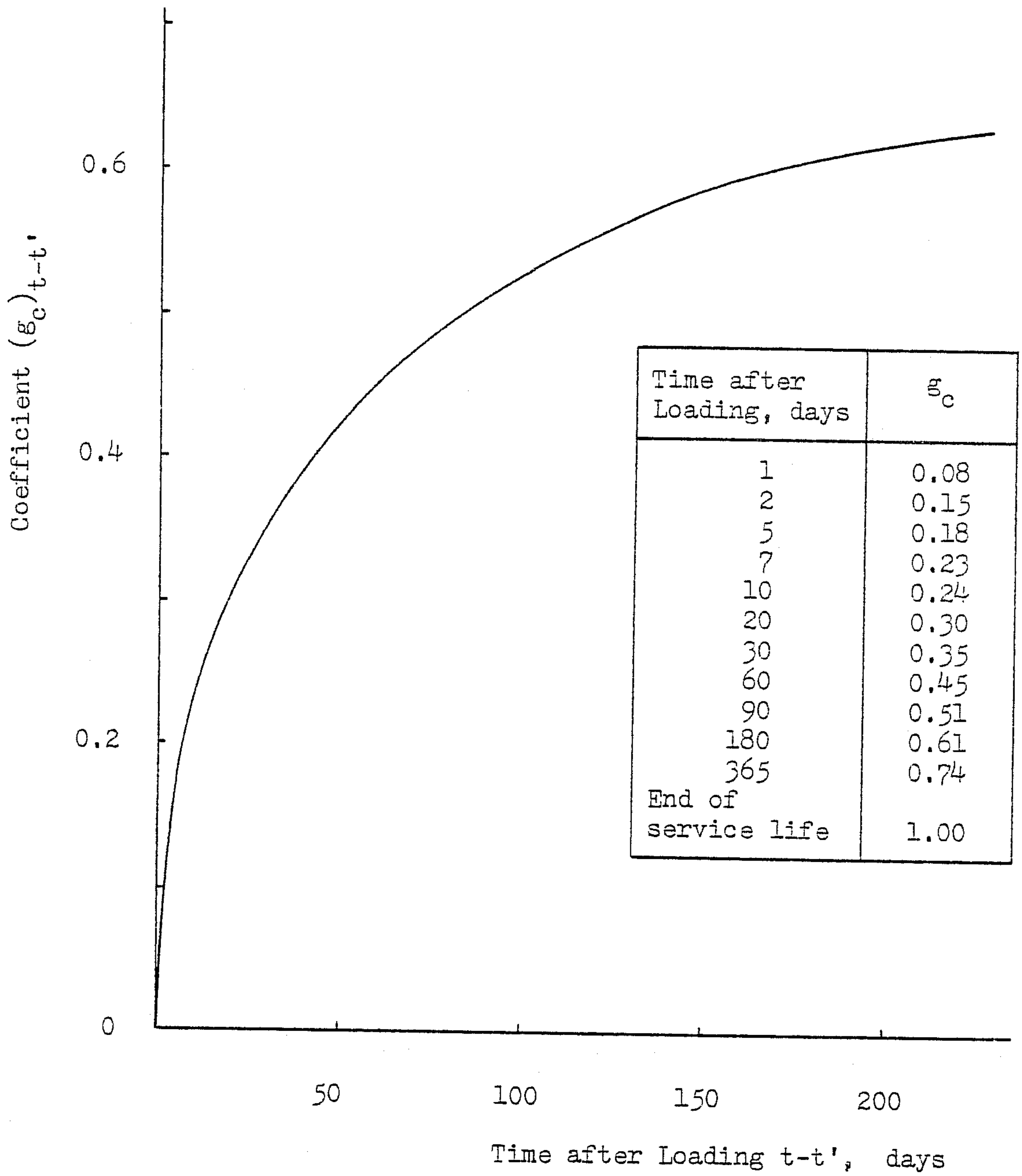
Volume/Surface Ratic, in.	CC_T
1	1.05
2	0.96
3	0.87
4	0.77
>5	0.68

Fig. 2.7 The P.C.I.'s Creep Prediction Curves.



Age at Loading days	Peroid of Cured days	CC_{LA}
3	3	1.14
5	5	1.07
7	7	1.00
10	7	0.96
20	7	0.84
30	7	0.72
40	7	0.60

Fig. 2.7 Cont.



Time after Loading, days	g_c
1	0.08
2	0.15
5	0.18
7	0.23
10	0.24
20	0.30
30	0.35
60	0.45
90	0.51
180	0.61
365	0.74
End of service life	1.00

Fig. 2.7 Cont.

Lightweight concrete, accelerated cure

$$(c_\varepsilon)_\infty = 2.291 \times 10^{-6} - 7.273 \times 10^{-13} E_c \geq 4.00 \times 10^{-6}$$

$(c_\varepsilon)_\infty$ is in in./in./psi..

The C.E.B. (84) proposed that creep deformation is composed of two parts: a permanent irreversible part (deferred plasticity) which is very sensitive to the age of concrete at the time of loading and a reversible part (deferred elasticity) which is independent of the aging of concrete. Creep strain may be estimated following the C.E.B. as:

For normal weight concrete

$$(\varepsilon_c)_{t,t'} = [(f_c)_{t'}/(E_{cs})_{28}]\ (c)_{t,t'}$$

where $(\varepsilon_c)_{t,t'}$ = creep strain in concrete at time t due to $(f_c)_{t'}$, sustained load f_c applied at time t',

$(f_c)_{t'}$ = sustained load f_c applied at time t',

and $(E_{cs})_{28}$ = basic value for scant modulus of longitudinal deformation of concrete at age of 28 days,

$$(E_{cs})_{28} = 9500\ \sqrt[3]{|(f'_c)_{28}| + 8}\ \text{MPa.}$$

The creep coefficient, $(c)_{t,t'}$, may be estimated from a series of curves as follows:

$$(c)_{t,t'} = CC_D (g_d)_{t-t'} + CC_{FO}\ [(g_f)_t - (g_f)_{t'}]$$

where CC_D = deferred coefficient of elasticity which may be taken as constant and equal to 0.4,

$(g_d)_{t-t'}$ = function representing development with time of deferred elastic deformation, evaluate at time t-t' after loading,

CC_{FO} = $CC_{F1} CC_{F2}$; CC_{F1} is the coefficient taking into account the consistency of concrete and the surrounding conditions, and CC_{F2} is the coefficient depending on the theoretical thickness of the member, h_{th}, and g_f = function representing development with time of deferred flow. $(g_f)_t$ and $(g_f)_{t'}$ are the values of g_f evaluated at t and t', respectively. g_f is dependent on the theoretical thickness of the member, h_{th}.

The theoretical thickness of the member, h_{th}, is defined as:

$$h_{th} = B_H(2V/S)$$

where B_H = coefficient dependent of surrounding medium.

The values of the coefficients, CC_{F1} and B_H, are given in Table 2.1. The values of the coefficients, g_d, CC_{F2}, and g_f, are given as curves as shown in Fig. 2.8. In the Figure, the times t and t' are the ages of concrete in days at the time considered and at the time of loading, respectively. Since the values of the coefficients given are for normal setting cement concrete hardening at a normal temperature, the age of concrete in other cases must be corrected as follows:

$$t = B_S \, \Sigma[\Delta t(T + 10)/30]$$

where t = corrected age,

B_S = coefficient depending on speed of setting of cement,

for normal and slow setting cement: $B_S = 1$

for rapid setting cement: $B_S = 2$

for rapid setting cement of high strength: $B_S = 3$

for shrinkage coefficients, always use $B_S = 1$,

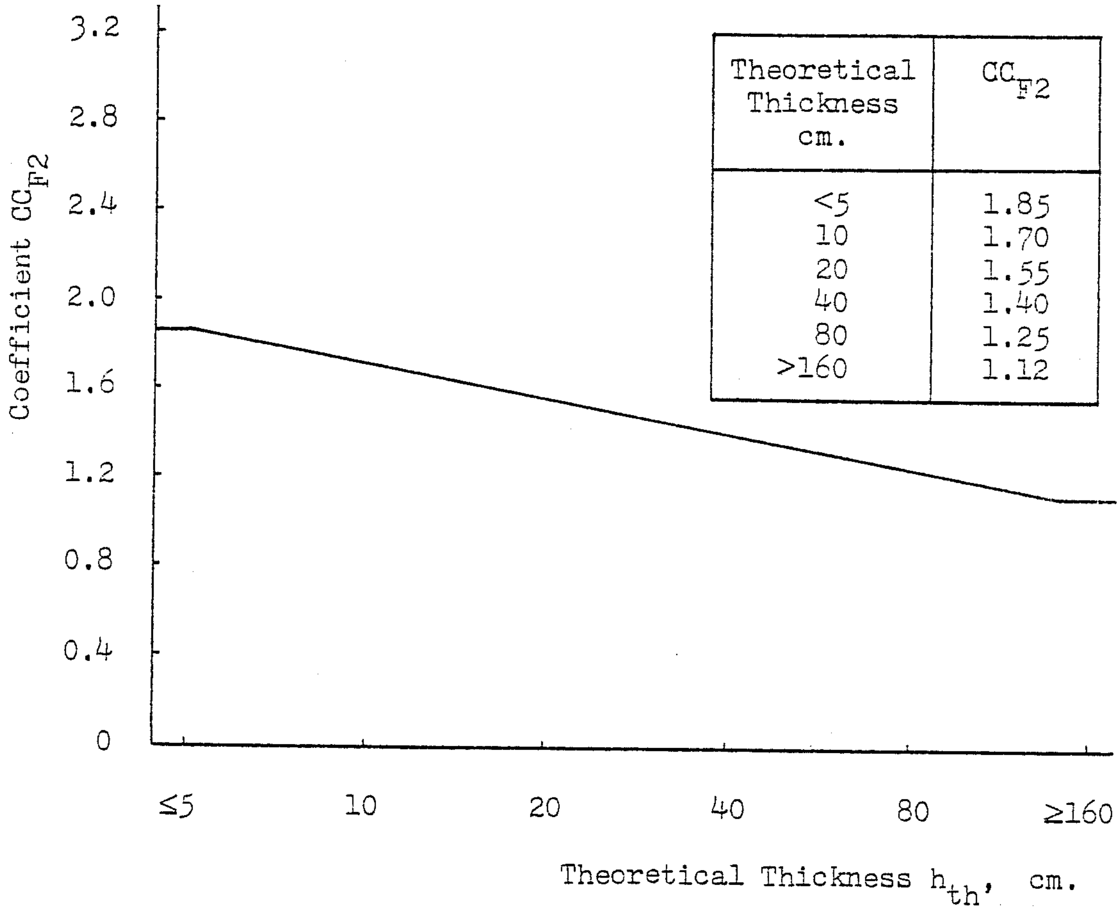
and Δt = number of days during which hardening takes place at temperature T of concrete, the temperatures are in ^oC.

Table 2.1

Coefficients for Estimating Creep and Shrinkage by the C.E.B.

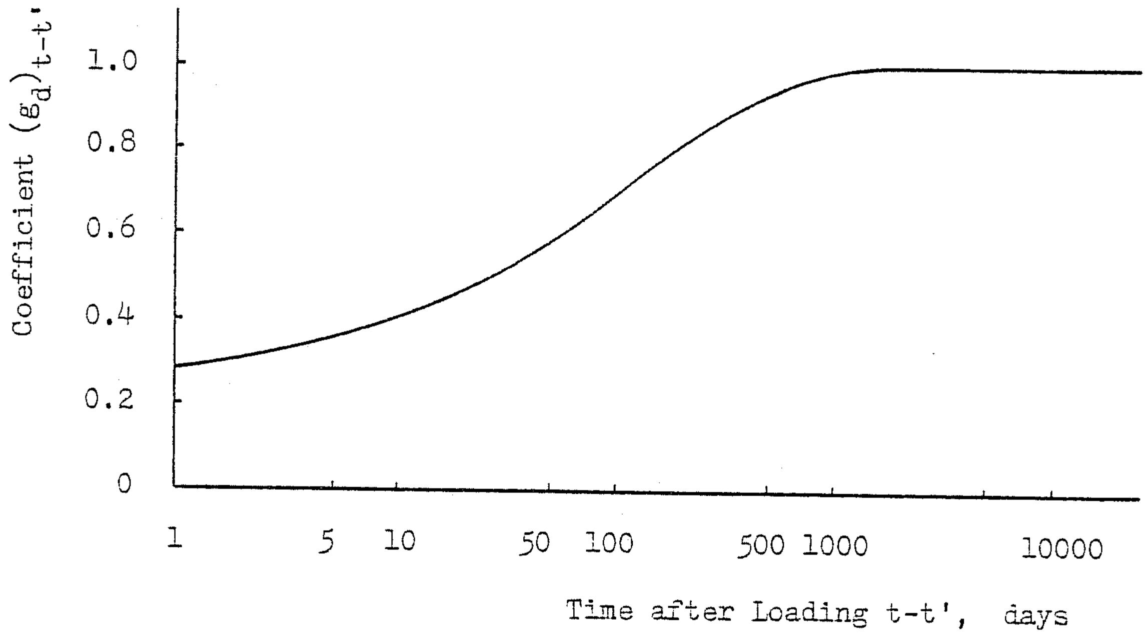
Surrounding Medium	Relative Humidity	Coefficients *		B_H
		Creep CC_{F1}	Shrinkage $(\varepsilon_{s1})_\infty x\ 10^{-5}$	
Water		0.8	+ 10	30
Very damp atmosphere	90%	1.0	- 10	5
Usual exterior	70%	2.0	- 25	1.5
Dry atmosphere or dry interior	40%	3.0	- 40	1

* The values of these coefficients differ according to the consistency of the concrete. The values shown in the table are for the concrete of consistencies of grades K_3 and K_4. They should be reduced by 25% for grades K_1 and K_2 and increased by 25% for grades K_5 and K_6. The concrete of grade K_1 is the stiffest while the concrete of grade K_6 is the softest. The grade K_1 and grade K_2 concretes have slump tests of 0 cm., grade K_3 and grade K_4 from 0 cm. to 4 cm., and grade K_5 and grade K_6 from 5 cm. to 15 cm..



Theoretical Thickness cm.	CC_{F2}
<5	1.85
10	1.70
20	1.55
40	1.40
80	1.25
>160	1.12

Fig. 2.8 The C.E.B.'s Creep Prediction Curves.


Coefficient $(g_d)_{t-t'}$
1.0
0.8
0.6
0.4
0.2
0
1
5
10
50
100
500
1000
10000
Time after Loading t-t', days

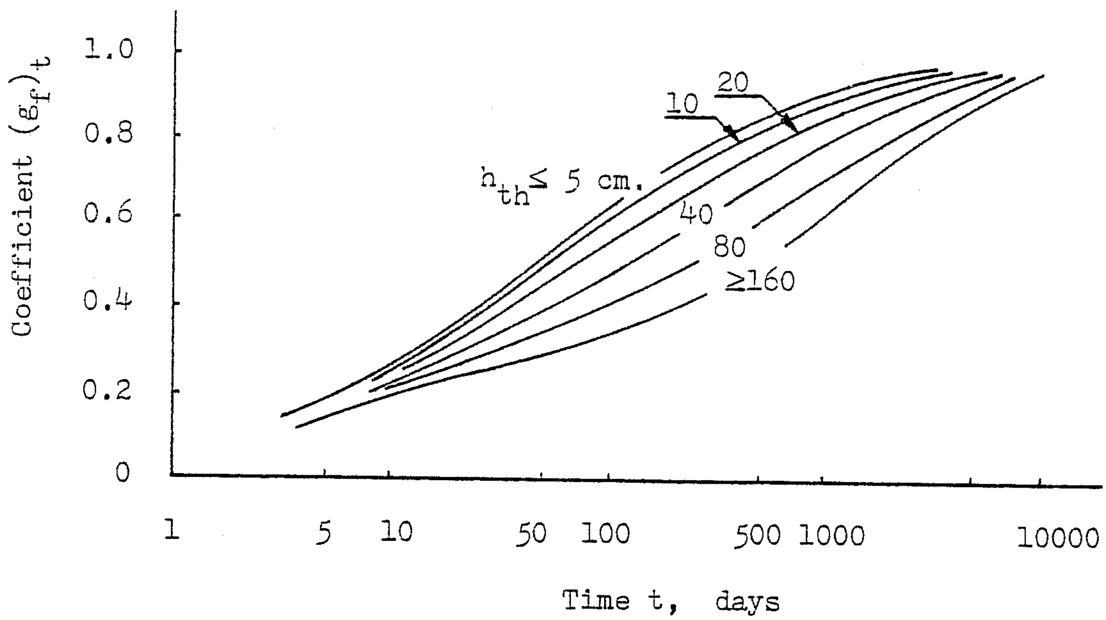

Coefficient $(g_f)_t$
1.0
0.8
0.6
0.4
0.2
0
$h_{th} \leq 5$ cm.
10
20
40
80
≥160
1
5
10
50
100
500
1000
10000
Time t, days

Fig. 2.8 Cont.

For lightweight concrete following the C.E.B.

$$(\varepsilon_c)_{t,t'} = [|(f_c)_{t'}|/(E_{cs})_{28}]\ K_{1c}(c)_{t,t'}$$

$$(E_{cs})_{28} = 9500\ (w/2400)^2\ [|(f'_c)_{28}| + 8]^{1/3}$$

(where w is in kg./m.^{3}, E_{cs} and f'_c are in MPa.)

where K_{1c} = reduction coefficient which can be taken as a value from 0.5 to 0.8.

The creep coefficient, $(c)_{t,t'}$, is determined in the same manner as that for normal weight concrete.

The most complete creep prediction procedures are those recommended by the A.C.I. Committee 209, the P.C.I. Committee on Prestress Losses, and the C.E.B.. In practice, creep-time response of a specimen can be conveniently estimated using one of these procedures with minimal data. Because of the scattering of the experimental data, as suggested by the ranges of the empirical constants for the function recommended by the A.C.I. Committee 209 (see p. 45), these procedures may not give enough accuracy. It may be preferable to perform a short term test simulating the actual surrounding atmospheric conditions, and use the creep-time curve in the form of one of the three methods as a basis for estimating the creep-time response. The expression in the form recommended by the A.C.I. Committee 209 was adopted by many investigators (8,13,72,94) with satisfactory results. In this study, the measured data on the creep-responses will be used when available. In the absence of the long-term measurements, the A.C.I. Committee 209 recommendation will be used.

2.3.2. Creep of Concrete under Variable Stress.

The creep functions previously mentioned represent the experiment data of concrete under constant stress. In reality, under a complex system of structure and loading, stress in every part of the structure is changing, gradually or abruptly, with time. Although attemps (49, 58) have been made with considerable success to use a single creep function to predict creep under gradually decreasing sustained stress, rather poor results were obtained in the case of abruptly changing stress. Several techniques have been proposed to handle this situation.

If it is assumed that there is a creep function representing creep-time relation of concrete under a constant stress, and assuming that creep is proportional to the applied stress, several methods are available to estimate the amount of creep under time-dependent stress. They may be divided into three broad categories: (1) creep depends on the stress at the time of consideration only, (2) rate of creep depends on the stress at the time of consideration, and (3) rate of creep depends on the complete history of the stress application. The following are the most commonly used methods.

The Effective Modulus Method.

The effectie modulus method is the oldes, simplest, and most widely used method. The method uses an elastic approach, taking into account creep effects, exclusive of shrinkage, by using the effective modulus instead of the normal modulus of elasticity. The effective modulus is a function of time and can be defined as follows:

$$(E_{eff})_t = (E_c)_t / [1 + (c)_t]$$

where $(E_{eff})_t$ = effective modulus of elasticity of concrete at time t,

and $(E_c)_t$ = modulus of elasticity of concrete at time t.

A modification of the effective modulus method called age-adjusted effective modulus method has been advanced by Bazant (8). The modified method includes the effects of the aging of concrete and the dependence of creep on the age of concrete at loading. The effective modulus is modified as:

$$(E_{eff})_{t,t'} = (E_c)_{t'} / [1 + (X)_{t,t'} (c)_{t,t'}]$$

where $(E_{eff})_{t,t'}$ = effective modulus of elasticity of concrete at time t subjected to sustained load applied at time t',

$(E_c)_{t'}$ = modulus of elasticity of concrete at time t',

and $(X)_{t,t'}$ = aging coefficient at time t for concrete loaded at time t'.

The aging coefficient, $(X)_{t,t'}$, may be numerically estimated for a given creep function and an elastic modulus-time relationship. The values of $(X)_{t,t'}$ for typical creep functions and elastic modulus-time relationship are tabulated in Bazant's paper (8).

The effective modulus method is of the first category, creep at any time depends on stress at that instant only. Stress history is disregarded. Upon the removal of stress, complete creep recovery, which is rarely the case for concrete, will be predicted. The method will overestimate creep under gradually increasing stress and underestimate creep under gradually decreasing stress. Satisfactory results will be obtained for creep under approximately constant stress.

The Rate of Creep Method.

Assuming that rate of creep at any age of concrete is independent of the time at which concrete is loaded, creep may be estimated as:

$$(\varepsilon_c)_{t_n} = \sum_{i=0}^{n-1} (f_c)_{iave} \, (\Delta c_\varepsilon)_i$$

where n = number of time increments in the interval of interest,

t_n = time at the end of time increment n,

$(f_c)_{iave}$ = average value of f_c in time increment i,

and $(\Delta c_\varepsilon)_i$ = $(c_\varepsilon)_{t_i} - (c_\varepsilon)_{t_{i-i}}$, specific creep increment in time increment i.

The method takes into account, to some extent, the history of the applied stress. Since the rate of creep in concrete decreases with the age of concrete, the method will underestimate the amount of creep due to stress applied at the later date. The rate of creep method will underestimate creep under gradually increasing stress and overestimate creep under gradually decreasing stress. No creep recovery will be predict-ted upon the removal of load. Under constant load, the method gives adequate accuracy.

The Rate of Flow Method.

England and Illston (25) advanced a method called the rate of flow method to calculate creep under variable stress. The method assumes that, exclusive of shrinkage strain, strain due to load in the order of 0.4 to 0.5 of the ultimate strength of the concrete consists of three components: elastic strain, flow, and delayed elastic strain. Elastic strain is the strain at the instant of loading. It is equal to the applied stress, positive or negative, divided by the modulus of elasticity of concrete at the time of loading. It should be noted that this definition of the elastic strain is different from that previously defined. Part of the elastic strain will be unrecoverable upon the removal of load if the modulus of elasticity is increased. Flow is a time dependent irrecoverable strain. It is independent of stress history. The rate of flow is proportional to the applied stress and, under a constant stress, it decreases with the aging of the concrete. Delayed elastic strain is a time dependent strain that is fully recoverable upon the removal of stress. It has a limiting value that is proportional to the applied stress and that varies little with age of concrete. Its rate of occurrence is proportional to the delayed elastic strain yet to come so that the rate will decrease with time. Each of these components may be numerically estimated as:

Elastic strain

$$(\varepsilon_e)_{t_n} = \sum_{i=0}^{n} (f_c)_{t_i}/(E_c)_{t_i}$$

where $(\varepsilon_e)_{t_n}$ = elastic strain at time t_n.

Flow

$$(\varepsilon_f)_{t_n} = \sum_{i=0}^{n-1} (f_c)_{iave}(\Delta c_{\varepsilon f})_i$$

where $(\varepsilon_f)_{t_n}$ = flow of concrete at time t_n,

and $(\Delta c_{\varepsilon f})_i = (c_{\varepsilon f})_{t_i} - (c_{\varepsilon f})_{t_{i-1}}$, specific flow increment in time increment i.

Delayed elastic strain

$$(\varepsilon_{de})_{t_n} = \sum_{i=0}^{n-1} \sum_{j=1}^{m} [(f_c)_{iave}(c_{\varepsilon dej})_\infty - (\varepsilon_{dej})_{t_i}]$$
$$[1-e^{-(\Delta c_{\varepsilon f})_i/Q_j}]$$

where $(\varepsilon_{de})_{t_n}$ = delayed elastic strain of concrete at time t_n,

$(c_{\varepsilon dej})_\infty$ = j term of ultimate specific delayed elastic strain,

$(\varepsilon_{dej})_{t_i}$ = j term of delayed elastic strain of concrete at time t_i,

and Q_j = empirical constant.

Good agreement with experimental data was found (44) by using m equal to 3. Only two terms of the series, i.e. m equal to 2, may be used by neglecting to treat separately the rapid strain occurring in the first few minutes after loading (44).

The Superposition Method.

The superposition method is of the third category, rate of creep depends on the complete history of the applied stress. According to McHenry (63), the superposition hypothesis may be stated as:

The strain produced in concrete at any time t by stress increments applied at time t' (t > t') are independent of the effects of any stresses applied either earlier or later than the time t'. The stress increments may be either positive or negative but the stresses which appraoch the ultimate strength are excluded.

Creep strain may then be written as:

$$(\varepsilon_c)_{t_n} = \sum_{i=0}^{n-1} (f_c)_{t_i} (c)_{t_n, t_i}$$

where n = number of load increments in the interval of interest.

Davies (21) conducted an experiment on creep of concrete under variable stress to examine the validity of the superposition hypothesis. Three sets of specimens were used. Each set of the specimens was subjected to different patterns of loading: constant load, the same constant load for a period of time with subsequent removal of part of the load, and constant load equal to the amount of the removal load applied at the age of specimens equal to the time of removal of load in the second set. The results showed that from 12 hours after removal of load the theoretical recovery was always larger than the actual values.

Rao and Dilger (72) introduced a reduction factor, $(R)_{t,t_i'}$, which is the ratio of the specific creep recovery response to specific creep for the removal of load at time t_i', the load is applied at time t_0' $(t_i' > t_0')$. The value of $(R)_{t,t_i'}$ was found to be a function of time after unloading and may be represented as a hyperbolic function of time as:

$$(R)_{t,t_i'} = 0.6 + (t - t_i')/\left[40 + 3.2(t - t_0')\right]$$

The C.E.B. (84) also proposed the use of the superposition method (called superimposition method) for calculating creep under variable stress. The irrecoverable part of creep is recognized by introducing a deferred flow term in creep function. According to the C.E.B., creep under variable stress may be determined as follows:

$$(\varepsilon_c)_{t_n} = \left[1/(E_{cs})_{28}\right] \sum_{i=0}^{n-1} (f_c)_{t_i} \left[CC_D (g_d)_{t_n - t_i} + CC_{FO} \{(g_f)_{t_n} - (g_f)_{t_i}\}\right]$$

Several investigators have compared the accuracy of the creep predictions using different methods of analysis. Ross (75) compared, in their original forms, the effective modulus method, the rate of creep method, and the superposition method with the measurements of creep under gradually increasing and decreasing stresses and under severely variable stresses. The effective modulus method gave the poorest results. The rate of creep method gave results comparable with the superposition method. The rate of creep method underestimated creep under gradually increasing stress and vice versa. The superposition method gave errors in the opposite sense. It predicted higher creep in the case of gradually increasing stress and lower creep for gradually decreasing stress. For severely variable stress, both methods estimated creep approximately the same magnitude as the experimental data. However, the lack of creep recovery in the rate of creep method upon the removal of stress led to the error in prediction of the general shape of the strain-time response. The trend of the strain-time response predicted by the superposition method agreed well with the data.

Errors in the prediction of creep by the rate of creep method arise from the theoretical deficiency of the method. For the superposition method, as Illston (44) points out, the overestimating of creep under gradually increasing stress was due to the use of the series of creep-time curves for concrete under the first time loading as a basis is the calculation. The creep caused by initial stress is greater than that, at the same age, caused by the stress of the same magnitude applied to concrete which has been loaded previously. The underestimating of creep under gradually decreasing stress was due to the neglect of irrecoverable part of creep.

England and Illston (25) compared the rate of creep method, the superposition method, and the rate of flow method. The rate of flow method gave superior results. But it should be noted that there was only a limited amount of experimental verification on the rate of flow method, and further investigation is needed.

After comparing the accuracy and the calculations involved, it was decided to use both the rate of creep method and the superposition method in the present study. The superposition method used will be a modified form in which the recovery response is a fraction of creep response, as proposed by Rao and Dilger (72), recognizing the irrecoverable part of creep. Also to simplify the problem, the creep recovery ratio will be taken as a constant independent of time after unloading has occurred.

2.3.3. Shrinkage of Concrete.

As in the creep-time relationship, shrinkage increases with time at a decreasing rate, providing that there is no change in ambient conditions. Shrinkage also tends to approach a finite value. While the final value of shrinkage of concrete depends on many factors, i.e. the composition of concrete, degree of exposure to the atmosphere and ambient conditions, the shape of the shrinkage-time curves for various concretes under different conditions are remarkably similar. It is then convenient to express the shrinkage-time relationship as a product of ultimate shrinkage and a function of time. Several types of shrinkage functions have been used with satisfactory results.

Ross (73) probably was the first to express the shrinkage-time relationship as a mathematical function. He proposed a rheological model to represent the behavior of concrete. The model consists of a spring connected in series with a parallel connection of another spring and a dashpot. A spring produces instantaneous deformation proportional to the load and a dashpot produces a velocity proportional to the load at any instant. The shrinkage is then determined by assuming a fictitious internal stress acting upon the spring and the dashpot which are connected in parallel. The resulting shrinkage function may be written in the form of:

$$(\varepsilon_s)_t = (\varepsilon_s)_\infty(1 - e^{-bt})$$

where $(\varepsilon_s)_t$ = shrinkage strain of concrete at time t days.

$(\varepsilon_s)_\infty$ = ultimate shrinkage strain of concrete,

and b = empirical constant.

From his experimental data, he found the ultimate shrinkage, $(\varepsilon_s)_\infty$, to be in the order of -2.00×10^{-4} in./in. and the constant, a, in the order of 0.0055.

Arutyunyan (6) also showed that the shrinkage-time relationship could be represented fairly well by the expression in the same form as Ross's. From data of various types of concrete, he found the ultimate shrinkage , $(\varepsilon_s)_\infty$, ranged from -2.00×10^{-4} in./in. to -4.20×10^{-4} in./in. and the constant, a, ranged from 0.0085 to 0.0100.

Troxell, et al., (87) measured shrinkage of 4 in. cylinders mostly stored at 70°F and 50 percent relative humidity. The results were plotted with the logarithm of time. Despite the variation of mixes and curing conditions, the values plotted fell on a relative narrow band. The average values for a period of more than 20 years could be approximately represented by the following expressions:

For 0 days $\leq t \leq$ 90 days

$$(\varepsilon_s)_t/(\varepsilon_s)_{7300} = 0.227 \ln(t + 1) - 0.374$$

For 90 days < t

$$(\varepsilon_s)_t/(\varepsilon_s)_{7300} = 0.080 \ln(t/90) + 0.650$$

Dutron (24) proposed a shrinkage function:

$$(\varepsilon_s)_t = (\varepsilon_s)_\infty(1 - e^{-b_1 t^{b_2}})$$

The ultimate shrinkage strain, $(\varepsilon_s)_\infty$, may be found as a function of the ultimate shrinkage of cement paste and the volume concentrations of each constituent. He also gave an expression for adjusting the shrinkage at 50 percent relative humidity to shrinkage at other humidities:

$$\varepsilon_{sH} = \varepsilon_{s50} [0.96 \log \{(150 - H)/5\}]$$

where ε_{sh} = free drying shrinkage strain of concrete stored in relative humidity of H percent,

and ε_{s50} = free drying shrinkage strain of concrete stored in 50 percent relative humidity.

Wallo and Kesler (89) assumed that the ultimate shrinkage was proportional to the concentration of hydrated cement paste and decreased with increasing concentration of restraining particles at a particular humidity. Using the relative humidity correction and shrinkage-time relationship similar to those of Dutron's, for Type I portland cement, water cement ratio from 0.4 to 0.8 by weight, aggregate cement ratio about 4 to 9 by weight, cement content from 376 to 752 lb./yd.^{3}, and at a constant temperature of 70°F, the following expressions were recommended:

$$(\varepsilon_s)_t = (\varepsilon_s)_\infty(1 - e^{-0.1(S/V)t^{0.65}})$$

$$(\varepsilon_s)_\infty = -(2400 - 2100V_{hc})(1 - V_s)[0.96 \log \{(150 - H)/5\}] \times 10^{-6} \text{ in./in.}$$

where S = surface that exposes to atmosphere,

V = volume,

V_{hc} = ratio of volume of hydrated cement, including gel pores, to volume of concrete,

and V_s = ratio of volume of solids to volume of concrete.

Kingham, et al., (53) in the study of shrinkage in conjunction with creep of concrete and relaxation of steel, proposed the shrinkage expression:

$$(\varepsilon_s)_t = -0.000280(1 - e^{-t/166})^{0.50} + 0.000087(1 - e^{-t/10})\sin(d' + 60) \text{ in./in.}$$

where d' = number of days from January 1.

The second term is the seasonal correction of shrinkage.

Hansen and Mattock (34) assumed that shrinkage-time relationship could be represented by a hyperbolic expression:

$$(\varepsilon_s)_t = (\varepsilon_s)_\infty t/(a + t)$$

Comparing to data from specimens stored at 70°F and 50 percnet relative humidity, the curve fit the data well for age greater than 100 days and tended to overestimate shrinkage at early age. The constant, a, and the ultimate shrinkage, $(\varepsilon_s)_\infty$, were found to be functions of volume-surface ratio, V/S, as:

$$a = 26.0\ e^{0.36(V/S)}$$

For sand stone concrete

$$(\varepsilon_s)_\infty = -1420\ e^{-0.07(V/S)}$$

For gravel concrete

$$(\varepsilon_s)_\infty = -1080\ e^{-0.12(V/S)}$$

Based on the work by Branson and Christiason (13), the A.C.I. Committee 209 (2) recommended the following expression to predict shrinkage:

$$(\varepsilon_s)_t = (\varepsilon_s)_\infty t^b/(a + t^b)$$

For normal weight, sand-lightweight, and all lightweight, both moist cured and steam cured, and Type I and Type III cement concretes, the constants, a and b, were found to range from 20 to 130 and 0.90 to 1.10, respectively. The ultimate shrinkage, $(\varepsilon_s)_\infty$, was found to range from -415×10^{-6} in./in. to -1070×10^{-6} in./in..

Standard shrinkage equations were suggested. The equations are for 4 in. or less slump concrete placed at ambient relative humidity of 40 percent and minimum thickness of member 6 in. or less. They are:

Shrinkage after 7 days, moist cured concrete

$$(\varepsilon_s)_t = (\varepsilon_{ss})_\infty t/(35 + t)$$

Shrinkage after 1 to 3 days, steam cured concrete

$$(\varepsilon_s)_t = (\varepsilon_{ss})_\infty t/(55 + t)$$

where $(\varepsilon_{ss})_\infty$ = ultimate shrinkage at standard conditions.

The average suggested value for $(\varepsilon_{ss})_\infty$ is -800×10^{-6} in./in. for moist cured concrete and -730×10^{-6} in./in. for steam cured concrete. The following corrections are needed for concrete of other conditions:

shrinkage correction factor for ambient humidity greater than 40 percent, CS_H, H is percent of relative humidity

$$CS_H = 1.40 - 0.010\,H \qquad 40 \le H \le 80$$

$$CS_H = 3.00 - 0.030\,H \qquad 80 < H \le 100$$

Shrinkage correction factor for member thickness, CS_T, T is the minimum thickness of member in in.

$CS_T = 1.23 - 0.038\ T$ for < 1 yr. of drying

$CS_T = 1.17 - 0.029\ T$ for ultimate value

Shrinkage correction factor for consistency of concrete, CS_s, S is the slump in in.

$CS_S = 0.89 + 0.041\ S$

Shrinkage correction factor for cement content of concrete, CS_B, B is the number of 94 lb. sacks of cement per cubic yard.

$CS_B = 0.75 + 0.034\ B$

Shrinkage correction factor for fine aggregate content of concrete, CS_F, F is the percent of fine aggregate by weight

$CS_F = 0.30 + 0.0140\ F \quad F \leq 50$

$CS_F = 0.90 + 0.0020\ F \quad F > 50$

Shrinkage correction factor for air content, CS_A, A is the air content in percent

$CS_A = 0.95 + 0.0080\ A$

For shrinkage of moist cured concrete from 1 day, a correction factor of 1.20 is needed. A linear interpolation may be used between 1.20 at 1 day and 1.00 at 7 days.

The P.C.I. Committee on Prestress Losses (67) recommended equations to calculate prestress loss due to shrinkage. By dividing the values by the modulus of elasticity of prestressing steel (27.5 x 10^6 psi.), the values may be written in terms of shrinkage strain, $(\varepsilon_s)_t$, as:

$$(\varepsilon_s)_t = (\varepsilon_{sl})\ CS_T (g_s)_t$$

where (ε_{sl}) = basic value for ultimate shrinkage,

CS_T = correction factor for shape and size of the member,

and $(g_s)_t$ = function representing development with time of shrinkage, evaluated at time t.

The basic value for ultimate shrinkage, $(\varepsilon_{s1})_\infty$, may be estimated as:

For normal weight concrete

$$(\varepsilon_{s1})_\infty = -9.818 \times 10^{-4} + 1.091 \times 10^{-10} E_c \leq -4.36 \times 10^{-6}$$

For lightweight concrete

$$(\varepsilon_{s1})_\infty = -1.491 \times 10^{-3} + 3.636 \times 10^{-10} E_c \leq -4.36 \times 10^{-6}$$

The values are in./in.. The correction factor for shape and size of the member, CS_T, and the shrinkage-time function, g_s, are shown in Fig. 2.9.

The C.E.B. (84) proposed the following expression to estimate shrinkage:

$$(\varepsilon_s)_{t-t_0} = (\varepsilon_s)_\infty \left[(g_s)_t - (g_s)_{t_0}\right]$$

where $(\varepsilon_s)_{t-t_0}$ = shrinkage strain increment in time interval t_0 to t,

$(\varepsilon_s)_\infty$ = $(\varepsilon_{s1})_\infty CS_{h_{th}}$, ultimate shrinkage,

$(\varepsilon_{s1})_\infty$ = basic value for ultimate shrinkage,

$CS_{h_{th}}$ = coefficient depending on the theoretical thickness, h_{th}, and concrete consistency,

and g_s = function representing development with time of shrinkage. $(g_s)_t$ and $(g_s)_{t_0}$ are the values of g_s evaluated at t and t_0, respectively.

The values of the coefficient $(\varepsilon_{s1})_\infty$ are given in Table 2.1 (p. 54) and the values of the coefficients $CS_{h_{th}}$ and g_s are given as curves as shown in Fig. 2.10.

The age of concrete at the time of consideration, t, and the age of concrete at the time from which the effect of shrinkage is considered, t_0, must be corrected as was the case for

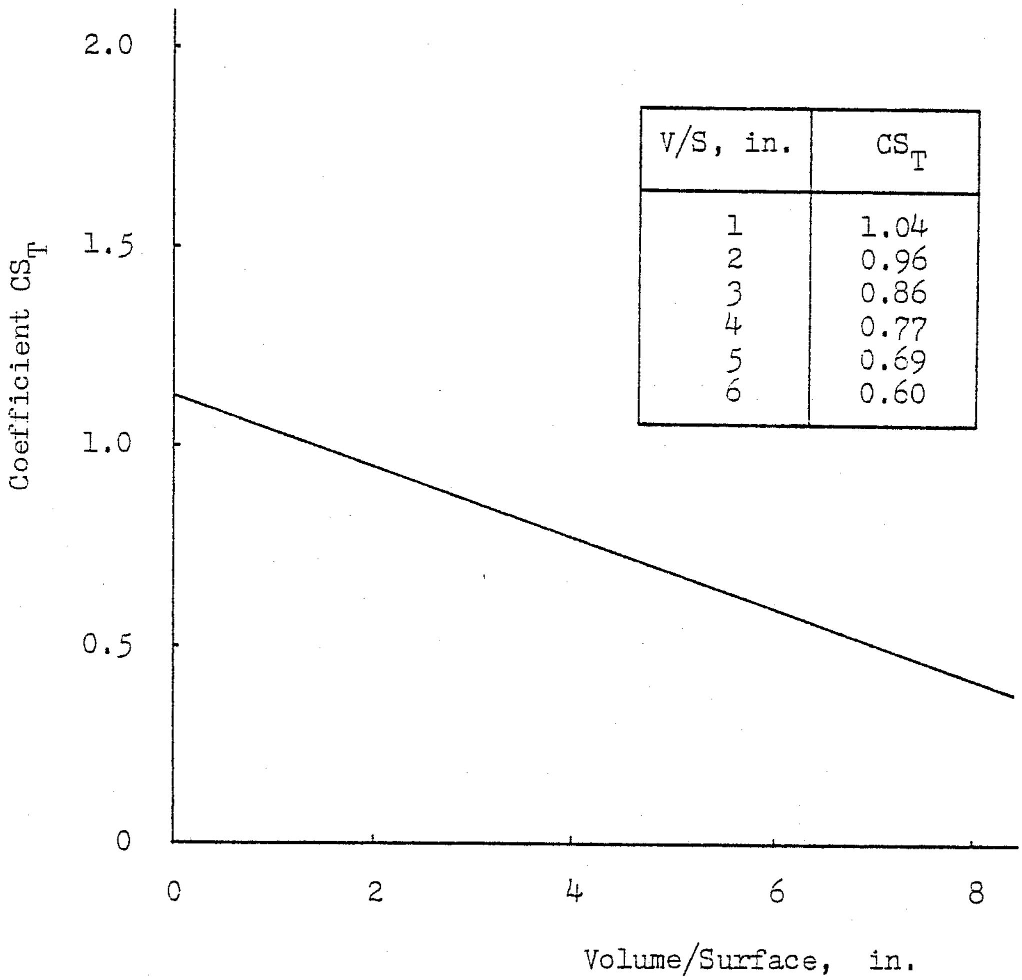
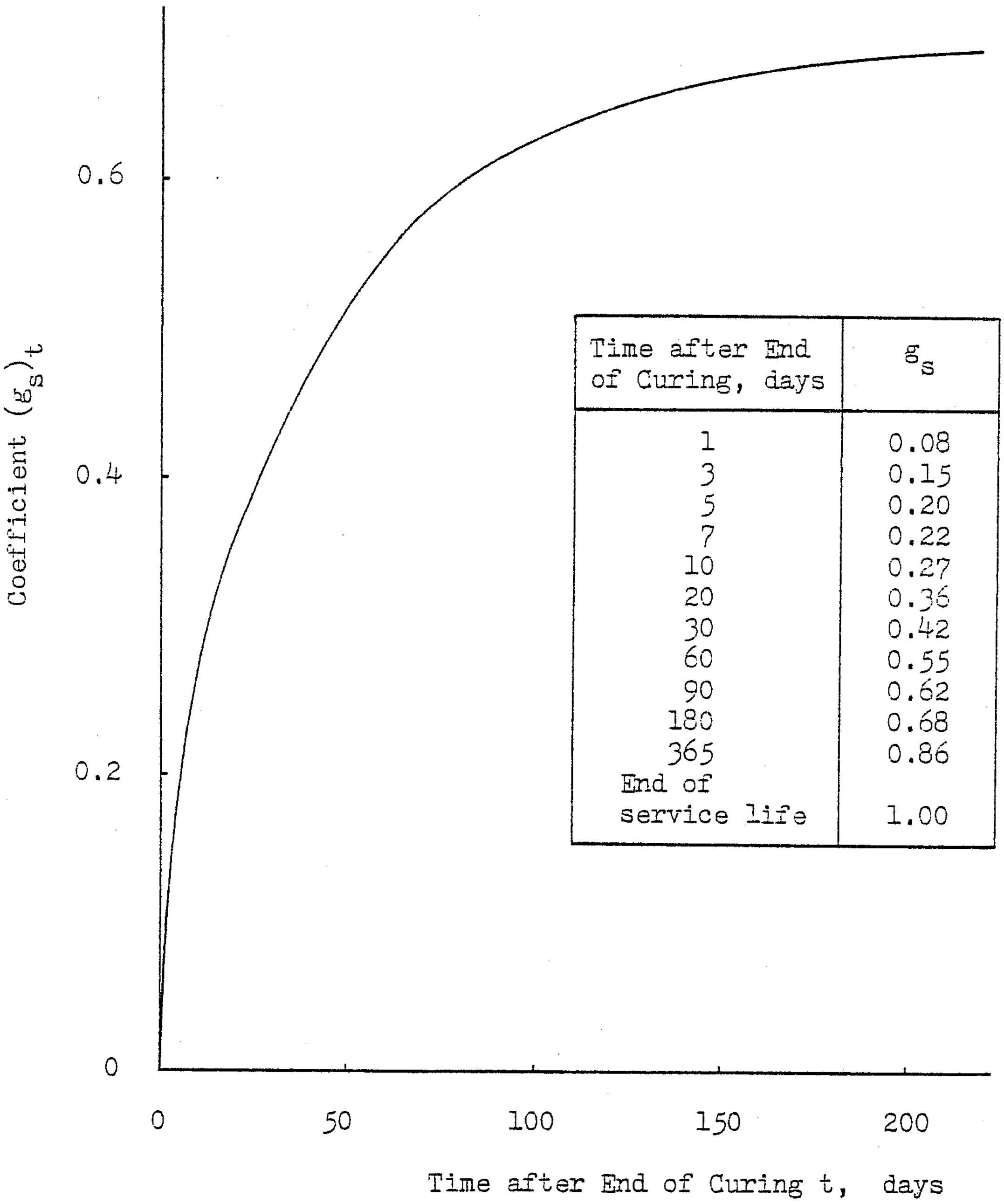


Fig. 2.9 The P.C.I.'s Shrinkage Prediction Curves.



Time after End of Curing, days	g_s
1	0.08
3	0.15
5	0.20
7	0.22
10	0.27
20	0.36
30	0.42
60	0.55
90	0.62
180	0.68
365	0.86
End of service life	1.00

Fig. 2.9 Cont.

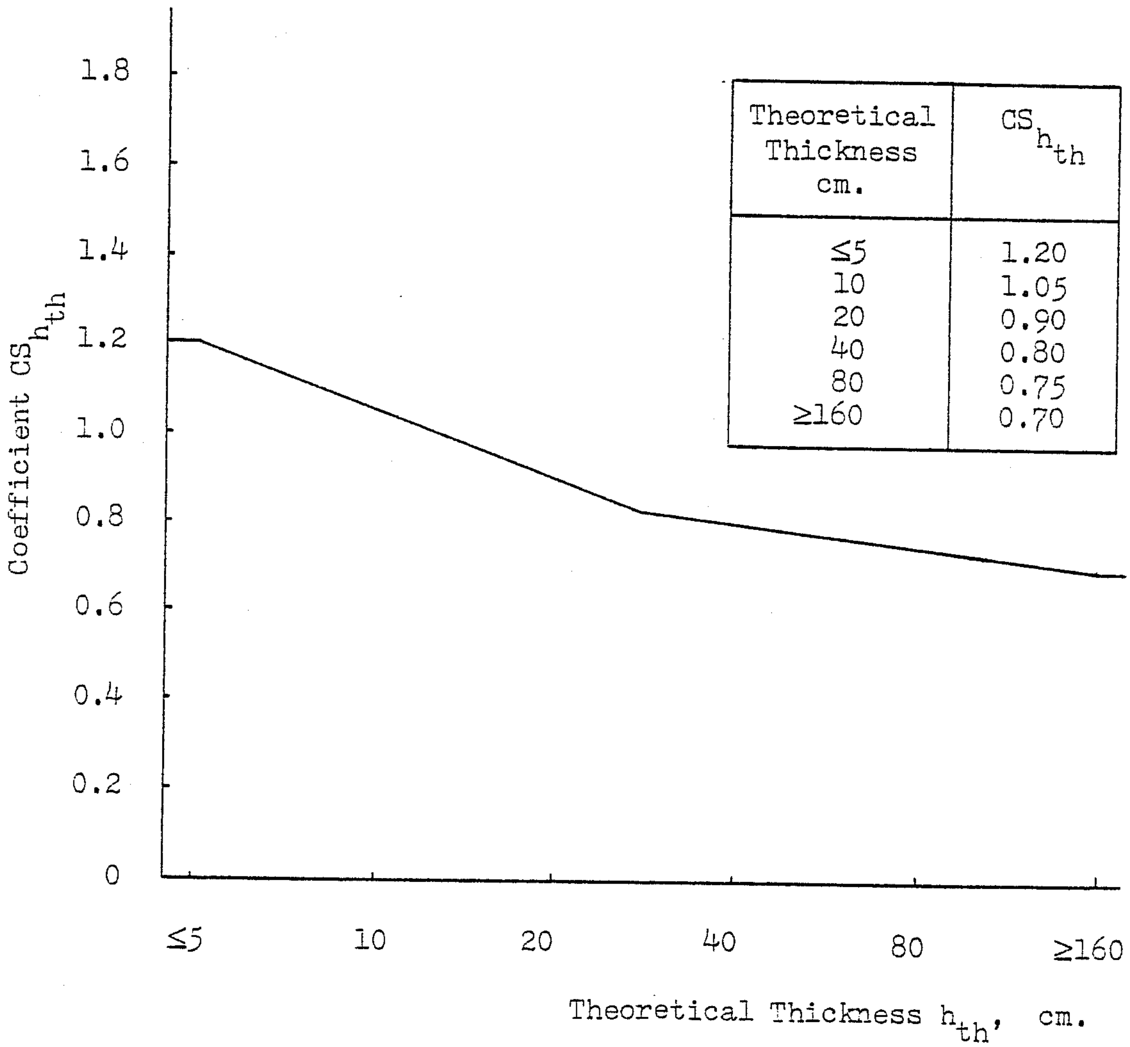
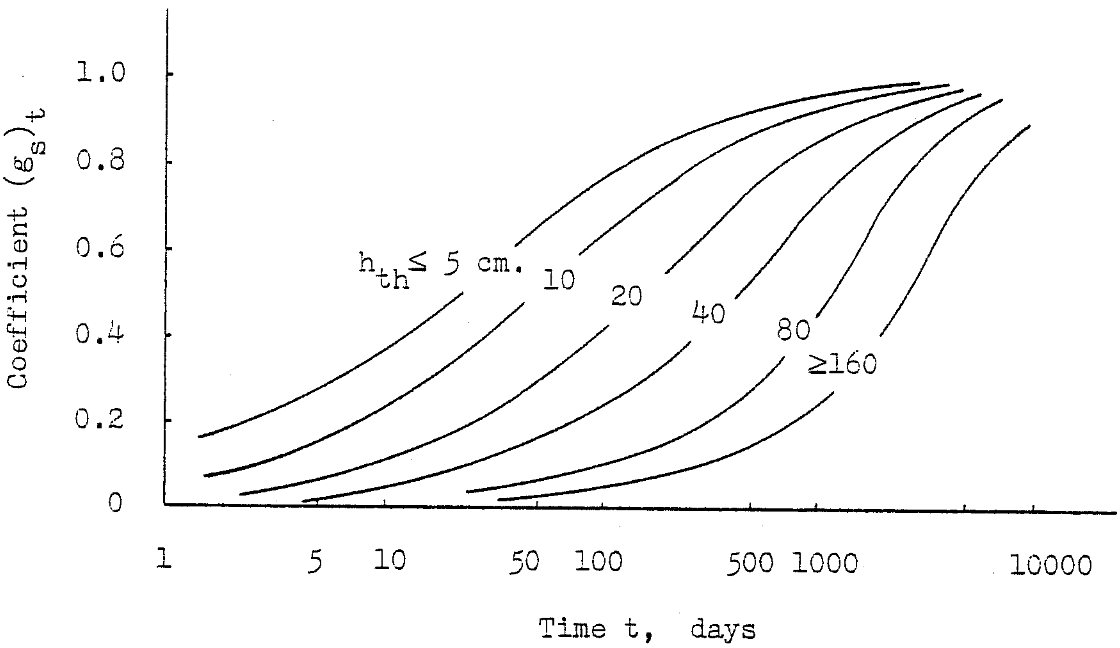


Fig. 2.10 The C.E.B.'s Shrinkage Prediction Curves.



1.0
0.8
0.6
0.4
0.2
0
Coefficient $(g_s)_t$
$h_{th} \leq 5$ cm.
10
20
40
80
≥160
1
5
10
50
100
500
1000
10000
Time t, days

Fig. 2.10 Cont.

creep (see p. 53), except that the value of the coefficient B_S used is taken as a constant and equal to 1, independent of the types of cement used.

As for creep, shrinkage of a specimen may be estimated by one of the procedures recommended by the A.C.I. Committee 209, the P.C.I. Committee on Prestress Losses, and the C.E.B. with minimal data. Since the experimental data were scattering, the predicted value may not have enough accuracy. It may be preferable to perform short-term measurements on specimens simulating the actual surrounding conditions and use a shrinkage-time curve in the form of one of those used in the procedures as a basis for estimating the shrinkage over the interval of interest. The expression in the form proposed by the A.C.I. Committee 209 was used by several investigators (13, 78, 81, 94) with satisfactory resutls. In this study, the measured values of shrinkage from the comparable specimens will be used where available. In the absence of such data, the A.C.I. Committee 209 recommendations will be used.

2.4 Stress-Strain Relationship of Steel.

As will be seen later, the approach used in the present study requires stress in the member to be determined from strain. The problem is less complicated in the case of steel, since there is no change in strain of steel due to change of moisture content. Total strain in steel may be considered as the sum of instantaneous strain and relaxation strain. Relaxation will be defined as the time-dependent loss of stress of steel under relatively constant stress. Relaxation strain will be defined as the reduction in strain that gives the reduction in stress equal to relaxation, utilizing the stress-strain relationship based on the instantaneous stress-strain relationship of the material. In the following sections, the instantaneous stress-strain relationship and the relaxation characteristic of steel will be discussed briefly.

2.4.1. Instantaneous Stress-Strain Relationship of Steel.

Instantaneous stress-strain relationship of steel is usually obtained from uniaxial tensile test of a sample taken from the steel of interest. Unlike concrete, the tensile stress-strain curve of steel can be obtained up to the ultimate strain of steel with relatively ease. The stress-strain curve is commonly assumed to have symmetry about the origin, i.e., the stress-strain response in compression is the same as in tension. Since there is no aging effect in steel, the stress-strain curve can be used to represent the instantaneous tensile response without any modification. Typical stress-strain relationship of reinforcing steel and prestressing steel are shown in Fig. 2.11 and Fig. 2.12, respectively.

2.4.2. Relaxation of Steel Under Constant Strain.

For prestressed concrete members, the relaxation of prestressing steel is of concern. Under service load, the stress in reinforcing steel, which may be used to increase the load carrying capacity of a prestressed member, is much lower than its yielding stress and relaxation is small, if any. Prestressing steel, on the other hand, may be stressed up to 0.8 of its ultimate strength (3). In that range, relaxation over a long period of time may be as high as 15 percent of the initial stress (70). Although relaxation does not decrease the

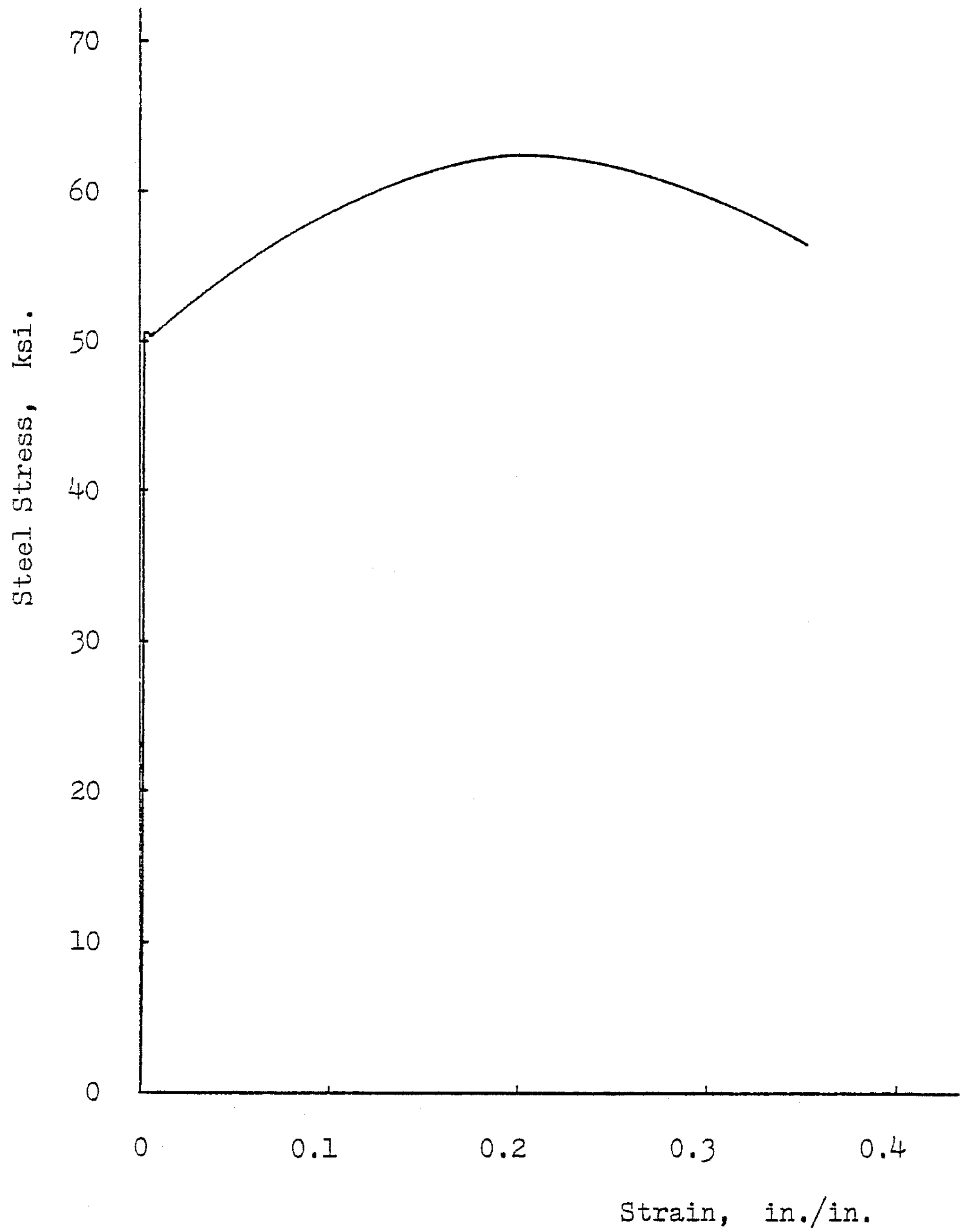


Fig. 2.11 Typical Reinforcing Steel Stress-Strain Curve.

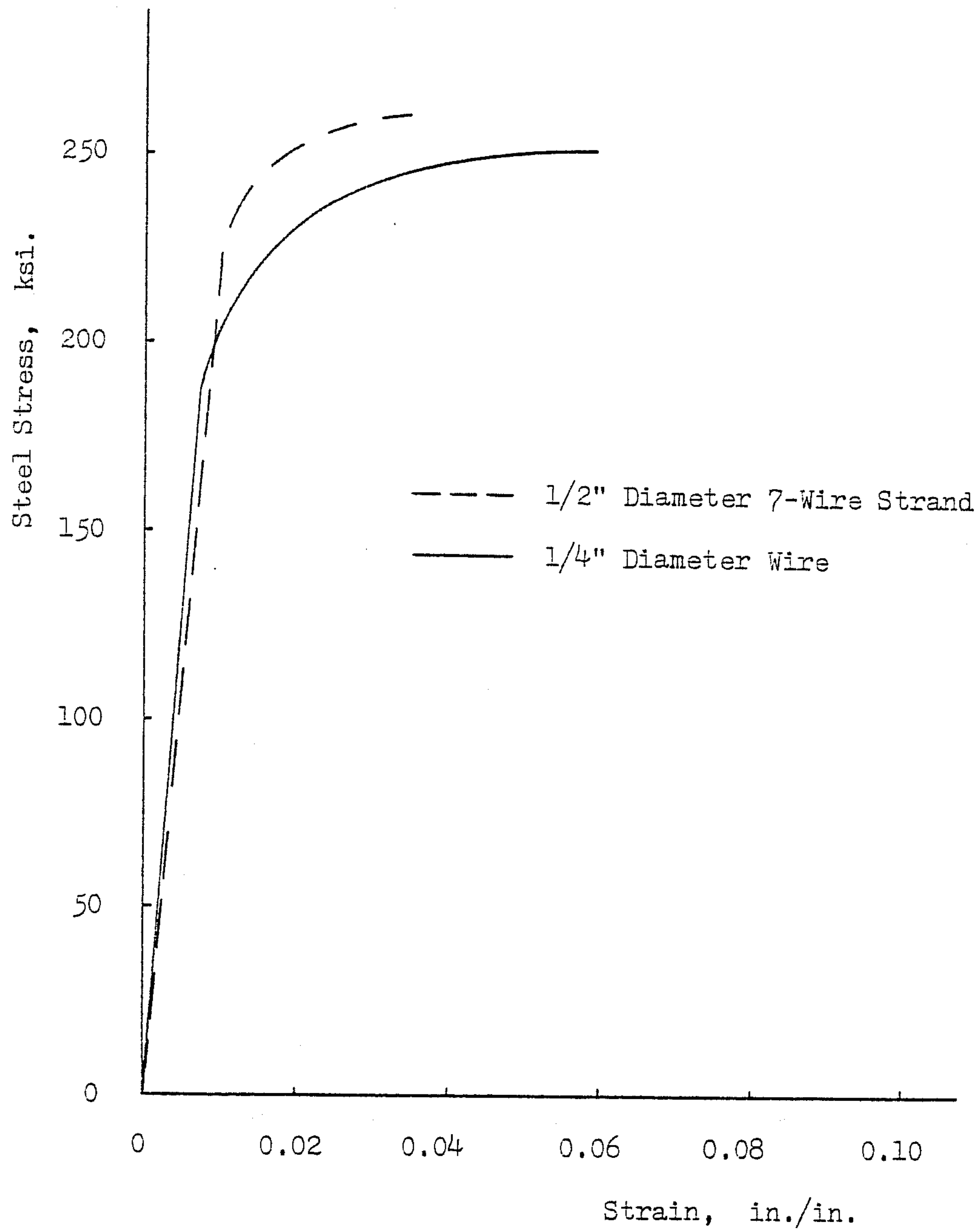


Fig. 2.12 Typical Prestressing Steel Stress-Strain Curves.

flexural strength of a bonded prestressed member, it affects the servicibility of the member.

Relaxation is a function of the type of steel, initial stress-strenght ratio, and temperature. It is also affected to some degree by rate of loading. High temperature may increase long-term relaxation several times (79), but under ordinary ambient conditions the temperature effect is negligible. The effect of rate of loading may also be neglected, since it has been shown that the rate of loading has an effect at the initial stress-strength ratio of about 0.80 to 0.94 (70), well above the stress level that would occur under service load.

Although many papers have been published reporting relaxation test results, relatively few investigators have attempted to describe relaxation as mathematical functions. The following are summaries of some of them.

Based on the creep formula suggested by Ros, Kajfasz (48) represented relaxation-time relationship as a logarithm of time:

$$(f_{sr})_t = a(f_{si}/f_{sy0.2\%}) \ln t$$

where $(f_{sr})_t$ = steel relaxation stress at time t,

a = empirical constant,

f_{si} = initial stress of steel,

and $f_{sy0.2\%}$ = specified yield stress of steel at 0.2% offset.

The empirical constant, a, was found to be a linear function of the ratio of initial stress to the 0.2 percent off-set stress for both single wires and twin-twisted wires of various pitches. The relaxation function may then be written as:

$$(f_{sr})_t = [2.41(f_{si}/f_{sy0.2\%}) - 1.395] \ (\ln t - \ln t_0) + (f_{sr})_{t_0}$$

where $(f_{sr})_{t_0}$ = steel relaxation stress at time t_0 ($t_0 < t$).

The equation is valid for the initial stress/0.2 percent offset stress ratio of more than 0.58. For the ratio less than 0.55, relaxation is practically insignificant.

Kingham, et al., (53) used a power function of initial stress/strength ratio and time to describe relaxtion of prestressing steel.

$$(f_{sr})_t = a \, f_{si}(f_{si}/f_{su})^{b_1} t^{b_2}$$

where f_{su} = ultimate strength of prestressing steel.

The empirical constants, a, b_1, and b_2, were found by a regression analysis to vary for different types of steel.

Magura, et al., (61) assumed that relaxation-time relationship could be represented by an S-shape curve of stress and logarithm of time as:

$$(f_s)_t = f_{si}/(1 + 10^q)$$

where $(f_s)_t$ = stress in steel at time t,

and q = function of time and initial stress/strength ratio.

From extensive studies, the function q was found to be described satisfactory by:

$$q = -1.3 + [(\log t)/3] \ (f_{si}/f_{sy} - 0.55)$$

where f_{sy} = specific yield strength of prestressing steel.

The relaxation-time expression was approximated by the expressions:

$$(f_s)_t/f_{si} = 1 - [(\log t)/10] \ (f_{si}/f_{sy} - 0.55)$$

$$f_{si}/f_{sy} \geq 0.55$$

The approximate expression gave satisfactory results up to a time of about 50 years, which is quite adequate.

Glodowski and Lorenzetti (30) proposed a relaxation function inthe form of quadratic function of logarithm of time as:

$$(f_{sr})_t = a + a_1 \ln t + a_2(\ln t)^2$$

where a, a_1, and a_2 are functions of the stress level ratio.

The expression was said to be more accurate than that of Magura, et al., for short time relaxation and quite accurate for long time relaxation as well.

The P.C.I. Committee on Prestress Losses (67) recommended the relaxation expression of Magura, et al., (61) but the distinction between stress-relieved steel and low-relaxation steel is made. The following expressions are used for different types of steel:

For stress-relieved steel

$$(f_{sr})_t - (f_{sr})_{t_1} = (f_s)_t \ [(\log 24t - \log 24t_1)/10] \ [(f_s)_t/f_{sy} - 0.55]$$

$$(f_s)_t/f_{sy} \geq 0.60; \ f_{sy} = 0.85 \ f_{su}$$

For low-relaxation steel

$$(f_{sr})_t - (f_{sr})_{t_1} = (f_s)_t \ [(\log 24t - \log 24t_1)/45] \ [(f_s)_t/f_{sy} - 0.55]$$

$$(f_s)_t/f_{sy} \geq 0.60; \ f_{sy} = 0.90 f_{su}$$

where f_{sr} = relaxation stress of prestressing, $(f_{sr})_t$ and $(f_{sr})_{t1}$ are the values of f_{sr} evaluated at t and t_1, respectively

$(f_s)_t$ = stress in prestressing at time t,

f_{sy} = specified yield strength of steel,

and f_{su} = ultimate strength of steel.

In this study, relaxation will be based upon test data. In the absence of such data, the P.C.I. Committee on Prestress Losses recommended expressions will be used.

2.4.3. Relaxation of Steel Under Variable Strain.

Strain variation in prestressing steel is not as severe as stress variation in concrete. In an ordinary prestressed concrete member, the changes in strain of prestressing steel under service load rarely exceeds 20 percent of the initial strain, including prestretching, if any. Consequently, not much attention has been paid to relaxation under variable strain. Most of the relaxation test data were obtained under constant strain, and the relaxation functions previously mentioned were based on this type of data. Under varying strain, it is assumed that the method equivalent to the rate of creep method is adequate to handle the situation (67).

Since steel relaxation is not proportional to initial strain, the use of a superposition method will give erroneous results. So it was decided to use the method equivalent to the rate of creep method in determining steel relaxation under variable strain.

C H A P T E R III

DERIVATION OF ANALYSIS

In this chapter, a program, called PBEAM, is developed to analyze both instantaneous and time dependent responses of prestressed concrete beams. The program is capable of analyzing noncomposite or composite, bonded, pre-tensioned or post-tensioned prestressed beams subjected to static loads and supported linearly or nonlinearly in any of the three directions, i.e. the member axis direction, the transverse direction, and the rotational direction. The beams are modeled using a discrete element technique. A tangent stiffness method for solving nonlinear responses is used in the instantaneous response analysis and a step-by-step method is used in the time-dependent response analysis.

3.1 Assumptions and Limitations.

To simplify the problem, assumptions are made in developing the analysis. The assumptions and the associated limitations are listed below:

(1) Beams are straight in their original positions and are of cross-sectional shape having one axis of symmetry.

(2) Bernoulli's hypothesis holds, i.e. strain increment distributions vary linearly through the depths of the beams.

(3) The deformations (strains and curvatures) are small although the displacements (horizontal, vertical, and rotational) can be any size.

(4) Shear deformation is negligible.

(5) No out of plane movement is considered, i.e. it is assumed that no lateral or local buckling occurs.

(6) Only statically applied loads in the plane passing through the axis of symmetry of the cross-section are considered.

(7) Material properties in the beams can be represented by the uniaxial behaviors of those materials.

(8) Equilibrium equations are written in the deformed state.

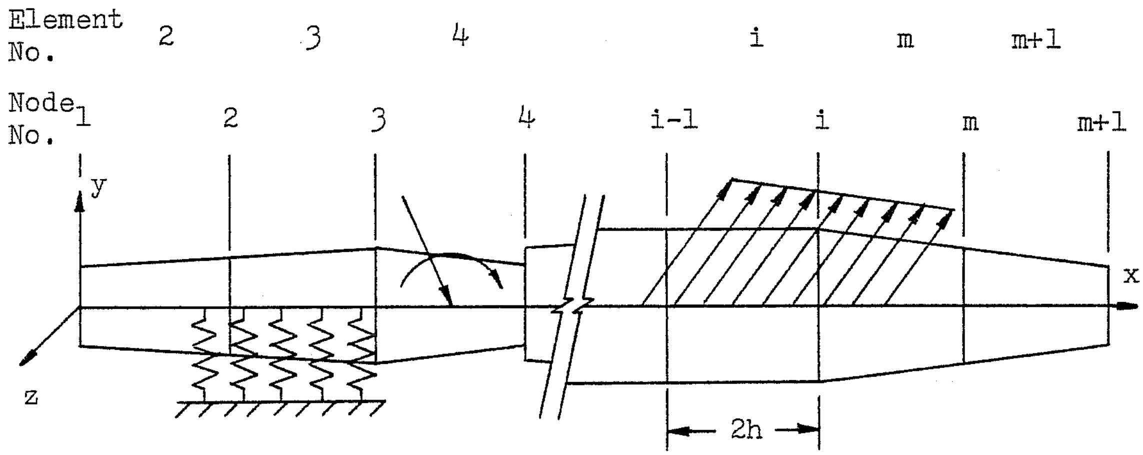
(9) Soil and other restraints can be represented by sets of linear or nonlinear springs.

3.2 Discrete Element Model.

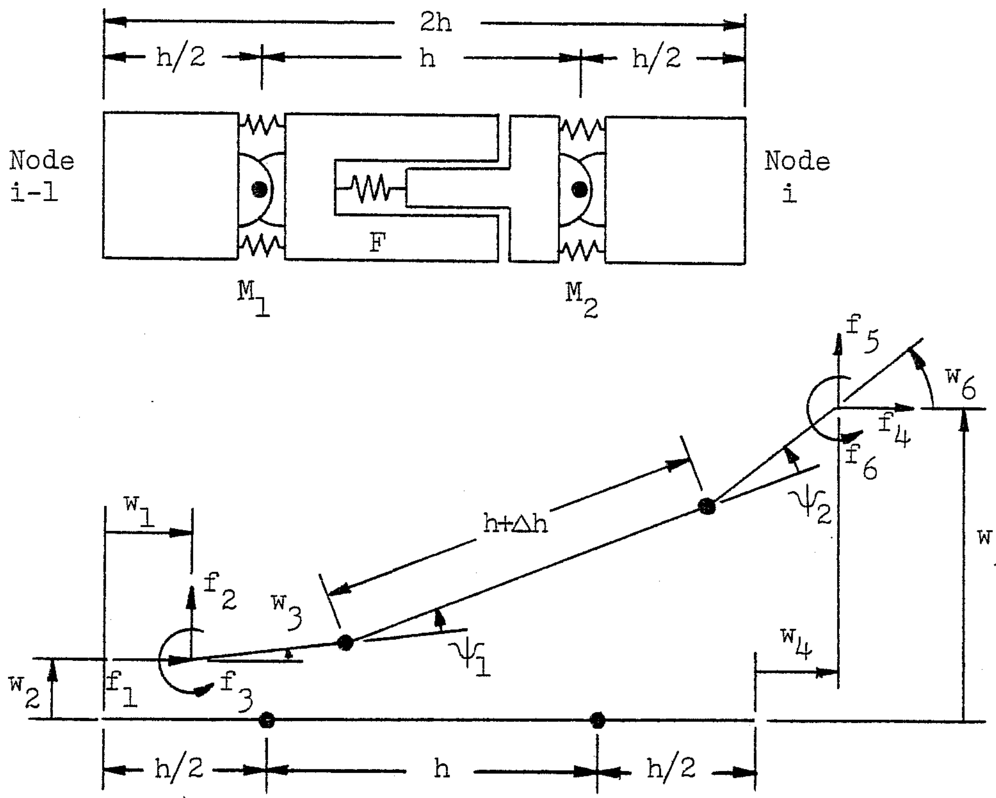
A general prestressed concrete member may have a variable cross-section along its length. Loads and restraints may be applied in any of the three directions, i.e. the member axis direction, the transverse direction, and the rotational direction. Applied loads may be concentrated or linearly distributed. Restraints may be linear or nonlinear and may also be concentrated or linearly distributed. A general prestressed concrete member is shown in Fig. 3.1a.

The beam is assumed to be straight in its original position, of cross-sectional shape having one axis of symmetry, and loaded by statically applied loads in the plane passing through the axis of symmetry of the cross-section. It is idealized as a straight line passing through its centroidal axis, and can be modeled as a series of discrete elements connecting end-to-end at nodal points.

A discrete element is a mechanical model that has discrete changes in rotation. The six degree of freedom discrete model as developed by Hays and Matlock (37) consists of a rigid piston with an axial spring, two rotational springs and two rigid end blocks, as shown in Fig. 3.1b. The material properties of the element are discretized into these springs. The axial spring represents the axial response of the element and the two rotational springs represent the rotational responses at both ends of the element. The end blocks are rigidly connected to



a) General Prestressed Concrete Member



b) Mechanical and Discrete-Line-Element Model of Element i

Fig. 3.1 Discrete Element Representation of a Prestressed Concrete Member.

the adjacent elements at nodal points to preserve the compatibility at the nodal points. The discrete line element model which is equivalent to the mechanical model but with the blocks reduced to bar sizes and the springs reduced to point sizes is shown in Fig. 3.1b.

From the geometry of the element, the deformations of the springs, i.e. the axial shortening, Δh, and the rotations of the rotational springs, ψ_1 and ψ_2, can be found as functions of the end displacements, w_1, w_2, w_3, w_4, w_5, and w_6. The axial thrust, F, and the bending moments, M_1 and M_2, can be found from the deformations and the properties of the springs. The element end forces, f_1, f_2, f_3, f_4, f_5, and f_6, are then obtained by applying the laws of statics to the free body of the center bar and the end bars. Thus the element end force-displacement relationship is obtained. The tangent stiffness of an element (6 x 6 matrix) is found by applying Castigliano's first theorem to the element end force-displacement equations. The details of the derivation of the element end force-displacement relationship and the tangent stiffness of an element are well documented in the report by Hays and Matlock (37).

3.3 Tangent Stiffness Method.

The tangent stiffness method for nonlinear analysis uses an iterative procedure in which the displacements of the system under consideration are successively corrected until an equilibrium position is obtained. It is an extension of the direct stiffness technique where the incremental stiffness matrix based on the current position of the system is used instead of a constant stiffness matrix. It is mathematically equivalent to the Newton-Raphson Method (40). The method will be illustrated below.

Consider a single degree of freedom system. Assume that the load-deformation relationship of the system can be represented by a function:

$$P = g_u$$

as shown in Fig. 3.2. And further assume that the current state of the system is at the load level of P_i and at the deformation of u_i. It is required to determine the deformation at the new load level of P_{i+1}.

Start with a trial deformation of u_{i+1}, $\bar{u}_{i+1,0} = u_i$ and the additional applied load of $\Delta P_0 = (P_{i+1} - P_i)$. By assuming that the load-deformation is linear at that deformation level and using the tangent stiffness at that level as the stiffness of the system, the deformation increment can be calculated as:

$$\Delta u_0 = (g_u'^{-1})_{\bar{u}_{i+1,0}}$$

where $(g_u'^{-1})_{\bar{u}_{i+1,0}}$ is the reciprocal of the tangent stiffness, i.e. the reciprocal of g_u', the first derivertive of the function g_u evaluated at $\bar{u}_{i+1,0}$.

The new deformation level can be estimated by summing the previous trial deformation and the deformation increment as:

$$\bar{u}_{i+1,1} = \bar{u}_{i+1,0} + \Delta u_0$$

With the deformation of $\bar{u}_{i+1,1}$, the load level that the system carries is obtained from the function:

$$\bar{P}_{i+1,1} = (g_u)_{\bar{u}_{i+1,1}}$$

For a nonlinear system, $\bar{P}_{i+1,1}$ will rarely be equal to P_{i+1}. The difference is the equilibrium error.

$$\Delta P_1 = P_{i+1} - \bar{P}_{i+1,1}$$

The equilibrium error, ΔP_1, is then compared with the specified tolerance limit. If the limit is exceeded, the equilibrium error, ΔP_1, is used as the additional load applied to

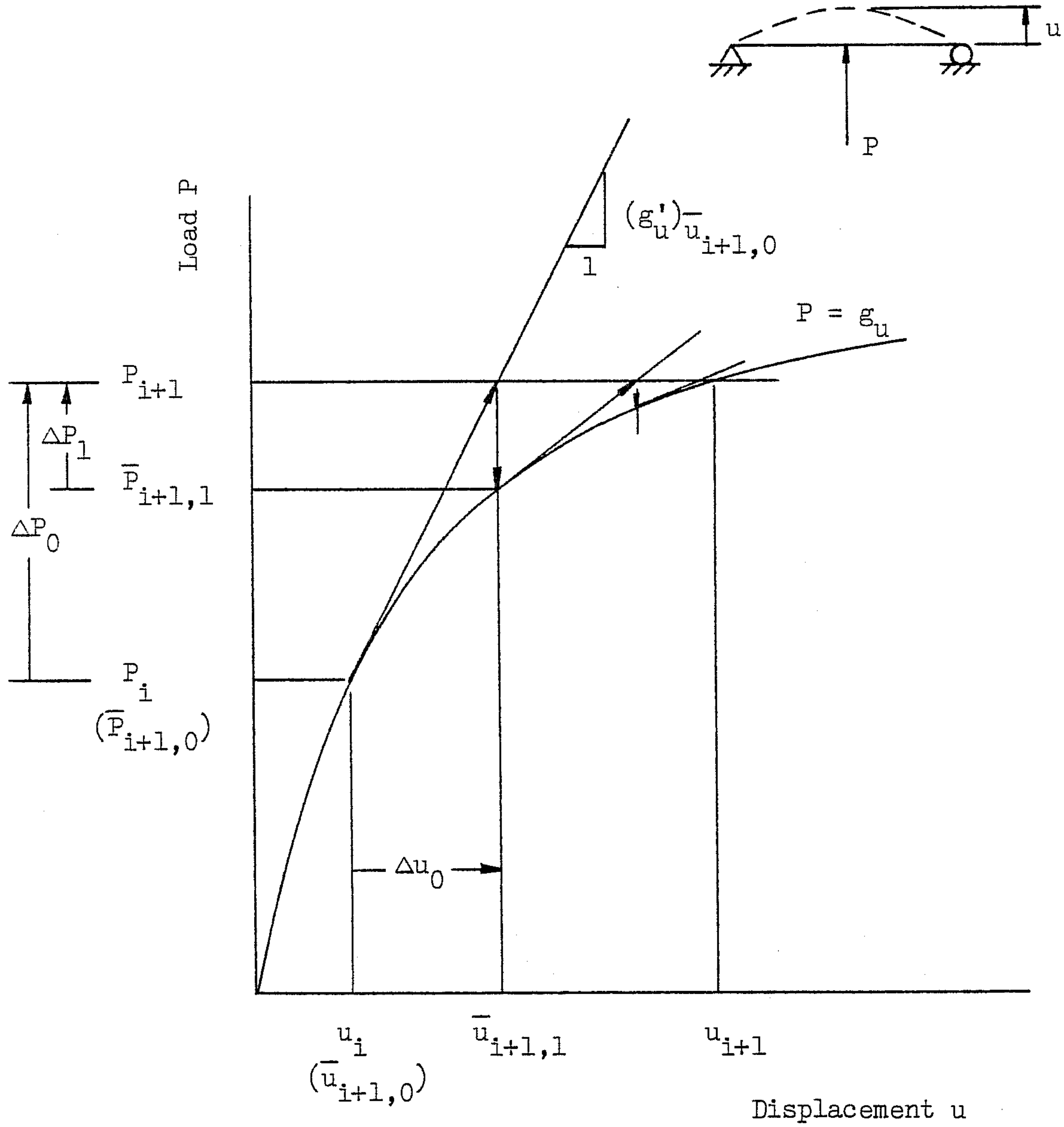


Fig. 3.2 Tangent Stiffness Method.

the system at the trial deformation level of $\bar{u}_{i+1,1}$. The process is repeated until the equilibrium error is within the specified limit, and the solution is assumed to be converged. Under some circumstances, such as the case where the new load level exceeds the maximum capacity of the system or the new load level is less than the capacity but with some unusual shape of the load-deformation relationship, the solution may diverge. An equilibrium state of the system under the applied load is obtained if the solution converges. The procedure is summarized in Fig. 3.2 and the flow diagram is shown in Fig. 3.3.

3.4 Instantaneous Response Analysis.

A member is idealized as a straight line passing through its centroidal axis. It is modeled as several equal discrete elements connecting end to end at nodal points. Each nodal point has three degrees of freedom, in the horizontal direction, the vertical direction, and the rotational direction. Loads and restraints in any of the three directions are lumped and applied only at the nodal points. The tangent stiffness method for nonlinear analysis is used to obtain an equilibrium position of the nodal points after loading that satisfies the compatibility and the boundary conditions at the nodal points. For convenience, the member axis will be referred to as the x-axis, the transverse axis as the y-axis with the x-y plane as the plane passing through the axis of symmetry of the cross-section of the member, and the rotational direction as the z-direction. The sign convention for loads and deformations will be used according to the right hand Cartesian coordinate system.

The discrete elements are used to represent material and cross-section properties of the member. Cross-section of an element is assumed to be constant and can be represented by

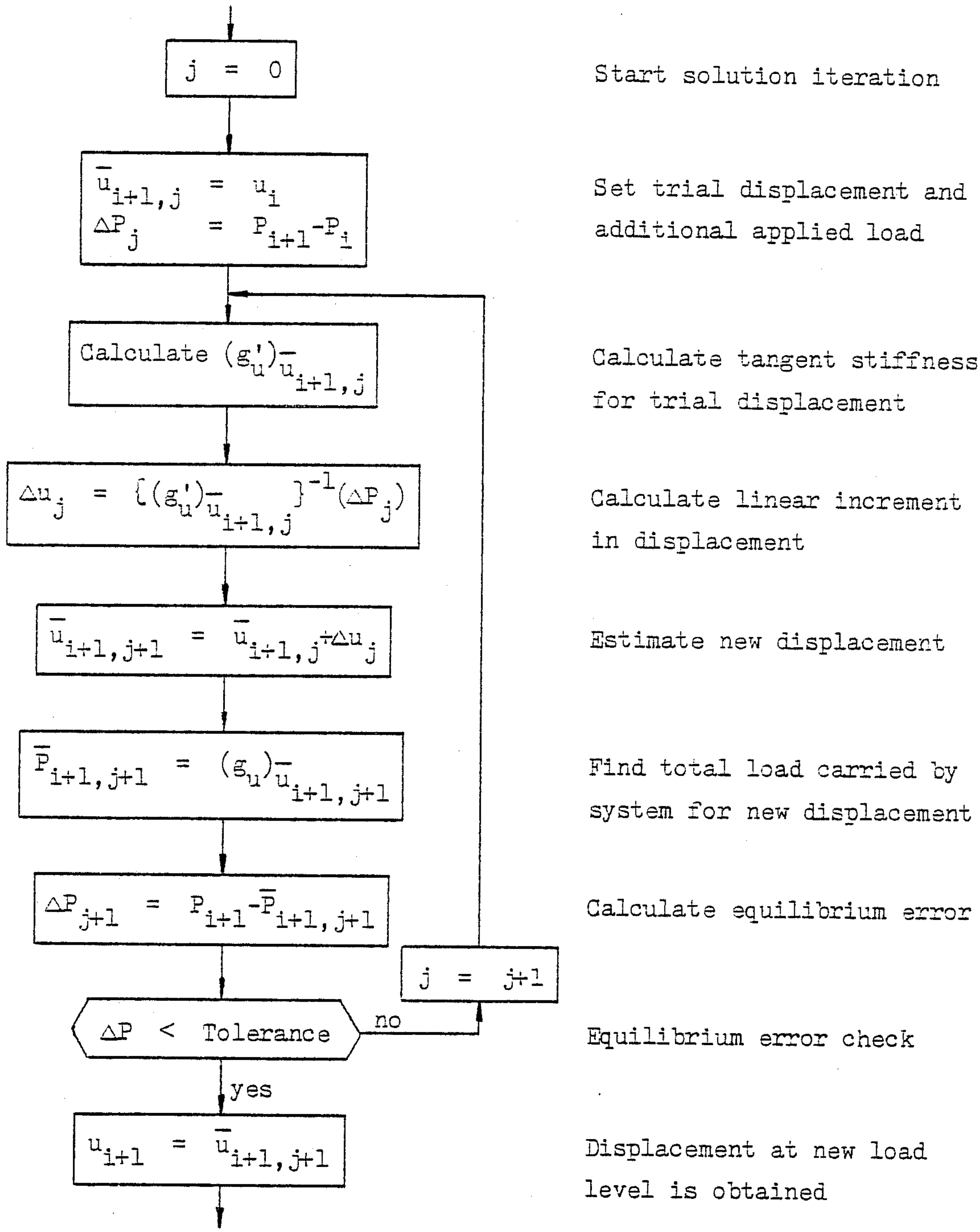


Fig. 3.3 Tangent Stiffness Iteration Procedure for One Load Level.

the cross-section at the middle of the element. The relationship between the element deformations and forces is estimated by approximating the cross-section as a series of rectangular fibers. By assuming that strain in each fiber is constant and can be represented by the strain at the centroidal axis of the fiber, the discrete element forces, F, M_1, and M_2, can be calculated from the spring deformations, Δh, ψ_1, and ψ_2, as follows:

For the element shown in Fig. 3.4, consider the right side of the element:

Strain at the member axis, EP $= \Delta h/TH$

Curvature at the 2nd rotational spring, CUR2 $= 2\Psi_2/TH$

where TH is the length of the element.

Imposing a linear strain variation over the depth of the cross-section, strain at the centroidal axis of fiber i, $\varepsilon_{tot,i}$, can be estimated as:

$$\varepsilon_{tot,i} = EP - y_i \; CUR2$$

where y_i is the distance from the centroid of the cross-section to the centroid of the fiber i.

Instantaneous strain of fiber i,

$$\varepsilon_{e,i} = \varepsilon_{tot,i} + \varepsilon_{si,i} - \varepsilon_{time,i} - \varepsilon_{com,i}$$

where $\varepsilon_{si,i}$, $\varepsilon_{time,i}$, and $\varepsilon_{com,i}$ are initial strain, time dependent strain, and offset strain due to composite action of fiber i, respectively.

From the stress-strain relationship of the material, stress level of fiber i, σ_i, at the instantaneous strain of $\varepsilon_{e,i}$ can be found, and then

Axial force, $F_2 = \sum_{i=1}^{n} \sigma_i A_i$

Bending moment, $M_2 = -\sum_{i=1}^{n} \sigma_i A_i y_i$

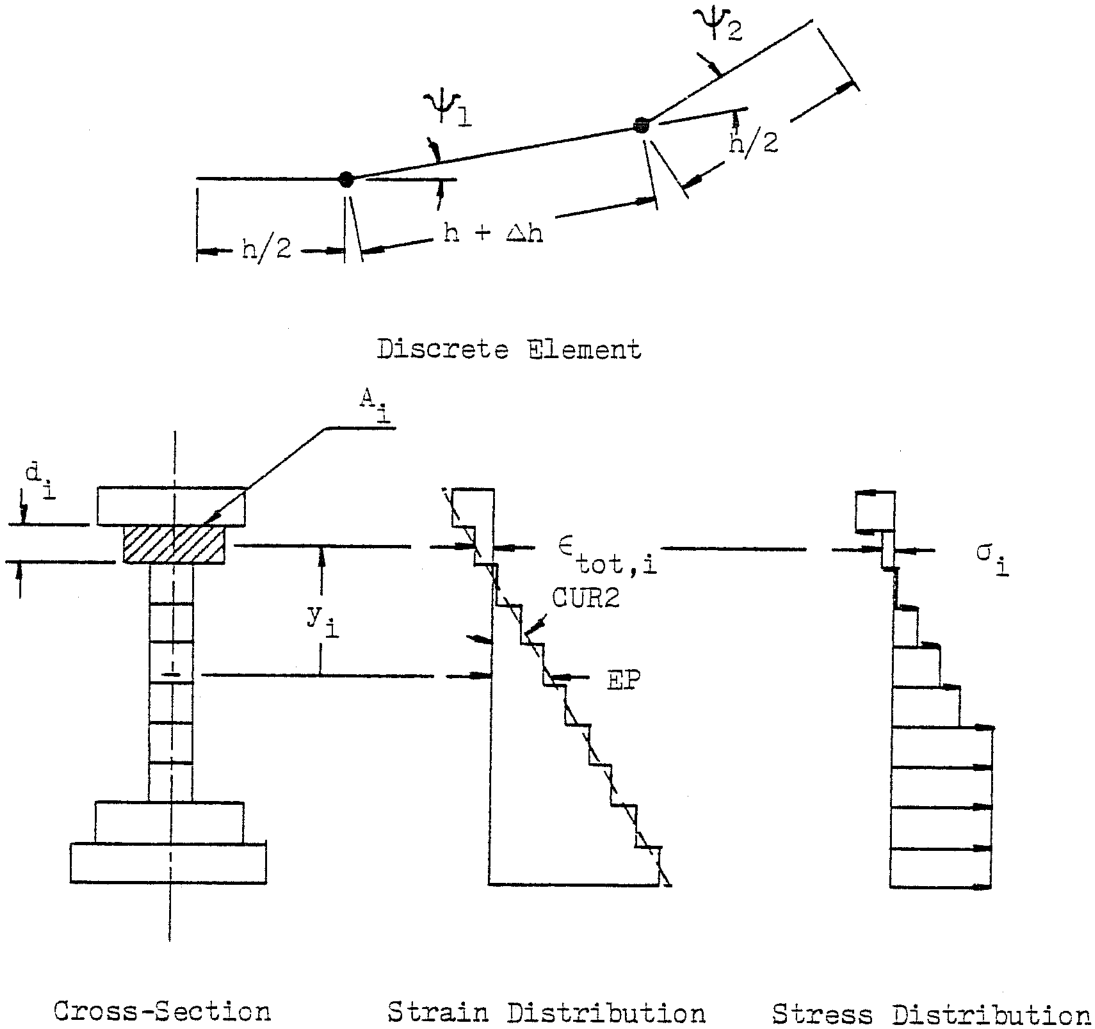


Fig. 3.4 Strain and Stress Distributions in a Discrete Element.

where n is the number of fibers in the cross section, and A_i is the cross-sectional area of fiber i.

Similarly, from the left side of the element, the axial force, F_1, and the bending moment, M_1, can be estimated. The element axial force, F, is found by averaging F_1 and F_2.

3.5 Prestressing Forces.

Two methods of constructing prestressed concrete beams have been used; pre-tensioning and post-tensioning. Pre-tensioning is the technique in which prestressing tendons (usually 7-wire strands) are tensioned in a rigidly fixed bed before casting of concrete. Then concrete is cast around the stressed tendons and the prestressing forces are transferred to concrete through bond after concrete has attained enough strength to carry the forces. Post-tensioning is the technique where, at first, concrete is cast with all or part of prestressing tendons unstressed and unbonded to the concrete. The unbonded tendons are then stressed against the hardened concrete to obtain the desired precompression stress in the concrete. After tensioning, the unbonded prestressing tendons may be left unbonded or grouted to provide bond between the tendons and the surrounding materials. In this study, only the perfectly bonded pre-tensioned or post-tensioned tendons are included in the analysis.

Prestressing forces are taken into account by specifying initial prestressing strains in the tendons. The tendon initial strains are defined as the strains in tendons due to prestressing forces before releasing of the forces, i.e. the prestressing strains at the zero deflection state of the member. Since the initial prestressing force in a pre-tensioned tendon is usually known, the strain that produces that stress level can be estimated from the stress level and the instantaneous stress-strain relationship of the tendon. This strain may vary a little between the holdings points along the length of the tendon, but the variation is customarily neglected in the analysis. The initial strain with respect to the zero deflection state of the member is equal to the summation of the prestressing strain and the total strain of concrete at the prestressing tendon level just before transferring. For the post-tensioning method of construction, only sequences and magnitudes of jacking forces and forces after releasing at the ends of the tendons can be easily obtained. If the strain variations along the lengths of the tendons after releasing are known, the initial strain can be estimated as the summation of the effective prestressing strain and the total strain of concrete at the tendon level just after transferring. A method for calculating the strain variation in a post-tensioning tendon from the jacking sequences and end releasing forces is presented below.

The variation of prestressing force along a post-tensioned tendon is caused by the friction between the tendon and surrounding materials. Friction losses are a function of the stress in the tendon, the profile of the tendon, the unintentional out-of-plane deflection or wobble of the tendon, and the coefficient of friction between the tendon and the surrounding materials. The A.C.I. Code (ACI 318-71) (3) and the P.C.I. Committee on Prestress Losses (67) recommend an expression to estimate the variation of prestressing force for a single end force as follow:

$$P_x = P_s e^{-(K\ell+\mu\alpha)}$$

where P_s = steel force at jacking end,

P_x = steel force at point x,

e = base of Napierian logarithms,

K = wobble friction coefficient

ℓ = length along prestressing tendon from jacking end to point x,

μ = curvature friction coefficient,

and α = total angular change of prestressing tendon profile in radians from jacking end to point x.

The suggested values of K and μ for various post-tensioning tendon are given in Table 3.1. Assume that the change in curvature of tendon due to prestressing force is negligible comparing to the original curvature of the tendon, α can be found as a function of the original tendon profile. And by approximating ℓ as the distance along the member axis, prestressing force variation along the length of the tendon, under sequences of application of end prestressing forces, can be estimated in the manner shown in Fig. 3.5. In the figure, x is the distance along the member axis from the left end of the tendon to a point on the tendon and s is the length of the tendon. P_1 and P_2 are jacking forces at the opposite ends, and P_3 and P_4 are releasing forces. $\alpha_{x,0}$ and $\alpha_{x,s}$ are the total angular changes of the prestressing tendon profile from 0 to x and from s to x, respectively. The solid line is the effective prestressing force along the length of the tendon.

The centroidal distance along the length of a prestressing tendon usually varies so that a desired eccentricity variation can be achieved. In order that the effect of prestressing can be taken into account, it is required by the program PBEAM that the eccentricity and the prestressing force of the tendon are specified at the middle of each element. In practice, it is usually adequate to represent a tendon profile as a series of straight line and parabolic segments. For convenience of the users of the program, typical tendon profiles, as shown in Fig. 3.6, may be generated internally by the program by inputting

Table 3.1

Friction Coefficients for Post-Tensioned Tendons (67)

Type of Tendon	Wobble Coefficient,μ K, per foot	Curvature Coefficient,
Tendons in flexible metal sheathing		
Wire tendons	0.0010 - 0.0015	0.15 - 0.25
7-wire strand	0.0005 - 0.0020	0.15 - 0.25
High strength bars	0.0001 - 0.0006	0.08 - 0.30
Tendons in rigid metal duct		
7-wire strand	0.0002	0.15 - 0.25
Pre-greased tendons		
Wire tendons and 7-wire strand	0.0003 - 0.0020	0.05 - 0.15
Mastic-coated tendons		
Wire tendons and 7-wire strand	0.0010 - 0.0020	0.05 - 0.15

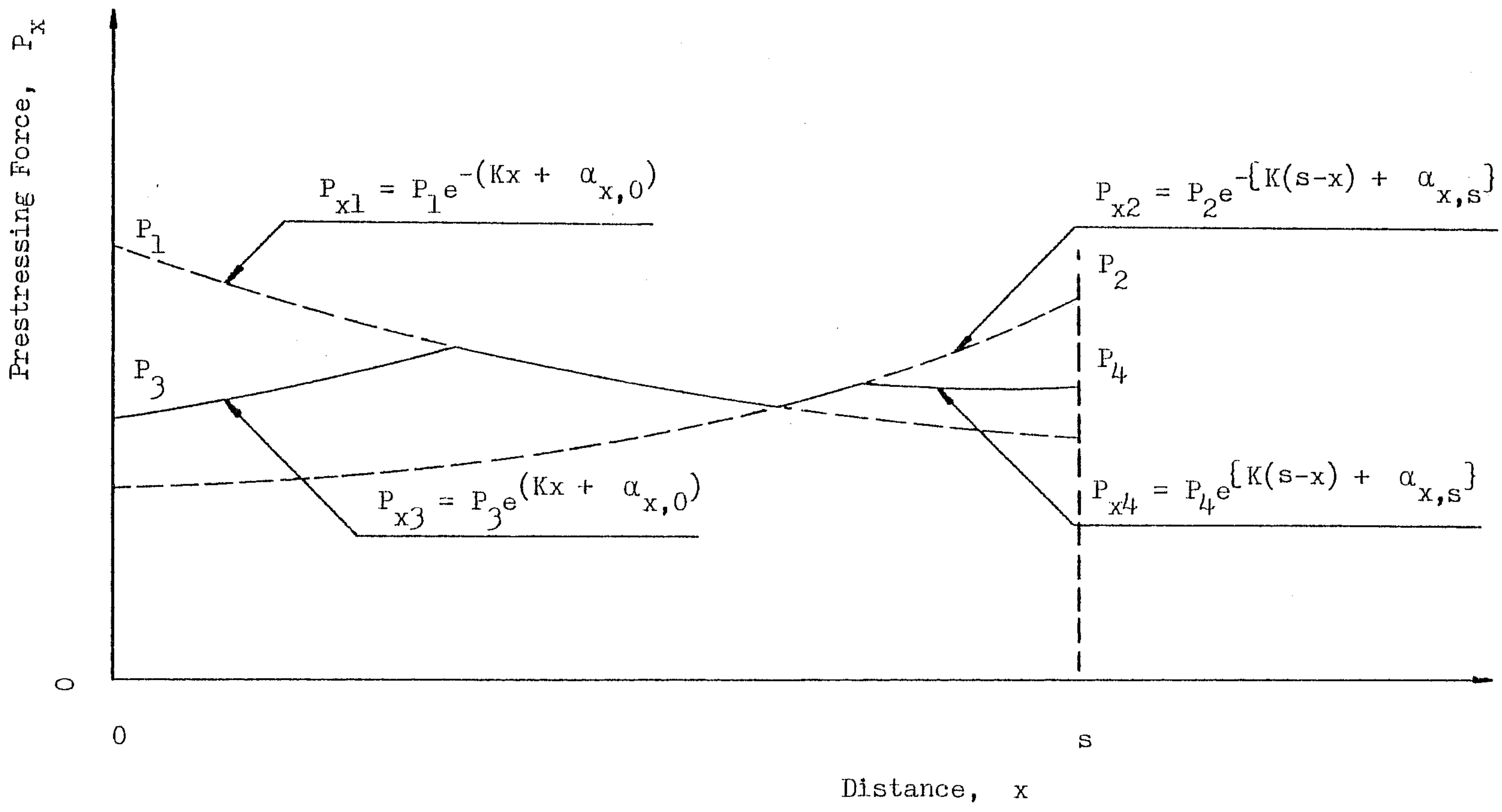
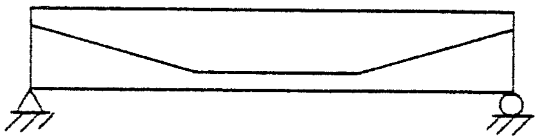
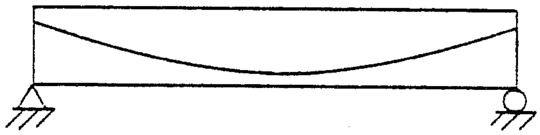


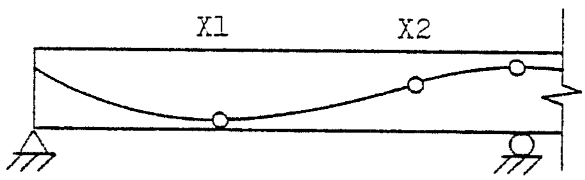
Fig. 3.5 Prestressing Force in a Post-Tensioned Tendon Resulting from Sequences of Jacking Forces P_1 and P_2 and Release Forces P_3 and P_4.



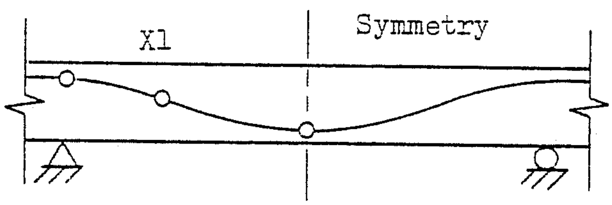
Linear Segments



Parabolic Segment



Typical Endspan Tendon Profile
(Parabolic Segments Joining at X1 and X2)



Typical Interior Span Tendon Profile
(Parabolic Segments Joining at X1)

Fig. 3.6 Linear and Parabolic Segments That Can Be Generated by the Program.

some control points. For a post-tensioned tendon, after the tendon profile is established, prestressing force variation along the length of the tendon is estimated by the program PBEAM using the procedure described above to account for friction and wobble effects. The details of the input data (including prestressing forces and eccentricities for beams) are presented in Appendix A and Appendix B.

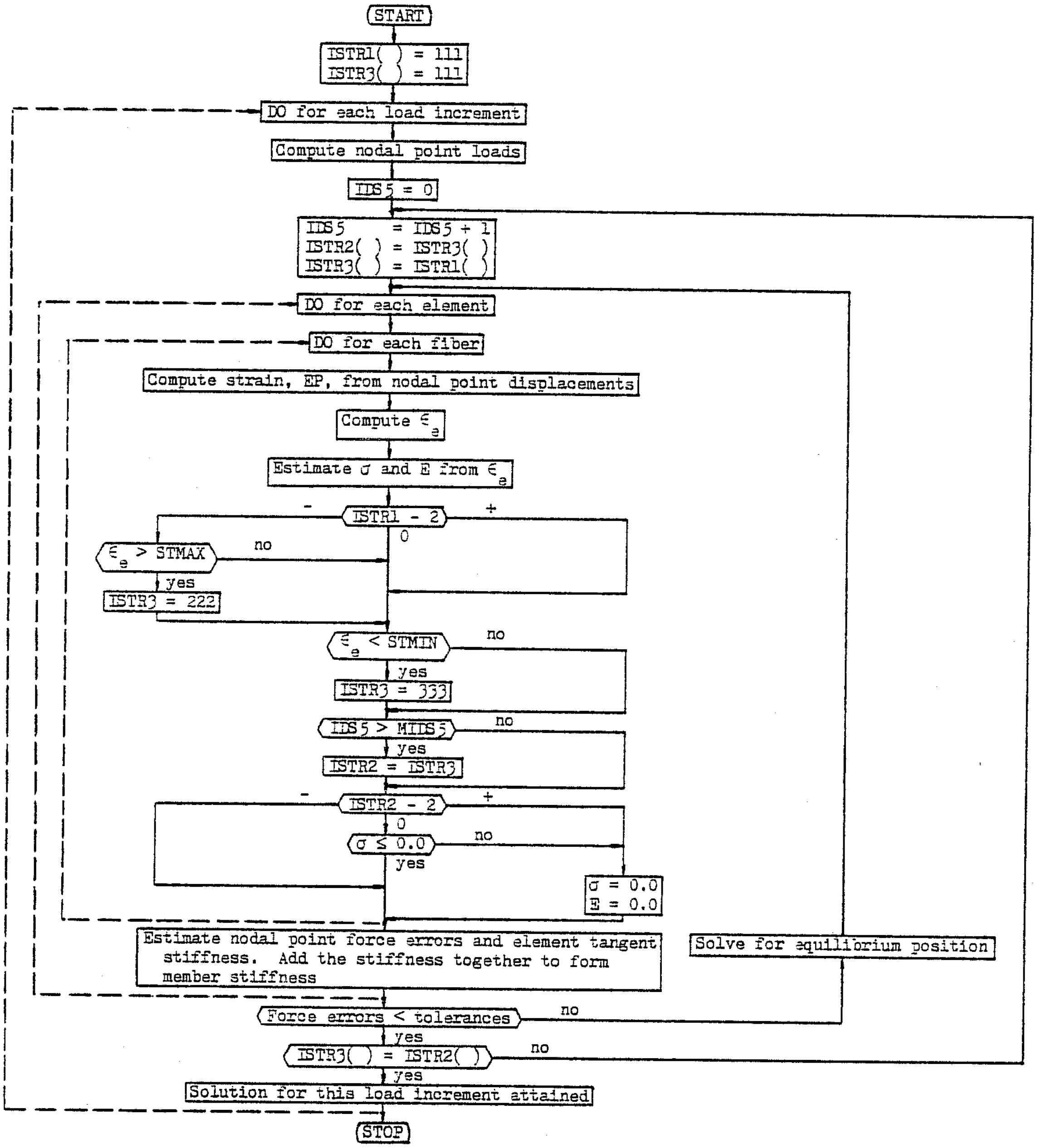
3.6 Convergence of Solution.

The divergence of a solution often indicates that a load level assumed exceeds the capacity of the beam under consideration. However, in some cases the divergence may be the result of applying too large a load increment. Since the method of analysis uses the tangent technique, for nonlinear members, strains in some portions of the member, at the early iterations, will be overestimated while others will be underestimated. The strains in some fibers may exceed the failure limits, thus indicating that the fibers have "failed". These strains are the basis for determining the stiffness of elements and the member. If the load increment is large enough, even though it does not necessarily exceed the ultimate strength of the member, these initial indications of "failure" may cause the member solution to diverge. To ensure the convergence of the member solution in this case, the following technique is used.

Strain indicators are used in the program to track the history of overstraining of each fiber in the member. The indicator 111 shows that the fiber has never been strained exceeding its failure limits, the indicator 222 indicates that the fiber was strained exceeding its tensile limit, and the fiber was strained exceeding its compressive limit if its strain indicator is 333. Three sets of strain indicators at different stages of calculations are kept. The first set is the set of strain indicators for the state of fiber strains before loads are applied, the second set is the set of strain indicators at the beginning of the iteration, and the third set is the set of strain indicators based on the current position of the member within the member iterations. At the start of the iteration process, the three sets of the strain indicators are set to be the same and equal to those of the first set. Stresses are calculated based on the strain levels and the indicators in the second set. The current strain indicators are obtained based on the current positions of the member and the first set of the indicators. When the equilibrium position is reached, the indicators in the second set and the third set are compared. If there are any differences, the strain indicators in the second set are updated to be equal to those of the third set and the iteration process is repeated. This, in effect, freezes member cracks in the iterative cycle. After a specified number of cycles, there may be some incorrect third set indicators and another iterative cycle is needed. In the next iterative cycle, the cracks will not be frozen. The indicators of the second set will be set equal to those of the third set and the solution is attained if it converges. From experience, three or four cycles in which cracks are frozen should be adequate to assure the convergence of the solution. The flow chart of the process is illustrated in Fig. 3.7.

3.7 Time-Dependent Response Analysis.

A numerical method using the instantaneous solution previously described is modified to analyze the time dependent responses of a continuous prestressed concrete beam. A time



ISTR1, ISTR2, and ISTR3 are strain indicators for each fiber in first, second, and third sets.

ISTR1( ), ISTR2( ), and ISTR3( ) are arrays of ISTR1, ISTR2, and ISTR3.

IIS5 is number of crack freezing-releasing iterative cycles.

MIIS5 is maximum number of IIS5 specified.

STMAX and STMIN are maximum and minimum strain limits.

Fig. 3.7 Flow Diagram for Crack Freezing Iterative Cycles to Ensure Convergence of the Solution.

interval under consideration is divided into several small time increments. In each time increment, it is assumed that material properties and the responses of each segment of the fibers of the beam follow the functions of time and stress level history up to the starting of the time increment. The equilibrium position of the beam can be found and is used as the basis for the analysis of the responses in the next time increment. Starting from the beginning of the interval, the whole range of the time-dependent responses can be obtained.

The time-dependent response analysis includes time-dependent properties of the materials. They are creep, shrinkage, relaxation, and aging of the materials. Creep will be defined as the time-dependent deformations of the concrete materials which are the functions of stress levels and the time at which the stresses are applied. Shrinkage represents the time dependent deformation for concrete that is independent of stress levels, it is the function of time only. Relaxation is defined as the time-dependent stress decrements of steel materials under stresses which are the functions of both stresses and the time when stresses are applied. The aging of material (concrete) is reflected in the changing of the stress-strain curve of the material with time. The stress-strain curve intrinsic shape is assumed to be the same, but the stress at the same strain level will be a function of time.

Time at which loads are applied is also considered. Loads may be applied any time after the erection time of the beam and they will be accumulated. Some portions of the cross-sections of the beam may be added later, i.e. the composite beam action is taken into account. Restraints are independent of time and are applied at the beginning of the problem.

As previously mentioned, in determining the instantaneous responses of a continuous beam, the beam is subdivided into several equal elements connected end-to-end at nodal points. Each of the elements is subdivided vertically into fibers. A fiber is assumed to carry only axial strain and the strain is constant throughout the individual fiber. The fiber is compatible to the element only at its ends. Loads and restraints are discretized and applied only at the nodal points.

Since the strain in each of the fibers is assumed to be constant throughout the fiber, the analysis of time-dependent responses of the beam may be included by assuming that the strain in each fiber consists of time-dependent strain parts in addition to instantaneous strain parts. Time-dependent strains of concrete consist of shrinkage strains and creep strains and those of prestressing steel are relaxation strains. Shrinkage strain are the function of time alone, thus they can be found immediately at any given time increments. Creep strains under constant stresses may be represented by creep functions. For creep under variable stresses, as in the beam, two methods of predicting creep strains under variable stresses may be used. The methods are the rate of creep method and the superposition method. The rate of creep method uses the stresses at the beginning of the time increment as the basis for finding the creep increment strains. For the superposition method, the stress history at every time increment up to the beginning of the current time increment is used in the calculation.

The creep-time relationships of concrete used in this study are represented as functions of time and the ratio of creep strains to the "instantaneous" strains at the time of loading. Since the "instantaneous" strains are obtained from stress-strain curves of the materials at the time under consideration in which the effects of the aging of the materials are included, creep strains need to be corrected for the time variations of the "instantaneous" strains. A corrected creep strain may be calculated as follows:

Creep strain at time t of a fiber subjected to a constant sustained load f_0 applied at time t_0

$$(\varepsilon_{c,f_0})_{t,t_0} = \{1 + (c)_{t,t_0}\} (\varepsilon_{e,f_0})_{t_0} - (\varepsilon_{e,f_0})_t$$

where $(c)_{t,t_0}$ = creep coefficient at time t due to constant sustained load f_0 applied at time t_0,

$(\varepsilon_{e,f_0})_{t_0}$ = instantaneous strain at time t_0 due to load f_0,

and $(\varepsilon_{e,f_0})_t$ = instantaneous strain at time t due to load f_0.

Creep strain increment in time interval t_1 to t_2 of a fiber subjected to a constant load f_0 applied from time t_0

$$(\Delta\varepsilon_{c,f_0})_{t_2-t_1,t_0} = (\varepsilon_{c,f_0})_{t_2,t_0} - (\varepsilon_{c,f_0})_{t_1,t_0}$$

For a fiber subjected to a series of stepwise variable loads, f_0, f_1, .. , f_{n-1}, applied at time intervals, t_0 to t_1, t_1 to t_2, .. , t_{n-1} to t_n, respectively, creep strain at time t_n, $(\varepsilon_c)_{t_n}$, can be represented, using the rate of creep method, as:

$$(\varepsilon_c)_{t_n} = \sum_{i=0}^{n-1} (\Delta\varepsilon_{c,f_i})_{t_{i+1}-t_i,t_0}$$

Using the superposition method, creep strain at time t_n of the fiber can be estimated as follows:

Instantaneous strain increment at time t_0

$$(\Delta\varepsilon_e)_{t_0} = (\varepsilon_{e,f_0})_{t_0}$$

Instantaneous strain increment at time $t_i, t_i > t_0$

$$(\Delta\varepsilon_e)_{t_i} = (\varepsilon_{e,f_i})_{t_i} - (\varepsilon_{e,f_{i-1}})_{t_i}$$

Assuming that the same creep function can be applied to both the compressive and the tensile strain increments, the corrected creep strain at time t_n taking into account the aging of the material

$$(\varepsilon_c)_{t_n} = \sum_{i=0}^{n-1} \{(\varepsilon_{e,f_i})_{t_i} - (\varepsilon_{e,f_i})_{t_{i-1}} + (\Delta\varepsilon_e)_{t_i} (c)_{t_n,t_i}\}$$

Taking into account the difference between the creep responses due to applied loads and the creep recovery responses, using a constant creep recovery ratio, R, the instantaneous strain increment at time t_i, $i > 0$, is adjusted as:

If $(\varepsilon_{e,f_i})_{t_i}$ and $(\varepsilon_{e,f_{i-1}})_{t_i}$ are of the same sense,

For $|(\varepsilon_{e,f_i})_{t_i}| \geq |(\varepsilon_{e,f_{i-1}})_{t_i}|$

$$(\Delta\varepsilon_e)_{t_i} = (\varepsilon_{e,f_i})_{t_i} - (\varepsilon_{e,f_{i-1}})_{t_i}$$

For $|(\varepsilon_{e,f_i})_{t_i}| < |(\varepsilon_{e,f_{i-1}})_{t_i}|$

$$(\Delta\varepsilon_e)_{t_i} = R\,\{(\varepsilon_{e,f_i})_{t_i} - (\varepsilon_{e,f_{i-1}})_{t_i}\}$$

If $(\varepsilon_{e,f_i})_{t_i}$ and $(\varepsilon_{e,f_{i-1}})_{t_i}$ are of the opposite senses,

$$(\Delta\varepsilon_e)_{t_i} = (\varepsilon_{e,f_i})_{t_i} - R\,(\varepsilon_{e,f_{i-1}})_{t_i}$$

It should be noted that zero stress is assumed to produce zero instantaneous strain.

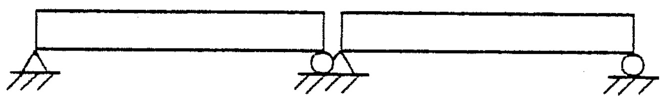
In this study, creep strains are determined by subdividing the time interval of interest into smaller time increments and using the above methods, assuming that stress in each fiber is constant over each time increment and can be approximated by the stress at the beginning of each time increment. The accuracy of the creep strain prediction may be improved if the averages of the stresses at the beginning and at the end of each time increment are used in the calculation. But the solution converges very slowly, and in some cases, with "large" time increment, the solution may diverge. The method used will give satisfactory accuracy if the expected time-dependent deformation increments are kept small.

The relaxation strains are treated the same way as the creep strains. But instead of determining the creep strains, relaxation stresses are calculated from the stress history and only the method similar to the rate of creep method is used. The method similar to the superposition method is invalid since relaxation is not a linear function of stress level. The relaxation stresses are then converted to strains based on the current strain levels.

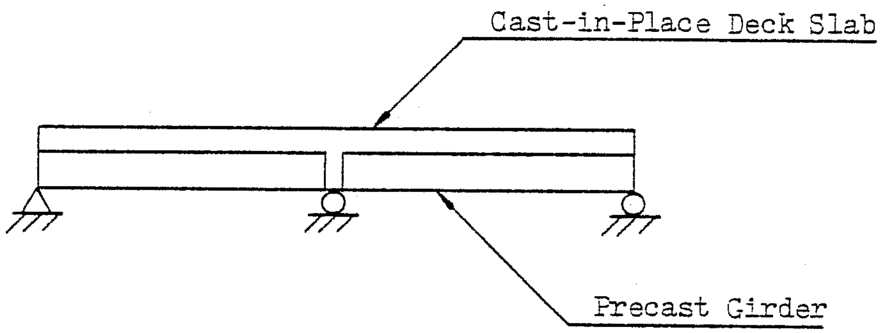
3.8 Composite Beam Action.

Prestressed beams are frequently used as composite beams, where the beams are precast and the slab portions of the composite beams are cast-in-place on the top of the precast sections at some later date, as shown in Fig. 3.8. At the time of casting of the deck slabs, the beams may be shored, i.e. the precast beams do not carry any slab loads at the time of casting, or unshored, that is the precast beams carry slab loads and formwork at the time of casting of the slabs. After the slabs have gained strength forming the composite beams, the beams and the slabs act together under the additional loads.

In order to analyze the composite beam action, the following technique is used. There are three specified times associated with each fiber of a member: TIMESS1, the time when the fiber is cast, TIMESS2, the time when the fiber is added to the member, and TIMESS3, the time when the fiber can carry loads. TIMESS1 is used as the reference in estimating strength and creep properties of the fiber. Gravity load of the fiber, if applicable, is added to the member at TIMESS2. The fiber is compatible to the rest of the cross-section in carrying additional loads and loads induced by time-dependent properties of the cross-section after TIMESS3. Shrinkage of the fiber also starts at TIMESS3. Since strains in each fiber are calculated from the deflected shape of the beam and the locations of the fibers, the strains induced by loads and time-dependent strains at any time after TIMESS3s of the fibers are the differences between the strains at those locations at the times just before TIMESS3s of the fibers and the strains at



Precast Girders, Simply Supported



Precast Girders and Cast-in-Place Deck Slab, Composite Beam

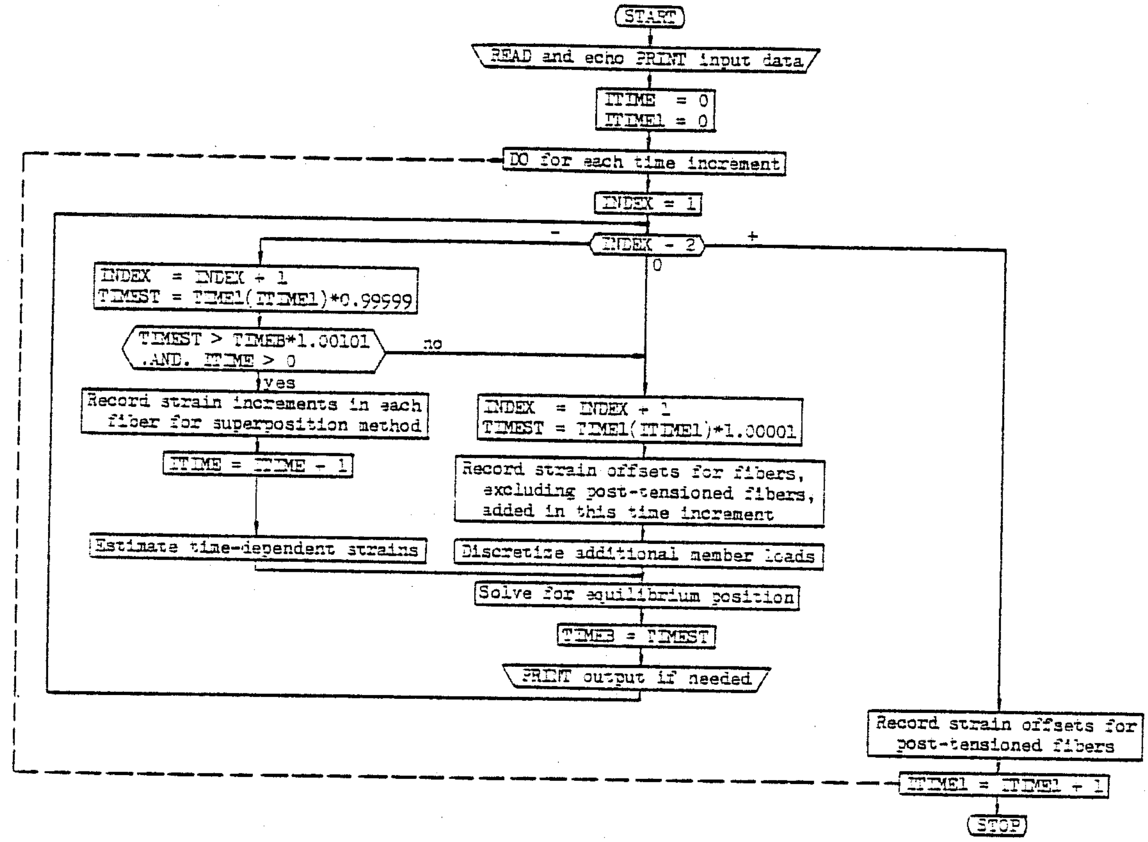
Fig. 3.8 Sequence of Construction of a Two-Span Composite Beam.

those locations at that time. The offset strain taking into account the composite beam action of fiber i, $\varepsilon_{com,i}$, is the strain at the location of fiber i at the time just before TIMESS3 of the fiber.

The difference between shored and unshored composite beams is taken into account by specifying TIMESS2s of the added fibers differ from their TIMESS3s. If their TIMESS2s are equal to or greater than their TIMESS3s, the fibers carry the additional gravity loads at the time they are added to the beam. It is a shored composite beam. If their TIMESS2s are less than their TIMESS3s, the added fibers carry loads after they are added to the beam. The beam acts as an unshored beam.

3.9 Program PBEAM.

With the procedures described in the previous sections, a method of analysis of both instantaneous and time-dependent responses of general prestressed beams is developed. The method can be summarized as a flow diagram in Fig. 3.9. The steps include reading and echo printing of input data. A series of time increments are specified. It is assumed that loads and parts of cross-section are added only at the beginning of specified time increments. For each time increment, at the time just before the end of the increments, an equilibrium position of the member is estimated for the changes in time-dependent strains in each fiber in the increment. The estimation of the time-dependent responses is skipped for the time increment which is less than 0.00101 of the time at the beginning of the increment. The offset strains for the additional fibers, excluding post-tensioned



ITIME = Number of times strain increments are recorded
ITIME1 = Time increment number
TIME1( ) = Stored values of time increments
TIMEB = Time at beginning of increment or at beginning of problem
TIMEST = Time at end of increment

Fig. 3.9 Flow Diagram for the Program PBEAM.

fibers, which can carry loads after the time increment are then recorded. The additional loads are discretized as nodal point loads and a new equilibrium position of the beam under the new loading condition, including pre-tensioned or post-tensioned forces on the added fibers, is estimated. Then the offset strains for the post-tensioned fibers are recorded. The steps are omitted if they are not applicable at the time increment being considered and solution output may be printed if needed. The process is repeated for all other time increments over the interval of interest.

CHAPTER IV

EXAMPLE PROBLEMS

The computer program, called PBEAM, was developed to analyze both instantaneous and time-dependent responses of prestressed concrete beams. It was written in FORTRAN IV and was implemented and checked out on the CDC 6600 computer at the Computer Center of the University of Texas at Austin. The MNF compiler was used. As presently dimensioned, 70200_8 words of storage are required to compile the program and 131000_8 words of storage to load the program. The program is subjected to the assumptions and the associated limitations as previously mentioned in Chapter III. The program input and output details, input guide, the listings of the input data and selected example problems, the grossary of the notations used in the program, and the listing of the program are presented in Appendix A to Appendix E.

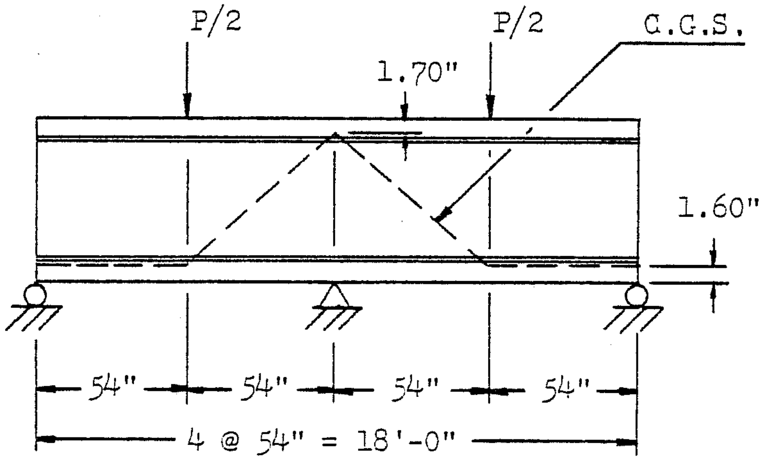
In this chapter, five example problems are presented to establish the validity of the proposed method and the program PBEAM. Each of the problems represents a typical type of prestressed concrete member and loading that can be analyzed by the program. The example problems are: (1) failure load analysis of a pre-tensioned continuous prestressed beam, (2) failure load analysis of a simply supported pre-tensioned composite beam, (3) time-dependent analysis of simply supported pre-tensioned prestressed beams, (4) time-dependent analysis of simply supported post-tensioned bonded prestressed beams, and (5) time-dependent analysis of a continuous pre-tensioned composite beam.

The first two example problems are selected to illustrate the capability of the program in analyzing instantaneous load-deflection responses up to failure of the beams. The third example problem shows time-dependent load-deflection response analysis of the beam. The last two example problems show time-dependent load-deflection response analyses and load-deflection response analyses after long-term sustained loading of the beams. It will be noted carefully in each example problem whether known experimental material properties or projected material properties as programmed are being used. The basis for the assumptions about materials built into the program was shown in Chapter 2. The results from the program are compared with existing experimental measurements and previous analytical results, if available. The errors of the analysis are expressed in percentages and are defined as:

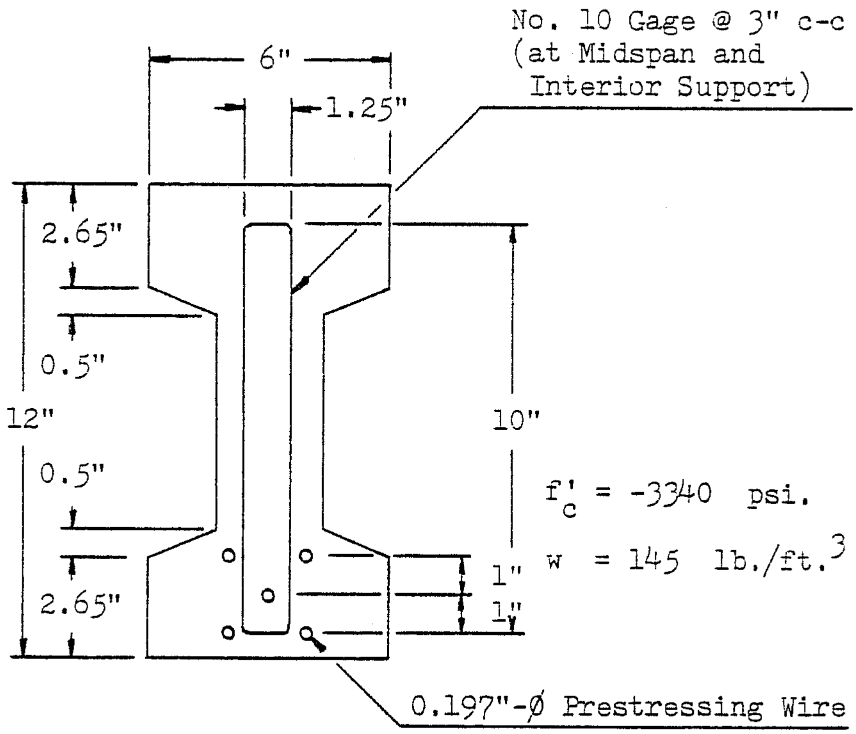
$$\text{Error} = \frac{\text{Computed Value} - \text{Measured Value}}{\text{Measured Value}} \times 100\%$$

4.1 Example Problem 1 - Instantaneous Response of a Continuous Pre-tensioned Beam with Draped Tendons.

A two-span continuous pre-tensioned concrete beam was selected as one of the example problem. The short term loading strength and behavior of he beam, designated as beam BW.10.072, was reported by Hawkins, et al., (36) from an investigation of prestressed concrete beams for highway bridges. The load-deflection response of the beam was previously analyzed by Atkins (7) and Hays and Matlock (38) using the computer programs developed in their studies. The details of the cross-section, beam loading arrangement, and material properties are shown in Fig. 4.1.



Loading Arrangement and Tendon Profile

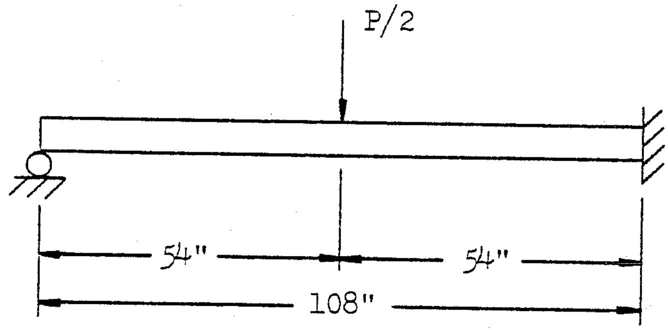


Cross-Section at Midspan

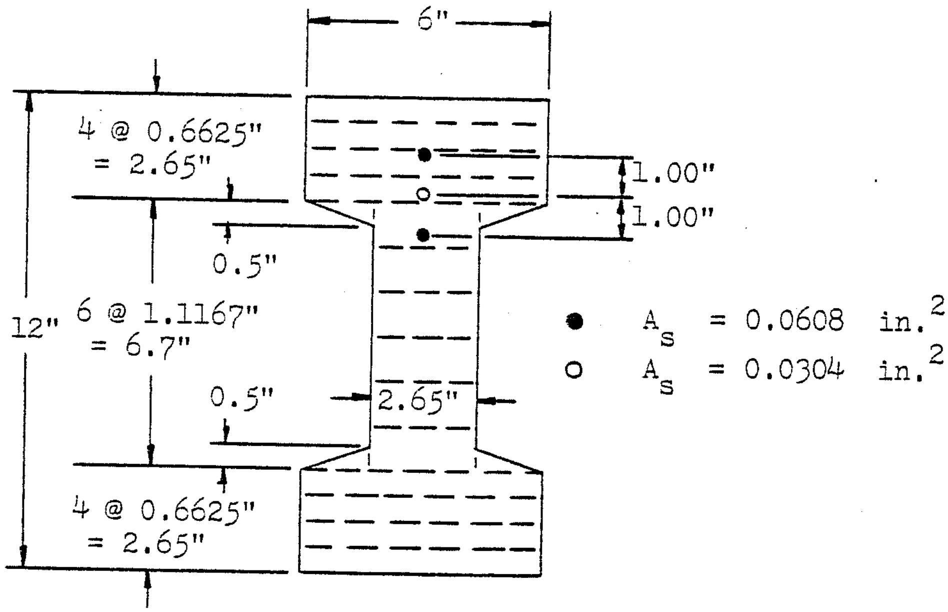
Fig. 4.1 Details of Loading Arrangement, Tendon Profile, and Cross-Section of Beam BW.10.072.

The beam consists of two nine-foot spans loaded with a single concentrated load at the middle of each span. The beam is of concrete, I-shape in cross-section, pre-tensioned with five prestressing wires draped in straight segments from the center support to the loading points. Lateral reinforcement was adequately provided to ensure the flexural failure of the beam. The amount of the lateral reinforcement was varied along the length of the beam. The stirrup dimension and spacing at critical sections, i.e. at the middle of each span and at the interior support, are also shown in Fig. 4.1. The beam was prestressed at the age of 5 days and loaded to failure at the age of 13 days.

In order to reduce the amount of calculation, only half of the beam is analyzed taking advantage of the symmetry about the center support of the beam and loading. The beam is modeled as a twenty-element member supported only in the transverse direction at the left end and completely fixed at the right end, i.e. supported in the member axis direction, the transverse direction, and the rotational direction. The member is longitudinally divided into several horizontal fibers. Fig. 4.2 shows the beam boundary conditions and the modeled cross-section. Although the beam had end blocks, their effects were minimal and they are neglected in the modeling of the beam. The proposed concrete stress-strain curve is used with the maximum stress, f''_c, equal to the cylinder compressive strength, f'_c, the strain at 0.5 f''_c on the falling branch of the stress-strain curve, ε_{50c}, equal to -8.295×10^{-3} in./in., and the modulus of elasticity of concrete, E_c, equal to $33\, w^{1.5} \sqrt{|f''_c|}$. The modulus of rupture of concrete, f_r, is taken to be equal to $7.5 \sqrt{|f''_c|}$. The



Modeled Boundary Conditions and Loading Arrangement



Modeled Section

Fig. 4.2 Modeled Boundary Conditions, Loading Arrangement, and Cross-Section for Beam BW.10.072.

stress-strain curve of the prestressing wires is shown in Fig. 4.3. The initial strains of the wires (before transfer) are assumed to be constant throughout the lengths of the wires and equal to 4.181×10^{-3} in./in., which results in the average prestressing stress (after transfer) varying from the maximum of 117.2 ksi. at 6.75 ft. from the end support to the minimum of 113.8 ksi. at the end support. The test measurements showed the effective prestressing stress to be 114 ksi. at the end support and 112 ksi. at the center support.

The short-term load-deflection response of the beam at the loaded point from the test measurements and from the program PBEAM are compared in Fig. 4.4. The program PBEAM predicts the response in agreement with the measured data except at the load level over about 70% of the ultimate load. At loads approaching ultimate, the program gives a smaller deflection at the same load level than was shown by the measured data. The difference may be due to the higher effective prestressing stress used in the calculation. With the load increment of 0.2 kip near the ultimate load, the solution diverges at the applied load level of 41.8 kips. The reported ultimate load was 42.8 kips, excluding the weight of the beam. The beam is also analyzed by the program PBEAM using the Hognestad stress-strain curve for concrete with the stress at the strain of -0.0038 in./in. equal to 0.85 f''_c. Almost identical results are obtained which are expected. In this range of concrete strength, the ascending branches of the two stress-strain curves are about the same. Although the descending branch of the proposed stress-strain curve depends upon both the concrete strength and the degree of lateral confinement, the concrete strength and the lateral reinforcement for

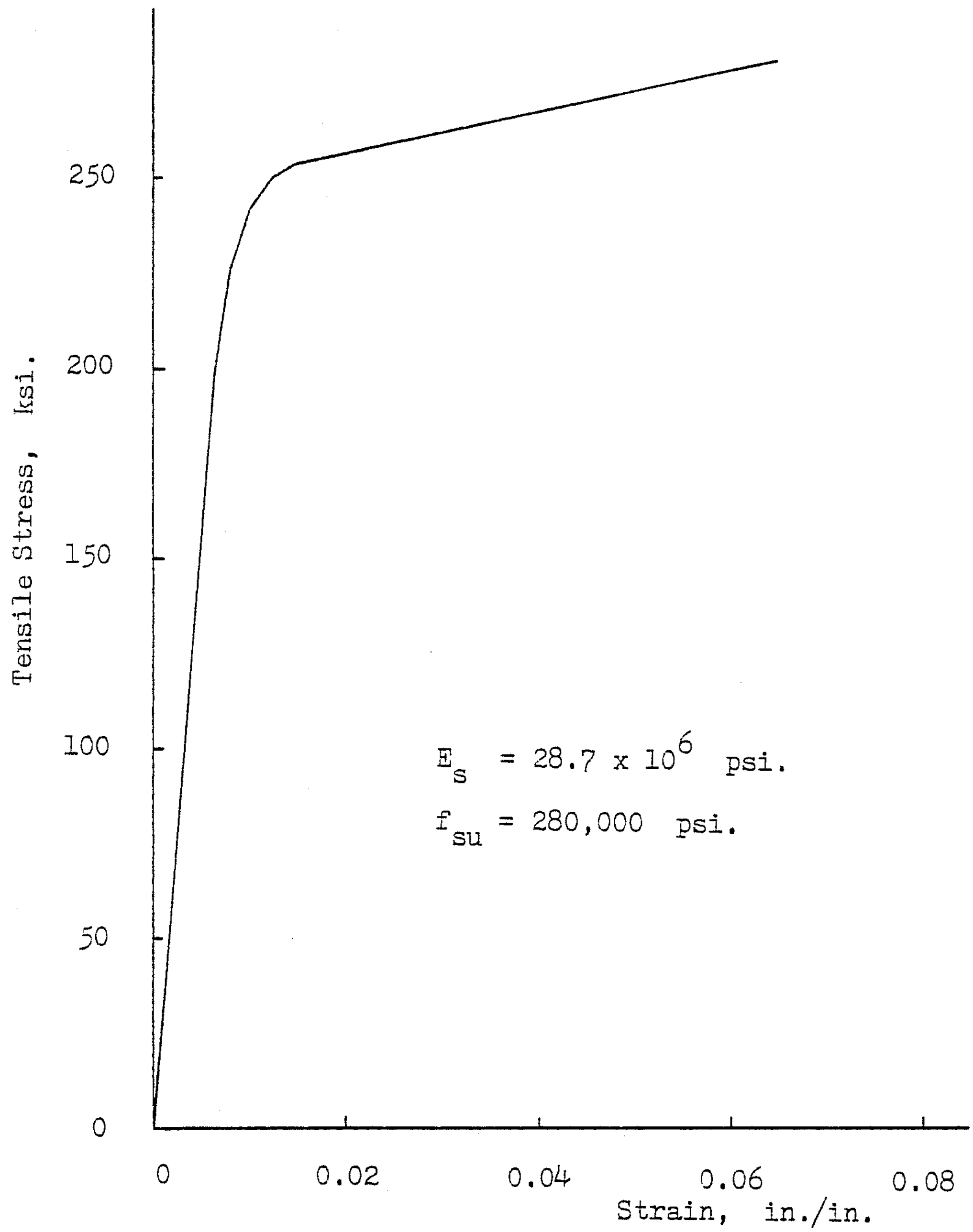


Fig. 4.3 Instantaneous Stress-Strain Relationship in Tension of Prestressing Wires for Beam BW.10.072.

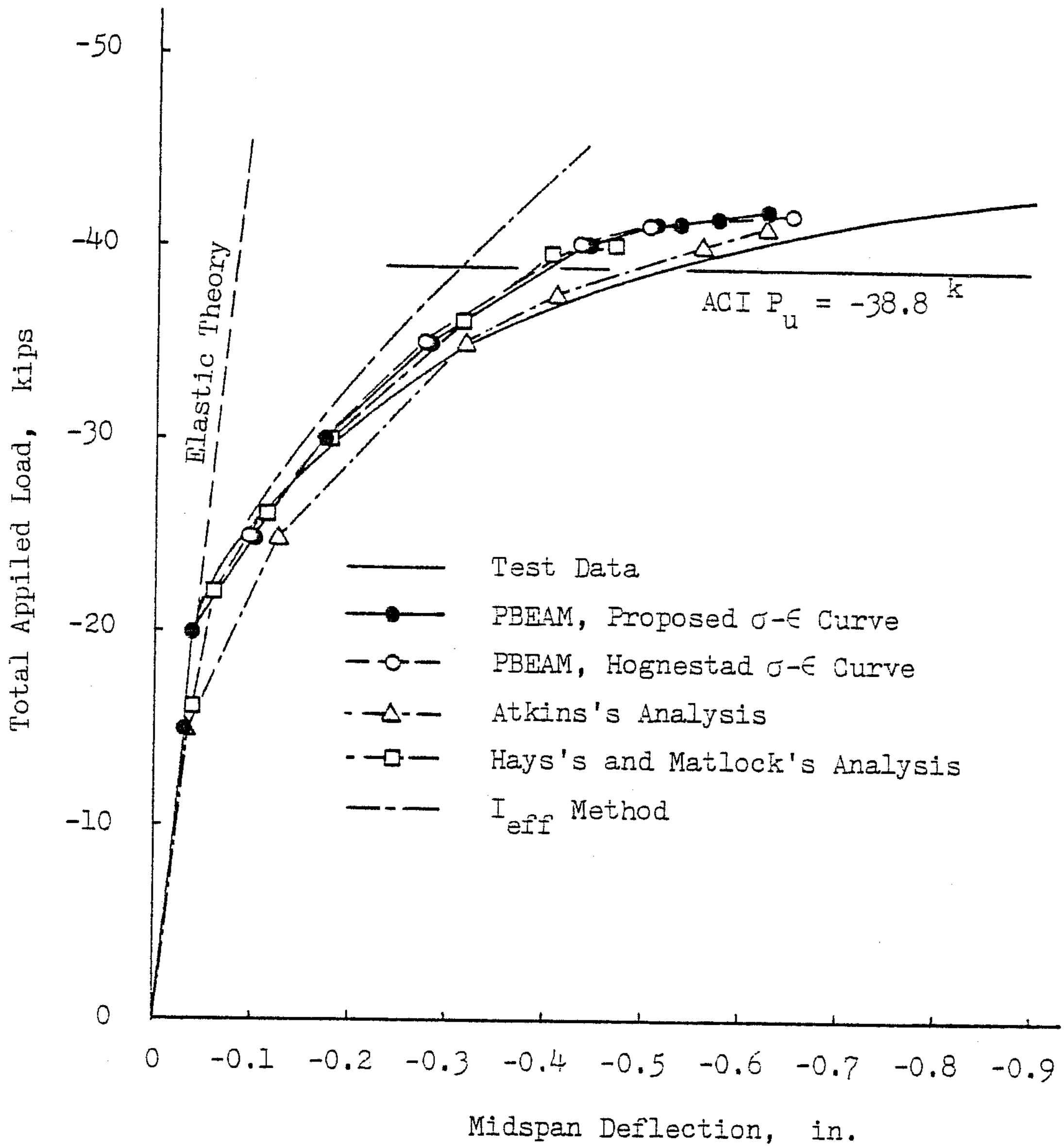


Fig. 4.4 Comparison of the Measured Load-Deflection Response and the Analytical Results of BW.10.072.

the beam yield almost the same descending branch. Fig. 4.4 also shows the analytical results from Atkins's program, Hay's and Matlock's program, and from hand calculations using elastic theory, the effective moment of inertia method (3), and the ultimate load as computed by the A.C.I. method (3). For the effective moment of inertia method, the effective moment of inertia of the section at midspan is used to represent the effective moment of inertia of the beam as recommended by Branson (10).

All of the analytical results give about the same load-deflection response before the load at first cracking. The program PBEAM, Atkin's program, and Hays's and Matlock's program yield about the same member stiffness after the first cracking load while a stiffer member is predicted using the effective moment of inertia method. About the same load at the first cracking results from all of the analytical methods except from Atkins's. Atkins gives a lower load at the first cracking which apparently results from the use of a lower modulus of rupture of concrete in his analysis. The ultimate applied loads as estimated by different methods are 41.8 kips by the program PBEAM, 40 kips by Hays's and Matlock's program, 41 kips by Atkins's program, and 38.8 kips by the A.C.I. method. The A.C.I. value is obtained from the ultimate moments at the critical sections estimated according to the A.C.I. Code 318-71 with the capacity reduction factor, ϕ, equal to 1, assuming full moment redistribution.

The number of discrete elements used in modeling the structure also affects the results to some degree. Fig. 4.5 shows the comparison of the predicted load-deflection responses from the program PBEAM using 10 elements, 20 elements, and 40

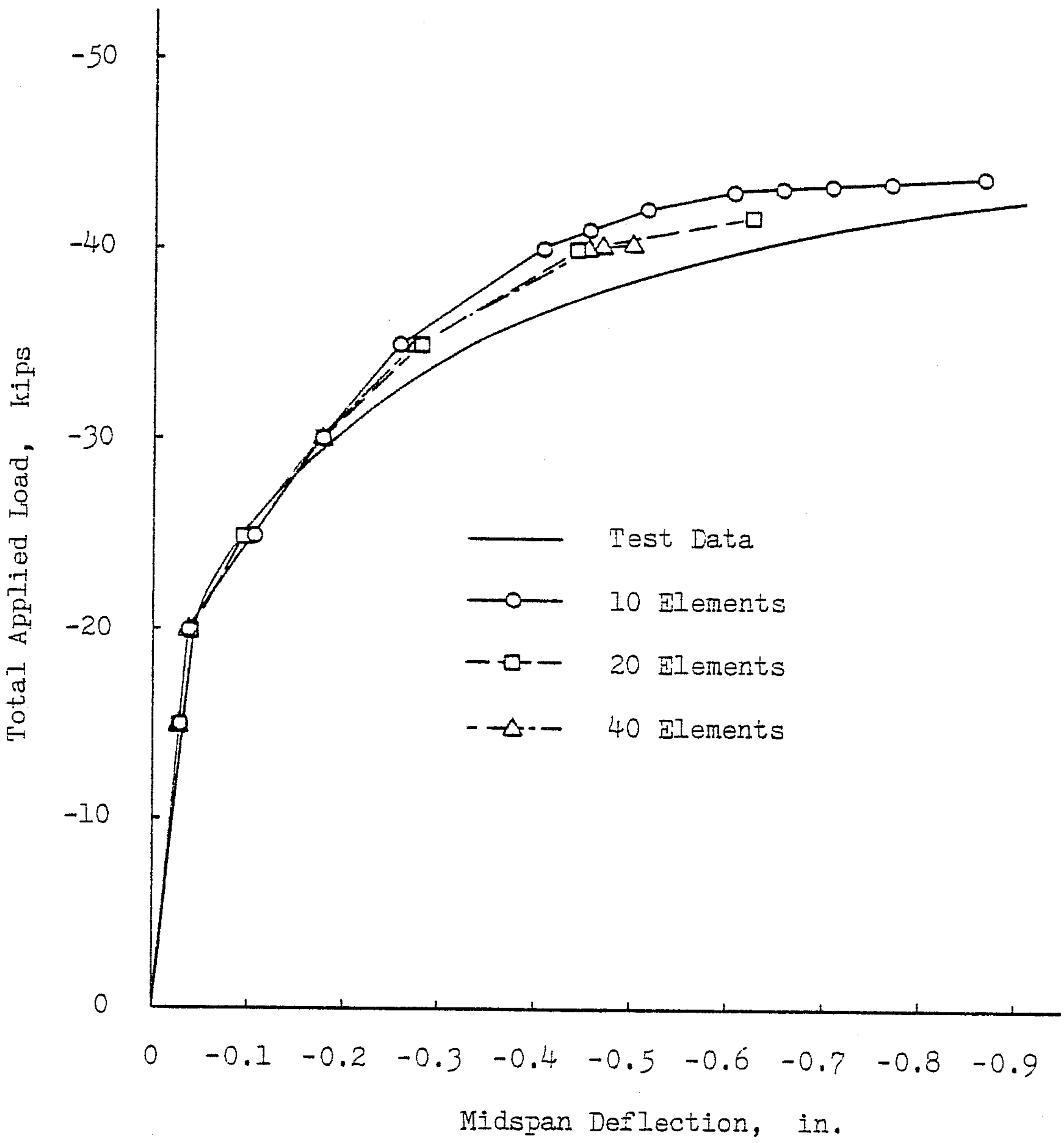


Fig. 4.5 Effects of Number of Elements on the Predicted Load-Deflection Response for Beam BW.10.072.

elements. As expected, a stiffer member results from using a smaller number of discrete elements, especially in the region after the section is cracked. With the same load increments near ultimate load, the 10 element member has the highest ultimate strength and the 40 element member has the lowest ultimate strength. The solution of the 10 element member diverges at the applied load of 44.0 kips, the 20 element member at 41.8 kips, and the 40 element member at 40.2 kips. A more ductile member also results from using a smaller number of discrete elements in modeling the member. The difference in the predicted responses at the ultimate load is partly because of the approximation in using the discrete elements in modeling the member. The cross-section properties of an element are assumed to be constant and represented by the cross-section of the member at the middle of the element. The axial spring at the middle of the element represents the axial response of the element and the rotational springs at the quarter points of the element represent the rotational responses of the element. In this case, each of the predicted ultimate loads produces the failure moments in the corresponding member at the rotational springs closest to the center support and closest to the loading point.

Time consumed in the calculation (TM time) per iteration for the beam by the program PBEAM is roughly proportional to the number of fibers in the member. Fig. 4.6 illustrates the relationship between the number of fibers in the member and the computational time required per iteration. The values obtained are the averages of those from zero load level to the ultimate load. The number of fibers of 1800 corresponds to the 10 element member, 3600 to the 20 element member, and 7200

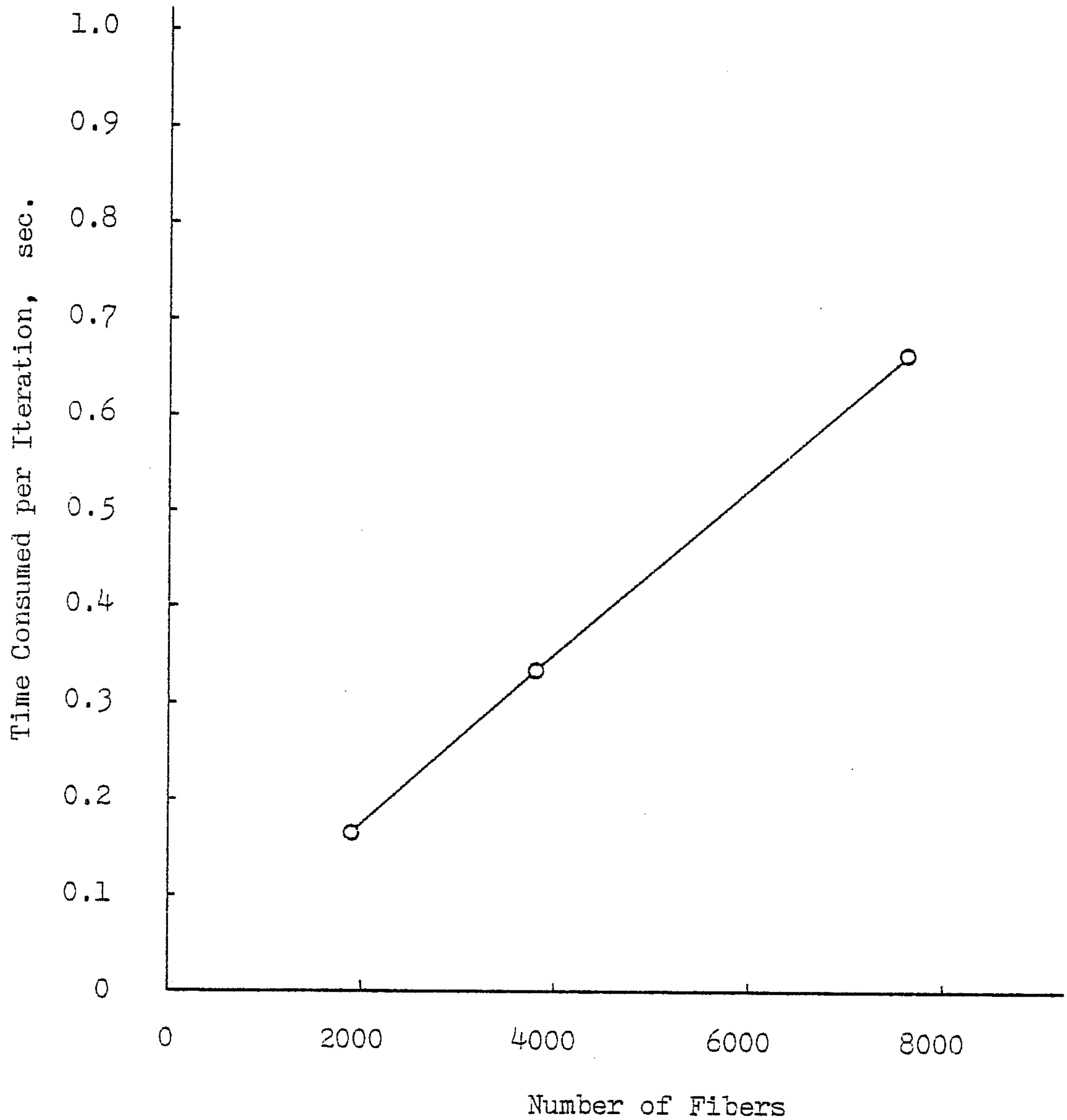


Fig. 4.6 Relationship between Number of Fibers in the Member and Time Consumed (TM Time) per Iteration.

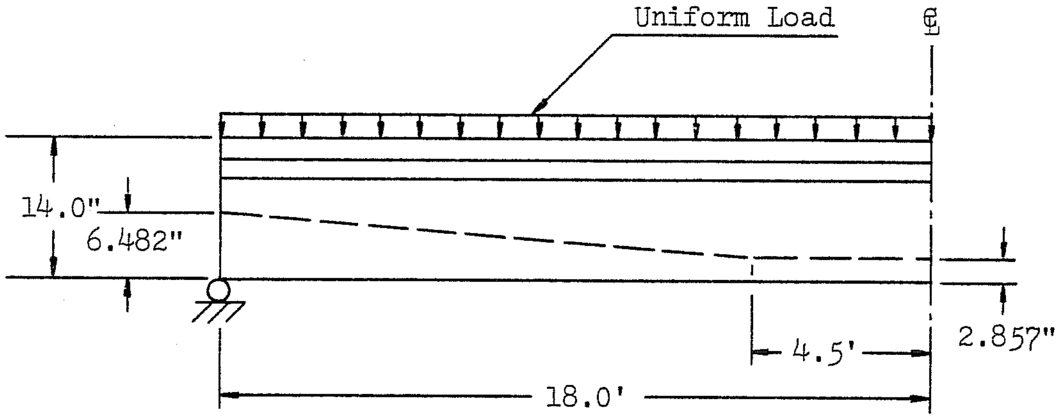
to the 40 element member. The number of iterations required for a crack frozen iterative cycle is about 5 iterations. The number of iterations required for the cycle in which cracks are not frozen depends on the severity of the cracks that are developed in that cycle. It may require as much as 10 iterations or may not converge if the member cracks extensively in that iterative cycle.

Although in this example problem, the best load-deflection response, in term of the ultimate load and the ductility at the ultimate load, is obtained by using 10 elements in modeling the member, theoretically, the use of more elements should give more accurate results. But the use of more elements requires more computational time. Judging from the results using 10 to 40 elements in modeling the member, the use of 20 elements should be adequate for most problems.

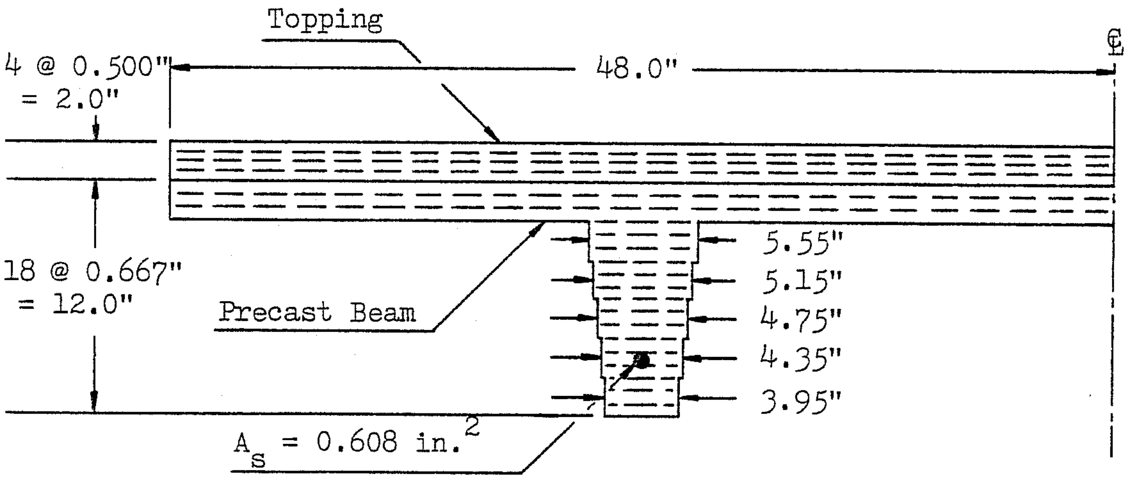
4.2 Example Problem 2 - Instantaneous Response of a Simply Supported Composite Pre-tensioned Beam with Draped Tendons.

A standard double tee section from the P.C.I Design Handbook with 36 ft. simply supported span was selected to test the ability of the program in analyzing the composite beam action. The load-deflection response of the section under different levels of prestressing was previously investigated analytically by Lo (57) using a modified form of the program PCCBM developed by Chang (19). Since no measured data for the actual behavior of the beam is available, Lo's results and hand calculation results using eleastic theory together with the effective moment of inertia method will be used to compare with the results from the program PBEAM developed in the present study.

The symmetrical half of the beam (Fig. 4.7) is analyzed as a twenty-element member, supported at the left end in the



Loading Arrangement and Tendon Profile



Modeled Beam Cross-Section at Midspan

Concrete Properties:

f'_{cb} = -5000 psi. (Precast Beam)

f'_{cs} = -3000 psi. (Topping)

$f''_{c} = f'_{c}$

$f_r = 7.5 \sqrt{|f'_c|}$ psi.

$E_c = 33\, w^{1.5} \sqrt{|f'_c|}$ psi.

w = 150 psf.

Steel Properties:

7-Wire Strands, 270 k. Grade

F_{si} = 189.0 kips (before transfer)

Fig. 4.7 The 8 DT 12+2 Composite Section from the Report by Lo (57).

transverse direction and at the right end in both the member axis direction and the rotational direction. The detail of the longitudinal section, loading condition, the modeled section, and material properties are shown in Fig. 4.7 and Fig. 4.8. The beam is assumed to be unshored when the topping is cast. Loading is increased step-by-step until the uniform load reaches 223 psf., including the weight of the beam and topping, where the solution diverges. The PBEAM results accompanied by the results from Lo's analysis and hand calculation analysis are shown for the early stage of loading in Fig. 4.9 and with a smaller scale plot of the total load-deflection response shown in Fig. 4.10.

The load-deflection responses from the program PBEAM and from elastic theory are almost exactly the same up to the cracking load of the beam. A stiffer section before the composite beam action starts is predicted by Lo's program. No change in the stiffness of the section after the composite beam action starts is reflected in Lo's results. He evidently has shown the camber for a stiffer section and thus his curve begins with less initial deflection upward prior to downward load application. Lo's results and elastic theory results give about the same cracking load. A slightly higher cracking load is given by the program PBEAM which is probably because of the approximation in modeling the section. The form of the response to applied load after the composite beam action starts (Fig. 4.9 and Fig. 4.10) by the two programs shows good agreement. The effective moment of inertia method predicts a less stiff section after cracking and does not show the ductility of the beam in the range where the

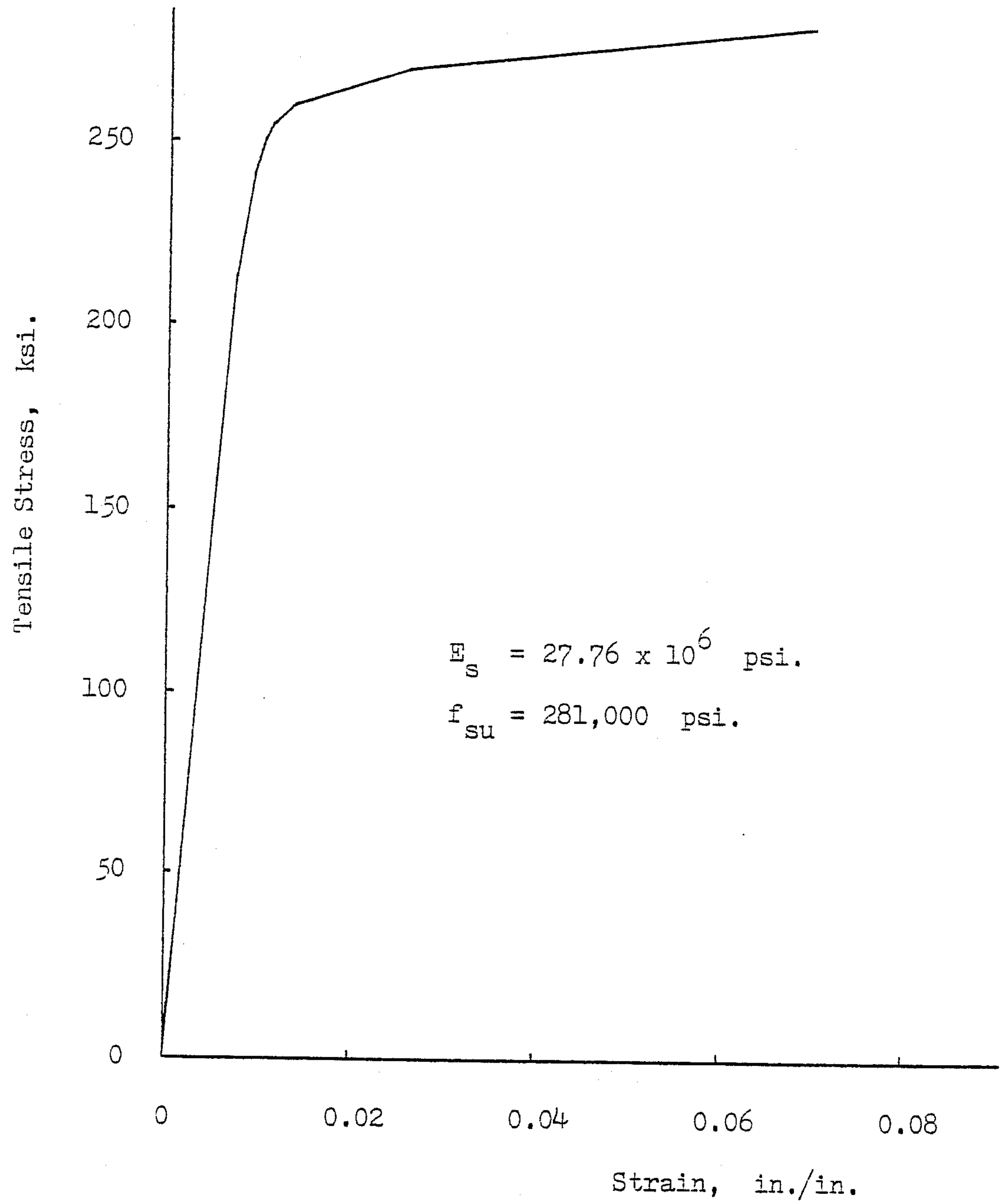


Fig. 4.8 Instantaneous Stress-Strain Relationship of Prestressing Strands for the 8 DT 12+2 Composite Section.

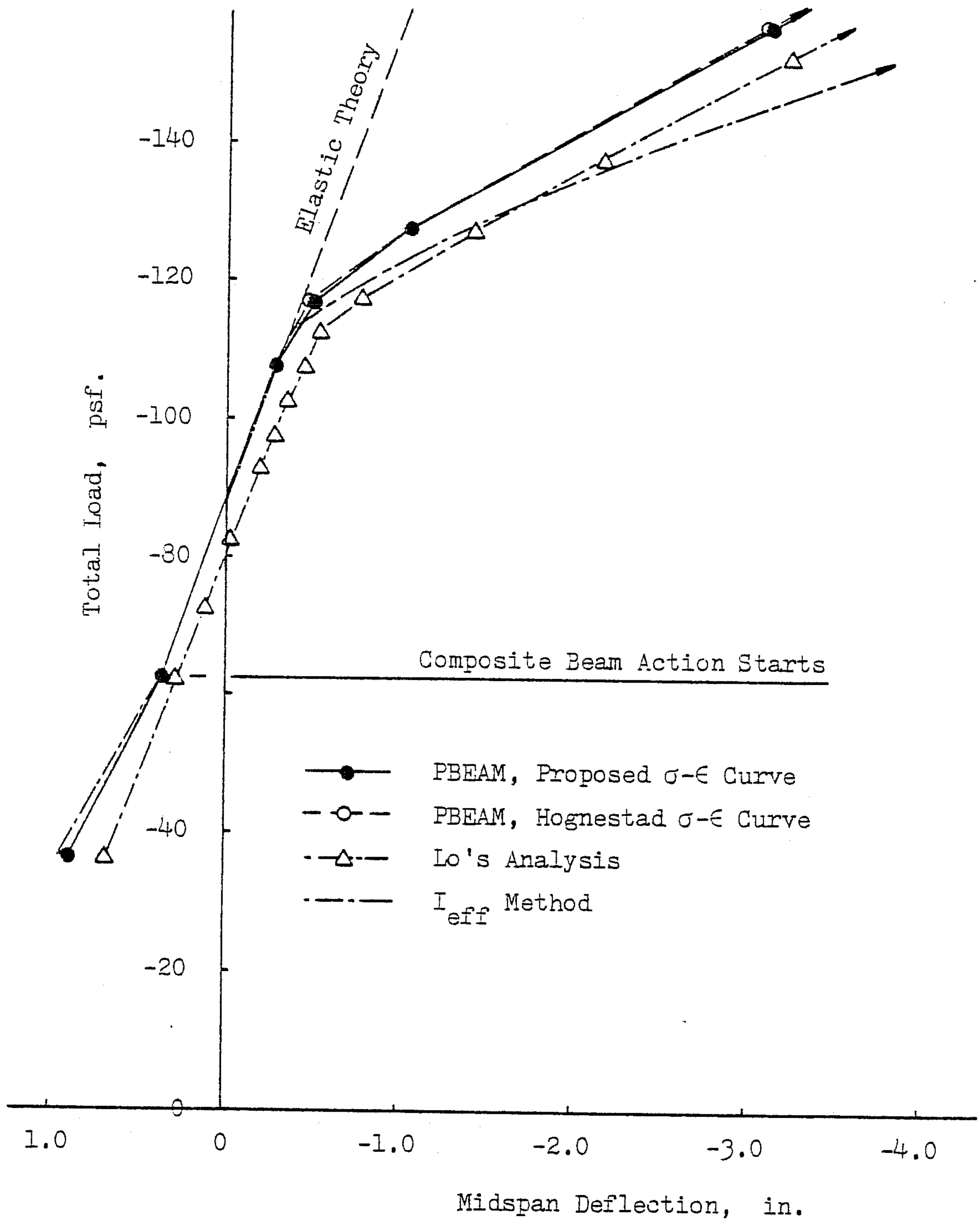


Fig. 4.9 Comparison of Load-Deflection Responses of the 8 DT 12+2 Composite Section from the Program PBEAM, Lo's Analysis, and Hand Calculation at Low Load Level.

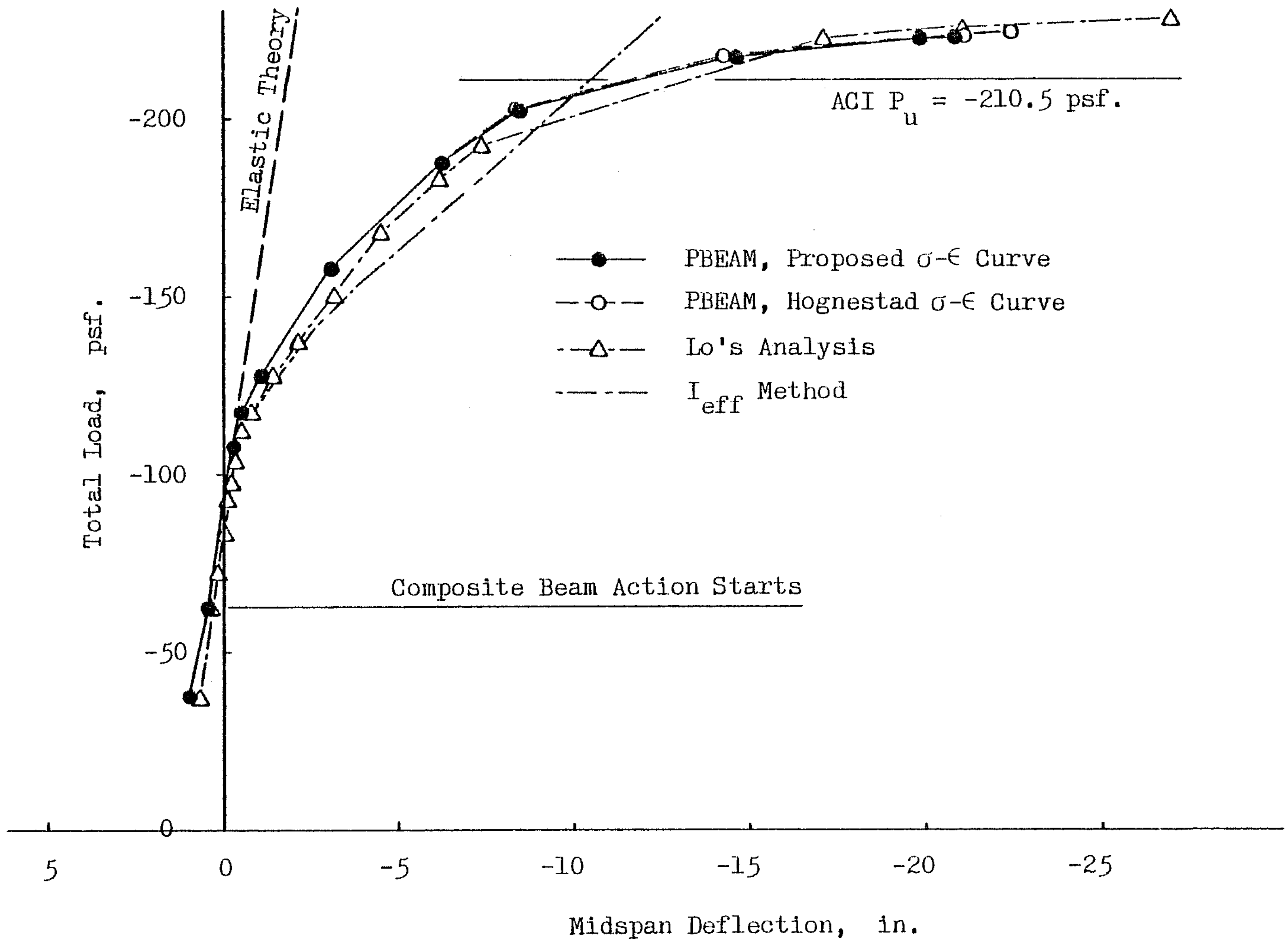


Fig. 4.10 Comparison of Load-Deflection Responses of the 8 DT 12+2 Composite Section from the Program PBEAM, Lo's Analysis, and Hand Calculation.

prestressing steel yields. The ultimate applied loads as predicted by different methods are 222.8 psf. by the program PBEAM, 227 psf. by Lo's program, and 210.5 psf. by the A.C.I. method which are within about 8% of one another.

Fig. 4.9 and Fig. 4.10 also show the load-deflection response of the beam as predicted by the program PBEAM using the Hognestad concrete stress-strain curve with the stress on the falling branch of 0.85 f'_c at the strain of -0.0038 in./in.. The results are almost the same as those from the program PBEAM using the proposed concrete stress-strain curve with a slightly higher ultimate applied load and a slightly higher deflection at the ultimate applied load.

The problem is also analyzed as 10 , 20, and 40 element members. Fig. 4.11 shows the comparison of the results. As in the first example problem, a slightly stiffer section is obtained by using less elements in modeling the member. A higher ultimate load and a more ductile member are also obtained by using less elements, but to a less extent since the moment gradient near the critical section is not as severe as in the first example problem.

4.3 Example Problem 3 - Time-Dependent Response of Simply Supported Pre-Tensioned Beams.

An investigation of the time-dependent responses of noncomposite, simply supported pre-tensioned prestressed concrete beams, prior to cracking, was conducted by Zundelevich, et al., (94) at the University of Hawaii, in conjunction with the State of Hawaii Department of Transportation, Highway Division. The beams were of normal weight and lightweight concrete manufactured with Hawaiian aggregates. Three sets of specimens, made from basalt, cinderlite,

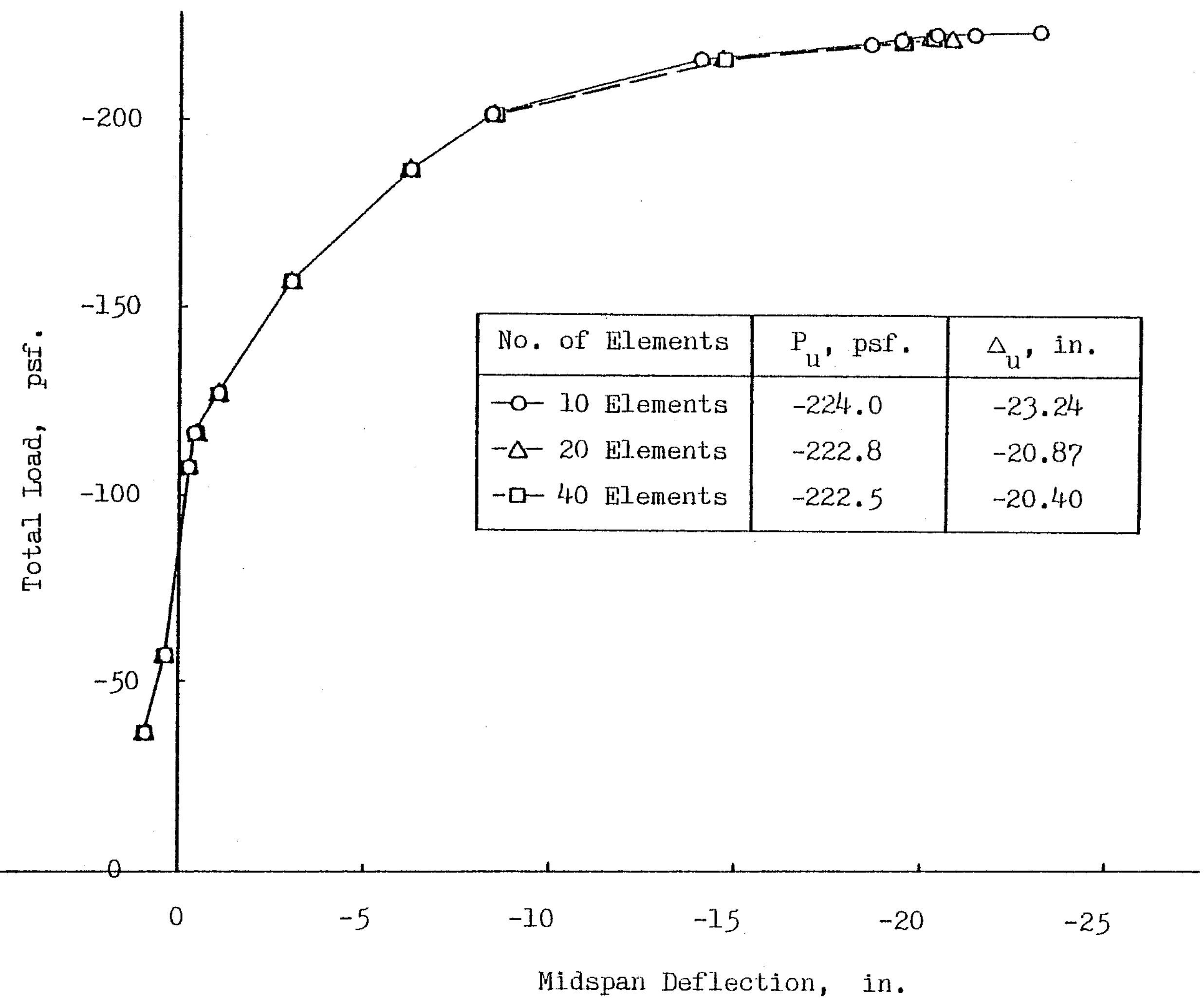
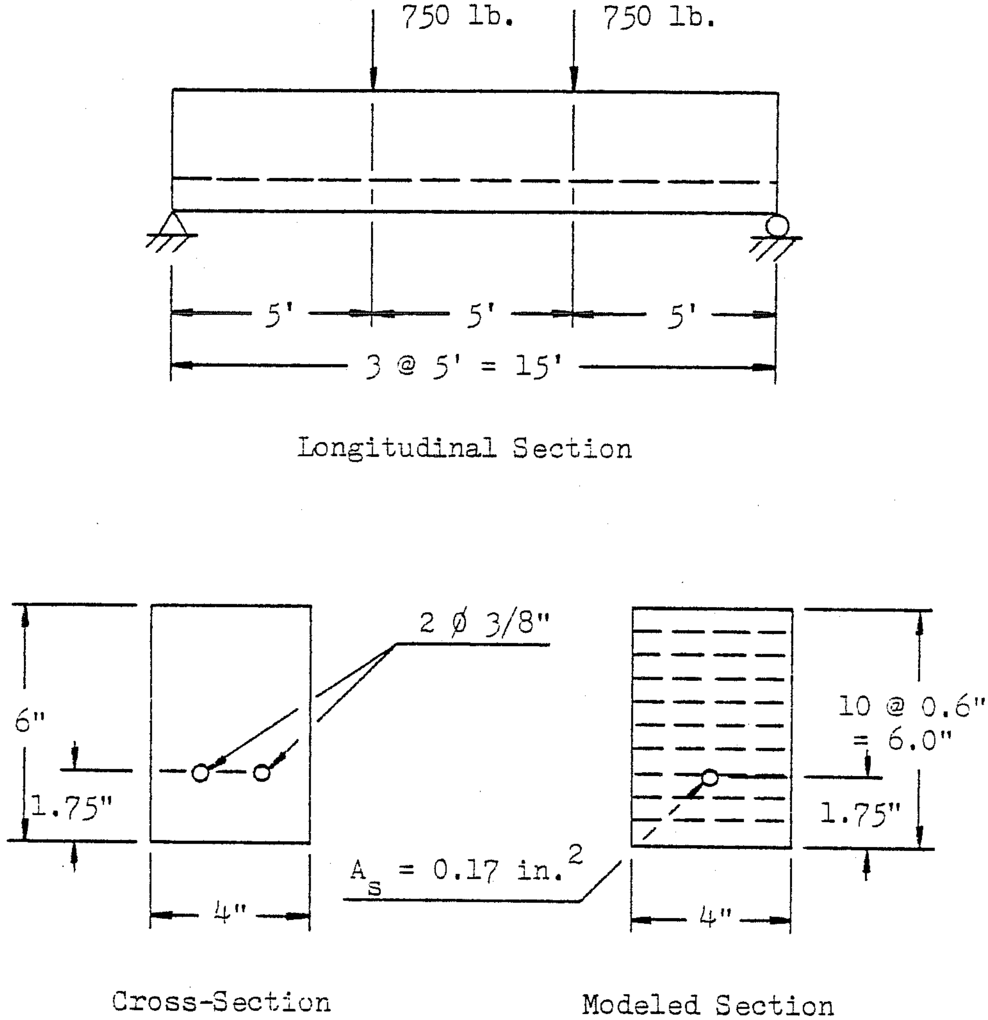


Fig. 4.11 Effects of Number of Elements on the Predicted Load-Deflection Response for the 8 DT 12+2 Composite Section.

and valcanite aggregates, respectively, were used. Each set contained seven beams, three for studying camber, three for studying deflection, and the other as a shrinkage specimen. The averages of the camber and the deflection responses of the basalt specimens, designated as BEAM I series, were selected as the example problems.

The beams were 4 in. by 6 in. in cross-section, 15 ft. 6 in. long and were simply supported over 15 ft. span. They were prestressed at the age of 7 days by two straight seven wire strands at an eccentricity of 1.25 in.. Instead of overtensioning to compensate for the relaxation of steel from the time of initial stressing to the time of transferring, the strands were tensioned to 15 kips per strand, the desired prestressing force, 2 1/2 days before casting of concrete. The strands were then retensioned to 15 kips per strand just before the casting of concrete. The details of the beam cross-section amd material properties are shown in Fig. 4.12. The camber specimens were observed for camber growth with the beams carrying only their own weight. For the deflection specimens, the beams were loaded at the third points by two 750 lb. loads per beam, loaded at 28 days age of concrete. The loading arrangement of the deflection specimens is also shown in Fig. 4.12.

The analytical results from the program PBEAM and other analytical methods are compared with the experimental measurements. Fig. 4.13 shows the variations of the midspan deflection with time from the measurements, the program PBEAM using the rate of creep method and the superposition method, Sinno's and Furr's program (81), and from hand calculation by Branson's method (10). In the analyses, the



Material Properties:

Type I Cement

$(f'_c)_{28}$ = -5900 psi.

w = 150 lb./ft.^{3}

E_s = 28.0×10^6 psi.

f_{su} = 270,000 psi.

Fig. 4.12 Beam I from the Report by Zundelevich, et al.. (94)

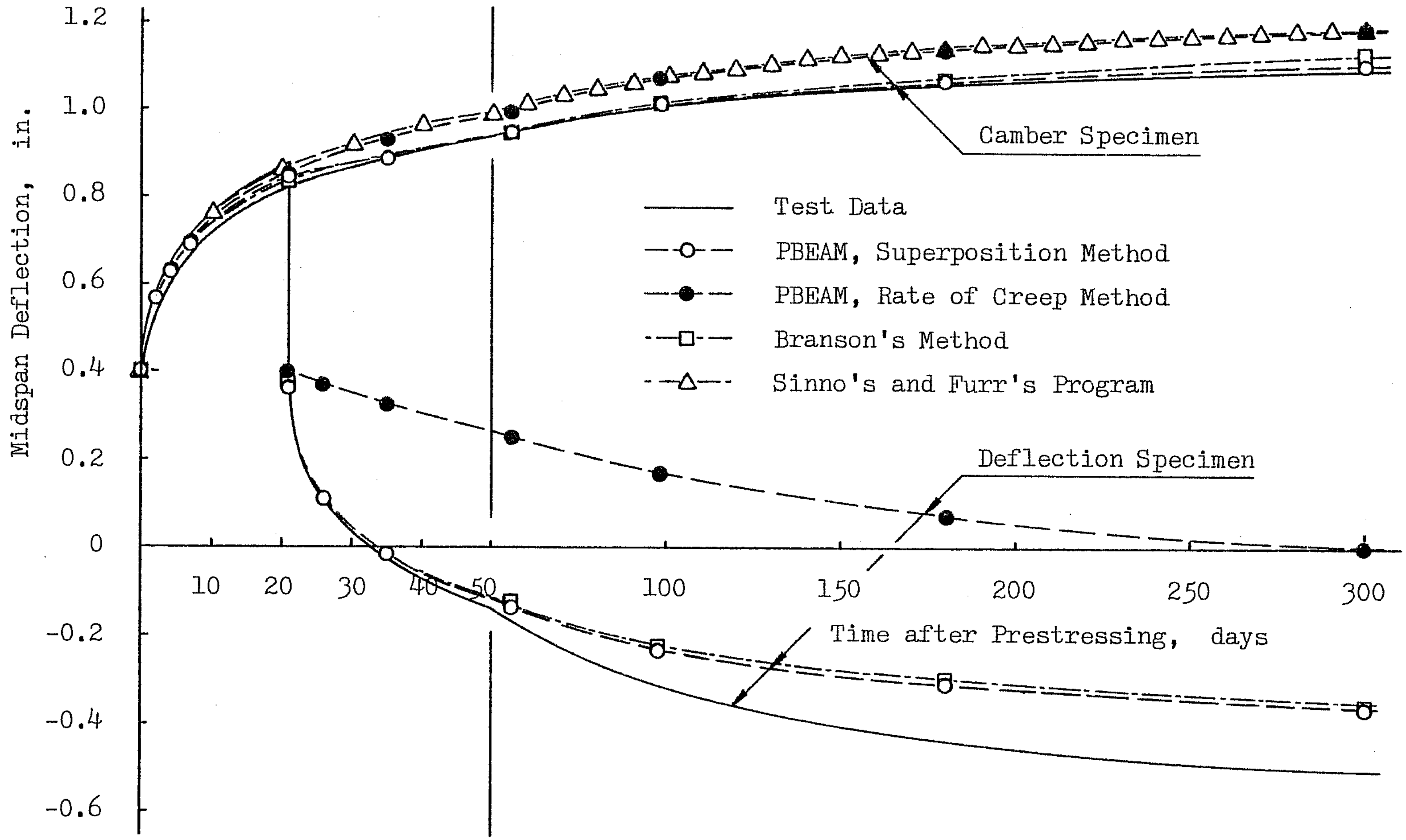


Fig. 4.13 Comparison of Time Variations of Midspan Deflection as Predicted by Various Methods with Experimental Data for Beams in Example Problem 3.

age function, the creep function, and the shrinkage function recommended by the A.C.I. Committee 209 (2) are used where applicable. The ultimate creep coefficient and the ultimate shrinkage strain are 3.7 and -1.050×10^{-3} in./in., which are the values suggested by Zundelevich, et al., (94) for the specimens and the surrounding conditions. Modulus of elasticity of concrete, E_c, is taken as equal to $33\ w^{1.5}\sqrt{f'_c}$. Relaxation losses are estimated by the relaxation function recommended by the P.C.I. Committee on Prestress Losses (67) with the estimated strain in the prestressing steel just before transfer of 6.223×10^{-3} in./in., which corresponds to the initial prestressing force of 29.62 kips for each beam. For Branson's method, the average of the values of prestress losses at the end and at the midspan of the beam is used in estimating the time variations of the camber and the deflection of the beams.

The predicted cambers just after prestressing by different methods are in excellent agreement with the measured data. They are within 0.75% of the average of the reported values for the camber specimens. The changes of camber growth with time, as shown in Fig. 4.14 and, at some calculated points, in Table 4.1, also agree well with the experimental data. About the same results are obtained by the program PBEAM using the superposition method and by Branson's method. The methods slightly overestimate the changes in cambers of the beams throughout the range of the reported data. This may be due to the overestimating of the creep coefficient of the concrete at the age when the prestressing forces are transferred or the underestimating of the relaxation of prestressing steel. The program PBEAM, using the rate of creep

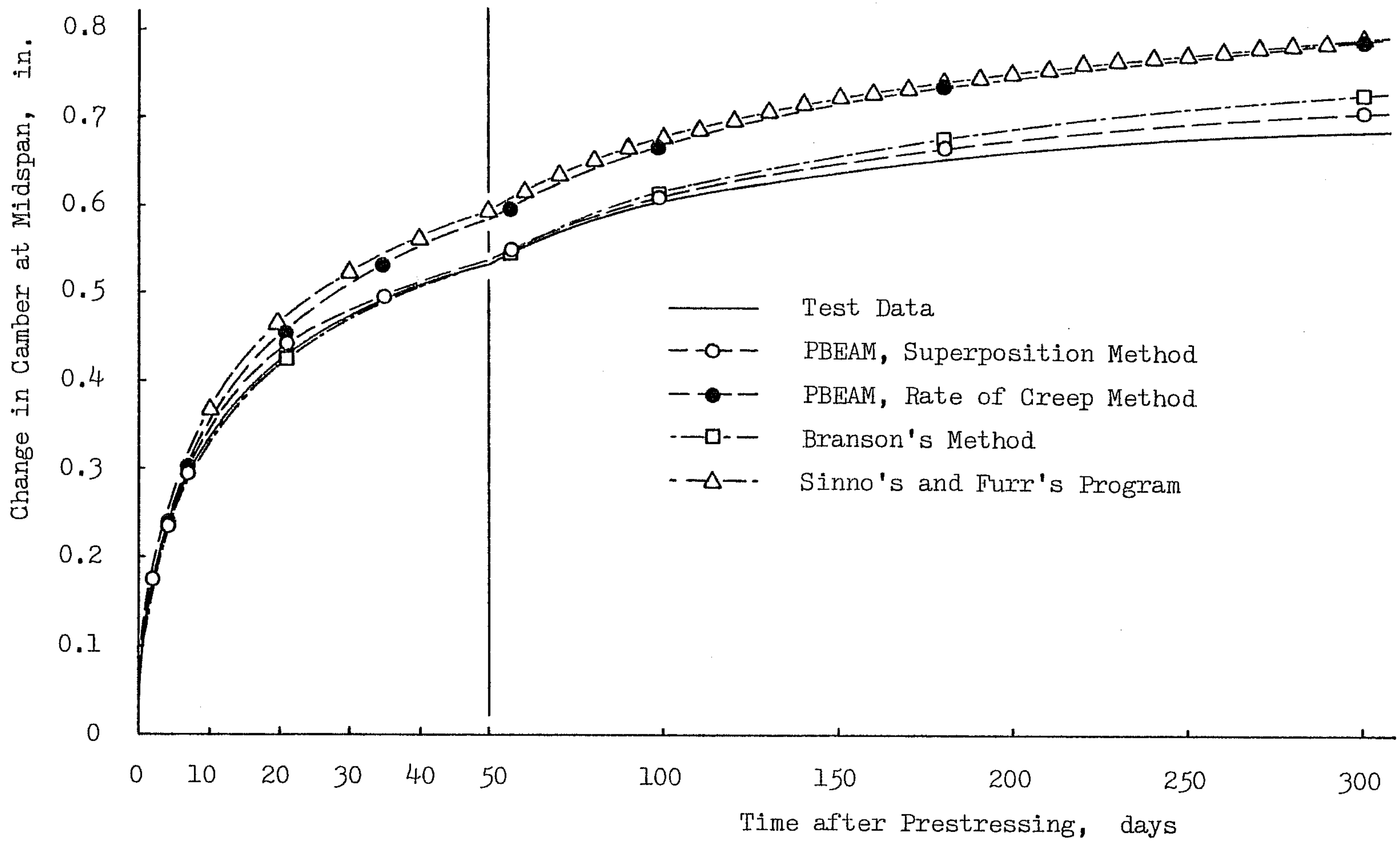


Fig. 4.14 Comparison of Time Variations of Change in Camber at Midspan after Prestressing of Camber Specimen, Example Problem 3, as Predicted by Various Methods with Experimental Data.

Table 4.1

Time Variations of Change in Camber at Midspan for Beam BEAM I Series, Camber Specimens, at Some Calculated Points.

Time after Prestressing, days		21	56	98	180	300
Experimental Data	$d\Delta_{℄}$, in.	0.420	0.550	0.602	0.652	0.681
PBEAM, Superposition Method	$d\Delta_{℄}$, in. Error, %	0.444 5.71	0.550 0.0	0.610 1.33	0.666 2.15	0.704 3.38
PBEAM, Rate of Creep Method	$d\Delta_{℄}$, in. Error, %	0.459 9.29	0.596 8.36	0.668 10.96	0.737 11.50	0.785 15.27
Branson's Method	$d\Delta_{℄}$, in. Error, %	0.427 1.67	0.549 -0.18	0.614 1.99	0.677 3.83	0.724 6.31
Sinno's and Furr's Method	$d\Delta_{℄}$, in. Error, %	0.472 12.38	0.607 10.36	0.676 12.29	0.741 13.65	0.788 15.71

method, and Sinno's and Furr's program give less accurate results. They overestimate the change in camber at 300 days after prestressing by about 16%. The results are expected since the rate of creep method generally overestimate creep under gradually decreasing stress.

The predicted instantaneous deflections due to the applied loads are in good agreement with the experimental data. The analytical values from the program PBEAM and by elastic theory are almost identical and equal to 0.919 of the average of the measured data from the deflection specimens (0.495 in.). This slight error may be due to the overestimating of the modulus of elasticity of concrete at the time of loading. The analytical results for the time variation of the change in the midspan deflection after loading by the program PBEAM and Branson's method are compared with the test data in Fig. 4.15 and Table 4.2. Sinno's and Furr's program is not applicable for the problem where additional loads are applied. As expected, the program PBEAM, using the rate of creep method, gives rather poor results. The program PBEAM, using the superposition method, and Branson's method give about the same results which are satisfactory as shown in Fig. 14.5. The former underestimates the change in midspan deflection at 279 days after loading by about 14% and the latter by about 18%. The underestimations may be partly because of the underestimating of the relaxation of the prestressing steel and the overestimating of the modulus of elasticity of concrete at loading age, as previously observed, and partly because of the underestimating of the creep coefficient of the concrete at the time of loading.

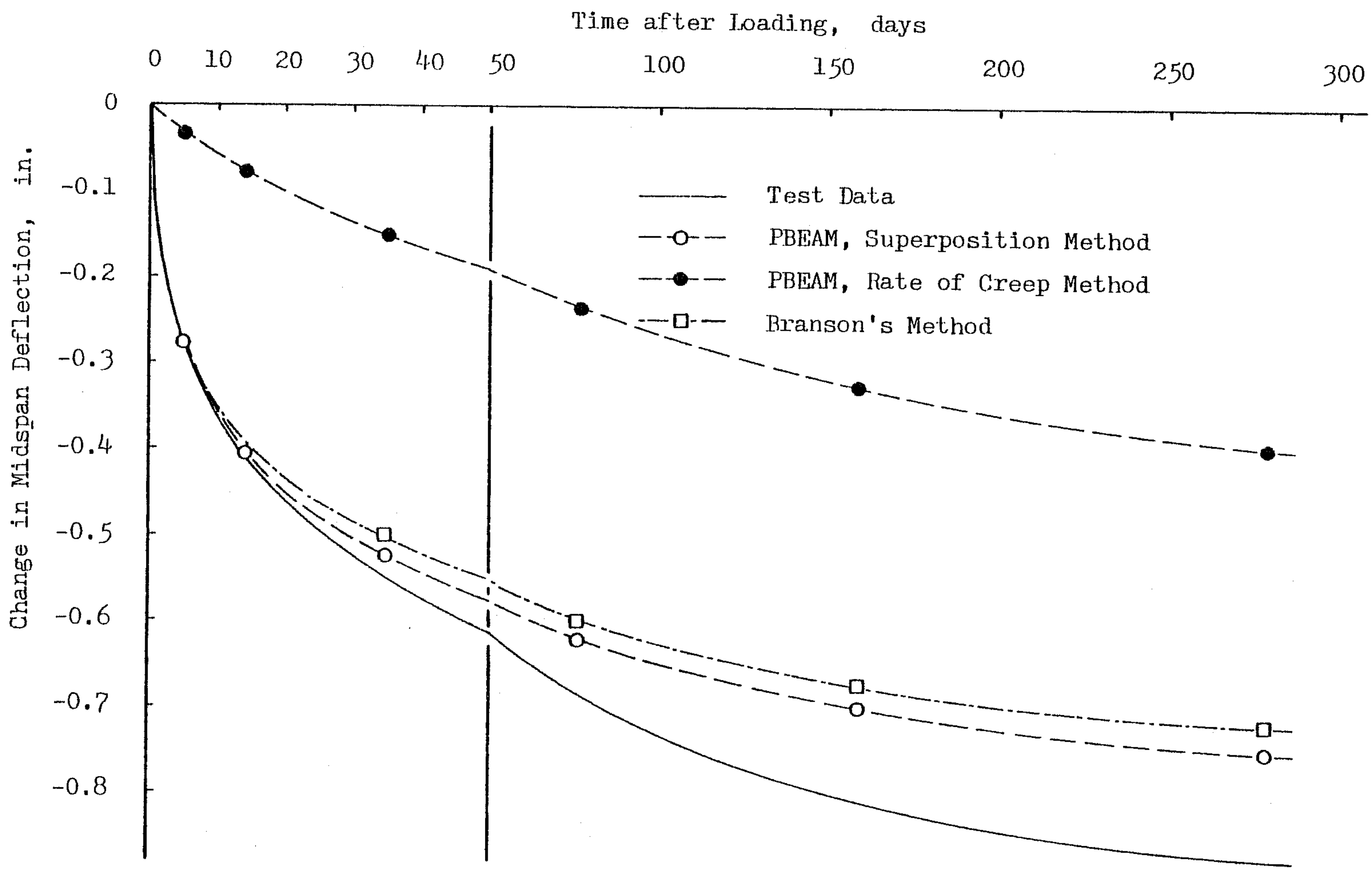


Fig. 4.15 Comparison of Time Variations of Change in Midspan Deflection after Loading of Deflection Specimen, Example Problem 3, as Predicted by Various Methods with Experimental Data.

Table 4.2

Time Variations of Change in Midspan Deflection for Beam BEAM I Series, Deflection Specimens, at Some Calculated Points.

Time after Loading, days		35	77	159	279
Experimental Data	$d\Delta_{\mathrm{C\!\!\!L}}$, in.	-0.545	-0.686	-0.809	-0.872
PBEAM, Superposition Method	$d\Delta_{\mathrm{C\!\!\!L}}$, in. Error, %	-0.524 -3.85	-0.620 -9.62	-0.697 -13.84	-0.748 -14.22
PBEAM, Rate of Creep Method	$d\Delta_{\mathrm{C\!\!\!L}}$, in. Error, %	-0.148 -72.84	-0.236 -65.60	-0.326 -59.70	-0.395 -54.70
Branson's Method	$d\Delta_{\mathrm{C\!\!\!L}}$, in. Error, %	-0.499 -8.44	-0.596 -13.12	-0.671 -17.06	-0.718 -17.66

The difference in time requirements in the computation by the program PBEAM using the rate of creep method and the superposition method of estimating creep response for the camber specimen (220 fibers) can be seen in Fig. 4.16. Time consumed (TM time) per time increment for the rate of creep method is almost constant for every increment because the amount of creep computation is constant in each increment. Since the superposition method uses strain increments in every fiber of the member in each time increment in estimating creep strains, the amount of creep computation increases proportionally to the number of time increments. The superposition method also requires time in recording and retrieving the strain increment information from a scratch file. The computational time required per time increment for the superposition method is about 1.06 of that required by the rate of creep method at the first time increment and larger at the later time increment as indicated in Fig. 4.16.

4.4 Example Problem 4 - Failure Load Responses of Grouted Post-Tensioned Concrete Beams after 12 Years of Sustained Loads.

Long-term effects of various sustained load levels on the strength and behavior of simply supported prestressed concrete beams were investigated at the Naval Civil Engineering Laboratory, Port Hueneme, California. (16, 17, 50) The beams used in the study included grouted and ungrouted post-tensioned I-beams with different types of prestressing steels and post-tensioned hollow box beams. The beams were designed based on the minimum compressive strength of concrete of 5000 psi. at the time of prestressing. Permissible maximum stresses in the concrete were 2000 psi. compression and zero tension under any combination of design loads. They were

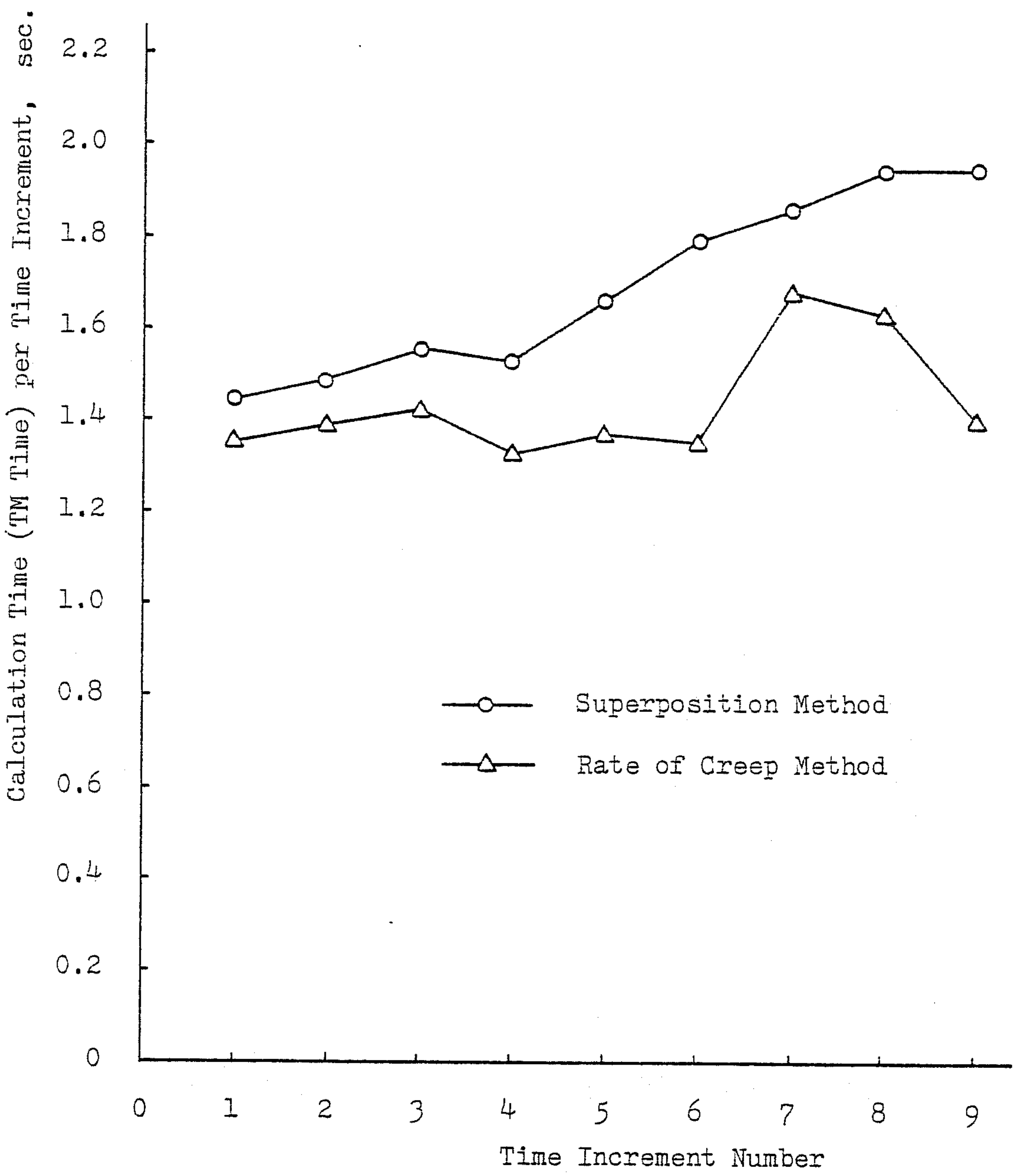
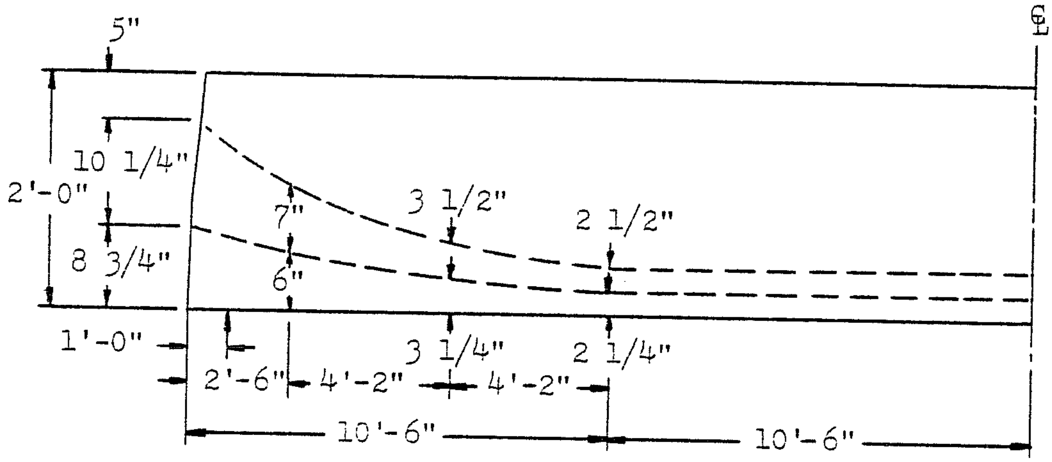


Fig. 4.16 Time Consumed per Time Increment for BEAM I Using the Rate of Creep Method and the Superposition Method.

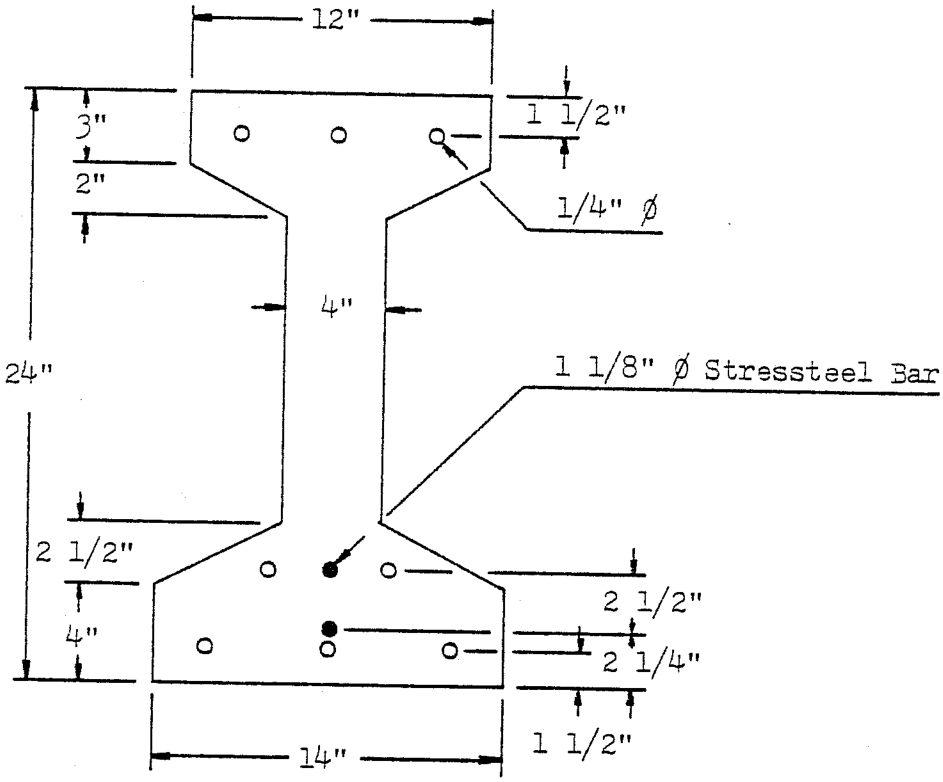
loaded to failure at 21 days and after 10 to 12 years of different levels of sustained loads ranging from dead load only to dead load plus 1.5 design live load. Since the program PBEAM does not take into account the effects of unbonded tendons after transferring of prestressing forces, four grouted post-tensioned prestressed beams were selected to illustrate the capability and the validity of the program. The beams were subjected to dead load only, and sustained loads of 0.5, 1.0 and 1.5 design live loads in addition to dead load. All of the beams, except the beam with the sustained load of 0.5 design live load, were loaded to failure at the ages of the beams of about 12 years.

The beams were 42 ft. long, with an I-shape section, as shown in Fig. 4.17. They were prestressed 8 days after casting by two prestressing bars 1 1/8 in. in diameter placing in 1 1/2 in. diameter flexible steel sheaths. Prestressing forces at both ends of the bars were estimated to be 197 kips at the time of transferring. The beams were grouted one day later. Within the hour after grouting was completed, the beams were lifted and placed on 40 ft. center-to-center supporting walls to act as simply supported beams. At the age of concrete of 22 days, the loaded beams were loaded at quarter points to produce the sustained loads of 0.5, 1.0, and 1.5 design live loads. The loads were sustained until about 12 years after casting of concrete when the loads were removed. The beams were then loaded to failure.

Neglecting the effects of end blocks, diaphragms, and the overhanging portions of the beams, the profiles and the cross-sections of the beams are modeled as shown in Fig. 4.18. Only the symmetrical halves of the beams are analyzed as

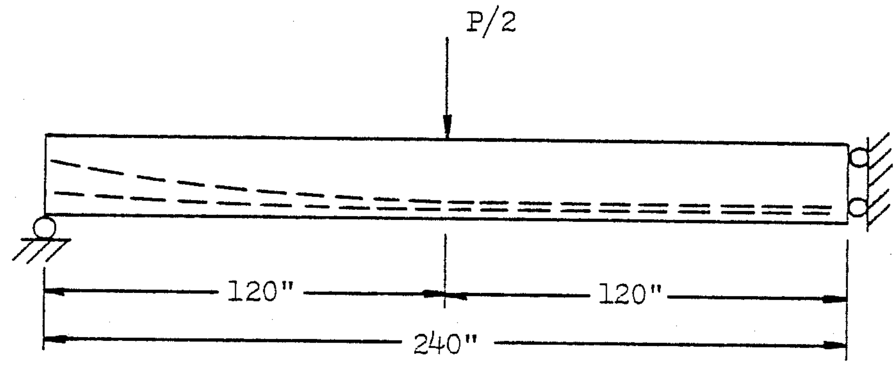


Layout of Prestressing Bars

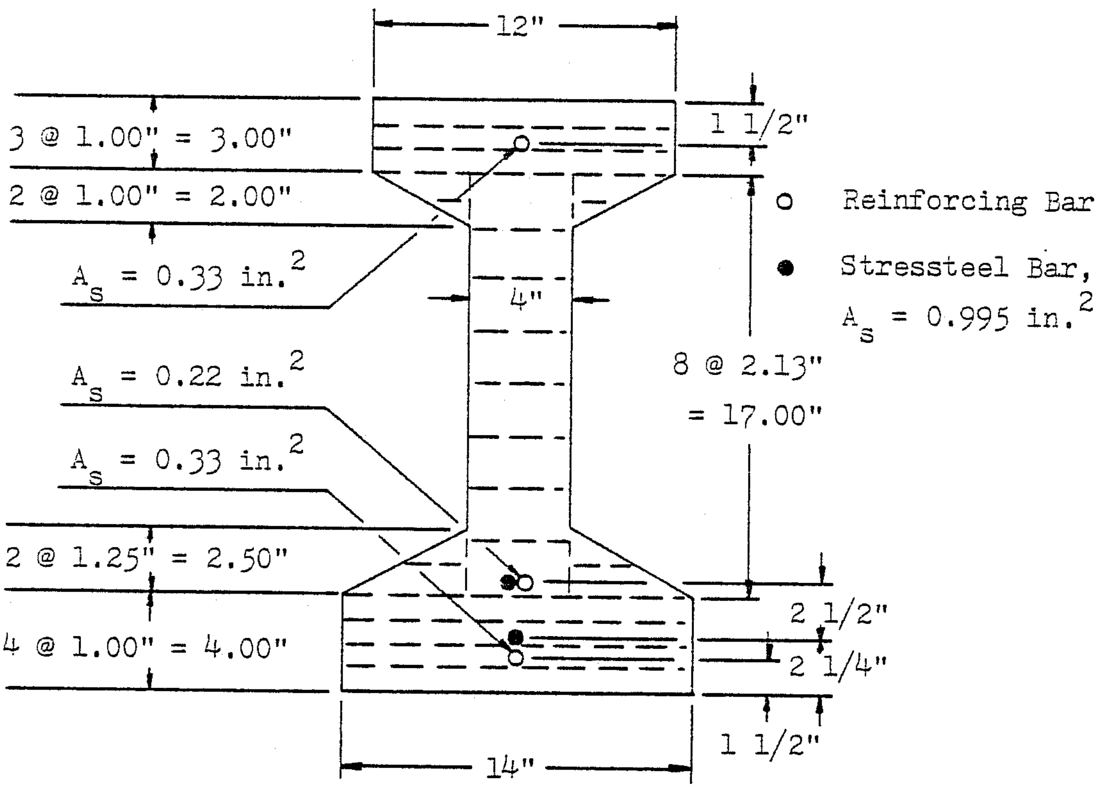


Cross-Section at Center Line

Fig. 4.17 **Prestressing Bar Layout and Cross-Section for Beams in Example Problem 4.**



Loading Arrangement and Boundary Conditions



Modeled Section

Fig. 4.18 Loading Arrangement, Boundary Conditions, and Modeled Cross-Section for Beams in Example Problem 4.

20-element members with appropriate boundary conditions to simulate the actual supports. The beams were assumed to be prestressed and grouted at the age of concrete of 8 days neglecting the time-dependent effects which occurred in the time between prestressing and grouting. The material properties used in the analysis are as follows:

Prestressing bar:

Measured data

F_i = 197,000 lb. at both ends

Stress-strain curve is as shown in Fig. 4.19

Assumed data

$$(f_{sr})_{t_1} - (f_{sr})_{t_0} = (f_s)_{t_0}[\log(t_1/t_0)/10] \times [(f_s)_{t_0}/f_{sy} - 0.55]$$

where $(f_s)_{t_0}/f_{sy} \geq 0.60$

K = 2.917×10^{-5} per in.

μ = 0.19 per rad.

Mild reinforcement:

Measured data

E_s = 26.6×10^6 psi.

f_y = 49,000 psi.

Assumed data

Flat-topped stress-strain curve

Concrete, moist cured, Type III cement:

Measured data

Strength is as shown in Fig. 4.20

Modulus of elasticity is as shown in Fig. 4.21

w = 146 lb./ft.^{3}

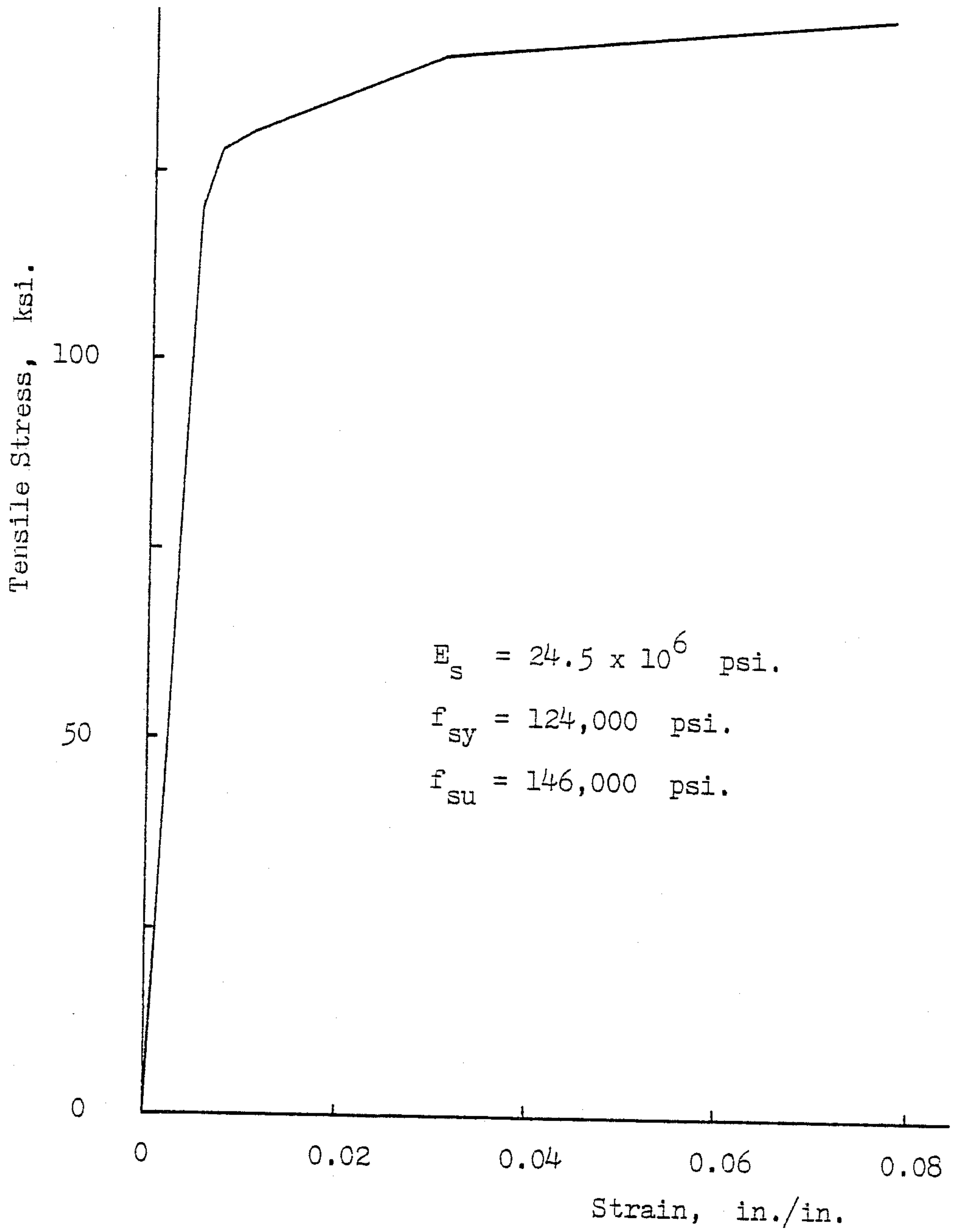


Fig. 4.19 Instantaneous Stress-Strain Relationship in Tension of Stressteel Bars for Beams in Example Problem 4.

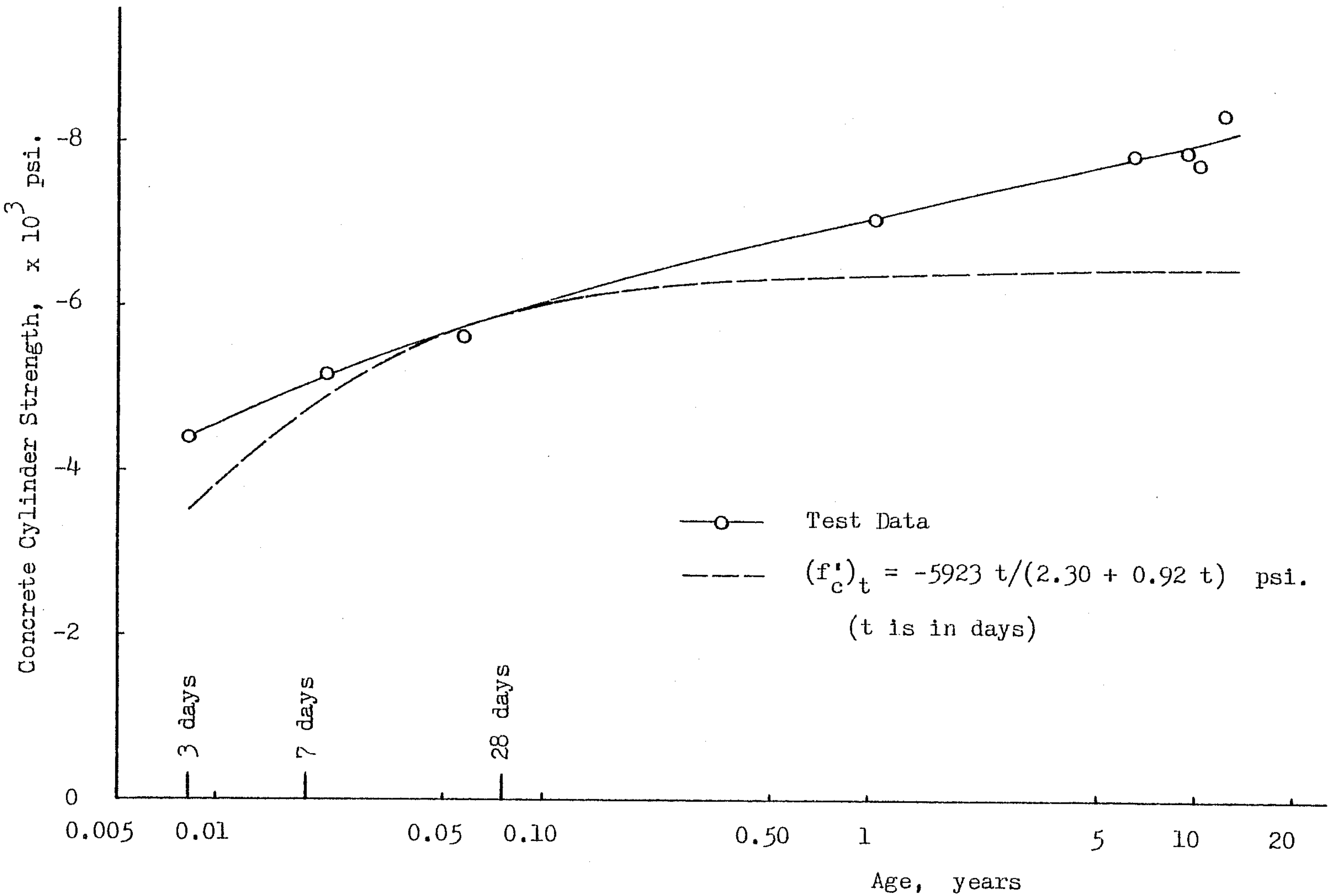


Fig. 4.20 Age-Strength Relationships of Concrete for Beams in Example Problem 4.

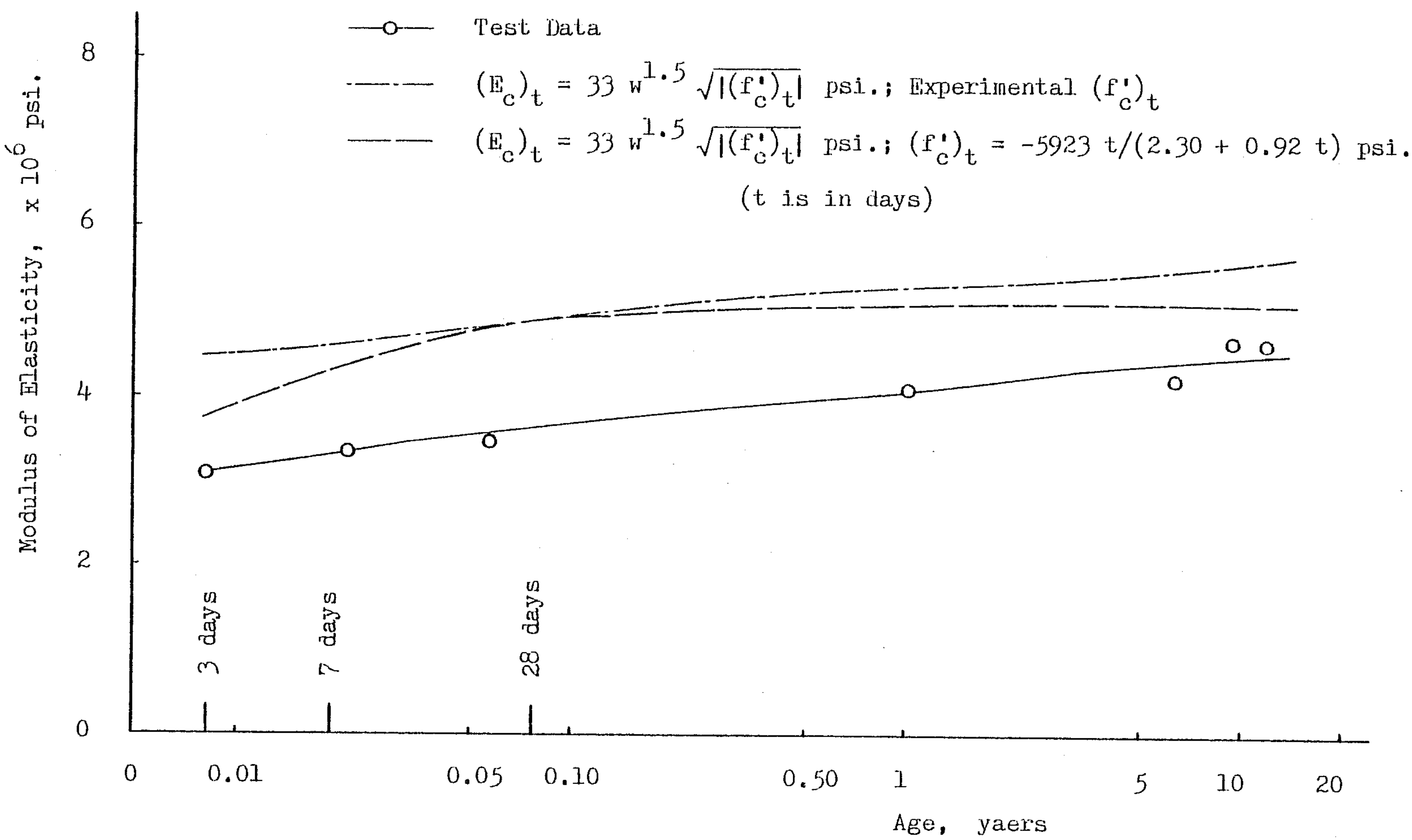


Fig. 4.21 Time-Variations of Modulus ofElasticity of Concrete for Beams in Example Problem 4. The Modulus of Elasticity is Based on the Axial Strain Induced by Raising the Compressive Stress from 350 psi. to 1000 psi..

Assumed data

$(c)_{t,t'}/(c)_\infty = (CC_{LA})_{t'}(t - t')^{0.6}/[10 + (t - t')^{0.6}]$

$(CC_{LA})_{t'} \quad = 1.25\ t'^{-0.118}$

$(\varepsilon_s)_t/(\varepsilon_s)_\infty = t/(35 + t)$

Proposed stress-strain curve where

$f''_c \quad = f'_c$

$f_r \quad = 7.5 \sqrt{|f''_c|}$

Fig. 4.20 and Fig. 4.21 also show the comparisons between the test values and the predicted values of concrete cylinder strength and modulus of elasticity at different ages. The predicted values for the concrete cylinder strength are obtained using the age function recommended by the A.C.I. Committee 209 (2) based on the test value of cylinder strength at 28 days. The predicted values for the modulus of elasticity are obtained using Pauw's expression for the modulus of elasticity of concrete together with the test values and the predicted values of the concrete cylinder strength. The proposed stress-strain curve for concrete is used in determining the increase in strain of concrete by raising the compressive stress from 350 psi. to 1000 psi..

The beams were exposed to surrounding conditions similar to those of structures in actual service in the Port Hueneme, California, area. During the test period, the average daily temperature ranged from the minimum of 47 $^{\circ}F$ in the winter to the maximum of 71 $^{\circ}F$ in the summer. Relative humidity ranged from the minimum of 45% in the winter to the maximum of 95% in the summer. The ultimate creep coefficient, $(c)_\infty$, and the ultimate shrinkage, $(\varepsilon_s)_\infty$ are estimated, using the values recommended by the A.C.I. Committee 209(2), to be

1.88 and -5.60 x 10^{-4} in./in.. The beams are also analyzed with the above material properties using Branson's method together with the effective moment of inertia method and by the program PBEAM using the predicted values of strength and modulus of elasticity of concrete based on the age function recommended by the A.C.I. Committee 209 (2) with the measured concrete cylinder strength at 28 days and Pauw's expression for E_c instead of the measured values. The analytical results by various methods are compared with the measured data in Fig. 4.22 to Fig. 4.29 and in Table 4.3 to Table 4.5 In the time-dependent analysis by the program PBEAM, only the superposition method is used in estimating creep in concrete since the rate of creep method gives poor results for structures which are loaded at some later date.

Fig. 4.22 shows the comparison of the time-dependent responses of the beams at different sustained load levels as predicted by the program PBEAM, by Branson's method, and from experiment. Table 4.3 summarizes the instantaneous deflections due to prestressing force and sustained loads applied at the age of the beams of 22 days. Fig. 4.23 and Table 4.4 illustrate the change in camber at midspan after transferring of prestressing force for the unloaded beam. Fig. 4.24 to Fig. 4.26 and Table 4.5 show the changes in midspan deflections after loading for the beams with the sustained loads of 0.5, 1.0, and 1.5 design live load. The program PBEAM and the transformed area method using the test values for E_c and f'_c predict the same instantaneous responses for the uncracked beams, i.e. the beam with no applied load and the beams with the applied loads of 0.5 and 1.0 design live load. They underestimate the midspan camber due to prestressing force by about 12% and overestimate the instantaneous midspan deflections due to the loads

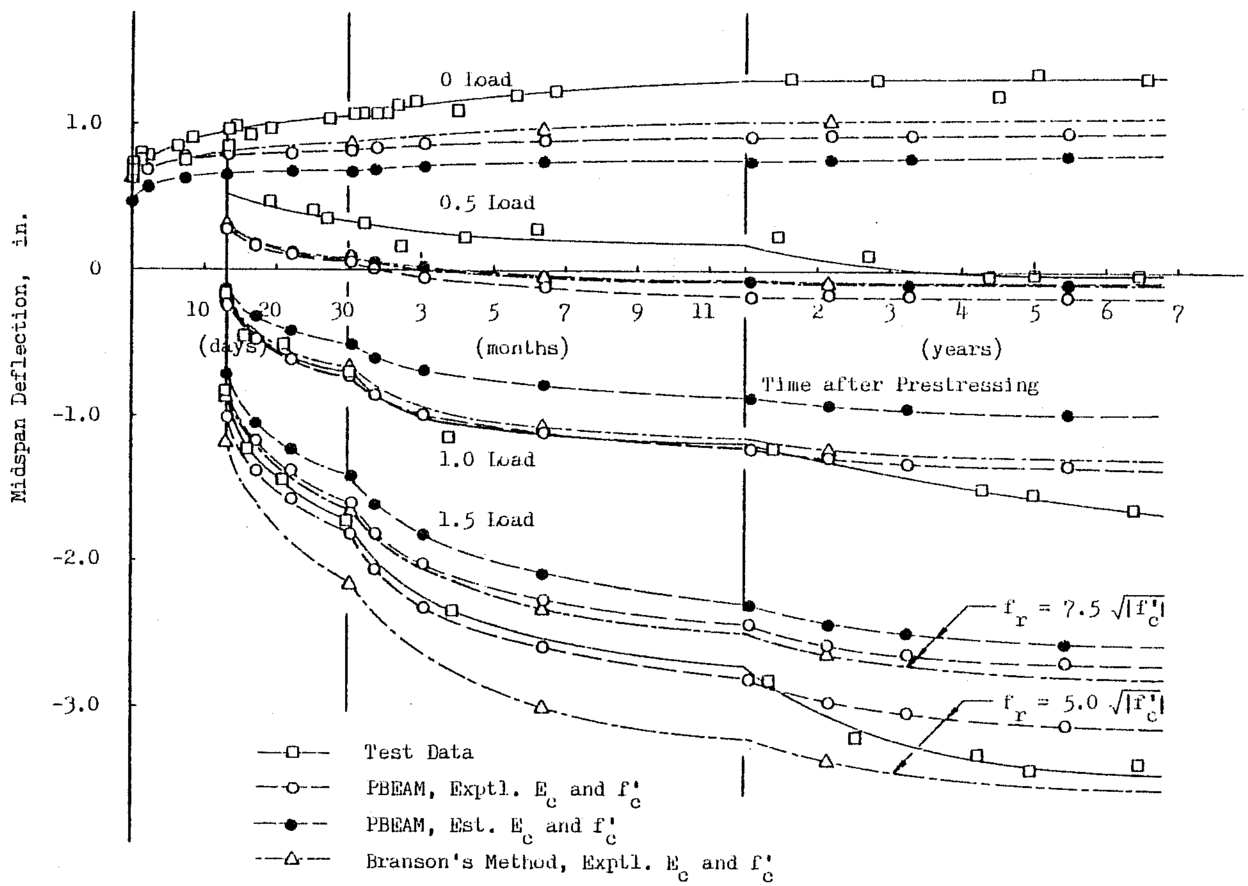


Fig. 4.22 Comparison of Time Variations of Midspan Deflection of Beams in Example Problem 4 from Various Methods and Experiment.

Table 4.3

Instantaneous Midspan Deflections Due to Prestressing Force and Applied Loads.

Total Applied Load, kips		0	15.2	30.4	45.6
Experimental Data	$\Delta_{℄}$ in.	0.69	-0.50	-1.01	-1.81
PBEAM, Exptl. E_c and f'_c, $f_r = 7.5\sqrt{\lvert f'_c \rvert}$	$\Delta_{℄}$, in. Error, %	0.61 -11.6	-0.52 4.0	-1.03 2.0	-1.61 -11.0
PBEAM, Exptl. E_c and f'_c, $f_r = 5.0\sqrt{\lvert f'_c \rvert}$	$\Delta_{℄}$, in. Error, %	0.61 -11.6	-0.52 4.0	-1.03 2.0	-1.81 0
PBEAM, Est. E_c and f'_c, $f_r = 7.5\sqrt{\lvert f'_c \rvert}$	$\Delta_{℄}$, in. Error, %	0.49 -29.0	-0.39 -22.0	-0.77 -23.8	-1.41 -22.1
I_{eff} Method, Exptl. E_c and f'_c, $f_r = 7.5\sqrt{\lvert f'_c \rvert}$	$\Delta_{℄}$, in. Error, %	0.61 -11.6	-0.52 4.0	-1.04 3.0	-1.69 -6.6
I_{eff} Method, Exptl. E_c and f'_c, $f_r = 5.0\sqrt{\lvert f'_c \rvert}$	$\Delta_{℄}$, in. Error, %	0.61 -11.6	-0.52 4.0	-1.04 3.0	-2.00 10.5

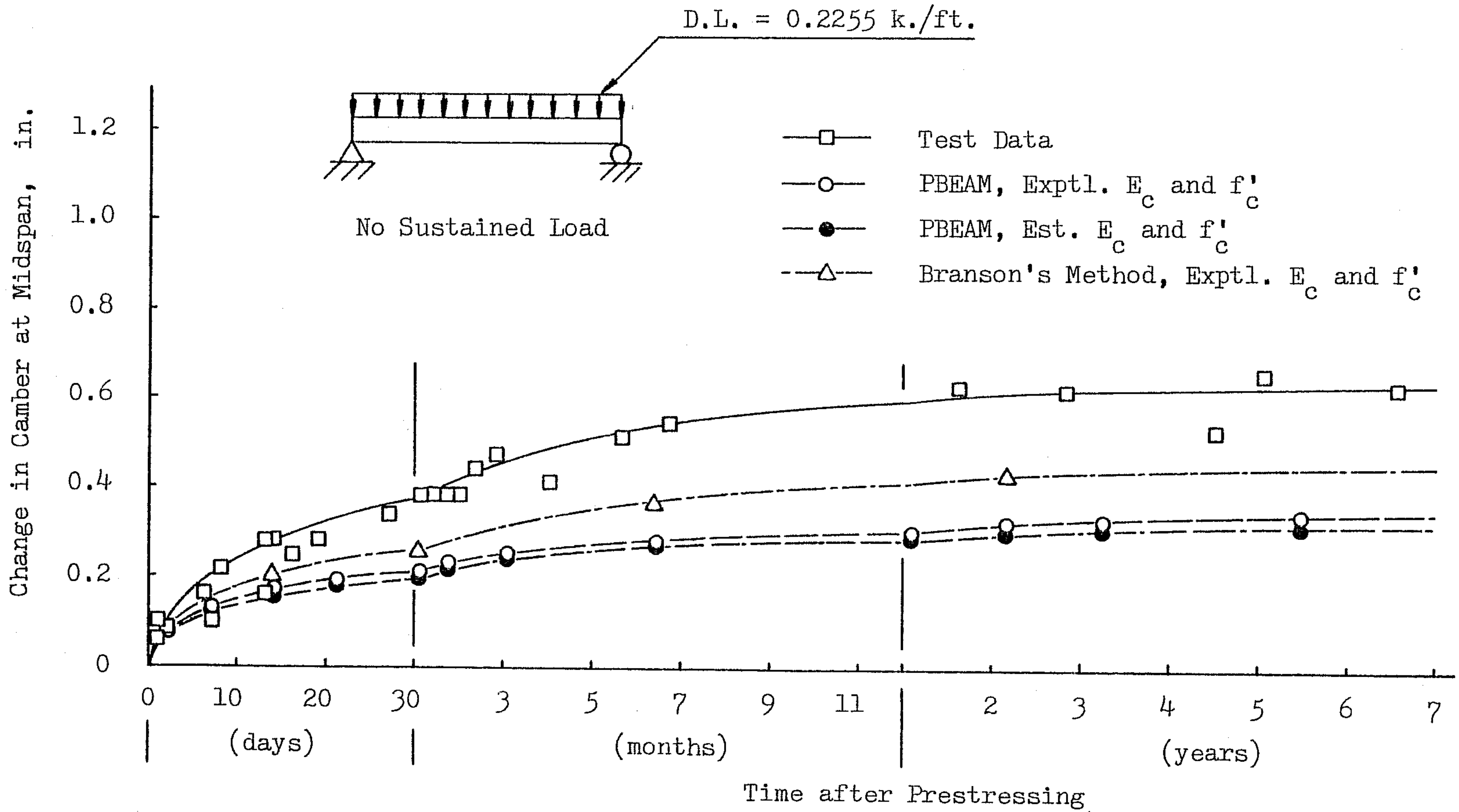


Fig. 4.23 **Comparison of Time Variations of Change in Midspan Camber after Prestressing of Beam with No Sustained Load Predicted by Various Methods with Experimental Data.**

Table 4.4

Time Variations of Change in Camber at Midspan for Beam in Example Problem 4, Unloaded Beam, at Some Calculated Points.

Time after Prestressing, days		14	32	192	792	4600+
Experimental Data*	$d\Delta_{℄}$, in.	0.28	0.38	0.53	0.62	0.65
PBEAM, Exptl. E_c and f'_c	$d\Delta_{℄}$, in. Error, %	0.17 -39.3	0.21 -44.7	0.28 -47.2	0.32 -48.4	0.36 -44.6
PBEAM, Est. E_c and f'_c	$d\Delta_{℄}$, in. Error, %	0.16 -42.7	0.19 -50.0	0.26 -50.9	0.30 -51.6	0.33 -49.2
Branson's Method, Exptl. E_c and f'_c	$d\Delta_{℄}$, in. Error, %	0.20 -28.6	0.26 -31.6	0.37 -30.2	0.43 -30.6	0.46 -29.2

*Estimated from Curve Averaging the Experimental Data

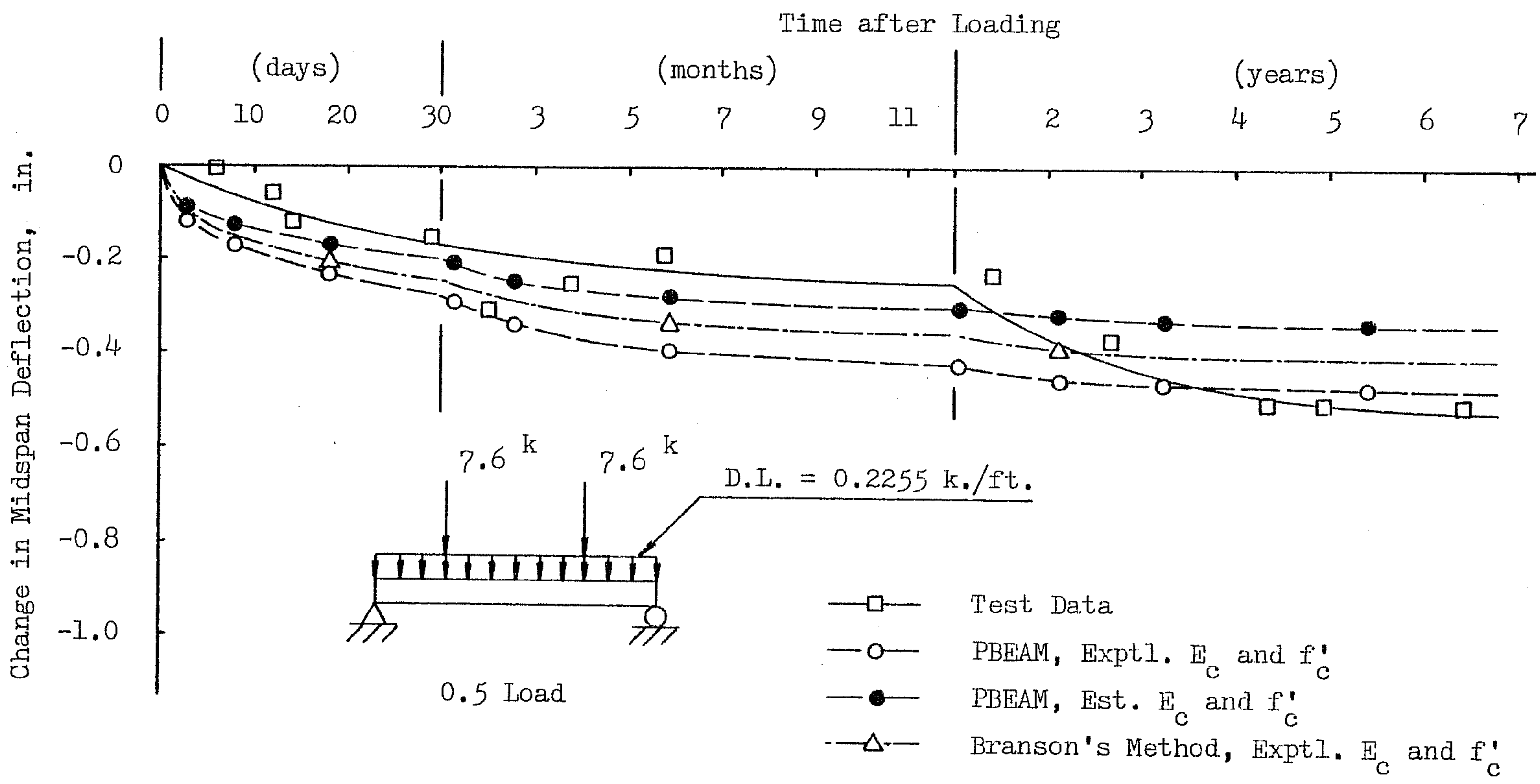


Fig. 4.24 Comparison of Time Variations of Change in Midspan Deflection after Loading of Beam with Sustained Load of 0.5 Design Live Load by Various Methods with Experimental Data.

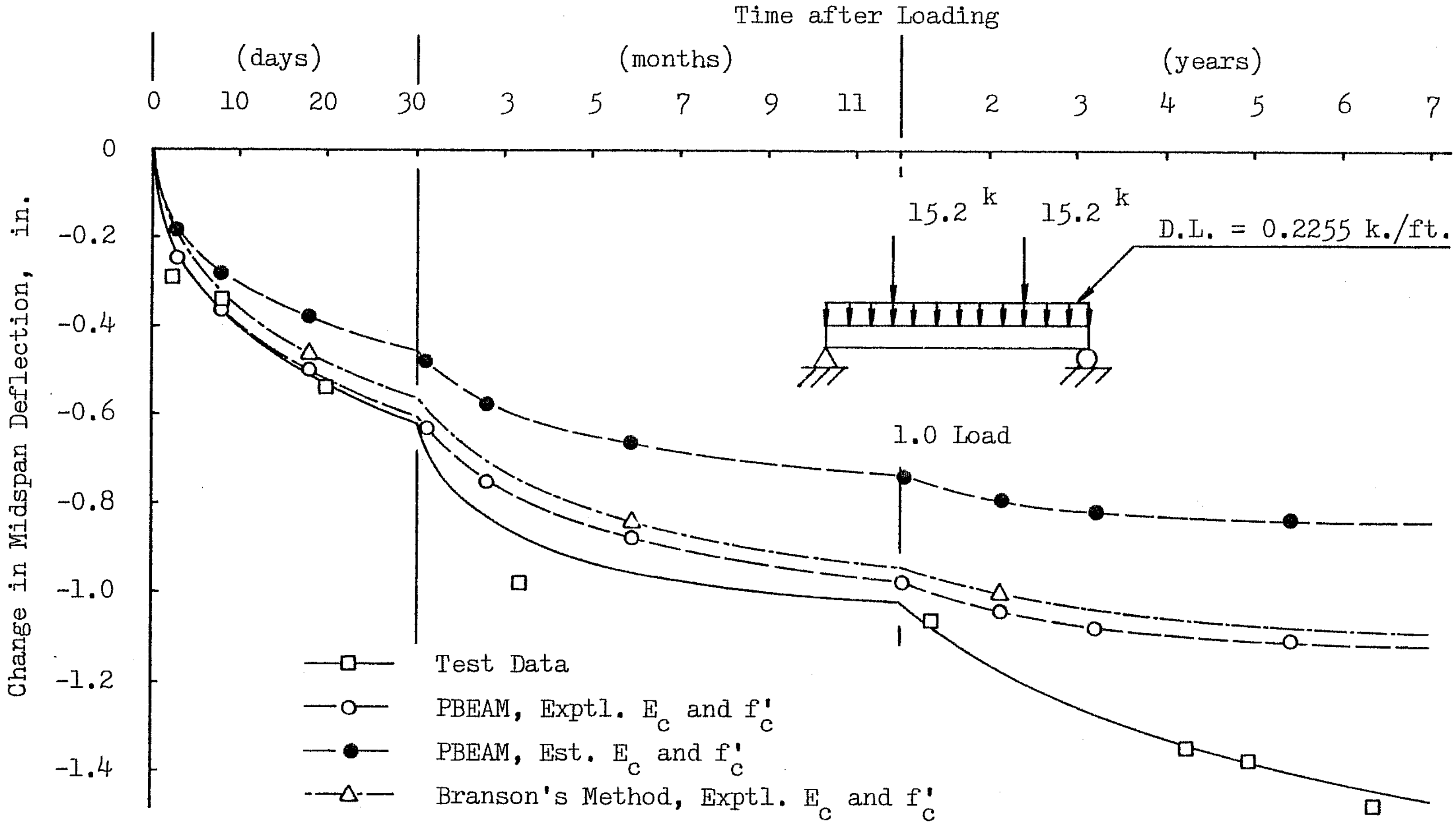


Fig. 4.25 Comparison of Time Variations of Change in Midspan Deflection after Loading of Beam with Sustained Load of 1.0 Design Live Load by Various Methods with Experimental Data.

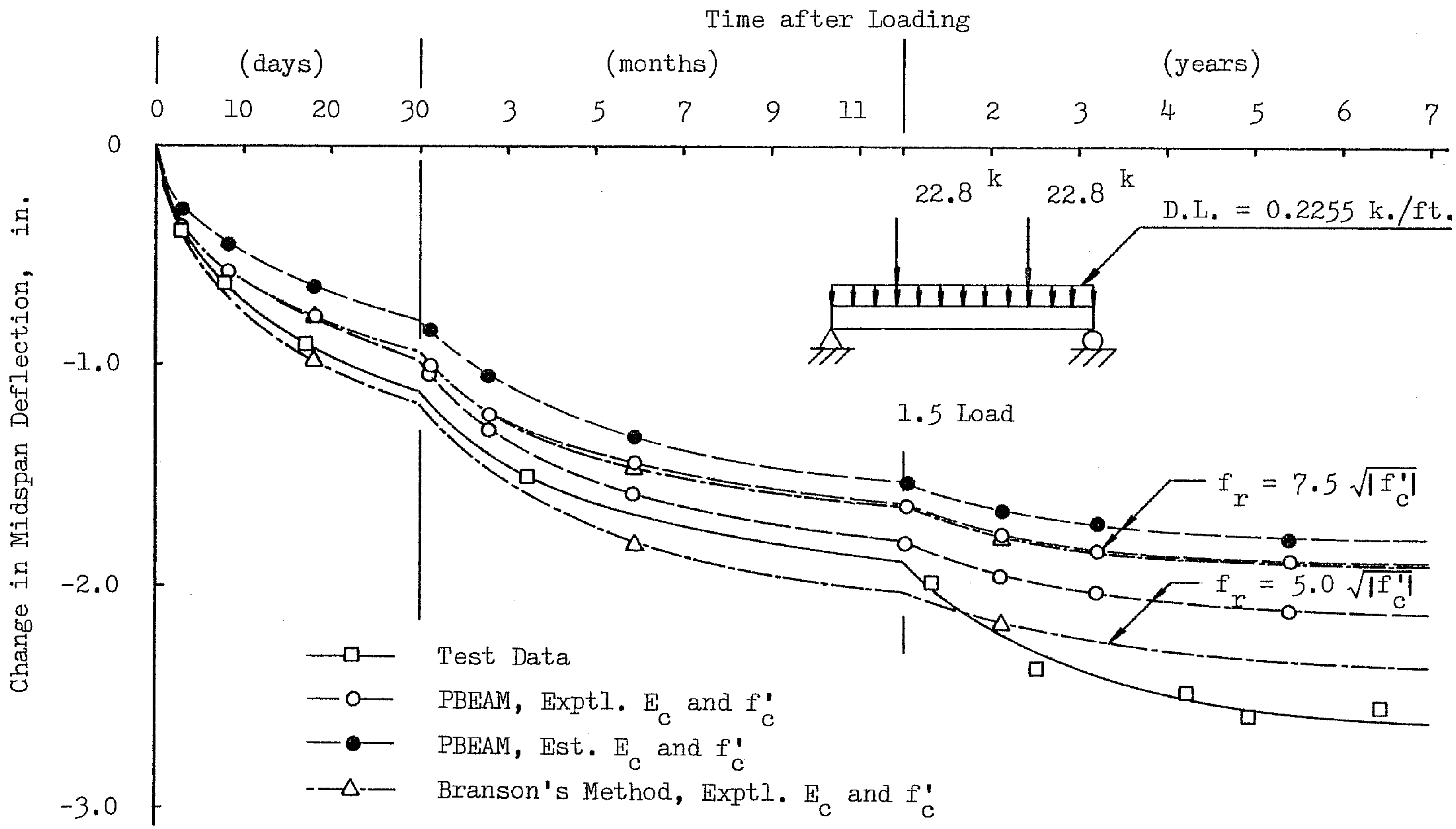


Fig. 4.26 Comparison of Time Variations of Change in Midspan Deflection after Loading of Beam with Sustained Load of 1.5 Design Live Load by Various Methods with Experimental Data.

Table 4.5

Time Variations of Change in Midspan Deflection for Beams in Example Problem 4, Loaded Beams, at Some Calculated Points.

Time after Loading, days			18	178	778	4600+
0.5 Load	Experimental Data*	$d\Delta_{℄}$, in.	-0.13	-0.22	-0.37	-0.52
	PBEAM, Exptl. E_c and f'_c	$d\Delta_{℄}$, in.	-0.23	-0.39	-0.45	-0.47
		Error, %	76.9	77.3	21.6	-9.6
	PBEAM, Est. E_c and f'_c	$d\Delta_{℄}$, in.	-0.17	-0.28	-0.32	-0.34
		Error, %	30.8	27.3	13.5	34.6
	Branson's Method, Exptl. E_c and f'_c	$d\Delta_{℄}$, in.	-0.20	-0.34	-0.38	-0.42
		Error, %	53.8	54.5	2.7	-19.2
1.0 Load	Experimental Data*	$d\Delta_{℄}$, in.	-0.51	-0.96	-1.37	-1.48
	PBEAM, Exptl. E_c and f'_c	$d\Delta_{℄}$, in.	-0.50	-0.88	-1.04	-1.13
		Error, %	-2.0	-8.3	-24.1	-23.6
	PBEAM, Est. E_c and f'_c	$d\Delta_{℄}$, in.	-0.38	-0.66	-0.78	-0.85
		Error, %	-25.5	-31.3	-43.1	-42.6
	Branson's Method, Exptl. E_c and f'_c	$d\Delta_{℄}$, in.	-0.46	-0.84	-0.99	-1.10
		Error, %	-9.8	-12.5	-27.7	-25.7
1.5 Load	Experimental Data*	$d\Delta_{℄}$, in.	-0.92	-1.67	-2.21	-2.65
	PBEAM, Exptl. E_c and f'_c #	$d\Delta_{℄}$, in.	-0.78	-1.44	-1.75	-1.94
		Error, %	-15.2	-13.8	-20.8	-26.8
	PBEAM, Exptl. E_c and f'_c ##	$d\Delta_{℄}$, in.	-0.79	-1.57	-1.94	-2.18
		Error, %	-14.1	-6.0	-12.2	-17.7
	PBEAM, Est. E_c and f'_c #	$d\Delta_{℄}$, in.	-0.65	-1.32	-1.65	-1.84
		Error, %	-29.3	-21.0	-25.3	-29.4
	Branson's Method, Exptl. E_c and f'_c #	$d\Delta_{℄}$, in.	-0.79	-1.47	-1.76	-1.95
		Error, %	-14.1	-12.0	-20.4	-26.4
	Branson's Method, Exptl. E_c and f'_c ##	$d\Delta_{℄}$, in.	-0.96	-1.80	-2.16	-2.39
		Error, %	4.3	7.8	-2.3	-9.8

* Estimated from Curves Averaging the Experimental Data.

\# $f_r = 7.5\sqrt{f'_c}$

\## $f_r = 5.0\sqrt{f'_c}$

of 0.5 and 1.0 design live load by about 4 % and 2 %, respectively. Using the estimated values of E_c and f'_c, the program PBEAM underestimates the midspan camber due to prestressing force by about 29 % and the midspan deflections due to the loads of 0.5 and 1.0 design live load by about 22 % and 24 %, respectively. The underestimations are expected since, as shown in Fig. 4.21, the predicted values for E_c based on the predicted f'_c at the concrete age of 8 days, the time the prestressing force is released, and 22 days, the time the loads are applied, are about 1.28 and 1.37 of the test values. The effective moment of inertia method, where the effective moment of inertia of the section at midspan is used to represent the average moment of inertia of the member, predicts a less stiff cracked member than that given by the program PBEAM using the same material properties. Using the modulus of rupture of concrete, f_r, of $7.5\sqrt{f'_c}$ and the experimental values of f'_c and E_c, the effective moment of inertia method estimates the instantaneous deflection at midspan due to the load of 1.5 design live load to be 1.69 in. while the program PBEAM predicts the midspan deflection of 1.61 in. comparing to the observed value of 1.81. With the estimated E_c and f'_c, the program PBEAM gives the midspan deflection of 1.41 in..

The anlaytical results of the time-dependent responses by the program PBEAM and by Branson's method are, in general, in good agreement with the reported values. They underestimate both the change in camber after prestressing with time of the unloaded beam and the changes in deflections after loading with time of the loaded beams. The program PBEAM and Branson's method, using the experimental E_c and f'_c, and the program PBEAM, using the estimated E_c and f'_c, underestimate the final change in midspan camber of the unloaded beam by about 45%, 29 %, and 49 %, respectively. Using the test values for E_c and f'_c, both methods underestimate the final changes in the midspan deflections after loading due to different sustained load levels by a maximum of 27 %. The errors may have resulted partly from the use of a higher modulus of elasticity of concrete at the time of prestressing than the actual value for the beams and from an underestimate of the creep coefficient. For the beam loaded with the sustained load of 1.5 design live load, the analytical methods (using $f_r = 7.5\sqrt{|f'_c|}$ and experimental E_c and f'_c) underestimate the instantaneous deflection due to the applied load. By using f_r equal to $5.0\sqrt{|f'_c|}$ instead of $7.5\sqrt{|f'_c|}$, the program predicts the midspan deflection of 1.81 in. and the effective moment of inertia method predicts the midspan deflection of 2.00 in.. Better time-dependent responses are also predicted since a larger initial deflection results in a larger time-dependent deflection for the same material properties. Using the estimated E_c and f'_c and f_r equal to $7.5\sqrt{|f'_c|}$, the program PBEAM underestimates the final changes in the midspan deflections after loading for the loaded beams by a maximum of 43 %.

The failure load responses of the beams after about 12 years under different levels of sustained loads are predicted by the program PBEAM and by the effective moment of inertia method using the experimental values for E_c and f'_c are compared with the test data in Fig. 4.27 to Fig. 4.29. The program PBEAM, as well as the elastic theory, gives the beam stiffness before cracking about the same as the data. Cracking moments lower than the test data are obtained by the program for all beams. The elastic theory, using the effective prestressing forces from Branson's method, also gives about the same cracking moments as the program. The program predicts the same beam

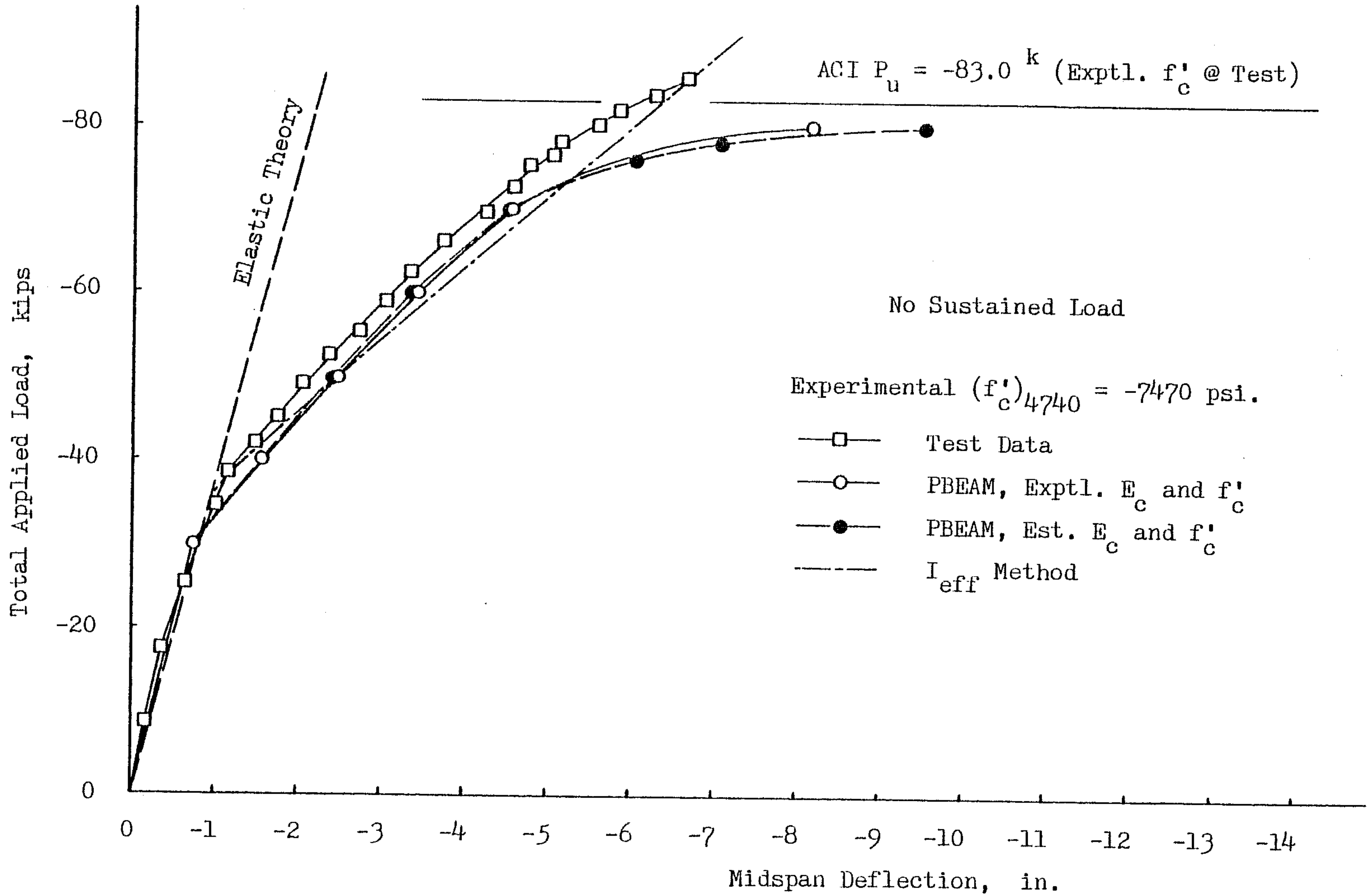


Fig. 4.27 Load Deflection Responses of Beam with no Sustained Load, at the Age of Concrete of 4740 days, Predicted by Various Methods and from Experiment.

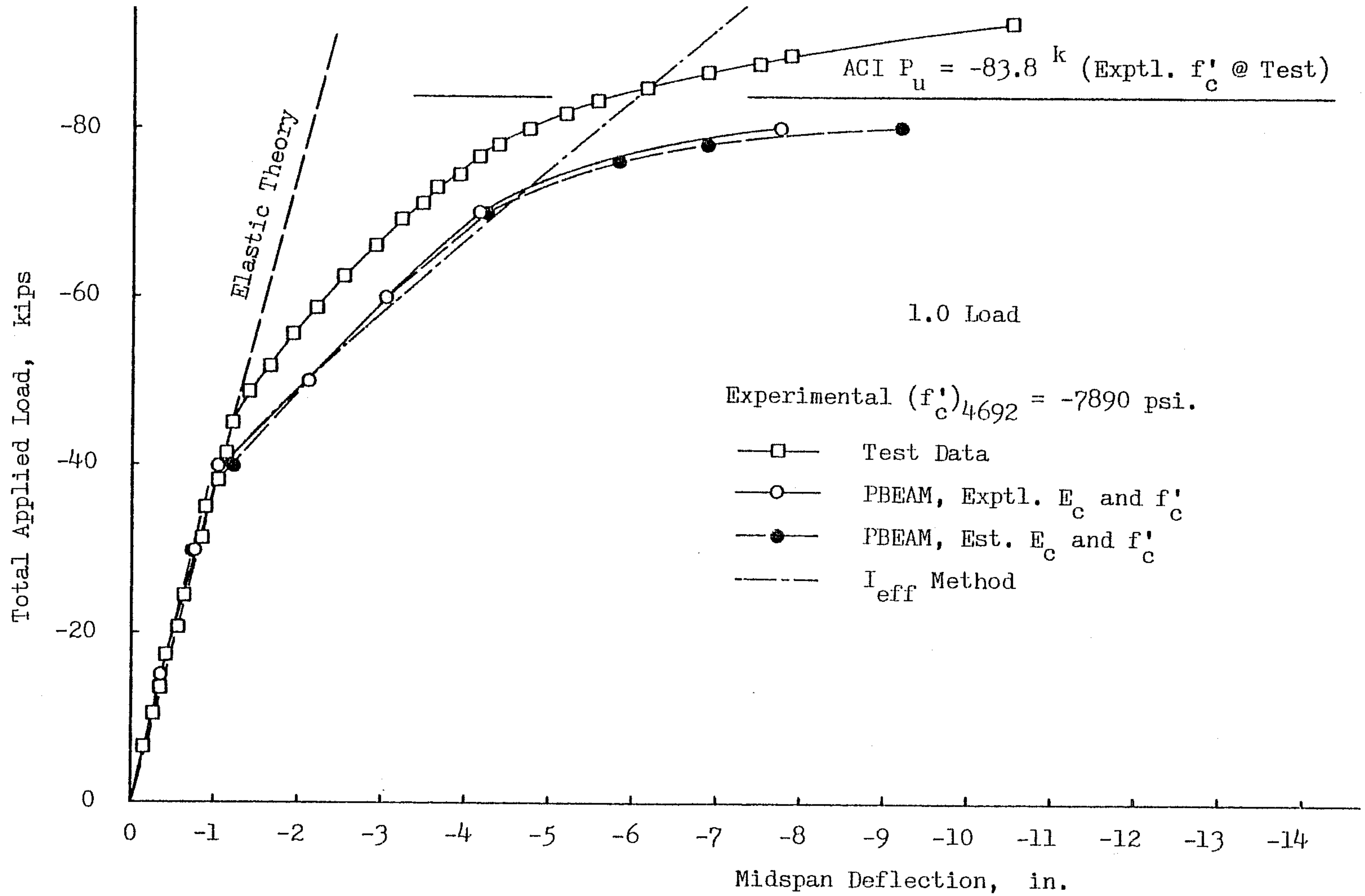


Fig. 4.28 Load-Deflection Responses of Beam with Sustained Load of 1.0 Design Live Load, at the Age of Concrete of 4692 days, Predicted by Various Methods and from Experiment.

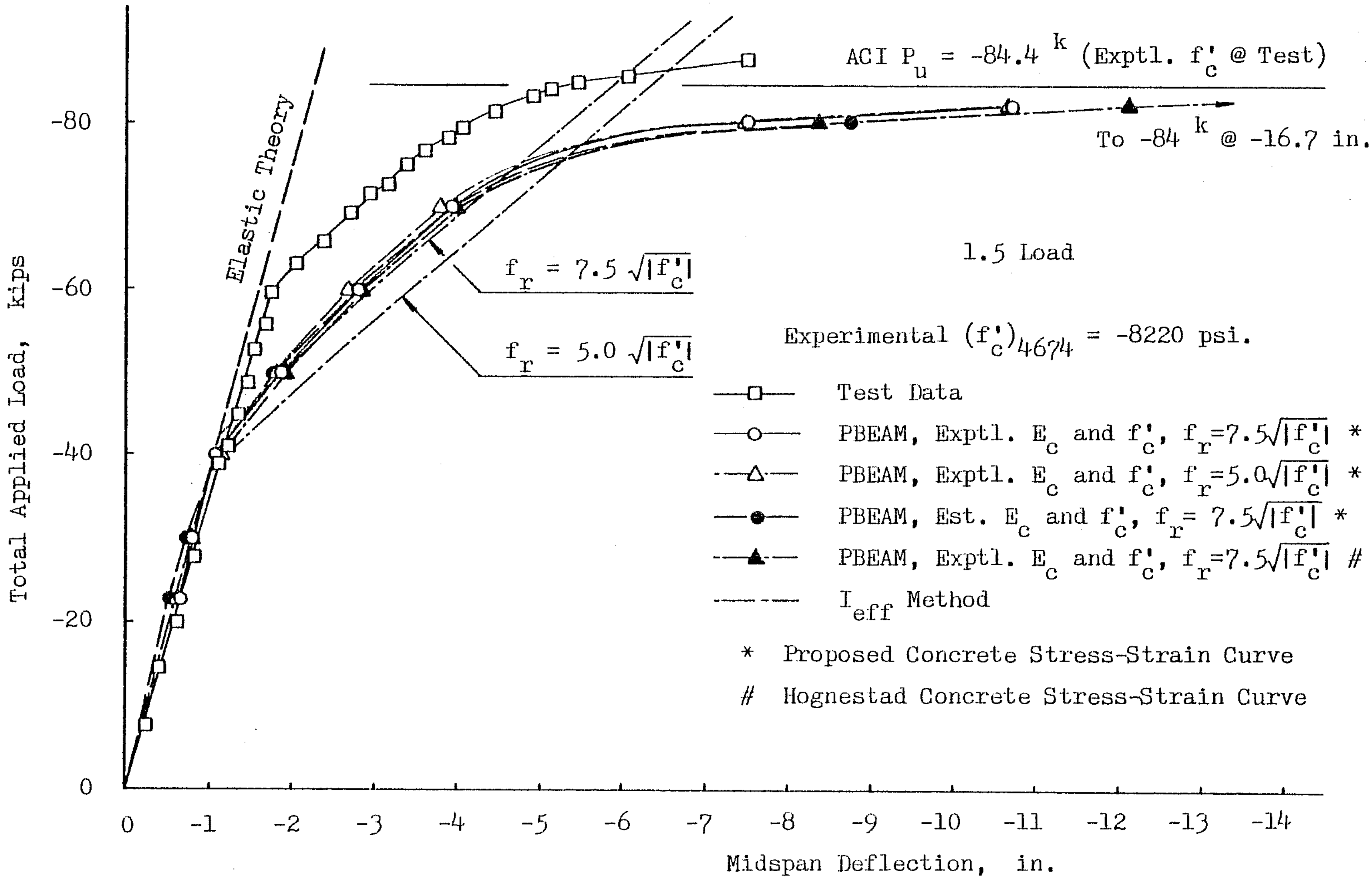


Fig. 4.29 Load-Deflection Responses of Beam with Sustained Load of 1.5 Design Live Load, at the Age of Concrete of 4674 days, Predicted by Various Methods and from Experiment.

stiffness as the data while the effective moment of inertia method predicts slightly less stiff members for the beams after cracking. With the load increment of 2 kips near the ultimate loads, the solutions by the program fail to converge at the total applied loads of 82 kips, 82 kips, and 84 kips for the beams with no sustained load and with the sustained loads of 1.0 and 1.5 design live load, respectively. Fig. 4.27 to Fig. 4.29 also show the analytical results from the program PBEAM using the estimated values of E_c and f'_c based on the experimental $(f'_c)_{28}$ instead of the test values. For all beams, slightly stiffer sections are predicted in the elastic range compared to those using the test values for E_c and f'_c. This results from the overestimating of the modulus of elasticity of concrete at the time of testing. The load-deflection responses up to failure after cracking are about the same. The error in estimating f'_c has little effect in the prediction of the failure loads of these underreinforced beams. The predicted failure loads are the same for the beams with no applied sustained load and with the applied sustained load of 1.0 design live load. The solution fails to converge at the applied load of 82 kips compared to 84 kips for the beam with the applied sustained load of 1.5 design live load. Using the A.C.I. method with the reduction factor, ϕ, equal to 1, the ultimate loads for the corresponding beams are estimated, based on the experimental values for f'_c at the time of testing, to be 83.0 kips, 83.8 kips, and 84.4 kips, respectively. The A.C.I. method, using the experimental $(f'_c)_{28}$ and the estimated f'_c at the time of testing based on the experimental $(f'_c)_{28}$, predicts the ultimate applied loads for the three beams of 78.8 kips and 80.5 kips. The test data show the failure loads of 85.5 kips, 92.6 kips, and 87.5 kips, respectively, for the three beams.

The beam with the sustained load of 1.5 design live load is also analyzed by various methods using the experimental values for E_c and f'_c and the modulus of rupture of concrete, f_r, of 5.0 $\sqrt{|f'_c|}$, and by the program PBEAM using the Hognestad stress-strain curve. The Hognestad stress-strain curve is used with the experimental E_c and f'_c, the concrete stress of 0.85 f'_c at the strain of -0.0038 in./in., and f_r of 7.5 $\sqrt{|f'_c|}$. The results are shown in Fig. 4.29. The results from the program PBEAM using f_rs of 7.5 $\sqrt{|f'_c|}$ and 5.0$\sqrt{|f'_c|}$ are nearly the same since the beam was cracked from previous loading. The elastic theory gives a lower cracking moment for the later case. The use of the Hognestad stress-strain curve for concrete gives about the same ultimate load as that using the proposed concrete stress-strain curve but at a much higher deflection. For the strength of concrete in this range, the descending branch of the stress-strain curve of concrete falls sharply. The moment-curvature response of the section also falls sharply as the moment reaches the ultimate moment. The curvature at the ultimate moment results in the strain at the extreme compressive fiber near ε_0 of the concrete. For the experimental values for the concrete strength and modulus of elasticity, ε_0 for the Hognestad stress-strain curve is estimated to be -0.003288 in./in.. The proposed stress-strain curve uses a fixed value of -0.0022 in./in. for ε_0 independent of E_c and f'_c. The ratio of the deflections at the ultimate load as predicted using the Hognestad stress-strain curve and the proposed stress-strain curve for concrete corresponds roughly to the ratio of the two ε_0s.

4.5 Example Problem 5 - Time-Dependent and Failure Load Responses of a Two-Span Composite Beam.

An extensive investigation of prestressed concrete bridge construction was conducted by Mattock (62) at the Research and Development Laboratories of the Portland Cement Association. The bridges included precast-prestressed girders with a continuous situ-cast deck slab. Long-term behavior of the structures which illustrated the effects of creep and differential shrinkage of half-scale models of girders and situ-cast deck slab was recorded. Two such half-scale model structures, girder 1/2 and girder 3/4, were tested. They were virtually identical except that girder 3/4 incorporated a positive moment connection at the interior support. It was decided to select girder 3/4 shown in Fig. 4.30 as an example problem.

The girders were manufactured in a prestressing bed. They were I-shaped in cross-section and 33 ft. long. Each girder was prestressed with 28 7-wire stress relieved strands of 1/4 in. diameter. The strands were tensioned at the initial prestressing force of 175 kips about one day before casting of the girders. The prestressing force was released at the age of the girders of about 8 days. After the release of the prestressing force, each pair of girders was positioned in line on tops of three columns, with their adjacent ends 3 in. apart. About 13 days after positioning the girders, 800 lb. concrete blocks were hung at points 3 ft. apart along the entire length of each girder to compensate for the dead weight of the half-scale model. The continuity reinforcement was placed and the deck slab was then cast at the age of girders of about 28 days. The deck slab formwork was removed 7 days later. Since the precast girders were unshored at the time of casting of the deck slab, the dead weight of the girders, deck slab, and the

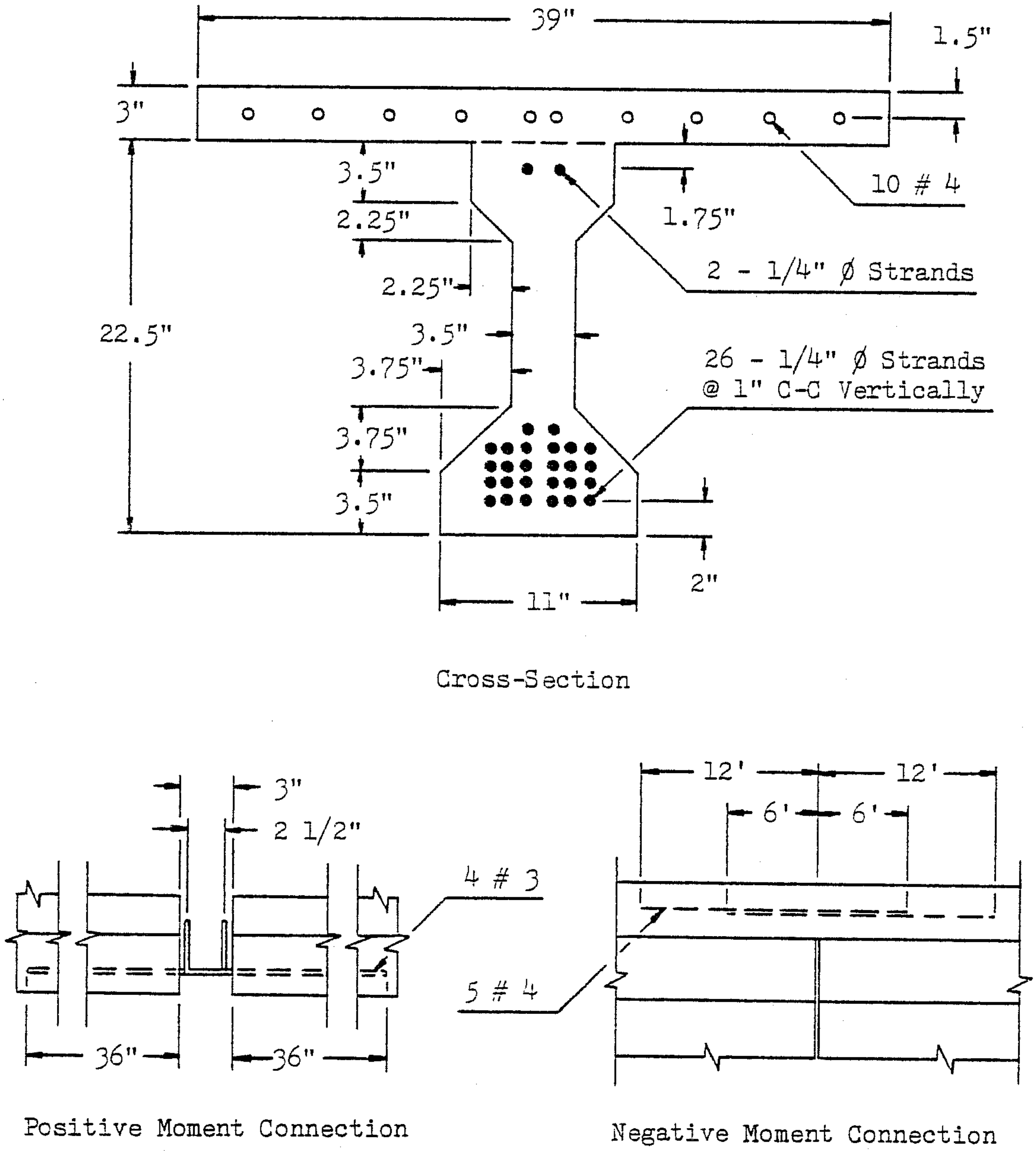


Fig. 4.30 Details of Cross-Section and Continuity Reinforcement for Girder 3/4.

concrete blocks were carried by the precast girders as 33 ft. span simple beams. After the removal of the slab formwork, the girders were loaded at intervals throughout the test period by concentrated loads applied at the middle of each span. The loads were put on incrementally and the maximum loads produced a bending moment equal to 1.3 times the design service load bending moment, including impact, at the center support section of the girders. The girders were then loaded to failure at the age of girders of about 680 days.

The details of the cross-section, the continuity connections, and boundary conditions and loading arrangements are shown in Fig. 4.30 and Fig. 4.31. Modeled cross-section is shown in Fig. 4.32. The structure is modeled as a 22-element member. Two extra elements at the right support are provided to simulate the actual condition of the structure. They are input in such a way that they have relatively small rotational stiffness before the composite beam action starts and relatively large stiffness with the moment capacity equal to the moment capacity of the connection after the composite beam action starts. The following material properties are used in the analysis:

Prestressing steel:

Measured data

F (initial) = 175,000 lb.

f_{su} = 280,000 psi.

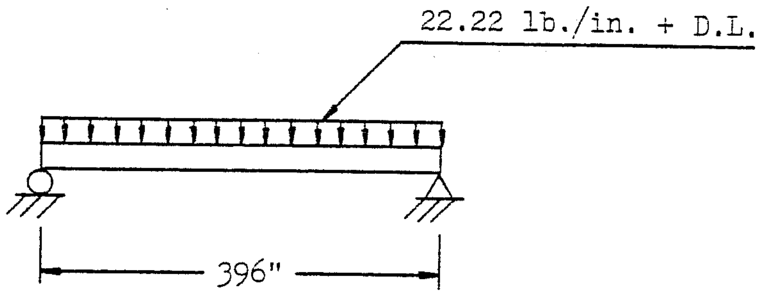
f_{sy} = 254,000 psi.

E_s = 28.7×10^6 psi.

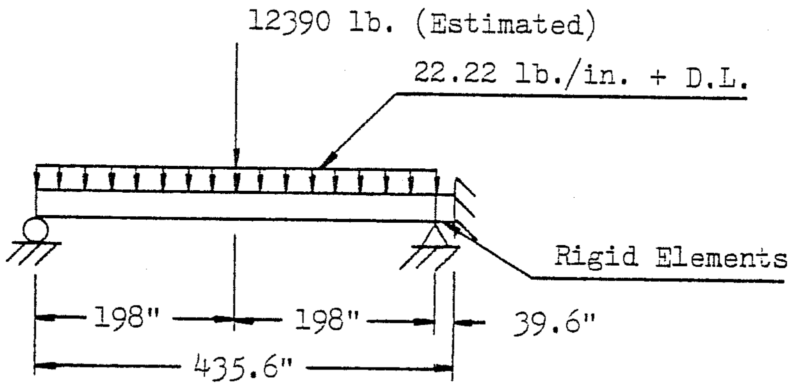
Assumed data

Stress-strain curve is shown in Fig. 4.33

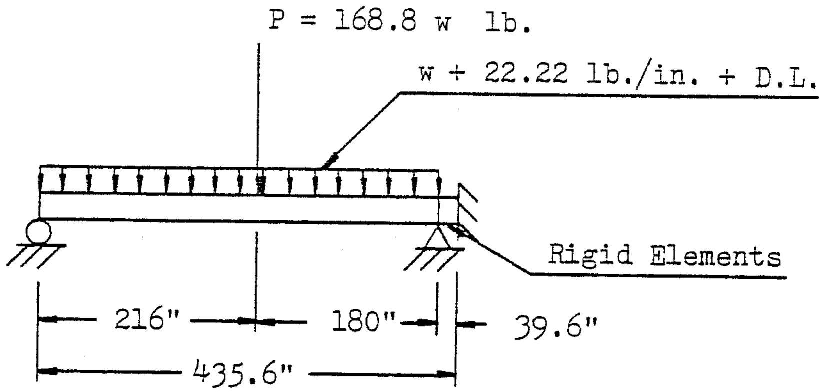
$$(f_{sr})_{t_1} - (f_{sr})_{t_0} = (f_s)_{t_0} \{\log(t_1/t_0)/10\} \{(f_s)_{t_0}/f_{sy} - 0.55\}$$



Dead Load and Dead Weight Blocks



Intermittent Service Load



Failure Load

Fig. 4.31 Longitudinal Section and Loading Arrangements for Girder 3/4.

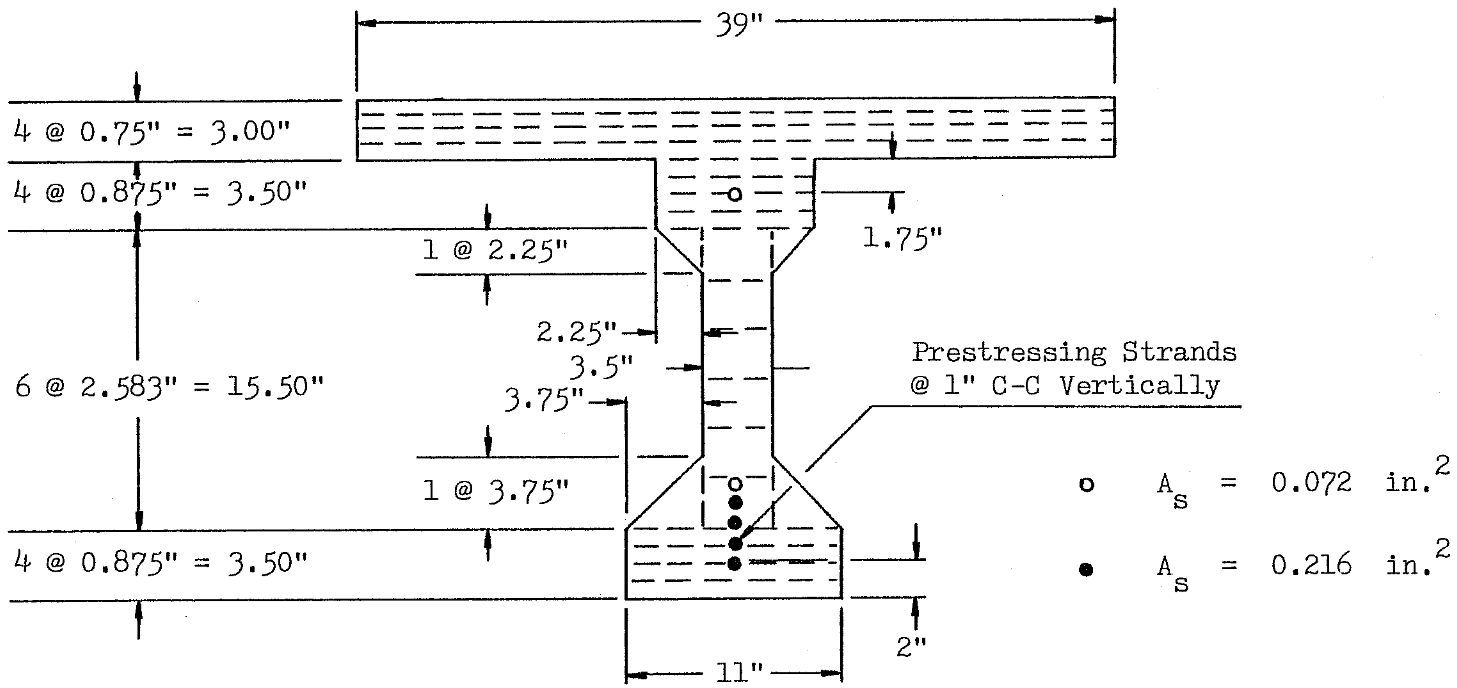


Fig. 4.32 Modeled Cross-Section at Midspan for Girder 3/4 .

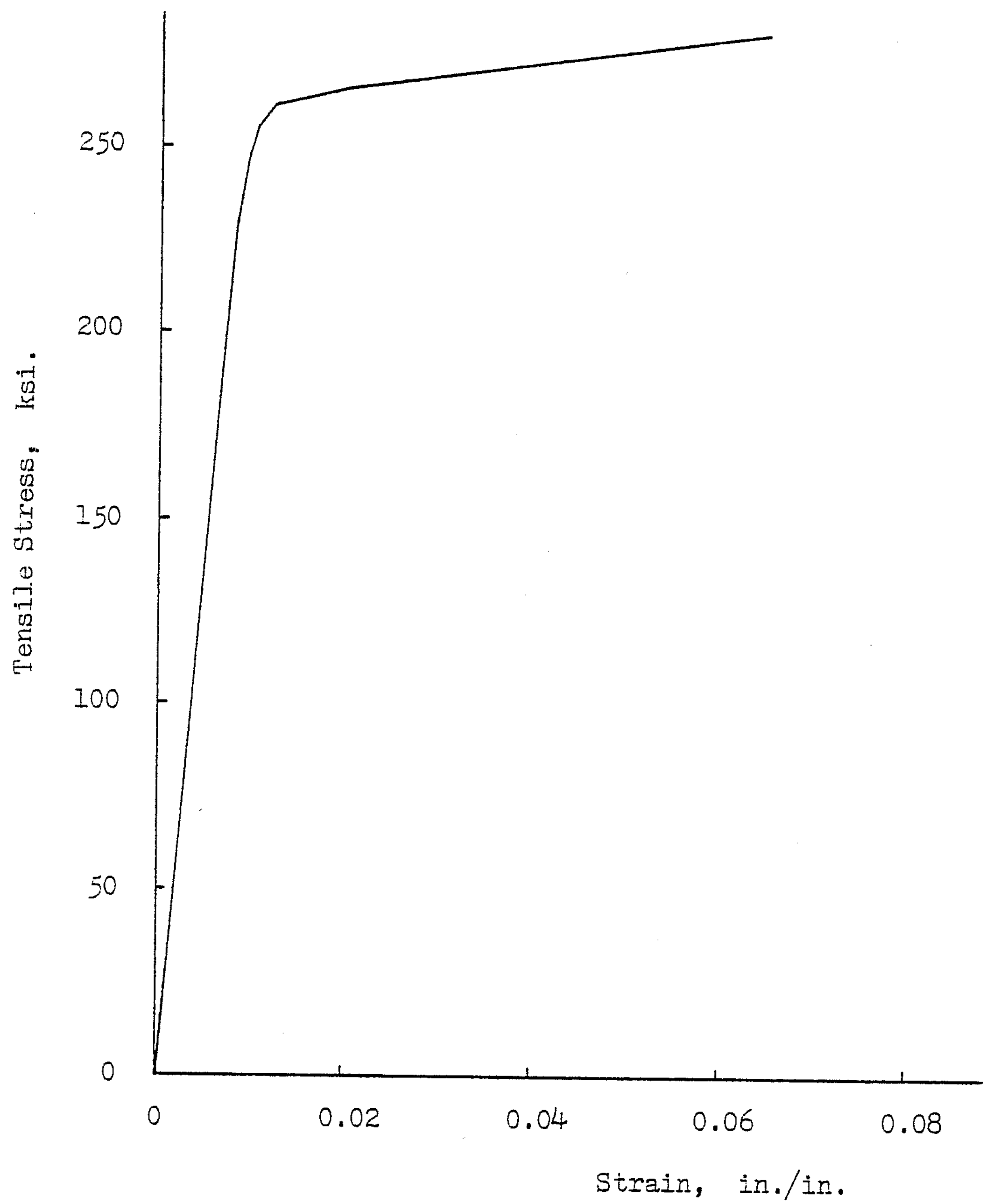


Fig. 4.33 Instantaneous Stress-Strain Relationship in Tension of Prestressing Strands for Girder 3/4.

where $(f_s)_{t_0}/f_{sy} \geq 0.60$

Negative reinforcement:

Measured data

$f_y = 48{,}500$ psi.

Assumed data

$E_s = 29.5 \times 10^6$ psi.

$\varepsilon_u = 0.10$ in./in.

Flat-topped stress-strain curve

Positive reinforcement:

Measured data

$f_y = 50{,}000$ psi.

Assumed data

$E_s = 29.5 \times 10^6$ psi.

$\varepsilon_u = 0.10$ in./in.

Flat-topped stress-strain curve

Girder concrete:

Measured data

Moist cured, Type III cement, 5.2 bags per cubic yard

$(f'_c)_{28} = 5{,}450$ psi.

Assumed Data

$w = 150$ lb./ft.^{3}

$E_c = 33\, w^{1.5}\sqrt{f'_c}$

$(c)_{t,t'}/(c)_\infty = (CC_{LA})_{t'}(t - t')^{0.6}/\{10 + (t - t')^{0.6}\}$

$(CC_{LA})_{t'} = 1.25\, t'^{-0.118}$

$(\varepsilon_s)_t/(\varepsilon_s)_\infty = t/(35 + t)$

$(f'_c)_t = 5457\, t/(2.30 + 0.92t)$

Proposed stress-strain curve where:

$f''_c = f'_c$

$f_r = 7.5\sqrt{f'_c}$

Deck Slab and diaphragm concrete:

Measured data

Moist cured, Type I cement, 4.1 bags per cubic yard

$(f'_c)_{28}$ = 4,820 psi.

Assumed Data

$w = 150 \text{ lb./ft.}^3$

$E_c = 33\, w^{1.5} \sqrt{f'_c}$

$(c)_{t,t'}/(c)_\infty = (CC_{LA})_{t'}(t - t')^{0.6}/\{10 + (t - t')^{0.6}\}$

$(CC_{LA})_{t'} = 1.25\, t'^{-0.118}$

$(\varepsilon_s)_t/(\varepsilon_s)_\infty = t/(35 + t)$

$(f'_c)_t = 4786\, t/(4.00 + 0.85t)$

Proposed stress-strain curve where:

$f''_c = f'_c$

$f_r = 7.5 \sqrt{f'_c}$

The structure was stored at 70°F and 50% relative humidity. Using the values recommended by the A.C.I. Committee 209 (2), the ultimate creep coefficients at the standard age for girder concrete and slab concrete are estimated to be 2.197 and the ultimate shrinkage strains at the standard age to be -6.673 x 10^{-4} in./in. and -6.404 x 10^{-4} in./in., respectively.

The measurements and the analytical results, both time-dependent and failure load responses, are compared in Fig. 4.34 to Fig. 4.38 and in Table 4.6 and Table 4.7. Fig. 4.34 shows the time variations of the interior support reaction as estimated by the program PBEAM and from the test measurement assuming that the reaction before the removal of the deck slab formwork is equal to that predicted by the program PBEAM. The analytical values of the change in the center support reaction with time after the removal of the deck slab framework by Mattock (62) using the effective modulus method and the rate of creep method, by Mossiossian and Gamble (64) using a revised rate of creep method,

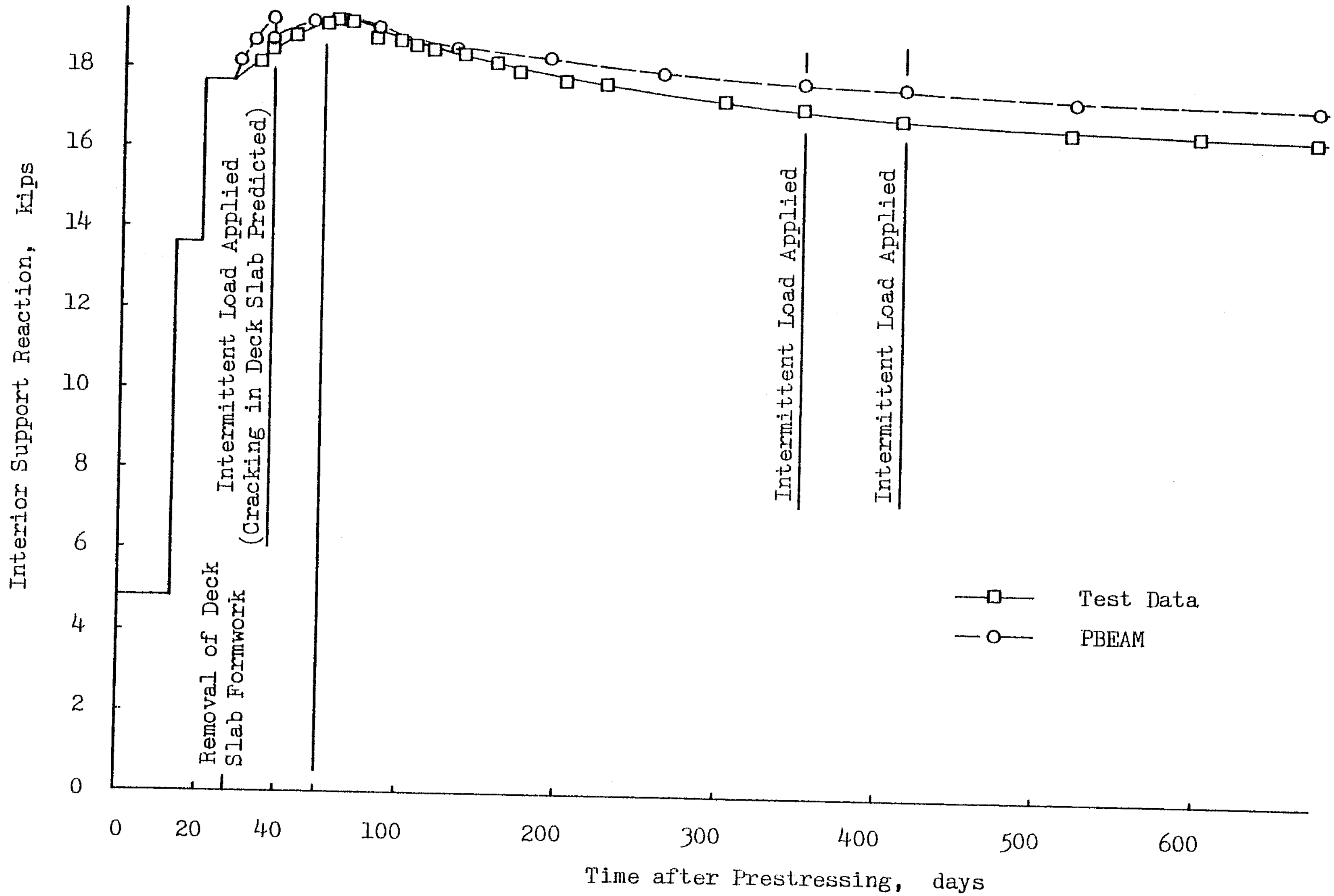


Fig. 4.34 Time Variations of Interior Support Reaction, Girder 3/4.

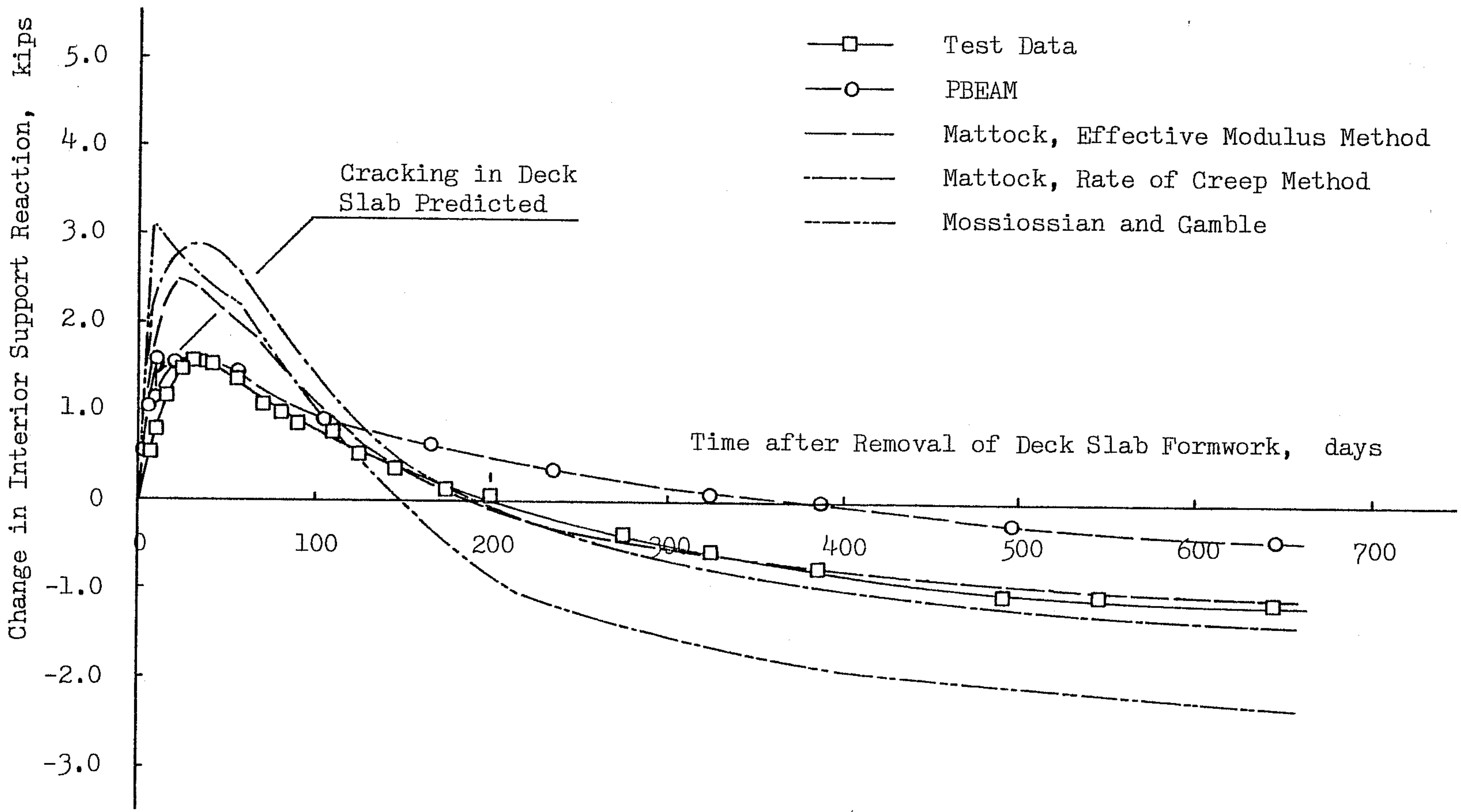


Fig. 4.35 Time Variations of Change in Interior Support Reaction after Removal of Deck Slab Formwork, Girder 3/4.

Table 4.6

Time Variations of Change in Interior Support Reaction after Removal of Deck Slab Formwork of Girder 3/4 at Some Calculated Points.

Time after Removal of Deck Slab Formwork, days		35	105	324	495	645
Experimental Data*	ΔR, kips	1.51	0.78	- 0.56	- 1.05	- 1.12
PBEAM	ΔR, kips Error, %	1.55 2.6	0.92 17.9	0.09 -116.1	- 0.25 -76.0	- 0.40 -64.3
Mattock's Results, Rate of Creep Method	ΔR, kips Error, %	2.89 91.4	1.33 70.5	- 0.80 42.9	- 1.18 13.5	- 1.35 20.5
Mattock's Results, E_{eff} Method	ΔR, kips Error, %	2.34 55.0	0.98 25.6	- 0.64 14.3	- 0.92 11.5	- 1.05 - 6.3
Mossiossian's and Gamble's Results#	ΔR, kips Error, %	2.44 61.6	0.90 15.4	- 1.59 183.9	- 2.03 95.2	- 2.30 105.4

*Estimated from Curve Averaging the Experimental Data.

#Estimated from Curve Representing the Analytical Results.

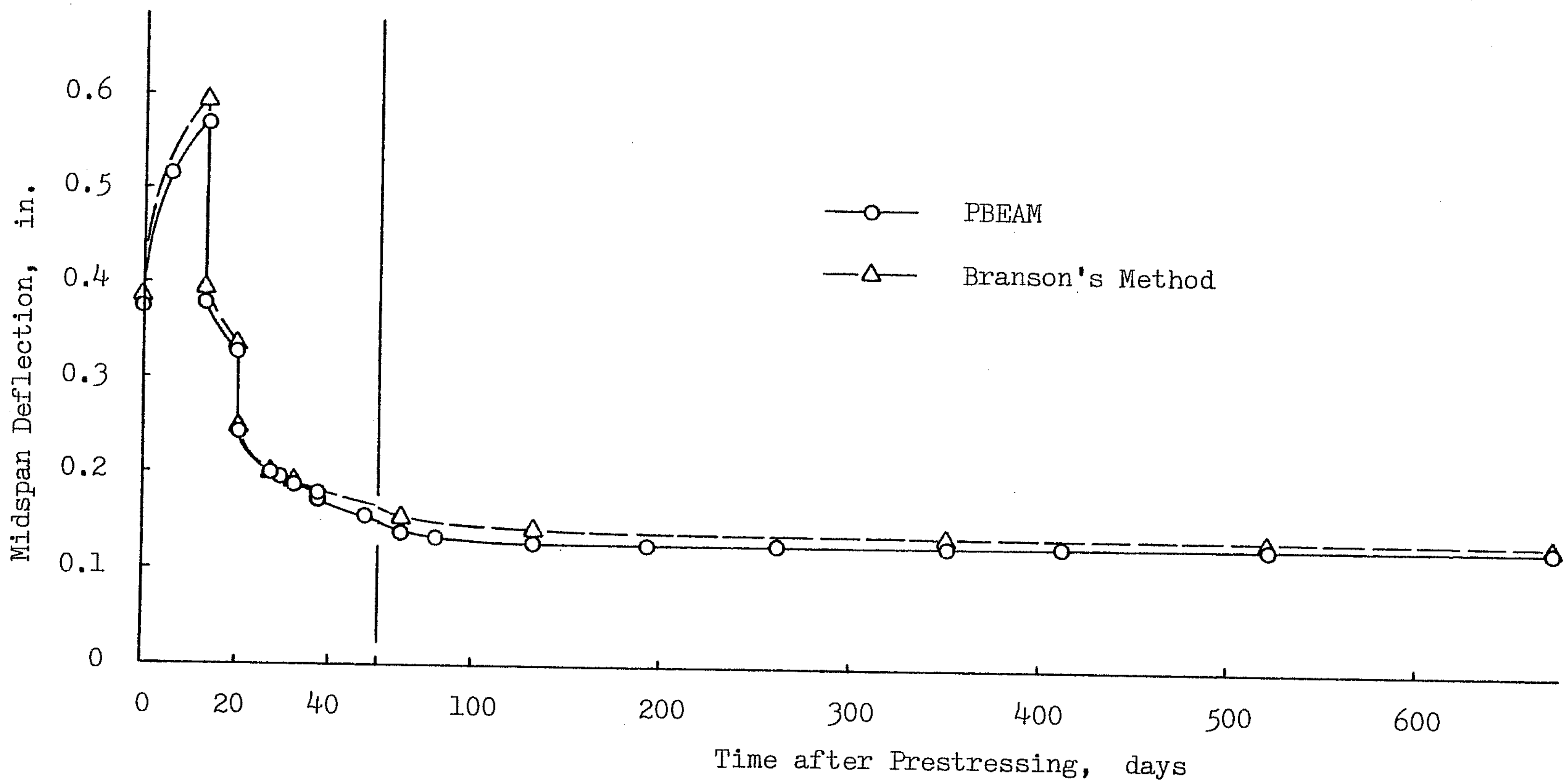


Fig. 4.36 Time Variations of Midspan Deflection, Girder 3/4.

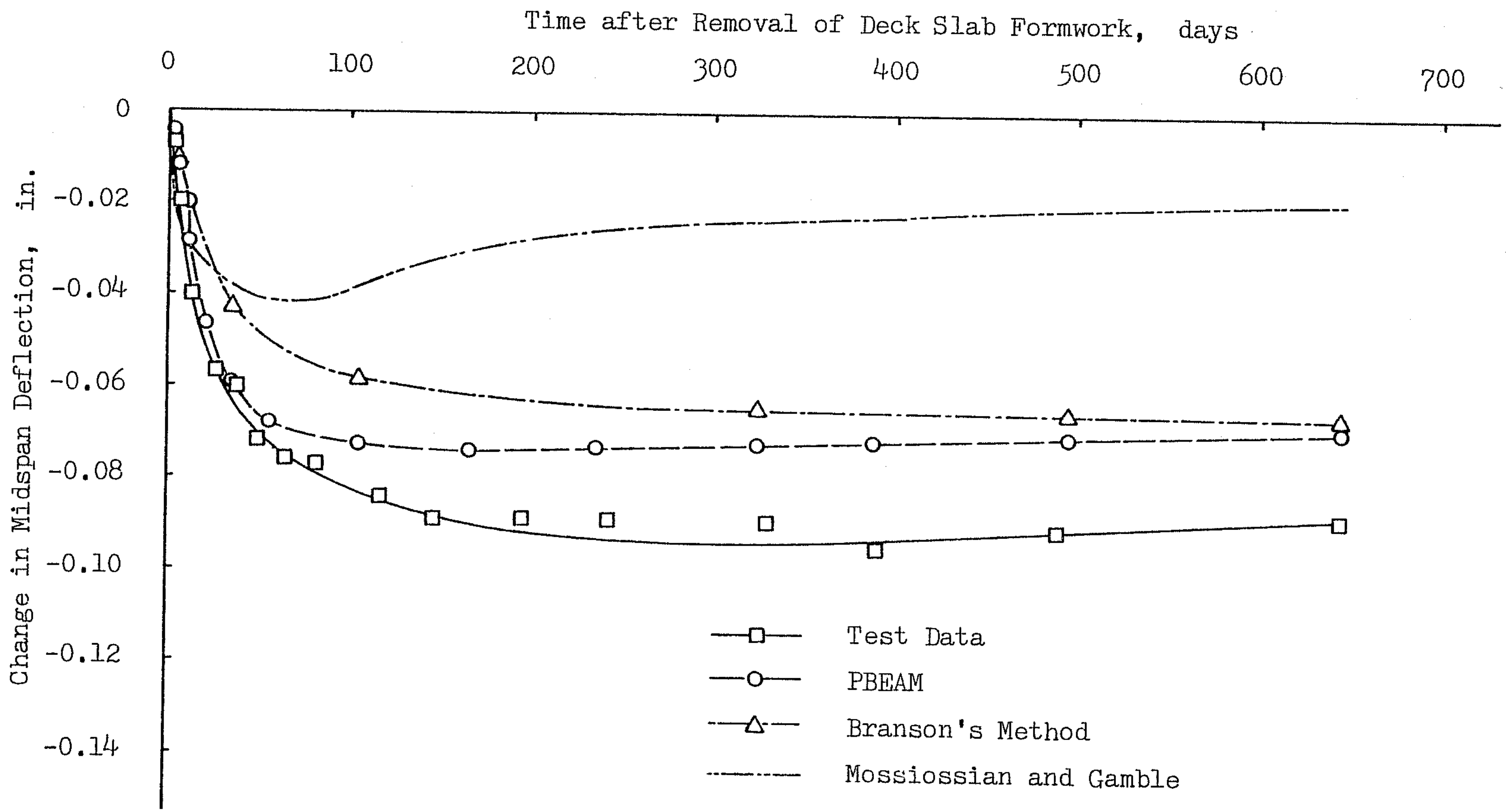


Fig. 4.37 Time Variations of Change in Midspan Deflection after Removal of Deck Slab Formwork, Girder 3/4.

Table 4.7

Time Variations of Change in Midspan Deflection after Removal of Deck Slab Formwork of Girder 3/4 at Some Calculated Points.

Time after Removal of Deck Slab Formwork, days		35	105	324	495	645
Experimental Data *	$d\Delta_{℄}$, in.	0.063	0.084	0.094	0.091	0.087
PBEAM	$d\Delta_{℄}$, in. Error, %	0.060 -4.8	0.073 -13.1	0.072 -23.4	0.070 -23.1	0.069 -20.7
Branson's Method	$d\Delta_{℄}$, in. Error, %	0.043 -31.7	0.058 -31.0	0.064 -31.9	0.065 -28.6	0.066 -24.1
Mossiossian's and Gamble's Results #	$d\Delta_{℄}$, in. Error, %	0.037 -41.3	0.039 -53.6	0.023 -75.0	0.020 -78.0	0.019 -78.2

* Estimated from Curve Averaging the Experimental Data.

\# Estimated from Curve Representing the Analytical Results.

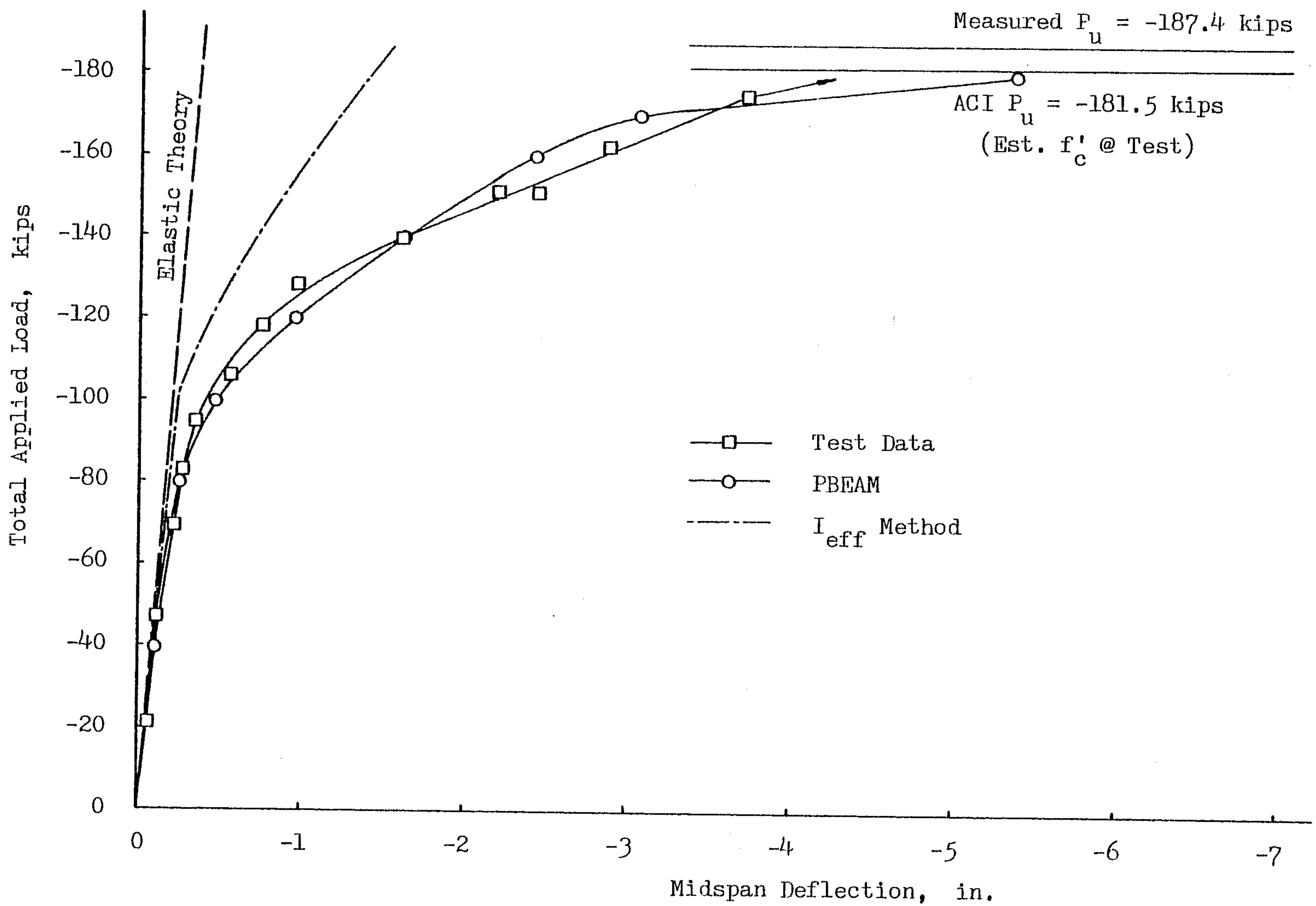


Fig. 4.38 Failure Load-Deflection Responses at the Age of Girder of 680 days, Girder 3/4.

and by the program PBEAM using the superposition method are compared with the measured data in Fig. 4.35 and, at some calculated points, in Table 4.6. The analytical results by Mattock and by Mossiossian and Gamble overestimate the increase in the interior support reaction at the early date. At the later date, the analytical results by Mattock agree well with the measured results while Ref. 64 overestimates the decrease in the reaction. The program PBFAM gives about the same increase in the reaction as others up to 10 days after the removal of the deck slab formwork when the first intermittent service load test causes cracking in the deck slab which results in a sharp drop in the reaction. After the first intermittent service load test, the analytical results by the program agree well with the measured results until the later date where the program underestimates the decrease in the reaction. This suggests the deck slab cracks gradually under the differential shrinkage after the removal of the deck slab formwork. The underestimating of the decrease in the reaction may be the result of the underestimating of creep in the girders.

The time-variations in the change in the midspan deflection of the structure after the removal of the deck slab formwork are compared in Fig. 4.37 and Table 4.7. Since Mossiosian and Gamble (64) does not take into account the cracking of concrete, it gives rather poor estimation of the time-varioation in the midspan deflection. Branson's method underestimates the change in the deflection by about 32% at the early date and by about 24% at the later date. The program PBEAM gives results agreeable with the measured values at the early date and about 21% lower than the test data at the later date. This, again, may be the results of the understimating of the creep in the girders.

Fig. 4.38 shows the comparison of the failure load response of the structure at the age of girders of about 680 days. For the effective moment of inertia method, the average moment of inertia of the structure is taken equal to 0.85 I_m + 0.15 I_c, where I_m and I_c are the effective moments of inertia of the structure at midspan and at the interior support, respectively. The expression is recommended by Branson (10) for uniformly loaded beams with one end continuous. The program PBEAM gives the load-deflection response of the structure in good agreement with the test data. A slighly stiffer member after the cracking at midspan is predicted by the program. The effective moment of inertia gives a much stiffer section after cracking. The analytical results from the program converges at the total applied load level of 180 kips but diverges at the total applied load level of 190 kips. The A.C.I. method with the reduction factor, Ø, equal to 1 and full moment redistribution gives the ultimate applied load of 181.5 kips, based on the estimated f'_c at the time of testing, and 179.3 kips, based on the measured $(f'_c)_{28}$. The reported ultimate load is 187.4 kips.

4.6 Summary of the Comparisons of Analytical Results with Results.

Five example problems were presented to establish the validity of the proposed method and the program PBEAM. The example problems included the analyses of failure load responses, time-dependent responses, and failure load responses after long-term sustained loads of both pre-tensioned and post-tensioned bonded beams. The types of beams included noncomposite and composite, simply supported and continuous beams. The analytical results from the program were compared with some other method of analysis and test results. The instantaneous load-deflection responses up to failure of the beams as predicted by various methods and the experimental data are shown in Fig. 4.4, Fig. 4.9, Fig. 4.10, Fig. 4.27 to Fig. 4.29, and Fig. 4.38. The analytical results for the time-dependent responses of the beams by various methods were compared with the test measurements in Fig. 4.13 to Fig. 4.15, Fig. 4.22 to Fig. 4.26, Fig. 4.34 to Fig. 4.37, Table 4.1, Table 4.2, and Table 4.4 to Table 4.7.

The analytical results from the program PBEAM for the instantaneous load-deflection responses up to failure of the beams are, in general, in good agreement with the test data, in both the elastic range and the inelastic range. The effective moment of inertia method also predicts the load-deflection responses in the cracked members where reinforcing steel, both prestressed and nonprestressed, are not yielded. The method does not account for the decrease in the stiffnesses of the sections lower than their cracked moments of inertia after the yielding of the reinforcing steels, thus underestimates the deflections in the load levels near ultimate loads for the simply supported beams and in the high load levels for the continuous beams. The ultimate loads for the beams estimated by the program and the A.C.I. method are compared with the reported values in Table 4.8. The table shows the ranges of the ultimate loads that would be predicted by the program. The failure loads were determined by increasing the applied loads incrementally until the solutions fail to converge. For a member, the highest load level at which the solution

Table 4.8

Comparison of Analytical and Experimental Ultimate Applied Loads for Beams in the Example Problems.

Prob. No.	Beam	Measured	PBEAM				ACI Code 318-71			
			Exptl. f'_c @ Test		Est. f'_c @ Test Based on Exptl. $(f'_c)_{28}$		Exptl. f'_c @ Test		Exptl. $(f'_c)_{28}$	
			Analytical	Analytical / Measured	Analytical	Analytical / Measured	Analytical	Analytical / Measured	Analytical	Analytical / Measured
1	BW.10.072	42.8	41.6-41.8	0.97-0.98	---	---	38.8	0.91	---	---
4	No LL. Beam	85.5	80-82	0.94-0.96	80-82	0.94-0.96	83.3	0.97	78.8	0.92
4	1.0 LL. Beam	92.6	80-82	0.86-0.89	80-82	0.86-0.89	83.8	0.90	78.8	0.85
4	1.5 LL. Beam	87.5	82-84	0.94-0.96	80-82	0.91-0.94	84.4	0.96	78.8	0.90
5	Girder 3/4	187.4	---	---	180-190	0.96-1.01	---	---	179.3	0.96
			Avg.	0.93-0.95	Avg.	0.92-0.95	Avg.	0.94	Avg.	0.91

converges and the lowest load level at which the solution diverges bound the ultimate load of the member. The A.C.I. values are obtained from the estimated ultimate moments using the A.C.I. Code 318-71 with the capacity reduction factor, ϕ, of 1 assuming full moment redistribution in the case of the continuous beams. It can be seen from the table, the program PBEAM gives the results of the same accuracy as the A.C.I. method. The program underestimates the ultimate loads by an average of 7% comparing to an average of 6% by the A.C.I. method using the concrete strength at the time of testing. About the same accuracy is obtained from the program PBEAM using the estimated values of f'_c at the time of testing instead of the experimental values. The A.C.I. method, using the experimental values of f'_c at the age of concrete of 28 days, underestimates the applied failure loads by an average of 9%.

The program PBEAM also gives time-dependent responses in fairly good agreement with the test data considering the accuracy of the prediction of the time-dependent properties of the materials. Table 4.9 summarizes the results of time-dependent response analysis and the basis for material properties used in the analysis. The program PBEAM, using the superposition method of estimating creep strain, predicts the time variations of the change in midspan deflection after prestressing (for camber specimens) or after loading (for loaded specimens) in Example Problems 3 and 5 with a maximum error of 24%. For Example Problem 4, although the analytical results show large percentages of error in the change in midspan deflection, the overall time-dependent responses as predicted by the program PBEAM are in fairly good agreement with the test data.

Table 4.9

Summary of the Time-Dependent Response Analysis of the Example Problems.

Prob. No.	Beam	Method of Analysis	Max. Error in $d\Delta_t$, %	Material Properties
3	Camber Specimens	PBEAM	5.7	Pauw's E_c, ACI Comm. 209's age, creep, and shrinkage functions, measured $(f'_c)_{28}$, $(c)_\infty$, and $(\varepsilon_s)_\infty$, measured E_s and f_{su} for prestressing steel.
		Branson	-6.3	
	Deflection Specimens	PBEAM	-14.2	
		Branson	-17.7	
4	No LL. Beam	PBEAM	-51.6	Pauw's E_c, ACI Comm. 209's age, creep, and shrinkage relationships, measured $(f'_c)_{28}$, measured σ-ϵ curve for prestressing steel, measured E_s and f_y for mild steel.
	0.5 LL. BEAM	PBEAM	54.6	
	1.0 LL. Beam	PBEAM	-45.1	
	1.5 LL. Beam	PBEAM, $f_r=7.5\sqrt{f'_c}$	-29.4	
	No LL. Beam	PBEAM	-48.4	Measured E_c and f'_c, ACI Comm. 209's creep and shrinkage relationships, measured σ-ϵ curve for prestressing steel, measured E_s and f_y for mild steel.
		Branson	-31.6	
	0.5 LL. Beam	PBEAM	77.3	
		Branson	54.5	
	1.0 LL. Beam	PBEAM	-24.1	
		Branson	-27.7	
	1.5 LL. Beam	PBEAM, $f_r=7.5\sqrt{f'_c}$	-26.8	
		PBEAM, $f_r=5.0\sqrt{f'_c}$	-17.7	
		Branson, $f_r=7.5\sqrt{f'_c}$	-26.4	
		Branson, $f_r=5.0\sqrt{f'_c}$	-9.8	
5	Girder 3/4	PBEAM	-23.4	Pauw's E_c, ACI Comm. 209's age, creep, and shrinkage relationships, measured $(f'_c)_{28}$, $f_r = 7.5\sqrt{f'_c}$, measured E_s, f_{sy}, and f_{su} for prestressing steel, measured f_y for mild steel.
		Branson	-31.9	

Notes: 1) The relaxation relationship for prestressing steel recommended by the P.C.I. Committee on Prestress Losses is used by the program PBEAM. The relaxation relationship recommended by Branson is used in Branson's method.

2) The superposition method is used in estimating creep strains in the program PBEAM.

In Example Problem 4, the accuracy of the analytical results is improved by using known time variations of modulus of elasticity of concrete.

The errors obtained from PBEAM for time-dependent deflections are reasonable although larger than the errors in predicting strength. From a study by ACI Committee 435 on the variability of deflections of simply supported reinforced concrete beams (4), using the deflection criteria given in ACI 381-71 under controlled laboratory conditions, it is concluded that there is approximately a 90 percent chance that the deflection of a particular beam will be within 20 percent less than to 30 percent more than the calculated value.

The analytical results from the program PBEAM are as good as or better than the analytical results from the other methods with which compared. For the methods other than the proposed method compared in this study, Branson's procedure gives the best results in general for the beams analyzed. Table 4.9 also shows the maximum errors in the change in midspan deflection as predicted by Branson's method. It should be noted that, at present, Branson's method is a hand calculation method. It is quite time-consuming to analyze the beams over the whole range of interest.

Since the program PBEAM accurately predicts the instantaneous load-deflection responses up to failure and time-dependent responses of the beams analyzed, it can be concluded that the procedure developed in this study is a valid method for analysis of both instantaneous and time-dependent responses of prestressed beams under load levels up to their ultimate loads providing that the time-dependent properties of the materials are accurately represented.

As illustrated in Table 1.1 and in the discussion above, the proposed method has other advantages over the other methods in its generality. Although it is not shown in the example problems, the program PBEAM can be used to analyze time-dependent responses of prestressed beams subjected to wider varieties of loads and support conditons than any of the other methods. In addition to the transverse load and moment analysis found in most other methods, PBEAM can treat axial loads and various linear and nonlinear support conditions. The instantaneous response analysis of a beam under axial loading, linear and nonlinear support conditions is adopted from the program developed by Hays and Matlock (38). It was verified by Hays and Matlock (38) against test data with satisfactory results. In the program PBEAM, support conditions are treated as independent of time. The time-dependent analysis for axial loads is extended from the instantaneous response analysis in the same manner as those for transverse loads and moments.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary.

A computer program called PBEAM was developed to analyze time-dependent response and strength in flexure of prestressed concrete beams. The program uses the discrete element technique and the recursive form of solution developed by Lytton and Matlock (60) and Hays and Matlock (38) in determining instantaneous responses of the beams. The step-by-step method is used in the estimation of the time-dependent responses. The time interval of interest is divided into several smaller time increments and the responses in each time increment are treated as instantaneous responses. The beams can be partially or fully prestressed, of varying cross-section, noncomposite or composite, loaded and supported in any reasonable manner. Materials may be elastic or inelastic. The program includes the effects of aging, creep, and shrinkage of concrete and relaxation of prestressing steel, and also takes into account sequences of construction and loading in the time-dependent response analysis. Both the rate of creep method and the superposition method are used in estimating creep strains of concrete under variable stresses. A method similar to the rate of creep method is used in determining relaxation stresses of prestressing steel under variable stresses. The beams can be pre-tensioned or post-tensioned, but the program analyzes only beams containing tendons that are bonded to the surrounding materials after transferring of prestressing forces.

In Chapter I, the basic problem was introduced, available methods of analysis were reviewed, and the scope and the objectives of the study were presented. Table 1.1 showed the generality of the analysis compared to some other studies. Chapter II discussed stress-strain relationships, both instantaneous and time-dependent, of concrete, reinforcing steel, and prestressing steel. The derivation of the analysis was discussed in Chapter III and Chapter IV illustrated the application of the analysis to each of the five sample problems.

The example problems in Chapter IV demonstrated the domain of validity and the application of the program develped in this study. Example Problem 1 was the analysis of load-deflection response up to failure of a two-span pre-tensioned prestressed beam with draped tendons. Example Problem 2 was the analysis of load-deflection response up to failure of a simply supported pre-tensioned prestressed composite beam. Example Problem 3 was the time-dependent response analyses of companion simply supported pre-tensioned prestressed beams, a camber specimen under its own weight and a loaded specimen. The fourth example problem was concerned with the analyses of time-dependent responses and load-deflection responses up to failure after long-term sustained loads of simply supported post-tensioned prestressed beams. Four such beams were analyzed; a camber specimen under its own weight and three specimens loaded with sustained loads of 0.5, 1.0, and 1.5 times the design service load. The beams, except the one with the sustained load of 0.5 design live load, were loaded to failure about 12 years after casting. The final example problem was the time-dependent and failure load analyses of a two-span composite beam where the girder in each span was pre-tensioned and precast individually and the deck slab was cast-in-place later to form the composite beam. The beam in the last problem was a half-scale model loaded with a sustained uniform load to compensate for its own weight. It was loaded intermittently at 1.3 times the design service load and was loaded to failure at the age of girders of about 680 days. The proposed stress-strain curve for concrete and, in some example problems (Prob. 1, Prob. 2, and part of Prob. 4), the Hognestad stress-strain curve for concrete (see p. 34 and p. 15) with the measured f'_c together with the experimental steel stress-strain curve were used in analyzing the instantaneous responses in the example problems. The relationship with time of strength, creep, and shrinkage of concrete recommended by the A.C.I. Committee 209 (2) together with the relaxation-time relationship of prestressing steel recommended by the P.C.I. Committee on Prestress Losses (67) were used in time-dependent analyses. The experimental data for time-dependent properties of concrete, where available, were also used in some cases instead of the values recommended by the A.C.I. Committee 209 (2). The analytical results for each of the example problems were compared with the measured data for actual beams or the existing analytical results.

5.2 Conclusions.

It was demonstrated in the example problems that the results of analysis utilizing the program PBEAM were in agreement with the data obtained from the measurements of the actual beams or as good as or better than the analytical results from the other methods with which compared. The PBEAM results were for the analysis of the instantaneous load-deflection responses up to failure, the time-dependent sustained load responses, and the load-deflection responses up to failure after long-term sustained load of the prestressed beams. It can be concluded that the procedure developed in this study is a valid method for analysis, subject to the assumptions and associated limitations listed in Chapter 3 (pp. 84 - 85), for both instantaneous and time-dependent responses of prestressed concrete beams under load levels up to their ultimate loads. Providing that the properties of the materials are accurately represented, the results of PBEAM were shown by the example problems to be in good agreement with the test data. Using assumed material properties based on the relationships discussed in Chapter 2, the results of PBEAM yielded less accuracy than was obtained using the measured material properties. The analytical results from PBEAM were of the same degree of accuracy as the other methods compared when subjected to this same limitation on accuracy of material data.

The proposed method has a unique advantage over the other methods in that it can analyze both time-dependent response and instantaneous load-deflection response up to failure for a prestressed beam in a single run. This is convenient in estimating load-deflection responses and strength for beams under long-term sustained loads. At present, the available methods can not treat both problems together. The proposed method has other distinct advantages over other time-dependent response analysis methods in its generality. As shown in Table 1.1 (p.11), the proposed method may be used to analyze a wide range of prestressed beams while the other methods listed are more restricted. The most general method of analysis presently available is Branson's method which is a hand calculation procedure. To obtain accuracy with Branson's method to the same degree as PBEAM results is an extremely time consuming hand calculation. The program PBEAM not only handles the wide range of analysis for beam performance summarized above, but the use of computer avoids the extremely long hand calculation for obtaining results for the time-dependent response only with Branson's method.

The capability of PBEAM to consider the cracked section in the analysis is an important feature. With the growing interest in partially prestressed concrete, the capability of PBEAM to predict the response of a cracked section to sustained loading may be an important advance in analysis over the other computer methods. Example 4 illustrated the use of PBEAM for a cracked prestressed simple beam with sustained load of 1.5 times design load. Example 5 showed its application to analysis of a 2-span composite beam which developed continuity with unstressed bars at the center support, resulting in cracking at this critical section.

From the limited number of example problems, the following conclusions can be drawn concerning the time-dependent response analysis:

1) Both the rate of creep method and the superposition method of estimating creep under variable stresses could be applied with equally good results for the prestressed beams which were loaded with the sustained load within a short period of time after transferring of the prestressing forces (Example Problem 3, camber specimens). For the prestressed beams which were loaded at some later date, the rate of creep method gave poor results (Example Problem 3, deflection specimens), while the results from the analysis using the superposition method (the program PBEAM) and a modified step function method (Branson's method) were in good agreement with the measured data (Example Problems 3, 4, and 5).

2) Acceptable results for the analysis of the time-dependent responses of the example problems were obtained by representing in PBEAM the relationships with time of strength, creep, and shrinkage of concrete by the functions recommended by the A.C.I. Committee 209, the modulus of elasticity of concrete by Pauw's expression, and the relationship with time of relaxation of prestressing steel by the expression recommended by the P.C.I. Committee on Prestress Losses (Example Problems 3, 4, and 5). The results were improved considerably by using experimental data for time-dependent properties of concrete where available (Example Problem 4).

3) The analytical results from the program PBEAM were as good as or better than those from the other methods compared. The program PBEAM, using the superposition method of predicting creep under variable stresses, predicted the

changes in midspan deflection after prestressing (for camber specimens) or after loading (for loaded specimens) for pre-tensioned beams in Example Problems 3 and 5 with a maximum error of 24% (Table 4.9). For the other methods, the best overall results were obtained by using Branson's procedure. It gave a maximum error of 32% for the beams mentioned above. For the post-tensioned beams of Example Problem 4, PBEAM results showed larger percentages of error in midspan deflection than any of the example problems (Table 4.9). The form of the predicted responses showed good agreement with the test measurements (Fig. 4.22 to Fig. 4.26). The same results and magnitude of maximum error were obtained by Branson's procedure using the same material properties.

The following conclusions can be made regarding the instantaneous load-deflection response analysis:

1) By representing the relationship of stress and "instantaneous" strain (strain caused by loading and pre-stressing excluding time-dependent strain) by the proposed stress-strain curve with the measured f'_c at the time of testing and that of steel by the experimental curve, the program PBEAM predicted load-deflection responses up to the ultimate strength for the beams analyzed in excellent agreement with the test data (Example Problems 1 and 4), and other analytical results (Example Problems 1 and 2). The use of the predicted values of f'_c at the time of testing based on the measured $(f'_c)_{28}$, using the age function recommended by the A.C.I. Committee 209, instead of the measured f'_c at the time of testing also gave the results to the same accuracy (Example Problems 4 and 5). The use of the measured values for E_c improved the accuracy of the

predictions of the responses in elastic range, but about the same responses were obtained for the load levels in inelastic range (Example Problem 4). The failure load-deflection response analysis for the underreinforced beams were not so sensitive to the same factors of uncertainty as in the time-dependent response analysis.

2) The program PBEAM predicted the failure loads in good agreement with the measured data and other analytical methods. PBEAM underestimated the ultimate applied loads by an average of 8% (Table 4.8). Using the A.C.I. Building Code (ACI 318-71) method for estimating the ultimate moment (with the reduction factor, ϕ, equal to 1 and the measured $(f'_c)_{28}$, assuming full moment redistribution for continuous members) the predicted ultimate applied loads averaged 9% lower than the test data. Using the measured cylinder strength of concrete, f'_c, at the time of testing, the A.C.I. method underestimated the ultimate applied loads by an average of 6%. While the A.C.I. Code may give similar accuracy in predicting failure load, it does not give the load-deflection response and ultimate deflection which are obtained with PBEAM. The strength prediction is shown to be more accurate than time-dependent response prediction.

3) The effective moment of inertia method gave good predictions of load-deflection responses for beams subjected to low load levels after cracking. For high load levels where the reinforcing steel yields, the effective moment of inertia method overestimated the stiffnesses of the members analyzed.

5.3 Recommendations for Further Research.

In addition to the types of problems used as the example problems, the program may be used to study the following:

1) The effects of various material properties, both instantaneous and time-dependent, on the behavior of prestressed concrete beams.

2) The instantaneous and time-dependent effects of possible sequences of loading and construction.

3) Nonlinearity of both concentrated and distributed supports.

4) The instantaneous and time-dependent behaviors of conventional reinforced concrete beams and beams of other materials besides concrete.

5) The effects of additional nonprestressed reinforcement on the behavior of prestressed concrete beams.

The program was written to analyze time-dependent response and failure load response of prestressed beams in general. For a particular type of problem, such as computing response of an elastic beam, the program may not be efficient to use. The program could be modified to reduce the computer storage requirements and computational time for such limited problems which do not require the full generality of the program.

REFERENCES

1. ACI Committee 209, ACI Annotated Bibliography No. 7: Shrinkage and Creep in Concrete, American Concrete Institute, Detroit,1967.

2. ACI Committee 209, "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structure," Designing for Effects of Creep Shrinkage Temperature in Concrete Structures, SP-27, American Concrete Institute, Detroit, 1971.

3. ACI Committee 318, Building Code Requirements for Reinforced Concrete (ACI 318-71), American Concrete Institute, Detroit, 1971.

4. ACI Committee 435, "Variability of Deflections of Simply Supported Reinforced Concrete Beams," ACI JOURNAL, Proceedings V. 69, No. 1, Jan. 1972.

5. Ali, I. and Kesler, C. E., "Rheology of Concrete, A Review of Research," Engineering Experiment Station, University of Illinois, Bulletin 476, V. 62, No. 68, Mar. 1965.

6. Arutyunyan, N. Kh., Some Problems in the Theory of Creep, Pergamon Press, London, 1966.

7. Atkins, W. D., "A Generalized Numerical Solution for Prestressed Concrete Beams," unpublished Master's thesis, The University of Texas, Austin, Texas, Aug. 1965.

8. Bazant, Z. P., "Prediction of Concrete Creep Effects Using Age-Adjusted Effective Modulus Method," ACI JOURNAL, Proceedings V. 69, No. 4, Apr. 1972.

9. Bertero, V. V. and Felippa, C., Discussion of the paper by Roy, H. E. H. and Sozen, M. A., "Ductility of Concrete," Proceedings of the International Symposium on Flexural Mechanics of Reinforced Concrete, ASCE-ACI, Miami, Nov. 1964.

10. Branson, D. E., Deformation of Concrete Structures, McGraw-Hill, New York, 1977.

11. Branson, D. E., "The Deformation of Noncomposite and Composite Prestressed Concrete Members," Deflections of Concrete Structures, SP-43, American Concrete Institute, Detroit, 1974.

12. Branson, D. E., "Time-Dependent Effects in Composite Concrete Beams," ACI JOURNAL, Proceedings V. 61, Feb. 1964.

13. Branson, D. E. and Christiason, M. L., "Time-Dependent Concrete Properties Related to Design--Strength and Elastic Properties, Creep and Shrinkage," Designing for Effects of Creep Shrinkage Temperature in Concrete Structures, SP-27, American Concrete Institute, Detroit, 1971.

14. Branson, D. E., Meyers, B. L., and Kripanarayanan, K. M., "Time-Dependent Deformation of Noncomposite and Composite Prestressed Concrete Structures," Highway Research Record No. 324, Symposium on Concrete Deformation, Washington, D. C., 1970.

15. Branson, D. E. and Ozell, A. M., "Camber of Prestressed Concrete Beams," ACI JOURNAL, Proceedings V. 32, June 1961.

16. Breckenridge, R. A., Valent, P. J., and Bugg, S. L. , "Effects of Long-Term Loads of Prestressed Concrete Beams," Technical Report R 518, U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, Mar. 1967.

17. Bugg, S. L., "Long-Term Creep of Prestressed Concrete I-Beams," Technical Report R 212, U.S. Naval Civil Engineering Laboratory, Port Hueneme, California, Oct. 1962.

18. Chang, D.C., "Behavior of Multipanal Reinforced Concrete Frames Subjected to Vertical and Lateral Loads," published Ph.D. Dissertation, The University of Texas, Austin, May, 1977.

19. Chang, D. C., "A Numerical Method of Analyzing Composite Prestressed Concrete Members," unpublished Master's thesis, The University of Texas, Austin, Texas, May 1969.

20. Corley, W. G., Sozen, M. A., and Siess, C. P., "Time-Dependent Deflections of Prestressed Concrete Beams," Bulletin No. 307, Highway Research Board, Washington, D. C., 1961.

21. Davies, R. D., "Some Experiments on the Applicability of the Principle of Superposition to the Strains of Concrete Subjected to Changes of Stress, with Particular Reference to Prestressed Concrete," Magazine of Concrete Research (London), V. 9, No. 27, Nov. 1957.

22. Desayi, P. and Krishnan, S., "Equation for the Stress-Strain Curve of Concrete," ACI JOURNAL, Proceedings V. 61, Mar. 1964.

23. Drysdale, R. G., "The Behaviour of Slender Reinforced Concrete Columns Subjected to Sustained Biaxial Bending," Ph.D. Thesis, University of Toronto, 1967.

24. Dutron, R., "Creep in Concrete," RILEM Bulletin (Paris), No. 34, 1957.

25. England, G. L. and Illston, J. M., "Methods of Computing Stress in Concrete from a History of Measured Strain," Civil Engineering and Public Works Review (London), V. 60, Part 1, 2 and 3, Apr., May, and June, 1965.

26. Erzen, C. Z., "Expression for Creep and Its Application to Prestressed Concrete," ACI JOURNAL, Proceedings V. 53, Aug. 1956.

27. Fadl, A. I. and Gamble, W.L., "Time-Dependent Behavior of Noncomposite and Composite Post-tensioned Concrete Girder Bridges," University of Illinois Engineering Experiment Station, Structural Research Series No. 430, Oct. 1976.

28. Fadl, A. I., Gamble, W. L., and Mohraz, B., "Tests of a Precast Post-tensioned Composite Bridge Girder Having Two Spans of 124 Feet," University of Illinois Engineering Experiment Station, Structural Research Series No. 439, Apr. 1977.

29. Friedrich, E., "On the Shrinkage and Creep of Concrete (Uber das Schwinden und Kriechen des Betons)," Osterreichische Bauzeitschrift, V. 5, No. 8, Aug. 1950.

30. Glodowski, R. J. and Lorenzetti, J. J., "A Method for Predicting Prestress Losses in a Prestressed Concrete Structure," PCI JOURNAL, V. 17, No. 2, Mar.-Apr. 1972.

31. Goral, M. L., "Empirical Time-Strength Relationships of Concrete," ACI JOURNAL, Proceedings V. 53, Aug. 1956.

32. Grouni, H. N., "Prestressed Concrete--A Simplified Method for Loss Computation," ACI JOURNAL, Proceedings V. 70, No. 2, Feb. 1973.

33. Hamada, H. S., Watari, J. T., and Chiu, S. N. L., "Creep and Shrinkage of Concrete Made from Hawaiian Aggregated," Technical Report CE71-R2, Civil Engineering Department, University of Hawaii, Honolulu, Feb. 1972.

34. Hansen, T. C. and Matlock, A. H., "Influence of Size and Shape of Member on the Shrinkage and Creep of Concrete," ACI JOURNAL, Proceedings V. 63, No. 2, Feb. 1966.

35. Hansen, T. C. and Nielsen, K. E. C., "Influence of Aggregate Properties on Concrete Shrinkage," ACI JOURNAL, Proceedings V. 62, July 1965.

36. Hawkins, N. M., Sozen, M. A. and Siess, C. P., "Strength and Behavior of Two-Span Continuous Prestressed Concrete Beams," University of Illinois Engineering Experiment Station, Structural Research Series No. 225, Sept. 1961.

37. Hays, C. O. and Matlock, H., "Linear Elastic Analysis of Statically Loaded Plane Frames Using a Discrete Element Model," Research Report No. 56-21, Center of Highway Research, The University of Texas, Austin, Texas, June 1971.

38. Hays, C. O. and Matlock, H., "A Nonlinear Analysis of Statically Loaded Plane Frames Using a Discrete Element Model," Research Report No. 56-23, Center of Highway Research, The University of Texas, Austin, Texas, May 1972.

39. Hernandez, H. D. and Gamble, W. L., "Time-Dependent Prestress Losses in Prestressed Concrete Construction," University of Illinois Engineering Experiment Station, Structural Research Series No. 417, May 1975.

40. Hilderbrand, F. B., Introduction to Numerical Analysis, McGraw-Hill, New York, 1956.

41. Hognestad, E., "A Study of Combined Bending and Axial Load in Reinforced Concrete Members," University of Illinois Engineering Experiment Station, Bulletin Series No. 399, Nov. 1951.

42. Hognestad, E., Hanson, N. W., and McHenry, D., "Concrete Stress Distribution in the Ultimate Strength Design," ACI JOURNAL, Proceedings V. 52, Dec. 1955.

43. Huang, T., "Direct Method for Estimating Prestress Losses," National Research Council, Concrete and Steel Bridges, Transportation Research Record No. 547, 1975.

44. Illston, J. M., "Components of Creep in Mature Concrete," ACI JOURNAL, Proceedings V. 65, No. 3, Mar. 1968.

45. "Investigation of Creep in Concrete; Review of Literature on Creep in Concrete," U. S. Army Engineer Waterway Experiment Station, Corps of Engineers, Vicksberg, Miss., Miscellaneous Paper No. 6-132, Report No. 1, June 1955.

46. Iqbal, M. and Hatcher, D. S., "Post-Crushing Behavior of Unbonded Concrete Beams," Proceedings, ASCE, V. 101, No. ST11, Nov. 1975.

47. Kabaila, A., Discussion of the Paper by D. Desayi and S. Krishman, "Equation for the Stress-Strain Curve of Concrete," ACI JOURNAL, Proceedings V. 61, Sept. 1964.

48. Kajfasz, S., "Some Relaxation Tests on Prestressing Wire," Magazine of Concrete Research (London), V. 10, No. 30, Nov. 1958.

49. Kajfasz, S. and Szulc, J., "Approximation of Experimental Data by a Creep Function," RELIM, Matériaux et Constructions V. 3 , No. 18, 1970.

50. Keenan, W. A., Brink, F. E., Priniski, G. S., and Breckenridge, R. A., "Strength of Prestressed Concrete Beams After 12 Years of Live Load," Technical Report R658, Naval Civil Engineering Laboratory, Port Hueneme, California, Feb. 1970.

51. Kent, D. C. and Park, R., "Flexural Members with Confined Concrete," Proceedings, ASCE, V. 97, No. ST7, July 1971.

52. Khalifa, S., "A Study of the Effect of Age on the Elastic Properties of Stressed and Unstressed Plain Concrete," Ph.D. Thesis, University of Toronto, 1967.

53. Kingham, R. I., Fisher, J. W., and Viest, I. M., "Creep and Shrinkage of Concrete in Outdoor Exposure and Relaxation of Prestressing Steel," Special Report No. 66, AASHO Road Test Technical Staff Papers, Ottawa, 1961.

54. Kriz, L. B. and Lee, S. L., "Ultimate Strength of Over-Reinforced Beams," Proceedings, ASCE, V. 86, No. EM3, June 1960.

55. Lee, L. N. H., "Inelastic Behavior of Reinforced Concrete Members," Transactions, ASCE, V. 120, 1955.

56. Liebenberg, A. C., "A Stress-Strain Function for Concrete Subjected to Short Term Loading," Magazine of Concrete Research (London), V. 14, No. 41, July 1962.

57. Lo, Y., "Comparison of Analytical and Measured Performance of Pretensioned Prestressed Concrete Beams," unpublished Master's report, The University of Texas, Austin, Texas, June 1975.

58. Lorman, W. R., "The Theory of Concrete Creep," ASTM, Proceedings V. 40, 1940.

59. Lyse, I., "Shrinkage and Creep of Concrete," ACI JOURNAL, Proceedings V. 56, Feb. 1960.

60. Lytton, R. L., "A General Numerical Solution for the Mechanics of Beams," unpublished Master's thesis, The University of Texas, Austin, Texas, Aug. 1961.

61. Magura, D. D., Sozen, M. A. and Siess, C. P., "A Study of Stress Relaxation in Prestressing Reinforcement," PCI JOURNAL, V. 9, No. 2, Apr. 1964.

62. Mattock, A. M., "Precast-Prestressed Concrete Bridges 5., Creep and Shrinkage Studies," Bulletin No. 46, PCA Research and Development Laboratories, Skokie, Illinois, May 1961.

63. McHenry, D., "A New Aspect of Creep and Its Application to Design," Proceedings, ASTM, V. 43, 1943.

64. Mossiosian, V. and Gamble, W. L., "Time-Dependent Behavior of Noncomposite and Composite Prestressed Concrete Structures under Field and Laboratory Conditions," University of Illinois Structural Research Series No. 385, May 1972.

65. Neville, A. M., Creep of Concrete: Plain, Reinforced, and Prestressed, North Holland Publishing Company, Amsterdam, 1970.

66. Pauw, A., "Static Modulus of Elasticity of Concrete as Affected by Density," ACI JOURNAL, Proceedings V. 57, Dec. 1960.

67. PCI Committee on Prestress Losses, "Recommendation for Estimating Prestress Losses," PCI JOURNAL, V. 20, No. 4, July-Aug. 1975.

68. Pierce, D. M., "A Numerical Method of Analyzing Prestressed Concrete Members Containing Unbonded Tendons," Ph.D. Dissertation, The University of Texas, Austin, Texas, June 1968.

69. Plowman, J. M., "Maturity and Strength of Concrete," Magazine of Concrete Research (London), V. 8, No. 24, Nov. 1956.

70. Podolny, W., Jr. and Melville, T., "Understanding the Relaxation in Prestressing," PCI JOURNAL, V. 14, No. 4, Aug. 1969.

71. Popovics, S., "A Review of Stress-Strain Relationships for Concrete," ACI JOURNAL, Proceedings V. 67, No. 3, Mar. 1970.

72. Rao, V. J. and Dilger, W. H., "Time-Dependent Deflections of Composite Prestressed Concrete Beams," Deflection of Concrete Structures, SP-43, American Concrete Institute, Detroit, 1974.

73. Ross, A.D., "Creep and Shrinkage in Plain, Reinforced, and Pre-Stressed Concrete: A General Method of Calculation," Institution of Civil Engineers, V. 21, No. 1, 1943.

74. Ross, A. D., "Concrete Creep Data," The Structural Engineer (London), V. 15, No. 8, 1937.

75. Ross, A. D., "Creep of Concrete under Variable Stress," ACI JOURNAL, Proceedings V. 54, Mar. 1958.

76. Saenz, L. P., Discussion of the paper by P. Desayi and S. Krishnan, "Equation for the Stress-Strain Curve of Concrete," ACI JOURNAL, Proceedings V. 61, Sept. 1964.

77. Saliger, R., Uber neue Theorie des Stahlbetons, Vienna, Franz Deuticke, 1947.

78. Sargin, M., "Stress-Strain Relationships for Concrete and the Analysis of Structural Concrete Sections," Study No. 4, Solid Mechanic Division, University of Waterloo, Waterloo, Ontario, Canada, 1971.

79. Schwier, F., "Wires and Bars for Prestressed Concrete," RILEM Symposium on Special Reinforcements for Reinforced Concrete and on Prestressing Reinforcements, Liege, Belgium, 1958.

80. Shank, J. R., "The Mechanics of Plastic Flow of Concrete," ACI JOURNAL, Proceedings V. 32, 1936.

81. Sinno, R. and Furr, H. L., "Computer Program for Predicting Prestress Loss and Camber," PCI JOURNAL, V. 17, No. 5, Sept.-Oct. 1972.

82. Soliman, M. T. M. and Yu, C. W., "The Flexural Stress-Strain Relationship of Concrete Confined by Rectangular Transverse Reinforcement," Magazine of Concrete Research (London), V. 19, No. 61, Dec. 1967.

83. Straub, L. G., "Plastic Flow in Concrete Arches," Transactions, ASCE, V. 95, 1931.

84. "Système International de Réglementation Technique Unifiée des Structures Volume II - Code Modele Pour les Structures En Béton (3 ème Project; Version Originale), " Bulletin D'Information, No. 117-F, Comíte Euro-International Du Béton, Paris, Dec. 1976.

85. Tudros, M. K., Ghali, A, and Dilger, W. H., "Time-Dependent Prestress Loss and Deflection in Prestressed Concrete Members," PCI JOURNAL, V. 20, No. 3, May-June 1975.

86. Thomas, F. G., "Concept of Creep of Unreinforced Concrete and an Estimation of the Limiting Values," The Structural Engineer (London), V. 11, No. 2, 1933.

87. Troxell, G. E., Raphael, J. M., and Davis, R. E., "Long Time Creep and Shrinkage Tests of Plain and Reinforced Concrete," Proceedings, ASTM, V. 58, 1958.

88. Tulin, L. C. and Gerstle, K. H., Discussion of the paper by D. Desayi and S. Krishnan, "Equation for the Stress-Strain Curve of Concrete," ACI JOURNAL, Proceedings V. 61, Sept. 1964.

89. Wallo, E. M. and Kesler, C. E., "Prediction of Creep in Structural Concrete," Engineering Experiment Station, University of Illinois, Bulletin 498 V. 66, No. 39, Nov. 1968.

90. Washa, W. G. and Wendt, K. F., "Fifty Year Properties of Concrete," ACI JOURNAL, Proceedings V. 72, No. 1, Jan. 1975.

91. Wawaruck, J., Sozen, M. A., and Siess, C. P., "Strength and Behavior in Flexural of Prestressed Concrete Beams," University of Illinois Engineering Experiment Station, Bulletin No. 464, Aug. 1962.

92. Wu, H., "The Effect of Volume/Surface Ratio on the Behaviour of Reinforced Concrete under Sustained Loading," Ph.D. Thesis, University of Toronto, 1973.

93. Young, L. E., "Simplifying Ultimate lexural Theory by Maximizing the Moment of the Stress Block," ACI JOURNAL, Proceedings V. 57, Nov. 1960.

94. Zundelevich, S., Lee, D. L. N., and Chiu, A. N. L., "Camber and Deflection Behavior of Prestressed Concrete Beams," Technical Report CE71-R1, Civil Engineering Department, University of Hawaii, Honolulu, Hawaii, Sept. 1971.

A P P E N D I X   A

INPUT AND OUTPUT DETAILS

Input and output of the program PBEAM are printed out in the form of tables. Table 1 to Table 5C are echo print-outs of the input data. The rest of the tables (Table 6 to Table 9) give the solution output which are printed out at every specified time increment. Further information and the format of the input data will be presented in Appendix B. The following is the detail of the tables printed out.

INPUT TABLES.

Identification of Run: Two cards are needed for each run to identify the run. They can be of any alphanumerics up to 80 characters per cards.

Identification of Problem: One card for each problem is required to identify the problem. In the first five columns of the card (column 1 to column 5), the characters START or CEASE are needed. The characters START mark the beginning of the data of a new problem. The program will stop execution if the characters CEASE are specified instead of START.

If there are any errors in the input data or the solutions fail to converge, the program will be terminated and an appropriate message will be printed out to indicate the first error found or the nonconvergence of the problem. The program will continue to search for the characters START or CEASE in the first five columns of the input data and execute accordingly.

Table 1, Program Control Data: Two cards are needed in this table to input the problem type, hold options for input tables, output table options, number of cards added in each input table for this problem, and a solution option. One of the four types of problems: 12, 2, 13, and 3 may be specified. In Type 12 and Type 2 problems, the program uses the rate of creep theory in determining creep strains. The superposition theory is used in Type 13 and Type 3 problems. Type 12 and Type 13 problems are the first problems of the series of Type 2 and Type 3. Type 2 and Type 3 problems may use the information from the previous problems through the hold options. All problems start with zero displacements.

If 1 is encountered in any of the hold options of the input tables, the data in the corresponding tables, will be saved from the previous problem. Data added in this problem will be accumulated. The hold option for Table 5A, Applied Load Table, may be set equal to 2 if loads in the table are desired to be increased from the previous problem by specified percentages. Output tables may be suppressed by entering 1 in the corresponding output options. There are two types of the solution options, 0 for which the large angle theory will be used in estimating fiber strains, and 1 for which the small angle theory will be used instead.

Table 2, Time Increment and Iteration Control Data: Two arrays of time increments are input; time increments for calculation of time-dependent responses and time increments at which solution outputs need to be printed out. The program will divide time intervals of interest into smaller time increments at the specified time increments and at the time increments just before adding loads for time-dependent response calculation purposes. Note that the program will skip the time-dependent response calculation at the time increment which is less than 1.00101 times the latest time increment. Solution outputs will be printed out at the first time increments that are equal to or larger than those specified. Time increments must be less than 1.0×10^{50} units of time.

Ad additional card is needed to input a maximum number of cycles in which member cracks are frozen, a maximum number of iterations in each cycle, an iteration output option for Table 6, closure tolerances for force and moment equilibrium errors, and maximum force and moment equilibrium errors. The maximum number of cycles in which member cracks are frozen is input to aid the convergence of the solution where loading is within the capacity of the member but the member has extensive cracking. The specified number of three or four cycles should be adequate for most problems. The maximum number of iterations and the maximum equilibrium errors are specified to stop the iteration process if the number of iterations is excessive or the equilibrium errors are so large that there is no chance that the solution will converge. The program solves an equilibrium position of a member under loading conditions iteratively. The equilibrium position is assumed to be obtained if the solution converges, i.e. nodal point equilibrium errors are within the specified tolerances. The solution usually converge within five to ten iterations. In some cases, such as with a large load increment, the solution converges very slowly or may not converge at all. If the solution does not converge within the specified maximum number of iterations in any cycle or the equilibrium errors, the program will skip the rest of the problem and search for a new independent problem. The solution output of the last time increment will be printed out with messages indicating the nonconvergence of the solution. The solution obtained is not correct but it is printed out to help in locating the sources of the divergence.

Iteration output in Table 6 may be controlled through the iteration output option. If the iteration output is equal to 0, no iteration output will be printed out. If it is equl to 1, partial iteration output will be printed out. And if it is equal to 2, full iteration output will be printed out.

Table 3A, Material Properties: Material properties are given in this table. A card is needed to specified the number of materials input in this problem. A set of at least two cards is needed for each material. The first card of the set gives material number, relaxation indicator, stress-strain curve number, age function number, creep or relaxation function number, shrinkage function number, and unit weight of the material. The second card specifies modulus of elasticity of the material if it is elastic material or stress and strain multiplers if the material is inelastic material, and strain limits. At least an additional card is needed for each of the age function, the creep function or the relaxation function, and the shrinkage function specified to input the coefficients of the functions or the curves defining the functions.

A material may be specified more than once in a problem, but the latest values will be recorded. The relaxation indicator and the stress-strain curve number are input to specify types of time-dependent response and instantaneous response under stresses of the material, respectively. The information about the material are then input accordingly. All of the time-dependent response functions of materials included in the program are listed in Appendix B. For the built-in functions, only their coefficients need to be input. If different functions are required, they can be easily included in the program in the appropriate subroutines. Spaces are provided for that purpose. They may also be input as linearly piecewise curves as illustrated in Appendix B.

Stress-strain relationship of a material can be given either in form of modulus of elasticity or as a stress-strain curve. Integer stress-strain curves are defined in Table 3B. The actual stress-strain curve of the material is the product of the integer stress-strain curve and the stress multiplier and the strain multiplier for that material. The multipliers are subjected to the correction due to aging effects, if applicable. Strain limits are specified as the cut-off points of the stress-strain relationship. Material undergoes an instantaneous strain exceeding its maximum strain limit fails in tension and material that is subjected to instantaneous compressive strain more than its minimum strain limit fails in compression.

The unit weight of the material is input for the convenience of the user of the program. The gravity load will be automatically included in the calculation if the unit weight of the material is input.

Table 3B, Stress-Strain Curves: Stress-strain curves, referred to in Table 3A, are given in this table. A stress-strain curve is input as series of integer stress values and corresponding integer strain values. The integer stress-strain curves are multiplied by stress and strain multipliers to obtain the actual stress-strain relationships of the materials at the required stages. The multipliers are subjected to the correction due to aging effects of the materials, if applicable.

The proposed stress-strain curve (p. 34), or the Hognestad stress-strain curve for concrete may be generated internally within the program. By inputting some control points, a twelve integer point stress-strain curve will be generated accordingly. The curve is exact, i.e., it is equal to the proposed or the Hognestad curve, at these twelve integer points. The rest of the curve is composed of straight lines connecting between consecutive points on the curve.

Table 4, Cross-Section Properties: The first card of Table 4 inputs a number of elements of the member and the length of the member. This card is skipped for continuing problems (type 2 or Type 3 problems). The member is subdivided into discrete elements in the calculation. The more the number of elements, the more accurate the solution will be but it will involve a larger amount of computation. For most problems, the number of elements equal to twenty will yield satisfactory result.

Geometry and cross-section properties of a member are input as sub-rectangles. A sub-rectangle is composed of a material, rectangular in cross-section with its width, depth, centroidal distance, and initial strain constant or vary along its length. Material properties are defined in Table 3A and Table 3B. Widths, depths, centroidal distances, and initial strains are input at specified points along the member length, and the program will linearly interpolate the values between the points. If desired, by inputting some key values, straight or parabolic variations of widths, depths, and centroidal distances of sub-rectangles may be generated by the program. A sub-rectangle may be subdivided vertically into smaller fibers for calculation purposes by specifying the number of vertical divisions required.

Three types of times are specified in association with a sub-rectangle; casting time, time when the sub-rectangle is added to the structure, and time when the sub-rectangle can carry loads. The casting time of the material is used as a reference in estimating aging and creeping effects of the sub-rectangle, i.e. age of the sub-rectangle starts at that time. The gravity load of the sub-rectangle is added to the structure at the time when the sub-rectangle is added to the structure. All of the fibers in the sub-rectangle have zero deformations and start shrinking just before the time when the sub-rectangle can carry loads.

A sub-rectangle (e.g. a prestressing tendon) may be pretensioned or post-tensioned. For a pre-tensioned tendon, initial strain of the tendon, the pre-tensioned strain just before transfer, which may be constant or vary, is specified. For a post-tensioned tendon, tendon profile, wobble friction coefficient, curvature friction coefficient, sequences and magnitudes of end jacking forces just after transfer for the tendon are specified. Post-tensioning force after transfer will be estimated by deducting friction losses as computed by the expression recommended by the A.C.I. Code (3). Post-tensioning force after transfer for a post-tensioned tendon, which may be constant or vary, may also be specified at points along the length of the tendon, if desired. All of the pre-tensioned tendons are bonded to the rest of the structure before transfer and all of the post-tensioned tendons are bonded to the rest of the structure after transfer.

Table 5A, Applied Loads: External loads may be applied in any of the three directions: the x-direction, the y-direction, and the z-direction. Gravity loads have already been included by specifying appropriate material unit weights. External loads may be input as distributed loads or concentrated loads. Distributed loads may be constant or vary along the length of the member. A set of distributed loads is input by specifying the magnitudes and the directions of loads at points along the length of the member. They are assumed to be linearly distributed between the consecutive points from the first point to the last point of the set. Both of the distributed loads and the concentrated loads are additive and may be applied at any time after the structure has gained enough strength to carry the loads.

Table 5B, Spring Restraints: Member spring restraints are specified in this table. As in Table 5A, Applied Loads, spring restraints may be input as sets of distributed spring restraints or point spring restraints in any of the three directions. Spring restraints may be linear or nonlinear. For linear spring restraints, spring constants are input. For nonlinear spring restraints, q-w (force-displacement) curve numbers, q-multipliers, and w-multipliers are specified. The integer q-w curves will be defined in Table 5C. The actual q-w curves at specified points will be generated by the program when needed by multiplying the integer q-w curves with the corresponding q-multipliers and w-multipliers.

Member nodal points may be forces to deflect specified amounts by specifying large spring restraints and forces equal to the products of the required deflections and the negative of the spring constants in the desired directions at those nodal points. Forces must be greater than 1.0×10^{30} force units so that the program recognizes the specified deflections and skips the equilibrium check at those locations since the equilibrium check at the specified deflections is invalid. Caution should also be made in specifying large member spring restraints, they should be exactly at member nodal points or undesirable effects will be obtained.

Table 5C, Nonlinear Support Curves (q-w Curves): Table 5C gives member q-w curves. The integer q-w curves are input using the same format as the integer stress-strain curves in Table 3B. Note that stable q-w curves have q-values in the opposite directions of the w-values, i.e. q-values and w-values have opposite signs.

OUTPUT TABLES.

Solution output will be printed out at the time increments that are equal to or the closest time increments that are larger than those specified in Table 2. For the time increments which solutions are printed out, iteration data, member results, fiber strains, and fiber stresses are given. Some or all of the output tables may be suppressed according to Table 1, Program Control Data. The details of the output tables are presented below.

Table 6, Iteration Data: For each iteration, nodal point displacements and equilibrium errors will be given. The errors will be less than the corresponding specified tolerance limits if the solutions converge. The errors in a divergent solution will be greater than the limits set. The results of the divergent solution will not be correct. Partial iteration data may be obtained by specifying in Table 2. For partial iteration data, only displacements and equilibrium errors at the second, the center line, and the next to last stations will be given. The sign convention used in the table will be the same as previously used.

Messages will be given in the table if the solution does not converge, nodal point displacements are off the q-w curves for nonlinear spring restraints, or instantaneous strains are off the stress-strain curves for nonlinear materials.

Table 7, Member Results: Member results are given in Table 7. Member displacements, reactions, and forces are listed at nodal points of the member. Displacements and reactions are given in the x-direction, the y-direction, and the z-direction. For member forces, axial forces, shear forces, and bending moments will be printed out. Ordinary beam sign convention will be used, i.e. axial forces are tension if they are positive, positive shear forces have positive shear forces at the left sides of the sections, and positive bending moments cause compression at the top fiber of the beam.

Table 8, Fiber Strains: The information about strain levels for every fiber is given in this table. For each of the fibers, shrinkage strains, creep or relaxation strains, instantaneous strains, and strain indicators will be printed out. Positive strains are elongational strains. Normal shrinkage strains will have negative sign and creep or relaxation strains of a fiber are of the same signs of those of the instantaneous strains in the fiber. If a material does not exhibit time-dependent response, zero strains will be listed in the corresponding time-dependent strains. The strain indicators reflect the history of strain levels of the fibers up to the current time increment. The indicator 111 shows that the fiber has never been strained exceeding its failure limits, the indicator 222 indicates that the fiber was strained exceeding its tensile limit, and the fiber was strained exceeding its compressive limit if its strain indicator is 333.

Table 9, Fiber Stresses: Stress levels in every fiber are given in Table 9. Stress levels printed are generated from the instantaneous strains and the strain indicators shown in Table 8 since the fiber stresses are not stored by the program. Positive stresses are tensile stresses and negative stresses are compressive stresses. Zero stresses will be listed if the fiber does not exist, the fiber failed in tension and is subjected to tensile strain, or the fiber failed in compression.

A P P E N D I X   B

DATA INPUT GUIDE

GENERAL PROGRAM NOTES

The data cards must be stacked in proper order for the program to run. Blanks will be intepreted as zeros.

The units of force, distance, and time must be consistent throughout the problem. The units of force, distance, and time are indicated below all dimensional input as (f), (d), and (t), respectively.

Integers are all in I-FORMAT.

Floating-point decimal numbers are all in E-FORMAT.

All numbers must be right justified.

All of the input curves are defined by points along the curves. For a curve, at least two points must be specified. The points must be input in such a way that their abscissas are in algebraically increasing order. The program generates the curve when needed by linearly connecting the consecutive points. The curve is extended indefinitely beyond its ends at the slopes the same as the end slopes of the curve, or otherwise indicated.

INPUT DATA

IDENTIFICATION OF RUN (two alphanumeric cards per run)

1 80

1 80

IDENTIFICATION OF PROBLEM (one alphanumeric card per problem)

Prob. No.	Description of Problem (Alphanumeric)
*	

1 5 10 80

* Use START for starting a new problem, CEASE for stopping the program.

TABLE 1, PROGRAM CONTROL DATA (two cards per problem)

Prob. Type	Hold Options for Tables 2 Through 5C							Output Options for Tables 6 Through 9			
	2	3A	3B	4	5A	5B	5C	6	7	8	9
1–5	10	15	20	25	30	35	40	45	50	55	60

No. of Cards in Tables 2 Through 5C							
2	3A	3B	4	5A	5B	5C	ISMALL
6–10	15	20	25	30	35	40	45

Type 12 and Type 2 problems use the rate of creep theory in estimating creep strains.

Type 13 and Type 3 problems use the superposition theory in estimating creep strains.

Type 12 and Type 13 problems are the first problems of the series of Type 2 and Type 3 problems, respectively. Type 2 and Type 3 problems may use the information from the previous problems through the hold options.

All problems start with zero displacements.

Enter 1 in each of the hold options to hold prior data in the corresponding tables. New data are accumulated in Tables 1 through 5C until the corresponding hold options are left blank, where only the new data are kept.

Hold option for Table 5A may be input as 2 to increase member loads by percentages. The increasing percentages are specified in Table 5A.

With Type 12 and Type 13 problems, no data may be held from the previous problems.

Enter 1 in output options to suppress output for the corresponding tables.

ISMALL = solution option.

ISMALL = 0 : large-angle solution.

ISMALL = 1 : small-angle solution.

TABLE 2, TIME INCREMENTS AND ITERATION CONTROL DATA (number of cards per Table 1)

NTIME	NPRIN	Beginning Time Increment	Final Time Increment
1–5	5–10	(t) 10–20	(t) 20–30

TIMEls, Time Increments for Calculating Time-Dependent Responses, 8 per Card

(t) 1–10	(t) 10–20	(t) 20–30	(t) 30–40	(t) 40–50	(t) 50–60	(t) 60–70	(t) 70–80

TPRINTs, Time Increments for Printing Out Solution, 8 per Card

(t) 1–10	(t) 10–20	(t) 20–30	(t) 30–40	(t) 40–50	(t) 50–60	(t) 60–70	(t) 70–80

MIDS5	MNITM	MB	Closure Tolerances Force	Closure Tolerances Moment	Max. Equilibrium Errors Force	Max. Equilibrium Errors Moment
1–5	5–10	10–15	(f) 21–30	(f-d) 30–40	(f) 40–50	(f-d) 50–60

Total number of time increments in each time array must not exceed 50.

NTIME and NPRIN are the numbers of TIME1s and TPRINTs added in this problem, respectively.

The structure is assumed to be loaded or prestressing at or after the beginning time increment. Loads or prestressing forces applied before the beginning time increment will be accumulated and applied at the beginning time increment.

The problem will be stopped when the time increment is equal to or greater than the final time increment.

Time increments when new sub-rectangles are added and additional loads are applied are also kept in TIME1 array, spaces must be provided for them.

Solution will be printed out for the first time increments that are equal to or larger than those specified in TPRINT array.

Time increments must be less than 1.0×10^{50} units of time. Repeating time increments are disregard.

TIME1 or TPRINT card is skipped if the corresponding NTIME or NPRIN is equal to zero.

MIDS5, number of iterative cycles in which member cracks are frozen, must be greater than 0. MIDS5 of 3 or 4 should be adequate for most problems where members crack extensively.

MNITM = maximum number of iterations in a iterative cycle.

Iteration process will be stopped when:

(1) The solution converges, i.e. the equilibrium errors are within the closure tolerances.

(2) The solution diverges, i.e. the equilibrium errors are greater than the maximum equilibrium error limits or the number of iteration is greater than MNITM.

MB = iteration output for Table 6, Iteration Data. No, partial, or full iteration data output will be printed out for MB equal to 0, 1, or 2, respectively.

TABLE 3A, MATERIAL PROPERTIES (number of cards per Table 1)

MATER
1 5

MATER = number of materials specified in this problem. The following set of cards is needed for each material.

The first card of the set is:

Mat. No.	IRELA	NSS	NEQA	NEQC	NEQS	Unit Weight
1 5	10	15	20	25	30	(f/d^3) 40

The following cards are needed according to the conditions specified in the first card of the set.

If NSS, stress-strain curve number for the material, is equal to 0, the material is elastic. A card is needed to define its modulus of elasticity, maximum strain limit, and minimum strain limit.

Modulus of Elasticity		Strain Limits: Maximum	Strain Limits: Minimum
1 (f/d^2) 10		21 (d/d) 30	(d/d) 40

If NSS is greater than 0, the material is inelastic. A card is needed to define its stress-multiplier, strain multiplier, maximum strain limit, and minimum strain limit. The specified stress-strain curve must be defined in Table 3B.

Multipliers: Stress	Multipliers: Strain	Strain Limits: Maximum	Strain Limits: Minimum
1 (f/d^2) 10	(d/d) 20	(d/d) 30	(d/d) 40

If NEQA, age function number for the material, is from 1 to 10, internally provided age function is used for the material. A card is needed to input coefficients for the function.

A(1) - A(8), Coefficients for Age Function

1 – 10	20	30	40	50	60	70	80

If NEQA is greater than 10, age function for the material is defined by two curves, ratios of stresses at different ages/stress at standard age VS. time curve and ratios of strains at different ages/strain at standard age VS. time curve.

A(1) - A(8), Ratios of Stresses at Different Ages/Stress at Standard Age

1 – 10	20	30	40	50	60	70	80

AT(1) - AT(8), Ages of Material

1 (t) 10	(t) 20	(t) 30	(t) 40	(t) 50	(t) 60	(t) 70	(t) 80

A1(1) - A1(8), Ratios of Strains at Different Ages/Strain at Standard Age

1–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80

A1T(1) - A1T(8), Ages of Material

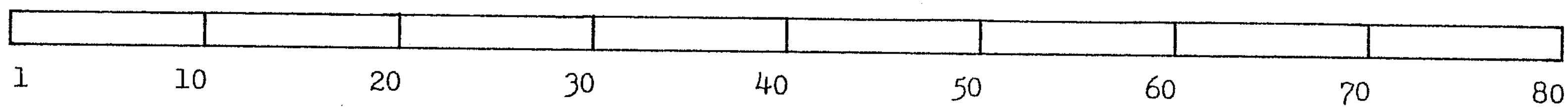
1 (t) 10	(t) 20	(t) 30	(t) 40	(t) 50	(t) 60	(t) 70	(t) 80

If IRELA, relaxation indicator for the material, is equal to 0 or blank, the material creeps. The following cards are needed to input creep-time relationship for the material. The first card specifies ultimate creep coefficient and creep recovery ratio of the material.

Ultimate Creep Coefficient	Creep Recovery Ratio
1–10	10–20

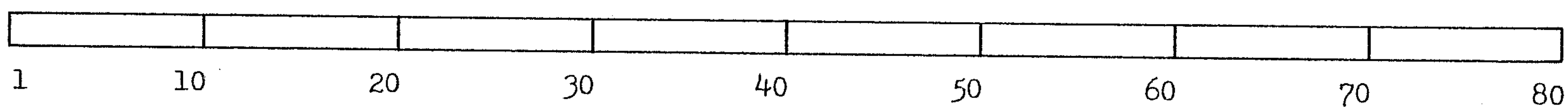
If NEQC, creep function number for the material, is from 1 to 10, internally provided creep function is used for the material. An additional card is needed to input coefficients for the function.

C(1) - C(8), Coefficients for Creep Function

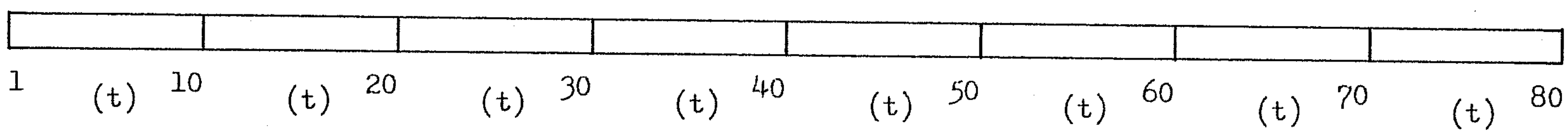


If NEQC is greater than 10, creep function for the material is defined by two curves, creep-time curve and loading time correction curve.

C(1) - C(8), Values of Creep Function



CT(1) - CT(8), Times after Loading



C1(1) - C1(8), Loading Age Correction Factors

1	10	20	30	40	50	60	70	80

C1T(1) - C1T(8), Ages at Loading

1	10	20	30	40	50	60	70	80
	(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)

If IRELA is greater than 0, the material relaxes. The following card or cards are needed to input relaxation-time relationship for the material.

If NEQC, relaxation function number for the material, is from 1 to 10, internally provided relaxation function is used. A card is needed to input coefficients for the function.

C(1) - C(8), Coefficients for Relaxation Function

1	10	20	30	40	50	60	70	80

If NEQC is greater than 10, relaxation function for the material is defined by two curves, relaxation-time curve and ratio of ultimate relaxation/initial stress VS. stress level curve.

C(1) - C(8), Values of Relaxation Function

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80

CT(1) - CT(8), Times after Loading

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
(t)	(t)	(t)	(t)	(t)	(t)	(t)	(t)

C1(1) - C1(8), Ratios of Ultimate Relaxation Stress/Initial Stress

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80

C1T(1) - C1T(8), Stress Levels

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
(f/d^2)	(f/d^2)	(f/d^2)	(f/d^2)	(f/d^2)	(f/d^2)	(f/d^2)	(f/d^2)

If NEQS, shrinkage function number for the material, is from 1 to 10, internally provided shrinkage function is used for the material. A card is needed to input coefficients for the function.

S(1) - S(8), Coefficients for Shrinkage Function

1	10	20	30	40	50	60	70	80

If NEQS is greater than 10, shrinkage function for the material is defined by a shrinkage-time curve.

S(1) - S(8), Values of Shrinkage Function

1	10	20	30	40	50	60	70	80

SRT(1) - SRT(8), Times after Material Can Carry Loads

1	(t)	10	(t)	20	(t)	30	(t)	40	(t)	50	(t)	60	(t)	70	(t)	80

Total number of materials must not exceed 10.

Materials may be specified either in this problem or through hold option for Tabel 3A. For the materials that are specified more than once, the latest values will be used.

Materials are numbered from 1 to the total number of materials. No specific order of numbering of materials is required.

Relaxation indicators specify types of materials. Relaxtion indicator of less than or equal to zero defines the material creeps. Relaxation indicator of greater than zero defines that the material relaxes.

Stress-strain curve numbers specify stress-strain relationships of materials.

Stress-strain curve number = 0 defines the material is elastic. Its modulus of elasticity, maximum and minimum strain limits are defined in the succeeding card.

Stress-strain curve number > 0 defines the material is inelastic. Its stress and strain multipliers, maximum and minimum strain limits are defined in the succeeding card instead.

Stress-strain curve numbers must not exceed 10. For the material with stress-strain curve number from 1 to 10, its integer stress-strain curve is defined in Table 3B. The actual stress-strain curve is the product of the stress and strain multipliers and the integer stress-strain curve for the material.

Stress multipliers may be of any real values, but strain multipliers must be greater than 0.

Age function numbers, creep or relaxation function numbers, and shrinkage function numbers may be blanks, 0, or any positive integers. Blank or 0 defines the corresponding effect as not applicable. The internally provided functions are used if the function numbers are between 1 to 10. For function numbers of greater than 10, the corresponding functions must be input as curves.

Cards define time-dependent functions are skipped if the corresponding functions are not applicable.

For each of the internally provided functions specified, an additional card, or two in case of creep functions, are needed to input the coefficients of the function. The functions are as follows:

Age function:

No. 1, the A.C.I. Committee 209 recommended function,

$$(f'_c)_t/(f'_c)_{t0} = t/\left[A(1) + A(2)\ t\right]$$

Creep functions:

No. 1, the A.C.I. Committee 209 recommended function,

$$(c)_{t,t'}/C(9) = CC_{LA}\ (t - t')^{C(1)}/\left[C(2) + (t - t')^{C(1)}\right]$$

$$CC_{LA} = C(3)\ t'^{C(4)}$$

No. 2, the A.C.I. Committee 209 recommended function without loading time correction factor,

$$(c)_{t,t'}/C(9) = (t - t')^{C(1)}/\left[C(2) + (t - t')^{C(1)}\right]$$

No. 3, the P.C.I. Committee on Prestress Losses recommended function,

$$(c)_{t,t'}/C(9) = f(t,t')$$

No. 4, the P.C.I. Committee on Prestress Losses recommended function without loading time correction factor,

$$(c)_{t,t'}/C(9) = g(t,t')$$

Creep strain under sustained stress f_c, $(\epsilon_c)_{t,t'}$, f_c may be compression or tension, is estimated as:

$$(\epsilon_c)_{t,t'} = (c)_{t,t'}\ f_c \qquad \text{for applied stress } f_c$$

or

$$(\epsilon_c)_{t,t'} = (c)_{t,t'}\ f_c\ C(10) \qquad \text{for removed stress } f_c$$

where $C(9)$ = Ultimate creep coefficient,

and $C(10)$ = Creep recovery ratio.

Relaxation function:

No. 1, the P.C.I. Committee on Prestress Losses recommended function,

For $(f_s)_t/C(1) \geq C(4)$

$$(f_r)_t - (f_r)_{t1} = (f_s)_t \left[(\log 24t - \log 24t1)/C(2)\right]\left[(f_s)_t/C(1) - C(3)\right]$$

For $(f_s)_t/C(1) < C(4)$

$$(f_r)_t - (f_r)_{t1} = 0$$

Shrinkage functions:

No. 1, the A.C.I. Committee 209 recommended function,

$$(\epsilon_s)_t/S(1) = t/\left[t + S(2)\right]$$

No. 2, the general A.C.I. Committee 209 recommended function,

$$(\epsilon_s)_t/S(1) = t^{S(2)}/\left[t^{S(2)} + S(3)\right]$$

No. 3, the P.C.I. Committee on Prestress Losses recommended function,

$$(\epsilon_s)_t/S(1) = f(t)$$

Coefficients which are not applicable are input as blanks.

Functions may be specified as curves.

Age function may be defined by two curves: a curve of ratio of stresses at different ages to the stress at a standard age VS. time and a curve of ratio of strains at different ages to the strain at a standard age VS. time.

Creep function may be defined by two curves: a creep-time curve and a loading time correction curve.

Relaxation function may be defined by two curves: a relaxation-time curve and a ratio of ultimate relaxation stress to initial stress VS. time curve.

Shrinkage function may be defined by a shrinkage-time curve.

For functions specified as curves, eight points along the curves must be specified per curve. The curves will be extended indefinitely beyond the first and the last points of the curves by zero slope straight lines.

TABLE 3B, MATERIAL STRESS-STRAIN CURVES (two cards per curve, number of cards per Table 1)

Curve No.	No. of Pts.	Sym. Option		Integer Stress Values											
1	5	10	15	21	25	30	35	40	45	50	55	60	65	70	75	80

	Integer Strain Values											
21	25	30	35	40	45	50	55	60	65	70	75	80

Material stress-strain curves must be numbered from 1 to 10.

Number of points specified per curve may be from 0 to 12.

For number of points = 0, the proposed concrete stress-strain curve will be generated by the program. Three points need to be input in such a way that:

f''_c = integer stress (1) x stress multiplier

ϵ_0 = integer strain (1) x strain multiplier

$0.5\ f''_c$ = integer stress (2) x stress multiplier

ϵ_{50c} = integer strain (2) x strain multiplier

and E_c = [integer stress (3) x stress multiplier] / [integer strain (3) x strain multiplier]

For number of points = 1, the Hognestad concrete stress-strain curve will be generated by the program, Two points need to be input in such a way that:

f''_c = integer stress (1) x stress multiplier

ϵ_0 = integer strain (1) x strain multiplier

f_c @ ϵ_u = integer stress (2) x stress multiplier

and ϵ_u = integer strain (2) x strain multiplier

For number of points from 2 to 12, the curve is input using the format above.

A symmetrical curve may be input by specifying its symmetry option equal to 1 and its positive strain branch, including the (0,0) point. The rest of the curve will be generated internally.

TABLE 4, CROSS-SECTION PROPERTIES (number of cards per Table 1)

No. of Elements	Member Length
1–5	11–20 (d)

NSUB
1–5

NSUB = number of sub-rectangles specfied in this problem. The following set of cards is needed for each sub-rectangle.

The first card of the set is:

NPOST	NMAT	NDIV	NPTS	NSYM	Casting Time	Time Added to Member	Time Can Be Loaded
1–5	10	15	20	25	31–40 (t)	50 (t)	60 (t)

The following cards are needed according to the conditions specified in the first card of the set.

If NPTS, number of points along member axis where width, depth, centroidal distance, and STRI, initial pretensioning strain or post-tensioning force, of the sub-rectangle are specified, is equal to 0, cross-section of the sub-rectangle is vary and is input as segments at control points. The rest of the segments will be generated internally by the program.

No. of Segments Width	Depth	C.G.	NPST	Wobble Friction Coefficient	Curvature Friction Coefficient	Datum STRI
1–5	10	15	20	(/d) 30	(/rad) 40	(d/d) or (f) 50

An additional card is needed for each segment.

Indicator	X1	X2	X3	X4	E1	E2	E3
1–5	11 (d) 20	(d) 30	(d) 40	(d) 50	(d) 60	(d) 70	(d) 80

For a pretensioned sub-rectangle (NPOST = 0), NPST = number of segments of pretensioning strain specified. An additional card is needed for each NPST.

Indicator		X1	X2	X3	X4	E1	E2	E3
1–5		11–20 (d)	30 (d)	40 (d)	50 (d)	60 (d/d)	70 (d/d)	80 (d/d)

For a post-tensioned sub-rectangle (NPOST = 1), NPST = number of end forces specified. An additional card is needed for each NPST.

Indicator		End Force
1–5		11–20 (f)

If NPTS is equal to 1, cross-section of the sub-rectangle is constant. A card is needed to input its properties.

Width	Depth	C.G.	STRI
11 (d) 20	(d) 30	(d) 40	(d/d) or (f) 50

If NPTS is greater than 1, cross-section of the sub-rectangle is variable. Width, depth centroidal distance, and initial strain or post-tensioning force of the sub-rectangle are input as curves at points along the axis of the sub-rectangle. A card is needed for each point.

X-Coordinate	Width	Depth	C.G.	STRI
1 (d) 10	(d) 20	(d) 30	(d) 40	(d/d) or (f) 50

The card for number of elements and member length is skipped for continuing problems (Type 2 or Type 3 problems).

Number of elements may be any even integer from 4 to 80. Number of elements of 20 will be assumed if specified outside this range.

Total number of sub-rectangles must not exceed 30.

NPOST = post-tension indicator for a sub-rectangle.

For NPOST = 0, the sub-rectangle is pretensioned. Its initial strain needs to be specified.

For NPOST = 1, the sub-rectangle is post-tensioned. Its post-tensioning force needs to be specified instead of the initial strain.

NMAT = material number for the sub-rectangle.

NDIV = number of vertical divisions for the sub-rectangle.

Total number of fibers in a member, i.e. the product of the total number of vertical divisions and number of elements, must not exceed 1500.

For NPTS = 0, cross-section of the sub-rectangle is variable. Width, depth, and centroidal distance for the sub-rectangle are input as continuing segments at control points, one segment per card as follows:

Indicator = 0, linear segment is generated. X1, X2, E1, and E2 need to be input.

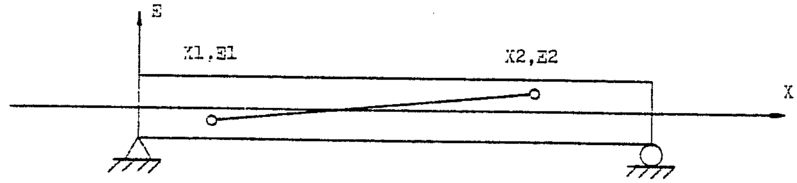
Indicator = 1, parabolic segment is generated. X1, X2, X3, E1, E2, and E3 need to be input.

Indicator = 2, typical left end span tendon profile is generated. X1, X2, X3, X4, E1, E2, and E3 need to be input.

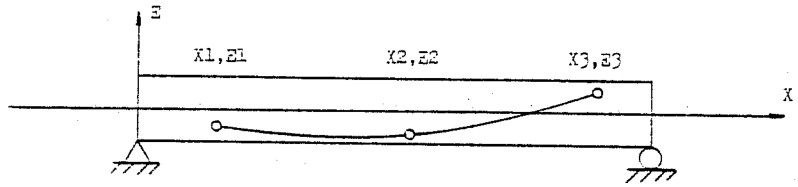
Indicator = 3, typical interior span tendon profile is generated. X1, X2, X3, E1, and E2 need to be input.

Indicator = 4, typical right end span tendon profile is generated. X1, X2, X3, X4, E1, E2, and E3 need to be input.

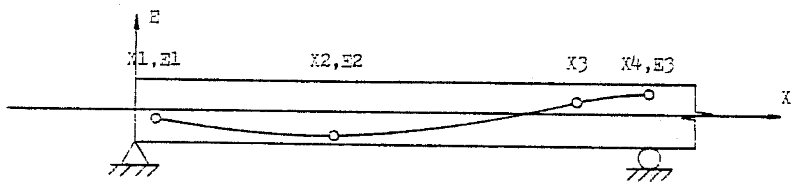
The generated profiles and the necessary input are shown in Fig. B1.



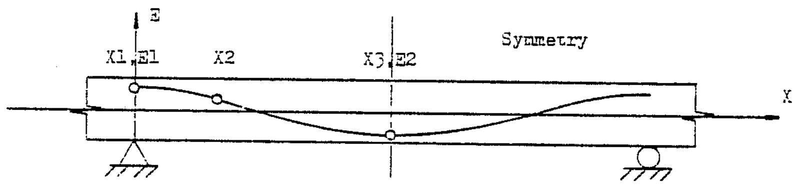
Linear Segment



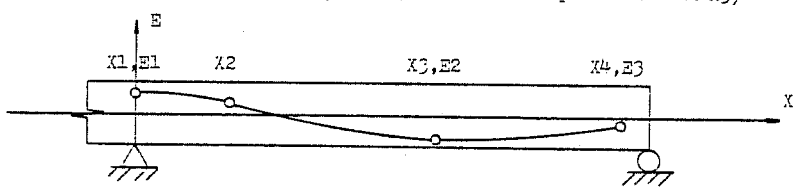
Parabolic Segment



Typical Left Endspan Tendon Profile
(Parabolic Segments Joining at X2 and X3, with Zero Slopes at X2 and X4)



Typical Interior Span Tendon Profile
(Parabolic Segments Joining at X2, with Zero Slopes at X1 and X3)



Typical Right Endspan Tendon Profile
(Parabolic Segments Joining at X2 and X3, with Zero Slopes at X1 and X3)

Fig. B1 Linear and Parabolic Segments That Can Be Generated by the Program.

X1 and E1 for a continuing segment need not to be specified.

For a pretensioned sub-rectangle (NPOST = 0), a constant initial strain may be specified by inputting NPST = 0 and datum STRI = the constant initial strain. A variable initial strain may be input as continuing segments using the same format as inputting width, depth, or centroidal distance. Datum STRI will be disregarded in the later case.

For a post-tensioned sub-rectangle (NPOST = 1), post-tensioning force may be specified by inputting datum STRI = a constant initial force and end forces acccording to the sequences of jacking and releasing of the end forces. The program will calculate the post-tensioning force taking into account the initial force and the friction between the sub-rectangle and the surrounding materials.

Indicators for specifying end forces are input as follows:

Indicator = 0 : left end

Indicator = 1 : right end.

For NPTS = 1, cross-section of the sub-rectangle is constant. Width, depth, centroidal distance, and initial strain or post-tensioning force for the sub-rectangle need to be input in the succeeding card.

For NPTS > 1, cross-section of the sub-rectangle is variable. Width, depth, centroidal distance, and initial strain or post-tensioning force along the sub-rectangle axis are input the same way as specifying curves with the horizontal distance as abscissa, one point per card. The first and the last points specify the ends of the sub-rectangle.

Distances specified must be within 0.0 and the length of the member.

Total NPTS must not exceed 100.

The product of number of elements and the number of sub-rectangles in which their NPTS = 0 must not exceed 400.

NSYM, sub-rectangle symmetry option, is applicable for the sub-rectangle input the same way as curves (NPTS > 1). By specifying the corresponding NSYM = 1, only the left side of a symmetry sub-rectangle may be input, the rest of the sub-rectangle will be generated by the program.

TABLE 5A, APPLIED LOADS (number of cards per Table 1)

If hold option for Table 5A is equal to 2, a card is needed to input increasing percentages in the distributed and concentrated loads previously defined.

Increasing Percentages Distr. Loads	Conc. Loads
1 – 10	20

For loads specified in this problem, the following cards are needed.

NDLD	NCLD
1 – 5	10

The following cards are needed according to the conditions on the preceding card.

If NDLD, number of sets of distributed loads, is greater than 0, the following cards are needed for each set of the loads.

No. of Points	Time Load Applied
1–5	11–20 (t)

If number of points specified for the set = 1, the load is uniformly distributed. A card is needed to input the magnitude of the load.

Load Parallel to X-Axis	Load Parallel to Y-Axis	Moment about Z-Axis
11–20 (f)	20–30 (f)	30–40 (f-d)

If number of points specified for the set > 1, the load varies and is input as curve, one point per card.

X-Coordinate	Load Parallel to X-Axis	Load Parallel to Y-Axis	Moment about Z-Axis
1 (d) 10	(f) 20	(f) 30	(f-d) 40

If NCLD, number of concentrated loads, is greater than 0, a card is needed for each concentrated load.

Time Load Applied	X-Coordinate	Load Parallel to X-Axis	Load Parallel to Y-Axis	Moment about Z-Axis
1 (t) 10	(d) 20	(f) 30	(f) 40	(f-d) 50

For hold option for Table 5A = 2, the absulute values of the previously defined loads will be increased by the percentages specified. The increasing percentages may be negative, zero, or positive.

New loads may be added even if the hold option is equal to 1 or 2.

Total number of sets of distributed loads must not exceed 20.

Total number of concentrated loads must not exceed 30.

For number of points specified for a set of distributed load = 1, the load is uniformly distributed. The magnitude of the load is defined in the succeeding card.

For number of points specified for a set of distributed load > 1, the load is variable and is input as curve, one point per card. The first and the last points specified the ends of the load.

Total number of points specified for distributed loads must not exceed 40.

X-coordinates specified must be from 0.0 to the length of the member.

All loads are accumulated and sustained after they are applied.

Time-dependent response calculation between any two loads is skipped if the later load is applied within 1.00101 of the time the former load is applied.

TABLE 5B, SPRING RESTRAINTS (number of cards per Table 1)

NDS	NCS
1–5	10

The following cards are needed according to the conditions on the preceding card.

If NDS, number of sets of distributed spring restraints, is greater than 0, for each set of the restraints, the following cards are needed.

No. of Points
1–5

If number of points specified per set = 1, the restraint is uniformly distributed. The following card is needed to input the spring properties.

q-Multiplier or Spring Constant // X-Axis // Y-Axis about Z-Axis

w-Multiplier // X-Axis // Y-Axis about Z-Axis

Columns	Field	Format
11–14	NSXD	
14–17	NSYD	
17–20	NSZD	
20–30		(f/d) or (f)
30–40		(f/d) or (f)
40–50		(f/d) or (f)
50–60		(d) or (d/d)
60–70		(d) or (d/d)
70–80		(d) or (d/d)

If number of points specified per set > 1, the restraint is variable and is input as curve, one point per card.

q-Multiplier or Spring Constant // X-Axis // Y-Axis about Z-Axis

w-Multiplier // X-Axis // Y-Axis about Z-Axis

Columns	Field	Format
1–10	X-Coordinate	(d)
10–14	NSXD	
14–17	NSYD	
17–20	NSZD	
20–30		(f/d) or (f)
30–40		(f/d) or (f)
40–50		(f/d) or (f)
50–60		(d) or (d/d)
60–70		(d) or (d/d)
70–80		(d) or (d/d)

If NCS, number of concentrated spring restraints, is greater than 0, for each concentrated spring restraint, the following card is needed.

X-Coordinate	NSXP	NSYP	NSZP	q-Multiplier or Spring Constant // X-Axis	// Y-Axis about Z-Axis		w-Multiplier // X-Axis	// Y-Axis about Z-Axis	
1 (d) 10	14	17	20	(f/d) or (f) 30	(f/d) or (f) 40	(f/d) or (f) 50	(d) or (d/d) 60	(d) or (d/d) 70	(d) or (d/d) 80

All restraints are applied to the member at the beginning of the problem.

Total number of sets of distributed spring restraints must not exceed 10.

Total number of concentrated spring restraints must not exceed 20.

For number of points for a set of distributed spring restraint = 1, the restraint is uniformly distributed. The magnitude of the restraint is defined in the succeeding card.

For number of points for a set of distributed spring restraint > 1, the restraint is variable along member axis and is input as curve, one point per card. The first and the last points specify the ends of the restraint.

Total number of points specified for the distributed spring restraints must not exceed 20.

X-coordinates specified must be from 0.0 to the length of the member.

NSXD, NSYD, and NSZD = q-w curve numbers for distributed spring restraints in the x-direction, the y-direction, and the z-direction, respectively.

NSXP, NSYP, and NSZP = q-w curve numbers for concentrated spring restraints in the x-direction, the y-direction, and the z-direction, respectively.

For numbers of q-w curves = 0, the restraints at the corresponding points are linear and the spring constants for the restraints need to be specified.

For numbers of q-w curves > 0, the restraints at the corresponding points are nonlinear and the q-multipliers and the w-multipliers need to be specified instead of the spring constants. The actual q-w curves for the restraints are the products of the q-multipliers and the w-multipliers and the integer q-w curves defined in Table 5C.

A stable spring constant has a negative value.

q-multipliers may be of any real values but w-multipliers must be greater than 0.0.

Linear and nonlinear restraints may be mixed. Linear restraints will be treated as nonlinear restraints with the q-w curves that have constant q/w ratios equal to the spring constants of the linear restraints.

Member nodal point displacements may be enforced by specifying large concentrated restraints in the directions of the required displacements and forces in the same directions equal to the products of the restraints and the required displacements. The forces must be greater than 1.0×10^{30} units for the program to recognize the specified displacements.

Large restraints should be specified as concentrated spring restraints exactly at member nodal points or undesirable effects may be obtained.

TABLE 5C, NONLINEAR SUPPORT CURVES (two cards per curve, number of cards per Table 1)

Curve No.	No. of Pts.	Sym. Option		Integer q-Values											
1–5	5–10	10–15		21–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75	75–80

	Integer w-Values											
	21–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75	75–80

Curve numbers must be from 1 to 10.

Up to 12 integer points on a q-w curve may be specified for the curve.

Normal q-w curves have opposite signs for displacements (w-values) and forces (q-values).

A symmetric curve may be input by specifying its symmetry option equal to 1 and its positive displacement branch, including the (0, 0) point. The rest of the curve will be generated internally by the program.

A P P E N D I X C

LISTING OF PROGRAM PBEAM

```
C                           NOTATIONS FOR PROGRAM PREAM

C      A( , )               COEFFICIENT FOR AGE FUNCTION OR STRESS RATIO FOR STRESS
C                             RATIO-AGE CURVE
C      AFI                  AVERAGE VALUE OF AF1 AND AF2
C      AFY                  EA TIMES CENTROIDAL DISTANCE FOR FIBER
C      AFY1,AFY2            SUMMATIONS OF AFY OVER CROSS-SECTION AT FIRST AND SECOND
C                             ROTATIONAL SPRINGS IN ELEMENT
C      AF1,AF2              SUMMATIONS OF EA OVER CROSS-SECTION AT FIRST AND SECOND
C                             ROTATIONAL SPRINGS IN ELEMENT
C      AN1( )               ALPHANUMERIC IDENTIFIER
C      AN2( )               ALPHANUMERIC IDENTIFIER
C      AT( , )              TIME AFTER CASTING FOR STRESS RATIO-AGE CURVE
C      ATIME                COMPUTER ELAPSED TIME AT START OF TIME INCREMENT
C      ATIMET               TOTAL COMPUTER ELAPSED TIME FOR TIME INCREMENT
C      AUWT                 ABSOLUTE VALUE OF UNIT WEIGHT OF MATERIAL
C      AI( , )              STRAIN RATIO FOR STRAIN RATIO-AGE CURVE
C      AIT( , )             TIME AFTER CASTING FOR STRAIN RATIO-AGE CURVE

C      B                    CROSS-SECTIONAL AREA OF FIBER OR SUB-RECTANGLE
C      B( , )               ELEMENT DEFORMATION-DISPLACEMENT MATRIX
C      BI( )                WIDTH OR AREA ALONG MEMBER AXIS FOR SUB-RECTANGLE
C      BIP( )               WIDTH OR AREA ALONG MEMBER AXIS FOR SUB-RECTANGLE
C      BIT( )               DUMMY ARRAY
C      BM                   BENDING MOMENT
C      BM1,BM2              BENDING MOMENTS AT FIRST AND SECOND ROTATIONAL SPRINGS IN
C                             ELEMENT
C      BM1S( ),             BENDING MOMENTS AT FIRST AND SECOND ROTATIONAL SPRINGS IN
C      BM2S( )                ELEMENTS, STORED FOR ALL ELEMENTS
C      BT( , )              TRANSPOSE OF B( , )
C      B1,B2,B3             DISTANCES ALONG MEMBER AXIS
C      B1,B2,B3             WIDTHS, DEPTHS, CENTROIDAL DISTANCES, INITIAL STRAINS, OR
C                             INITIAL FORCES ALONG MEMBER AXIS

C      C( , )               COEFFICIENT FOR CREEP FUNCTION OR RATIO OF CREEP STRAIN/
C                             ULTIMATE CREEP STRAIN FOR CREEP-TIME CURVE
C      C( , )               COEFFICIENT FOR RELAXATION FUNCTION OR RATIO OF RELAXATION
C                             STRESS/FINAL RELAXATION STRESS FOR RELAXATION-TIME CURVE
C      CCLA                 LOADING TIME CORRECTION FACTOR FOR CREEP
C      CG( )                CENTROIDAL DISTANCE ALONG MEMBER AXIS FOR SUB-RECTANGLE
C      CGP( )               CENTROIDAL DISTANCE ALONG MEMBER AXIS FOR SUB-RECTANGLE
C      CGT                  CENTROIDAL DISTANCE OF SUB-RECTANGLE
C      COSCOS               COSI+COSIM1
C      COSI                 COSINE OF ROTATION OF MEMBER AT NODAL POINT I
C      COSIM1               COSINE OF ROTATION OF MEMBER AT NODAL POINT IM1
C      COST                 COS(THETA)
C      CT( , )              TIME AFTER LOADING FOR CREEP-TIME CURVE
C      CT( , )              TIME AFTER LOADING FOR RELAXATION-TIME CURVE
C      CUR1,CUR2            CURVATURES AT FIRST AND SECOND ROTATIONAL SPRINGS IN ELEMENT
C      C1( , )              LOADING TIME CORRECTION FACTOR FOR LOADING TIME CORRECTION
C                             FACTOR-TIME AFTER CASTING CURVE
C      C1( , )              RATIO OF FINAL RELAXATION STRESS/INITIAL STRESS FOR FINAL
C                             RELAXATION-STRESS LEVEL CURVE
C      C1T( , )             TIME AFTER CASTING FOR LOADING TIME CORRECTION FACTOR-TIME
C                             AFTER CASTING CURVE
C      C1T( , )             STRESS LEVEL FOR RELAXATION-STRESS LEVEL CURVE

C      D                    DEPTH OF SUB-RECTANGLE
C      D( )                 TEMPORARY VALUE FOR NODAL POINT DISPLACEMENT
C      D( , )               ELEMENT FORCE-DEFORMATION MATRIX
C      DDX,DDY              DIFFERENCES OF HORIZONTAL AND VERTICAL DISPLACEMENTS AT
C                             ELEMENT ENDS
C      DDX1                 DISTANCE FROM X1
C      DDX2                 DISTANCE TO X2
C      DELTA                AXIAL DEFORMATION IN ELEMENT
C      DEPTH                DEPTH OF FIBER
C      DET                  SHRINKAGE STRAIN
C      DETER                DETERMINANT OF SQUARE MATRIX (3 X 3 MATRIX)
C      DETT                 TEMPORARY VALUE FOR DET
C      DI( )                DEPTH ALONG MEMBER AXIS FOR SUB-RECTANGLE
C      DIP( )               DEPTH ALONG MEMBER AXIS FOR SUB-RECTANGLE
C      DIS                  DISTANCE ALONG MEMBER AXIS
C      DIT( )               DUMMY ARRAY
C      DIT( )               TEMPORARY VALUE FOR DI( )
C      DS                   CHANGE IN STRESS
C      DS( , )              MATRIX D( , ) STORED FOR ALL ELEMENTS
C      DSTRAI( , )          FIBER STRAIN JUST BEFORE FIBER CAN CARRY LOAD
C      DSTRN( , )           FIBER STRAIN AT BEGINNING OF CURRENT TIME INCREMENT OR
C                             FIBER STRAIN INCREMENT
C      DT                   DEPTH OF SUB-RECTANGLE
C      DTC                  FIBER CREEP STRAIN INCREMENT PER UNIT STRESS OR FIBER
C                             RELAXATION STRESS INCREMENT
C      DTC1,DTC2            FIBER CREEP STRAIN PER UNIT STRESS OR FIBER RELAXATION
C                             STRESS AT BEGINNING AND END OF CURRENT TIME
C                             INCREMENT
C      DTHET                SUMMATION OF FRICTION COEFFICIENT ALONG AXIS OF
C                             SUB-RECTANGLE
C      DX( ),DY( ),         MEMBER NODAL POINT DISPLACEMENTS IN X, Y, AND Z
C      DZ( )                  DIRECTIONS
C      DX1,DX2              DISTANCES FROM ENDS OF SEGMENT OF DISTRIBUTED SUPPORT TO
C                             LEFT CLOSEST NODAL POINT
C      DX1,DX2              X-DISPLACEMENTS AT ENDS OF ELEMENT
C      DY1,DY2              Y-DISPLACEMENTS AT ENDS OF ELEMENT
C      DZ1,DZ2              ROTATIONS AT ENDS OF ELEMENT
C      D1,D2                DISPLACEMENTS AT ENDS OF ELEMENT OR ENDS OF SEGMENT OF
C                             DISTRIBUTED SUPPORT

C      E                    STRAIN RATIO
C      E                    TANGENT MODULUS
C      EA                   TANGENT MODULUS TIMES CROSS-SECTIONAL AREA OF FIBER
C      EC                   MODULUS OF ELASTICITY OF CONCRETE
C      EI                   TANGENT MODULUS TIMES MOMENT OF INERTIA OF FIBER
C      EI1,EI2              SUMMATIONS OF EI OVER CROSS-SECTION AT FIRST AND SECOND
C                             ROTATIONAL SPRINGS IN ELEMENT
C      EM( )                STRAIN MULTIPLIER FOR MATERIAL STRESS-STRAIN CURVE
C      EP                   AXIAL STRAIN
C      EPST( ),             TEMPORARY VALUES OF STRAINS FOR STRESS-STRAIN CURVES OR
C      EPST1( ),              DISPLACEMENTS FOR SUPPORT CURVES AT TIME FIBER CAN CARRY
C      EPST2( )               LOAD, AT BEGINNING AND END OF CURRENT TIME
C                             INCREMENT
C      EPT                  TEMPORARY VALUE FOR EP
C      EP1,EP2              FIBER STRAINS AT FIRST AND SECOND ROTATIONAL SPRINGS IN
C                             ELEMENT
C      ERR1,ERR2            MAXIMUM NODAL POINT EQUILIBRIUM ERROR LIMITS FOR FORCES AND
C                             MOMENTS
C      ERX( ),ERY( ),       MEMBER NODAL POINT FORCE ERRORS IN X, Y, AND Z DIRECTIONS
C      ERZ( )
C      ER1,ER2              TOLERANCE LIMITS FOR NODAL POINT EQUILIBRIUM ERRORS FOR
C                             FORCES AND MOMENTS
```

```
C     ET                 TEMPORARY VALUE FOR MODULUS OF ELASTICITY
C     ETIME( , )         FIBER CREEP OR RELAXATION STRAIN
C     FT1,FT2            TEMPORARY VALUES FOR TANGENT MODULII AT BEGINNING AND
C                          END OF CURRENT TIME INCREMENT

C     F                  COEFFICIENT IN LOAD MATRIX
C     F                  STRESS RATIO
C     FAC                INCREASING PERCENTAGE FOR LOADS
C     FEM( )             NODAL POINT EQUILIBRIUM ERROR
C     FF                 COEFFICIENT IN LOAD MATRIX
C     FTIME              FINAL TIME INCREMENT FOR THIS PROBLEM

C     H                  HALF OF ELEMENT LENGTH
C     HO2                H/2
C     HPD                H+DELTA
C     HPDE1T             1/HPD
C     HPDE2              HPD*HPD
C     HPDE2I             HPDE1T*HPDE1T
C     HPDE3I             HPDE2I*HPDE1I
C     HPR                H+R
C     HPRC1              HPR*COSIM1
C     HPRC2              HPR*COSI
C     HPRE2              HPR*HPR
C     HPRS               HPRE2-SE2
C     HPRS1              HPR*SINIM1
C     HPRS2              HPR*SINI

C     I                  DISCRETE ELEMENT NUMBER
C     I                  DUMMY VARIABLE FOR DO LOOP
C     IABAN              FATAL ERROR FLAG
C     IC                 BACKWARDS COUNTER
C     ICLD( )            IF = 1, CORRESPONDING CONCENTRATED LOAD WAS DISCRETIZED
C     ID                 INDEX FOR SUBROUTINE FAEUP
C     ID                 TEMPORARY VALUE FOR FUNCTION NUMBER
C     IDLD( )            IF = 1, CORRESPONDING SET OF DISTRIBUTED LOADS WAS
C                          DISCRETIZED
C     IDS                IF = 1, D( , ) IS STORED IN DS( , )
C     IDS5               COUNTER FOR CRACK FROZEN ITERATIVE CYCLES
C     ID1                IF > 0, LOAD IS ADDED IN CURRENT TIME INCREMENT
C     ID2                IF > 0, PRE-TENSIONED SUB-RECTANGLE IS ADDED IN CURRENT
C                          TIME INCREMENT
C     ID3                IF > 0, POST-TENSIONED SUB-RECTANGLE IS ADDED IN CURRENT
C                          TIME INCREMENT
C     IHB                (BANDWIDTH OF EQUATION - 1)/2
C     II                 DUMMY VARIABLE FOR DO LOOP
C     II                 POINTER FOR SUB-RECTANGLE PROPERTIES
C     III                DUMMY VARIABLE
C     IIJJ               II+JJ
C     IM1                I-1
C     IN                 INDICATOR SPECIFIES PROFILE OF SEGMENT OR LEFT OR RIGHT END
C     INDEX              COUNTER FOR CYCLES OF CALCULATION IN TIME INCREMENT
C     INDEXT             TEMPORARY VALUE FOR ITIMES( )
C     IP                 NUMBER OF EQUIVALENT FIBER
C     IPRIN              POINTER FOR ARRAY IPRINT( )
C     IP1                I+1
C     IP6-IP9            PRINT OPTIONS FOR TABLES 6-9
C     IRELAT             TEMPORARY VALUE FOR IRELAX( )
C     IRELAX( )          RELAXATION INDICATOR FOR MATERIAL (IF = 1, MATERIAL RELAXES)
C     IRELA1             IF = 1, AT LEAST ONE MATERIAL RELAXES
C     ISJT               TEMPORARY VALUE FOR ISS( ) OR ISM( )
C     ISJT,ISJT1,        CURVE SYMMETRY OPTIONS (IF = 1, SYMMETRY)
C     ISJT2
C     ISM( )             MEMBER SUPPORT CURVE SYMMETRY OPTION (IF = 1, SYMMETRY)
C     ISMALL             SMALL OR LARGE ANGLE SOLUTION OPTION (IF = 1, SMALL ANGLE
C                          SOLUTION)
C     ISMT,ISM1,ISM2     TEMPORARY VALUES FOR ISM( )
C     ISS( )             STRESS-STRAIN CURVE SYMMETRY OPTION (IF = 1, SYMMETRY)
C     ISSTT              SYMMETRY OPTION (IF = 1, SYMMETRY)
C     ISTR( , )          FIBER FAILURE INDICATOR (111 = NORMAL, 222 = TENSILE FAILURE
C                          333 = COMPRESSIVE FAILURE)
C     ISTRT              TEMPORARY VALUE FOR ISTR( , )
C     ISTR1,ISTR2        FIBER FAILURE INDICATORS AT FIRST AND SECOND ROTATIONAL
C                          SPRINGS IN ELEMENT
C     ISUB( )            INDICATOR FOR SUB-RECTANGLE
C     ISYM               SYMMETRY OPTION (IF = 1, SYMMETRY)
C     ITIME              NUMBER OF FIBER STRAIN INCREMENTS RECORDED
C     ITIME( ),          INDICATOR FOR ACTIONS IN TIME INCREMENT TIME1( )
C     ITIMES( )
C     ITIME1             POINTER FOR TIME1( )
C     ITIMP1             ITIME+1
C     ITYPEL             IF = 1, FIRST PROBLEM OF SERIES
C     ITYPET             OPTION FOR METHOD OF CREEP CALCULATION
C     IXI                IX1+I+1
C     IX1                FIXED POINT VALUE FOR X1/TH+1
C     IX2                FIXED POINT VALUE FOR X2/TH+1
C     IZ                 FIXED POINT VALUE FOR Z/TH
C     IZ1,IZ2            NODAL POINT NUMBERS AT ENDS OF ELEMENT WHERE LOAD OR
C                          SUPPPORT IS APPLIED
C     I1                 FIBER FAILURE INDICATOR AT BEGINNING OF CURRENT TIME
C                          INCREMENT
C     I1,I2              DO LOOP PARAMETERS
C     I10                CURRENT FIBER FAILURE INDICATOR
C     I11                I1+1
C     I100               FIBER FAILURE INDICATOR AT BEGINNING OF CURRENT ITERATIVE
C                          CYCLE
C     I1001,I1002        I100 AT FIRST AND SECOND ROTATIONAL SPRINGS IN ELEMENT
C     I1001T,I1002T      TEMPORARY VALUE FOR I1001 AND I1002
C     I11,I12            I1 AT FIRST AND SECOND ROTATIONAL SPRINGS IN ELEMENT
C     I21                I2+1

C     J,JJ,JJJ           DUMMY VARIABLES FOR DO LOOPS
C     J,JT               DUMMY VARIABLES
C     J,JT               TEMPORARY VALUES FOR ITIMES( )
C     JM1                J-1
C     J1                 EQUATION NUMBER

C     K,KK               DUMMY VARIABLE FOR DO LOOP
C     KEEP2-KEEP5C       HOLD OPTIONS FOR TABLE 2 - TABLE 5C
C     KEKE               CHECK FOR INDEPENDENT PROBLEM
C     KOFFC              IF = 1, DISPLACEMENT OR STRAIN IS OFF CURVE
C     KOFFQW             IF = 1, DISPLACEMENT IS OFF Q-W CURVE
C     KOFFSE             IF = 1, STRAIN IS OFF STRESS-STRAIN CURVE

C     L,L1,L4            DIMENSION LIMITS

C     M                  NUMBER OF DISCRETE ELEMENTS IN MEMBER
C     MATER              NUMBER OF MATERIALS SPECIFIED
C     MB                 ITERATION OUTPUT OPTION (0 = NO ITERATION OUTPUT,
C                          1 = PARTIAL ITERATION OUTPUT, 2 = FULL ITERATION OUTPUT)
C     MBT                TEMPORARY VALUE FOR MB
C     MIDS5              SPECIFIED MAXIMUM NUMBER OF ITERATIVE CYCLES THAT MEMBER
C                          CRACKS ARE FROZEN
C     MTSUB              MAXIMUM TOTAL NUMBER OF SUB-RECTANGLES PERMITTED
C     MTSUB1             MTSUB+1
```

```
C     MMTER          MAXIMUM NUMBER OF MATERIALS PERMITTED
C     MMCLD          MAXIMUM NUMBER OF CONCENTRATED LOADS PERMITTED
C     MMCS           MAXIMUM NUMBER OF CONCENTRATED SPRING RESTRAINTS PERMITTED
C     MMDLD          MAXIMUM NUMBER OF SETS OF DISTRIBUTED LOADS PERMITTED
C     MMDS           MAXIMUM NUMBER OF SETS OF DISTRIBUTED SPRING RESTRAINTS
C                      PERMITTED
C     MNE            MAXIMUM NUMBER OF ELEMENTS PERMITTED
C     MNEQ           MAXIMUM NUMBER OF INTERNALLY PROVIDED FUNCTION PERMITTED
C     MNITM          MAXIMUM NUMBER OF MEMBER ITERATION SPECIFIED
C     MNFC           NUMBER OF FIBERS IN CROSS-SECTION
C     MNPCS          MAXIMUM NUMBER OF FIBERS IN MEMBER PERMITTED
C     MNPD           MAXIMUM TOTAL NUMBER OF POINTS DEFINING DISTRIBUTED LOADS
C                      PERMITTED
C     MNPDS          MAXIMUM TOTAL NUMBER OF CONCENTRATED LOADS PERMITTED
C     MNPTS          MAXIMUM NUMBER OF POINTS DEFINING SUB-RECTANGLES WITH
C                      NPTS( ) GREATER THAN 0 PERMITTED
C     MNQW           MAXIMUM NUMBER OF SOIL SUPPORT CURVES PERMITTED
C     MNSS           MAXIMUM STRESS-STRAIN CURVE NUMBER PERMITTED
C     MPOST          MAXIMUM NUMBER OF SUB-RECTANGLES WITH NPTS( ) EQUAL TO 0
C                      MUST NOT EXCEED MPOST/M
C     MP1            M+1
C     MP22           (M/2)+1
C     MTIME,MTIME1   MAXIMUM NUMBER OF TIME1( ) OR TPRINT( ) PERMITTED PLUS 1
C     M2             M/2

C     N              DUMMY VARIABLE
C     N              NUMBER OF POINTS
C     NBI            NUMBER OF SEGMENTS SPECIFIED FOR WIDTH OF SUB-RECTANGLE
C     NC             CURVE NUMBER
C     NCD            SUB-RECTANGLE NUMBER, SET NUMBER FOR DISTRIBUTED SPRING
C                      RESTRAINTS, OR CONCENTRATED SPRING RESTRAINT NUMBER
C     NCD2-NCD5      NUMBERS OF CARDS SPECIFIED IN THIS PROBLEM FOR TABLE 2 -
C                      TABLE 5C
C     NCG            NUMBER OF SEGMENTS SPECIFIED FOR CENTROIDAL DISTANCE OF
C                      SUB-RECTANGLE
C     NCLD           TOTAL NUMBER OF CONCENTRATED LOADS
C     NCLDT          NUMBER OF CONCENTRATED LOADS SPECIFIED
C     NCR            NUMBER OF CARDS READ
C     NCS            TOTAL NUMBER OF CONCENTRATED SPRING RESTRAINTS
C     NCST           NUMBER OF CONCENTRATED SPRING RESTRAINTS SPECIFIED
C     NDI            NUMBER OF SEGMENTS SPECIFIED FOR DEPTH OF SUB-RECTANGLE
C     NDIV( )        NUMBER OF VERTICAL DIVISIONS FOR SUB-RECTANGLE
C     NDIVT          VERTICAL DIVISION NUMBER WITH RESPECT TO SUB-RECTANGLE
C     NDLD           TOTAL NUMBER OF SETS OF DISTRIBUTED LOADS
C     NDLDT          NUMBER OF SETS OF DISTRIBUTED LOADS SPECIFIED
C     NDS            TOTAL NUMBER OF SETS OF DISTRIBUTED SPRING RESTRAINTS
C     NDST           NUMBER OF SETS OF DISTRIBUTED SPRING RESTRAINTS SPECIFIED
C     NEG            INDICATOR FOR NEGATIVE DISPLACEMENT OR STRAIN ON SYMMETRY
C                      CURVE
C     NELE           TOTAL NUMBER OF FIBERS
C     NELEM          NUMBER FOR LAST VERTICAL DIVISION OF SUB-RECTANGLE
C     NELEMT         FIBER NUMBER
C     NELEM1         NUMBER FOR FIRST VERTICAL DIVISION FOR SUB-RECTANGLE
C     NEQ,NE1,NE2    TEMPORARY VALUES FOR MEMBER SUPPORT CURVE NUMBERS
C     NEPS( , )      INTEGER STRAIN VALUE FOR MATERIAL STRESS-STRAIN CURVE
C     NEPT( )        TEMPORARY VALUE FOR NEPS( , )
C     NEQA( )        AGE FUNCTION NUMBER FOR MATERIAL
C     NEQAT          TEMPORARY VALUE FOR NEQA( )
C     NEQC( )        CREEP OR RELAXATION FUNCTION NUMBER FOR MATERIAL
C     NEQCT          TEMPORARY VALUE FOR NEQC( )
C     NEQS( )        SHRINKAGE FUNCTION NUMBER FOR MATERIAL
C     NEQST          TEMPORARY VALUE FOR NEQS( )
```

```
C     NITM           NUMBER OF MEMBER ITERATIONS IN ITERATIVE CYCLE
C     NL             NUMBER OF SIMULTANEOUS EQUATIONS
C     NMAT( )        MATERIAL NUMBER FOR SUB-RECTANGLE
C     NMATT          TEMPORARY VALUE FOR NMAT( )
C     NN             TEMPORARY VALUE FOR NTIM1 OR NPRINL
C     NOTIME         TEMPORARY VALUE FOR NTIM1 OR NPRINL
C     NOTIM1         BACKWARDS POINTER
C     NP             NUMBER OF POINTS
C     NPD( )         CUMULATIVE NUMBER OF POINTS DEFINED IN SETS OF DISTRIBUTED
C                      LOADS
C     NPDS( )        CUMULATIVE NUMBER OF POINTS DEFINED IN SETS OF DISTRIBUTED
C                      SPRING RESTRAINTS
C     NPDT           NUMBER OF POINTS DEFINING SET OF DISTRIBUTED SPRING
C                      RESTRAINTS
C     NPRIN          NUMBER OF TIME INCREMENTS WHEN OUTPUTS NEED TO BE PRINTED
C                      OUT SPECIFIED
C     NPRINL         TOTAL NUMBER OF TIME INCREMENTS WHEN OUTPUTS NEED TO BE
C                      PRINTED OUT
C     NPROB( )       ALPHANUMERIC PROBLEM NUMBER
C     NPOST( )       POST-TENSION INDICATOR FOR SUB-RECTANGLE (IF = 1, POST-
C                      TENSIONED)
C     NPOSTL         TOTAL NUMBER OF SUB-RECTANGLES WITH NUMBER OF POINTS
C                      DEFINING SUB-RECTANGLE EQUAL TO 0
C     NPST           NUMBER OF SEGMENTS SPECIFIED FOR INITIAL STRAIN OF SUB-
C                      RECTANGLE WITH NPOST( ) EQUAL TO 0 OR NUMBER OF END FORCES
C                      SPECIFIED FOR SUB-RECTANGLE WITH NPOST( ) EQUAL TO 1
C     NPT            NUMBER OF POINTS ON CURVE
C     NPTM( )        NUMBER OF POINTS ON MEMBER SUPPORT CURVE
C     NPTS( )        CUMULATIVE NUMBER OF POINTS DEFINED ON SUB-RECTANGLES
C     NPTST          NUMBER OF POINTS ON STRESS-STRAIN CURVE OR NUMBER OF POINTS
C                      SPECIFIED FOR SUB-RECTANGLE
C     NPTT,NPTT1,    NUMBERS OF POINTS ON CURVES
C     NPTT2
C     NPTX1,NPTX2    NPTM( ) AT X1 AND X2
C     NQ             NUMBER OF ELEMENTS BETWEEN TWO POINTS
C     NQM( , )       INTEGER VALUE OF FORCE ON MEMBER SUPPORT CURVE
C     NSIG( , )      INTEGER STRESS VALUE FOR MATERIAL STRESS-STRAIN CURVE
C     NSIT( )        TEMPORARY VALUE FOR NSIG( , )
C     NSS( )         STRESS-STRAIN CURVE NUMBER FOR NONLINEAR MATERIAL
C     NSST           TEMPORARY VALUE FOR NSS( )
C     NSTST( )       NUMBER OF POINTS ON STRESS-STRAIN CURVE SPECIFIED
C     NSUB           TOTAL NUMBER OF SUB-RECTANGLES
C     NSUBT          NUMBER OF SUB-RECTANGLES SPECIFIED
C     NSXD( ),       Q-W CURVE NUMBERS FOR DISTRIBUTED SPRING RESTRAINTS IN
C     NSYD( ),NSZD( )  X, Y, AND Z DIRECTIONS
C     NSXP( ),       Q-W CURVE NUMBERS FOR CONCENTRATED SPRING RESTRAINTS IN
C     NSYP( ),NSZP( )  X, Y, AND Z DIRECTIONS
C     NSYM( )        SUB-RECTANGLE SYMMETRY OPTION (IF = 1, SYMMETRY) OR
C                      NEGATIVE OF SUB-RECTANGLE NUMBER
C     NT             DUMMY VARIABLE
C     NTIM1          TOTAL NUMBER OF TIME1( )
C     NTIME          NUMBER OF TIME INCREMENTS SPECIFIED FOR CALCULATING TIME-
C                      DEPENDENT RESPONSES
C     NWM( , )       INTEGER VALUE OF DISPLACEMENT FOR MEMBER SUPPORT CURVE
C     N1             STARTING INDEX TO TAKE ADVANTAGE OF SYMMETRY IN FORMING
C                      ELEMENT STIFFNESS MATRIX
C     N1,N2          DO LOOP PARAMETERS
C     N11            N1+1
C     N123           CONTROL WHICH CYCLES 1, 2, 3

C     PERC           INCREASING PERCENTAGE FOR CONCENTRATED LOADS
C     PERD           INCREASING PERCENTAGE FOR DISTRIBUTED LOADS
```

```
C     Q( )            RESISTIVE SPRING FORCE AT NODAL POINT
C     QI              EQUIVALENT CONCENTRATED LOAD OR SPRING
C     QJ,QJ1,QJ2,     RESISTIVE SPRING FORCES OR RESISTIVE SPRING FORCES PER UNIT
C     QJ21,QJ22         LENGTH
C     QJN             NEW STRESS LEVEL
C     QM,QM1,QM2      TEMPORARY VALUES FOR FORCE MULTIPLIERS FOR Q-W CURVES OR
C                       SPRING CONSTANTS FOR MEMBER SUPPORTS
C     QMXD( ),        FORCE MULTIPLIERS FOR Q-W CURVES OR SPRING CONSTANTS FOR
C     QMYD( ),QMZD( )  DISTRIBUTED SPRING RESTRAINTS IN X, Y, AND Z DIRECTIONS
C     QMXP( ),        FORCE MULTIPLIERS FOR Q-W CURVES OR SPRING CONSTANTS FOR
C     QMYP( ),QMZP( )  CONCENTRATED SPRING RESTRAINTS IN X, Y, AND Z DIRECTIONS
C     QO( )           CONCENTRATED NODAL POINT LOAD OR SPRING
C     QQ( ),QQ1( ),   VALUES OF FORCES ON SUPPORTS OR STRESS-STRAIN CURVES
C     QQ2( )
C     QX( ),QY( ),    NODAL POINT LOADS IN X, Y, AND Z DIRECTIONS
C     QZ( )
C     QXC( ),QYC( ),  MEMBER CONCENTRATED LOADS IN X, Y, AND Z DIRECTIONS
C     QZC( )
C     QXD( ),QYD( ),  MEMBER DISTRIBUTED LOADS IN X, Y, AND Z DIRECTIONS
C     QZD( )
C     QXI,QYI,QZI     EQUIVALENT CONCENTRATED LOADS OR SPRING FORCES IN X, Y, AND
C                       Z DIRECTIONS
C     QX1,QY1,QZ1     DISTRIBUTED LOADS OR SPRIN FORCES IN X, Y, AND Z DIRECTIONS
C                       AT LEFT ENDS OF DISTRIBUTED LOADS OR SPRINGS OR AT LEFT
C                       ENDS OF ELEMENTS
C     QX2,QY2,QZ2     DISTRIBUTED LOADS OR SPRING FORCES IN X, Y, AND Z DIRECTIONS
C                       AT RIGHT ENDS OF DISTRIBUTED LOADS OR SPRINGS OR AT RIGHT
C                       ENDS OF ELEMENTS
C     Q1,Q2           AREAS OF SUB-RECTANGLE AT LEFT AND RIGHT ENDS OF SUB-
C                       RECTANGLE OR AT LEFT OR RIGHT ENDS OF ELEMENT

C     R               DIFFERENCE IN AXIAL DISPLACEMENTS BETWEEN DISCRETE
C                       ROTATIONAL SPRINGS IN ELEMENT
C     RATIO           RATIO OF DISTANCE FROM POINT IN SEGMENT/LENGTH OF SEGMENT
C     REPS            STRAIN CORRECTION FACTOR FOR STRESS-STRAIN CURVE DUE TO AGE
C     RK              CONSTANT K IN PROPOSED STRESS-STRAIN CURVE
C     RK              WOBBLE FRICTION COEFFICIENT PER UNIT LENGTH
C     RKT             TEMPORARY VALUE FOR RK
C     RM              CURVATURE FRICTION COEFFICIENT PER RADIAN
C     RM( , )         RECURSION MULTIPLIER
C     RMT             TEMPORARY VALUE FOR RM
C     RO( )           RECURSION MULTIPLIER
C     RSTG            STRESS CORRECTION FACTOR FOR STRESS-STRAIN CURVE DUE TO AGE
C     R1,R2           RATIOS OF EQUIVALENT RESTRAINTS APPLIED AT ENDS OF ELEMENT

C     S               DIFFERENCE IN LATERAL DISPLACEMENTS BETWEEN DISCRETE
C                       ROTATIONAL SPRINGS IN ELEMENT
C     S( )            RESISTING SPRING FORCE AT NODAL POINT
C     S( , )          COEFFICIENT FOR SHRINKAGE FUNCTION OR SHRINKAGE STRAIN FOR
C                       SHRINKAGE-TIME CURVE
C     SC1             S*COSIM1
C     SC2             S*COSI
C     SFET( , )       ELEMENT STIFFNESS MATRIX (6 X 6)
C     SEM( , )        3 X 6 MEMBER STIFFNESS MATRIX USED IN MEMBER SOLUTION,
C                       COMPOSED OF 3 X 3 SUB-MATRICES OF ELEMENT STIFFNESS MATRIX
C     SEMS( , )       3 X 3 PORTION OF SEM( , ) STORED FOR ELEMENT IP1 WHILE
C                       FORMING SEM( , ) FOR NODAL POINT I
C     SF2             S*S
C     SHSTR( )        SHRINKAGE STRAIN FOR SUB-RECTANGLE
C     SI              EQUIVALENT TANGENT SPRING STIFFNESS OF MEMBER SUPPORT
C     STG,STG1,STG2   STRESS VALUES
C     SIGNT           PLUS OR MINUS SIGN
C     SIGNT           SIGN FOR BASED END FORCE MINUS END POST-TENSIONING FORCE FOR
C                       POST-TENSIONED SUB-RECTANGLE
C     SIGT( ),        TEMPORARY VALUES FOR STRESSES ON STRESS-STRAIN CURVES OR
C     SIGT1( ),         FORCES ON SUPPORT CURVES
C     SIGT2( )
C     SINI            SINE OF ROTATION AT NODAL POINT I
C     SINIM1          SINE OF ROTATION AT NODAL POINT IM1
C     SINSIN          SINI+SINIM1
C     SINT            SIN(THETA)
C     SJEND           SPECIFIED END POST-TENSIONING FORCE
C     SL( )           VECTOR OF STIFFNESS MATRIX
C     SLOPEI          SLOPE AT LEFT END OF SEGMENT OF SEB-RECTANGLE
C     SLOPET          SLOPE OF SUB-RECTANGLE PROFILE AT NODAL POINT
C     SM( )           STRESS MULTIPLIER FOR MATERIAL STRESS-STRAIN CURVE OR
C                       MODULUS OF ELASTICITY FOR ELEASTIC MATERIAL
C     SQX( ),SQY( ),  RESISTIVE SPRING FORCES AT NODAL POINTS IN X, Y, AND Z
C     SQZ( )            DIRECTIONS
C     SRT( , )        TIME AFTER MATRERIAL CAN BE LOADED FOR SHRINKAGE-TIME CURVE
C     SS1             S*SINIM1
C     SS2             S*SINI
C     STMAX( )        MAXIMUM STRAIN LIMIT FOR MATERIAL
C     STMIN( )        MINIMUM STRAIN LIMIT FOR MATERIAL
C     STRI( )         INITIAL PRE-TENSIONING STRAIN OR POST-TENSIONING FORCE IN
C                       SUB-RECTANGLE
C     STRIP( )        INITIAL PRE-TENSIONING STRAIN OR POST-TENSIONING FORCE IN
C                       SUB-RECTANGLE
C     STRIT           FIBER INITIAL PRE-TENSIONING STRAIN OR POST-TENSIONING FORCE
C     STRN( , )       FIBER STRAIN AT END OF CURRENT TIME INCREMENT
C     SU( )           COEFFICIENT OF STIFFNESS MATRIX (ONE ROW)
C     SX( ),SY( ),    RESISTIVE SPRING STIFFNESS AT NODAL POINTS IN X, Y, AND Z
C     SZ( )             DIRECTIONS
C     S2,S21,S22,     TANGENT SPRING STIFFNESSES OF MEMBER SUPPORTS
C     S221,S222

C     T               THRUST
C     T               TIME UNDER CONSIDERATION
C     TAU1,TAU2       DISCRETE ANGLE CHANGES AT FIRST AND SECOND ROTATIONAL
C                       SPRINGS IN ELEMENT
C     TH              ELEMENT LENGTH
C     THETA           ANGLE AXIALLY DEFORMABLE BAR IN ELEMENT MAKES WITH MEMBER
C                       AXIS
C     TIME( )         TEMPORARY VALUE FOR TIME1( ) OR TPRINT( )
C     TIMEB           TIME AT BEGINNING OF CURRENT TIME INCREMENT
C     TIMEC( )        TIME CONCENTRATED LOADS ARE APPLIED
C     TIMED( )        TIME DISTRIBUTED LOADS ARE APPLIED
C     TIMEO           TIME AT BEGINNING OF PROBLEM
C     TIMESS( , )     CASTING TIME, TIME ADDED TO STRUCTURE, AND TIME CAN BE
C                       LOADED FOR SUB-RECTANGLE
C     TIMEST          TIME AT END OF CURRENT TIME INCREMENT
C     TIMET           TEMPORARY VALUE FOR TIME1( ) OR TPRINT( )
C     TIME00          REFERENCE TIME
C     TIME1           TIME AT BEGINNING OF CURRENT TIME INCREMENT
C     TIME1( )        TIME INCREMENT FOR CALCULATION
C     TM( , )         TEMPORARY MATRIX TO STORE PORTIONS OF ELEMENT STIFFNESS
C                       MATRIX DUE TO INITIAL FORCES (INITIAL STIFFNESS MATRIX)
C     TPRINT( )       TIME INCREMENT WHEN OUTPUT IS PRINTED OUT
C     TT              AXIAL THRUST IN AXIALLY DEFORMABLE BAR IN ELEMENT
C     TTHETA          TAN(THETA)
C     TTM             TT*HDREST
C     TTMH02          TTH*H02
C     TTS( )          THRUST IN ELEMENT STORED FOR ALL ELEMENTS
```

```
C     TTIME            TIME INCREMENT
C     T0,T1,T2         FUNCTIONS OF TIME
C     T1,T2            THRUSTS AT FIRST AND SECOND ROTATIONAL SPRINGS IN ELEMENT

C     UNT( )           UNIT WEIGHT OF MATERIAL
C     UWTT             TEMPORARY VALUE FOR UWT( )
C     U1T,U2T          AXIAL FORCES ON END OF ELEMENT

C     V                SHEAR FORCE
C     VT               SHEAR FORCE IN AXIALLY DEFORMABLE BAR IN ELEMENT
C     VTM              VT*HPDE3T
C     VTMH02           VTM*H02
C     V1T,V2T          SHEAR FORCES AT ENDS OF ELEMENT

C     W( )             VECTOR OF DISPLACEMENT INCREMENTS FROM SUBROUTINE GRIP2A
C     WJ,WJN,WJN1,     DISPLACEMENTS OR STRAINS
C     WJN2
C     WJT              TEMPORARY VALUE FOR WJ
C     WM,WM1,WM2       TEMPORARY VALUES FOR DISPLACEMENT MULTIPLIERS FOR MEMBER
C                        SUPPORT CURVES
C     WMXD( ),         DISPLACEMENT MULTIPLIERS FOR DISTRIBUTED MEMBER SUPPORT
C     WMYD( ),WMZD( )    CURVES IN X, Y, AND Z DIRECTIONS
C     WMXP( ),         DISPLACEMENT MULTIPLIERS FOR CONCENTRATED MEMBER SUPPORT
C     WMYP( ),WMZP( )    CURVES IN X, Y, AND Z DIRECTIONS
C     WW( ),WW1( ),    VALUES OF DISPLACEMENTS ON SUPPORT CURVES OR STRAINS ON
C     WW2( )             STRESS-TRAIN CURVES
C     W1T,W2T          BENDING MOMENTS ON ENDS OF ELEMENT

C     X                DISTANCE ALONG MEMBER AXIS
C     X                DISTANCE TO MID-ELEMENT
C     XD( )            X-COORDINATE FOR SPECIFYING MEMBER DISTRIBUTED SUPPORT
C     XP( )            X-COORDINATE FOR SPECIFYING MEMBER CONCENTRATED SUPPORT
C     XS( )            X-COORDINATE FOR SPECIFYING MEMBER CROSS-SECTION
C     XSC( )           X-COORDINATE FOR SPECIFYING MEMBER CONCENTRATED LOAD
C     XSD( )           X-COORDINATE FOR SPECIFYING MEMBER DISTRIBUTED LOAD
C     XST( )           DUMMY ARRAY
C     XT               DISTANCE TO LEFT END OF SUB-RECTANGLE, SEGMENT OF
C                        DISTRIBUTED SUPPORT, OR ELEMENT
C     XX               DISTANCE TO RIGHT END OF SUB-RECTANGLE OR ELEMENT
C     XXMXT            XX-XT
C     XXT              DISTANCE AT WHICH SUB-RECTANGLE HAS SAME CROSS-SECTION AS
C                        AT XX
C     X1,X2            DISTANCE AT ENDS OF SUB-RECTANGLE OR SEGMENT OF DISTRIBUTED
C                        MEMBER SUPPORT
C     X1,X2,X3,X4,X5   DISTANCES ALONG MEMBER AXIS
C     X2T              TEMPORARY VALUE FOR X2
C     X2X1             X2-X1

C     Y                CENTROIDAL DISTANCE OF FIBER
C     YT               CENTROIDAL DISTANCE OF SUB-RECTANGLE

C     Z                X-COORDINATE OF CONCENTRATED LOAD OR SPRING RESTRAINT
C     ZI,ZI1,ZI2       FLOATING VALUES FOR I, I1, AND I2
C     ZL               MEMBER LENGTH
C     ZMUL             RATIO OF DISTANCE TO MID-ELEMENT/MEMBER TOTAL LENGTH
C     ZS               DISTANCE TO CENTROID OF PART OF DISTRIBUTED MEMBER SUPPORT
C     ZZ               DISTANCE FROM NODAL POINT ON LEFT TO CONCENTRATED LOAD OR
C                        SPRING RESTRAINT
```

```
      OVERLAY(PREAM,0,0)
      PROGRAM PREAM(INPUT,OUTPUT,TAPE1)
      DIMENSION AN1(40),AN2(20),NPROB(2)
      COMMON/BLOCK1/   ITIMES(51), TIME1(51),TPRINT(51)
      COMMON/BLOCK2/       EM(10),IRFLAX(10),  NFOA(10),  NEQC(10),
     1       NEQS(10),   NSS(10),      SM(10), STMAX(10), STMIN(10),
     2        UWT(10),
     3     A(10,8),     AT(10,8),     A1(10,8),     A1T(10,8),
     4    C(10,10),     CT(10,8),     C1(10,8),   C1T(10,8),
     5     S(10,8),    SRT(10,8)
      COMMON/BLOCK3/     ISS(10), NSTST(10),
     1   NEPS(10,12),  NSIG(10,12)
      COMMON/BLOCK4/     ISUB(30),   NDIV(30),   NMAT(30),   NSYM(30),
     1      NPOST(30),  NPTS(31),TIMESS(30,3),
     2        RI(100),    DI(100),    CG(100),    XS(100), STRI(100),
     3       RIP(400),   DIP(400),  CGP(400),STRIP(400)
      COMMON/BLOCK5/     IOLD(20), TIMED(20),    NPD(21),
     1        QXD(40),    QYD(40),    QZD(40),    XSD(40),
     2       ICLD(30),    QXC(30),    QYC(30),    QZC(30), TIMEC(30),
     3        XSC(30)
      COMMON/BLOCK6/     NPDS(11),   NSXD(20),   NSYD(20),   NSZD(20),
     1       QMXD(20),   QMYD(20),   QMZD(20),   WMXD(20),   WMYD(20),
     2       WMZD(20),     XD(20),
     3       NSXP(20),   NSYP(20),   NSZP(20),   QMXP(20),   QMYP(20),
     4       QMZP(20),   WMXP(20),   WMYP(20),   WMZP(20),     XP(20)
      COMMON/BLOCK7/      ISM(10),  NPTM(10),
     1    NOM(10,12),   NWM(10,12)
      COMMON/BLOCK8/     BM1S(81),   BM2S(81),     DX(81),     DY(81),
     1         DZ(81),    ERX(81),    ERY(81),    ERZ(81),     QX(81),
     2         QY(81),     QZ(81),    SQX(81),    SQY(81),    SQZ(81),
     3         SX(81),     SY(81),     SZ(81),    TTS(81),   DS(81,5)
      COMMON/BLOCK9/    SHSTR(30),DSTRAI(1500,2), DSTRN(1500,2),
     1          ETIME(1500,2),  ISTR(1500,2),  STRN(1500,2)
      COMMON/BLOC10/   SL(5), SU(6), RO(243), W(243), RM(5,243)
      COMMON/BLOC11/     EPST(12), EPST1(12), EPST2(12),  SIGT(12),
     1      SIGT1(12), SIGT2(12)
      COMMON/BLOC12/      BIT(80),    DIT(81)
      COMMON/BLOC13/   SFET(6,6)
      COMMON/BLK1/    IABAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1        KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2         MISUB, MMTER, MNCLD,  MNCS, MNDLD,  MNDS,   MNF,  MNEQ,
     3        MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,  MNSS, MPOST,MTIME1
      COMMON/BLK2/   NPRINL, NTIM1, FTIME, TIMEO,TIMEST
      COMMON/BLK3/     ERR1,  ERR2,   FR1,   ER2,    MR, MNITM,  NITM
      COMMON/BLK4/        H,   IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1        MIDS5,   MP1,  MP22,  NELE,    TH,    ZL
      COMMON/BLK5/     MNPC,  NCLD,   NCS,  NDLD,   NDS,NPOSTL,  NSUB
      COMMON/RT/         NL,    J1
C
COMMENT - SET CONTROL CONSTANTS
C
      MISUB=30
      MMTER=10
      MNCLD=30
      MNCS=20
      MNDLD=20
      MNDS=10
      MNF=80
      MNEQ=10
      MNPCS=1500
      MNPD=40
      MNPDS=10
      MNPTS=100
      MNQW=10
      MNSS=10
      MPOST=400
      MTIME1=51
      L1=MNE+1
      L4=6
      ITIME1=0
C
COMMENT - READ RUN ID, PRINT PROGRAM ID AND RUN ID
C
      READ 940, (AN1(II),II=1,40)
      PRINT 930
      PRINT 920
      PRINT 950, (AN1(II),II=1,40)
C
COMMENT - RETURN HERE TO READ NEW PROBLEM
C
   10 CONTINUE
      READ 960, NPROB,AN2(19),AN2(20),(AN2(II),II=1,18)
      IF (NPROB(1).EQ.4HCEAS) GO TO 910
C
COMMENT - INPUT AND ECHO PRINT PROGRAM CONTROL DATA (TABLE 1)
C
      READ 1050, ITYPET,KEEP2,KEEP3A,KEEP3B,KEEP4,KEEP5A,KEEP5B,KEEP5C,I
     1P6,IP7,IP8,IP9,NCD2,NCD3A,NCD3B,NCD4,NCD5A,NCD5B,NCD5C,ISMALL
C
COMMENT - START INDEPENDENT SOLUTION HERE, COME FROM 1520
C
   20 CONTINUE
      PRINT 930
      PRINT 950, (AN1(II),II=1,40)
      PRINT 980, AN2(19),AN2(20),(AN2(II),II=1,18)
      PRINT 1000, ISMALL
      PRINT 1060, ITYPET,KEEP2,NCD2,KEEP3A,NCD3A,KEEP3B,NCD3B,KEEP4,NCD4
     1,KEEP5A,NCD5A,KEEP5B,NCD5B,KEEP5C,NCD5C,IP6,IP7,IP8,IP9,ISMALL
C
COMMENT - CHECK FOR KEEP OPTION ON FIRST PROBLEM OF RUN
C
      KEKE=KEEP2+KEEP3A+KEEP3B+KEEP4+KEEP5A+KEEP5B+KEEP5C
      ITYPEL=ITYPET/10
      ITYPET=ITYPET-10*ITYPEL
      IF (ITIME1.EQ.0.AND.KEKE.NE.0) GO TO 30
      IF (ITYPEL.EQ.1.AND.KEKE.NE.0) GO TO 30
      GO TO 40
   30 CONTINUE
      PRINT 1020
C
COMMENT - ABORT PROBLEM,SEARCH FOR INDEPENDENT PROBLEM
C
      GO TO 890
   40 CONTINUE
C
COMMENT - MAIN PROGRAM STARTS HERE
COMMENT - CALL *INPUT* SUBPROGRAMS, INPUT DATA
C         REPLACE THE OVERLAY CARD BY THE NONOVER CARD UNLESS THE CDC
C         OVERLAY SYSTEM IS USED
COMMENT - IABAN * 0 INDICATES FATAL ERROR FOUND IN SUBROUTINE
C         PROBLEM ABANDONED IN SEARCH OF AN INDEPENDENT PROBLEM
C
      IABAN=0
```

```
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      CALL OVERLAY (5HCNTRL,1,0)
C
C     CALL CNTRL
C
      IF (IABAN.NE.0) GO TO 840
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      CALL OVERLAY (4HMTRL,2,0)
C
C     CALL MTRL
C
      IF (IABAN.NE.0) GO TO 840
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      CALL OVERLAY (4HSCTN,3,0)
C
C     CALL SCTN
C
      IF (IABAN.NE.0) GO TO 840
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      CALL OVERLAY (5HRDMLD,4,0)
C
C     CALL RDMLD
C
      IF (IABAN.NE.0) GO TO 840
C
COMMENT - INITIALIZE VARIABLES FOR NEW PROBLEM
C
      IF (ITYPET.EQ.3) REWIND 1
      IRELA1=0
      ITIME=0
      IPRIN=1
      ITIME1=0
      NL=3*MP1
      MP22=1+M/2
      NELE=MNPC*M
      TIMER=TIMEO
      DO 50 I=1,MP1
         DX(I)=0.0
         DY(I)=0.0
         DZ(I)=0.0
         QX(I)=0.0
         QY(I)=0.0
         QZ(I)=0.0
   50 CONTINUE
      DO 60 I=1,NELE
      DO 60 J=1,2
         ETIME(I,J)=0.0
         STRN(I,J)=0.0
         DSTRN(I,J)=0.0
         DSTRA1(I,J)=0.0
         ISTR(I,J)=111
   60 CONTINUE
      DO 70 I=1,NSUB
         SHSTR(I)=0.0
   70 CONTINUE
      CALL SECOND (ATIME)
      INDEXT=0
      DO 80 I=1,NTIM1
         ITIME1=ITIME1+1
         INDEXT=INDEXT+ITIMES(ITIME1)
         IF ((TIMER-TIME1(ITIME1)).LT.1.0E-30) GO TO 90
   80 CONTINUE
   90 CONTINUE
      ID3=INDEXT/10000
      ID2=(INDEXT-ID3*10000)/100
      ID1=INDEXT-ID3*10000-ID2*100
      IF ((ID2+ID3).GT.0) GO TO 100
      PRINT 1210
      GO TO 880
  100 CONTINUE
      TIMEST=TIME1(ITIME1)*0.99999
      DO 110 I=1,NSUB
         CALL SHRINK (TIMEST,I,SHSTR(I))
  110 CONTINUE
      GO TO 160
C
COMMENT - RETURN HERE FOR NEW TIME INCREMENT
C
  120 CONTINUE
      ITIME1=ITIME1+1
      INDEXT=ITIMES(ITIME1)
      INDEX=1
      ID3=INDEXT/10000
      ID2=(INDEXT-ID3*10000)/100
      ID1=INDEXT-ID3*10000-ID2*100
  130 CONTINUE
      CALL SECOND (ATIME)
      GO TO (140,160,290), INDEX
  140 CONTINUE
      INDEX=2
      TIMEST=TIME1(ITIME1)
      SIGNT=4H
      IF (INDEXT.LE.0) GO TO 150
      TIMEST=TIME1(ITIME1)*0.99999
      SIGNT=4H (-)
  150 CONTINUE
      IF (TIMEST.GT.TIMER*1.00101) GO TO 320
      GO TO 130
  160 CONTINUE
      IF (INDEXT.EQ.0) GO TO 120
      INDEX=3
      TIMEST=TIME1(ITIME1)*1.00001
      SIGNT=4H (+)
      IF (ID1.GT.0) CALL DISCLD (L1)
      IF (ID2.EQ.0) GO TO 190
      DO 170 I=2,MP1
         CALL DEFORM (I,DELTA,TAU1,TAU2)
         CALL FAEUP (I,DELTA,TAU1,TAU2,1)
  170 CONTINUE
      DO 180 I=1,NSUB
         IF (NPOST(I).GT.0) GO TO 180
         IF (TIMEST.LT.TIMESS(I,3)) GO TO 180
         ISUP(I)=4
  180 CONTINUE
  190 CONTINUE
      IF (ID3.EQ.0) GO TO 650
      NELEM=0
      DO 200 J=1,NSUB
         NELEM1=NELEM+1
         NELEM=NELEM+NDIV(J)
```

```
      IF (NPOST(J).LE.0) GO TO 280
      IF (ISUB(J).EQ.4) GO TO 280
      IF (TIMEST.LT.TIMESS(J,3)) GO TO 280
      CALL SSCRV (SIGT,EPST,TIMESS(J,1),TIMEST,NMAT(J),ISJT,NPTT,ET)
      N1=NPTS(J)+1
      N2=NPTS(J+1)
      IF (N2-N1) 250,200,220
200   CONTINUE
      IF (ABS(BI(N1)).LE.1.0E-30) GO TO 280
      SIG=STRI(N1)/BI(N1)
      CALL CURVEI (SIGT,EPST,0.0,SIG,NPTT,ISJT,SIG2,WJN2,ET)
      DO 210 JJ=1,M
      DO 210 K=NELEM1,NELEM
         NELEMT=K+(JJ-1)*MNPC
         STRN(NELEMT,1)=WJN2
         STRN(NELEMT,2)=WJN2
210   CONTINUE
      GO TO 280
220   CONTINUE
      DO 240 JJ=1,M
         ZMUL=JJ-1
         ZMUL=ZMUL+0.5
         X=TH*ZMUL
         IF (NSYM(J).EQ.1.AND.X.GT.XS(N2)) X=2.0*XS(N2)-X
         IF (X.LT.XS(N1).OR.X.GT.XS(N2)) GO TO 240
         CALL SCURV (X,XS,BI,DI,STRI,MNPTS,N1,N2,BT,DT,STRIT)
         IF (ABS(BT).LT.1.0E-30) GO TO 240
         SIG=STRIT/BT
         CALL CURVEI (SIGT,EPST,0.0,SIG,NPTT,ISJT,SIG2,WJN2,ET)
         DO 230 K=NELEM1,NELEM
            NELEMT=K+(JJ-1)*MNPC
            STRN(NELEMT,1)=WJN2
            STRN(NELEMT,2)=WJN2
230      CONTINUE
240   CONTINUE
      GO TO 280
250   CONTINUE
      II=(-NSYM(J)-1)*M
      DO 270 JJ=1,M
         IIJJ=II+JJ
         IF (ABS(BIP(IIJJ)).LE.1.0E-30) GO TO 270
         SIG=STRIP(IIJJ)/BIP(IIJJ)
         CALL CURVEI (SIGT,EPST,0.0,SIG,NPTT,ISJT,SIG2,WJN2,ET)
         DO 260 K=NELEM1,NELEM
            NELEMT=K+(JJ-1)*MNPC
            STRN(NELEMT,1)=WJN2
            STRN(NELEMT,2)=WJN2
260      CONTINUE
270   CONTINUE
280 CONTINUE
    GO TO 650
290 CONTINUE
    IF (ID3.EQ.0) GO TO 120
    DO 300 I=2,MP1
      CALL DEFORM (I,DELTA,TAU1,TAU2)
      CALL FAEUP (I,DELTA,TAU1,TAU2,2)
300 CONTINUE
    DO 310 I=1,NSUB
      IF (TIMEST.LT.TIMESS(I,3)) GO TO 310
      ISUB(I)=4
310 CONTINUE
    GO TO 120
C
COMMENT - TIME-DEPENDENT STRAIN CALCULATION
C
  320 CONTINUE
      DO 330 I=1,NSUB
         CALL SHRINK (TIMEST,I,SHSTR(I))
  330 CONTINUE
      IF (ITYPET.EQ.3) GO TO 430
C
COMMENT - RATE OF CREEP METHOD
C
      NELEM=0
      DO 420 J=1,NSUB
         NELEM1=NELEM+1
         NELEM=NELEM+NDIV(J)
         IF (TIMEST.LE.TIMESS(J,3)) GO TO 420
         NMATT=NMAT(J)
         IF (NEQA(NMATT).LE.0.AND.NEQC(NMATT).LE.0) GO TO 420
         CALL SSCRV (SIGT1,EPST1,TIMESS(J,1),TIMEB,NMATT,ISJT1,NPTT1,ET1
     1   )
         IF (NEQA(NMATT).GT.0) CALL SSCRV (SIGT2,EPST2,TIMESS(J,1),TIMES
     1   T,NMATT,ISJT2,NPTT2,ET2)
         IF (IRELAX(NMATT).LE.0) GO TO 370
         DO 360 K=NELEM1,NELEM
         DO 360 JJ=1,M
            NELEMT=K+(JJ-1)*MNPC
         DO 360 JJJ=1,2
            CALL CURVE (SIGT1,EPST1,STRN(NELEMT,JJJ),NPTT1,ISJT1,SIG,ET1
     1      ,KOFFC)
            IF (NEQA(NMATT).LE.0) GO TO 340
            CALL CURVEI (SIGT2,EPST2,0.0,SIG,NPTT2,ISJT2,SIG2,WJN2,ET2)
            ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+STRN(NELEMT,JJJ)-WJN2
  340       CONTINUE
            IF (NEQC(NMATT).LE.0) GO TO 350
            CALL RELAX (TIMESS(J,3),TIMEB,TIMEST,SIG,NMATT,DTC)
            CALL CURVEI (SIGT1,EPST1,STRN(NELEMT,JJJ),DTC,NPTT1,ISJT1,SI
     1      G1,WJN1,ET1)
            ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+STRN(NELEMT,JJJ)-WJN1
  350       CONTINUE
  360    CONTINUE
         GO TO 420
  370    CONTINUE
         IF (NEQC(NMATT).LE.0) GO TO 380
         IF (NEQA(NMATT).GT.0) CALL SSCRV (SIGT,EPST,TIMESS(J,1),TIMESS(
     1   J,3),NMATT,ISJT,NPTT,ET)
         CALL CREEP (TIMESS(J,1),TIMESS(J,3),TIMEB,NMATT,DTC1)
         CALL CREEP (TIMESS(J,1),TIMESS(J,3),TIMEST,NMATT,DTC2)
         DTC=DTC2-DTC1
  380    CONTINUE
         DO 410 K=NELEM1,NELEM
         DO 410 JJ=1,M
            NELEMT=K+(JJ-1)*MNPC
         DO 410 JJJ=1,2
            WJN=STRN(NELEMT,JJJ)
            CALL CURVE (SIGT1,EPST1,WJN,NPTT1,ISJT1,SIG,ET1,KOFFC)
            IF (NEQA(NMATT).LE.0) GO TO 390
            CALL CURVEI (SIGT2,EPST2,0.0,SIG,NPTT2,ISJT2,SIG,WJN2,ET2)
            ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+STRN(NELEMT,JJJ)-WJN2
  390       CONTINUE
            IF (NEQC(NMATT).LE.0) GO TO 400
            IF (NEQA(NMATT).GT.0) CALL CURVEI (SIGT,EPST,0.0,SIG,NPTT,IS
     1      JT,SIG,WJN,ET)
```

```
           ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+WJN*DTC
  400      CONTINUE
  410    CONTINUE
  420 CONTINUE
      GO TO 650
C
COMMENT - SUPERPOSITION METHOD
C
  430 CONTINUE
      IF (ITIME.GT.0) GO TO 450
      DO 440 I=1,NELE
      DO 440 J=1,2
         DSTRN(I,J)=STRN(I,J)
  440 CONTINUE
      GO TO 500
  450 CONTINUE
      NELEM=0
      DO 490 J=1,NSUB
         NELEM1=NELEM+1
         NELEM=NELEM+NDIV(J)
         IF (TIMEST.LE.TIMESS(J,3)) GO TO 490
         NMATT=NMAT(J)
         IF (NEQC(NMATT).LE.0) GO TO 490
         IF (IRELAX(NMATT).GT.0) GO TO 490
         DO 480 K=NELEM1,NELEM
         DO 480 JJ=1,M
            NELEMT=K+(JJ-1)*MNPC
         DO 480 JJJ=1,2
            IF ((DSTRN(NELEMT,JJJ)*STRN(NELEMT,JJJ)).GT.1.0E-30) GO TO 4
     1      60
            DSTRN(NELEMT,JJJ)=STRN(NELEMT,JJJ)-C(NMATT,10)*DSTRN(NELEMT,
     1      JJJ)
            GO TO 470
  460       CONTINUE
            DSTRN(NELEMT,JJJ)=STRN(NELEMT,JJJ)-DSTRN(NELEMT,JJJ)
            IF ((DSTRN(NELEMT,JJJ)*STRN(NELEMT,JJJ)).LT.-1.0E-30) DSTRN(
     1      NELEMT,JJJ)=C(NMATT,10)*DSTRN(NELEMT,JJJ)
  470       CONTINUE
  480    CONTINUE
  490 CONTINUE
  500 CONTINUE
      WRITE (1) TIMEB
      WRITE (1) ((DSTRN(I,J),I=1,NELE),J=1,2)
      IF (ITIME.LE.0) GO TO 520
      DO 510 I=1,NELE
      DO 510 J=1,2
         DSTRN(I,J)=STRN(I,J)
  510 CONTINUE
  520 CONTINUE
      REWIND 1
      ITIME=ITIME+1
      NELEM=0
      DO 550 J=1,NSUB
         NELEM1=NELEM+1
         NELEM=NELEM+NDIV(J)
         IF (TIMEST.LE.TIMESS(J,3)) GO TO 550
         NMATT=NMAT(J)
         IF (IRELAX(NMATT).LE.0) GO TO 530
         IRELA1=1
         GO TO 550
  530    CONTINUE
         IF (NEQA(NMATT).LE.0) GO TO 550
         CALL SSCRV (SIGT1,EPST1,TIMESS(J,1),TIMEB,NMATT,ISJT1,NPTT1,ET1
     1   )
         CALL SSCRV (SIGT2,EPST2,TIMESS(J,1),TIMEST,NMATT,ISJT2,NPTT2,ET
     1   2)
         DO 540 K=NELEM1,NELEM
         DO 540 JJ=1,M
            NELEMT=K+(JJ-1)*MNPC
         DO 540 JJJ=1,2
            CALL CURVE (SIGT1,EPST1,STRN(NELEMT,JJJ),NPTT1,ISJT1,SIG,ET1
     1      ,KOFFC)
            CALL CURVEI (SIGT2,EPST2,0.0,SIG,NPTT2,ISJT2,SIG2,DSTRN(NELE
     1      MT,JJJ),ET2)
            ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+STRN(NELEMT,JJJ)-DSTRN(N
     1      ELEMT,JJJ)
  540    CONTINUE
  550 CONTINUE
      IF (IRELA1.NE.1) GO TO 600
      NELEM=0
      DO 590 J=1,NSUB
         NELEM1=NELEM+1
         NELEM=NELEM+NDIV(J)
         IF (TIMEST.LE.TIMESS(J,3)) GO TO 590
         NMATT=NMAT(J)
         IF (NEQA(NMATT).LE.0.AND.NEQC(NMATT).LE.0) GO TO 590
         IF (IRELAX(NMATT).LE.0) GO TO 590
         CALL SSCRV (SIGT1,EPST1,TIMESS(J,1),TIMEB,NMATT,ISJT1,NPTT1,ET1
     1   )
         IF (NEQA(NMATT).GT.0) CALL SSCRV (SIGT2,EPST2,TIMESS(J,1),TIMES
     1   T,NMATT,ISJT2,NPTT2,ET2)
         DO 580 K=NELEM1,NELEM
         DO 580 JJ=1,M
            NELEMT=K+(JJ-1)*MNPC
         DO 580 JJJ=1,2
            CALL CURVE (SIGT1,EPST1,STRN(NELEMT,JJJ),NPTT1,ISJT1,SIG,ET1
     1      ,KOFFC)
            IF (NEQA(NMATT).LE.0) GO TO 560
            CALL CURVEI (SIGT2,EPST2,0.0,SIG,NPTT2,ISJT2,SIG2,WJN2,ET2)
            ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+STRN(NELEMT,JJJ)-WJN2
  560       CONTINUE
            IF (NEQC(NMATT).LE.0) GO TO 570
            CALL RELAX (TIMESS(J,3),TIMEB,TIMEST,SIG,NMATT,DTC)
            CALL CURVEI (SIGT1,EPST1,STRN(NELEMT,JJJ),DTC,NPTT1,ISJT1,SI
     1      G1,WJN1,ET1)
            ETIME(NELEMT,JJJ)=ETIME(NELEMT,JJJ)+STRN(NELEMT,JJJ)-WJN1
  570       CONTINUE
  580    CONTINUE
  590 CONTINUE
  600 CONTINUE
      DO 640 I=1,ITIME
         READ (1) TTIME
         READ (1) ((STRN(J,K),J=1,NELE),K=1,2)
         NELEM=0
         DO 630 J=1,NSUB
            NELEM1=NELEM+1
            NELEM=NELEM+NDIV(J)
            IF (TIMEST.LE.TIMESS(J,3)) GO TO 630
            IF (TTIME.LT.TIMESS(J,3)) GO TO 630
            NMATT=NMAT(J)
            IF (NEQC(NMATT).LE.0) GO TO 630
            IF (IRELAX(NMATT).GT.0) GO TO 630
            CALL CREEP (TIMESS(J,1),TTIME,TIMEB,NMATT,DTC1)
            CALL CREEP (TIMESS(J,1),TTIME,TIMEST,NMATT,DTC2)
```

```
      DTC=DTC2-DTC1
      DO 620 K=NELEM1,NELEM
      DO 620 JJ=1,M
         NELEMT=K+(JJ-1)*MNPC
      DO 620 JJJ=1,2
         IF (NFOC(NMATT).LE.0) GO TO 610
         ETIME(NELEMT,JJJ)=FTIME(NELEMT,JJJ)+DTC*STRN(NELEMT,JJJ)
  610    CONTINUE
  620 CONTINUE
  630    CONTINUE
  640 CONTINUE
  650 CONTINUE
C
COMMENT - CALCULATE EQUILIBRIUM POSITION
C
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      PRINT 1000, ISMALL
      PRINT 1110, ITIME1,TIMEST,SIGNT
      PRINT 1150
      PRINT 1030, ATIME
      MHT=MH
      IF (TIMEST.LT.TPRINT(IPRIN)) MH=0
      CALL MEMSOL (L1,L4)
      MH=MHT
      CALL SECOND (ATIMET)
      ATIMET=ATIMET-ATIME
      PRINT 1040, ATIMET
      IF (NITM.LE.MNITM) GO TO 660
      PRINT 1080
      GO TO 670
  660 CONTINUE
      IF (TIMEST.LT.TPRINT(IPRIN)) GO TO 830
      IPRIN=IPRIN+1
  670 CONTINUE
C
COMMENT - PRINT TABLE 7 - MEMBER RESULTS
C
      IF (IP7.EQ.1) GO TO 730
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(I),I=1,18)
      PRINT 1000, ISMALL
      PRINT 1110, ITIME1,TIMEST,SIGNT
      PRINT 1070
      IF (NITM.GT.MNITM) PRINT 1080
      PRINT 1090
      DIS=0.0
      I=1
      T=-SQX(I)
      V=SQY(I)
      BM=-SQZ(I)
      PRINT 1100, I,DIS,DX(I),DY(I),DZ(I),SQX(I),SQY(I),SQZ(I),T,V,BM
      IP1=2
      IF (ISMALL.EQ.1) GO TO 680
      CALL ELEMFO (DX(I),DY(I),DZ(I),DX(IP1),DY(IP1),DZ(IP1),IP1,U1T,V1T
     1,W1T,U2T,V2T,W2T)
      GO TO 690
  680 CONTINUE
      CALL ELEMF2 (DX(I),DY(I),DZ(I),DX(IP1),DY(IP1),DZ(IP1),IP1,U1T,V1T
     1,W1T,U2T,V2T,W2T)
  690 CONTINUE
      DO 720 I=2,M
         T=U2T
         V=-V2T
         BM=W2T
         IP1=I+1
         DIS=DIS+TH
         IF (ISMALL.EQ.1) GO TO 700
         CALL ELEMFO (DX(I),DY(I),DZ(I),DX(IP1),DY(IP1),DZ(IP1),IP1,U1T,
     1   V1T,W1T,U2T,V2T,W2T)
         GO TO 710
  700    CONTINUE
         CALL ELEMF2 (DX(I),DY(I),DZ(I),DX(IP1),DY(IP1),DZ(IP1),IP1,U1T,
     1   V1T,W1T,U2T,V2T,W2T)
  710    CONTINUE
         T=(T-U1T)/2.0
         V=(V+V1T)/2.0
         BM=(BM-W1T)/2.0
         PRINT 1100, I,DIS,DX(I),DY(I),DZ(I),SQX(I),SQY(I),SQZ(I),T,V,BM
  720 CONTINUE
      I=MP1
      DIS=DIS+TH
      T=SQX(I)
      V=-SQY(I)
      BM=SQZ(I)
      PRINT 1100, I,DIS,DX(I),DY(I),DZ(I),SQX(I),SQY(I),SQZ(I),T,V,BM
  730 CONTINUE
C
COMMENT - PRINT TABLE 8 - FIBER STRAINS
C
      IF (IP8.EQ.1) GO TO 750
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      PRINT 1000, ISMALL
      PRINT 1110, ITIME1,TIMEST,SIGNT
      PRINT 1120
      PRINT 1130
      NELEM=0
      DO 740 JJ=1,M
      DO 740 J=1,NSUB
         NELEM1=NELEM+1
         NELEM=NELEM+NDIV(J)
         NDIVT=0
      DO 740 K=NELEM1,NELEM
         NDIVT=NDIVT+1
         PRINT 1140, JJ,J,NDIVT,SHSTR(J),ETIME(K,1),FTIME(K,2),STRN(K,1)
     1   ,STRN(K,2),ISTR(K,1),ISTR(K,2)
  740 CONTINUE
  750 CONTINUE
C
COMMENT - PRINT TABLE 9 - FIBER STRESSES
C
      IF (IP9.EQ.1) GO TO 830
      PRINT 930
      PRINT 990, AN2(19),AN2(20),(AN2(II),II=1,18)
      PRINT 1000, ISMALL
      PRINT 1110, ITIME1,TIMEST,SIGNT
      PRINT 1160
      IF (NITM.GT.MNITM) PRINT 1080
      PRINT 1170
      NELEM=0
      DO 820 JJ=1,M
      DO 820 J=1,NSUB
         NELEM1=NELEM+1
```

```
      NELEM=NELEM+NDIV(J)
      NDIVT=0
      IF (TIMEST.GE.TIMESS(J,3)) CALL SSCRV (SIGT,EPST,TIMESS(J,1),TI
     1 MEST,NMAT(J),ISJT,NPTT,ET)
      DO 820 K=NELEM1,NELEM
      NDIVT=NDIVT+1
      SIG1=0.0
      SIG2=0.0
      IF (TIMEST.LT.TIMESS(J,3)) GO TO 810
      IF (ISTR(K,1)-222) 770,760,780
  760 CONTINUE
      IF (STRN(K,1).GE.0.0) GO TO 780
  770 CONTINUE
      CALL CURVE (SIGT,EPST,STRN(K,1),NPTT,ISJT,SIG1,ET,KOFFC)
  780 CONTINUE
      IF (ISTR(K,2)-222) 800,790,810
  790 CONTINUE
      IF (STRN(K,2).GE.0.0) GO TO 810
  800 CONTINUE
      CALL CURVE (SIGT,EPST,STRN(K,2),NPTT,ISJT,SIG2,FT,KOFFC)
  810 CONTINUE
      PRINT 1140, JJ,J,NDIVT,SIG1,SIG2
  820 CONTINUE
  830 CONTINUE
      IF (NITM.GT.MNITH) GO TO 880
      IF (TIMEST.GE.FTIME) GO TO 10
      TIMEB=TIMEST
      GO TO 130
  840 CONTINUE
      GO TO (850,860,870,880), IABAN
  850 PRINT 1180
      GO TO 880
  860 PRINT 1190
      GO TO 880
  870 PRINT 1200
  880 PRINT 1010
  890 CONTINUE
C
COMMENT - SOLUTION ABANDONED, SEARCH FOR INDEPENDENT PROBLEM BEGIN HERE
C
      READ 960, NPROB,AN2(19),AN2(20),(AN2(II),II=1,18)
      IF (NPROB(1).EQ.4HSTAR) GO TO 900
      IF (NPROB(1).EQ.4HCEAS) GO TO 910
      PRINT 970, NPROB,AN2(19),AN2(20),(AN2(II),II=1,18)
      GO TO 890
  900 CONTINUE
      READ 1050, ITYPET,KEEP2,KEEP3A,KEEP3B,KEEP4,KEEP5A,KEEP5B,KEEP5C,I
     1P6,IP7,IP8,IP9,NCD2,NCD3A,NCD3B,NCD4,NCD5A,NCD5B,NCD5C,ISMALL
      KEKE=KEEP2+KEEP3A+KEEP3B+KEEP4+KEEP5A+KEEP5B+KEEP5C
      IF (KEKE.EQ.0) GO TO 20
      PRINT 980, AN2(19),AN2(20),(AN2(II),II=1,18)
      PRINT 1060, ITYPET,KEEP2,NCD2,KEEP3A,NCD3A,KEEP3B,NCD3B,KEEP4,NCD4
     1,KEEP5A,NCD5A,KEEP5B,NCD5B,KEEP5C,NCD5C,IP6,IP7,IP8,IP9,ISMALL
      GO TO 890
  910 CONTINUE
      STOP
C
  920 FORMAT (18H     PROGRAM PBEAM,/,26H     ANALYSIS OF TIME DEPE,46HN
     1DENT RESPONDS OF PRESTRESSED CONTINUOUS BEAMS,/,25H     BY C. SUTT
     2IKAN, 1977,/)
  930 FORMAT (5H1     )
  940 FORMAT (20A4)
  950 FORMAT (5X,20A4)
  960 FORMAT (A4,A1,A4,A1,A2,17A4)
  970 FORMAT (1X,A4,A1,A4,A1,A2,17A4)
  980 FORMAT (///,10H     PROB ,/,5X,A4,A1,5X,A2,17A4)
  990 FORMAT (///,17H     PROB (CONTD),/,/,5X,A4,A1,5X,A2,17A4,/)
 1000 FORMAT (10X,7HISMALL=,I3,36H (0=LARGE, 1=SMALL ANGLES SOLUTION )/)
 1010 FORMAT (///51H     SOLUTION ABANDONED IN SEARCH OF AN INDEPENDENT,
     110H PROBLEM  ,//,49H     THE FOLLOWING CARDS WERE DISCARDED IN SEA
     2RCH,//)
 1020 FORMAT (//,50H     NO HOLD OPTIONS MAY BE EXERCISED ON FIRST PRO,1
     15HBLEM OF RUN    )
 1030 FORMAT (/,10X,14HTIME ELAPESD =,F8.3,35H SECONDS AT THE START OF T
     1HIS TIME ,9HINCREMENT)
 1040 FORMAT (//,10X,15HTIME CONSUMED =,F8.3,31H SECONDS BY THIS TIME IN
     1CREMENT)
 1050 FORMAT (12I5,/,5X,8I5)
 1060 FORMAT (8/,35H     TABLE 1 - PROGRAM CONTROL DATA,/,17H     PROBLE
     1M TYPE,I5,///,25X,12HINPUT TABLES,//,10X,45H  TABLE     HOLD DATA F
     2ROM     NUMBER OF CARDS,/,10X,45H NUMBER     LAST PROBLEM      ADD
     3ED FOR THIS ,/,10X,45H          (1 = YES,0 = NO)     PROBLEM
     4 ,//,10X,5H     2,10X,I5,15X,I5,/,10X,5H    3A,10X,I5,15X,I5,/,10X,5
     5H    3B,10X,I5,15X,I5,/,10X,5H     4,10X,I5,15X,I5,/,10X,5H    5A,10X
     6,I5,15X,I5,/,10X,5H    5B,10X,I5,15X,I5,/,10X,5H    5C,10X,I5,15X,I5
     7,//,25X,13HOUTPUT TABLES,//,10X,25H TABLE   SUPPRESS OUTPUT ,/,10X
     8,25H NUMBER  (1 = YES,0 = NO),/,10X,5H     6,10X,I5,/,10X,5H     7,1
     90X,I5,/,10X,5H     8,10X,I5,/,10X,5H     9,10X,I5,//,9X,7HISMALL=,I5
     *,40H (0=LARGE, 1=SMALL  ANGLES SOLUTION  )  )
 1070 FORMAT (29H     TABLE 7 - MEMBER RESULTS,/)
 1080 FORMAT (/,31H     SOLUTION DID NOT CONVERGED,/)
 1090 FORMAT (34X,52HDISPLACEMENTS                          REACTIONS
     1 ,29H                  FORCES,/,53H      STA.  DISTANCE
     2AXIAL      LATERAL   ROTATI,53HONAL      AXIAL      LATERAL    ROTAT
     3IONAL      AXIAL    ,22H     SHEAR        MOMENT)
 1100 FORMAT (5X,I5,10E12.3)
 1110 FORMAT (19H     TIME INCREMENT,I5,14H     TIME    = ,E12.3,A4,/)
 1120 FORMAT (28H     TABLE 8 - FIBER STRAINS,/)
 1130 FORMAT (53H     ELEMENT  SUB-RECT. DIVISION  SHR. STRAINS CREEP ,5
     13HOR RELAX. STRAINS  INSTANTANEOUS STRAINS  STRAIN INDI,6HCATORS,/
     2,50X,49HLEFT         RIGHT         LEFT        RIGHT        LEF,13HT
     3   RIGHT)
 1140 FORMAT (5X,I5,2I10,5E12.3,I7,I10)
 1150 FORMAT (29H     TABLE 6 - ITERATION DATA,//)
 1160 FORMAT (29H     TABLE 9 - FIBER STRESSES,/)
 1170 FORMAT (46H     ELEMT  SUB-RECT. DIVISION          STRESSES,/,38X,16
     1HLEFT        RIGHT,/)
 1180 FORMAT (//,53H     ERROR IN NUMBER OF CARDS SPECIFIED OR CARDS REA
     1D)
 1190 FORMAT (//,39H     COMPUTER STORAGE PROVIDED EXCEEDED)
 1200 FORMAT (//,40H     ERROR(S) IN PRECEDING INPUT CARD(S))
 1210 FORMAT (//,52H     NO MEMBER EXISTS AT THE STARTING OF THE PROBLEM
     1)
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE AGE (TIME00,TIMEST,NMATT,REPS,RSIG)
C
COMMENT - SUBROUTINE AGE FINDS STRESS AND STRAIN CORRECTION FACTORS DUE
C         TO AGING OF MATERIAL AT TIME TIMEST OF MATERIAL CASTED
C         AT TIME TIME00
```

```
C
      DIMENSION XST(8),BIT(8)
      COMMON/BLOCK2/        EM(10),IRELAX(10),  NEQA(10),  NEQC(10),
     1         NEQS(10),   NSS(10),     SM(10), STMAX(10), STMIN(10),
     2         UWT(10),
     3        A(10,8),     AT(10,8),     A1(10,8),    A1T(10,8),
     4       C(10,10),     CT(10,8),     C1(10,8),    C1T(10,8),
     5        S(10,8),    SRT(10,8)
      T=TIMEST-TIME00
      ID=NEQA(NMATT)
      IF (ID.GT.10) GO TO 120
      GO TO (10,30,40,50,60,70,80,90,100,110), ID
   10 CONTINUE
C
COMMENT - THE A.C.I.=S AGE FUNCTION
C
      IF (T.GT.0.0) GO TO 20
      RSIG=0.0
      REPS=1.0
      GO TO 200
   20 CONTINUE
      RSIG=T/(A(NMATT,1)+A(NMATT,2)*T)
      IF (RSIG.LE.0.0) GO TO 210
      REPS=SQRT(RSIG)
      GO TO 200
   30 CONTINUE
      GO TO 210
   40 CONTINUE
      GO TO 210
   50 CONTINUE
      GO TO 210
   60 CONTINUE
      GO TO 210
   70 CONTINUE
      GO TO 210
   80 CONTINUE
      GO TO 210
   90 CONTINUE
      GO TO 210
  100 CONTINUE
      GO TO 210
  110 CONTINUE
      GO TO 210
  120 CONTINUE
      IF (T.LE.AT(NMATT,1)) GO TO 140
      IF (T.GE.AT(NMATT,8)) GO TO 150
      DO 130 I=1,8
         BIT(I)=A(NMATT,I)
         XST(I)=AT(NMATT,I)
  130 CONTINUE
      CALL SCURV1 (T,XST,BIT,8,8,1,8,RSIG)
      GO TO 160
  140 RSIG=A(NMATT,1)
      GO TO 160
  150 RSTG=A(NMATT,8)
  160 CONTINUE
      IF (T.LE.A1T(NMATT,1)) GO TO 180
      IF (T.GE.A1T(NMATT,8)) GO TO 190
      DO 170 I=1,8
         BIT(I)=A1(NMATT,I)
         XST(I)=A1T(NMATT,I)
  170 CONTINUE
      CALL SCURV1 (T,XST,BIT,8,8,1,8,REPS)
      GO TO 200
  180 REPS=A1(NMATT,1)
      GO TO 200
  190 REPS=A1(NMATT,8)
  200 CONTINUE
      RETURN
  210 PRINT 220
      STOP
C
  220 FORMAT (//, 48H     ERROR FOUND IN AGE FUNCTION, EXECUTION STOP)
C
      END
C***********************************************************************
C*                       S U B R O U T I N E                           *
C***********************************************************************
C
      SUBROUTINE CONLD (QI,Z,QO,L1)
C
COMMENT - SUBROUTINE CONLD DISTRIBUTES CONCENTRATED VALUE OF LOADS,
C         SPRINGS, STIFFNESSES AND RESISTIVE SPRING FORCES TO ADJACENT
C         STATIONS I AND IP1
C
       DIMENSION QO(L1)
      COMMON/BLK4/        H,   IDS,  IDS5,ISHALL,KOFFQW,KOFFSE,     M,
     1            MIDS5,   MP1,  MP22,  NELE,     TH,     ZL
      ZI=Z/TH+1.0
      I=ZI
      IF (I.EQ.MP1) GO TO 10
      ZZ=Z-I*TH+TH
      IP1=I+1
      QO(I)=QO(I)+QI*(TH-ZZ)/TH
      QO(IP1)=QO(IP1)+QI*ZZ/TH
      GO TO 20
   10 QO(I)=QO(I)+QI
   20 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                       S U B R O U T I N E                           *
C***********************************************************************
C
      SUBROUTINE CREEP(TIME00,TIME1,TIMEST,NMATT,DTC)
C
COMMENT - SUBROUTINE CREEP CALCULATES SPECIFIC CREEP AT TIME TIMEST FOR
C         MATERIAL CASTED AT TIME TIME00 AND LOADED AT TIME TIME1
C
      DIMENSION BIT(8),XST(8)
      COMMON/BLOCK2/        EM(10),IRELAX(10),  NEQA(10),  NEQC(10),
     1         NEQS(10),   NSS(10),     SM(10), STMAX(10), STMIN(10),
     2         UWT(10),
     3        A(10,8),     AT(10,8),     A1(10,8),    A1T(10,8),
     4       C(10,10),     CT(10,8),     C1(10,8),    C1T(10,8),
     5        S(10,8),    SRT(10,8)
      CCLA=1.0
      ID=NEQC(NMATT)
      IF (ID.GT.10) GO TO 170
      GO TO (10,20,30,70,110,120,130,140,150,160), ID
   10 CONTINUE
C
COMMENT - THE A.C.I.=S CREEP FUNCTION
```

```
C
      CCLA=C(NMATT,3)*(TIME1-TIME00)**C(NMATT,4)
   20 CONTINUE
      T1=(TIMEST-TIME1)**C(NMATT,1)
      DTC=T1/(C(NMATT,2)+T1)
      GO TO 250
   30 CONTINUE
C
COMMENT - THE P.C.I.*S CREEP FUNCTION
C
      T0=TIME1-TIME00
      IF (T0.LE.0.0) GO TO 50
      IF (T0.GE.40.0) GO TO 60
      IF (T0.GT.7.17) GO TO 40
      CCLA=1.245-0.035*T0
      GO TO 70
   40 CCLA=1.08-0.012*T0
      GO TO 70
   50 CCLA=1.245
      GO TO 70
   60 CCLA=0.60
   70 CONTINUE
      T1=TIMEST-TIME1
      IF (T1.LE.1.0) GO TO 90
      IF (T1.GE.2100.0) GO TO 100
      IF (T1.GT.23.4) GO TO 80
      DTC=0.0856+0.1608*ALOG10(T1)
      GO TO 250
   80 DTC=-0.1817+0.3559*ALOG10(T1)
      GO TO 250
   90 DTC=0.0856*T1
      GO TO 250
  100 DTC=1.0
      GO TO 250
  110 CONTINUE
      GO TO 260
  120 CONTINUE
      GO TO 260
  130 CONTINUE
      GO TO 260
  140 CONTINUE
      GO TO 260
  150 CONTINUE
      GO TO 260
  160 CONTINUE
      GO TO 260
  170 CONTINUE
C
COMMENT - CREEP FUNCTIONS INPUT AS CURVES
C
      T0=TIME1-TIME00
      IF (T0.LE.C1T(NMATT,1)) GO TO 190
      IF (T0.GE.C1T(NMATT,8)) GO TO 200
      DO 180 I=1,8
         BIT(I)=C1(NMATT,I)
         XST(I)=C1T(NMATT,I)
  180 CONTINUE
      CALL SCURV1 (T0,XST,BIT,8,8,1,8,CCLA)
      GO TO 210
  190 CCLA=C1(NMATT,1)
      GO TO 210
  200 CCLA=C1(NMATT,8)
  210 CONTINUE
      T1=TIMEST-TIME1
      IF (T1.LE.CT(NMATT,1)) GO TO 230
      IF (T1.GE.CT(NMATT,8)) GO TO 240
      DO 220 I=1,8
         BIT(I)=C(NMATT,I)
         XST(I)=CT(NMATT,I)
  220 CONTINUE
      CALL SCURV1 (T1,XST,BIT,8,8,1,8,DTC)
      GO TO 250
  230 CONTINUE
      DTC=C(NMATT,1)
      GO TO 250
  240 CONTINUE
      DTC=C(NMATT,8)
  250 CONTINUE
      DTC=DTC*CCLA*C(NMATT,9)
      RETURN
  260 PRINT 270
      STOP
C
  270 FORMAT (//, 50H     ERROR FOUND IN CREEP FUNCTION, EXECUTION STOP)
C
      END
C**********************************************************************
C*                       S U B R O U T I N E                          *
C**********************************************************************
C
      SUBROUTINE CURVE (QQ,WW,WJ,NPT,ISYM,QJ,S2,KOFFC)
C
COMMENT - SUBROUTINE CURVE INTERPOLATES ALONG A STRESS-STRAIN OR
C          SUPPORT CURVE TO FIND THE STRESS OR FOR
C          CORRESPONDING TO THE STRAIN OR DISPLACEMENT WJ AND THE
C          SLOPE OF THE CURVE S2 BETWEEN ADJECENT POINTS
C          ON THE CURVE, IF WJ IS OFF CURVE, KOFFC IS SET EQUAL TO 1,
C          IF WJ IS EXACTLY ON A POINT, THE SLOPE OF THE SEGMENT TO THE
C          RIGHT (INCREASING DEFORMATION) IS USED
C          OR ESTIMATE WJ IF S2 IS GIVEN
C
      DIMENSION QQ(12),WW(12)
      IF (NPT.LE.0) GO TO 90
      NEG=0
      WJT=WJ
      IF (ISYM.EQ.1.AND.WJT.LT.0.0) GO TO 10
      GO TO 20
   10 CONTINUE
      WJT=-WJT
      NEG=1
   20 CONTINUE
      DO 30 NP=2,NPT
         IF (WJT-WW(NP)) 50,40,30
   30 CONTINUE
      NP=NPT
      GO TO 60
   40 CONTINUE
      IF (NP.EQ.NPT) GO TO 70
      IF (WJT.GT.0.0) NP=NP+1
      GO TO 70
   50 CONTINUE
      IF (WJT-WW(1)) 60,70,70
   60 CONTINUE
      KOFFC=1
```

```
   70 CONTINUE
      S2=(QQ(NP)-QQ(NP-1))/(WW(NP)-WW(NP-1))
      QJ=QQ(NP-1)+S2*(WJT-WW(NP-1))
      IF (NEG.EQ.0) GO TO 80
      QJ=-QJ
      WJT=-WJT
   80 CONTINUE
      GO TO 100
   90 CONTINUE
      QJ=WJ*S2
  100 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                         S U B R O U T I N E                         *
C***********************************************************************
C
      SUBROUTINE CURVEI (QQ,WW,WJ,DS,NPT,ISYM,QJN,WJN,S2)
C
COMMENT - SUBROUTINE CURVEI INTERPOLATES ALONG A STRESS-STRAIN CURVE TO
C         FIND STRESS, STRAIN AND SLOPE OF THE CURVE GIVEN THE
C         OLD STRAIN LEVEL AND THE CHANGE OF STRESS.
C         FOR DECREASING STRESS, THE CLOSEST LOWER STRAIN WILL BE USED.
C         FOR INCREASING STRESS, THE CLOSEST HIGHER STRAIN WILL BE USED.
C
      DIMENSION QQ(12),WW(12)
      IF (NPT.LE.0) GO TO 170
      WJT=WJ
      NEG=1
      IF (ISYM.EQ.1.AND.WJT.LT.0.0) GO TO 10
      GO TO 20
   10 CONTINUE
      WJT=-WJT
      DS=-DS
      NEG=-NEG
      GO TO 30
   20 CONTINUE
      IF (WJT.GT.WW(1)) GO TO 30
      NP=2
      GO TO 60
   30 CONTINUE
      IF (WJT.LT.WW(NPT)) GO TO 40
      NP=NPT
      GO TO 60
   40 CONTINUE
      DO 50 NP=2,NPT
         IF (WJT.LE.WW(NP)) GO TO 60
   50 CONTINUE
   60 CONTINUE
      QJ=QQ(NP-1)+(QQ(NP)-QQ(NP-1))*(WJT-WW(NP-1))/(WW(NP)-WW(NP-1))
      QJN=QJ+DS
      IF (ABS(DS).GT.1.0E-30) GO TO 70
      WJN=WJT
      S2=(QQ(NP)-QQ(NP-1))/(WW(NP)-WW(NP-1))
      GO TO 160
   70 CONTINUE
      IF (ISYM.EQ.1.AND.QJN.LT.0.0) GO TO 80
      GO TO 90
   80 CONTINUE
      WJT=-WJT
      DS=-DS
      QJN=-QJN
      NEG=-NEG
      NP=2
   90 CONTINUE
      IF (DS.GT.0.0) GO TO 110
      DO 100 I=2,NP
         N=NP-I+1
         IF (QJN-QQ(N)) 100,130,140
  100 CONTINUE
      IF (QQ(1).LT.QQ(2)) GO TO 140
      WJN=-1.0E30
      QJN=0.0
      S2=0.0
      GO TO 160
  110 CONTINUE
      DO 120 N=NP,NPT
         IF (QJN-QQ(N)) 150,130,120
  120 CONTINUE
      IF (QQ(NPT).GT.QQ(NPT-1)) GO TO 150
      WJN=1.0E30
      QJN=0.0
      S2=0.0
      GO TO 160
  130 CONTINUE
      IF (N.EQ.1) N=N+1
      WJN=WW(N)
      S2=(QQ(N)-QQ(N-1))/(WW(N)-WW(N-1))
      GO TO 160
  140 N=N+1
  150 S2=(QQ(N)-QQ(N-1))/(WW(N)-WW(N-1))
      WJN=WW(N-1)+(QJN-QQ(N-1))/S2
  160 CONTINUE
      IF (NEG.EQ.1) GO TO 180
      WJT=-WJT
      DS=-DS
      QJN=-QJN
      WJN=-WJN
      GO TO 180
  170 CONTINUE
      WJN=WJ+DS/S2
      QJN=WJN*S2
  180 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                         S U B R O U T I N E                         *
C***********************************************************************
C
      SUBROUTINE DEFORM(I,DELTA,TAU1,TAU2)
C
COMMENT - SUBROUTINE DEFORM COMPUTES AXIAL AND ROTATIONAL DEFORMATIONS
C         OF A DISCRETE ELEMENT FROM DX, DY AND DZ
C
      COMMON/BLOCKA/     BM1S(81),  BM2S(81),    DX(81),    DY(81),
     1            DZ(81),   ERX(81),   ERY(81),   ERZ(81),   QX(81),
     2            QY(81),    QZ(81),   SQX(81),   SQY(81),  SQZ(81),
     3            SX(81),    SY(81),    SZ(81),   TTS(81),   DS(81,5)
      COMMON/BLK4/        H,   IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1            MIDS5,   MP1,  MP22,   NELE,     TH,     ZL
      IM1=I-1
      DDX=DX(I)-DX(IM1)
```

```
      DDY=DY(I)-DY(IM1)
      DZ1=DZ(IM1)
      DZ2=DZ(I)
      IF (ISMALL.EQ.1) GO TO 10
      COSIM1=COS(DZ1)
      COSI=COS(DZ2)
      SINIM1=SIN(DZ1)
      SINI=SIN(DZ2)
      COSCOS=COSI+COSIM1
      SINSIN=SINI+SINIM1
      R=DDX+H*(1.0-0.5*COSCOS)
      S=DDY-0.5*H*SINSIN
      HPR=H+R
      HPD=(HPR*HPR+S*S)**0.5
      DELTA=HPD-H
      THETA=ATAN(S/HPR)
      GO TO 20
   10 CONTINUE
      R=DDX
      S=DDY-0.5*H*(DZ1+DZ2)
      HPR=H+R
      DELTA=DDX
      THETA=S/HPR
   20 CONTINUE
      TAU1=THETA-DZ1
      TAU2=DZ2-THETA
      RETURN
C
      END
C***********************************************************************
C*                       S U B R O U T I N E                           *
C***********************************************************************
C
      SUBROUTINE DISCLD (L1)
C
COMMENT - SUBROUTINE DISCLD DISCRETE GRAVITY AND MEMBER LOADS TO THE
C         STATION LOADS
C
      COMMON/BLOCK2/       EM(10),IRELAX(10),  NEQA(10),  NEQC(10),
     1         NEQS(10),   NSS(10),    SM(10), STMAX(10), STMIN(10),
     2          UWT(10),
     3       A(10,8),     AT(10,8),     A1(10,8),   A1T(10,8),
     4      C(10,10),     CT(10,8),     C1(10,8),   C1T(10,8),
     5       S(10,8),    SRT(10,8)
      COMMON/BLOCK4/       ISUR(30),  NDIV(30),  NMAT(30),  NSYM(30),
     1        NPOST(30),  NPTS(31),TIMESS(30,3),
     2          BI(100),   DI(100),   CG(100),   XS(100), STRI(100),
     3         BIP(400),  DIP(400),  CGP(400),STRIP(400)
      COMMON/BLOCK5/       IDLD(20), TIMED(20),    NPD(21),
     1          QXD(40),   QYD(40),   QZD(40),   XSD(40),
     2         ICLD(30),   QXC(30),   QYC(30),   QZC(30), TIMEC(30),
     3          XSC(30)
      COMMON/BLOCK8/       BM1S(81),  BM2S(81),     DX(81),     DY(81),
     1          DZ(81),    ERX(81),   ERY(81),   ERZ(81),    QX(81),
     2          QY(81),     QZ(81),   SQX(81),   SQY(81),   SQZ(81),
     3          SX(81),     SY(81),    SZ(81),   TTS(81),   DS(81,5)
      COMMON/BLK1/    IABAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1        KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2         MTSUB, MMTER, MNCLD,  MNCS, MNDLD,  MNDS,   MNE,  MNEQ,
     3         MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,  MNSS, MPOST,MTIME1
      COMMON/BLK2/   NPRINL, NTIM1, FTIME, TIMEO,TIMEST
      COMMON/BLK4/          H,    IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1         MIDS5,    MP1,   MP22,   NELE,     TH,     ZL
      COMMON/BLK5/      MNPC,  NCLD,    NCS,   NDLD,    NDS,NPOSTL,  NSUB
C
COMMENT - DISCRETE GRAVITY LOAD
C
      DO 90 J=1,NSUB
         IF (ISUR(J).GT.0) GO TO 90
         IF (TIMEST.LT.TIMESS(J,2)) GO TO 90
         ISUR(J)=1
         NMATT=NMAT(J)
         AUWT=ABS(UWT(NMATT))
         IF (AUWT.LT.1.0E-30) GO TO 90
         N1=NPTS(J)+1
         N2=NPTS(J+1)
         IF (N2-N1) 50,70,10
   10    CONTINUE
         X2=XS(N2)
         IF (NSYM(J).EQ.1) X2=2.0*X2-XS(N1)
         ZI1=XS(N1)/TH
         I1=ZI1
         ZI2=X2/TH
         I2=ZI2
         XT=XS(N1)
         Q1=BI(N1)
         NQ=I2-I1-1
         IF (I2*TH.GE.X2) NQ=NQ-1
         IF (NQ.LT.0) GO TO 40
         XX=(I1+1)*TH
         XXT=XX
         IF (XXT.GT.XS(N2).AND.NSYM(J).EQ.1) XXT=2.0*XS(N2)-XXT
         CALL SCURV1 (XXT,XS,BI,MNPTS,MNPTS,N1,N2,Q2)
         QI=-0.5*(Q1+Q2)*(XX-XT)*UWT(NMATT)
         Z=XT+(XX-XT)/3.0*(Q1+2.0*Q2)/(Q1+Q2)
         CALL CONLD (QI,Z,QY,L1)
         IF (NQ.EQ.0) GO TO 30
         DO 20 I=1,NQ
            Q1=Q2
            XT=XX
            XX=(I1+I+1)*TH
            XXT=XX
            IF (XXT.GT.XS(N2).AND.NSYM(J).EQ.1) XXT=2.0*XS(N2)-XXT
            CALL SCURV1 (XXT,XS,BI,MNPTS,MNPTS,N1,N2,Q2)
            QI=-0.5*(Q1+Q2)*TH*UWT(NMATT)
            Z=XT+TH/3.0*(Q1+2.0*Q2)/(Q1+Q2)
            CALL CONLD (QI,Z,QY,L1)
   20    CONTINUE
   30    CONTINUE
         Q1=Q2
         XT=XX
   40    CONTINUE
         XX=X2
         Q2=BI(N2)
         IF (NSYM(J).EQ.1) Q2=BI(N1)
         QI=-0.5*(Q1+Q2)*(XX-XT)*UWT(NMATT)
         Z=XT+(XX-XT)/3.0*(Q1+2.0*Q2)/(Q1+Q2)
         CALL CONLD (QI,Z,QY,L1)
         GO TO 90
   50    CONTINUE
         N=(-NSYM(J)-1)*M
         DO 60 I=1,M
            QI=BIP(N+I)*UWT(NMATT)*H
            QY(I)=QY(I)-QI
```

```
         IP1=I+1
         QY(IP1)=QY(IP1)-QI
   60    CONTINUE
         GO TO 90
   70    CONTINUE
         QI=BI(N1)*UWT(NMATT)*H
         QY(1)=QY(1)-QI
         QY(MP1)=QY(MP1)-QI
         QI=2.0*QI
         DO 80 I=2,M
            QY(I)=QY(I)-QI
   80    CONTINUE
   90 CONTINUE
C
COMMENT - DISCRETE DISTRIBUTED LOADS
C
      IF (NDLD.LE.0) GO TO 170
      DO 160 J=1,NDLD
         IF (TIMEST.LT.TIMED(J)) GO TO 160
         IF (IDLD(J).GT.0) GO TO 160
         IDLD(J)=1
         N1=NPD(J)+1
         N2=NPD(J+1)
         IF (N2.EQ.N1) GO TO 140
         N11=N1+1
         DO 130 II=N11,N2
            ZI1=XSD(II-1)/TH
            I1=ZI1
            ZI2=XSD(II)/TH
            I2=ZI2
            XT=XSD(II-1)
            QX1=QXD(II-1)
            QY1=QYD(II-1)
            QZ1=QZD(II-1)
            NQ=I2-I1-1
            IF (I2*TH.GE.XSD(II)) NQ=NQ-1
            IF (NQ.LT.0) GO TO 120
            XX=(I1+1)*TH
            CALL SCURV (XX,XSD,QXD,QYD,QZD,MNDLD,N1,N2,QX2,QY2,QZ2)
            XXMXT=XX-XT
            Z=XT+XXMXT/3.0
            QXI=0.5*QX1*XXMXT
            CALL CONLD (QXI,Z,QX,L1)
            QYI=0.5*QY1*XXMXT
            CALL CONLD (QYI,Z,QY,L1)
            QZI=0.5*QZ1*XXMXT
            CALL CONLD (QZI,Z,QZ,L1)
            Z=XT+2.0*XXMXT/3.0
            QXI=0.5*QX2*XXMXT
            CALL CONLD (QXI,Z,QX,L1)
            QYI=0.5*QY2*XXMXT
            CALL CONLD (QYI,Z,QY,L1)
            QZI=0.5*QZ2*XXMXT
            CALL CONLD (QZI,Z,QZ,L1)
            IF (NQ.EQ.0) GO TO 110
            DO 100 I=1,NQ
               XT=XX
               XX=(I1+I+1)*TH
               QX1=QX2
               QY1=QY2
               QZ1=QZ2
               CALL SCURV (XX,XSD,QXD,QYD,QZD,MNDLD,N1,N2,QX2,QY2,QZ2)
               Z=XT+TH/3.0
               QXI=0.5*QX1*TH
               CALL CONLD (QXI,Z,QX,L1)
               QYI=0.5*QY1*TH
               CALL CONLD (QYI,Z,QY,L1)
               QZI=0.5*QZ1*TH
               CALL CONLD (QZI,Z,QZ,L1)
               Z=XT+2.0*TH/3.0
               QXI=0.5*QX2*TH
               CALL CONLD (QXI,Z,QX,L1)
               QYI=0.5*QY2*TH
               CALL CONLD (QYI,Z,QY,L1)
               QZI=0.5*QZ2*TH
               CALL CONLD (QZI,Z,QZ,L1)
  100       CONTINUE
  110       CONTINUE
            XT=XX
            QX1=QX2
            QY1=QY2
            QZ1=QZ2
  120       CONTINUE
            XX=XSD(II)
            QX2=QXD(II)
            QY2=QYD(II)
            QZ2=QZD(II)
            XXMXT=XX-XT
            Z=XT+XXMXT/3.0
            QXI=0.5*QX1*XXMXT
            CALL CONLD (QXI,Z,QX,L1)
            QYI=0.5*QY1*XXMXT
            CALL CONLD (QYI,Z,QY,L1)
            QZI=0.5*QZ1*XXMXT
            CALL CONLD (QZI,Z,QZ,L1)
            Z=XT+2.0*XXMXT/3.0
            QXI=0.5*QX2*XXMXT
            CALL CONLD (QXI,Z,QX,L1)
            QYI=0.5*QY2*XXMXT
            CALL CONLD (QYI,Z,QY,L1)
            QZI=0.5*QZ2*XXMXT
            CALL CONLD (QZI,Z,QZ,L1)
  130    CONTINUE
         GO TO 160
  140    CONTINUE
         QXI=QXD(N1)*H
         QX(1)=QX(1)+QXI
         QX(MP1)=QX(MP1)+QXI
         QXI=2.0*QXI
         QYI=QYD(N1)*H
         QY(1)=QY(1)+QYI
         QY(MP1)=QY(MP1)+QYI
         QYI=2.0*QYI
         QZI=QZD(N1)*H
         QZ(1)=QZ(1)+QZI
         QZ(MP1)=QZ(MP1)+QZI
         QZI=2.0*QZI
         DO 150 I=2,M
            QX(I)=QX(I)+QXI
            QY(I)=QY(I)+QYI
            QZ(I)=QZ(I)+QZI
  150    CONTINUE
  160 CONTINUE
  170 CONTINUE
```

```
C
COMMENT - DISCRETE CONCENTRATED LOADS
C
      IF (NCLD.LE.0) GO TO 190
      DO 180 J=1,NCLD
         IF (TIMEST.LT.TIMEC(J)) GO TO 180
         IF (ICLD(J).GT.0) GO TO 180
         ICLD(J)=1
         CALL CONLD (QXC(J),XSC(J),QX,L1)
         CALL CONLD (QYC(J),XSC(J),QY,L1)
         CALL CONLD (QZC(J),XSC(J),QZ,L1)
  180 CONTINUE
  190 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                          S U B R O U T I N E                        *
C***********************************************************************
C
      SUBROUTINE ELEMFO (DX1,DY1,DZ1,DX2,DY2,DZ2,I,U1T,V1T,W1T,U2T,V2T,
     1    W2T)
C
COMMENT - SUBROUTINE ELEMFO EVALUATES THE END-FORCES ON A DISCRETE
C         ELEMENT,GIVEN THE ELEMENT-END-DISPLACEMENTS
C         ACCORDING TO LARGE DEFLECTION THEORY
C
      DIMENSION D(6,6)
      COMMON/BLOCK8/     BM1S(81),  BM2S(81),    DX(81),     DY(81),
     1          DZ(81),   ERX(81),   ERY(81),   ERZ(81),     QX(81),
     2          QY(81),    QZ(81),   SQX(81),   SQY(81),    SQZ(81),
     3          SX(81),    SY(81),    SZ(81),   TTS(81),    DS(81,5)
      COMMON/BLK4/          H,   IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1          MIDS5,   MP1,  MP22,  NELE,     TH,     ZL
C
COMMENT - COMPUTE THE ELEMENT DEFORMATIONS
C
      DDX=DX2-DX1
      DDY=DY2-DY1
      COSIM1=COS(DZ1)
      COSI=COS(DZ2)
      SINIM1=SIN(DZ1)
      SINI=SIN(DZ2)
      COSCOS=COSI+COSIM1
      SINSIN=SINI+SINIM1
      R=DDX+H*(1.0-0.5*COSCOS)
      S=DDY-0.5*H*SINSIN
      DELTA=((H+R)*(H+R)+S*S)**0.5-H
      TTHETA=S/(H+R)
      THETA=ATAN(TTHETA)
      TAU1=THETA-DZ1
      TAU2=DZ2-THETA
      SINT=S/(H+DELTA)
      COST=(H+R)/(H+DELTA)
C
COMMENT - CALL FAE TO COMPUTE THE INTERNAL FORCES IN THE ELEMENT
C
      CALL FAE (DELTA,TAU1,TAU2,I,D,TT,BM1,BM2)
      VT=(BM2-BM1)/(H+DELTA)
      U2T=TT*COST+VT*SINT
      V2T=TT*SINT-VT*COST
      U1T=-U2T
      V1T=-V2T
      W1T=-BM1+0.5*(-U1T*SINIM1+V1T*COSIM1)*H
      W2T=BM2+0.5*(-U1T*SINI+V1T*COSI)*H
C
COMMENT - STORE FOR USE BY ELEMST
C
      IF (IDS.NE.1) GO TO 10
      DS(I,1)=D(1,1)
      DS(I,2)=D(2,1)
      DS(I,3)=D(3,1)
      DS(I,4)=D(2,2)
      DS(I,5)=D(3,3)
      TTS(I)=TT
      BM1S(I)=BM1
      BM2S(I)=BM2
   10 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                          S U B R O U T I N E                        *
C***********************************************************************
C
      SUBROUTINE ELEMF2 (DX1,DY1,DZ1,DX2,DY2,DZ2,I,U1T,V1T,W1T,U2T,V2T,W
     12T)
C
COMMENT - USING SMALL DEFLECTION THEORY
C
      DIMENSION D(6,6)
      COMMON/BLOCK8/     BM1S(81),  BM2S(81),    DX(81),     DY(81),
     1          DZ(81),   ERX(81),   ERY(81),   ERZ(81),     QX(81),
     2          QY(81),    QZ(81),   SQX(81),   SQY(81),    SQZ(81),
     3          SX(81),    SY(81),    SZ(81),   TTS(81),    DS(81,5)
      COMMON/BLK4/          H,   IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1          MIDS5,   MP1,  MP22,  NELE,     TH,     ZL
C
COMMENT - COMPUTE THE ELEMENT DEFORMATIONS
C
      DDX=DX2-DX1
      DDY=DY2-DY1
      R=DDX
      HPR=H+R
      S=DDY-0.5*H*(DZ1+DZ2)
      THETA=S/HPR
      DELTA=DDX
      TAU1=THETA-DZ1
      TAU2=DZ2-THETA
C
COMMENT - CALL FAE TO COMPUTE THE INTERNAL FORCES IN THE ELEMENT
C
      CALL FAE (DELTA,TAU1,TAU2,I,D,TT,BM1,BM2)
      VT=(BM2-BM1)/HPR
      U2T=TT+VT*THETA
      V2T=TT*THETA-VT
      U1T=-U2T
      V1T=-V2T
      W1T=-BM1+0.5*H*(U2T*DZ1+V1T)
      W2T=BM2+0.5*H*(U2T*DZ2+V1T)
      IF (IDS.NE.1) GO TO 10
      DS(I,1)=D(1,1)
      DS(I,2)=D(2,1)
      DS(I,3)=D(3,1)
```

```
      DS(I,4)=D(2,2)
      DS(I,5)=D(3,3)
   10 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                       S U B R O U T I N E                           *
C***********************************************************************
C
      SUBROUTINE ELEMST (I)
C
COMMENT - SUBROUTINE ELEMST FORMS THE ELEMENT 6 X 6 STIFFNESS MATRI
C         ACCORDING TO LARGE DEFLECTION THEORY
C
      DIMENSION R(6,6), BT(6,6), D(6,6), TM(6,6)
      COMMON/BLOCKA/    BM1S(81),  BM2S(81),    DX(81),    DY(81),
     1          DZ(81),   ERX(81),   ERY(81),   ERZ(81),   QX(81),
     2          QY(81),    QZ(81),   SQX(81),   SQY(81),   SQZ(81),
     3          SX(81),    SY(81),    SZ(81),   TTS(81),   DS(81,5)
      COMMON/BLOC13/   SFET(6,6)
      COMMON/BLK4/       H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1         MIDS5,   MP1,  MP22,  NELE,    TH,     ZL
C
COMMENT - COMPUTE ELEMENT DEFORMATIONS
C
      IM1=I-1
      DDX=DX(I)-DX(IM1)
      DDY=DY(I)-DY(IM1)
      DZ1=DZ(IM1)
      DZ2=DZ(I)
      COSIM1=COS(DZ1)
      COSI=COS(DZ2)
      SINIM1=SIN(DZ1)
      SINI=SIN(DZ2)
      COSCOS=COSI+COSIM1
      SINSIN=SINI+SINIM1
      R=DDX+H*(1.0-0.5*COSCOS)
      S=DDY-0.5*H*SINSIN
      HPR=H+R
      HPD=(HPR*HPR+S*S)**0.5
      THETA=ATAN(S/HPR)
C
COMMENT - COMPUTE FOR CONVENIENCE
C
      HPRS1=HPR*SINIM1
      HPRS2=HPR*SINI
      HPRC1=HPR*COSIM1
      HPRC2=HPR*COSI
      SC1=S*COSIM1
      SC2=S*COSI
      SS1=S*SINIM1
      SS2=S*SINI
      HPDE1I=1.0/HPD
      HPDE2I=HPDE1I*HPDE1I
      HO2=0.5*H
C
COMMENT - FORM THE TRANSPOSE OF THE ELEMENT DEFORMATION-DISPLACEMENT
C         MATRIX
C
      BT(1,1)=-HPR*HPDE1I
      BT(2,1)=-S*HPDE1I
      BT(3,1)=HO2*HPDE1I*(HPRS1-SC1)
      BT(4,1)=-BT(1,1)
      BT(5,1)=-BT(2,1)
      BT(6,1)=HO2*HPDE1I*(HPRS2-SC2)
      BT(1,2)=S*HPDE2I
      BT(2,2)=-HPR*HPDE2I
      BT(3,2)=-1.0-HO2*HPDE2I*(HPRC1+SS1)
      BT(4,2)=-BT(1,2)
      BT(5,2)=-BT(2,2)
      BT(6,2)=-HO2*HPDE2I*(HPRC2+SS2)
      BT(1,3)=BT(4,2)
      BT(2,3)=BT(5,2)
      BT(3,3)=HO2*HPDE2I*(HPRC1+SS1)
      BT(4,3)=BT(1,2)
      BT(5,3)=BT(2,2)
      BT(6,3)=1.0-BT(6,2)
      D(1,1)=DS(I,1)
      D(1,2)=DS(I,2)
      D(1,3)=DS(I,3)
      D(2,1)=DS(I,2)
      D(2,2)=DS(I,4)
      D(2,3)=0.0
      D(3,1)=DS(I,3)
      D(3,2)=0.0
      D(3,3)=DS(I,5)
      TT=TTS(I)
      BM1=BM1S(I)
      BM2=BM2S(I)
C
COMMENT - FORM FIRST PART OF TRIPLE PRODUCT
C
      CALL MATMPY (BT,6,3,D,3,TM)
C
COMMENT - FORM THE ELEMENT DEFORMATION-DISPLACEMENT MATRIX
C
      DO 10 K=1,3
      DO 10 J=1,6
   10 B(K,J)=BT(J,K)
C
COMMENT - COMPLETE THE TRIPLE PRODUCT
C
      CALL MATMPY (TM,6,3,B,6,SFET)
C
COMMENT - COMPUTE FOR CONVENIENCE
C
      HPDE3I=HPDE2I*HPDE1I
      SE2=S*S
      HPRE2=HPR*HPR
      TTM=TT*HPDE3I
      TTMHO2=TTM*HO2
      HPDE2=HPD*HPD
C
COMMENT - COMPUTE THE PORTION OF THE INITIAL STRESS MATRIX DUE TO T
C
      TM(1,1)=TTM*SE2
      TM(1,2)=-TTM*S*HPR
      TM(1,3)=-TTMHO2*S*(SS1+HPRC1)
      TM(1,4)=-TM(1,1)
      TM(1,5)=-TM(1,2)
      TM(1,6)=-TTMHO2*S*(SS2+HPRC2)
      TM(2,2)=TTM*HPRE2
      TM(2,3)=TTM*HO2*HPR*(SS1+HPRC1)
```

```
      TM(2,4)=TM(1,5)
      TM(2,5)=-TM(2,2)
      TM(2,6)=TTMH02*HPR*(SS2+HPRC2)
      TM(3,3)=TTMH02*(H02*(SS1+HPRC1)**2+HPDE2*(SS1+HPRC1))
      TM(3,4)=-TM(1,3)
      TM(3,5)=-TM(2,3)
      TM(3,6)=TTMH02*H02*(SS1+HPRC1)*(SS2+HPRC2)
      TM(4,4)=TM(1,1)
      TM(4,5)=TM(1,2)
      TM(4,6)=-TM(1,6)
      TM(5,5)=TM(2,2)
      TM(5,6)=-TM(2,6)
      TM(6,6)=TTMH02*(H02*(SS2+HPRC2)**2+HPDE2*(SS2+HPRC2))
      N1=0
C
COMMENT - ADD ON TO ELEMENT STIFFNESS MATRIX
C
      DO 20 K=1,6
         N1=N1+1
      DO 20 J=N1,6
         SEET(K,J)=SEET(K,J)+TM(K,J)
         SEET(J,K)=SEET(K,J)
   20 CONTINUE
      VT=(RM2-RM1)/HPD
      VTM=VT*HPDE3I
      VTMH02=VTM*H02
      HPRS=HPRE2-SE2
C
COMMENT - COMPUTE THE PORTION OF THE INITIAL STRESS MATRIX DUE TO S
C
      TM(1,1)=-VTM*HPR*S*2.0
      TM(1,2)=VTM*HPRS
      TM(1,3)=VTMH02*(HPRS*COSIM1+S*HPR*SINIM1*2.0)
      TM(1,4)=-TM(1,1)
      TM(1,5)=-TM(1,2)
      TM(1,6)=VTMH02*(HPRS*COSI+S*HPR*SINI*2.0)
      TM(2,2)=-TM(1,1)
      TM(2,3)=VTMH02*(-HPRS*SINIM1+S*HPR*COSIM1*2.0)
      TM(2,4)=TM(1,5)
      TM(2,5)=-TM(2,2)
      TM(2,6)=VTMH02*(-HPRS*SINI+S*HPR*COSI*2.0)
      TM(3,3)=-VTMH02*(HPDE2*(HPR*SINIM1-S*COSIM1)+H*HPRS*SINIM1*COSIM1+
     1H*HPR*S*(SINIM1**2-COSIM1**2))
      TM(3,4)=-TM(1,3)
      TM(3,5)=-TM(2,3)
      TM(3,6)=-VTMH02*H02*(HPRS*(SINIM1*COSI+COSIM1*SINI)+S*HPR*(SINIM1*
     1SINI-COSIM1*COSI)*2.0)
      TM(4,4)=TM(1,1)
      TM(4,5)=TM(1,2)
      TM(4,6)=-TM(1,6)
      TM(5,5)=TM(2,2)
      TM(5,6)=-TM(2,6)
      TM(6,6)=-VTMH02*(HPDE2*(HPR*SINI-S*COSI)+H*HPRS*SINI*COSI+H*HPR*S*
     1(SINI**2-COSI**2))
      N1=0
C
COMMENT - ADD ON TO ELEMENT STIFFNESS MATRIX
C
      DO 30 K=1,6
         N1=N1+1
      DO 30 J=N1,6
         SEET(K,J)=SEET(K,J)+TM(K,J)
```

```
         SEET(J,K)=SEET(K,J)
   30 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE    ELEMS2  (I)
C
COMMENT - SUBROUTINE ELEMST FORMS THE ELEMENT 6 X 6 STIFFNESS MATRIX
C            ACCORDING TO SMALL DEFLECTION THEORY
C
      DIMENSION B(6,6), BT(6,6), D(6,6), TM(6,6)
      COMMON/BLOCKB/     BM1S(81),  BM2S(81),    DX(81),    DY(81),
     1           DZ(81),    ERX(81),   ERY(81),   ERZ(81),   QX(81),
     2           QY(81),    QZ(81),    SQX(81),   SQY(81),   SQZ(81),
     3           SX(81),    SY(81),    SZ(81),    TTS(81),   DS(81,5)
      COMMON/BLOC13/   SEET(6,6)
      COMMON/BLK4/          H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     H,
     1           MIDS5,    MP1,  MP22,   NELE,     TH,     ZL
C
COMMENT - COMPUTE ELEMENT DEFORMATIONS
C
      IM1=I-1
      DDX=DX(I)-DX(IM1)
      DDY=DY(I)-DY(IM1)
      DZ1=DZ(IM1)
      DZ2=DZ(I)
      R=DDX
      HPR=H+R
      S=DDY-0.5*H*(DZ1+DZ2)
      THETA=S/HPR
C
COMMENT - FORM THE ELEMENT DEFORMATION-DISPLACEMENT MATRIX
C
      B(1,1)=-1.0
      B(1,2)=-THETA
      B(1,3)=0.5*H*(DZ1-THETA)
      B(1,4)=1.0
      B(1,5)=-B(1,2)
      B(1,6)=0.5*H*(DZ2-THETA)
      B(2,1)=THETA/HPR
      B(2,2)=-1.0/HPR
      B(2,3)=-1.0-0.5*H/HPR*(1.0+THETA*DZ1)
      B(2,4)=-B(2,1)
      B(2,5)=-B(2,2)
      B(2,6)=-0.5*H/HPR*(1.0+THETA*DZ2)
      B(3,1)=B(2,4)
      B(3,2)=B(2,5)
      B(3,3)=-B(2,3)-1.0
      B(3,4)=B(2,1)
      B(3,5)=B(2,2)
      B(3,6)=-B(2,6)+1.0
      DO 10 J=1,6
      DO 10 K=1,3
   10 BT(J,K)=B(K,J)
      D(1,1)=DS(I,1)
      D(1,2)=DS(I,2)
      D(1,3)=DS(I,3)
      D(2,1)=DS(I,2)
```

```
      D(2,2)=DS(I,4)
      D(2,3)=0.0
      D(3,1)=DS(I,3)
      D(3,2)=0.0
      D(3,3)=DS(I,5)
      CALL MATMPY (BT,6,3,D,3,TM)
      CALL MATMPY (TM,6,3,B,6,SEET)
      RETURN
C
      END
C***********************************************************************
C*                     S U B R O U T I N E                             *
C***********************************************************************
C
      SUBROUTINE  FAE (DELTA, TAU1, TAU2, I, D, TT, BM1, BM2)
C
COMMENT - SUBROUTINE FAE COMPUTES THE AVERAGE AXIAL THRUST AND THE
C         BENDING MOMENTS AT THE TWO DISCRETE HINGES IN AN ELEMENT,
C         AND ALSO THE INCREMENTAL FORCE DOFORMATION MATRIX
C
      DIMENSION D(6,6)
      COMMON/BLOCK2/        EM(10),IRELAX(10),  NEQA(10),  NERC(10),
     1       NEQS(10),   NSS(10),    SM(10), STMAX(10), STMIN(10),
     2         UWT(10),
     3      A(10,8),    AT(10,8),    A1(10,8),   A1T(10,8),
     4     C(10,10),    CT(10,8),    C1(10,8),   C1T(10,8),
     5      S(10,8),   SRT(10,8)
      COMMON/BLOCK4/      ISUB(30),  NDIV(30),  NMAT(30),  NSYM(30),
     1      NPOST(30),  NPTS(31),TIMESS(30,3),
     2        BI(100),   DI(100),   CG(100),    XS(100), STRI(100),
     3       BIP(400),  DIP(400),  CGP(400),STRIP(400)
      COMMON/BLOCK9/    SHSTR(30),DSTRAI(1500,2), DSTRN(1500,2),
     1              FTIME(1500,2),  ISTR(1500,2),  STRN(1500,2)
      COMMON/BLOC11/     EPST(12), EPST1(12), EPST2(12),  SIGT(12),
     1       SIGT1(12), SIGT2(12)
      COMMON/BLK1/    IABAN, KEEP2,KEFP3A,KEFP3B, KEEP4,KEEP5A,KEEP5B,
     1        KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2         MISUB, MMTER, MNCLD,  MNCS, MNDLD,  MNDS,   MNE,  MNEQ,
     3         MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,  MNSS, MPOST,MTIME1
      COMMON/BLK2/   NPRINL, NTIM1, FTIME, TIMEO,TIMEST
      COMMON/BLK4/          H,   IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1         MIDS5,   MP1,  MP22,  NELE,    TH,    ZL
      COMMON/BLK5/      MNPC,  NCLD,    NCS,  NDLD,    NDS,NPOSTL,   NSUB
      ZMUL=I-2
      ZMUL=ZMUL+0.5
      X=TH*ZMUL
      NELEM=(I-2)*MNPC
C
COMMENT - COMPUTE DEFORMATIONS IN ELEMENT
C
      FP=DELTA/TH
      CUR1=TAU1/H
      CUR2=TAU2/H
C
COMMENT - ZERO ELEMENT THRUST, BENDING MOMENTS, AND STIFFNESS TERMS
C
      BM1=0.0
      BM2=0.0
      T1=0.0
      T2=0.0
      EI1=0.0
      EI2=0.0
      AE1=0.0
      AE2=0.0
      AEY1=0.0
      AEY2=0.0
      D(2,3)=0.0
      D(3,2)=0.0
      DO 160 NCD=1,NSUB
         IF (TIMEST.LT.TIMESS(NCD,3)) GO TO 150
         N1=NPTS(NCD)+1
         N2=NPTS(NCD+1)
         IF (N2-N1) 10,20,30
   10    CONTINUE
         II=(-NSYM(NCD)-1)*M+I-1
         B=BIP(II)
         DT=DIP(II)
         YT=CGP(II)
         IF (NPOST(NCD).LE.0) GO TO 50
         IF (ISUB(NCD).EQ.4) GO TO 50
         STRIT=STRIP(II)
         GO TO 40
   20    CONTINUE
         B=BI(N1)
         DT=DI(N1)
         YT=CG(N1)
         IF (NPOST(NCD).LE.0) GO TO 50
         IF (ISUB(NCD).EQ.4) GO TO 50
         STRIT=STRI(N1)
         GO TO 40
   30    CONTINUE
         IF (NSYM(NCD).EQ.1.AND.X.GT.XS(N2)) X=2.0*XS(N2)-X
         IF (X.LT.XS(N1).OR.X.GT.XS(N2)) GO TO 150
         CALL SCURV (X,XS,BI,DI,CG,MNPTS,N1,N2,B,DT,YT)
         IF (NPOST(NCD).LE.0) GO TO 50
         IF (ISUB(NCD).EQ.4) GO TO 50
         CALL SCURV1 (X,XS,STRI,MNPTS,MNPTS,N1,N2,STRIT)
   40    CONTINUE
         BM1=BM1-YT*STRIT
         BM2=BM2-YT*STRIT
         T1=T1+STRIT
         T2=T2+STRIT
         GO TO 150
   50    CONTINUE
         NMATT=NMAT(NCD)
         CALL SSCRV (SIGT,EPST,TIMESS(NCD,1),TIMEST,NMATT,ISJT,NPTT,ET)
         NDIVT=NDIV(NCD)
         B=B/NDIVT
         DEPTH=DT/NDIVT
         DO 140 IP=1,NDIVT
            NELEMT=NELEM+IP
            Y=YT+DT/2.0-DEPTH*IP+DEPTH/2.0
            EP1=EP-Y*CUR1-SHSTR(NCD)-ETIME(NELEMT,1)-DSTRAI(NELEMT,1)
            EP2=EP-Y*CUR2-SHSTR(NCD)-ETIME(NELEMT,2)-DSTRAI(NELEMT,2)
C
COMMENT - CHECK THE STRAIN LIMITS
C
            I1001=ISTR(NELEMT,1)/100
            I1002=ISTR(NELEMT,2)/100
            ISTRT1=(ISTR(NELEMT,1)-I1001*100)/10
            ISTRT2=(ISTR(NELEMT,2)-I1002*100)/10
            IF (IDS.NE.1) GO TO 130
            STRN(NELEMT,1)=EP1
            STRN(NELEMT,2)=EP2
```

```
      I11=ISTR(NELEMT,1)-I1001*100-ISTRT1*10
      I12=ISTR(NELEMT,2)-I1002*100-ISTRT2*10
      I1001T=I11
      I1002T=I12
      GO TO (60,70,80), I11
   60 IF (EP1.LE.STMAX(NMATT)) GO TO 70
      I1001T=2
   70 IF (EP1.GE.STMIN(NMATT)) GO TO 80
      I1001T=3
   80 CONTINUE
      GO TO (90,100,110), I12
   90 IF (EP2.LE.STMAX(NMATT)) GO TO 100
      I1002T=2
  100 IF (EP2.GE.STMIN(NMATT)) GO TO 110
      I1002T=3
  110 CONTINUE
      IF (IDS5.LE.MIDS5) GO TO 120
      ISTRT1=I1001T
      ISTRT2=I1002T
  120 CONTINUE
      ISTR(NELEMT,1)=I1001T*100+ISTRT1*10+I11
      ISTR(NELEMT,2)=I1002T*100+ISTRT2*10+I12
  130 CONTINUE
C
COMMENT - CALL FAEJR TO COMPUTE AXIAL THRUST, BENDING MOMENT AND
COMMENT - STIFFNESS TERMS FOR ONE RECTANGLE AT LOCATION OF FIRST
COMMENT - DISCRETE SPRING IN ELEMENT
C
      CALL FAEJR (T,BM,EA,EI,AEY,ISJT,NPTT,ET,ISTRT1,Y,B,EP1)
C
COMMENT - ACCUMULATE VALUES FOR ALL RECTANGLES
C
      BM1=BM1+BM
      EI1=EI1+EI
      AEY1=AEY1+AEY
      AE1=AE1+EA
      T1=T1+T
      CALL FAEJR (T,BM,EA,EI,AEY,ISJT,NPTT,ET,ISTRT2,Y,B,EP2)
      BM2=BM2+BM
      EI2=EI2+EI
      AEY2=AEY2+AEY
      AE2=AE2+EA
      T2=T2+T
  140 CONTINUE
  150 CONTINUE
      NELEM=NELEM+NDIV(NCD)
  160 CONTINUE
C
COMMENT - COMPUTE AVERAGE THRUST AND AXIAL STIFFNESS FOR ELEMENT
C
      TT=0.5*(T1+T2)
      AEI=0.5*(AE1+AE2)
C
COMMENT - COMPUTE INCREMENTAL FORCE DEFORMATION MATRIX FOR ELEMENT
C
      D(1,1)=AEI/TH
      D(2,2)=EI1/H
      D(3,3)=EI2/H
      D(1,2)=-AEY1/TH
      D(2,1)=D(1,2)
      D(1,3)=-AEY2/TH
      D(3,1)=D(1,3)
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE FAEJR(T,BM,EA,EI,AEY,ISSTT,NPTST,E,ISTRT,Y,B,EP)
C
COMMENT - SUBROUTINE FAEJR COMPUTES THRUST, BENDING MOMENT, AND
C         STIFFNESS TERMS FOR ONE FIBER
C
      COMMON/BLOC11/    EPST(12), EPST1(12), EPST2(12),  SIGT(12),
     1       SIGT1(12), SIGT2(12)
      COMMON/BLK4/       H,    IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1         MIDS5,   MP1,  MP22,  NELE,     TH,     ZL
      CALL CURVE (SIGT,EPST,EP,NPTST,ISSTT,SIG,E,KOFFSE)
      GO TO (30,10,20), ISTRT
   10 IF (SIG.LT.0.0) GO TO 30
   20 CONTINUE
      T=0.0
      BM=0.0
      EA=0.0
      EI=0.0
      AEY=0.0
      GO TO 40
   30 CONTINUE
      T=SIG*B
      BM=-Y*T
      EA=E*B
      EI=EA*Y*Y
      AEY=EA*Y
   40 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE FAEUP(I,DELTA,TAU1,TAU2,ID)
C
COMMENT - SUBROUTINE FAEUP ESTIMATES PRE-TENSIONED FIBER STRAINS JUST
C         BEFORE THE FIBERS CAN CARRY LOADS (ID = 1) OR POST-TENSIONED
C         FIBER STRAINS JUST AFTER TRANSFER (ID = 2)
C
      COMMON/BLOCK4/      ISUR(30),  NDIV(30),  NMAT(30),  NSYM(30),
     1       NPOST(30),  NPTS(31),TIMESS(30,3),
     2        BI(100),   DI(100),   CG(100),    XS(100), STRI(100),
     3       RIP(400),  DIP(400),  CGP(400),STRIP(400)
      COMMON/BLOCK8/      BM1S(81),  BM2S(81),    DX(81),     DY(81),
     1         DZ(81),    ERX(81),   ERY(81),   ERZ(81),     QX(81),
     2         QY(81),     QZ(81),   SQX(81),   SQY(81),    SQZ(81),
     3         SX(81),     SY(81),    SZ(81),   TTS(81),    DS(81,5)
      COMMON/BLOCK9/     SHSTR(30),DSTRAI(1500,2), DSTRN(1500,2),
     1              ETIME(1500,2),  ISTR(1500,2),  STRN(1500,2)
      COMMON/BLK1/     IARAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1          KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2           MISUR, MMTER, MNCLD,  MNCS, MNDLD,  MNDS,   MNE,  MNEQ,
     3           MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,  MNSS, MPOST,MTIME1
      COMMON/BLK2/   NPRINL, NTIM1, FTIME, TIMED,TIMEST
      COMMON/BLK4/         H,    IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
```

```
     1          MIDS5,    MP1,   MP22,   NELF,     TH,      ZL
      COMMON/BLK5/      MNPC,   NCLD,     NCS,  NDLD.    NDS,NPOSTL,   NSUB
      EP=DELTA/TH
      CUR1=TAU1/H
      CUR2=TAU2/H
      NELEM=(I-2)*MNPC
      ZMUL=I-2
      ZMUL=ZMUL+0.5
      X=TH*ZMUL
      IF (ID.EQ.2) GO TO 80
      DO 70 NCD=1,NSUB
         IF (NPOST(NCD).GT.0) GO TO 60
         IF (ISUB(NCD).EQ.4) GO TO 60
         IF (TIMEST.LT.TIMESS(NCD,3)) GO TO 60
         N1=NPTS(NCD)+1
         N2=NPTS(NCD+1)
         IF (N2-N1) 10,20,30
 10      CONTINUE
         II=(-NSYM(NCD)-1)*M+I-1
         DT=DIP(II)
         YT=CGP(II)
         STRIT=STRIP(II)
         GO TO 40
 20      CONTINUE
         DT=DI(N1)
         YT=CG(N1)
         STRIT=STRI(N1)
         GO TO 40
 30      CONTINUE
         IF (NSYM(NCD).EQ.1.AND.X.GT.XS(N2)) X=2.0*XS(N2)-X
         IF (X.LT.XS(N1).OR.X.GT.XS(N2)) GO TO 60
         CALL SCURV (X,XS,DI,CG,STRI,MNPTS,N1,N2,DT,YT,STRIT)
 40      CONTINUE
         NDIVT=NDIV(NCD)
         DEPTH=DT/NDIVT
         DO 50 IP=1,NDIVT
            NELEMT=NELEM+IP
            Y=YT+DT/2.0-DEPTH*IP+DEPTH/2.0
            DSTRAI(NELEMT,1)=EP-Y*CUR1-STRIT
            DSTRAI(NELEMT,2)=EP-Y*CUR2-STRIT
 50      CONTINUE
 60      CONTINUE
         NELEM=NELEM+NDIV(NCD)
 70   CONTINUE
      GO TO 160
 80   CONTINUE
      DO 150 NCD=1,NSUB
         IF (NPOST(NCD).LE.0) GO TO 140
         IF (ISUB(NCD).EQ.4) GO TO 140
         IF (TIMEST.LT.TIMESS(NCD,3)) GO TO 140
         N1=NPTS(NCD)+1
         N2=NPTS(NCD+1)
         IF (N2-N1) 90,100,110
 90      CONTINUE
         II=(-NSYM(NCD)-1)*M+I-1
         DT=DIP(II)
         YT=CGP(II)
         GO TO 120
 100     CONTINUE
         DT=DI(N1)
         YT=CG(N1)
         GO TO 120
 110     CONTINUE
         IF (NSYM(NCD).EQ.1.AND.X.GT.XS(N2)) X=2.0*XS(N2)-X
         IF (X.LT.XS(N1).OR.X.GT.XS(N2)) GO TO 140
         CALL SCURV (X,XS,DI,CG,STRI,MNPTS,N1,N2,DT,YT,STRIT)
 120     CONTINUE
         NDIVT=NDIV(NCD)
         DEPTH=DT/NDIVT
         DO 130 IP=1,NDIVT
            NELEMT=NELEM+IP
            Y=YT+DT/2.0-DEPTH*IP+DEPTH/2.0
            DSTRAI(NELEMT,1)=EP-Y*CUR1-STRN(NELEMT,1)
            DSTRAI(NELEMT,2)=EP-Y*CUR2-STRN(NELEMT,2)
 130     CONTINUE
 140     CONTINUE
         NELEM=NELEM+NDIV(NCD)
 150  CONTINUE
 160  CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                          S U B R O U T I N E                        *
C***********************************************************************
C
      SUBROUTINE FSUB22 (SU,FF,L4)
C
COMMENT - FSUB22 FURNISHES THE RIGHT SIDE OF SYMMETRIC STIFFNESS MATRIX
COMMENT - SU AND LOAD TERM FF TO GRIP2A FOR MEMBER SOLUTIONS
COMMENT - SU IS ONE ROW OF STIFFNESS MATRIX AND FF IS CORRESPONDING LOAD
COMMENT - FSUB22 FORMS SEM ( 3 ROWS OF SU ) AND FEM ( 3 LOADS ) EVERY
COMMENT - THIRD CALL FROM GRIP2A AND FURNISHES SU AND FF FOR EACH CALL
C
      DIMENSION SU(L4)
      DIMENSION SEMS(3,3),SEM(3,6),FEM(3)
      COMMON/BLOCK8/     BM1S(81),  BM2S(81),    DX(81),    DY(81),
     1             DZ(81),   ERX(81),   ERY(81),   ERZ(81),    QX(81),
     2             QY(81),    QZ(81),   SQX(81),   SQY(81),   SQZ(81),
     3             SX(81),    SY(81),    SZ(81),   TTS(81),   DS(81,5)
      COMMON/BLOC13/   SEET(6,6)
      COMMON/BLK4/          H,     IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1          MIDS5,    MP1,   MP22,   NELE,     TH,      ZL
      COMMON/RI/            NL,      J1
C
COMMENT - I IS STATION NUM -- IP1 IS ELEMENT NUM -- J1 IS EQUATION NUM
C
      I=(J1-1)/3+1
C
COMMENT - SKIP FOR EVERY SECOND AND THIRD EQUATION
C
      IF (J1.NE.3*I-2) GO TO 110
      IF (I.NE.1) GO TO 20
      DO 10 JJ=1,3
      DO 10 KK=1,3
         SEMS(JJ,KK)=0.0
   10 CONTINUE
   20 CONTINUE
      IF (I.LT.MP1) GO TO 40
      DO 30 JJ=1,6
      DO 30 KK=1,6
         SEET(JJ,KK)=0.0
   30 CONTINUE
      GO TO 70
```

```
   40 CONTINUE
      IP1=I+1
C
COMMENT - CALL ELEMST TO OBTAIN 6 X 6 ELEMENT STIFFNESS MATRIX
C
      IF (ISMALL.EQ.1) GO TO 50
C
COMMENT - USING LARGE DEFLECTION THEORY
C
      CALL ELEMST (IP1)
      GO TO 60
   50 CONTINUE
C
COMMENT - USING SMALL DEFLECTION THEORY
C
      CALL ELEMS2 (IP1)
   60 CONTINUE
   70 CONTINUE
C
COMMENT - FORM THREE ROWS OF MEMBER STIFFNESS MATRIX SEM
C
      DO 80 JJ=1,3
      DO 80 KK=1,3
         SEM(JJ,KK)=SEFT(JJ,KK)+SEMS(JJ,KK)
         SEM(JJ,KK+3)=SEET(JJ,KK+3)
         SEMS(JJ,KK)=SEET(JJ+3,KK+3)
   80 CONTINUE
C
COMMENT - ADD IN SPRING STIFFNESSES
C
      SEM(1,1)=SEM(1,1)+SX(I)
      SEM(2,2)=SEM(2,2)+SY(I)
      SEM(3,3)=SEM(3,3)+SZ(I)
      FEM(1)=ERX(I)
      FEM(2)=ERY(I)
      FEM(3)=ERZ(I)
      DO 90 K=1,5
         SEM(2,K)=SEM(2,K+1)
   90 CONTINUE
      DO 100 K=1,4
         SEM(3,K)=SEM(3,K+2)
  100 CONTINUE
      SEM(2,6)=0.0
      SEM(3,6)=0.0
      SEM(3,5)=0.0
  110 CONTINUE
      N123=J1-3*I+3
      IC=6
C
COMMENT - FORM SU FROM ONE ROW OF SEM
C
      DO 120 JJ=1,6
         SU(JJ)=SEM(N123,IC)
         IC=IC-1
  120 CONTINUE
      FF=FEM(N123)
      RETURN
C
      END
C*********************************************************************
C*                       S U B R O U T I N E                         *
C*********************************************************************
C
      SUBROUTINE GRIP2A(L4,IHB)
C
C---------RM(M,NL) , RO(NL)    , W(NL) , SL(M) , SU(M+1)   -**-  DIMENSION
C         NL IS ORDER
C   ***    NL MUST BE GREATER THAN 2
C         M  IS HALF-WIDTH  ( J = 2*M + 1 ), WHERE J IS THE BAND WIDTH
C   ***    M MUST BE GREATER THAN 1
C         RM(  )      RECURSION MULTIPLIERS
C         F           CONSTANT TERM FOR THE I-TH ROW
C         W (  )      SOLUTION VECTOR
C
      COMMON/BLOC10/   SL(5), SU(6), RO(243), W(243), RM(5,243)
      COMMON/RI/          NL,     J1
C
COMMENT -  M=IHB       =HALF BAND WIDTH
C
      M=IHB
      J1=1
      M1=M-1
      MP=M+1
      NLM1=NL-1
      NLMM=NL-M
      IZ=0
      I2=1
      I3=1
C
COMMENT - CALCULATE RECURSION MULTIPLIERS
C
      SL(1)=0.0
      CALL FSUB22 (SU,F,L4)
      RM(M,1)=-1.0/SU(MP)
      DO 10 I=1,M1
         IB=MP-I
         RM(I,IB)=SU(I+1)
   10 CONTINUE
      RO(1)=SU(1)
      W(1)=RM(M,1)*(-F)
      DO 100 J=2,NL
         J1=J-1
         IF (J.GT.M) J1=M1
         DO 20 I=1,J1
            IB=J1+2-I
            SL(IB)=SL(IB-1)
   20    CONTINUE
         SL(1)=SU(1)
         J1=J
         CALL FSUB22 (SU,F,L4)
         J1=J-1
         IF (J.GT.M) J1=M1
         IX=J+M1
         IF (IX-NL-1) 50,40,30
   30    CONTINUE
         I3=I3+1
   40    CONTINUE
         IZ=IZ-1
         I2=I2+1
   50    CONTINUE
         II=IX+IZ
         IE=I3
         DO 60 I=I2,M
            RM(I,II)=SU(I+1)
```

```
         II=II-1
   60    CONTINUE
         RO(J)=SU(1)
         DO 80 L=1,J1
            TEMP=RM(M,J-L)*RM(M-L,J)
            IF ((J+M-L).LE.NL) RM(L,M+J-L)=RM(L,M+J-L)+SL(L)*TEMP
            LXX=1
            IF (IE.GT.1) LXX=IE
            IF (IE.GT.1) IE=IE-1
            LXX=LXX+L
            DO 70 I=LXX,M
               RM(I,J+M-I)=RM(I,J+M-I)+RM(I-L,J+M-I)*TEMP
   70       CONTINUE
   80    CONTINUE
         IF (J.GT.M) RM(M,J)=RM(M,J)+SL(M)*RM(M,J-M)*SL(M)
         RM(M,J)=-1./RM(M,J)
C
COMMENT - COMPUTE PRELIMINARY VALUE FOR W(J)
C
         W(J)=0.0
         DO 90 I=1,J1
            W(J)=W(J)+RM(M-I,J)*W(J-I)
   90    CONTINUE
         IF (J.GT.M) W(J)=W(J)+RO(J-M)*W(J-M)
         W(J)=RM(M,J)*(W(J)-F)
  100 CONTINUE
C
COMMENT - CALCULATE RECURSION EQUATION
C
      K=0
      DO 130 L=1,NLM1
         J=NL-L
         TEMP=W(J)
         W(J)=0
         K=K+1
         DO 110 I=1,M1
            W(J)=W(J)+RM(M-I,J+I)*W(J+I)
            IF (I.EQ.K) GO TO 120
  110    CONTINUE
  120    CONTINUE
         IF (J.LE.NLMM) W(J)=W(J)+RO(J)*W(J+M)
         W(J)=RM(M,J)*W(J)+TEMP
  130 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE MATMPY (A,M1,N1,B,N2,C)
C
COMMENT - SUBROUTINE MATMPY MULTIPLIES A N1XM1 MATRIX A TIMES A N1XN2
COMMENT - MATRIX B TO YIELD THE M1XN2 MATRIX C
C
      DIMENSION A(6,6),B(6,6),C(6,6)
      DO 10 I=1,M1
      DO 10 J=1,N2
         C(I,J)=0
      DO 10 K=1,N1
         C(I,J)=A(I,K)*B(K,J)+C(I,J)
   10 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE MATM33 (AA,BB,CC)
C
COMMENT - THIS SUBROUTINE MULTIPLIES A 3X3 MATRIX ,AA, TIMES A
COMMENT - 3X3 MATRIX ,BB, TO PRODUCE A 3X3 MATRIX ,CC
C
      DIMENSION AA(3,3),BB(3,3),CC(3,3)
      DO 10 I=1,3
      DO 10 J=1,3
         CC(I,J)=0.0
      DO 10 K=1,3
         CC(I,J)=AA(I,K)*BB(K,J)+CC(I,J)
   10 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE MATM31 (AA,B,C)
C
COMMENT - THIS SUBROUTINE MULTIPLIES A 3X3 MATRIX ,AA, TIMES A
COMMENT - 3X1 MATRIX ,B, TO PRODUCE A 3X1 MATRIX ,C
C
      DIMENSION AA(3,3),B(3),C(3)
      DO 10 I=1,3
         C(I)=0.0
      DO 10 K=1,3
         C(I)=AA(I,K)*B(K)+C(I)
   10 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE MEMSOL(L1,L4)
C
COMMENT - SUBROUTINE MEMSOL DOES THE ITERATIVE NONLINEAR MEMBER SOLUTION
C
      COMMON/BLOCK8/     BM1S(81),  BM28(81),    DX(81),    DY(81),
     1          DZ(81),   ERX(81),   ERY(81),   ERZ(81),    QX(81),
     2          QY(81),    QZ(81),   SQX(81),   SQY(81),   SQZ(81),
     3          SX(81),    SY(81),    SZ(81),   TTS(81),   DS(81,5)
      COMMON/BLOCK9/    SHSTR(30),DSTRAI(1500,2), DSTRN(1500,2),
     1             ETIME(1500,2),  ISTR(1500,2),  STRN(1500,2)
      COMMON/BLOC10/    SL(5), SU(6), RO(243), W(243), RM(5,243)
      COMMON/BLK3/       ERR1,   ERR2,    ER1,    ER2,    MB, MNITM,  NITM
      COMMON/BLK4/          H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,      M,
     1         MIDS5,   MP1,  MP22,   NELE,     TH,     ZL
C
COMMENT - SET TEMPORARY CONTROL CONSTANTS
C
      IDS5=1
```

```
   10 CONTINUE
      PRINT 340, IDS5
      NITM=0
      ERCHK1=0
      ERCHK2=0
      ERCHK3=0
   20 CONTINUE
      NITM=NITM+1
      KOFFSE=0
      KOFFOW=0
      CALL NLSS (L1)
      DO 30 I=1,MP1
         ERX(I)=0.0
         ERY(I)=0.0
         ERZ(I)=0.0
   30 CONTINUE
C
COMMENT - DO FOR EACH ELEMENT
C
      IDS=1
      DO 60 I=2,MP1
         IM1=I-1
C
COMMENT - COMPUTE FORCES ON ENDS OF DISCRETE ELEMENT
C
         IF (ISMALL.EQ.1) GO TO 40
C
COMMENT - USING LARGE DEFLECTION THEORY
C
         CALL FLEMFO (DX(IM1),DY(IM1),DZ(IM1),DX(I),DY(I),DZ(I),I,U1T,V1
     1   T,W1T,U2T,V2T,W2T)
         GO TO 50
   40    CONTINUE
C
COMMENT - USING SMALL DEFLECTION THEORY
C
         CALL ELEMF2 (DX(IM1),DY(IM1),DZ(IM1),DX(I),DY(I),DZ(I),I,U1T,V1
     1   T,W1T,U2T,V2T,W2T)
   50    CONTINUE
C
COMMENT - COMPUTE PARTIAL EQUILIBRIUM ERRORS BY SUMMING FORCES ON
COMMENT - ADJACENT ELEMENTS
C
         ERX(IM1)=ERX(IM1)+U1T
         ERY(IM1)=ERY(IM1)+V1T
         ERZ(IM1)=ERZ(IM1)+W1T
         ERX(I)=ERX(I)+U2T
         ERY(I)=ERY(I)+V2T
         ERZ(I)=ERZ(I)+W2T
   60 CONTINUE
      IDS=0
      DO 70 I=1,MP1
C
COMMENT - ADD STATIONS LOADS AND STATION RESISTIVE SPRING FORCES TO
COMMENT - COMPLETE COMPUTATION OF EQUILIBRIUM ERRORS
C
         ERX(I)=QX(I)-ERX(I)+SQX(I)
         ERY(I)=QY(I)-ERY(I)+SQY(I)
         ERZ(I)=QZ(I)-ERZ(I)+SQZ(I)
   70 CONTINUE
      IF (NITM.EQ.1) GO TO 90
      DO 80 I=1,MP1
         IF (ABS(QX(I)).GE.1.0E+30) ERX(I)=0.0
         IF (ABS(QY(I)).GE.1.0E+30) ERY(I)=0.0
         IF (ABS(QZ(I)).GE.1.0E+30) ERZ(I)=0.0
   80 CONTINUE
   90 CONTINUE
      IF (MB.LE.0) GO TO 120
      PRINT 260, NITM
      IF (MB.EQ.2) GO TO 100
      PRINT 280, DX(2),DY(2),DZ(2),ERX(2),ERY(2),ERZ(2),MP22,DX(MP22),DY
     1(MP22),DZ(MP22),ERX(MP22),ERY(MP22),ERZ(MP22),M,DX(M),DY(M),DZ(M),
     2ERX(M),ERY(M),ERZ(M)
      GO TO 120
  100 CONTINUE
      DO 110 I=1,MP1
         PRINT 270, I,DX(I),DY(I),DZ(I),ERX(I),ERY(I),ERZ(I)
  110 CONTINUE
  120 CONTINUE
      IF (KOFFOW.EQ.1) PRINT 320
      IF (KOFFSE.EQ.1) PRINT 330
C
COMMENT - COMPARE EQULIBRIUM ERRORS WITH SPECIFED TOLERANCES
C
      DO 130 I=1,MP1
         ERCHK3=ERX(I)
         IF (ABS(ERX(I)).GT.ER1) GO TO 140
         ERCHK3=ERY(I)
         IF (ABS(ERY(I)).GT.ER1) GO TO 140
         ERCHK3=ERZ(I)
         IF (ABS(ERZ(I)).GT.ER2) GO TO 140
  130 CONTINUE
      GO TO 190
  140 CONTINUE
      IF (NITM.EQ.1) GO TO 170
      DO 150 I=1,MP1
         IF (ABS(ERX(I)).GT.ERR1) GO TO 160
         IF (ABS(ERY(I)).GT.ERR1) GO TO 160
         IF (ABS(ERZ(I)).GT.ERR2) GO TO 160
  150 CONTINUE
      IF (NITM.LE.MNITM) GO TO 170
  160 CONTINUE
      PRINT 310, NITM,IDS5
      NITM=MNITM+1
      GO TO 250
C
COMMENT - SOLVE MEMBER FOR LINEAR INCREMENTS OF DISPLACEMENT
C
  170 CONTINUE
      DCARP=1.0
      IF (ABS(ERCHK3-ERCHK1).LT.ERCHK3/20.0) DCARP=0.5
      IF (ABS(ERCHK3-ERCHK2).LT.ERCHK3/20.0) DCARP=0.5
      ERCHK1=ERCHK2
      ERCHK2=ERCHK3
      CALL GRIP2A (L4,5)
C
COMMENT - INCREMENT MEMBER DISPLACEMENTS
C
      J=1
      DO 180 I=1,MP1
         DX(I)=DX(I)+W(J)*DCARP
         J=J+1
         DY(I)=DY(I)+W(J)*DCARP
         J=J+1
```

```
      DZ(I)=DZ(I)+W(J)*DCARP
        J=J+1
  180 CONTINUE
      GO TO 20
  190 CONTINUE
      PRINT 290, NITM
      IF (IDS5.GT.MIDS5) GO TO 210
      DO 200 I=1,NELE
      DO 200 J=1,2
         I100=ISTR(I,J)/100
         I10=(ISTR(I,J)-I100*100)/10
         IF (I10.NE.I100) GO TO 230
  200 CONTINUE
  210 CONTINUE
      PRINT 300, IDS5
      DO 220 I=1,NELE
      DO 220 J=1,2
         I100=ISTR(I,J)/100
         ISTR(I,J)=I100*100+I100*10+I100
  220 CONTINUE
      GO TO 250
  230 CONTINUE
      IDS5=IDS5+1
      DO 240 II=1,NELE
      DO 240 J=1,2
         I100=ISTR(II,J)/100
         I10=(ISTR(II,J)-I100*100)/10
         I1=ISTR(II,J)-I100*100-I10*10
         ISTR(II,J)=I1*100+I100*10+I1
  240 CONTINUE
      GO TO 10
  250 CONTINUE
      RETURN
C
  260 FORMAT (/, 19H      ITEERATION NO.,I5,//, 53H       STA.        DX
     1        DY             DZ          ER, 25HX          ERY          ERZ,/)
  270 FORMAT (5X,I5,6E12.3)
  280 FORMAT (5X,  5H    2,6E12.3,2(/,5X,I5,6E12.3))
  290 FORMAT (//, 37H      MEMBER CONVERGED AFTER ITERATION,I5,//)
  300 FORMAT (//, 33H      MEMBER CONVERGED AFTER CYCLE,I5,//)
  310 FORMAT (//, 41H      MEMBER NOT CONVERGED AFTER ITERATION,I5,  6H C
     1YCLE,I5,//)
  320 FORMAT (46H      ** LIMIT OF MEMBERS Q-W CURVE EXCEEDED ON,24H PREC
     1EEDING ITERATION **)
  330 FORMAT (44H      ** LIMIT OF MEMBERS STRESS-STRAIN CURVE,40H EXCEED
     1ED ON PRECEEDING ITERATION ***    )
  340 FORMAT (/, 14H      CYCLE NO.,I5)
C
      END
C*********************************************************************
C*                      S U B R O U T I N E                          *
C*********************************************************************
C
      SUBROUTINE NLSS (L1)
C
COMMENT - SUBROUTINE NLSS DISCRETIZES DISTRIBUTED MEMBER Q - W CURVES
COMMENT - TO STATION VALUES OF RESISTIVE SPRING FORCES  SQX, SQY, SQZ
COMMENT - AND SPRING STIFFNESS  SX, SY, SZ
C
      COMMON/BLOCK6/     NPDS(11),  NSXD(20),  NSYD(20),  NSZD(20),
     1         QMXD(20),  QMYD(20),  QMZD(20),  WMXD(20),  WMYD(20),
     2         WMZD(20),    XD(20),
     3         NSXP(20),  NSYP(20),  NSZP(20),  QMXP(20),  QMYP(20),
     4         QMZP(20),  WMXP(20),  WMYP(20),  WMZP(20),    XP(20)
      COMMON/BLOCK8/     BM1S(81),  BM2S(81),    DX(81),    DY(81),
     1           DZ(81),   ERX(81),   ERY(81),   ERZ(81),    QX(81),
     2           QY(81),    QZ(81),   SQX(81),   SQY(81),   SQZ(81),
     3           SX(81),    SY(81),    SZ(81),   TTS(81),    DS(81,5)
      COMMON/BLK4/          H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1         MIDS5,    MP1,   MP22,   NELE,    TH,     ZL
      COMMON/BLK5/       MNPC,  NCLD,    NCS,  NDLD,    NDS,NPOSTL,  NSUB
      DO 10 I=1,MP1
         SX(I)=0.0
         SY(I)=0.0
         SZ(I)=0.0
         SQX(I)=0.0
         SQY(I)=0.0
         SQZ(I)=0.0
   10 CONTINUE
C
COMMENT - DISCRETE DISTRIBUTED SPRINGS
C
      IF (NDS.LE.0) GO TO 50
      DO 40 NCD=1,NDS
         N1=NPDS(NCD)+2
         N2=NPDS(NCD+1)
         IF (N2.LT.N1) GO TO 30
         DO 20 J=N1,N2
            JM1=J-1
            CALL NLSSD (SX,SQX,DX,L1,NSXD(JM1),NSXD(J),QMXD(JM1),QMXD(J)
     1      ,WMXD(JM1),WMXD(J),XD(JM1),XD(J))
            CALL NLSSD (SY,SQY,DY,L1,NSYD(JM1),NSYD(J),QMYD(JM1),QMYD(J)
     1      ,WMYD(JM1),WMYD(J),XD(JM1),XD(J))
            CALL NLSSD (SZ,SQZ,DZ,L1,NSZD(JM1),NSZD(J),QMZD(JM1),QMZD(J)
     1      ,WMZD(JM1),WMZD(J),XD(JM1),XD(J))
   20    CONTINUE
         GO TO 40
   30    CONTINUE
         N=N1-1
         CALL NLSSDU (SX,SQX,DX,L1,NSXD(N),QMXD(N),WMXD(N))
         CALL NLSSDU (SY,SQY,DY,L1,NSYD(N),QMYD(N),WMYD(N))
         CALL NLSSDU (SZ,SQZ,DZ,L1,NSZD(N),QMZD(N),WMZD(N))
   40 CONTINUE
C
COMMENT - DISCRETE CONCENTRATED SPRING
C
   50 CONTINUE
      IF (NCS.LE.0) GO TO 90
      DO 80 NCD=1,NCS
         Z=XP(NCD)
         IZ=Z/TH
         IF (IZ.LT.M) GO TO 60
         R1=0.0
         R2=1.0
         IZ1=M
         IZ2=MP1
         GO TO 70
   60    CONTINUE
         X1=Z-IZ*TH
         R2=X1/TH
         R1=1.0-R2
         IZ1=IZ+1
         IZ2=IZ+2
   70    CONTINUE
```

```
      CALL NLSSPT (SX,SQX,DX,L1,NSXP(NCD),QMXP(NCD),WMXP(NCD),IZ1,IZ2
     1 ,R1,R2)
      CALL NLSSPT (SY,SQY,DY,L1,NSYP(NCD),QMYP(NCD),WMYP(NCD),IZ1,IZ2
     1 ,R1,R2)
      CALL NLSSPT (SZ,SQZ,DZ,L1,NSZP(NCD),QMZP(NCD),WMZP(NCD),IZ1,IZ2
     1 ,R1,R2)
   80 CONTINUE
   90 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                        S U B R O U T I N E                          *
C***********************************************************************
C
      SUBROUTINE NLSSD(S,Q,D,L,NE1,NE2,QM1,QM2,WM1,WM2,X1,X2)
C
COMMENT - SUBROUTINE NLSSD DISCRETES DISTRIBUTED SPRINGS, FURNISHES
C         THE MEMBER DISCRETIZED VALUES OF RESISTIVE SPRING FORCES AND
C         TANGENT SPRING STIFFNESSES TO NLSS
C
      DIMENSION S(L),Q(L),D(L)
      DIMENSION QQ1(12),WW1(12),QQ2(12),WW2(12)
      COMMON/BLOCK7/      ISM(10),  NPTM(10),
     1   NQM(10,12),   NWM(10,12)
      COMMON/BLK4/         H,   IOS,  IDS5,ISMALL,KOFFQW,KOFFSE,      M,
     1         MIDS5,   MP1,  MP22,  NELE,    TH,     ZL
      IF (ABS(QM1).LT.1.0E-30.AND.ABS(QM2).LT.1.0E-30) GO TO 100
      IF (NE1.LE.0) GO TO 20
      NPTX1=NPTM(NE1)
      ISM1=ISM(NE1)
      DO 10 I=1,NPTX1
         QQ1(I)=NQM(NE1,I)*QM1
         WW1(I)=NWM(NE1,I)*WM1
   10 CONTINUE
      GO TO 30
   20 CONTINUE
      NPTX1=0
      S221=QM1
   30 CONTINUE
      IF (NE2.LE.0) GO TO 50
      NPTX2=NPTM(NE2)
      ISM2=ISM(NE2)
      DO 40 I=1,NPTX2
         QQ2(I)=NQM(NE2,I)*QM2
         WW2(I)=NWM(NE2,I)*WM2
   40 CONTINUE
      GO TO 60
   50 CONTINUE
      NPTX2=0
      S222=QM2
   60 CONTINUE
      IX1=X1/TH+1
      IX2=X2/TH+1
      DX1=X1-(IX1-1)*TH
      DX2=X2-(IX2-1)*TH
      NQ=IX2-IX1-1
      IF ((IX2-1)*TH.GE.X2) NQ=NQ-1
      XT=X1
      X2X1=X2-X1
      D1=D(IX1)+(D(IX1+1)-D(IX1))*DX1/TH
      CALL CURVE (QQ1,WW1,D1,NPTX1,ISM1,QJ1,S221,KOFFQW)
      S21=S221
      IF (NQ.LT.0) GO TO 90
      D2=D(IX1+1)
      CALL CURVE (QQ1,WW1,D2,NPTX1,ISM1,QJ21,S221,KOFFQW)
      CALL CURVE (QQ2,WW2,D2,NPTX2,ISM2,QJ22,S222,KOFFQW)
      DDX1=IX1*TH-X1
      S22=S221+(S222-S221)*DDX1/X2X1
      QJ2=QJ21+(QJ22-QJ21)*DDX1/X2X1
      SI=-0.5*S21*DDX1
      QI=0.5*QJ1*DDX1
      ZS=XT+DDX1/3.0
      CALL CONLD (SI,ZS,S,L)
      CALL CONLD (QI,ZS,Q,L)
      SI=-0.5*S22*DDX1
      QI=0.5*QJ2*DDX1
      ZS=XT+2.0*DDX1/3.0
      CALL CONLD (SI,ZS,S,L)
      CALL CONLD (QI,ZS,Q,L)
      IF (NQ.EQ.0) GO TO 80
      DO 70 I=1,NQ
         XT=(IX1+I-1)*TH
         S21=S22
         QJ1=QJ2
         IXI=IX1+I+1
         D2=D(IXI)
         CALL CURVE (QQ1,WW1,D2,NPTX1,ISM1,QJ21,S221,KOFFQW)
         CALL CURVE (QQ2,WW2,D2,NPTX2,ISM2,QJ22,S222,KOFFQW)
         DDX1=(IXI-1)*TH-X1
         S22=S221+(S222-S221)*DDX1/X2X1
         QJ2=QJ21+(QJ22-QJ21)*DDX1/X2X1
         SI=-0.5*S21*TH
         QI=0.5*QJ1*TH
         ZS=XT+TH/3.0
         CALL CONLD (SI,ZS,S,L)
         CALL CONLD (QI,ZS,Q,L)
         SI=-0.5*S22*TH
         QI=0.5*QJ2*TH
         ZS=XT+2.0*TH/3.0
         CALL CONLD (SI,ZS,S,L)
         CALL CONLD (QI,ZS,Q,L)
   70 CONTINUE
   80 CONTINUE
      S21=S22
      QJ1=QJ2
      XT=(IX2-1)*TH
   90 CONTINUE
      D2=D(IX2)+(D(IX2+1)-D(IX2))*DX2/TH
      CALL CURVE (QQ2,WW2,D2,NPTX2,ISM2,QJ2,S222,KOFFQW)
      S22=S222
      DDX2=X2-XT
      SI=-0.5*S21*DDX2
      QI=0.5*QJ1*DDX2
      ZS=XT+DDX2/3.0
      CALL CONLD (SI,ZS,S,L)
      CALL CONLD (QI,ZS,Q,L)
      SI=-0.5*S22*DDX2
      QI=0.5*QJ2*DDX2
      ZS=XT+2.0*DDX2/3.0
      CALL CONLD (SI,ZS,S,L)
      CALL CONLD (QI,ZS,Q,L)
  100 CONTINUE
      RETURN
```

```
C
      END
C***********************************************************************
C*                         S U B R O U T I N E                        *
C***********************************************************************
C
      SUBROUTINE NLSSDU(S,Q,D,L,NEQ,QM,WM)
C
COMMENT - SUBROUTINE NLSSDU DISCRETIZES UNIFORMLY DISTRIBUTED SPRINGS,
C         FURNISHES THE MEMBER DISCRETIZED VALUES OF RESISTIVE
C         SPRING FORCES AND TANGENT SPRING STIFFNESSES TO NLSS
C
      DIMENSION S(L),Q(L),D(L)
      DIMENSION QQ(12),WW(12)
      COMMON/BLOCK7/       ISM(10),  NPTM(10),
     1     NQM(10,12),   NWM(10,12)
      COMMON/BLK4/         H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1           MIDS5,   MP1,   MP22,   NELE,     TH,      ZL
      IF (ABS(QM).LE.1.0E-30) GO TO 50
      IF (NEQ.LE.0) GO TO 20
      NPTT=NPTM(NEQ)
      ISMT=ISM(NEQ)
      DO 10 I=1,NPTT
         QQ(I)=NQM(NEQ,I)*QM
         WW(I)=NWM(NEQ,I)*WM
   10 CONTINUE
      GO TO 30
   20 CONTINUE
      NPTT=0
      S2=QM
   30 CONTINUE
      CALL CURVE (QQ,WW,D(1),NPTT,ISMT,QJ,S2,KOFFQW)
      QI=QJ*H/3.0
      SI=-S2*H/3.0
      Q(1)=Q(1)+2.0*QI
      Q(2)=Q(2)+QI
      S(1)=S(1)+2.0*SI
      S(2)=S(2)+SI
      CALL CURVE (QQ,WW,D(MP1),NPTT,ISMT,QJ,S2,KOFFQW)
      QI=QJ*H/3.0
      SI=-S2*H/3.0
      Q(M)=Q(M)+QI
      Q(MP1)=Q(MP1)+2.0*QI
      S(M)=S(M)+SI
      S(MP1)=S(MP1)+2.0*SI
      DO 40 I=2,M
         IM1=I-1
         IP1=I+1
         CALL CURVE (QQ,WW,D(I),NPTT,ISMT,QJ,S2,KOFFQW)
         QI=QJ*H/3.0
         SI=-S2*H/3.0
         Q(IM1)=Q(IM1)+QI
         Q(I)=Q(I)+4.0*QI
         Q(IP1)=Q(IP1)+QI
         S(IM1)=S(IM1)+SI
         S(I)=S(I)+4.0*SI
         S(IP1)=S(IP1)+SI
   40 CONTINUE
   50 CONTINUE
      RETURN
C
      END
```

```
C***********************************************************************
C*                         S U B R O U T I N E                        *
C***********************************************************************
C
      SUBROUTINE NLSSPT(S,Q,D,L,NEQ,QM,WM,I1,I2,R1,R2)
C
COMMENT - SUBROUTINE NLSSPT DISCRETE CONCENTRATED SPRINGS, FURNISHES
C         THE MEMBER DISCRETIZED VALUES OF RESISTIVE SPRING FORCES AND
C         TANGENT SPRING STIFFNESSES TO NLSS
C
      DIMENSION S(L),Q(L),D(L)
      DIMENSION QQ(12),WW(12)
      COMMON/BLOCK7/       ISM(10),  NPTM(10),
     1     NQM(10,12),   NWM(10,12)
      COMMON/BLK4/         H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1           MIDS5,   MP1,   MP22,   NELE,     TH,      ZL
      IF (ABS(QM).LT.1.0E-30) GO TO 40
      IF (NEQ.EQ.0) GO TO 20
      NPTT=NPTM(NEQ)
      DO 10 J=1,NPTT
         QQ(J)=NQM(NEQ,J)*QM
         WW(J)=NWM(NEQ,J)*WM
   10 CONTINUE
      GO TO 30
   20 CONTINUE
      NPTT=0
      S2=QM
   30 CONTINUE
      CALL CURVE (QQ,WW,D(I1),NPTT,ISM(NEQ),QJ,S2,KOFFQW)
      S(I1)=S(I1)-S2*R1
      Q(I1)=Q(I1)+QJ*R1
      CALL CURVE (QQ,WW,D(I2),NPTT,ISM(NEQ),QJ,S2,KOFFQW)
      S(I2)=S(I2)-S2*R2
      Q(I2)=Q(I2)+QJ*R2
   40 CONTINUE
      RETURN
C
      END
C***********************************************************************
C*                         S U B R O U T I N E                        *
C***********************************************************************
C
      SUBROUTINE RANKT(TIMET,TIME,ITIME,NN,MTIME,JT,IABAN)
C
COMMENT - SUBROUTINE RANKT REARRANGES TIME IN ASCENDING ORDER
C
      DIMENSION TIME(MTIME),ITIME(MTIME)
      NOTIME=NN
      J=JT
      IF (NOTIME.GT.0) GO TO 10
      TIME(1)=TIMET
      IF (J.GE.0) ITIME(1)=J
      NOTIME=1
      GO TO 80
   10 CONTINUE
      DO 20 I=1,MTIME
         N=I
         IF (TIMET-TIME(I)) 40,70,20
   20 CONTINUE
   30 CONTINUE
      IABAN=2
      GO TO 80
```

```
   40 CONTINUE
      IF (NOTIME.GE.MTIME) GO TO 30
      NOTIME=NOTIME+1
      IF (N.EQ.NOTIME) GO TO 60
      NT=NOTIME-N
      DO 50 I=1,NT
         NOTIM1=NOTIME+1-I
         TIME(NOTIM1)=TIME(NOTIM1-1)
         IF (J.GE.0) ITIME(NOTIM1)=ITIME(NOTIM1-1)
   50 CONTINUE
   60 CONTINUE
      TIME(N)=TIMET
      IF (J.GE.0) ITIME(N)=J
      GO TO 80
   70 CONTINUE
      IF (J.GE.0) ITIME(N)=ITIME(N)+J
   80 CONTINUE
      NN=NOTIME
      RETURN
C
      END
C***********************************************************************
C*                         S U B R O U T I N E                         *
C***********************************************************************
C
      SUBROUTINE RELAX (TIME00,TIME1,TIMEST,SIG,NMATT,DCT)
C
COMMENT - SUBROUTINE RELAX COMPUTES LELAXATION FROM TIME TIME1 TO TIME
C         TIMEST FOR AN ELEMENT LOADED AT TIME T1. THE NEGATIVE VALUE OF
C         RELAXATION WILL BE GIVEN.
C
      DIMENSION BIT(8),XST(8)
      COMMON/BLOCK2/         EM(10),IRELAX(10),  NEQA(10),  NEQC(10),
     1        NEQS(10),   NSS(10),     SM(10), STMAX(10), STMIN(10),
     2         UWT(10),
     3        A(10,8),     AT(10,8),     A1(10,8),   A1T(10,8),
     4       C(10,10),     CT(10,8),     C1(10,8),   C1T(10,8),
     5       S(10,8),    SRT(10,8)
      IF (TIMEST.LT.TIME1) GO TO 230
      DCT=0.0
      ID=NEQC(NMATT)
      IF (ID.GT.10) GO TO 110
      GO TO (10,20,30,40,50,60,70,80,90,100), ID
   10 CONTINUE
      F=SIG/C(NMATT,1)
      IF (F.LT.C(NMATT,4)) GO TO 240
      T1=24.0*(TIMEST-TIME00)
      T2=24.0*(TIME1-TIME00)
      IF (T1.LT.1.0) T1=1.0
      IF (T2.LT.1.0) T2=1.0
      DCT=-SIG*ALOG10(T1/T2)*(F-C(NMATT,3))/C(NMATT,2)
      GO TO 240
   20 CONTINUE
      GO TO 230
   30 CONTINUE
      GO TO 230
   40 CONTINUE
      GO TO 230
   50 CONTINUE
      GO TO 230
   60 CONTINUE
      GO TO 230
   70 CONTINUE
      GO TO 230
   80 CONTINUE
      GO TO 230
   90 CONTINUE
      GO TO 230
  100 CONTINUE
      GO TO 230
  110 CONTINUE
      DCT2=0.0
      IF (SIG.GT.C1T(NMATT,1)) GO TO 120
      DCT=C1(NMATT,1)
      GO TO 150
  120 CONTINUE
      IF (SIG.GE.C1T(NMATT,8)) GO TO 140
      DO 130 I=1,8
         BIT(I)=C1(NMATT,I)
         XST(I)=C1T(NMATT,I)
  130 CONTINUE
      CALL SCURV1 (SIG,XST,BIT,8,8,1,8,DCT)
      GO TO 150
  140 CONTINUE
      DCT=C1(NMATT,8)
  150 CONTINUE
      DO 160 I=1,8
         BIT(I)=C(NMATT,I)
         XST(I)=CT(NMATT,I)
  160 CONTINUE
      T2=TIME1-TIME00
      IF (T2.LE.0.0) GO TO 190
      IF (T2.LE.XST(1)) GO TO 170
      IF (T2.GE.XST(8)) GO TO 180
      CALL SCURV1 (T2,XST,BIT,8,8,1,8,DCT2)
      GO TO 190
  170 CONTINUE
      DCT2=BIT(1)
      GO TO 190
  180 CONTINUE
      DCT2=BIT(8)
  190 CONTINUE
      T1=TIMEST-TIME00
      IF (T1.LE.XST(1)) GO TO 200
      IF (T1.GE.XST(8)) GO TO 210
      CALL SCURV1 (T1,XST,BIT,8,8,1,8,DCT1)
      GO TO 220
  200 CONTINUE
      DCT1=BIT(1)
      GO TO 220
  210 DCT1=BIT(8)
  220 CONTINUE
      DCT=DCT*SIG*(DCT2-DCT1)
      GO TO 240
  230 CONTINUE
      PRINT 250
      STOP
  240 CONTINUE
      RETURN
C
  250 FORMAT (//, 53H      ERROR FOUND IN RELAXATION FUNCTION, EXECUTION
     1ST,  2HOP)
C
      END
```

```
C************************************************************************
C*                          S U B R O U T I N E                        *
C************************************************************************
C
      SUBROUTINE SCURV(X,XS,BI,DI,CG,L,I1,I2,B,D,CGT)
C
COMMENT - SUBROUTINE SCURV INTERPORATES ALONG CURVES OF BI, DI, AND CG
C           THE VALUES OF B, D, AND CGT, GIVEN THE X-COORDINATE OF THE
C           CURVES
C
      DIMENSION XS(L),BI(L),DI(L),CG(L)
      IF (X.LT.XS(I1)) GO TO 40
      IF (X.GT.XS(I2)) GO TO 40
      I11=I1+1
      DO 10 I=I11,I2
         J=I
         IF (X-XS(I)) 20,30,10
   10 CONTINUE
   20 JM1=J-1
      RATIO=(X-XS(JM1))/(XS(J)-XS(JM1))
      B=BI(JM1)+(BI(J)-BI(JM1))*RATIO
      D=DI(JM1)+(DI(J)-DI(JM1))*RATIO
      CGT=CG(JM1)+(CG(J)-CG(JM1))*RATIO
      GO TO 50
   30 CONTINUE
      B=BI(J)
      D=DI(J)
      CGT=CG(J)
      GO TO 50
   40 B=0.0
      D=0.0
      CGT=0.0
   50 CONTINUE
      RETURN
C
      END
C************************************************************************
C*                          S U B R O U T I N E                        *
C************************************************************************
C
      SUBROUTINE SCURV1(X,XST,BIT,L1,L2,I1,I2,B)
C
COMMENT - SUBROUTINE SCURV1 INTERPORATES ALONG BIT CURVE THE VALUE OF
C           B, GIVEN X-COORDINATE OF THE CURVE
C
      DIMENSION XST(L1),BIT(L2)
      IF (X.LT.XST(I1)) GO TO 40
      IF (X.GT.XST(I2)) GO TO 40
      I11=I1+1
      DO 10 I=I11,I2
         J=I
         IF (X-XST(I)) 20,30,10
   10 CONTINUE
   20 JM1=J-1
      RATIO=(X-XST(JM1))/(XST(J)-XST(JM1))
      B=BIT(JM1)+(BIT(J)-BIT(JM1))*RATIO
      GO TO 50
   30 B=BIT(J)
      GO TO 50
   40 B=0.0
   50 CONTINUE
      RETURN
C
      END
C************************************************************************
C*                          S U B R O U T I N E                        *
C************************************************************************
C
      SUBROUTINE SHRINK(TIMEST,I,DET)
C
COMMENT - SUBROUTINE SHRINK CALCULATES SHRINKAGE FOR SUB-RECTANGLE I
C           FROM TIME SUB-MEMBER CAN BE LOADED TIMESS(I,3) TO TIMEST
C
      DIMENSION BIT(8),XST(8)
      COMMON/BLOCK2/        EM(10),IRELAX(10),  NEQA(10),   NEQC(10),
     1           NEQS(10),   NSS(10),    SM(10), STMAX(10), STMIN(10),
     2            UWT(10),
     3          A(10,8),     AT(10,8),     A1(10,8),    A1T(10,8),
     4        C(10,10),     CT(10,8),     C1(10,8),    C1T(10,8),
     5          S(10,8),    SRT(10,8)
      COMMON/BLOCK4/         ISUR(30),  NDIV(30),   NMAT(30),  NSYM(30),
     1          NPOST(30),  NPTS(31),TIMESS(30,3),
     2            BI(100),    DI(100),    CG(100),    XS(100), STRI(100),
     3           BIP(400),  DIP(400),   CGP(400),STRIP(400)
      DETT=0.0
      TIME00=TIMESS(I,3)
      IF (TIMEST.LE.TIME00) GO TO 200
      T=TIMEST-TIME00
      NMATT=NMAT(I)
      IF (NEQS(NMATT).LE.0) GO TO 200
      ID=NEQS(NMATT)
      IF (ID.GT.10) GO TO 150
      GO TO (10,20,30,80,90,100,110,120,130,140), ID
   10 CONTINUE
C
COMMENT - THE A.C.I.*S SHRINKAGE FUNCTION
C
      DETT=T*S(NMATT,1)/(S(NMATT,2)+T)
      GO TO 200
   20 CONTINUE
C
COMMENT - THE GENERAL A.C.I.*S SHRINKAGE FUNCTION
C
      T=T**S(NMATT,2)
      DETT=T*S(NMATT,1)/(S(NMATT,3)+T)
      GO TO 200
   30 CONTINUE
C
COMMENT - THE P.C.I.*S SHRINKAGE FUNCTION
C
      IF (T.GT.1.0) GO TO 40
      DETT=0.11*T
      GO TO 70
   40 IF (T.LT.625.0) GO TO 50
      DETT=1.0
      GO TO 70
   50 IF (T.GT.90.0) GO TO 60
      T=ALOG10(T)
      DETT=0.11+0.05*T+0.108*T*T
      GO TO 70
   60 DETT=0.2*T**0.25
   70 DETT=DETT*S(NMATT,1)
      GO TO 200
   80 CONTINUE
```

```
      GO TO 190
   90 CONTINUE
      GO TO 190
  100 CONTINUE
      GO TO 190
  110 CONTINUE
      GO TO 190
  120 CONTINUE
      GO TO 190
  130 CONTINUE
      GO TO 190
  140 CONTINUE
      GO TO 190
  150 CONTINUE
C
COMMENT - SHRINKAGE FUNCTION INPUT AS A CURVE
C
      IF (T.LE.SRT(NMATT,1)) GO TO 170
      IF (T.GE.SRT(NMATT,8)) GO TO 180
      DO 160 I=1,8
         BIT(I)=S(NMATT,I)
         XST(I)=SRT(NMATT,I)
  160 CONTINUE
      CALL SCURV1 (T,XST,BIT,8,8,1,8,DETT)
      GO TO 200
  170 DETT=S(NMATT,1)
      GO TO 200
  180 CONTINUE
      DETT=S(NMATT,8)
      GO TO 200
  190 PRINT 210
      STOP
  200 CONTINUE
      DET=DETT
      RETURN
C
  210 FORMAT (//, 52H      ERROR FOUND IN SHRINKAGE FUNCTION, EXECUTION S
     1T,  2HOP)
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      SUBROUTINE SSCRV(SIGT,EPST,T1,T2,NMATT,ISJT,NPTT,ET)
C
COMMENT - SUBROUTINE SSCRV GENERATES MATERIAL STRESS-STRAIN CURVE OR
C         MODULUS OF ELASTICITY AT TIME T2, MATERIAL CASTED AT TIME T1,
C         TAKING INTO ACCOUNT AGING OF MATERIAL
C
      DIMENSION SIGT(12),EPST(12)
      COMMON/BLOCK2/        EM(10),IRELAX(10),  NEQA(10),   NEQC(10),
     1          NEQS(10),    NSS(10),     SM(10), STMAX(10), STMIN(10),
     2          UWT(10),
     3        A(10,8),     AT(10,8),     A1(10,8),    A1T(10,8),
     4       C(10,10),     CT(10,8),     C1(10,8),    C1T(10,8),
     5        S(10,8),    SRT(10,8)
      COMMON/BLOCK3/       ISS(10), NSTST(10),
     1     NEPS(10,12),  NSIG(10,12)
      NC=NSS(NMATT)
      IF (NC.LE.0) GO TO 20
      ISJT=ISS(NC)
```

```
      NPTT=NSTST(NC)
      DO 10 I=1,NPTT
         SIGT(I)=NSIG(NC,I)*SM(NMATT)
         EPST(I)=NEPS(NC,I)*EM(NMATT)
   10 CONTINUE
      GO TO 30
   20 CONTINUE
      NPTT=0
      ET=SM(NMATT)
   30 CONTINUE
      IF (NEQA(NMATT).LE.0) GO TO 60
      CALL AGE (T1,T2,NMATT,REPS,RSIG)
      IF (NC.LE.0) GO TO 50
      DO 40 I=1,NPTT
         SIGT(I)=SIGT(I)*RSIG
         EPST(I)=EPST(I)*REPS
   40 CONTINUE
      GO TO 60
   50 CONTINUE
      ET=ET*RSIG/REPS
   60 CONTINUE
      RETURN
C
      END
C*********************************************************************
C*                        S U B R O U T I N E                        *
C*********************************************************************
C
      OVERLAY (CNTRL,1,0)
      PROGRAM CNTRL
C
COMMENT - SUBROUTINE CNTRL INPUS TIME INCREMENT DATA AND ITERATION
C         CONTROL DATA
C         REPLACE THE OVERLAY CARD BY THE NONOVERLAY CARD UNLESS THE CDC
C         OVERLAY SYSTEM IS BEING USED
C     SUBROUTINE CNTRL
C
      COMMON/BLOCK1/    ITIMES(51), TIME1(51),TPRINT(51)
      COMMON/BLOC12/        BIT(80),    DIT(81)
      COMMON/BLK1/     IABAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1          KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2             MISUB, MMTER, MNCLD,  MNCS, MNDLD,  MNDS,   MNE,  MNEQ,
     3            MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,  MNSS, MPOST,MTIME1
      COMMON/BLK2/    NPRINL, NTIM1, FTIME, TIMEO,TIMEST
      COMMON/BLK3/       ERR1,  ERR2,   ER1,   ER2,     MB, MNITM,  NITM
      COMMON/BLK4/          H,    IDS,  IDS5,ISMALL,KOFFQW,KOFFSE,     M,
     1          MIDS5,   MP1,   MP22,  NELE,     TH,      ZL
      PRINT 120
      IF (KEEP2.EQ.1) GO TO 20
      NTIM1=0
      NPRINL=0
      DO 10 I=1,MTIME1
         ITIMES(I)=0
         TIME1(I)=1.0E50
         TPRINT(I)=1.0E50
   10 CONTINUE
      IF (NCD2.LE.0) GO TO 90
      GO TO 30
   20 CONTINUE
      PRINT 150
      IF (NCD2.GT.0) GO TO 30
      PRINT 160
```

```
      GO TO 110
   30 CONTINUE
C
COMMENT - READ IN TIME INCREMENTS FOR ESTIMATING TIME DEPENDENT
C         RESPONSE
C
      NCR=1
      READ 130, NTIME,NPRIN,TIMEO,FTIME
      PRINT 140, NTIME,NPRIN,TIMEO,FTIME
      IF (TIMEO.LT.-0.0) GO TO 100
      IF (FTIME.GT.1.0E50) GO TO 100
      IF (FTIME.LT.TIMEO) GO TO 100
      IF (NTIME.LE.0) GO TO 50
      NCR=NCR+(NTIME+7)/8
      PRINT 200
      READ 170, (BIT(I),I=1,NTIME)
      PRINT 180, (BIT(I),I=1,NTIME)
      DO 40 I=1,NTIME
         IF (BIT(I).LT.-0.0.OR.BIT(I).GE.1.0E50) GO TO 100
         CALL RANKT (BIT(I),TIME1,ITIMES,NTIM1,MTIME1,0,IABAN)
         IF (IABAN.NE.0) GO TO 110
   40 CONTINUE
   50 CONTINUE
      CALL RANKT (TIMEO,TIME1,ITIMES,NTIM1,MTIME1,0,IABAN)
      IF (IABAN.NE.0) GO TO 110
      CALL RANKT (FTIME,TIME1,ITIMES,NTIM1,MTIME1,0,IABAN)
      IF (IABAN.NE.0) GO TO 110
      PRINT 190
      IF (NPRIN.GT.0) GO TO 60
      PRINT 180, FTIME
      GO TO 80
   60 CONTINUE
C
COMMENT - READ IN OUTPUT PRINT OUT TIME STEPS
C
      CALL RANKT (FTIME,TPRINT,ITIMES,NPRINL,MTIME1,-1,IABAN)
      IF (IABAN.NE.0) GO TO 110
      NCR=NCR+(NPRIN+7)/8
      READ 170, (BIT(I),I=1,NPRIN)
      PRINT 180, (BIT(I),I=1,NPRIN)
      DO 70 I=1,NPRIN
         IF (BIT(I).LT.-0.0.OR.BIT(I).GE.1.0E50) GO TO 100
         CALL RANKT (BIT(I),TPRINT,ITIMES,NPRINL,MTIME1,-1,IABAN)
         IF (IABAN.NE.0) GO TO 110
   70 CONTINUE
   80 CONTINUE
      NCR=NCR+1
      READ 210, MIDS5,MNITM,MB,ER1,ER2,ERR1,ERR2
      IF (MIDS5.LT.1) MIDS5=1
      IF (MNITM.LE.0) MNITM=20
      ER1=ABS(ER1)
      ER2=ABS(ER2)
      ERR1=ABS(ERR1)
      ERR2=ABS(ERR2)
      IF (ER1.LT.1.0E-30) ER1=1.0E-30
      IF (ER2.LT.1.0E-30) ER2=1.0E-30
      IF (ERR1.LT.ER1*1.0E10) ERR1=ER1*1.0E10
      IF (ERR2.LT.ER2*1.0E10) ERR2=ER2*1.0E10
      PRINT 220, MIDS5,MNITM,MB,ER1,ER2,ERR1,ERR2
      IF (NCR.NE.NCD2) GO TO 90
      GO TO 110
   90 IABAN=1
      GO TO 110
  100 IABAN=3
  110 CONTINUE
      RETURN
C
  120 FORMAT ( 52H       TABLE 2 - TIME INCREMENT AND ITERATION CONTROL ,
     1 4HDATA,///)
  130 FORMAT (2I5,2E10.3)
  140 FORMAT (40H      NUMBER OF CALCULATING TIME STEPS  =,I5,/,40H     N
     1UMBER OF OUTPUT PRINTED           =,I5,//,40H      TIME LOADING STAR
     2TS                  =,E12.3,/,40H      FINAL TIME STEP
     3   =,E12.3)
  150 FORMAT (52H      HOLDING DATA FROM THE PREVIOUS PROBLEM PLUS THE,10
     1H FOLLOWING,//)
  160 FORMAT (10H      NONE )
  170 FORMAT (8E10.3)
  180 FORMAT (5X,8E13.3)
  190 FORMAT (5/,45H      TIMES OUTPUT WILL BE PRINTED OUT, DAYS   ,/)
  200 FORMAT (5/,35H      CALCULATING TIME STEPS          ,/)
  210 FORMAT (3I5,5X,4E10.3)
  220 FORMAT (5/, 42H      NO. OF CYCLES CRACKS ARE FROZEN      =,I5,/, 42
     1H      MAXIMUM NO. OF ITERATIONS/CYCLE      =,I5,/, 42H      ITERATIO
     2N PRINTOUT INDICATOR          =,I5,/, 42H      CLOSURE TOLERANCE FOR
     3FORCE ERRORS  =,E12.3,/, 42H      CLOSURE TOLERANCE FOR MOMENT ERRO
     4RS =,E12.3,/, 42H      MAXIMUM FORCE ERRORS                 =,E12.3,
     5/, 42H      MAXIMUM MOMENT ERRORS                =,E12.3)
C
      END
C***********************************************************************
C*                         S U B R O U T I N E                         *
C***********************************************************************
C
      OVERLAY (MTRL,2,0)
      PROGRAM MTRL
C
COMMENT - SUBROUTINE MTRL INPUTS MATERIAL DATA
C         REPLACE THE OVERLAY CARD BY THE NONOVERLAY CARD UNLESS THE CDC
C         OVERLAY SYSTEM IS BEING USED
C     SUBROUTINE MTRL
C
      DIMENSION NSIT(12),NEPT(12)
      COMMON/BLOCK2/      EM(10),IRELAX(10),  NEQA(10),  NEQC(10),
     1        NEQS(10),    NSS(10),     SM(10), STMAX(10), STMIN(10),
     2         UWT(10),
     3       A(10,8),    AT(10,8),    A1(10,8),    A1T(10,8),
     4      C(10,10),    CT(10,8),    C1(10,8),    C1T(10,8),
     5       S(10,8),   SRT(10,8)
      COMMON/BLOCK3/        ISS(10), NSTST(10),
     1     NEPS(10,12),  NSIG(10,12)
      COMMON/BLK1/     IABAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1         KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2          MISUB, MHTER, MNCLD,  MNCS, MNOLD,  MNDS,   MNE,  MNEQ,
     3          MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,  MNSS, MPOST,MTIME1
C
COMMENT - INPUT TABLE 3, MATERIAL DATA
C
      PRINT 400
      NCR=0
      IF (KEEP3A.EQ.1) GO TO 20
      IF (NCD3A.LE.0) GO TO 360
C
COMMENT - INITIALIZE MATERIAL INDICATORS FOR ALL NEW DATA
```

```
C
      DO 10 I=1,MMTER
        NSS(I)=-1
   10 CONTINUE
      GO TO 30
   20 CONTINUE
      PRINT 420
      IF (NCD3A.GT.0) GO TO 30
      PRINT 430
      GO TO 240
   30 CONTINUE
C
COMMENT - READ IN NEW MATERIAL DATA
C
      NCR=NCR+1
      READ 450, MATER
      PRINT 460, MATER
      DO 230 I=1,MATER
         NCR=NCR+1
         READ 440, NMATT,IRELAT,NSST,NEQAT,NEQCT,NEQST,UWTT
         IF (IRELAT.GT.0) GO TO 40
         PRINT 470, NMATT,IRELAT,NSST,NEQAT,NEQCT,NEQST,UWTT
         GO TO 50
   40    CONTINUE
         PRINT 480, NMATT,IRELAT,NSST,NEQAT,NEQCT,NEQST,UWTT
   50    CONTINUE
         IF (NMATT.LE.0.OR.NMATT.GT.MMTER) GO TO 370
         IF (NSST.GT.MNSS) GO TO 370
         IF (NSS(NMATT).NE.-1) PRINT 490
         IRELAX(NMATT)=IRELAT
         NSS(NMATT)=NSST
         NEQA(NMATT)=NEQAT
         NEQC(NMATT)=NEQCT
         NEQS(NMATT)=NEQST
         UWT(NMATT)=UWTT
         NCR=NCR+1
         READ 500, SM(NMATT),EM(NMATT),STMAX(NMATT),STMIN(NMATT)
         IF (NSS(NMATT).GT.0) GO TO 60
C
COMMENT - ELASTIC MATERIAL
C
         PRINT 510, SM(NMATT),STMAX(NMATT),STMIN(NMATT)
         GO TO 70
   60    CONTINUE
C
COMMENT - INELASTIC MATERIAL
C
         PRINT 520, SM(NMATT),EM(NMATT),STMAX(NMATT),STMIN(NMATT)
         IF (EM(NMATT).LE.0.0) GO TO 370
   70    CONTINUE
         IF (STMAX(NMATT).LE.STMIN(NMATT)) GO TO 370
         IF (NEQAT.LE.0) GO TO 110
C
COMMENT - READ IN AGE DATA
C
         IF (NEQAT.GT.MNEQ) GO TO 80
         NCR=NCR+1
         READ 530, (A(NMATT,II),II=1,8)
         PRINT 540
         PRINT 560, (A(NMATT,II),II=1,8)
         GO TO 110
   80    CONTINUE
         NCR=NCR+4
         READ 530, (A(NMATT,II),II=1,8)
         READ 530, (AT(NMATT,II),II=1,8)
         PRINT 660
         PRINT 700, (A(NMATT,II),II=1,8)
         PRINT 700, (AT(NMATT,II),II=1,8)
         DO 90 II=2,8
            IF (AT(NMATT,II).LE.AT(NMATT,II-1)) GO TO 370
   90    CONTINUE
         READ 530, (A1(NMATT,II),II=1,8)
         READ 530, (A1T(NMATT,II),II=1,8)
         PRINT 670
         PRINT 700, (A1(NMATT,II),II=1,8)
         PRINT 700, (A1T(NMATT,II),II=1,8)
         IF (A1(NMATT,1).LE.0.0) GO TO 370
         DO 100 II=2,8
            IF (A1(NMATT,II).LE.0.0) GO TO 370
            IF (A1T(NMATT,II).LE.A1T(NMATT,II-1)) GO TO 370
  100    CONTINUE
  110    CONTINUE
         IF (NEQCT.LE.0) GO TO 190
C
COMMENT - READ IN CREEP DATA OR RELAXATION DATA
C
         IF (NEQCT.GT.MNEQ) GO TO 130
         IF (IRELAT.LE.0) GO TO 120
         NCR=NCR+1
         READ 530, (C(NMATT,II),II=1,8)
         PRINT 640
         PRINT 560, (C(NMATT,II),II=1,8)
         GO TO 190
  120    CONTINUE
         NCR=NCR+2
         READ 530, C(NMATT,9),C(NMATT,10)
         PRINT 550, C(NMATT,9),C(NMATT,10)
         READ 530, (C(NMATT,II),II=1,8)
         PRINT 560, (C(NMATT,II),II=1,8)
         GO TO 190
  130    CONTINUE
         IF (IRELAT.LE.0) GO TO 160
         NCR=NCR+4
         PRINT 640
         READ 530, (C(NMATT,II),II=1,8)
         READ 530, (CT(NMATT,II),II=1,8)
         PRINT 710
         PRINT 700, (C(NMATT,II),II=1,8)
         PRINT 700, (CT(NMATT,II),II=1,8)
         DO 140 II=2,8
            IF (CT(NMATT,II).LE.CT(NMATT,II-1)) GO TO 370
  140    CONTINUE
         READ 530, (C1(NMATT,II),II=1,8)
         READ 530, (C1T(NMATT,II),II=1,8)
         PRINT 720
         PRINT 700, (C1(NMATT,II),II=1,8)
         PRINT 700, (C1T(NMATT,II),II=1,8)
         DO 150 II=2,8
            IF (C1T(NMATT,II).LE.C1T(NMATT,II-1)) GO TO 370
  150    CONTINUE
         GO TO 190
  160    CONTINUE
         NCR=NCR+5
         READ 530, C(NMATT,9),C(NMATT,10)
```

```
      PRINT 550, C(NMATT,9),C(NMATT,10)
      READ 530, (C(NMATT,II),II=1,8)
      READ 530, (CT(NMATT,II),II=1,8)
      PRINT 680
      PRINT 700, (C(NMATT,II),II=1,8)
      PRINT 700, (CT(NMATT,II),II=1,8)
      DO 170 II=2,8
         IF (CT(NMATT,II).LE.CT(NMATT,II-1)) GO TO 370
  170 CONTINUE
      READ 530, (C1(NMATT,II),II=1,8)
      READ 530, (C1T(NMATT,II),II=1,8)
      PRINT 690
      PRINT 700, (C1(NMATT,II),II=1,8)
      PRINT 700, (C1T(NMATT,II),II=1,8)
      DO 180 II=2,8
         IF (C1T(NMATT,II).LE.C1T(NMATT,II-1)) GO TO 370
  180 CONTINUE
  190 CONTINUE
      IF (NEQST.LE.0) GO TO 220
C
COMMENT - READ IN SHRINKAGE DATA
C
      IF (NEQST.GT.MNEQ) GO TO 200
      NCR=NCR+1
      READ 530, (S(NMATT,II),II=1,8)
      PRINT 570
      PRINT 560, (S(NMATT,II),II=1,8)
      GO TO 220
  200 CONTINUE
      NCR=NCR+2
      READ 530, (S(NMATT,II),II=1,8)
      READ 530, (SRT(NMATT,II),II=1,8)
      PRINT 570
      PRINT 730
      PRINT 700, (S(NMATT,II),II=1,8)
      PRINT 700, (SRT(NMATT,II),II=1,8)
      DO 210 II=2,8
         IF (SRT(NMATT,II).LE.SRT(NMATT,II-1)) GO TO 370
  210 CONTINUE
  220 CONTINUE
  230 CONTINUE
  240 CONTINUE
      IF (NCR.NE.NCD3A) GO TO 360
C
COMMENT - INPUT TABLE 3B - STRESS-STRAIN CURVES
C
      PRINT 580
      IF (KEEP3B.EQ.1) GO TO 260
      DO 250 II=1,MNSS
         NSTST(II)=-1
  250 CONTINUE
      IF (NCD3B.GT.0) GO TO 270
      PRINT 410
      GO TO 340
  260 CONTINUE
      PRINT 420
      IF (NCD3B.GT.0) GO TO 270
      PRINT 430
      GO TO 340
  270 CONTINUE
      PRINT 590
      N2=NCD3B/2
      IF (N2*2.NE.NCD3B) GO TO 360
      DO 330 II=1,N2
         READ 600, NC,NPTT,ISJT,(NSIT(I),I=1,12),(NEPT(I),I=1,12)
         IF (NC.LE.0.OR.NC.GT.MNSS) GO TO 290
         IF (NSTST(NC).NE.-1) PRINT 650, NC
         IF (NPTT.GE.2) GO TO 290
         CALL STRSTR (NSIT,NEPT,NC,NPTT,IABAN)
         IF (IABAN.EQ.0) GO TO 280
         PRINT 610, NC,NPTT,ISJT,(NSIT(I),I=1,12)
         PRINT 620, (NEPT(I),I=1,12)
         GO TO 390
  280    CONTINUE
         PRINT 610, NC,NSTST(NC),ISS(NC),(NSIG(NC,I),I=1,NPTT)
         PRINT 620, (NEPS(NC,I),I=1,NPTT)
         GO TO 330
  290    CONTINUE
         PRINT 610, NC,NPTT,ISJT,(NSIT(I),I=1,12)
         PRINT 620, (NEPT(I),I=1,12)
         IF (NPTT.GT.12) GO TO 370
         IF (NC.LE.0.OR.NC.GT.MNSS) GO TO 370
         DO 300 I=2,NPTT
            IF (NEPT(I).LE.NEPT(I-1)) GO TO 370
  300    CONTINUE
         IF (ISJT.NE.1) GO TO 310
         IF (NSIT(1).NE.0.OR.NEPT(1).NE.0) GO TO 370
  310    CONTINUE
         NSTST(NC)=NPTT
         ISS(NC)=ISJT
         DO 320 I=1,NPTT
            NSIG(NC,I)=NSIT(I)
            NEPS(NC,I)=NEPT(I)
  320    CONTINUE
  330 CONTINUE
  340 CONTINUE
C
COMMENT - CHECK IF STRESS - STRAIN CURVES HAVE BEEN ALL DEFINED
C
      DO 350 I=1,MMTER
         IF (NSS(I).LT.0) GO TO 350
         NC=NSS(I)
         IF (NSTST(NC).EQ.-1) GO TO 380
  350 CONTINUE
      GO TO 390
  360 IABAN=1
      GO TO 390
  370 IABAN=3
      GO TO 390
  380 PRINT 630
      IABAN=4
  390 CONTINUE
      RETURN
C
  400 FORMAT ( 35H      TABLE 3A - MATERIAL PROPERTIES,///)
  410 FORMAT ( 26H      NO DATA IN THIS TABLE)
  420 FORMAT (52H      HOLDING DATA FROM THE PREVIOUS PROBLEM PLUS THE,10
     1H FOLLOWING,//)
  430 FORMAT (10H      NONE )
  440 FORMAT (6I5,E10.3)
  450 FORMAT (I5)
  460 FORMAT ( 42H      NO. OF MATERIALS                       =,I5)
  470 FORMAT (3/, 17H      MATERIAL NO.,I3,/, 42H      RELAXATION INDICATO
     1R                    =,I5,/, 42H      STRESS-STRAIN CURVE NO.
```

```
    2   =,I5,/, 42H     AGE EQUATION NO.                 =,I5,/, 42H
    3      CREEP EQUATION NO.                 =,I5,/, 42H     SHRINKAGE
    4 EQUATION NO.              =,I5,/, 42H     UNIT WEIGHT
    5                  =,F12.3)
  480 FORMAT (3/, 17H      MATERIAL NO.,I3,/, 42H     RELAXATION INDICATO
    1R                 =,I5,/, 42H     STRESS-STRAIN CURVE NO.
    2   =,I5,/, 42H     AGE EQUATION NO.                 =,I5,/, 42H
    3      RELAXATION EQUATION NO.            =,I5,/, 42H     SHRINKAGE
    4 EQUATION NO.              =,I5,/, 42H     UNIT WEIGHT
    5                  =,F12.3)
  490 FORMAT (/, 53H     THIS MATERIAL HAS BEEN PREVIOUSLY DEFINED, NEW
    1D, 40HATA ARE RECORDED AND MAY NOT BE THE SAME)
  500 FORMAT (4F10.3)
  510 FORMAT (/, 42H     MODULUS OF ELASTICITY                =,F12.3,/,
    142H     MAXIMUM STRAIN ALLOWED                =,F12.3,/, 42H     MIN
    2IMUM STRAIN ALLOWED                =,E12.3)
  520 FORMAT (/, 42H     STRESS MULTIPLIER                    =,E12.3,/,
    142H     STRAIN MULTIPLIER                =,E12.3,/, 42H     MAX
    2IMUM STRAIN ALLOWED                =,F12.3,/, 42H     MINIMUM STRAIN
    3 ALLOWED              =,E12.3)
  530 FORMAT (8F10.3)
  540 FORMAT (//,15H     AGE DATA  ,/)
  550 FORMAT (//, 15H     CREEP DATA,//, 42H     ULTIMATE CREEP COEFFICI
    1ENT                =,F12.3,/, 42H     CREEP RECOVERY RATIO
    2  =,E12.3)
  560 FORMAT ( 21H     COEFFICIENTS ARE,//,5X,8E12.3)
  570 FORMAT (//,20H     SHRINKAGE DATA ,/)
  580 FORMAT (3/, 36H     TABLE 3B - STRESS-STRAIN CURVES,///)
  590 FORMAT (30H     CURVE NUMB SYMT(1 = YES) ,/,30H     NUMB  PTS  OPT
    1     )
  600 FORMAT (3I5,5X,12I5,/,20X,12I5)
  610 FORMAT (/,5X,3I5,/,8H      SIG,17X,12I5)
  620 FORMAT (8H      EPS,17X,12I5)
  630 FORMAT (40H     NOT ALL OF THE CURVES ARE DEFINED  )
  640 FORMAT (//,30H     RELAXATION DATA           ,/)
  650 FORMAT (/,14H     CURVE NO.,I5,30H  HAS BEEN PREVIOUSLY DEFINED.,4
    10H THE PREVIOUS CURVE HAS BEEN REPLACED   )
  660 FORMAT (/, 28H     STRESS RATIO-TIME CURVE,/)
  670 FORMAT (/, 28H     STRAIN RATIO-TIME CURVE,/)
  680 FORMAT (/,30H     CREEP-TIME CURVE           ,/)
  690 FORMAT (/,49H     CREEP CORRECTION FACTOR-LOADING TIME CURVE   ,/)
  700 FORMAT (5X,8F12.3)
  710 FORMAT (/,49H     RELAXATION COEFFICIENT-TIME CURVE              ,/)
  720 FORMAT (/,49H     RELAXATION COEFFICIENT-STRESS CURVE            ,/)
  730 FORMAT (/,30H     SHRINKAGE-TIME CURVE       ,/)
C
      END
C*************************************************************************
C*                        S U B R O U T I N E                            *
C*************************************************************************
C
      SUBROUTINE STRSTR(NSIT,NEPT,J,NPTT,IARAN)
C
COMMENT - SUBROUTINE STRSTR GENERATES PROPOSED OR HOGNESTAD STRESS-
C         STRAIN CURVE
C
      DIMENSION NSIT(12),NEPT(12)
      COMMON/BLOCK3/      ISS(10), NSTST(10),
     1   NEPS(10,12),  NSIG(10,12)
      NC=J
      NSTST(NC)=12
      IF (NPTT) 100,10,20
   10 CONTINUE
      EC=NSIT(3)
      EC=EC/NEPT(3)
      IF (EC.LE.1.0E-30) GO TO 100
   20 CONTINUE
      IF (NEPT(1)) 50,100,30
   30 CONTINUE
      DO 40 I=1,2
         NEPT(I)=-NEPT(I)
         NSIT(I)=-NSIT(I)
   40 CONTINUE
   50 CONTINUE
      IF (NEPT(2).GE.NEPT(1)) GO TO 100
      NEPS(NC,7)=0.8*NEPT(1)
      NEPS(NC,8)=0.7*NEPT(1)
      NEPS(NC,9)=0.6*NEPT(1)
      NEPS(NC,10)=0.4*NEPT(1)
      NEPS(NC,11)=0.2*NEPT(1)
      IF (NPTT.EQ.1) GO TO 70
      NSIG(NC,1)=-0.5+0.2*NSIT(1)
      NSIG(NC,2)=NSIG(NC,1)
      Z=NEPT(2)-NEPT(1)
      Z=Z/(NSIT(2)-NSIT(1))
      NEPS(NC,2)=-0.5+NEPT(1)-0.8*NSIT(1)*Z
      NEPS(NC,1)=NEPS(NC,2)-2
      NEPS(NC,3)=NEPT(1)
      NEPS(NC,4)=0.97*NEPT(1)
      NEPS(NC,5)=0.93*NEPT(1)
      NEPS(NC,6)=0.87*NEPT(1)
      RK=EC*(1.0+(NSIT(1)/(EC*NEPT(1))-1.0)**2)
      RK=(RK*NEPT(1))/NSIT(1)
      DO 60 I=3,11
         E=NEPS(NC,I)
         E=E/NEPT(1)
         NSIG(NC,I)=-0.5+NSIT(1)*(RK*E-E*E)/(1.0+(RK-2.0)*E)
   60 CONTINUE
      GO TO 90
   70 CONTINUE
      NEPS(NC,1)=NEPT(2)
      NEPS(NC,2)=NEPT(1)
      NEPS(NC,3)=0.97*NEPT(1)
      NEPS(NC,4)=0.93*NEPT(1)
      NEPS(NC,5)=0.9*NEPT(1)
      NEPS(NC,6)=0.85*NEPT(1)
      DO 80 I=2,11
         E=NEPS(NC,I)
         E=E/NEPT(1)
         NSIG(NC,I)=-0.5+NSIT(1)*(2.0*E-E*E)
   80 CONTINUE
      NSIG(NC,1)=NSIT(2)
   90 CONTINUE
      NSIG(NC,12)=-NSIG(NC,11)
      NEPS(NC,12)=-NEPS(NC,11)
      ISS(NC)=0
      NPTT=12
      GO TO 110
  100 CONTINUE
      IARAN=3
  110 CONTINUE
      RETURN
C
```

```
      END
C***********************************************************************
C*                          S U B R O U T I N E                        *
C***********************************************************************
C
      OVERLAY (SCTN,3,0)
      PROGRAM SCTN
C
COMMENT - SUBROUTINE SCTN INPUTS CROSS-SECTION PROPERTIES OF THE
C            STRUCTURE (TABLE 4)
C            REPLACE THE OVERLAY CARD BY THE NONOVERLAY CARD UNLESS THE CDC
C            OVERLAY SYSTEM IS BEING USED
C     SUBROUTINE SCTN
C
      COMMON/BLOCK1/   ITIMES(51), TIME1(51),TPRINT(51)
      COMMON/BLOCK2/        EM(10),IRELAX(10),  NEQA(10),   NEQC(10),
     1      NEQS(10),    NSS(10),     SM(10), STMAX(10), STMIN(10),
     2       UWT(10),
     3     A(10,8),     AT(10,8),     A1(10,8),    A1T(10,8),
     4    C(10,10),     CT(10,8),     C1(10,8),    C1T(10,8),
     5     S(10,8),    SPT(10,8)
      COMMON/BLOCK4/     ISUB(30),   NDIV(30),   NMAT(30),   NSYM(30),
     1     NPOST(30),   NPTS(31),TIMESS(30,3),
     2      BI(100),    DI(100),     CG(100),    XS(100), STRI(100),
     3     BIP(400),   DIP(400),   CGP(400),STRIP(400)
      COMMON/BLOC12/        BIT(80),    DIT(81)
      COMMON/BLK1/     IABAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1      KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2       MISUB, MMTER, MNCLD,  MNCS, MNDLD,  MNDS,   MNE,  MNEQ,
     3       MNPCS,  MNPD, MNPDS, MNPTS,  MNDW,  MNSS, MPOST,MTIME1
      COMMON/BLK2/   NPRTNL, NTIM1, FTIME, TIMEO,TIMEST
      COMMON/BLK4/           H,    IDS,  IDS5,ISMALL,KOFFDW,KOFFSE,    M,
     1      MIDS5,    MP1,   MP22,   NELE,     TH,      ZL
      COMMON/BLK5/     MNPC,   NCLD,    NCS,   NDLD,    NDS,NPOSTL,  NSUB
      PRINT 370
      DO 10 I=1,MISUB
         ISUB(I)=0
   10 CONTINUE
      NCR=0
      IF (KEEP4.EQ.1) GO TO 30
      IF (NCD4.LE.0) GO TO 320
      NPOSTL=0
      NSUB=0
      MNPC=0
      MISUB1=MISUB+1
      DO 20 I=1,MISUB1
         NPTS(I)=0
   20 CONTINUE
C
COMMENT - READ IN NEW DATA
C
      NCR=NCR+1
      READ 390, M,ZL
      M2=M/2
      M=M2*2
      IF (M.LT.4.OR.M.GT.MNE) M=20
      PRINT 380, M,ZL
      MP1=M+1
      TH=ZL/M
      H=0.5*TH
      GO TO 70
   30 CONTINUE
      IF (KEEP2.EQ.1) GO TO 60
      DO 50 I=1,NSUB
         NMATT=NMAT(I)
         IF (ABS(UWT(NMATT)).LE.1.0E-30) GO TO 40
         CALL RANKT (TIMESS(I,2),TIME1,ITIMES,NTIM1,MTIME1,1,IABAN)
         IF (IABAN.NE.0) GO TO 360
   40    CONTINUE
         II=100
         IF (NPOST(I).LT.0) II=10000
         CALL RANKT (TIMESS(I,3),TIME1,ITIMES,NTIM1,MTIME1,II,IABAN)
         IF (IABAN.NE.0) GO TO 360
   50 CONTINUE
   60 CONTINUE
      PRINT 400
      IF (NCD4.GT.0) GO TO 70
      PRINT 410
      GO TO 360
   70 CONTINUE
      NCR=NCR+1
      READ 390, NSUBT
      PRINT 420, NSUBT
      IF (NSUBT.LE.0) GO TO 340
      I1=NSUB+1
      NSUB=NSUB+NSUBT
      IF (NSUB.GT.MISUB) GO TO 330
      DO 310 I=I1,NSUB
         NCR=NCR+1
         READ 450, NPOST(I),NMAT(I),NDIV(I),NPTST,NSYM(I),TIMESS(I,1),TI
     1   MESS(I,2),TIMESS(I,3)
         IF (NDIV(I).LE.0) NDIV(I)=1
         IF (TIMESS(I,2).GT.TIMESS(I,3)) TIMESS(I,2)=TIMESS(I,3)
         PRINT 470, I,NPOST(I),NMAT(I),NDIV(I),NPTST,NSYM(I),TIMESS(I,1)
     1   ,TIMESS(I,2),TIMESS(I,3)
         NMATT=NMAT(I)
         IF (NMATT.LE.0.OR.NMATT.GT.MMTER) GO TO 340
         IF (NSS(NMATT).EQ.-1) GO TO 340
         IF (NPTST.LT.0) GO TO 340
         IF (ABS(UWT(NMATT)).LE.1.0E-30) GO TO 80
         CALL RANKT (TIMESS(I,2),TIME1,ITIMES,NTIM1,MTIME1,1,IABAN)
         IF (IABAN.NE.0) GO TO 360
   80    CONTINUE
         II=100
         IF (NPOST(I).GT.0) II=10000
         CALL RANKT (TIMESS(I,3),TIME1,ITIMES,NTIM1,MTIME1,II,IABAN)
         IF (IABAN.NE.0) GO TO 360
         N2=NPTS(I)+NPTST
         IF (N2.GT.MNPTS) GO TO 330
         IP1=I+1
         NPTS(IP1)=N2
         IF (NPTST.EQ.0) GO TO 120
         IF (NPOST(I).LE.0) PRINT 480
         IF (NPOST(I).GT.0) PRINT 490
         N1=NPTS(I)+1
         NCR=NCR+NPTST
         READ 440, ((XS(II),BI(II),DI(II),CG(II),STRI(II)),II=N1,N2)
         PRINT 500, XS(N1),BI(N1),DI(N1),CG(N1),STRI(N1)
         IF (XS(N1).LT.-0.0) GO TO 340
         IF (NPTST.LT.2) GO TO 100
         N11=N1+1
         DO 90 II=N11,N2
            PRINT 500, XS(II),BI(II),DI(II),CG(II),STRI(II)
            IF (XS(II).LE.XS(II-1)) GO TO 340
```

```
 90     CONTINUE
        IF (XS(N2).GT.ZL) GO TO 340
        IF (NSYM(I).EQ.1.AND.(2.0*XS(N2)-XS(N1)).GT.ZL) GO TO 340
100     CONTINUE
        DO 110 II=N1,N2
           HI(II)=HI(II)*DI(II)
110     CONTINUE
        GO TO 300
120     CONTINUE
        N1=NPOSTL*M+1
        NPOSTL=NPOSTL+1
        IF (NPOSTL.GT.NPOST) GO TO 340
        NSYM(I)=-NPOSTL
        N2=NPOSTL*M
        NCR=NCR+1
        READ 460, NBI,NDI,NCG,NPST,RK,RM,STRIT
        IF (NPOST(I).GT.0) GO TO 130
        PRINT 510
        PRINT 530, NBI,NDI,NCG,NPST,STRIT
        GO TO 140
130     CONTINUE
        PRINT 520
        PRINT 540, NBI,NDI,NCG,NPST,RK,RM,STRIT
140     CONTINUE
        IF (NBI.LE.0) GO TO 340
        IF (NDI.LE.0) GO TO 340
        IF (NCG.LE.0) GO TO 340
        IF (NPST.LT.0) GO TO 340
        NCR=NCR+NBI+NDI+NCG+NPST
        J=1
        PRINT 560
        PRINT 570
        CALL CENTR (J,NBI,RK,RM)
        III=0
        DO 150 II=N1,N2
           III=III+1
           BIP(II)=BIT(III)
150     CONTINUE
        PRINT 580
        PRINT 570
        CALL CENTR (J,NDI,RK,RM)
        III=0
        DO 160 II=N1,N2
           III=III+1
           DIP(II)=BIT(III)
           BIP(II)=BIP(II)*BIT(III)
160     CONTINUE
        IF (NPOST(I).GT.0.AND.NPST.GT.0) J=2
        PRINT 590
        PRINT 570
        CALL CENTR (J,NCG,RK,RM)
        III=0
        DO 170 II=N1,N2
           III=III+1
           CGP(II)=BIT(III)
170     CONTINUE
        DO 180 II=N1,N2
           STRIP(II)=STRIT
180     CONTINUE
        IF (NPOST(I).GT.0) GO TO 210
        IF (NPST.LE.0) GO TO 300
        PRINT 610
190     CONTINUE
        PRINT 570
        CALL CENTR (J,NPST,RK,RM)
        III=0
        DO 200 II=N1,N2
           III=III+1
           STRIP(II)=BIT(III)
200     CONTINUE
        GO TO 300
210     CONTINUE
        IF (NPST) 220,300,230
220     CONTINUE
        PRINT 620
        NPST=-NPST
        GO TO 190
230     CONTINUE
        PRINT 600
        E=2.718282
        DO 290 K=1,NPST
           READ 390, IN,SJEND
           PRINT 430, IN,SJEND
           IF (IN.EQ.1) GO TO 260
           SIGNT=ABS(STRIP(N1)-SJEND)
           IF (SIGNT.LE.1.0E-30) GO TO 290
           SIGNT=(STRIP(N1)-SJEND)/SIGNT
           DO 250 II=N1,N2
              STRIT=SJEND*E**(SIGNT*DIT(II-N1+1))
              IF (SIGNT*(STRIP(II)-STRIT)) 290,290,240
240           CONTINUE
              STRIP(II)=STRIT
250        CONTINUE
           GO TO 290
260        CONTINUE
           SIGNT=ABS(STRIP(N2)-SJEND)
           IF (SIGNT.LE.1.0E-30) GO TO 290
           SIGNT=(STRIP(N2)-SJEND)/SIGNT
           DO 280 II=1,M
              STRIT=SJEND*E**(SIGNT*(DIT(MP1)-DIT(MP1-II)))
              IF (SIGNT*(STRIP(N2-II+1)-STRIT)) 290,290,270
270           CONTINUE
              STRIP(N2-II+1)=STRIT
280        CONTINUE
290     CONTINUE
300     CONTINUE
        MNPC=MNPC+NDIV(I)
310  CONTINUE
     IF (MNPCS.LT.MNPC*M) GO TO 350
     IF (NCR.NE.NCD4) GO TO 320
     GO TO 360
320  IARAN=1
     GO TO 360
330  IARAN=2
     GO TO 360
340  IARAN=3
     GO TO 360
350  PRINT 550
     IARAN=4
360  CONTINUE
     RETURN
C
370  FORMAT ( 39H     TABLE 4 - CROSS-SECTION PROPERTIES,///)
380  FORMAT ( 42H     NO. OF DISCRETE ELEMENTS              =,I5,/, 42H
```

```
  1    MEMBER LENGTH                          =,E12.3)
390 FORMAT (I5,5X,E10.3)
400 FORMAT ( 52H     HOLDING DATA FROM THE PREVIOUS PROBLEM PLUS THE,
   110H FOLLOWING,//)
410 FORMAT (  9H      NONE)
420 FORMAT (3/, 42H       NO. OF SUB-RECTANGLES                  =,I5)
430 FORMAT (5X,I5,E12.3)
440 FORMAT (5E10.3)
450 FORMAT (5I5,5X,3E10.3)
460 FORMAT (4I5,3E10.3)
470 FORMAT (//, 22H       SUB-RECTANGLE NO.,I5,/, 42H      POST-TENSION I
   1NDICATOR (IF=1,YES)    =,I5,/, 42H      MATERIAL NO.
   2          =,I5,/, 42H      NO. OF VERTICAL DIVISIONS          =,I5,/
   3, 42H      NO. OF POINTS SPECIFIED             =,I5,/, 42H      SYMM
   4ETRIC INDICATOR (IF=1,YES)       =,I5,/, 42H      CASTING TIME
   5               =,E12.3,/, 42H      TIME ADDED TO STRUCTURE
   6        =,E12.3,/, 42H      TIME WHEN CAN CARRY LOAD          =,E1
   72.3)
480 FORMAT (/, 53H      HOR.DISTANCE     WIDTH        DEPTH          CG.
   1 , 11H INT.STRAIN,/)
490 FORMAT (/, 53H      HOR.DISTANCE     WIDTH        DEPTH          CG.
   1 , 11H INT. FORCE,/)
500 FORMAT (5X,5E12.3)
510 FORMAT (/, 32H      PRE-TENSIONED SUB-RECTANGLE,/)
520 FORMAT (/, 33H      POST-TENSIONED SUB-RECTANGLE,/)
530 FORMAT ( 42H      NO. OF WIDTH SEGMENTS                =,I5,/, 42H
   1   NO. OF DEPTH SEGMENTS                 =,I5,/, 42H      NO. OF CG.
   2SEGMENTS                =,I5,/, 42H      NO. OF INITIAL STRAIN SEG
   3MENTS       =,I5,/, 42H      DATUM INITIAL STRAIN                =,E
   412.3)
540 FORMAT ( 42H      NO. OF WIDTH SEGMENTS                =,I5,/, 42H
   1   NO. OF DEPTH SEGMENTS                 =,I5,/, 42H      NO. OF CG.
   2SEGMENTS                =,I5,/, 42H      NO. OF POST-TENSION JACKI
   3NGS         =,I5,/, 42H      WOBBLE FRICTION COEFFICIENT         =,E
   412.3,/, 42H      CURVATURE FRICTION COEFFICIENT      =,F12.3,/, 42H
   5      DATUM INITIAL FORCE                 =,E12.3)
550 FORMAT ( 53H      NUMBER OF FIBERS IN THE STRUCTURE EXCEEDS THE ST,
   1 13HORAGE ALLOWED)
560 FORMAT (//, 10H      WIDTH)
570 FORMAT (//, 53H      INDICATOR      X1            X2            X3
   1 , 40H  X4          E1            E2            E3,/)
580 FORMAT (//, 10H      DEPTH)
590 FORMAT (//, 20H      CENTROIDAL DISTANCE)
600 FORMAT (//, 20H      POST-TENSIONING,3/, 26H          END  JACKING FO
   1RCE)
610 FORMAT (//, 19H      INITIAL STRAIN)
620 FORMAT (//, 27H      POST-TENSIONING FORCES)
C
      END
      SUBROUTINE CENTR(JT,N,RKT,RMT)
      COMMON/BLOC12/        BIT(80),     DIT(81)
      COMMON/BLK4/          H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,      M,
     1          MIDS5,   MP1,  MP22,   MELE,      TH,      ZL
      J=JT
      RK=RKT
      RM=RMT
      DTHET=0.0
      IF (J.LT.2) GO TO 20
      DO 10 I=1,MP1
         DIT(I)=0.0
   10 CONTINUE
   20 CONTINUE
      DO 30 I=1,M
         BIT(I)=0.0
   30 CONTINUE
      DO 110 II=1,N
         IF (II.GT.1) GO TO 40
         READ 140, IN,X1,X2,X3,X4,E1,E2,E3
         PRINT 150, IN,X1,X2,X3,X4,E1,E2,E3
         GO TO 50
   40    CONTINUE
         READ 160, IN,X2,X3,X4,E2,E3
         PRINT 150, IN,X1,X2,X3,X4,E1,E2,E3
   50    CONTINUE
         IF (X1.LT.-0.0) GO TO 120
         IF (X2.LE.X1) GO TO 120
         IF (IN.LE.0.OR.IN.GT.4) GO TO 60
         IF (X3.LE.X2) GO TO 120
         GO TO (70,80,90,100), IN
   60    CONTINUE
         IF (X2.GT.ZL) GO TO 120
         B2=(E2-E1)/(X2-X1)
         B3=E1-B2*X1
         IF (II.EQ.1) SLOPEI=B2
         CALL ST (0.0,B2,B3,SLOPEI,DTHET,TH,X1,X2,RK,RM,J)
         X1=X2
         E1=E2
         GO TO 110
   70    CONTINUE
         IF (X3.GT.ZL) GO TO 120
         DETER=X1*X1*X2+X2*X2*X3+X3*X3*X1-X3*X3*X2-X2*X2*X1-X1*X1*X3
         IF (ABS(DETER).LT.1.0E-30) GO TO 120
         B1=(E1*X2+E2*X3+E3*X1-E3*X2-E2*X1-E1*X3)/DETER
         B2=(X1*X1*E2+X2*X2*E3+X3*X3*E1-X3*X3*E2-X2*X2*E1-X1*X1*E3)/DETE
     1   R
         B3=(X1*X1*X2*E3+X2*X2*X3*E1+X3*X3*E2*X1-X3*X3*X2*E1-X2*X2*X1*E3
     1   -X1*X1*E2*X3)/DETER
         IF (II.EQ.1) SLOPEI=2.0*B1*X1+B2
         CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X1,X3,RK,RM,J)
         X1=X3
         E1=E3
         GO TO 110
   80    CONTINUE
         IF (X4.LE.X3) GO TO 120
         IF (X4.GT.ZL) GO TO 120
         B1=(E1-E2)/((X2-X1)*(X2-X1))
         B2=-2.0*B1*X2
         B3=B1*X2*X2+E2
         IF (II.EQ.1) SLOPEI=2.0*B1*X1+B2
         CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X1,X2,RK,RM,J)
         B1=(E3-E2)/((X4-X2)*(X3-X2))
         B2=-2.0*B1*X2
         B3=B1*X2*X2+E2
         CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X2,X3,RK,RM,J)
         B1=(E2-E3)/((X4-X3)*(X4-X2))
         B2=-2.0*B1*X4
         B3=B1*X4*X4+E3
         CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X3,X4,RK,RM,J)
         X1=X4
         E1=E3
         GO TO 110
   90    CONTINUE
         X5=2.0*X3-X1
         IF (X5.GT.ZL) GO TO 120
```

```
      B1=(E2-E1)/((X2-X1)*(X3-X1))
      B2=-2.0*B1*X1
      B3=B1*X1*X1+E1
      IF (I1.EQ.1) SLOPEI=2.0*B1*X1+B2
      CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X1,X2,RK,RM,J)
      B1=(E1-E2)/((X3-X2)*(X3-X1))
      B2=-2.0*B1*X3
      B3=B1*X3*X3+E2
      X4=2.0*X3-X2
      CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X2,X4,RK,RM,J)
      B1=(E2-E1)/((X2-X1)*(X3-X1))
      B2=-2.0*B1*X5
      B3=B1*X5*X5+E1
      CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X4,X5,RK,RM,J)
      X1=X5
      GO TO 110
100   CONTINUE
      IF (X4.LE.X3) GO TO 120
      IF (X4.GT.ZL) GO TO 120
      B1=(E2-E1)/((X2-X1)*(X3-X1))
      B2=-2.0*B1*X1
      B3=B1*X1*X1+E1
      CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X1,X2,RK,RM,J)
      B1=(E1-E2)/((X3-X2)*(X3-X1))
      B2=-2.0*B1*X3
      B3=B1*X3*X3+E2
      CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X2,X3,RK,RM,J)
      B1=(E3-E2)/((X4-X3)**2)
      B2=-2.0*B1*X3
      B3=B1*X3*X3+E2
      CALL ST (B1,B2,B3,SLOPEI,DTHET,TH,X3,X4,RK,RM,J)
      X1=X4
      E1=E3
110 CONTINUE
    GO TO 130
120 TABAN=3
130 CONTINUE
    RETURN
C
140 FORMAT (I5,5X,7E10.3)
150 FORMAT (5X,I5,7E12.3)
160 FORMAT (I5,15X,3E10.3,10X,2E10.3)
C
    END
    SUBROUTINE ST(B1,B2,B3,SLOPEI,DT,TH,X1,X2,RK,RM,J)
    COMMON/BLOC12/      BIT(80),    DIT(81)
    SLOPET=2.0*B1*X1+B2
    DTHET=DT+ABS(SLOPET-SLOPEI)*RM
    SLOPEI=SLOPET
    Z11=X1/TH+1.5
    I1=Z11
    Z12=X2/TH+0.5
    I2=Z12
    X2T=I2*TH-0.5*TH
    IF (X2T.GE.X2) X2=X2T+TH*0.00001
    IF (J.NE.2) GO TO 30
    IF (I2.LT.I1) GO TO 20
    DO 10 I=I1,I2
       X=I*TH-0.5*TH
       SLOPET=2.0*B1*X+B2
       DIT(I)=DTHET+ABS(SLOPET-SLOPET)ARM+(X-X1)*RK
 10 CONTINUE
 20 CONTINUE
    SLOPET=2.0*B1*X2+B2
    DTHET=DTHET+ABS(SLOPET-SLOPET)*RM+(X2-X1)*RK
    I21=I2+1
    DIT(I21)=DTHET
    SLOPEI=SLOPET
 30 CONTINUE
    IF (I2.LT.I1) GO TO 50
    DO 40 I=I1,I2
       X=I*TH-0.5*TH
       BIT(I)=B1*X*X+B2*X+B3
 40 CONTINUE
 50 CONTINUE
    DT=DTHET
    RETURN
C
    END
C***********************************************************************
C*                        S U B R O U T I N E                          *
C***********************************************************************
C
      OVERLAY (RDMLD,4,0)
      PROGRAM RDMLD
C
COMMENT - SUBROUTINE RDMLD INPUTS MEMBER LOAD DATA AND MEMBER RESTRAINT
C           REPLACE OVERLAY CARD BY NONOVERLAY CARD UNLESS THE CDC OVERLAY
C           SYSTEM IS BEING USED
C     SUBROUTINE RDMLD
C
      DIMENSION NSIT(12),NEPT(12)
      COMMON/BLOCK1/   ITIMES(51), TIME1(51),TPRINT(51)
      COMMON/BLOCK5/      IDLD(20), TIMED(20),    NPD(21),
     1          QXD(40),    QYD(40),    QZD(40),    XSD(40),
     2          ICLD(30),   QXC(30),    QYC(30),    QZC(30), TIMEC(30),
     3          XSC(30)
      COMMON/BLOCK6/      NPDS(11),  NSXD(20),  NSYD(20),  NSZD(20),
     1          QMXD(20),  QMYD(20),  QMZD(20),  WMXD(20),  WMYD(20),
     2          WMZD(20),    XD(20),
     3          NSXP(20),  NSYP(20),  NSZP(20),  QMXP(20),  QMYP(20),
     4          QMZP(20),  WMXP(20),  WMYP(20),  WMZP(20),     XP(20)
      COMMON/BLOCK7/        ISM(10),   NPTM(10),
     1      NQM(10,12),   NWM(10,12)
      COMMON/BLK1/     IABAN, KEEP2,KEEP3A,KEEP3B, KEEP4,KEEP5A,KEEP5B,
     1         KEEP5C,  NCD2, NCD3A, NCD3B,  NCD4, NCD5A, NCD5B, NCD5C,
     2            MISUB, MMTER, MNCLD,  MNCS, MNDLD,   MNDS,    MNE,  MNEQ,
     3            MNPCS,  MNPD, MNPDS, MNPTS,  MNQW,   MNSS, MPOST,MTIME1
      COMMON/BLK2/   NPRINL, NTIM1, FTIME, TIMEO,TIMEST
      COMMON/BLK4/          H,    IDS,   IDS5,ISMALL,KOFFQW,KOFFSE,      M,
     1            MIDS5,   MP1,   MP22,   NELE,     TH,      ZL
      COMMON/BLK5/       MNPC,  NCLD,    NCS,  NDLD,    NDS,NPOSTL,  NSUB
      PRINT 500
      NCR=0
      DO 10 I=1,MNDLD
         IDLD(I)=0
   10 CONTINUE
      DO 20 I=1,MNCLD
         ICLD(I)=0
   20 CONTINUE
      IF (KEEP5A.EQ.1.OR.KEEP5A.EQ.2) GO TO 50
C
COMMENT - INITIALIZE CONTROL CONSTANTS
C
```

```
      NDLD=0
      NCLD=0
      I2=MNDLD+1
      DO 30 I=1,I2
         NPD(I)=0
   30 CONTINUE
      I2=MNPDS+1
      DO 40 I=1,I2
         NPDS(I)=0
   40 CONTINUE
      IF (NCD5A.GT.0) GO TO 170
      PRINT 570
      GO TO 230
   50 CONTINUE
      IF (KEEP2.EQ.1) GO TO 90
      IF (NDLD.LE.0) GO TO 70
      DO 60 I=1,NDLD
         CALL RANKT (TIMED(I),TIME1,ITIMES,NTIM1,MTIME1,1,IABAN)
         IF (IABAN.NE.0) GO TO 490
   60 CONTINUE
   70 CONTINUE
      IF (NCLD.LE.0) GO TO 90
      DO 80 I=1,NCLD
         CALL RANKT (TIMEC(I),TIME1,ITIMES,NTIM1,MTIME1,1,IABAN)
         IF (IABAN.NE.0) GO TO 490
   80 CONTINUE
   90 CONTINUE
      IF (KEEP5A.EQ.2) GO TO 100
      PRINT 510
      IF (NCD5A.GT.0) GO TO 170
      PRINT 580
      GO TO 230
  100 CONTINUE
C
COMMENT - READ IN PERCENT INCREASES
C
      NCR=NCR+1
      READ 540, PERD,PERC
      PRINT 520, PERD,PERC
C
COMMENT - INCREASE DISTRIBUTED LOADS
C
      I2=NPD(NDLD+1)
      IF (I2.GT.0) GO TO 110
      PRINT 560
      GO TO 130
  110 CONTINUE
      FAC=1.0+PERD/100.0
      DO 120 I=1,I2
         QXD(I)=QXD(I)*FAC
         QYD(I)=QYD(I)*FAC
         QZD(I)=QZD(I)*FAC
  120 CONTINUE
  130 CONTINUE
C
COMMENT - INCREASE CONCENTRATED LOADS
C
      IF (NCLD.GT.0) GO TO 140
      PRINT 550
      GO TO 160
  140 CONTINUE
      FAC=1.0+PERC/100.0
      DO 150 I=1,NCLD
         QXC(I)=QXC(I)*FAC
         QYC(I)=QYC(I)*FAC
         QZC(I)=QZC(I)*FAC
  150 CONTINUE
  160 CONTINUE
      IF (NCR.GE.NCD5A) GO TO 220
      PRINT 530
  170 CONTINUE
C
COMMENT - READ IN NUMBER OF SETS OF DIST. LOADS AND NUMBER OF CONC.
C         LOADS
C
      NCR=NCR+1
      READ 590, NDLDT,NCLDT
      PRINT 600, NDLDT,NCLDT
      IF (NDLDT.LT.0.OR.NCLDT.LT.0) GO TO 470
      IF (NDLDT.EQ.0) GO TO 200
C
COMMENT - READ IN AND PRINT DISTRIBUTED LOAD DATA
C
      I1=NDLD+1
      NDLD=NDLD+NDLDT
      IF (NDLD.GT.MNDLD) GO TO 460
      PRINT 680
      DO 190 I=I1,NDLD
         NCR=NCR+1
         READ 610, NPDT,TIMED(I)
         PRINT 620, I,NPDT,TIMED(I)
         IF (NPDT.LT.0) GO TO 470
         CALL RANKT (TIMED(I),TIME1,ITIMES,NTIM1,MTIME1,1,IABAN)
         IF (IABAN.NE.0) GO TO 490
         NCR=NCR+NPDT
         N1=NPD(I)+1
         N2=NPD(I)+NPDT
         IF (N2.GT.MNPD) GO TO 460
         IP1=I+1
         NPD(IP1)=N2
         READ 630, ((XSD(II),QXD(II),QYD(II),QZD(II)),II=N1,N2)
         PRINT 640, XSD(N1),QXD(N1),QYD(N1),QZD(N1)
         IF (NPDT.LE.1) GO TO 190
         IF (XSD(N1).LT.-0.0) GO TO 470
         N11=N1+1
         DO 180 II=N11,N2
            PRINT 640, XSD(II),QXD(II),QYD(II),QZD(II)
            IF (XSD(II).LE.XSD(II-1)) GO TO 470
  180    CONTINUE
         IF (XSD(N2).GT.ZL) GO TO 470
  190 CONTINUE
  200 CONTINUE
      IF (NCLDT.LE.0) GO TO 220
      PRINT 660
      I1=NCLD+1
      NCLD=NCLD+NCLDT
      IF (NCLD.GT.MNCLD) GO TO 460
      NCR=NCR+NCLDT
      DO 210 I=I1,NCLD
         READ 670, TIMEC(I),XSC(I),QXC(I),QYC(I),QZC(I)
         PRINT 650, I,TIMEC(I),XSC(I),QXC(I),QYC(I),QZC(I)
         IF (XSC(I).LT.-0.0.OR.XSC(I).GT.ZL) GO TO 470
         CALL RANKT (TIMEC(I),TIME1,ITIMES,NTIM1,MTIME1,1,IABAN)
         IF (IABAN.NE.0) GO TO 490
```

```
  210 CONTINUE
  220 CONTINUE
      IF (NCR.NE.NCD5A) GO TO 450
  230 CONTINUE
      PRINT 690
      IF (KEEP5A.EQ.1) GO TO 240
      NDS=0
      NCS=0
      IF (NCD5A.GT.0) GO TO 250
      GO TO 450
  240 CONTINUE
      PRINT 510
      IF (NCD5A.GT.0) GO TO 250
      PRINT 580
      GO TO 300
  250 CONTINUE
      NCR=1
      READ 590, NDST,NCST
      PRINT 700, NDST,NCST
      IF (NDST.LT.0.OR.NCST.LT.0) GO TO 470
      IF (NDST.EQ.0) GO TO 280
C
COMMENT - READ IN DISTRIBUTED SPRING DATA
C
      I1=NDS+1
      NDS=NDS+NDST
      IF (NDS.GT.MNDS) GO TO 460
      PRINT 710
      DO 270 I=I1,NDS
         NCR=NCR+1
         READ 590, NPDT
         PRINT 810, I,NPDT
         IF (NPDT.LT.1) GO TO 470
         PRINT 730
         N1=NPDS(I)+1
         N2=NPDS(I)+NPDT
         IF (N2.GT.MNPDS) GO TO 460
         IP1=I+1
         NPDS(IP1)=N2
         NCR=NCR+NPDT
         READ 720, XD(N1),NSXD(N1),NSYD(N1),NSZD(N1),QMXD(N1),QMYD(N1),Q
    1    MZD(N1),WMXD(N1),WMYD(N1),WMZD(N1)
         PRINT 820, XD(N1),NSXD(N1),NSYD(N1),NSZD(N1),QMXD(N1),QMYD(N1),
    1    QMZD(N1),WMXD(N1),WMYD(N1),WMZD(N1)
         IF (NSXD(N1).GT.MNOW) GO TO 460
         IF (NSYD(N1).GT.MNOW) GO TO 460
         IF (NSZD(N1).GT.MNOW) GO TO 460
         IF (NSXD(N1).GT.0.AND.WMXD(N1).LE.0.0) GO TO 470
         IF (NSYD(N1).GT.0.AND.WMYD(N1).LE.0.0) GO TO 470
         IF (NSZD(N1).GT.0.AND.WMZD(N1).LE.0.0) GO TO 470
         IF (NPDT.LT.2) GO TO 270
         N11=N1+1
         DO 260 II=N11,N2
            READ 720, XD(II),NSXD(II),NSYD(II),NSZD(II),QMXD(II),QMYD(II
    1       ),QMZD(II),WMXD(II),WMYD(II),WMZD(II)
            PRINT 820, XD(II),NSXD(II),NSYD(II),NSZD(II),QMXD(II),QMYD(I
    1       I),QMZD(II),WMXD(II),WMYD(II),WMZD(II)
            IF (NSXD(II).GT.MNOW) GO TO 460
            IF (NSYD(II).GT.MNOW) GO TO 460
            IF (NSZD(II).GT.MNOW) GO TO 460
            IF (NSXD(II).GT.0.AND.WMXD(II).LE.0.0) GO TO 470
            IF (NSYD(II).GT.0.AND.WMYD(II).LE.0.0) GO TO 470
            IF (NSZD(II).GT.0.AND.WMZD(II).LE.0.0) GO TO 470
            IF (XD(II).LE.XD(II-1)) GO TO 470
  260    CONTINUE
  270 CONTINUE
  280 CONTINUE
      IF (NCST.LE.0) GO TO 300
C
COMMENT - READ IN POINT SPRING DATA
C
      PRINT 740
      PRINT 730
      I1=NCS+1
      NCS=NCS+NCST
      IF (NCS.GT.MNCS) GO TO 460
      NCR=NCR+NCST
      DO 290 I=I1,NCS
         READ 720, XP(I),NSXP(I),NSYP(I),NSZP(I),QMXP(I),QMYP(I),QMZP(I)
    1    ,WMXP(I),WMYP(I),WMZP(I)
         PRINT 820, XP(I),NSXP(I),NSYP(I),NSZP(I),QMXP(I),QMYP(I),QMZP(I
    1    ),WMXP(I),WMYP(I),WMZP(I)
         IF (NSXP(I).GT.MNOW) GO TO 460
         IF (NSYP(I).GT.MNOW) GO TO 460
         IF (NSZP(I).GT.MNOW) GO TO 460
         IF (NSXP(I).GT.0.AND.WMXP(I).LE.0.0) GO TO 470
         IF (NSYP(I).GT.0.AND.WMYP(I).LE.0.0) GO TO 470
         IF (NSZP(I).GT.0.AND.WMZP(I).LE.0.0) GO TO 470
  290 CONTINUE
      IF (NCR.NE.NCD5B) GO TO 450
  300 CONTINUE
C
COMMENT - INPUT TABLE 5C - NONLINEAR SUPPORT CURVES
C
      PRINT 800
      IF (KEEP5C.EQ.1) GO TO 320
      DO 310 I=1,MNOW
         NPTM(I)=-1
  310 CONTINUE
      IF (NCD5C.GT.0) GO TO 330
      PRINT 570
      GO TO 490
  320 CONTINUE
      PRINT 510
      IF (NCD5C.GT.0) GO TO 330
      PRINT 580
      GO TO 490
  330 CONTINUE
      PRINT 750
      I2=NCD5C/2
      IF (I2*2.NE.NCD5C) GO TO 450
      DO 370 I=1,I2
         READ 760, NC,NPTT,ISJT,(NSIT(II),II=1,12),(NEPT(II),II=1,12)
         IF (NPTM(NC).NE.-1) PRINT 830, NC
         PRINT 770, NC,NPTT,ISJT,(NSIT(II),II=1,NPTT)
         PRINT 780, (NEPT(II),II=1,NPTT)
         IF (NPTT.LT.2.OR.NPTT.GT.12) GO TO 470
         IF (NC.LE.0.OR.NC.GT.MNOW) GO TO 470
         DO 340 II=2,NPTT
            IF (NEPT(II).LE.NEPT(II-1)) GO TO 470
  340    CONTINUE
         IF (ISJT.NE.1) GO TO 350
         IF (NSIT(1).NE.0.OR.NEPT(1).NE.0) GO TO 470
  350    CONTINUE
```

```
      NPTH(NC)=NPTT
      ISH(NC)=IBJT
      DO 360 II=1,NPTT
         NQM(NC,II)=NSIT(II)
         NWM(NC,II)=NFPT(II)
  360 CONTINUE
  370 CONTINUE
C
COMMENT - CHECK IF Q - W CURVES HAVE BEEN ALL SPECIFIED
COMMENT - DISTRIBUTED SPRINGS
C
      IF (NDS.LE.0) GO TO 410
      DO 400 I=1,NDS
         II=NSXD(I)
         IF (II.LE.0) GO TO 380
         IF (NPTH(II).EQ.-1) GO TO 480
  380    CONTINUE
         II=NSYD(I)
         IF (II.LE.0) GO TO 390
         IF (NPTH(II).EQ.-1) GO TO 480
  390    CONTINUE
         II=NSZD(I)
         IF (II.LE.0) GO TO 400
         IF (NPTH(II).EQ.-1) GO TO 480
  400 CONTINUE
  410 CONTINUE
C
COMMENT - POINT SPRINGS
C
      IF (NCS.LE.0) GO TO 490
      DO 440 I=1,NCS
         II=NSXP(I)
         IF (II.LE.0) GO TO 420
         IF (NPTH(II).EQ.-1) GO TO 480
  420    CONTINUE
         II=NSYP(I)
         IF (II.LE.0) GO TO 430
         IF (NPTH(II).EQ.-1) GO TO 480
  430    CONTINUE
         II=NSZP(I)
         IF (II.LE.0) GO TO 440
         IF (NPTH(II).EQ.-1) GO TO 480
  440 CONTINUE
      GO TO 490
  450 IABAN=1
      GO TO 490
  460 IABAN=2
      GO TO 490
  470 IABAN=3
      GO TO 490
  480 PRINT 790
      IABAN=4
  490 CONTINUE
      RETURN
C
  500 FORMAT ( 29H     TABLE 5A - APPLIED LOADS,///)
  510 FORMAT (52H     HOLDING DATA FROM THE PREVIOUS PROBLEM PLUS THE,10
     1H FOLLOWING,//)
  520 FORMAT ( 52H     LOADS INCREASED BY PERCENTAGES OVER LAST PROBLE,
     1 1HM,//, 42H     PERCENT CHANGE FOR DIST. LOADS        =,F12.3,/, 42
     2H     PERCENT CHANGE FOR CONC. LOADS       =,F12.3)
  530 FORMAT (//, 23H     PLUS THE FOLLOWING,//)
  540 FORMAT (2E10.3)
  550 FORMAT ( 30H     NO CONC. LOAD TO INCREASE)
  560 FORMAT ( 30H     NO DIST. LOAD TO INCREASE)
  570 FORMAT (30H     NO DATA IN THIS TABLE     )
  580 FORMAT (10H     NONE )
  590 FORMAT (3I5)
  600 FORMAT ( 42H     NUMBER OF SETS OF DIST. LOADS        =,I5,/, 42H
     1    NUMBER OF CONC. LOADS                  =,I5)
  610 FORMAT (I5,5X,F10.3)
  620 FORMAT (/, 12H     SET NO.,I5,/, 42H     NO. OF POINTS
     1             =,I5,/, 42H     TIME LOAD APPLIED                      =,E
     212.3,//, 53H                              DISTANCE          FX          F,
     3 13HY          FZ,/)
  630 FORMAT (4E10.3)
  640 FORMAT (22X,4E12.3)
  650 FORMAT (5X,I5,5E12.3)
  660 FORMAT (//, 23H     CONCENTRATED LOADS,//, 53H          NO.      TIME
     1       DISTANCE           FX              F, 13HY            FZ,//)
  670 FORMAT (5E10.3)
  680 FORMAT ( 21H     DISTRIBUTED LOAD)
  690 FORMAT (5/, 33H     TABLE 5B - SPRING RESTRAINTS,///)
  700 FORMAT ( 42H     NO. OF SETS OF DIST. RESTRAINTS      =,I5,/, 42H
     1    NO. OF CONC. RESTRAINTS                =,I5)
  710 FORMAT (//,30H     DISTRIBUTED SPRING DATA  )
  720 FORMAT (E10.3,I4,2I3,6F10.3)
  730 FORMAT (/,46H                    Q-W CURVE NO.              0,49H -
     1MULTIPLIER                     W = MULTIPLIER/,46H         DISTANC
     2E   (IF < 1 LINEAR)          (IF   ,20HLINEAR SPRING, S)    /,46H
     3                   X     Y     Z            X      ,49H       Y             Z
     4              X           Y       ,10H        Z    ,/)
  740 FORMAT (//,30H     CONCENTRATED SPRING DATA )
  750 FORMAT (30H     CURVE NUMB SYMT(1 = YES) ,/,30H     NUMB  PTS   OPT
     1       )
  760 FORMAT (3I5,5X,12I5,/,20X,12I5)
  770 FORMAT (/,5X,3I5,/,8H     SIG,17X,12I5)
  780 FORMAT (8H     EPS,17X,12I5)
  790 FORMAT ( 35H     NOT ALL Q-W CURVES ARE DEFINED)
  800 FORMAT (5/, 4RH     TABLE 5C - NONLINEAR SUPPORT CURVES,///)
  810 FORMAT (/, 12H     SET NO.,I5,/, 42H     NO. OF POINTS
     1             =,I5)
  820 FORMAT (5X,F12.3,3I5,6F12.3)
  830 FORMAT (/, 18H     Q-W CURVE NO.,I3, 28H HAS BEEN PREVIOUSLY DEFIN
     1ED, 46H NEW DATA ARE RECORDED AND MAY NOT BE THE SAME)
C
      END
```

A P P E N D I X   D

SAMPLE INPUT

```
UNIVERSITY OF ILLINOIS TEST BEAM
TESTING PROGRAM PBEAM, APRIL 7, 1977
START     12-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS
   12                                                           1     1
        4     5     4    20    16     3
       16 1.000E+00 1.015E+00
 1.000E+00 1.001E+00 1.002E+00 1.003E+00 1.004E+00 1.005E+00 1.006E+00 1.007E+00
 1.008E+00 1.009E+00 1.010E+00 1.011E+00 1.012E+00 1.013E+00 1.014E+00 1.015E+00
    5   20           1.000E+00 1.000E+00 1.000E+10 1.000E+10
    2
    1         1                8.391E-02
 1.000E+00 1.000E-06 1.332E-04-1.000E-02
    2         2
 1.000E+02 1.000E-04 6.530E-02-6.530E-02
    1                -3340-1670-3330
                     -2200-8295-1000
    2    8    1          0 2009 2250 2420 2500 2540 2560 2800
                         0   70   83  130  122  150  200  650
   20      1.000E+02
    7
         1    4    1
           6.000E+00 2.650E+00-1.325E+00
         1    1    1
           1.675E+00 5.000E-01-2.817E+00
         1    6    1
           2.650E+00 6.700E+00-6.000E+00
         1    1    1
           1.675E+00 5.000E-01-9.183E+00
         1    4    1
           6.000E+00 2.650E+00-1.068E+01
         2    1    3
 0.000E+00 3.000E-02 1.000E+00-1.000E+01 4.181E-03
 5.400E+01 3.000E-02 1.000E+00-1.000E+01 4.181E-03
 1.080E+02 3.000E-02 1.000E+00-1.700E+00 4.181E-03
         2    2    3
 0.000E+00 6.080E-02 2.000E+00-1.000E+01 4.181E-03
 5.400E+01 6.080E-02 2.000E+00-1.000E+01 4.181E-03
 1.080E+02 6.080E-02 2.000E+00-1.700E+00 4.181E-03
        15
 1.001E+00 5.400E+01                -7.500E+03
 1.002E+00 5.400E+01                -2.500E+03
 1.003E+00 5.400E+01                -2.500E+03
 1.004E+00 5.400E+01                -2.500E+03
 1.005E+00 5.400E+01                -2.500E+03
 1.006E+00 5.400E+01                -2.500E+03
 1.007E+00 5.400E+01                -5.000E+02
 1.008E+00 5.400E+01                -3.000E+02
 1.009E+00 5.400E+01                -1.000E+02
 1.010E+00 5.400E+01                -1.000E+02
 1.011E+00 5.400E+01                -1.000E+02
 1.012E+00 5.400E+01                -1.000E+02
 1.013E+00 5.400E+01                -1.000E+02
 1.014E+00 5.400E+01                -1.000E+02
 1.015E+00 5.400E+01                -1.000E+02
         2
 0.000E+00                          -1.000E+30
 1.080E+02           -1.000E+30-1.000E+30-1.000E+30
CEASE
```

30

```
PROBLEM W-2 B DT 12+2, COMPOSITE SECTION
FROM YOUNG LO S REPORT, PP 42-46
START     2TEST PROGRAM 4/3/77
   12                                                                  1     1
        4     7     6    20    31     3
       16 1.000E+00 1.016E+00
 1.000E+00 1.001E+00 1.002E+00 1.003E+00 1.004E+00 1.005E+00 1.006E+00 1.007E+00
 1.008E+00 1.009E+00 1.010E+00 1.011E+00 1.012E+00 1.013E+00 1.014E+00 1.015E+00
    5    20           1.000E+00 1.000E+00 1.000E+10 1.000E+10
    3
    1         1                 8.681E-02
 1.000E+00 1.000E-06 1.177E-04-1.000E-02
    2         2                 8.681E-02
 1.000E+00 1.000E-06 1.228E-04-1.000E-02
    3         3
 1.000E+02 1.000E-05 7.000E-02-7.000E-02
    1                -5000-2500-4287
                     -2200-3250-1000
    2                -3000-1500-3321
                     -2200-4500-1000
    3    11     1        0 1943 2125 2270 2400 2450 2510 2555 2595 2690 2810
                         0  700  790  860  940  990 1077 1190 1390 2600 7000
   20       2.160E+02
    8
        2     4     1                        1.001E+00 1.002E+00
         4.800E+01 2.000E+00 3.000E+00
        1     3     1
         4.800E+01 2.000E+00 1.000E+00
        1     3     1
         5.550E+00 2.000E+00-1.000E+00
        1     3     1
         5.150E+00 2.000E+00-3.000E+00
        1     3     1
         4.750E+00 2.000E+00-5.000E+00
        1     3     1
         4.350E+00 2.000E+00-7.000E+00
        1     3     1
         3.950E+00 2.000E+00-9.000E+00
        3     1     3
 0.000E+00 1.000E+00 6.080E-01-3.518E-00 5.600E-03
 1.620E+02 1.000E+00 6.080E-01-7.143E-00 5.600E-03
 2.160E+02 1.000E+00 6.080E-01-7.143E-00 5.600E-03
   15
    1       1.002E+00
                      -1.500E+01
    1       1.003E+00
                      -3.333E+00
    1       1.004E+00
                      -3.333E+00
    1       1.005E+00
                      -1.000E+01
    1       1.006E+00
                      -1.000E+01
    1       1.007E+00
                      -5.000E+00
    1       1.008E+00
                      -5.000E+00
    1       1.009E+00
                      -1.500E+00
    1       1.010E+00
                      -1.000E-01
    1       1.011E+00
                      -1.000E-01
    1       1.012E+00
                      -1.000E-01
    1       1.013E+00
                      -1.000E-01
    1       1.014E+00
                      -1.000E-01
    1       1.015E+00
                      -1.000E-01
    1       1.016E+00
                      -1.000E-01
            2
 0.000E+00                      -1.000E+30
 2.160E+02            -1.000E+30           -1.000E+30
CEASE
```

```
UNIVERSITY OF HAWII
TECHNICAL REPORT CE71-01
START     1BEAM-I, DEFLECTION SPECIMEN, RATE OF CREEP METHOD
   12                                                               1    1
         6   10          6    2    3    0
    9   12 7.000E+00 3.070E+02
 9.000E+00 1.100E+01 1.400E+01 3.300E+01 4.200E+01 6.300E+01 1.050E+02 1.870E+02
 3.070E+02
 7.000E+00 9.000E+00 1.100E+01 1.400E+01 2.700E+01 2.800E+01 3.300E+01 4.200E+01
 6.300E+01 1.050E+02 1.870E+02 3.070E+02
    3   20    0        1.000E-01 1.000E-01 1.000E+10 1.000E+10
    2
    1              1    1    1 8.681E-02
 4.640E+06             1.237E-04-1.000E-02
 4.000E+00 8.500E-01
 3.700E+00 1.000E+00
 6.000E-01 1.000E+01 1.250E+00-1.180E-01
-1.050E-03 3.500E+01
    2    1    0    0    1    0 0.000E+00
 2.800E+07             6.530E-02-6.530E-02
 2.295E+05 1.000E+01 5.500E-01 6.000E-01
   20      9.000E+01
    2
         1   10    1             0.000E+00 7.000E+00 7.000E+00
           4.000E+00 6.000E+00 0.000E+00 0.000E+00
         2    1    1            -2.500E+00-2.500E+00-2.500E+00
           1.000E+00 1.700E-01-1.250E+00 6.223E-03
         1
 2.800E+01 6.000E+01            -7.500E+02
         2
 0.000E+00                      -1.000E+30
 9.000E+01             -1.000E+30          -1.000E+30
START     1BEAM-I, DEFLECTION SPECIMEN, SUPERPOSITION METHOD
    3    1    1    1    1    1    1    1                        1    1

START     1BEAM-I, CAMBER SPECIMEN, RATE OF CREEP METHOD
    2         1    1    1              1    1                        1    1
         6
    9   12 7.000E+00 3.070E+02
 9.000E+00 1.100E+01 1.400E+01 2.800E+01 4.200E+01 6.300E+01 1.050E+02 1.870E+02
 3.070E+02
 7.000E+00 9.000E+00 1.100E+01 1.400E+01 2.800E+01 2.800E+01 2.800E+01 4.200E+01
 6.300E+01 1.050E+02 1.870E+02 3.070E+02
    3   20    0        1.000E-01 1.000E-01 1.000E+10 1.000E+10
START     1BEAM-I, CAMBER SPECIMEN, SUPERPOSITION METHOD
    3    1    1    1    1    1    1    1                        1    1

CEASE
```

```
U.S. NAVAL CIVIL ENGINEERING LABORATORY
GROUTED POST-TENSIONED BEAM, 40 FT. SIMPLE SPAN.
START    4DBEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL FC, 7.5 SQRT(FC)
   13
         8    15     6    36    18     3
   14    29 8.000E+00 4.688E+03
 8.000E+00 1.000E+01 1.500E+01 2.500E+01 3.000E+01 4.000E+01 6.000E+01 1.000E+02
 2.000E+02 4.000E+02 8.000E+02 1.200E+03 2.000E+03 4.674E+03
 8.000E+00 1.000E+01 1.500E+01 2.100E+01 2.200E+01 2.500E+01 3.000E+01 4.000E+01
 6.000E+01 1.000E+02 2.000E+02 4.000E+02 8.000E+02 1.200E+03 2.000E+03 4.674E+03
 4.675E+03 4.676E+03 4.677E+03 4.678E+03 4.679E+03 4.680E+03 4.681E+03 4.682E+03
 4.683E+03 4.684E+03 4.685E+03 4.686E+03 4.687E+03
    5    20                1.000E+00 1.000E+00 1.000E+10 1.000E+10
    3
    1           1    11      1     1
 1.000E+00 1.000E-06 1.655E-04-1.000E-02
 1.000E+00 1.083E+00 1.173E+00 1.417E+00 1.473E+00 1.604E+00 1.667E+00 1.713E+00
 3.000E+00 8.000E+00 2.200E+01 1.830E+02 3.650E+02 1.825E+03 3.650E+03 4.670E+03
 1.000E+00 9.932E-01 1.063E+00 1.111E+00 1.118E+00 1.123E+00 1.146E+00 1.172E+00
 3.000E+00 8.000E+00 2.200E+01 1.830E+02 3.650E+02 1.825E+03 3.650E+03 4.670E+03
 1.880E+00 1.000E+00
 6.000E-01 1.000E+01 1.250E+00-1.180E-01
-5.600E-04 3.500E+01
    2     1     2              1
 1.000E+03 1.000E-05 7.700E-02-7.700E-02
 1.240E+05 1.000E+01 5.500E-01 6.000E-01
    3           3
 1.000E+03 1.000E-05 7.700E-02-7.700E-02
    1                     -4800-2400 3033
                          -1877-2297 1000
    2     7     1             0  100  120  128  130  140  146
                              0  408  500  722 1000 3000 7700
    3     3     1             0   49   49
                              0  184 7700
   20       2.400E+02
   12
          1    3    1                0.000E+00 0.000E+00 7.000E+00
            1.200E+01 3.000E+00 1.050E+01
          1    1    1                0.000E+00 0.000E+00 7.000E+00
            6.000E+00 1.000E+00 8.556E+00
          1    1    1                0.000E+00 0.000E+00 7.000E+00
            2.000E+00 1.000E+00 7.667E+00
          1    8    1                0.000E+00 0.000E+00 7.000E+00
            4.000E+00 1.700E+01 5.000E-01
          1    1    1                0.000E+00 0.000E+00 7.000E+00
            2.500E+00 1.250E+00-6.333E+00
          1    1    1                0.000E+00 0.000E+00 7.000E+00
            7.500E+00 1.250E+00-7.444E+00
          1    4    1                0.000E+00 0.000E+00 7.000E+00
            1.400E+01 4.000E+00-1.000E+01
          3    1    1
            3.300E-01 1.000E+00 1.050E+01
          3    1    1
            2.200E-01 1.000E+00-7.250E+00
          3    1    1
            3.300E-01 1.000E+00-1.050E+01
    1     2    1                     8.000E+00 8.000E+00 8.000E+00
    1     1    2     1 2.917E-05 1.900E-01
            0.000E+00 2.400E+02                           9.950E-01 9.950E-01
            0.000E+00 2.400E+02                           1.000E+00 1.000E+00
    1       0.000E+00 6.600E+01 1.140E+02                 4.439E+00-5.250E+00-7.250E+00
                      2.400E+02                                     -7.250E+00
            9.805E+04
    1     2    1                     8.000E+00 8.000E+00 8.000E+00
    1     1    2     1 2.917E-05 1.900E-01
            0.000E+00 2.400E+02                           9.950E-01 9.950E-01
            0.000E+00 2.400E+02                           1.000E+00 1.000E+00
    1       0.000E+00 6.600E+01 1.140E+02                -4.518E+00-8.750E+00-9.750E+
                      2.400E+02                                     -9.750E+00
            9.830E+04
    1    15
    1       8.000E+00
                      -1.879E+01
  2.200E+01 1.200E+02            -2.280E+04
  4.675E+03 1.200E+02             1.140E+04
  4.676E+03 1.200E+02             1.140E+04
  4.677E+03 1.200E+02            -1.500E+04
  4.678E+03 1.200E+02            -5.000E+03
  4.679E+03 1.200E+02            -5.000E+03
  4.680E+03 1.200E+02            -5.000E+03
  4.681E+03 1.200E+02            -5.000E+03
  4.682E+03 1.200E+02            -3.000E+03
  4.683E+03 1.200E+02            -1.000E+03
  4.684E+03 1.200E+02            -1.000E+03
  4.685E+03 1.200E+02            -1.000E+03
  4.686E+03 1.200E+02            -1.000E+03
  4.687E+03 1.200E+02            -1.000E+03
  4.688E+03 1.200E+02            -1.000E+03
          2
  0.000E+00                      -1.000E+30
  2.400E+02           -1.000E+30            -1.000E+30
CEASE
```

```
PCA#3 BEAM
HALF SCALE MODEL, TWO SPAN CONTINUOUS COMPOSITE GIRDER, GIRDER 3-4
START     5SUPERPOSITION METHOD
   13                                                                          1     1
        9    20    10    38    55     4     2
   12    35 0.000E+00 6.810E+02
 1.000E+01 1.000E+01 2.300E+01 3.000E+01 3.700E+01 4.000E+01 5.500E+01 7.000E+01
 9.000E+01 1.000E+02 2.000E+02 2.700E+02
 8.000E+00 1.000E+01 2.000E+01 2.100E+01 2.700E+01 2.800E+01 3.500E+01 3.700E+01
 4.000E+01 4.500E+01 4.501E+01 4.502E+01 5.500E+01 7.000E+01 9.000E+01 1.400E+02
 2.000E+02 2.700E+02 3.590E+02 3.592E+02 4.220E+02 4.222E+02 5.300E+02 5.322E+02
 6.800E+02 6.801E+02 6.802E+02 6.803E+02 6.804E+02 6.805E+02 6.806E+02 6.807E+02
 6.808E+02 6.809E+02 6.810E+02
    5    20                1.000E+00 1.000E+00 1.000E+10 1.000E+10
    5
    1           1     1      1     1 8.681E-02
 1.000E+00 1.000E-06 1.173E-04-1.000E-02
 2.300E+00 9.200E-01
 2.197E+00 9.000E-01
 6.000E-01 1.000E+01 1.250E+00-1.180E-01
-6.673E-04 3.500E+01
    2           2     1      1     1
 1.000E+00 1.000E-06 1.174E-04-1.000E-02
 4.000E+00 8.500E-01
 2.197E+00 9.000E-01
 6.000E-01 1.000E+01 1.250E+00-1.180E-01
-6.404E-04 3.500E+01
    3     1     3            1
 1.000E+02 1.000E-05 6.530E-02-6.530E-02
 2.540E+05 1.000E+01 5.500E-01 6.000E-01
    4           4
 1.000E+02 1.000E-05 1.000E-01-1.000E-01
    5           5
 1.000E+02 1.000E-05 1.000E-01-1.000E-01
    1                     -5457-2729 4478
                          -2114-3000 1000
    2                     -4786-2393 4194
                          -2036-3073 1000
    3     7     1             0 2296 2471 2540 2603 2648 2800
                              0  800  900 1000 1200 2000 6530
    4     3     1             0  485  485
                              0  164 6530
    5     3     1             0  500  500
                              0  169 6530
   22        4.356E+02
   10
        2     4     2                  2.800E+01 2.800E+01 3.500E+01
 0.000E+00 3.900E+01 3.000E+00 1.500E+00
 3.960E+02 3.900E+01 3.000E+00 1.500E+00
        1     4     2                  0.000E+00 8.000E+00 8.000E+00
 0.000E+00 8.000E+00 3.500E+00-1.750E+00
 3.960E+02 8.000E+00 3.500E+00-1.750E+00
        1     1     2                  0.000E+00 8.000E+00 8.000E+00
 0.000E+00 2.250E+00 2.250E+00-4.250E+00
 3.960E+02 2.250E+00 2.250E+00-4.250E+00
        1     6     2                  0.000E+00 8.000E+00 8.000E+00
 0.000E+00 3.500E+00 1.550E+01-1.125E+01
 3.960E+02 3.500E+00 1.550E+01-1.125E+01
        1     1     2                  0.000E+00 8.000E+00 8.000E+00
 0.000E+00 3.750E+00 3.750E+00-1.775E+01
 3.960E+02 3.750E+00 3.750E+00-1.775E+01
```

```
        1     4     2                0.000E+00 8.000E+00 8.000E+00
 0.000E+00 1.100E+01 3.500E+00-2.075E+01
 3.960E+02 1.100E+01 3.500E+00-2.075E+01
        3     4     2               -1.000E+00 8.000E+00 8.000E+00
 0.000E+00 2.160E-01 4.000E+00-1.900E+01 5.861E-03
 3.960E+02 2.160E-01 4.000E+00-1.900E+01 5.861E-03
        3     2     2               -1.000E+00 8.000E+00 8.000E+00
 0.000E+00 4.881E-03 2.950E+01-9.125E+00 5.861E-03
 3.960E+02 4.881E-03 2.950E+01-9.125E+00 5.861E-03
        4     2     6                2.800E+01 2.800E+01 3.500E+01
 2.520E+02 1.000E+01 1.000E-01 1.500E+00
 3.240E+02 1.000E+01 1.000E-01 1.500E+00
 3.241E+02 2.000E+01 1.000E-01 1.500E+00
 3.960E+02 2.000E+01 1.000E-01 1.500E+00
 3.961E+02 2.000E+00 2.000E+03 0.000E+00
 4.356E+02 2.000E+00 2.000E+03 0.000E+00
        5     2     4                0.000E+00 8.000E+00 8.000E+00
 3.600E+02 4.400E+00 1.000E-01-2.050E+01
 3.960E+02 4.400E+00 1.000E-01-2.050E+01
 3.961E+02 1.000E+00 1.000E-02 0.000E+00
 4.356E+02 1.000E+00 1.000E-02 0.000E+00
   12    18
    2      2.100E+01
 0.000E+00           -2.222E+01
 3.960E+02           -2.222E+01
    2      2.800E+01
 0.000E+00           -1.016E+01
 3.960E+02           -1.016E+01
    2      6.801E+02
 0.000E+00           -3.541E+01
 3.960E+02           -3.541E+01
    2      6.802E+02
 0.000E+00           -3.541E+01
 3.960E+02           -3.541E+01
    2      6.803E+02
 0.000E+00           -1.770E+01
 3.960E+02           -1.770E+01
    2      6.804E+02
 0.000E+00           -1.770E+01
 3.960E+02           -1.770E+01
    2      6.805E+02
 0.000E+00           -1.770E+01
 3.960E+02           -1.770E+01
    2      6.806E+02
 0.000E+00           -1.770E+01
 3.960E+02           -1.770E+01
    2      6.807E+02
 0.000E+00           -8.853E+00
 3.960E+02           -8.853E+00
    2      6.808E+02
 0.000E+00           -8.853E+00
 3.960E+02           -8.853E+00
    2      6.809E+02
 0.000E+00           -8.853E+00
 3.960E+02           -8.853E+00
    2      6.810E+02
 0.000E+00           -8.853E+00
 3.960E+02           -8.853E+00
 4.501E+01 1.980E+02           -1.239E+04
 4.502E+01 1.980E+02            1.239E+04
 3.591E+02 1.980E+02           -1.239E+04
 3.592E+02 1.980E+02            1.239E+04
```

```
4.221E+02 1.980E+02           -1.239E+04
4.222E+02 1.980E+02            1.239E+04
5.301E+02 1.980E+02           -1.239E+04
5.302E+02 1.980E+02            1.239E+04
6.801E+02 2.160E+02           -5.978E+03
6.802E+02 2.160E+02           -5.978E+03
6.803E+02 2.160E+02           -2.989E+03
6.804E+02 2.160E+02           -2.989E+03
6.805E+02 2.160E+02           -2.989E+03
6.806E+02 2.160E+02           -2.989E+03
6.807E+02 2.160E+02           -1.495E+03
6.808E+02 2.160E+02           -1.495E+03
6.809E+02 2.160E+02           -1.495E+03
6.810E+02 2.160E+02           -1.495E+03
        3
0.000E+00                     -1.000E+30
3.960E+02           -1.000E+30-1.000E+30
4.158E+02          1                        1.000E+03                          1.000E-06
   1    9             619  618  591  313    0-2142-2234-2248-2249
                    -9999-2671-1760   -3    0  102  621 1144 9999
EASE
```

A P P E N D I X E

SAMPLE OUTPUT

```
PROGRAM PBEAM
ANALYSIS OF TIME DEPENDENT RESPONDS OF PRESTRESSED CONTINUOUS BEAMS
BY C. SUTTIKAN, 1977

UNIVERSITY OF ILLINOIS TEST BEAM
TESTING PROGRAM PBEAM, APRIL 7, 1977
```

```
UNIVERSITY OF ILLINOIS TEST BEAM
TESTING PROGRAM PREAM, APRIL 7, 1977


PROB
    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS
     ISMALL= -Ø (Ø=LARGE, 1=SMALL ANGLES SOLUTION )




TABLE 1 - PROGRAM CONTROL DATA
PROBLEM TYPE    12

                      INPUT TABLES

     TABLE     HOLD DATA FROM      NUMBER OF CARDS
    NUMBER     LAST PROBLEM        ADDED FOR THIS
              (1 = YES,Ø = NO)     PROBLEM

       2              -Ø                  4
      3A              -Ø                  5
      3B              -Ø                  4
       4              -Ø                 2Ø
      5A              -Ø                 16
      5B              -Ø                  3
      5C              -Ø                 -Ø

                      OUTPUT TABLES

    TABLE   SUPPRESS OUTPUT
    NUMBER  (1 = YES,Ø = NO)
       6           -Ø
       7           -Ø
       8            1
       9            1

   ISMALL=   -Ø (Ø=LARGE, 1=SMALL  ANGLES SOLUTION  )
```

```
PROB (CONTD)

    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

TABLE 2 - TIME INCREMENT AND ITERATION CONTROL DATA


NUMBER OF CALCULATING TIME STEPS  =   -0
NUMBER OF OUTPUT PRINTED          =   16

TIME LOADING STARTS               =   1.000E+00
FINAL TIME STEP                   =   1.015E+00


TIMES OUTPUT WILL BE PRINTED OUT, DAYS

    1.000E+00   1.001E+00   1.002E+00   1.003E+00   1.004E+00   1.005E+00   1.006E+00   1.007E+00
    1.008E+00   1.009E+00   1.010E+00   1.011E+00   1.012E+00   1.013E+00   1.014E+00   1.015E+00


NO. OF CYCLES CRACKS ARE FROZEN      =    5
MAXIMUM NO. OF ITERATIONS/CYCLE      =   20
ITERATION PRINTOUT INDICATOR         =   -0
CLOSURE TOLERANCE FOR FORCE ERRORS   =   1.000E+00
CLOSURE TOLERANCE FOR MOMENT ERRORS  =   1.000E+00
MAXIMUM FORCE ERRORS                 =   1.000E+10
MAXIMUM MOMENT ERRORS                =   1.000E+10
```

PROB (CONTD)

```
    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

TABLE 3A - MATERIAL PROPERTIES


NO. OF MATERIALS                    =    2


MATERIAL NO.  1
RELAXATION INDICATOR                =   -0
STRESS-STRAIN CURVE NO.             =    1
AGE EQUATION NO.                    =   -0
CREEP EQUATION NO.                  =   -0
SHRINKAGE EQUATION NO.              =   -0
UNIT WEIGHT                         =   8.391E-02

STRESS MULTIPLIER                   =   1.000E+00
STRAIN MULTIPLIER                   =   1.000E-06
MAXIMUM STRAIN ALLOWED              =   1.302E-04
MINIMUM STRAIN ALLOWED              =  -1.000E-02


MATERIAL NO.  2
RELAXATION INDICATOR                =   -0
STRESS-STRAIN CURVE NO.             =    2
AGE EQUATION NO.                    =   -0
CREEP EQUATION NO.                  =   -0
SHRINKAGE EQUATION NO.              =   -0
UNIT WEIGHT                         =  -0.000E+00

STRESS MULTIPLIER                   =   1.000E+02
STRAIN MULTIPLIER                   =   1.000E-04
MAXIMUM STRAIN ALLOWED              =   6.530E-02
MINIMUM STRAIN ALLOWED              =  -6.530E-02


TABLE 3B - STRESS-STRAIN CURVES


CURVE NUMB SYMT(1 = YES)
NUMB  PTS  OPT

   1   12    0
SIG                  -668 -668-3340-3338-3331-3307-3260-3151-2985-2441-1511 1511
EPS                 *1195*1195-2200-2130-2046-1914-1760-1540-1320 -880 -440  440

   2    8    1
SIG                     0 2009 2250 2420 2500 2540 2560 2800   -0   -0   -0   -0
EPS                     0   70   83  100  122  150  200  650   -0   -0   -0   -0
```

```
PROB (CONTD)

    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

TABLE 4 - CROSS-SECTION PROPERTIES


NO. OF DISCRETE ELEMENTS              =   20
MEMBER LENGTH                         =   1.080E+02


NO. OF SUB-RECTANGLES                 =    7


SUB-RECTANGLE NO.    1
POST-TENSION INDICATOR (IF=1,YES)     =   -0
MATERIAL NO.                          =    1
NO. OF VERTICAL DIVISIONS             =    4
NO. OF POINTS SPECIFIED               =    1
SYMMETRIC INDICATOR (IF=1,YES)        =   -0
CASTING TIME                          =  -0.000E+00
TIME ADDED TO STRUCTURE               =  -0.000E+00
TIME WHEN CAN CARRY LOAD              =  -0.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN

  -0.000E+00   6.000E+00   2.650E+00  -1.325E+00  -0.000E+00

SUB-RECTANGLE NO.    2
POST-TENSION INDICATOR (IF=1,YES)     =   -0
MATERIAL NO.                          =    1
NO. OF VERTICAL DIVISIONS             =    1
NO. OF POINTS SPECIFIED               =    1
SYMMETRIC INDICATOR (IF=1,YES)        =   -0
CASTING TIME                          =  -0.000E+00
TIME ADDED TO STRUCTURE               =  -0.000E+00
TIME WHEN CAN CARRY LOAD              =  -0.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN

  -0.000E+00   1.675E+00   5.000E-01  -2.817E+00  -0.000E+00

SUB-RECTANGLE NO.    3
POST-TENSION INDICATOR (IF=1,YES)     =   -0
MATERIAL NO.                          =    1
NO. OF VERTICAL DIVISIONS             =    6
NO. OF POINTS SPECIFIED               =    1
SYMMETRIC INDICATOR (IF=1,YES)        =   -0
CASTING TIME                          =  -0.000E+00
TIME ADDED TO STRUCTURE               =  -0.000E+00
TIME WHEN CAN CARRY LOAD              =  -0.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN
```

```
  -0.000E+00    2.650E+00    6.700E+00   -6.000E+00   -0.000E+00

 SUB-RECTANGLE NO.     4
 POST-TENSION INDICATOR (IF=1,YES)     =    -0
 MATERIAL NO.                          =     1
 NO. OF VERTICAL DIVISIONS             =     1
 NO. OF POINTS SPECIFIED               =     1
 SYMMETRIC INDICATOR (IF=1,YES)        =    -0
 CASTING TIME                          =   -0.000E+00
 TIME ADDED TO STRUCTURE               =   -0.000E+00
 TIME WHEN CAN CARRY LOAD              =   -0.000E+00

 HOR.DISTANCE     WIDTH         DEPTH          CG.       INT.STRAIN

   -0.000E+00    1.675E+00    5.000E-01   -9.183E+00   -0.000E+00

 SUB-RECTANGLE NO.     5
 POST-TENSION INDICATOR (IF=1,YES)     =    -0
 MATERIAL NO.                          =     1
 NO. OF VERTICAL DIVISIONS             =     4
 NO. OF POINTS SPECIFIED               =     1
 SYMMETRIC INDICATOR (IF=1,YES)        =    -0
 CASTING TIME                          =   -0.000E+00
 TIME ADDED TO STRUCTURE               =   -0.000E+00
 TIME WHEN CAN CARRY LOAD              =   -0.000E+00

 HOR.DISTANCE     WIDTH         DEPTH          CG.       INT.STRAIN

   -0.000E+00    6.000E+00    2.650E+00   -1.068E+01   -0.000E+00

 SUB-RECTANGLE NO.     6
 POST-TENSION INDICATOR (IF=1,YES)     =    -0
 MATERIAL NO.                          =     2
 NO. OF VERTICAL DIVISIONS             =     1
 NO. OF POINTS SPECIFIED               =     3
 SYMMETRIC INDICATOR (IF=1,YES)        =    -0
 CASTING TIME                          =   -0.000E+00
 TIME ADDED TO STRUCTURE               =   -0.000E+00
 TIME WHEN CAN CARRY LOAD              =   -0.000E+00

 HOR.DISTANCE     WIDTH         DEPTH          CG.       INT.STRAIN

    0.000E+00    3.040E-02    1.000E+00   -1.040E+01    4.181E-03
    5.000E+01    3.040E-02    1.000E+00   -1.040E+01    4.181E-03
    1.000E+02    3.040E-02    1.000E+00   -1.700E+00    4.181E-03

 SUB-RECTANGLE NO.     7
 POST-TENSION INDICATOR (IF=1,YES)     =    -0
 MATERIAL NO.                          =     2
 NO. OF VERTICAL DIVISIONS             =     2
 NO. OF POINTS SPECIFIED               =     3
 SYMMETRIC INDICATOR (IF=1,YES)        =    -0
 CASTING TIME                          =   -0.000E+00
 TIME ADDED TO STRUCTURE               =   -0.000E+00
 TIME WHEN CAN CARRY LOAD              =   -0.000E+00

 HOR.DISTANCE     WIDTH         DEPTH          CG.       INT.STRAIN
```

0.000E+00	6.080E-02	2.000E+00	-1.040E+01	4.181E-03
5.400E+01	6.080E-02	2.000E+00	-1.040E+01	4.181E-03
1.080E+02	6.080E-02	2.000E+00	-1.700E+00	4.181E-03

PROB (CONTD)

1 2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

TABLE 5A - APPLIED LOADS

NUMBER OF SETS OF DIST. LOADS = -0
NUMBER OF CONC. LOADS = 15

CONCENTRATED LOADS

NO.	TIME	DISTANCE	FX	FY	FZ
1	1.001E+00	5.400E+01	-0.000E+00	-7.500E+03	-0.000E+00
2	1.002E+00	5.400E+01	-0.000E+00	-2.500E+03	-0.000E+00
3	1.003E+00	5.400E+01	-0.000E+00	-2.500E+03	-0.000E+00
4	1.004E+00	5.400E+01	-0.000E+00	-2.500E+03	-0.000E+00
5	1.005E+00	5.400E+01	-0.000E+00	-2.500E+03	-0.000E+00
6	1.006E+00	5.400E+01	-0.000E+00	-2.500E+03	-0.000E+00
7	1.007E+00	5.400E+01	-0.000E+00	-5.000E+02	-0.000E+00
8	1.008E+00	5.400E+01	-0.000E+00	-3.000E+02	-0.000E+00
9	1.009E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00
10	1.010E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00
11	1.011E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00
12	1.012E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00
13	1.013E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00
14	1.014E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00
15	1.015E+00	5.400E+01	-0.000E+00	-1.000E+02	-0.000E+00

TABLE 5B - SPRING RESTRAINTS

NO. OF SETS OF DIST. RESTRAINTS = -0
NO. OF CONC. RESTRAINTS = 2

CONCENTRATED SPRING DATA

DISTANCE	Q-W CURVE NO. (IF < 1 LINEAR)			Q - MULTIPLIER (IF LINEAR SPRING, S)			W - MULTIPLIER		
	X	Y	Z	X	Y	Z	X	Y	Z
0.000E+00	-0	-0	-0	-0.000E+00	-1.000E+30	-0.000E+00	-0.000E+00	-0.000E+00	-0.000E+00
1.080E+02	-0	-0	-0	-1.000E+30	-1.000E+30	-1.000E+30	-0.000E+00	-0.000E+00	-0.000E+00

TABLE 5C - NONLINEAR SUPPORT CURVES

NO DATA IN THIS TABLE

```
PROB (CONTD)

    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

     ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION )

TIME INCREMENT    2     TIME   =    1.000E+00 (+)

TABLE 6 - ITERATION DATA


     TIME ELAPSED =  14.322 SECONDS AT THE START OF THIS TIME INCREMENT

CYCLE NO.    1

MEMBER CONVERGED AFTER ITERATION    3


MEMBER CONVERGED AFTER CYCLE    1


     TIME CONSUMED =   1.005 SECONDS BY THIS TIME INCREMENT
```

PROP (CONTD)

1 2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

ISMALL = -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 2 TIME = 1.000E+00 (+)

TABLE 7 - MEMBER RESULTS

		DISPLACEMENTS			REACTIONS			FORCES		
STA.	DISTANCE	AXIAL	LATERAL	ROTATIONAL	AXIAL	LATERAL	ROTATIONAL	AXIAL	SHEAR	MOMENT
1	0.000E+00	4.235E-03	-3.621E-28	1.084E-03	0.000E+00	3.621E+02	0.000E+00	0.000E+00	3.621E+02	0.000E+00
2	5.400E+00	4.593E-03	5.454E-03	9.357E-04	0.000E+00	0.000E+00	0.000E+00	-1.763E-04	3.389E+02	1.893E+03
3	1.080E+01	4.930E-03	1.012E-02	7.907E-04	0.000E+00	0.000E+00	0.000E+00	-1.390E-05	3.157E+02	3.660E+03
4	1.620E+01	5.248E-03	1.400E-02	6.490E-04	0.000E+00	0.000E+00	0.000E+00	6.796E-05	2.925E+02	5.303E+03
5	2.160E+01	5.548E-03	1.713E-02	5.104E-04	0.000E+00	0.000E+00	0.000E+00	8.804E-05	2.693E+02	6.819E+03
6	2.700E+01	5.831E-03	1.952E-02	3.745E-04	0.000E+00	0.000E+00	0.000E+00	7.093E-05	2.461E+02	8.211E+03
7	3.240E+01	6.099E-03	2.118E-02	2.412E-04	0.000E+00	0.000E+00	0.000E+00	4.047E-05	2.228E+02	9.477E+03
8	3.780E+01	6.353E-03	2.213E-02	1.101E-04	0.000E+00	0.000E+00	0.000E+00	1.470E-05	1.996E+02	1.062E+04
9	4.320E+01	6.594E-03	2.238E-02	-1.880E-05	0.000E+00	0.000E+00	0.000E+00	6.078E-06	1.764E+02	1.163E+04
10	4.860E+01	6.824E-03	2.193E-02	-1.459E-04	0.000E+00	0.000E+00	0.000E+00	1.707E-05	1.532E+02	1.252E+04
11	5.400E+01	7.044E-03	2.081E-02	-2.714E-04	0.000E+00	0.000E+00	0.000E+00	6.154E-05	1.300E+02	1.329E+04
12	5.940E+01	7.168E-03	1.904E-02	-3.814E-04	0.000E+00	0.000E+00	0.000E+00	1.852E-04	1.068E+02	1.393E+04
13	6.480E+01	7.105E-03	1.677E-02	-4.610E-04	0.000E+00	0.000E+00	0.000E+00	3.938E-04	8.356E+01	1.444E+04
14	7.020E+01	6.855E-03	1.415E-02	-5.100E-04	0.000E+00	0.000E+00	0.000E+00	6.319E-04	6.035E+01	1.483E+04
15	7.560E+01	6.416E-03	1.135E-02	-5.280E-04	0.000E+00	0.000E+00	0.000E+00	8.285E-04	3.714E+01	1.509E+04
16	8.100E+01	5.791E-03	8.530E-03	-5.150E-04	0.000E+00	0.000E+00	0.000E+00	9.171E-04	1.393E+01	1.523E+04
17	8.640E+01	4.982E-03	5.867E-03	-4.713E-04	0.000E+00	0.000E+00	0.000E+00	8.603E-04	-9.284E+00	1.524E+04
18	9.180E+01	3.993E-03	3.523E-03	-3.972E-04	0.000E+00	0.000E+00	0.000E+00	6.649E-04	-3.250E+01	1.513E+04
19	9.720E+01	2.829E-03	1.659E-03	-2.934E-04	0.000E+00	0.000E+00	0.000E+00	3.901E-04	-5.571E+01	1.489E+04
20	1.026E+02	1.495E-03	4.335E-04	-1.606E-04	0.000E+00	0.000E+00	0.000E+00	1.386E-04	-7.892E+01	1.453E+04
21	1.080E+02	7.786E-11	-1.021E-28	-1.404E-26	-7.786E-11	1.021E+02	1.404E+04	-7.786E-11	-1.021E+02	1.404E+04

```
PROB (CONTD)

    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

     ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION )

TIME INCREMENT    3     TIME   =    1.001E+00 (+)

TABLE 6 - ITERATION DATA


     TIME ELAPESD =  15.654 SECONDS AT THE START OF THIS TIME INCREMENT

CYCLE NO.    1

MEMBER CONVERGED AFTER ITERATION     3


MEMBER CONVERGED AFTER CYCLE     1


     TIME CONSUMED =    .985 SECONDS BY THIS TIME INCREMENT
```

PROB (CONTD)

1 2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 3 TIME = 1.001E+00 (+)

TABLE 7 - MEMBER RESULTS

		DISPLACEMENTS			REACTIONS			FORCES		
STA.	DISTANCE	AXIAL	LATERAL	ROTATIONAL	AXIAL	LATERAL	ROTATIONAL	AXIAL	SHEAR	MOMENT
1	0.000E+00	1.030E-02	-2.710E-27	1.088E-04	0.000E+00	2.710E+03	0.000E+00	0.000E+00	2.710E+03	0.000E+00
2	5.400E+00	1.059E-02	2.168E-04	-2.749E-05	0.000E+00	0.000E+00	0.000E+00	-1.270E-05	2.687E+03	1.457E+04
3	1.080E+01	1.070E-02	-2.273E-04	-1.360E-04	0.000E+00	0.000E+00	0.000E+00	-3.177E-05	2.664E+03	2.902E+04
4	1.620E+01	1.065E-02	-1.182E-03	-2.168E-04	0.000E+00	0.000E+00	0.000E+00	-5.279E-05	2.640E+03	4.334E+04
5	2.160E+01	1.043E-02	-2.500E-03	-2.703E-04	0.000E+00	0.000E+00	0.000E+00	-6.916E-05	2.617E+03	5.754E+04
6	2.700E+01	1.005E-02	-4.033E-03	-2.966E-04	0.000E+00	0.000E+00	0.000E+00	-7.462E-05	2.594E+03	7.161E+04
7	3.240E+01	9.496E-03	-5.636E-03	-2.960E-04	0.000E+00	0.000E+00	0.000E+00	-6.448E-05	2.571E+03	8.555E+04
8	3.780E+01	8.783E-03	-7.164E-03	-2.688E-04	0.000E+00	0.000E+00	0.000E+00	-4.008E-05	2.548E+03	9.937E+04
9	4.320E+01	7.909E-03	-8.473E-03	-2.152E-04	0.000E+00	0.000E+00	0.000E+00	-1.277E-05	2.524E+03	1.131E+05
10	4.860E+01	6.876E-03	-9.422E-03	-1.354E-04	0.000E+00	0.000E+00	0.000E+00	-8.504E-06	2.501E+03	1.266E+05
11	5.400E+01	5.683E-03	-9.870E-03	-2.971E-05	0.000E+00	0.000E+00	0.000E+00	-5.564E-05	-1.272E+03	1.401E+05
12	5.940E+01	4.479E-03	-9.734E-03	7.829E-05	0.000E+00	0.000E+00	0.000E+00	-1.128E-04	-5.045E+03	1.129E+05
13	6.480E+01	3.409E-03	-9.074E-03	1.644E-04	0.000E+00	0.000E+00	0.000E+00	-1.144E-04	-5.068E+03	8.559E+04
14	7.020E+01	2.479E-03	-8.010E-03	2.278E-04	0.000E+00	0.000E+00	0.000E+00	-6.891E-05	-5.092E+03	5.816E+04
15	7.560E+01	1.691E-03	-6.666E-03	2.678E-04	0.000E+00	0.000E+00	0.000E+00	-1.980E-05	-5.115E+03	3.061E+04
16	8.100E+01	1.048E-03	-5.171E-03	2.839E-04	0.000E+00	0.000E+00	0.000E+00	-3.792E-06	-5.138E+03	2.929E+03
17	8.640E+01	5.498E-04	-3.655E-03	2.758E-04	0.000E+00	0.000E+00	0.000E+00	-2.663E-05	-5.161E+03	-2.488E+04
18	9.180E+01	1.976E-04	-2.248E-03	2.433E-04	0.000E+00	0.000E+00	0.000E+00	-6.203E-05	-5.185E+03	-5.281E+04
19	9.720E+01	-9.967E-06	-1.082E-03	1.863E-04	0.000E+00	0.000E+00	0.000E+00	-7.154E-05	-5.208E+03	-8.087E+04
20	1.026E+02	-7.482E-05	-2.895E-04	1.051E-04	0.000E+00	0.000E+00	0.000E+00	-3.944E-05	-5.231E+03	-1.091E+05
21	1.080E+02	-1.127E-11	-5.254E-27	1.374E-25	1.127E-11	5.254E+03	-1.374E+05	1.127E-11	-5.254E+03	-1.374E+05

```
PROB (CONTD)

    1      2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

     ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION )

TIME INCREMENT     4      TIME    =     1.002E+00 (+)

TABLE 6 - ITERATION DATA


     TIME ELAPESD =  16.968 SECONDS AT THE START OF THIS TIME INCREMENT

CYCLE NO.     1

MEMBER CONVERGED AFTER ITERATION     3


MEMBER CONVERGED AFTER CYCLE     1


     TIME CONSUMED =     .988 SECONDS BY THIS TIME INCREMENT
```

PROB (CONTD)

1 2-SPAN PRESTRESSED BEAM WITH DRAPED TENDONS, FAILURE LOAD ANALYSIS

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 4 TIME = 1.002E+00 (+)

TABLE 7 - MEMBER RESULTS

STA.	DISTANCE	DISPLACEMENTS AXIAL	LATERAL	ROTATIONAL	REACTIONS AXIAL	LATERAL	ROTATIONAL	FORCES AXIAL	SHEAR	MOMENT
1	0.000E+00	1.233E-02	-3.493E-27	-2.163E-04	0.000E+00	3.493E+03	0.000E+00	0.000E+00	3.493E+03	0.000E+00
2	5.400E+00	1.259E-02	-1.529E-03	-3.485E-04	0.000E+00	0.000E+00	0.000E+00	-4.348E-08	3.470E+03	1.880E+04
3	1.080E+01	1.264E-02	-3.674E-03	-4.448E-04	0.000E+00	0.000E+00	0.000E+00	-6.601E-07	3.446E+03	3.747E+04
4	1.620E+01	1.246E-02	-6.243E-03	-5.054E-04	0.000E+00	0.000E+00	0.000E+00	-7.620E-07	3.423E+03	5.602E+04
5	2.160E+01	1.206E-02	-9.044E-03	-5.305E-04	0.000E+00	0.000E+00	0.000E+00	-9.738E-07	3.400E+03	7.444E+04
6	2.700E+01	1.146E-02	-1.188E-02	-5.203E-04	0.000E+00	0.000E+00	0.000E+00	-1.032E-06	3.377E+03	9.274E+04
7	3.240E+01	1.063E-02	-1.457E-02	-4.751E-04	0.000E+00	0.000E+00	0.000E+00	-8.390E-07	3.354E+03	1.109E+05
8	3.780E+01	9.598E-03	-1.693E-02	-3.952E-04	0.000E+00	0.000E+00	0.000E+00	-1.585E-07	3.330E+03	1.290E+05
9	4.320E+01	8.352E-03	-1.876E-02	-2.807E-04	0.000E+00	0.000E+00	0.000E+00	4.870E-07	3.307E+03	1.469E+05
10	4.860E+01	6.897E-03	-1.987E-02	-1.319E-04	0.000E+00	0.000E+00	0.000E+00	1.465E-07	3.284E+03	1.647E+05
11	5.400E+01	5.234E-03	-2.010E-02	5.086E-05	0.000E+00	0.000E+00	0.000E+00	-7.353E-07	-1.739E+03	1.823E+05
12	5.940E+01	3.586E-03	-1.933E-02	2.315E-04	0.000E+00	0.000E+00	0.000E+00	-1.615E-06	-6.762E+03	1.459E+05
13	6.480E+01	2.181E-03	-1.769E-02	3.728E-04	0.000E+00	0.000E+00	0.000E+00	-1.719E-06	-6.786E+03	1.093E+05
14	7.020E+01	1.024E-03	-1.540E-02	4.737E-04	0.000E+00	0.000E+00	0.000E+00	-1.021E-06	-6.809E+03	7.262E+04
15	7.560E+01	1.185E-04	-1.267E-02	5.330E-04	0.000E+00	0.000E+00	0.000E+00	4.183E-08	-6.832E+03	3.579E+04
16	8.100E+01	-5.318E-04	-9.739E-03	5.502E-04	0.000E+00	0.000E+00	0.000E+00	-3.416E-07	-6.855E+03	-1.159E+03
17	8.640E+01	-9.266E-04	-6.829E-03	5.248E-04	0.000E+00	0.000E+00	0.000E+00	-1.186E-06	-6.878E+03	-3.824E+04
18	9.180E+01	-1.067E-03	-4.172E-03	4.568E-04	0.000E+00	0.000E+00	0.000E+00	-9.347E-07	-6.902E+03	-7.544E+04
19	9.720E+01	-9.559E-04	-1.996E-03	3.462E-04	0.000E+00	0.000E+00	0.000E+00	-6.512E-07	-6.925E+03	-1.128E+05
20	1.026E+02	-5.981E-04	-5.306E-04	1.937E-04	0.000E+00	0.000E+00	0.000E+00	-1.694E-07	-6.948E+03	-1.502E+05
21	1.080E+02	-1.729E-43	-6.971E-27	1.878E-25	1.729E-13	6.971E+03	-1.878E+05	1.729E-13	-6.971E+03	-1.878E+05

```
PROGRAM PBEAM
ANALYSIS OF TIME DEPENDENT RESPONDS OF PRESTRESSED CONTINUOUS BEAMS
BY C. SUTTIKAN, 1977

U.S. NAVAL CIVIL ENGINEERING LABORATORY
GROUTED POST-TENSIONED BEAM, 40 FT. SIMPLE SPAN.
```

U.S. NAVAL CIVIL ENGINEERING LABORATORY
GROUTED POST-TENSIONED BEAM, 40 FT. SIMPLE SPAN.

PROB
40 BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)
ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TABLE 1 - PROGRAM CONTROL DATA
PROBLEM TYPE 13

INPUT TABLES

TABLE NUMBER	HOLD DATA FROM LAST PROBLEM (1 = YES,0 = NO)	NUMBER OF CARDS ADDED FOR THIS PROBLEM
2	-0	8
3A	-0	15
3B	-0	6
4	-0	36
5A	-0	18
5B	-0	3
5C	-0	-0

OUTPUT TABLES

TABLE NUMBER	SUPPRESS OUTPUT (1 = YES,0 = NO)
6	-0
7	-0
8	-0
9	-0

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

PROB (CONTD)

4D   BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

TABLE 2 - TIME INCREMENT AND ITERATION CONTROL DATA

```
NUMBER OF CALCULATING TIME STEPS  =   14
NUMBER OF OUTPUT PRINTED          =   29

TIME LOADING STARTS               =   0.000E+00
FINAL TIME STEP                   =   4.688E+03
```

CALCULATING TIME STEPS

0.000E+00	1.000E+01	1.500E+01	2.500E+01	3.000E+01	4.000E+01	6.000E+01	1.000E+02
2.000E+02	4.000E+02	8.000E+02	1.200E+03	2.000E+03	4.674E+03		

TIMES OUTPUT WILL BE PRINTED OUT, DAYS

0.000E+00	1.000E+01	1.500E+01	2.100E+01	2.200E+01	2.500E+01	3.000E+01	4.000E+01
6.000E+01	1.000E+02	2.000E+02	4.000E+02	8.000E+02	1.200E+03	2.000E+03	4.674E+03
4.675E+03	4.676E+03	4.677E+03	4.678E+03	4.679E+03	4.680E+03	4.681E+03	4.682E+03
4.683E+03	4.684E+03	4.685E+03	4.686E+03	4.687E+03			

```
NO. OF CYCLES CRACKS ARE FROZEN       =    5
MAXIMUM NO. OF ITERATIONS/CYCLE       =   20
ITERATION PRINTOUT INDICATOR          =   -0
CLOSURE TOLERANCE FOR FORCE ERRORS    =   1.000E+00
CLOSURE TOLERANCE FOR MOMENT ERRORS   =   1.000E+00
MAXIMUM FORCE ERRORS                  =   1.000E+10
MAXIMUM MOMENT ERRORS                 =   1.000E+10
```

PROB (CONTD)

4D   BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

TABLE 3A - MATERIAL PROPERTIES

```
NO. OF MATERIALS                      =     3


MATERIAL NO.  1
RELAXATION INDICATOR                  =   -0
STRESS-STRAIN CURVE NO.               =    1
AGE EQUATION NO.                      =   11
CREEP EQUATION NO.                    =    1
SHRINKAGE EQUATION NO.                =    1
UNIT WEIGHT                           =  -0.000E+00

STRESS MULTIPLIER                     =   1.000E+00
STRAIN MULTIPLIER                     =   1.000E-06
MAXIMUM STRAIN ALLOWED                =   1.655E-04
MINIMUM STRAIN ALLOWED                =  -1.000E-02

STRESS RATIO-TIME CURVE

   1.000E+00   1.083E+00   1.173E+00   1.417E+00   1.473E+00   1.604E+00   1.667E+00   1.713E+00
   3.000E+00   8.000E+00   2.200E+01   1.830E+02   3.650E+02   1.825E+03   3.650E+03   4.670E+03

STRAIN RATIO-TIME CURVE

   1.000E+00   9.932E-01   1.063E+00   1.111E+00   1.118E+00   1.123E+00   1.146E+00   1.172E+00
   3.000E+00   8.000E+00   2.200E+01   1.830E+02   3.650E+02   1.825E+03   3.650E+03   4.670E+03

CREEP DATA

ULTIMATE CREEP COEFFICIENT            =   1.860E+00
CREEP RECOVERY RATIO                  =   1.000E+00
COEFFICIENTS ARE

   6.000E-01   1.000E+01   1.250E+00  -1.180E-01  -0.000E+00  -0.000E+00  -0.000E+00  -0.000E+00

SHRINKAGE DATA

COEFFICIENTS ARE

  -5.600E-04   3.500E+01  -0.000E+00  -0.000E+00  -0.000E+00  -0.000E+00  -0.000E+00  -0.000E+00


MATERIAL NO.  2
RELAXATION INDICATOR                  =    1
STRESS-STRAIN CURVE NO.               =    2
AGE EQUATION NO.                      =   -0
RELAXATION EQUATION NO.               =    1
```

```
SHRINKAGE EQUATION NO.              =   -0
UNIT WEIGHT                         =  -0.000E+00

STRESS MULTIPLIER                   =   1.000E+03
STRAIN MULTIPLIER                   =   1.000E-05
MAXIMUM STRAIN ALLOWED              =   7.700E-02
MINIMUM STRAIN ALLOWED              =  -7.700E-02


RELAXATION DATA

COEFFICIENTS ARE

   1.240E+05   1.000E+01   5.500E-01   6.000E-01  -0.000E+00  -0.000E+00  -0.000E+00  -0.000E+00


MATERIAL NO.  3
RELAXATION INDICATOR                =   -0
STRESS-STRAIN CURVE NO.             =    3
AGE EQUATION NO.                    =   -0
CREEP EQUATION NO.                  =   -0
SHRINKAGE EQUATION NO.              =   -0
UNIT WEIGHT                         =  -0.000E+00

STRESS MULTIPLIER                   =   1.000E+03
STRAIN MULTIPLIER                   =   1.000E-05
MAXIMUM STRAIN ALLOWED              =   7.700E-02
MINIMUM STRAIN ALLOWED              =  -7.700E-02


TABLE 3B - STRESS-STRAIN CURVES


CURVE NUMB SYMT(1 = YES)
NUMB  PTS  OPT

   1   12    0
SIG                   -960 -960-4800-4781-4712-4543-4283-3839-3348-2279-1155 1155
EPS                  -2551-2549-1877-1820-1745-1632-1501-1313-1126 -750 -375  375

   2    7    1
SIG                      0  100  120  128  130  140  146   -0   -0   -0   -0   -0
EPS                      0  400  500  722 1000 3000 7700   -0   -0   -0   -0   -0

   3    3    1
SIG                      0   49   49   -0   -0   -0   -0   -0   -0   -0   -0   -0
EPS                      0  184 7700   -0   -0   -0   -0   -0   -0   -0   -0   -0
```

PROB (CONTD)

4D   BEAM X, L.L. = 1.5 DESIGN LL., EXPERIMENTAL FC, 7.5 SQRT(FC)

TABLE 4 - CROSS-SECTION PROPERTIES

NO. OF DISCRETE ELEMENTS	=	20
MEMBER LENGTH	=	2.400E+02

NO. OF SUB-RECTANGLES	=	12

SUB-RECTANGLE NO. 1

POST-TENSION INDICATOR (IF=1,YES)	=	-0
MATERIAL NO.	=	1
NO. OF VERTICAL DIVISIONS	=	3
NO. OF POINTS SPECIFIED	=	1
SYMMETRIC INDICATOR (IF=1,YES)	=	-0
CASTING TIME	=	0.000E+00
TIME ADDED TO STRUCTURE	=	0.000E+00
TIME WHEN CAN CARRY LOAD	=	7.000E+00

HOR.DISTANCE	WIDTH	DEPTH	CG.	INT.STRAIN
-0.000E+00	1.200E+01	3.000E+00	1.050E+01	-0.000E+00

SUB-RECTANGLE NO. 2

POST-TENSION INDICATOR (IF=1,YES)	=	-0
MATERIAL NO.	=	1
NO. OF VERTICAL DIVISIONS	=	1
NO. OF POINTS SPECIFIED	=	1
SYMMETRIC INDICATOR (IF=1,YES)	=	-0
CASTING TIME	=	0.000E+00
TIME ADDED TO STRUCTURE	=	0.000E+00
TIME WHEN CAN CARRY LOAD	=	7.000E+00

HOR.DISTANCE	WIDTH	DEPTH	CG.	INT.STRAIN
-0.000E+00	6.000E+00	1.000E+00	8.556E+00	-0.000E+00

SUB-RECTANGLE NO. 3

POST-TENSION INDICATOR (IF=1,YES)	=	-0
MATERIAL NO.	=	1
NO. OF VERTICAL DIVISIONS	=	1
NO. OF POINTS SPECIFIED	=	1
SYMMETRIC INDICATOR (IF=1,YES)	=	-0
CASTING TIME	=	0.000E+00
TIME ADDED TO STRUCTURE	=	0.000E+00
TIME WHEN CAN CARRY LOAD	=	7.000E+00

HOR.DISTANCE	WIDTH	DEPTH	CG.	INT.STRAIN

```
 -0.000E+00   2.000E+00   1.000E+00   7.667E+00  -0.000E+00

SUB-RECTANGLE NO.     4
POST-TENSION INDICATOR (IF=1,YES)      =    -0
MATERIAL NO.                           =     1
NO. OF VERTICAL DIVISIONS              =     8
NO. OF POINTS SPECIFIED                =     1
SYMMETRIC INDICATOR (IF=1,YES)         =    -0
CASTING TIME                           =    0.000E+00
TIME ADDED TO STRUCTURE                =    0.000E+00
TIME WHEN CAN CARRY LOAD               =    7.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN

 -0.000E+00   4.000E+00   1.700E+01   5.000E-01  -0.000E+00

SUB-RECTANGLE NO.     5
POST-TENSION INDICATOR (IF=1,YES)      =    -0
MATERIAL NO.                           =     1
NO. OF VERTICAL DIVISIONS              =     1
NO. OF POINTS SPECIFIED                =     1
SYMMETRIC INDICATOR (IF=1,YES)         =    -0
CASTING TIME                           =    0.000E+00
TIME ADDED TO STRUCTURE                =    0.000E+00
TIME WHEN CAN CARRY LOAD               =    7.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN

 -0.000E+00   2.500E+00   1.250E+00  -6.333E+00  -0.000E+00

SUB-RECTANGLE NO.     6
POST-TENSION INDICATOR (IF=1,YES)      =    -0
MATERIAL NO.                           =     1
NO. OF VERTICAL DIVISIONS              =     1
NO. OF POINTS SPECIFIED                =     1
SYMMETRIC INDICATOR (IF=1,YES)         =    -0
CASTING TIME                           =    0.000E+00
TIME ADDED TO STRUCTURE                =    0.000E+00
TIME WHEN CAN CARRY LOAD               =    7.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN

 -0.000E+00   7.500E+00   1.250E+00  -7.444E+00  -0.000E+00

SUB-RECTANGLE NO.     7
POST-TENSION INDICATOR (IF=1,YES)      =    -0
MATERIAL NO.                           =     1
NO. OF VERTICAL DIVISIONS              =     4
NO. OF POINTS SPECIFIED                =     1
SYMMETRIC INDICATOR (IF=1,YES)         =    -0
CASTING TIME                           =    0.000E+00
TIME ADDED TO STRUCTURE                =    0.000E+00
TIME WHEN CAN CARRY LOAD               =    7.000E+00

HOR.DISTANCE     WIDTH        DEPTH          CG.       INT.STRAIN

 -0.000E+00   1.400E+01   4.000E+00  -1.000E+01  -0.000E+00
```

```
SUB-RECTANGLE NO.    8
POST-TENSION INDICATOR (IF=1,YES)    =   -0
MATERIAL NO.                         =    3
NO. OF VERTICAL DIVISIONS            =    1
NO. OF POINTS SPECIFIED              =    1
SYMMETRIC INDICATOR (IF=1,YES)       =   -0
CASTING TIME                         =   -0.000E+00
TIME ADDED TO STRUCTURE              =   -0.000E+00
TIME WHEN CAN CARRY LOAD             =   -0.000E+00

HOR.DISTANCE    WIDTH       DEPTH        CG.       INT.STRAIN

 -0.000E+00   3.300E-01   1.000E+00   1.050E+01  -0.000E+00


SUB-RECTANGLE NO.    9
POST-TENSION INDICATOR (IF=1,YES)    =   -0
MATERIAL NO.                         =    3
NO. OF VERTICAL DIVISIONS            =    1
NO. OF POINTS SPECIFIED              =    1
SYMMETRIC INDICATOR (IF=1,YES)       =   -0
CASTING TIME                         =   -0.000E+00
TIME ADDED TO STRUCTURE              =   -0.000E+00
TIME WHEN CAN CARRY LOAD             =   -0.000E+00

HOR.DISTANCE    WIDTH       DEPTH        CG.       INT.STRAIN

 -0.000E+00   2.200E-01   1.000E+00  -7.250E+00  -0.000E+00


SUB-RECTANGLE NO.   10
POST-TENSION INDICATOR (IF=1,YES)    =   -0
MATERIAL NO.                         =    3
NO. OF VERTICAL DIVISIONS            =    1
NO. OF POINTS SPECIFIED              =    1
SYMMETRIC INDICATOR (IF=1,YES)       =   -0
CASTING TIME                         =   -0.000E+00
TIME ADDED TO STRUCTURE              =   -0.000E+00
TIME WHEN CAN CARRY LOAD             =   -0.000E+00

HOR.DISTANCE    WIDTH       DEPTH        CG.       INT.STRAIN

 -0.000E+00   3.300E-01   1.000E+00  -1.050E+01  -0.000E+00


SUB-RECTANGLE NO.   11
POST-TENSION INDICATOR (IF=1,YES)    =    1
MATERIAL NO.                         =    2
NO. OF VERTICAL DIVISIONS            =    1
NO. OF POINTS SPECIFIED              =   -0
SYMMETRIC INDICATOR (IF=1,YES)       =   -0
CASTING TIME                         =   8.000E+00
TIME ADDED TO STRUCTURE              =   8.000E+00
TIME WHEN CAN CARRY LOAD             =   8.000E+00

POST-TENSIONED SUB-RECTANGLE

NO. OF WIDTH SEGMENTS                =    1
NO. OF DEPTH SEGMENTS                =    1
NO. OF CG. SEGMENTS                  =    2
NO. OF POST-TENSION JACKINGS         =    1
```

WOBBLE FRICTION COEFFICIENT = 2.917E-05
CURVATURE FRICTION COEFFICIENT = 1.900E-01
DATUM INITIAL FORCE = -0.000E+00

WIDTH

INDICATOR	X1	X2	X3	X4	E1	E2	E3
-0	0.000E+00	2.400E+02	-0.000E+00	-0.000E+00	9.950E-01	9.950E-01	-0.000E+00

DEPTH

INDICATOR	X1	X2	X3	X4	E1	E2	E3
-0	0.000E+00	2.400E+02	-0.000E+00	-0.000E+00	1.000E+00	1.000E+00	-0.000E+00

CENTROIDAL DISTANCE

INDICATOR	X1	X2	X3	X4	E1	E2	E3
1	0.000E+00	6.600E+01	1.140E+02	-0.000E+00	4.439E+00	-5.250E+00	-7.250E+00
-0	1.140E+02	2.400E+02	-0.000E+00	-0.000E+00	-7.250E+00	-7.250E+00	-0.000E+00

POST-TENSIONING

END	JACKING FORCE
-0	9.805E+00

SUB-RECTANGLE NO. 12
POST-TENSION INDICATOR (IF=1,YES) = 1
MATERIAL NO. = 2
NO. OF VERTICAL DIVISIONS = 1
NO. OF POINTS SPECIFIED = -0
SYMMETRIC INDICATOR (IF=1,YES) = -0
CASTING TIME = 0.000E+00
TIME ADDED TO STRUCTURE = 0.000E+00
TIME WHEN CAN CARRY LOAD = 0.000E+00

POST-TENSIONED SUB-RECTANGLE

NO. OF WIDTH SEGMENTS = 1
NO. OF DEPTH SEGMENTS = 1
NO. OF CG. SEGMENTS = 2
NO. OF POST-TENSION JACKINGS = 1
WOBBLE FRICTION COEFFICIENT = 2.917E-05
CURVATURE FRICTION COEFFICIENT = 1.900E-01
DATUM INITIAL FORCE = -0.000E+00

WIDTH

INDICATOR	X1	X2	X3	X4	E1	E2	E3

-0	0.000E+00	2.400E+02	-0.000E+00	-0.000E+00	9.950E-01	9.950E-01	-0.000E+00

DEPTH

INDICATOR	X1	X2	X3	X4	F1	F2	E3
-0	0.000E+00	2.400E+02	-0.000E+00	-0.000E+00	1.000E+00	1.000E+00	-0.000E+00

CENTROIDAL DISTANCE

INDICATOR	X1	X2	X3	X4	E1	E2	E3
1	0.000E+00	6.600E+01	1.140E+02	-0.000E+00	-4.518E+00	-8.750E+00	-9.750E+00
-0	1.140E+02	2.400E+02	-0.000E+00	-0.000E+00	-9.750E+00	-9.750E+00	-0.000E+00

POST-TENSIONING

END	JACKING FORCE
-0	9.830E+04

PROB (CONTD)

40 BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

TABLE 5A - APPLIED LOADS

NUMBER OF SETS OF DIST. LOADS = 1
NUMBER OF CONC. LOADS = 15
DISTRIBUTED LOAD

SET NO. 1
NO. OF POINTS = 1
TIME LOAD APPLIED = 0.000E+00

DISTANCE	FX	FY	FZ
-0.000E+00	-0.000E+00	-1.879E+01	-0.000E+00

CONCENTRATED LOADS

NO.	TIME	DISTANCE	FX	FY	FZ
1	2.200E+01	1.200E+02	-0.000E+00	-2.280E+04	-0.000E+00
2	4.675E+03	1.200E+02	-0.000E+00	1.140E+04	-0.000E+00
3	4.676E+03	1.200E+02	-0.000E+00	1.140E+04	-0.000E+00
4	4.677E+03	1.200E+02	-0.000E+00	-1.500E+04	-0.000E+00
5	4.678E+03	1.200E+02	-0.000E+00	-5.000E+03	-0.000E+00
6	4.679E+03	1.200E+02	-0.000E+00	-5.000E+03	-0.000E+00
7	4.680E+03	1.200E+02	-0.000E+00	-5.000E+03	-0.000E+00
8	4.681E+03	1.200E+02	-0.000E+00	-5.000E+03	-0.000E+00
9	4.682E+03	1.200E+02	-0.000E+00	-3.000E+03	-0.000E+00
10	4.683E+03	1.200E+02	-0.000E+00	-1.000E+03	-0.000E+00
11	4.684E+03	1.200E+02	-0.000E+00	-1.000E+03	-0.000E+00
12	4.685E+03	1.200E+02	-0.000E+00	-1.000E+03	-0.000E+00
13	4.686E+03	1.200E+02	-0.000E+00	-1.000E+03	-0.000E+00
14	4.687E+03	1.200E+02	-0.000E+00	-1.000E+03	-0.000E+00
15	4.688E+03	1.200E+02	-0.000E+00	-1.000E+03	-0.000E+00

TABLE 5B - SPRING RESTRAINTS

NO. OF SETS OF DIST. RESTRAINTS = -0
NO. OF CONC. RESTRAINTS = 2

CONCENTRATED SPRING DATA

DISTANCE	Q-W CURVE NO. (IF < 1 LINEAR)	Q - MULTIPLIER (IF LINEAR SPRING, S)	W - MULTIPLIER

	X	Y	Z	X	Y	Z	X	Y	Z
0.000E+00	-0	-0	-0	-0.000E+00	-1.000E+30	-0.000E+00	-0.000E+00	-0.000E+00	-0.000E+00
2.400E+02	-0	-0	-0	-1.000E+30	-0.000E+00	-1.000E+30	-0.000E+00	-0.000E+00	-0.000E+00

TABLE 5C - NONLINEAR SUPPORT CURVES

NO DATA IN THIS TABLE

```
PROB (CONTD)
   40     BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL FC, 7.5 SQRT(FC)
     ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION )
TIME INCREMENT    3      TIME   =     8.000E+00 (+)
TABLE 6 - ITERATION DATA


     TIME ELAPESD =  14.105 SECONDS AT THE START OF THIS TIME INCREMENT
CYCLE NO.    1

MEMBER CONVERGED AFTER ITERATION    4


MEMBER CONVERGED AFTER CYCLE    1


     TIME CONSUMED =   1.790 SECONDS BY THIS TIME INCREMENT
```

PROB (CONTD)

40 BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 3 TIME = 8.000E+00 (+)

TABLE 7 - MEMBER RESULTS

STA.	DISTANCE	DISPLACEMENTS AXIAL	DISPLACEMENTS LATERAL	DISPLACEMENTS ROTATIONAL	REACTIONS AXIAL	REACTIONS LATERAL	REACTIONS ROTATIONAL	FORCES AXIAL	FORCES SHEAR	FORCES MOMENT
1	0.000E+00	7.341E-02	-4.510E-27	4.555E-03	0.000E+00	4.510E+03	0.000E+00	0.000E+00	4.510E+03	0.000E+00
2	1.200E+01	6.936E-02	5.470E-02	4.566E-03	0.000E+00	0.000E+00	0.000E+00	3.522E-04	4.284E+03	5.274E+04
3	2.400E+01	6.539E-02	1.091E-01	4.505E-03	0.000E+00	0.000E+00	0.000E+00	3.522E-04	4.059E+03	1.028E+05
4	3.600E+01	6.150E-02	1.624E-01	4.382E-03	0.000E+00	0.000E+00	0.000E+00	3.295E-04	3.833E+03	1.501E+05
5	4.800E+01	5.767E-02	2.139E-01	4.207E-03	0.000E+00	0.000E+00	0.000E+00	2.945E-04	3.608E+03	1.948E+05
6	6.000E+01	5.391E-02	2.630E-01	3.988E-03	0.000E+00	0.000E+00	0.000E+00	2.722E-04	3.382E+03	2.367E+05
7	7.200E+01	5.020E-02	3.094E-01	3.737E-03	0.000E+00	0.000E+00	0.000E+00	2.492E-04	3.157E+03	2.759E+05
8	8.400E+01	4.653E-02	3.525E-01	3.462E-03	0.000E+00	0.000E+00	0.000E+00	2.229E-04	2.931E+03	3.124E+05
9	9.600E+01	4.290E-02	3.923E-01	3.173E-03	0.000E+00	0.000E+00	0.000E+00	1.970E-04	2.706E+03	3.462E+05
10	1.080E+02	3.929E-02	4.286E-01	2.879E-03	0.000E+00	0.000E+00	0.000E+00	1.708E-04	2.480E+03	3.773E+05
11	1.200E+02	3.571E-02	4.614E-01	2.590E-03	0.000E+00	0.000E+00	0.000E+00	1.425E-04	2.255E+03	4.057E+05
12	1.320E+02	3.213E-02	4.908E-01	2.309E-03	0.000E+00	0.000E+00	0.000E+00	1.175E-04	2.029E+03	4.314E+05
13	1.440E+02	2.855E-02	5.169E-01	2.035E-03	0.000E+00	0.000E+00	0.000E+00	9.549E-05	1.804E+03	4.544E+05
14	1.560E+02	2.498E-02	5.397E-01	1.767E-03	0.000E+00	0.000E+00	0.000E+00	7.634E-05	1.578E+03	4.747E+05
15	1.680E+02	2.140E-02	5.593E-01	1.504E-03	0.000E+00	0.000E+00	0.000E+00	5.938E-05	1.353E+03	4.923E+05
16	1.800E+02	1.783E-02	5.758E-01	1.246E-03	0.000E+00	0.000E+00	0.000E+00	4.334E-05	1.127E+03	5.072E+05
17	1.920E+02	1.426E-02	5.892E-01	9.923E-04	0.000E+00	0.000E+00	0.000E+00	2.902E-05	9.019E+02	5.193E+05
18	2.040E+02	1.070E-02	5.996E-01	7.414E-04	0.000E+00	0.000E+00	0.000E+00	1.681E-05	6.764E+02	5.288E+05
19	2.160E+02	7.129E-03	6.070E-01	4.929E-04	0.000E+00	0.000E+00	0.000E+00	7.825E-06	4.510E+02	5.356E+05
20	2.280E+02	3.564E-03	6.114E-01	2.460E-04	0.000E+00	0.000E+00	0.000E+00	1.328E-06	2.255E+02	5.396E+05
21	2.400E+02	-2.682E-41	6.129E-01	-5.410E-25	2.682E-11	0.000E+00	5.410E+05	2.682E-11	0.000E+00	5.410E+05

PROB (CONTD)

4D BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 3 TIME = 8.000E+00 (+)

TABLE 8 - FIBER STRAINS

ELEMENT	SUB-RECT.	DIVISION	SHR. STRAINS	CREEP OR RELAX. STRAINS LEFT	CREEP OR RELAX. STRAINS RIGHT	INSTANTANEOUS STRAINS LEFT	INSTANTANEOUS STRAINS RIGHT	STRAIN INDICATORS LEFT	STRAIN INDICATORS RIGHT
1	1	1	-1.555E-05	0.000E+00	0.000E+00	-3.186E-04	-3.255E-04	111	111
1	1	2	-1.555E-05	0.000E+00	0.000E+00	-3.180E-04	-3.243E-04	111	111
1	1	3	-1.555E-05	0.000E+00	0.000E+00	-3.174E-04	-3.231E-04	111	111
1	2	1	-1.555E-05	0.000E+00	0.000E+00	-3.168E-04	-3.219E-04	111	111
1	3	1	-1.555E-05	0.000E+00	0.000E+00	-3.163E-04	-3.209E-04	111	111
1	4	1	-1.555E-[illegible]	0.000E+00	0.000E+00	-3.165E-04	-3.212E-04	111	111
1	4	2	-1.555E-05	0.000E+00	0.000E+00	-3.152E-04	-3.186E-04	111	111
1	4	3	-1.555E-05	0.000E+00	0.000E+00	-3.139E-04	-3.161E-04	111	111
1	4	4	-1.555E-05	0.000E+00	0.000E+00	-3.126E-04	-3.135E-04	111	111
1	4	5	-1.555E-05	0.000E+00	0.000E+00	-3.113E-04	-3.110E-04	111	111
1	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.100E-04	-3.084E-04	111	111
1	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.088E-04	-3.059E-04	111	111
1	4	8	-1.555E-05	0.000E+00	0.000E+00	-3.075E-04	-3.033E-04	111	111
1	5	1	-1.555E-05	0.000E+00	0.000E+00	-3.078E-04	-3.041E-04	111	111
1	6	1	-1.555E-05	0.000E+00	0.000E+00	-3.072E-04	-3.027E-04	111	111
1	7	1	-1.555E-05	0.000E+00	0.000E+00	-3.065E-04	-3.015E-04	111	111
1	7	2	-1.555E-05	0.000E+00	0.000E+00	-3.059E-04	-3.003E-04	111	111
1	7	3	-1.555E-05	0.000E+00	0.000E+00	-3.053E-04	-2.991E-04	111	111
1	7	4	-1.555E-05	0.000E+00	0.000E+00	-3.047E-04	-2.979E-04	111	111
1	8	1	0.000E+00	0.000E+00	0.000E+00	-3.336E-04	-3.398E-04	111	111
1	9	1	0.000E+00	0.000E+00	0.000E+00	-3.228E-04	-3.185E-04	111	111
1	10	1	0.000E+00	0.000E+00	0.000E+00	-3.209E-04	-3.146E-04	111	111
1	11	1	0.000E+00	0.000E+00	0.000E+00	4.011E-03	4.011E-03	111	111
1	12	1	0.000E+00	0.000E+00	0.000E+00	4.027E-03	4.027E-03	111	111
2	1	1	-1.555E-05	0.000E+00	0.000E+00	-2.432E-04	-2.497E-04	111	111
2	1	2	-1.555E-05	0.000E+00	0.000E+00	-2.485E-04	-2.545E-04	111	111
2	1	3	-1.555E-05	0.000E+00	0.000E+00	-2.539E-04	-2.593E-04	111	111
2	2	1	-1.555E-05	0.000E+00	0.000E+00	-2.589E-04	-2.638E-04	111	111
2	3	1	-1.555E-05	0.000E+00	0.000E+00	-2.637E-04	-2.680E-04	111	111
2	4	1	-1.555E-05	0.000E+00	0.000E+00	-2.623E-04	-2.667E-04	111	111
2	4	2	-1.555E-05	0.000E+00	0.000E+00	-2.736E-04	-2.769E-04	111	111
2	4	3	-1.555E-05	0.000E+00	0.000E+00	-2.850E-04	-2.871E-04	111	111
2	4	4	-1.555E-05	0.000E+00	0.000E+00	-2.964E-04	-2.973E-04	111	111
2	4	5	-1.555E-05	0.000E+00	0.000E+00	-3.078E-04	-3.075E-04	111	111
2	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.192E-04	-3.177E-04	111	111
2	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.306E-04	-3.278E-04	111	111
2	4	8	-1.555E-05	0.000E+00	0.000E+00	-3.419E-04	-3.380E-04	111	111
2	5	1	-1.555E-05	0.000E+00	0.000E+00	-3.387E-04	-3.351E-04	111	111
2	6	1	-1.555E-05	0.000E+00	0.000E+00	-3.447E-04	-3.404E-04	111	111
2	7	1	-1.555E-05	0.000E+00	0.000E+00	-3.503E-04	-3.455E-04	111	111
2	7	2	-1.555E-05	0.000E+00	0.000E+00	-3.557E-04	-3.503E-04	111	111
2	7	3	-1.555E-05	0.000E+00	0.000E+00	-3.610E-04	-3.551E-04	111	111
2	7	4	-1.555E-05	0.000E+00	0.000E+00	-3.664E-04	-3.599E-04	111	111
2	8	1	0.000E+00	0.000E+00	0.000E+00	-2.641E-04	-2.700E-04	111	111
2	9	1	0.000E+00	0.000E+00	0.000E+00	-3.592E-04	-3.551E-04	111	111
2	10	1	0.000E+00	0.000E+00	0.000E+00	-3.766E-04	-3.706E-04	111	111

2	11	1	0.000E+00	0.000E+00	0.000E+00	3.993E-03	3.993E-03	111	111
2	12	1	0.000E+00	0.000E+00	0.000E+00	4.018E-03	4.018E-03	111	111
3	1	1	-1.555E-05	0.000E+00	0.000E+00	-1.779E-04	-1.841E-04	111	111
3	1	2	-1.555E-05	0.000E+00	0.000E+00	-1.884E-04	-1.941E-04	111	111
3	1	3	-1.555E-05	0.000E+00	0.000E+00	-1.989E-04	-2.041E-04	111	111
3	2	1	-1.555E-05	0.000E+00	0.000E+00	-2.088E-04	-2.135E-04	111	111
3	3	1	-1.555E-05	0.000E+00	0.000E+00	-2.182E-04	-2.224E-04	111	111
3	4	1	-1.555E-05	0.000E+00	0.000E+00	-2.154E-04	-2.197E-04	111	111
3	4	2	-1.555E-05	0.000E+00	0.000E+00	-2.377E-04	-2.409E-04	111	111
3	4	3	-1.555E-05	0.000E+00	0.000E+00	-2.601E-04	-2.621E-04	111	111
3	4	4	-1.555E-05	0.000E+00	0.000E+00	-2.825E-04	-2.833E-04	111	111
3	4	5	-1.555E-05	0.000E+00	0.000E+00	-3.048E-04	-3.045E-04	111	111
3	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.272E-04	-3.257E-04	111	111
3	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.496E-04	-3.470E-04	111	111
3	4	8	-1.555E-05	0.000E+00	0.000E+00	-3.719E-04	-3.682E-04	111	111
3	5	1	-1.555E-05	0.000E+00	0.000E+00	-3.656E-04	-3.621E-04	111	111
3	6	1	-1.555E-05	0.000E+00	0.000E+00	-3.773E-04	-3.732E-04	111	111
3	7	1	-1.555E-05	0.000E+00	0.000E+00	-3.884E-04	-3.838E-04	111	111
3	7	2	-1.555E-05	0.000E+00	0.000E+00	-3.989E-04	-3.938E-04	111	111
3	7	3	-1.555E-05	0.000E+00	0.000E+00	-4.094E-04	-4.038E-04	111	111
3	7	4	-1.555E-05	0.000E+00	0.000E+00	-4.200E-04	-4.137E-04	111	111
3	8	1	0.000E+00	0.000E+00	0.000E+00	-2.039E-04	-2.096E-04	111	111
3	9	1	0.000E+00	0.000E+00	0.000E+00	-3.908E-04	-3.869E-04	111	111
3	10	1	0.000E+00	0.000E+00	0.000E+00	-4.250E-04	-4.193E-04	111	111
3	11	1	0.000E+00	0.000E+00	0.000E+00	3.975E-03	3.975E-03	111	111
3	12	1	0.000E+00	0.000E+00	0.000E+00	4.010E-03	4.010E-03	111	111
4	1	1	-1.555E-05	0.000E+00	0.000E+00	-1.227E-04	-1.286E-04	111	111
4	1	2	-1.555E-05	0.000E+00	0.000E+00	-1.376E-04	-1.430E-04	111	111
4	1	3	-1.555E-05	0.000E+00	0.000E+00	-1.525E-04	-1.574E-04	111	111
4	2	1	-1.555E-05	0.000E+00	0.000E+00	-1.666E-04	-1.710E-04	111	111
4	3	1	-1.555E-05	0.000E+00	0.000E+00	-1.798E-04	-1.837E-04	111	111
4	4	1	-1.555E-05	0.000E+00	0.000E+00	-1.758E-04	-1.799E-04	111	111
4	4	2	-1.555E-05	0.000E+00	0.000E+00	-2.074E-04	-2.104E-04	111	111
4	4	3	-1.555E-05	0.000E+00	0.000E+00	-2.391E-04	-2.410E-04	111	111
4	4	4	-1.555E-05	0.000E+00	0.000E+00	-2.707E-04	-2.715E-04	111	111
4	4	5	-1.555E-05	0.000E+00	0.000E+00	-3.024E-04	-3.021E-04	111	111
4	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.340E-04	-3.326E-04	111	111
4	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.656E-04	-3.632E-04	111	111
4	4	8	-1.555E-05	0.000E+00	0.000E+00	-3.973E-04	-3.937E-04	111	111
4	5	1	-1.555E-05	0.000E+00	0.000E+00	-3.883E-04	-3.854E-04	111	111
4	6	1	-1.555E-05	0.000E+00	0.000E+00	-4.048E-04	-4.010E-04	111	111
4	7	1	-1.555E-05	0.000E+00	0.000E+00	-4.206E-04	-4.162E-04	111	111
4	7	2	-1.555E-05	0.000E+00	0.000E+00	-4.354E-04	-4.306E-04	111	111
4	7	3	-1.555E-05	0.000E+00	0.000E+00	-4.503E-04	-4.450E-04	111	111
4	7	4	-1.555E-05	0.000E+00	0.000E+00	-4.652E-04	-4.593E-04	111	111
4	8	1	0.000E+00	0.000E+00	0.000E+00	-1.532E-04	-1.586E-04	111	111
4	9	1	0.000E+00	0.000E+00	0.000E+00	-4.175E-04	-4.138E-04	111	111
4	10	1	0.000E+00	0.000E+00	0.000E+00	-4.659E-04	-4.605E-04	111	111
4	11	1	0.000E+00	0.000E+00	0.000E+00	3.957E-03	3.957E-03	111	111
4	12	1	0.000E+00	0.000E+00	0.000E+00	4.002E-03	4.002E-03	111	111
5	1	1	-1.555E-05	0.000E+00	0.000E+00	-7.778E-05	-8.331E-05	111	111
5	1	2	-1.555E-05	0.000E+00	0.000E+00	-9.621E-05	-1.013E-04	111	111
5	1	3	-1.555E-05	0.000E+00	0.000E+00	-1.146E-04	-1.192E-04	111	111
5	2	1	-1.555E-05	0.000E+00	0.000E+00	-1.321E-04	-1.362E-04	111	111
5	3	1	-1.555E-05	0.000E+00	0.000E+00	-1.484E-04	-1.521E-04	111	111
5	4	1	-1.555E-05	0.000E+00	0.000E+00	-1.435E-04	-1.473E-04	111	111
5	4	2	-1.555E-05	0.000E+00	0.000E+00	-1.826E-04	-1.854E-04	111	111
5	4	3	-1.555E-05	0.000E+00	0.000E+00	-2.218E-04	-2.236E-04	111	111
5	4	4	-1.555E-05	0.000E+00	0.000E+00	-2.610E-04	-2.617E-04	111	111
5	4	5	-1.555E-05	0.000E+00	0.000E+00	-3.002E-04	-2.999E-04	111	111
5	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.393E-04	-3.381E-04	111	111
5	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.785E-04	-3.762E-04	111	111

5	4	8	-1.555E-05	0.000E+00	0.000E+00	-4.177E-04	-4.144E-04	111	111
5	5	1	-1.555E-05	0.000E+00	0.000E+00	-4.066E-04	-4.035E-04	111	111
5	6	1	-1.555E-05	0.000E+00	0.000E+00	-4.270E-04	-4.235E-04	111	111
5	7	1	-1.555E-05	0.000E+00	0.000E+00	-4.465E-04	-4.424E-04	111	111
5	7	2	-1.555E-05	0.000E+00	0.000E+00	-4.649E-04	-4.604E-04	111	111
5	7	3	-1.555E-05	0.000E+00	0.000E+00	-4.834E-04	-4.783E-04	111	111
5	7	4	-1.555E-05	0.000E+00	0.000E+00	-5.018E-04	-4.963E-04	111	111
5	8	1	0.000E+00	0.000E+00	0.000E+00	-1.118E-04	-1.168E-04	111	111
5	9	1	0.000E+00	0.000E+00	0.000E+00	-4.390E-04	-4.355E-04	111	111
5	10	1	0.000E+00	0.000E+00	0.000E+00	-4.989E-04	-4.939E-04	111	111
5	11	1	0.000E+00	0.000E+00	0.000E+00	3.939E-03	3.939E-03	111	111
5	12	1	0.000E+00	0.000E+00	0.000E+00	3.993E-03	3.993E-03	111	111
6	1	1	-1.555E-05	0.000E+00	0.000E+00	-4.281E-05	-4.799E-05	111	111
6	1	2	-1.555E-05	0.000E+00	0.000E+00	-6.399E-05	-6.871E-05	111	111
6	1	3	-1.555E-05	0.000E+00	0.000E+00	-8.517E-05	-8.944E-05	111	111
6	2	1	-1.555E-05	0.000E+00	0.000E+00	-1.052E-04	-1.090E-04	111	111
6	3	1	-1.555E-05	0.000E+00	0.000E+00	-1.240E-04	-1.274E-04	111	111
6	4	1	-1.555E-05	0.000E+00	0.000E+00	-1.183E-04	-1.218E-04	111	111
6	4	2	-1.555E-05	0.000E+00	0.000E+00	-1.633E-04	-1.659E-04	111	111
6	4	3	-1.555E-05	0.000E+00	0.000E+00	-2.083E-04	-2.099E-04	111	111
6	4	4	-1.555E-05	0.000E+00	0.000E+00	-2.532E-04	-2.540E-04	111	111
6	4	5	-1.555E-05	0.000E+00	0.000E+00	-2.982E-04	-2.980E-04	111	111
6	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.432E-04	-3.420E-04	111	111
6	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.882E-04	-3.861E-04	111	111
6	4	8	-1.555E-05	0.000E+00	0.000E+00	-4.332E-04	-4.301E-04	111	111
6	5	1	-1.555E-05	0.000E+00	0.000E+00	-4.204E-04	-4.176E-04	111	111
6	6	1	-1.555E-05	0.000E+00	0.000E+00	-4.440E-04	-4.406E-04	111	111
6	7	1	-1.555E-05	0.000E+00	0.000E+00	-4.663E-04	-4.625E-04	111	111
6	7	2	-1.555E-05	0.000E+00	0.000E+00	-4.875E-04	-4.832E-04	111	111
6	7	3	-1.555E-05	0.000E+00	0.000E+00	-5.087E-04	-5.040E-04	111	111
6	7	4	-1.555E-05	0.000E+00	0.000E+00	-5.299E-04	-5.247E-04	111	111
6	8	1	0.000E+00	0.000E+00	0.000E+00	-7.954E-05	-8.427E-05	111	111
6	9	1	0.000E+00	0.000E+00	0.000E+00	-4.554E-04	-4.522E-04	111	111
6	10	1	0.000E+00	0.000E+00	0.000E+00	-5.242E-04	-5.195E-04	111	111
6	11	1	0.000E+00	0.000E+00	0.000E+00	3.921E-03	3.921E-03	111	111
6	12	1	0.000E+00	0.000E+00	0.000E+00	3.985E-03	3.985E-03	111	111
7	1	1	-1.555E-05	0.000E+00	0.000E+00	-1.774E-05	-2.256E-05	111	111
7	1	2	-1.555E-05	0.000E+00	0.000E+00	-4.086E-05	-4.526E-05	111	111
7	1	3	-1.555E-05	0.000E+00	0.000E+00	-6.397E-05	-6.795E-05	111	111
7	2	1	-1.555E-05	0.000E+00	0.000E+00	-8.580E-05	-8.938E-05	111	111
7	3	1	-1.555E-05	0.000E+00	0.000E+00	-1.063E-04	-1.096E-04	111	111
7	4	1	-1.555E-05	0.000E+00	0.000E+00	-1.001E-04	-1.034E-04	111	111
7	4	2	-1.555E-05	0.000E+00	0.000E+00	-1.492E-04	-1.517E-04	111	111
7	4	3	-1.555E-05	0.000E+00	0.000E+00	-1.983E-04	-1.999E-04	111	111
7	4	4	-1.555E-05	0.000E+00	0.000E+00	-2.475E-04	-2.481E-04	111	111
7	4	5	-1.555E-05	0.000E+00	0.000E+00	-2.966E-04	-2.964E-04	111	111
7	4	6	-1.555E-05	0.000E+00	0.000E+00	-3.457E-04	-3.446E-04	111	111
7	4	7	-1.555E-05	0.000E+00	0.000E+00	-3.948E-04	-3.928E-04	111	111
7	4	8	-1.555E-05	0.000E+00	0.000E+00	-4.440E-04	-4.411E-04	111	111
7	5	1	-1.555E-05	0.000E+00	0.000E+00	-4.300E-04	-4.273E-04	111	111
7	6	1	-1.555E-05	0.000E+00	0.000E+00	-4.557E-04	-4.525E-04	111	111
7	7	1	-1.555E-05	0.000E+00	0.000E+00	-4.801E-04	-4.765E-04	111	111
7	7	2	-1.555E-05	0.000E+00	0.000E+00	-5.032E-04	-4.992E-04	111	111
7	7	3	-1.555E-05	0.000E+00	0.000E+00	-5.263E-04	-5.219E-04	111	111
7	7	4	-1.555E-05	0.000E+00	0.000E+00	-5.494E-04	-5.446E-04	111	111
7	8	1	0.000E+00	0.000E+00	0.000E+00	-5.641E-05	-6.081E-05	111	111
7	9	1	0.000E+00	0.000E+00	0.000E+00	-4.667E-04	-4.637E-04	111	111
7	10	1	0.000E+00	0.000E+00	0.000E+00	-5.419E-04	-5.375E-04	111	111
7	11	1	0.000E+00	0.000E+00	0.000E+00	3.903E-03	3.903E-03	111	111
7	12	1	0.000E+00	0.000E+00	0.000E+00	3.977E-03	3.977E-03	111	111
8	1	1	-1.555E-05	0.000E+00	0.000E+00	-2.434E-06	-6.894E-06	111	111
8	1	2	-1.555E-05	0.000E+00	0.000E+00	-2.670E-05	-3.078E-05	111	111

8	1	3	-1,555E-05	0,000E+00	0,000E+00	-5,097E-05	-5,466E-05	111	111
8	2	1	-1,555E-05	0,000E+00	0,000E+00	-7,388E-05	-7,720E-05	111	111
8	3	1	-1,555E-05	0,000E+00	0,000E+00	-9,546E-05	-9,843E-05	111	111
8	4	1	-1,555E-05	0,000E+00	0,000E+00	-8,889E-05	-9,197E-05	111	111
8	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,405E-04	-1,427E-04	111	111
8	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,920E-04	-1,935E-04	111	111
8	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,436E-04	-2,442E-04	111	111
8	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,952E-04	-2,950E-04	111	111
8	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,468E-04	-3,457E-04	111	111
8	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,983E-04	-3,965E-04	111	111
8	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,499E-04	-4,472E-04	111	111
8	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,352E-04	-4,328E-04	111	111
8	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,622E-04	-4,593E-04	111	111
8	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,878E-04	-4,845E-04	111	111
8	7	2	-1,555E-05	0,000E+00	0,000E+00	-5,121E-04	-5,084E-04	111	111
8	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,364E-04	-5,323E-04	111	111
8	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,606E-04	-5,562E-04	111	111
8	8	1	0,000E+00	0,000E+00	0,000E+00	-4,226E-05	-4,633E-05	111	111
8	9	1	0,000E+00	0,000E+00	0,000E+00	-4,730E-04	-4,702E-04	111	111
8	10	1	0,000E+00	0,000E+00	0,000E+00	-5,519E-04	-5,478E-04	111	111
8	11	1	0,000E+00	0,000E+00	0,000E+00	3,885E-03	3,885E-03	111	111
8	12	1	0,000E+00	0,000E+00	0,000E+00	3,968E-03	3,968E-03	111	111
9	1	1	-1,555E-05	0,000E+00	0,000E+00	3,225E-06	-8,778E-07	111	111
9	1	2	-1,555E-05	0,000E+00	0,000E+00	-2,142E-05	-2,516E-05	111	111
9	1	3	-1,555E-05	0,000E+00	0,000E+00	-4,606E-05	-4,945E-05	111	111
9	2	1	-1,555E-05	0,000E+00	0,000E+00	-6,932E-05	-7,238E-05	111	111
9	3	1	-1,555E-05	0,000E+00	0,000E+00	-9,123E-05	-9,397E-05	111	111
9	4	1	-1,555E-05	0,000E+00	0,000E+00	-8,457E-05	-8,740E-05	111	111
9	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,369E-04	-1,390E-04	111	111
9	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,893E-04	-1,906E-04	111	111
9	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,417E-04	-2,422E-04	111	111
9	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,940E-04	-2,938E-04	111	111
9	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,464E-04	-3,454E-04	111	111
9	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,988E-04	-3,970E-04	111	111
9	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,511E-04	-4,487E-04	111	111
9	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,362E-04	-4,340E-04	111	111
9	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,636E-04	-4,610E-04	111	111
9	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,896E-04	-4,866E-04	111	111
9	7	2	-1,555E-05	0,000E+00	0,000E+00	-5,143E-04	-5,109E-04	111	111
9	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,389E-04	-5,352E-04	111	111
9	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,636E-04	-5,595E-04	111	111
9	8	1	0,000E+00	0,000E+00	0,000E+00	-3,697E-05	-4,072E-05	111	111
9	9	1	0,000E+00	0,000E+00	0,000E+00	-4,744E-04	-4,718E-04	111	111
9	10	1	0,000E+00	0,000E+00	0,000E+00	-5,545E-04	-5,507E-04	111	111
9	11	1	0,000E+00	0,000E+00	0,000E+00	3,868E-03	3,868E-03	111	111
9	12	1	0,000E+00	0,000E+00	0,000E+00	3,960E-03	3,960E-03	111	111
10	1	1	-1,555E-05	0,000E+00	0,000E+00	-6,450E-07	-4,391E-06	111	111
10	1	2	-1,555E-05	0,000E+00	0,000E+00	-2,489E-05	-2,831E-05	111	111
10	1	3	-1,555E-05	0,000E+00	0,000E+00	-4,914E-05	-5,223E-05	111	111
10	2	1	-1,555E-05	0,000E+00	0,000E+00	-7,203E-05	-7,482E-05	111	111
10	3	1	-1,555E-05	0,000E+00	0,000E+00	-9,359E-05	-9,608E-05	111	111
10	4	1	-1,555E-05	0,000E+00	0,000E+00	-8,703E-05	-8,961E-05	111	111
10	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,386E-04	-1,404E-04	111	111
10	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,901E-04	-1,913E-04	111	111
10	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,416E-04	-2,421E-04	111	111
10	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,931E-04	-2,929E-04	111	111
10	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,447E-04	-3,438E-04	111	111
10	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,962E-04	-3,946E-04	111	111
10	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,477E-04	-4,454E-04	111	111
10	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,330E-04	-4,310E-04	111	111
10	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,600E-04	-4,576E-04	111	111
10	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,856E-04	-4,828E-04	111	111

10	7	2	-1,555E-05	0,000E+00	0,000E+00	-5,098E-04	-5,067E-04	111	111
10	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,341E-04	-5,307E-04	111	111
10	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,583E-04	-5,546E-04	111	111
10	8	1	0,000E+00	0,000E+00	0,000E+00	-4,045E-05	-4,387E-05	111	111
10	9	1	0,000E+00	0,000E+00	0,000E+00	-4,708E-04	-4,685E-04	111	111
10	10	1	0,000E+00	0,000E+00	0,000E+00	-5,496E-04	-5,462E-04	111	111
10	11	1	0,000E+00	0,000E+00	0,000E+00	3,850E-03	3,850E-03	111	111
10	12	1	0,000E+00	0,000E+00	0,000E+00	3,952E-03	3,952E-03	111	111
11	1	1	-1,555E-05	0,000E+00	0,000E+00	-8,687E-06	-1,208E-05	111	111
11	1	2	-1,555E-05	0,000E+00	0,000E+00	-3,226E-05	-3,536E-05	111	111
11	1	3	-1,555E-05	0,000E+00	0,000E+00	-5,584E-05	-5,864E-05	111	111
11	2	1	-1,555E-05	0,000E+00	0,000E+00	-7,809E-05	-8,062E-05	111	111
11	3	1	-1,555E-05	0,000E+00	0,000E+00	-9,905E-05	-1,013E-04	111	111
11	4	1	-1,555E-05	0,000E+00	0,000E+00	-9,268E-05	-9,502E-05	111	111
11	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,428E-04	-1,445E-04	111	111
11	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,929E-04	-1,940E-04	111	111
11	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,430E-04	-2,434E-04	111	111
11	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,931E-04	-2,929E-04	111	111
11	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,432E-04	-3,424E-04	111	111
11	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,933E-04	-3,918E-04	111	111
11	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,434E-04	-4,413E-04	111	111
11	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,291E-04	-4,272E-04	111	111
11	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,553E-04	-4,531E-04	111	111
11	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,802E-04	-4,777E-04	111	111
11	7	2	-1,555E-05	0,000E+00	0,000E+00	-5,038E-04	-5,010E-04	111	111
11	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,274E-04	-5,243E-04	111	111
11	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,509E-04	-5,475E-04	111	111
11	8	1	0,000E+00	0,000E+00	0,000E+00	-4,782E-05	-5,091E-05	111	111
11	9	1	0,000E+00	0,000E+00	0,000E+00	-4,663E-04	-4,641E-04	111	111
11	10	1	0,000E+00	0,000E+00	0,000E+00	-5,429E-04	-5,398E-04	111	111
11	11	1	0,000E+00	0,000E+00	0,000E+00	3,847E-03	3,847E-03	111	111
11	12	1	0,000E+00	0,000E+00	0,000E+00	3,949E-03	3,949E-03	111	111
12	1	1	-1,555E-05	0,000E+00	0,000E+00	-1,590E-05	-1,893E-05	111	111
12	1	2	-1,555E-05	0,000E+00	0,000E+00	-3,888E-05	-4,165E-05	111	111
12	1	3	-1,555E-05	0,000E+00	0,000E+00	-6,186E-05	-6,437E-05	111	111
12	2	1	-1,555E-05	0,000E+00	0,000E+00	-8,356E-05	-8,582E-05	111	111
12	3	1	-1,555E-05	0,000E+00	0,000E+00	-1,040E-04	-1,060E-04	111	111
12	4	1	-1,555E-05	0,000E+00	0,000E+00	-9,778E-05	-9,987E-05	111	111
12	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,466E-04	-1,481E-04	111	111
12	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,955E-04	-1,964E-04	111	111
12	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,443E-04	-2,447E-04	111	111
12	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,931E-04	-2,930E-04	111	111
12	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,420E-04	-3,413E-04	111	111
12	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,908E-04	-3,895E-04	111	111
12	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,397E-04	-4,378E-04	111	111
12	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,258E-04	-4,241E-04	111	111
12	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,513E-04	-4,493E-04	111	111
12	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,756E-04	-4,733E-04	111	111
12	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,986E-04	-4,960E-04	111	111
12	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,215E-04	-5,188E-04	111	111
12	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,445E-04	-5,415E-04	111	111
12	8	1	0,000E+00	0,000E+00	0,000E+00	-5,443E-05	-5,720E-05	111	111
12	9	1	0,000E+00	0,000E+00	0,000E+00	-4,624E-04	-4,605E-04	111	111
12	10	1	0,000E+00	0,000E+00	0,000E+00	-5,371E-04	-5,343E-04	111	111
12	11	1	0,000E+00	0,000E+00	0,000E+00	3,846E-03	3,846E-03	111	111
12	12	1	0,000E+00	0,000E+00	0,000E+00	3,947E-03	3,947E-03	111	111
13	1	1	-1,555E-05	0,000E+00	0,000E+00	-2,233E-05	-2,501E-05	111	111
13	1	2	-1,555E-05	0,000E+00	0,000E+00	-4,478E-05	-4,723E-05	111	111
13	1	3	-1,555E-05	0,000E+00	0,000E+00	-6,724E-05	-6,945E-05	111	111
13	2	1	-1,555E-05	0,000E+00	0,000E+00	-8,844E-05	-9,043E-05	111	111
13	3	1	-1,555E-05	0,000E+00	0,000E+00	-1,084E-04	-1,102E-04	111	111
13	4	1	-1,555E-05	0,000E+00	0,000E+00	-1,023E-04	-1,042E-04	111	111

13	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,500E-04	-1,514E-04	111	111
13	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,978E-04	-1,986E-04	111	111
13	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,455E-04	-2,458E-04	111	111
13	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,932E-04	-2,931E-04	111	111
13	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,409E-04	-3,403E-04	111	111
13	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,886E-04	-3,875E-04	111	111
13	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,363E-04	-4,347E-04	111	111
13	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,228E-04	-4,213E-04	111	111
13	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,477E-04	-4,460E-04	111	111
13	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,714E-04	-4,694E-04	111	111
13	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,939E-04	-4,917E-04	111	111
13	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,163E-04	-5,139E-04	111	111
13	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,388E-04	-5,361E-04	111	111
13	8	1	0,000E+00	0,000E+00	0,000E+00	-6,034E-05	-6,278E-05	111	111
13	9	1	0,000E+00	0,000E+00	0,000E+00	-4,589E-04	-4,572E-04	111	111
13	10	1	0,000E+00	0,000E+00	0,000E+00	-5,319E-04	-5,294E-04	111	111
13	11	1	0,000E+00	0,000E+00	0,000E+00	3,844E-03	3,844E-03	111	111
13	12	1	0,000E+00	0,000E+00	0,000E+00	3,946E-03	3,946E-03	111	111
14	1	1	-1,555E-05	0,000E+00	0,000E+00	-2,799E-05	-3,031E-05	111	111
14	1	2	-1,555E-05	0,000E+00	0,000E+00	-4,997E-05	-5,209E-05	111	111
14	1	3	-1,555E-05	0,000E+00	0,000E+00	-7,196E-05	-7,388E-05	111	111
14	2	1	-1,555E-05	0,000E+00	0,000E+00	-9,272E-05	-9,444E-05	111	111
14	3	1	-1,555E-05	0,000E+00	0,000E+00	-1,123E-04	-1,138E-04	111	111
14	4	1	-1,555E-05	0,000E+00	0,000E+00	-1,063E-04	-1,079E-04	111	111
14	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,530E-04	-1,542E-04	111	111
14	4	3	-1,555E-05	0,000E+00	0,000E+00	-1,998E-04	-2,005E-04	111	111
14	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,465E-04	-2,468E-04	111	111
14	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,932E-04	-2,931E-04	111	111
14	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,399E-04	-3,394E-04	111	111
14	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,867E-04	-3,857E-04	111	111
14	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,334E-04	-4,320E-04	111	111
14	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,201E-04	-4,188E-04	111	111
14	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,445E-04	-4,430E-04	111	111
14	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,677E-04	-4,660E-04	111	111
14	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,897E-04	-4,878E-04	111	111
14	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,117E-04	-5,096E-04	111	111
14	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,337E-04	-5,314E-04	111	111
14	8	1	0,000E+00	0,000E+00	0,000E+00	-6,553E-05	-6,765E-05	111	111
14	9	1	0,000E+00	0,000E+00	0,000E+00	-4,558E-04	-4,543E-04	111	111
14	10	1	0,000E+00	0,000E+00	0,000E+00	-5,273E-04	-5,251E-04	111	111
14	11	1	0,000E+00	0,000E+00	0,000E+00	3,843E-03	3,843E-03	111	111
14	12	1	0,000E+00	0,000E+00	0,000E+00	3,944E-03	3,944E-03	111	111
15	1	1	-1,555E-05	0,000E+00	0,000E+00	-3,287E-05	-3,483E-05	111	111
15	1	2	-1,555E-05	0,000E+00	0,000E+00	-5,445E-05	-5,624E-05	111	111
15	1	3	-1,555E-05	0,000E+00	0,000E+00	-7,603E-05	-7,765E-05	111	111
15	2	1	-1,555E-05	0,000E+00	0,000E+00	-9,641E-05	-9,787E-05	111	111
15	3	1	-1,555E-05	0,000E+00	0,000E+00	-1,156E-04	-1,169E-04	111	111
15	4	1	-1,555E-05	0,000E+00	0,000E+00	-1,098E-04	-1,111E-04	111	111
15	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,556E-04	-1,566E-04	111	111
15	4	3	-1,555E-05	0,000E+00	0,000E+00	-2,015E-04	-2,021E-04	111	111
15	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,474E-04	-2,476E-04	111	111
15	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,932E-04	-2,931E-04	111	111
15	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,391E-04	-3,386E-04	111	111
15	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,849E-04	-3,841E-04	111	111
15	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,308E-04	-4,296E-04	111	111
15	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,178E-04	-4,167E-04	111	111
15	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,417E-04	-4,405E-04	111	111
15	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,645E-04	-4,631E-04	111	111
15	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,861E-04	-4,845E-04	111	111
15	7	3	-1,555E-05	0,000E+00	0,000E+00	-5,077E-04	-5,059E-04	111	111
15	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,293E-04	-5,273E-04	111	111
15	8	1	0,000E+00	0,000E+00	0,000E+00	-7,000E-05	-7,179E-05	111	111

18	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,372E-04	-3,370E-04	111	111
18	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,813E-04	-3,809E-04	111	111
18	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,254E-04	-4,249E-04	111	111
18	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,129E-04	-4,124E-04	111	111
18	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,359E-04	-4,353E-04	111	111
18	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,578E-04	-4,572E-04	111	111
18	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,786E-04	-4,778E-04	111	111
18	7	3	-1,555E-05	0,000E+00	0,000E+00	-4,993E-04	-4,985E-04	111	111
18	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,201E-04	-5,192E-04	111	111
18	8	1	0,000E+00	0,000E+00	0,000E+00	-7,914E-05	-7,996E-05	111	111
18	9	1	0,000E+00	0,000E+00	0,000E+00	-4,474E-04	-4,469E-04	111	111
18	10	1	0,000E+00	0,000E+00	0,000E+00	-5,149E-04	-5,141E-04	111	111
18	11	1	0,000E+00	0,000E+00	0,000E+00	3,838E-03	3,838E-03	111	111
18	12	1	0,000E+00	0,000E+00	0,000E+00	3,939E-03	3,939E-03	111	111
19	1	1	-1,555E-05	0,000E+00	0,000E+00	-4,461E-05	-4,515E-05	111	111
19	1	2	-1,555E-05	0,000E+00	0,000E+00	-6,521E-05	-6,570E-05	111	111
19	1	3	-1,555E-05	0,000E+00	0,000E+00	-8,580E-05	-8,625E-05	111	111
19	2	1	-1,555E-05	0,000E+00	0,000E+00	-1,052E-04	-1,056E-04	111	111
19	3	1	-1,555E-05	0,000E+00	0,000E+00	-1,236E-04	-1,239E-04	111	111
19	4	1	-1,555E-05	0,000E+00	0,000E+00	-1,180E-04	-1,184E-04	111	111
19	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,618E-04	-1,620E-04	111	111
19	4	3	-1,555E-05	0,000E+00	0,000E+00	-2,055E-04	-2,057E-04	111	111
19	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,493E-04	-2,494E-04	111	111
19	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,931E-04	-2,930E-04	111	111
19	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,368E-04	-3,367E-04	111	111
19	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,806E-04	-3,804E-04	111	111
19	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,244E-04	-4,240E-04	111	111
19	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,119E-04	-4,116E-04	111	111
19	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,348E-04	-4,344E-04	111	111
19	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,565E-04	-4,561E-04	111	111
19	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,771E-04	-4,767E-04	111	111
19	7	3	-1,555E-05	0,000E+00	0,000E+00	-4,977E-04	-4,972E-04	111	111
19	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,183E-04	-5,178E-04	111	111
19	8	1	0,000E+00	0,000E+00	0,000E+00	-8,076E-05	-8,125E-05	111	111
19	9	1	0,000E+00	0,000E+00	0,000E+00	-4,463E-04	-4,460E-04	111	111
19	10	1	0,000E+00	0,000E+00	0,000E+00	-5,133E-04	-5,128E-04	111	111
19	11	1	0,000E+00	0,000E+00	0,000E+00	3,836E-03	3,836E-03	111	111
19	12	1	0,000E+00	0,000E+00	0,000E+00	3,937E-03	3,937E-03	111	111
20	1	1	-1,555E-05	0,000E+00	0,000E+00	-4,561E-05	-4,578E-05	111	111
20	1	2	-1,555E-05	0,000E+00	0,000E+00	-6,611E-05	-6,627E-05	111	111
20	1	3	-1,555E-05	0,000E+00	0,000E+00	-8,662E-05	-8,677E-05	111	111
20	2	1	-1,555E-05	0,000E+00	0,000E+00	-1,060E-04	-1,061E-04	111	111
20	3	1	-1,555E-05	0,000E+00	0,000E+00	-1,242E-04	-1,243E-04	111	111
20	4	1	-1,555E-05	0,000E+00	0,000E+00	-1,187E-04	-1,188E-04	111	111
20	4	2	-1,555E-05	0,000E+00	0,000E+00	-1,622E-04	-1,623E-04	111	111
20	4	3	-1,555E-05	0,000E+00	0,000E+00	-2,058E-04	-2,059E-04	111	111
20	4	4	-1,555E-05	0,000E+00	0,000E+00	-2,494E-04	-2,494E-04	111	111
20	4	5	-1,555E-05	0,000E+00	0,000E+00	-2,930E-04	-2,930E-04	111	111
20	4	6	-1,555E-05	0,000E+00	0,000E+00	-3,365E-04	-3,365E-04	111	111
20	4	7	-1,555E-05	0,000E+00	0,000E+00	-3,801E-04	-3,800E-04	111	111
20	4	8	-1,555E-05	0,000E+00	0,000E+00	-4,237E-04	-4,236E-04	111	111
20	5	1	-1,555E-05	0,000E+00	0,000E+00	-4,113E-04	-4,112E-04	111	111
20	6	1	-1,555E-05	0,000E+00	0,000E+00	-4,341E-04	-4,340E-04	111	111
20	7	1	-1,555E-05	0,000E+00	0,000E+00	-4,557E-04	-4,556E-04	111	111
20	7	2	-1,555E-05	0,000E+00	0,000E+00	-4,762E-04	-4,761E-04	111	111
20	7	3	-1,555E-05	0,000E+00	0,000E+00	-4,967E-04	-4,966E-04	111	111
20	7	4	-1,555E-05	0,000E+00	0,000E+00	-5,172E-04	-5,171E-04	111	111
20	8	1	0,000E+00	0,000E+00	0,000E+00	-8,167E-05	-8,183E-05	111	111
20	9	1	0,000E+00	0,000E+00	0,000E+00	-4,456E-04	-4,455E-04	111	111
20	10	1	0,000E+00	0,000E+00	0,000E+00	-5,123E-04	-5,121E-04	111	111
20	11	1	0,000E+00	0,000E+00	0,000E+00	3,835E-03	3,835E-03	111	111
20	12	1	0,000E+00	0,000E+00	0,000E+00	3,936E-03	3,936E-03	111	111

PROB (CONTD)

40 BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL FC, 7.5 SQRT(FC)

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 3 TIME = 8.000E+00 (+)

TABLE 9 - FIBER STRESSES

ELEMT	SUB-RECT.	DIVISION	STRESSES LEFT	STRESSES RIGHT
1	1	1	-1.070E+03	-1.093E+03
1	1	2	-1.068E+03	-1.089E+03
1	1	3	-1.066E+03	-1.085E+03
1	2	1	-1.064E+03	-1.081E+03
1	3	1	-1.062E+03	-1.078E+03
1	4	1	-1.063E+03	-1.079E+03
1	4	2	-1.059E+03	-1.070E+03
1	4	3	-1.054E+03	-1.062E+03
1	4	4	-1.050E+03	-1.053E+03
1	4	5	-1.046E+03	-1.044E+03
1	4	6	-1.041E+03	-1.036E+03
1	4	7	-1.037E+03	-1.027E+03
1	4	8	-1.033E+03	-1.019E+03
1	5	1	-1.034E+03	-1.021E+03
1	6	1	-1.032E+03	-1.017E+03
1	7	1	-1.029E+03	-1.012E+03
1	7	2	-1.027E+03	-1.008E+03
1	7	3	-1.025E+03	-1.004E+03
1	7	4	-1.023E+03	-1.000E+03
1	8	1	-8.883E+03	-9.050E+03
1	9	1	-8.597E+03	-8.482E+03
1	10	1	-8.545E+03	-8.378E+03
1	11	1	9.832E+04	9.832E+04
1	12	1	9.869E+04	9.869E+04
2	1	1	-8.167E+02	-8.385E+02
2	1	2	-8.347E+02	-8.546E+02
2	1	3	-8.527E+02	-8.707E+02
2	2	1	-8.697E+02	-8.859E+02
2	3	1	-8.856E+02	-9.002E+02
2	4	1	-8.808E+02	-8.959E+02
2	4	2	-9.190E+02	-9.301E+02
2	4	3	-9.573E+02	-9.603E+02
2	4	4	-9.955E+02	-9.985E+02
2	4	5	-1.034E+03	-1.033E+03
2	4	6	-1.072E+03	-1.067E+03
2	4	7	-1.110E+03	-1.101E+03
2	4	8	-1.148E+03	-1.135E+03
2	5	1	-1.138E+03	-1.126E+03
2	6	1	-1.158E+03	-1.143E+03
2	7	1	-1.177E+03	-1.160E+03
2	7	2	-1.195E+03	-1.176E+03
2	7	3	-1.213E+03	-1.193E+03
2	7	4	-1.231E+03	-1.209E+03
2	8	1	-7.033E+03	-7.191E+03
2	9	1	-9.565E+03	-9.456E+03

349

2	10	1	-1.003E+04	-9.870E+03
2	11	1	9.787E+04	9.787E+04
2	12	1	9.849E+04	9.849E+04
3	1	1	-5.973E+02	-6.183E+02
3	1	2	-6.327E+02	-6.518E+02
3	1	3	-6.680E+02	-6.853E+02
3	2	1	-7.014E+02	-7.170E+02
3	3	1	-7.328E+02	-7.468E+02
3	4	1	-7.233E+02	-7.377E+02
3	4	2	-7.984E+02	-8.090E+02
3	4	3	-8.735E+02	-8.802E+02
3	4	4	-9.487E+02	-9.515E+02
3	4	5	-1.024E+03	-1.023E+03
3	4	6	-1.099E+03	-1.094E+03
3	4	7	-1.174E+03	-1.165E+03
3	4	8	-1.249E+03	-1.237E+03
3	5	1	-1.228E+03	-1.216E+03
3	6	1	-1.267E+03	-1.253E+03
3	7	1	-1.303E+03	-1.288E+03
3	7	2	-1.337E+03	-1.321E+03
3	7	3	-1.372E+03	-1.353E+03
3	7	4	-1.406E+03	-1.386E+03
3	8	1	-5.431E+03	-5.583E+03
3	9	1	-1.041E+04	-1.030E+04
3	10	1	-1.132E+04	-1.117E+04
3	11	1	9.743E+04	9.743E+04
3	12	1	9.828E+04	9.828E+04
4	1	1	-4.122E+02	-4.320E+02
4	1	2	-4.623E+02	-4.803E+02
4	1	3	-5.123E+02	-5.286E+02
4	2	1	-5.595E+02	-5.742E+02
4	3	1	-6.039E+02	-6.171E+02
4	4	1	-5.904E+02	-6.040E+02
4	4	2	-6.967E+02	-7.067E+02
4	4	3	-8.029E+02	-8.093E+02
4	4	4	-9.092E+02	-9.119E+02
4	4	5	-1.015E+03	-1.015E+03
4	4	6	-1.122E+03	-1.117E+03
4	4	7	-1.228E+03	-1.220E+03
4	4	8	-1.332E+03	-1.320E+03
4	5	1	-1.303E+03	-1.292E+03
4	6	1	-1.357E+03	-1.344E+03
4	7	1	-1.408E+03	-1.394E+03
4	7	2	-1.457E+03	-1.441E+03
4	7	3	-1.505E+03	-1.488E+03
4	7	4	-1.554E+03	-1.535E+03
4	8	1	-4.080E+03	-4.223E+03
4	9	1	-1.112E+04	-1.102E+04
4	10	1	-1.201E+04	-1.226E+04
4	11	1	9.698E+04	9.698E+04
4	12	1	9.808E+04	9.808E+04
5	1	1	-2.612E+02	-2.798E+02
5	1	2	-3.231E+02	-3.401E+02
5	1	3	-3.850E+02	-4.004E+02
5	2	1	-4.435E+02	-4.573E+02
5	3	1	-4.985E+02	-5.109E+02
5	4	1	-4.818E+02	-4.946E+02
5	4	2	-6.134E+02	-6.228E+02
5	4	3	-7.450E+02	-7.509E+02
5	4	4	-8.765E+02	-8.791E+02
5	4	5	-1.008E+03	-1.007E+03
5	4	6	-1.140E+03	-1.135E+03

5	4	7	-1.271E+03	-1.263E+03
5	4	8	-1.399E+03	-1.388E+03
5	5	1	-1.362E+03	-1.352E+03
5	6	1	-1.429E+03	-1.418E+03
5	7	1	-1.493E+03	-1.480E+03
5	7	2	-1.553E+03	-1.538E+03
5	7	3	-1.613E+03	-1.597E+03
5	7	4	-1.674E+03	-1.656E+03
5	8	1	-2.976E+03	-3.111E+03
5	9	1	-1.169E+04	-1.160E+04
5	10	1	-1.329E+04	-1.315E+04
5	11	1	9.654E+04	9.654E+04
5	12	1	9.787E+04	9.787E+04
6	1	1	-1.438E+02	-1.612E+02
6	1	2	-2.149E+02	-2.308E+02
6	1	3	-2.860E+02	-3.004E+02
6	2	1	-3.532E+02	-3.661E+02
6	3	1	-4.164E+02	-4.280E+02
6	4	1	-3.972E+02	-4.091E+02
6	4	2	-5.483E+02	-5.571E+02
6	4	3	-6.994E+02	-7.050E+02
6	4	4	-8.505E+02	-8.529E+02
6	4	5	-1.002E+03	-1.001E+03
6	4	6	-1.153E+03	-1.149E+03
6	4	7	-1.302E+03	-1.295E+03
6	4	8	-1.450E+03	-1.439E+03
6	5	1	-1.408E+03	-1.398E+03
6	6	1	-1.485E+03	-1.474E+03
6	7	1	-1.558E+03	-1.545E+03
6	7	2	-1.627E+03	-1.613E+03
6	7	3	-1.696E+03	-1.681E+03
6	7	4	-1.765E+03	-1.748E+03
6	8	1	-2.118E+03	-2.244E+03
6	9	1	-1.213E+04	-1.204E+04
6	10	1	-1.396E+04	-1.383E+04
6	11	1	9.610E+04	9.610E+04
6	12	1	9.767E+04	9.767E+04
7	1	1	-5.958E+01	-7.576E+01
7	1	2	-1.372E+02	-1.520E+02
7	1	3	-2.149E+02	-2.282E+02
7	2	1	-2.881E+02	-3.002E+02
7	3	1	-3.572E+02	-3.680E+02
7	4	1	-3.362E+02	-3.473E+02
7	4	2	-5.011E+02	-5.093E+02
7	4	3	-6.661E+02	-6.713E+02
7	4	4	-8.311E+02	-8.333E+02
7	4	5	-9.961E+02	-9.953E+02
7	4	6	-1.161E+03	-1.157E+03
7	4	7	-1.324E+03	-1.317E+03
7	4	8	-1.485E+03	-1.475E+03
7	5	1	-1.439E+03	-1.432E+03
7	6	1	-1.523E+03	-1.513E+03
7	7	1	-1.603E+03	-1.591E+03
7	7	2	-1.678E+03	-1.665E+03
7	7	3	-1.754E+03	-1.739E+03
7	7	4	-1.829E+03	-1.814E+03
7	8	1	-1.542E+03	-1.619E+03
7	9	1	-1.243E+04	-1.235E+04
7	10	1	-1.443E+04	-1.431E+04
7	11	1	9.567E+04	9.567E+04
7	12	1	9.747E+04	9.747E+04
8	1	1	-8.175E+00	-2.315E+01

8	1	2	-8.968E+01	-1.034E+02
8	1	3	-1.712E+02	-1.836E+02
8	2	1	-2.481E+02	-2.593E+02
8	3	1	-3.206E+02	-3.306E+02
8	4	1	-2.985E+02	-3.089E+02
8	4	2	-4.718E+02	-4.793E+02
8	4	3	-6.450E+02	-6.498E+02
8	4	4	-8.182E+02	-8.202E+02
8	4	5	-9.914E+02	-9.906E+02
8	4	6	-1.165E+03	-1.161E+03
8	4	7	-1.335E+03	-1.329E+03
8	4	8	-1.504E+03	-1.495E+03
8	5	1	-1.456E+03	-1.448E+03
8	6	1	-1.544E+03	-1.535E+03
8	7	1	-1.628E+03	-1.617E+03
8	7	2	-1.707E+03	-1.695E+03
8	7	3	-1.787E+03	-1.773E+03
8	7	4	-1.866E+03	-1.851E+03
8	8	1	-1.125E+03	-1.234E+03
8	9	1	-1.260E+04	-1.252E+04
8	10	1	-1.470E+04	-1.459E+04
8	11	1	9.523E+04	9.523E+04
8	12	1	9.726E+04	9.726E+04
9	1	1	1.083E+01	-2.948E+00
9	1	2	-7.193E+01	-8.451E+01
9	1	3	-1.547E+02	-1.661E+02
9	2	1	-2.328E+02	-2.431E+02
9	3	1	-3.064E+02	-3.156E+02
9	4	1	-2.840E+02	-2.935E+02
9	4	2	-4.599E+02	-4.668E+02
9	4	3	-6.358E+02	-6.402E+02
9	4	4	-8.116E+02	-8.135E+02
9	4	5	-9.875E+02	-9.868E+02
9	4	6	-1.163E+03	-1.160E+03
9	4	7	-1.337E+03	-1.331E+03
9	4	8	-1.508E+03	-1.500E+03
9	5	1	-1.459E+03	-1.452E+03
9	6	1	-1.549E+03	-1.540E+03
9	7	1	-1.634E+03	-1.624E+03
9	7	2	-1.714E+03	-1.703E+03
9	7	3	-1.795E+03	-1.783E+03
9	7	4	-1.875E+03	-1.862E+03
9	8	1	-9.846E+02	-1.084E+03
9	9	1	-1.263E+04	-1.256E+04
9	10	1	-1.477E+04	-1.467E+04
9	11	1	9.480E+04	9.480E+04
9	12	1	9.706E+04	9.706E+04
10	1	1	-2.166E+00	-1.475E+01
10	1	2	-8.360E+01	-9.509E+01
10	1	3	-1.650E+02	-1.754E+02
10	2	1	-2.419E+02	-2.513E+02
10	3	1	-3.143E+02	-3.227E+02
10	4	1	-2.923E+02	-3.010E+02
10	4	2	-4.653E+02	-4.717E+02
10	4	3	-6.384E+02	-6.424E+02
10	4	4	-8.114E+02	-8.131E+02
10	4	5	-9.845E+02	-9.839E+02
10	4	6	-1.158E+03	-1.155E+03
10	4	7	-1.328E+03	-1.323E+03
10	4	8	-1.497E+03	-1.489E+03
10	5	1	-1.449E+03	-1.442E+03
10	6	1	-1.537E+03	-1.529E+03

10	7	1	-1.621E+03	-1.612E+03
10	7	2	-1.700E+03	-1.690E+03
10	7	3	-1.779E+03	-1.768E+03
10	7	4	-1.858E+03	-1.846E+03
10	8	1	-1.077E+03	-1.168E+03
10	9	1	-1.254E+04	-1.248E+04
10	10	1	-1.464E+04	-1.455E+04
10	11	1	9.437E+04	9.437E+04
10	12	1	9.686E+04	9.686E+04
11	1	1	-2.918E+01	-4.056E+01
11	1	2	-1.084E+02	-1.187E+02
11	1	3	-1.875E+02	-1.969E+02
11	2	1	-2.623E+02	-2.707E+02
11	3	1	-3.327E+02	-3.403E+02
11	4	1	-3.112E+02	-3.191E+02
11	4	2	-4.795E+02	-4.853E+02
11	4	3	-6.478E+02	-6.514E+02
11	4	4	-8.160E+02	-8.176E+02
11	4	5	-9.843E+02	-9.837E+02
11	4	6	-1.153E+03	-1.150E+03
11	4	7	-1.319E+03	-1.314E+03
11	4	8	-1.483E+03	-1.476E+03
11	5	1	-1.436E+03	-1.430E+03
11	6	1	-1.522E+03	-1.514E+03
11	7	1	-1.603E+03	-1.595E+03
11	7	2	-1.680E+03	-1.671E+03
11	7	3	-1.757E+03	-1.747E+03
11	7	4	-1.830E+03	-1.823E+03
11	8	1	-1.273E+03	-1.356E+03
11	9	1	-1.242E+04	-1.236E+04
11	10	1	-1.446E+04	-1.438E+04
11	11	1	9.429E+04	9.429E+04
11	12	1	9.678E+04	9.678E+04
12	1	1	-5.339E+01	-6.357E+01
12	1	2	-1.306E+02	-1.399E+02
12	1	3	-2.078E+02	-2.162E+02
12	2	1	-2.806E+02	-2.882E+02
12	3	1	-3.493E+02	-3.560E+02
12	4	1	-3.284E+02	-3.354E+02
12	4	2	-4.924E+02	-4.976E+02
12	4	3	-6.564E+02	-6.597E+02
12	4	4	-8.205E+02	-8.218E+02
12	4	5	-9.845E+02	-9.840E+02
12	4	6	-1.149E+03	-1.146E+03
12	4	7	-1.311E+03	-1.307E+03
12	4	8	-1.471E+03	-1.465E+03
12	5	1	-1.425E+03	-1.420E+03
12	6	1	-1.509E+03	-1.502E+03
12	7	1	-1.588E+03	-1.581E+03
12	7	2	-1.663E+03	-1.655E+03
12	7	3	-1.738E+03	-1.729E+03
12	7	4	-1.813E+03	-1.803E+03
12	8	1	-1.450E+03	-1.523E+03
12	9	1	-1.231E+04	-1.226E+04
12	10	1	-1.430E+04	-1.423E+04
12	11	1	9.426E+04	9.426E+04
12	12	1	9.674E+04	9.674E+04
13	1	1	-7.499E+01	-8.398E+01
13	1	2	-1.504E+02	-1.586E+02
13	1	3	-2.258E+02	-2.332E+02
13	2	1	-2.970E+02	-3.037E+02
13	3	1	-3.640E+02	-3.700E+02

13	4	1	-3.436E+02	-3.499E+02
13	4	2	-5.030E+02	-5.084E+02
13	4	3	-6.642E+02	-6.670E+02
13	4	4	-8.244E+02	-8.256E+02
13	4	5	-9.847E+02	-9.842E+02
13	4	6	-1.145E+03	-1.143E+03
13	4	7	-1.304E+03	-1.300E+03
13	4	8	-1.460E+03	-1.454E+03
13	5	1	-1.415E+03	-1.410E+03
13	6	1	-1.497E+03	-1.491E+03
13	7	1	-1.574E+03	-1.568E+03
13	7	2	-1.648E+03	-1.640E+03
13	7	3	-1.721E+03	-1.713E+03
13	7	4	-1.794E+03	-1.786E+03
13	8	1	-1.607E+03	-1.672E+03
13	9	1	-1.222E+04	-1.218E+04
13	10	1	-1.416E+04	-1.410E+04
13	11	1	9.422E+04	9.422E+04
13	12	1	9.671E+04	9.671E+04
14	1	1	-9.399E+01	-1.018E+02
14	1	2	-1.678E+02	-1.749E+02
14	1	3	-2.417E+02	-2.481E+02
14	2	1	-3.114E+02	-3.172E+02
14	3	1	-3.770E+02	-3.822E+02
14	4	1	-3.571E+02	-3.624E+02
14	4	2	-5.140E+02	-5.179E+02
14	4	3	-6.709E+02	-6.734E+02
14	4	4	-8.278E+02	-8.289E+02
14	4	5	-9.847E+02	-9.840E+02
14	4	6	-1.142E+03	-1.140E+03
14	4	7	-1.297E+03	-1.294E+03
14	4	8	-1.450E+03	-1.445E+03
14	5	1	-1.407E+03	-1.402E+03
14	6	1	-1.486E+03	-1.482E+03
14	7	1	-1.562E+03	-1.557E+03
14	7	2	-1.634E+03	-1.628E+03
14	7	3	-1.706E+03	-1.699E+03
14	7	4	-1.778E+03	-1.770E+03
14	8	1	-1.745E+03	-1.801E+03
14	9	1	-1.214E+04	-1.210E+04
14	10	1	-1.404E+04	-1.398E+04
14	11	1	9.419E+04	9.419E+04
14	12	1	9.668E+04	9.668E+04
15	1	1	-1.104E+02	-1.170E+02
15	1	2	-1.829E+02	-1.889E+02
15	1	3	-2.554E+02	-2.608E+02
15	2	1	-3.238E+02	-3.287E+02
15	3	1	-3.882E+02	-3.926E+02
15	4	1	-3.686E+02	-3.732E+02
15	4	2	-5.227E+02	-5.260E+02
15	4	3	-6.767E+02	-6.788E+02
15	4	4	-8.307E+02	-8.316E+02
15	4	5	-9.848E+02	-9.844E+02
15	4	6	-1.139E+03	-1.137E+03
15	4	7	-1.292E+03	-1.289E+03
15	4	8	-1.442E+03	-1.438E+03
15	5	1	-1.399E+03	-1.395E+03
15	6	1	-1.477E+03	-1.473E+03
15	7	1	-1.552E+03	-1.547E+03
15	7	2	-1.622E+03	-1.617E+03
15	7	3	-1.693E+03	-1.687E+03
15	7	4	-1.763E+03	-1.757E+03

15	8	1	-1.864E+03	-1.912E+03
15	9	1	-1.207E+04	-1.203E+04
15	10	1	-1.393E+04	-1.389E+04
15	11	1	9.416E+04	9.416E+04
15	12	1	9.664E+04	9.664E+04
16	1	1	-1.242E+02	-1.295E+02
16	1	2	-1.955E+02	-2.004E+02
16	1	3	-2.668E+02	-2.713E+02
16	2	1	-3.342E+02	-3.382E+02
16	3	1	-3.976E+02	-4.012E+02
16	4	1	-3.783E+02	-3.820E+02
16	4	2	-5.299E+02	-5.326E+02
16	4	3	-6.815E+02	-6.832E+02
16	4	4	-8.331E+02	-8.339E+02
16	4	5	-9.847E+02	-9.845E+02
16	4	6	-1.136E+03	-1.135E+03
16	4	7	-1.287E+03	-1.285E+03
16	4	8	-1.434E+03	-1.431E+03
16	5	1	-1.393E+03	-1.390E+03
16	6	1	-1.470E+03	-1.466E+03
16	7	1	-1.543E+03	-1.539E+03
16	7	2	-1.612E+03	-1.608E+03
16	7	3	-1.682E+03	-1.677E+03
16	7	4	-1.751E+03	-1.746E+03
16	8	1	-1.964E+03	-2.003E+03
16	9	1	-1.201E+04	-1.198E+04
16	10	1	-1.384E+04	-1.381E+04
16	11	1	9.412E+04	9.412E+04
16	12	1	9.661E+04	9.661E+04
17	1	1	-1.353E+02	-1.395E+02
17	1	2	-2.057E+02	-2.096E+02
17	1	3	-2.761E+02	-2.796E+02
17	2	1	-3.426E+02	-3.457E+02
17	3	1	-4.052E+02	-4.080E+02
17	4	1	-3.862E+02	-3.890E+02
17	4	2	-5.358E+02	-5.379E+02
17	4	3	-6.854E+02	-6.867E+02
17	4	4	-8.350E+02	-8.356E+02
17	4	5	-9.846E+02	-9.844E+02
17	4	6	-1.134E+03	-1.133E+03
17	4	7	-1.283E+03	-1.281E+03
17	4	8	-1.429E+03	-1.426E+03
17	5	1	-1.387E+03	-1.385E+03
17	6	1	-1.463E+03	-1.461E+03
17	7	1	-1.536E+03	-1.533E+03
17	7	2	-1.604E+03	-1.601E+03
17	7	3	-1.673E+03	-1.669E+03
17	7	4	-1.741E+03	-1.737E+03
17	8	1	-2.046E+03	-2.076E+03
17	9	1	-1.196E+04	-1.193E+04
17	10	1	-1.377E+04	-1.374E+04
17	11	1	9.409E+04	9.409E+04
17	12	1	9.657E+04	9.657E+04
18	1	1	-1.439E+02	-1.469E+02
18	1	2	-2.136E+02	-2.163E+02
18	1	3	-2.832E+02	-2.857E+02
18	2	1	-3.490E+02	-3.513E+02
18	3	1	-4.110E+02	-4.130E+02
18	4	1	-3.921E+02	-3.942E+02
18	4	2	-5.402E+02	-5.417E+02
18	4	3	-6.883E+02	-6.892E+02
18	4	4	-8.364E+02	-8.368E+02

18	4	5	-9.844E+02	-9.843E+02
18	4	6	-1.133E+03	-1.132E+03
18	4	7	-1.280E+03	-1.279E+03
18	4	8	-1.424E+03	-1.422E+03
18	5	1	-1.383E+03	-1.381E+03
18	6	1	-1.458E+03	-1.456E+03
18	7	1	-1.530E+03	-1.528E+03
18	7	2	-1.598E+03	-1.595E+03
18	7	3	-1.665E+03	-1.663E+03
18	7	4	-1.733E+03	-1.730E+03
18	8	1	-2.108E+03	-2.129E+03
18	9	1	-1.192E+04	-1.190E+04
18	10	1	-1.371E+04	-1.369E+04
18	11	1	9.406E+04	9.406E+04
18	12	1	9.654E+04	9.654E+04
19	1	1	-1.498E+02	-1.516E+02
19	1	2	-2.190E+02	-2.206E+02
19	1	3	-2.882E+02	-2.897E+02
19	2	1	-3.535E+02	-3.548E+02
19	3	1	-4.150E+02	-4.162E+02
19	4	1	-3.962E+02	-3.975E+02
19	4	2	-5.432E+02	-5.441E+02
19	4	3	-6.902E+02	-6.908E+02
19	4	4	-8.372E+02	-8.375E+02
19	4	5	-9.842E+02	-9.841E+02
19	4	6	-1.131E+03	-1.131E+03
19	4	7	-1.277E+03	-1.277E+03
19	4	8	-1.420E+03	-1.419E+03
19	5	1	-1.380E+03	-1.379E+03
19	6	1	-1.455E+03	-1.453E+03
19	7	1	-1.526E+03	-1.524E+03
19	7	2	-1.593E+03	-1.592E+03
19	7	3	-1.660E+03	-1.659E+03
19	7	4	-1.728E+03	-1.726E+03
19	8	1	-2.151E+03	-2.164E+03
19	9	1	-1.189E+04	-1.188E+04
19	10	1	-1.367E+04	-1.366E+04
19	11	1	9.403E+04	9.403E+04
19	12	1	9.651E+04	9.651E+04
20	1	1	-1.532E+02	-1.538E+02
20	1	2	-2.220E+02	-2.226E+02
20	1	3	-2.909E+02	-2.914E+02
20	2	1	-3.559E+02	-3.564E+02
20	3	1	-4.171E+02	-4.175E+02
20	4	1	-3.985E+02	-3.989E+02
20	4	2	-5.449E+02	-5.452E+02
20	4	3	-6.912E+02	-6.914E+02
20	4	4	-8.376E+02	-8.376E+02
20	4	5	-9.839E+02	-9.839E+02
20	4	6	-1.130E+03	-1.130E+03
20	4	7	-1.276E+03	-1.276E+03
20	4	8	-1.418E+03	-1.418E+03
20	5	1	-1.378E+03	-1.377E+03
20	6	1	-1.452E+03	-1.452E+03
20	7	1	-1.523E+03	-1.523E+03
20	7	2	-1.590E+03	-1.590E+03
20	7	3	-1.657E+03	-1.657E+03
20	7	4	-1.724E+03	-1.724E+03
20	8	1	-2.175E+03	-2.179E+03
20	9	1	-1.187E+04	-1.186E+04
20	10	1	-1.364E+04	-1.364E+04
20	11	1	9.399E+04	9.399E+04

20	12	1	9.647E+04	9.647E+04

```
PROB (CONTD)
   4D     BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL FC, 7.5 SQRT(FC)
     ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION )
TIME INCREMENT    4     TIME   =    1.000E+01
TABLE 6 - ITEPATION DATA

     TIME FLAPESD =  18.527 SECONDS AT THE START OF THIS TIME INCREMENT
CYCLE NO.    1

MEMBER CONVERGED AFTER ITERATION    4


MEMBER CONVERGED AFTER CYCLE    1


     TIME CONSUMED =   2.459 SECONDS BY THIS TIME INCREMENT
```

PROB (CONTD)

4D BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 4 TIME = 1.000E+01

TABLE 7 - MEMBER RESULTS

STA.	DISTANCE	DISPLACEMENTS AXIAL	DISPLACEMENTS LATERAL	DISPLACEMENTS ROTATIONAL	REACTIONS AXIAL	REACTIONS LATERAL	REACTIONS ROTATIONAL	FORCES AXIAL	FORCES SHEAR	FORCES MOMENT
1	0.000E+00	9.206E-02	-4.510E-27	5.168E-03	0.000E+00	4.510E+03	0.000E+00	0.000E+00	4.510E+03	0.000E+00
2	1.200E+01	8.700E-02	6.206E-02	5.182E-03	0.000E+00	0.000E+00	0.000E+00	3.503E-07	4.284E+03	5.274E+04
3	2.400E+01	8.204E-02	1.238E-01	5.113E-03	0.000E+00	0.000E+00	0.000E+00	-1.417E-06	4.059E+03	1.028E+05
4	3.600E+01	7.716E-02	1.843E-01	4.972E-03	0.000E+00	0.000E+00	0.000E+00	-1.332E-06	3.833E+03	1.501E+05
5	4.800E+01	7.237E-02	2.427E-01	4.771E-03	0.000E+00	0.000E+00	0.000E+00	-9.265E-07	3.608E+03	1.947E+05
6	6.000E+01	6.766E-02	2.984E-01	4.521E-03	0.000E+00	0.000E+00	0.000E+00	-9.911E-07	3.382E+03	2.367E+05
7	7.200E+01	6.300E-02	3.509E-01	4.234E-03	0.000E+00	0.000E+00	0.000E+00	-2.745E-07	3.157E+03	2.759E+05
8	8.400E+01	5.841E-02	3.998E-01	3.920E-03	0.000E+00	0.000E+00	0.000E+00	-1.793E-06	2.931E+03	3.124E+05
9	9.600E+01	5.386E-02	4.448E-01	3.590E-03	0.000E+00	0.000E+00	0.000E+00	-2.126E-06	2.706E+03	3.462E+05
10	1.080E+02	4.934E-02	4.859E-01	3.256E-03	0.000E+00	0.000E+00	0.000E+00	-9.235E-07	2.480E+03	3.773E+05
11	1.200E+02	4.484E-02	5.230E-01	2.927E-03	0.000E+00	0.000E+00	0.000E+00	-1.715E-06	2.255E+03	4.057E+05
12	1.320E+02	4.035E-02	5.562E-01	2.607E-03	0.000E+00	0.000E+00	0.000E+00	-1.238E-07	2.029E+03	4.314E+05
13	1.440E+02	3.586E-02	5.856E-01	2.296E-03	0.000E+00	0.000E+00	0.000E+00	6.589E-07	1.804E+03	4.544E+05
14	1.560E+02	3.137E-02	6.113E-01	1.993E-03	0.000E+00	0.000E+00	0.000E+00	1.397E-07	1.578E+03	4.747E+05
15	1.680E+02	2.688E-02	6.334E-01	1.694E-03	0.000E+00	0.000E+00	0.000E+00	-1.813E-06	1.353E+03	4.923E+05
16	1.800E+02	2.240E-02	6.520E-01	1.404E-03	0.000E+00	0.000E+00	0.000E+00	-1.148E-06	1.127E+03	5.071E+05
17	1.920E+02	1.792E-02	6.671E-01	1.118E-03	0.000E+00	0.000E+00	0.000E+00	5.018E-07	9.019E+02	5.193E+05
18	2.040E+02	1.344E-02	6.788E-01	8.347E-04	0.000E+00	0.000E+00	0.000E+00	-1.499E-06	6.764E+02	5.288E+05
19	2.160E+02	8.955E-03	6.871E-01	5.548E-04	0.000E+00	0.000E+00	0.000E+00	3.685E-07	4.510E+02	5.355E+05
20	2.280E+02	4.477E-03	6.921E-01	2.769E-04	0.000E+00	0.000E+00	0.000E+00	4.198E-08	2.255E+02	5.396E+05
21	2.400E+02	3.157E-44	6.938E-01	-5.409E-25	-3.157E-14	0.000E+00	5.409E+05	-3.157E-14	0.000E+00	5.409E+05

PROB (CONTD)

4D BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 4 TIME = 1.000E+01

TABLE 8 - FIBER STRAINS

ELEMENT	SUB-RECT.	DIVISION	SHR. STRAINS	CREEP OR RELAX. STRAINS LEFT	CREEP OR RELAX. STRAINS RIGHT	INSTANTANEOUS STRAINS LEFT	INSTANTANEOUS STRAINS RIGHT	STRAIN INDICATORS LEFT	STRAIN INDICATORS RIGHT
1	1	1	-4.421E-05	-7.768E-05	-7.936E-05	-2.954E-04	-3.022E-04	111	111
1	1	2	-4.421E-05	-7.754E-05	-7.906E-05	-2.948E-04	-3.010E-04	111	111
1	1	3	-4.421E-05	-7.739E-05	-7.877E-05	-2.942E-04	-2.997E-04	111	111
1	2	1	-4.421E-05	-7.725E-05	-7.849E-05	-2.936E-04	-2.986E-04	111	111
1	3	1	-4.421E-05	-7.712E-05	-7.823E-05	-2.930E-04	-2.975E-04	111	111
1	4	1	-4.421E-05	-7.716E-05	-7.831E-05	-2.932E-04	-2.978E-04	111	111
1	4	2	-4.421E-05	-7.685E-05	-7.769E-05	-2.919E-04	-2.953E-04	111	111
1	4	3	-4.421E-05	-7.653E-05	-7.707E-05	-2.905E-04	-2.927E-04	111	111
1	4	4	-4.421E-05	-7.622E-05	-7.645E-05	-2.892E-04	-2.901E-04	111	111
1	4	5	-4.421E-05	-7.591E-05	-7.582E-05	-2.879E-04	-2.876E-04	111	111
1	4	6	-4.421E-05	-7.559E-05	-7.520E-05	-2.866E-04	-2.850E-04	111	111
1	4	7	-4.421E-05	-7.528E-05	-7.456E-05	-2.852E-04	-2.824E-04	111	111
1	4	8	-4.421E-05	-7.497E-05	-7.396E-05	-2.839E-04	-2.798E-04	111	111
1	5	1	-4.421E-05	-7.505E-05	-7.413E-05	-2.843E-04	-2.806E-04	111	111
1	6	1	-4.421E-05	-7.489E-05	-7.381E-05	-2.836E-04	-2.792E-04	111	111
1	7	1	-4.421E-05	-7.474E-05	-7.350E-05	-2.829E-04	-2.779E-04	111	111
1	7	2	-4.421E-05	-7.459E-05	-7.321E-05	-2.823E-04	-2.767E-04	111	111
1	7	3	-4.421E-05	-7.444E-05	-7.291E-05	-2.817E-04	-2.755E-04	111	111
1	7	4	-4.421E-05	-7.429E-05	-7.262E-05	-2.810E-04	-2.743E-04	111	111
1	8	1	0.000E+00	0.000E+00	0.000E+00	-4.166E-04	-4.242E-04	111	111
1	9	1	0.000E+00	0.000E+00	0.000E+00	-4.028E-04	-3.975E-04	111	111
1	10	1	0.000E+00	0.000E+00	0.000E+00	-4.003E-04	-3.926E-04	111	111
1	11	1	0.000E+00	1.638E-04	1.638E-04	3.766E-03	3.765E-03	111	111
1	12	1	0.000E+00	1.665E-04	1.665E-04	3.780E-03	3.780E-03	111	111
2	1	1	-4.421E-05	-5.929E-05	-6.087E-05	-2.267E-04	-2.331E-04	111	111
2	1	2	-4.421E-05	-6.059E-05	-6.204E-05	-2.315E-04	-2.374E-04	111	111
2	1	3	-4.421E-05	-6.190E-05	-6.321E-05	-2.363E-04	-2.416E-04	111	111
2	2	1	-4.421E-05	-6.313E-05	-6.431E-05	-2.409E-04	-2.456E-04	111	111
2	3	1	-4.421E-05	-6.429E-05	-6.535E-05	-2.451E-04	-2.494E-04	111	111
2	4	1	-4.421E-05	-6.394E-05	-6.504E-05	-2.438E-04	-2.482E-04	111	111
2	4	2	-4.421E-05	-6.672E-05	-6.752E-05	-2.540E-04	-2.573E-04	111	111
2	4	3	-4.421E-05	-6.949E-05	-7.000E-05	-2.642E-04	-2.663E-04	111	111
2	4	4	-4.421E-05	-7.227E-05	-7.248E-05	-2.745E-04	-2.753E-04	111	111
2	4	5	-4.421E-05	-7.504E-05	-7.497E-05	-2.847E-04	-2.843E-04	111	111
2	4	6	-4.421E-05	-7.782E-05	-7.745E-05	-2.949E-04	-2.934E-04	111	111
2	4	7	-4.421E-05	-8.060E-05	-7.993E-05	-3.051E-04	-3.024E-04	111	111
2	4	8	-4.421E-05	-8.337E-05	-8.241E-05	-3.153E-04	-3.114E-04	111	111
2	5	1	-4.421E-05	-8.258E-05	-8.171E-05	-3.124E-04	-3.088E-04	111	111
2	6	1	-4.421E-05	-8.403E-05	-8.301E-05	-3.177E-04	-3.136E-04	111	111
2	7	1	-4.421E-05	-8.541E-05	-8.424E-05	-3.228E-04	-3.180E-04	111	111
2	7	2	-4.421E-05	-8.672E-05	-8.541E-05	-3.276E-04	-3.223E-04	111	111
2	7	3	-4.421E-05	-8.802E-05	-8.658E-05	-3.324E-04	-3.265E-04	111	111
2	7	4	-4.421E-05	-8.933E-05	-8.774E-05	-3.372E-04	-3.308E-04	111	111
2	8	1	0.000E+00	0.000E+00	0.000E+00	-3.363E-04	-3.436E-04	111	111
2	9	1	0.000E+00	0.000E+00	0.000E+00	-4.448E-04	-4.397E-04	111	111
2	10	1	0.000E+00	0.000E+00	0.000E+00	-4.646E-04	-4.573E-04	111	111

2	11	1	0,000E+00	1,606E-04	1,606E-04	3,753E-03	3,753E-03	111	111
2	12	1	0,000E+00	1,650E-04	1,650E-04	3,769E-03	3,769E-03	111	111
3	1	1	-4,421E-05	-4,336E-05	-4,488E-05	-1,673E-04	-1,734E-04	111	111
3	1	2	-4,421E-05	-4,593E-05	-4,732E-05	-1,768E-04	-1,823E-04	111	111
3	1	3	-4,421E-05	-4,850E-05	-4,975E-05	-1,863E-04	-1,913E-04	111	111
3	2	1	-4,421E-05	-5,092E-05	-5,205E-05	-1,952E-04	-1,997E-04	111	111
3	3	1	-4,421E-05	-5,320E-05	-5,421E-05	-2,036E-04	-2,077E-04	111	111
3	4	1	-4,421E-05	-5,251E-05	-5,356E-05	-2,011E-04	-2,053E-04	111	111
3	4	2	-4,421E-05	-5,796E-05	-5,873E-05	-2,212E-04	-2,243E-04	111	111
3	4	3	-4,421E-05	-6,342E-05	-6,390E-05	-2,414E-04	-2,433E-04	111	111
3	4	4	-4,421E-05	-6,887E-05	-6,908E-05	-2,615E-04	-2,623E-04	111	111
3	4	5	-4,421E-05	-7,432E-05	-7,425E-05	-2,816E-04	-2,814E-04	111	111
3	4	6	-4,421E-05	-7,978E-05	-7,942E-05	-3,018E-04	-3,004E-04	111	111
3	4	7	-4,421E-05	-8,523E-05	-8,460E-05	-3,219E-04	-3,194E-04	111	111
3	4	8	-4,421E-05	-9,069E-05	-8,977E-05	-3,421E-04	-3,384E-04	111	111
3	5	1	-4,421E-05	-8,913E-05	-8,830E-05	-3,363E-04	-3,330E-04	111	111
3	6	1	-4,421E-05	-9,211E-05	-9,102E-05	-3,468E-04	-3,429E-04	111	111
3	7	1	-4,421E-05	-9,482E-05	-9,369E-05	-3,568E-04	-3,523E-04	111	111
3	7	2	-4,421E-05	-9,738E-05	-9,613E-05	-3,663E-04	-3,612E-04	111	111
3	7	3	-4,421E-05	-9,995E-05	-9,856E-05	-3,757E-04	-3,702E-04	111	111
3	7	4	-4,421E-05	-1,025E-04	-1,010E-04	-3,852E-04	-3,791E-04	111	111
3	8	1	0,000E+00	0,000E+00	0,000E+00	-2,669E-04	-2,738E-04	111	111
3	9	1	0,000E+00	0,000E+00	0,000E+00	-4,807E-04	-4,760E-04	111	111
3	10	1	0,000E+00	0,000E+00	0,000E+00	-5,199E-04	-5,130E-04	111	111
3	11	1	0,000E+00	1,575E-04	1,575E-04	3,737E-03	3,737E-03	111	111
3	12	1	0,000E+00	1,635E-04	1,635E-04	3,757E-03	3,758E-03	111	111
4	1	1	-4,421E-05	-2,993E-05	-3,136E-05	-1,171E-04	-1,228E-04	111	111
4	1	2	-4,421E-05	-3,356E-05	-3,487E-05	-1,305E-04	-1,358E-04	111	111
4	1	3	-4,421E-05	-3,719E-05	-3,837E-05	-1,440E-04	-1,487E-04	111	111
4	2	1	-4,421E-05	-4,062E-05	-4,168E-05	-1,566E-04	-1,609E-04	111	111
4	3	1	-4,421E-05	-4,384E-05	-4,480E-05	-1,686E-04	-1,724E-04	111	111
4	4	1	-4,421E-05	-4,286E-05	-4,385E-05	-1,649E-04	-1,689E-04	111	111
4	4	2	-4,421E-05	-5,058E-05	-5,130E-05	-1,935E-04	-1,964E-04	111	111
4	4	3	-4,421E-05	-5,829E-05	-5,875E-05	-2,220E-04	-2,238E-04	111	111
4	4	4	-4,421E-05	-6,601E-05	-6,620E-05	-2,505E-04	-2,513E-04	111	111
4	4	5	-4,421E-05	-7,372E-05	-7,365E-05	-2,790E-04	-2,787E-04	111	111
4	4	6	-4,421E-05	-8,143E-05	-8,110E-05	-3,075E-04	-3,062E-04	111	111
4	4	7	-4,421E-05	-8,915E-05	-8,855E-05	-3,361E-04	-3,337E-04	111	111
4	4	8	-4,421E-05	-9,699E-05	-9,612E-05	-3,645E-04	-3,610E-04	111	111
4	5	1	-4,421E-05	-9,479E-05	-9,400E-05	-3,564E-04	-3,532E-04	111	111
4	6	1	-4,421E-05	-9,882E-05	-9,790E-05	-3,713E-04	-3,676E-04	111	111
4	7	1	-4,421E-05	-1,027E-04	-1,016E-04	-3,854E-04	-3,812E-04	111	111
4	7	2	-4,421E-05	-1,063E-04	-1,051E-04	-3,989E-04	-3,941E-04	111	111
4	7	3	-4,421E-05	-1,099E-04	-1,086E-04	-4,123E-04	-4,070E-04	111	111
4	7	4	-4,421E-05	-1,135E-04	-1,121E-04	-4,257E-04	-4,200E-04	111	111
4	8	1	0,000E+00	0,000E+00	0,000E+00	-2,083E-04	-2,149E-04	111	111
4	9	1	0,000E+00	0,000E+00	0,000E+00	-5,110E-04	-5,065E-04	111	111
4	10	1	0,000E+00	0,000E+00	0,000E+00	-5,664E-04	-5,599E-04	111	111
4	11	1	0,000E+00	1,544E-04	1,544E-04	3,719E-03	3,719E-03	111	111
4	12	1	0,000E+00	1,621E-04	1,621E-04	3,745E-03	3,746E-03	111	111
5	1	1	-4,421E-05	-1,896E-05	-2,031E-05	-7,627E-05	-8,166E-05	111	111
5	1	2	-4,421E-05	-2,346E-05	-2,469E-05	-9,289E-05	-9,781E-05	111	111
5	1	3	-4,421E-05	-2,795E-05	-2,907E-05	-1,095E-04	-1,140E-04	111	111
5	2	1	-4,421E-05	-3,220E-05	-3,320E-05	-1,252E-04	-1,292E-04	111	111
5	3	1	-4,421E-05	-3,619E-05	-3,709E-05	-1,400E-04	-1,436E-04	111	111
5	4	1	-4,421E-05	-3,498E-05	-3,591E-05	-1,355E-04	-1,392E-04	111	111
5	4	2	-4,421E-05	-4,453E-05	-4,521E-05	-1,708E-04	-1,735E-04	111	111
5	4	3	-4,421E-05	-5,408E-05	-5,451E-05	-2,061E-04	-2,078E-04	111	111
5	4	4	-4,421E-05	-6,363E-05	-6,382E-05	-2,414E-04	-2,421E-04	111	111
5	4	5	-4,421E-05	-7,319E-05	-7,312E-05	-2,767E-04	-2,765E-04	111	111
5	4	6	-4,421E-05	-8,274E-05	-8,242E-05	-3,120E-04	-3,108E-04	111	111
5	4	7	-4,421E-05	-9,241E-05	-9,183E-05	-3,472E-04	-3,450E-04	111	111

5	4	8	-4,421E-05	-1,020E-04	-1,012E-04	-3,825E-04	-3,793E-04	111	111
5	5	1	-4,421E-05	-9,925E-05	-9,850E-05	-3,725E-04	-3,695E-04	111	111
5	6	1	-4,421E-05	-1,042E-04	-1,034E-04	-3,910E-04	-3,875E-04	111	111
5	7	1	-4,421E-05	-1,090E-04	-1,080E-04	-4,085E-04	-4,045E-04	111	111
5	7	2	-4,421E-05	-1,135E-04	-1,124E-04	-4,251E-04	-4,207E-04	111	111
5	7	3	-4,421E-05	-1,180E-04	-1,167E-04	-4,417E-04	-4,368E-04	111	111
5	7	4	-4,421E-05	-1,225E-04	-1,211E-04	-4,584E-04	-4,530E-04	111	111
5	8	1	0,000E+00	0,000E+00	0,000E+00	-1,606E-04	-1,667E-04	111	111
5	9	1	0,000E+00	0,000E+00	0,000E+00	-5,353E-04	-5,311E-04	111	111
5	10	1	0,000E+00	0,000E+00	0,000E+00	-6,039E-04	-5,978E-04	111	111
5	11	1	0,000E+00	1,514E-04	1,514E-04	3,700E-03	3,700E-03	111	111
5	12	1	0,000E+00	1,607E-04	1,607E-04	3,734E-03	3,735E-03	111	111
6	1	1	-4,421E-05	-1,044E-05	-1,170E-05	-4,469E-05	-4,973E-05	111	111
6	1	2	-4,421E-05	-1,560E-05	-1,675E-05	-6,376E-05	-6,836E-05	111	111
6	1	3	-4,421E-05	-2,076E-05	-2,181E-05	-8,283E-05	-8,699E-05	111	111
6	2	1	-4,421E-05	-2,564E-05	-2,658E-05	-1,008E-04	-1,046E-04	111	111
6	3	1	-4,421E-05	-3,023E-05	-3,107E-05	-1,178E-04	-1,211E-04	111	111
6	4	1	-4,421E-05	-2,883E-05	-2,970E-05	-1,126E-04	-1,161E-04	111	111
6	4	2	-4,421E-05	-3,980E-05	-4,044E-05	-1,532E-04	-1,557E-04	111	111
6	4	3	-4,421E-05	-5,077E-05	-5,118E-05	-1,937E-04	-1,953E-04	111	111
6	4	4	-4,421E-05	-6,175E-05	-6,192E-05	-2,342E-04	-2,349E-04	111	111
6	4	5	-4,421E-05	-7,272E-05	-7,266E-05	-2,747E-04	-2,745E-04	111	111
6	4	6	-4,421E-05	-8,369E-05	-8,339E-05	-3,152E-04	-3,141E-04	111	111
6	4	7	-4,421E-05	-9,478E-05	-9,425E-05	-3,556E-04	-3,535E-04	111	111
6	4	8	-4,421E-05	-1,058E-04	-1,050E-04	-3,962E-04	-3,931E-04	111	111
6	5	1	-4,421E-05	-1,026E-04	-1,019E-04	-3,846E-04	-3,819E-04	111	111
6	6	1	-4,421E-05	-1,084E-04	-1,076E-04	-4,058E-04	-4,026E-04	111	111
6	7	1	-4,421E-05	-1,138E-04	-1,129E-04	-4,260E-04	-4,222E-04	111	111
6	7	2	-4,421E-05	-1,190E-04	-1,179E-04	-4,450E-04	-4,409E-04	111	111
6	7	3	-4,421E-05	-1,241E-04	-1,230E-04	-4,641E-04	-4,595E-04	111	111
6	7	4	-4,421E-05	-1,293E-04	-1,280E-04	-4,832E-04	-4,781E-04	111	111
6	8	1	0,000E+00	0,000E+00	0,000E+00	-1,236E-04	-1,293E-04	111	111
6	9	1	0,000E+00	0,000E+00	0,000E+00	-5,537E-04	-5,497E-04	111	111
6	10	1	0,000E+00	0,000E+00	0,000E+00	-6,325E-04	-6,267E-04	111	111
6	11	1	0,000E+00	1,483E-04	1,483E-04	3,681E-03	3,681E-03	111	111
6	12	1	0,000E+00	1,592E-04	1,592E-04	3,723E-03	3,724E-03	111	111
7	1	1	-4,421E-05	-4,326E-06	-5,500E-06	-2,225E-05	-2,692E-05	111	111
7	1	2	-4,421E-05	-9,962E-06	-1,103E-05	-4,304E-05	-4,731E-05	111	111
7	1	3	-4,421E-05	-1,560E-05	-1,657E-05	-6,383E-05	-6,769E-05	111	111
7	2	1	-4,421E-05	-2,092E-05	-2,179E-05	-8,345E-05	-8,693E-05	111	111
7	3	1	-4,421E-05	-2,593E-05	-2,671E-05	-1,019E-04	-1,051E-04	111	111
7	4	1	-4,421E-05	-2,440E-05	-2,521E-05	-9,631E-05	-9,954E-05	111	111
7	4	2	-4,421E-05	-3,638E-05	-3,697E-05	-1,405E-04	-1,429E-04	111	111
7	4	3	-4,421E-05	-4,836E-05	-4,873E-05	-1,847E-04	-1,862E-04	111	111
7	4	4	-4,421E-05	-6,034E-05	-6,049E-05	-2,288E-04	-2,295E-04	111	111
7	4	5	-4,421E-05	-7,231E-05	-7,225E-05	-2,730E-04	-2,728E-04	111	111
7	4	6	-4,421E-05	-8,429E-05	-8,401E-05	-3,172E-04	-3,161E-04	111	111
7	4	7	-4,421E-05	-9,639E-05	-9,590E-05	-3,613E-04	-3,593E-04	111	111
7	4	8	-4,421E-05	-1,084E-04	-1,077E-04	-4,054E-04	-4,026E-04	111	111
7	5	1	-4,421E-05	-1,050E-04	-1,043E-04	-3,929E-04	-3,903E-04	111	111
7	6	1	-4,421E-05	-1,112E-04	-1,105E-04	-4,160E-04	-4,129E-04	111	111
7	7	1	-4,421E-05	-1,172E-04	-1,163E-04	-4,379E-04	-4,345E-04	111	111
7	7	2	-4,421E-05	-1,228E-04	-1,218E-04	-4,587E-04	-4,548E-04	111	111
7	7	3	-4,421E-05	-1,284E-04	-1,274E-04	-4,795E-04	-4,752E-04	111	111
7	7	4	-4,421E-05	-1,341E-04	-1,329E-04	-5,003E-04	-4,956E-04	111	111
7	8	1	0,000E+00	0,000E+00	0,000E+00	-9,721E-05	-1,025E-04	111	111
7	9	1	0,000E+00	0,000E+00	0,000E+00	-5,663E-04	-5,626E-04	111	111
7	10	1	0,000E+00	0,000E+00	0,000E+00	-6,522E-04	-6,468E-04	111	111
7	11	1	0,000E+00	1,454E-04	1,454E-04	3,662E-03	3,663E-03	111	111
7	12	1	0,000E+00	1,578E-04	1,578E-04	3,713E-03	3,714E-03	111	111
8	1	1	-4,421E-05	-5,935E-07	-1,681E-06	-8,777E-06	-1,310E-05	111	111
8	1	2	-4,421E-05	-6,511E-06	-7,503E-06	-3,057E-05	-3,452E-05	111	111

8	1	3	-4,421E-05	-1,243E-05	-1,333E-05	-5,236E-05	-5,593E-05	111	111
8	2	1	-4,421E-05	-1,801E-05	-1,882E-05	-7,294E-05	-7,615E-05	111	111
8	3	1	-4,421E-05	-2,327E-05	-2,400E-05	-9,231E-05	-9,519E-05	111	111
8	4	1	-4,421E-05	-2,167E-05	-2,242E-05	-8,642E-05	-8,940E-05	111	111
8	4	2	-4,421E-05	-3,425E-05	-3,480E-05	-1,327E-04	-1,349E-04	111	111
8	4	3	-4,421E-05	-4,682E-05	-4,717E-05	-1,790E-04	-1,804E-04	111	111
8	4	4	-4,421E-05	-5,940E-05	-5,954E-05	-2,253E-04	-2,259E-04	111	111
8	4	5	-4,421E-05	-7,197E-05	-7,192E-05	-2,717E-04	-2,714E-04	111	111
8	4	6	-4,421E-05	-8,454E-05	-8,429E-05	-3,180E-04	-3,170E-04	111	111
8	4	7	-4,421E-05	-9,724E-05	-9,678E-05	-3,642E-04	-3,623E-04	111	111
8	4	8	-4,421E-05	-1,098E-04	-1,092E-04	-4,105E-04	-4,079E-04	111	111
8	5	1	-4,421E-05	-1,062E-04	-1,056E-04	-3,973E-04	-3,949E-04	111	111
8	6	1	-4,421E-05	-1,128E-04	-1,121E-04	-4,215E-04	-4,187E-04	111	111
8	7	1	-4,421E-05	-1,191E-04	-1,183E-04	-4,445E-04	-4,413E-04	111	111
8	7	2	-4,421E-05	-1,250E-04	-1,241E-04	-4,663E-04	-4,627E-04	111	111
8	7	3	-4,421E-05	-1,309E-04	-1,299E-04	-4,881E-04	-4,842E-04	111	111
8	7	4	-4,421E-05	-1,368E-04	-1,357E-04	-5,099E-04	-5,056E-04	111	111
8	8	1	0,000E+00	0,000E+00	0,000E+00	-8,129E-05	-8,623E-05	111	111
8	9	1	0,000E+00	0,000E+00	0,000E+00	-5,732E-04	-5,697E-04	111	111
8	10	1	0,000E+00	0,000E+00	0,000E+00	-6,632E-04	-6,583E-04	111	111
8	11	1	0,000E+00	1,424E-04	1,424E-04	3,645E-03	3,645E-03	111	111
8	12	1	0,000E+00	1,564E-04	1,564E-04	3,704E-03	3,705E-03	111	111
9	1	1	-4,421E-05	7,863E-07	-2,140E-07	-4,141E-06	-8,113E-06	111	111
9	1	2	-4,421E-05	-5,222E-06	-6,135E-06	-2,623E-05	-2,986E-05	111	111
9	1	3	-4,421E-05	-1,123E-05	-1,206E-05	-4,833E-05	-5,161E-05	111	111
9	2	1	-4,421E-05	-1,690E-05	-1,765E-05	-6,918E-05	-7,214E-05	111	111
9	3	1	-4,421E-05	-2,224E-05	-2,291E-05	-8,882E-05	-9,147E-05	111	111
9	4	1	-4,421E-05	-2,062E-05	-2,131E-05	-8,285E-05	-8,559E-05	111	111
9	4	2	-4,421E-05	-3,339E-05	-3,389E-05	-1,298E-04	-1,318E-04	111	111
9	4	3	-4,421E-05	-4,615E-05	-4,647E-05	-1,767E-04	-1,780E-04	111	111
9	4	4	-4,421E-05	-5,892E-05	-5,906E-05	-2,237E-04	-2,242E-04	111	111
9	4	5	-4,421E-05	-7,169E-05	-7,164E-05	-2,706E-04	-2,704E-04	111	111
9	4	6	-4,421E-05	-8,446E-05	-8,422E-05	-3,176E-04	-3,166E-04	111	111
9	4	7	-4,421E-05	-9,735E-05	-9,693E-05	-3,644E-04	-3,627E-04	111	111
9	4	8	-4,421E-05	-1,101E-04	-1,095E-04	-4,113E-04	-4,090E-04	111	111
9	5	1	-4,421E-05	-1,065E-04	-1,059E-04	-3,980E-04	-3,958E-04	111	111
9	6	1	-4,421E-05	-1,132E-04	-1,125E-04	-4,225E-04	-4,200E-04	111	111
9	7	1	-4,421E-05	-1,195E-04	-1,188E-04	-4,459E-04	-4,429E-04	111	111
9	7	2	-4,421E-05	-1,255E-04	-1,247E-04	-4,680E-04	-4,647E-04	111	111
9	7	3	-4,421E-05	-1,315E-04	-1,306E-04	-4,901E-04	-4,864E-04	111	111
9	7	4	-4,421E-05	-1,375E-04	-1,365E-04	-5,121E-04	-5,082E-04	111	111
9	8	1	0,000E+00	0,000E+00	0,000E+00	-7,567E-05	-8,021E-05	111	111
9	9	1	0,000E+00	0,000E+00	0,000E+00	-5,745E-04	-5,713E-04	111	111
9	10	1	0,000E+00	0,000E+00	0,000E+00	-6,658E-04	-6,612E-04	111	111
9	11	1	0,000E+00	1,395E-04	1,395E-04	3,629E-03	3,629E-03	111	111
9	12	1	0,000E+00	1,550E-04	1,550E-04	3,697E-03	3,697E-03	111	111
10	1	1	-4,421E-05	-1,573E-07	-1,071E-06	-8,219E-06	-1,184E-05	111	111
10	1	2	-4,421E-05	-6,069E-06	-6,903E-06	-2,992E-05	-3,323E-05	111	111
10	1	3	-4,421E-05	-1,198E-05	-1,274E-05	-5,161E-05	-5,461E-05	111	111
10	2	1	-4,421E-05	-1,756E-05	-1,824E-05	-7,210E-05	-7,479E-05	111	111
10	3	1	-4,421E-05	-2,282E-05	-2,343E-05	-9,139E-05	-9,380E-05	111	111
10	4	1	-4,421E-05	-2,122E-05	-2,185E-05	-8,552E-05	-8,802E-05	111	111
10	4	2	-4,421E-05	-3,378E-05	-3,424E-05	-1,316E-04	-1,335E-04	111	111
10	4	3	-4,421E-05	-4,634E-05	-4,664E-05	-1,777E-04	-1,789E-04	111	111
10	4	4	-4,421E-05	-5,891E-05	-5,903E-05	-2,238E-04	-2,243E-04	111	111
10	4	5	-4,421E-05	-7,147E-05	-7,142E-05	-2,699E-04	-2,698E-04	111	111
10	4	6	-4,421E-05	-8,403E-05	-8,382E-05	-3,161E-04	-3,152E-04	111	111
10	4	7	-4,421E-05	-9,672E-05	-9,633E-05	-3,620E-04	-3,605E-04	111	111
10	4	8	-4,421E-05	-1,093E-04	-1,087E-04	-4,081E-04	-4,060E-04	111	111
10	5	1	-4,421E-05	-1,057E-04	-1,052E-04	-3,950E-04	-3,930E-04	111	111
10	6	1	-4,421E-05	-1,123E-04	-1,117E-04	-4,191E-04	-4,168E-04	111	111
10	7	1	-4,421E-05	-1,185E-04	-1,178E-04	-4,421E-04	-4,394E-04	111	111

10	7	2	-4.421E-05	-1.244E-04	-1.237E-04	-4.637E-04	-4.608E-04	111	111
10	7	3	-4.421E-05	-1.303E-04	-1.295E-04	-4.854E-04	-4.821E-04	111	111
10	7	4	-4.421E-05	-1.363E-04	-1.353E-04	-5.071E-04	-5.035E-04	111	111
10	8	1	0.000E+00	0.000E+00	0.000E+00	-8.020E-05	-8.434E-05	111	111
10	9	1	0.000E+00	0.000E+00	0.000E+00	-5.703E-04	-5.674E-04	111	111
10	10	1	0.000E+00	0.000E+00	0.000E+00	-6.600E-04	-6.559E-04	111	111
10	11	1	0.000E+00	1.366E-04	1.366E-04	3.614E-03	3.615E-03	111	111
10	12	1	0.000E+00	1.536E-04	1.536E-04	3.690E-03	3.691E-03	111	111
11	1	1	-4.421E-05	-2.118E-06	-2.944E-06	-1.610E-05	-1.938E-05	111	111
11	1	2	-4.421E-05	-7.866E-06	-8.621E-06	-3.715E-05	-4.015E-05	111	111
11	1	3	-4.421E-05	-1.361E-05	-1.430E-05	-5.820E-05	-6.091E-05	111	111
11	2	1	-4.421E-05	-1.904E-05	-1.966E-05	-7.807E-05	-8.051E-05	111	111
11	3	1	-4.421E-05	-2.415E-05	-2.470E-05	-9.679E-05	-9.897E-05	111	111
11	4	1	-4.421E-05	-2.260E-05	-2.317E-05	-9.109E-05	-9.336E-05	111	111
11	4	2	-4.421E-05	-3.481E-05	-3.523E-05	-1.358E-04	-1.375E-04	111	111
11	4	3	-4.421E-05	-4.702E-05	-4.729E-05	-1.806E-04	-1.816E-04	111	111
11	4	4	-4.421E-05	-5.924E-05	-5.935E-05	-2.253E-04	-2.257E-04	111	111
11	4	5	-4.421E-05	-7.145E-05	-7.141E-05	-2.700E-04	-2.699E-04	111	111
11	4	6	-4.421E-05	-8.367E-05	-8.348E-05	-3.147E-04	-3.140E-04	111	111
11	4	7	-4.421E-05	-9.601E-05	-9.566E-05	-3.594E-04	-3.580E-04	111	111
11	4	8	-4.421E-05	-1.082E-04	-1.077E-04	-4.041E-04	-4.021E-04	111	111
11	5	1	-4.421E-05	-1.047E-04	-1.043E-04	-3.914E-04	-3.895E-04	111	111
11	6	1	-4.421E-05	-1.111E-04	-1.106E-04	-4.147E-04	-4.126E-04	111	111
11	7	1	-4.421E-05	-1.172E-04	-1.166E-04	-4.370E-04	-4.345E-04	111	111
11	7	2	-4.421E-05	-1.229E-04	-1.223E-04	-4.580E-04	-4.553E-04	111	111
11	7	3	-4.421E-05	-1.287E-04	-1.279E-04	-4.791E-04	-4.761E-04	111	111
11	7	4	-4.421E-05	-1.344E-04	-1.336E-04	-5.001E-04	-4.968E-04	111	111
11	8	1	0.000E+00	0.000E+00	0.000E+00	-8.923E-05	-9.298E-05	111	111
11	9	1	0.000E+00	0.000E+00	0.000E+00	-5.649E-04	-5.623E-04	111	111
11	10	1	0.000E+00	0.000E+00	0.000E+00	-6.520E-04	-6.482E-04	111	111
11	11	1	0.000E+00	1.361E-04	1.361E-04	3.612E-03	3.613E-03	111	111
11	12	1	0.000E+00	1.530E-04	1.530E-04	3.689E-03	3.689E-03	111	111
12	1	1	-4.421E-05	-3.876E-06	-4.615E-06	-2.318E-05	-2.611E-05	111	111
12	1	2	-4.421E-05	-9.480E-06	-1.015E-05	-4.365E-05	-4.633E-05	111	111
12	1	3	-4.421E-05	-1.508E-05	-1.569E-05	-6.413E-05	-6.655E-05	111	111
12	2	1	-4.421E-05	-2.037E-05	-2.092E-05	-8.346E-05	-8.564E-05	111	111
12	3	1	-4.421E-05	-2.535E-05	-2.585E-05	-1.017E-04	-1.036E-04	111	111
12	4	1	-4.421E-05	-2.384E-05	-2.435E-05	-9.612E-05	-9.815E-05	111	111
12	4	2	-4.421E-05	-3.575E-05	-3.612E-05	-1.396E-04	-1.411E-04	111	111
12	4	3	-4.421E-05	-4.765E-05	-4.789E-05	-1.831E-04	-1.841E-04	111	111
12	4	4	-4.421E-05	-5.956E-05	-5.966E-05	-2.267E-04	-2.271E-04	111	111
12	4	5	-4.421E-05	-7.147E-05	-7.143E-05	-2.702E-04	-2.700E-04	111	111
12	4	6	-4.421E-05	-8.338E-05	-8.321E-05	-3.137E-04	-3.130E-04	111	111
12	4	7	-4.421E-05	-9.541E-05	-9.510E-05	-3.571E-04	-3.558E-04	111	111
12	4	8	-4.421E-05	-1.073E-04	-1.069E-04	-4.006E-04	-3.988E-04	111	111
12	5	1	-4.421E-05	-1.039E-04	-1.035E-04	-3.882E-04	-3.866E-04	111	111
12	6	1	-4.421E-05	-1.102E-04	-1.097E-04	-4.110E-04	-4.091E-04	111	111
12	7	1	-4.421E-05	-1.161E-04	-1.155E-04	-4.326E-04	-4.304E-04	111	111
12	7	2	-4.421E-05	-1.217E-04	-1.211E-04	-4.530E-04	-4.506E-04	111	111
12	7	3	-4.421E-05	-1.273E-04	-1.266E-04	-4.735E-04	-4.708E-04	111	111
12	7	4	-4.421E-05	-1.329E-04	-1.321E-04	-4.940E-04	-4.911E-04	111	111
12	8	1	0.000E+00	0.000E+00	0.000E+00	-9.734E-05	-1.007E-04	111	111
12	9	1	0.000E+00	0.000E+00	0.000E+00	-5.603E-04	-5.579E-04	111	111
12	10	1	0.000E+00	0.000E+00	0.000E+00	-6.450E-04	-6.417E-04	111	111
12	11	1	0.000E+00	1.359E-04	1.359E-04	3.612E-03	3.612E-03	111	111
12	12	1	0.000E+00	1.528E-04	1.528E-04	3.689E-03	3.689E-03	111	111
13	1	1	-4.421E-05	-5.444E-06	-6.097E-06	-2.949E-05	-3.208E-05	111	111
13	1	2	-4.421E-05	-1.092E-05	-1.151E-05	-4.945E-05	-5.182E-05	111	111
13	1	3	-4.421E-05	-1.639E-05	-1.693E-05	-6.942E-05	-7.156E-05	111	111
13	2	1	-4.421E-05	-2.156E-05	-2.205E-05	-8.826E-05	-9.019E-05	111	111
13	3	1	-4.421E-05	-2.643E-05	-2.686E-05	-1.060E-04	-1.077E-04	111	111
13	4	1	-4.421E-05	-2.495E-05	-2.540E-05	-1.006E-04	-1.024E-04	111	111

13	4	2	-4,421E-05	-3,658E-05	-3,691E-05	-1,430E-04	-1,443E-04	111	111
13	4	3	-4,421E-05	-4,821E-05	-4,842E-05	-1,855E-04	-1,863E-04	111	111
13	4	4	-4,421E-05	-5,985E-05	-5,994E-05	-2,279E-04	-2,282E-04	111	111
13	4	5	-4,421E-05	-7,148E-05	-7,145E-05	-2,703E-04	-2,702E-04	111	111
13	4	6	-4,421E-05	-8,312E-05	-8,296E-05	-3,127E-04	-3,121E-04	111	111
13	4	7	-4,421E-05	-9,487E-05	-9,460E-05	-3,550E-04	-3,539E-04	111	111
13	4	8	-4,421E-05	-1,065E-04	-1,061E-04	-3,974E-04	-3,959E-04	111	111
13	5	1	-4,421E-05	-1,032E-04	-1,028E-04	-3,854E-04	-3,839E-04	111	111
13	6	1	-4,421E-05	-1,093E-04	-1,089E-04	-4,076E-04	-4,059E-04	111	111
13	7	1	-4,421E-05	-1,151E-04	-1,146E-04	-4,286E-04	-4,267E-04	111	111
13	7	2	-4,421E-05	-1,205E-04	-1,200E-04	-4,486E-04	-4,465E-04	111	111
13	7	3	-4,421E-05	-1,260E-04	-1,254E-04	-4,686E-04	-4,662E-04	111	111
13	7	4	-4,421E-05	-1,315E-04	-1,308E-04	-4,885E-04	-4,859E-04	111	111
13	8	1	0,000E+00	0,000E+00	0,000E+00	-1,046E-04	-1,075E-04	111	111
13	9	1	0,000E+00	0,000E+00	0,000E+00	-5,561E-04	-5,541E-04	111	111
13	10	1	0,000E+00	0,000E+00	0,000E+00	-6,388E-04	-6,358E-04	111	111
13	11	1	0,000E+00	1,356E-04	1,356E-04	3,611E-03	3,612E-03	111	111
13	12	1	0,000E+00	1,525E-04	1,525E-04	3,689E-03	3,689E-03	111	111
14	1	1	-4,421E-05	-6,823E-06	-7,389E-06	-3,504E-05	-3,728E-05	111	111
14	1	2	-4,421E-05	-1,218E-05	-1,270E-05	-5,455E-05	-5,660E-05	111	111
14	1	3	-4,421E-05	-1,755E-05	-1,801E-05	-7,406E-05	-7,592E-05	111	111
14	2	1	-4,421E-05	-2,261E-05	-2,303E-05	-9,248E-05	-9,415E-05	111	111
14	3	1	-4,421E-05	-2,737E-05	-2,775E-05	-1,098E-04	-1,113E-04	111	111
14	4	1	-4,421E-05	-2,592E-05	-2,631E-05	-1,045E-04	-1,061E-04	111	111
14	4	2	-4,421E-05	-3,731E-05	-3,760E-05	-1,460E-04	-1,471E-04	111	111
14	4	3	-4,421E-05	-4,871E-05	-4,889E-05	-1,875E-04	-1,882E-04	111	111
14	4	4	-4,421E-05	-6,010E-05	-6,017E-05	-2,289E-04	-2,292E-04	111	111
14	4	5	-4,421E-05	-7,149E-05	-7,146E-05	-2,704E-04	-2,703E-04	111	111
14	4	6	-4,421E-05	-8,288E-05	-8,275E-05	-3,119E-04	-3,113E-04	111	111
14	4	7	-4,421E-05	-9,439E-05	-9,416E-05	-3,532E-04	-3,523E-04	111	111
14	4	8	-4,421E-05	-1,058E-04	-1,054E-04	-3,947E-04	-3,933E-04	111	111
14	5	1	-4,421E-05	-1,025E-04	-1,022E-04	-3,829E-04	-3,816E-04	111	111
14	6	1	-4,421E-05	-1,085E-04	-1,081E-04	-4,045E-04	-4,031E-04	111	111
14	7	1	-4,421E-05	-1,142E-04	-1,137E-04	-4,251E-04	-4,235E-04	111	111
14	7	2	-4,421E-05	-1,195E-04	-1,191E-04	-4,447E-04	-4,428E-04	111	111
14	7	3	-4,421E-05	-1,249E-04	-1,244E-04	-4,642E-04	-4,621E-04	111	111
14	7	4	-4,421E-05	-1,302E-04	-1,297E-04	-4,837E-04	-4,814E-04	111	111
14	8	1	0,000E+00	0,000E+00	0,000E+00	-1,109E-04	-1,135E-04	111	111
14	9	1	0,000E+00	0,000E+00	0,000E+00	-5,524E-04	-5,507E-04	111	111
14	10	1	0,000E+00	0,000E+00	0,000E+00	-6,333E-04	-6,307E-04	111	111
14	11	1	0,000E+00	1,354E-04	1,354E-04	3,611E-03	3,611E-03	111	111
14	12	1	0,000E+00	1,523E-04	1,523E-04	3,688E-03	3,689E-03	111	111
15	1	1	-4,421E-05	-8,013E-06	-8,491E-06	-3,982E-05	-4,172E-05	111	111
15	1	2	-4,421E-05	-1,328E-05	-1,371E-05	-5,895E-05	-6,068E-05	111	111
15	1	3	-4,421E-05	-1,854E-05	-1,893E-05	-7,807E-05	-7,963E-05	111	111
15	2	1	-4,421E-05	-2,351E-05	-2,386E-05	-9,612E-05	-9,753E-05	111	111
15	3	1	-4,421E-05	-2,818E-05	-2,850E-05	-1,131E-04	-1,144E-04	111	111
15	4	1	-4,421E-05	-2,676E-05	-2,709E-05	-1,079E-04	-1,093E-04	111	111
15	4	2	-4,421E-05	-3,794E-05	-3,818E-05	-1,486E-04	-1,495E-04	111	111
15	4	3	-4,421E-05	-4,913E-05	-4,928E-05	-1,892E-04	-1,898E-04	111	111
15	4	4	-4,421E-05	-6,031E-05	-6,037E-05	-2,298E-04	-2,301E-04	111	111
15	4	5	-4,421E-05	-7,149E-05	-7,147E-05	-2,705E-04	-2,704E-04	111	111
15	4	6	-4,421E-05	-8,267E-05	-8,256E-05	-3,111E-04	-3,107E-04	111	111
15	4	7	-4,421E-05	-9,398E-05	-9,378E-05	-3,516E-04	-3,508E-04	111	111
15	4	8	-4,421E-05	-1,052E-04	-1,049E-04	-3,922E-04	-3,911E-04	111	111
15	5	1	-4,421E-05	-1,020E-04	-1,017E-04	-3,807E-04	-3,796E-04	111	111
15	6	1	-4,421E-05	-1,078E-04	-1,075E-04	-4,019E-04	-4,007E-04	111	111
15	7	1	-4,421E-05	-1,134E-04	-1,130E-04	-4,221E-04	-4,207E-04	111	111
15	7	2	-4,421E-05	-1,186E-04	-1,182E-04	-4,412E-04	-4,397E-04	111	111
15	7	3	-4,421E-05	-1,239E-04	-1,235E-04	-4,604E-04	-4,586E-04	111	111
15	7	4	-4,421E-05	-1,292E-04	-1,287E-04	-4,795E-04	-4,776E-04	111	111
15	8	1	0,000E+00	0,000E+00	0,000E+00	-1,164E-04	-1,186E-04	111	111

365

15	9	1	0,000E+00	0,000E+00	0,000E+00	-5,492E-04	-5,477E-04	111	111
15	10	1	0,000E+00	0,000E+00	0,000E+00	-6,285E-04	-6,263E-04	111	111
15	11	1	0,000E+00	1,352E-04	1,352E-04	3,610E-03	3,611E-03	111	111
15	12	1	0,000E+00	1,521E-04	1,521E-04	3,688E-03	3,688E-03	111	111
16	1	1	-4,421E-05	-9,013E-06	-9,405E-06	-4,385E-05	-4,540E-05	111	111
16	1	2	-4,421E-05	-1,419E-05	-1,455E-05	-6,264E-05	-6,406E-05	111	111
16	1	3	-4,421E-05	-1,937E-05	-1,969E-05	-8,143E-05	-8,271E-05	111	111
16	2	1	-4,421E-05	-2,426E-05	-2,455E-05	-9,917E-05	-1,003E-04	111	111
16	3	1	-4,421E-05	-2,887E-05	-2,913E-05	-1,159E-04	-1,169E-04	111	111
16	4	1	-4,421E-05	-2,746E-05	-2,773E-05	-1,108E-04	-1,119E-04	111	111
16	4	2	-4,421E-05	-3,847E-05	-3,867E-05	-1,507E-04	-1,515E-04	111	111
16	4	3	-4,421E-05	-4,948E-05	-4,960E-05	-1,907E-04	-1,912E-04	111	111
16	4	4	-4,421E-05	-6,048E-05	-6,054E-05	-2,306E-04	-2,308E-04	111	111
16	4	5	-4,421E-05	-7,149E-05	-7,147E-05	-2,705E-04	-2,704E-04	111	111
16	4	6	-4,421E-05	-8,249E-05	-8,240E-05	-3,104E-04	-3,101E-04	111	111
16	4	7	-4,421E-05	-9,362E-05	-9,346E-05	-3,503E-04	-3,496E-04	111	111
16	4	8	-4,421E-05	-1,046E-04	-1,044E-04	-3,902E-04	-3,893E-04	111	111
16	5	1	-4,421E-05	-1,015E-04	-1,013E-04	-3,788E-04	-3,780E-04	111	111
16	6	1	-4,421E-05	-1,073E-04	-1,070E-04	-3,997E-04	-3,987E-04	111	111
16	7	1	-4,421E-05	-1,127E-04	-1,124E-04	-4,195E-04	-4,184E-04	111	111
16	7	2	-4,421E-05	-1,179E-04	-1,176E-04	-4,383E-04	-4,371E-04	111	111
16	7	3	-4,421E-05	-1,231E-04	-1,227E-04	-4,571E-04	-4,557E-04	111	111
16	7	4	-4,421E-05	-1,283E-04	-1,279E-04	-4,759E-04	-4,744E-04	111	111
16	8	1	0,000E+00	0,000E+00	0,000E+00	-1,210E-04	-1,228E-04	111	111
16	9	1	0,000E+00	0,000E+00	0,000E+00	-5,465E-04	-5,453E-04	111	111
16	10	1	0,000E+00	0,000E+00	0,000E+00	-6,244E-04	-6,226E-04	111	111
16	11	1	0,000E+00	1,350E-04	1,350E-04	3,610E-03	3,610E-03	111	111
16	12	1	0,000E+00	1,518E-04	1,518E-04	3,687E-03	3,688E-03	111	111
17	1	1	-4,421E-05	-9,824E-06	-1,013E-05	-4,710E-05	-4,831E-05	111	111
17	1	2	-4,421E-05	-1,494E-05	-1,521E-05	-6,563E-05	-6,673E-05	111	111
17	1	3	-4,421E-05	-2,005E-05	-2,030E-05	-8,415E-05	-8,515E-05	111	111
17	2	1	-4,421E-05	-2,487E-05	-2,510E-05	-1,016E-04	-1,025E-04	111	111
17	3	1	-4,421E-05	-2,942E-05	-2,962E-05	-1,181E-04	-1,189E-04	111	111
17	4	1	-4,421E-05	-2,803E-05	-2,824E-05	-1,131E-04	-1,139E-04	111	111
17	4	2	-4,421E-05	-3,889E-05	-3,905E-05	-1,525E-04	-1,531E-04	111	111
17	4	3	-4,421E-05	-4,976E-05	-4,985E-05	-1,918E-04	-1,922E-04	111	111
17	4	4	-4,421E-05	-6,062E-05	-6,066E-05	-2,312E-04	-2,313E-04	111	111
17	4	5	-4,421E-05	-7,148E-05	-7,147E-05	-2,705E-04	-2,705E-04	111	111
17	4	6	-4,421E-05	-8,234E-05	-8,227E-05	-3,099E-04	-3,096E-04	111	111
17	4	7	-4,421E-05	-9,333E-05	-9,320E-05	-3,491E-04	-3,486E-04	111	111
17	4	8	-4,421E-05	-1,042E-04	-1,040E-04	-3,885E-04	-3,878E-04	111	111
17	5	1	-4,421E-05	-1,011E-04	-1,009E-04	-3,773E-04	-3,766E-04	111	111
17	6	1	-4,421E-05	-1,068E-04	-1,066E-04	-3,979E-04	-3,971E-04	111	111
17	7	1	-4,421E-05	-1,122E-04	-1,119E-04	-4,174E-04	-4,165E-04	111	111
17	7	2	-4,421E-05	-1,173E-04	-1,170E-04	-4,360E-04	-4,350E-04	111	111
17	7	3	-4,421E-05	-1,224E-04	-1,221E-04	-4,545E-04	-4,534E-04	111	111
17	7	4	-4,421E-05	-1,275E-04	-1,272E-04	-4,730E-04	-4,718E-04	111	111
17	8	1	0,000E+00	0,000E+00	0,000E+00	-1,248E-04	-1,262E-04	111	111
17	9	1	0,000E+00	0,000E+00	0,000E+00	-5,443E-04	-5,433E-04	111	111
17	10	1	0,000E+00	0,000E+00	0,000E+00	-6,211E-04	-6,197E-04	111	111
17	11	1	0,000E+00	1,348E-04	1,348E-04	3,609E-03	3,609E-03	111	111
17	12	1	0,000E+00	1,516E-04	1,516E-04	3,687E-03	3,687E-03	111	111
18	1	1	-4,421E-05	-1,045E-05	-1,066E-05	-4,960E-05	-5,046E-05	111	111
18	1	2	-4,421E-05	-1,550E-05	-1,570E-05	-6,791E-05	-6,870E-05	111	111
18	1	3	-4,421E-05	-2,056E-05	-2,074E-05	-8,623E-05	-8,694E-05	111	111
18	2	1	-4,421E-05	-2,534E-05	-2,550E-05	-1,035E-04	-1,042E-04	111	111
18	3	1	-4,421E-05	-2,984E-05	-2,998E-05	-1,198E-04	-1,204E-04	111	111
18	4	1	-4,421E-05	-2,847E-05	-2,862E-05	-1,148E-04	-1,154E-04	111	111
18	4	2	-4,421E-05	-3,922E-05	-3,933E-05	-1,538E-04	-1,542E-04	111	111
18	4	3	-4,421E-05	-4,997E-05	-5,004E-05	-1,927E-04	-1,930E-04	111	111
18	4	4	-4,421E-05	-6,072E-05	-6,075E-05	-2,316E-04	-2,317E-04	111	111
18	4	5	-4,421E-05	-7,147E-05	-7,146E-05	-2,705E-04	-2,705E-04	111	111

18	4	6	-4,421E-05	-8,222E-05	-8,217E-05	-3,094E-04	-3,092E-04	111	111
18	4	7	-4,421E-05	-9,309E-05	-9,300E-05	-3,482E-04	-3,479E-04	111	111
18	4	8	-4,421E-05	-1,038E-04	-1,037E-04	-3,872E-04	-3,866E-04	111	111
18	5	1	-4,421E-05	-1,008E-04	-1,007E-04	-3,761E-04	-3,756E-04	111	111
18	6	1	-4,421E-05	-1,064E-04	-1,063E-04	-3,964E-04	-3,959E-04	111	111
18	7	1	-4,421E-05	-1,117E-04	-1,116E-04	-4,158E-04	-4,151E-04	111	111
18	7	2	-4,421E-05	-1,168E-04	-1,166E-04	-4,341E-04	-4,334E-04	111	111
18	7	3	-4,421E-05	-1,219E-04	-1,217E-04	-4,524E-04	-4,516E-04	111	111
18	7	4	-4,421E-05	-1,269E-04	-1,267E-04	-4,707E-04	-4,699E-04	111	111
18	8	1	0,000E+00	0,000E+00	0,000E+00	-1,276E-04	-1,286E-04	111	111
18	9	1	0,000E+00	0,000E+00	0,000E+00	-5,425E-04	-5,418E-04	111	111
18	10	1	0,000E+00	0,000E+00	0,000E+00	-6,185E-04	-6,175E-04	111	111
18	11	1	0,000E+00	1,345E-04	1,345E-04	3,608E-03	3,608E-03	111	111
18	12	1	0,000E+00	1,514E-04	1,514E-04	3,686E-03	3,686E-03	111	111
19	1	1	-4,421E-05	-1,088E-05	-1,101E-05	-5,133E-05	-5,185E-05	111	111
19	1	2	-4,421E-05	-1,590E-05	-1,602E-05	-6,950E-05	-6,997E-05	111	111
19	1	3	-4,421E-05	-2,092E-05	-2,103E-05	-8,767E-05	-8,809E-05	111	111
19	2	1	-4,421E-05	-2,566E-05	-2,576E-05	-1,048E-04	-1,052E-04	111	111
19	3	1	-4,421E-05	-3,012E-05	-3,021E-05	-1,210E-04	-1,213E-04	111	111
19	4	1	-4,421E-05	-2,877E-05	-2,886E-05	-1,161E-04	-1,164E-04	111	111
19	4	2	-4,421E-05	-3,944E-05	-3,950E-05	-1,547E-04	-1,549E-04	111	111
19	4	3	-4,421E-05	-5,011E-05	-5,015E-05	-1,933E-04	-1,934E-04	111	111
19	4	4	-4,421E-05	-6,078E-05	-6,080E-05	-2,319E-04	-2,320E-04	111	111
19	4	5	-4,421E-05	-7,145E-05	-7,144E-05	-2,705E-04	-2,705E-04	111	111
19	4	6	-4,421E-05	-8,212E-05	-8,209E-05	-3,091E-04	-3,090E-04	111	111
19	4	7	-4,421E-05	-9,291E-05	-9,286E-05	-3,476E-04	-3,474E-04	111	111
19	4	8	-4,421E-05	-1,036E-04	-1,035E-04	-3,862E-04	-3,859E-04	111	111
19	5	1	-4,421E-05	-1,005E-04	-1,005E-04	-3,752E-04	-3,749E-04	111	111
19	6	1	-4,421E-05	-1,061E-04	-1,060E-04	-3,954E-04	-3,951E-04	111	111
19	7	1	-4,421E-05	-1,114E-04	-1,113E-04	-4,146E-04	-4,142E-04	111	111
19	7	2	-4,421E-05	-1,165E-04	-1,163E-04	-4,327E-04	-4,323E-04	111	111
19	7	3	-4,421E-05	-1,215E-04	-1,214E-04	-4,509E-04	-4,504E-04	111	111
19	7	4	-4,421E-05	-1,265E-04	-1,264E-04	-4,691E-04	-4,686E-04	111	111
19	8	1	0,000E+00	0,000E+00	0,000E+00	-1,296E-04	-1,302E-04	111	111
19	9	1	0,000E+00	0,000E+00	0,000E+00	-5,412E-04	-5,408E-04	111	111
19	10	1	0,000E+00	0,000E+00	0,000E+00	-6,166E-04	-6,160E-04	111	111
19	11	1	0,000E+00	1,343E-04	1,343E-04	3,607E-03	3,607E-03	111	111
19	12	1	0,000E+00	1,511E-04	1,511E-04	3,685E-03	3,685E-03	111	111
20	1	1	-4,421E-05	-1,112E-05	-1,116E-05	-5,230E-05	-5,247E-05	111	111
20	1	2	-4,421E-05	-1,612E-05	-1,616E-05	-7,038E-05	-7,054E-05	111	111
20	1	3	-4,421E-05	-2,112E-05	-2,115E-05	-8,846E-05	-8,861E-05	111	111
20	2	1	-4,421E-05	-2,584E-05	-2,587E-05	-1,055E-04	-1,057E-04	111	111
20	3	1	-4,421E-05	-3,028E-05	-3,031E-05	-1,216E-04	-1,217E-04	111	111
20	4	1	-4,421E-05	-2,893E-05	-2,896E-05	-1,167E-04	-1,168E-04	111	111
20	4	2	-4,421E-05	-3,955E-05	-3,958E-05	-1,551E-04	-1,552E-04	111	111
20	4	3	-4,421E-05	-5,018E-05	-5,019E-05	-1,936E-04	-1,936E-04	111	111
20	4	4	-4,421E-05	-6,080E-05	-6,081E-05	-2,320E-04	-2,320E-04	111	111
20	4	5	-4,421E-05	-7,143E-05	-7,143E-05	-2,704E-04	-2,704E-04	111	111
20	4	6	-4,421E-05	-8,205E-05	-8,204E-05	-3,088E-04	-3,088E-04	111	111
20	4	7	-4,421E-05	-9,280E-05	-9,278E-05	-3,472E-04	-3,471E-04	111	111
20	4	8	-4,421E-05	-1,034E-04	-1,034E-04	-3,856E-04	-3,855E-04	111	111
20	5	1	-4,421E-05	-1,004E-04	-1,004E-04	-3,746E-04	-3,746E-04	111	111
20	6	1	-4,421E-05	-1,060E-04	-1,059E-04	-3,947E-04	-3,946E-04	111	111
20	7	1	-4,421E-05	-1,112E-04	-1,112E-04	-4,138E-04	-4,137E-04	111	111
20	7	2	-4,421E-05	-1,162E-04	-1,162E-04	-4,319E-04	-4,318E-04	111	111
20	7	3	-4,421E-05	-1,212E-04	-1,212E-04	-4,500E-04	-4,498E-04	111	111
20	7	4	-4,421E-05	-1,262E-04	-1,262E-04	-4,681E-04	-4,679E-04	111	111
20	8	1	0,000E+00	0,000E+00	0,000E+00	-1,307E-04	-1,309E-04	111	111
20	9	1	0,000E+00	0,000E+00	0,000E+00	-5,400E-04	-5,403E-04	111	111
20	10	1	0,000E+00	0,000E+00	0,000E+00	-6,154E-04	-6,152E-04	111	111
20	11	1	0,000E+00	1,341E-04	1,341E-04	3,606E-03	3,606E-03	111	111
20	12	1	0,000E+00	1,509E-04	1,509E-04	3,684E-03	3,684E-03	111	111

PROB (CONTD)

4D BEAM X, LL. = 1.5 DESIGN LL., EXPERIMENTAL EC, 7.5 SQRT(FC)

ISMALL= -0 (0=LARGE, 1=SMALL ANGLES SOLUTION)

TIME INCREMENT 4 TIME = 1.000E+01

TABLE 9 - FIBER STRESSES

ELEMT	SUB-RECT.	DIVISION	STRESSES LEFT	STRESSES RIGHT
1	1	1	-9.940E+02	-1.017E+03
1	1	2	-9.919E+02	-1.013E+03
1	1	3	-9.898E+02	-1.009E+03
1	2	1	-9.878E+02	-1.005E+03
1	3	1	-9.859E+02	-1.001E+03
1	4	1	-9.865E+02	-1.002E+03
1	4	2	-9.820E+02	-9.935E+02
1	4	3	-9.776E+02	-9.848E+02
1	4	4	-9.731E+02	-9.762E+02
1	4	5	-9.686E+02	-9.675E+02
1	4	6	-9.641E+02	-9.588E+02
1	4	7	-9.597E+02	-9.502E+02
1	4	8	-9.552E+02	-9.415E+02
1	5	1	-9.565E+02	-9.440E+02
1	6	1	-9.541E+02	-9.395E+02
1	7	1	-9.519E+02	-9.352E+02
1	7	2	-9.498E+02	-9.311E+02
1	7	3	-9.477E+02	-9.270E+02
1	7	4	-9.456E+02	-9.229E+02
1	8	1	-1.109E+04	-1.130E+04
1	9	1	-1.073E+04	-1.059E+04
1	10	1	-1.066E+04	-1.046E+04
1	11	1	9.230E+04	9.229E+04
1	12	1	9.264E+04	9.266E+04
2	1	1	-7.629E+02	-7.843E+02
2	1	2	-7.790E+02	-7.986E+02
2	1	3	-7.952E+02	-8.129E+02
2	2	1	-8.104E+02	-8.264E+02
2	3	1	-8.248E+02	-8.391E+02
2	4	1	-8.204E+02	-8.352E+02
2	4	2	-8.548E+02	-8.656E+02
2	4	3	-8.891E+02	-8.960E+02
2	4	4	-9.234E+02	-9.263E+02
2	4	5	-9.577E+02	-9.567E+02
2	4	6	-9.921E+02	-9.871E+02
2	4	7	-1.026E+03	-1.017E+03
2	4	8	-1.061E+03	-1.048E+03
2	5	1	-1.051E+03	-1.039E+03
2	6	1	-1.069E+03	-1.055E+03
2	7	1	-1.086E+03	-1.070E+03
2	7	2	-1.102E+03	-1.084E+03
2	7	3	-1.118E+03	-1.099E+03
2	7	4	-1.134E+03	-1.113E+03
2	8	1	-8.957E+03	-9.151E+03
2	9	1	-1.184E+04	-1.171E+04

2	10	1	-1.237E+04	-1.218E+04
2	11	1	9.199E+04	9.199E+04
2	12	1	9.237E+04	9.239E+04
3	1	1	-5.629E+02	-5.833E+02
3	1	2	-5.948E+02	-6.134E+02
3	1	3	-6.267E+02	-6.435E+02
3	2	1	-6.568E+02	-6.720E+02
3	3	1	-6.851E+02	-6.987E+02
3	4	1	-6.765E+02	-6.906E+02
3	4	2	-7.443E+02	-7.546E+02
3	4	3	-8.121E+02	-8.186E+02
3	4	4	-8.798E+02	-8.826E+02
3	4	5	-9.476E+02	-9.466E+02
3	4	6	-1.015E+03	-1.011E+03
3	4	7	-1.083E+03	-1.075E+03
3	4	8	-1.151E+03	-1.139E+03
3	5	1	-1.132E+03	-1.120E+03
3	6	1	-1.167E+03	-1.154E+03
3	7	1	-1.200E+03	-1.185E+03
3	7	2	-1.232E+03	-1.215E+03
3	7	3	-1.264E+03	-1.246E+03
3	7	4	-1.295E+03	-1.275E+03
3	8	1	-7.108E+03	-7.292E+03
3	9	1	-1.280E+04	-1.268E+04
3	10	1	-1.384E+04	-1.366E+04
3	11	1	9.160E+04	9.160E+04
3	12	1	9.208E+04	9.210E+04
4	1	1	-3.940E+02	-4.133E+02
4	1	2	-4.392E+02	-4.568E+02
4	1	3	-4.843E+02	-5.003E+02
4	2	1	-5.270E+02	-5.413E+02
4	3	1	-5.671E+02	-5.800E+02
4	4	1	-5.549E+02	-5.682E+02
4	4	2	-6.509E+02	-6.606E+02
4	4	3	-7.469E+02	-7.530E+02
4	4	4	-8.428E+02	-8.454E+02
4	4	5	-9.388E+02	-9.378E+02
4	4	6	-1.035E+03	-1.030E+03
4	4	7	-1.131E+03	-1.123E+03
4	4	8	-1.226E+03	-1.215E+03
4	5	1	-1.199E+03	-1.188E+03
4	6	1	-1.249E+03	-1.237E+03
4	7	1	-1.296E+03	-1.282E+03
4	7	2	-1.340E+03	-1.324E+03
4	7	3	-1.384E+03	-1.367E+03
4	7	4	-1.428E+03	-1.409E+03
4	8	1	-5.547E+03	-5.722E+03
4	9	1	-1.361E+04	-1.349E+04
4	10	1	-1.508E+04	-1.491E+04
4	11	1	9.115E+04	9.116E+04
4	12	1	9.179E+04	9.181E+04
5	1	1	-2.566E+02	-2.747E+02
5	1	2	-3.125E+02	-3.291E+02
5	1	3	-3.684E+02	-3.834E+02
5	2	1	-4.212E+02	-4.347E+02
5	3	1	-4.709E+02	-4.830E+02
5	4	1	-4.558E+02	-4.683E+02
5	4	2	-5.746E+02	-5.830E+02
5	4	3	-6.934E+02	-6.982E+02
5	4	4	-8.122E+02	-8.147E+02
5	4	5	-9.310E+02	-9.302E+02
5	4	6	-1.050E+03	-1.046E+03

5	4	7	-1.168E+03	-1.161E+03
5	4	8	-1.286E+03	-1.276E+03
5	5	1	-1.253E+03	-1.243E+03
5	6	1	-1.314E+03	-1.303E+03
5	7	1	-1.372E+03	-1.358E+03
5	7	2	-1.426E+03	-1.411E+03
5	7	3	-1.480E+03	-1.464E+03
5	7	4	-1.535E+03	-1.517E+03
5	8	1	-4.276E+03	-4.439E+03
5	9	1	-1.426E+04	-1.414E+04
5	10	1	-1.608E+04	-1.592E+04
5	11	1	9.068E+04	9.069E+04
5	12	1	9.151E+04	9.153E+04
6	1	1	-1.504E+02	-1.673E+02
6	1	2	-2.145E+02	-2.300E+02
6	1	3	-2.787E+02	-2.927E+02
6	2	1	-3.393E+02	-3.519E+02
6	3	1	-3.963E+02	-4.076E+02
6	4	1	-3.789E+02	-3.906E+02
6	4	2	-5.153E+02	-5.238E+02
6	4	3	-6.516E+02	-6.571E+02
6	4	4	-7.880E+02	-7.903E+02
6	4	5	-9.243E+02	-9.235E+02
6	4	6	-1.061E+03	-1.057E+03
6	4	7	-1.197E+03	-1.189E+03
6	4	8	-1.331E+03	-1.321E+03
6	5	1	-1.293E+03	-1.284E+03
6	6	1	-1.363E+03	-1.352E+03
6	7	1	-1.429E+03	-1.416E+03
6	7	2	-1.491E+03	-1.477E+03
6	7	3	-1.554E+03	-1.539E+03
6	7	4	-1.616E+03	-1.600E+03
6	8	1	-3.291E+03	-3.444E+03
6	9	1	-1.475E+04	-1.464E+04
6	10	1	-1.684E+04	-1.669E+04
6	11	1	9.021E+04	9.022E+04
6	12	1	9.125E+04	9.127E+04
7	1	1	-7.485E+01	-9.058E+01
7	1	2	-1.448E+02	-1.592E+02
7	1	3	-2.147E+02	-2.277E+02
7	2	1	-2.808E+02	-2.925E+02
7	3	1	-3.430E+02	-3.535E+02
7	4	1	-3.240E+02	-3.349E+02
7	4	2	-4.727E+02	-4.806E+02
7	4	3	-6.213E+02	-6.264E+02
7	4	4	-7.700E+02	-7.721E+02
7	4	5	-9.186E+02	-9.178E+02
7	4	6	-1.067E+03	-1.064E+03
7	4	7	-1.215E+03	-1.209E+03
7	4	8	-1.361E+03	-1.352E+03
7	5	1	-1.320E+03	-1.312E+03
7	6	1	-1.396E+03	-1.386E+03
7	7	1	-1.468E+03	-1.457E+03
7	7	2	-1.536E+03	-1.523E+03
7	7	3	-1.600E+03	-1.590E+03
7	7	4	-1.672E+03	-1.657E+03
7	8	1	-2.589E+03	-2.731E+03
7	9	1	-1.508E+04	-1.498E+04
7	10	1	-1.737E+04	-1.722E+04
7	11	1	8.975E+04	8.977E+04
7	12	1	9.100E+04	9.102E+04
8	1	1	-2.953E+01	-4.407E+01

8	1	2	-1.029E+02	-1.161E+02
8	1	3	-1.762E+02	-1.882E+02
8	2	1	-2.450E+02	-2.562E+02
8	3	1	-3.106E+02	-3.203E+02
8	4	1	-2.908E+02	-3.008E+02
8	4	2	-4.466E+02	-4.539E+02
8	4	3	-6.024E+02	-6.070E+02
8	4	4	-7.582E+02	-7.602E+02
8	4	5	-9.140E+02	-9.133E+02
8	4	6	-1.070E+03	-1.066E+03
8	4	7	-1.225E+03	-1.219E+03
8	4	8	-1.378E+03	-1.369E+03
8	5	1	-1.335E+03	-1.327E+03
8	6	1	-1.414E+03	-1.405E+03
8	7	1	-1.489E+03	-1.479E+03
8	7	2	-1.561E+03	-1.549E+03
8	7	3	-1.632E+03	-1.619E+03
8	7	4	-1.704E+03	-1.689E+03
8	8	1	-2.165E+03	-2.296E+03
8	9	1	-1.526E+04	-1.517E+04
8	10	1	-1.766E+04	-1.753E+04
8	11	1	8.933E+04	8.934E+04
8	12	1	9.079E+04	9.081E+04
9	1	1	-1.393E+01	-2.730E+01
9	1	2	-8.827E+01	-1.005E+02
9	1	3	-1.626E+02	-1.736E+02
9	2	1	-2.328E+02	-2.427E+02
9	3	1	-2.988E+02	-3.078E+02
9	4	1	-2.787E+02	-2.880E+02
9	4	2	-4.367E+02	-4.434E+02
9	4	3	-5.946E+02	-5.989E+02
9	4	4	-7.526E+02	-7.544E+02
9	4	5	-9.106E+02	-9.099E+02
9	4	6	-1.069E+03	-1.065E+03
9	4	7	-1.226E+03	-1.220E+03
9	4	8	-1.381E+03	-1.373E+03
9	5	1	-1.337E+03	-1.330E+03
9	6	1	-1.417E+03	-1.409E+03
9	7	1	-1.494E+03	-1.484E+03
9	7	2	-1.566E+03	-1.555E+03
9	7	3	-1.639E+03	-1.627E+03
9	7	4	-1.711E+03	-1.698E+03
9	8	1	-2.015E+03	-2.136E+03
9	9	1	-1.530E+04	-1.521E+04
9	10	1	-1.773E+04	-1.761E+04
9	11	1	8.894E+04	8.895E+04
9	12	1	9.061E+04	9.062E+04
10	1	1	-2.765E+01	-3.985E+01
10	1	2	-1.007E+02	-1.118E+02
10	1	3	-1.737E+02	-1.837E+02
10	2	1	-2.426E+02	-2.516E+02
10	3	1	-3.075E+02	-3.156E+02
10	4	1	-2.877E+02	-2.961E+02
10	4	2	-4.429E+02	-4.490E+02
10	4	3	-5.980E+02	-6.019E+02
10	4	4	-7.531E+02	-7.548E+02
10	4	5	-9.083E+02	-9.077E+02
10	4	6	-1.063E+03	-1.061E+03
10	4	7	-1.218E+03	-1.213E+03
10	4	8	-1.370E+03	-1.363E+03
10	5	1	-1.327E+03	-1.321E+03
10	6	1	-1.406E+03	-1.399E+03

10	7	1	-1,481E+03	-1,473E+03
10	7	2	-1,552E+03	-1,543E+03
10	7	3	-1,623E+03	-1,613E+03
10	7	4	-1,694E+03	-1,683E+03
10	8	1	-2,136E+03	-2,246E+03
10	9	1	-1,519E+04	-1,511E+04
10	10	1	-1,758E+04	-1,747E+04
10	11	1	8,858E+04	8,860E+04
10	12	1	9,045E+04	9,047E+04
11	1	1	-5,418E+01	-6,521E+01
11	1	2	-1,250E+02	-1,351E+02
11	1	3	-1,958E+02	-2,049E+02
11	2	1	-2,627E+02	-2,709E+02
11	3	1	-3,256E+02	-3,330E+02
11	4	1	-3,065E+02	-3,141E+02
11	4	2	-4,570E+02	-4,626E+02
11	4	3	-6,075E+02	-6,110E+02
11	4	4	-7,580E+02	-7,595E+02
11	4	5	-9,085E+02	-9,079E+02
11	4	6	-1,059E+03	-1,056E+03
11	4	7	-1,209E+03	-1,204E+03
11	4	8	-1,357E+03	-1,351E+03
11	5	1	-1,315E+03	-1,309E+03
11	6	1	-1,392E+03	-1,385E+03
11	7	1	-1,465E+03	-1,457E+03
11	7	2	-1,534E+03	-1,525E+03
11	7	3	-1,603E+03	-1,593E+03
11	7	4	-1,671E+03	-1,661E+03
11	8	1	-2,376E+03	-2,476E+03
11	9	1	-1,504E+04	-1,497E+04
11	10	1	-1,736E+04	-1,726E+04
11	11	1	8,854E+04	8,855E+04
11	12	1	9,041E+04	9,043E+04
12	1	1	-7,798E+01	-8,786E+01
12	1	2	-1,469E+02	-1,559E+02
12	1	3	-2,158E+02	-2,239E+02
12	2	1	-2,808E+02	-2,881E+02
12	3	1	-3,420E+02	-3,486E+02
12	4	1	-3,234E+02	-3,302E+02
12	4	2	-4,698E+02	-4,748E+02
12	4	3	-6,162E+02	-6,194E+02
12	4	4	-7,626E+02	-7,639E+02
12	4	5	-9,090E+02	-9,085E+02
12	4	6	-1,055E+03	-1,053E+03
12	4	7	-1,201E+03	-1,197E+03
12	4	8	-1,346E+03	-1,340E+03
12	5	1	-1,305E+03	-1,300E+03
12	6	1	-1,380E+03	-1,373E+03
12	7	1	-1,450E+03	-1,443E+03
12	7	2	-1,517E+03	-1,509E+03
12	7	3	-1,584E+03	-1,576E+03
12	7	4	-1,651E+03	-1,642E+03
12	8	1	-2,592E+03	-2,682E+03
12	9	1	-1,492E+04	-1,486E+04
12	10	1	-1,718E+04	-1,709E+04
12	11	1	8,853E+04	8,854E+04
12	12	1	9,041E+04	9,042E+04
13	1	1	-9,922E+01	-1,079E+02
13	1	2	-1,664E+02	-1,743E+02
13	1	3	-2,336E+02	-2,408E+02
13	2	1	-2,970E+02	-3,034E+02
13	3	1	-3,567E+02	-3,625E+02

13	4	1	-3.385E+02	-3.405E+02
13	4	2	-4.812E+02	-4.856E+02
13	4	3	-6.240E+02	-6.268E+02
13	4	4	-7.667E+02	-7.679E+02
13	4	5	-9.094E+02	-9.090E+02
13	4	6	-1.052E+03	-1.050E+03
13	4	7	-1.194E+03	-1.191E+03
13	4	8	-1.335E+03	-1.330E+03
13	5	1	-1.296E+03	-1.291E+03
13	6	1	-1.368E+03	-1.363E+03
13	7	1	-1.437E+03	-1.431E+03
13	7	2	-1.503E+03	-1.496E+03
13	7	3	-1.568E+03	-1.560E+03
13	7	4	-1.634E+03	-1.625E+03
13	8	1	-2.785E+03	-2.864E+03
13	9	1	-1.481E+04	-1.475E+04
13	10	1	-1.701E+04	-1.693E+04
13	11	1	8.852E+04	8.853E+04
13	12	1	9.041E+04	9.042E+04
14	1	1	-1.179E+02	-1.254E+02
14	1	2	-1.835E+02	-1.904E+02
14	1	3	-2.492E+02	-2.554E+02
14	2	1	-3.112E+02	-3.168E+02
14	3	1	-3.695E+02	-3.746E+02
14	4	1	-3.518E+02	-3.570E+02
14	4	2	-4.913E+02	-4.951E+02
14	4	3	-6.308E+02	-6.332E+02
14	4	4	-7.703E+02	-7.713E+02
14	4	5	-9.098E+02	-9.094E+02
14	4	6	-1.049E+03	-1.048E+03
14	4	7	-1.188E+03	-1.185E+03
14	4	8	-1.326E+03	-1.322E+03
14	5	1	-1.288E+03	-1.284E+03
14	6	1	-1.359E+03	-1.354E+03
14	7	1	-1.426E+03	-1.421E+03
14	7	2	-1.490E+03	-1.484E+03
14	7	3	-1.554E+03	-1.547E+03
14	7	4	-1.618E+03	-1.610E+03
14	8	1	-2.955E+03	-3.023E+03
14	9	1	-1.471E+04	-1.466E+04
14	10	1	-1.686E+04	-1.680E+04
14	11	1	8.850E+04	8.851E+04
14	12	1	9.040E+04	9.041E+04
15	1	1	-1.340E+02	-1.404E+02
15	1	2	-1.983E+02	-2.042E+02
15	1	3	-2.627E+02	-2.679E+02
15	2	1	-3.234E+02	-3.281E+02
15	3	1	-3.806E+02	-3.848E+02
15	4	1	-3.632E+02	-3.676E+02
15	4	2	-4.999E+02	-5.031E+02
15	4	3	-6.366E+02	-6.386E+02
15	4	4	-7.733E+02	-7.742E+02
15	4	5	-9.100E+02	-9.097E+02
15	4	6	-1.047E+03	-1.045E+03
15	4	7	-1.183E+03	-1.180E+03
15	4	8	-1.318E+03	-1.315E+03
15	5	1	-1.280E+03	-1.277E+03
15	6	1	-1.350E+03	-1.346E+03
15	7	1	-1.416E+03	-1.412E+03
15	7	2	-1.479E+03	-1.474E+03
15	7	3	-1.541E+03	-1.536E+03
15	7	4	-1.604E+03	-1.598E+03

15	8	1	-3.101E+03	-3.158E+03
15	9	1	-1.463E+04	-1.459E+04
15	10	1	-1.674E+04	-1.668E+04
15	11	1	8.849E+04	8.849E+04
15	12	1	9.039E+04	9.040E+04
16	1	1	-1.475E+02	-1.528E+02
16	1	2	-2.107E+02	-2.155E+02
16	1	3	-2.740E+02	-2.783E+02
16	2	1	-3.337E+02	-3.375E+02
16	3	1	-3.899E+02	-3.933E+02
16	4	1	-3.728E+02	-3.764E+02
16	4	2	-5.071E+02	-5.098E+02
16	4	3	-6.415E+02	-6.431E+02
16	4	4	-7.758E+02	-7.765E+02
16	4	5	-9.102E+02	-9.099E+02
16	4	6	-1.045E+03	-1.043E+03
16	4	7	-1.178E+03	-1.176E+03
16	4	8	-1.312E+03	-1.308E+03
16	5	1	-1.274E+03	-1.272E+03
16	6	1	-1.343E+03	-1.339E+03
16	7	1	-1.408E+03	-1.404E+03
16	7	2	-1.469E+03	-1.465E+03
16	7	3	-1.531E+03	-1.526E+03
16	7	4	-1.592E+03	-1.587E+03
16	8	1	-3.223E+03	-3.271E+03
16	9	1	-1.455E+04	-1.452E+04
16	10	1	-1.663E+04	-1.658E+04
16	11	1	8.847E+04	8.848E+04
16	12	1	9.037E+04	9.038E+04
17	1	1	-1.585E+02	-1.626E+02
17	1	2	-2.208E+02	-2.245E+02
17	1	3	-2.831E+02	-2.865E+02
17	2	1	-3.420E+02	-3.450E+02
17	3	1	-3.974E+02	-4.001E+02
17	4	1	-3.805E+02	-3.833E+02
17	4	2	-5.129E+02	-5.150E+02
17	4	3	-6.454E+02	-6.467E+02
17	4	4	-7.778E+02	-7.784E+02
17	4	5	-9.102E+02	-9.100E+02
17	4	6	-1.043E+03	-1.042E+03
17	4	7	-1.175E+03	-1.173E+03
17	4	8	-1.306E+03	-1.304E+03
17	5	1	-1.269E+03	-1.267E+03
17	6	1	-1.337E+03	-1.334E+03
17	7	1	-1.401E+03	-1.398E+03
17	7	2	-1.461E+03	-1.458E+03
17	7	3	-1.522E+03	-1.518E+03
17	7	4	-1.583E+03	-1.579E+03
17	8	1	-3.323E+03	-3.360E+03
17	9	1	-1.449E+04	-1.447E+04
17	10	1	-1.654E+04	-1.650E+04
17	11	1	8.845E+04	8.846E+04
17	12	1	9.036E+04	9.036E+04
18	1	1	-1.669E+02	-1.698E+02
18	1	2	-2.285E+02	-2.312E+02
18	1	3	-2.901E+02	-2.925E+02
18	2	1	-3.483E+02	-3.505E+02
18	3	1	-4.031E+02	-4.050E+02
18	4	1	-3.864E+02	-3.884E+02
18	4	2	-5.174E+02	-5.188E+02
18	4	3	-6.483E+02	-6.492E+02
18	4	4	-7.793E+02	-7.796E+02

18	4	5	-9.102E+02	-9.101E+02
18	4	6	-1.041E+03	-1.040E+03
18	4	7	-1.172E+03	-1.170E+03
18	4	8	-1.302E+03	-1.300E+03
18	5	1	-1.265E+03	-1.264E+03
18	6	1	-1.332E+03	-1.330E+03
18	7	1	-1.395E+03	-1.393E+03
18	7	2	-1.455E+03	-1.453E+03
18	7	3	-1.515E+03	-1.513E+03
18	7	4	-1.575E+03	-1.572E+03
18	8	1	-3.399E+03	-3.425E+03
18	9	1	-1.445E+04	-1.443E+04
18	10	1	-1.647E+04	-1.644E+04
18	11	1	8.843E+04	8.843E+04
18	12	1	9.034E+04	9.034E+04
19	1	1	-1.727E+02	-1.744E+02
19	1	2	-2.338E+02	-2.354E+02
19	1	3	-2.950E+02	-2.964E+02
19	2	1	-3.527E+02	-3.540E+02
19	3	1	-4.070E+02	-4.082E+02
19	4	1	-3.905E+02	-3.917E+02
19	4	2	-5.204E+02	-5.213E+02
19	4	3	-6.503E+02	-6.508E+02
19	4	4	-7.802E+02	-7.804E+02
19	4	5	-9.101E+02	-9.100E+02
19	4	6	-1.040E+03	-1.040E+03
19	4	7	-1.169E+03	-1.169E+03
19	4	8	-1.298E+03	-1.297E+03
19	5	1	-1.262E+03	-1.261E+03
19	6	1	-1.329E+03	-1.327E+03
19	7	1	-1.391E+03	-1.390E+03
19	7	2	-1.451E+03	-1.450E+03
19	7	3	-1.510E+03	-1.509E+03
19	7	4	-1.570E+03	-1.568E+03
19	8	1	-3.451E+03	-3.467E+03
19	9	1	-1.441E+04	-1.440E+04
19	10	1	-1.642E+04	-1.640E+04
19	11	1	8.841E+04	8.841E+04
19	12	1	9.032E+04	9.032E+04
20	1	1	-1.760E+02	-1.765E+02
20	1	2	-2.368E+02	-2.373E+02
20	1	3	-2.976E+02	-2.981E+02
20	2	1	-3.551E+02	-3.555E+02
20	3	1	-4.092E+02	-4.095E+02
20	4	1	-3.927E+02	-3.931E+02
20	4	2	-5.220E+02	-5.223E+02
20	4	3	-6.513E+02	-6.515E+02
20	4	4	-7.806E+02	-7.806E+02
20	4	5	-9.099E+02	-9.098E+02
20	4	6	-1.039E+03	-1.039E+03
20	4	7	-1.168E+03	-1.168E+03
20	4	8	-1.296E+03	-1.296E+03
20	5	1	-1.261E+03	-1.260E+03
20	6	1	-1.326E+03	-1.326E+03
20	7	1	-1.389E+03	-1.389E+03
20	7	2	-1.448E+03	-1.448E+03
20	7	3	-1.507E+03	-1.507E+03
20	7	4	-1.567E+03	-1.566E+03
20	8	1	-3.481E+03	-3.486E+03
20	9	1	-1.439E+04	-1.439E+04
20	10	1	-1.639E+04	-1.638E+04
20	11	1	8.838E+04	8.838E+04

20	12	1	9.029E+04	9.029E+04

A P P E N D I X F

BRANSON'S METHOD FOR CALCULATING TIME-DEPENDENT RESPONSES OF PRESTRESSED BEAMS

The following presentation is adopted from Branson (10, 11). Ref. 10 or Ref. 11 should be consulted for more information.

Loss of Prestress

Noncomposite beams. The loss of prestress at any time including ultimate values is computed by Eq. (1) for noncomposite beams.

$$(\Delta f_s)_{i,t} = \underset{(1)}{(nf_{ci})} + \underset{(2)}{(nf_{ci})(k_r C_t)\left(1 - \frac{\Delta P_t}{2P_0}\right)} + \underset{(3)}{k_r(\varepsilon_{sh})_t E_s/(1 + b_{11})} + \underset{(4)}{(f_{sr})_t} - \underset{(5)}{(m\, f_{cs})} - \underset{(6)}{(m\, f_{cs})(k_r\, C_{ts})/(1 + b_{11})} \qquad (1)$$

where:

Term (1) is the prestress loss due to elastic shortening.

Term (2) is the prestress loss due to concrete creep.

Term (3) is the prestress loss due to concrete shrinkage.

Term (4) is the prestress loss due to steel relaxation. The following expressions are recommended for wire and strand for the usual range of f_{si}/f_y = 0.65 to 0.80 (11).

Stress relieved steel

$(f_{sr})_t = 0.015\ f_{si} \log t$, t is in hour

Stabilized (low relaxation) steel

$(f_{sr})_t = 0.007\ f_{si} \log t$, t is in hour

Term (5) is the elastic prestress gain due to the superimposed sustained load.

Term (6) is the prestress gain due to concrete creep under the superimposed sustained load.

Unshored and shored composite beams. The loss of prestress at any time including ultimate values is computed by Eq. (2) for both unshored and shored composite beams. Subscripts 1 and 2 are used to refer to the slab (or effect of the slab such as under slab dead load) and precast beam, respectively.

$$\begin{aligned}(\Delta f_s)_{i,t} &= \overset{(1)}{(n\ f_{ci})} + \overset{(2)}{(n\ f_{ci})(k_r C_{s2})(1 - \frac{\Delta P_s}{2P_0})} + (n\ f_{ci}) \\ &\overset{(3)}{[(k_r\ C_{t2})\ (1 - \frac{\Delta P_t}{2P_0}) - (k_r\ C_{s2})(1 - \frac{\Delta P_s}{2P_0})]} \\ &\frac{I_2}{I_c} + \overset{(4)}{k_r(\varepsilon_{sh})_t\ E_s/(1 + b_{11})} + \overset{(5)}{(f_{sr})_t} - \overset{(6)}{(m\ f_{cs1})} \\ &- \overset{(7)}{[(m\ f_{cs1})(k_r\ C_{ts1})/(1 + b_{11})]\ \frac{I_2}{I_c}} - \overset{(8)}{(f_{sds})} \qquad (2)\end{aligned}$$

where:

Term (1) is the prestress loss due to elastic shortening.

Term (2) is the prestress loss due to creep up to the time of slab casting.

Term (3) is the prestress loss due to concrete creep for any period of following slab casting.

Term (4) is the prestress loss due to shrinkage of precast beam concrete. Since this term refers to shrinkage of the precast beam only, the effect of b_{11} is assumed to refer to the precast beam section both before and after slab casting.

Term (5) is the prestress loss due to steel relaxation. See term (4) of Eq. (1) for equations.

Term (6) is the elastic prestress gain due to slab dead load.

Term (7) is the prestress gain due to creep under slab dead load. For shared construction, k_r and b_{11} refer to the composite section, and I_2/I_c is deleted.

Term (8) is the prestress gain due to differential shrinkage and creep. $f_{sds} = m\ f_{cds}$, where $f_{cds} = Q_{ds}\ y_{cs}\ e_c/I_c$. See Ref. 11 for the effect of continuity on differential shrinkage and creep and the information about Q_{ds}.

Camber and Deflection

Noncomposite beams. Camber or deflection at any time including ultimate values is computed by Eq. (3).

$$\Delta_{i,t} = \overset{(1)}{(\Delta_i)_{P_0}} - \overset{(2)}{(\Delta_i)_D} + \overset{(3)}{\left[-\frac{\Delta P_t}{P_0} + (k_r\, C_t)(1 - \frac{\Delta P_t}{2P_0})\right] (\Delta_i)_{P_0}}$$

$$- \overset{(4)}{(k_r\, C_t)(\Delta_i)_D} - \overset{(5)}{\Delta_L} - \overset{(6)}{(\Delta_i)_s} - \overset{(7)}{(k_r\, C_{ts})(\Delta_i)_s} \qquad (3)$$

where:

Term (1) is the initial camber due to the initial prestress moment after elastic loss, P_0 e.

Term (2) is the initial dead load deflection of the beam.

Term (3) is the creep (time-dependent) camber of the beam due to the prestress moment. This expression includes the effects of creep and loss of prestress.

Term (4) is the dead load deflection of the beam.

Term (5) is the live load deflection of the beam.

Term (6) is the initial deflection of the beam under the superimposed sustained load.

Term (7) is the creep deflection of the beam under the superimposed sustained load.

Unshored and shored composite beams. Camber or deflection at any time including ultimate values is computed by Eq. (4) for unshored construction and Eq. (5) for shored construction. Subscripts 1 and 2 are used to refer to the slab (or effect of the slab such as under slab dead load) and precast beam, respectively.

Unshored construction

$$\Delta_{i,t} = \underset{(1)}{(\Delta_i)_{P_0}} - \underset{(2)}{(\Delta_i)_2} + \underset{(3)}{\left[-\frac{\Delta P_s}{P_0} + (k_r\, C_{s2})\left(1 - \frac{\Delta P_s}{2P_0}\right)\right] (\Delta_i)_{P_0}}$$

$$+ \underset{(4)}{\left[-\frac{\Delta P_t - \Delta P_s}{P_0} + (k_r\, C_{t2})\left(1 - \frac{\Delta P_t}{2P_0}\right) - (k_r\, C_{s2})\left(1 - \frac{\Delta P_s}{2P_0}\right)\right]}$$

$$(\Delta_i)_{P_0} \frac{I_2}{I_c} - \underset{(5)}{(k_r\, C_{s2})(\Delta_i)_2} - \underset{(6)}{k_r(C_{t2} - C_{s2})(\Delta_i)_2 \frac{I_2}{I_c}} - \underset{(7)}{(\Delta_i)_1}$$

$$- \underset{(8)}{(k_r\, C_{t1})(\Delta_i)_1 \frac{I_2}{I_c}} - \underset{(9)}{\Delta_{ds}} - \underset{(10)}{\Delta_L} \qquad (4)$$

where:

Term (1) is the initial camber due to the initial prestress moment after elastic loss, P_0 e.

Term (2) is the initial dead load deflection of the precast beam.

Term (3) is the creep (time-dependent) camber of the beam, due to the prestress moment.

Term (4) is the creep camber of the composite beam, due to prestress moment, for any period following slab casting.

Term (5) is the creep deflection of the precast beam up to the time of slab casting due to the precast beam dead load.

Term (6) is the creep deflection of the composite beam for any period following slab casting due to the precast beam dead load.

Term (7) is the initial deflection of the precast beam under slab dead load.

Term (8) is the creep deflection of the composite beam due to slab dead load.

Term (9) is the deflection due to differential shrinkage and creep. For simple span, $\Delta_{ds} = (4/3)(Q_{ds}\ y_{cs}\ L^2)/8\ E_c\ I_c$. See Ref. 11 for the effect of continuity and the information about Q_{ds}.

Term (10) is the live load deflection of the composite beam.

Shored construction

$\Delta_{i,t}$ = Eq. (4), with Terms (7) and (8) modified as follows: (5)

Term (7) is the initial deflection of the composite beam under slab dead load.

Term (8) is the creep deflection of the composite beam under slab dead load = $(k_r\ C_{t1})(\Delta_i)_1$. The composite-section effect is already included in Term (7).

Notation for Above Expressions

1	=	subscript denoting cast-in-place slab or the effect of the slab, such as under slab dead load
2	=	subscript denoting precast beam
A	=	area of cross-section
A_g	=	area of gross-section, neglecting the steel
A_{ns}	=	area of nonprestressed tension steel
A_{ps}	=	are of prestressing steel
b_{11}	=	$n(\rho_{ps})(1 + e^2/r^2)(1 + \eta\ C_t)$
b_{12}	=	$n(\rho_{ns})(1 + e_{ps}\ e_{ns}/r^2)(1 + \eta\ C_t)$
C	=	creep coefficient defined as the ratio of creep strain to initial strain
C_{s2}	=	creep coefficient of the precast beam concrete at the time of slab casting

C_t = creep coefficient at any time, t

C_{t1} = creep coefficient of the composite beam under slab dead load

C_{t2} = creep coefficient due to the precast beam dead load

C_{ts} = creep coefficient where the age of the beam concrete at the time of load application is taken into account

D = subscript denoting dead load

ds = subscript denoting differential shrinkage and creep

E_s = modulus of elasticity of steel

E_c = modulus of elasticity of concrete at age 28 days

e = steel eccentricity

e_c = eccentricity of steel in composite section

e_{ns} = eccentricity of nonprestressed steel

e_{ps} = eccentricity of prestressing steel

f_{ci} = initial concrete stress at steel c.g.s. due to prestress and dead load

f_{cs} = concrete stress at steel c.g.s. due to slab dead load or superimposed sustained load

f_{cds} = concrete stress at steel c.g.s. due to differential shrinkage and creep

Δf_s = loss of prestress

f_{sds} = steel stress due to differential shrinkage and creep

f_{si} = initial stress in prestressing steel

f_{sr} = relaxation of steel stress

f_y = yield point or yield strength of steel

I = moment of inertia of cross-section

I_2 = moment of inertia of precast beam

I_c = moment of inertia of composite section with transformed slab

i = subscript denoting initial value

k_r = $1/(1 + b_{12})$

L = span length of the beam

m = modular ratio at the time of additional sustained load application, including the time of slab casting

n = modular ratio at the time of prestressing

ns = subscript denoting nonprestressing steel

P_0 = prestress force at transfer (after elastic loss)

ΔP_s = total loss of prestress at slab casting time minus the initial elastic loss

ΔP_t = total loss of prestress at any time minus the initial elastic loss

ps = subscript denoting prestressing steel

Q_{ds} = differential shrinkage and creep force

r = $\sqrt{I/A}$

s = subscript denoting slab or superimposed sustained load

t = time in hours in the steel relaxation equations, time in days in other equations, subscript denoting time-dependent

y_{cs} = distance from centroid of composite section to centroid of slab

Δ = maximum camber (positive) or deflection (negative)

$(\Delta_i)_1$ = initial deflection under slab dead load

$(\Delta_i)_2$ = initial deflection under precast beam dead load

Δ_{ds} = deflection due to differential creep and shrinkage

$(\Delta_i)_D$ = initial dead load deflection of the beam

$(\Delta_i)_{P_0}$ = initial camber due to the initial prestressing force, P_0

$(\Delta_i)_s$ = initial deflection under superimposed sustained load

Δ_L = deflection under live load

$(\varepsilon_{sh})_t$ = shrinkage strain in in./in. at any time

η = relaxation coefficient. Typical values of η range from 0.75 to 0.90, with an average value of 0.88.

ρ_{ns} = A_{ns}/A_g, nonprestressing steel ratio

ρ_{ps} = A_{ps}/A_g, prestressing steel ratio

VITA

Chaichan Suttikan was born in Lopburi, Thailand, on February 10, 1948, the son of Panya Suttikan and Tipyalux Suttikan. After graduating from Tream Udon Suksa High School, Bangkok, Thailand, in 1965, he entered Chulalongkorn University, Bangkok, and received the degree of Bachelor of Engineering in 1969. From September 1969 until March 1970, he was employed by the Metropolitan Water Work Authority, Bangkok. He was awarded Thai Government Scholarship to continue his studies in the USA. He entered the Graduate School of the University of Iowa in September 1970 and received the degree of Master of Science in Civil Engineering in January 1972. In September 1972, he entered the Graduate School of the University of Texas at Austin.

Permanent address: 79 Ponthong
Banmee, Lopburi
Thailand