INSTRUMENTATION OF SEGMENTAL BOX GIRDER BRIDGES AND MULTIPIECE WINGED BOXES

PRELIMINARY INSTRUMENTATION PLAN

by

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Interim Report

Project No. 3-5-90-1234

"Instrumentation of Segmental Box Girder Bridges and Multi-Piece Winged Boxes"

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1. INTRODUCTION

1.1 Problem Statement

Project 3-5-90-1234, "Instrumentation of Segmental Box Girder Bridges and Multipiece Winged Boxes", was initiated to develop in an orderly way improved instrumentation procedures for field studies and to investigate areas of design uncertainty in segmental box girder bridges. A major new interim AASHTO specification for segmental bridges has been developed under the NCHRP Project 29-7/32. There were a number of areas where professional judgement had to be used to develop specification provisions in the absence of actual data. This project will pinpoint these areas where data is lacking, instrument an actual bridge to accumulate appropriate data, and propose modifications to the specification where necessary.

1.2 Purpose of This Interim Report

During the review of the original Project 3-5-40-1234 proposal, FHWA reviewer James R. Craig requested that further detailed information be provided prior to actual instrumentation of the San Antonio "Y" bridge structure. This Interim Report is being furnished to specifically respond to that request and to brief the sponsors on current progress and plans

1.3 Areas of Uncertainty

As stated in the original project proposal, some of the key areas of uncertainty in the development of the interim AASHTO Specification are:

1. Prestress losses for external tendon systems,

2. Temperature gradient effects in externally post-tensioned box girders,

3. Transverse diffusion of external post-tensioning forces,

4. Construction stress distributions in partially complete box girders,

5. Anchorage zone and deviator details,

6. Joint efficiency.

Another problem which has since been identified is the approach recommended for calculating effective flange widths. The method is complex and confusing, and the complex calculations are not always required.

These areas of uncertainty have caused problems in previous segmental box girder bridges. In a major in-house study, the Florida Department of Transportation made measurements after the completion of some of the Florida Key bridges. Csagoly and Bollman reported orally to the PTI-NCHRP group that their measurements indicated substantial opening of some of the dry joints under daily thermal fluctuations and a substantial deficiency of post-tensioning in some spans due to combinations of underestimation of losses and apparent high friction. The Key bridges have also suffered damage in expansion joints apparently due to higher than expected creep deformations.

Some sections of the Washington D.C. Metro system, which were built using externally post-tensioned box girders, experienced severe cracking in the end diaphragms and at deviator locations[1]. Extensive strengthening was required to alleviate the problems.

These examples illustrate the need for continued re-examination and revision of current AASHTO provisions to provide a complete and clear set of specifications to guide designers toward safer and more serviceable structures.

1.4 Project Objectives

The project objectives as stated in the original proposal are as follows:

1. To identify the major design uncertainties and areas where verifications of assumptions are necessary in segmental box girders.

2. To study available instrumentation devices and systems in order to select devices and prepare instrumentation plans for an upcoming box girder project.

3. To evaluate candidate instrumentation systems under laboratory and field conditions.

4. To prepare special provisions to alert the prospective contractors of this upcoming project of the field studies and any possible disruptions to their operations.

5. To instrument selected segments and spans of the bridge project to obtain desired information about the bridge's behavior.

6. To interpret the field measurements obtained.

7. To develop proposed changes to the AASHTO Interim Design and Construction Provisions for Segmental Box Girder Construction.

1.5 Detailed Work Plan

The program's detailed work plan as originally stated comprises the following 13 steps:

1. A comprehensive literature review of applicable North American and European Literature will be made to determine areas of uncertainty in segmental box girder design and construction, as well as successful field instrumentation for measuring box girder performance.

2. In depth interviews will be carried out with SDHPT design personnel involved with design of the San Antonio "Y" as well as SDHPT field forces and contractor personnel involved in the construction of previous phases of the "Y" project. These interviews will be aimed at the determination of design uncertainties, problem areas, and assumptions needing verification, as well as field problems which have occurred in the past.

3. Based on 1) and 2), and a careful examination of the San Antonio "Y" Phase IIC plans, a preliminary determination of priorities and needs for instrumentation will be made.

4. Special provisions to alert constructors of possible interruptions and care required because of field instrumentation studies, as well as provision of access holes and instrumentation connection boxes will be developed and furnished to the SDHPT for review and plan inclusion.

5. Candidate instruments and systems for carrying out the instrumentation plan will be developed and evaluated.

6. The most promising systems will be acquired and evaluated under laboratory conditions to ensure accuracy, applicability, ruggedness and especially installation care and efficiency so as to reduce field delays to a minimum.

7. The most promising systems from the laboratory trials will be installed in limited numbers and evaluated under field conditions in San Antonio "Y" Phase IC.

8. Based on the laboratory and field evaluations in 6) and 7), the final instrumentation systems will be selected.

9. The overall field measurement program for San Antonio "Y" Phase IIC will be carried out. This will involve installation and monitoring of devices with emphasis on several heavily instrumented spans.

10. The measurements obtained will be interpreted using accepted analysis principles and will be checked against current design and construction criteria.

11. Special provisions will be developed for possible instrumentation of the winged box girder alternate of the Austin US183 project since it has a number of features not found in the San Antonio "Y" designs. Final decisions as to carrying out such measurements will be made by SDHPT at a future date.

12. Detailed recommendations for suggested changes to the AASHTO Specifications for Design and Construction of Segmental Bridges as well as to SDHPT design procedures and criteria will be made as warranted.

13. A comprehensive final report will summarize all results and include design and construction recommendations in a format for inclusion in AASHTO Segmental Bridge Specifications.

1.6 Report Organization

This interim report will detail the work that has been performed to date. Each step of the work plan will be addressed and progress will be described. A schedule for the completion of the work plan will also be included.

2. LITERATURE REVIEW

The literature review has been focused on two distinct areas of interest:

1. Segmental Box Girder Bridges in General: design, construction, future trends, model studies, field studies, and previously implemented instrumentation methods.

2. Instrumentation Systems: systems used in previous bridge instrumentation projects and also systems used successfully in other areas such as geotechnical and mechanical engineering.

Many data bases of published articles and several library systems were searched to compile a complete group of pertinent publications. The search included the following resources:

1. Phil M. Ferguson Structural Engineering Laboratory (FSEL) library and the extensive personal notes and correspondence of FSEL faculty,

2. University of Texas Library System,

3. Transportation Research Information System database,

4. CONTENDEX-Engineering Service's database,

5. National Technical Internal Service database, and

6. Technology Transfer System database.

The literature review provided valuable information in both areas of focus. Based on the articles and books new areas of uncertainty were uncovered and previous problems encountered with segmental box girder construction were discovered. Also the information gained on previous bridge instrumentation projects helped considerably in the selection of systems for investigation for this project. In addition the plethora of publications on design and construction of box girder bridges increased general understanding of the structure and how it could be best instrumented to derive the greatest benefit from the instrumentation systems.

3. INTERVIEWS WITH CONTRACTORS AND DESIGNERS

Substantial opportunities enhanced the collection of many points of view on areas of concern in segmental box girder design and construction. Interviews have been conducted with personnel from several design firms and two construction firms experienced in segmental technology. These interviews have expanded the areas of concern in design and construction considerably. They have also given guidance and advice on the implementation of the proposed instrumentation systems.

Interviews with designers showed their interest in the following areas:

1. Checking the correctness of the computer model used to simulate the effects of the bottom slab closure pour between adjacent spans.

2. Investigating the behavior of dual boxes connected with cast in place closure pours and post-tensioning.

3. Investigating the stability of segments with one full and one truncated cantilever wing.

4. Investigating the use of so called "female-female" keys. These were used on previous projects to reduce the amount of surface area actually in contact on the wings. This reduces the amount of epoxy required and reduces the amount of temporary post-tensioning force required to develop the proper pressure to set the epoxy.

5. Studying the problems of segments warping during casting due to various reasons such as temperature gradients and wing-tip prestressing.

6. Verifying the effectiveness of temporary post-tensioning in closing the joints and setting the epoxy.

7. Studying the changes in support reactions both during construction and after completion of the unit. Changes in support reactions due to moment redistribution due to creep and changes due to temperature gradients were of special interest.

8. Studying a particular unit on the project which utilizes the so called "poor-boy" method of continuity. This method has not been previously used in San Antonio and so there is great interest in its behavior.

Several discussions have taken place with contractors of previous San Antonio "Y" projects. They pointed out aspects of the design and fabrication which made the construction difficult. Some of their concerns and suggestions are as follows:

1. They suggest the use of more repetition in design. Special pier designs, gore areas and unique spans greatly reduce their productivity, and hence increase their costs.

2. They greatly dislike diaphragms in typical segments. Diaphragms increase the difficulty both in casting and erection.

3. They discourage any protrusion of reinforcing bars out of precast segments. It is very costly to build and wreck forms around protruding bars.

4. They indicated problems with differential shrinkage in segments. The wingtips experienced more shrinkage than the areas of the boxes near the webs. These differences made matching and temporary post-tensioning difficult.

5. They also described a problem known as the "banana shaped" segment. This occurs when the match cast segment is deformed due to temperature gradients set up by the heat of the hydrating cement in the new cast segment. When the match cast segment returns to its original shape it no longer matches the new segment.

6. Problems were also encountered due to differential deflections of wingtips caused by transverse prestressing.

Overall the designers and contractors were very enthusiastic about segmental box girders. They feel that with continued improvements in design and construction techniques segmental construction will continue to be a popular and cost effective method for construction of new bridge structures.

4. RESEARCH PLAN

This section describes the specific aspects of segmental design and construction to be studied in this program. The measurements required for each specific aspect are also presented. The spans of the current San Antonio "Y" IIC project which were selected for extensive instrumentation are presented and the preliminary instrumentation layouts are detailed.

4.1 Areas of Study

4.1.1 Prestress Losses. The primary measurement which must be made is the amount of force in the tendons. The losses which will be studied include not only initial losses due to friction across deviators, anchor seat, and elastic shortening, but also long term losses caused by creep, shrinkage and relaxation. In order to monitor the bridge's response to these changes in prestress, related measurements such as overall deflections of the structure and concrete strains will be required. Material properties of both the steel and concrete must be determined.

4.1.2 Effects of Temperature Gradients. Two aspects will be studied: the effects of environmental conditions on the magnitude and distribution of temperature in the box girder, and the behavior of the bridge subjected to these thermal gradients. The first aspect will require the measurement of environmental conditions such as ambient air temperature, wind speed, relative humidity and solar radiation. It will also require the measurement of temperatures within the concrete of the box girder and of the temperature of the air inside of the box. Measurements of the response of the bridge to the thermal gradients include the change in the deflection of the spans, changes in support reactions and changes in concrete strains. The thermal properties of the concrete will also be of interest.

4.1.3 Transverse Diffusion of Post-tensioning Forces. Measurements required to study this problem are primarily concrete strains. The measurements of reinforcing steel strains, made in conjunction with the study of the anchorage zone, will also give insight into the flow of forces away from the anchorage devices. The stress-strain characteristics of the concrete must be known to relate measured strains to stresses.

4.1.4 Effects of Construction Loads and Procedures. This will primarily involve a close observation of construction procedures and the types of unusual loads to which the incomplete structure is subjected. Measurements involved will be the deflection of the erection falsework during construction operations, the distribution of concrete strains induced by the temporary post-tensioning system, deflections of the structure under heavy loads such as the erection crane and the haul trucks delivering the precast segments.

4.1.5 Anchorage Zone and Deviator Details. Since the safest methods of design of these critical areas are based on neglecting any concrete tensile strength, the most important measurements in these areas are steel strains. Careful visual examination of the regions will also be performed to locate and record any cracks which may occur.

4.1.6 Joint Efficiency. Current design practice recommends no tension across precast joints. Measurements of joint openings will indicate if the joints become completely decompressed. Properties of the epoxy used in the joints will be valuable in the evaluation of joint efficiency.

4.1.7 Effective Flange Widths. The IIC project provides an excellent opportunity to study the shear lag problem because it consists of several different cross-sectional shapes. One small, narrow box shape should not be greatly affected, while another, very wide box shape has the potential to be greatly affected by shear lag problems. The critical measurement to study the shear lag phenomenon is concrete strain. The distribution of strains across the top and bottom flanges will give a good indication of how much of the cross section is effective in resisting bending moments. Also the deflection of the structure will indicate how the shear lag effect has changed the stiffness of the overall structure. The stress-strain properties of the concrete must be measured.

4.1.8 Banana Shaped Segment Phenomenon. The measurements required to study this problem are the temperatures within the hydrating concrete of the new cast segment and within the concrete of the match cast segment. Also the measurement of the deformations in the match cast segment should be measured. Environmental conditions on the day of the cast should also be noted.

4.1.9 Behavior of the "Poor-boy" Continuous Unit. The deflections of the spans are of interest and the strains in the top slab closure pour are also important. Movements of the spans at the bearing pads over the interior, "continuous", pier should also be measured.

4.1.10 Effects of Transverse Prestressing. Segments are often transversely pretensioned or post-tensioned. In locations where parallel boxes are joined, a combination of pretensioning and post-tensioning is sometimes used. Differential wingtip deflections occur because the new segment is cast against a match cast segment, whose pretensioning has been released and whose wings are deflected upwards. When the new segment's pretensioning is released and its wings camber upwards, the wings of the segments no longer match. The problem can be compounded by differential creep while the segments are in storage. This differential wingtip deflection has caused field difficulties in the past. The problem will be studied by measuring transverse wingtip deflections due to initial pretensioning, creep, and later post-tensioning.

4.2 Summary of Required Measurements

Based on the previous discussion of required measurements, a list of required measurements has been compiled. The measurements to be made are as follows:

<u>The structure:</u>

1. Tendon Forces,
2. Reinforcing Steel Strains,
3. Concrete Strains,
4. Span and Wingtip Deflections,
5. Concrete Temperature,
6. Joint Openings,
7. Bearing Pad movements.

<u>The materials:</u>

1. Reinforcing steel stress-strain characteristics,
2. Post-tensioning steel stress-strain characteristics,
3. Post-tensioning steel relaxation characteristics,
4. Concrete stress-strain characteristics,
5. Concrete compressive strength,
6. Concrete tensile strength,
7. Concrete creep and shrinkage characteristics,
8. Concrete coefficient of thermal expansion,
9. Fabric bearing pad stress-strain and creep characteristics.

<u>The environment:</u>

1. Ambient air temperature,
2. Relative humidity,
3. Wind speed and direction,
4. Solar radiation.

4.3 Instrumentation Layout

Based on these areas of concern which will be studied, and based on the basic layout of the IIC project and the projected construction schedule, three spans have been selected for extensive instrumentation. In addition one of the "poor-boy" continuous spans will be less heavily instrumented. Figure 1 shows the location of the spans to be studied. Span CC-9 is one of the two "poor-boy" continuous spans. Span CC-11 is a span of narrow "Type I" boxes with slightly truncated wings on one side. The truncated side will eventually be connected to the adjacent mainline span. This presents the opportunity to study dual box behavior. Spans AA-43 and AA-44 are wide Type III box sections. They are 110' spans and have the greatest number of external tendons.

Appendix A presents the preliminary instrumentation layouts which were developed to more firmly establish our instrumentation needs and were used as the basis for the writing of the special provisions for the contractors. The layouts for tendon forces, concrete strains, thermocouples, deflections, bearing movements, and joint openings are included. Locations of gages on reinforcing steel cannot be finalized until the contractor's working drawings are completed and approved.

5. SPECIAL PROVISIONS FOR CONTRACTORS

Based on the preliminary instrumentation plan, special provisions to inform contractors of delays and special requirements during the project were developed. The provisions were reviewed by members of the Bridge Division of the SDHPT and were revised per their suggestions. These provisions were included in the contract documents as part of item 8099 in the project specifications. The provisions are presented in Appendix B.

6. INSTRUMENTATION SYSTEMS

This section outlines the development of the final instrumentation plan. For each type of measurement required a complete list of all systems considered is compiled. A brief description of each type of system is included. Some systems were eliminated without further investigation. The reasoning for such elimination is also provided. Promising systems were chosen for further investigation.

A presentation of lab and field studies follows the complete listing. Finally the selected system for each type of measurement is described.

6.1 Tendon Stresses

This is one of the most important measurements required on this project. Many problems are inherent in measuring total tendon forces. Each strand which makes up a multi-strand tendon carries a slightly different force due to the variations in seating at the anchor head. Also each wire in a seven wire strand has a slightly different stress [2]. Due to this problem, a single electrical resistance strain gage, placed on a single wire of a single strand in a multi-strand tendon will not provide an accurate measure of the average stress in the entire tendon. Other problems with electrical resistance gages are their short useful life (normally caused by moisture shorting the system) and their lack of an absolute zero resistance.

6.1.1 Candidate Systems. Since standard electrical resistance gages did not seem adequate for this project, many other systems were investigated. A listing follows.

<u>Tensiomag</u> This is a system developed by Freyssinnett France. It measures the tension in a strand or bar or tendon based on the magnetic permeability of the steel. This system was eliminated due to the high cost, the lower sensitivity on multiple strands, and the lack of availability in the United States.

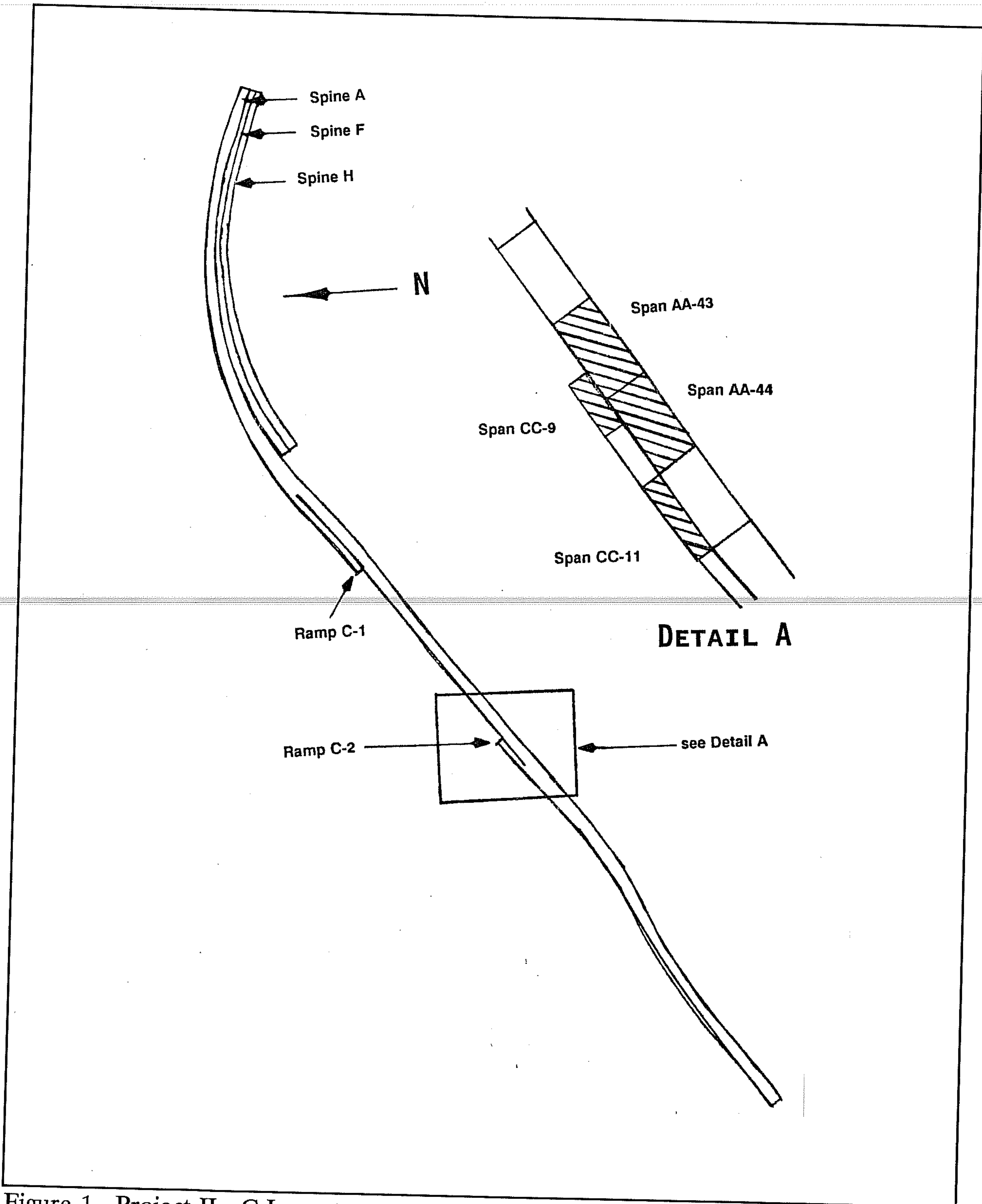

Figure 1. Project II - C Layout

DynaTension This system is based on the dynamic response of cables under tension. The cable is excited and the natural frequency is determined. With the free length of the cable, the modulus of the cable material, the cross-sectional properties of the cable and the natural frequency all known, the tension can be calculated. This system has been used successfully on single strand tendons. However it was eliminated from further consideration because of the uncertainty about cross-sectional properties of a grouted multi-strand tendon.

Cable Tensiometer This system calculates the tension in a single strand by measuring the speed of electrical impulses through the strand. It is a relatively easy and repeatable system, but it is predictable only for single strands. It was eliminated due to its inadaptability to multistrand tendons.

Fulmer Tension Meter This system determines the tension in a single strand based on the amount of force required to deflect the strand a set distance. It has been used very successfully on single strands. It is accurate to within 5% and has very good repeatability. Unfortunately it had to be eliminated due to the difficulty in adapting the system to a multi-strand tendon.

Mechanical Extensometers This system involves attaching two locating discs or points at a set gage length apart on the tendon and measuring the change in that distance caused by tension changes. This system was chosen for further study and refinements. The primary problem was attaching the locating discs to the entire tendon. The tests are described in detail in the next section.

Bondable Strain Gages These are a very popular method of determination of strains. The gage is glued or epoxied to a single wire of a single strand and the change in resistance through the gage can be equated to the strain in the material to which it is attached. They are very reliable for short term readings but problems often occur during grouting operations. Other problems were discussed at the beginning of this section. This system was, however, chosen for further laboratory study which is detailed in the next section.

Electrical Load Cells This system measures the force between two objects by the deformation in the cell which is located between the objects in question. The deformation in the cell is measured by electrical resistance gages located at several points on the cell. This system could only be used at the tendon anchorage points where it could be placed between the wedge plate and the anchor plate. It was eliminated primarily due to the high cost of the cells and to the fact that measurements at the anchorages gives no information on losses across deviators.

Photoelastic Load Cells This system works in a similar manner to the Electrical Load Cell except the cell is fabricated of a photoelastic material. This system was also eliminated due to its limited usefulness (it can only be located at tendon anchorage points) and its high cost.

Calibrated Hydraulic Jacks The force in the tendon at the stressing location is calculated by multiplying the measured pressure in the hydraulic hoses by the area of the piston of the ram. This is an easy system to use, since the contractor is required to measure the pressure in the lines during stressing. The pressure can be easily recorded by the investigators.

Hydraulic Load Cells Similar to Photoelastic and Electrical load cells, this system determines the force by measuring a hydraulic pressure. It was eliminated due to high cost and limited applicability.

Optical Bondable Strain Gages This type of gage is currently being developed and refined, so it is not widely available. It measures the strain in an optical fiber based on the amount of light transmitted through and reflected back through that fiber. It was eliminated due to lack of availability, the untested/experimental nature of the system and the high cost.

6.1.2 Testing Program. The primary systems chosen for further tests were the Mechanical Extensometer and the Bondable Electrical Resistance Gages. The hydraulic ram pressure will be measured in the field, but no tests were performed.

The mechanical extensometer system developed for testing is pictured in Figure 2. First two epoxy sleeves are cast around the group of strands at a predetermined distance. After the epoxy has set, Demec locating disks are epoxied to the sleeves. Demec locating discs are small stainless steel discs with a small hole drilled in the center. The Demec extensometer, pictured in Figure 3, has two small points which seat firmly into the holes in the locating discs. The dial gage reading indicates the change in distance between the two discs.

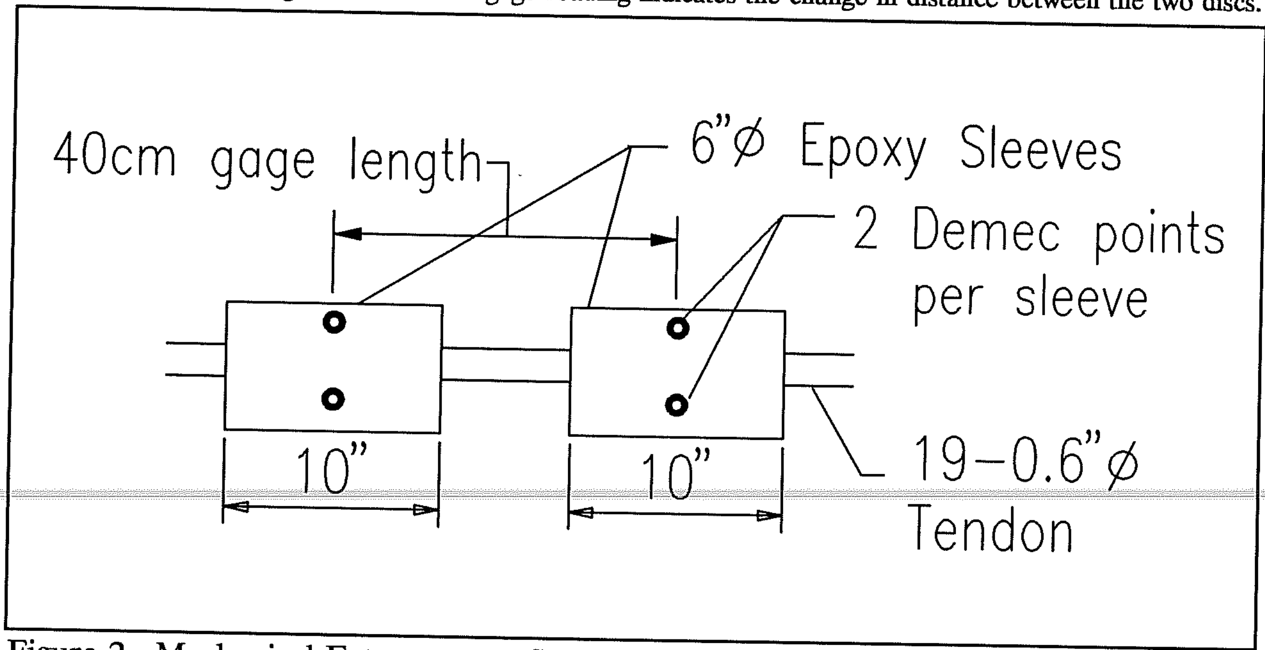

Figure 2. Mechanical Extensometer System

This system was studied in the laboratory. It was used successfully on single 0.6" diameter strands, as well as 7 and 12 strand tendons. The size of the epoxy sleeve required to bond to the tendon without cracking and without changing the behavior of the tendon was determined.

The system was then field tested twice in San Antonio on a 19 strand tendon. The epoxy performed very well and the readings were in good agreement with bondable electrical resistance gages. One of the side benefits of the epoxy sleeves is that between the sleeves the 19 strands behave almost identically. Electrical resistance gages placed between the sleeves give very similar readings.

Many tests and other investigations of the electrical resistance gages indicate that many of the problems with the use of such strain gages can be eliminated by the selection of the proper gage, the proper bonding system, and the combined use of such strain gages in conjunction with the epoxy sleeve.

High resistance gages (350 ohm) were selected due to their higher excitation voltage and therefore lower signal-to-noise ratio. A permanent stay in place data acquisition system was selected so that the gages will be constantly attached, thereby eliminating changing resistances caused by hooking and unhooking connections. A two part epoxy will be used to attach the gages. It is more labor intensive but also more reliable than normal glue for long periods of time.

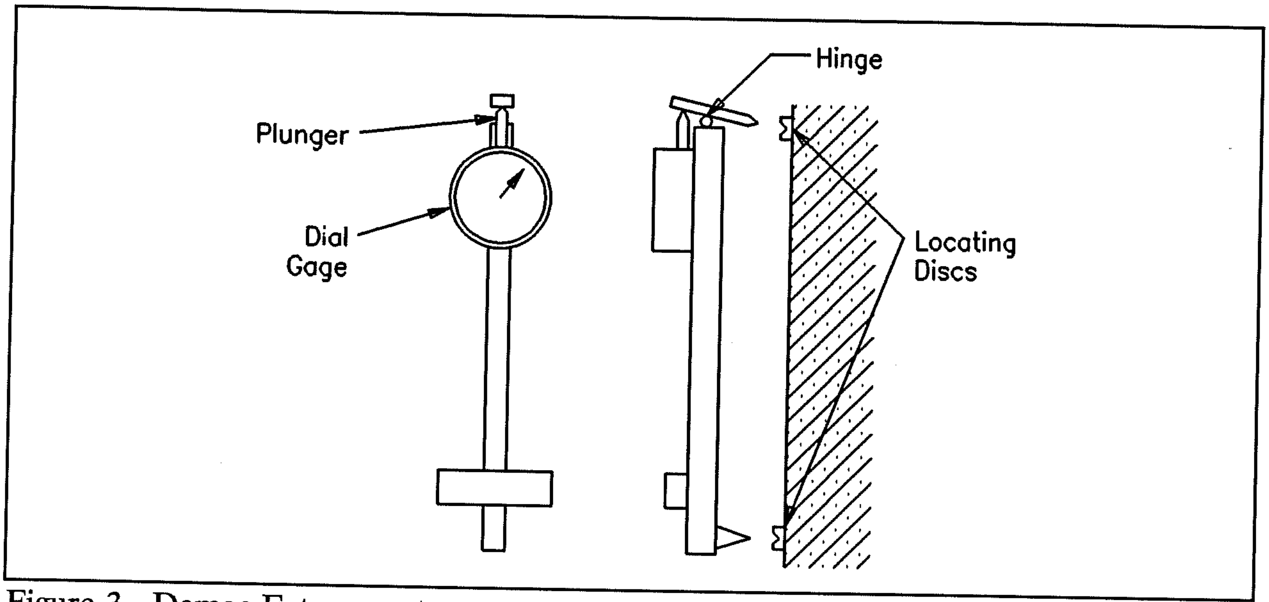

Figure 3. Demec Extensometer

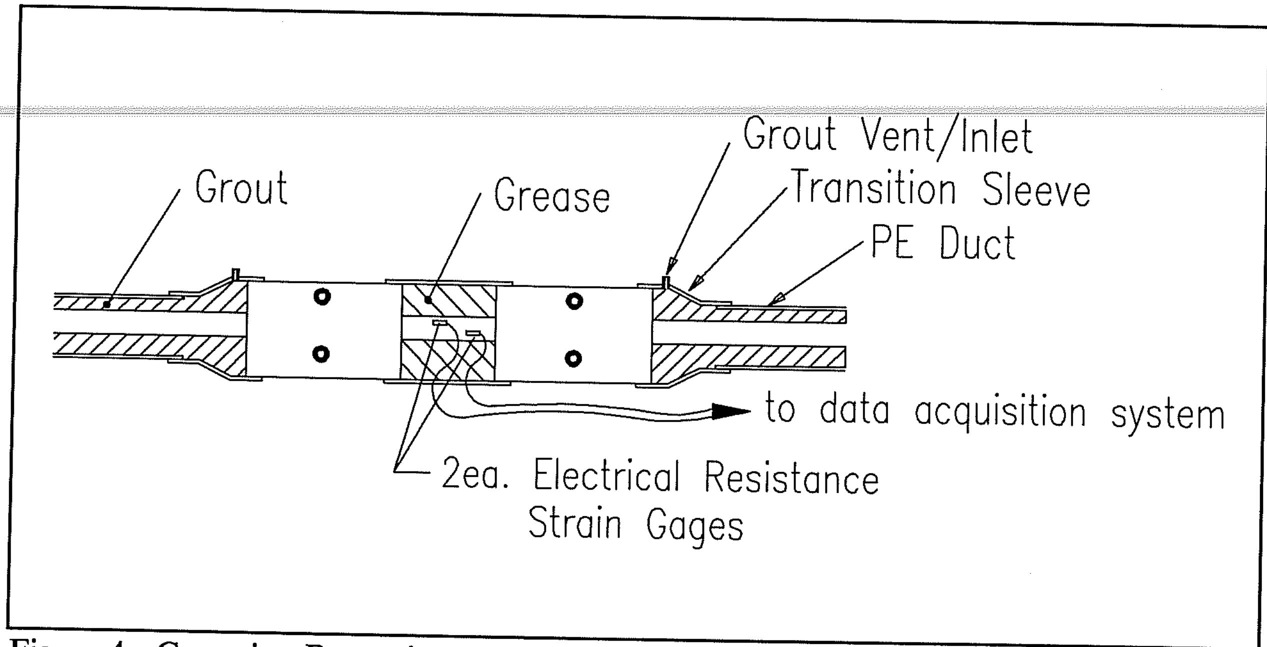

Figure 4. Corrosion Protection System for Tendon in Instrumentation Area

Finally since the gages will be placed between the epoxy sleeves they will not be exposed to grout (see Figure 4). A grout bypass system is currently being developed in the lab. The section of the tendon between the sleeves will be protected by a corrosion resistant grease which is much less harmful to gages than grout.

The final system will consist of a combination of epoxy sleeves and electrical resistance gages. Two electrical resistance gages will be placed on the strand between the epoxy sleeves in all locations. In selected locations 4 gages will be placed. Two will be initially connected to the permanent data acquisition system. The others will be used in the case of failure of the original gages. The number of additional gages will be limited by the time available to install the gages. The investigators will have only three days to install all instrumentation, so additional gages will be installed as time permits.

If a gage fails in the future where additional gages have not been provided, the enclosure and the grease can be removed, the gage replaced, and the grease and enclosure replaced.

6.2 Reinforcing Steel Stresses

Reinforcing steel stresses are to be measured in anchorage zones and deviators. The gages must be reliable and must survive the casting process and several months in the segments before stressing operations. Since stressing is the most critical time for the anchor zones and deviators, long term readings are not as important as stressing readings. Still the gages must last until stressing.

6.2.1 Candidate systems.

Electrical Resistance Gages As described in the previous section, this system is highly accurate and reliable for short term readings. Modifications and refinements to the bonding system and the moisture protection system must be made to ensure the long term reliability of the gages.

6.2.2 Testing Program. No tests have been performed on electrical gages applied to reinforcing steel as part of this program to date. However, the investigators have had substantial previous experience with the use of such embedded gages on reinforcement. The system will be designed to ensure the longest possible life span of the gages.

6.3 Concrete Strains

The system for measuring concrete strains must be very accurate and very stable over long periods of time. Due to the numerous locations that the gages will be used, time required to collect data, ease of installation and cost are also important criteria in the selection of a system.

6.3.1 Candidate Systems.

Demec Type Extensometer As described in Section 6.1.2, this system involves two stainless steel discs bonded to the surface of the concrete. A mechanical extensometer measures the change in the distance between the two points. For experienced users it is a very accurate system, however it is not very precise. Precision to within 25 microstrain, however, is easily attainable. This system was chosen for further study.

Whittemore Type Extensometers This system is very similar to the Demec system. It was not selected for further study primarily because the investigators were already familiar with the Demec gage, and the laboratory currently owns several Demec extensometers.

Prewitt Scratch Gages This system is similar to the Demec type extensometer also. The system was eliminated due to its low sensitivity and limited availability.

Surface Mounted Vibrating Wire Strain Gages The vibrating wire system measures the elongation of a small wire inside a gage which is bonded to the surface of the concrete. The elongation is calculated by measuring the natural frequency of this small wire. The system is very accurate, very precise and very reliable, but it was eliminated due to its high cost.

Surface Bondable Electrical Resistance Gages These gages work exactly like bondable ER gages on steel. The primary problem is the difficulty in bonding the gages to rough concrete surfaces. There are also problems caused by weather conditions and the difficulties in moisture protection. This system was not selected for further study.

Embedded Vibrating Wire Strain Gages This system is exactly like the surface mounted Vibrating Wire gages except the entire gage is embedded in the concrete. It was also eliminated due to its high cost.

Carlson Elastic Wire Strain Meters This is a very sensitive embedded vibrating wire gage. It has been used very successfully in the past. It was eliminated primarily due to its high cost and incompatibility with data acquisition systems at the Ferguson Lab.

Eaton Corporation Polyester Mold Gages This system uses electrical resistance gages, affixed to a material and then waterproofed and embedded. The material, theoretically, behaves exactly like the concrete it displaces. This system was eliminated due to its low sensitivity and limited availability.

Mustran Gages This system is very similar to the Eaton Corporation gages. The gages, however, can be easily assembled in the laboratory. They have been used with some success in the Ferguson Lab in the past. This system could be utilized on this project, although its long term stability is questionable.

6.3.2 Testing Program. The primary problem encountered with the use of Demec gages in the past has been the de-bonding of the locating discs. Weather conditions and solar radiation tend to degrade the epoxy which adheres the discs to the concrete. In many cases the discs have fallen off completely.

In the lab many systems were studied to develop a new, more reliable mounting system for the gages. Specimens were made to investigate the ease of installation, the reliability of the readings and the performance under harsh environmental cycling (salt water, freeze-thaw cycles, and solar radiation).

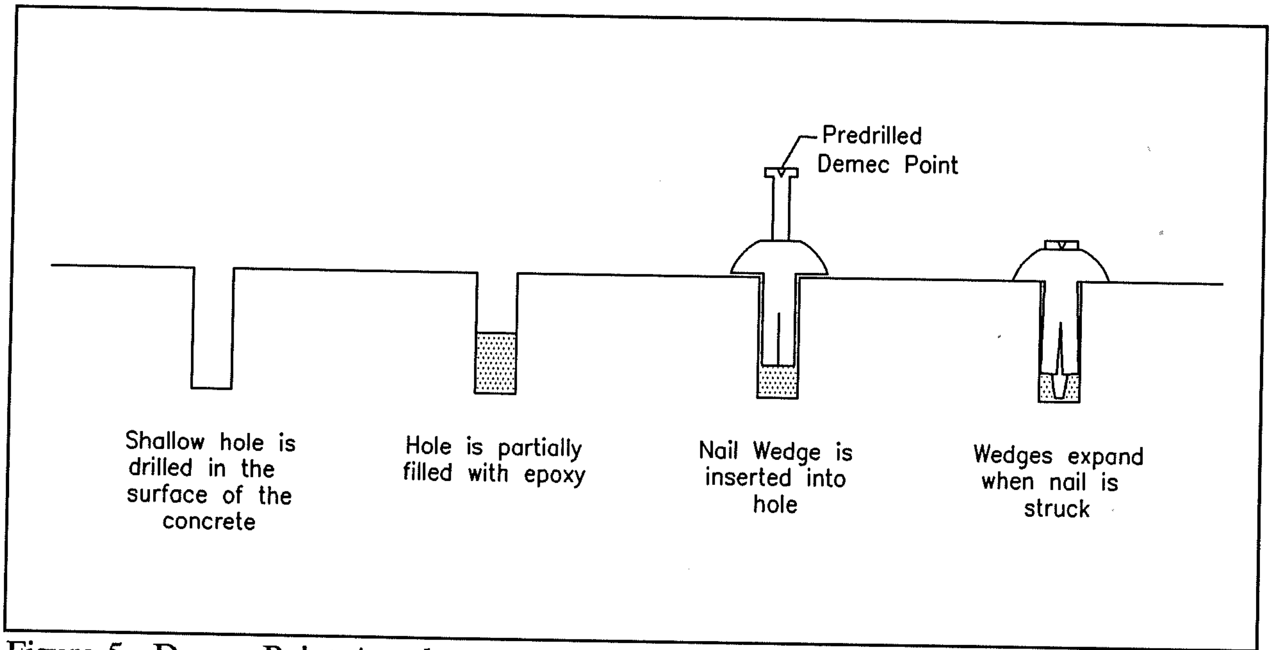

Figure 5. Demec Point Attachment System

The system selected is shown in Figure 5. It is a stainless steel nail wedge system. The hole drilled for the nail in the concrete will be filled with epoxy before the nail is inserted and expanded. In this way the system will have both a mechanical and an epoxy attachment to the concrete.

Field tests in San Antonio were performed. The tests provided a realistic approximation of time required for reading a series of gages along the length of a span. It also showed the readings to be very repeatable even with different investigators reading the gage.

6.4 Deflections

The primary criteria for the selection of a deflection measurement system are ease of installation, ease and speed of readings, accuracy, reliability, and cost. The system should have and accuracy of better than 0.01in.

6.4.1 Candidate Systems.

Pauw-Breen Piano Wire Base Line System This system, developed at the University of Missouri [3] and refined at FSEL, utilizes a highly tensioned piano wire attached at two points. The distance from this base line wire to points along a beam can be easily measured with high repeatability and good precision. If the wire is damaged or broken, a new wire can be installed and tensioned to the same level. Readings can continue as before.

Bradbury-Breen Modified Piano Wire System The original Pauw-Breen system was slightly modified by Bradbury [4]. The wire is tensioned by tightening a screw instead of hanging a dead weight. A system similar to these piano wire systems was chosen for further study.

Hydrostatic Systems This system is based on the law of communicating vessels. The system consists of a horizontal tube and a number of vertical tubes, all interconnected. The tubes are filled with a liquid and that liquid rises to the same elevation in each vertical tube. Distances from reference points on the bridge to the top of the liquid can be measured. This system was eliminated due to its difficult installation procedures, long reading process, temperature problems and problems caused by bubbles in the system.

Optical Methods This system involves conventional surveying methods to determine elevations along the bridge. It was eliminated due to its low precision and the difficulty in reading after the bridge is opened to traffic.

6.4.2 Testing Program. Lab investigations were performed using various modifications to the Breen-Pauw piano wire system. In the lab, on short beams (approximately 40 feet), the refined system was found to compare very well with linear potentiometers fixed to the floor.

A prototype system was fabricated and installed on Span CC-35 of Phase IC of the San Antonio "Y" project for practical use evaluation. Figure 6 shows the basic system layout. Brackets are attached to the bottom side of the top slab of the box girder inside the box. One bracket holds the dead end of the wire, the other has a very low friction roller system. The wire is fed over the roller and a weight is suspended, thus insuring a constant tension in the wire. Small corrosion-proof plates are attached at the quarter points to the "ceiling" of the box. A very high precision sliding digital ruler is magnetically attached to the plates. It is held in position by a set of guides. Changes in the distance between the base of the ruler and the taut wire can be read very accurately.

The field test indicated that the readings can be made quickly and repeatably. The replacement of the wire is easy and does not change the readings. This system also has the great advantage of being installed inside of the box. Measurements can continue uninterrupted even after the bridge has been opened to traffic.

The transverse wingtip deflections will be measured in a similar fashion. The anchor and roller bracket will be fixed to the wingtips and measuring plates embedded along the top slab (see Figure 7). Measurements will be taken before and after release of the pretensioning, while the segments are in storage, and before and after transverse post-tensioning, on span C11.

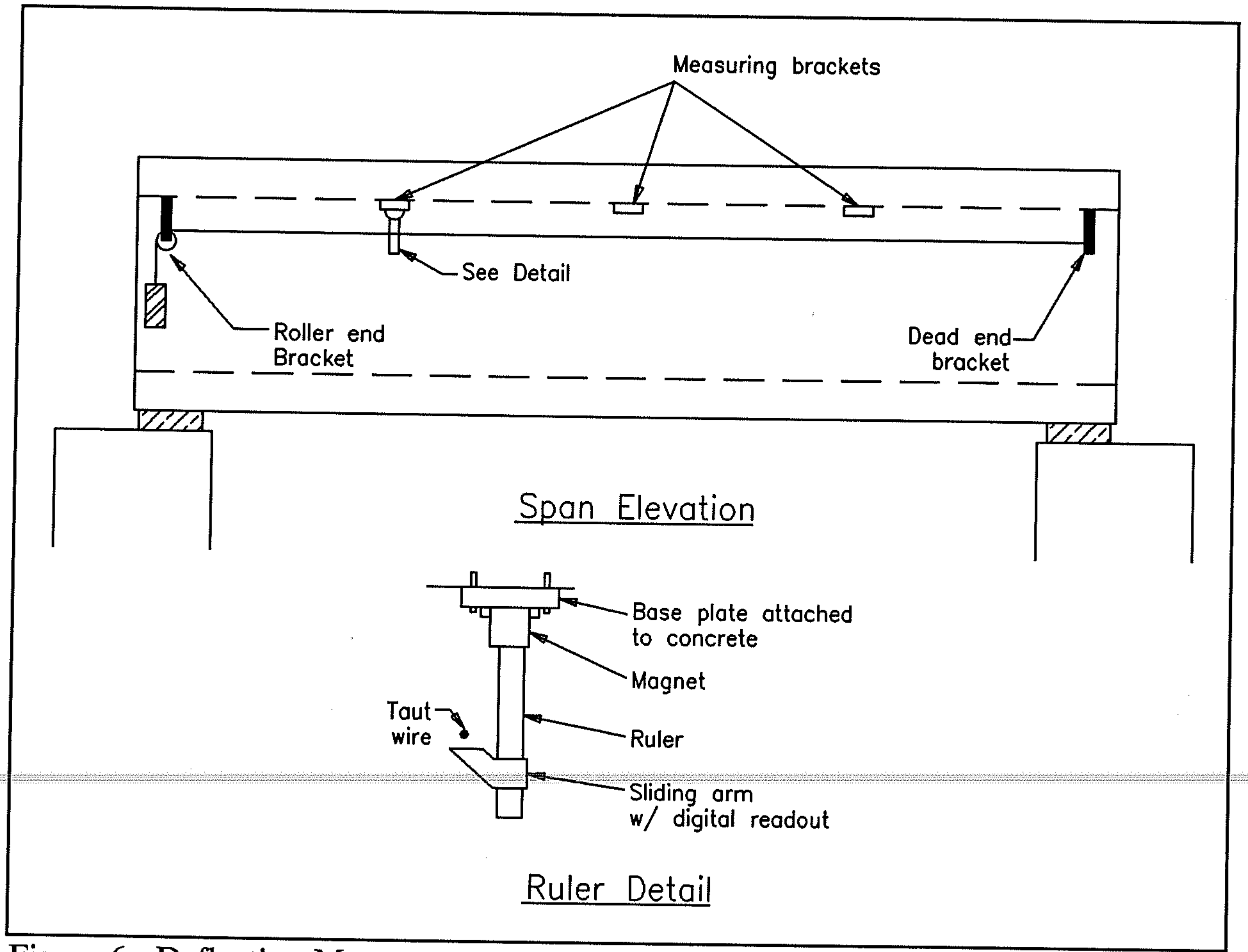

Figure 6. Deflection Measurement System

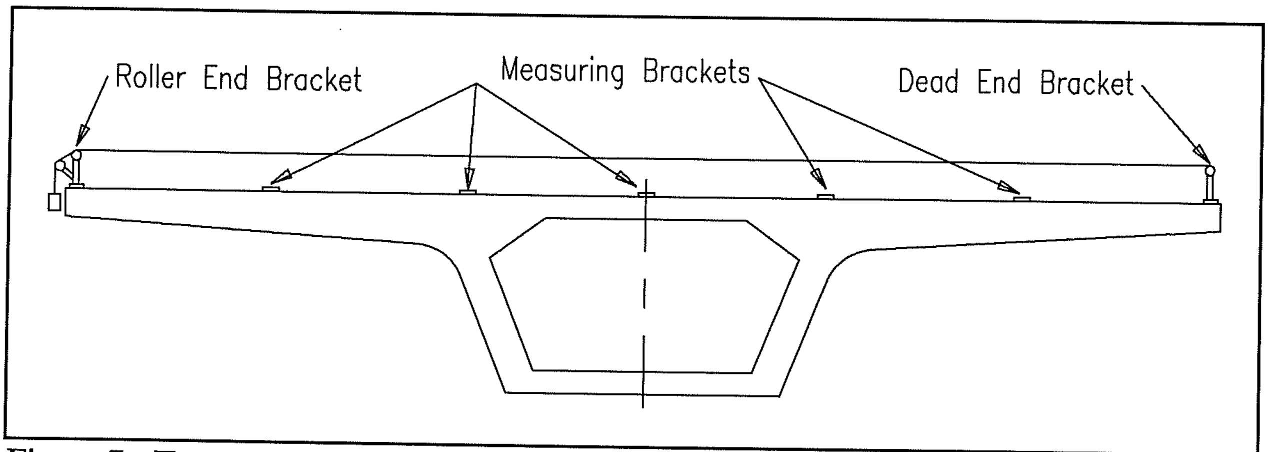

Figure 7. Transverse Deflection Measurement System

6.5 Temperature

The temperature of the concrete in the segments is of great interest during hydration, when the segment is in the match cast position, as well as after erection when temperatures are affected by environmental factors. The system chosen must be accurate, stable over the long term and easy to install and read.

6.5.1 Candidate Systems.

Thermocouples Thermocouples operate on the principle that currents are set up between unlike materials which have been connected to complete a circuit. These currents change with temperature and the currents can be read and related to a temperature. The readings are very accurate, very reliable over the long term, and the system is inexpensive. This system was chosen based on very good performance in the past.

Thermistors- Thermistors are resistors used as part of a Wheatstone bridge (similar to electric resistance strain gages). They are more limited than thermocouples because they require completion circuits, excitation voltage, and they have lower ranges of optimum operating temperatures.

6.5.2 Testing Program. No tests have been performed in this program. Thermocouples have been used so successfully on field box girder studies by FSEL personnel in the past [5], and are so simple, that no tests were deemed necessary. A system to facilitate quick and easy reading of the thermocouples has been developed at FSEL.

6.6 Solar Radiation

The two primary variables affecting thermal gradients in box girders are the wind speed and the intensity of solar radiation. To correlate thermal gradients with influencing factors the solar radiation must be measured. The weather stations in the San Antonio area do not routinely measure solar radiation, therefore a system must be procured for the project

6.6.1 Candidate Systems.

Electrical Pyranometers This system used a silicon photodiode to measure solar radiation. The readings are recorded at desired intervals by a remote data acquisition system. The unit is very simple, not exceedingly expensive and very accurate.

Mechanical Pyranometers This system is similar to the electric system except the level of solar radiation is recorded as a line of a rolling sheet of graph paper. The accuracy is not as good as the electric system and the set up takes more time. Both systems were lab tested.

6.6.2 Testing Program. The LI-COR Pyranometer (Model LI-200SZ) and a mechanical pyranometer were compared in tests at the laboratory. The tests revealed both systems to be reasonably accurate, or at least they compared very well with each other. The electric pyranometer, however, was much easier to use and the data was more precise.
The LI-COR was then set up on one of the spans of the San Antonio IC project. Again it proved to be a very easy, very precise method of measuring solar radiation.

6.7 Joint Openings

This system must be able to record very small movements at critical locations at joints. The system must be easy to install, durable, and accurate.

6.7.1 Candidate Systems.

Systems with Mechanical Extensometers- Dial gages, see Figure 8, can measure very small movements. The gage can be attached at one location and the plunger placed on some reference plane. The changes in the extension of the plunger can then be easily measured. This system was eliminated for measuring joint openings because of the difficulty of installation and the risk of the gages getting bumped or displaced.

Grid Crack Monitors This system is made up of two small transparent plastic plates. One plate is

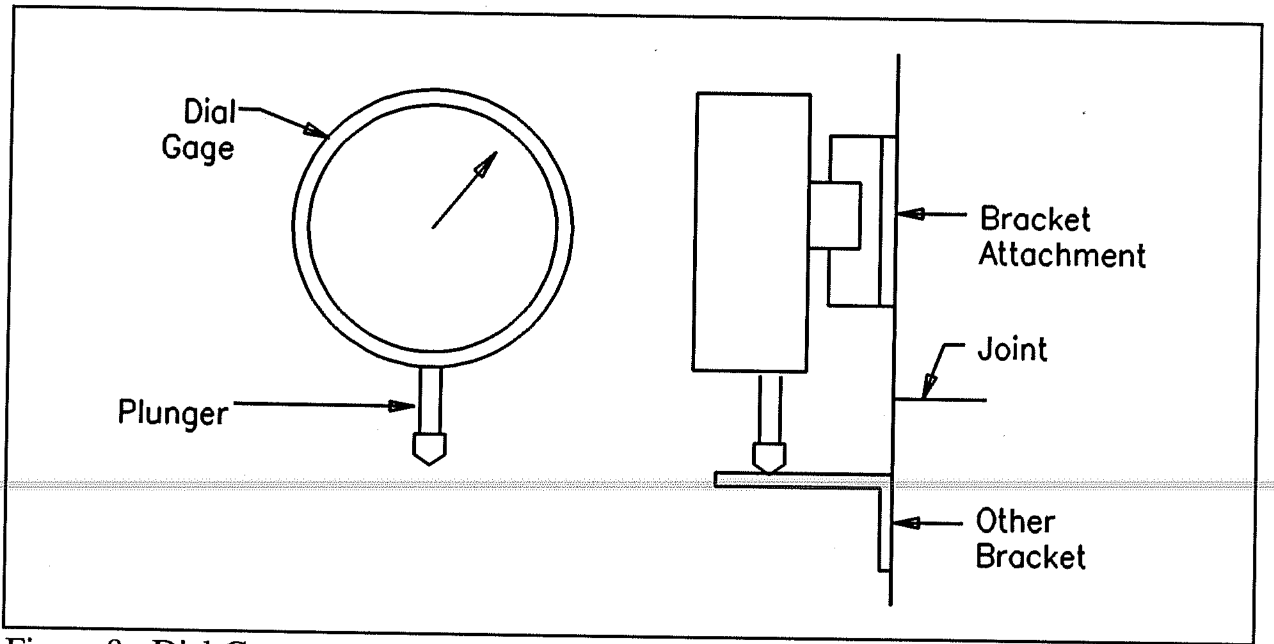

Figure 8. Dial Gage

mounted on one side of the joint, the other is mounted on the other side but overlays part of the first plate. If the plates move relative to one another (if the joint opens) the amount of movement can be read off of grids on the plates. This system is very easy, very inexpensive and very durable. It performed extremely well in the laboratory tests of box girder bridge models reported by MacGregor[6].

Linear Potentiometers- These are electrical measuring devices which operate similarly to the dial gages, except that a signal is sent to a data acquisition system which very precisely measures the plunger's movements. This system is much more precise than the mechanical dial gages, but is also more expensive, and has many of the same mounting problems.

6.7.2 Testing Program. No laboratory tests have been run on these systems because they have been used extensively in the past. It is felt that for joint openings the Grid Crack Monitors used in conjunction with Demec locating discs are the best solution. The Demec readings will provide information on the average strain across the joints. If joints should open, the average tensile strain which caused the crack will be known.

6.8 Bearing Movements

Longitudinal and transverse movements, as well as vertical movements of the bearings must be measured. The purpose of measuring the vertical movement is to relate it to a change in force, so systems for measuring forces were also investigated. The bearings for the spans to be instrumented comprise both sliding and fixed bearings. Both types incorporate preformed fabric pads. The measurement system selected must be versatile enough to be used with all bearing types, must be easily read, and must be accurate to at least a 0.001" vertical movement and a 0.01" horizontal movement.

6.8.1 Candidate systems

Load Cells - Load cells, both hydraulic and electrical, are used to measure forces, and could be used to measure changes in reactions at the piers. There are several problems involved with the use of these devices. First the cost is very high. For load cells to measure the very high reaction forces (over 500 kips on some bearings) the cost per bearing would exceed $8000.00. The second problem is that alterations in the design of the bearings would be required to facilitate the installation of the load cells.

Flat Hydraulic Jacks - These systems are similar to hydraulic loads cells, and have similar problems. Their shape, wide but flat, is more conducive to use as a bearing pad replacement, but the bearings would still need redesign to accommodate the jacks. This constraint and the high cost made these jacks unacceptable.

Mechanical Measuring Devices - The sliding bearings consist of a bottom plate fixed to the top of the pier, a top plate fixed with dry packed mortar to the underside of the pier segment, and a fabric pad between the two plates. The fabric pad is held in place, relative to the bottom plate, by guide plates on all sides. A sheet of teflon between the fabric pad and the top plate allows the top plate to slide relative to the pier. Rulers can be used to measure the relative movement of the top and bottom plates in the transverse and longitudinal directions (see Figure 9).

The configuration of the plates also allows the use of inside dial gages and inside micrometers to measure the changes in the deflections of the fabric pad.

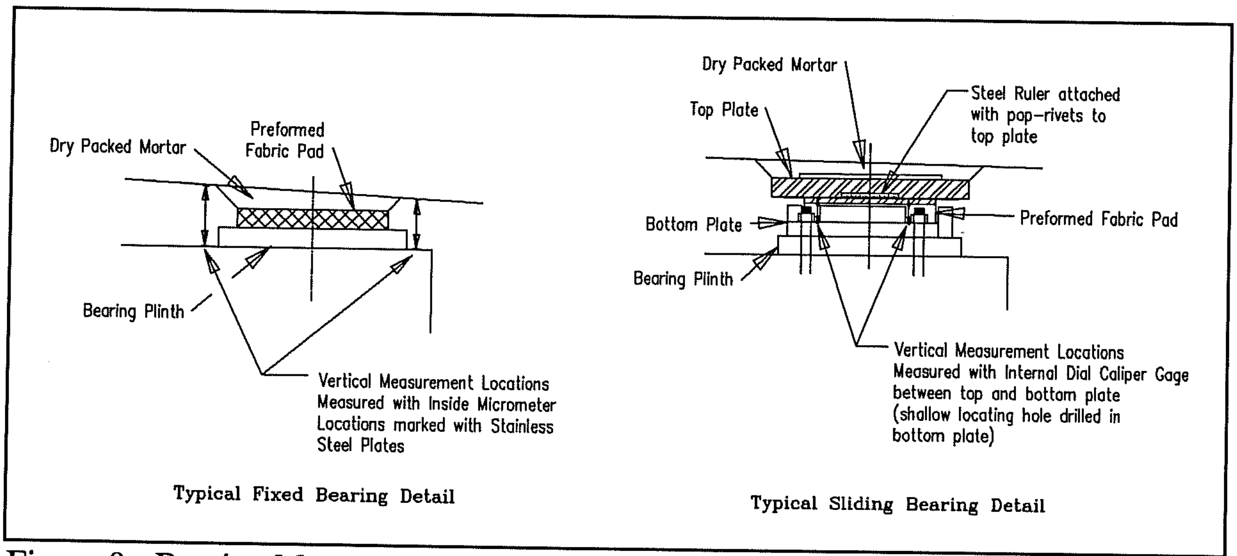

Figure 9. Bearing Measurement Details

These methods will produce accuracies of 0.01" for the horizontal movements and 0.001" for the vertical movements, and the cost will be very low.

6.8.2 Testing Program

No tests have been performed on the measurements systems, however, due to their low cost and easy installation, the mechanical measurement systems were chosen for the project. Because a vertical deflection, not a force, is measured, the modulus of the pad must be known to make the correlation. Samples of the pads will be tested to determine the stress-strain and creep characteristics.

6.9 Data Acquisition Systems

The main requirements for the data acquisition system are as follows:

1. Large number of channels (30-40 per instrumented span),
2. Low cost,
3. Readily available technology and software for data retrieval with a Personal Computer,
4. Battery operated,
5. Compatibility of retrieved data with standard PC spreadsheet programs.

6.9.1 Candidate Systems. Four systems were thoroughly examined:

1. OPTIM Electronics Systems,
2. Campbell Scientific Systems,
3. Hewlett Packard Systems,
4. Personal Computer Cards Based Systems.

The system selected is produced by Campbell Scientific Systems and consists of a 21XL Micrologger, two AM416 channel multiplexers, and communications software. A portable laptop computer has been purchased for data retrieval. This system was chosen because of its good accuracy, robust nature, readily available software, good performance to price ratio, and short installation time. Also this system had been used very successfully in a previous field project [7].

6.9.2 Testing Program. The system has been utilized in the field and in the laboratory. The programming and the data retrieval have proven to be very quick and easy.

An innovative solution for obtaining up to 70 channels for quarter bridge strain gages was devised. It has been successfully tested in the lab.

The basic system for a single span consists of two multiplexers and the micrologger. These components are permanently installed in a portable, waterproof case. On the outside of the case ports for the connection of the gage wires, the portable computer, and a battery are provided. All gages are permanently attached to the system. The Micrologger is then programmed to collect data at specified intervals, and the system is left permanently in the bridge structure. At intervals of approximately 2 weeks the data must be retrieved with a portable computer and the battery must be replaced.

6.10 Conclusion

Based on these field and lab tests, the final systems were determined as follows:

Tendon Forces -	Primary - Electrical Resistance Gages Secondary - Epoxy Sleeve System
Reinforcing Steel Strains -	350 ohm Electrical Resistance Gages
Concrete Strains -	20cm Demec Gages with Modified Attachment System
Deflections -	Piano Wire System with Digital Ruler
Temperature -	Type K Thermocouples
Solar Radiation -	LI-COR LI-200SZ Pyranometer
Joint Openings -	Grid Crack Monitors with Demec Gages
Data Acquisition -	Campbell Scientific 21X System
Bearing Movements -	Inside Calipers, Inside Micrometers, Precision Rulers

In addition to measurements of the bridge behavior, material properties will also be measured. For the reinforcing steel and post-tensioning strand, modulus and ultimate strength tests will be performed. The relaxation tests are difficult to perform and so the manufacturer's test data will be accepted as accurate.

Concrete cylinders will be made for all segments in instrumented spans. Modulus, compressive strength, tensile strength, creep and shrinkage tests and coefficient of thermal expansion tests will be performed.

Other environmental data such as relative humidity, ambient air temperature, and wind speed will be acquired from a local weather station.

With these systems, all data required for the evaluation of the bridge should be available.

7. FUTURE WORK

In the next year and a half the remainder of the work plan shall be completed. According to the contractor, segment casting will begin in early March and erection operations will begin in late July or early August. It is expected that all four instrumented spans will be erected by December of 1991. Long term data will be collected on a regular schedule and as much as possible will be included in the project's final report.

In the lab, work is progressing in assembling and finalizing all instrumentation systems. Many items cannot be finalized until the contractor's segment shop drawings have been reviewed and approved for construction. The literature review continues with the accumulation and review of all pertinent new publications.

8. CONCLUSION

In conclusion, the project is proceeding according to schedule. The instrumentation systems have been selected and are currently being finalized and fabricated. The casting and erection should proceed smoothly since the contractor is very experienced in segmental construction. The contractor, Austin Bridge Company of

Dallas, has already completed 3 of the 5 Phases of the San Antonio "Y" project. Their experience and enthusiasm for the project should be a great asset to the investigators.

A master's thesis, which includes an in depth literature review and a more extensive discussion of instrumentation systems should be completed this spring. This will provide the background for the first formal report from the project.

Based on the experience in San Antonio a tentative instrumentation program for the Austin US183 bridge will be developed.

This program will provide important new data, and will give valuable new insights into the behavior of externally post-tensioned segmental concrete box girder bridges. Changes will be proposed, where required, to the AASHTO Specification and general recommendations will be made concerning the design and construction of these types of bridges. With further refinements the use of the Specification should ensure safe and serviceable box girder bridges in the USA.

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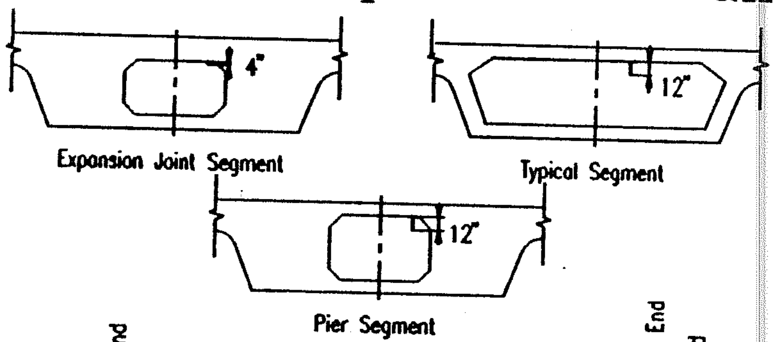
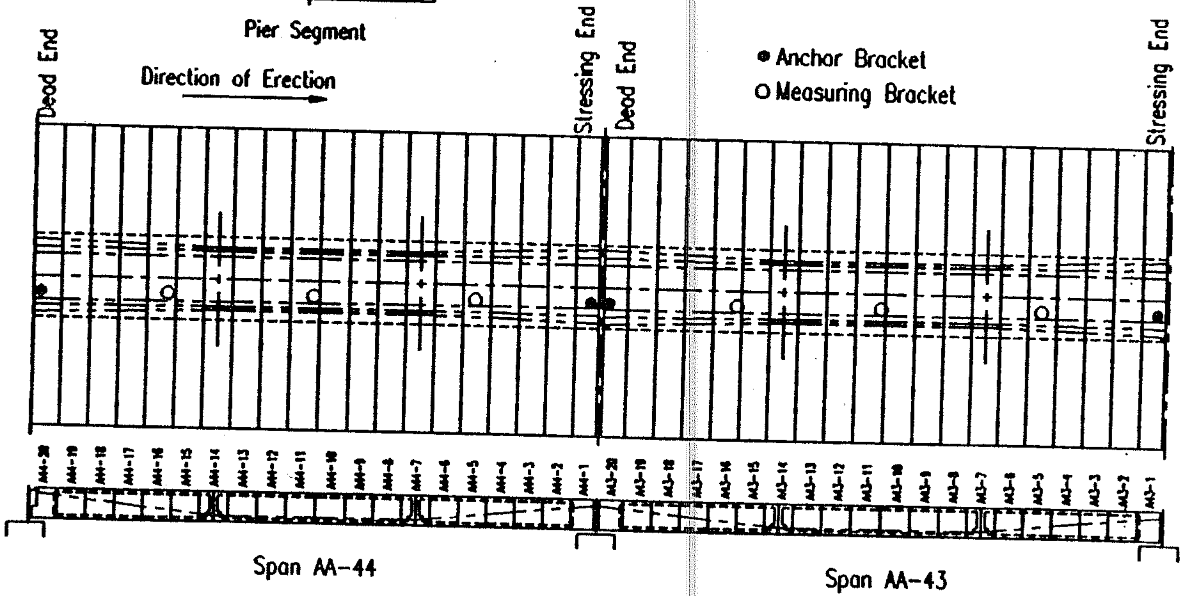
APPENDIX A

Instrumentation Layout
Deflection Measurements
Spans AA–43 and AA–44

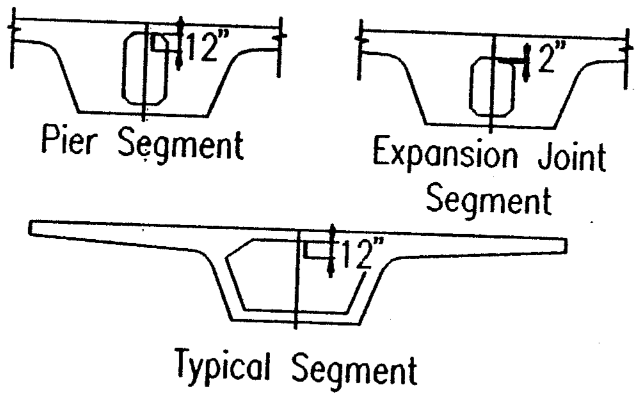


Objective: To measure the instantaneous and long term deflections of the span

Materials Required:
1ea. 4" anchor bracket
3ea. 12" anchor brackets
6ea. 12" ruler brackets
Piano wire

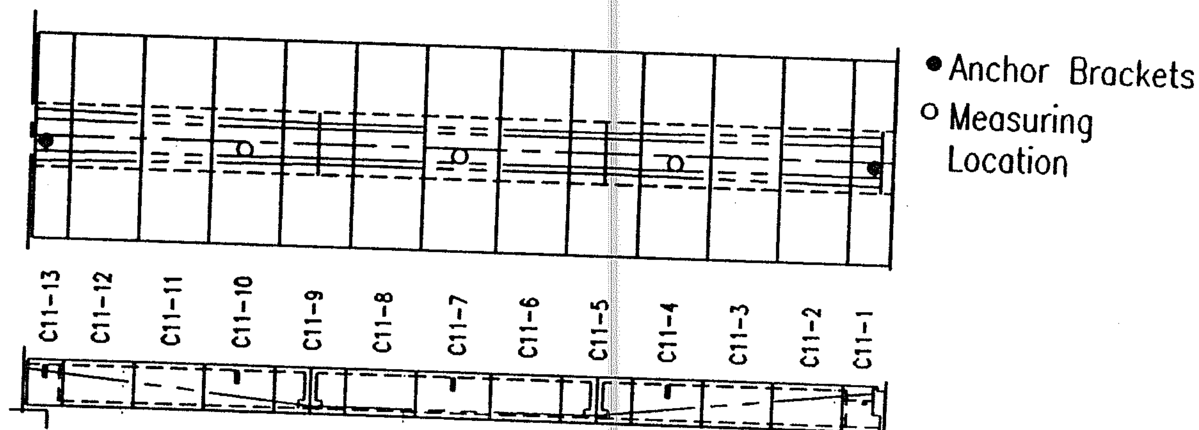


Instrumentation Layout
Deflection Measurements
Span CC–11

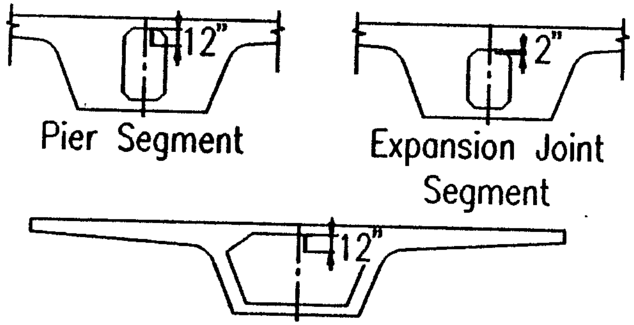


Objective: To measure instantaneous and long term deflections

Required Materials:
1ea. 2" anchor bracket
3ea 12" ruler brackets
1ea. 12" anchor bracket
Piano wire



Instrumentation Layout
Deflection Measurements
Span CC-9



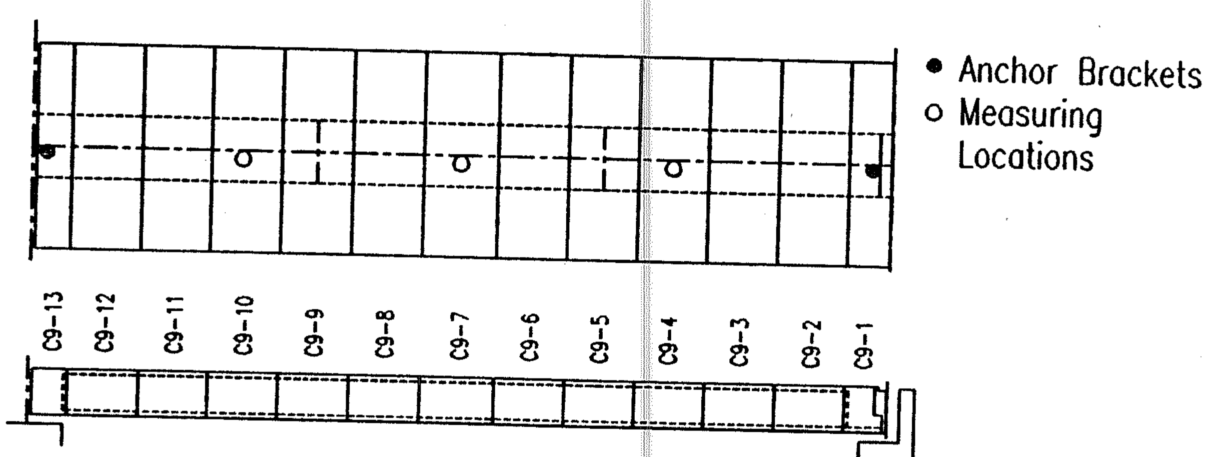
Pier Segment

Expansion Joint Segment

Typical Segment

Objective: To measure instantaneous and long term deflections

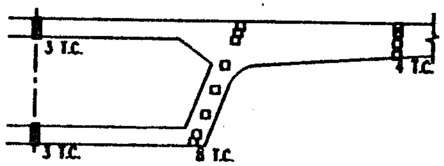
Required Materials:
1ea. 2" anchor bracket
3ea 12" ruler brackets
1ea. 12" anchor bracket
piano wire



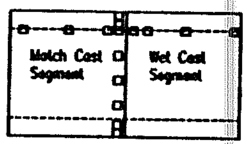
Instrumentation Layout

Thermocouples

Spans AA−43 and AA−44

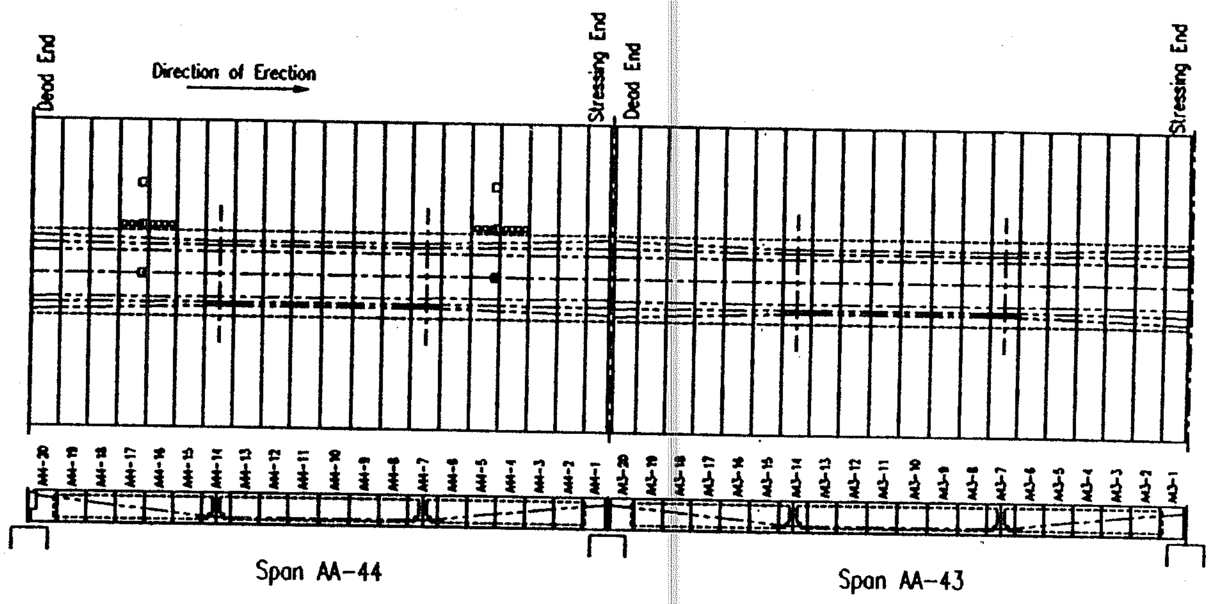


Typical Segment

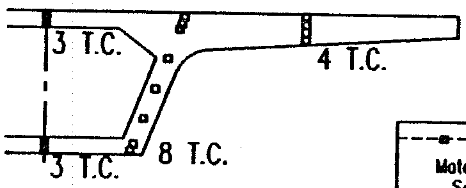


Objective: To record temperature gradients through the depth of the box due to solar radiation and to record temperature gradients caused by match casting

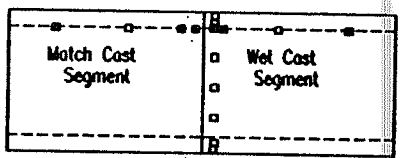
Required Materials: 60 thermocouples
thermometer



Instrumentation Layout
Thermocouples
Span CC−11

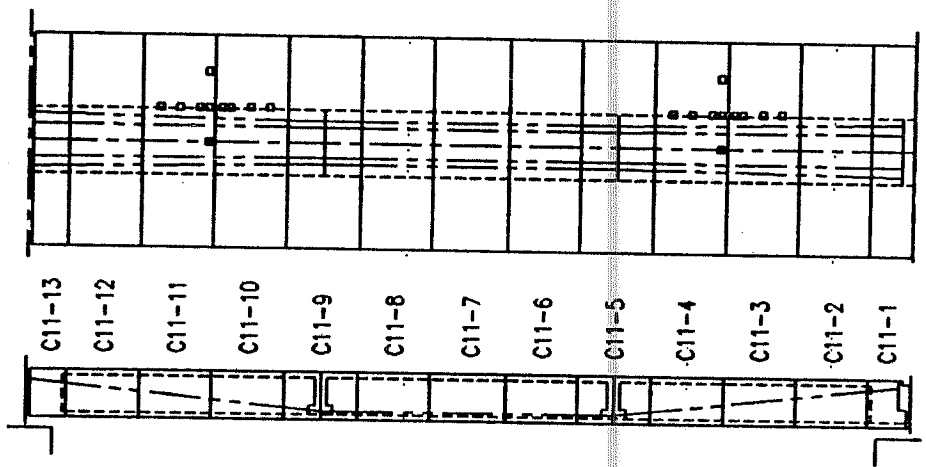


Typical Segment

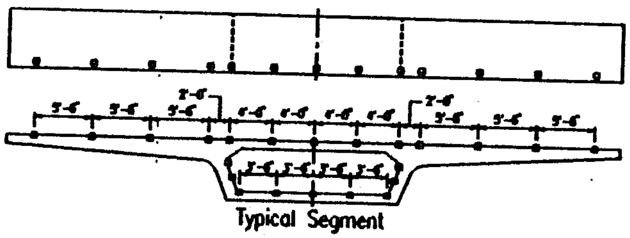


Objective: To record temperature gradients through the depth of the box due to solar radiation, and to record temperature gradients caused by match casting.

Required Materials: 60 thermocouples
thermometer

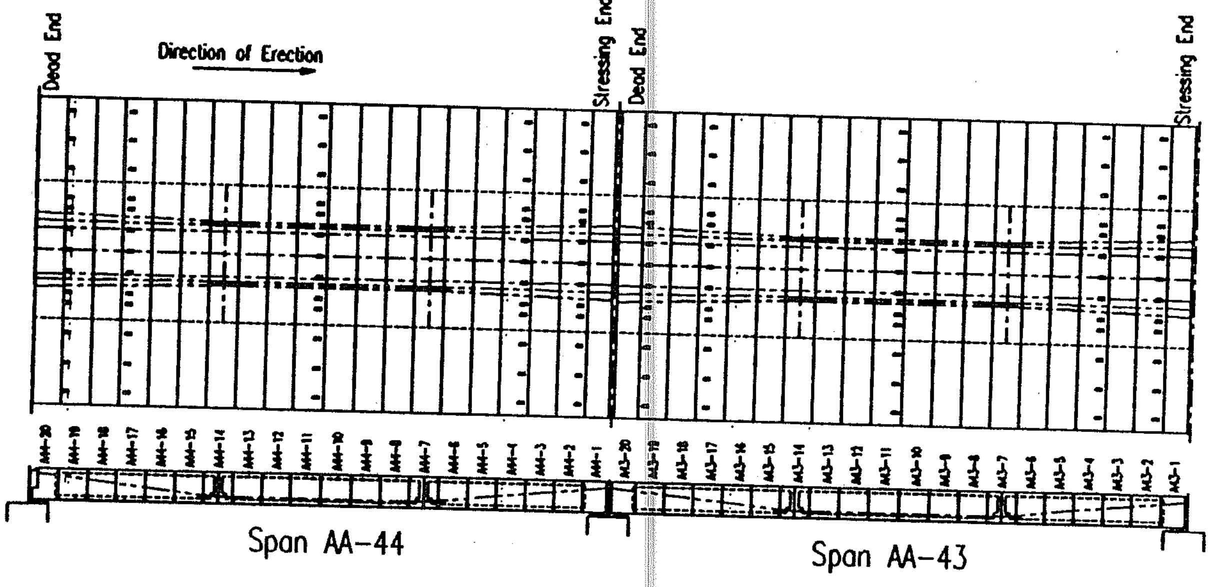


Instrumentation Layout
Demec Points
Spans AA−43 and AA−44

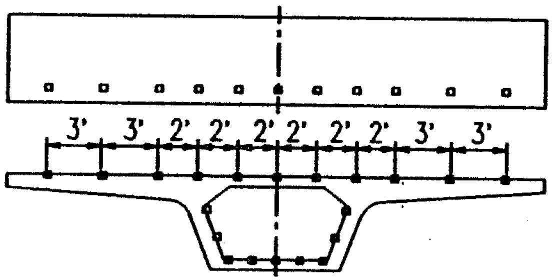


Objective: To track spread of Post−Tensioning Forces into span, and to study distribution of bending stresses caused by shear lag.

Required Materials: 220 demec points per span −− total 440 points
2ea. 20cm gage length demec gages



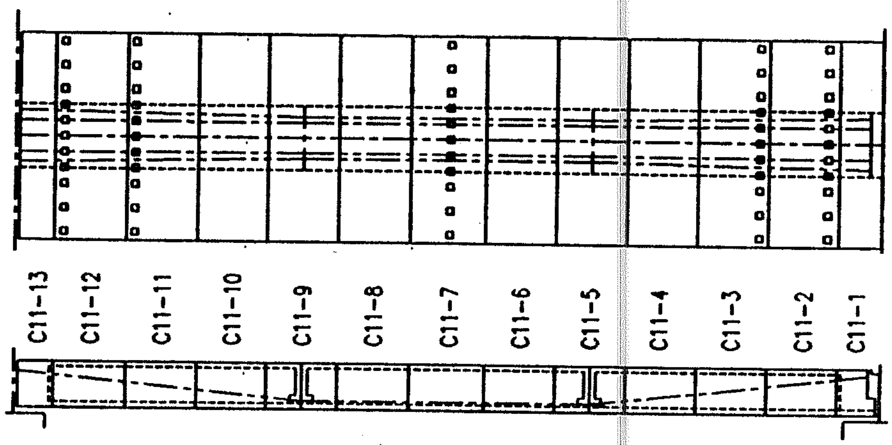
Instrumentation Layout
Demec Points
Span CC-11



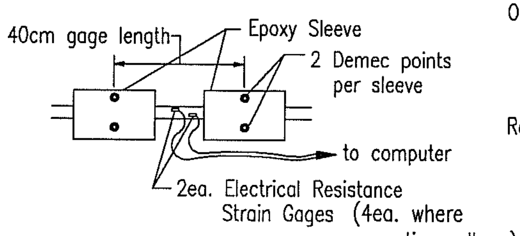
Typical Segment Elevation

Objective: To track spread of Post-tensioning forces into span, and to study distribution of bending stresses caused by shear lag.

Required Materials: 200 demec points
2ea. 20cm gage length demec gages



Instrumentation Layout
Tendon Forces
Spans AA-43 and AA-44

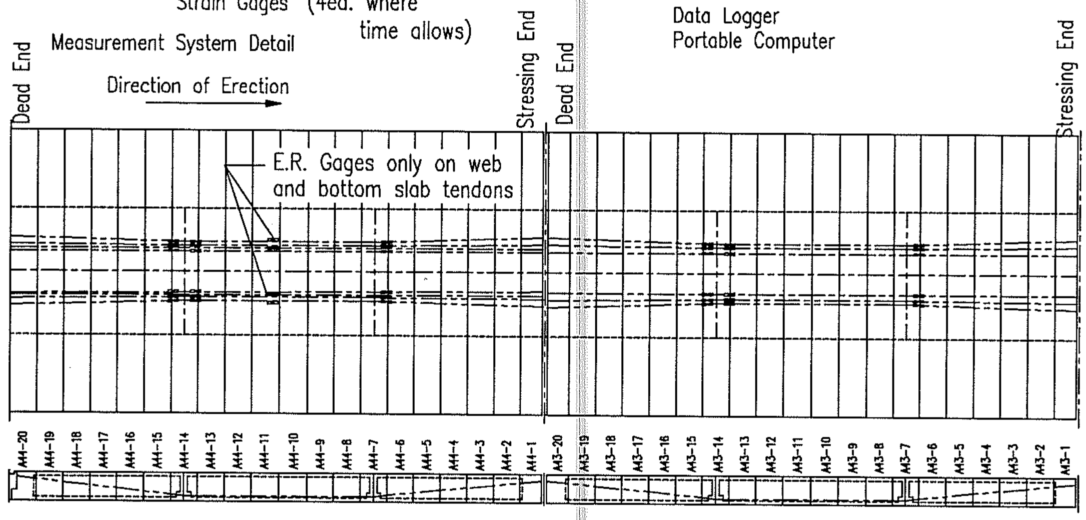


Measurement System Detail

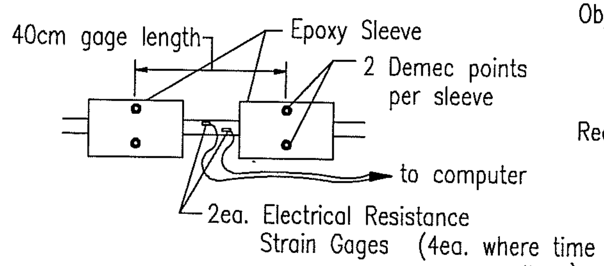
Objective: To measure the tendon forces at the time of stressing, and to monitor changes in tendon forces with time.

Required Materials:		AA-44	AA-43
Electrical Resistance Gages	–	44	36
Demec points	–	72	72
Epoxy Sleeves	–	72	72

Data Logger
Portable Computer



Instrumentation Layout
Tendon Forces
Span CC–11



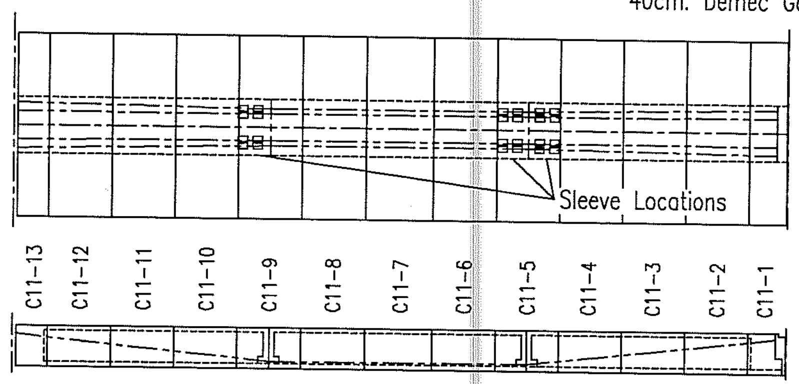
Measurement System Detail

Objective: To measure the tendon forces at the time of stressing, and to monitor changes in tendon forces with time.

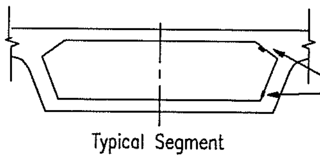
Required Materials:

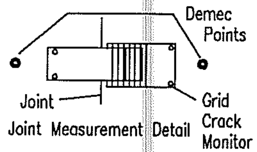
Electrical Resistance Gages	24
Demec Points	48
Epaoxy Sleeves	24

Data Logger
Portable Computer
40cm. Demec Gage



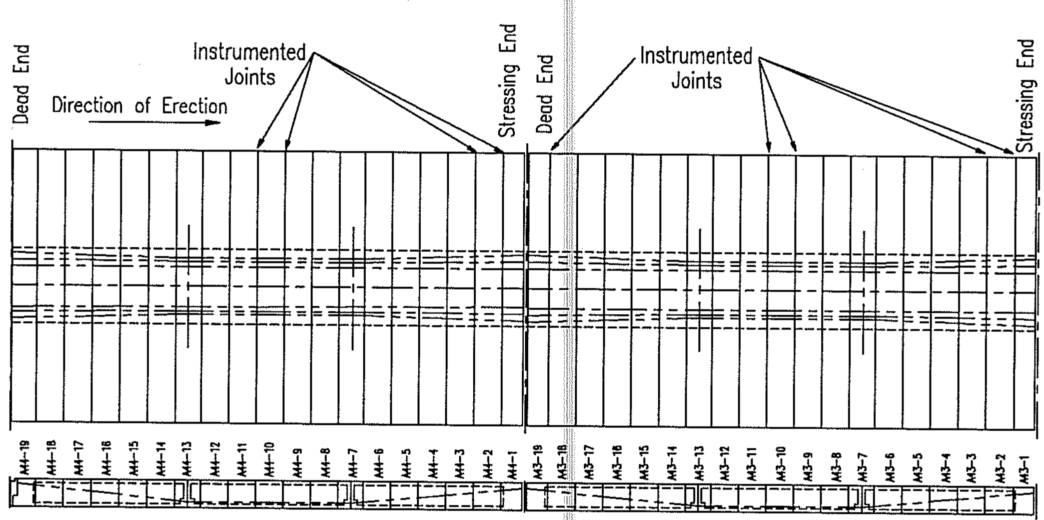
Instrumentation Layout
Joint Opening Measurements
Spans AA-43 and AA-44



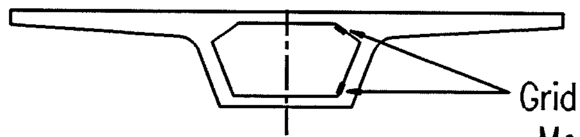


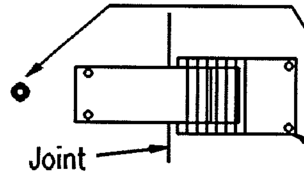
Objective: To monitor joint openings

Materials Required: 18 Grid Crack Monitors
36 Demec Points



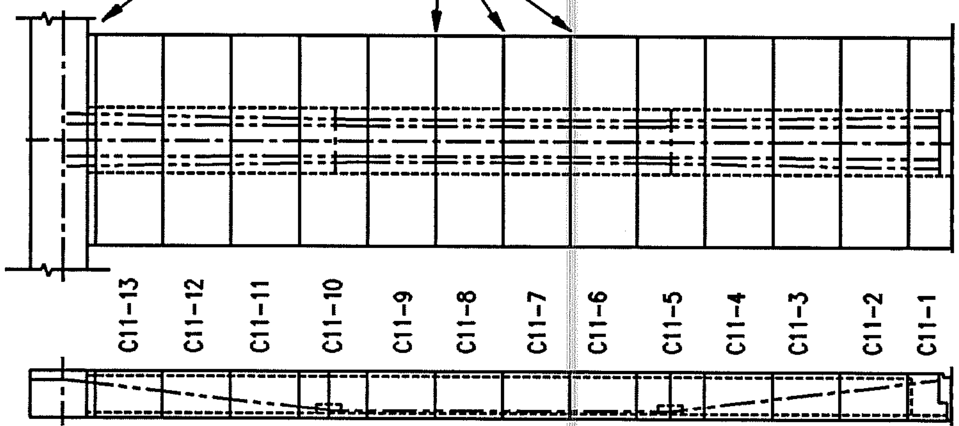
Instrumentation Layout
Joint Opening Measurements
Span CC−11



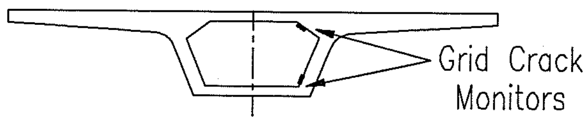


Objective: To monitor joint openings

Required Materials: 8 Grid Crack Monitors
16 Demec Points

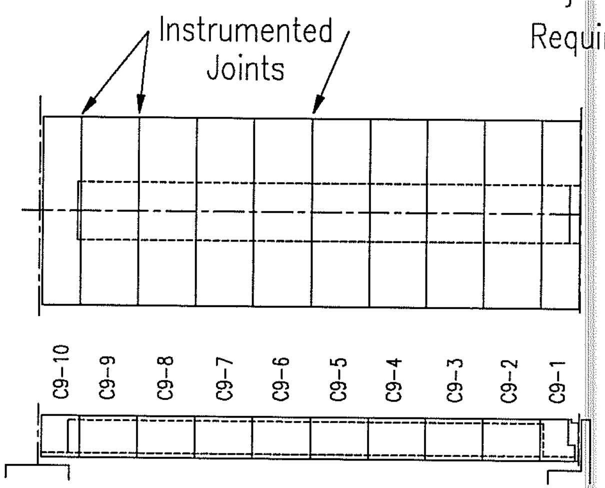


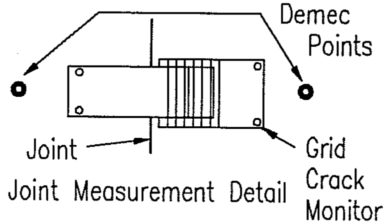
Instrumentation Layout
Joint Opening Measurements
Span CC-9



Objective: To monitor joint openings

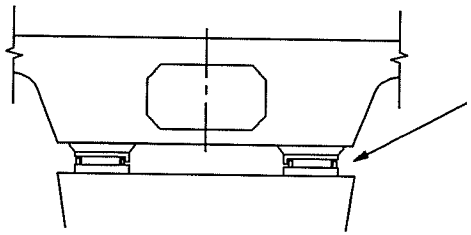
Required Materials: 6 Grid Crack Monitors
12 Demec Points





Joint Measurement Detail

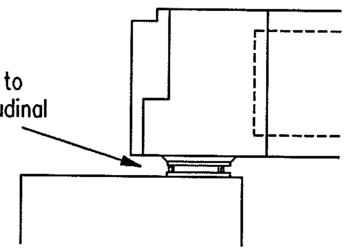
Instrumentation Layout
Bearing Movements
Spans AA−43 and AA−44



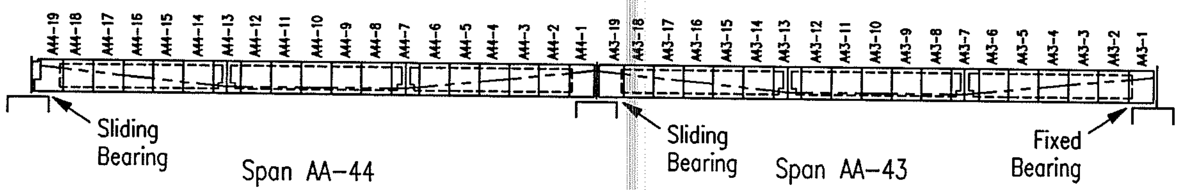
Pier or Expansion Joint Segment

Objective: To measure movements at bearing pads

Materials Required: 12 Precision Rulers
Inside Calipers
Inside Micrometer



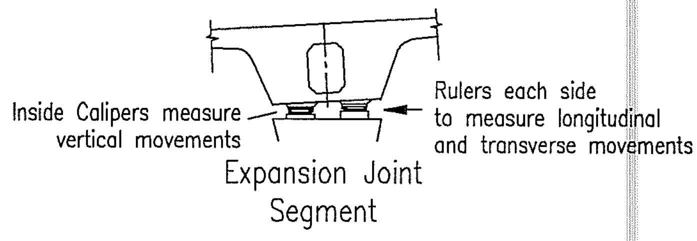
Section at Expansion Joint

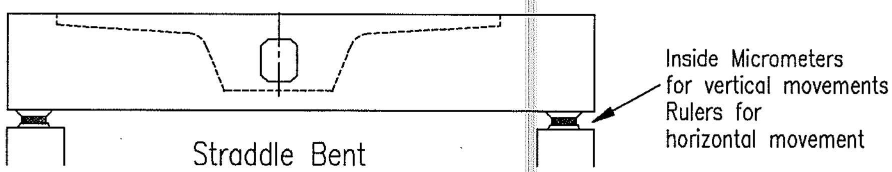


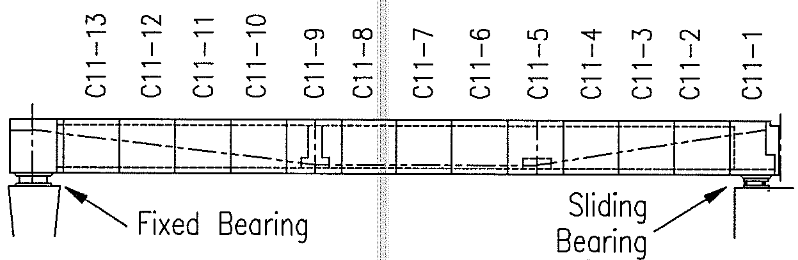
Instrumentation Layout
Bearing Movements
Span CC−11

Objective: To measure movements at bearing pads

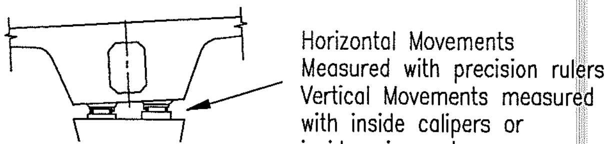
Required Materials: Inside Calipers
Inside Micrometer
8 Precision Rulers



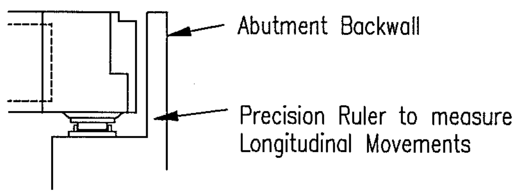




Instrumentation Layout
Bearing Movements
Span CC-9



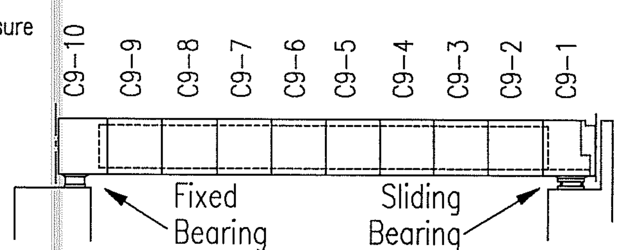
Pier or Expansion Joint Segment



Elevation of Expansion Jt. at Abutment

Objective: To measure movements at bearing pads

Required Materials: 8 Precision Rulers
Inside Calipers
Inside Micrometer



APPENDIX B

SPECIAL PROVISIONS FOR BRIDGE INSTRUMENTATION

A team of investigators from the University of Texas at Austin will be instrumenting and monitoring three of the spans. The exact spans will be determined after the contractor has finalized his erection schedule. The following section describes special services required of the contractor and indicates possible delays and work stoppages involved in the field study.

1. Casting Yard Operations

A. Reinforcing steel for the up station expansion joint segment and the up station deviator segment of one of the spans to be instrumented must be made available to the investigators no less than one week prior to casting of the segments to allow time for placement of gages. The gaged reinforcing bars will subsequently be placed in the reinforcing cages and special attention will be required to ensure that the gages not be damaged. The completed cage shall be made available for a check of the condition of the strain gages, and time shall be allowed for the replacement of any damaged gages.

B. Thermocouples will be placed in four segments of two of the specified spans. The thermocouples will be placed in the forms after the reinforcing cage is in place. Approximately one hour will be required for installation. A small work area for the investigators will be required adjacent to the casting bed for additional equipment.

C. In addition to normal quality assurance requirements, the investigators will require 12 concrete compression cylinders from each instrumented segment in each of the three spans to be investigated.

D. The contractor shall place the segments designated for further instrumentation in these three spans in storage so as to be fully accessible to the investigators for the placement of additional instrumentation. The bottom surface of the boxes need not be accessible, but the top surface and interior must be fully accessible.

E. The investigators will place four small blockout forms in the webs and bottom slabs of one segment of one span. The blockouts will be positions over the tendon ducts to allow access to the tendons during erection.

2. Erection Site Operations

A. While erecting each of the three spans selected for monitoring the contractor shall stop work on the span for up to 72 hours to allow for testing equipment installation. This stop shall take place after all epoxying and temporary post-tensioning has been performed, after all web and external tendons have been placed in the ducts and after all tendons have been seated with a small initial stress of approximately 15 ksi.

At this point the investigators will require up to 3 days to prepare for stressing operation measurements.

B. The contractor shall provide current calibration charts for all rams used during stressing operations. The contractor shall also provide a manifold on his hydraulic system with a Parker-Hannifin 3000 series female quick-disconnect connections which is required for the connection of an electronic pressure transducer.

C. The contractor shall allow the following pauses for instrumentation readings during stressing operations:

Span AA-43*	-	after stressing of T1 left and right	45 min.
		after stressing of T2 and T3 left and right	45 min.
		after stressing T4 left and right	45 min.
		after stressing of T6 and T7 left and right	45 min.
Span AA-44*	-	after stressing of T1 left and right	45 min.
		after stressing of T2 and T3 left and right	45 min.
		after stressing of T4 left and right	45 min.
		after stressing of T6 and T7 left and right	45 min.
Span CC-11*	-	after stressing of T1 left and right	45 min.
		after stressing of T2 left and right	45 min.
		after stressing of T4 left and right	45 min.
		after stressing of T5 left and right	45 min.

* possible spans to be instrumented. The exact span designations will be determined after the contractor's schedule has been finalized.

D. The external tendons which have been instrumented will require special grouting procedures. These will be presented in detail after the exact spans are designated.

E. The contractors will make reasonable efforts to cooperate with the investigators and to avoid damaging the instrumentation systems.