PERFORMANCE OF POST-INSTALLED ANCHORS UNDER OBLIQUE AND GROUP LOADING CONDITIONS IN UNCRACKED CONCRETE

by

Winston Wayne Clendennen II, B.S.C.E.

THESIS

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

MASTER OF SCIENCE IN ENGINEERING

THE UNIVERSITY OF TEXAS AT AUSTIN
May 1994

PERFORMANCE OF POST-INSTALLED ANCHORS UNDER OBLIQUE AND GROUP LOADING CONDITIONS IN UNCRACKED CONCRETE

APPROVED BY
SUPERVISING COMMITTEE:

Richard E. Klingner

Michael D. Engelhardt

To Maria and Alex,

For your love, patience and understanding

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Richard E. Klingner for his assistance in the research and writing of this thesis. Also, I would like to thank Dr. Michael Engelhardt for being the second reader.

For all the people on the anchor bolt team who worked with me toward the completion of the research project and this thesis, I am very grateful and appreciative: Yonggang Zhang, Milton Rodriquez, David Dorr, Tom Pechillo, Chanaka Gunasekara, Ranjit Gupta, Pete Almaraz and others.

Also, I would like to thank the technicians and office staff at the Phil M. Ferguson Structural Engineering Laboratory for all the assistance they provided for us during this research project and a special thanks to Sharon Cunningham for the use of her computer skills in assembling this thesis.

Finally, I would like to thank all of my family for their support, prayers and encouragement.

Wayne Clendennen

Austin, Texas

February 1994

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Objective of Research Project

Section 105 of the *Uniform Building Code* [1] addresses the issue of alternate materials and methods of construction not explicitly covered in the *Code* provisions. This section allows for the use of alternatives if approved by the building official. Part of the approval process requires that evidence be presented to the building official showing that the alternate material or method of construction will perform as claimed. The ICBO Evaluation Service (ICBO-ES) [2] considers alternate criteria, and issues evaluation reports based on the performance provisions of the Uniform Building Code. An ICBO-ES evaluation report provides the building official an accepted means evaluating alternate materials or methods of construction.

The objective of this research project was to test post-installed expansion anchors according to ICBO-ES provisions in order to obtain an evaluation report. The following tests were conducted to meet those provisions:

(1) single anchor tension

(2) single anchor shear

(3) single anchor oblique tension

(4) group anchor tension

(5) group anchor shear

1.2 Objective of Thesis

The objectives of this thesis are:

(1) To evaluate the performance of wedge anchors tested under the following load conditions:

(a) single anchors tested in oblique tension

(b) groups of four anchors tested in tension

(c) groups of two anchors tested in shear

(2) To comment on the significance of the tests performed, and to recommend changes and/or improvements to ICBO-ES qualification criteria for expansion anchors in non-cracked concrete.

2.0 BACKGROUND

This chapter serves as an introduction to anchorage systems. It describes the purpose of anchors, and lists some specific examples of use. Anchor types are presented under two categories: cast-in-place and post-installed. In the latter category, expansion anchors are described and typical failure modes identified. Reference 3 provided much of the background information for this Chapter.

2.1 Anchor Applications

Anchors are primarily used to connect other structural elements to concrete. Anchors transfer load from the element to the concrete at the point of connection. Load-transfer mechanisms are characteristic of the anchor employed, and typically include mechanical interlock, friction and bond. Some examples of anchor use would be the attachment of the following elements to concrete:

- structural steel members
- mechanical equipment
- signs
- light posts
- railings

Figure 2.1 shows anchors used to fasten a steel column to a concrete surface.

2.2 Anchor Classification

There are two basic categories of anchors: cast-in-place and post-installed.

2.2.1 Cast-in-Place Anchors. Cast-in-place anchors are placed into position before the concrete is cast and therefore limited to new construction. Examples of cast-in-place anchors include:

- Headed bolts
- L-bolts
- J-bolts
- Headed studs
- Bonded anchors

2.2.2 Post-installed Anchors. Post-installed anchors are placed into hardened concrete. They can be used in new construction or in the rehabilitation of existing structures. Examples of post-installed anchors include:

- expansion anchors
- undercut anchors
- bonded anchors
- self-drilling anchors

Research conducted for this project involved only post-installed, wedge-type expansion anchors such as those shown in Figure 2.2. The remainder of this thesis will focus on this type of anchor.

2.3 Wedge-Type Expansion Anchors

2.3.1 Functioning of Wedge-Type Expansion Anchors. Wedge-type expansion anchors transfer load to the concrete primarily through friction. The anchor is placed in a predrilled hole and is torqued to a specified value. This causes the anchor to retract, drawing a cone-shaped mandrel into a metal clip and expanding the clip against the side of the hole. The amount of frictional force created depends on the normal force generated by the expanding clip, and on the mechanical interlock between the clip and surrounding concrete. Figure 2.3 depicts an embedded wedge anchor.

2.3.2 Effects of Prestress on Anchor Behavior. The torque applied to an anchor during installation acts to prestress the fastening system. The internal axial tension in the anchor is balanced by a compressive force in the concrete between the attached element and the expanded metal clip. Prestressing is important because it reduces displacement under service load. External loads can be resisted partly by reduced concrete compression until the prestressing is overcome. This is possible because the stiffness in the concrete is at least as large as that of the anchor. Once the external loads become high enough to reduce the concrete compression to zero, the anchor alone resists further load and the flexibility increases.

Prestress losses can occur due to concrete relaxation and redistribution of stresses. These losses range from 40% to 60% of the initial prestress force [3]. Re-tightening after a period of time will compensate for prestress losses.

2.4 Anchor Failure Modes

An anchor fails when applied external load exceeds the anchor capacity as governed by the capacity of the concrete, or as governed by the steel capacity of the anchor. Factors which influence these capacities include:

- steel strength
- cross-section area of anchor

- expansion mechanism
- concrete strength
- edge distance
- embedment depth
- spacing

The steel strength, cross-sectional area of the anchor, expansion mechanism, and concrete strength determine the anchor capacity. Edge distances, embedment depth and spacing influence anchor capacity as governed by concrete. Anchors tested in this program exhibited the following failure modes.

2.4.1 Tension Failure Modes.

Cone Failure: Cone failure is characterized by the development of cracks at the inside of the hole. These propagate at an angle to the concrete surface, creating a cone-shaped volume of concrete around the anchor. Cone failure typically occurs at shallow embedment depths. Figure 2.4 illustrates a cone failure.

Cone/Edge Failure: Cone/edge failure, shown in Figure 2.5, is a variant of cone failure. However, the anchor is not spaced far enough from the edge to allow complete cone development. The capacity associated with a cone/edge failure is less than that of a cone failure.

Anchor Fracture: Anchor fracture, shown in Figure 2.6, occurs when the capacity of other failure mechanisms exceeds the tensile capacity of the anchor shaft. This condition is often encountered at deep embedments; displacement results mainly from anchor yield.

Anchor Pullout: Anchor pullout, depicted in Figure 2.7, is characterized by removal of the entire anchor from the drilled hole. This occurs when the frictional force produced by the expansion mechanism is less than the load required to reach concrete cone failure. Concrete around the expansion mechanism begins to crush, allowing the anchor to slip in the hole. This type of failure can occur in anchors deeply embedded in low-strength concrete.

Anchor Pull-Through: Anchor pull-through occurs when the mandrel portion of the anchor shaft pulls through the expansion clip. The body of the anchor then slides out of the drilled hole, leaving the expansion clip behind. Factors contributing to this type of anchor failure are insufficient area of the expansion sleeve, and low frictional resistance between the collar and the mandrel. This type of failure is common at deeper embedments. Figure 2.8 illustrates anchor pull-through.

Anchor Slip: Anchors failures that began as slip, but did not involve complete removal from the concrete, were given this classification. Since the anchor was still embedded, it could not be determined for certain if the actual failure mode was pull-through or pull-out. Results from other tests with the affected anchors indicate a high probability of the failure mode being pull-through.

2.4.2 Shear Failure Modes.

Anchor Steel Fracture: Anchor steel fracture generally occurs when the anchor is placed far from a free edge, and the embedment is sufficient to develop capacity, as governed by the concrete, greater than that governed by the steel. Figure 2.9 shows anchor steel fracture [4].

Side Blowout: Side blowout usually occurs when the anchor is loaded toward a nearby free edge. If the capacity of the anchor is governed by concrete, a lateral failure cone will form. The apex of the cone is typically located near the anchor head for shallow embedment depths, and rises along the anchor shaft as embedment depth increases. Figure 2.10 illustrates this type of failure.

Anchor Pullout: Anchor pullout is shown in Figure 2.11. In this failure mode the concrete crushes between the anchor and the point of loading. This crushing allows the anchor head to rotate and fail the concrete on the side of the anchor opposite from the point of loading [4].

2.4.3 Oblique Failure Modes. Oblique loads can be reduced to tension and shear components. Anchor failure modes for oblique loads are therefore a combination of the failure modes described for tension and shear load conditions.

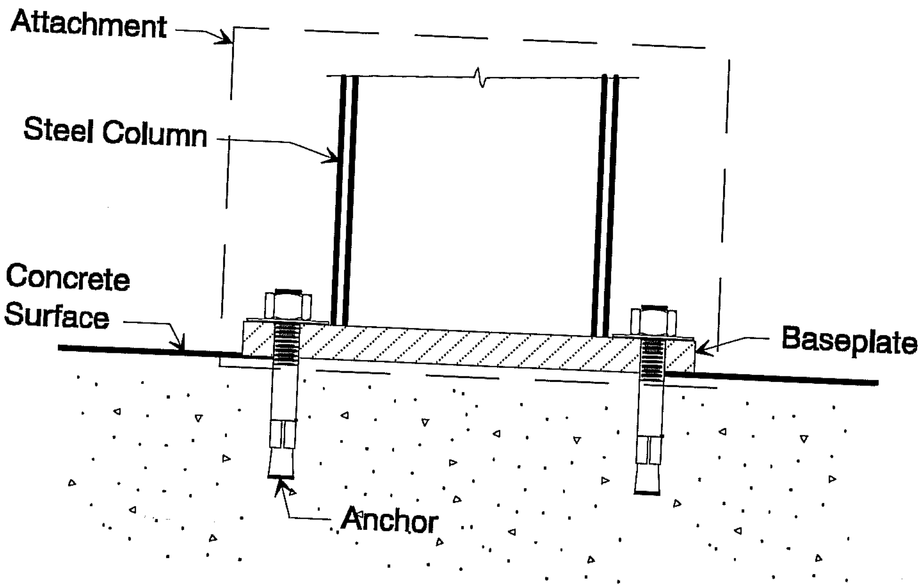


Figure 2.1 Typical steel to-concrete connection

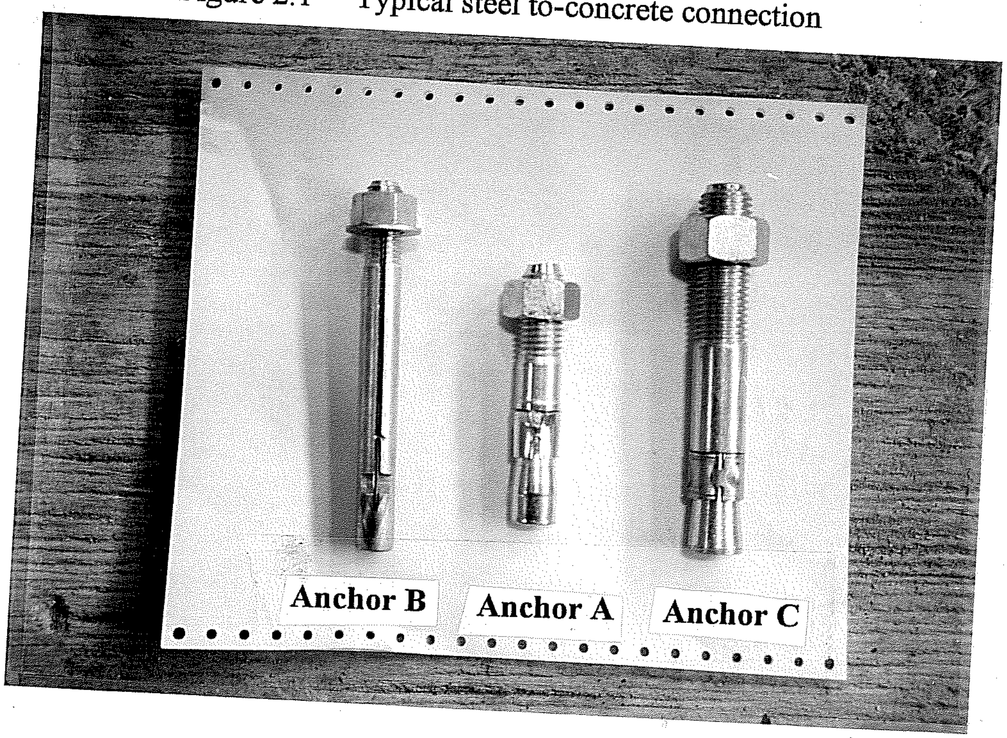


Figure 2.2 Wedge-type expansion anchor

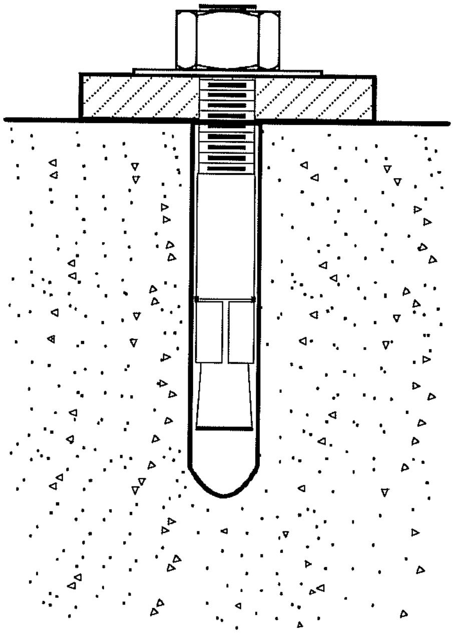


Figure 2.3 Wedge anchor installed in hole

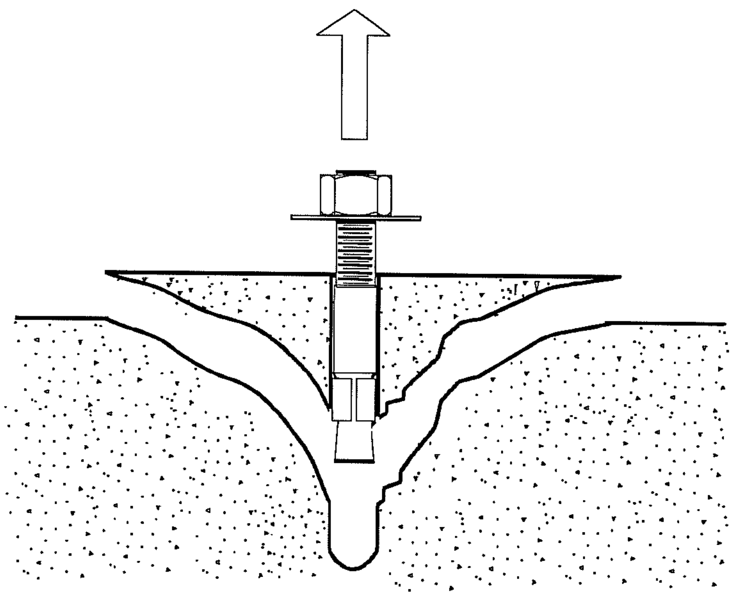


Figure 2.4 Tensile concrete cone failure

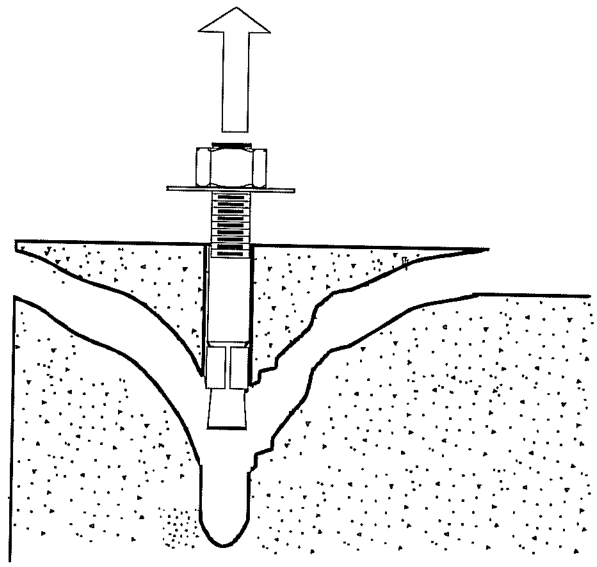


Figure 2.5 Tensile concrete cone-edge failure

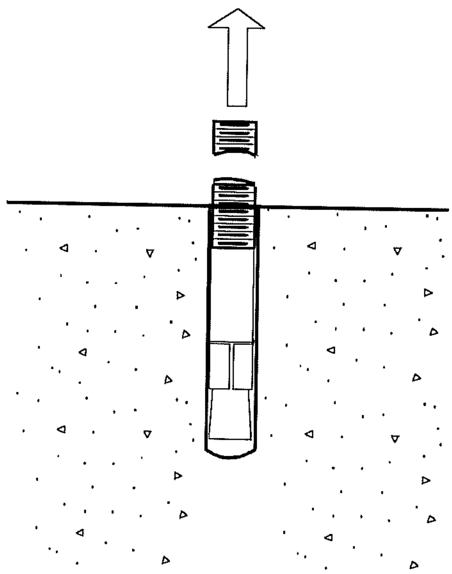


Figure 2.6 Tensile anchor fracture

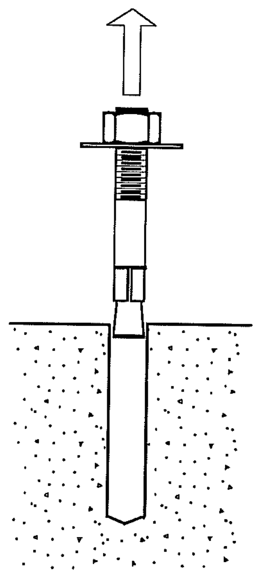


Figure 2.7 Tensile anchor pullout

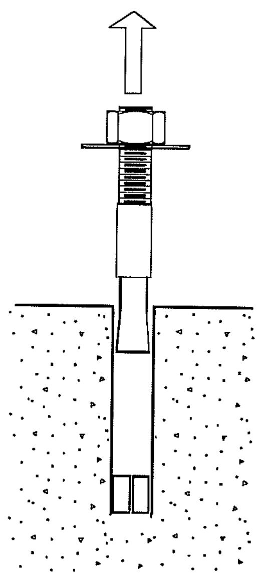


Figure 2.8 Tensile anchor pull-through

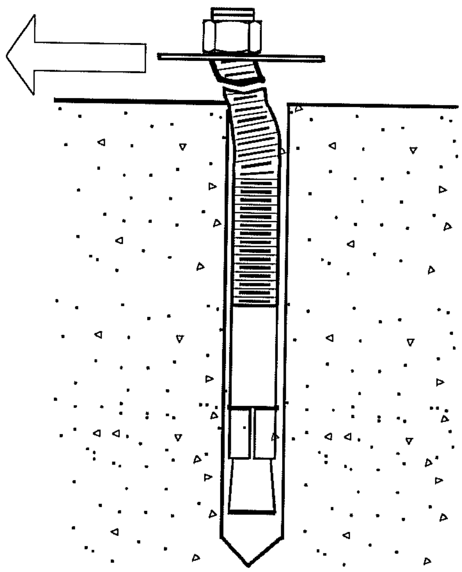


Figure 2.9 Shear anchor fracture

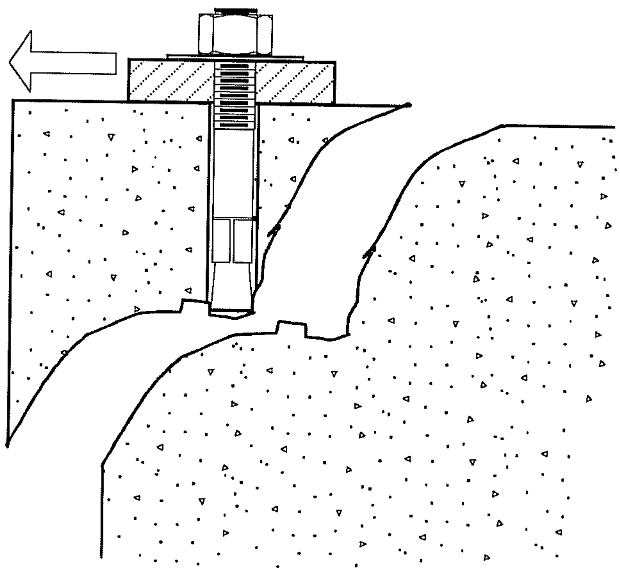


Figure 2.10 Side blowout failure

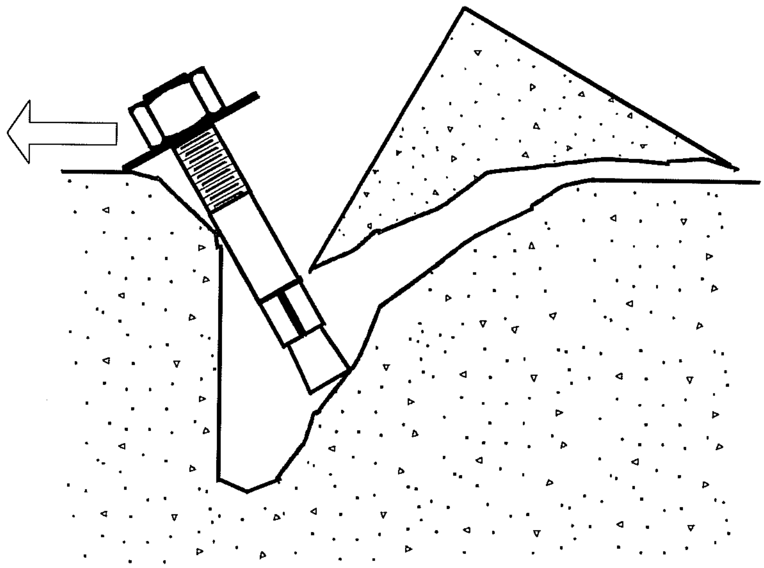


Figure 2.11 Shear anchor pullout

3.0 DESCRIPTION OF TEST PROGRAM

This chapter describes the test program. First, the anchors are described. Next, the specifications and conditions which govern the anchor testing are presented in the form of a test matrix. Then a description is given of the concrete specimens, test equipment, and data acquisition system used during testing. Finally, the test procedures followed in this program are described.

3.1 Description of Anchors Tested

This program tested three different post-installed wedge anchors, here referred to as Anchors A, B and C. Tables 3.1, 3.2 and 3.3 give the dimensions of each anchor; beneath each table is a listing of the permitted tolerances and the basic materials used in the manufacture of the anchors.

3.2 Test Matrix

Anchors were tested in this program under three static load conditions: tension loading; shear loading; and oblique tension loading. This thesis focuses on anchors tested in groups, either in tension or shear, and on single anchors subject to oblique tension loading.

Two types of test matrix were used to describe this test program: a general test matrix and a specific test matrix. Both are described in detail below.

3.2.1 General Test Matrix. The general test matrix summarizes the anchors to be tested, the concrete strength to be used, the anchor diameter, the number of anchors, and the number of tests. Each type of test described in the general test matrix is identified by a series number corresponding to a series in the ICBO ES requirements [2]. The general test matrices for Anchors A, B and C are shown in Tables 3.4, 3.5 and 3.6 respectively.

3.2.2 Specific Test Matrix. A specific test matrix was created for each series listed in the general test matrix. The first column in the specific test matrix identifies individual tests by a number: the number on the left of the hyphen represents the series and the number on the right represents a particular test within that series. All information regarding a test, with the exception of load and displacement results, may be referenced by entering a specific test matrix, finding the test number in the first column, and reading across the row from left to right. Table 3.7 is an example of a specific test matrix used in this program. The remaining specific test matrices may be found in the appendix.

At the top of each column is a title or symbol which describes the contents:

- Column 2 describes the test type: tension, shear, or oblique. A "G" prefix indicates a group test of four anchors if tension, or two anchors if shear.
- Column 3 gives the target compressive strength; the adjacent column lists the number of the particular block of concrete used for the test. More detailed information on the compressive strength of the concrete block can be obtained by referencing the block number listed here to the appropriate cylinder strength table.
- Column 5 lists the diameter of the anchor tested; the next column describes the bit type used in drilling the hole. For the purpose of this thesis, only medium bit sizes were used, with tolerances within the range listed in the "Hole Diameter" column.
- Column 8 describes the depth of the embedded anchor as either shallow, medium (standard), or deep. These descriptions are given in ASTM E488-90 Table 2 [5], and are a function of the ratio of embedment depth to anchor diameter.
- Column 9 shows the actual installation depth of the anchor in inches. This depth was specified by the anchor manufacturers.

- Column 10 lists the distance from the edge of the block to the centerline of the embedded anchor. This distance is referred to as the edge distance. The critical edge distance as used in this program corresponds to the value (m) and was developed according to Table 2 of ASTM E488-90 [5]. The minimum edge distance is a proportion of the critical edge distance, and depended on the test type and concrete strength.
- For anchors tested as a group, there is a column which defines the distance the anchors must be spaced from one another. As used in this thesis, the term "*maximum anchor spacing*" corresponds to the value (S), and was developed according to Table 2 of ASTM E488-90 [5]. It indicates the spacing at which closely-spaced anchors will begin to behave independently (not interfere with each other). Minimum spacing, in all cases, was taken as 1/2 the maximum anchor spacing.
- Column 12 shows the torque applied on the anchor during installation. For Anchors A and B, one column lists the manufacturer's recommended installation torque, and another column lists the actual installation torque applied to the anchor.
- Column 13 shows the time necessary to complete the test. All tests lasted at least two minuts, as specified by ASTM E488-90 [5].
- Column 14 gives the failure mode.

- Column 15 is reserved for miscellaneous information about the test, such as the number of anchors that failed or, in the case of Anchor types A and B, the number of revolutions applied on the nut at the installation torque.

3.3 Concrete

3.3.1 Strength of Concrete Test Specimens. Anchors tested in this program were placed in concrete of different strengths. This was done in order to simulate the variety of strength conditions encountered in the field. Mix designs were developed to achieve 2000-, 4000- and 6000-psi concrete within a specified tolerance of ± 10 percent. Testing was therefore permitted in concrete with the following ranges of compressive strength: 1800 to 2200 psi; 3600 to 4400 psi; and 5400 to 6600 psi. An exception to this procedure was permitted for Anchor Type B. Testing for this anchor was carried out in concrete with a compressive strength of 1400 to 2200 psi. Table 3.8 gives the mix design for each concrete strength.

Limestone was chosen as the coarse aggregate to be used in the concrete. Because it is softer than gravel, expansion anchors placed in a limestone-aggregate concrete perform more poorly than in concrete made with gravel aggregates. This is an attempt to represent a "worst case" scenario for anchor application.

The use of limestone aggregate presented problems because of its absorptive nature. To use slump as a consistent indicator of water/cement ratio, it was necessary to keep the aggregate as close to saturated surface dry condition as possible. This was achieved by constantly sprinkling the aggregate with water several days prior to batching. Once the concrete arrived on site, water was added as needed to obtain the desired slump.

3.3.2 Concrete Block Specimens. Anchor were tested in rectangular concrete blocks having dimensions of 39.5 × 24.0 × 87.5 inch. A typical concrete block specimen is shown in Figure 3.1. Blocks were transported using two 6-inch tie loops on each side. To prevent damage during transport, reinforcement (seven #6 bars) was placed at mid-height of the block. This reinforcement allowed testing on both the top and bottom surfaces of the blocks, and did not interfere with anchor testing.

3.3.3 Casting Concrete Blocks. Specimen concrete was ordered from a ready-mix company and delivered by truck to the casting site. A slump test was performed; if needed, water was added to obtain the target slump of either 6 or 8 inches. Concrete was placed using a bucket elevated above the formwork by an overhead crane. The concrete was then placed into the formwork, and was consolidated by hand-rodding. To reduce segregation and top-bar effects, mechanical vibration was not used. Once casting was complete, the blocks were allowed to set long enough for bleed water to surface and the concrete to stiffen. At this point the blocks were screeded level and finished smooth by hand troweling. The smooth surface was necessary to ensure the stability of equipment during anchor testing. After finishing, the blocks were covered with plastic. Two or three days after being cast, the formwork was stripped from the blocks. The blocks were then transported to a storage area, covered again with plastic and allowed to cure until they were needed for anchor testing. Figure 3.2 depicts the casting process.

3.3.4 Cylinders. Eighteen concrete cylinders were cast with each set of concrete blocks. The concrete cylinders were formed in plastic cylinder molds and consolidated by rodding. The cylinders were covered by plastic and placed next to the concrete blocks to keep their curing conditions as similar as possible to those of the blocks.

The strengths of the concrete test blocks were monitored by performing compression tests on the concrete cylinders. The cylinders were tested in compression at ages of 7, 14, 21 and 28 days. Cylinders were also tested when a block no longer had available space for anchor tests. This was a final cylinder test for the block. The cylinders were capped with a sulfur compound according to ASTM C617-87 [7], and were tested in compression following ASTM C39-86 [8]. Cylinders were tested in sets of three; the values were averaged to represent the compressive strength of a concrete block. Table 3.9 illustrates typical compression test results for a set of blocks.

3.4 Test Equipment

Some of the test equipment used in this program was common to all tests, while other equipment was used for a particular type of test only. An explanation of the common test equipment will be presented first, followed by a discussion of the specific equipment used for group tension, oblique tension, and group shear test.

3.4.1 Common Test Equipment.

Threaded Rod — Load was transferred from the hydraulic ram to the loading plate or shoe by a high-strength threaded steel rod. The rods varied in length and were 5/8-inch, 1-inch, or 1-1/4-inch in diameter, depending on the diameter of anchor tested.

Hydraulic Rams — Hydraulic rams were used to load the anchors. This program involved the use of either 20-ton or 60-ton capacity hydraulic rams.

Electric Pump — An electric pump was used to pressurize the hydraulic rams. The loading rate was controlled by a needle valve.

3.4.2 Specific Test Equipment

Group Tension Equipment (all anchors except 1-1/4-inch diameter)

- Loading Apparatus: The reaction beam was mounted on two short steel columns as shown in Figure 3.3. Load generated by the hydraulic ram was transferred to the concrete block by a reaction beam constructed of two steel channels bolted back to back using 2-inch spacers to provide access for a threaded rod.

- Loading Plate: Figure 3.4 shows a cross section of a typical loading plate and Figure 3.5 shows an actual loading plate. A number of steel loading plates were constructed and used in the group tension test. Each is square in shape, and dimensioned to accommodate the spacing requirements and load magnitude. At the center of each plate a hole was drilled through which a threaded rod could be passed. The bottom side of the plate was counter-bored to accept the nut that attached the rod to the plate. The nut was also rounded on top to give a ball-joint effect.

Group Tension Equipment (1-1/4-inch diameter anchors)

- Loading Apparatus: This system is shown in Figure 3.6. To test the 1-1/4-inch diameter anchors it was necessary to use two reaction beams. The beam described previously was used, as well as another similar beam.
- Inserts and Couplers: It was not practical to construct a loading plate large enough to test 1-1/4-inch diameter anchors in group tension. Instead, four threaded inserts with matching couplers were used. The inserts had an outside diameter of 1-1/2 inch and an inside diameter of 1-1/4 inch.

The coupler had an inside diameter and threads to match that of the insert. In the top of the coupler a threaded hole was provided to accept 1-1/4-inch threaded rod. See Figure 3.7.

Oblique Tension Test Equipment

- Loading Apparatus: The oblique loading apparatus shown in Figure 3.8 was constructed of steel channels, plates and threaded rods, bolted and welded together to form a triangular framework. The geometry of the apparatus ensured that the anchor would be loaded at a 45° angle to the surface of the concrete block.
- Loading Shoe: Three steel loading shoes (small, medium, and large) were used for the oblique tension test. A typical oblique loading shoe is shown in Figure 3.9. The loading shoes, like the oblique loading apparatus, were constructed so that a load would be applied at a 45° angle to the surface of the concrete block and at zero eccentricity.

Group Shear Test Equipment

- Loading Apparatus: The group shear loading apparatus, shown in Figure 3.10, was constructed of wide flange members welded together to form an L-shaped framework. A reaction beam was mounted on the vertical legs of the apparatus. A hydraulic ram could then be positioned on the reaction beam to apply load parallel to the surface of the block. The distance between the reaction points of the loading apparatus is adjustable and conformed to the requirements of ASTM E488-90 [5].

- Loading Shoe (Anchors A and B): The loading shoes for Anchors A and B were made of square steel plates with bearing surface areas and dimensions conforming to ASTM E488-90 [5]. The plates were provided with three holes: two for the anchors, and another to allow for a connecting plate to which a threaded rod could be attached. Figure 3.11 shows a loading shoe and connection.
- Loading Shoe (Anchor C): The required minimum spacing for Type C anchors was larger than for Types A and B. Therefore, two shear shoes were used in the group test, one for each anchor. Figure 3.12 shows the shear shoes used to test Anchor type C.
- PTFE: In all shear tests, a 0.020-inch sheet of PTFE (Teflon) was placed between the surface of the concrete and the loading shoe, as specified by ASTM E488-90 [5]. This was done in order to limit friction between the two surfaces.

3.5 Data Acquisition

Figure 3.13 shows a schematic diagram of the instrumentation used in the data acquisition system. The system comprises four main parts:

(1) linear potentiometer

(2) pressure transducer

(3) plotter

(4) micro-computer

(1) Linear Potentiometer: One or more linear potentiometers were used to measure displacement. When more than one linear potentiometer was used for a given direction, the displacement results reflect an average of the measurements provided by those potentiometers. Each potentiometer was excited by a 10-volt power supply.

(2) Pressure Transducer: Pressure transducers were used to measure the load. The capacity of the transducer varied with the application; 1000-psi, 5000-psi or 10000-psi. The transducers were excited by a 10-volt power supply, and the output signal was amplified from millivolts to volts using a precision amplifier.

(3) Plotter: A Hewlett-Packard Model 7090 plotter continuously read displacement and load signals from the linear potentiometer and pressure transducer. The plotter was set up to read data over a six-minute time interval. Since the plotter is able to read 1000 data points within a specified time interval, data was read at every 0.36 seconds. All data read by the plotter were stored temporarily in an internal buffer. Data were plotted immediately following each test. This raw plot validated the test and served as a reference to which final load - displacement graphs could be compared.

(4) Micro-computer: At the end of each test, data stored in the internal buffer of the plotter were transferred to a micro-computer using software provided by the manufacturer of the plotter. The data stored on the hard disk of the micro-computer allowed for convenient access, further reduction, and plotting.

3.6 Anchor Testing Procedure

The procedure used to test anchors is basically the same for each type of test and can be explained in four steps:

(1) Anchor Installation

(2) Equipment and Instrumentation Setup

(3) Anchor Testing

(4) Test Data Recording

3.6.1 Anchor Installation. Anchor installation involved the following steps:

(1) Obtain the specific test matrix corresponding to the series to be tested.

(2) Select the anchor to be tested and mark the desired embedment depth on the anchor.

(3) Select the appropriate drill bit and measure it with a micrometer to ensure that the actual diameter complies with the required tolerances given in the matrix.

(4) With a carpenter's square, lay out the edge distances on the concrete block surface.

(5) At the specified edge distance, drill the hole with a hammer drill, ensuring that the drill bit is plumb within ±6°.

(6) Clean hole of dust using compressed air and a vacuum cleaner.

(7) Place the anchor in the hole and seat to the proper depth by tapping lightly with a hammer.

(8) Place the loading shoe over the anchor.

(9) Install the washer and snug the nut to finger-tight.

(10) For Anchors A and B, the nut was given four revolutions after the finger-tight conditions, and the torque was recorded. However, the torque was not to exceed the manufacturer's specified torque. Anchor C was installed to the manufacturer's specified torque.

3.6.2 Equipment and Instrumentation Setup.

The equipment and instrumentation setup for each type of test can be described as follows:

(1) Once the anchor(s) were installed, a loading shoe (or plate) was placed over the anchor(s) and attached to the concrete by a washer and nut.

(2) A loading apparatus was then positioned about the shoe, and was connected to the shoe and a hydraulic ram by a threaded rod. An electric pump,

pressure gauge and pressure transducer were connected to the hydraulic ram by a high-pressure hose and manifold.

Linear potentiometers were used to monitor displacement. The position of the potentiometers depends on direction of displacement and therefore varies with the type of test.

Potentiometers for Group Tension Tests (all anchors except 1-1/4-inch diameter): Vertical displacement was monitored using two linear potentiometers positioned on opposite sides of the loading plate, between the anchors being tested.

Potentiometers for Group Tension Tests (1-1/4-inch diameter anchors): Four linear potentiometers were used, one for each anchor, to monitor vertical displacement.

Potentiometers for Oblique Tension Tests: One potentiometer was positioned on top of the loading shoe to measure vertical displacement, while another was positioned on the side of the loading shoe to measure horizontal displacement.

Potentiometers for Group Shear Tests (Anchors A and B): One potentiometer was positioned symmetrically between two anchors to monitor horizontal displacement.

Potentiometers for Group Shear Tests (Anchor C): This test used two shear shoes and therefore required two potentiometers to monitor horizontal displacement.

With the loading equipment and potentiometers in place, a final equipment and instrumental check was made to ensure all components were at the proper setting.

3.6.3 Anchor Testing. After the equipment was in position and all checks were completed, the pump operator began the test by starting the electric pump and pressurizing the hydraulic ram. The pump operator used a stopwatch to keep the loading rate constant and to ensure that the test lasted at least two minutes. The data acquisition system was started as the pump operator began the test. The test was completed when the anchor failed.

3.6.4 Data Recording. Load and displacement data were transmitted continually from the pressure transducer and linear potentiometer to the HP7090 Plotter, and were stored in its internal buffer. This information was then down-loaded to a computer where it could be removed via diskette. At the end of each test the plotter was used to produce a raw load-displacement graph used for validations. Figure 3.14 shows a typical raw graph produced by the HP7090 plotter. Other important information was recorded by hand on the graph:

- test number
- test duration
- test block number
- capacity of hydraulic ram
- capacity of pressure transducer
- loading rate
- dimension of anchor

- failure mode

Finally, the test specimen was labeled and photographed

3.6.5 Data Reduction. Data are stored in the microcomputer in units of voltage. To change the data to engineering units, a computer program was developed to:

(1) apply the calibration correction factors

(2) change the units from voltage to pounds and inches

(3) determine the following:

(a) maximum load and displacement

(b) maximum load divided by 4 and maximum displacement divided by 4. ICBO ES demands a safety factor of 4.

(4) write the output in a form readable by the graphics program.

One advantage of using this system is the ease of calibration corrections. The program is modified after every calibration, and automatically corrects the data.

After the programs are executed, a graph of load versus displacement and other relevant information is generated for each test by using a commercial graphics program. An example of this graph can be seen in Figure 3.15.

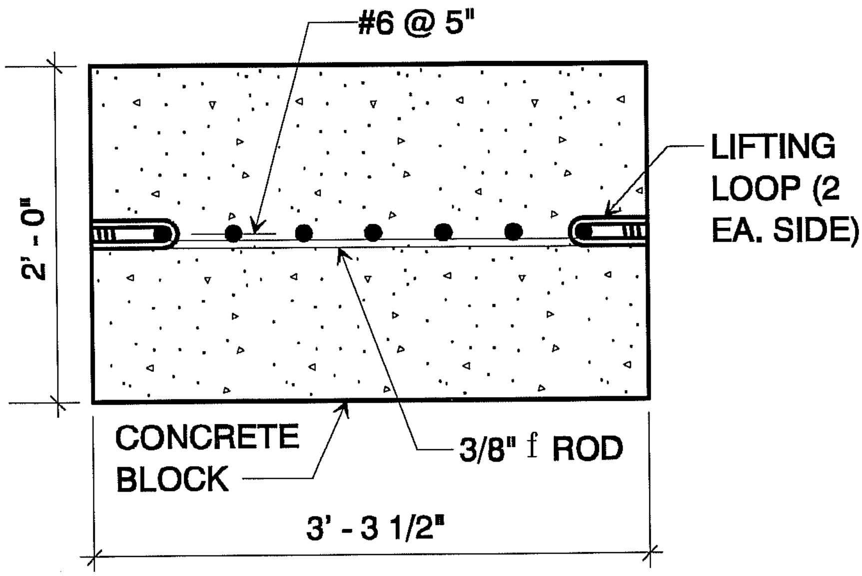


Figure 3.1 Typical concrete block [Ref. 4]

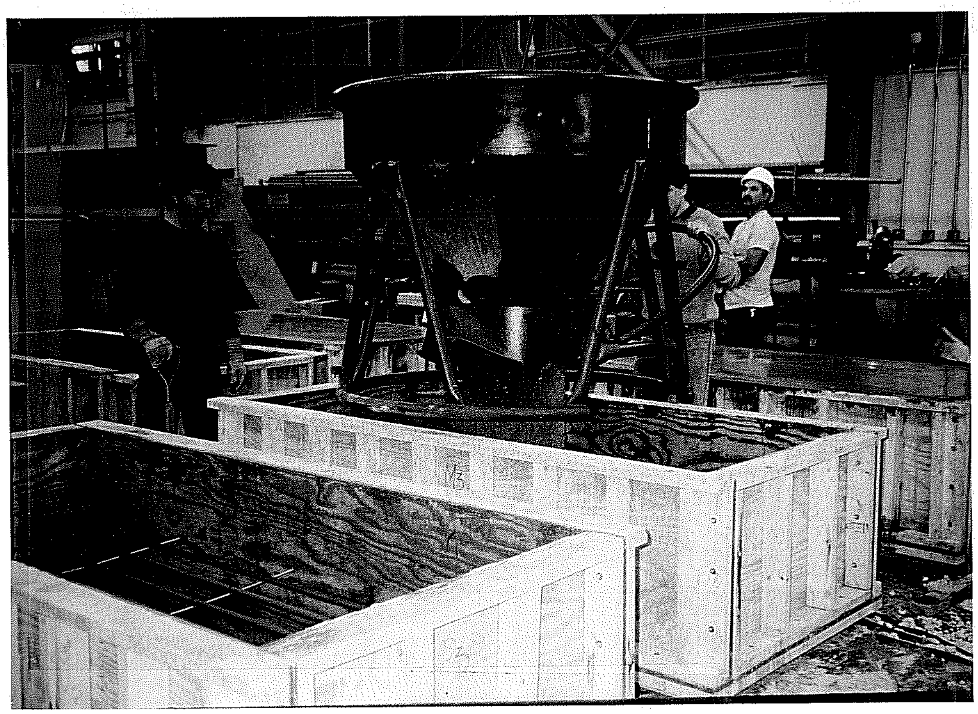
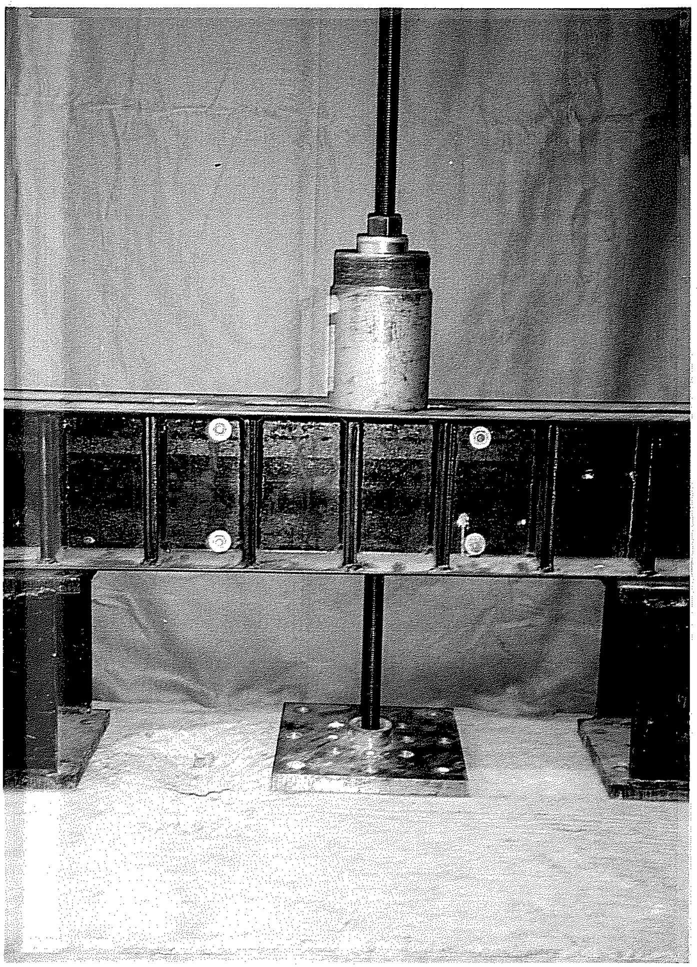
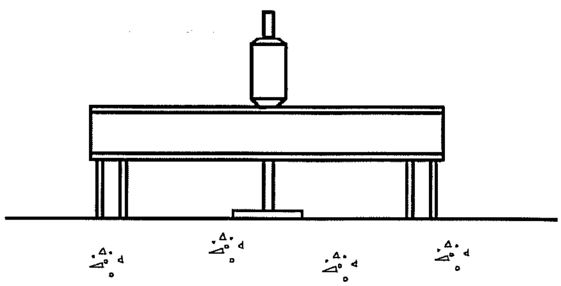


Figure 3.2 Pouring concrete from bucket into forms



(a)



(b)

Figure 3.3 Group tension loading apparatus

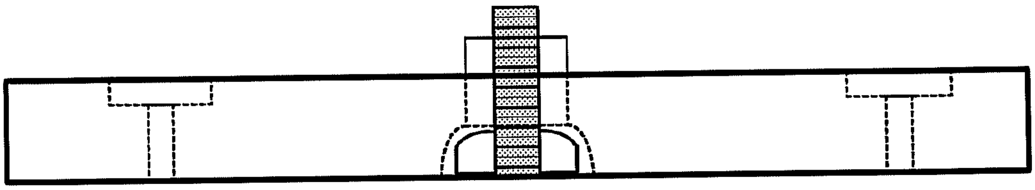
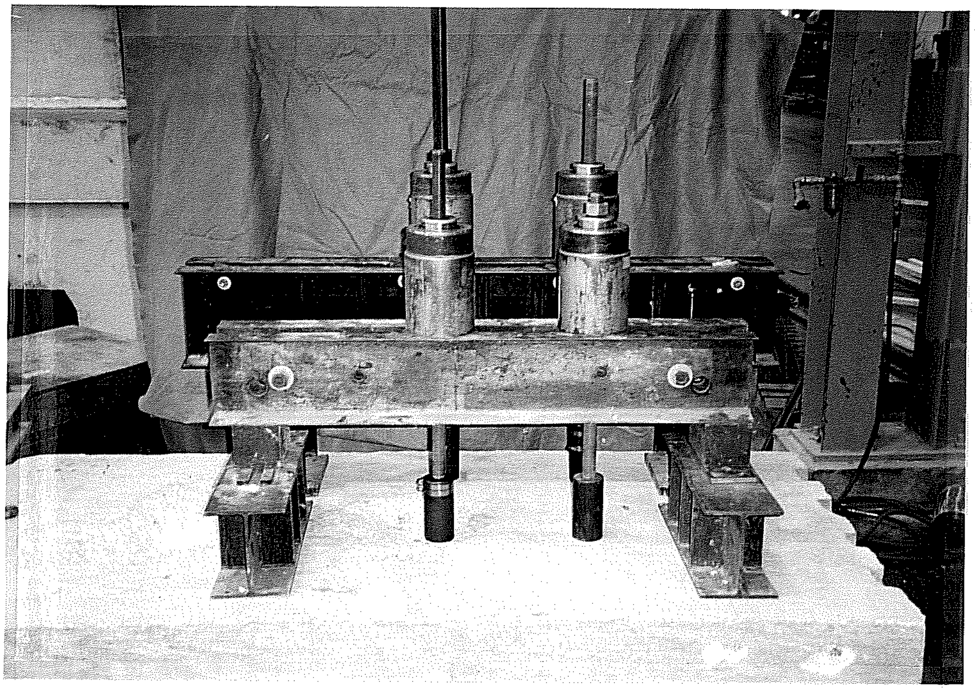
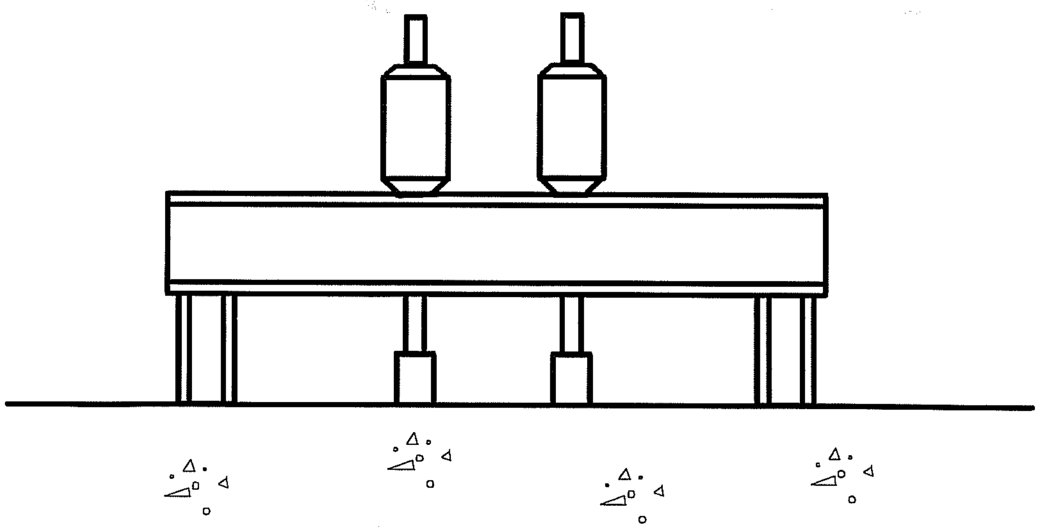


Figure 3.4 Cross-section of group tension loading plate

Figure 3.5 Group tension loading plate



(a)



(b)

Figure 3.6 Group tension loading apparatus for 1-1/4-in. anchors

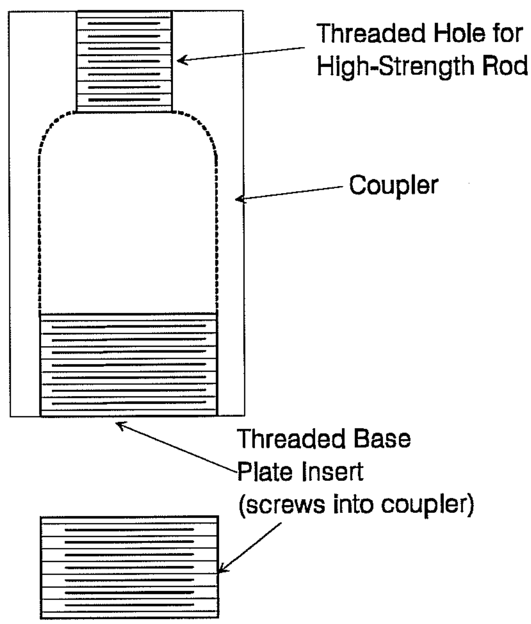
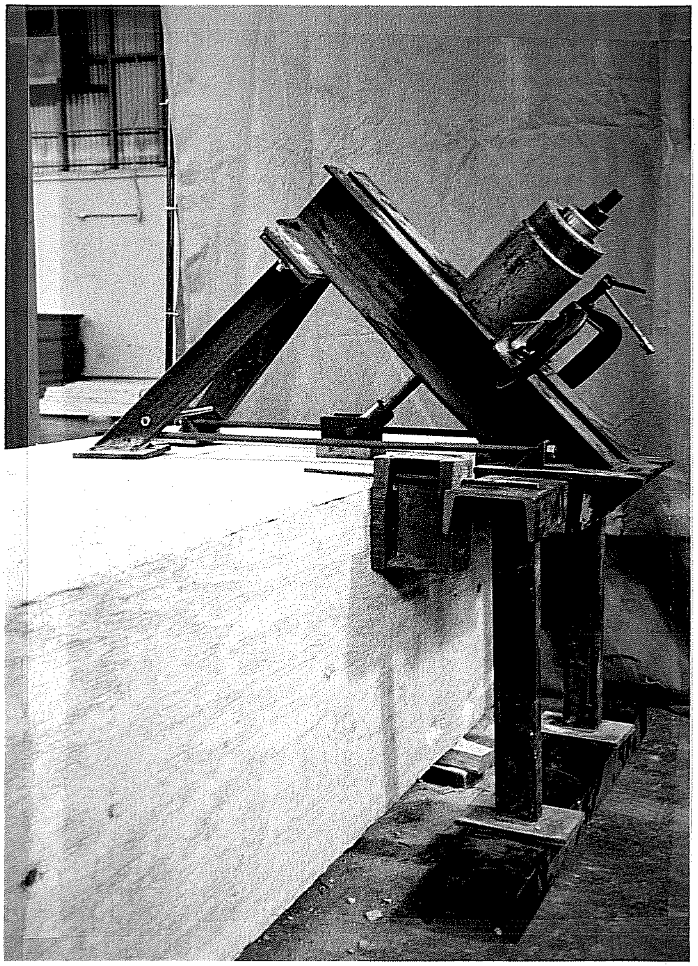
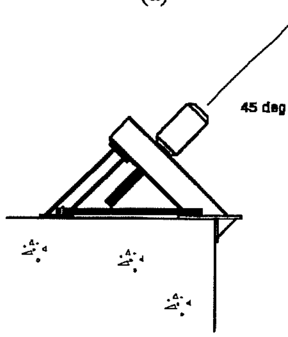


Figure 3.7 Coupler used for tensile loading of 1-1/4-in. anchors



(a)



(b)

Figure 3.8 Oblique test apparatus

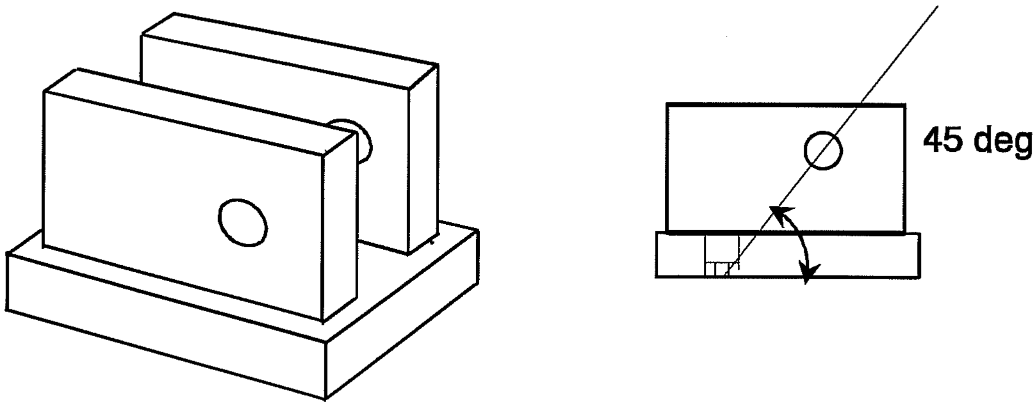


Figure 3.9 Oblique loading shoe

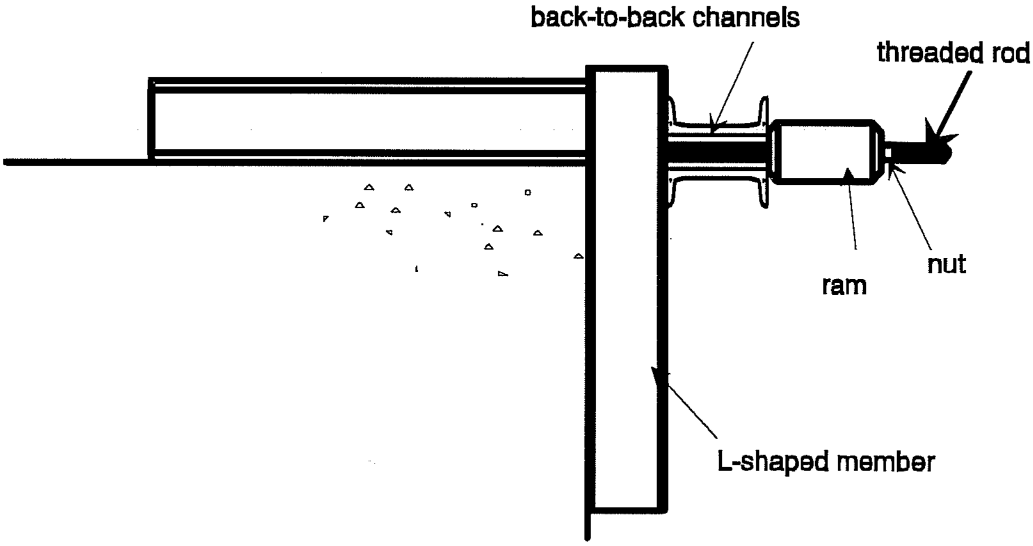


Figure 3.10 Group shear loading apparatus

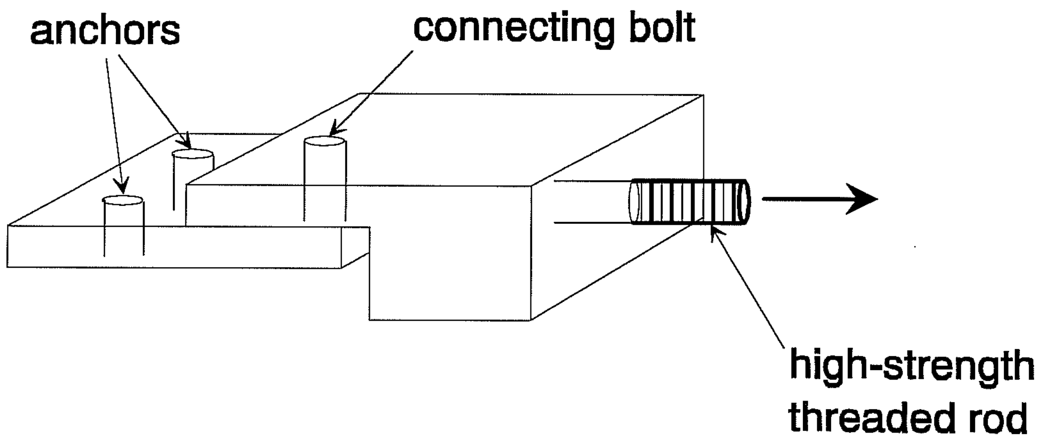
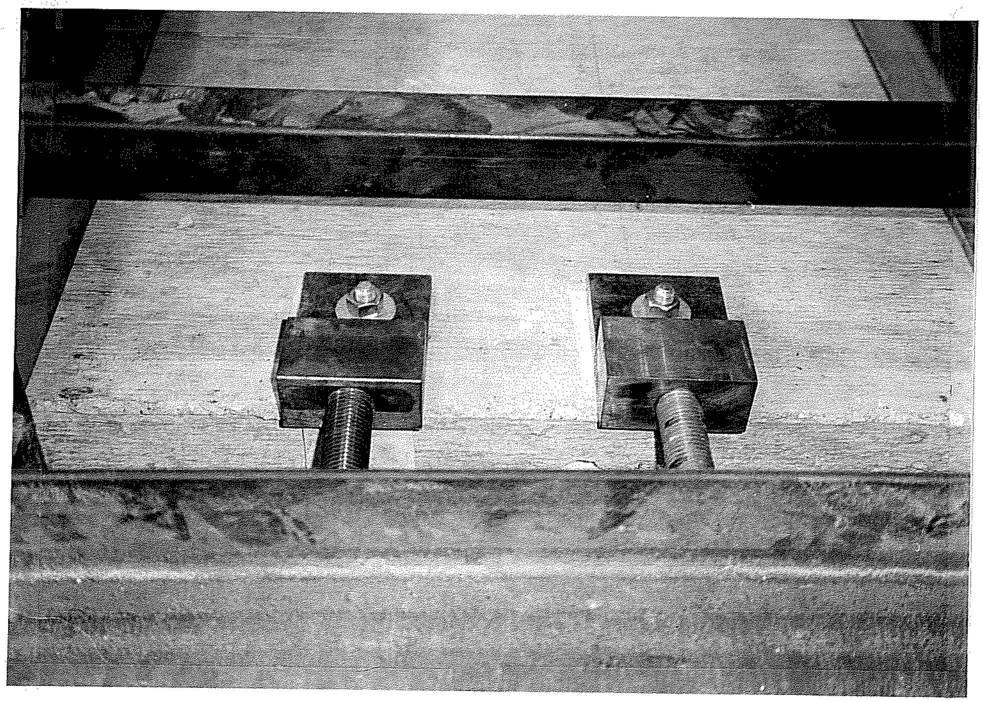
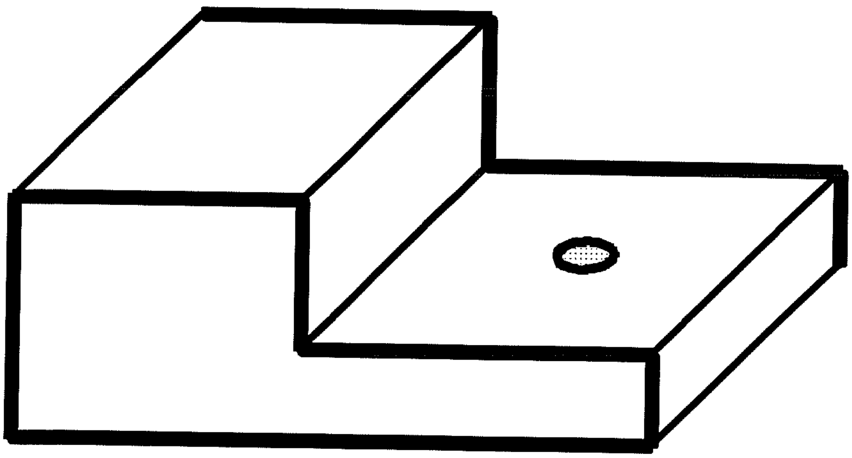


Figure 3.11 Group shear loading shoe (Anchors A and B)



(a)



(b)

Figure 3.12 Group shear loading shoes for Anchor C

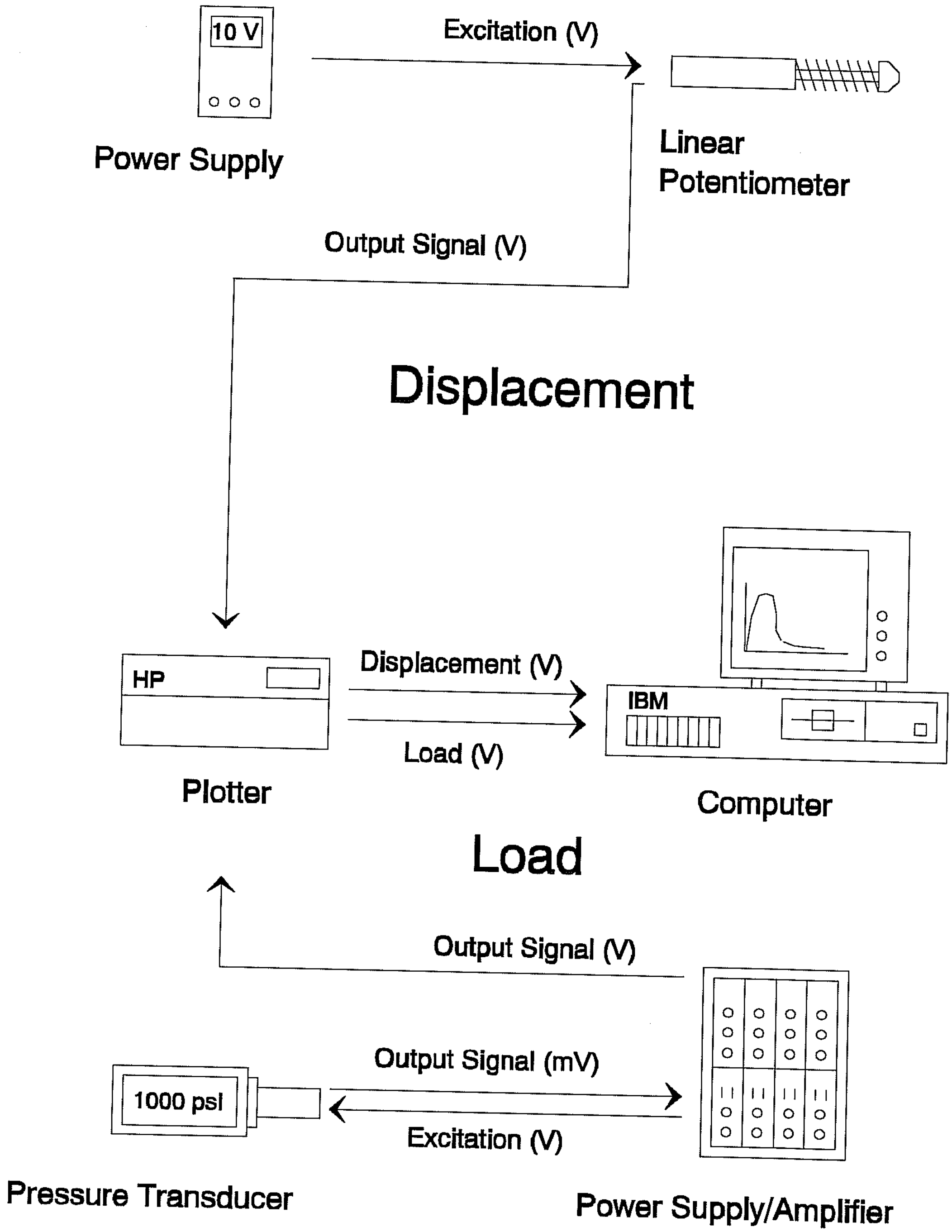


Figure 3.13 Schematic of data acquisition system for loads and displacement

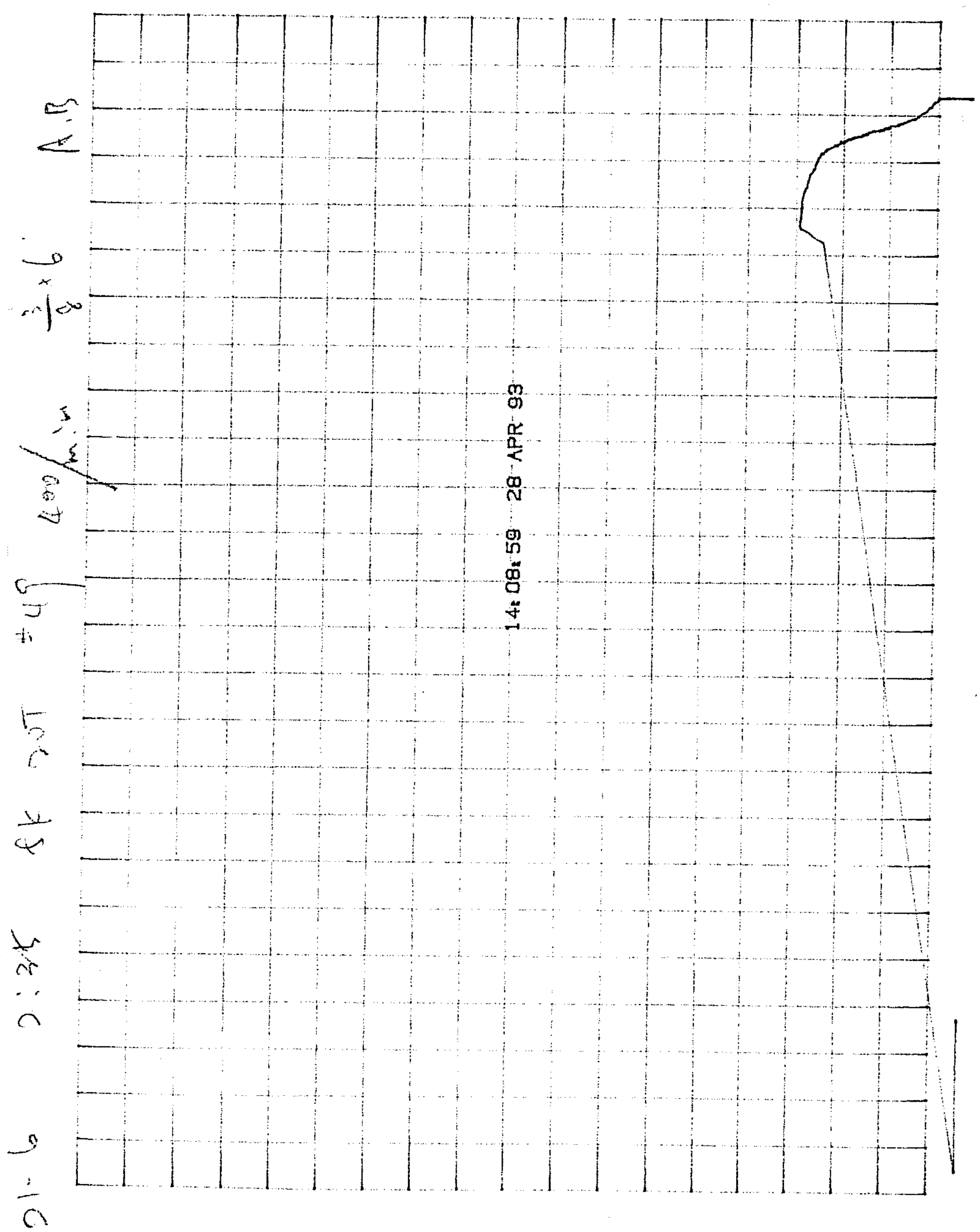


Figure 3.14 Raw graph produced by the HP7090 plotter

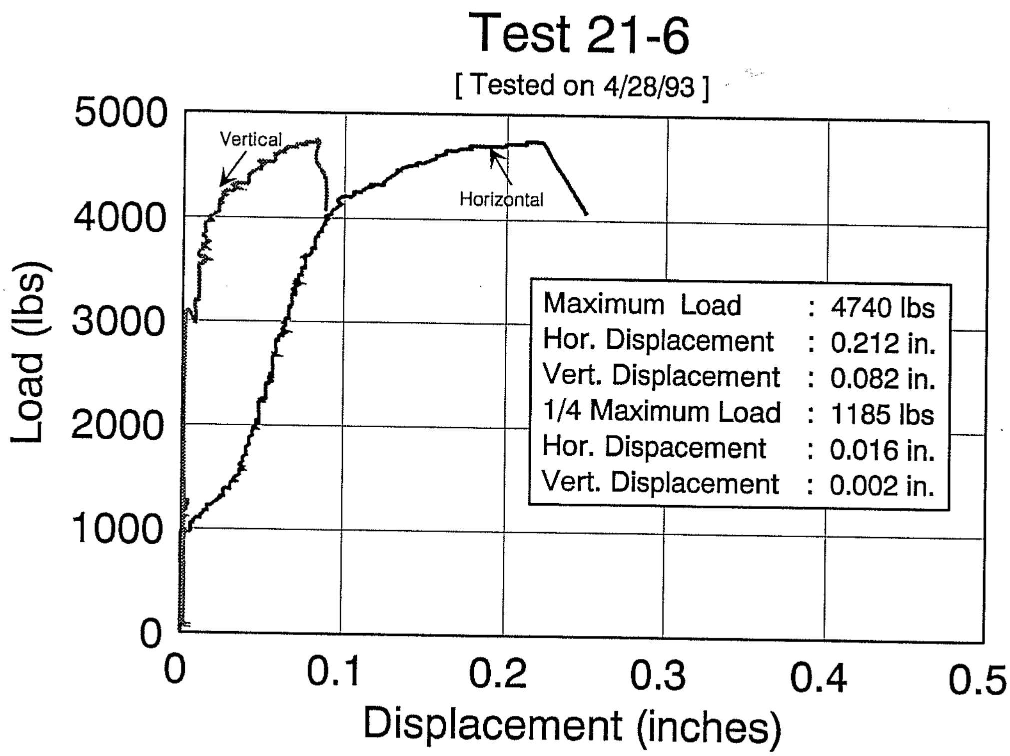


Figure 3.15 Example of final graph

Table 3.1 Description of Anchor A

Nominal Diameter (in.)	Anchor Length (in.)	Thread Size (UNC Class 2A)	Thread Length (in.)
3/8	2 - 1/4	3/8 - 16	1 - 1/4
3/8	2 - 3/4	3/8 - 16	1 - 1/4
1/2	2 - 3/4	1/2 - 13	1
5/8	3 - 1/2	5/8 - 11	1 - 1/4
3/4	4 - 1/4	3/4 - 10	1 - 1/2

Permitted Manufacturing Tolerances for Anchor A. Permitted manufacturing tolerances are ±0.015 inches for dimensions given to 1 decimal place, ±0.010 inches for dimensions given to 2 decimal places, and ±0.005 inches for dimensions given to 3 decimal places. Angular tolerances are ±1/2 degree.

Basic Materials for Anchor A. Anchors 1/4 through 3/4 inches in diameter (up to and including 7 inches long) are manufactured of AISI C1022 steel. Anchors 1/4 through 3/4 inches in diameter (longer than 7 inches) are manufactured of AISI C12L14 steel. All anchors are zinc plated to ASTM B-633, Type III, SC1.

Table 3.2 Description of Anchor B

Nominal Diameter (in.)	Anchor Length (in.)	Thread Size (UNC Class 2A)	Thread Length (in.)
1/4	1 - 3/4	1/4 - 20	1/2
5/16	3	5/16 - 18	5/8
1/2	2 - 3/4	1/2 - 13	1
3/8	2 - 3/4	3/8 - 16	3/4

Permitted Manufacturing Tolerances for Anchor B. Permitted manufacturing tolerances are ±0.015 inches for dimensions given to 1 decimal place, ±0.010 inches for dimensions given to 2 decimal places, and ±0.005 inches for dimensions given to 3 decimal places. Angular tolerances are ±1/2 degree.

Basic Materials for Anchor B. Anchors 1/4 through 3/4 inches in diameter (up to and including 7 inches long) are manufactured of AISI C1022 steel. Anchors 1/4 through 3/4 inches in diameter (longer than 7 inches) are manufactured of AISI C12L14 steel. All anchors are zinc plated to ASTM B-633, Type III, SC1.

Table 3.3 Description of Anchor C

Nominal Thread Size	Nominal Diameter (in.)	Anchor Length (in.)
1/4 - 20 UNC - 2A × 2 - 1/4	1/4	3 - 1/4
3/8 - 16 UNC - 2A × 2 - 1/2	3/8	5
1/2 - 13 UNC - 2A × 4 - 1/2	1/2	7
5/8/11 UNC - 2A × 1 - 7/8	5/8	10
3/4 - 10 UNC - 2A × 1 - 7/8	3/4	12
7/8-9 UNC 2A × 2 - 5/8	7/8	10
1" - 8 UNC - 2A × 2 - 5/8	1	12
1 - 1/4" - 7 UNC - 2A × 3 - 5/8	1 - 1/4	12

Permitted Manufacturing Tolerances for Anchors C. Permitted manufacturing tolerances are ±0.015 inches for dimensions given to 1 decimal place, ±0.010 inches for dimensions given to 2 decimal places, and ±0.005 inches for dimensions given to 3 decimal places. Angular tolerances are ±1/2 degree.

Basic Materials for Anchors C. Anchors 1/4 through 1/2 inches in diameter are manufactured of AISI C1015 to 1022 CHQ wire (minimum tensile strength 75 ksi). Anchors 5/8 inches in diameter (up to and including 7 inches in length) are also manufactured of AISI C1015 to 1022 CHQ wire (minimum tensile strength 75 ksi). Anchors 5/8 inches in diameter (8-1/2 and 10-inch length) are manufactured of AISI C1213 CRS. Anchors 3/4 inches in diameter (up to and including 7 inches in length) are manufactured of AISI C1015 to 1022 CHQ wire (minimum tensile strength 75 ksi). Anchors 3/4 inches in diameter (8-1/2, 10 and 12-inch lengths) are manufactured of AISI C1213 CRS. Anchors 7/8, 1, and 1/1/4 inches in diameter are also manufactured of AISI C1213 CRS. All Anchors are zinc plated per PDD Spec. 80-100.

Table 3.4 General Test Matrix - Anchor A

Series	Description	Concrete Strength	Anchor Tested	No. of Anchors	No. of Tests
11	Group tension, 4 anchors, maximum spacing, critical edge distance	2 ksi	small, medium large	60	15
12	Group tension, 4 anchors, minimum spacing, critical edge distance	2 ksi	small, medium, large	60	15
18	Group shear, 2 anchors, minimum spacing, critical edge distance	2 ksi	medium	10	5
19	Group shear, 2 anchors, minimum spacing, minimum edge distance	2 ksi	medium	10	5
20	Oblique tension	2 ksi	all	12	12
21	Oblique tension	6 ksi	all	12	12

NOTES:

Critical edge	=	minimum edge distance by ASTM E488-90 [5]
Minimum edge	=	0.75 critical edge distance for tension and shear in 2 ksi, and for shear in 6 ksi; otherwise 0.5 critical
All anchors	=	3/8, 1/2, 5/8, 3/4
Small, Medium, Large	=	3/8, 5/8, 3/4

Table 3.5 General Test Matrix - Anchor B

Series	Description	Concrete Strength	Anchors Tested	No. of Anchors	No. of Tests
11	Group tension, 4 anchors, maximum spacing, critical edge distance	2 ksi	small, medium, large	60	15
18	Group shear, 2 anchors, minimum spacing, critical edge distance	2 ksi	3/8	10	5
20	Oblique tension	2 ksi	all	12	12

NOTES:

Critical edge	=	minimum edge distance by ASTM E488-90 [5]
Minimum edge	=	0.75 critical edge distance for tension and shear in 2 ksi, and for shear in 6 ksi; otherwise, 0.5 critical edge distance
All anchors	=	1/4, 5/16, 3/8, 1/2
Small, medium, large	=	1/4, 3/8, 1/2

Table 3.6 General Test Matrix - Anchor C

Series	Description	Concrete Strength	Anchors Tested	No. of Anchor s	No. of Tests
11	Group tension, 4 anchors, maximum spacing, critical edge distance	2	small, medium, large	60	15
12	Group tension, 4 anchors, minimum spacing, critical edge distance	2	small, medium, large	60	15
18	Group shear, 2 anchors, minimum spacing, critical edge distance	2	medium	10	5
19	Group shear, 2 anchors, minimum spacing, minimum edge distance	2	medium	10	5
20	Oblique Tension	2	all	24	24
21	Oblique Tension	6	all	24	24

NOTES:

Critical edge = minimum edge distance by ASTM E488-90 [5]
Minimum edge = 1/2 critical edge distance
All anchors = 1/4, 3/8, 1/2, 5/8, 3/4, 7/8, 1, 1-1/4
Small, medium, large = 1/4, 5/8, 1-1/4

Table 3.7 Specific Test Matrix for Anchor C

Test Number Series-Test #	Test Type	f'c (ksi)	Block	dia. (in.)	Bit Type	hole diameter (in.,)	depth	depth (in.)	edge (in.)	min. anchor spacing (in.)	Torque (ft. - lbs.)	Time (min:sec)	Fail	Misc
12-01	G TENSION	2.00	61.00	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8.00	2:50	cone/edge	4 bolts
12-02	G TENSION	2.00	82.00	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8.00	2:45	cone/edge	4 bolts
12-03	G TENSION	2.00	82.00	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8.00	2:55	cone/edge	4 bolts
12-04	G TENSION	2.00	82.00	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8.00	2:35	cone/edge	4 bolts
12-05	G TENSION	2.00	81.00	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8.00	2:40	cone/edge	4 bolts
12-06	G TENSION	2.00	81.00	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	6.000	90.00	5:00	pull through	4 bolts
12-07	G TENSION	2.00	81.00	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	6.000	90.00	4:35	pull through	4 bolts
12-08	G TENSION	2.00	81.00	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	6.000	90.00	4:05	pull through	4 bolts
12-09	G TENSION	2.00	83.00	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	6.000	90.00	5:00	pull through	4 bolts
12-10	G TENSION	2.00	83.00	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	6.000	90.00	3:35	pull through	4 bolts
12-11	G TENSION	2.00	83.00	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	7.500	500.00	3:30	cone	4 bolts
12-12	G TENSION	2.00	84.00	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	7.500	500.00	2:54	cone	4 bolts
12-13	G TENSION	2.00	84.00	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	7.500	500.00	3:00	cone	4 bolts
12-14	G TENSION	2.00	83.00	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	7.500	500.00	3:10	cone	4 bolts
12-15	G TENSION	2.00	83.00	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	7.500	500.00	3:10	cone	4 bolts

Table 3.8 Concrete Mix Design

Target Strength (psi)	3/4-in. Crushed Limestone (pounds/yd^3)	Type I Portland Cement (pounds/yd^3)	Concrete Sand (pounds/yd^3)	Rheobuild 1000 Superplasticizer (ounces/yd^3)	Target Slump (in.)
2000	1970	335	1636	0	8
4000	1876	370	1457	44	6
6000	1870	470	1385	61	6

Table 3.9 Concrete Cylinder Strengths

Block:	83/84
f_c'	2000
Cast	6/7/93

No.	Date	Day	A	B	C	Average
1	6/14/93	7	1581	1556	1646	1594
2	6/21/93	14	1905	1943	1992	1947
3	6/28/93	21	2016	1979	2067	2021
4	7/5/93	28	2022	1963	1977	1987
5	7/7/93	30	2015	2108	2050	2058
6	7/12/93	35	2059	1973	2047	2026

4.0 TEST RESULTS

This chapter provides the test results for anchors tested in oblique tension, group tension, and group shear. The test results are presented in tabular form and represent information contained in the specific test matrix and the test summary. Embedment depth, edge distance and anchor spacing are defined in Section 3.2.2. All test results are located in Appendix A and include:

(1) Specific Test Matrix

(2) Load - Displacement Graph

(3) Cylinder Strength Table

4.1 Oblique Test Results

Oblique tests were conducted with load applied to the anchors at a 45° angle from the surface of the concrete block. Anchors were tested in concrete with target strengths of 2000 psi and 6000 psi, and labeled as Series 20 and 21, respectively, corresponding to Table No. II - Testing Schedule, as described in ICBO ES Acceptance Criteria for Expansion Anchors in Concrete and Masonry Elements [2]. Anchors A and B were tested at shallow embedments, while Anchor C was tested at deep embedments. All anchors were tested at critical edge distances. Oblique Test Results are identified in Table 4.1.

4.2 Group Tension Test Results

Group tension tests were conducted by applying a concentric load to a group of four anchors. All group tension tests were performed in concrete with a target strength of 2000 psi. These tests were labeled as Series 11 and Series 12 to conform with Table No. II ICBO ES Testing Schedule [2]. Tests labeled as Series 11 have a maximum spacing width between anchors, while tests labeled as Series 12 have a minimum spacing width between anchors. Anchors A and B were tested at shallow embedments and Anchor C was tested at deep embedment, as requested by the manufacturers. All anchors were tested at critical edge distances.

Group tension tests are identified in Table 4.2.

4.3 Group Shear Test Results

Group shear tests were conducted on two-anchor groups. A single loading shoe was used for group shear test of Anchors A and B. Load was applied so that both anchors were loaded equally and in the direction of a free edge. Group tests for Anchor C was performed with two loading shoes, one for each anchor. The load was applied simultaneously to each anchor and in the direction of a free edge.

These tests were labeled as Series 18 and Series 19 to conform with ICBO ES Testing Schedule. Series 18 represents group shear tests on anchors at a minimum spacing and critical edge distance. Series 19 represents group anchors tested at a minimum spacing and minimum edge distance. This edge distance was taken as 75% of the critical edge distance for Anchors A and B, and 50% of the critical edge distance for Anchor C.

All group shear tests were performed in concrete with a target strength of 2000 psi. Anchors A and B were tested at shallow embedment depths, and Anchor C was tested at deep embedments, as requested by the manufacturer. Group shear tests are identified in Tables 4.3.

Table 4.1 Identification of Results for Oblique Tension Tests

Concrete Strength	Anchor A	Anchor B	Anchor C
2000 psi	Series WA20, Table 4.4	Series WB20, Table 4.5	Series 20, Table 4.6
6000 psi	Series WA21, Table 4.7		Series 21, Table 4.8

Table 4.2 Identification of Results for Group Tension Test

Anchor Spacing	Anchor A	Anchor B	Anchor C
Maximum	Series WA11, Table 4.9	Series WB11, Table 4.10	Series 11, Table 4.11
Minimum	Series WA12, Table 4.12		Series 12, Table 4.13

Table 4.3 Identification of Results for Group Shear Test

Edge Distance	Anchor A	Anchor B	Anchor C
Critical Edge Distance	Series WA18, Table 4.14	Series WB18, Table 4.15	Series 18, Table 4.16
Minimum Edge Distance	Series WA19, Table 4.17		Series 19, Table 4.18

Table 4.4 Summary of Results for Oblique Tension Tests, Single Anchors (Anchor A)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Horiz. Disp. (inches)	Max. Vert. Disp. (inches)	1/4 Load (lbs.)	1/4 Horiz. Disp. (inches)	1/4 Vert. Disp. (inches)
WA20 - 1	0.375	cone/edge	1097	0.044	0.008	274	0.000	0.000
WA20 - 2	0.375	cone/edge	924	0.048	0.006	231	0.002	0.000
WA20 - 3	0.375	cone/edge	1266	0.070	0.022	316	0.012	0.002
Average			**1096**	**0.054**	**0.012**	**274**	**0.005**	**0.001**
WA20- 4	0.500	cone/edge	1926	0.094	0.032	482	0.014	0.000
WA20 - 5	0.500	cone/edge	1837	0.084	0.016	592	0.012	0.000
WA20 - 6	0.500	cone/edge	1861	0.038	0.012	465	0.006	0.002
Average			**1875**	**0.072**	**0.020**	**513**	**0.011**	**0.001**
WA20 - 7	0.625	cone/edge	2296	0.102	0.022	574	0.046	0.002
WA20 - 8	0.625	cone/edge	2542	0.124	0.014	635	0.028	0.000
WA20 - 9	0.625	cone/edge	2310	0.048	0.008	577	0.028	0.000
Average			**2383**	**0.091**	**0.015**	**595**	**0.034**	**0.001**
WA20 - 10	0.750	cone/edge	4785	0.058	0.002	1196	0.000	0.000
WA20 - 11	0.750	cone/edge	5038	0.110	0.024	1260	0.004	0.000
WA20 - 12	0.750	cone/edge	4902	0.112	0.020	1226	0.000	0.000
Average			**4908**	**0.093**	**0.015**	**1227**	**0.001**	**0.000**

Table 4.5 **Summary of Results for Oblique Tension Tests, Single Anchor (Anchor B)**

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Horiz. Disp. (inches)	Max. Vert. Disp. (inches)	1/4 Load (lbs.)	1/4 Horiz. Disp. (inches)	1/4 Vert. Disp. (inches)
WB20 - 1	0.250	cone	746	0.046	0.008	187	0.002	0.002
WB20 - 2	0.250	cone	624	0.067	0.008	156	0.016	0.000
WB20 - 3	0.250	side blowout	760	0.048	0.024	190	0.000	0.000
Average			**710**	**0.054**	**0.013**	**178**	**0.006**	**0.001**
WB20 - 4	0.313	side blowout	1420	0.077	0.044	355	0.004	0.000
WB20 - 5	0.313	pull out	1884	0.093	0.050	471	0.010	0.002
WB20 - 6	0.313	pull out	1889	0.192	0.121	472	0.016	0.002
Average			**1731**	**0.121**	**0.072**	**433**	**0.010**	**0.001**
WB20 - 7	0.375	cone/edge	1022	0.074	0.004	256	0.014	0.000
WB20 - 8	0.375	cone/edge	1313	0.112	0.022	328	0.022	0.002
WB20 - 9	0.375	cone	1214	0.060	0.016	304	0.006	0.000
Average			**1183**	**0.082**	**0.014**	**296**	**0.014**	**0.001**
WB20 - 10	0.500	cone/edge	2053	0.098	0.030	513	0.036	0.002
WB20 - 11	0.500	cone	1711	0.102	0.057	428	0.016	0.000
WB20 - 12	0.500	cone	1496	0.078	0.034	374	0.016	0.000
Average			**1753**	**0.093**	**0.040**	**438**	**0.023**	**0.001**

Table 4.6 Summary of Results for Oblique Tension Test (Anchor C)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Horiz. Disp. (inches)	Max. Vert. Disp. (inches)	1/4 Load (lbs.)	1/4 Horiz. Disp. (inches)	1/4 Vert. Disp. (inches)
20 - 1	0.250	side blowout	1525	0.162	0.030	381	0.002	0.000
20 - 2	0.250	side blowout	1584	0.154	0.020	396	0.002	0.000
20 - 3	0.250	side blowout	1744	0.158	0.020	436	0.002	0.002
Average			**1618**	**0.158**	**0.023**	**404**	**0.002**	**0.001**
20 - 4	0.375	anchor fracture	4857	0.323	0.085	1214	0.016	0.000
20 - 5	0.375	anchor fracture	4670	0.325	0.089	1167	0.046	0.000
20 - 6	0.375	anchor fracture	5397	0.222	0.034	1349	0.012	0.000
Average			**4975**	**0.290**	**0.069**	**1243**	**0.025**	**0.000**
20 - 7	0.500	anchor fracture	8143	0.839	0.214	2036	0.068	0.000
20 - 8	0.500	anchor slip	5819	0.357	0.128	1455	0.040	0.000
20 - 9	0.500	anchor fracture	8189	0.353	0.099	2047	0.004	0.000
Average			**7384**	**0.516**	**0.147**	**1846**	**0.037**	**0.000**
20 - 10	0.625	side blowout	9297	0.162	0.100	2324	0.010	0.000
20 - 11	0.625	side blowout	9297	0.164	0.078	2324	0.010	0.000
20 - 12	0.625	side blowout	11279	0.108	0.028	2820	0.018	0.000
Average			**9958**	**0.145**	**0.069**	**2489**	**0.013**	**0.000**
20 - 13	0.750	anchor slip	16474	0.489	0.305	4119	0.006	0.002
20 - 14	0.750	anchor slip	16816	0.228	0.087	4204	0.006	0.000
20 - 15	0.750	anchor slip	17910	0.821	0.400	4477	0.002	0.002
Average			**17067**	**0.513**	**0.264**	**4267**	**0.005**	**0.001**
20 - 16	0.875	side blowout	13398	0.515	0.228	3350	0.114	0.002
20 - 17	0.875	side blowout	10117	0.455	0.386	2529	0.002	0.000
20 - 18	0.875	anchor fracture	15596	0.547	0.263	3899	0.008	0.000
Average			**13037**	**0.506**	**0.292**	**3259**	**0.041**	**0.001**
20 - 19	1.000	anchor fracture	21601	0.907	0.529	5400	0.026	0.000
20 - 20	1.000	side blowout	20234	0.555	0.000	5059	0.018	0.000
20 - 21	1.000	side blowout	18252	0.146	0.026	4563	0.002	0.000
Average			**20029**	**0.536**	**0.185**	**5007**	**0.015**	**0.000**
20 - 22	1.250	side blowout	17978	0.186	0.004	4495	0.016	0.000
20 - 23	1.250	side blowout	19756	0.124	0.032	4939	0.006	0.002
20 - 24	1.250	side blowout	22353	0.110	0.030	5588	0.002	0.002
Average			**20029**	**0.140**	**0.022**	**5007**	**0.008**	**0.001**

Table 4.7 **Summary of Results for Oblique Tension Tests, Single Anchors (Anchor A)**

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Horiz. Disp. (inches)	Max. Vert. Disp. (inches)	1/4 Load (lbs.)	1/4 Horiz. Disp. (inches)	1/4 Vert. Disp. (inches)
WA21 - 1	0.375	pull out	1360	0.061	0.030	340	0.000	0.000
WA21 - 2	0.375	cone	1477	0.049	0.004	369	0.000	0.000
WA21 - 3	0.375	cone/edge	1430	0.034	0.006	357	0.000	0.000
Average			**1422**	**0.048**	**0.013**	**355**	**0.000**	**0.000**
WA21 - 4	0.500	side blowout	4329	0.080	0.034	1082	0.002	0.000
WA21 - 5	0.500	side blowout	3801	0.036	0.016	950	0.002	0.002
WA21 - 6	0.500	side blowout	3778	0.108	0.006	944	0.000	0.000
Average			**3969**	**0.075**	**0.019**	**992**	**0.001**	**0.001**
WA21 - 7	0.625	side blowout	4165	0.052	0.002	1041	0.000	0.000
WA21 - 8	0.625	side blowout	5079	0.085	0.002	1270	0.002	0.000
WA21 - 9	0.625	side blowout	5120	0.088	0.008	1280	0.002	0.000
Average			**4788**	**0.075**	**0.004**	**1197**	**0.001**	**0.000**
WA21 - 10	0.750	side blowout	7467	0.058	0.006	1867	0.000	0.000
WA21 - 11	0.750	side blowout	7221	0.092	0.012	1805	0.014	0.002
WA21 - 12	0.750	side blowout	6294	0.066	0.004	1573	0.000	0.000
Average			**6994**	**0.072**	**0.007**	**1748**	**0.005**	**0.001**

Table 4.8 Summary of Results for Oblique Tension Tests, Single Anchors (Anchor C)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Horiz. Disp. (inches)	Max. Vert. Disp. (inches)	1/4 Load (lbs.)	1/4 Horiz. Disp. (inches)	1/4 Vert. Disp. (inches)
21 - 1	0.250	side bl./anc. frac.	1711	0.048	0.024	428	0.002	0.000
21 - 2	0.250	anchor fracture	1945	0.144	0.010	486	0.000	0.000
21 - 3	0.250	anchor fracture	2006	0.148	0.012	501	0.000	0.002
Average			**1887**	**0.113**	**0.015**	**472**	**0.001**	**0.001**
21 - 4	0.375	anchor fracture	4717	0.200	0.048	1179	0.014	0.000
21 - 5	0.375	anchor fracture	4881	0.224	0.072	1220	0.020	0.002
21 - 6	0.375	anchor fracture	4740	0.212	0.082	1185	0.016	0.002
Average			**4779**	**0.212**	**0.067**	**1195**	**0.017**	**0.001**
21 - 7	0.500	anchor fracture	8307	0.503	0.118	2077	0.022	0.000
21 - 8	0.500	anchor fracture	8917	0.357	0.122	2229	0.042	0.000
21 - 9	0.500	anchor fracture	8166	0.399	0.114	2042	0.014	0.000
Average			**8463**	**0.420**	**0.118**	**2116**	**0.026**	**0.000**
21 - 10	0.625	anchor fracture	15517	0.561	0.172	3879	0.028	0.000
21 - 11	0.625	anchor fracture	15244	0.711	0.186	3811	0.034	0.002
21 - 12	0.625	anchor fracture	14902	0.597	0.160	3726	0.034	0.002
Average			**15221**	**0.623**	**0.173**	**3805**	**0.032**	**0.001**
21 - 13	0.750	anchor fracture	24541	0.679	0.042	6135	0.100	0.000
21 - 14	0.750	anchor fracture	24541	0.553	0.168	6135	0.032	0.000
21 - 15	0.750	anchor fracture	23515	0.627	0.172	5879	0.020	0.004
Average			**24199**	**0.620**	**0.127**	**6050**	**0.051**	**0.001**
21 - 16	0.875	side blowout	19892	0.126	0.020	4973	0.004	0.000
21 - 17	0.875	side bl./anc. frac.	19277	0.615	0.254	4819	0.030	0.002
21 - 18	0.875	side blowout	16133	0.168	0.026	4033	0.008	0.000
Average			**18434**	**0.303**	**0.100**	**4608**	**0.014**	**0.001**
21 - 19	1.000	side blowout	21396	0.118	0.008	5349	0.008	0.002
21 - 20	1.000	side blowout	18457	0.152	0.074	4614	0.020	0.000
21 - 21	1.000	anchor fracture	27617	0.475	0.146	6904	0.086	0.002
Average			**22490**	**0.248**	**0.076**	**5622**	**0.038**	**0.001**
21 - 22	1.250	side blowout	23994	0.351	0.012	5998	0.054	0.000
21 - 23	1.250	side blowout	27822	0.086	0.044	6955	0.036	0.012
21 - 24	1.250	side blowout	27002	0.130	0.016	6750	0.048	0.000
Average			**26273**	**0.189**	**0.024**	**6568**	**0.046**	**0.004**

Table 4.9 Summary of Results for Group Tension Tests (Anchor A)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
WA11-1	0.375	cone/edge	4453	0.003	1113	0.000
WA11-2	0.375	2 cones	4642	0.004	1161	0.000
WA11-3	0.375	3 cones/edge	2871	0.002	718	0.000
WA11-4	0.375	2 cone/edge	3556	0.006	889	0.001
WA11-5	0.375	2 cones	2966	0.002	741	0.000
Average			**3698**	**0.003**	**924**	**0.000**
WA11-6	0.625	4 cones	4957	0.005	1239	0.000
WA11-7	0.625	3 cones	6048	0.003	1512	0.000
WA11-8	0.625	2 cones	2842	0.045	710	0.001
WA11-9	0.625	3 cones	6116	0.005	1529	0.001
WA11-10	0.625	3 cones	5270	0.008	1318	0.000
Average			**5047**	**0.013**	**1262**	**0.000**
WA11-11	0.750	2 cones	13317	0.014	3329	0.002
WA11-12	0.750	2 cones	11460	0.015	2865	0.002
WA11-13	0.750	2 cones	15862	0.016	3966	0.000
WA11-14	0.750	2 cones	13111	0.002	3278	0.000
WA11-15	0.750	2 cones	10910	0.005	2727	0.001
Average			**12932**	**0.010**	**3233**	**0.001**

Table 4.10 Summary of Results for Group Tension Tests (Anchor B)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
WB11-1	0.250	4 cones/edge	2137	0.015	534	0.001
WB11-2	0.250	4 cones	2395	0.015	599	0.000
WB11-3	0.250	4 cones/edge	2142	0.023	535	0.001
WB11-4	0.250	4 cones	4062	0.073	1015	0.001
WB11-5	0.250	4 cones	3481	0.084	870	0.001
Average			**2843**	**0.042**	**711**	**0.001**
WB11-6	0.375	4 cones	1873	0.008	468	0.001
WB11-7	0.375	4 cones	2746	0.004	687	0.000
WB11-8	0.375	4 cones/edge	1901	0.003	475	0.000
WB11-9	0.375	4 cones/edge	2300	0.004	325	0.000
WB11-10	0.375	4 cones	1628	0.002	407	0.000
Average			**2090**	**0.004**	**472**	**0.000**
WB11-11	0.500	2 cones	6103	0.059	1526	0.001
WB11-12	0.500	4 cones	6580	0.049	1645	0.000
WB11-13	0.500	2 cones	7317	0.064	1829	0.001
WB11-14	0.500	2 cones	6021	0.150	1505	0.000
WB11-15	0.500	2 cones	5748	0.074	1437	0.000
Average			**6354**	**0.079**	**1588**	**0.000**

Table 4.11 **Summary of Results for Group Tension Test (Anchor C)**

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
11-1	0.250	cone/edge	7579	0.057	1895	0.000
11-2	0.250	cone/edge	7227	0.038	1807	0.000
11-3	0.250	cone/edge	7134	0.120	1783	0.000
11-4	0.250	cone/edge	9902	0.168	2476	0.001
11-5	0.250	anchor fracture	9668	0.153	2417	0.000
Average			**8302**	**0.107**	**2076**	**0.000**
11-6	0.625	pull through	31103	0.454	7776	0.000
11-7	0.625	pull through	25771	0.285	6443	0.000
11-8	0.625	pull through	25839	0.495	6460	0.000
11-9	0.625	pull through	32607	0.463	8152	0.001
11-10	0.625	pull through	32744	0.497	8186	0.001
Average			**29613**	**0.439**	**7403**	**0.000**
11-11	1.250	anchor slip	94881	0.518	23720	0.002
11-12	1.250	anchor slip	88592	0.817	22148	0.004
11-13	1.250	anchor slip	85038	0.532	21259	0.010
11-14	1.250	anchor slip	97342	0.949	24336	0.009
11-15	1.250	anchor slip	109920	0.922	27480	0.001
Average			**95155**	**0.748**	**23789**	**0.005**

Table 4.12 Summary of Results for Group Tension Tests (Anchor A)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
WA12-1	0.375	cone/edge	1205	0.003	301	0.000
WA12-2	0.375	cone/edge	793	0.005	198	0.001
WA12-3	0.375	cone/edge	1570	0.002	393	0.000
WA12-4	0.375	cone/edge	1458	0.001	364	0.000
WA12-5	0.375	cone/edge	2706	0.003	677	0.001
Average			**1546**	**0.003**	**387**	**0.000**
WA12-6	0.625	cone	8231	0.006	2058	0.000
WA12-7	0.625	cone	4857	0.007	1214	0.001
WA12-8	0.625	3 cone	7058	0.007	1764	0.000
WA12-9	0.625	cone	7883	0.010	1971	0.001
WA12-10	0.625	cone/edge	8159	0.024	2040	0.002
Average			**7238**	**0.011**	**1809**	**0.001**
WA12-11	0.750	cone	11110	0.017	2777	0.000
WA12-12	0.750	cone	9882	0.002	2470	0.000
WA12-13	0.750	cone	10782	0.017	2696	0.000
WA12-14	0.750	cone	13565	0.032	3391	0.000
WA12-15	0.750	cone	12215	0.035	3054	0.002
Average			**11511**	**0.021**	**2878**	**0.000**

Table 4.13 Summary of Results for Group Tension Tests (Anchor C)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
12 - 1	0.250	cone/edge	6617	0.013	1654	0.000
12 - 2	0.250	cone/edge	5467	0.035	1367	0.000
12 - 3	0.250	cone/edge	5327	0.011	1332	0.000
12 - 4	0.250	cone/edge	5303	0.021	1326	0.000
12 - 5	0.250	cone/edge	5702	0.008	1426	0.000
Average			**5683**	**0.018**	**1421**	**0.000**
12 - 6	0.625	pull through	25566	0.606	6392	0.001
12 - 7	0.625	pull through	31035	0.877	7759	0.000
12 - 8	0.625	pull through	26113	0.424	6528	0.001
12 - 9	0.625	pull through	32880	0.603	8220	0.000
12 - 10	0.625	pull through	37460	0.754	9365	0.000
Average			**30610**	**0.653**	**7653**	**0.000**
12 - 11	1.250	cone	75741	0.537	18935	0.016
12 - 12	1.250	cone	72186	0.411	18047	0.003
12 - 13	1.250	cone	74100	0.314	18525	0.011
12 - 14	1.250	cone	77382	0.367	19345	0.002
12 - 15	1.250	cone	77928	0.403	19482	0.001
Average			**75467**	**0.406**	**18867**	**0.007**

Table 4.14 Summary of Results for Group Shear Test (Anchor A)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
WA18 - 1	0.625	side blowout	5980	0.071	1495	0.000
WA18 - 2	0.625	side blowout	5843	0.075	1461	0.002
WA18 - 3	0.625	side blowout	5571	0.081	1393	0.000
WA18 - 4	0.625	side blowout	5980	0.095	1495	0.004
WA18 - 5	0.625	side blowout	5721	0.059	1430	0.002
Average			**5819**	**0.076**	**1455**	**0.002**

Table 4.15 Summary of Results for Group Shear Test (Anchor B)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
WB18 - 1	0.375	side blowout	1341	0.040	335	0.000
WB18 - 2	0.375	side blowout	1416	0.049	354	0.000
WB18 - 3	0.375	side blowout	1350	0.071	338	0.002
WB18 - 4	0.375	side blowout	1168	0.042	292	0.000
WB18 - 5	0.375	side blowout	1650	0.077	412	0.022
Average			**1385**	**0.056**	**346**	**0.005**

Table 4.16 Summary of Results for Group Shear Test (Anchor C)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
18 - 1	0.625	side blowout	18047	0.084	4512	0.026
18 - 2	0.625	side blowout	14743	0.056	3686	0.009
18 - 3	0.625	side blowout	16571	0.103	4143	0.048
18 - 4	0.625	side blowout	16162	0.094	4040	0.036
18 - 5	0.625	side blowout	16899	0.091	4225	0.026
Average			**16484**	**0.086**	**4121**	**0.029**

Table 4.17 Summary of Results for Group Shear Test (Anchor A)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
WA19 -1	0.625	side blowout	3756	0.046	939	0.000
WA19 - 2	0.625	side blowout	2569	0.065	642	0.000
WA19 - 3	0.625	side blowout	2419	0.083	608	0.002
WA19 - 4	0.625	side blowout	1941	0.055	485	0.000
WA19 - 5	0.625	side blowout	2542	0.089	635	0.002
Average			**2645**	**0.068**	**662**	**0.001**

Table 4.18 Summary of Results for Group Shear Test (Anchor C)

Test Number	Anchor Diameter (inches)	Failure Mode	Max. Load (lbs.)	Max. Displ. (inches)	1/4 Load (lbs.)	1/4 Displ (inches)
19 - 1	0.625	side blowout	8358	0.031	2089	0.001
19 - 2	0.625	side blowout	6230	0.049	1557	0.003
19 - 3	0.625	side blowout	5957	0.06	1489	0.010
19 - 4	0.625	side blowout	8112	0.097	2028	0.003
19 - 5	0.625	side blowout	6612	0.028	1653	0.001
Average			**7053.8**	**0.053**	**1763.2**	**0.002**

5.0 DISCUSSION OF TEST RESULTS

This chapter discusses the results for Anchors A, B and C under oblique tension, group tension, and group shear load conditions. Each type of test will be examined with respect to the following criteria:

- Failure Mode: Failure modes encountered during testing are described and factors influencing the specific failure modes are explained.
- Load - Displacement Behavior: Load - displacement characteristics are explained.
- Experimental vs. Predicted Results: The actual failure load recorded during testing is compared with the predicted values obtained by using the 1/7/93 draft of Chapter 22 of ACI 318-95 [6].

5.1 Oblique Tension

5.1.1 Failure Modes. The following failure modes occurred most often for anchors tested under oblique tension load conditions. These failure modes are defined in Chapter 2.

- cone failure
- cone/edge failure
- anchor slip (pull through) failure

- side blowout failure
- anchor fracture (shear) failure

The above list comprises failure modes typical of both tension and shear. Since oblique loads can be reduced to tension and shear components, the actual failure mode is determined by the component corresponding to the lower capacity.

Cone or cone/edge failures occurred when the capacity of the anchor, as governed by concrete, was larger in shear than in tension. This type of failure occurred only in anchors tested whose effective embedment depth was less than their edge distance. Anchors tested in Series WA20, WB20, and WB21 showed this type of failure mode.

Anchor slip, a tension failure mode encountered at deeper embedments, was displayed by some anchors in Test Series 20. This type of failure indicates that the tensile component of the applied load was large enough to allow the mandrel portion of the anchor shaft to pull through the expansion clip. This failure mode was not found in Series 21, which indicates that with all else equal, the higher strength concrete will not deform enough to allow the amount of clip expansion necessary for the mandrel portion of the shaft to pull through.

Side blowout failure mode occurred for anchors tested at both shallow and deep embedments. This type of failure indicates that the capacity of the anchor, as governed by concrete, was larger in tension than in shear. Test Series WA21 provided several anchors with this type of failure mode, which is contradictory to what should be expected. These anchors were tested in effective depths smaller than the edge distance. Observations of completed tests in Series WA21 indicate that while the same failure modes were predominantly side blowout, evidence of tensile failure could also be seen. This conclusion can be drawn because cracks began at some distance behind the embedded anchor and then propagated to the edge to form a lateral cone, whereas in pure side blowout cracks initiate at the anchor itself and then propagate outward to meet the free edge. Side blowout, which occurred for some anchors tested in Series 20 and 21, was the expected failure mode. At deep embedments, capacity as governed by concrete is often found to be much less in shear than in tension and less than the capacity as governed by steel failure in either tension or shear.

Anchor fracture was experienced for some anchors tested in Series 20 and 21. The embedment depth and edge distance were large enough to provide a capacity (as governed by concrete) which exceeded the shear strength of the anchor steel. Observed failed anchors show horizontal displacement, and the fractured anchor shaft is slightly bent in the direction of shear loading.

5.1.2 Load-Displacement Behavior. Load-displacement graphs are shown in Appendix A. Oblique test graphs depict vertical and horizontal displacements as a function of applied load. Oblique test results showed that the shear force needed to overcome preload was less than the tensile force needed to overcome preload.

Therefore, shear displacement at failure was usually much larger than tensile displacement.

The reasons for larger displacements can also be explained by examining completed tests. Very often a concrete spall is evident where the anchor bears against the edge of the hole. The spall is caused by crushing of the concrete by the shearing component of the applied load. Once this happens, the anchor must redistribute the load to accommodate the loss of load path. This may result in the anchor bending slightly in the direction of loading, or if the anchor is stiff enough, it may tilt in direction of loading, causing concrete crushing at the top and bottom bearing surfaces of the anchor.

5.1.3 Experimental vs. Predicted Results. The equations from Draft 1/7/93 for Chapter 22 of the ACI 318-95 Code [6] are found in Appendix B of this thesis:

N_y = nominal tensile yield strength of a single fastener

V_y = nominal shear yield strength of a single fastener

N_n = nominal concrete tensile breakout strength of a fastener or group of fasteners

V_n = nominal concrete shear breakout strength of a fastener or a group of fasteners.

$\frac{N_u}{N_n} + \frac{V_u}{V_n} \leq 1.2$ = an interaction equation for anchor subject to tensile and shear loading. Values exceeding 1.2 indicate observed capacities exceed predicted values. N_n and V_n represent the smallest of the fastener steel strength, concrete breakout strength, or pullout strength.

These predicted capacities were compared to the observed values. This was done to determine the validity of the equations as applied specifically to the wedge-type expansion anchors tested in this program. A sample calculation of the method used to predict capacities for oblique test is given in Appendix D.

Tables 5.1 to 5.5 were constructed to facilitate the comparison between experimental results and predicted capacities. The experimental results listed in the table reflect the average of three individual oblique tests. The lowest predicted value for a given anchor diameter can be compared with the experimental failure load. Also, the lowest predicted failure load should give an indication of the type of failure mode to expect. For instance, if the shear strength of the anchor (as governed by steel) has a predicted capacity lower than the shear strength of the anchor (as governed by concrete), then shear anchor fracture would be the expected failure mode. An example of this is seen in the average of Tests 21-7 through 21-9. Nominal shear yield strength of the anchor is predicted to be 6811 lb. This ls less than the predicted nominal concrete breakout strength of the anchor in tension (22887 lbs.) and shear (7320 lbs.). Therefore, this anchor is predicted to fail by shear yield.

Table notations other than the predicted capacities given previously are defined as follows:

P_{exp} = the experimental load applied to the anchor at the time of failure

N_u = the tensile component of the applied load at failure

V_u = the shear component of the applied load at failure

Note that equations do not exist for predicting the pullout or pull-through strength of wedge-type expansion anchors.

Comments on Series WA20: In tension, observed capacities were less than the predicted capacities for the two smaller diameter anchors, and greater than the predicted capacities for the larger diameter anchors. In shear, observed capacities were less than predicted capacities in all cases. This is reasonable because capacity, as governed by shear, could not be reached before tension failure occurred. When observed tension and shear loads are considered separately, they are less than predicted capacities for some anchors. However, the combined loading exceeds the predicted interaction curve in all cases.

Comments on Series WB20: Because of interaction between tension and shear, the tension and shear capacities for all anchors tested in this series were less than the predicted capacity under tension or shear alone. However, they exceeded the predicted interaction curve for combined loading. The results indicate that the capacity of Anchor B is predicted accurately by the formula of Ref. 6.

Comments on Series 20: The general trend in this series is that the observed shear capacity as governed by the concrete was somewhat greater than the predicted value under shear alone, while the observed shear capacity as governed by the steel was less than predicted. This resulted in anchor fracture failure for some anchors where the predicted failure mode was side blowout.

Comments on Series WA21: In this series the observed failure did not occur by cone failure as predicted, but rather as a mix of tensile and shear failures. The general trend seemed to be more tensile capacity than predicted and less shear capacity than predicted. Combined loading exceeded the predicted interaction curve for all anchors. With the exception of the smallest anchor, the interaction equation was conservative.

Comments on Series 21: The smaller anchors in Series 21 gave results similar to anchors in Series 20. Concrete shear capacities exceeded predicted capacities. Therefore, the experimental failure mode resulted in anchor fracture rather than side blowout. All other anchors failed as the capacity equations would predict. It should be noted that with the larger diameter anchor shear capacity as governed by concrete was less than predicted. The tension and shear capacities for most anchors tested in this series were less than the predicted capacity under tension and shear alone. With the exception of the two largest anchors, all other anchor exceeded the predicted interaction curve for combined loading.

Interaction equation values greater than 1.2 indicate that, for a combination of tension and shear, the observed capacities exceeded those predicted. Values greater than 1.2 were obtained for all but two tests, indicating the interaction equation was very successful at predicting failure capacities. In some cases the interaction equation was too conservative. However, this seems necessary if it is to be applied for a variety of anchors and installation conditions.

Figure 5.1 shows the ratio of observed capacities to predicted for the tension and shear components of the oblique tension test.

5.2 Group Tension

5.2.1 Failure Modes. The failure modes encountered in group tension tests included:

- cone failure
- cone/edge failure
- pull-through failure
- anchor slip failure

Cone or cone/edge type of failure occurred for anchors with relatively small edge distances and shallow embedments. Under these conditions the capacity of the anchor, as governed by the tensil strength of steel exceeded the capacity of the anchor as governed by concrete. This type of failure included all anchors for Series: WA11, WB11 and WA12, as well as the small anchor diameter in Series 11 and 12, and large diameter anchors in Series 12.

Pull-through type of failure occurred for the medium-diameter anchors of Series 11 and 12. The deep anchor embedment and mechanical interaction created a condition which enabled the mandrel portion of the anchor to pull through the expansion clip.

Anchor slip failure occurred for the larger-diameter anchors in Series 11. It is believed that this failure mode would have been pull-through had the anchors been removed from the concrete. Failure of these anchors caused some cracking in the block specimen. For two of the tests, cracks could be seen passing between anchors and continuing out to the edge of the block. These cracks ran parallel with the block width. As mentioned in Ref. 3, this type of cracking can occur if the concrete member dimensions are small relative to the anchor size and embedment, if the anchor is close to a free edge, or if the spacing between anchors in a group is too small. The group anchors were tested only in low-strength concrete. Higher-strength concrete is more resistant to the expansive force of the anchor, and is therefore less prone to cracking.

5.2.2 Load-Displacement Behavior. Three different load-displacement behavior patterns were found in group tension tests. Most of the shallow embedded anchors in Series WA11, WB11 and WA12 sustained increasing load with little or no displacement until failure. It would seem that the capacity as governed by concrete was reached before the anchor preload was overcome. All graphs showing this type of behavior represented cone failures.

Other anchors that showed cone failures were embedded deeply enough so that the capacity, as governed by concrete, was larger than the preload. In this circumstance the anchors showed no displacement until preload was overcome. At this point the displacement increased linearly with load until failure. Anchor C exhibited this type of behavior for the small-diameter anchors in Series 11 and 12, and for large-diameter anchors in Series 12. This type of behavior was also exhibited by some Anchors B in Series WB11; however, in this case the amount of preload was small, and therefore the capacity, as governed by concrete, remained to resist the applied load after the preload was exceeded.

The last type of load-displacement behavior exhibited in group tension test occurred for medium-diameter Anchors C in Series 11 and Series 12, and for large-diameter Anchors C in Series 11. The failure mode resulting from these tests is anchor pull-through, also evident by observing the load-displacement graph for these tests. The graphs show load increasing with no displacement until preload is reached. At this point load increases, but only with a large increase in displacement. In some tests the curve is composed of peaks and valleys. At points of decreasing load, the expansion clip probably slipped further down the mandrel portion of the anchor. Once a new clip position is established, the anchor is able to sustain an increase in load until the expansion clip slips again. This process is repeated until anchor failure occurs.

5.2.3 Observed vs. Predicted Results. Predicted capacities of group tension test were obtained from Ref. 6; a sample calculation using this method is located in Appendix D. Observed and predicted capacities are compared in Tables 5.6 through 5.10. Table notation is explained in 5.1.3. Ratios of observed to predicted capacities are presented graphically in Figure 5.2.

Comments on Series WA11, WB11 and WB12: There is no general trend in the comparison of observed vs. predicted values. Some anchor capacity predictions approximate observed capacities, and others do not. The decrease in anchor spacing from Series WA11 to Series WA12 corresponds with a decrease in capacity, as predicted. The exception is the medium-diameter anchor group which showed increased capacity.

Comments on Series 11 and Series 12: The observed capacities for anchor groups were greater than predicted. In fact, the large-diameter anchors are more than 90% stronger than predicted. An exception was found in the medium-diameter anchor, which failed below the predicted value in Series 11 and just above the predicted value in Series 12. In both cases, pull-through failure was observed. Single anchors of this diameter, embedment and edge distance also failed by pull-through. The average pull-through capacity of a single anchor multiplied by 4.0 gives a capacity very close to the experimental group test results. Table 5.11 shows maximum single anchor tensile capacities, multiplied by 4.0, to serve as a comparison with the results of the group tension test. Capacity prediction equations are not available for pull-through failure, and therefore must be obtained experimentally as was the case here. Reduced anchor spacing gave corresponding reductions in predicted and experimental capacities, with the exception as noted above.

5.3 Discussion of Group Shear Test Results

5.3.1 Failure Modes. All group shear tests conducted in Series 18 and Series 19 failed by side blowout. This failure mode, described in Chapter 2, is common for anchors placed close to a free edge and loaded in the direction of the free edge. For Series 18 and Series 19, the capacity as governed by the concrete was less than capacity as governed by the anchor steel. When the applied load exceeded the concrete capacity, failure occurred, resulting in a lateral cone spalling from the free edge of the concrete block.

The capacities of group anchors tested in Series 18 and Series 19, as governed by concrete, were influenced by anchor embedment, edge distance and spacing. Anchor A and Anchor C were the same diameter. However, the capacities of Anchor C groups were much larger than those of Anchor A. Much of the increase in capacity can be attributed to the deeper embedment, larger edge distances, and larger spacing specified for Anchor C tests. Series 18 tests were conducted at critical edge distance while tests for Series 19 were conducted at minimum edge distance. The change in edge distance is the only difference between group shear tests in both series.

5.3.2 Load-Displacement Behavior. All anchors tested for group shear in Series 18 and Series 19 displayed similar load-displacement behavior. Once load was applied to the anchor group, displacement remained approximately zero. When the applied load exceeded the preload, one of two things happened: Either the displacement increased linearly with load until the concrete failed, or there was a short interval in which the load remained constant or decreased with increasing displacement. After this interval, the load increased linearly with displacement until the concrete failed. This plateau or decrease in load with increasing displacement is apparent on the graph and may be attributed to an initial slip at the moment preload is overcome. The slip occurs when the loading shoe moves to take up the small amount of space between it and the anchor shaft. The space is a result of the hole tolerance between the loading shoe and the anchor. This slip would have been prevented had the loading shoe been placed firmly against the shaft of the anchor before testing began.

5.3.3 Experimental vs. Predicted Results. The methods used to predict group shear failure capacities were obtained using Ref. 6 and a sample calculation using this method is located in Appendix D. The predicted capacities were then compared to those observed. The definitions of table notation and use given in 5.1.3 are applicable for group shear tests as well. Table 5.12 shows a comparison between observed and predicted capacities. Ratios of observed to predicted capacities are presented graphically in Figure 5.3.

Comments on Group Shear Test: The observed group shear capacity exceeded the predicted failure capacity for all anchor series tested. Test results indicate that the predictive method provided by Ref. 6 is conservative. The decrease in edge distance from Series 18 to Series 19 led to a decrease in capacity.

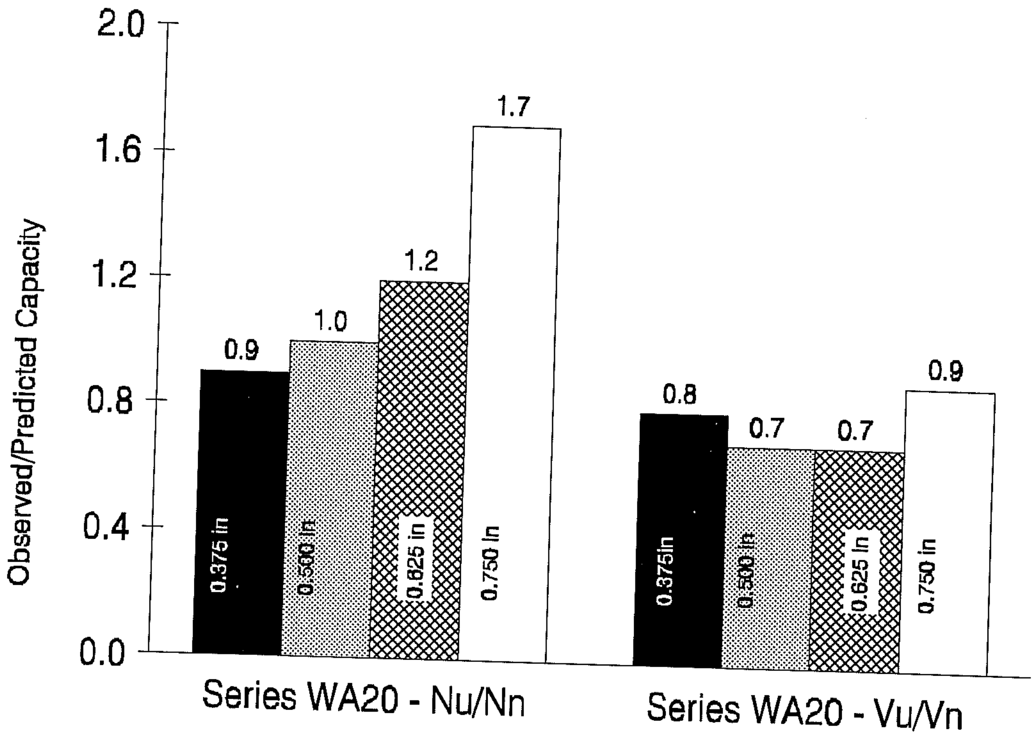


Figure 5.1(a) Observed vs. predicted capacities for oblique tension anchors

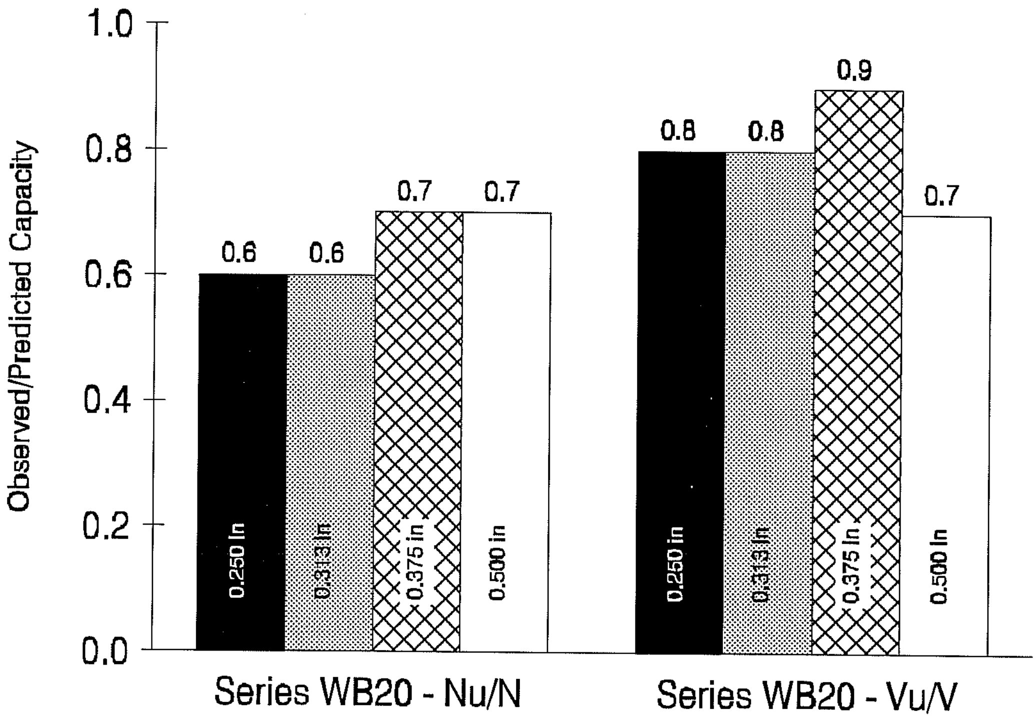


Figure 5.1(b) Observed vs. predicted capacities for oblique tension anchors

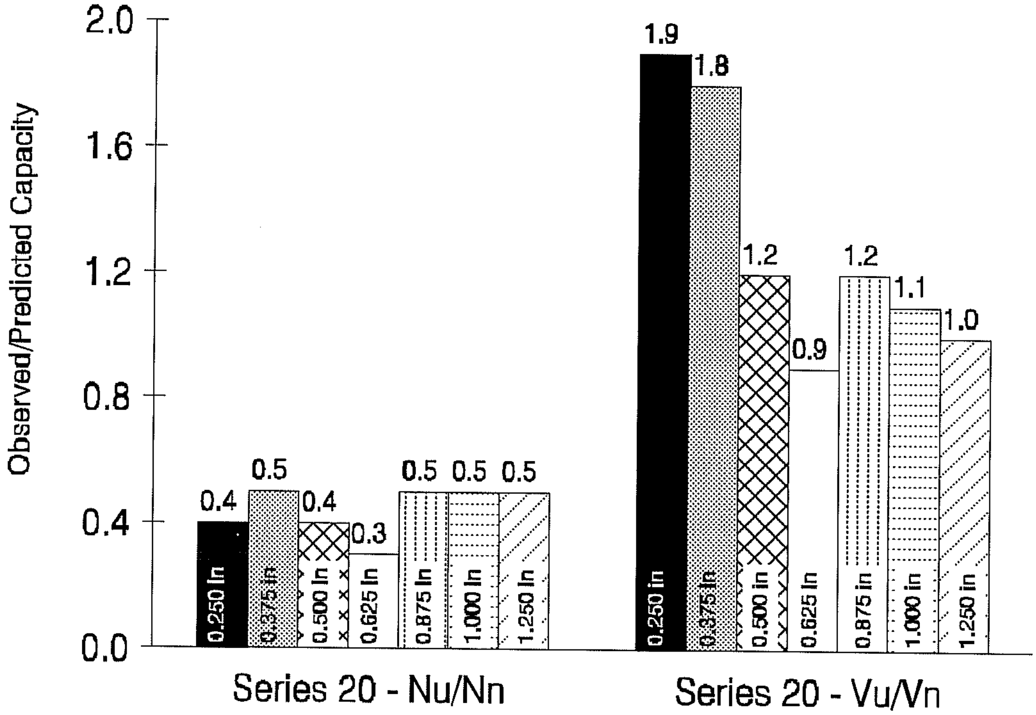


Figure 5.1(c) Observed vs. predicted capacities for oblique tension anchors

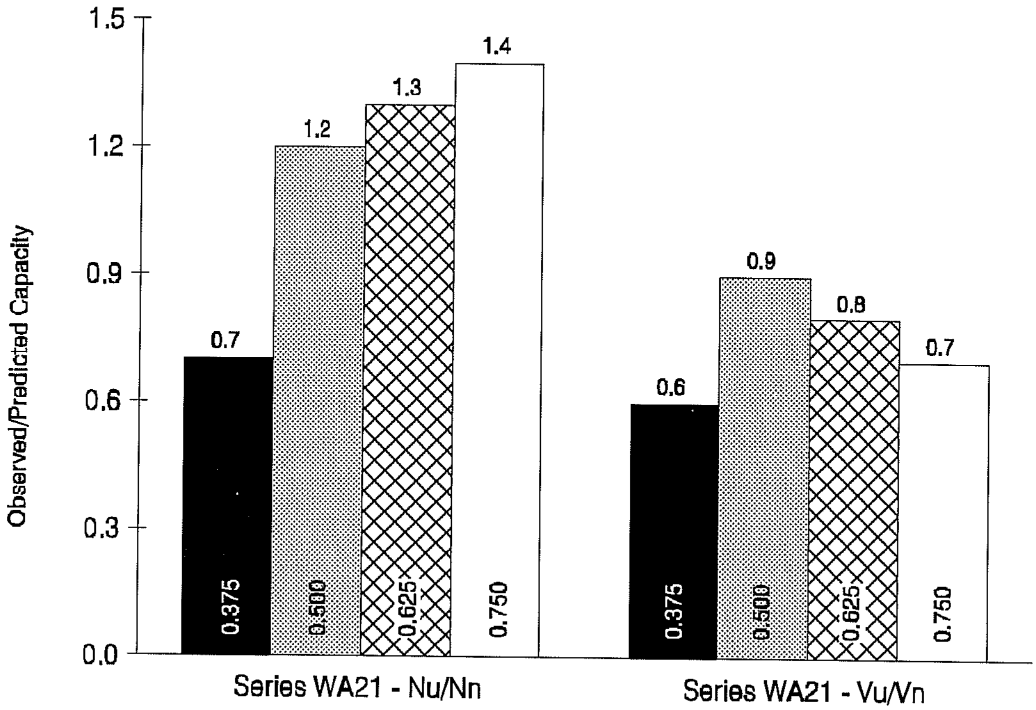


Figure 5.1(d) Observed vs. predicted capacities for oblique tension anchors

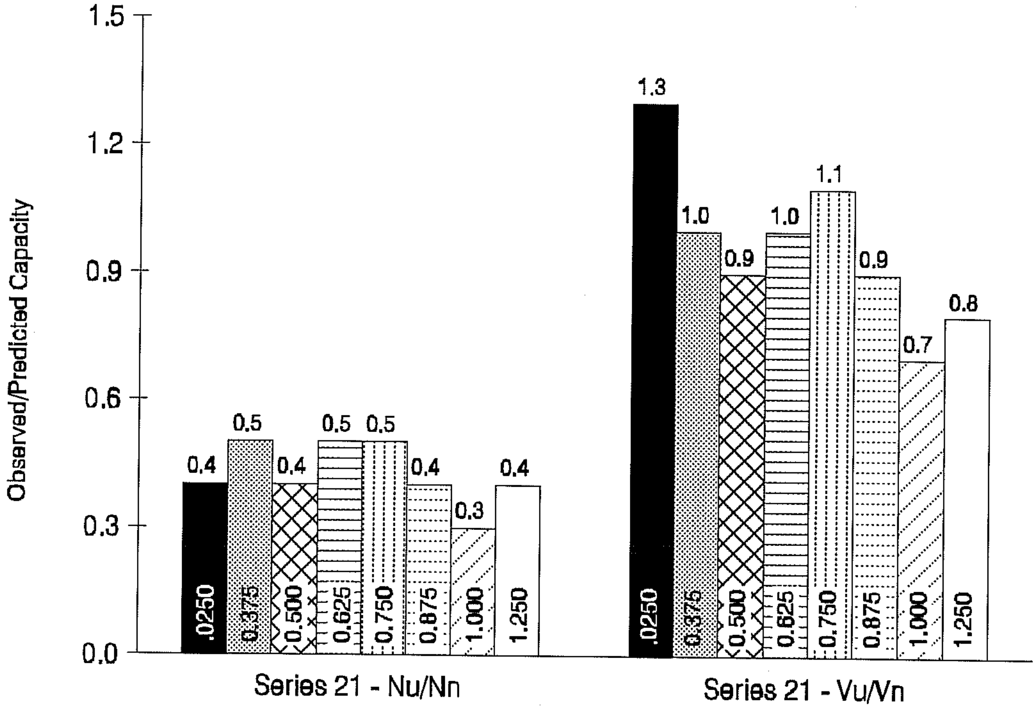


Figure 5.1(e) Observed vs. predicted capacities for oblique tension anchors

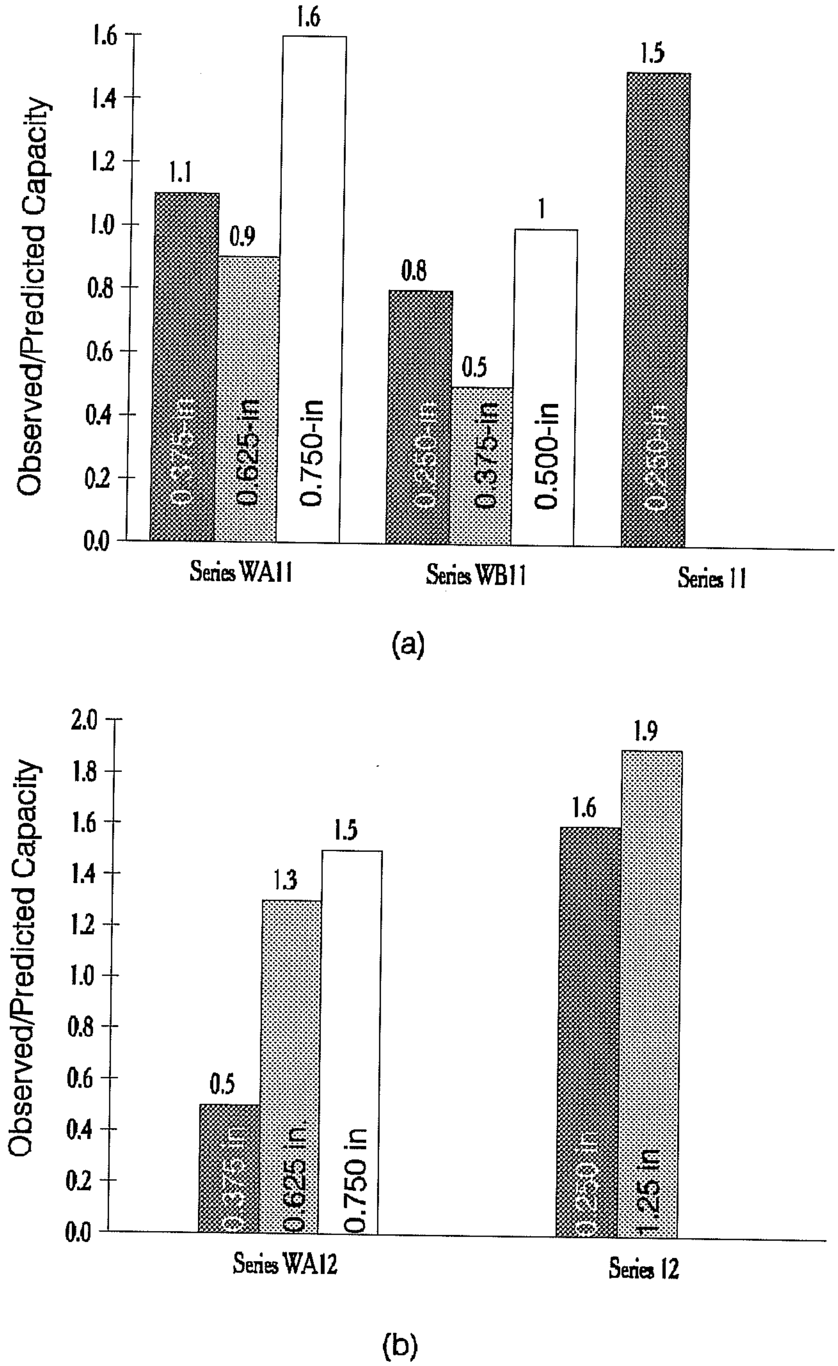


Figure 5.2 Observed vs. predicted capacities for group tension anchors

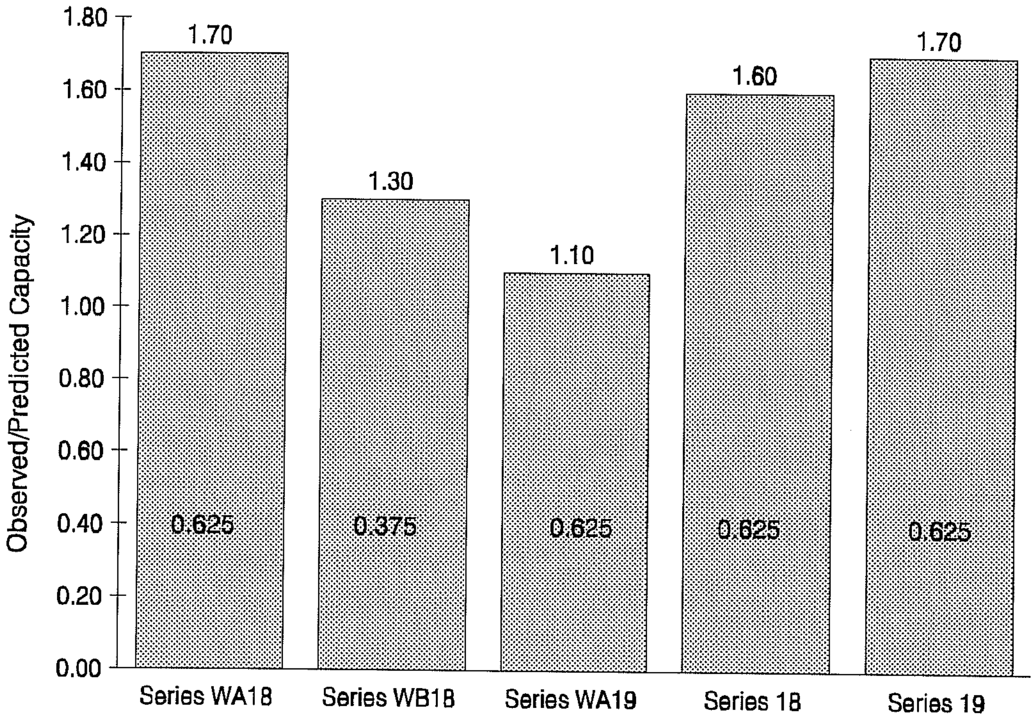


Figure 5.3 Observed vs. predicted capacities for group shear anchor

Table 5.1 Observed versus Predicted Capacities for Oblique Tension Tests, Series WA20

TEST NUMBER	ANCHOR DIAMETER (in.)	N_y (lb)	V_y (lb)	N_n (lb)	V_n (lb)	P_{exp} (lb)	N_u (lb)	V_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$	$\frac{V_u}{V_n}$	$\frac{N_u}{N_n}+\frac{V_u}{V_n}$
WA20-1 through WA20-3	0.375	7440	3720	855	930	1096	775	775	Cone/Edge	Cone	0.9	0.8	1.7
WA20-4 through WA20-6	0.500	13622	6811	1350	1793	1875	1326	1326	Cone/Edge	Cone	1.0	0.7	1.7
WA20-7 through WA20-9	0.625	21696	10848	1457	2404	2383	1685	1685	Cone/Edge	Cone	1.2	0.7	1.9
WA20-10 through WA20-12	0.750	32112	16056	2040	4039	4908	3470	3470	Cone/Edge	Cone	1.7	0.9	2.6

Table 5.2 Observed versus Predicted Capacities for Oblique Tension Tests, Series WB20

TEST NUMBER	ANCHOR DIAMETER (in.)	N_y (lb)	V_y (lb)	N_n (lb)	V_n (lb)	P_{exp} (lb)	N_u (lb)	V_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$	$\frac{V_u}{V_n}$	$\frac{N_u}{N_n}+\frac{V_u}{V_n}$
WB20-1 through WB20-3	0.250	3053	1526	921	607	710	502	502	Cone 2 anchors Side Blowout 1 anchor	Side Blowout	0.6	0.8	1.4
WB20-4 through WB20-6	0.313	5050	2525	2019	1546	1731	1224	1224	Pullout 2 anchors Side Blowout 1 anchor	Side Blowout	0.6	0.8	1.4
WB20-7 through WB20-9	0.375	7740	3720	1142	928	1183	837	837	Cone Edge	Side Blowout	0.7	0.9	1.6
WB20-10 through WB20-12	0.500	13622	6811	1797	1793	1753	1240	1240	Cone	Side Blowout	0.7	0.7	1.4

Table 5.3 Observed versus Predicted Capacities for Oblique Tension Tests, Series 20

TEST NUMBER	ANCHOR DIAMETER (in.)	N_y (lb)	V_y (lb)	N_n (lb)	V_n (lb)	P_{exp} (lb)	N_u (lb)	V_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$	$\frac{V_u}{V_n}$	$\frac{N_u}{N_n}+\frac{V_u}{V_n}$
20-1 through 20-3	0.250	3053	1526	2551	600	1618	1144	1144	Side Blowout	Side Blowout	0.4	1.9	2.4
20-4 through 20-6	0.375	7440	3720	7214	1987	4975	3518	3518	Anchor Fracture	Side Blowout	0.5	1.8	2.3
20-7 through 20-9	0.500	13622	6811	13130	4199	7384	5221	5221	Anchor Fracture	Side Blowout	0.4	1.2	1.6
20-10 through 20-13	0.625	21696	10848	21786	7523	9958	7041	7041	Side Blowout	Side Blowout	0.3	0.9	1.3
20-14 through 20-16	0.750	32112	16056	30682	11612	17067	12068	12068	Anchor Slip	Side Blowout	0.4	1.0	1.4
20-17 through 20-19	0.875	57811	28906	20127	7809	13037	9219	9219	Side Blowout 2 anchors Fracture 1 anchor	Side Blowout	0.5	1.2	1.7
20-19 through 20-21	1.000	58147	29074	31319	13340	20029	14163	14163	Fracture 1 anchor Side Blowout 2 anchors	Side Blowout	0.5	1.1	1.6
20-22 through 20-24	1.250	93034	46517	29434	13676	20029	14163	14163	Side Blowout	Side Blowout	0.5	1.0	1.5

Table 5.4 Observed versus Predicted Capacities for Oblique Tension Tests, Series WA21

TEST NUMBER	ANCHOR DIAMETER (in.)	N_y (lb)	V_y (lb)	N_n (lb)	V_n (lb)	P_{exp} (lb)	N_u (lb)	V_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$	$\frac{V_u}{V_n}$	$\frac{N_u}{N_n}+\frac{V_u}{V_n}$
WA21-1 through WA21-3	0.375	7440	3720	1503	1634	1422	1006	1006	Cone 1 anchor Pullout/Cone 1 anchor Side Blowout 1 anchor	Cone	0.7	0.6	1.3
WA21-4 through WA21-6	0.500	13622	6811	2420	3214	3969	2807	2807	Side Blowout/ Cone 1 anchor Cone/Edge 1 anchor Side Blowout 1 anchor	Cone	1.2	0.9	2.1
20-7 through 20-9	0.625	21696	10848	2612	4309	4788	3386	3386	Side Blowout 1 anchor Side Blowout /Cone 1 anchor Cone 1 anchor	Cone	1.3	0.8	2.1
WA21-10 through WA21-12	0.750	.32112	16056	3651	7229	6994	4946	4946	Side Blowout 2 anchor Side Blowout /Cone 1 anchor	Cone	1.4	0.7	2.1

Table 5.5 Observed versus Predicted Capacities for Oblique Tension Tests, Series 21

TEST NUMBER	ANCHOR DIAMETER (in.)	N_y (lb)	V_y (lb)	N_n (lb)	V_n (lb)	P_{exp} (lb)	N_u (lb)	V_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$	$\frac{V_u}{V_n}$	$\frac{N_u}{N_n}+\frac{V_u}{V_n}$
21-1 through 21-3	0.250	3053	1526	4327	1018	1887	1334	1334	Anchor Fracture	Side Blowout	0.4	1.3	1.7
21-4 through 21-6	0.375	7440	3720	12239	3370	4779	3379	3379	Anchor Fracture	Side Blowout	0.5	1.0	1.5
21-7 through 21-9	0.500	13622	6811	22887	7320	8463	5984	5984	Anchor Fracture	Anchor Fracture	0.4	0.9	1.3
21-10 through 21-12	0.625	21696	10848	36961	12763	15221	10763	10763	Anchor Fracture	Anchor Fracture	0.5	1.0	1.5
21-13 through 21-15	0.750	32112	16056	52052	19699	24199	17111	17111	Anchor Fracture	Anchor Fracture	0.5	1.1	1.6
21-16 through 21-18	0.875	57811	28906	36019	14119	18434	13035	13035	Side Blowout 2 anchors Anchor Fracture 1 anchor	Side Blowout	0.4	0.9	1.3
21-19 through 21-21	1.000	58147	29074	52585	22398	22490	15903	15903	Side Blowout 1 anchor Anchor Fracture 1 anchor	Side Blowout	0.3	0.7	1.0
21-22 through 21-24	1.250	93034	46517	49420	22962	26273	18578	18578	Side Blowout	Side Blowout	0.4	0.8	1.2

Table 5.6 Observed vs. Predicted Capacities for Group Tension Tests, Series WA11

TEST NUMBER	ANCHOR DIAMETER (in.)	$4N_y$ (lb)	N_n (lb)	N_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$
WA11-1 through WA11-5	0.375	30,960	3434	3698	Cone/Edge	Cone	1.1
WA11-6 through WA11-10	0.625	86,784	5861	5047	Cone	Cone	0.9
WA11-11 through WA11-15	0.750	128,448	8098	12932	Cone	Cone	1.6

Table 5.7 Observed vs. Predicted Capacities for Group Tension Tests, Series WB11

TEST NUMBER	ANCHOR DIAMETER (in.)	$4N_y$ (lb)	N_n (lb)	N_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$
WB11-1 through WB11-5	0.250	12,212	3683	2843	Cone/Edge	Cone	0.8
WB11-6 through WB11-10	0.375	30,960	4036	2090	Cone/Edge	Cone	0.5
WB11-11 through WB11-15	0.500	54,488	6349	6354	Cone/Edge	Cone	1.0

Table 5.8 Observed vs. Predicted Capacities for Group Tension Tests, Series 11

TEST NUMBER	ANCHOR DIAMETER (in.)	$4N_y$ (lb)	N_n (lb)	N_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$
11-1 through 11-5	0.250	12,212	5499	8302	Cone/Edge	Cone	1.5
11-6 through 11-10	0.625	86,784	43614	29613	Pull Through	Cone	0.7
11-11 through 11-15	1.250	372,136	47,609	95115	Anchor Slip	Cone	2.0

Table 5.9 Observed vs. Predicted Capacities for Group Tension Tests, Series WA12

TEST NUMBER	ANCHOR DIAMETER (in.)	$4N_y$ (lb)	N_n (lb)	N_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$
WA12-1 through WA12-5	0.375	30,960	2853	1546	Cone/Edge	Cone	0.5
WA12-6 through WA12-10	0.625	86,284	5477	7238	Cone	Cone	1.3
WA12-11 through WA12-15	0.750	128,448	7893	11511	Cone	Cone	1.5

Table 5.10 Observed vs. Predicted Capacities for Group Tension Tests, Series 12

TEST NUMBER	ANCHOR DIAMETER (in.)	$4N_y$ (lb)	N_n (lb)	N_u (lb)	FAILURE MODE	PREDICTED FAILURE MODE	$\frac{N_u}{N_n}$
12-1 through 12-5	0.250	12,212	3490	5683	Cone/Edge	Cone	1.6
12-6 through 12-10	0.625	86,784	27539	30611	Pull-Through	Cone	1.1
12-11 through 12-15	1.250	372,136	38907	75467	Cone	Cone	1.9

Table 5.11 Maximum Single Anchor Tensile Capacity ✱ 4

Anchor Diameter	Anchor A (lb)	Anchor B (lb)	Anchor C (lb)
0.250	----	----	9004
0.375	2680	3976	----
0.500	----	6168	----
0.625	9516	----	28200
0.750	13224	----	----
1.250	----	----	144522

Table 5.12 Observed vs. Predicted Capacities for Group Shear Test

SERIES NUMBER	ANCHOR DIAMETER (in.)	$2V_y$ (lb)	V_n (lb)	V_u (lb)	OBSERVED FAILURE MODE	PREDICTED FAILURE MODE	$\frac{V_u}{V_n}$
WA18-1 through WA18-5	0.625	21696	3340	5819	Side Blowout	Side Blowout	1.7
WB18-1 through WB18-5	0.375	7440	1093	1385	Side Blowout	Side Blowout	1.3
WA19-1 through WA19-5	0.625	21696	2351	2645	Side Blowout	Side Blowout	1.1
18-1 through 18-5	0.625	21696	10031	1648 4	Side Blowout	Side Blowout	1.6
19-1 through 19-5	0.625	21696	4203	7054	Side Blowout	Side Blowout	1.7

6.0 DISCUSSION OF ICBO ES QUALIFICATION CRITERIA

The purpose of this chapter is to comment on the significance of some provisions listed in ICBO ES Acceptance Criteria [2], and recommend changes and/or improvements to the criteria. Topics are discussed as they pertain to oblique tension, group tension, and group shear testing of wedge anchors under ICBO ES criteria.

6.1 Oblique Tension

Anchors were tested under oblique tension loading as required by ICBO ES Testing Schedules for Series 20 and 21 [2]. The loads applied to the anchor at failure were related to predicted capacities in an interaction equation as explained in Section 6.1.3. Values less than or equal to 1.2 indicate that the observed anchor capacity was less than the predicted value load. Likewise, values greater than 1.2 indicate that the anchor capacity exceeded the predicted value. All oblique tension tests except two resulted in ratios greater than 1.2. This particular interaction equation was conservative. Given this tension-shear interaction formula, the results of research conducted on this program suggest that oblique tension tests could be eliminated from ICBO ES testing requirements.

6.2 Group Tension

Group tension tests were conducted in this program as required by ICBO ES [2]. Test results indicate that adequate information about anchor groups loaded in tension can be obtained without testing. This can be accomplished by a combination of the two procedures. Procedure One, discussed in Section 6.2.1, uses the equations provided in Ref. 6 to predict anchor capacity. Procedure Two, discussed in Section 6.2.2, uses information obtained from single-anchor test results.

6.2.1 Procedure One for Avoiding Group Tension Tests. This method is used to predict group anchor capacity, as provided by Ref. 6. It assumes that an anchor will affect a surrounding potential breakout cone with a radius of 1.5 times effective embedment (h_{ef}). The effective embedment is the distance from the concrete surface to the point of bearing at the interface between the expansion clip and the concrete. Anchors spaced at a distance greater than or equal to $3h_{ef}$ should not adversely influence one another, and should achieve maximum concrete breakout capacities.

Anchors in Series WA11 and WB11 were spaced at distances greater than 3 h_{ef}. Anchors for Series 11 were spaced at the maximum anchor spacing according to ASTM E488-90. However, because embedments were very deep, maximum anchor spacing did not reach $3h_{ef}$.

The ratios of observed to predicted capacities are shown in Tables 5.6 to 5.10. For Anchors A and C, these results indicate that the observed capacity of the anchor group usually exceeded that predicted.

6.2.2 Procedure Two for Avoiding Group Tension Tests. An additional indication of anchor performance can be obtained by taking the maximum load of a single anchor tested in tension and multiplying it by the number of anchors in the group (n). The group anchor installation conditions must be the same as those of the single anchor. This calculated value represents an upper bound of anchor performance. It is greater than or equal to the value predicted by the group capacity equation. If the value given by the single anchor capacity times (n) is less than the predicted value, then the predicted value is questionable. Table 5.11 shows the maximum tensile load of a single anchor multiplied by n = 4. Notice that for the 0.625-inch-diameter Anchor C in Table 5.8, the predicted capacity is much larger than 4 times the single anchor capacity. Therefore, the predicted value is questionable. In this case, pull-through failure occurred. The capacity equations could not predict this failure; if pull-through failure occurs for a single anchor, it can be expected to occur for group anchors as well.

If anchor capacity can be reasonably predicted by methods provided in Ref. 6 and combined with information extrapolated from single anchor tests, the need for continued ICBO ES group tension test may not be warranted for anchors spaced at distances greater than or equal to $3h_{ef}$.

6.3 Group Shear Tests

6.3.1 Anchors were spaced at minimum spacing for Series 18 and 19 as required by ICBO ES provisions. This resulted in the spacing of anchors less than 3 times the edge distance. Anchors spaced at least 3 times the edge distance could be expected to achieve maximum capacity in shear (as governed by concrete) without adversely influencing one another.

For manufacturers desiring to specify anchor spacing at less than 3 times the edge distance, group shear test could be carried out. However, test results indicate that reasonable predictions can be obtained by using the equations provided by Ref. 6. The average applied load exceeded the predicted capacity for all group shear tests. Predicted capacities were conservative but not unreasonably so. To aid in predicting group shear capacities, results of single-anchor shear tests could be extrapolated to group shear test, and used as an upper bound to ensure that the values calculated from predictive equations are reasonable.

6.3.2 The minimum edge distance as specified in Series 19 is some fraction of the critical edge distance. Testing conducted in this program found that minimum edge distance could not arbitrarily be assigned the value of 50% of critical edge distance. Anchors tested in low-strength concrete at shallow embedments would often crack or spall the concrete during application of the installation torque. The minimum edge distance for some anchors had to be determined by trial and error. Once the minimum edge distance was determined for single anchors, it was then adequately defined for group anchors as well, and no installation problems were encountered.

If single-anchor testing can provide information about a particular anchor's performance with respect to spacing and edge distance, this information can be used in conjunction with predictive methods, and can eliminate the necessity for group testing. Based on test results obtained in this program, it is recommended that ICBO ES consider removing group shear tests from its provisions.

6.3.3 Test Equipment. ICBO ES provisions require that anchors tested in groups be loaded equally and simultaneously by a common fixture. These requirements are reasonable for most anchor diameters and spacing requirements. However, the 1-1/4-inch anchors tested in group tension required an anchor spacing of 15 inches. To construct a loading plate of sufficient stiffness would not have been feasible. Instead, each anchor in the group was loaded simultaneously but separately, as described in Section 3.4.2.

The spacing requirements for group shear test on Anchor C were large enough to allow separate loading shoes for each anchor. As with the group tension tests mentioned above, the anchors were loaded equally and simultaneously, but not by a common fixture.

The results obtained from group tests loaded by separate fixtures indicate no problems or inadequacies with this arrangement. It is therefore recommended that ICBO ES remove the requirement for a single test fixture for group testing.

7.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This program involved single anchors tested in oblique tension, and groups of anchors tested in tension and shear. The test results described the performance of the anchors, in terms of the following indices:

(1) failure mode

(2) load-displacement behavior

(3) observed vs. predicted capacities

These indices were discussed in detail for each type of test. Finally, the testing provisions specified by ICBO ES are discussed and some changes are recommended.

7.2 Conclusions.

7.2.1 Failure Modes. The failure modes of the wedge-type expansion anchors used in this program were largely a function of embedment, spacing and edge distance. In general, concrete failure occurred for anchors placed at shallow embedments, and/or close to an edge. Anchors placed at deep embedments usually failed by anchor fracture or anchor pull-through. An exception to those general trends occurs when the yield capacity of deeply embedded anchors exceeds the capacity as governed by concrete. This occurred for large-diameter anchors loaded in oblique tension, for minimum-spacing group tension, and for all deeply embedded anchors in group shear.

7.2.2 Load-Displacement Behavior. Test results indicate that load-displacement behavior is influenced by preload and by anchor failure mode. Anchor displacement is nearly zero until the preload is overcome. Oblique tension tests indicate that preload in shear can be overcome at lower loads than can preload in tension. After preload, the applied load will increase with increasing displacement. For anchors that failed by concrete breakout or anchor fracture, the load-displacement relationship was linear until failure. Anchors that failed by pull-through or slip did not exhibit a linear load-displacement relationship, and usually underwent large displacement before maximum loads were reached.

7.2.3 Comparison of Observed and Predicted Capacity. Mathematical equations for predicting anchor capacity in oblique tension, group tension, and group shear were obtained in Ref. 6. Failure loads often varied significantly for anchors of the same dimension in a given test series. Given this circumstance, these equations predicted failure loads that compared reasonably with the experimental failure loads for the three types of tests conducted. In comparing observed failure capacities with predicted failure capacities, the following trends were observed:

(1) For oblique tests, anchor fracture usually occurred at loads between 1% and 15% lower than predicted; concrete shear capacities were usually greater than predicted.

(2) For group tension tests the capacities of large-diameter anchors were usually greater than predicted. The 1-1/4-inch diameter anchor had a capacity more than 90% over what was predicted.

(3) Group shear capacities were greater than predicted

(4) Pull-through failures could not be predicted by the formulas provided in Ref. 6.

7.3 Recommended Changes to ICBO ES Provisions

(1) Remove the requirement for oblique testing. The tri-linear interaction equation provided in Ref. 6 can adequately predict tension and shear interaction, though it is slightly conservative.

(2) Remove the requirement for group tension tests for anchors spaced at greater than or equal to $3h_{ef}$. Predictive methods provided in Ref. 6 and results obtained from single anchor tests can be effectively used to determine anchor capacity.

(3) Remove the requirement for group shear tests. Predictive methods provided in Ref. 6 and results from single anchor tests can be effectively used to determine anchor capacity.

(4) Remove the requirement for a single test fixture for group tension tests. It is not necessary, and is difficult to comply with for large-diameter anchors.

APPENDIX A

Test Matrix

Load-Displacement Graphs

Cylinder Strength Tables

Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	max. anchor	Req. torque	Act. torque	Time	Fail	Misc.
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	spacing (in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WA11-1	G TENSION	2	93	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	4.375	25	20.8, 20.8, 19.2 & 12.5	4:35	cone/edge	3 - 4
WA11-2	G TENSION	2	93	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	4.375	25	12.5, 17.9, 14.2 & 10.4	4:40	2 cones	2 1/2
WA11-3	G TENSION	2	93	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	4.375	25	20.8, 13.3, 12.9 & 14.2	3:00	3 cones/edge	3
WA11-4	G TENSION	2	93	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	4.375	25	17.1, 12.5, 12.9 & 12.9	3:10	2 cones/edge	2 1/2
WA11-5	G TENSION	2	93	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	4.375	25	16.3, 16.3, 12.5 & 16.7	2:40	2 cones	2 1/2
WA11-6	G TENSION	2	90	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	7.000	95	30.0, 46.0, 20.0 & 42.0	2:40	4 cones	4
WA11-7	G TENSION	2	90	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	7.000	95	23.8, 18.3, 27.5 & 39.2	3:10	3 cones	4
WA11-8	G TENSION	2	93	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	7.000	95	45.0, 58.0, 35.0 & 43.0	2:30	2 cones	4
WA11-9	G TENSION	2	93	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	7.000	95	57.0, 55.0, 33.0 & 65.0	4:01	3 cones	4
WA11-10	G TENSION	2	93	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	7.000	95	17.5, 48.0, 50.0 & 58.0	2:55	3 cones	4
WA11-11	G TENSION	2	90	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	9.188	190	100.0, 68.0, 78.0 & 58.0	3:19	2 cones	4
WA11-12	G TENSION	2	90	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	9.188	190	123.0, 75.0, 85.0 & 82.0	2:45	2 cones	4
WA11-13	G TENSION	2	90	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	9.188	190	78.0, 68.0, 63.0 & 106.0	3:56	2 cones	4
WA11-14	G TENSION	2	90	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	9.188	190	120.0, 110.0, 90.0 & 74.0	3:10	2 cones	4
WA11-15	G TENSION	2	94	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	9.188	190	75.0, 70.0, 72.0 & 59.0	3:20	2 cones	4

Test Number	Test Type	f'c	Block	dia.	Bit Type	hole diameter	depth	depth	edge	max. anchor	Torque	Time	Fail	Misc
Series-Test #		(ksi)		(in.)		(in.)		(in.)	(in.)	spacing (in.)	(ft. - lbs.)	(min:sec)		
11 - 01	G TENSION	2	62	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	3.188	8	3:26	cone/edge	2 bolts
11 - 02	G TENSION	2	62	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	3.188	8	3:00	cone/edge	2 bolts
11 - 03	G TENSION	2	62	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	3.188	8	3:29	cone/edge	2 bolts
11 - 04	G TENSION	2	62	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	3.188	8	4:30	cone/edge	2 bolts
11 - 05	G TENSION	2	61	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	3.188	8	3:40	anchor fracture	2 bolts
11 - 06	G TENSION	2	84	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	12.0	90	4:40	pull through	4 bolts
11 - 07	G TENSION	2	84	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	12.0	90	2:45	pull through	4 bolts
11 - 08	G TENSION	2	84	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	12.0	90	2:30	pull through	4 bolts
11 - 09	G TENSION	2	84	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	12.0	90	3:15	pull through	4 bolts
11 - 10	G TENSION	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	12.0	90	3:10	pull through	4 bolts
11 - 11	G TENSION	2	82	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	15.0	500	3:00	anchor slip	blk. cracked
11 - 12	G TENSION	2	82	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	15.0	500	4:10	anchor slip	blk. cracked
11 - 13	G TENSION	2	81	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	15.0	500	3:20	anchor slip	blk. cracked
11 - 14	G TENSION	2	81	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	15.0	500	4:05	anchor slip	blk. cracked
11 - 15	G TENSION	2	83	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	15.0	500	4:30	anchor slip	blk. cracked

Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	min. anchor	Req. torque	Act. torque	Time	Fail	Misc.
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	spacing (in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WA12-1	G TENSION	2	90	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	25.0, 9.6, 16.3 & 8.8	2:57	cone/edge	4
WA12-2	G TENSION	2	90	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	8.3, 11.3, 2.5 & 2.5	2:22	cone/edge	4
WA12-3	G TENSION	2	90	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	9.6, 8.8, 10.8 & 11.7	3:27	cone/edge	4
WA12-4	G TENSION	2	90	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	11.7, 16.7, 18.3 & 19.2	3:23	cone/edge	4
WA12-5	G TENSION	2	93	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	19.2, 10.8, 25.0 & 25.0	3:50	cone/edge	3 1/2 - 4
WA12-6	G TENSION	2	93	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	36.7, 38.3, 33.3 & 40.8	5:00	cone	4
WA12-7	G TENSION	2	93	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	35.0, 15.0, 28.3 & 33.3	2:00	cone	3 3/4 - 4
WA12-8	G TENSION	2	94	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	33.3, 29.2, 47.1 & 48.3	2:55	3 cones	3
WA12-9	G TENSION	2	94	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	38.3, 33.3, 50.0 & 31.7	2:30	cone	3
WA12-10	G TENSION	2	94	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	29.2, 29.2, 27.1 & 37.5	3:00	cone/edge	.2 1/2 - 3 1/2
WA12-11	G TENSION	2	93	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	4.594	190	50.0, 46.0, 40.0 & 49.0	5:00	cone	4
WA12-12	G TENSION	2	93	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	4.594	190	58.0, 78.0, 93.0 & 124.0	3:05	cone	4
WA12-13	G TENSION	2	93	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	4.594	190	70.0, 62.0, 71.0 & 74.0	3:25	cone	4
WA12-14	G TENSION	2	90	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	4.594	190	58.0, 73.0, 50.0 & 65.0	4:50	cone	4
WA12-15	G TENSION	2	90	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	4.594	190	69.0, 60.0, 75.0 & 53.0	4:10	cone	4

Test Number	Test Type	f'c	Block	dia.	Bit Type	hole diameter	depth	depth	edge	min. anchor	Torque	Time	Fail	Misc
Series-Test #		(ksi)		(in.)		(in.,)		(in.)	(in.)	spacing (in.)	(ft. - lbs.)	(min:sec)		
12 - 01	G TENSION	2	61	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8	2:50	cone/edge	4 bolts
12 - 02	G TENSION	2	82	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8	2:45	cone/edge	4 bolts
12 - 03	G TENSION	2	82	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8	2:55	cone/edge	4 bolts
12 - 04	G TENSION	2	82	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8	2:35	cone/edge	4 bolts
12 - 05	G TENSION	2	81	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	1.594	8	2:40	cone/edge	4 bolts
12 - 06	G TENSION	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	6.0	90	5:00	pull through	4 bolts
12 - 07	G TENSION	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	6.0	90	4:35	pull through	4 bolts
12 - 08	G TENSION	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	6.0	90	4:05	pull through	4 bolts
12 - 09	G TENSION	2	83	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	6.0	90	5:00	pull through	4 bolts
12 - 10	G TENSION	2	83	0.625	MEDIUM	0.650 - 0.654	DEEP	8.0	6.0	6.0	90	3:35	pull through	4 bolts
12 - 11	G TENSION	2	83	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	7.5	500	3:30	cone	4 bolts
12 - 12	G TENSION	2	84	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	7.5	500	2:54	cone	4 bolts
12 - 13	G TENSION	2	84	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	7.5	500	3:00	cone	4 bolts
12 - 14	G TENSION	2	83	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	7.5	500	3:10	cone	4 bolts
12 - 15	G TENSION	2	83	1.250	MEDIUM	1.285 - 1.289	DEEP	10.0	7.5	7.5	500	3:10	cone	4 bolts

Test Number	Test Type	f'c	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	min. anchor	Req. torque	Act. torque	Time	Fail	Misc.
Series-Test #		(ksi)		(in.)		(in.,)		(in.)	(in.)	spacing (in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WA18-1	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	38 & 58	4:50	side blowout	4
WA18-2	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	95 & 55	4:40	side blowout	4
WA18-3	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	50 & 48	2:20	side blowout	4
WA18-4	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	40 & 72	2:30	side blowout	4
WA18-5	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	3.500	95	67 & 52	2:20	side blowout	4

Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	min. anchor	Req. torque	Act. torque	Time	Fail	Misc
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	spacing (in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WB18-1	G SHEAR	2	87	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	4.2 & 6.3	2:50	side blowout	4
WB18-2	G SHEAR	2	87	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	5.8 & 4.2	2:40	side blowout	4
WB18-3	G SHEAR	2	87	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	5.8 & 5.0	3:05	side blowout	4
WB18-4	G SHEAR	2	87	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	2.5 & 5.4	2:28	side blowout	4
WB18-5	G SHEAR	2	87	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	2.188	25	5.8 & 4.2	3:38	side blowout	4

Test Number	Test Type	f'c	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	spacing	Torque	Time	Fail
Series-Test #		(ksi)		(in.)		(in.)		(in.)	(in.)	minimum (in.)	(ft. - lbs.)	(min:sec)	
18 - 01	G SHEAR	2	68	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	6.00	6.00	90	3:24	side blowout
18 - 02	G SHEAR	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	6.00	6.00	90	3:45	side blowout
18 - 03	G SHEAR	2	84	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	6.00	6.00	90	3:10	side blowout
18 - 04	G SHEAR	2	68	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	6.00	6.00	90	2:10	side blowout
18 - 05	G SHEAR	2	68	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	6.00	6.00	90	2:04	side blowout

Test Number	Test Type	f'c	Block	dia.	Bit Type	hole diameter	depth	depth	min. edge	min. anchor	Req. torque	Act. torque	Time	Fail	Misc.
Series-Test #		(ksi)		(in.)		(in.,)		(in.)	(in.)	spacing (in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WA19-1	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	2.625	3.500	95	56 & 60	3:10	side blowout	4
WA19-2	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	2.625	3.500	95	64 & 60	2:20	side blowout	4
WA19-3	G SHEAR	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	2.625	3.500	95	55 & 50	2:15	side blowout	4
WA19-4	G SHEAR	2	90	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	2.625	3.500	95	31 & 35	3:35	side blowout	4
WA19-5	G SHEAR	2	90	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	2.625	3.500	95	46 & 34	3:15	side blowout	4

Test Number	Test Type	f'c	Block	dia.	Bit Type	hole diameter	depth	depth	min. edge	spacing	Torque	Time	Fail
Series-Test #		(ksi)		(in.)		(in.,)		(in.)	(in.)	minimum (in.)	(ft. - lbs.)	(min:sec)	
19 - 01	G SHEAR	2	68	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	3.00	6.00	90	2:24	side blowout
19 - 02	G SHEAR	2	82	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	3.00	6.00	90	2:35	side blowout
19 - 03	G SHEAR	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	3.00	6.00	90	2:10	side blowout
19 - 04	G SHEAR	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	3.00	6.00	90	2:50	side blowout
19 - 05	G SHEAR	2	81	0.625	MEDIUM	0.650 - 0.654	DEEP	8.00	3.00	6.00	90	2:15	side blowout

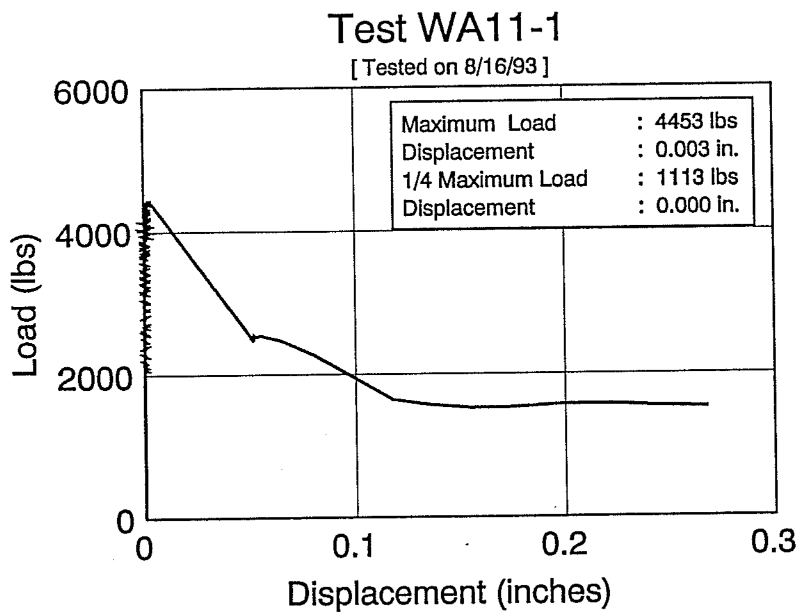
Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	Req. torque	Act. torque	Time	Fail	Misc
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WA21-1	OBLIQUE	6	91	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	15.0	4:30	pull out/cone	4
WA21-2	OBLIQUE	6	91	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	20.0	3:20	cone	4
WA21-3	OBLIQUE	6	91	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	23.0	2:50	side blowout	4
WA21-4	OBLIQUE	6	H25	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	42.0	2:50	side blowout/cone	4
WA21-5	OBLIQUE	6	H25	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	50.0	2:45	cone edge	4
WA21-6	OBLIQUE	6	H25	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	50.0	2:50	side blowout	3 3/4
WA21-7	OBLIQUE	6	H25	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	95	95.0	3:00	side blowout/cone	3 3/4
WA21-8	OBLIQUE	6	H25	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	95	84.0	3:15	cone	4
WA21-9	OBLIQUE	6	H25	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	95	95.0	3:40	side blowout	4
WA21-10	OBLIQUE	6	H25	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	190	128.0	3:40	side blowout	4
WA21-11	OBLIQUE	6	H25	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	190	90.0	2:25	side blowout	4
WA21-12	OBLIQUE	6	H25	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	190	186.0	2:20	side blowout/cone	4

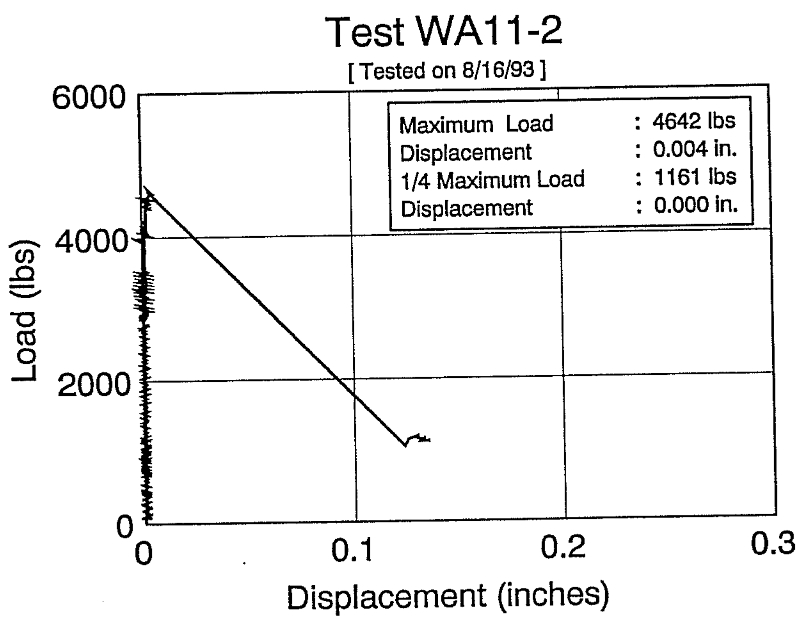
Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	Req. torque	Act. torque	Time	Fail	Misc
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WA20-1	OBLIQUE	2	82	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	16.0	2:25	cone/edge	4
WA20-2	OBLIQUE	2	82	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	11.0	2:10	cone/edge	4
WA20-3	OBLIQUE	2	82	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	16.0	2:50	cone/edge	4
WA20-4	OBLIQUE	2	85	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	28.0	4:30	cone/edge	4
WA20-5	OBLIQUE	2	85	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	46.0	2:50	cone/edge	4
WA20-6	OBLIQUE	2	85	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	43.0	2:50	cone/edge	4
WA20-7	OBLIQUE	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	95	29.0	3:45	cone/edge	4
WA20-8	OBLIQUE	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	95	29.0	4:05	cone/edge	4
WA20-9	OBLIQUE	2	85	0.625	MEDIUM	0.650 - 0.654	SHALLOW	2.000	3.500	95	33.0	3:45	cone/edge	4
WA20-10	OBLIQUE	2	82	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	190	155.0	2:00	cone/edge	4
WA20-11	OBLIQUE	2	82	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	190	90.0	2:30	cone/edge	4
WA20-12	OBLIQUE	2	82	0.750	MEDIUM	0.775 - 0.779	SHALLOW	2.625	4.594	190	60.0	2:30	cone/edge	4

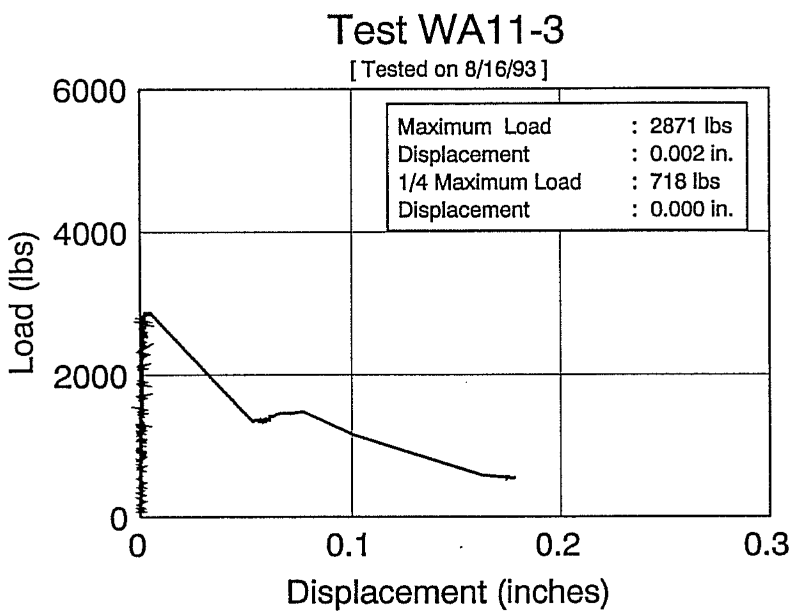
Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	Torque	Time	Fail
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	(ft. lbs.)	(min:sec)	
21 - 01	OBLIQUE	6	49	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	8	3:30	side blowout/anchor frac.
21 - 02	OBLIQUE	6	49	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	8	3:10	anchor fracture
21 - 03	OBLIQUE	6	49	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	8	2:55	anchor fracture
21 - 04	OBLIQUE	6	49	0.375	MEDIUM	0.390 - 0.393	DEEP	4.000	3.000	25	2:35	anchor fracture
21 - 05	OBLIQUE	6	49	0.375	MEDIUM	0.390 - 0.393	DEEP	4.000	3.000	25	2:40	anchor fracture
21 - 06	OBLIQUE	6	49	0.375	MEDIUM	0.390 - 0.393	DEEP	4.000	3.000	25	2:35	anchor fracture
21 - 07	OBLIQUE	6	49	0.500	MEDIUM	0.520 - 0.524	DEEP	6.000	4.500	55	4:00	anchor fracture
21 - 08	OBLIQUE	6	49	0.500	MEDIUM	0.520 - 0.524	DEEP	6.000	4.500	55	3:15	anchor fracture
21 - 09	OBLIQUE	6	49	0.500	MEDIUM	0.520 - 0.524	DEEP	6.000	4.500	55	3:00	anchor fracture
21 - 10	OBLIQUE	6	49	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	90	2:20	anchor fracture
21 - 11	OBLIQUE	6	49	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	90	2:18	anchor fracture
21 - 12	OBLIQUE	6	49	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	90	2:25	anchor fracture
21 - 13	OBLIQUE	6	49	0.750	MEDIUM	0.775 - 0.779	DEEP	10.000	7.500	175	3:53	anchor fracture
21 - 14	OBLIQUE	6	49	0.750	MEDIUM	0.775 - 0.779	DEEP	10.000	7.500	175	3:16	anchor fracture
21 - 15	OBLIQUE	6	49	0.750	MEDIUM	0.775 - 0.779	DEEP	10.000	7.500	175	2:56	anchor fracture
21 - 16	OBLIQUE	6	49	0.875	MEDIUM	0.905 - 0.909	DEEP	8.000	6.000	250	4:05	side blowout
21 - 17	OBLIQUE	6	49	0.875	MEDIUM	0.905 - 0.909	DEEP	8.000	6.000	250	3:04	side blowout/anchor frac.
21 - 18	OBLIQUE	6	49	0.875	MEDIUM	0.905 - 0.909	DEEP	8.000	6.000	250	2:26	side blowout
21 - 19	OBLIQUE	6	49	1.000	MEDIUM	1.030 - 1.034	DEEP	10.250	7.688	300	2:52	side blowout
21 - 20	OBLIQUE	6	49	1.000	MEDIUM	1.030 - 1.034	DEEP	10.250	7.688	300	2:40	side blowout
21 -21	OBLIQUE	6	49	1.000	MEDIUM	1.030 - 1.034	DEEP	10.250	7.688	300	3:40	anchor frac.
21 - 22	OBLIQUE	6	49	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	500	3:15	side blowout
21 - 23	OBLIQUE	6	H25	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	500	3:29	side blowout
21 - 24	OBLIQUE	6	49	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	500	3:03	side blowout

Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	Req. torque	Act. torque	Time	Fail	Misc
Series-Test #		ksi		(in.)		(in.)		(in.)	(in)	(ft. lbs.)	(ft. lbs.)	(min:sec)		(turns)
WB20-1	OBLIQUE	2	88	0.250	MEDIUM	0.260 - 0.263	SHALLOW	1.125	1.969	-	2.5	2:45	cone	4
WB20-2	OBLIQUE	2	88	0.250	MEDIUM	0.260 - 0.263	SHALLOW	1.125	1.969	-	3.3	3:15	cone	4
WB20-3	OBLIQUE	2	88	0.250	MEDIUM	0.260 - 0.263	SHALLOW	1.125	1.969	-	3.0	3:10	side blowout	4
WB20-4	OBLIQUE	2	88	0.313	MEDIUM	0.328 - 0.331	SHALLOW	1.875	3.281	-	3.3	4:25	side blowout	4
WB20-5	OBLIQUE	2	88	0.313	MEDIUM	0.328 - 0.331	SHALLOW	1.875	3.281	-	4.2	4:00	pull out	4
WB20-6	OBLIQUE	2	88	0.313	MEDIUM	0.328 - 0.331	SHALLOW	1.875	3.281	-	5.3	3:40	pull out	4
WB20-7	OBLIQUE	2	85	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	4.7	2:20	cone/edge	4
WB20-8	OBLIQUE	2	85	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	6.8	2:57	cone/edge	4
WB20-9	OBLIQUE	2	85	0.375	MEDIUM	0.390 - 0.393	SHALLOW	1.250	2.188	25	7.8	3:27	cone	4
WB20-10	OBLIQUE	2	85	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	15.0	4:20	cone/edge	4
WB20-11	OBLIQUE	2	85	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	12.5	2:38	cone	4
WB20-12	OBLIQUE	2	85	0.500	MEDIUM	0.520 - 0.524	SHALLOW	1.750	3.063	50	11.7	2:14	cone	4

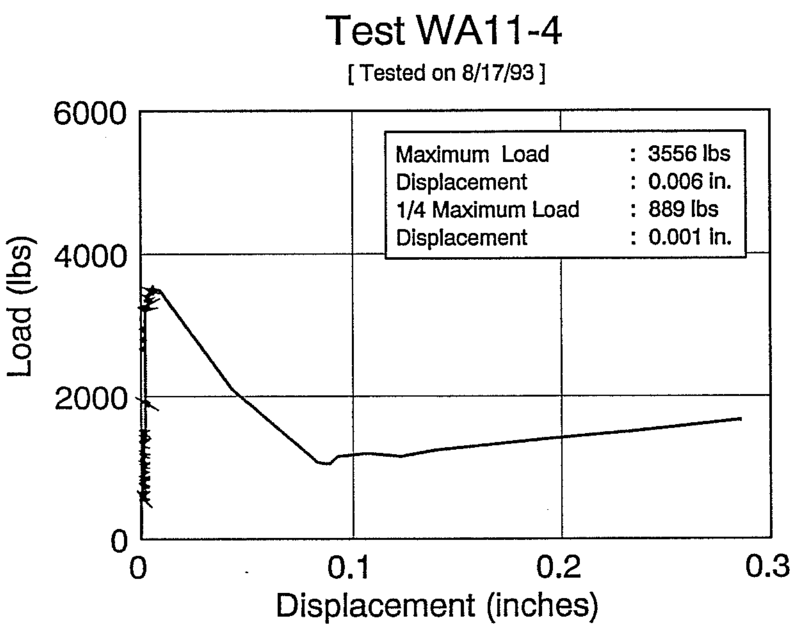
Test Number	Test Type	fc	Block	dia.	Bit Type	hole diameter	depth	depth	crit. edge	Torque	Time	Fail
Series-Test #		ksi		(in.)		(in.)		(in.)	(in.)	(ft. lbs.)	(min:sec)	
20 - 01	OBLIQUE	2	67	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	8	2:14	side blowout
20 - 02	OBLIQUE	2	67	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	8	2:40	side blowout
20 - 03	OBLIQUE	2	67	0.250	MEDIUM	0.260 - 0.263	DEEP	2.125	1.594	8	2:41	side blowout
20 - 04	OBLIQUE	2	67	0.375	MEDIUM	0.390 - 0.393	DEEP	4.000	3.000	25	4:31	anchor fracture
20 - 05	OBLIQUE	2	67	0.375	MEDIUM	0.390 - 0.393	DEEP	4.000	3.000	25	3:10	anchor fracture
20 - 06	OBLIQUE	2	67	0.375	MEDIUM	0.390 - 0.393	DEEP	4.000	3.000	25	4:10	anchor fracture
20 - 07	OBLIQUE	2	42	0.500	MEDIUM	0.520 - 0.524	DEEP	6.000	4.500	55	5:04	anchor fracture
20 - 08	OBLIQUE	2	42	0.500	MEDIUM	0.520 - 0.524	DEEP	6.000	4.500	55	2:54	anchor slip
20 - 09	OBLIQUE	2	67	0.500	MEDIUM	0.520 - 0.524	DEEP	6.000	4.500	55	5:15	anchor fracture
20 - 10	OBLIQUE	2	67	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	90	2:24	side blowout
20 - 11	OBLIQUE	2	67	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	90	2:32	side blowout
20 - 12	OBLIQUE	2	67	0.625	MEDIUM	0.650 - 0.654	DEEP	8.000	6.000	90	2:50	side blowout
20 - 13	OBLIQUE	2	67	0.750	MEDIUM	0.775 - 0.779	DEEP	10.000	7.500	175	3:19	anchor slip
20 - 14	OBLIQUE	2	67	0.750	MEDIUM	0.775 - 0.779	DEEP	10.000	7.500	175	3:20	anchor slip
20 - 15	OBLIQUE	2	67	0.750	MEDIUM	0.775 - 0.779	DEEP	10.000	7.500	175	4:45	anchor slip
20 - 16	OBLIQUE	2	82	0.875	MEDIUM	0.905 - 0.909	DEEP	8.000	6.000	200	2:35	side blowout
20 - 17	OBLIQUE	2	82	0.875	MEDIUM	0.905 - 0.909	DEEP	8.000	6.000	200	2:20	side blowout
20 - 18	OBLIQUE	2	82	0.875	MEDIUM	0.905 - 0.909	DEEP	8.000	6.000	200	3:05	anchor fracture
20 - 19	OBLIQUE	2	67	1.000	MEDIUM	1.030 - 1.034	DEEP	10.250	7.688	300	4:30	anchor fracture
20 - 20	OBLIQUE	2	67	1.000	MEDIUM	1.030 - 1.034	DEEP	10.250	7.688	300	3:28	side blowout
20 -21	OBLIQUE	2	67	1.000	MEDIUM	1.030 - 1.034	DEEP	10.250	7.688	300	3:03	side blowout
20 - 22	OBLIQUE	2	67	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	500	2:05	side blowout
20 - 23	OBLIQUE	2	67	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	500	2:35	side blowout
20 - 24	OBLIQUE	2	67	1.250	MEDIUM	1.285 - 1.289	DEEP	10.000	7.500	500	3:00	side blowout


Test WA11-1
[Tested on 8/16/93]
Maximum Load : 4453 lbs
Displacement : 0.003 in.
1/4 Maximum Load : 1113 lbs
Displacement : 0.000 in.
6000
4000
2000
0
Load (lbs)
0
0.1
0.2
0.3
Displacement (inches)

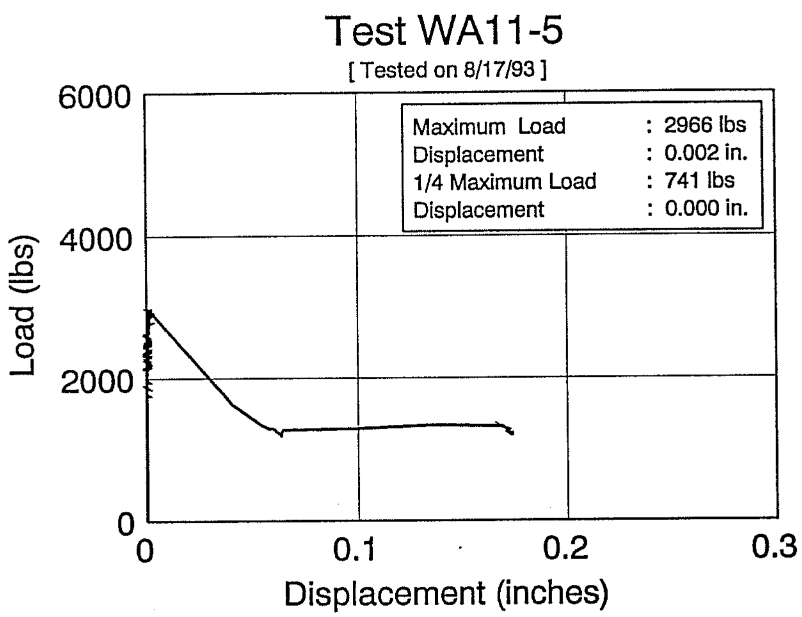

Test WA11-2
[Tested on 8/16/93]
Maximum Load : 4642 lbs
Displacement : 0.004 in.
1/4 Maximum Load : 1161 lbs
Displacement : 0.000 in.
6000
4000
2000
0
Load (lbs)
0
0.1
0.2
0.3
Displacement (inches)

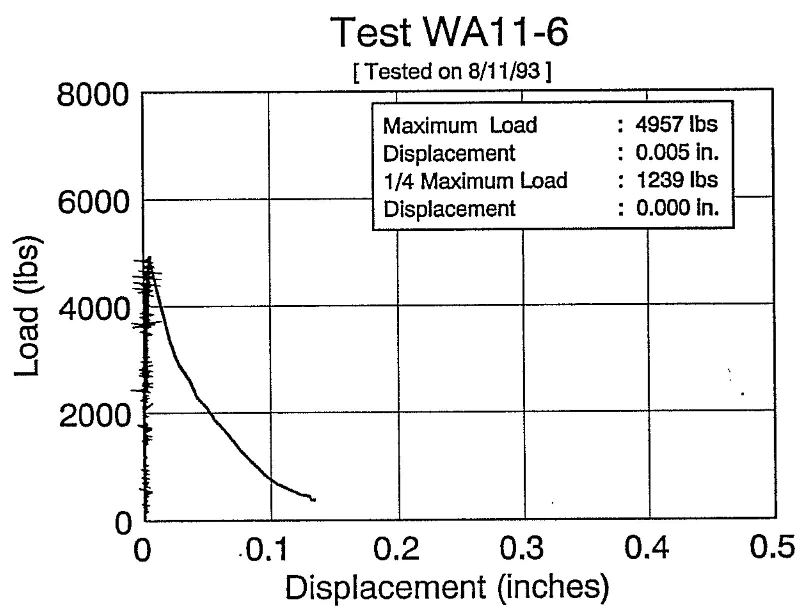


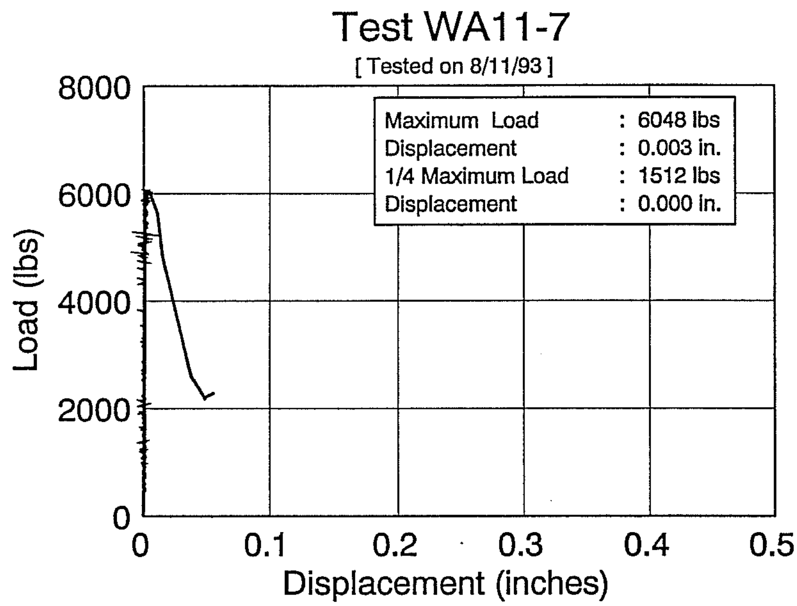
Test WA11-3
[Tested on 8/16/93]
Maximum Load : 2871 lbs
Displacement : 0.002 in.
1/4 Maximum Load : 718 lbs
Displacement : 0.000 in.
Load (lbs)
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

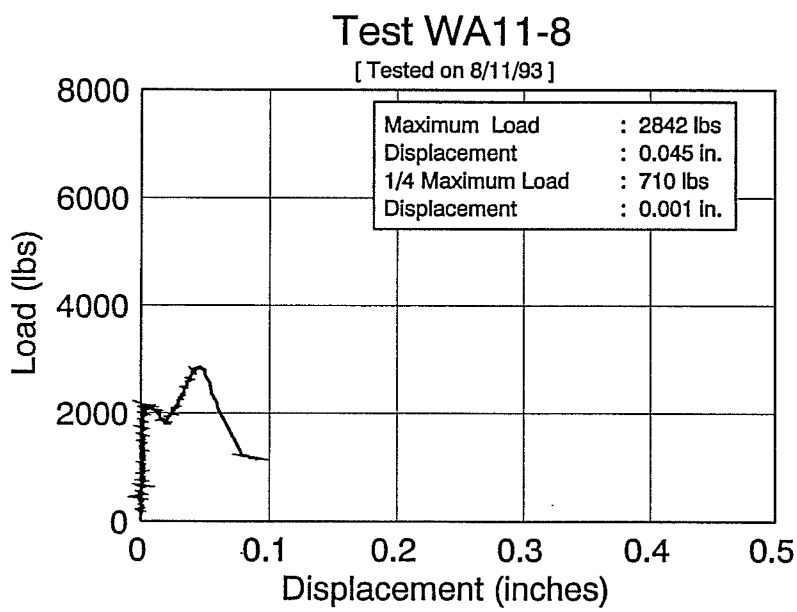


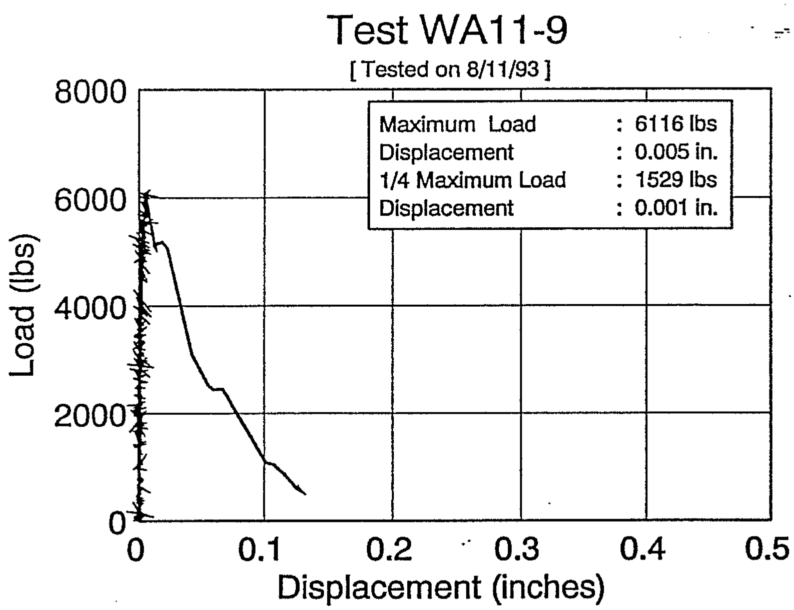
Test WA11-4
[Tested on 8/17/93]
Maximum Load : 3556 lbs
Displacement : 0.006 in.
1/4 Maximum Load : 889 lbs
Displacement : 0.001 in.
Load (lbs)
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

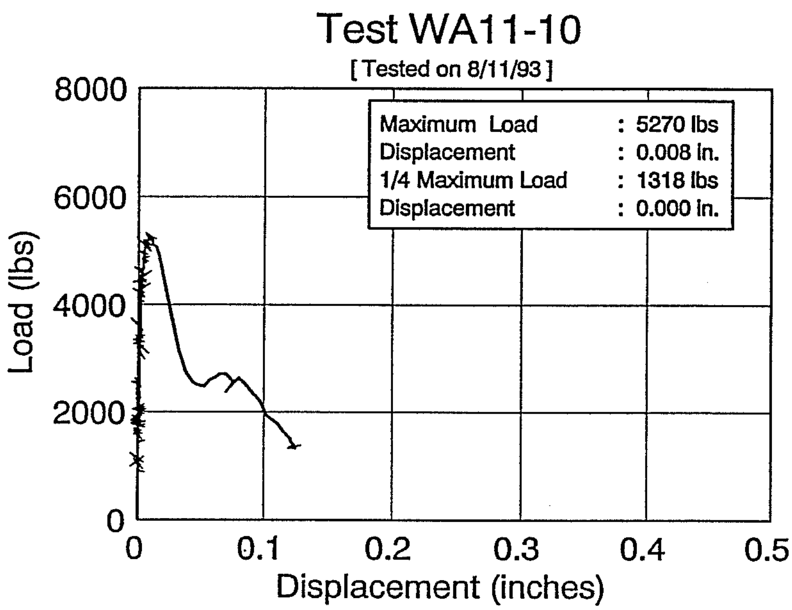

Test WA11-5
[Tested on 8/17/93]
Maximum Load : 2966 lbs
Displacement : 0.002 in.
1/4 Maximum Load : 741 lbs
Displacement : 0.000 in.
Load (lbs)
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

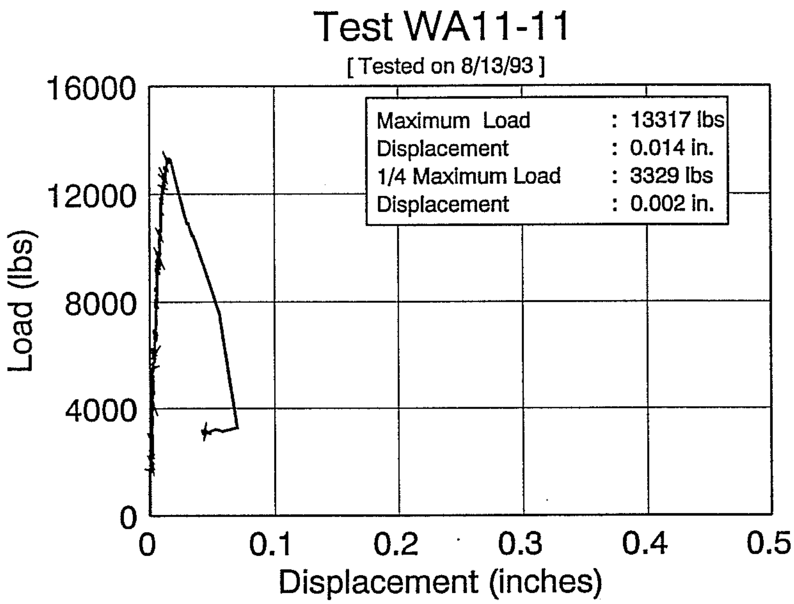

Test WA11-6
[Tested on 8/11/93]
Maximum Load : 4957 lbs
Displacement : 0.005 in.
1/4 Maximum Load : 1239 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

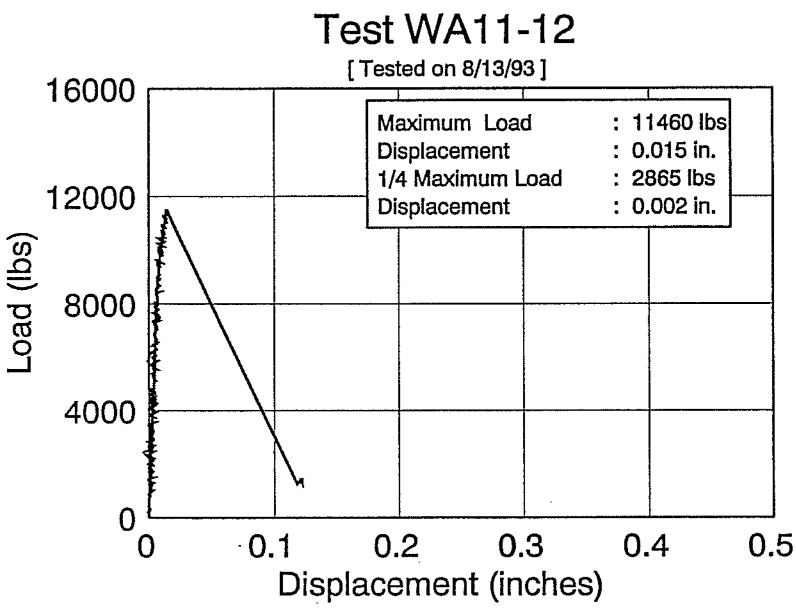

Test WA11-7
[Tested on 8/11/93]
Maximum Load : 6048 lbs
Displacement : 0.003 in.
1/4 Maximum Load : 1512 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

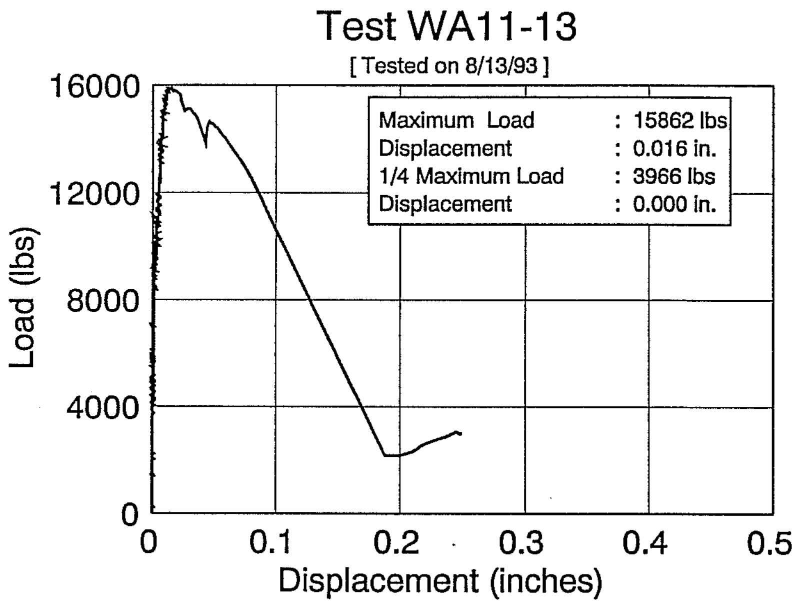

Test WA11-8
[Tested on 8/11/93]
Maximum Load : 2842 lbs
Displacement : 0.045 in.
1/4 Maximum Load : 710 lbs
Displacement : 0.001 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

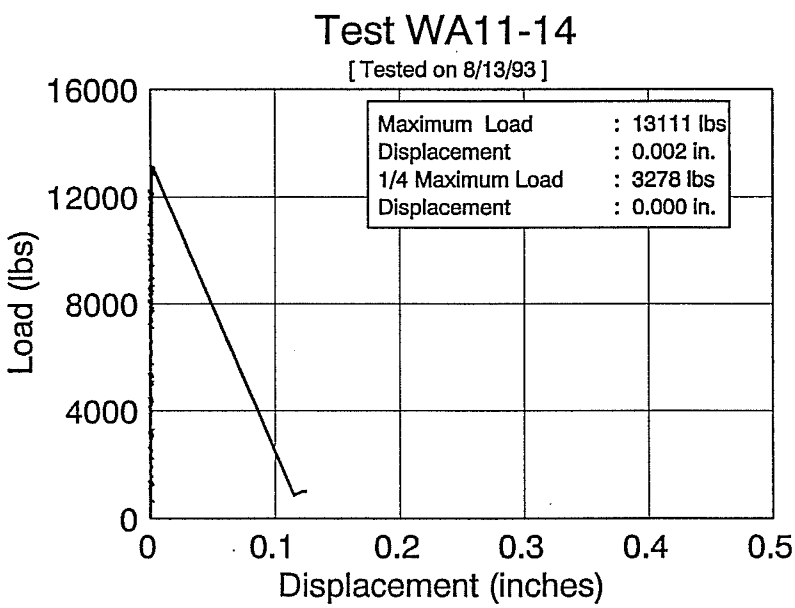

Test WA11-9
[Tested on 8/11/93]
Maximum Load : 6116 lbs
Displacement : 0.005 in.
1/4 Maximum Load : 1529 lbs
Displacement : 0.001 in.
Load (lbs)
0
2000
4000
6000
8000
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

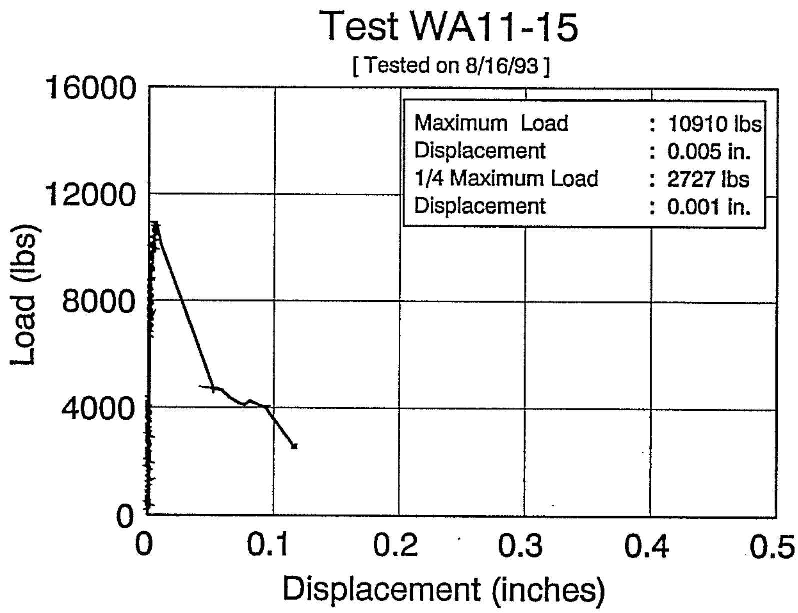

Test WA11-10
[Tested on 8/11/93]
Maximum Load : 5270 lbs
Displacement : 0.008 in.
1/4 Maximum Load : 1318 lbs
Displacement : 0.000 in.
Load (lbs)
0
2000
4000
6000
8000
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)


Test WA11-11
[Tested on 8/13/93]
Maximum Load : 13317 lbs
Displacement : 0.014 in.
1/4 Maximum Load : 3329 lbs
Displacement : 0.002 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

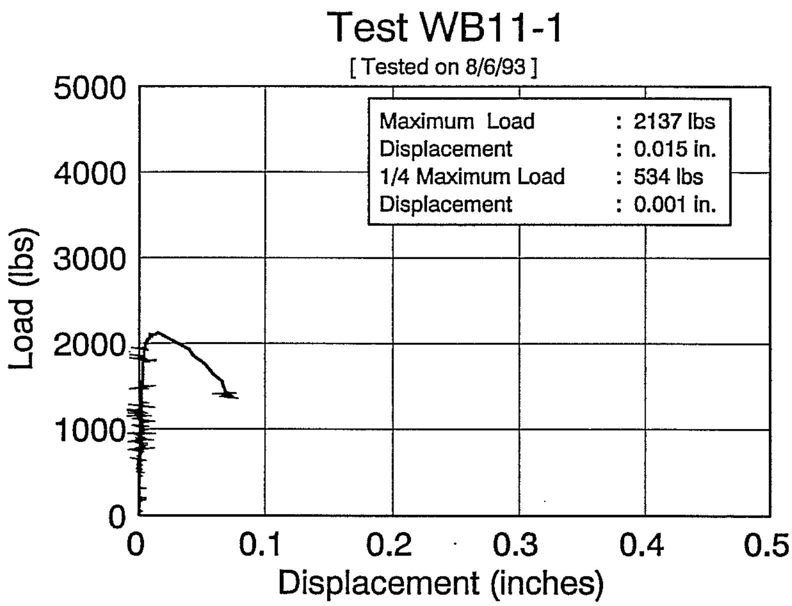

Test WA11-12
[Tested on 8/13/93]
Maximum Load : 11460 lbs
Displacement : 0.015 in.
1/4 Maximum Load : 2865 lbs
Displacement : 0.002 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

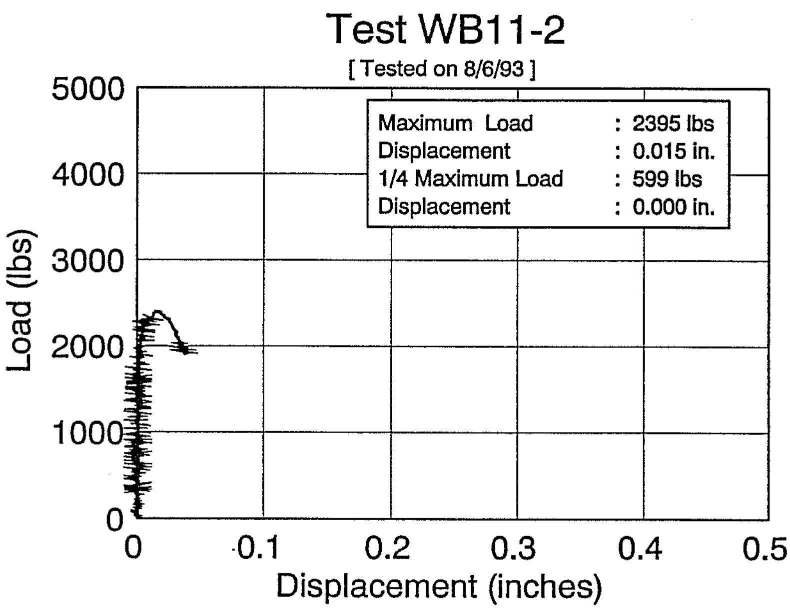

Test WA11-13
[Tested on 8/13/93]
Maximum Load : 15862 lbs
Displacement : 0.016 in.
1/4 Maximum Load : 3966 lbs
Displacement : 0.000 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

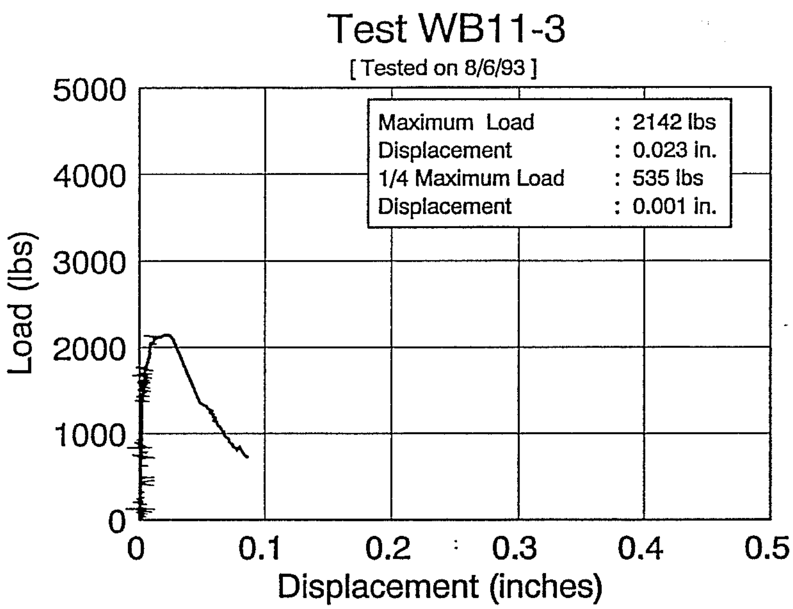

Test WA11-14
[Tested on 8/13/93]
Maximum Load : 13111 lbs
Displacement : 0.002 in.
1/4 Maximum Load : 3278 lbs
Displacement : 0.000 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

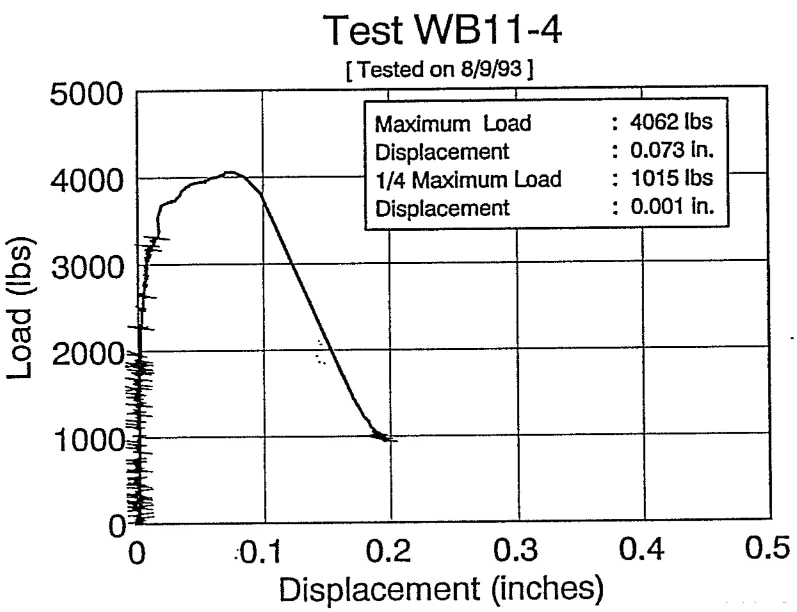


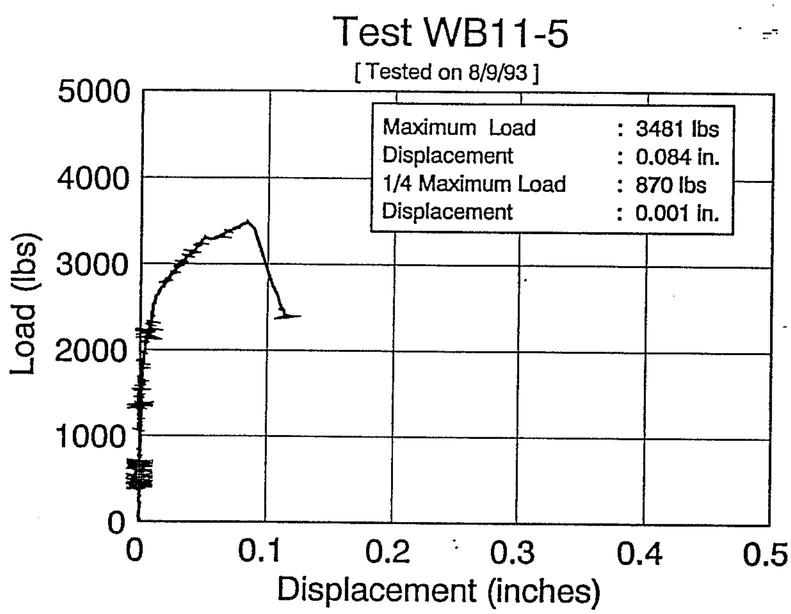
Test WA11-15
[Tested on 8/16/93]
Maximum Load : 10910 lbs
Displacement : 0.005 in.
1/4 Maximum Load : 2727 lbs
Displacement : 0.001 in.
16000
12000
8000
4000
0
Load (lbs)
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

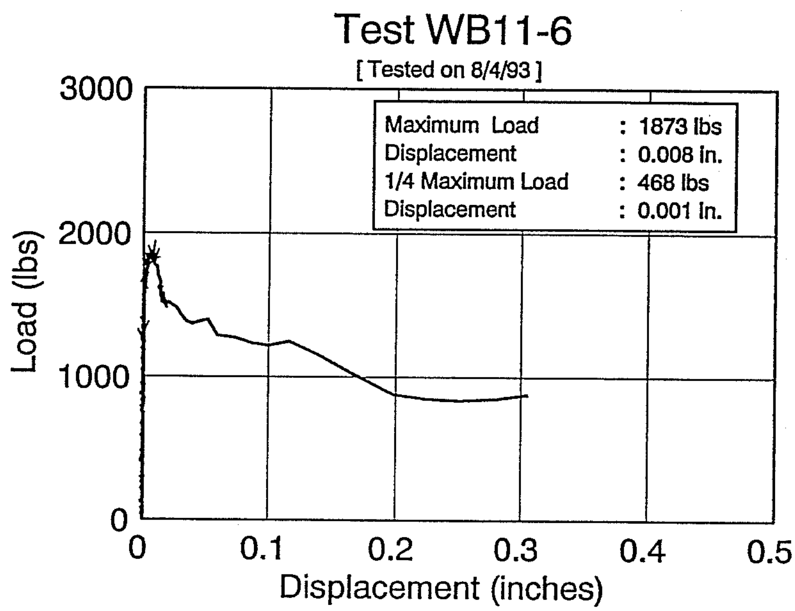

Test WB11-1
[Tested on 8/6/93]
Maximum Load : 2137 lbs
Displacement : 0.015 in.
1/4 Maximum Load : 534 lbs
Displacement : 0.001 in.
Load (lbs)
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

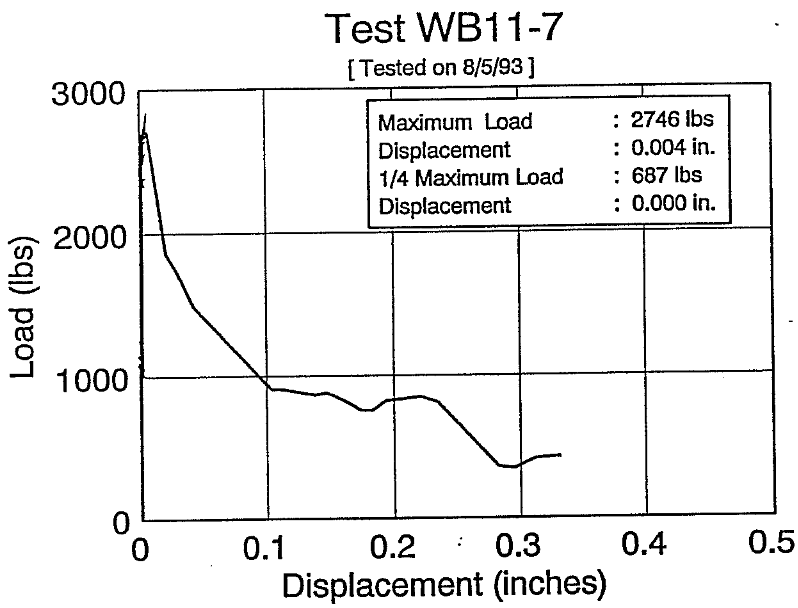

Test WB11-2
[Tested on 8/6/93]
Maximum Load : 2395 lbs
Displacement : 0.015 in.
1/4 Maximum Load : 599 lbs
Displacement : 0.000 in.
Load (lbs)
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

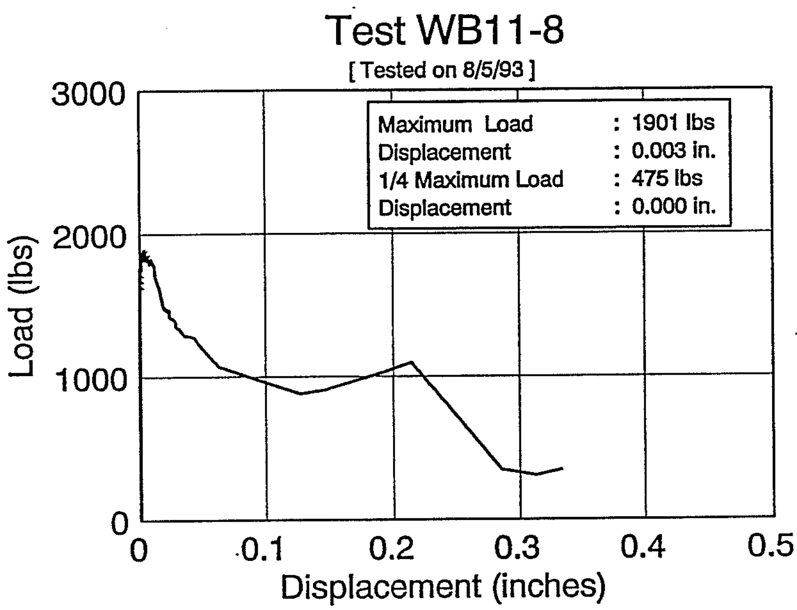

Test WB11-3
[Tested on 8/6/93]
Maximum Load : 2142 lbs
Displacement : 0.023 in.
1/4 Maximum Load : 535 lbs
Displacement : 0.001 in.
Load (lbs)
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

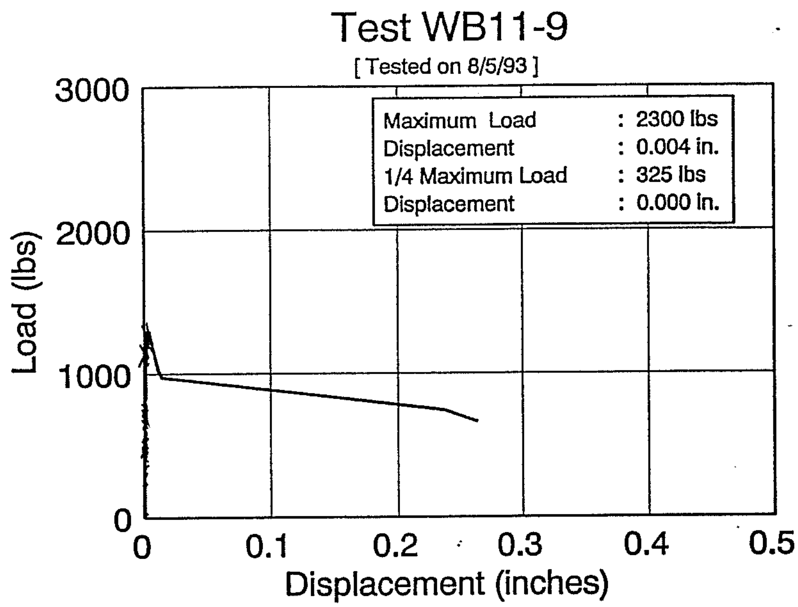

Test WB11-4
[Tested on 8/9/93]
Maximum Load : 4062 lbs
Displacement : 0.073 in.
1/4 Maximum Load : 1015 lbs
Displacement : 0.001 in.
Load (lbs)
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)


Test WB11-5
[Tested on 8/9/93]
Maximum Load : 3481 lbs
Displacement : 0.084 in.
1/4 Maximum Load : 870 lbs
Displacement : 0.001 in.
Load (lbs)
0
1000
2000
3000
4000
5000
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

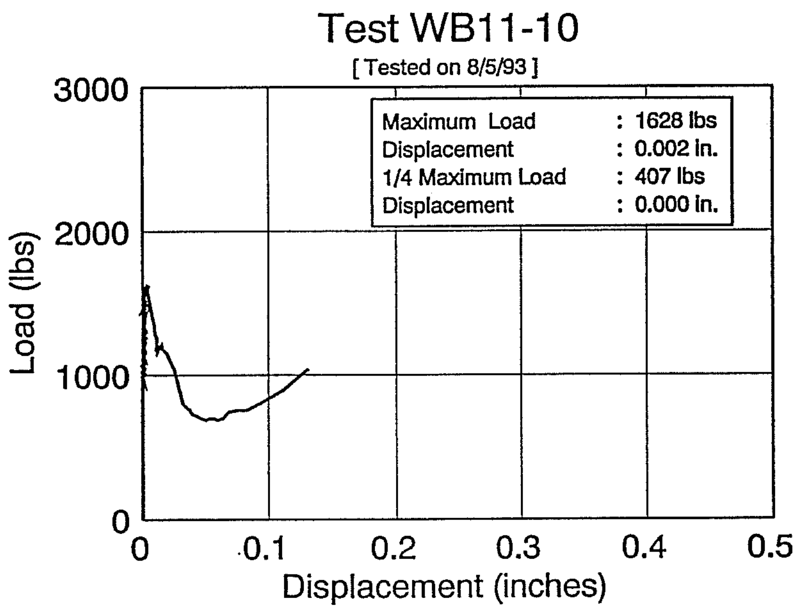

Test WB11-6
[Tested on 8/4/93]
Maximum Load : 1873 lbs
Displacement : 0.008 in.
1/4 Maximum Load : 468 lbs
Displacement : 0.001 in.
Load (lbs)
0
1000
2000
3000
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)


Test WB11-7
[Tested on 8/5/93]
Maximum Load : 2746 lbs
Displacement : 0.004 in.
1/4 Maximum Load : 687 lbs
Displacement : 0.000 in.
Load (lbs)
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

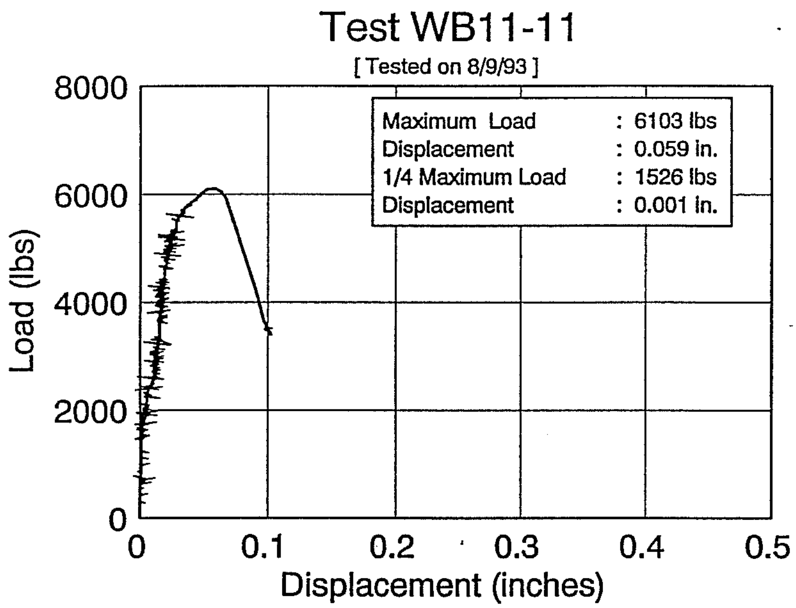

Test WB11-8
[Tested on 8/5/93]
Maximum Load : 1901 lbs
Displacement : 0.003 in.
1/4 Maximum Load : 475 lbs
Displacement : 0.000 in.
Load (lbs)
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



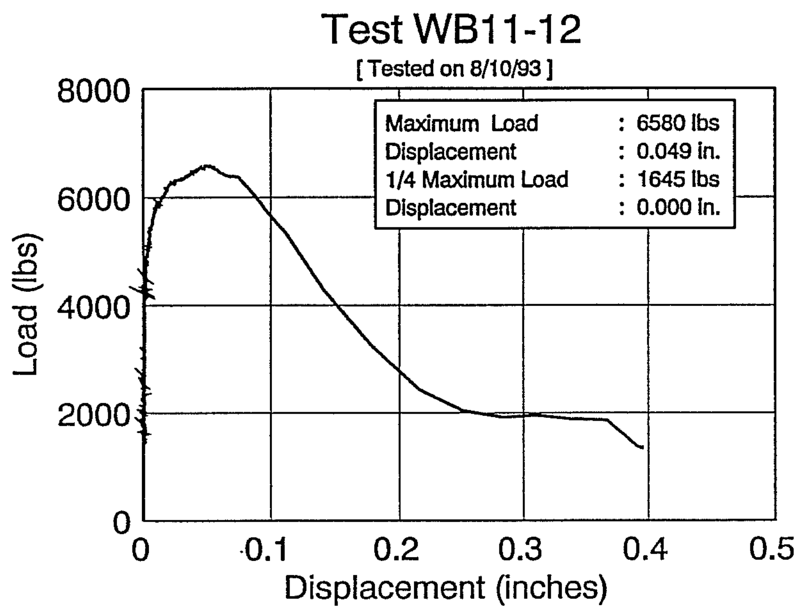
Test WB11-9
[Tested on 8/5/93]
Maximum Load : 2300 lbs
Displacement : 0.004 in.
1/4 Maximum Load : 325 lbs
Displacement : 0.000 in.
Load (lbs)
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



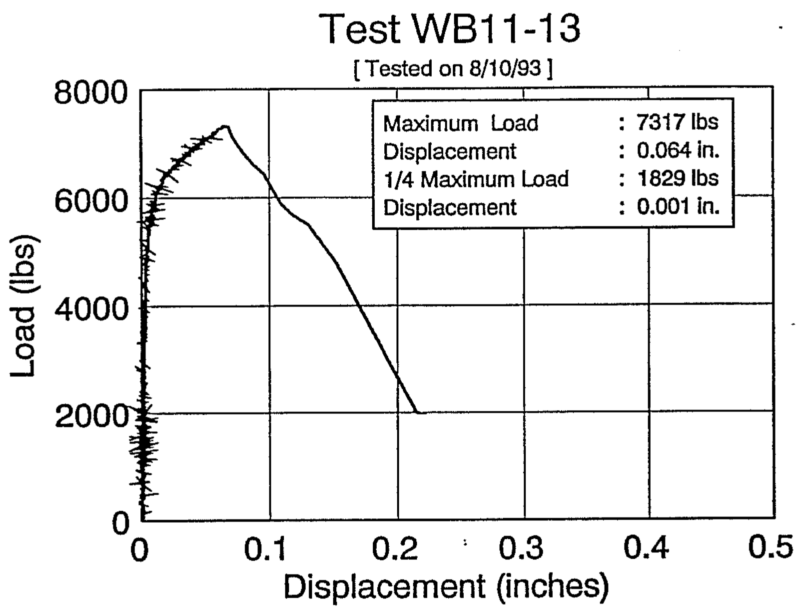
Test WB11-10
[Tested on 8/5/93]
Maximum Load : 1628 lbs
Displacement : 0.002 in.
1/4 Maximum Load : 407 lbs
Displacement : 0.000 in.
Load (lbs)
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



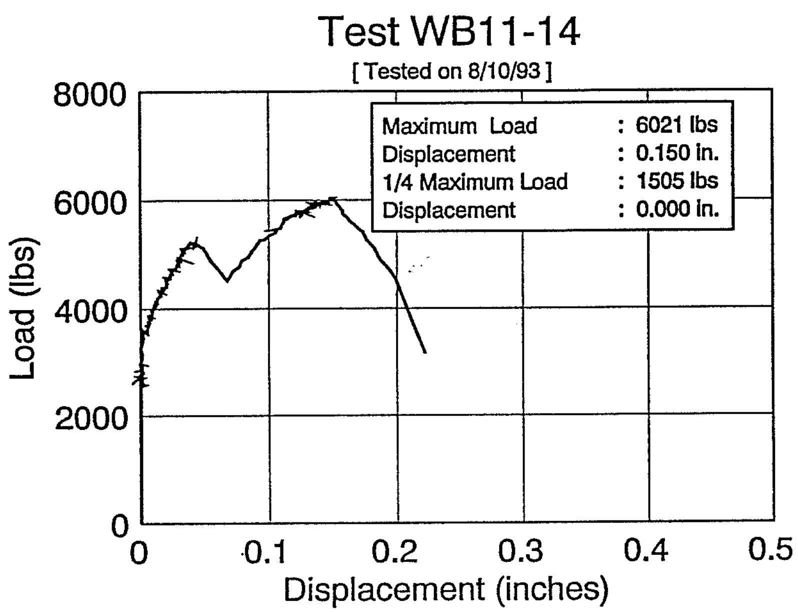
Test WB11-11
[Tested on 8/9/93]
Maximum Load : 6103 lbs
Displacement : 0.059 in.
1/4 Maximum Load : 1526 lbs
Displacement : 0.001 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



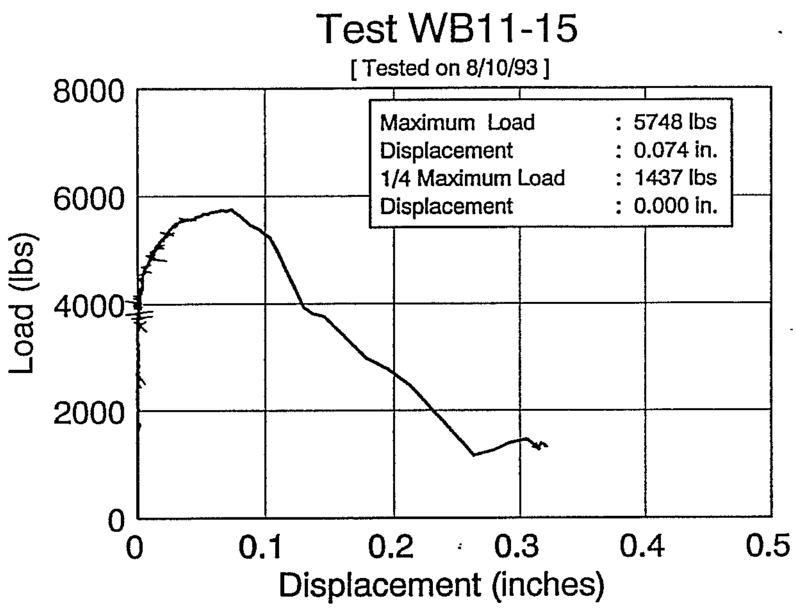
Test WB11-12
[Tested on 8/10/93]
Maximum Load : 6580 lbs
Displacement : 0.049 in.
1/4 Maximum Load : 1645 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



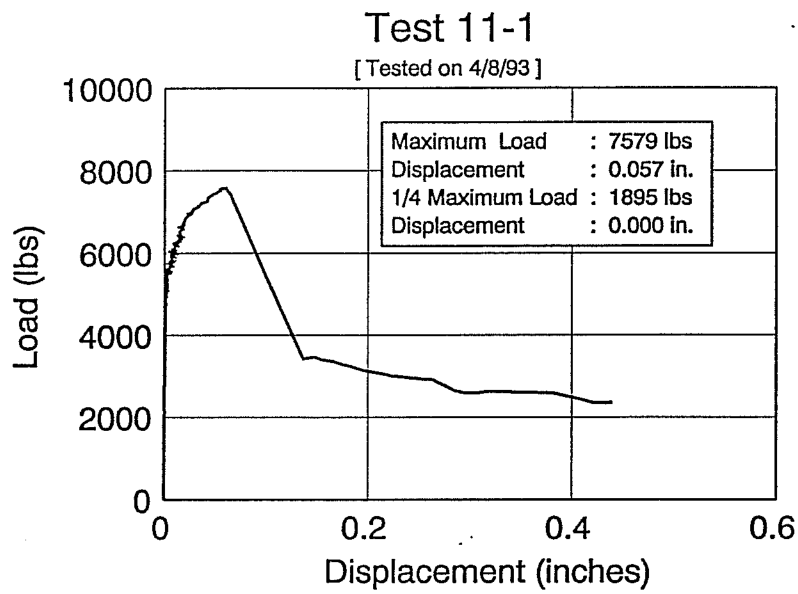
Test WB11-13
[Tested on 8/10/93]
Maximum Load : 7317 lbs
Displacement : 0.064 in.
1/4 Maximum Load : 1829 lbs
Displacement : 0.001 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



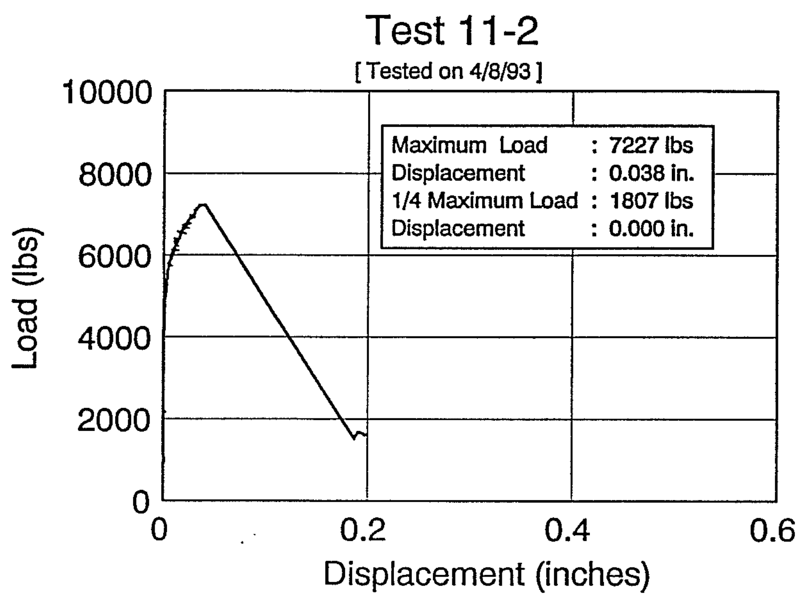
Test WB11-14
[Tested on 8/10/93]
Maximum Load : 6021 lbs
Displacement : 0.150 in.
1/4 Maximum Load : 1505 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



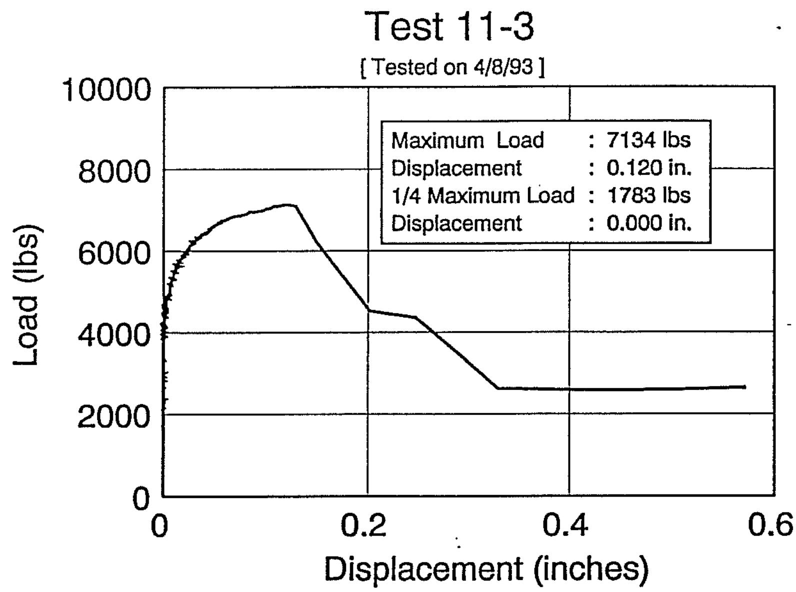
Test WB11-15
[Tested on 8/10/93]
Maximum Load : 5748 lbs
Displacement : 0.074 in.
1/4 Maximum Load : 1437 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)



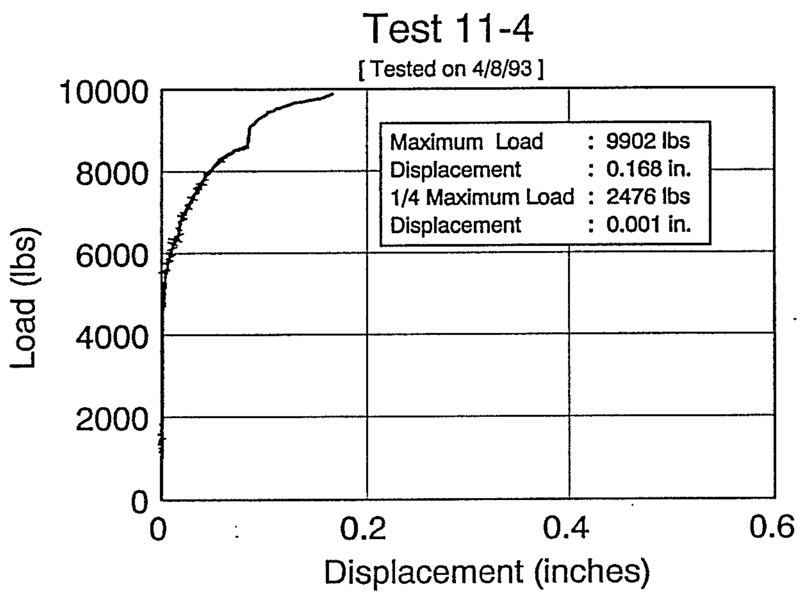
Test 11-1
[Tested on 4/8/93]
Maximum Load : 7579 lbs
Displacement : 0.057 in.
1/4 Maximum Load : 1895 lbs
Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)



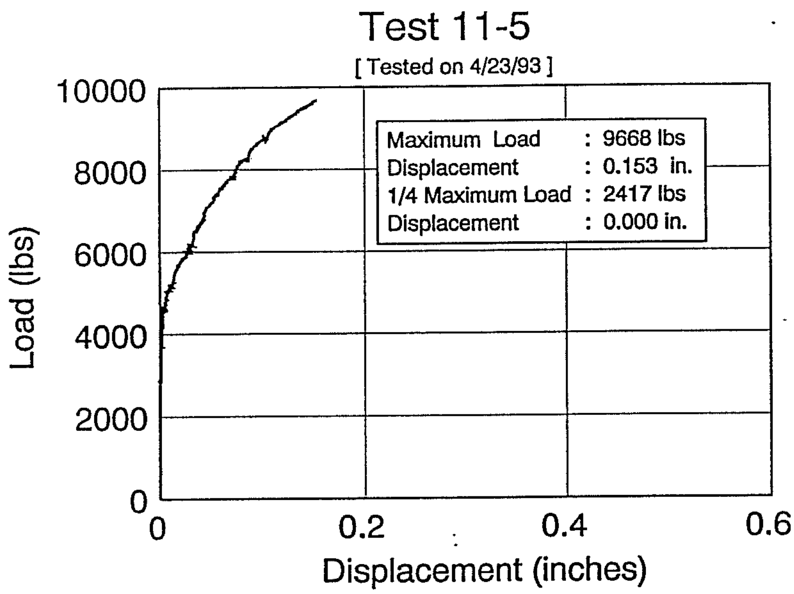
Test 11-2
[Tested on 4/8/93]
Maximum Load : 7227 lbs
Displacement : 0.038 in.
1/4 Maximum Load : 1807 lbs
Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)

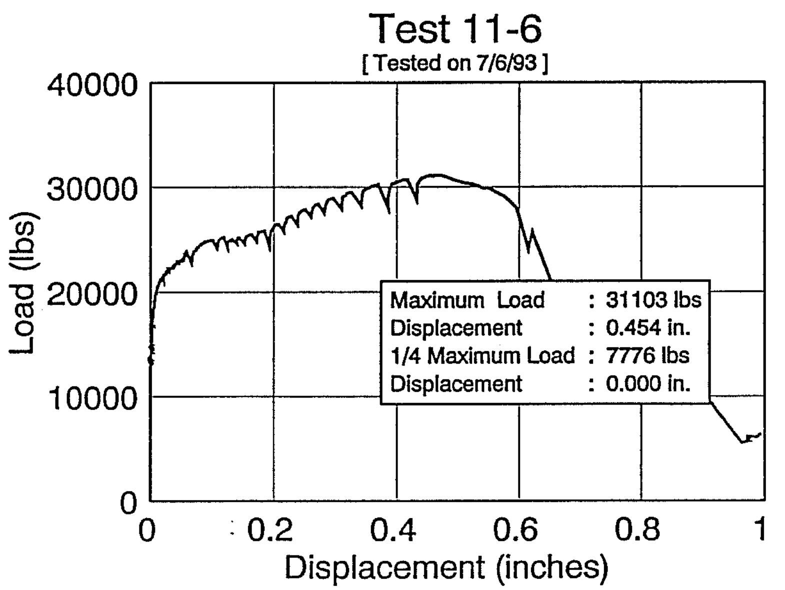


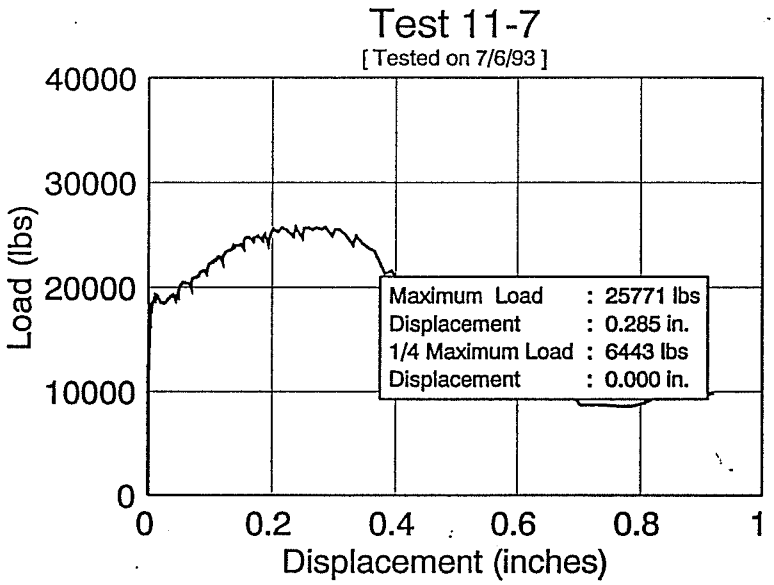
Test 11-3
[Tested on 4/8/93]
Maximum Load : 7134 lbs
Displacement : 0.120 in.
1/4 Maximum Load : 1783 lbs
Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)

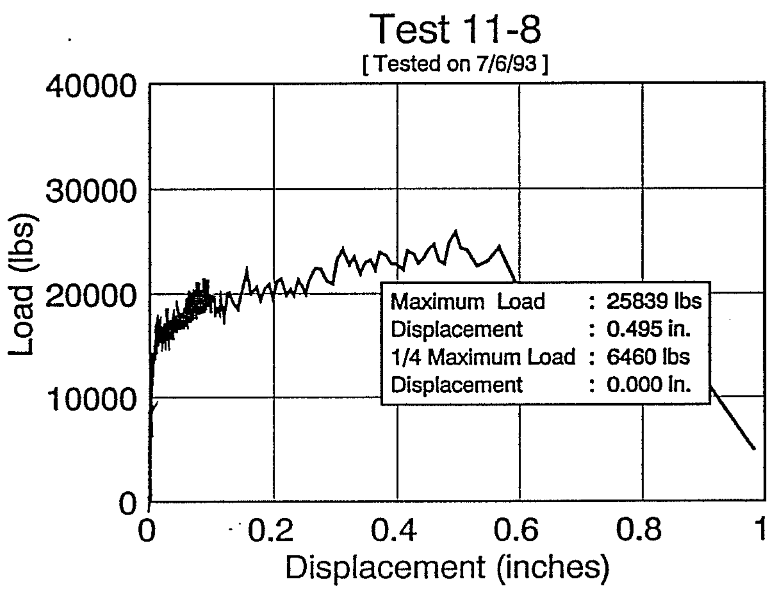


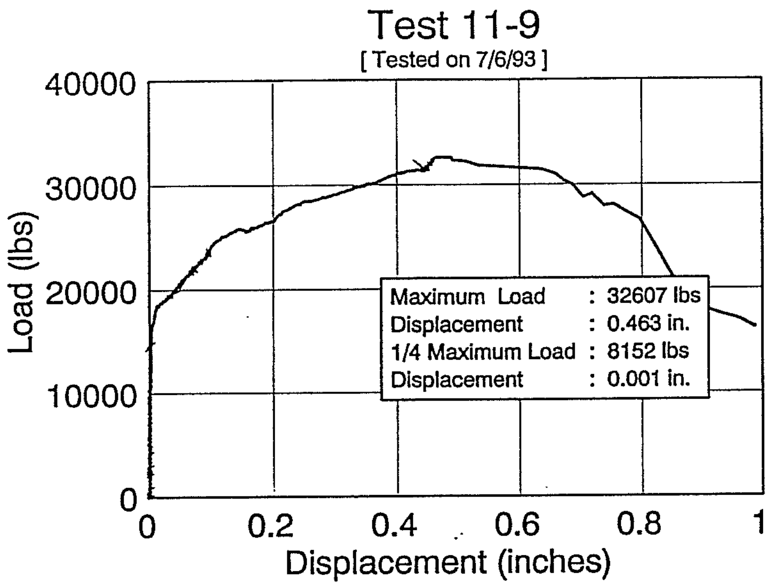
Test 11-4
[Tested on 4/8/93]
Maximum Load : 9902 lbs
Displacement : 0.168 in.
1/4 Maximum Load : 2476 lbs
Displacement : 0.001 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)

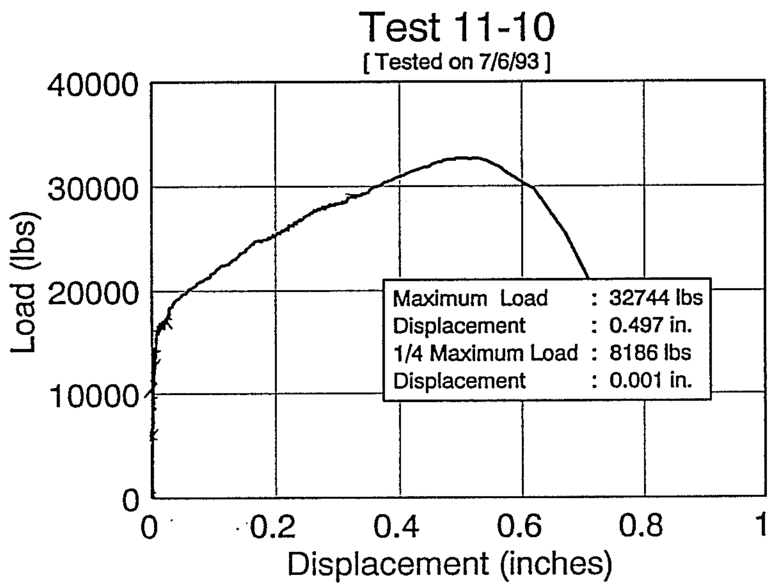

Test 11-5
[Tested on 4/23/93]
Maximum Load : 9668 lbs
Displacement : 0.153 in.
1/4 Maximum Load : 2417 lbs
Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)

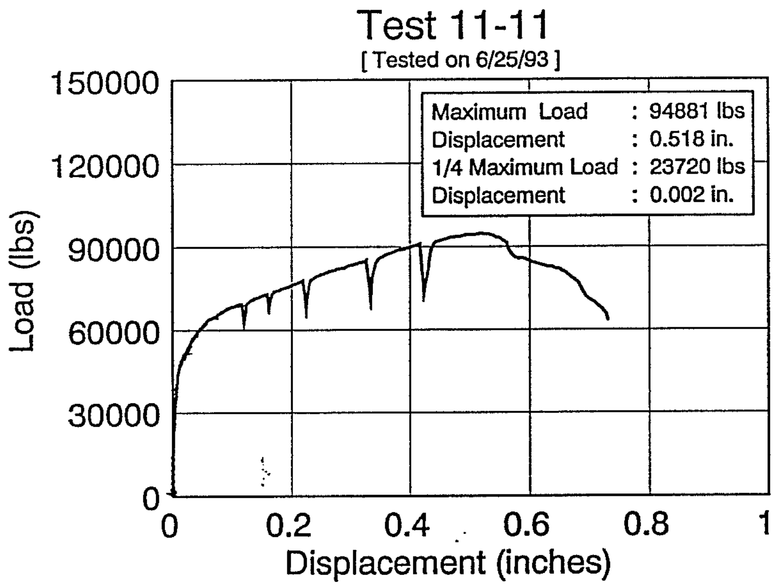

Test 11-6
[Tested on 7/6/93]
Maximum Load : 31103 lbs
Displacement : 0.454 in.
1/4 Maximum Load : 7776 lbs
Displacement : 0.000 in.
Load (lbs)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

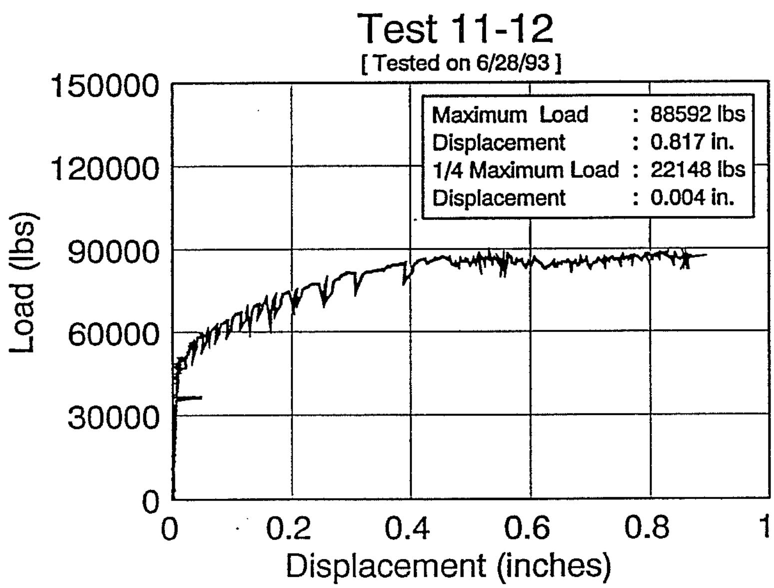

Test 11-7
[Tested on 7/6/93]
Load (lbs)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 25771 lbs
Displacement : 0.285 in.
1/4 Maximum Load : 6443 lbs
Displacement : 0.000 in.

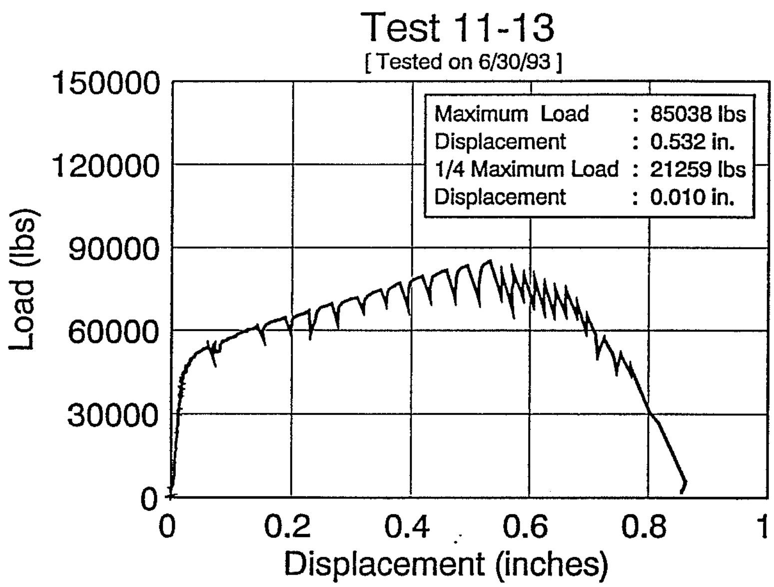

Test 11-8
[Tested on 7/6/93]
Load (lbs)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 25839 lbs
Displacement : 0.495 in.
1/4 Maximum Load : 6460 lbs
Displacement : 0.000 in.

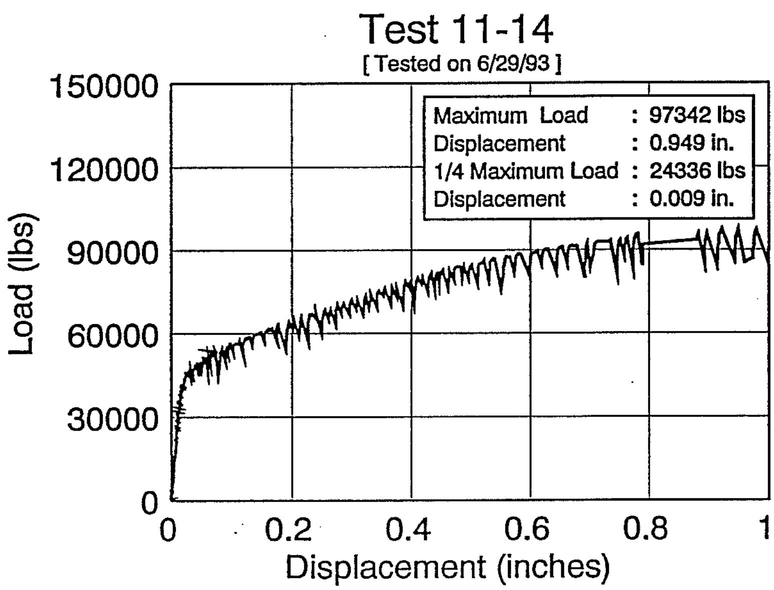

Test 11-9
[Tested on 7/6/93]
40000
30000
20000
10000
0
Load (lbs)
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 32607 lbs
Displacement : 0.463 in.
1/4 Maximum Load : 8152 lbs
Displacement : 0.001 in.

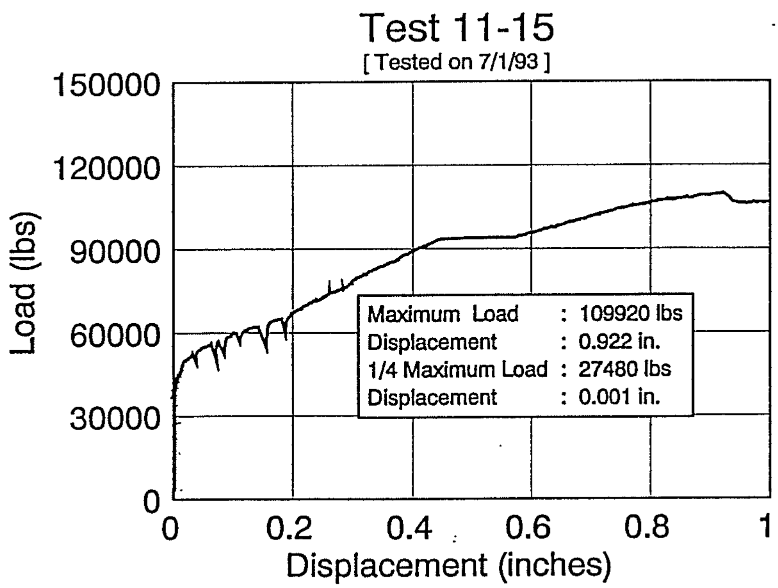

Test 11-10
[Tested on 7/6/93]
40000
30000
20000
10000
0
Load (lbs)
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 32744 lbs
Displacement : 0.497 in.
1/4 Maximum Load : 8186 lbs
Displacement : 0.001 in.


Test 11-11
[Tested on 6/25/93]
Maximum Load : 94881 lbs
Displacement : 0.518 in.
1/4 Maximum Load : 23720 lbs
Displacement : 0.002 in.
Load (lbs)
150000
120000
90000
60000
30000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

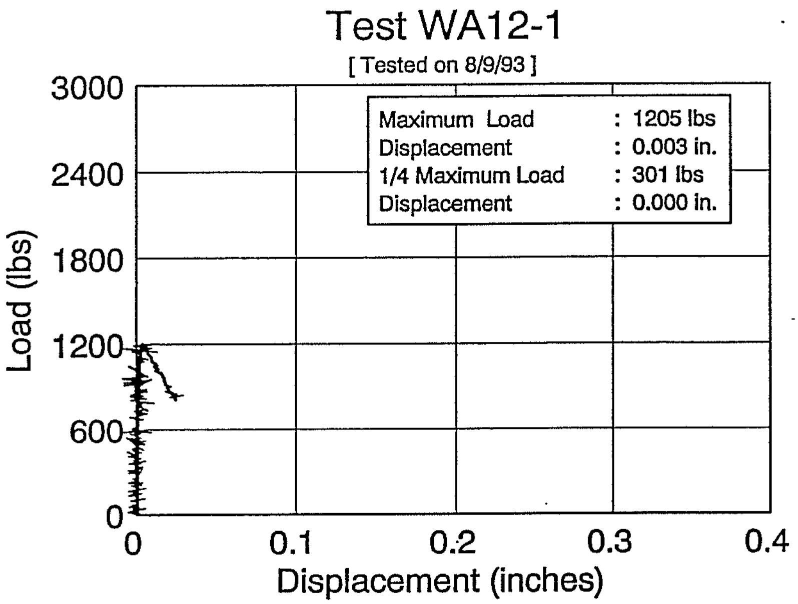

Test 11-12
[Tested on 6/28/93]
Maximum Load : 88592 lbs
Displacement : 0.817 in.
1/4 Maximum Load : 22148 lbs
Displacement : 0.004 in.
Load (lbs)
150000
120000
90000
60000
30000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)


Test 11-13
[Tested on 6/30/93]
Maximum Load : 85038 lbs
Displacement : 0.532 in.
1/4 Maximum Load : 21259 lbs
Displacement : 0.010 in.
Load (lbs)
150000
120000
90000
60000
30000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

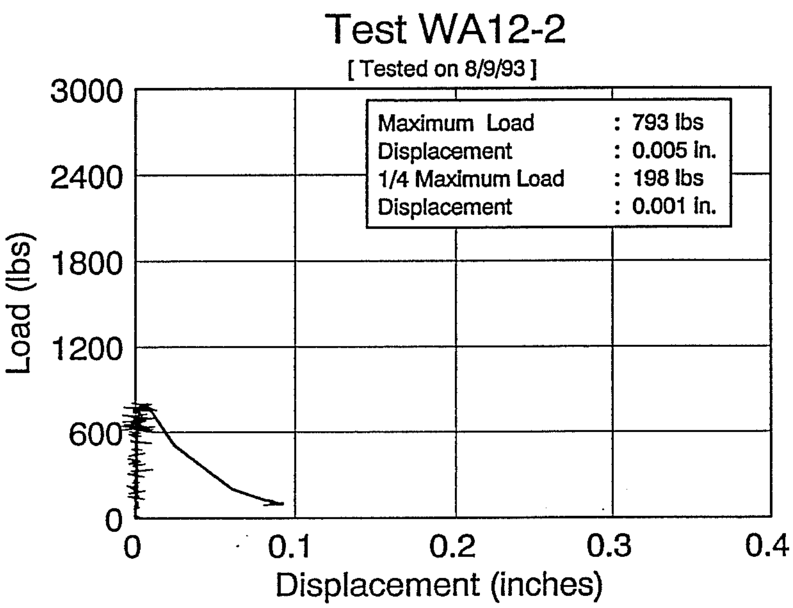

Test 11-14
[Tested on 6/29/93]
Maximum Load : 97342 lbs
Displacement : 0.949 in.
1/4 Maximum Load : 24336 lbs
Displacement : 0.009 in.
Load (lbs)
150000
120000
90000
60000
30000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)



Test 11-15
[Tested on 7/1/93]
150000
120000
90000
60000
30000
0
Load (lbs)
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 109920 lbs
Displacement : 0.922 in.
1/4 Maximum Load : 27480 lbs
Displacement : 0.001 in.

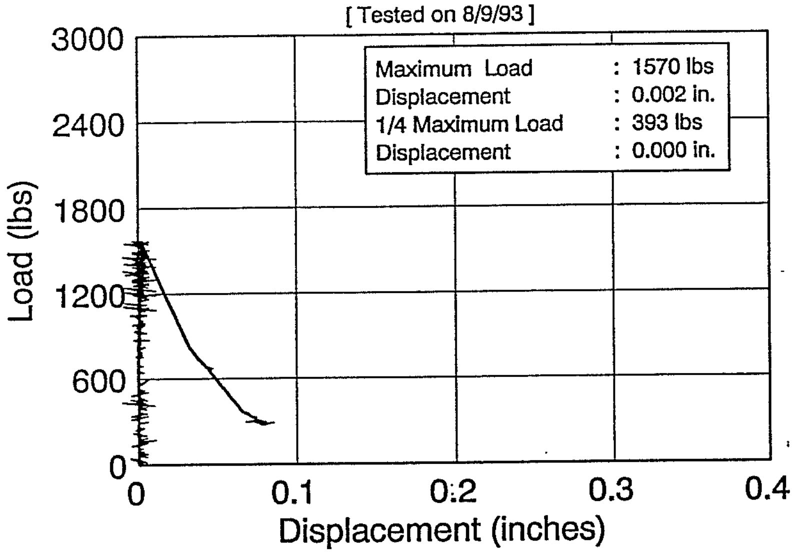


Test WA12-1
[Tested on 8/9/93]
Maximum Load : 1205 lbs
Displacement : 0.003 in.
1/4 Maximum Load : 301 lbs
Displacement : 0.000 in.
Load (lbs)
3000
2400
1800
1200
600
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

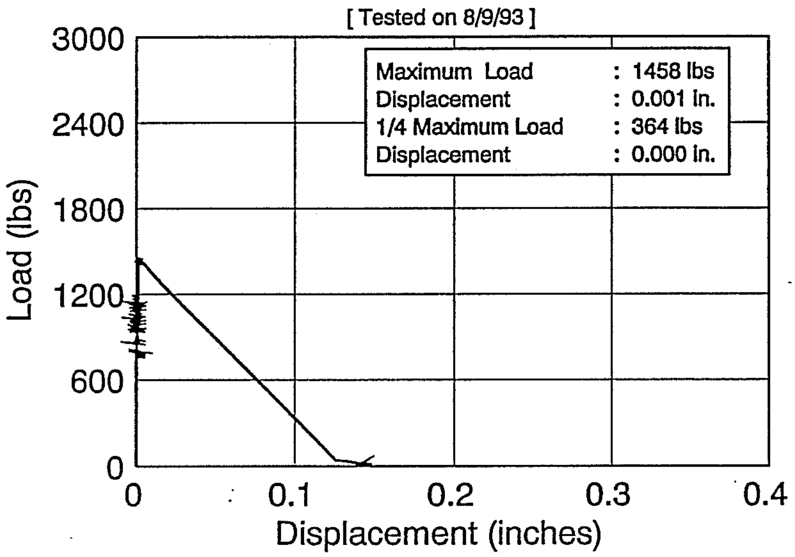


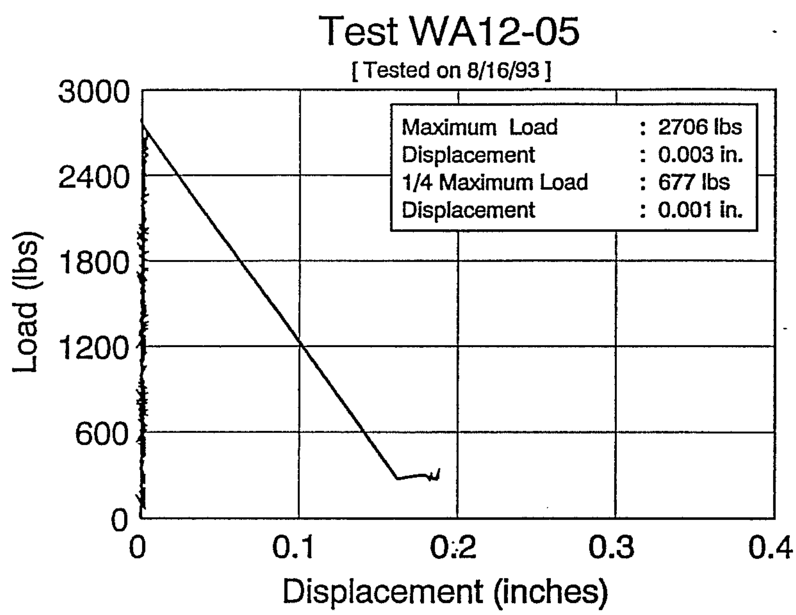
Test WA12-2
[Tested on 8/9/93]
Maximum Load : 793 lbs
Displacement : 0.005 in.
1/4 Maximum Load : 198 lbs
Displacement : 0.001 in.
Load (lbs)
3000
2400
1800
1200
600
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

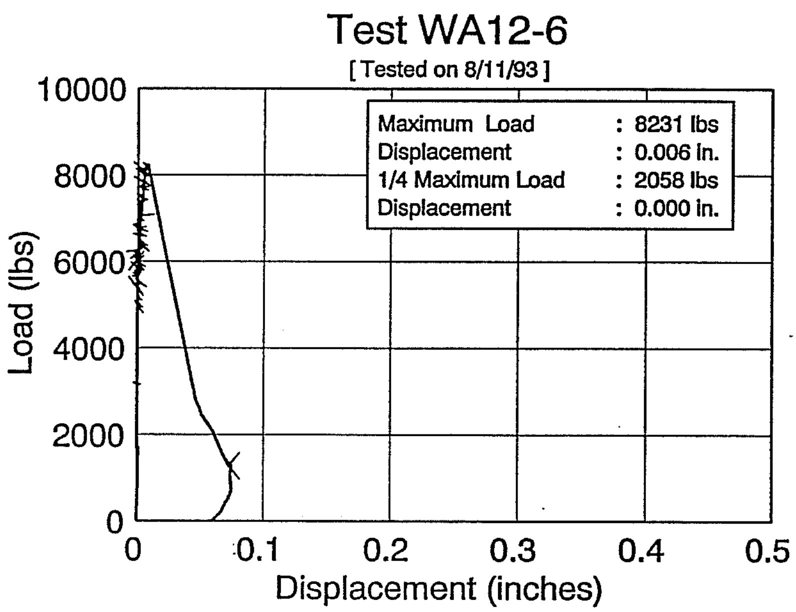
Test WA12-3

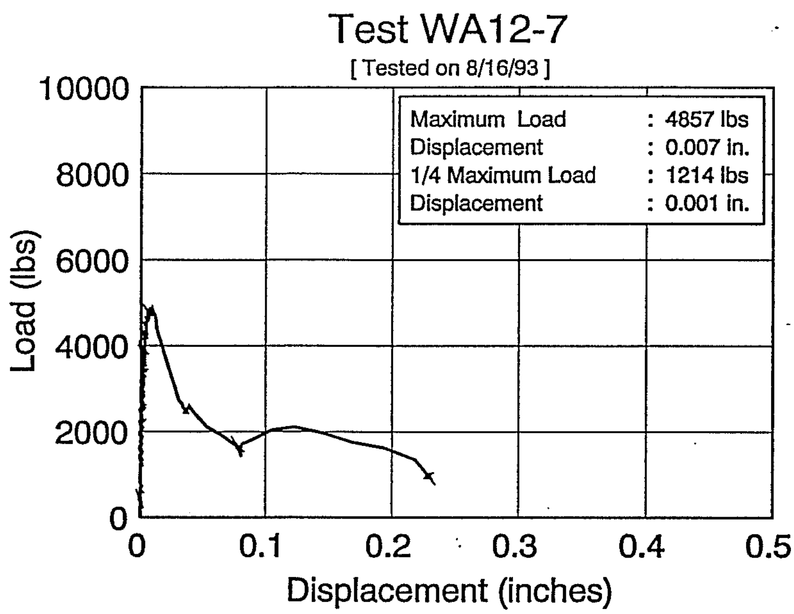


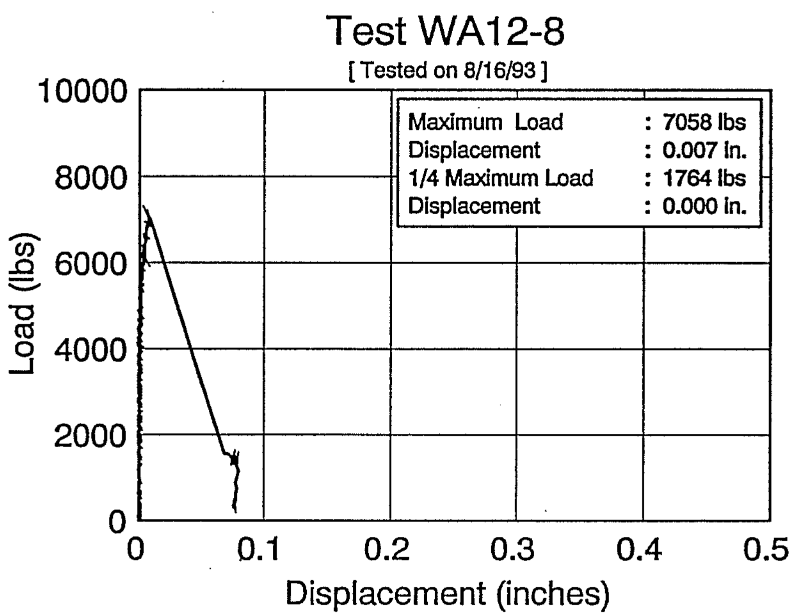
Test WA12-4

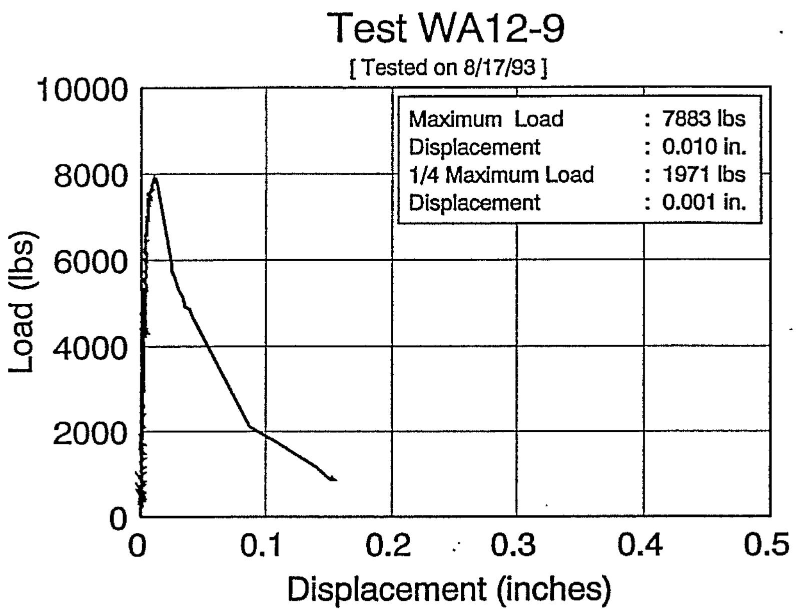


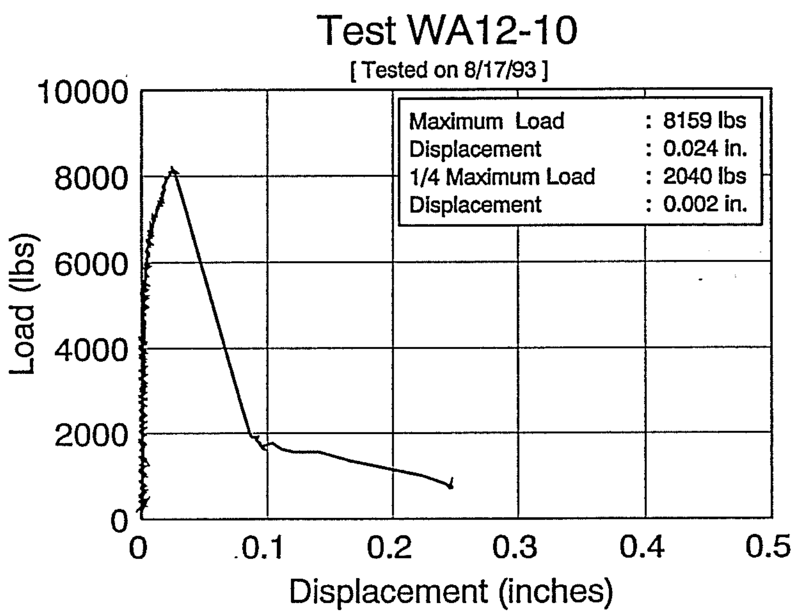

Test WA12-05
[Tested on 8/16/93]
Maximum Load : 2706 lbs
Displacement : 0.003 in.
1/4 Maximum Load : 677 lbs
Displacement : 0.001 in.
Load (lbs)
3000
2400
1800
1200
600
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

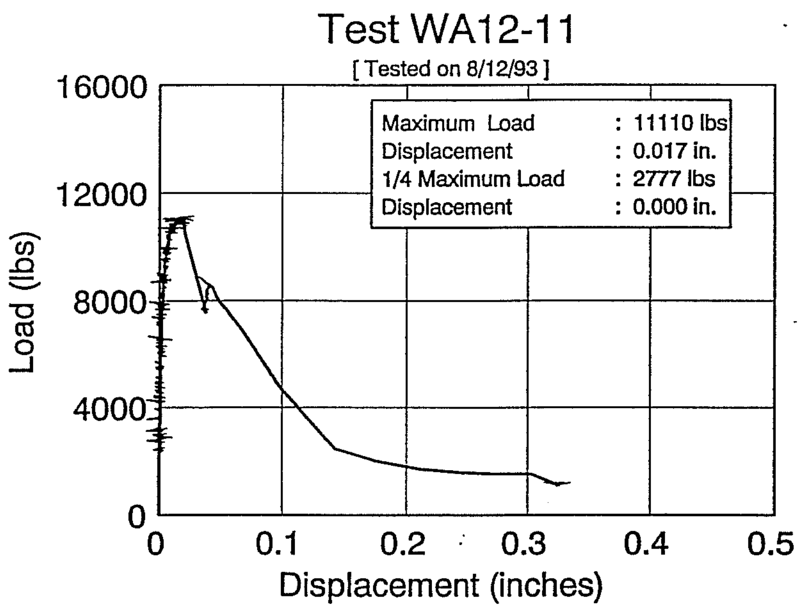

Test WA12-6
[Tested on 8/11/93]
Maximum Load : 8231 lbs
Displacement : 0.006 in.
1/4 Maximum Load : 2058 lbs
Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

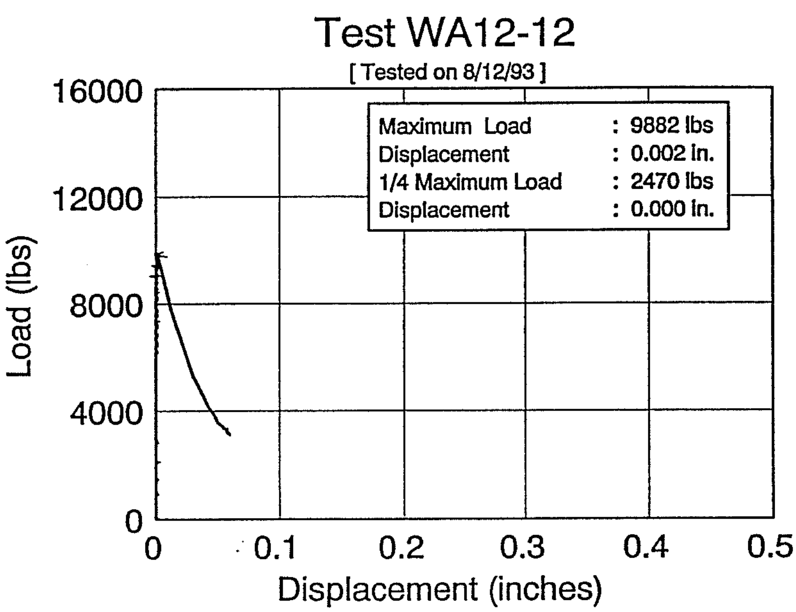

Test WA12-7
[Tested on 8/16/93]
Maximum Load : 4857 lbs
Displacement : 0.007 in.
1/4 Maximum Load : 1214 lbs
Displacement : 0.001 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

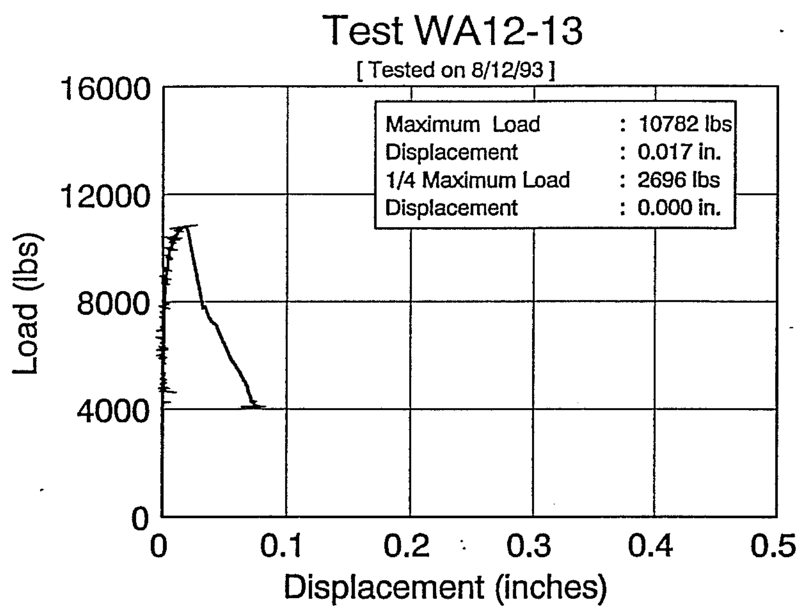

Test WA12-8
[Tested on 8/16/93]
Maximum Load : 7058 lbs
Displacement : 0.007 in.
1/4 Maximum Load : 1764 lbs
Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

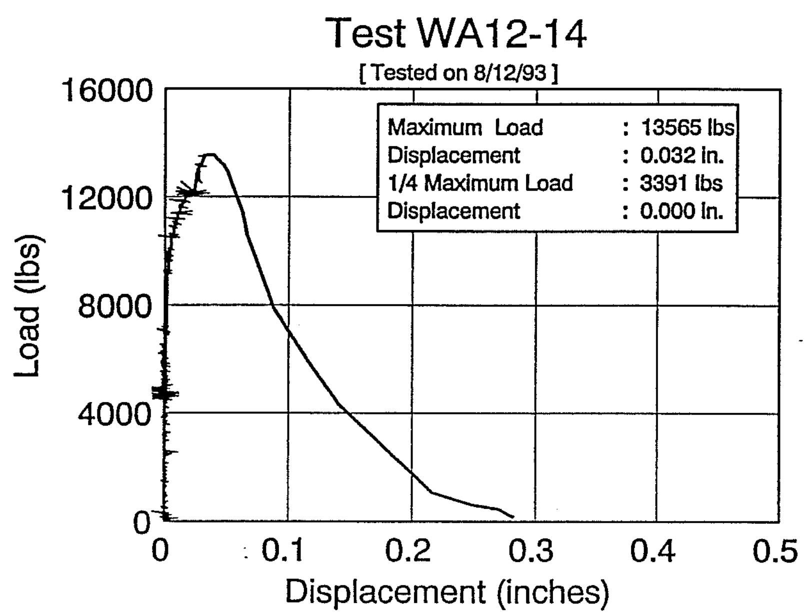

Test WA12-9
[Tested on 8/17/93]
Maximum Load : 7883 lbs
Displacement : 0.010 in.
1/4 Maximum Load : 1971 lbs
Displacement : 0.001 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

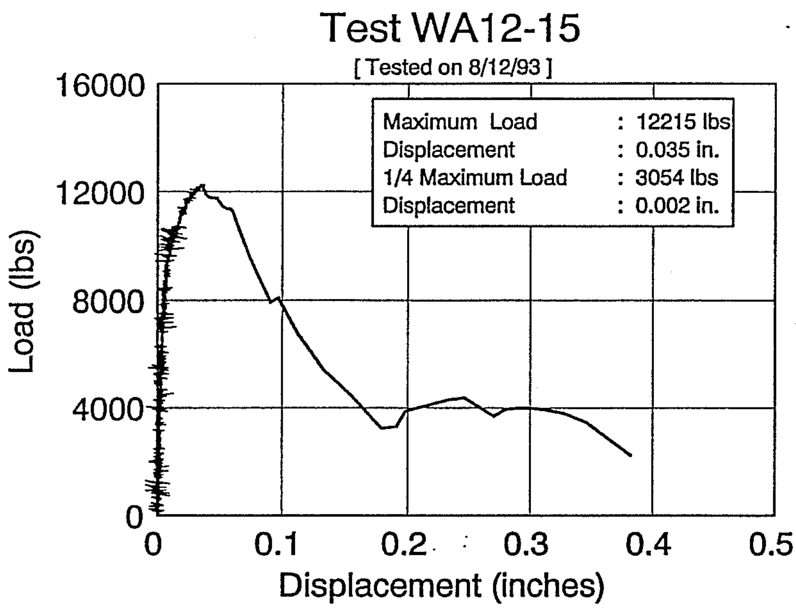

Test WA12-10
[Tested on 8/17/93]
Maximum Load : 8159 lbs
Displacement : 0.024 in.
1/4 Maximum Load : 2040 lbs
Displacement : 0.002 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)


Test WA12-11
[Tested on 8/12/93]
Maximum Load : 11110 lbs
Displacement : 0.017 in.
1/4 Maximum Load : 2777 lbs
Displacement : 0.000 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

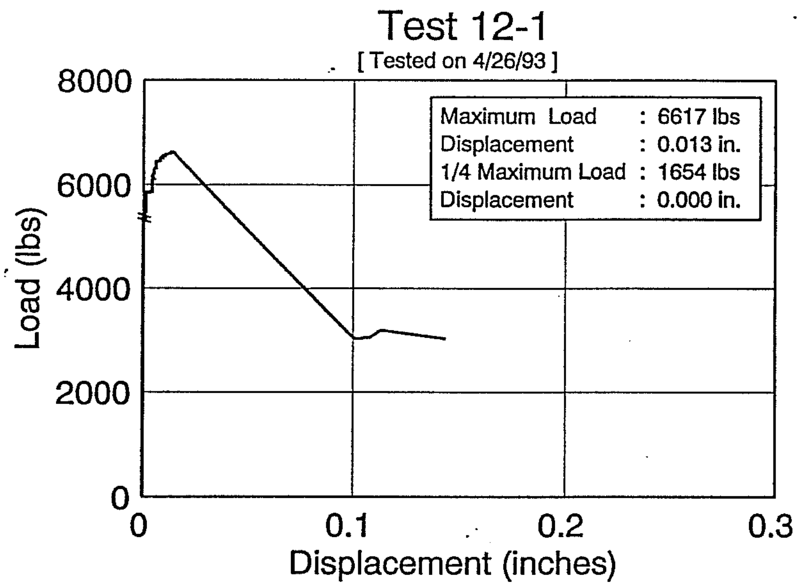

Test WA12-12
[Tested on 8/12/93]
Maximum Load : 9882 lbs
Displacement : 0.002 in.
1/4 Maximum Load : 2470 lbs
Displacement : 0.000 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

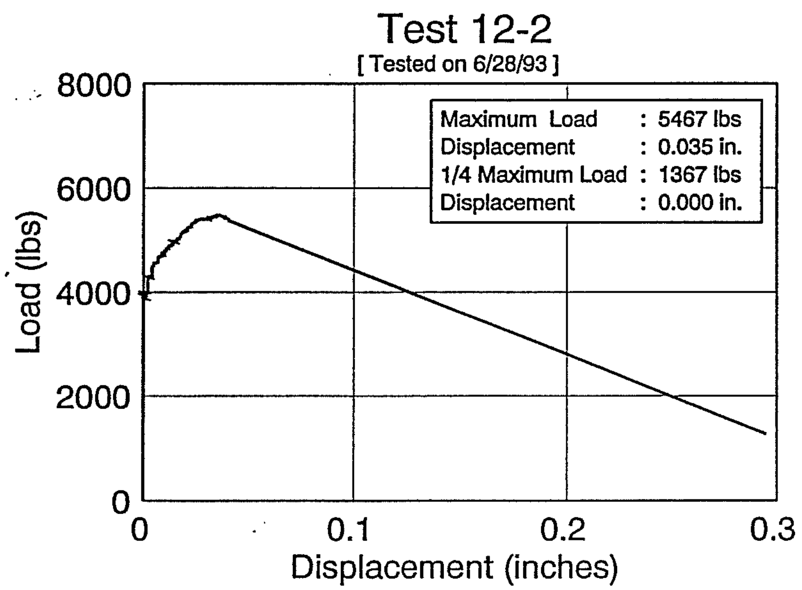

Test WA12-13
[Tested on 8/12/93]
Maximum Load : 10782 lbs
Displacement : 0.017 in.
1/4 Maximum Load : 2696 lbs
Displacement : 0.000 in.
Load (lbs)
0
4000
8000
12000
16000
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

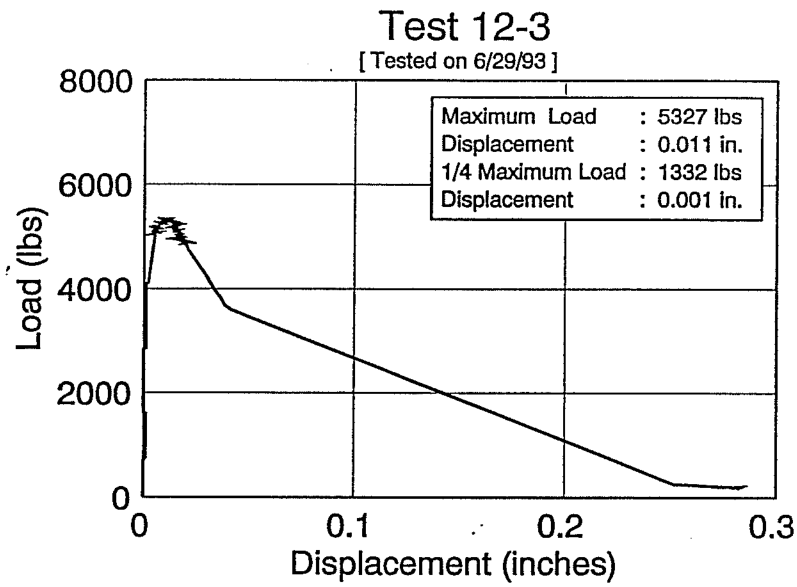

Test WA12-14
[Tested on 8/12/93]
Maximum Load : 13565 lbs
Displacement : 0.032 in.
1/4 Maximum Load : 3391 lbs
Displacement : 0.000 in.
Load (lbs)
0
4000
8000
12000
16000
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

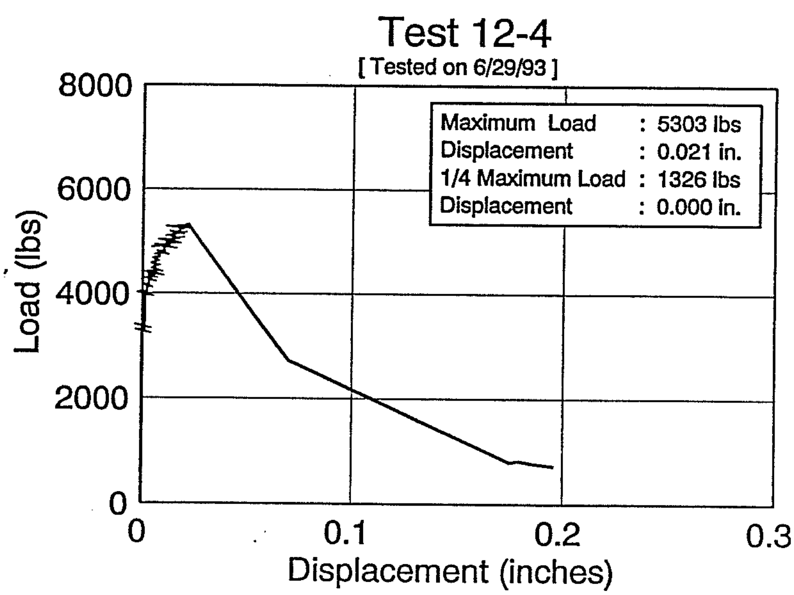


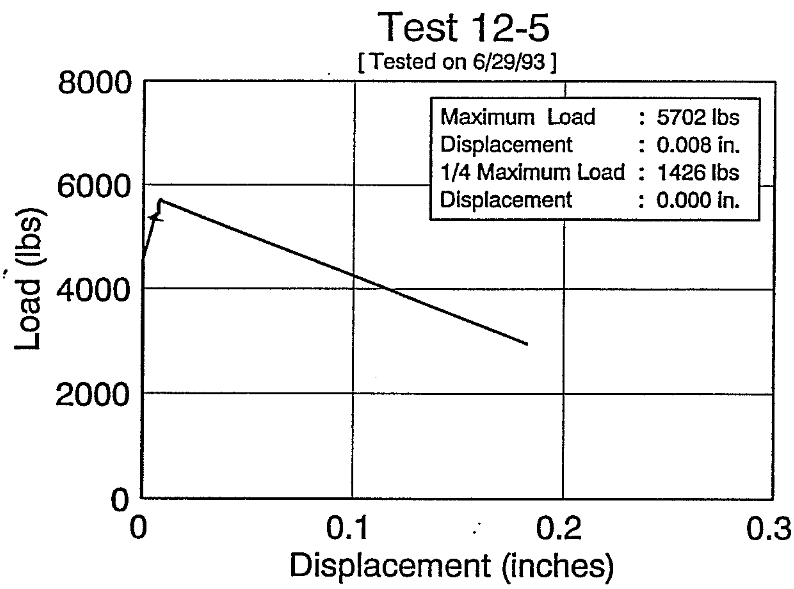
Test WA12-15
[Tested on 8/12/93]
Maximum Load : 12215 lbs
Displacement : 0.035 in.
1/4 Maximum Load : 3054 lbs
Displacement : 0.002 in.
Load (lbs)
16000
12000
8000
4000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

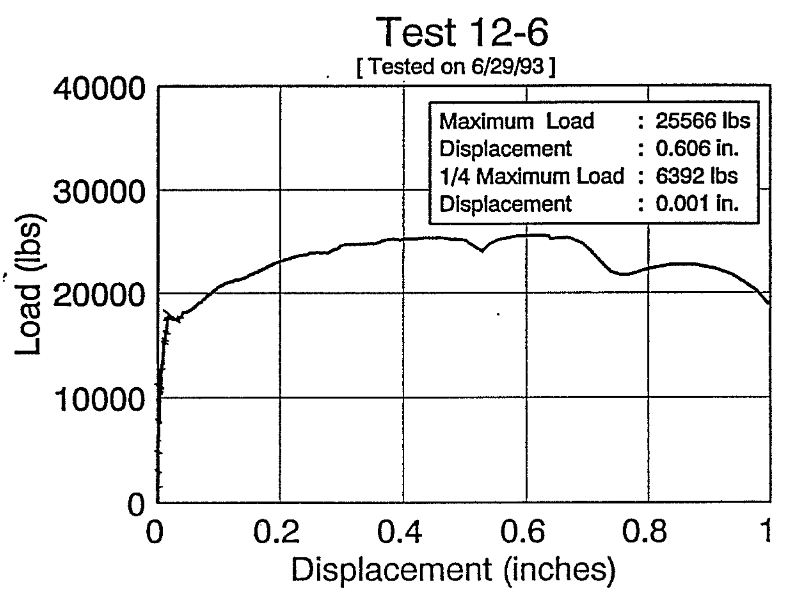

Test 12-1
[Tested on 4/26/93]
Maximum Load : 6617 lbs
Displacement : 0.013 in.
1/4 Maximum Load : 1654 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

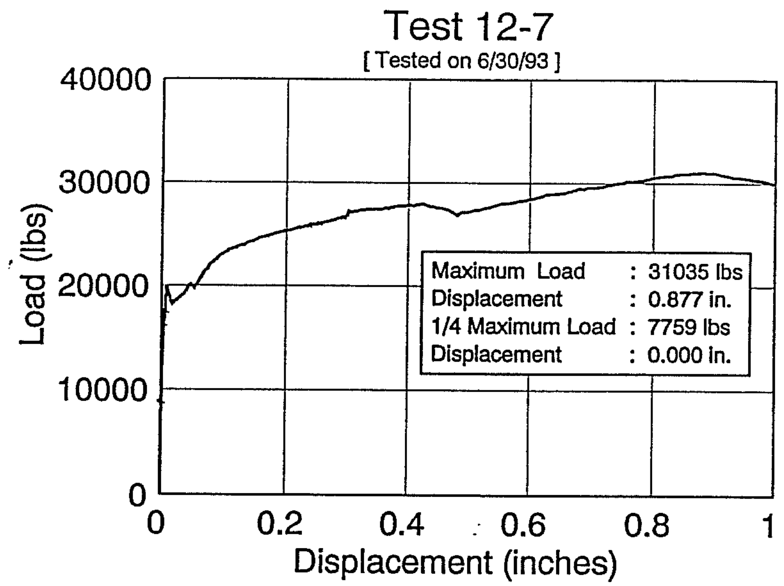

Test 12-2
[Tested on 6/28/93]
Maximum Load : 5467 lbs
Displacement : 0.035 in.
1/4 Maximum Load : 1367 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

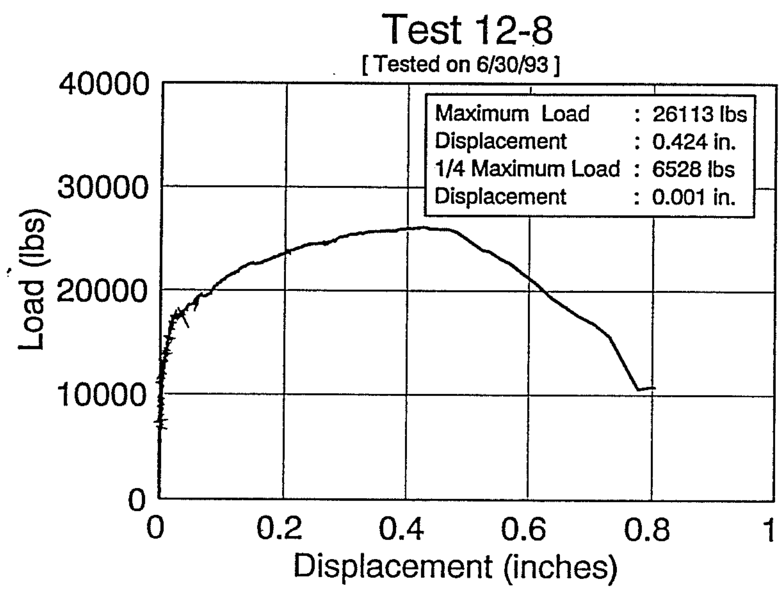

Test 12-3
[Tested on 6/29/93]
Maximum Load : 5327 lbs
Displacement : 0.011 in.
1/4 Maximum Load : 1332 lbs
Displacement : 0.001 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

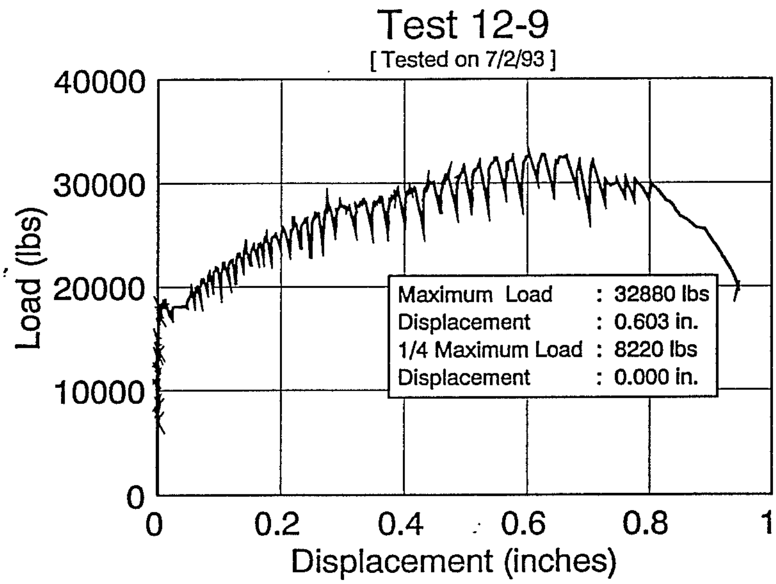

Test 12-4
[Tested on 6/29/93]
Maximum Load : 5303 lbs
Displacement : 0.021 in.
1/4 Maximum Load : 1326 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

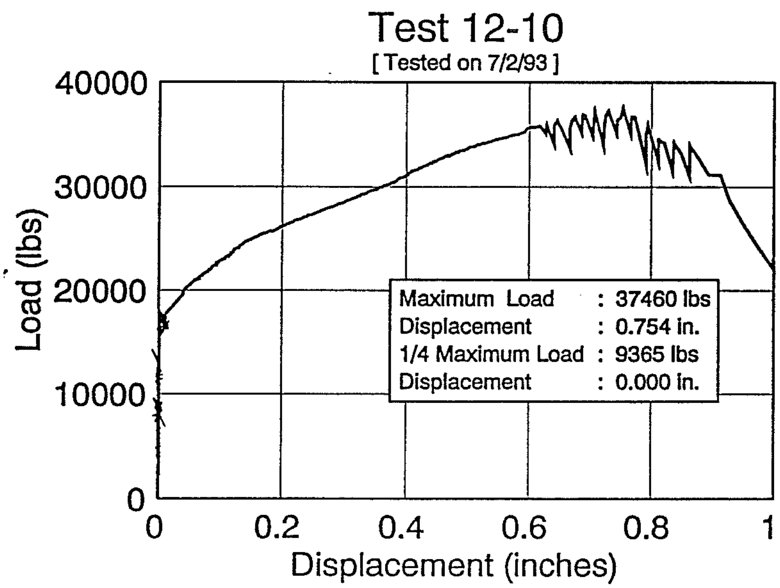

Test 12-5
[Tested on 6/29/93]
Maximum Load : 5702 lbs
Displacement : 0.008 in.
1/4 Maximum Load : 1426 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.1
0.2
0.3
Displacement (inches)

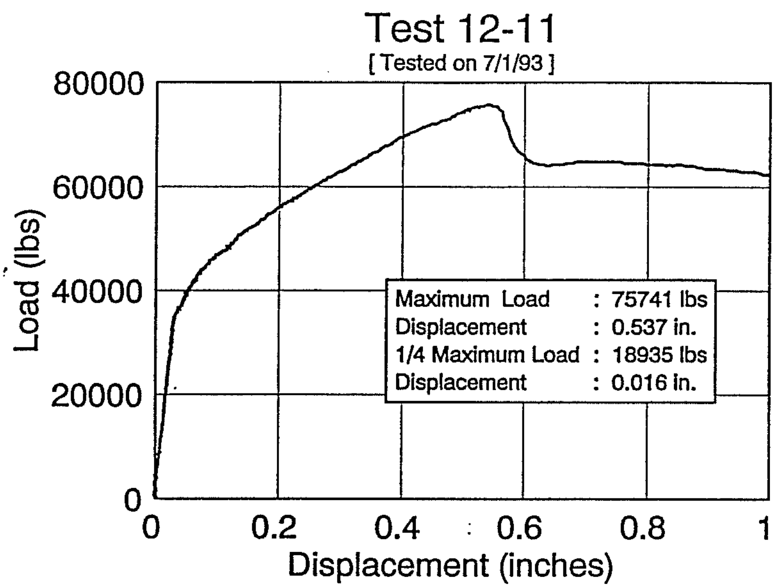

Test 12-6
[Tested on 6/29/93]
Maximum Load : 25566 lbs
Displacement : 0.606 in.
1/4 Maximum Load : 6392 lbs
Displacement : 0.001 in.
Load (lbs)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

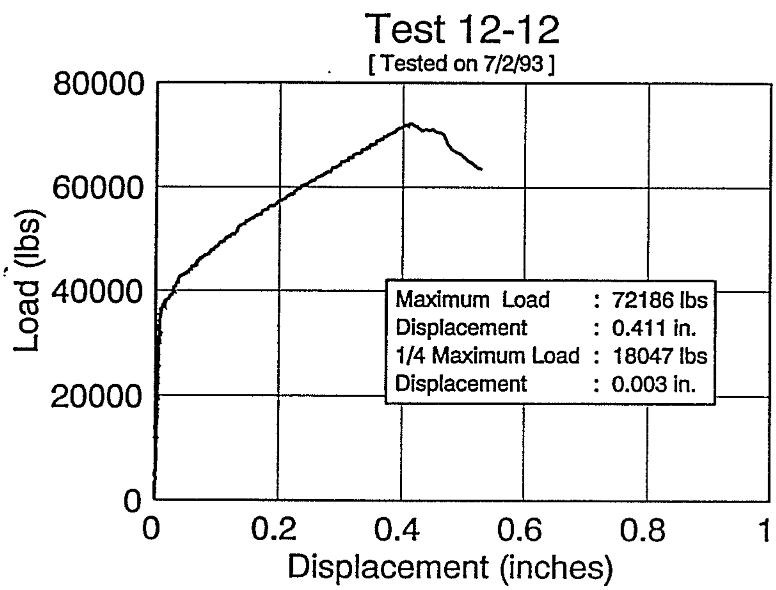

Test 12-7
[Tested on 6/30/93]
Load (lbs)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 31035 lbs
Displacement : 0.877 in.
1/4 Maximum Load : 7759 lbs
Displacement : 0.000 in.

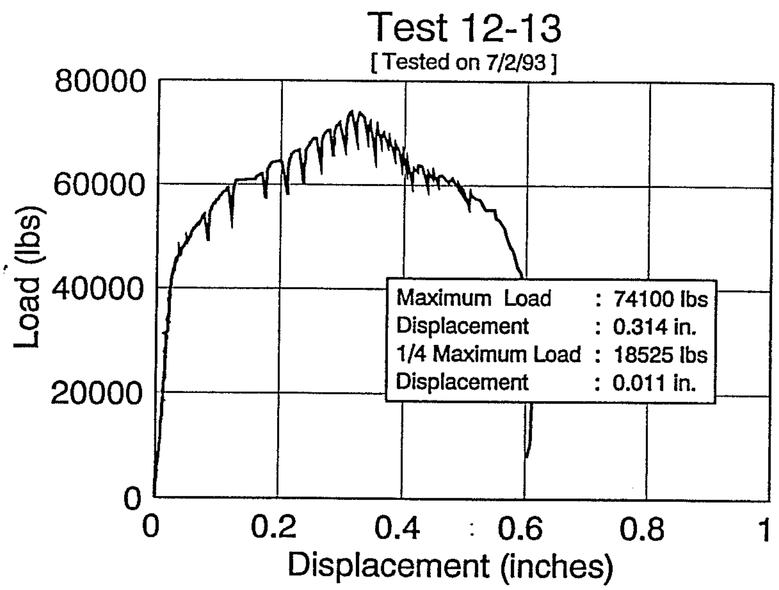

Test 12-8
[Tested on 6/30/93]
Load (lbs)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 26113 lbs
Displacement : 0.424 in.
1/4 Maximum Load : 6528 lbs
Displacement : 0.001 in.

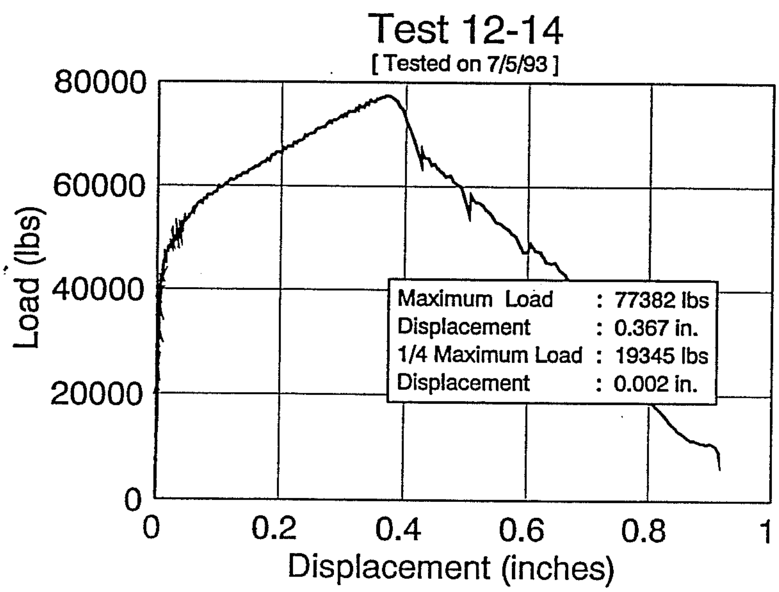

Test 12-9
[Tested on 7/2/93]
Load (lbs)
Displacement (inches)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Maximum Load : 32880 lbs
Displacement : 0.603 in.
1/4 Maximum Load : 8220 lbs
Displacement : 0.000 in.

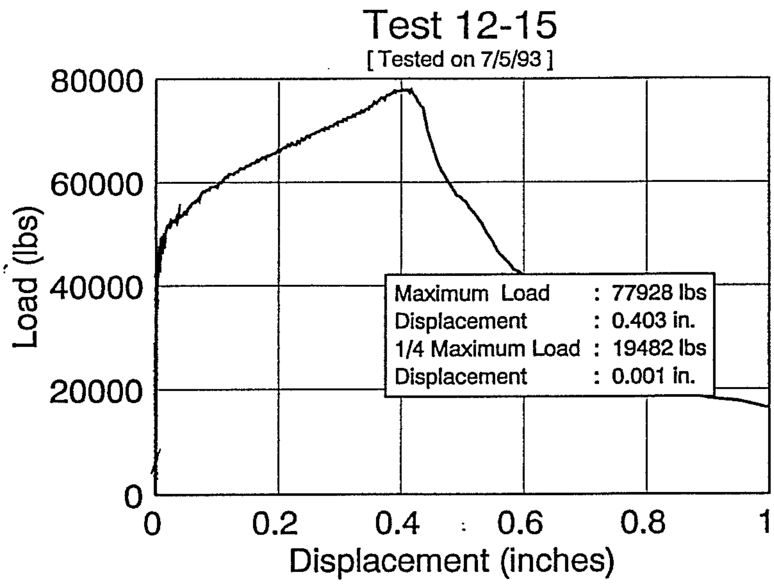

Test 12-10
[Tested on 7/2/93]
Load (lbs)
Displacement (inches)
40000
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
1
Maximum Load : 37460 lbs
Displacement : 0.754 in.
1/4 Maximum Load : 9365 lbs
Displacement : 0.000 in.

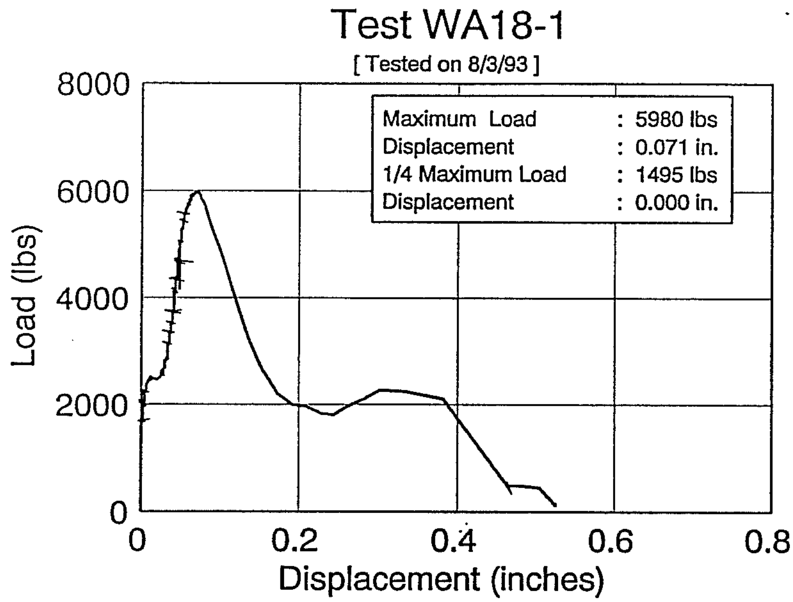

Test 12-11
[Tested on 7/1/93]
Load (lbs)
80000
60000
40000
20000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 75741 lbs
Displacement : 0.537 in.
1/4 Maximum Load : 18935 lbs
Displacement : 0.016 in.

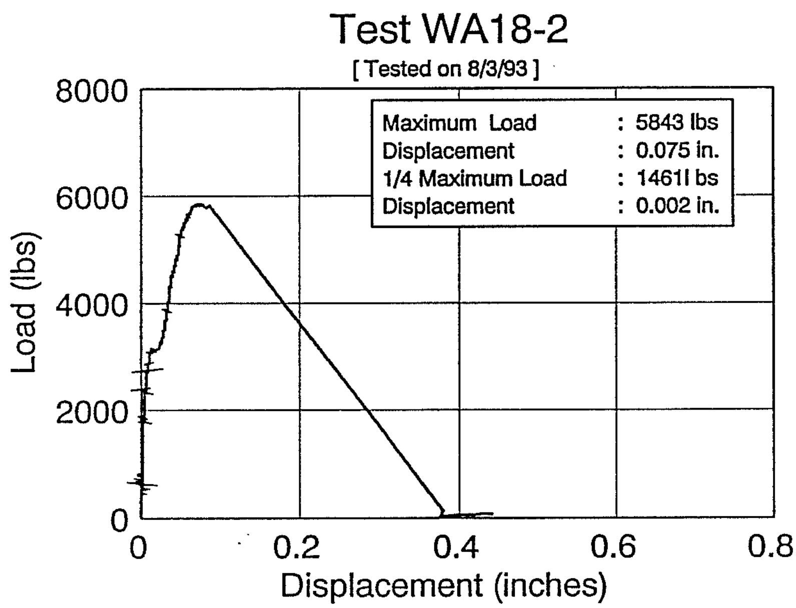

Test 12-12
[Tested on 7/2/93]
Load (lbs)
80000
60000
40000
20000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 72186 lbs
Displacement : 0.411 in.
1/4 Maximum Load : 18047 lbs
Displacement : 0.003 in.

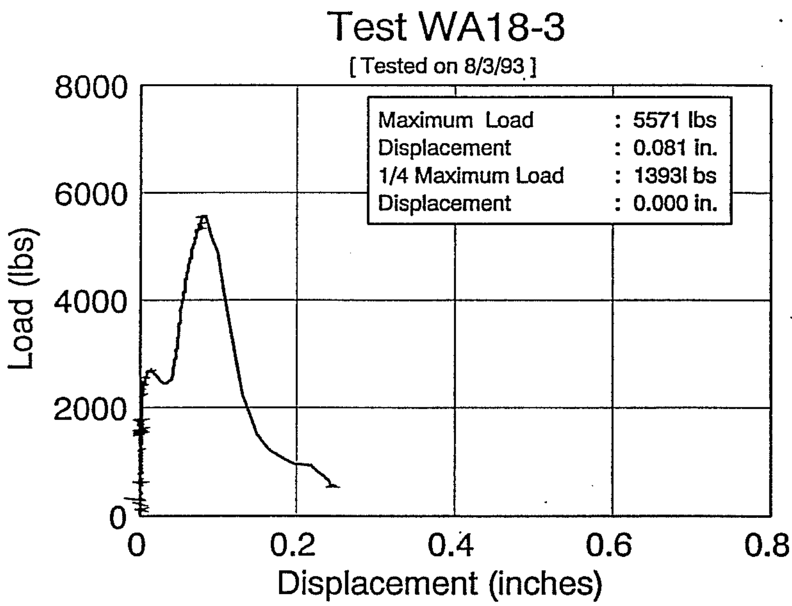

Test 12-13
[Tested on 7/2/93]
Load (lbs)
80000
60000
40000
20000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 74100 lbs
Displacement : 0.314 in.
1/4 Maximum Load : 18525 lbs
Displacement : 0.011 in.

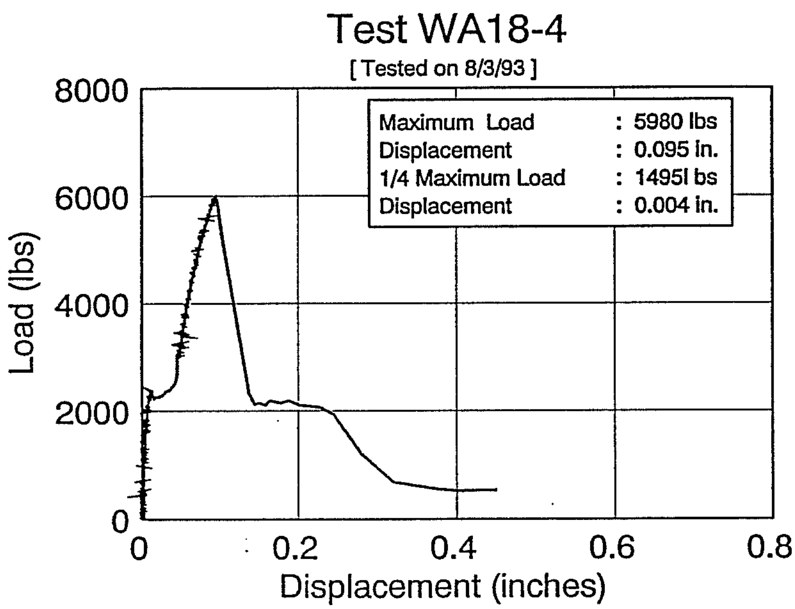

Test 12-14
[Tested on 7/5/93]
Load (lbs)
80000
60000
40000
20000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)
Maximum Load : 77382 lbs
Displacement : 0.367 in.
1/4 Maximum Load : 19345 lbs
Displacement : 0.002 in.

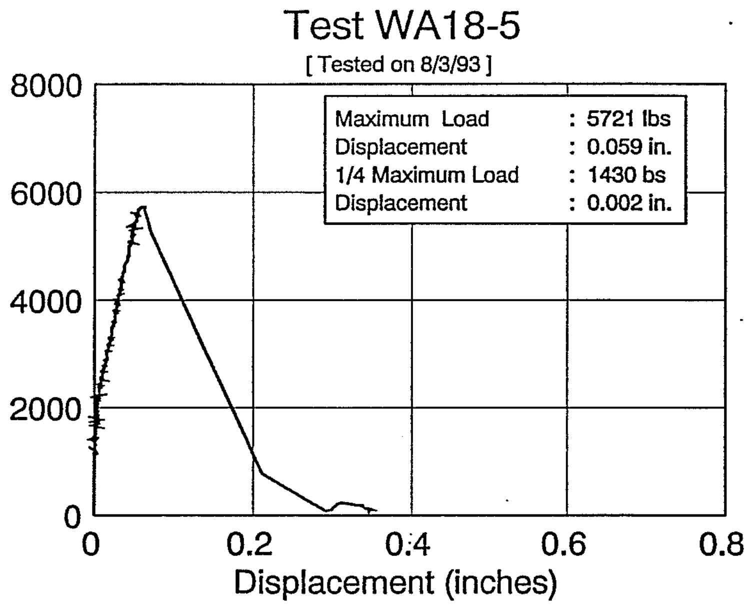

Test 12-15
[Tested on 7/5/93]
Load (lbs)
Displacement (inches)
0
20000
40000
60000
80000
0
0.2
0.4
0.6
0.8
1
Maximum Load : 77928 lbs
Displacement : 0.403 in.
1/4 Maximum Load : 19482 lbs
Displacement : 0.001 in.

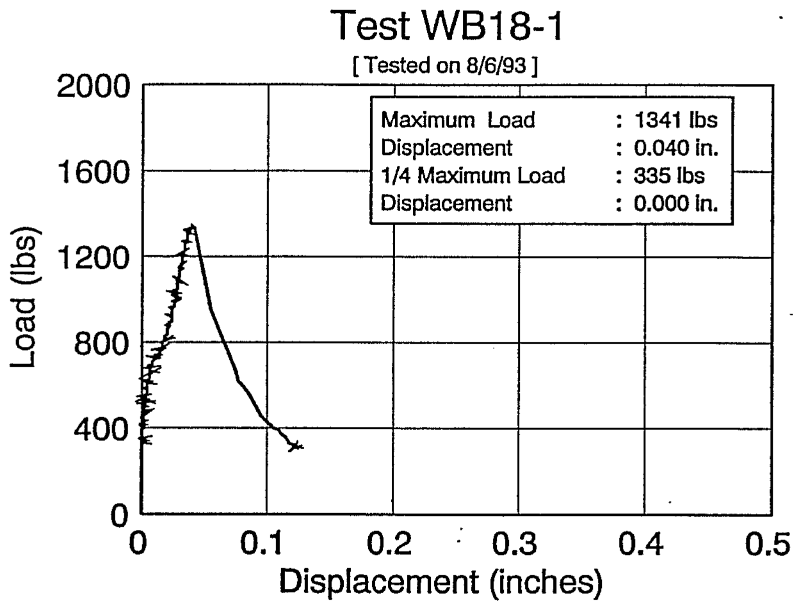

Test WA18-1
[Tested on 8/3/93]
Maximum Load : 5980 lbs
Displacement : 0.071 in.
1/4 Maximum Load : 1495 lbs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

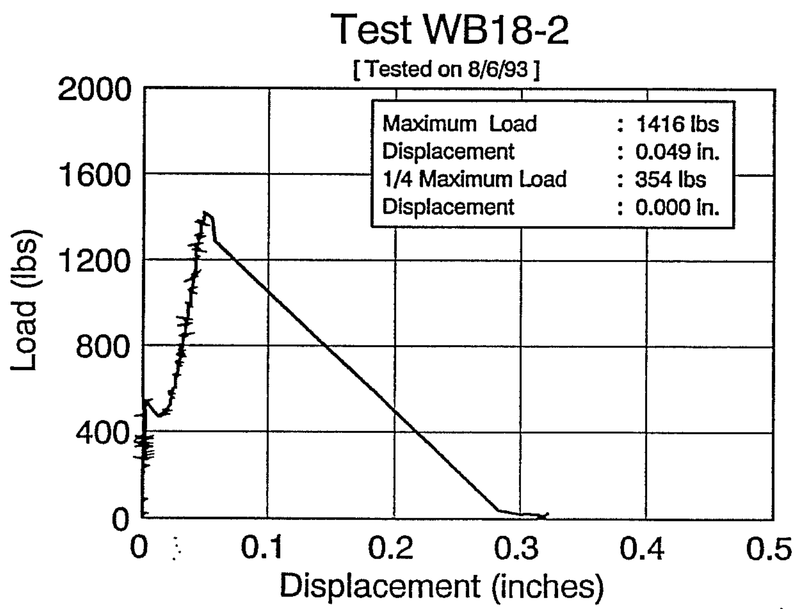

Test WA18-2
[Tested on 8/3/93]
Maximum Load : 5843 lbs
Displacement : 0.075 in.
1/4 Maximum Load : 1461l bs
Displacement : 0.002 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

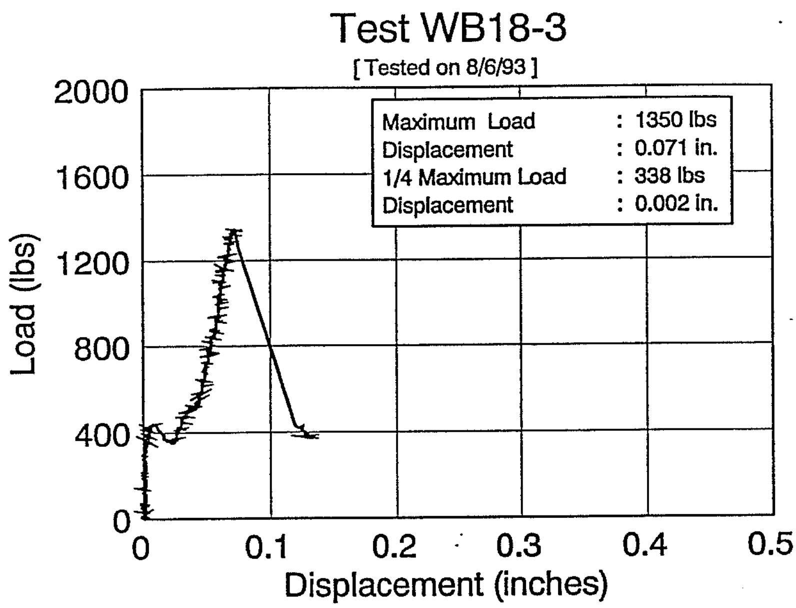

Test WA18-3
[Tested on 8/3/93]
Maximum Load : 5571 lbs
Displacement : 0.081 in.
1/4 Maximum Load : 1393l bs
Displacement : 0.000 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

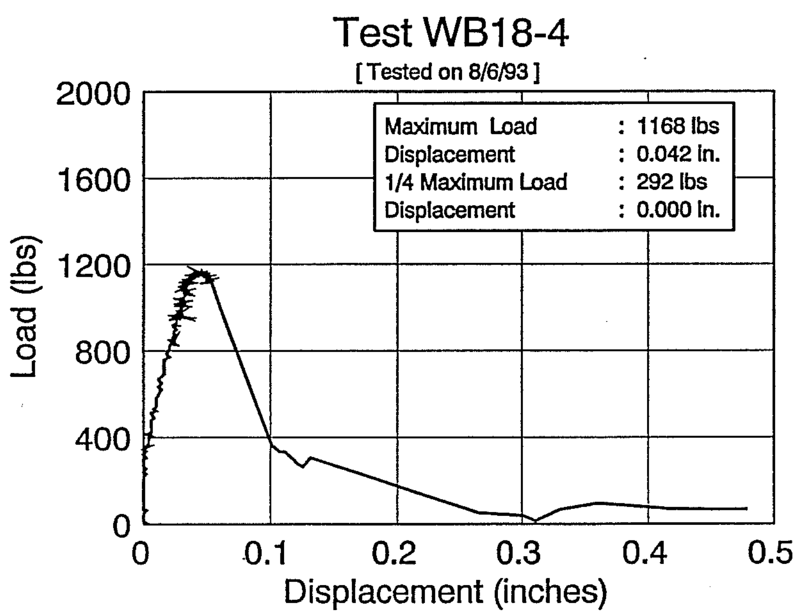

Test WA18-4
[Tested on 8/3/93]
Maximum Load : 5980 lbs
Displacement : 0.095 in.
1/4 Maximum Load : 1495l bs
Displacement : 0.004 in.
Load (lbs)
8000
6000
4000
2000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

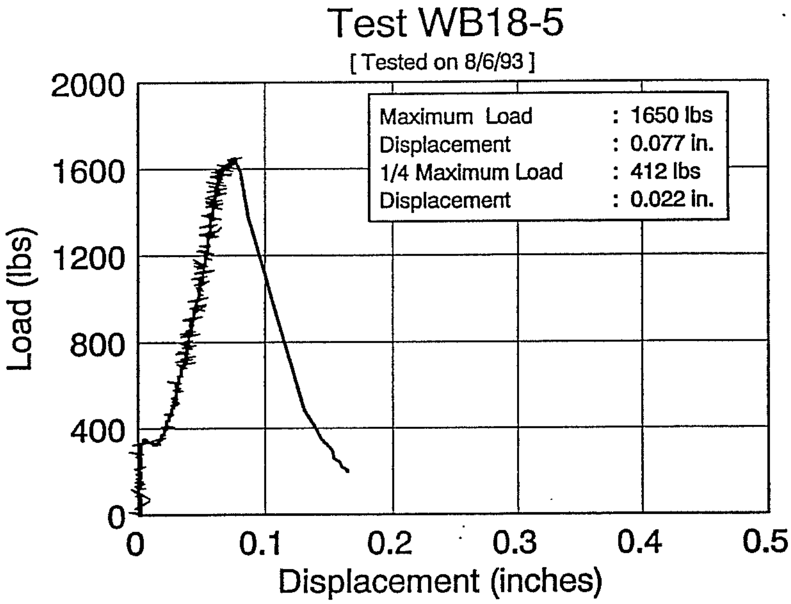

Test WA18-5
[Tested on 8/3/93]
Maximum Load : 5721 lbs
Displacement : 0.059 in.
1/4 Maximum Load : 1430 bs
Displacement : 0.002 in.
8000
6000
4000
2000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

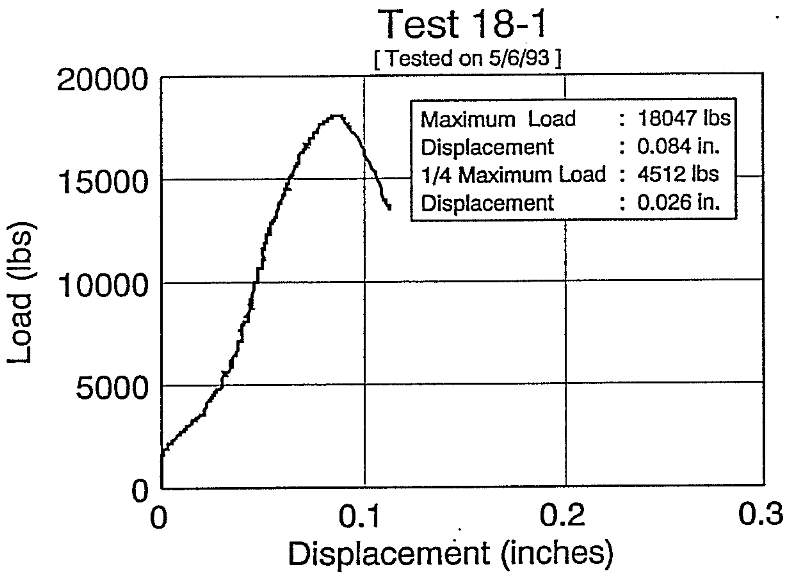

Test WB18-1
[Tested on 8/6/93]
Maximum Load : 1341 lbs
Displacement : 0.040 in.
1/4 Maximum Load : 335 lbs
Displacement : 0.000 in.
Load (lbs)
2000
1600
1200
800
400
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

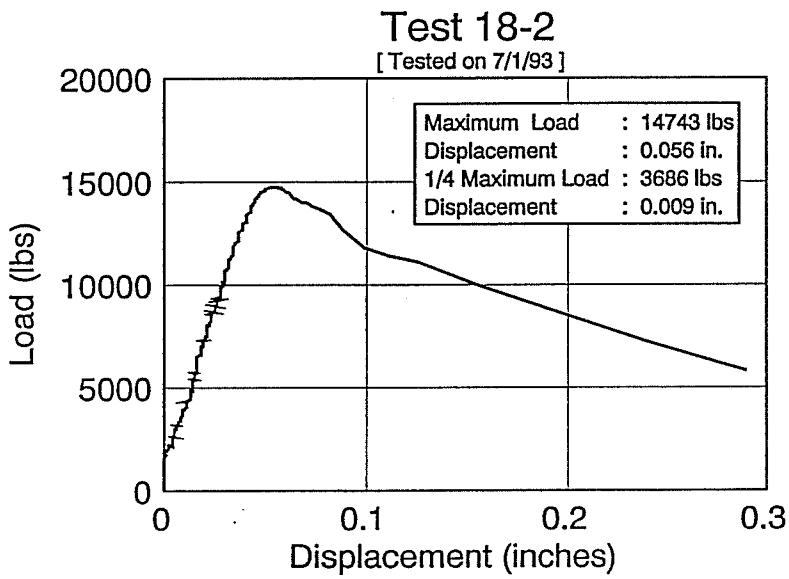

Test WB18-2
[Tested on 8/6/93]
Maximum Load : 1416 lbs
Displacement : 0.049 in.
1/4 Maximum Load : 354 lbs
Displacement : 0.000 in.
Load (lbs)
2000
1600
1200
800
400
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

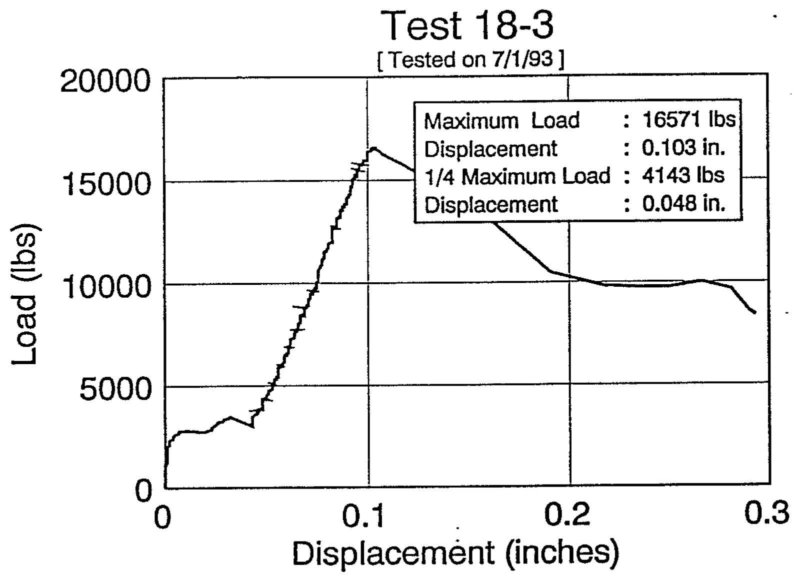

Test WB18-3
[Tested on 8/6/93]
Maximum Load : 1350 lbs
Displacement : 0.071 in.
1/4 Maximum Load : 338 lbs
Displacement : 0.002 in.
Load (lbs)
2000
1600
1200
800
400
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

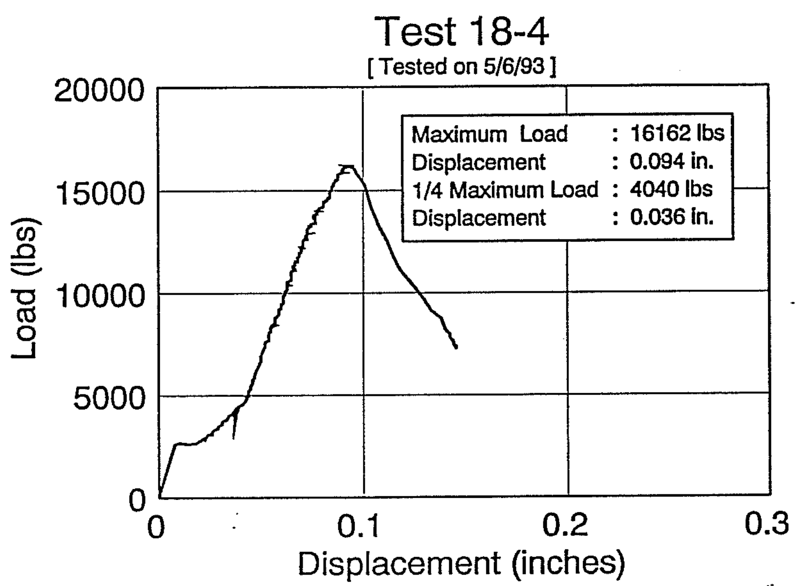

Test WB18-4
[Tested on 8/6/93]
Maximum Load : 1168 lbs
Displacement : 0.042 in.
1/4 Maximum Load : 292 lbs
Displacement : 0.000 in.
Load (lbs)
2000
1600
1200
800
400
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

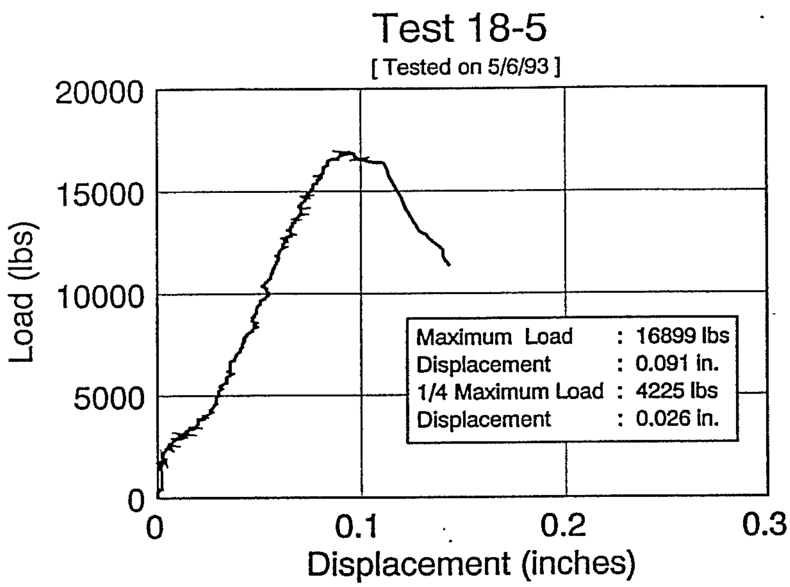

Test WB18-5
[Tested on 8/6/93]
Maximum Load : 1650 lbs
Displacement : 0.077 in.
1/4 Maximum Load : 412 lbs
Displacement : 0.022 in.
Load (lbs)
2000
1600
1200
800
400
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)

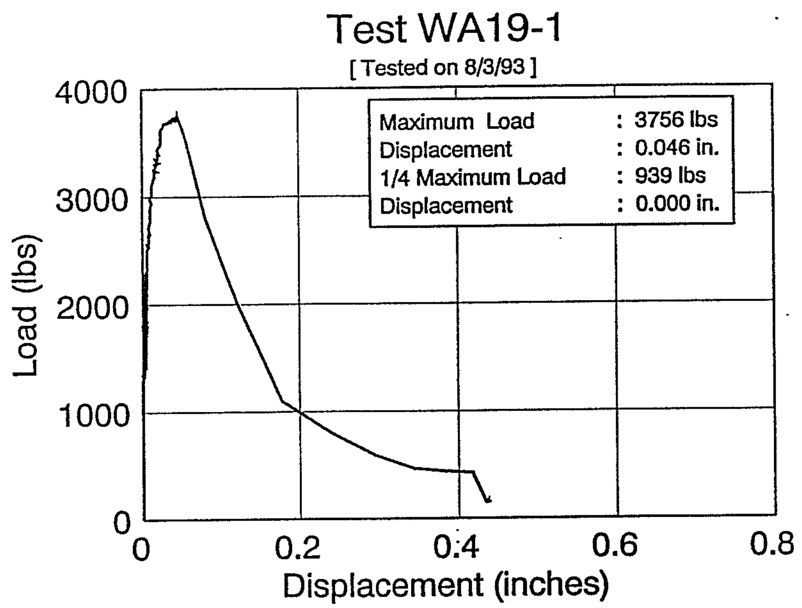

Test 18-1
[Tested on 5/6/93]
Maximum Load : 18047 lbs
Displacement : 0.084 in.
1/4 Maximum Load : 4512 lbs
Displacement : 0.026 in.
Load (lbs)
20000
15000
10000
5000
0
0
0.1
0.2
0.3
Displacement (inches)

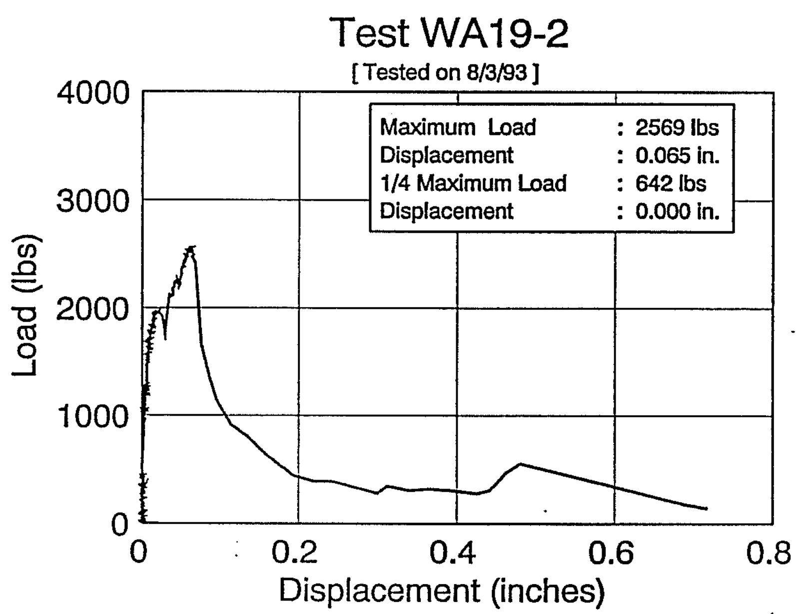

Test 18-2
[Tested on 7/1/93]
Maximum Load : 14743 lbs
Displacement : 0.056 in.
1/4 Maximum Load : 3686 lbs
Displacement : 0.009 in.
Load (lbs)
20000
15000
10000
5000
0
0
0.1
0.2
0.3
Displacement (inches)

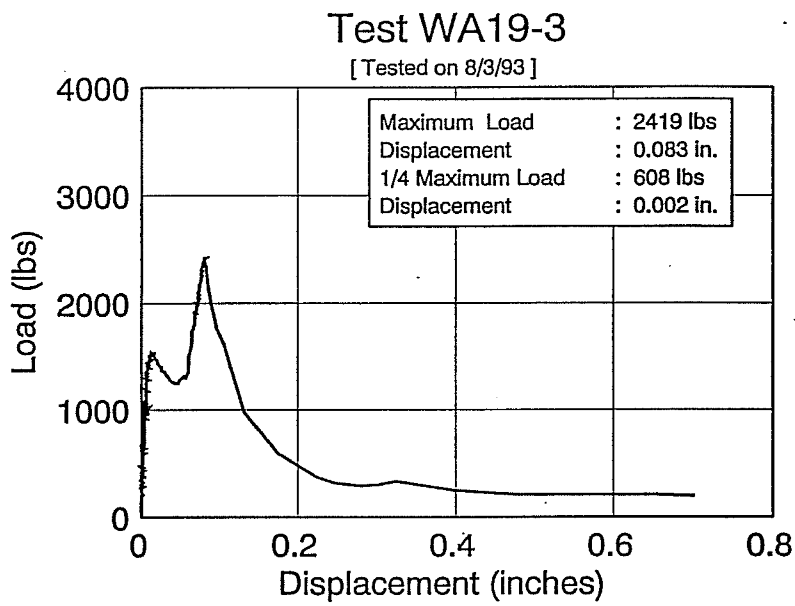

Test 18-3
[Tested on 7/1/93]
Maximum Load : 16571 lbs
Displacement : 0.103 in.
1/4 Maximum Load : 4143 lbs
Displacement : 0.048 in.
Load (lbs)
20000
15000
10000
5000
0
0
0.1
0.2
0.3
Displacement (inches)

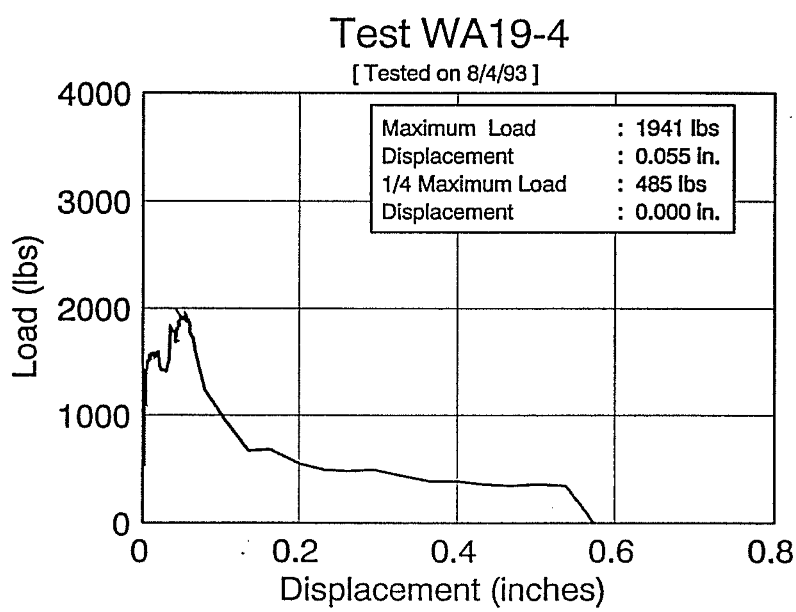

Test 18-4
[Tested on 5/6/93]
Maximum Load : 16162 lbs
Displacement : 0.094 in.
1/4 Maximum Load : 4040 lbs
Displacement : 0.036 in.
Load (lbs)
20000
15000
10000
5000
0
0
0.1
0.2
0.3
Displacement (inches)

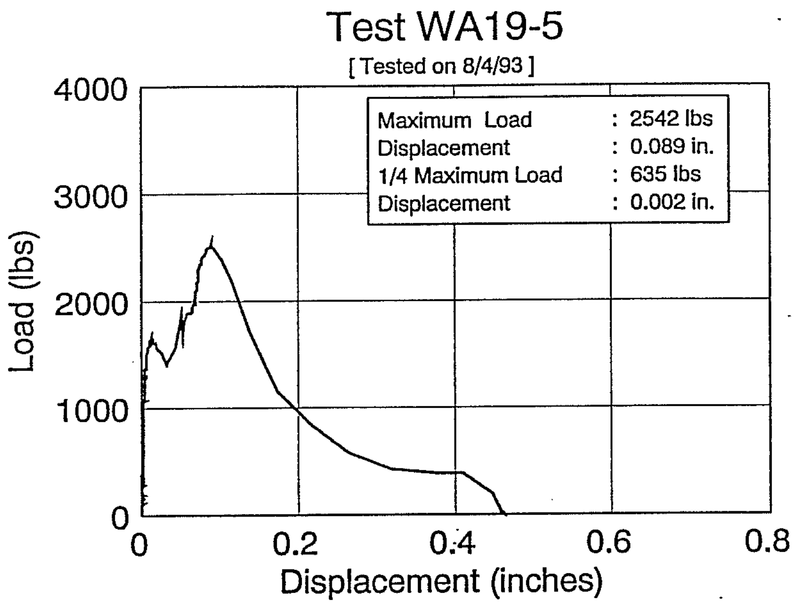

Test 18-5
[Tested on 5/6/93]
20000
15000
10000
5000
0
Load (lbs)
0
0.1
0.2
0.3
Displacement (inches)
Maximum Load : 16899 lbs
Displacement : 0.091 in.
1/4 Maximum Load : 4225 lbs
Displacement : 0.026 in.

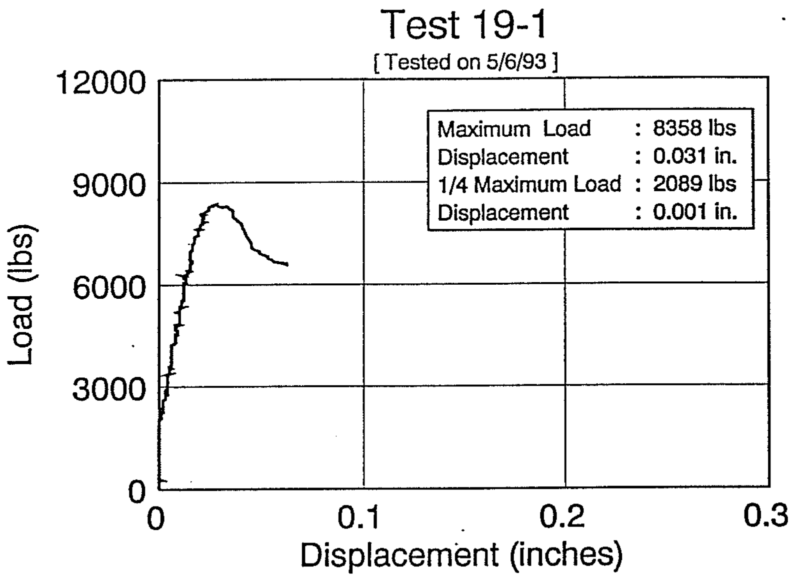

Test WA19-1
[Tested on 8/3/93]
Maximum Load : 3756 lbs
Displacement : 0.046 in.
1/4 Maximum Load : 939 lbs
Displacement : 0.000 in.
Load (lbs)
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test WA19-2
[Tested on 8/3/93]
Maximum Load : 2569 lbs
Displacement : 0.065 in.
1/4 Maximum Load : 642 lbs
Displacement : 0.000 in.
Load (lbs)
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

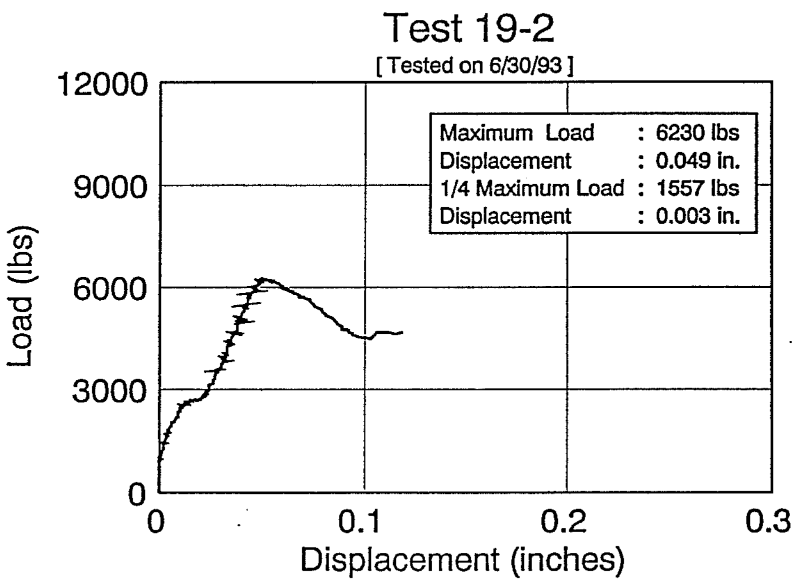

Test WA19-3
[Tested on 8/3/93]
Maximum Load : 2419 lbs
Displacement : 0.083 in.
1/4 Maximum Load : 608 lbs
Displacement : 0.002 in.
Load (lbs)
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test WA19-4
[Tested on 8/4/93]
Maximum Load : 1941 lbs
Displacement : 0.055 in.
1/4 Maximum Load : 485 lbs
Displacement : 0.000 in.
Load (lbs)
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

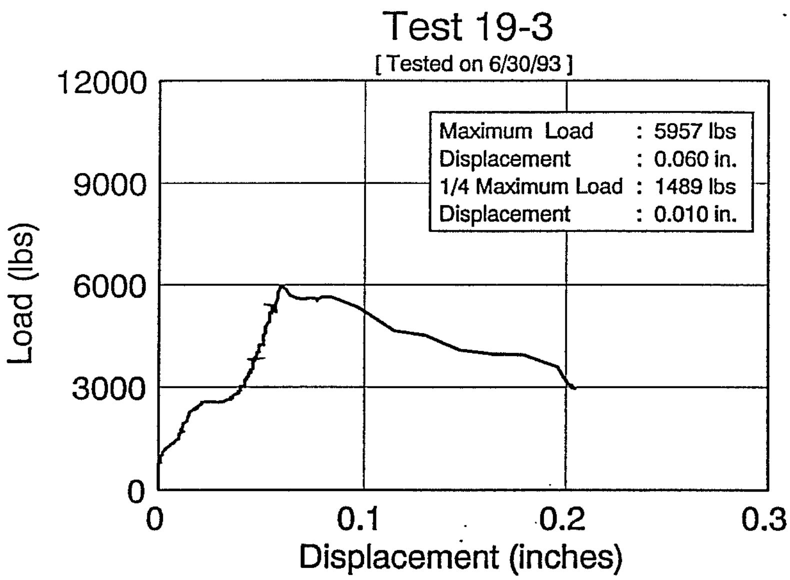

Test WA19-5
[Tested on 8/4/93]
Maximum Load : 2542 lbs
Displacement : 0.089 in.
1/4 Maximum Load : 635 lbs
Displacement : 0.002 in.
Load (lbs)
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

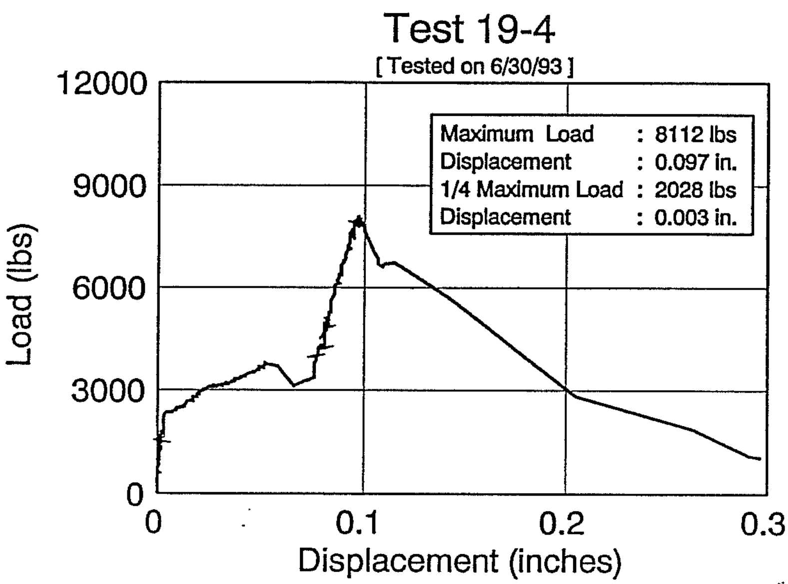


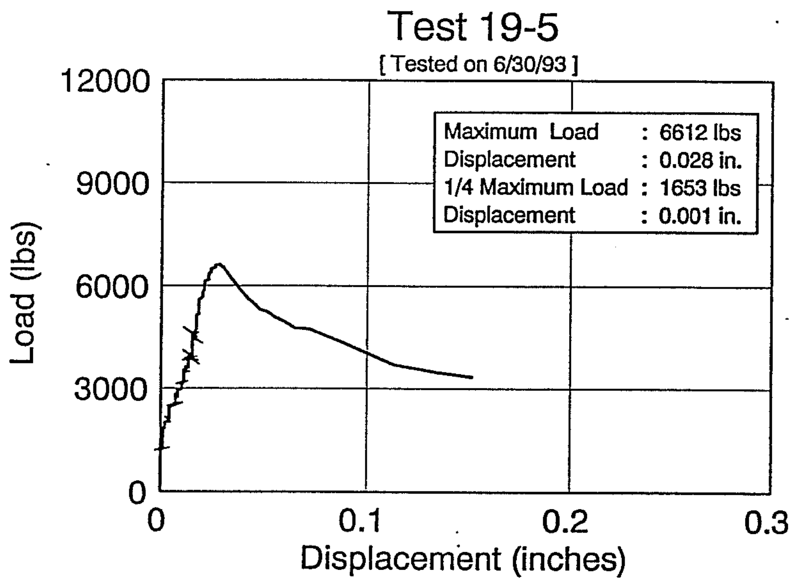
Test 19-1
[Tested on 5/6/93]
Maximum Load : 8358 lbs
Displacement : 0.031 in.
1/4 Maximum Load : 2089 lbs
Displacement : 0.001 in.
Load (lbs)
12000
9000
6000
3000
0
0
0.1
0.2
0.3
Displacement (inches)

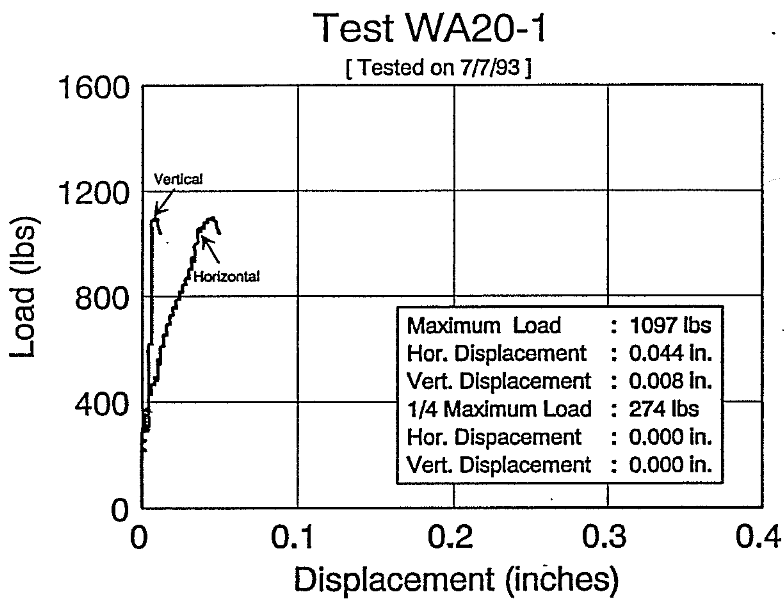


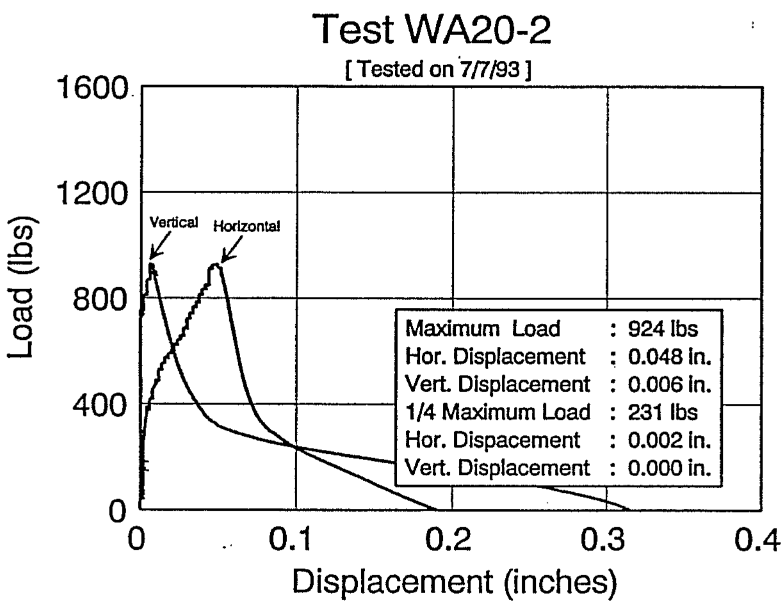
Test 19-2
[Tested on 6/30/93]
Maximum Load : 6230 lbs
Displacement : 0.049 in.
1/4 Maximum Load : 1557 lbs
Displacement : 0.003 in.
Load (lbs)
12000
9000
6000
3000
0
0
0.1
0.2
0.3
Displacement (inches)


Test 19-3
[Tested on 6/30/93]
Maximum Load : 5957 lbs
Displacement : 0.060 in.
1/4 Maximum Load : 1489 lbs
Displacement : 0.010 in.
Load (lbs)
12000
9000
6000
3000
0
0
0.1
0.2
0.3
Displacement (inches)


Test 19-4
[Tested on 6/30/93]
Maximum Load : 8112 lbs
Displacement : 0.097 in.
1/4 Maximum Load : 2028 lbs
Displacement : 0.003 in.
Load (lbs)
12000
9000
6000
3000
0
0
0.1
0.2
0.3
Displacement (inches)

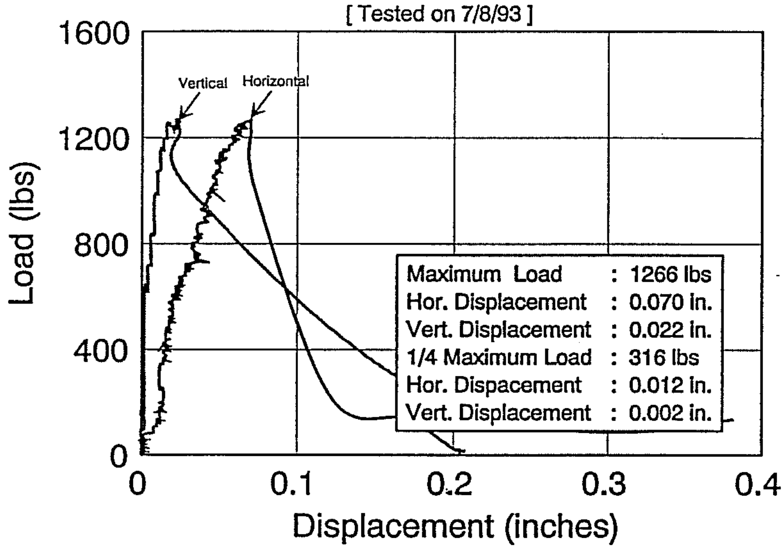

Test 19-5
[Tested on 6/30/93]
Maximum Load : 6612 lbs
Displacement : 0.028 in.
1/4 Maximum Load : 1653 lbs
Displacement : 0.001 in.
Load (lbs)
12000
9000
6000
3000
0
0
0.1
0.2
0.3
Displacement (inches)


Test WA20-1
[Tested on 7/7/93]
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 1097 lbs
Hor. Displacement : 0.044 in.
Vert. Displacement : 0.008 in.
1/4 Maximum Load : 274 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.


Test WA20-2
[Tested on 7/7/93]
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 924 lbs
Hor. Displacement : 0.048 in.
Vert. Displacement : 0.006 in.
1/4 Maximum Load : 231 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.

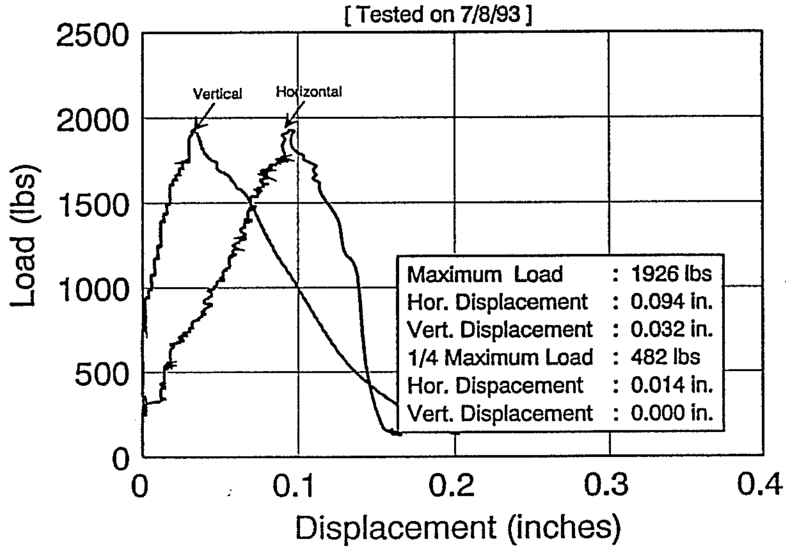
Test WA20-3

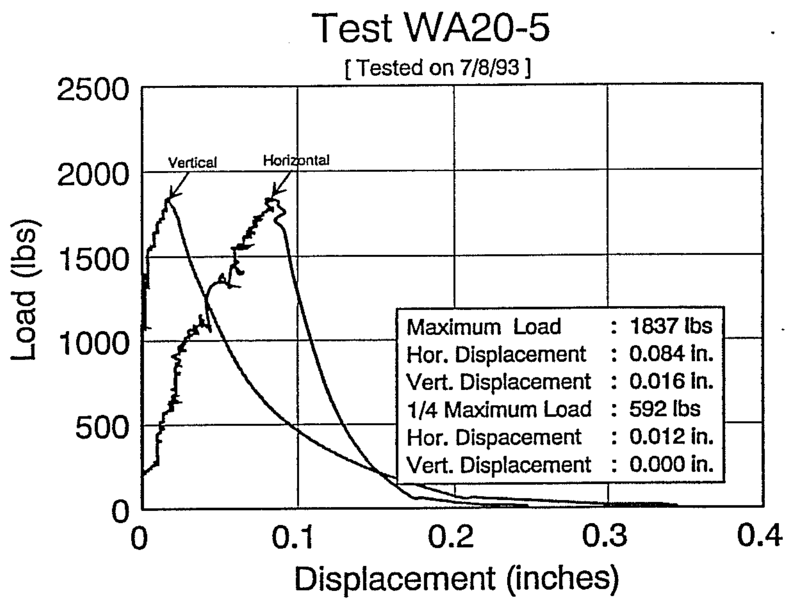
[Tested on 7/8/93]

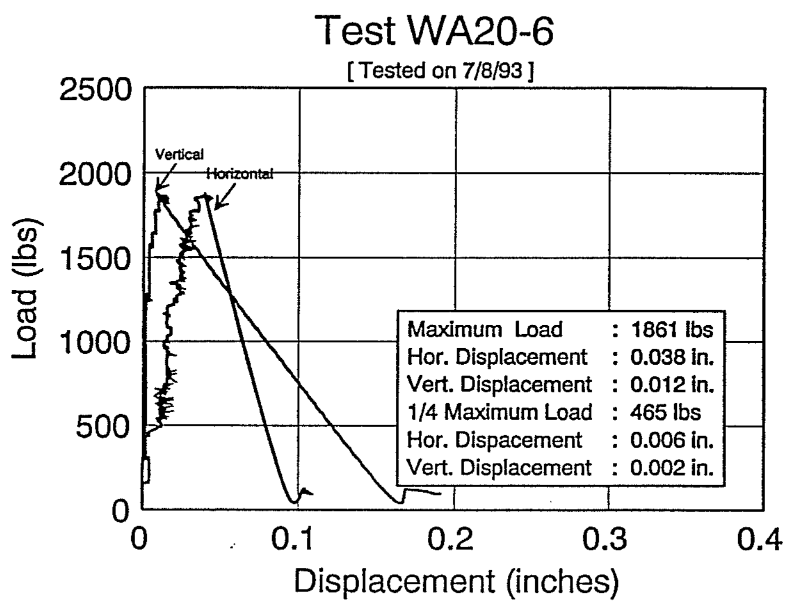


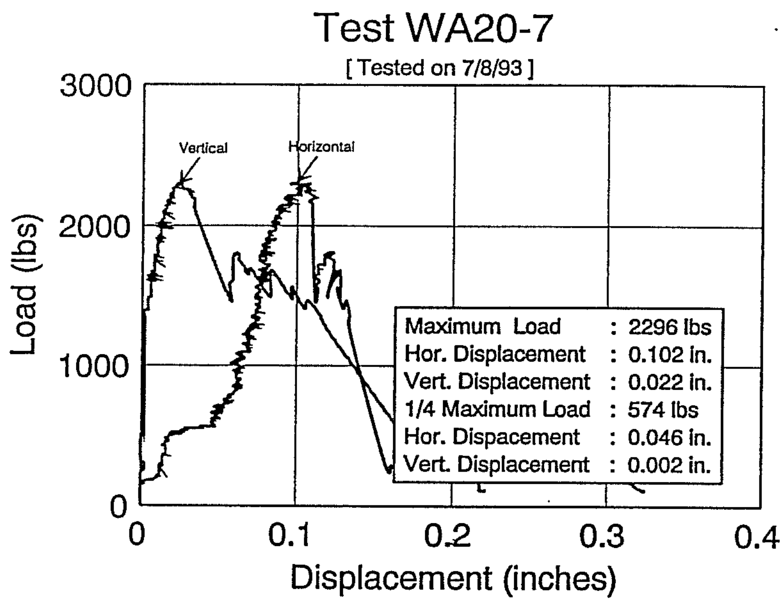
Test WA20-4

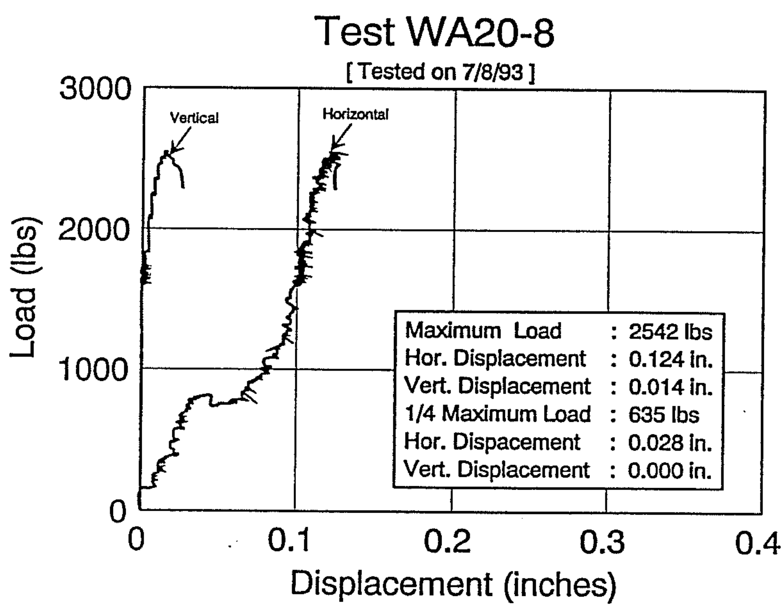
[Tested on 7/8/93]

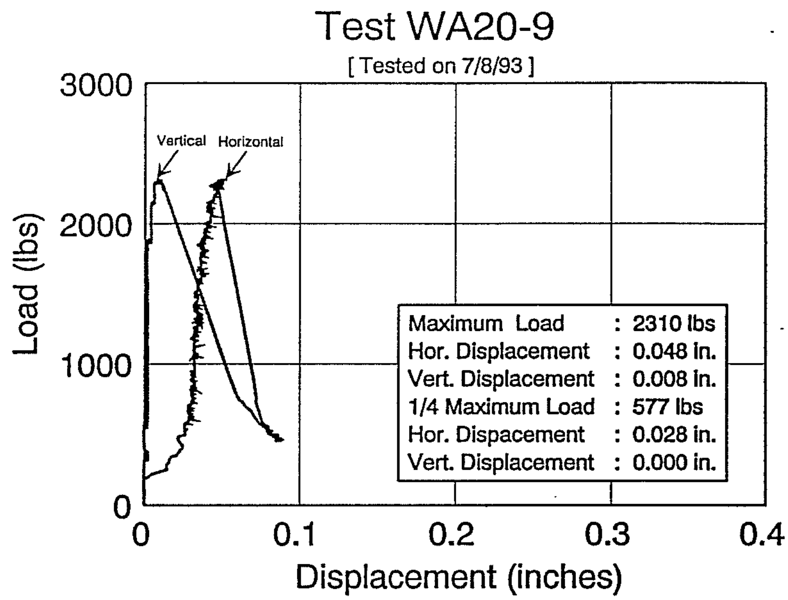


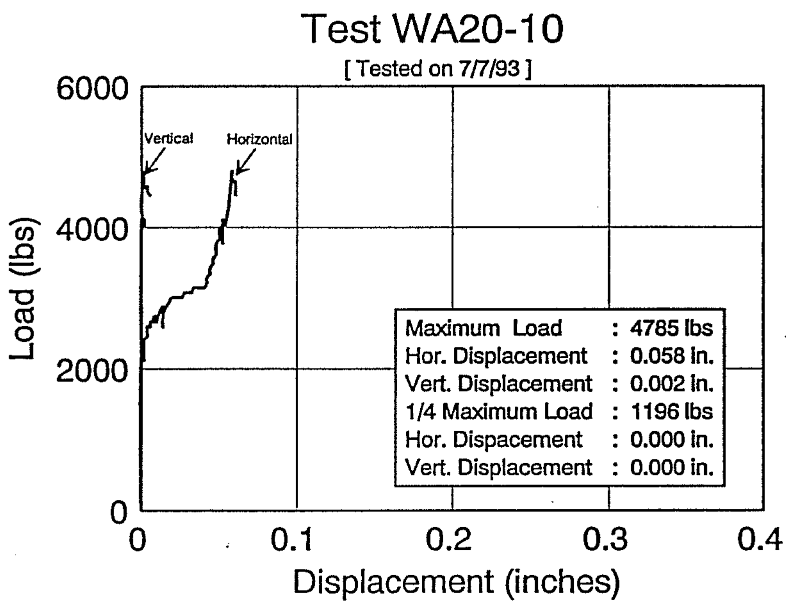

Test WA20-5
[Tested on 7/8/93]
Load (lbs)
2500
2000
1500
1000
500
0
Vertical
Horizontal
Maximum Load : 1837 lbs
Hor. Displacement : 0.084 in.
Vert. Displacement : 0.016 in.
1/4 Maximum Load : 592 lbs
Hor. Dispacement : 0.012 in.
Vert. Displacement : 0.000 in.
0
0.1
0.2
0.3
0.4
Displacement (inches)

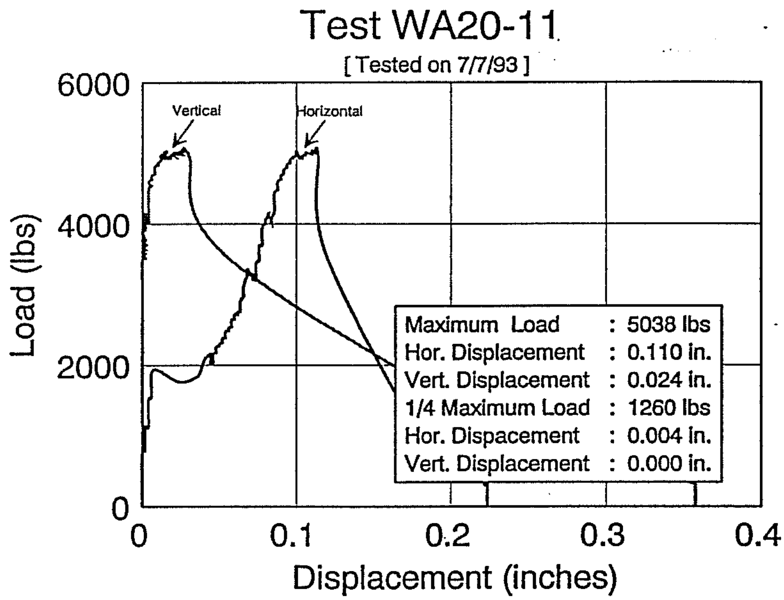

Test WA20-6
[Tested on 7/8/93]
Load (lbs)
2500
2000
1500
1000
500
0
Vertical
Horizontal
Maximum Load : 1861 lbs
Hor. Displacement : 0.038 in.
Vert. Displacement : 0.012 in.
1/4 Maximum Load : 465 lbs
Hor. Dispacement : 0.006 in.
Vert. Displacement : 0.002 in.
0
0.1
0.2
0.3
0.4
Displacement (inches)

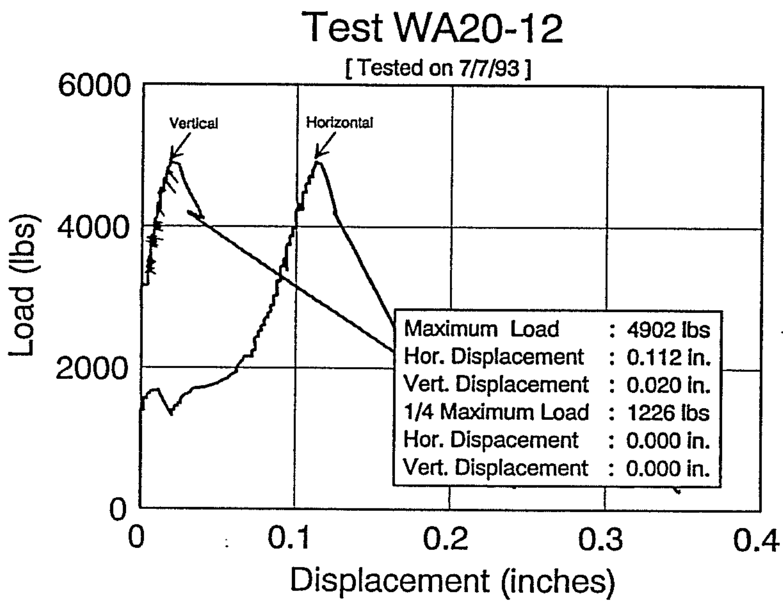

Test WA20-7
[Tested on 7/8/93]
3000
2000
1000
0
Load (lbs)
Vertical
Horizontal
0
0.1
0.2
0.3
0.4
Displacement (inches)
Maximum Load : 2296 lbs
Hor. Displacement : 0.102 in.
Vert. Displacement : 0.022 in.
1/4 Maximum Load : 574 lbs
Hor. Dispacement : 0.046 in.
Vert. Displacement : 0.002 in.

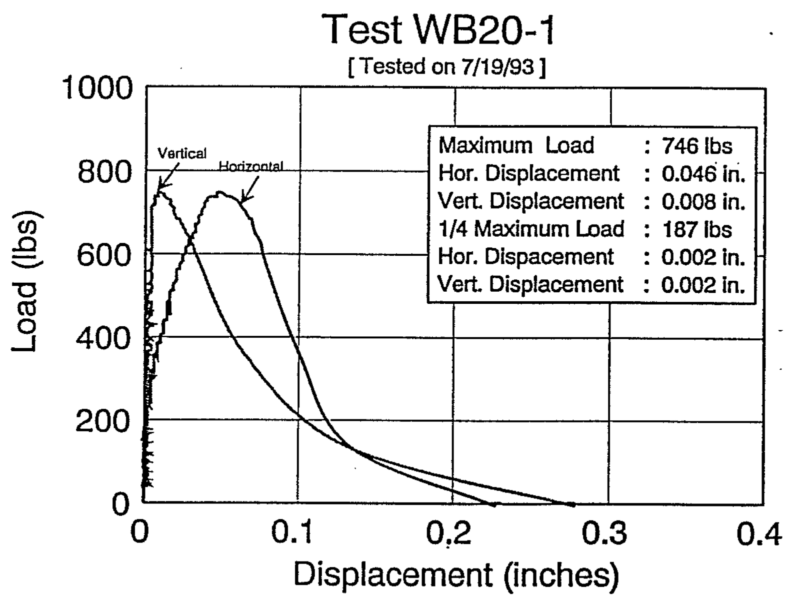

Test WA20-8
[Tested on 7/8/93]
3000
2000
1000
0
Load (lbs)
Vertical
Horizontal
0
0.1
0.2
0.3
0.4
Displacement (inches)
Maximum Load : 2542 lbs
Hor. Displacement : 0.124 in.
Vert. Displacement : 0.014 in.
1/4 Maximum Load : 635 lbs
Hor. Dispacement : 0.028 in.
Vert. Displacement : 0.000 in.

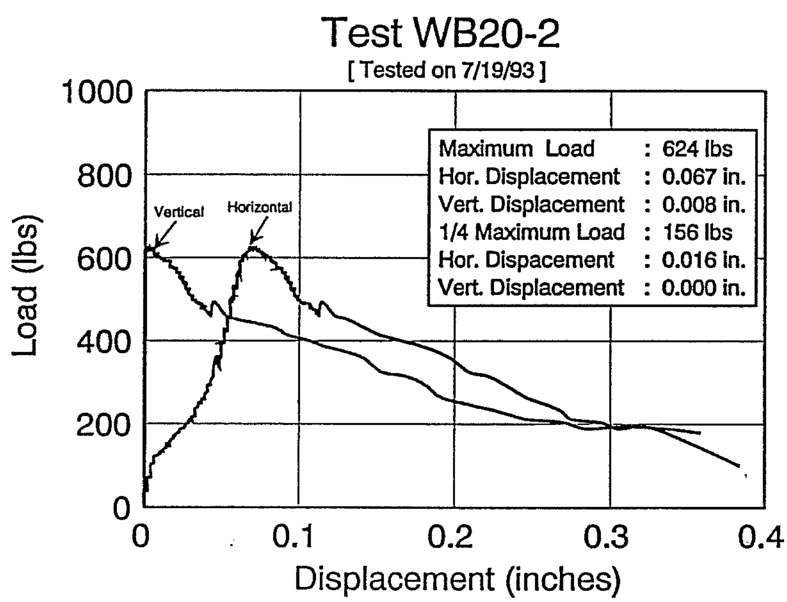

Test WA20-9
[Tested on 7/8/93]
3000
2000
1000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 2310 lbs
Hor. Displacement : 0.048 in.
Vert. Displacement : 0.008 in.
1/4 Maximum Load : 577 lbs
Hor. Dispacement : 0.028 in.
Vert. Displacement : 0.000 in.
0
0.1
0.2
0.3
0.4
Displacement (inches)

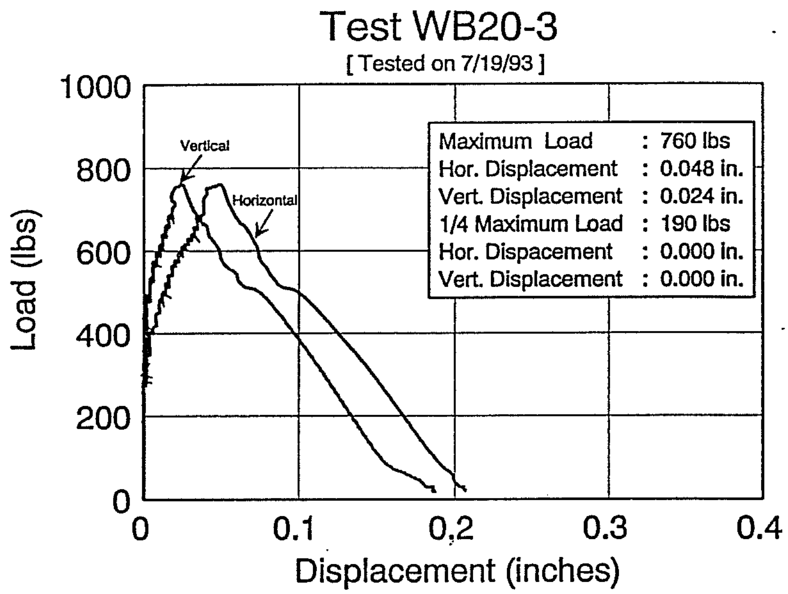

Test WA20-10
[Tested on 7/7/93]
6000
4000
2000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 4785 lbs
Hor. Displacement : 0.058 in.
Vert. Displacement : 0.002 in.
1/4 Maximum Load : 1196 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.
0
0.1
0.2
0.3
0.4
Displacement (inches)

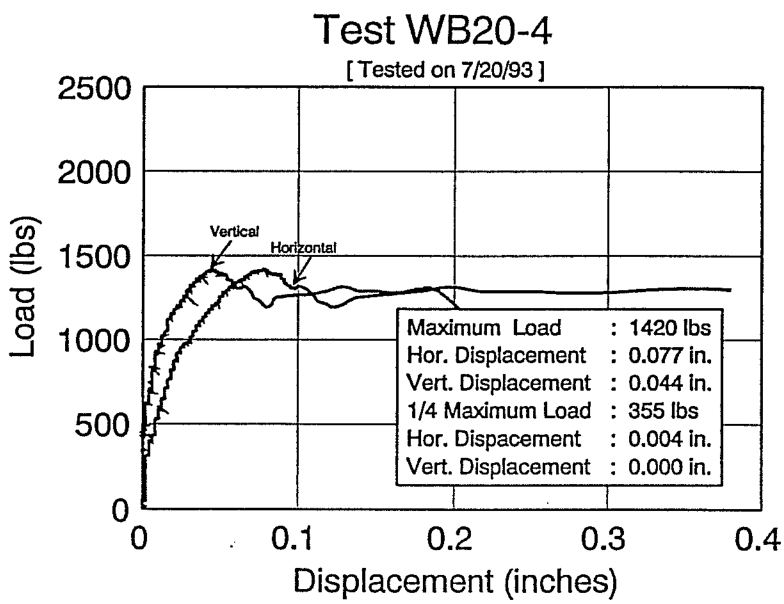

Test WA20-11
[Tested on 7/7/93]
Vertical
Horizontal
Maximum Load : 5038 lbs
Hor. Displacement : 0.110 in.
Vert. Displacement : 0.024 in.
1/4 Maximum Load : 1260 lbs
Hor. Dispacement : 0.004 in.
Vert. Displacement : 0.000 in.
Load (lbs)
0
2000
4000
6000
0
0.1
0.2
0.3
0.4
Displacement (inches)

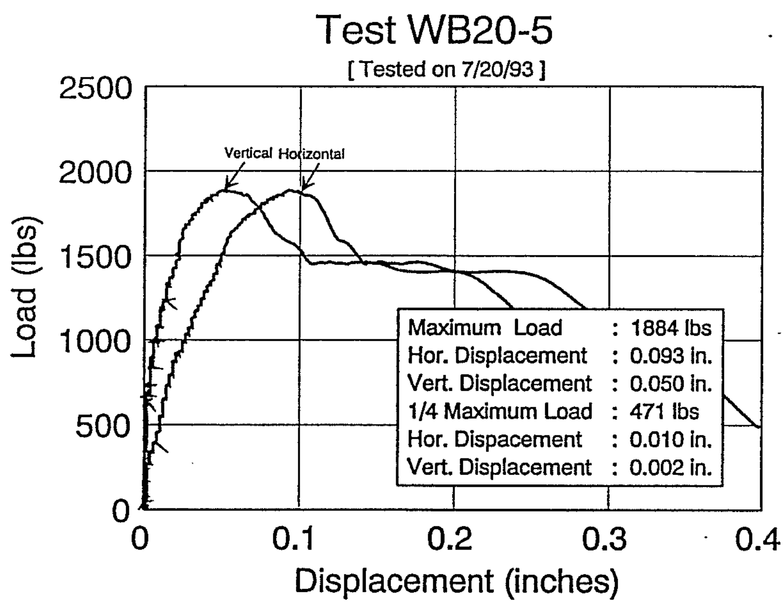

Test WA20-12
[Tested on 7/7/93]
Vertical
Horizontal
Maximum Load : 4902 lbs
Hor. Displacement : 0.112 in.
Vert. Displacement : 0.020 in.
1/4 Maximum Load : 1226 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.
Load (lbs)
0
2000
4000
6000
0
0.1
0.2
0.3
0.4
Displacement (inches)

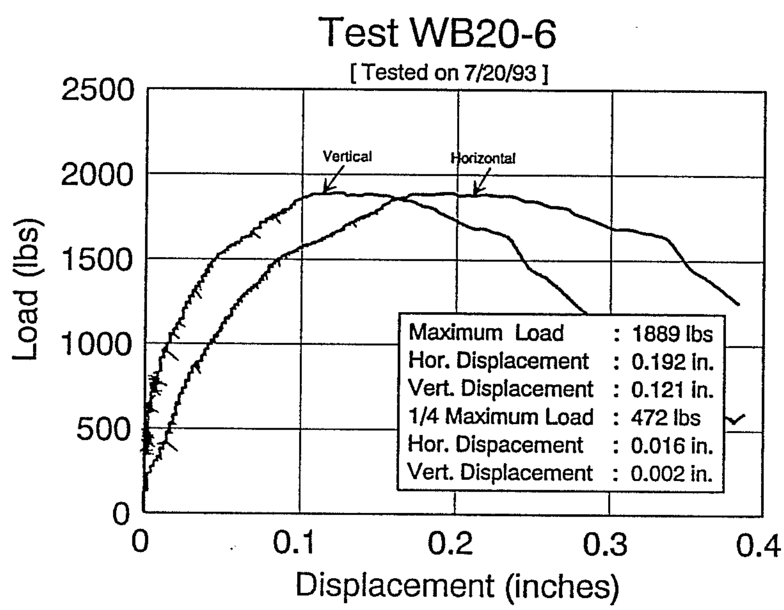

Test WB20-1
[Tested on 7/19/93]
Maximum Load : 746 lbs
Hor. Displacement : 0.046 in.
Vert. Displacement : 0.008 in.
1/4 Maximum Load : 187 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.002 in.
Vertical
Horizontal
Load (lbs)
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
Displacement (inches)


Test WB20-2
[Tested on 7/19/93]
Maximum Load : 624 lbs
Hor. Displacement : 0.067 in.
Vert. Displacement : 0.008 in.
1/4 Maximum Load : 156 lbs
Hor. Dispacement : 0.016 in.
Vert. Displacement : 0.000 in.
Vertical
Horizontal
Load (lbs)
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
Displacement (inches)


Test WB20-3
[Tested on 7/19/93]
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 760 lbs
Hor. Displacement : 0.048 in.
Vert. Displacement : 0.024 in.
1/4 Maximum Load : 190 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.

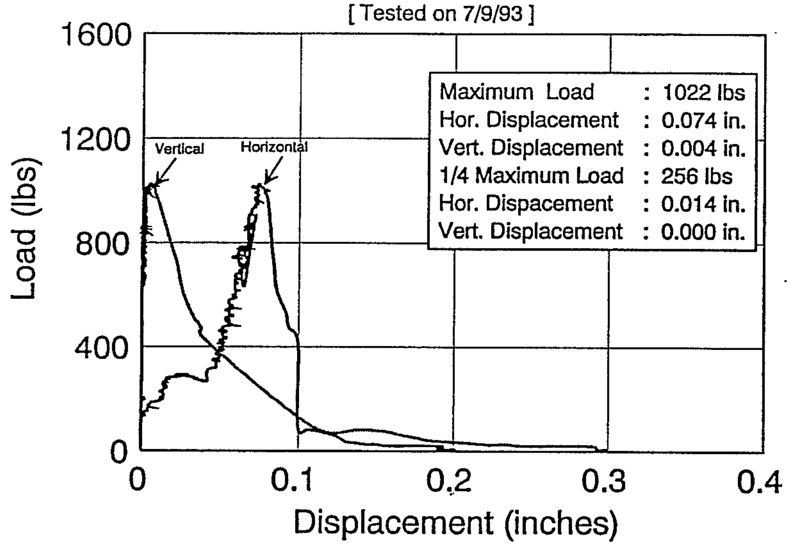

Test WB20-4
[Tested on 7/20/93]
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 1420 lbs
Hor. Displacement : 0.077 in.
Vert. Displacement : 0.044 in.
1/4 Maximum Load : 355 lbs
Hor. Dispacement : 0.004 in.
Vert. Displacement : 0.000 in.


Test WB20-5
[Tested on 7/20/93]
Vertical
Horizontal
Maximum Load : 1884 lbs
Hor. Displacement : 0.093 in.
Vert. Displacement : 0.050 in.
1/4 Maximum Load : 471 lbs
Hor. Dispacement : 0.010 in.
Vert. Displacement : 0.002 in.
Load (lbs)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
Displacement (inches)


Test WB20-6
[Tested on 7/20/93]
Vertical
Horizontal
Maximum Load : 1889 lbs
Hor. Displacement : 0.192 in.
Vert. Displacement : 0.121 in.
1/4 Maximum Load : 472 lbs
Hor. Dispacement : 0.016 in.
Vert. Displacement : 0.002 in.
Load (lbs)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

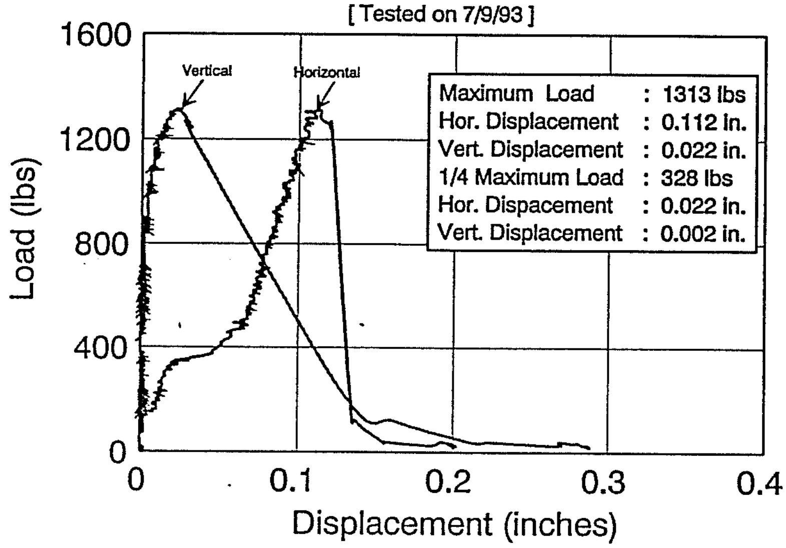
Test WB20-7

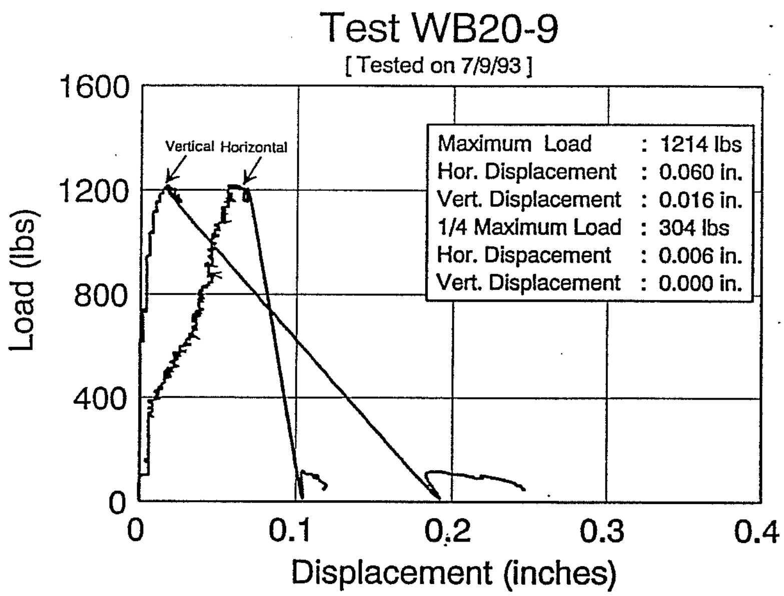
[Tested on 7/9/93]

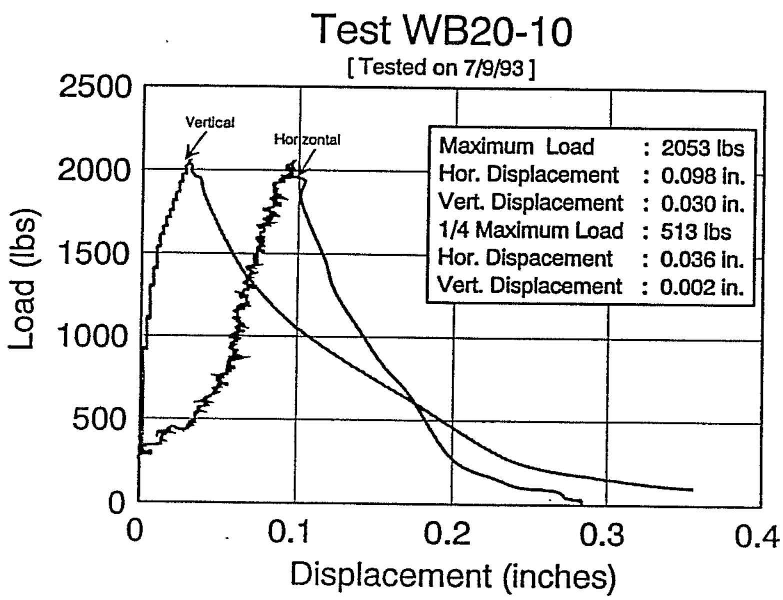


Test WB20-8

[Tested on 7/9/93]

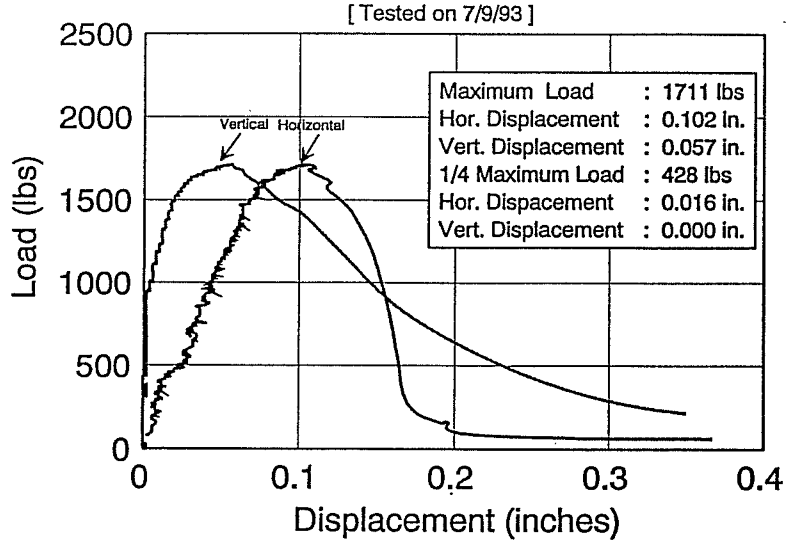



Test WB20-9
[Tested on 7/9/93]
Vertical
Horizontal
Maximum Load : 1214 lbs
Hor. Displacement : 0.060 in.
Vert. Displacement : 0.016 in.
1/4 Maximum Load : 304 lbs
Hor. Dispacement : 0.006 in.
Vert. Displacement : 0.000 in.
Load (lbs)
1600
1200
800
400
0
0
0.1
0.2
0.3
0.4
Displacement (inches)


Test WB20-10
[Tested on 7/9/93]
Vertical
Horizontal
Maximum Load : 2053 lbs
Hor. Displacement : 0.098 in.
Vert. Displacement : 0.030 in.
1/4 Maximum Load : 513 lbs
Hor. Dispacement : 0.036 in.
Vert. Displacement : 0.002 in.
Load (lbs)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

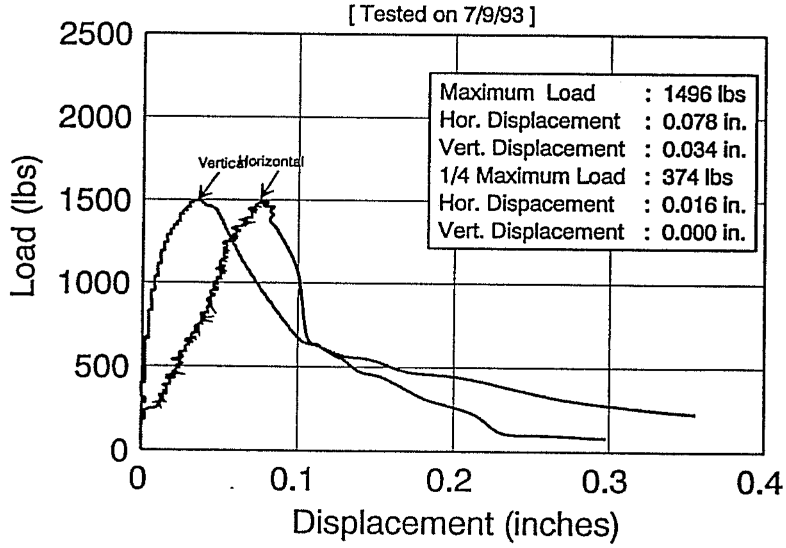
Test WB20-11

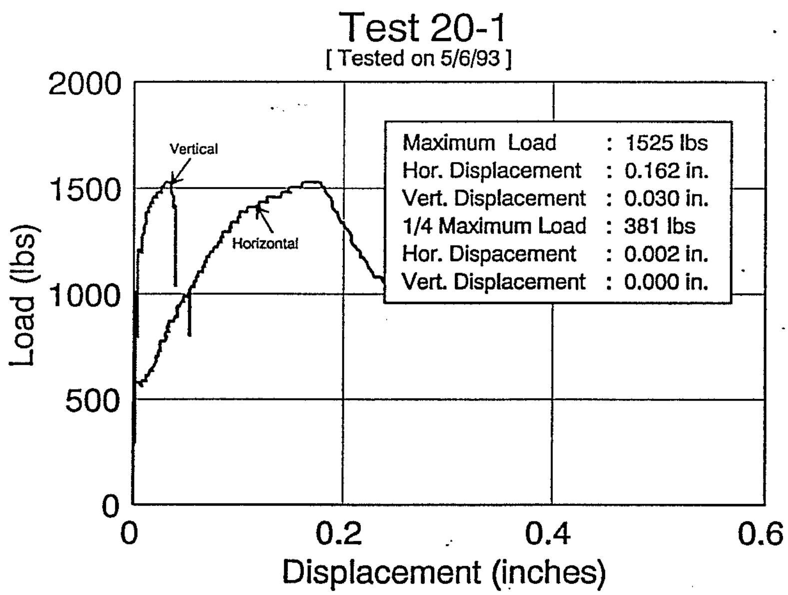
[Tested on 7/9/93]

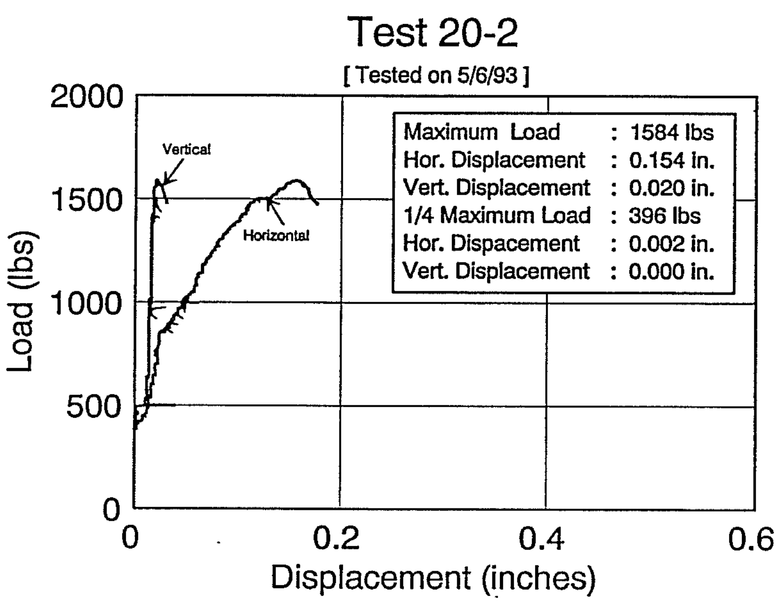


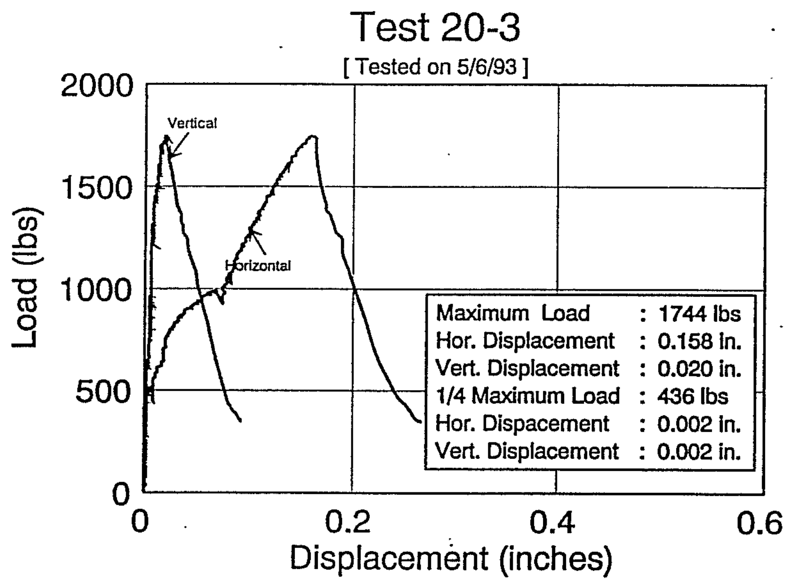
Test WB20-12

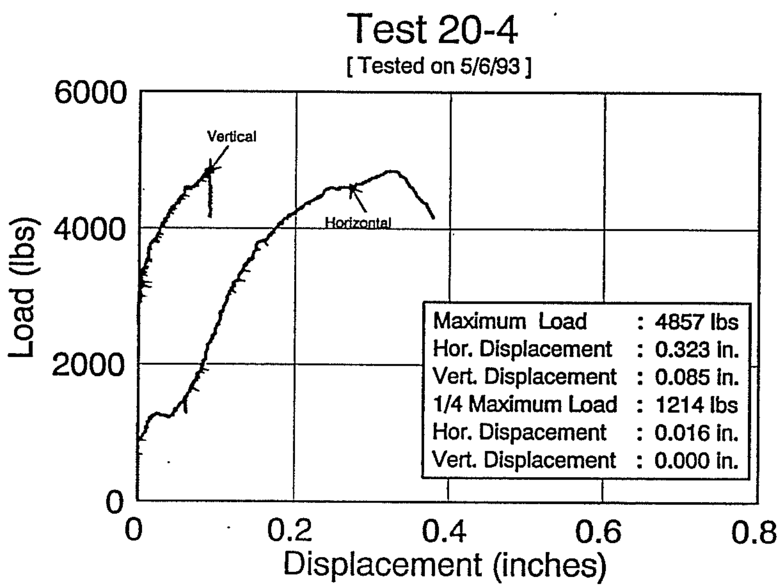
[Tested on 7/9/93]

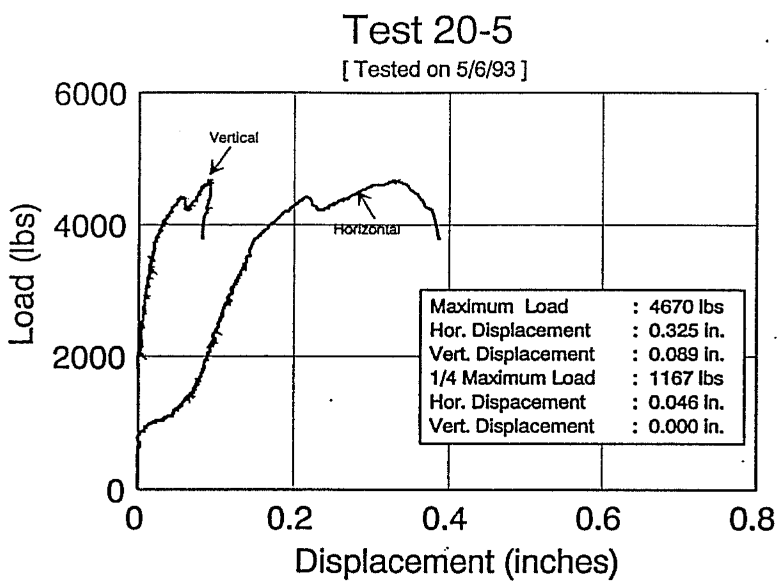


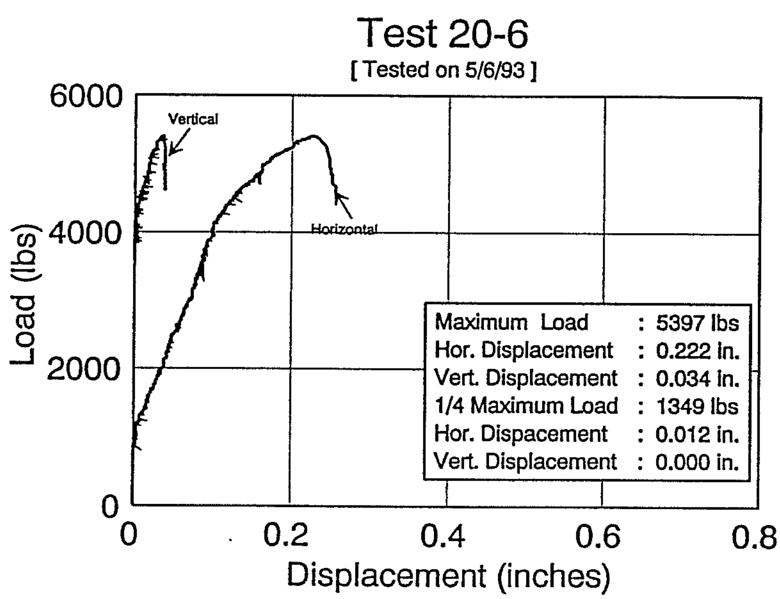

Test 20-1
[Tested on 5/6/93]
Maximum Load : 1525 lbs
Hor. Displacement : 0.162 in.
Vert. Displacement : 0.030 in.
1/4 Maximum Load : 381 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.
Vertical
Horizontal
Load (lbs)
Displacement (inches)
2000
1500
1000
500
0
0
0.2
0.4
0.6

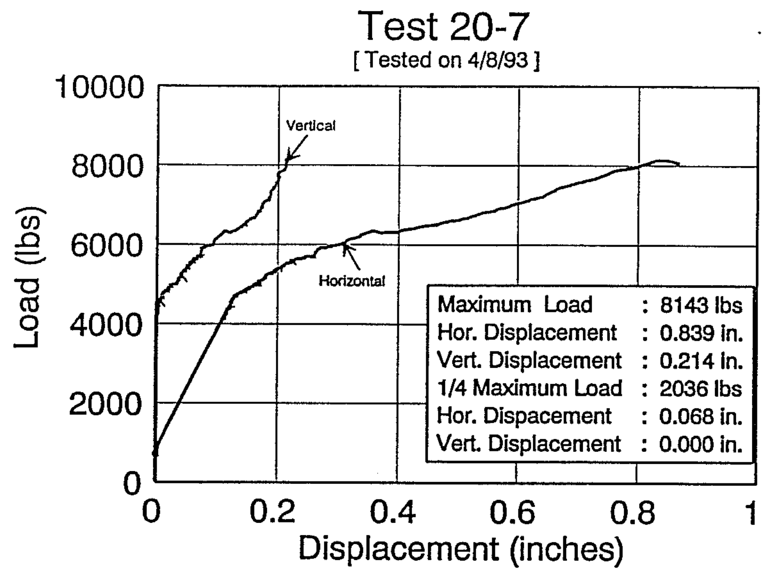

Test 20-2
[Tested on 5/6/93]
Maximum Load : 1584 lbs
Hor. Displacement : 0.154 in.
Vert. Displacement : 0.020 in.
1/4 Maximum Load : 396 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.
Vertical
Horizontal
Load (lbs)
Displacement (inches)
2000
1500
1000
500
0
0
0.2
0.4
0.6

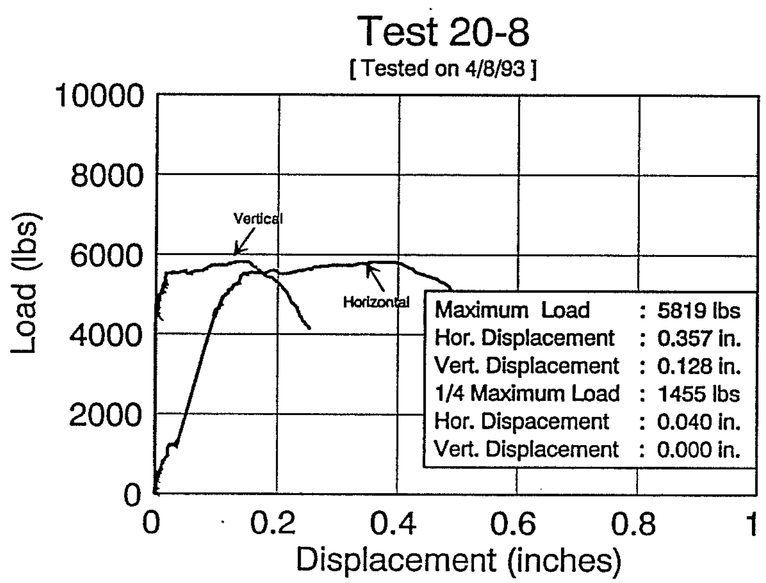

Test 20-3
[Tested on 5/6/93]
2000
1500
1000
500
0
Load (lbs)
0
0.2
0.4
0.6
Displacement (inches)
Vertical
Horizontal
Maximum Load : 1744 lbs
Hor. Displacement : 0.158 in.
Vert. Displacement : 0.020 in.
1/4 Maximum Load : 436 lbs
Hor. Displacement : 0.002 in.
Vert. Displacement : 0.002 in.

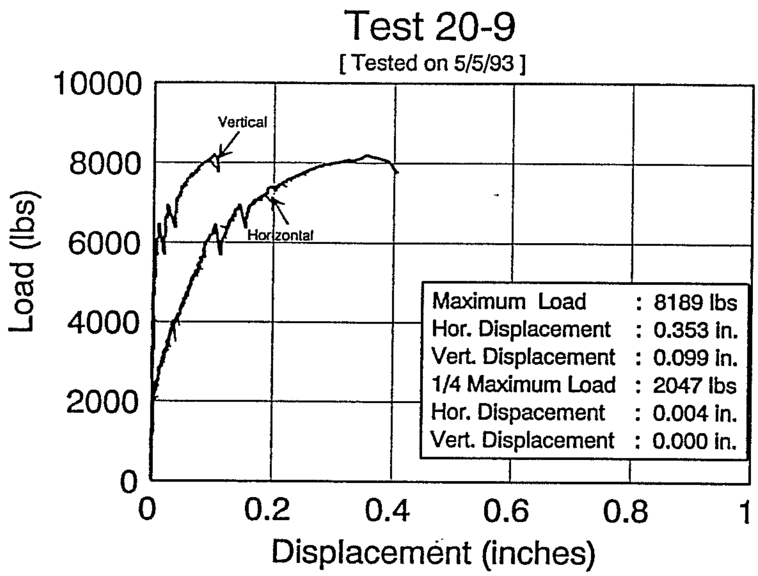

Test 20-4
[Tested on 5/6/93]
6000
4000
2000
0
Load (lbs)
0
0.2
0.4
0.6
0.8
Displacement (inches)
Vertical
Horizontal
Maximum Load : 4857 lbs
Hor. Displacement : 0.323 in.
Vert. Displacement : 0.085 in.
1/4 Maximum Load : 1214 lbs
Hor. Dispacement : 0.016 in.
Vert. Displacement : 0.000 in.

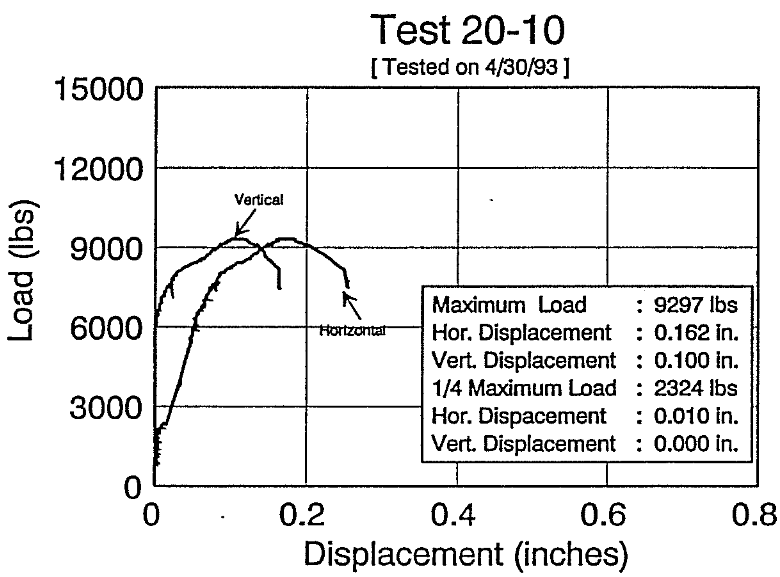

Test 20-5
[Tested on 5/6/93]
Vertical
Horizontal
Load (lbs)
Displacement (inches)
Maximum Load : 4670 lbs
Hor. Displacement : 0.325 in.
Vert. Displacement : 0.089 in.
1/4 Maximum Load : 1167 lbs
Hor. Dispacement : 0.046 in.
Vert. Displacement : 0.000 in.

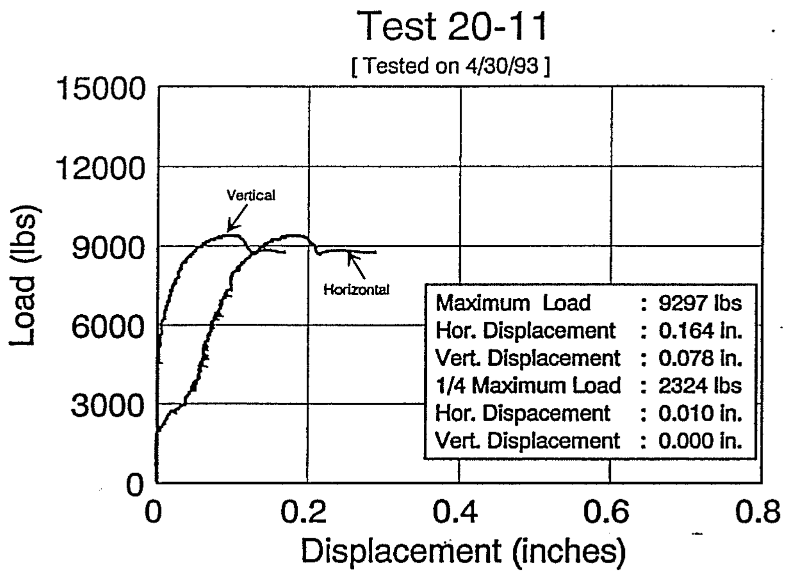

Test 20-6
[Tested on 5/6/93]
Vertical
Horizontal
Load (lbs)
Displacement (inches)
Maximum Load : 5397 lbs
Hor. Displacement : 0.222 in.
Vert. Displacement : 0.034 in.
1/4 Maximum Load : 1349 lbs
Hor. Dispacement : 0.012 in.
Vert. Displacement : 0.000 in.

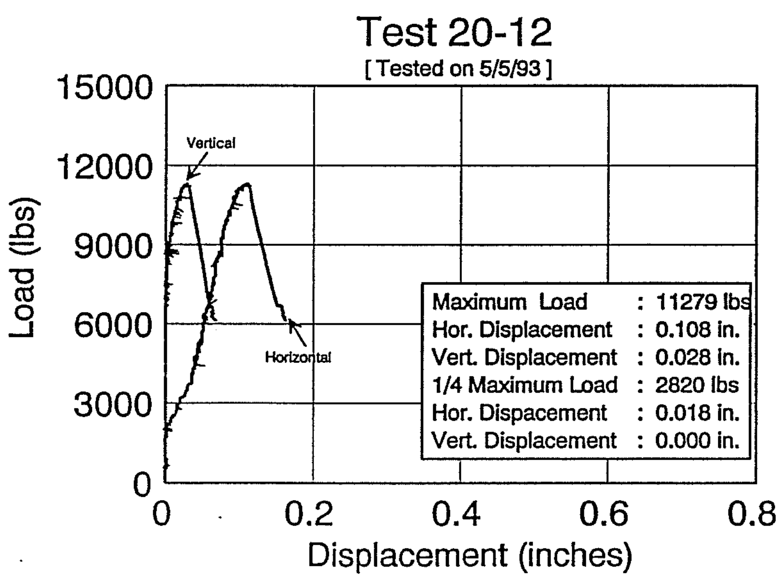

Test 20-7
[Tested on 4/8/93]
10000
8000
6000
4000
2000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 8143 lbs
Hor. Displacement : 0.839 in.
Vert. Displacement : 0.214 in.
1/4 Maximum Load : 2036 lbs
Hor. Dispacement : 0.068 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

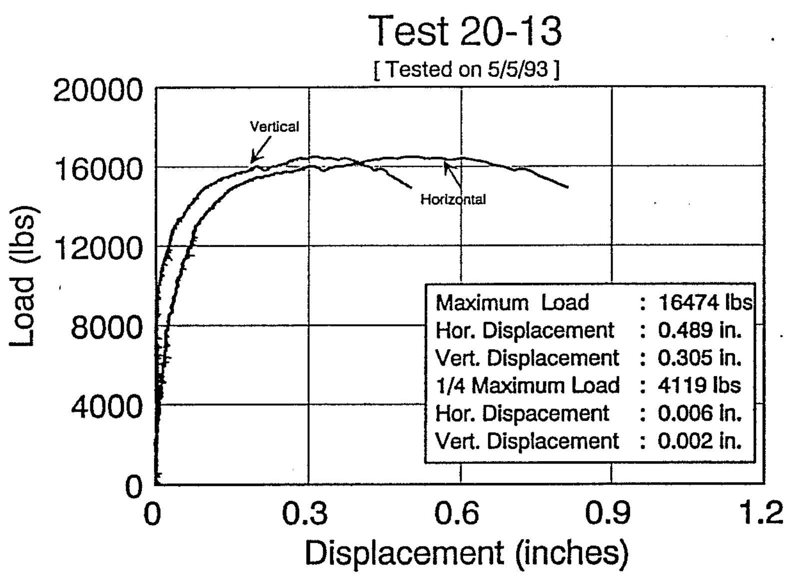

Test 20-8
[Tested on 4/8/93]
10000
8000
6000
4000
2000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 5819 lbs
Hor. Displacement : 0.357 in.
Vert. Displacement : 0.128 in.
1/4 Maximum Load : 1455 lbs
Hor. Dispacement : 0.040 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
1
Displacement (inches)


Test 20-9
[Tested on 5/5/93]
Load (lbs)
10000
8000
6000
4000
2000
0
Vertical
Horizontal
Maximum Load : 8189 lbs
Hor. Displacement : 0.353 in.
Vert. Displacement : 0.099 in.
1/4 Maximum Load : 2047 lbs
Hor. Dispacement : 0.004 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

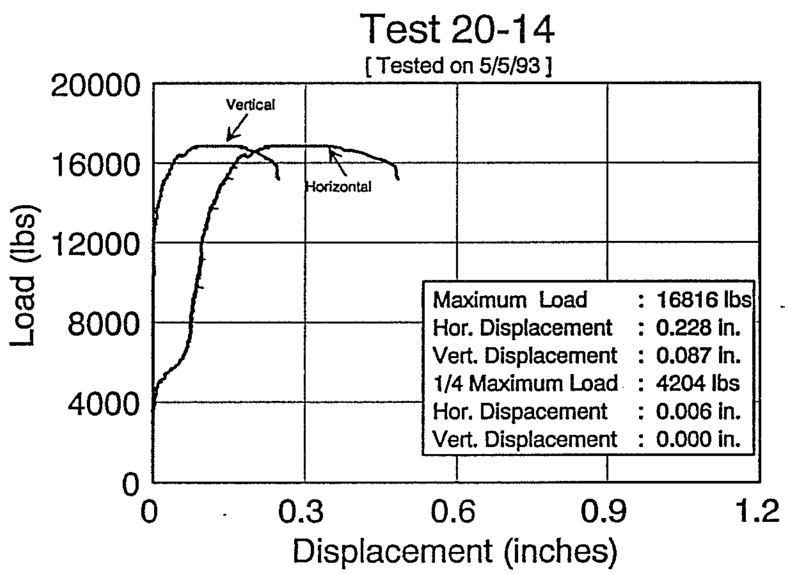

Test 20-10
[Tested on 4/30/93]
Load (lbs)
15000
12000
9000
6000
3000
0
Vertical
Horizontal
Maximum Load : 9297 lbs
Hor. Displacement : 0.162 in.
Vert. Displacement : 0.100 in.
1/4 Maximum Load : 2324 lbs
Hor. Dispacement : 0.010 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test 20-11
[Tested on 4/30/93]
15000
12000
9000
6000
3000
0
0
0.2
0.4
0.6
0.8
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 9297 lbs
Hor. Displacement : 0.164 in.
Vert. Displacement : 0.078 in.
1/4 Maximum Load : 2324 lbs
Hor. Dispacement : 0.010 in.
Vert. Displacement : 0.000 in.

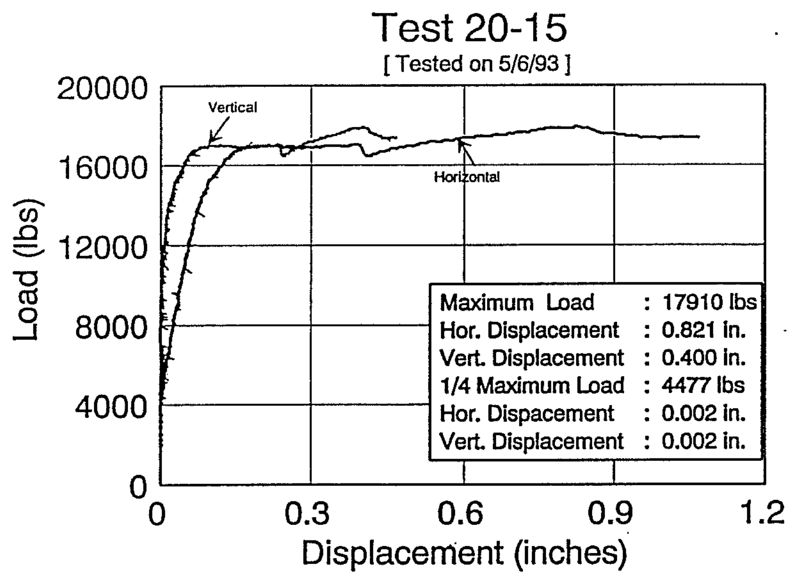

Test 20-12
[Tested on 5/5/93]
15000
12000
9000
6000
3000
0
0
0.2
0.4
0.6
0.8
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 11279 lbs
Hor. Displacement : 0.108 in.
Vert. Displacement : 0.028 in.
1/4 Maximum Load : 2820 lbs
Hor. Dispacement : 0.018 in.
Vert. Displacement : 0.000 in.

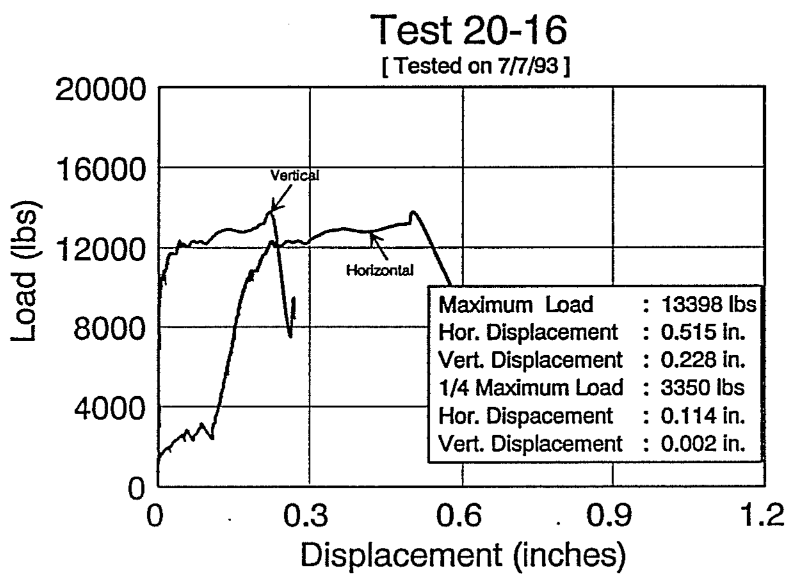


Test 20-13
[Tested on 5/5/93]
Load (lbs)
20000
16000
12000
8000
4000
0
0
0.3
0.6
0.9
1.2
Displacement (inches)
Vertical
Horizontal
Maximum Load : 16474 lbs
Hor. Displacement : 0.489 in.
Vert. Displacement : 0.305 in.
1/4 Maximum Load : 4119 lbs
Hor. Dispacement : 0.006 in.
Vert. Displacement : 0.002 in.

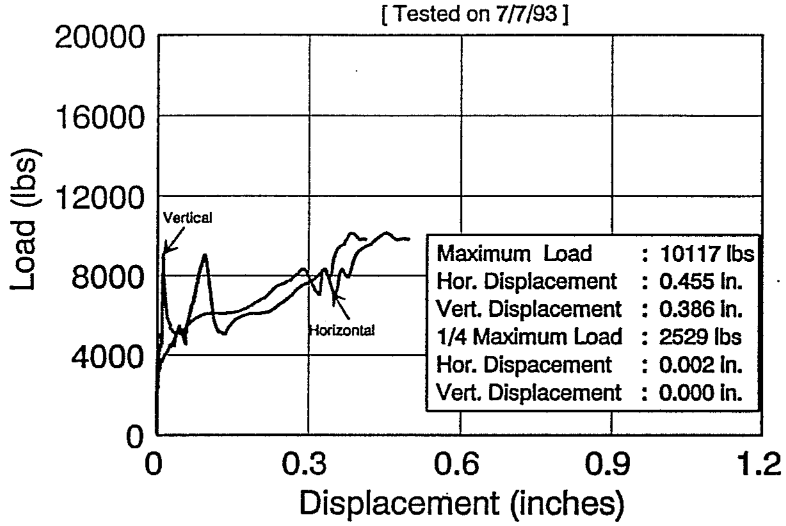


Test 20-14
[Tested on 5/5/93]
Load (lbs)
20000
16000
12000
8000
4000
0
0
0.3
0.6
0.9
1.2
Displacement (inches)
Vertical
Horizontal
Maximum Load : 16816 lbs
Hor. Displacement : 0.228 in.
Vert. Displacement : 0.087 in.
1/4 Maximum Load : 4204 lbs
Hor. Dispacement : 0.006 in.
Vert. Displacement : 0.000 in.

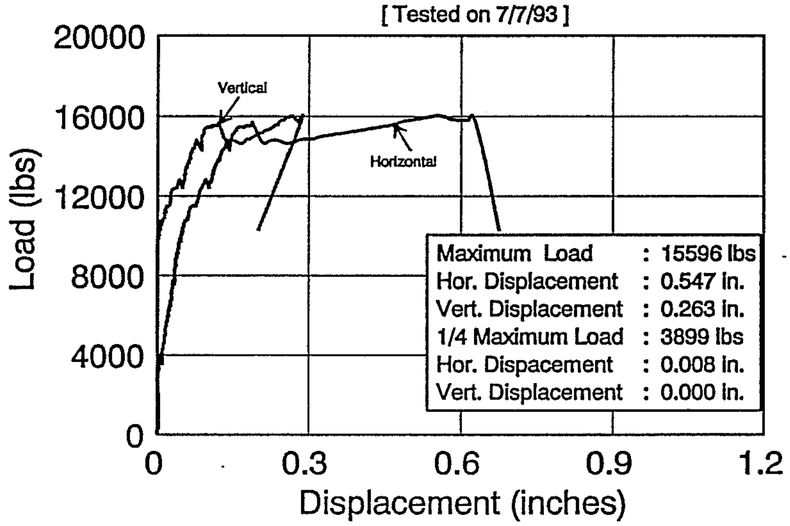

Test 20-15
[Tested on 5/6/93]
Vertical
Horizontal
Maximum Load : 17910 lbs
Hor. Displacement : 0.821 in.
Vert. Displacement : 0.400 in.
1/4 Maximum Load : 4477 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.002 in.
Load (lbs)
Displacement (inches)
20000
16000
12000
8000
4000
0
0
0.3
0.6
0.9
1.2

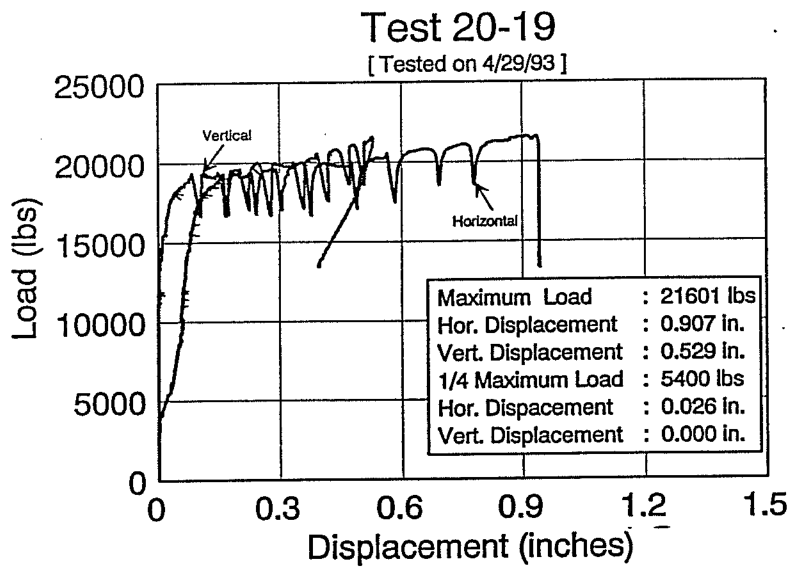

Test 20-16
[Tested on 7/7/93]
Vertical
Horizontal
Maximum Load : 13398 lbs
Hor. Displacement : 0.515 in.
Vert. Displacement : 0.228 in.
1/4 Maximum Load : 3350 lbs
Hor. Dispacement : 0.114 in.
Vert. Displacement : 0.002 in.
Load (lbs)
Displacement (inches)
20000
16000
12000
8000
4000
0
0
0.3
0.6
0.9
1.2

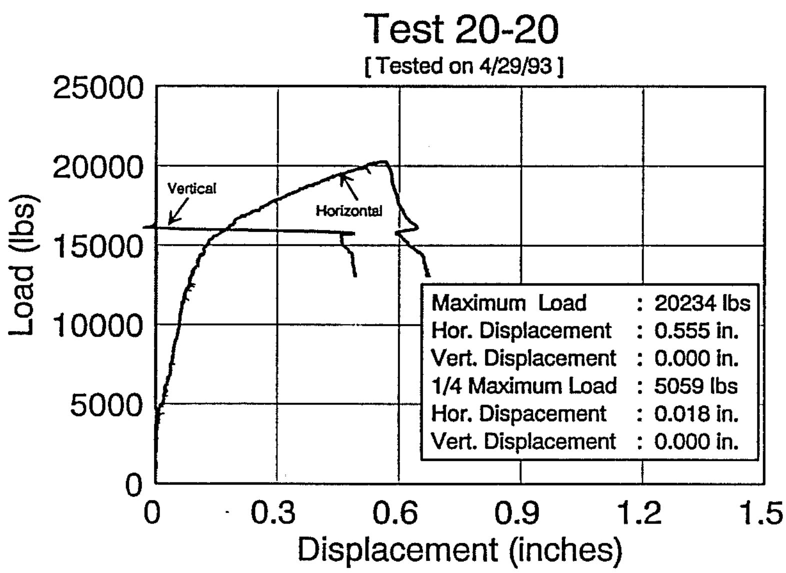
Test 20-17
[Tested on 7/7/93]

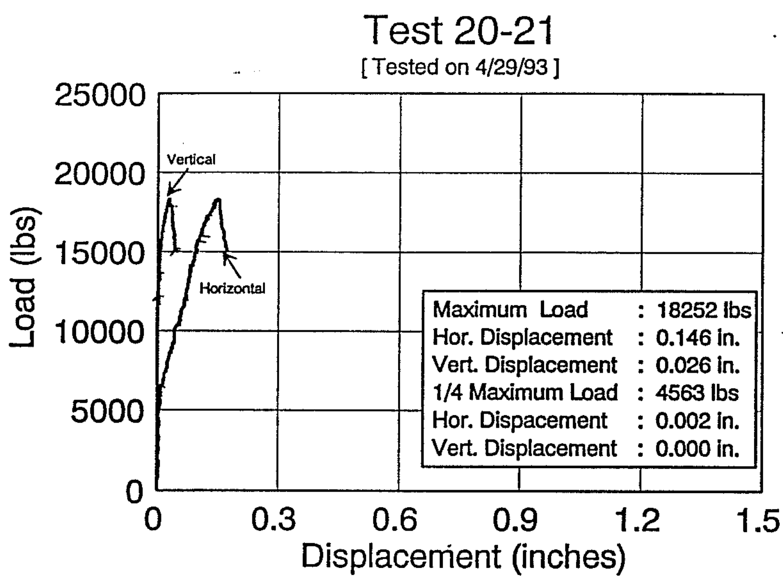


Test 20-18
[Tested on 7/7/93]

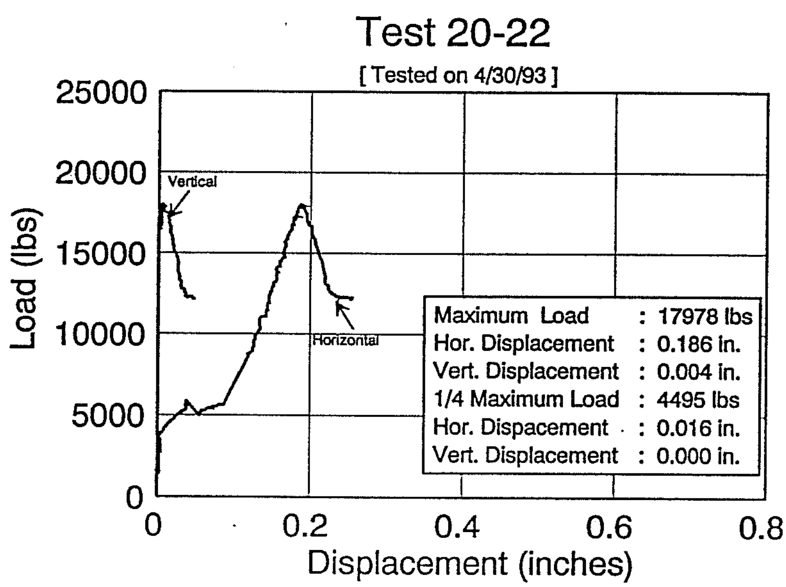



Test 20-19
[Tested on 4/29/93]
Load (lbs)
Displacement (inches)
25000
20000
15000
10000
5000
0
0
0.3
0.6
0.9
1.2
1.5
Vertical
Horizontal
Maximum Load : 21601 lbs
Hor. Displacement : 0.907 in.
Vert. Displacement : 0.529 in.
1/4 Maximum Load : 5400 lbs
Hor. Dispacement : 0.026 in.
Vert. Displacement : 0.000 in.

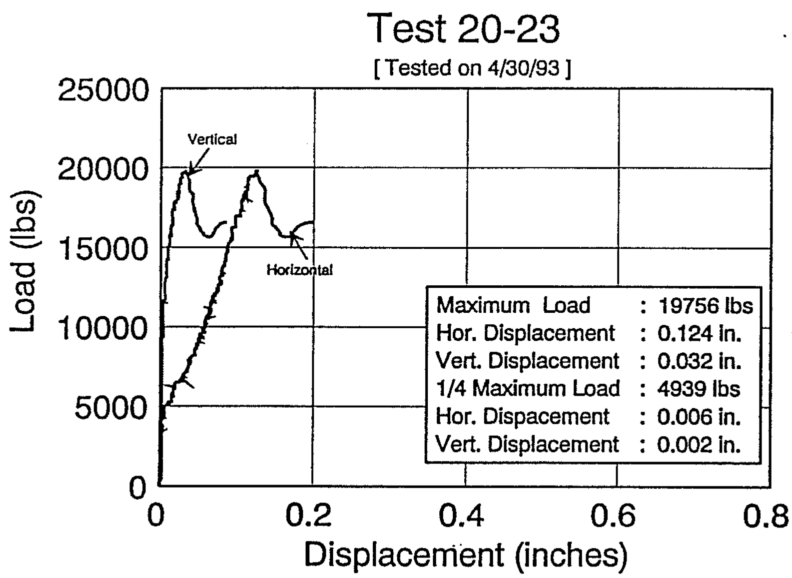

Test 20-20
[Tested on 4/29/93]
Load (lbs)
Displacement (inches)
25000
20000
15000
10000
5000
0
0
0.3
0.6
0.9
1.2
1.5
Vertical
Horizontal
Maximum Load : 20234 lbs
Hor. Displacement : 0.555 in.
Vert. Displacement : 0.000 in.
1/4 Maximum Load : 5059 lbs
Hor. Dispacement : 0.018 in.
Vert. Displacement : 0.000 in.

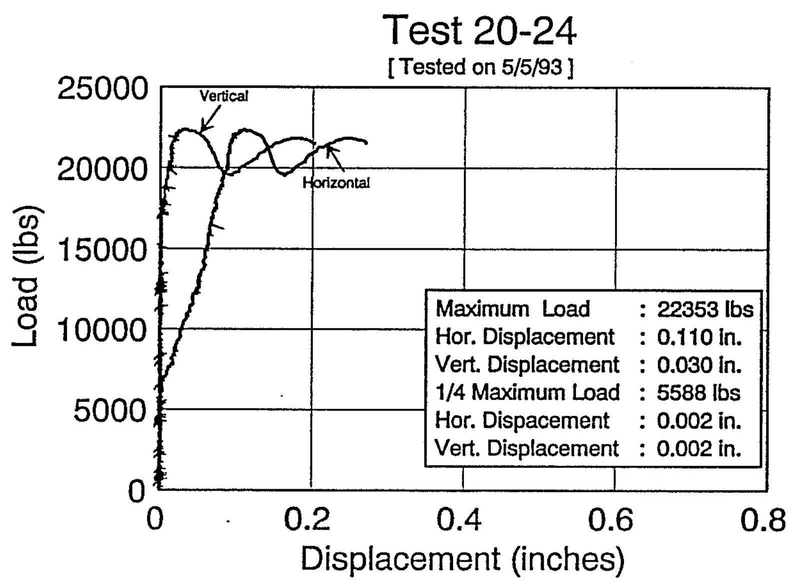


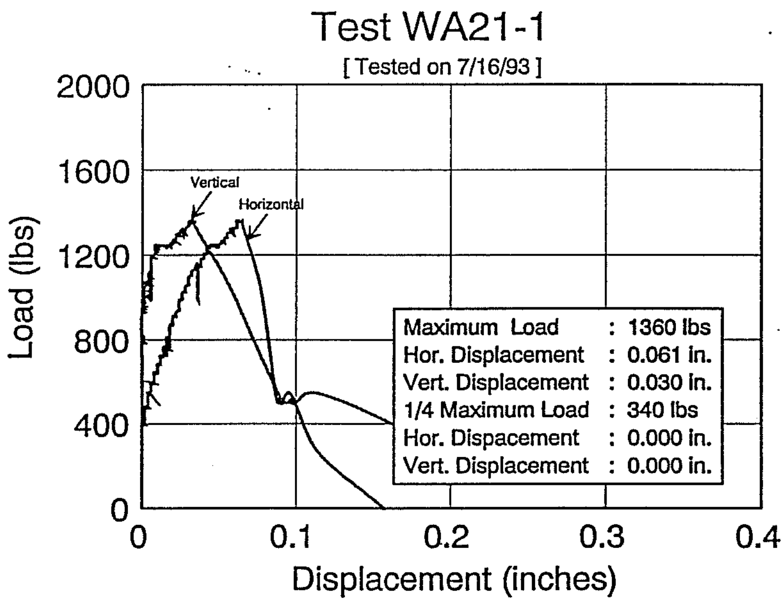
Test 20-21
[Tested on 4/29/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 18252 lbs
Hor. Displacement : 0.146 in.
Vert. Displacement : 0.026 in.
1/4 Maximum Load : 4563 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.
0
0.3
0.6
0.9
1.2
1.5
Displacement (inches)

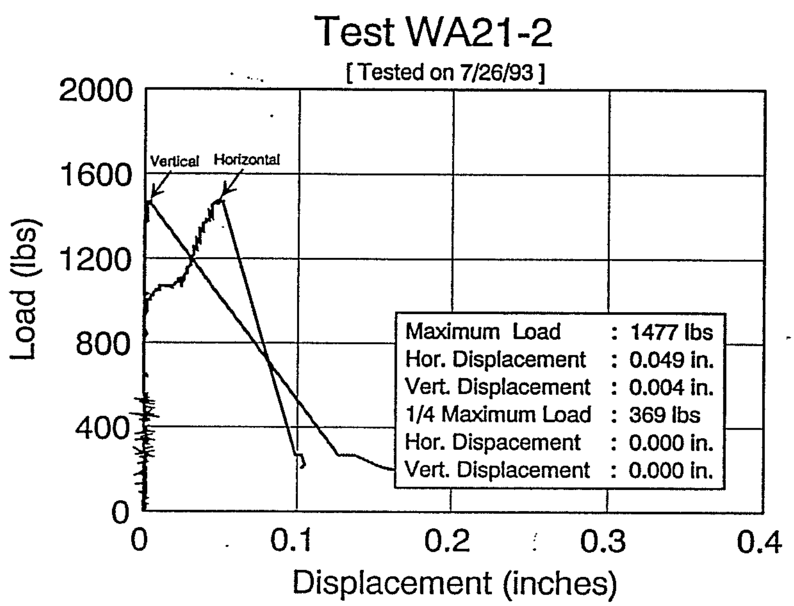


Test 20-22
[Tested on 4/30/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 17978 lbs
Hor. Displacement : 0.186 in.
Vert. Displacement : 0.004 in.
1/4 Maximum Load : 4495 lbs
Hor. Dispacement : 0.016 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test 20-23
[Tested on 4/30/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 19756 lbs
Hor. Displacement : 0.124 in.
Vert. Displacement : 0.032 in.
1/4 Maximum Load : 4939 lbs
Hor. Dispacement : 0.006 in.
Vert. Displacement : 0.002 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)

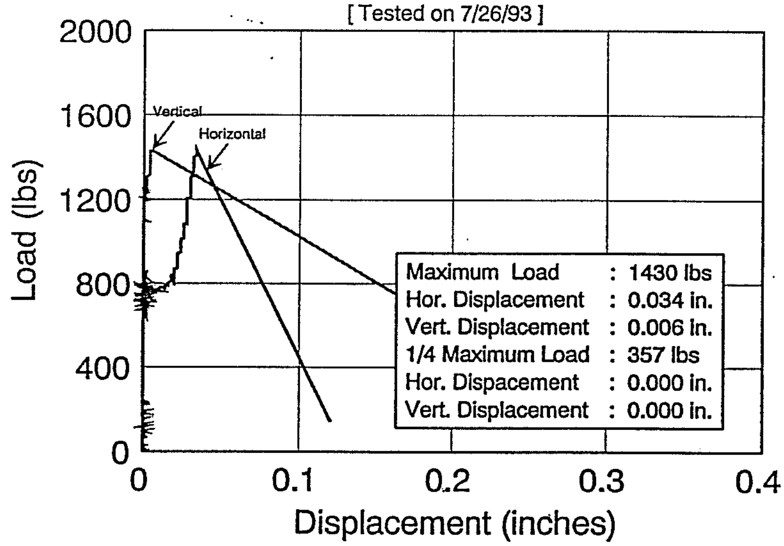

Test 20-24
[Tested on 5/5/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 22353 lbs
Hor. Displacement : 0.110 in.
Vert. Displacement : 0.030 in.
1/4 Maximum Load : 5588 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.002 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test WA21-1
[Tested on 7/16/93]
Load (lbs)
Displacement (inches)
Vertical
Horizontal
0
400
800
1200
1600
2000
0
0.1
0.2
0.3
0.4
Maximum Load : 1360 lbs
Hor. Displacement : 0.061 in.
Vert. Displacement : 0.030 in.
1/4 Maximum Load : 340 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.


Test WA21-2
[Tested on 7/26/93]
Load (lbs)
Displacement (inches)
Vertical
Horizontal
0
400
800
1200
1600
2000
0
0.1
0.2
0.3
0.4
Maximum Load : 1477 lbs
Hor. Displacement : 0.049 in.
Vert. Displacement : 0.004 in.
1/4 Maximum Load : 369 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.

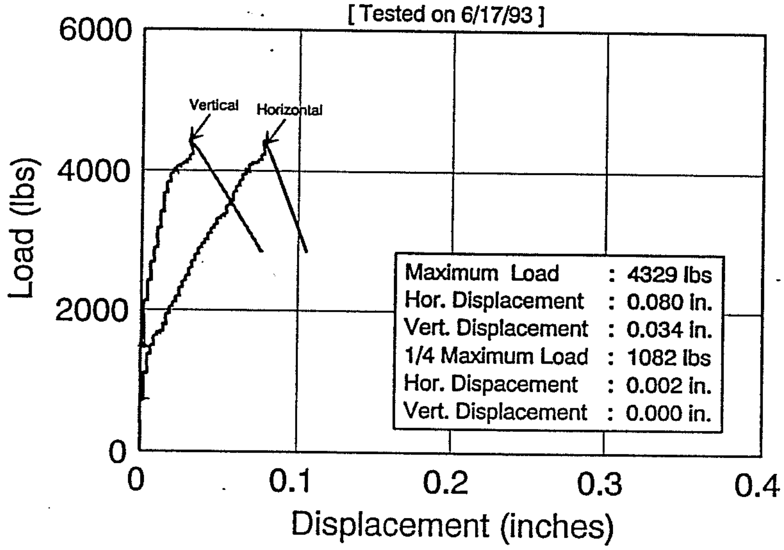
Test WA21-3

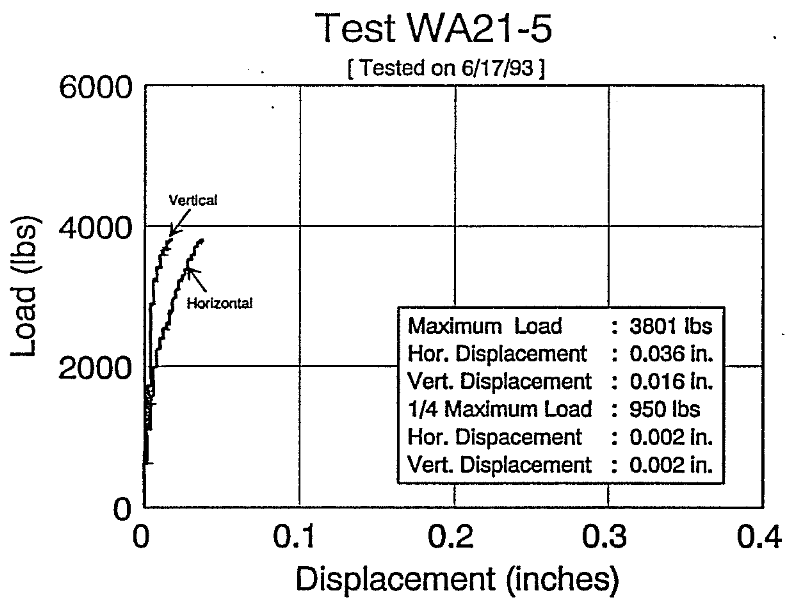
[Tested on 7/26/93]

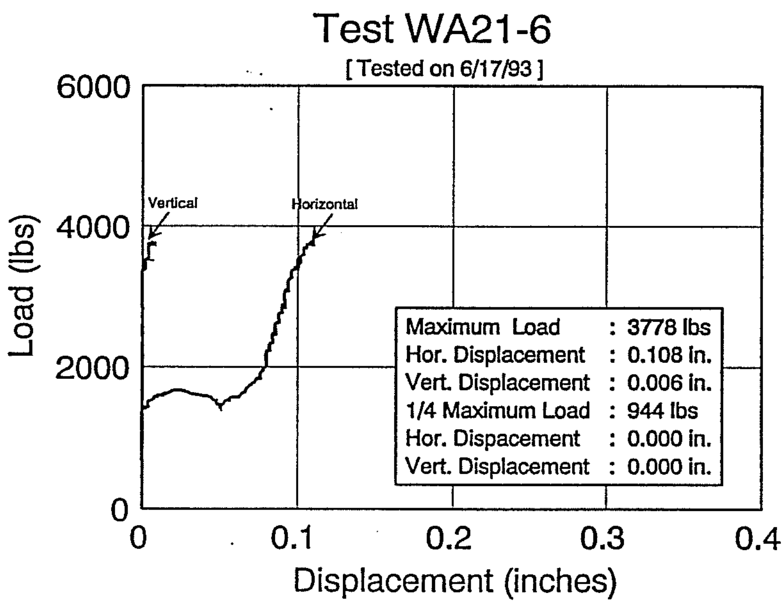


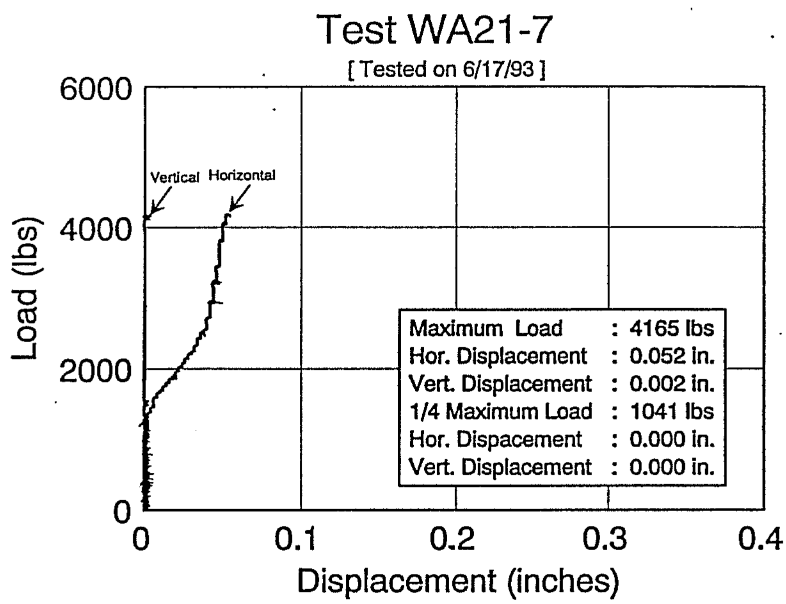
Test WA21-4

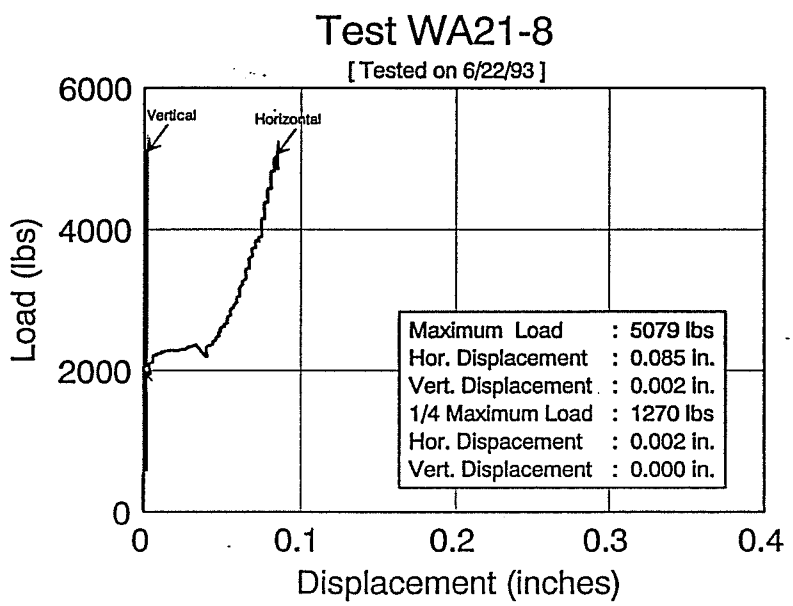
[Tested on 6/17/93]

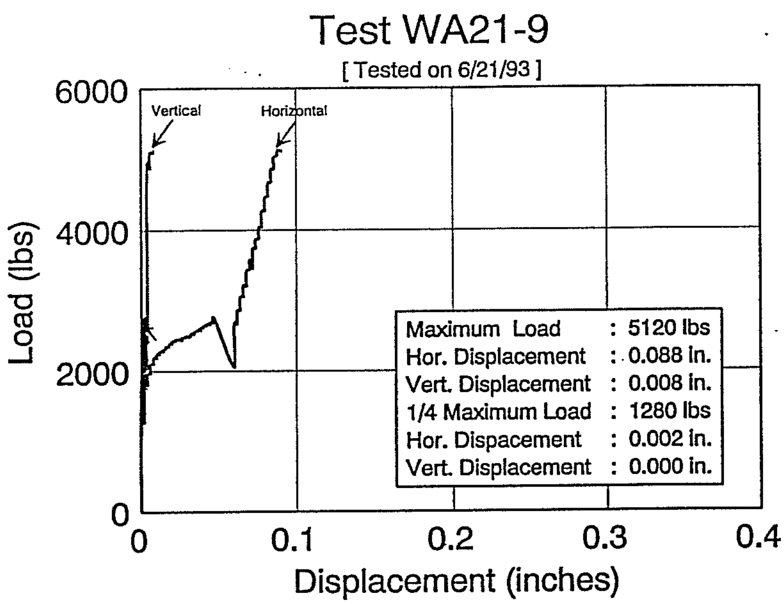


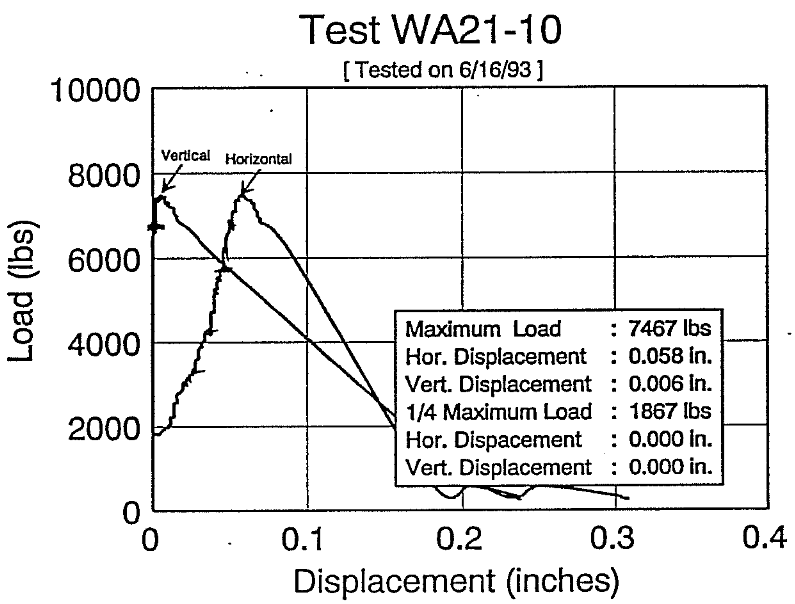

Test WA21-5
[Tested on 6/17/93]
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 3801 lbs
Hor. Displacement : 0.036 in.
Vert. Displacement : 0.016 in.
1/4 Maximum Load : 950 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.002 in.

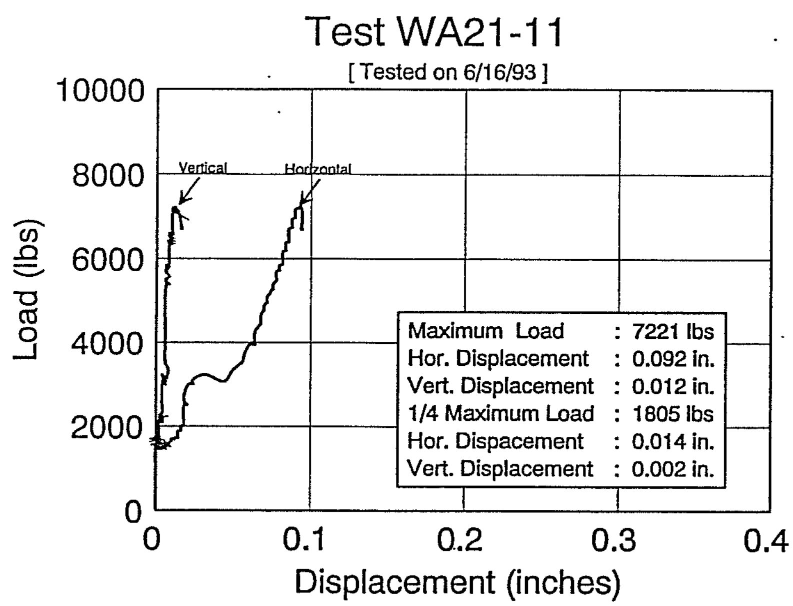

Test WA21-6
[Tested on 6/17/93]
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 3778 lbs
Hor. Displacement : 0.108 in.
Vert. Displacement : 0.006 in.
1/4 Maximum Load : 944 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.

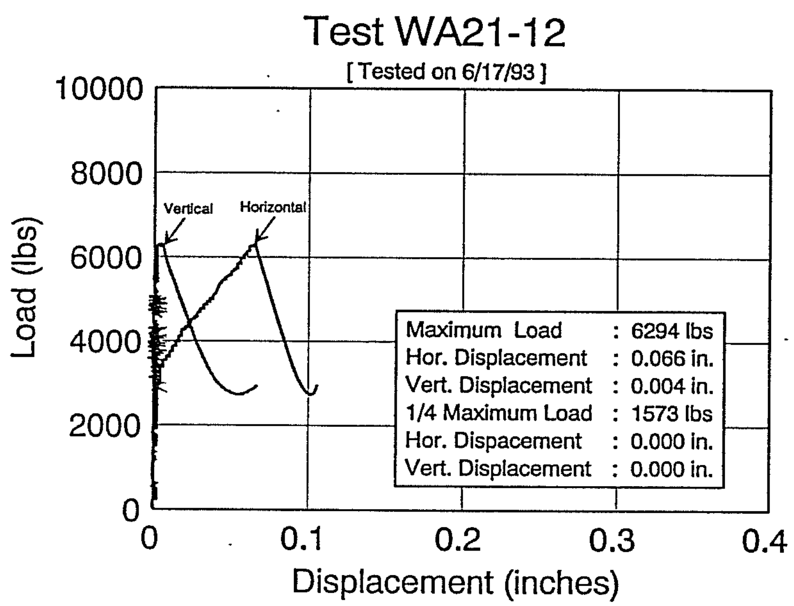

Test WA21-7
[Tested on 6/17/93]
6000
4000
2000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 4165 lbs
Hor. Displacement : 0.052 in.
Vert. Displacement : 0.002 in.
1/4 Maximum Load : 1041 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.
0
0.1
0.2
0.3
0.4
Displacement (inches)

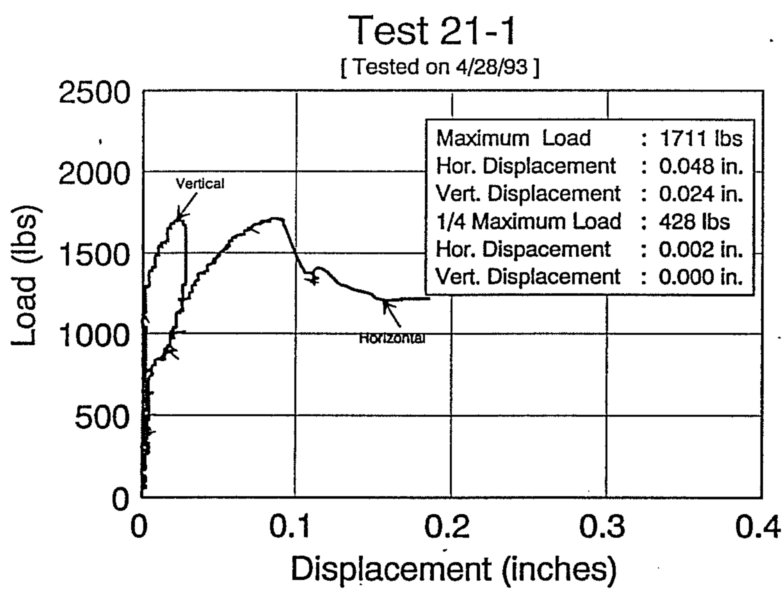

Test WA21-8
[Tested on 6/22/93]
6000
4000
2000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 5079 lbs
Hor. Displacement : 0.085 in.
Vert. Displacement : 0.002 in.
1/4 Maximum Load : 1270 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.
0
0.1
0.2
0.3
0.4
Displacement (inches)

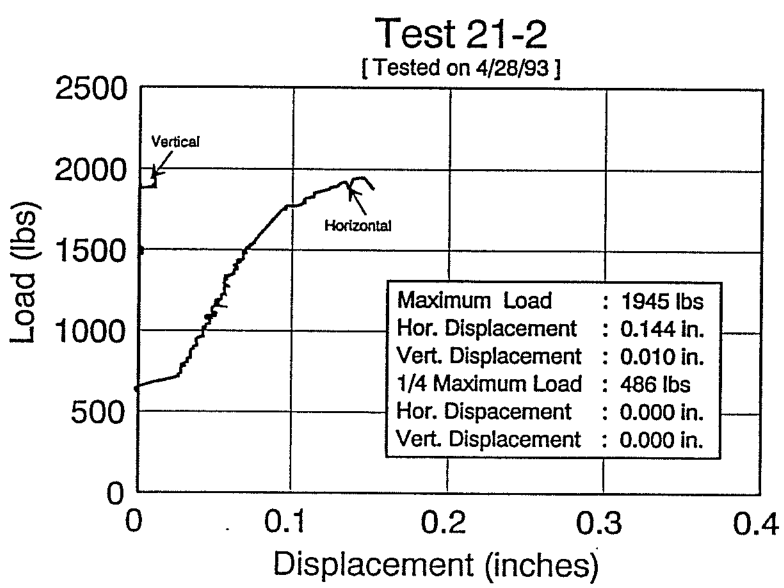

Test WA21-9
[Tested on 6/21/93]
Vertical
Horizontal
Maximum Load : 5120 lbs
Hor. Displacement : 0.088 in.
Vert. Displacement : 0.008 in.
1/4 Maximum Load : 1280 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.
Load (lbs)
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

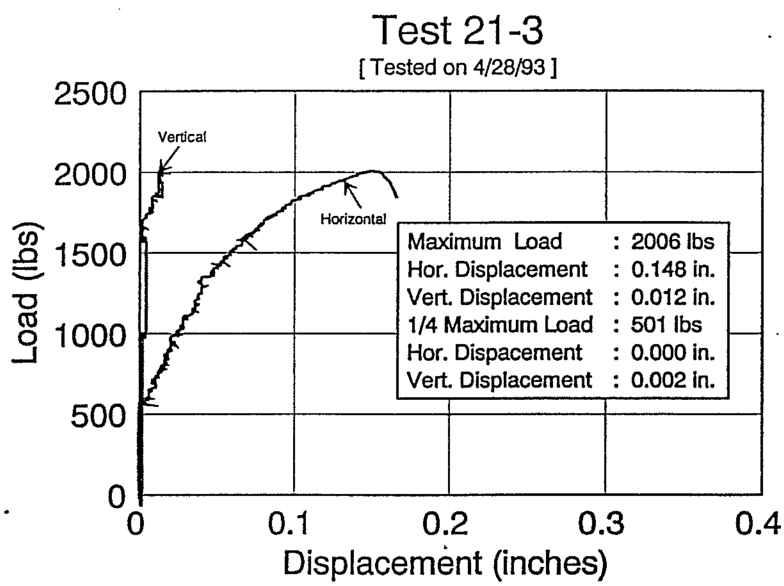

Test WA21-10
[Tested on 6/16/93]
Vertical
Horizontal
Maximum Load : 7467 lbs
Hor. Displacement : 0.058 in.
Vert. Displacement : 0.006 in.
1/4 Maximum Load : 1867 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Displacement (inches)

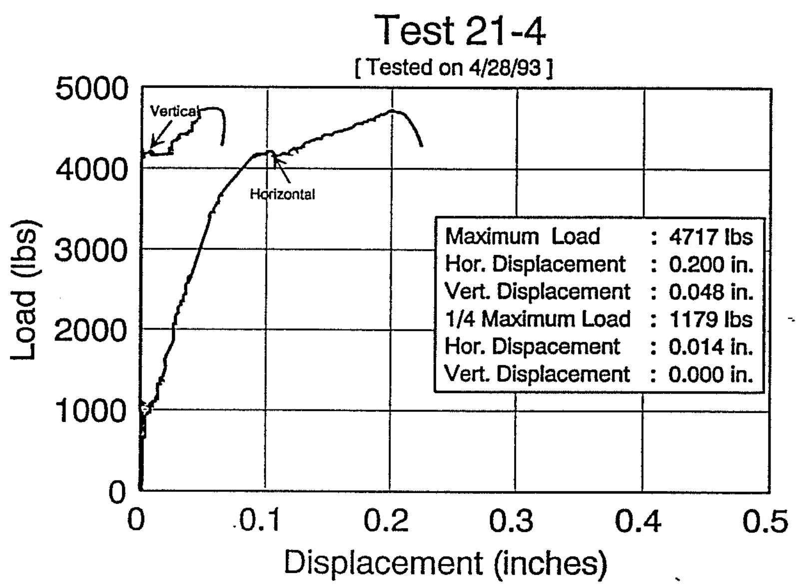

Test WA21-11
[Tested on 6/16/93]
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 7221 lbs
Hor. Displacement : 0.092 in.
Vert. Displacement : 0.012 in.
1/4 Maximum Load : 1805 lbs
Hor. Dispacement : 0.014 in.
Vert. Displacement : 0.002 in.

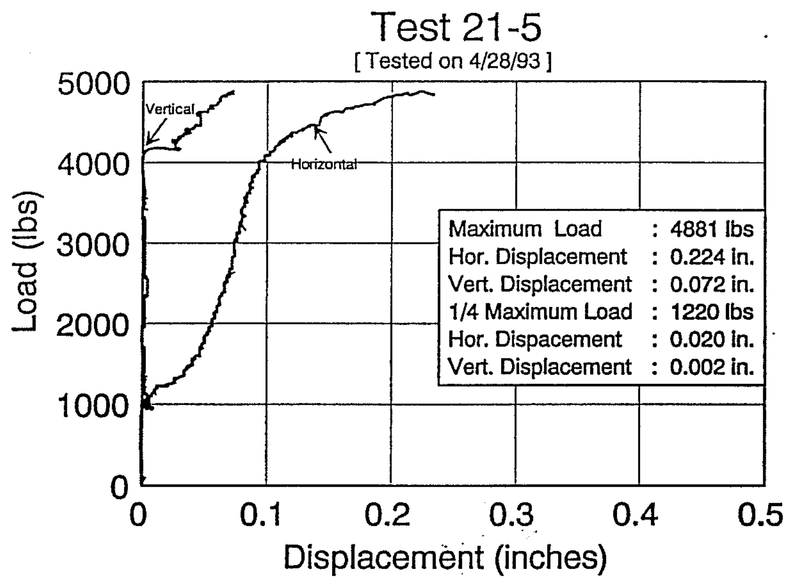

Test WA21-12
[Tested on 6/17/93]
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
Load (lbs)
Displacement (inches)
Vertical
Horizontal
Maximum Load : 6294 lbs
Hor. Displacement : 0.066 in.
Vert. Displacement : 0.004 in.
1/4 Maximum Load : 1573 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.


Test 21-1
[Tested on 4/28/93]
Maximum Load : 1711 lbs
Hor. Displacement : 0.048 in.
Vert. Displacement : 0.024 in.
1/4 Maximum Load : 428 lbs
Hor. Dispacement : 0.002 in.
Vert. Displacement : 0.000 in.
Vertical
Horizontal
Load (lbs)
Displacement (inches)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4

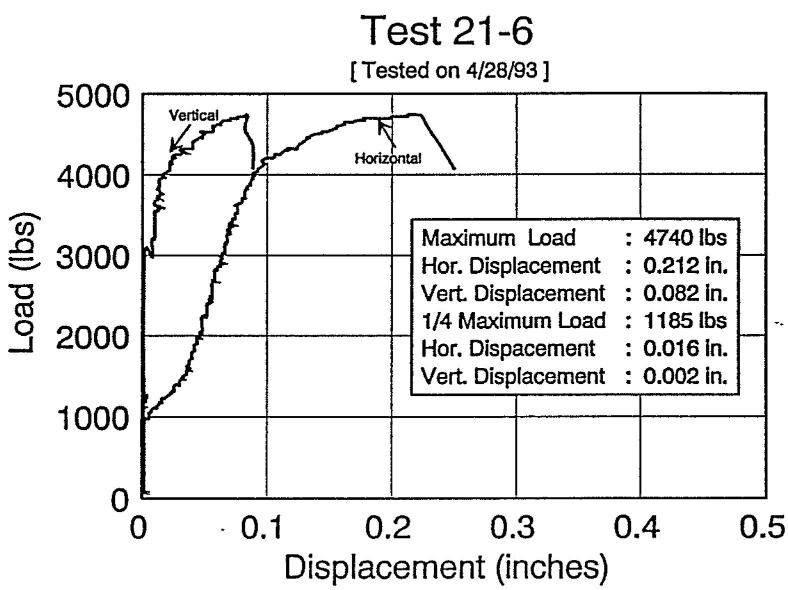

Test 21-2
[Tested on 4/28/93]
Maximum Load : 1945 lbs
Hor. Displacement : 0.144 in.
Vert. Displacement : 0.010 in.
1/4 Maximum Load : 486 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.000 in.
Vertical
Horizontal
Load (lbs)
Displacement (inches)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4


Test 21-3
[Tested on 4/28/93]
Vertical
Horizontal
Load (lbs)
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
Displacement (inches)
Maximum Load : 2006 lbs
Hor. Displacement : 0.148 in.
Vert. Displacement : 0.012 in.
1/4 Maximum Load : 501 lbs
Hor. Dispacement : 0.000 in.
Vert. Displacement : 0.002 in.

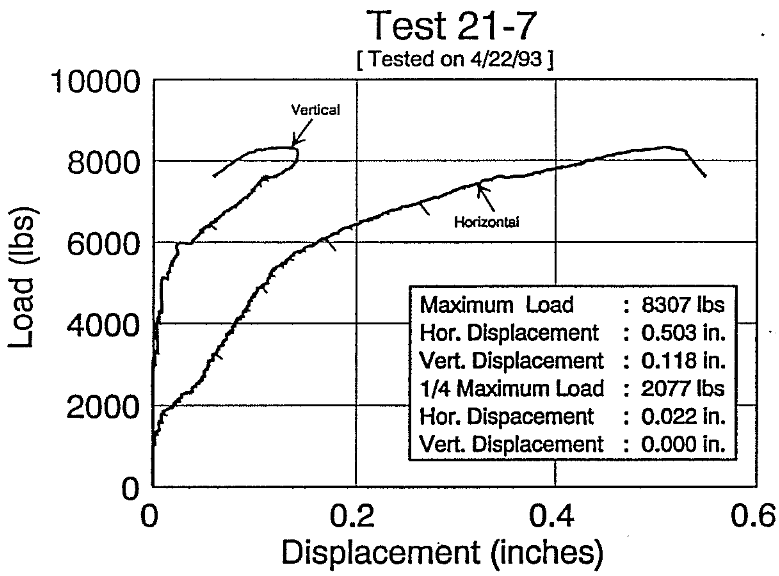

Test 21-4
[Tested on 4/28/93]
Vertical
Horizontal
Load (lbs)
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)
Maximum Load : 4717 lbs
Hor. Displacement : 0.200 in.
Vert. Displacement : 0.048 in.
1/4 Maximum Load : 1179 lbs
Hor. Dispacement : 0.014 in.
Vert. Displacement : 0.000 in.



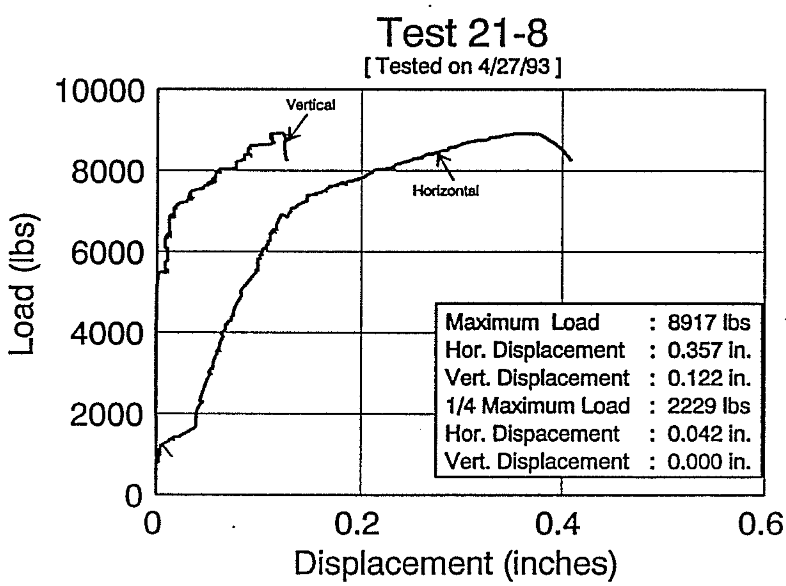
Test 21-5
[Tested on 4/28/93]
5000
4000
3000
2000
1000
0
Load (lbs)
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)
Vertical
Horizontal
Maximum Load : 4881 lbs
Hor. Displacement : 0.224 in.
Vert. Displacement : 0.072 in.
1/4 Maximum Load : 1220 lbs
Hor. Dispacement : 0.020 in.
Vert. Displacement : 0.002 in.



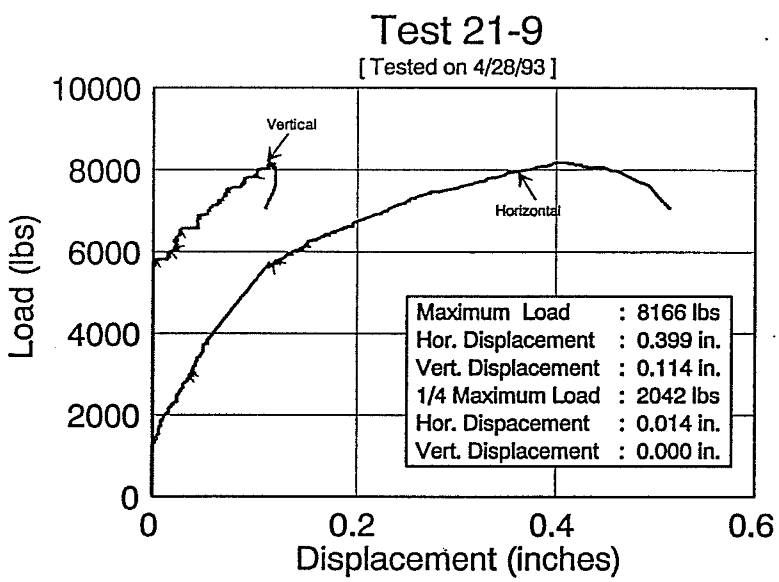
Test 21-6
[Tested on 4/28/93]
5000
4000
3000
2000
1000
0
Load (lbs)
0
0.1
0.2
0.3
0.4
0.5
Displacement (inches)
Vertical
Horizontal
Maximum Load : 4740 lbs
Hor. Displacement : 0.212 in.
Vert. Displacement : 0.082 in.
1/4 Maximum Load : 1185 lbs
Hor. Dispacement : 0.016 in.
Vert. Displacement : 0.002 in.

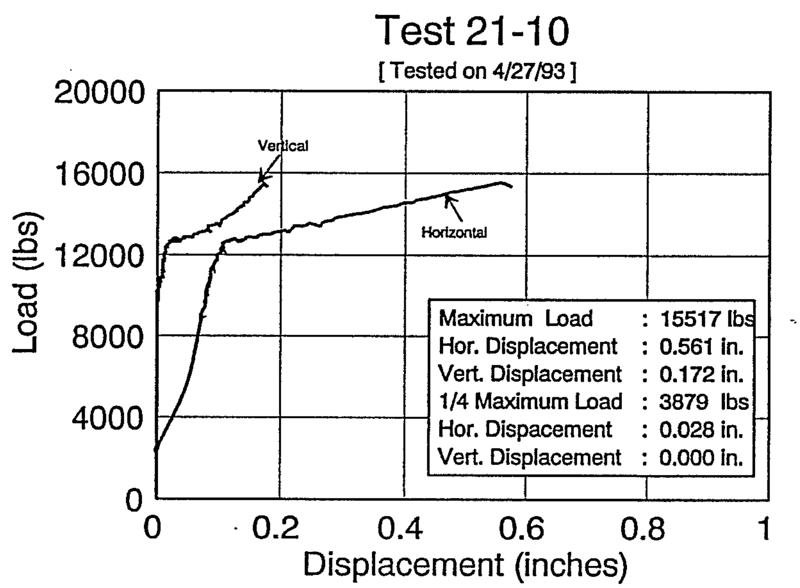


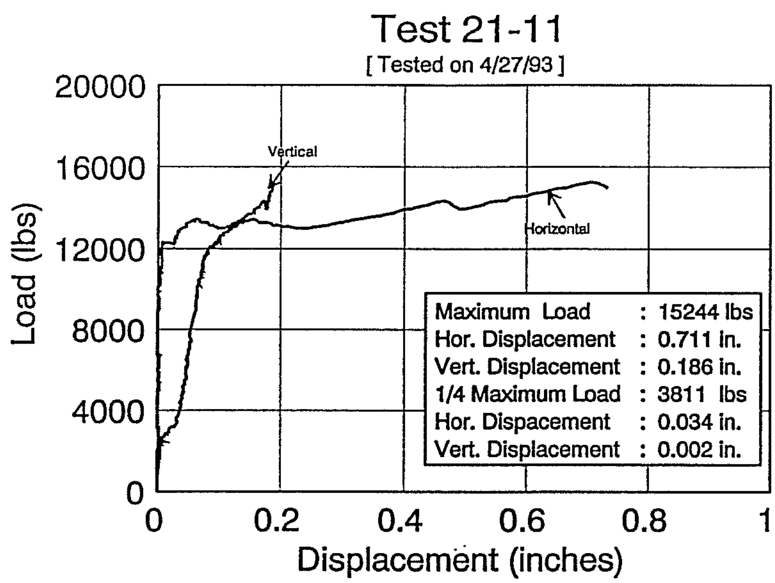
Test 21-7
[Tested on 4/22/93]
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)
Vertical
Horizontal
Maximum Load : 8307 lbs
Hor. Displacement : 0.503 in.
Vert. Displacement : 0.118 in.
1/4 Maximum Load : 2077 lbs
Hor. Dispacement : 0.022 in.
Vert. Displacement : 0.000 in.

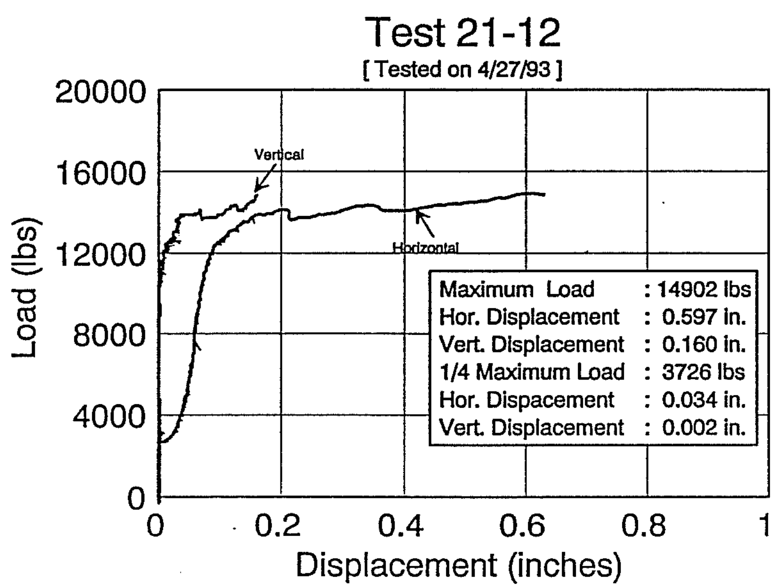


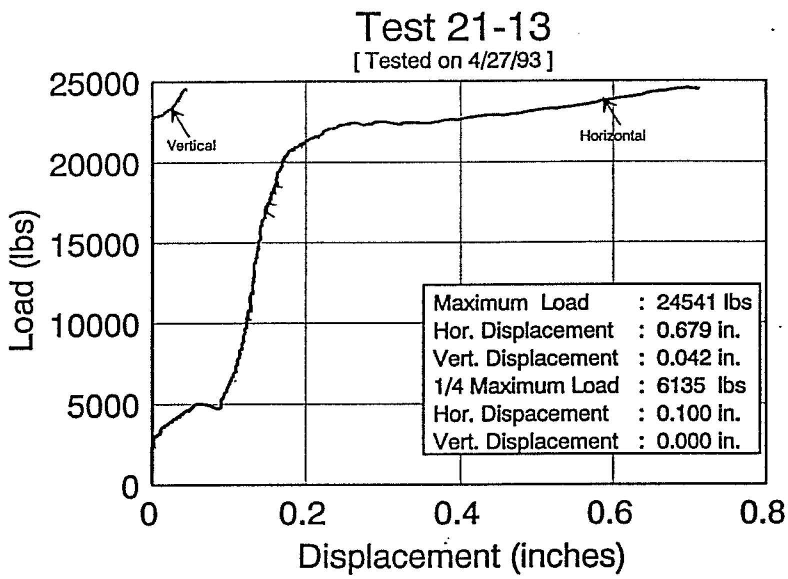
Test 21-8
[Tested on 4/27/93]
Load (lbs)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Displacement (inches)
Vertical
Horizontal
Maximum Load : 8917 lbs
Hor. Displacement : 0.357 in.
Vert. Displacement : 0.122 in.
1/4 Maximum Load : 2229 lbs
Hor. Dispacement : 0.042 in.
Vert. Displacement : 0.000 in.

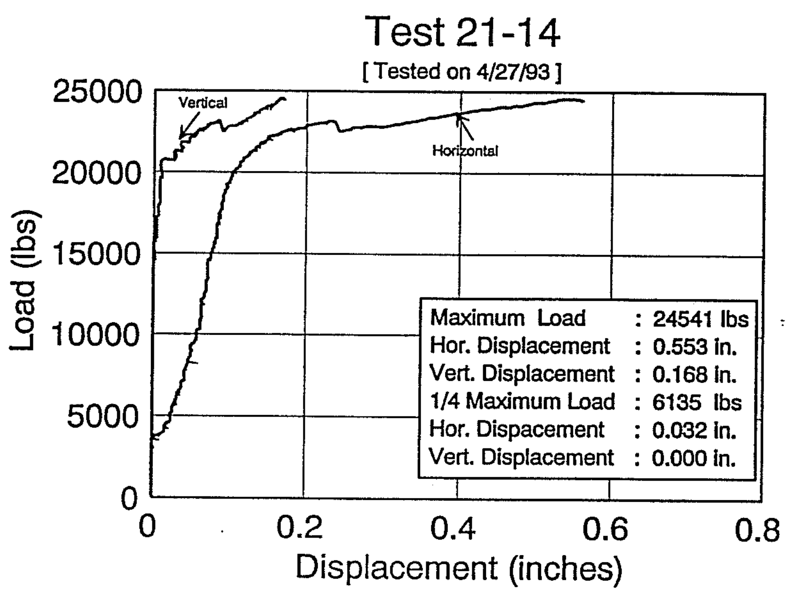

Test 21-9
[Tested on 4/28/93]
Load (lbs)
Displacement (inches)
10000
8000
6000
4000
2000
0
0
0.2
0.4
0.6
Vertical
Horizontal
Maximum Load : 8166 lbs
Hor. Displacement : 0.399 in.
Vert. Displacement : 0.114 in.
1/4 Maximum Load : 2042 lbs
Hor. Dispacement : 0.014 in.
Vert. Displacement : 0.000 in.

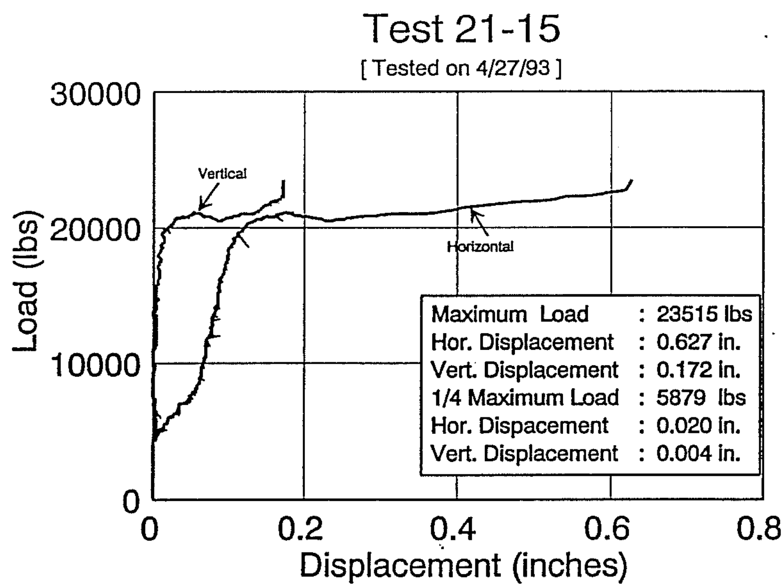

Test 21-10
[Tested on 4/27/93]
Load (lbs)
Displacement (inches)
20000
16000
12000
8000
4000
0
0
0.2
0.4
0.6
0.8
1
Vertical
Horizontal
Maximum Load : 15517 lbs
Hor. Displacement : 0.561 in.
Vert. Displacement : 0.172 in.
1/4 Maximum Load : 3879 lbs
Hor. Dispacement : 0.028 in.
Vert. Displacement : 0.000 in.

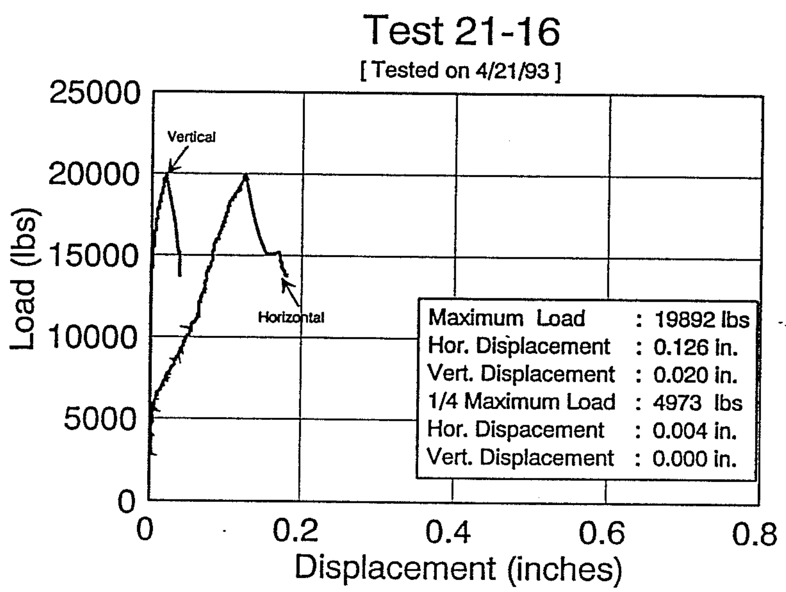

Test 21-11
[Tested on 4/27/93]
Vertical
Horizontal
Maximum Load : 15244 lbs
Hor. Displacement : 0.711 in.
Vert. Displacement : 0.186 in.
1/4 Maximum Load : 3811 lbs
Hor. Dispacement : 0.034 in.
Vert. Displacement : 0.002 in.
Load (lbs)
20000
16000
12000
8000
4000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

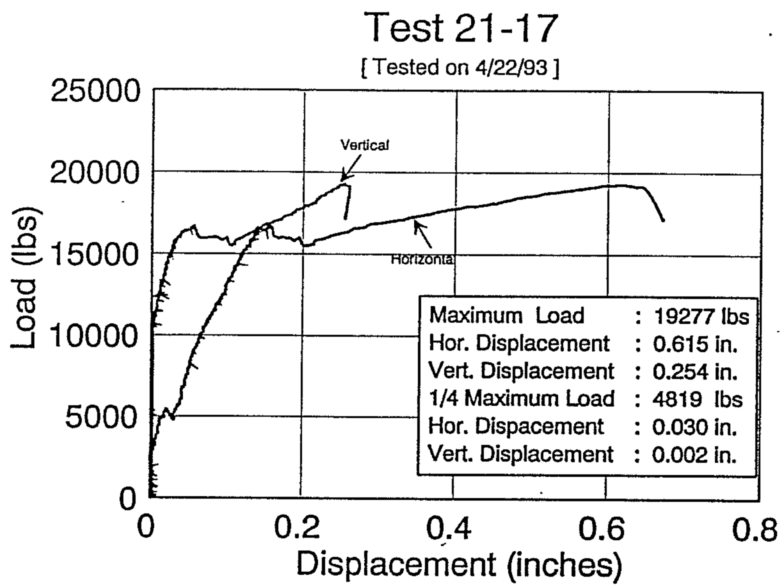

Test 21-12
[Tested on 4/27/93]
Vertical
Horizontal
Maximum Load : 14902 lbs
Hor. Displacement : 0.597 in.
Vert. Displacement : 0.160 in.
1/4 Maximum Load : 3726 lbs
Hor. Dispacement : 0.034 in.
Vert. Displacement : 0.002 in.
Load (lbs)
20000
16000
12000
8000
4000
0
0
0.2
0.4
0.6
0.8
1
Displacement (inches)

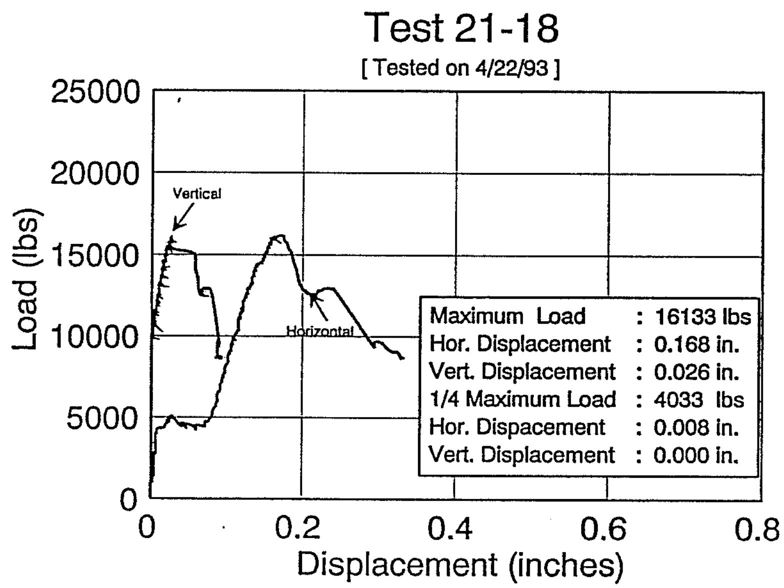

Test 21-13
[Tested on 4/27/93]
Vertical
Horizontal
Maximum Load : 24541 lbs
Hor. Displacement : 0.679 in.
Vert. Displacement : 0.042 in.
1/4 Maximum Load : 6135 lbs
Hor. Dispacement : 0.100 in.
Vert. Displacement : 0.000 in.
Load (lbs)
25000
20000
15000
10000
5000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

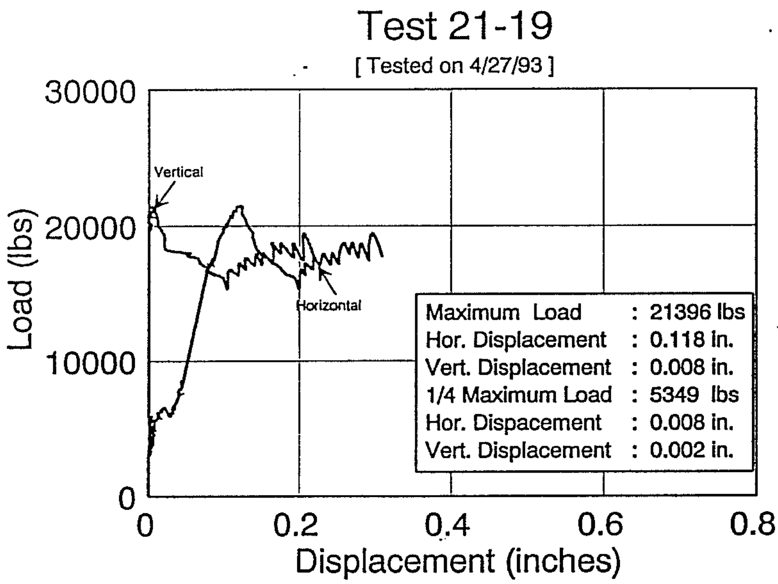

Test 21-14
[Tested on 4/27/93]
Vertical
Horizontal
Maximum Load : 24541 lbs
Hor. Displacement : 0.553 in.
Vert. Displacement : 0.168 in.
1/4 Maximum Load : 6135 lbs
Hor. Dispacement : 0.032 in.
Vert. Displacement : 0.000 in.
Load (lbs)
25000
20000
15000
10000
5000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

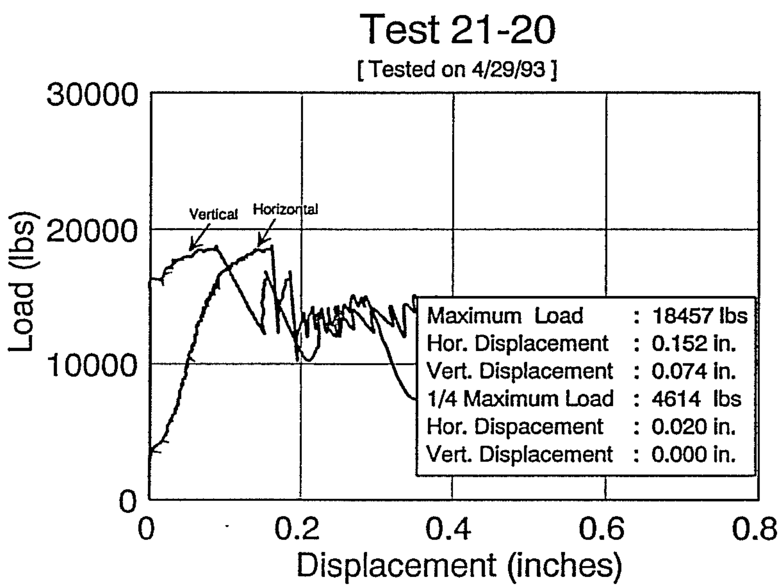

Test 21-15
[Tested on 4/27/93]
30000
20000
10000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 23515 lbs
Hor. Displacement : 0.627 in.
Vert. Displacement : 0.172 in.
1/4 Maximum Load : 5879 lbs
Hor. Dispacement : 0.020 in.
Vert. Displacement : 0.004 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)

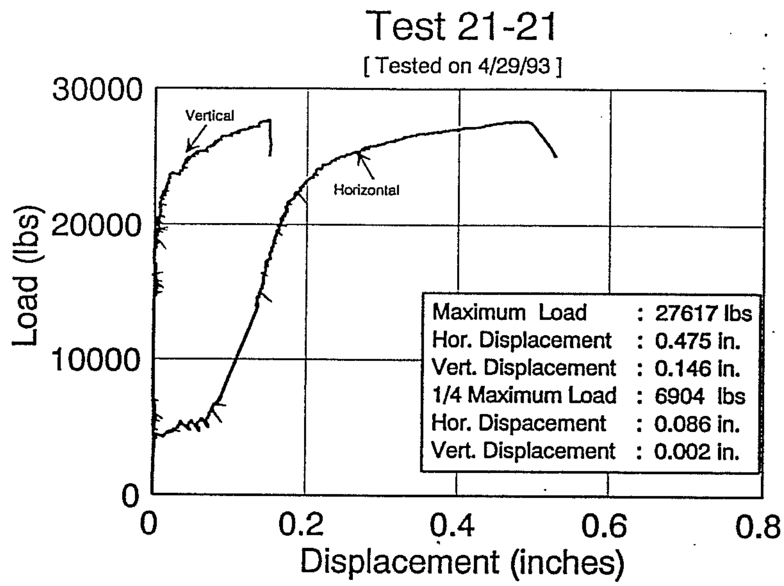

Test 21-16
[Tested on 4/21/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 19892 lbs
Hor. Displacement : 0.126 in.
Vert. Displacement : 0.020 in.
1/4 Maximum Load : 4973 lbs
Hor. Dispacement : 0.004 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)

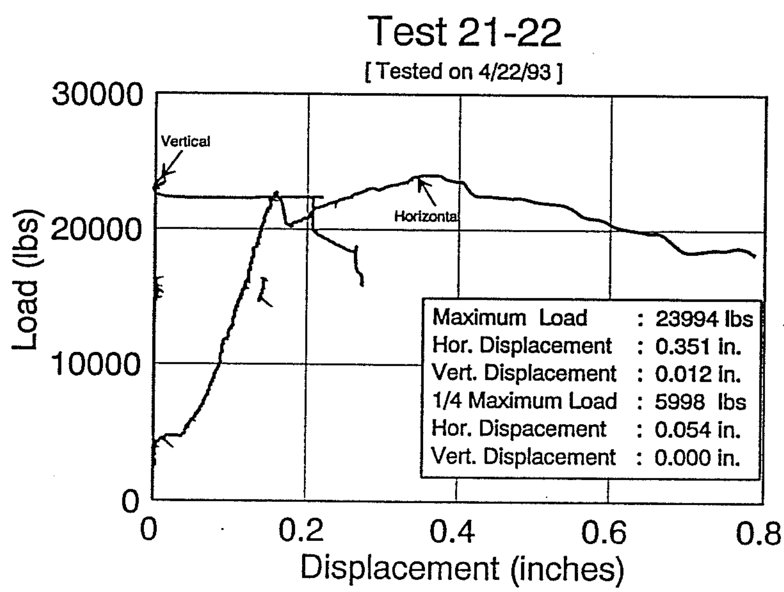

Test 21-17
[Tested on 4/22/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 19277 lbs
Hor. Displacement : 0.615 in.
Vert. Displacement : 0.254 in.
1/4 Maximum Load : 4819 lbs
Hor. Dispacement : 0.030 in.
Vert. Displacement : 0.002 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)

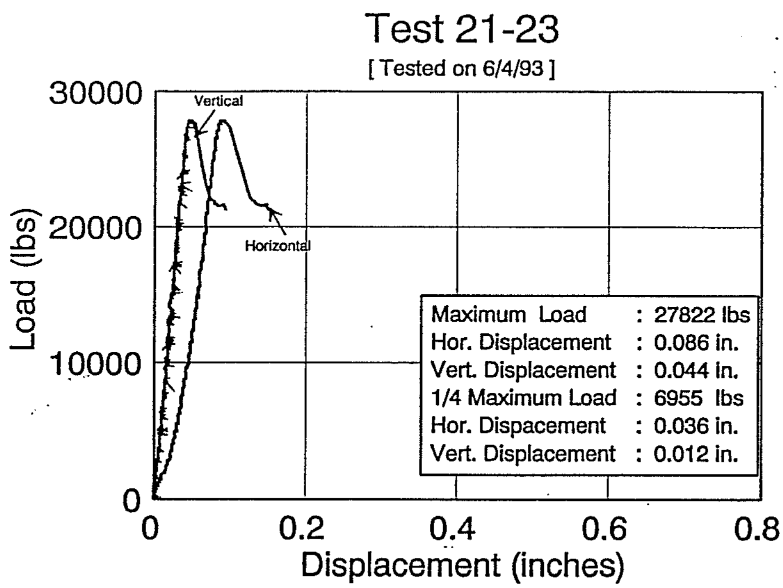

Test 21-18
[Tested on 4/22/93]
25000
20000
15000
10000
5000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 16133 lbs
Hor. Displacement : 0.168 in.
Vert. Displacement : 0.026 in.
1/4 Maximum Load : 4033 lbs
Hor. Dispacement : 0.008 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)

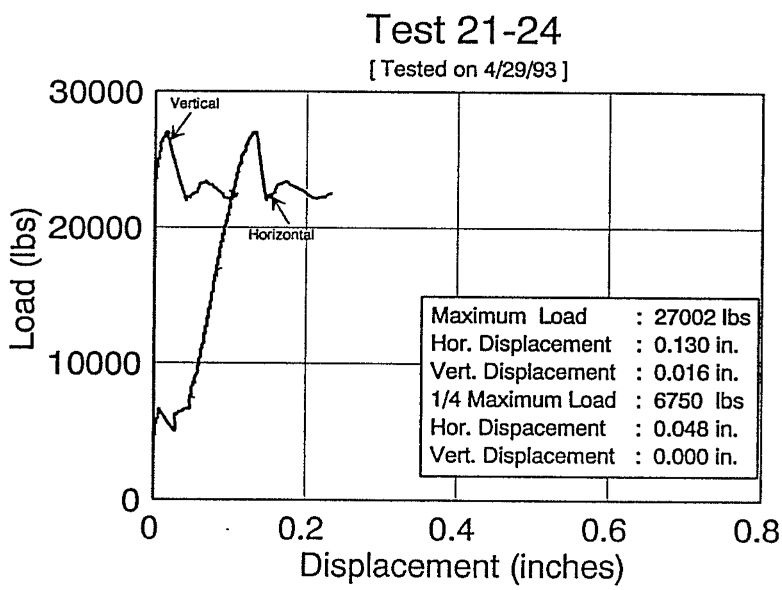

Test 21-19
[Tested on 4/27/93]
30000
20000
10000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 21396 lbs
Hor. Displacement : 0.118 in.
Vert. Displacement : 0.008 in.
1/4 Maximum Load : 5349 lbs
Hor. Dispacement : 0.008 in.
Vert. Displacement : 0.002 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test 21-20
[Tested on 4/29/93]
30000
20000
10000
0
Load (lbs)
Vertical
Horizontal
Maximum Load : 18457 lbs
Hor. Displacement : 0.152 in.
Vert. Displacement : 0.074 in.
1/4 Maximum Load : 4614 lbs
Hor. Dispacement : 0.020 in.
Vert. Displacement : 0.000 in.
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test 21-21
[Tested on 4/29/93]
Vertical
Horizontal
Maximum Load : 27617 lbs
Hor. Displacement : 0.475 in.
Vert. Displacement : 0.146 in.
1/4 Maximum Load : 6904 lbs
Hor. Dispacement : 0.086 in.
Vert. Displacement : 0.002 in.
Load (lbs)
Displacement (inches)
30000
20000
10000
0
0
0.2
0.4
0.6
0.8


Test 21-22
[Tested on 4/22/93]
Vertical
Horizontal
Maximum Load : 23994 lbs
Hor. Displacement : 0.351 in.
Vert. Displacement : 0.012 in.
1/4 Maximum Load : 5998 lbs
Hor. Dispacement : 0.054 in.
Vert. Displacement : 0.000 in.
Load (lbs)
Displacement (inches)
30000
20000
10000
0
0
0.2
0.4
0.6
0.8


Test 21-23
[Tested on 6/4/93]
Vertical
Horizontal
Maximum Load : 27822 lbs
Hor. Displacement : 0.086 in.
Vert. Displacement : 0.044 in.
1/4 Maximum Load : 6955 lbs
Hor. Dispacement : 0.036 in.
Vert. Displacement : 0.012 in.
Load (lbs)
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)


Test 21-24
[Tested on 4/29/93]
Vertical
Horizontal
Maximum Load : 27002 lbs
Hor. Displacement : 0.130 in.
Vert. Displacement : 0.016 in.
1/4 Maximum Load : 6750 lbs
Hor. Dispacement : 0.048 in.
Vert. Displacement : 0.000 in.
Load (lbs)
30000
20000
10000
0
0
0.2
0.4
0.6
0.8
Displacement (inches)

Block:	15/16					
f'c	4000					
Cast	6/1/92					
No	Date	Day	A	B	C	Average
1	6/9/92	8	2582	2644	2519	2582
2	6/17/92	16	2896	3015	2884	2932
3	6/23/92	22	3062	3050	3016	3043
4	6/29/92	28	3074	3081	2903	3019
6	9/25/92	116	2576	3780		3178
7	9/28/92	119	3652	3453		3553
Block:	23/24					
f'c	6000					
Cast	10/28/92					
No	Date	Day	A	B	C	Average
1	11/4/92	7	5229	4983	4978	5064
2	11/11/92	14	5314	5298	5299	5303
3	11/18/92	21	5677	6004	5612	5764
4	11/25/92	28	5893	5816	5702	5804
5	1/9/93	72	6274	6149	6328	6250
Block:	29/30					
f'c	2000					
Cast	11/20/92					
No	Date	Day	A	B	C	Average
1	11/27/92	7	1494	1478	1477	1483
2	12/4/92	17	1871	1907	1903	1894
3	12/11/92	21	1899	1970	1953	1941
4	12/18/92	28	1998	1938	2052	1996
5	1/6/93	46	2143	2132	2203	2159
6	2/12/93	83	2203	2165	2099	2156
Block:	35/36					
f'c	2000					
Cast	12/22/92					
No	Date	Day	A	B	C	Average
1	12/30/93	8	1634	1563	1594	1597
2	1/7/93	14	1788	1797	1620	1735
3	1/14/93	21	1879	1817	1855	1850
4	1/21/93	28	1978	1994	1984	1985
5	2/1/93	39	1983	1918	1925	1942

Block:	41/42/43/44					
f'c	2000					
Cast	1/21/93					
No	Date	Day	A	B	C	Average
1	1/28/93	7	1306	1336	1298	1313
2	2/4/93	14	1442	1572	1448	1487
3	2/11/93	21	1623	1622	1582	1609
4	2/18/93	28	1782	1822	1766	1790
5	2/22/93	32	1766			
6	2/24/93	35	1822	1870	1783	1825
7	4/20/93		1941	2119		2030
Block:	49/50/51/52					
f'c	6000					
Cast	2/10/93					
No	Date	Day	A	B	C	Average
1	2/17/93	7	4810	4940		4875
2	2/24/93	14	5905	5654	5248	5602
3	3/3/93	21	5920	5966	5272	5719
4	3/10/93	28	5860	5481	6040	5794
5	4/19/93	58	6321	6117	6066	6168
6	5/17/93	86	6598	5905	6381	6295
7	5/26/93	95	6453	6436		6445
Block:	61/62					
f'c	2000					
Cast	3/11/93					
No	Date	Day	A	B	C	Average
1	3/18/93	7	1497	1410	1490	1466
2	3/25/93	14	1692	1627	1691	1670
3	4/1/93	21	1733	1828	1786	1782
4	4/8/93	28	1887	1957	1967	1937
5	4/26/93	46	2028	2068	2041	2046
Block:	67/68					
f'c	2000					
Cast	4/2/93					
No	Date	Day	A	B	C	Average
1	4/9/93	7	1510	1574	1621	1568
2	4/16/93	14	1884	1932	1859	1892
3	4/23/93	21	1899	2032	2038	1990
4	4/30/93	28	2161	2175	2228	2188
5	5/3/93	31	2140	2197		2169
6	5/6/93	34	2189	2097		2143

Block:	69/70					
f'c	2000					
Cast	4/19/93					
No	Date	Day	A	B	C	Average
1	4/26/93	7	1068	1056	1023	1049
2	5/3/93	14	1267	1152	1017	1145
3	5/12/93	23	1338	1449	1313	1367
4	5/17/93	28	1407	1351	1354	1371
5	6/9/93	51	1518	1816	1450	1595
Block:	79/80					
f'c	4000					
Cast	5/26/93					
No	Date	Day	A	B	C	Average
1	6/2/93	7	3598	3686	3554	3613
2	6/9/93	14	3895	4030	3929	3951
3	6/16/93	21	4039	4018	3639	3899
4	6/23/93	28	4201	4142	4016	4120
5	7/12/93	47	3902	4120	4304	4109
Block:	81/82					
f'c	2000					
Cast	6/1/93					
No	Date	Day	A	B	C	Average
1	6/8/93	7	1556	1508	1447	1504
2	6/15/93	14	1765	1832	1726	1774
3	6/22/93	21	1889	1880	1903	1891
4	6/29/93	28	1933	1914	1930	1926
Block:	83/84					
f'c	2000					
Cast	6/7/93					
No	Date	Day	A	B	C	Average
1	6/14/93	7	1581	1556	1646	1594
2	6/21/93	14	1905	1943	1992	1947
3	6/28/93	21	2016	1979	2067	2021
4	7/5/93	28	2022	1963	1977	1987
5	7/7/93	30	2015	2108	2050	2058
6	7/12/93	35	2059	1973	2047	2026
Block:	85/86					
f'c	2000					
Cast	6/8/93					
No	Date	Day	A	B	C	Average
1	6/15/93	7	1314	1454	1418	1395
2	6/22/93	14	1743	1755	1851	1783
3	6/29/93	21	1961	1925	1910	1932
4	7/6/93	28	1756	1990	2013	1920
5	7/29/93	51	1982	1997	2060	2013
6	8/5/93	58	2105	2065	2084	2085

Block:	87/88					
f'c	2000					
Cast	6/9/93					
No	Date	Day	A	B	C	Average
1	6/16/93	7	1097	1098	1158	1118
2	6/23/93	14	1411	1387	1427	1408
3	6/30/93	21	1422	1425	1482	1443
4	7/7/93	28	1534	1516	1466	1505
5	8/11/93	63	1534	1450	1507	1497
Block:	89/90					
f'c	2000					
Cast	6/10/93					
No	Date	Day	A	B	C	Average
1	6/17/93	7	1441	1464	1458	1454
2	6/24/93	14	1696	1681	1658	1678
3	7/1/93	21	1780	1755	1768	1768
4	7/8/93	28	1880	1768	1861	1836
5	8/3/93	54	1968	1832	1944	1915
6	8/16/93	67	1937	1881	1869	1896
Block:	91/92					
f'c	6000					
Cast	6/17/93					
No	Date	Day	A	B	C	Average
1	6/24/93	7	5034	5007	5155	5065
2	7/1/93	14	5802	5666	5509	5659
3	7/8/93	21	5923	5803	5851	5859
4	7/15/93	28	5970	6080	5896	5982
5	7/29/93	42	5815	6156	5892	5954
Block:	93/94					
f'c	2000					
Cast	6/22/93					
No	Date	Day	A	B	C	Average
1	6/29/93	7	1505	1530	1505	1513
2	7/6/93	14	1755	1742	1771	1756
3	7/13/93	21	1869	1888	1785	1847
4	7/20/93	28	1873	1863	1905	1880
5	8/11/93	50	1881	1838	1909	1876
6	8/17/93	56	1958	1922	1943	1941
Block:	H3/H4					
f'c	6000					
Cast	12/16/92					
No	Date	Day	A	B	C	Average
1						
2	12/30/93	14	5461	5538	5346	5448
3	1/6/93	21	5597	5768	5712	5692
4	1/13/93	28	6111	6186	6239	6179
5	1/15/93	30	5740	6186	5737	5888

Block:	H21/H22					
f'c	4000					
Cast	3/11/93					
No	Date	Day	A	B	C	Average
1	3/17/93	6	3061	3018	3392	3157
2	3/27/93	16	3910	4021	4146	4026
3	3/30/93	19	3945	4039	4124	4036
4						
5	4/13/93		4250	4381	4190	4274
6	4/19/93		4290	4434	4240	4321
Block:	H25/H26					
f'c	6000					
Cast	3/24/93					
No	Date	Day	A	B	C	Average
1	4/2/93	9	4864	4865	4953	4894
2						
3						
4						
5	5/21/93		6003	5894	6294	6064
6	6/24/93		6383	6009		
7	6/25/93				6118	6170

APPENDIX B

ACI 318

9.3.2.5 - Fastening to Concrete

(a) Fasteners governed by ductile tensile failure of a metallic element where calculations indicate an initial concrete failure is precluded **0.90**.

(b) Fasteners governed by a brittle steel failure and fastener applications where calculations or tests indicate an initial concrete breakout or pullout failure governs

i) Shear Loads **0.75**

ii) Tension loads

Cast-in-situ headed studs and headed bolts **0.75**

Other cast-in-situ inserts and post-installed fasteners with the classification as determined from ASTM ZXXX :

Class 1 - Undercut or other fasteners which have no reduction in ultimate load in 0.3mm constant width cracks **0.75**

Class 2 - Heavy duty torque-controlled expansion anchors or other fasteners where tests have shown there is not greater than 20% reduction in ultimate load in 0.3mm constant width cracks **0.65**

Class 3 - Standard torque controlled expansion anchors or other fasteners where tests have shown there is not greater than 30% reduction in ultimate load in 0.3mm constant width cracks **0.55**

Chapter 22 - Fastening to Concrete

22.0 - Notation

$\mathbf{A_{No}}$ = Projected area of one fastener, for tensile strength calculation, if assumed not limited by actual edge distance or spacing, (Sect.22.5.3), in^2.

$\mathbf{A_N}$ = Actual projected area of a fastener or group of fasteners, for tensile strength calculation (Sect. 22.5.3), in^2. $\mathbf{A_N \le n\, A_{No}}$ where **n** is the number of fasteners in the group.

$\mathbf{A_{se}}$ = Effective cross-sectional area of fastener. If threaded,

$$A_{se} = \frac{\pi}{4} \cdot \left(d_o - \frac{0.9743}{n}\right)$$

where **n** is the number of threads per inch.

$\mathbf{A_{Vo}}$ = Projected area of one fastener, for shear strength calculation, if assumed not limited by actual corner influences or member thickness (Sect.22.6.3), in^2.

$\mathbf{A_V}$ = Actual projected area of a fastener or group of fasteners, for shear strength calculation (Sect. 22.6.3) in^2. $\mathbf{A_V \le n\, A_{Vo}}$ where **n** is the number of fasteners in the group.

c = Edge distance from center of a fastener to the edge of concrete, inches.

$\mathbf{c_1}$ = Edge distance from the center of a fastener to the edge of concrete in one direction. Where shear is present $\mathbf{c_1}$ is in the direction of the shear force, inches.

$\mathbf{c_{1crN}}$ = Critical edge distance for tensile load case, ($\mathbf{1.5h_{ef}}$ for headed studs, headed anchor bolts, expansion anchors and undercut anchors), inches.

$\mathbf{c_2}$ = Edge distance from center of a fastener to the edge of concrete in the direction orthogonal to $\mathbf{c_1}$. Where shear is present, $\mathbf{c_2}$ is in the direction perpendicular to shear force, inches.

$\mathbf{c_{2crV}}$ = Critical edge distance for shear force ($\mathbf{1.5c_1}$ for headed studs, headed anchor bolts, expansion anchors and undercut anchors), inches.

$\mathbf{d_o}$ = Outside diameter of fastener or shaft diameter of headed stud or headed anchor bolt, inches.

$\mathbf{d_u}$ = Diameter of head of headed stud or headed anchor bolt, inches.

$\mathbf{e_N}$ = Eccentricity of applied tension load on a group of fasteners, distance from the centroid of the complete fastener group to the point of tensile load application.

$\mathbf{e'_N}$ = Eccentricity of tensile force on a group of fasteners, distance from the centroid of the fasteners in tension to the point of tensile force application, inches.

$\mathbf{e_v}$ = Eccentricity of applied shear load on a group of fasteners, distance from the centroid of the complete fastener group to the point of shear load application.

$\mathbf{e'_V}$ = Eccentricity of shear force on a group of fasteners, distance from the centroid of the fasteners resisting shear in the direction of the applied shear to the point of shear force application, inches.

$\mathbf{f'_c}$ = Specified compressive strength of concrete, psi.

$\mathbf{f_y}$ = Minimum specified yield strength of fastener steel, psi.

$\mathbf{f_{ut}}$ = Minimum specified ultimate tensile strength of fastener steel, psi.

h = Thickness of member in which a fastener is anchored, inches.

h_{ef} = effective fastener embedment depth measured from the free surface to the bearing surface of the head, inches.

k = an effectiveness factor to be taken as:
20 for cast-in-situ headed studs and headed anchor bolts,
17 for post-installed fasteners

ℓ = Activated load bearing length of fastener **$<8d_o$**, inches.
= **h_{ef}** for fasteners with a constant overall stiffness, such as headed studs, undercut anchors, and torque controlled and expansion anchors where there is no distance sleeve or the expansion sleeve also has the function of the distance sleeve.
= **$2d_o$** for torque controlled expansion anchors with a distance sleeve separated from the expansion sleeve.

N_b = Basic concrete breakout tensile strength of a single fastener in cracked concrete (Sect. 22.5.2), lb.

N_n = Nominal tensile strength of a single fastener or group of fasteners, considering effects of edge distance, spacing, number of fasteners, presence of absence of significant concrete cracking, and other factors (Sect. 22.5.1), lb.

N_p = Basic pullout tensile strength of a single headed stud in cracked concrete (Sect. 22.10.4), lb.

N_{pn} = Nominal pullout tensile strength of a single fastener, considering the effects of presence or absence of significant concrete cracking, (Sect. 22.10.3.), lb.

N_y = Nominal material yield tensile strength of a single fastener (Sect 22.9.2), lb.

s = Fastener center to center spacing, inches.

s_{crN} = Critical spacing for tensile force calculations (**$3h_{ef}$** for headed studs, headed anchor bolts, expansion anchors and undercut anchors), inches.

s_{crV} = Critical spacing for shear force calculations (**$3c_1$** for headed studs, headed anchor bolts, expansion anchors and undercut anchors) , inches.

V_b = Basic concrete breakout shear strength of a single fastener in cracked concrete (Sect. 22.6.2), lb.

V_n = Nominal concrete breakout shear strength of a single fastener or group of fasteners, considering effects of edge distance, spacing, member thickness, number of fasteners, presence or absence of significant concrete cracking, and other factors (Sect. 22.6.1), lb.

V_y = Nominal material yield shear strength of a single fastener (Sect 22.9.3), lb.

λ = Coefficient for use with lightweight concrete:
$\lambda = 1$ for normal weight concrete,
$\lambda = 0.75$ for all-lightweight concrete, and
$\lambda = 0.85$ for sand-lightweight concrete.

Ψ_1 = Modification factor, for tensile strength, to account for fastener groups which are loaded eccentrically (Sect. 22.5.4).

Ψ_2 = Modification factor, for tensile strength, to account for edge distances smaller than c_{1crN}, (Sect. 22.5.5).

Ψ_3 = Modification factor, for tensile strength, to account for the absence or control of cracking, (Sect 22.5.6).

Ψ_4 = Modification factor, for shear strength, to account for fastener groups which are loaded eccentrically (Sect. 22.6.4).

Ψ_5 = Modification factor, for shear strength, to account for edge distance smaller than c_{2crV}, (Sect. 22.6.5).

Ψ_6 = Modification factor, for shear strength, to account for the absence or control of cracking, (Sect 22.6.6).

22.1 Definitions

Attachment - The structural element external to the surface of the concrete which transmits loads to the fastener.

Distance Sleeve - A sleeve which encases the center part of a torque-controlled on displacement controlled expansion anchor, but does not expand.

Edge Distance - The distance from the center of a single fastener or the center of the outermost fastener in a group to the nearest edge of the concrete surface.

Effective Embedment Depth - $\mathbf{h_{ef}}$, The depth of the fastener along which the fastener force is transferred to the surrounding concrete. The effective embedment depth will normally be the depth of the failure surface.

Expansion Anchor - A fastener installed into hardened concrete which transfers loads into the structural concrete member by direct bearing and/or friction. Expansion anchors may be torque-controlled, where the expansion is achieved by a torque acting on the screw or bolt, or displacement controlled, where the expansion is achieved by forces acting on a sleeve or plug and the anchorage is controlled by the length of travel of the plug.

Expansion Sleeve - The outer part of an expansion anchor which is forced outward by the center part, either by applied torque or impact, to bear against the sides of the predrilled hole.

Fastener - A metallic element cast into or post-installed into a concrete member used to transmit applied loads to the concrete structure. The fastener may be fabricated of plates, shapes, bolts, reinforcing bars, shear connectors, expansion anchors, inserts or any combination thereof.

Insert (specialty insert) - Commercially available, predesigned and prefabricated cast-in-situ fasteners which are specifically designed for attachment of bolted or slotted connections.

Projected Area - The area on the free surface of the concrete member which is the base of the rectilinear failure surface.

Undercut Anchor - A post-installed fastener anchored mainly by mechanical interlock provided by an undercutting in the anchoring concrete, which is achieved with a special drill before installing the fastener or alternatively by the fastener itself during its installation.

22.2 - Scope

22.2.1 - This chapter provides design requirements for fasteners used to transmit loads from attachments into concrete structures by means of tension, shear or a combination of tension and shear. The nominal tensile strength of fasteners is governed by the lowest of the yielding of the fastener, a concrete breakout type failure, or a fastener pullout failure in cracked concrete. The nominal shear strength is governed by the lower of the shearing of the fastener steel or a concrete breakout type failure. Regardless of the mode which governs for a given fastener at a given embedment depth, the suitability of the fastener for use in structural concrete must be demonstrated by the prequalification test of Section 22.2.2.

22.2.2 - With the exceptions of cast-in-situ reinforcement meeting the development length requirements of Chapter 12, or headed studs and headed anchor bolts whose pullout capacity can be evaluated using Equation 22-13, independent third party prequalification evaluation testing of all fasteners must be performed to ensure suitability for use in structural concrete. Both fasteners to be installed in potentially cracked concrete or to be installed in a region of a structural member where no cracking at service loads due to causes other than fastener forces is expected must meet the requirements of ASTM ZXXX Standard Specification for Proper Functioning and Suitability of Anchors for Use in Cracked and Non-Cracked Concrete.

22.2.3 - This chapter applies to both cast-in-situ type fasteners, such as headed studs, headed anchor bolts or specialty inserts, and fasteners post-installed into hardened concrete, such as expansion anchors and undercut anchors. Adhesive anchors and direct fasteners such as powder or pneumatic actuated nails or bolts are not currently included in this chapter.

22.3 - General Requirements

22.3.1 - Fasteners and fastener groups shall be designed for maximum effects of factored loads as determined by the theory of elastic analysis, as outlined in Chapter 8.

22.3.2 - Fasteners shall be designed for all static load combinations as outlined in Section 9.2. Load applications which are predominantly fatigue or impact are not covered by this chapter.

22.3.3 - When fastener design is governed by seismic load applications, the additional requirements of sections 22.3.3.1 through 22.3.3.2 shall apply.

22.3.3.1 - The prequalification evaluation testing of 22.2.2. shall also include tension, shear, and combined tension and shear loading tests in which the fastener must demonstrate the ability to withstand 5 cycles of cyclic loading at large displacements.

22.3.3.2 - In lieu of 22.3.3.1, the basic attachment which the fastener is connecting to the structure must be designed so that the attachment will undergo ductile yielding at a load level no greater than 75 percent of the fastener concrete breakout capacity.

22.3.4 - The strength reduction factors to be used in design of fasteners, as given in Section 9.3.2.5, are:

(a) Fasteners governed by ductile tensile failure of a metallic element where calculations indicate an initial concrete failure is precluded **ϕ = 0.90.**

(b) Fasteners governed by a brittle steel failure and fastener applications where calculations or tests indicate an initial concrete breakout or pullout failure governs

i) Shear Loads . . . . **ϕ = 0.75**

ii) Tension loads

Cast-in-situ headed studs and headed bolts. . . . . **ϕ = 0.75**

Other cast-in-situ inserts and post-installed fasteners with the classification as determined from ASTM ZXXX :

Class 1 - Undercut or other fasteners which have no reduction in ultimate load in 0.3mm constant width cracks. . . . . **ϕ = 0.75**

Class 2 - Heavy duty torque-controlled expansion anchors or other fasteners where tests have shown there is not greater than 20% reduction in ultimate load in 0.3mm constant width cracks. . . . . **ϕ = 0.65**

Class 3 - Standard torque controlled expansion anchors or other fasteners where tests have shown there is not greater than 30% reduction in ultimate load in 0.3mm constant width cracks. . . . . **ϕ = 0.55**

22.4 - Strength of Fasteners

22.4.1 - Strength design of fasteners shall be based on the computation or test evaluation of the steel tensile and shear strength of the fastener and the attachment, the concrete breakout tensile and shear strengths, and the tensile pullout strength of the fastener. The minimum of these strengths is to be taken as the nominal strength of the fastener for each load condition. The basic requirements for concrete breakout design models are given in Sections 22.4.2 through 22.4.5. A detailed procedure (Concrete Capacity Design (CCD)) which satisfies these requirements is given in Sections 22.5 through 22.7. Minimum edge distances and spacings to preclude splitting failures are given in Section 22.8. Fastener steel design requirements are given in Section 22.9 and pullout design requirements for cast-in-situ headed studs and bolts are given in Section 22.10. The design of fasteners for tension must recognize that the safety of fasteners is sensitive to appropriate installation and that some fastening devices are less sensitive to installation errors and tolerances. Thus, for the design of fasteners:

$$N_u \leq \phi\, N_n$$
$$V_u \leq \phi\, V_n$$

where ϕ for tensile loading is given in Section 22.3.4(b) and varies with the sensitivity of the fasteners' tensile strength to installation error and tolerances as reflected in ASTM ZXXX.

22.4.2 - The basic design concrete breakout tensile strength, $\mathbf{N_b}$, and the basic design concrete breakout shear strength, $\mathbf{V_b}$, for any fastener shall be based on design models which result in predictions of strength in substantial agreement with results of comprehensive tests and which reflect the indications of fracture mechanics theory to account for size effects. Limits on edge distances and fastener spacing in the design models should be consistent with the tests which have verified the model.

22.4.3 - The nominal design concrete breakout tensile strength, $\mathbf{N_n}$, and the nominal
design concrete breakout shear strength, $\mathbf{V_n}$,for any fastener or group of fasteners shall be based on the basic individual fastener breakout strength, with modifications made for the number of anchors, the effects of close spacing of fasteners, proximity to edges, depth of the structural member, eccentric loadings of fastener groups, presence or absence of significant cracking and other considerations which effect fastener strength.

22.4.4 - Interaction of tensile and shear loads shall be considered in design using a conservative interaction expression which results in predictions of strength in substantial agreement with results of comprehensive tests.

22.4.5 - The concrete breakout strength requirements of Sections 22.4.2 through 22.4.4 are satisfied by the Concrete Capacity Design procedure of Sections 22.5 through 22.7.

22.5 - Concrete Capacity Design Tensile Strength of Fasteners

22.5.1 - Nominal concrete breakout tensile strength of a fastener or group of fasteners:

$$N_n \; \frac{A_N}{A_{No}} \psi_1 \psi_2 \psi_3 N_b \qquad (Eq. 22\;\; 1)$$

22.5.2 Basic concrete breakout tensile strength of a single fastener in cracked concrete:

$$N_b \quad k\lambda\sqrt{f_c'}\,h_{ef}^{1.5} \qquad (Eq.22 \quad 2)$$

where **k = 20** for cast-in-situ headed studs and headed anchor bolts,

k = 17 for post-installed fasteners.

22.5.3 - The effects of multiple fasteners, spacing of fasteners, and edge distance on nominal concrete breakout tensile strength shall be included by applying the modification factor $\mathbf{A_N / A_{No}}$. $\mathbf{A_N}$ is the actual projected area of the failure surface for the fastener or group of fasteners which can be approximated as the base of the rectilinear geometrical figure which results from projecting the failure surface outward at a slope of about 35 degrees from the fastener, or in the case of a group of fasteners, from the axis lines between adjacent fasteners. $\mathbf{A_N}$ cannot exceed $\mathbf{n\ A_{No}}$, where **n** is the number of fasteners in the group. $\mathbf{A_{No}}$ is the maximum possible projected area of a single fastener remote from edges:

$$A_{No} \quad (2 \cdot c_{1crN})^2 \quad (2 \cdot 1.5h_{ef})^2 \quad 9h_{ef}^2 \qquad (Eq.22\ \ 3)$$

22.5.4 - Modification factor for eccentrically loaded fastener groups:

$$\psi_1 \quad \frac{1}{(1 \quad \frac{2e_N^{\prime}}{s_{crN}})} \le 1 \qquad (Eq.22\ \ 4)$$

The eccentricity $\mathbf{e'_N}$ shall not exceed **s/2**. If the loading on a fastener group is such that some fasteners are in compression while others are in tension, only those fasteners which are in tension shall be considered when determining the eccentricity, $\mathbf{e'_N}$,for use in Eq. 22-4. For this purpose, $\mathbf{e'_N}$ shall be taken as the distance between the resultant tension load on the tension fasteners and the centroid of the tension fasteners.

In the special case where eccentric loading exists about two axes, the modification factor, Ψ_1, shall be computed for each axis individually and the product of these factors used as Ψ_1 in Eq. 22-1.

22.5.5 - Modification factor for the disturbance of stress distribution caused by the proximity of a fastener to an edge:

$$\psi_2 \ \ 1 \ \ if \ c_1 \geq c_{1crN} \ \ 1.5h_{ef} \qquad (Eq.22 \ \ 5a)$$

$$\psi_2 \ \ 0.7 \ \ 0.3\frac{c_1}{c_{1crN}} \ \ if \ c_1 \leq c_{1crN} \ \ 1.5h_{ef} \qquad (Eq.22 \ \ 5b)$$

Where: c_1 = smallest actual edge distance.

22.5.6 - In the special case where a fastener is located in a region of a structural member where analysis indicates no cracking at service load levels other than the cracking due to fastener forces, fasteners meeting ASTM ZXXX are permitted and the following modification factor is allowed:

$$\Psi_3 = 1.4$$

22.5.7 - Where analysis indicates cracking at service load levels, other than cracking caused by fastener forces, and where such cracking may exceed the level controlled by the adequate distribution of flexural reinforcement in accordance with Section 10.6.4, special confining reinforcement shall be used with any fastener.

22.6 - Concrete Capacity Design Shear Strength of Fasteners

22.6.1 - Nominal concrete breakout shear strength of a fastener or group of fasteners:

$$V_n \;\frac{A_V}{A_{Vo}}\psi_4\psi_5\psi_6 V_b \qquad (Eq.22\;\;6)$$

However, because of the possibility of a pryout type failure at large edge distances:

$$V_n \leq 2N_n$$

22.6.2 - Basic concrete breakout shear strength of a single fastener in cracked concrete:

$$V_b \;\; 6\cdot\left(\frac{\ell}{d_o}\right)^{0.2}\cdot\sqrt{d_o}\cdot\lambda\cdot\sqrt{f_c'}\cdot c_1^{1.5} \qquad (Eq.22\;\;7)$$

22.6.3 - The effects of multiple fasteners, spacing of fasteners, edge distance and depth of the structural member on nominal concrete breakout shear strength shall be included by applying the reduction factor **A_V / A_{Vo}**. **A_V** is the actual projected area of the failure surface for a fastener or group of fasteners which can be approximated as the base of the rectilinear geometrical figure which results from projecting the failure surface outward at a slope of about 35 degrees from the point where the fastener crosses the surface of the concrete, or in the case of a group of fasteners, from the axis lines between adjacent anchors. **A_V** cannot exceed **n A_{Vo}**, where **n** is the number of fasteners in the group. **A_{Vo}** is the maximum possible projected area for a single fastener in a deep member and remote from edges in the direction perpendicular to the shear force :

$$A_{Vo} \quad c_{2crV} \cdot 2c_{2crV}$$

$$(1.5c_1)\cdot(3c_1) \quad 4.5c_1^2 \qquad (Eq. 22 \quad 8)$$

22.6.4 - Modification factor for eccentrically loaded fastener groups:

$$\psi_4 \quad \frac{1}{(1 \quad \frac{2e_V^{\prime}}{s_{crV}})} \leq 1 \qquad (Eq. 22 \quad 9)$$

The eccentricity **e'**$_V$ shall not exceed **s/2.**

22.6.5 - Modification factor for the disturbance of stress distribution caused by the
proximity of a fastener to an edge :

$$\psi_5 \quad 1 \quad \mathit{if} \; c_2 \geq c_{2crV} \quad 1.5c_1 \qquad (Eq. 22 \quad 10a)$$

$$\psi_5 \quad 0.7 \quad 0.3\frac{c_2}{c_{2crV}} \quad \mathit{if} \; c_2 \leq c_{2crV} \quad 1.5c_1 \qquad (Eq. 22 \quad 10b)$$

Where: $\mathbf{c_2}$ = smaller edge distance perpendicular to direction of shear,

22.6.6 - In the special case where a fastener is located in a region of a structural member where analysis indicates no cracking at service loads other than the cracking due to fastener forces, fasteners meeting ASTM ZXXX are permitted and the following modification factor is allowed:

Ψ_6 **= 1.4**

In the special case where a fastener is located in a region of a structural member where analysis indicates cracking at service load levels other than cracking due to fastener forces is expected and where special reinforcement has been provided which can control edge shear concrete breakouts, the following modification factors are allowed:

Ψ_6 **= 1.2** - for fasteners in cracked concrete with straight edge reinforcement having a bar diameter of ≥ 1/2 inch.

Ψ_6 **= 1.4** - for fasteners in cracked concrete with straight edge reinforcement and stirrups spaced at not more than 4 inches.

22.7 - Interaction of Shear and Normal Forces

Fasteners or groups of fasteners which are subjected to both shear and axial loads shall be designed to satisfy the requirements of Sections 22.7.1 through 22.7.3. The value of $\mathbf{N_n}$ shall be the smallest of the fastener steel strength, concrete breakout strength, or pullout strength. The value of $\mathbf{V_n}$ shall be the smaller of the steel strength or the concrete breakout strength.

22.7.1 - If $V_u \le 0.2\phi V_n$, then $N_u \le \phi N_n$.

22.7.2- If $N_u \le 0.2\phi N_n$, then $V_u \le \phi V_n$.

22.7.3 - if $V_u > 0.2\phi V_n$ and $N_u > 0.2\,\phi\,N_n$, then

$$\frac{N_u}{\phi N_n}\ \frac{V_u}{\phi V_n} \le 1.2 \qquad (\mathit{Eqn}.22\ \ 11)$$

22.8 - Minimum Spacings, Edge Distances and Thicknesses

This section provides minimum spacings, edge distances and thicknesses required to prevent splitting failures unless local reinforcement to control splitting and prevent failure of the concrete in tension is provided. Lesser values obtained from tests performed under ASTM ZXXX are acceptable if approved by the engineer of record.

22.8.1 - Minimum fastener center to center spacing shall be $\mathbf{1h_{ef}}$.

22.8.2 - Minimum edge distances shall be :

$\mathbf{1h_{ef}}$ - for undercut and headed fasteners,

$\mathbf{2h_{ef}}$ - for torque controlled and expansion anchors.

22.8.3 - In the absence of independently verified test data for fastener applications in thinner members, the minimum depth for member, **h**, in which a fastener is anchored - $\mathbf{1.5h_{ef}}$.

22.9 - Design Requirements for Fastener Steel

22.9.1 - The shear and tensile strength of a fastener, $\mathbf{N_y}$ and $\mathbf{V_y}$, must be evaluated based on the properties of the fastener material and the physical dimensions of the fastener. Test results are also acceptable to establish values of $\mathbf{N_y}$ and $\mathbf{V_y}$.

22.9.2 - The tensile strength of a fastener shall not exceed :

For ductile fastener material with a well defined yield point..... $\phi \mathbf{N_y} = \phi \mathbf{A_{se}\, f_y}$.

For fastener material without a well defined yield point.... $\phi \mathbf{N_y} = \phi \mathbf{A_{se}\, (0.8\, f_{ut})}$.

In no case shall $\mathbf{f_y}$ or $\mathbf{0.8f_{ut}}$ be taken greater than **120,000psi**.

22.9.3 - The shear strength of a fastener shall not exceed:

For ductile fastener material with a well defined yield point..... $\phi V_y = \phi\ 0.5\ A_{se}\ f_y$.

For fastener material without a well defined yield point.... $\phi V_y = \phi\ 0.5\ A_{se}\ (0.8\ f_{ut})$.

22.10 Design Requirements for Fastener Pullout

22.10.1- The pullout tensile strength of post-installed fasteners in cracked concrete cannot be calculated. The values of N_p must be derived from the results of tests performed according to ASTM ZXXX, using the test mean minus two standard deviations as the nominal pullout tensile strength.

22.10.2 - The pullout tensile strength of cast-in-situ headed studs and headed anchor bolts in cracked concrete can be evaluated using 22.10.3, which is based on the fastener's physical dimensions and the concrete properties. The values of N_p may also be derived from the results of tests performed according to ASTM ZXXX, using the test mean minus two standard deviations as the nominal pullout tensile strength. The cracked concrete values can be adjusted for uncracked concrete applications using 22.10.5.

22.10.3 - Nominal pullout tensile strength of a single headed stud or headed anchor bolt:

$$N_{pn}\ \psi_3\ N_p \qquad (Eq. 22\ 12)$$

22.10.4 - Basic pullout tensile strength of a single headed stud or headed anchor bolt in cracked concrete:

$$N_p \quad \frac{\pi}{4}(d_u^2 \quad d_o^2)\ 11\ \lambda\ f_c' \qquad (Eq.22\ \ 13)$$

22.10.5 - ψ_3 shall be taken as **1** except for the special case where a fastener is located in a region of a structural member where analysis indicates no cracking at service load levels due to causes other than fastener forces, in which case ψ_3**=1.4** is allowed.

Chapter 22 - Fastening to Concrete

22.1 - Definitions - Figure 22.1 shows typical effective embedment depths for a variety of fastener types.

22.2 - Scope - The 1995 ACI Building Code has included specific provisions for fastening to concrete for the first time. This reflects the increased demand from code users for comprehensive coverage of this important application, the considerable research and design development stimulated by ACI Committees 349 and 355, and increased cooperation with CEB.

22.2.1 - Under tension loadings fasteners can experience 4 different types of failures:

1. *Pullout* -This term is used to describe several similar failure modes. For cast-in-situ fasteners, a pullout failure occurs by pulling the headed stud out of the concrete without significantly damaging the surrounding concrete. This type of failure can occur when the head of the stud is small relative to the diameter of the shaft. For post-installed fasteners there are two types of pullout failure which are difficult to differentiate between, and often occur together. One type is a failure by sliding out of the fastening device or parts of it from the concrete. This type of failure indicates that the friction between the expansion sleeve and the concrete is inadequate, and it is highly dependent on installation procedures and the condition of the hole. A similar pullout mode is failure by pulling the center cone of the anchor through the expansion sleeve without significantly damaging the surrounding concrete. This type of failure is dependent on the friction between the inner and outer parts of the expansion mechanism, which is more dependent on the design of the fastener, and less on the installation procedures.

   Pullout failures are a function of the fastener construction, the anchor mechanism, the condition of the drilled hole, the size of the anchor head for headed studs and bolts and the deformability of the concrete. For post-installed fasteners and some types of cast-in-situ inserts, these types of failures cannot be predicted theoretically and capacities must be determined through comprehensive prequalification tests. An acceptable pullout failure mode is one which exhibits the load deflection characteristics of lines 1 or 2 shown in Figure 22.2.1(a). A method is presented in Section 22.10 to calculate the pullout strength of cast-in-situ headed studs and headed anchor bolts in cracked or uncracked concrete.

2. *Steel* - There are two types of steel failures which can occur. The first and more preferable is a ductile failure by yielding of the fastening device or the system fastened to the concrete before any breakout of the concrete occurs. Such ductile failures utilize a $\phi = \mathbf{0.80}$ according to Section 22.3.4(a). However, many fasteners are produced from brittle material and the initial steel failure can be brittle. In such cases design must be based on a lower ϕ factor reflecting this brittleness and also used for the more brittle concrete breakout, pullout, or splitting failures. Steel failure loads can be predicted when the properties of the fastener are known and when other types of failure are precluded.
3. *Concrete Breakout* - This type of failure consists of a breakout of a prism or cone of concrete from the structural concrete member before failure of the fastener or the attachment. Concrete breakout failures are a primary focus of this chapter. A highly transparent, user-friendly method of failure load calculation is presented. Other calculation methods or test procedures are acceptable if proven to offer comparable accuracy and conservatism.
4. *Splitting of Concrete*- This type of failure is caused by splitting of the structural member before failure of the fastener or the attachment. Splitting failures are currently addressed only indirectly with the inclusion of requirements for minimum edge and spacing dimensions which prevent this type of failure. A splitting failure perpendicular to the direction of the tension load can occur if a plane of closely spaced reinforcing steel is located near the embedded end of the fastener, see Figure 22.2.1(b). This type of failure must be prevented through proper detailing.

Under shear loadings fasteners can experience 3 different types of failures (see Figure 22.2.1(c):

1. *Steel Failure* - Failure by shearing of the fastener or the attachment before any breakout of the concrete occurs. Steel failure loads can be predicted when the properties of the fastener are known and when other types of failure are precluded.
2. *Edge Concrete Breakout* - Failure by breakout of a half prism or cone of concrete from the fastener to the edge of the concrete in the direction of the shear force, before failure of the fastener or the attachment. This type of concrete breakout failure is a primary focus of this chapter. A highly transparent, user-friendly method of failure load calculation is presented.
3. *Pryout Concrete Breakout* - Fasteners located distant from edges may fail by prying loose a cone of concrete on the side of the fastener away from the load. The failure is most likely to occur for short stiff fasteners or for anchor groups. The shear capacity for a fastener or fastener group remote from edges should never be taken as greater than twice the calculated tensile capacity.

Finally, under combined loadings fasteners will experience some combination of the mentioned shear and tension failure modes. An interaction equation is presented in Section 22.7 to determine fastener capacities under combined loadings.

22.2.2 - Typical cast-in-situ headed studs and headed anchor bolts have been extensively tested and have proven to behave predictably, so calculated pullout values are acceptable. Specialty inserts and post-installed fasteners do not have predictable pullout failure loads, therefore they must be tested. For a fastener to be used in conjunction with the requirements of this chapter, the results of the ASTM ZXXX test must indicate that, at the tested embedment depth, pullout failures exhibit the acceptable load displacement characteristics of Figure 22.2.1(a), or that pullout failures are precluded by another failure mode.

22.2.3 - The behavior of adhesive anchors is often substantially different than expansion anchors and undercut anchors. Adhesive anchors are widely used and can perform very adequately. Committee 318 intends to include in a future revision provisions for adhesive anchors. However, at this time such fasteners are outside the scope of this chapter.

Similarly, provisions for powder and pneumatic actuated nails and bolts are under development, but are not included in the current scope.

22.3.1 - When the failure of a fastener group is due to breakage of the concrete, the behavior is brittle and there is limited redistribution of the forces between the highly stressed and less stressed fasteners. In such a case the theory of elasticity must be used, assuming the attachment which distributes loads to the fasteners is sufficiently stiff. The forces in the fasteners are considered to be proportional to the external load and it's distance from the neutral axis of the fastener group.

If a fastener failure is governed by ductile failure of the fastener steel, significant redistribution of fastener forces may occur. In such a case, an analysis assuming the theory of elasticity will be conservative. In the future, a non-linear analysis, using theory of plasticity, may be allowed for the determination of the ultimate loading conditions of ductile fastener groups.

22.3.3 - For a fastener to be acceptable in seismic loading situations the system must be proven to have adequate ductility. The fastener must demonstrate the capacity to undergo large displacements through several cycles. If the fastener cannot meet these requirements then the attachment must yield at a load well below the fastener breakout capacity.

Under seismic conditions, it is possible that the direction of shear loading will not be precisely fixed. The full shear load must therefore be assumed in two orthogonal directions to ensure a safe design.

22.3.4 - The factor for ductile failures is indicative of less variability in steel tension failures than concrete breakout failures, and the greater amount of forewarning prior to a ductile failure. This value is purposely less than that associated with tension failures in reinforcement in order to recognize the higher variability in fabrication of some systems. The level of failure probability was selected to be in general agreement with proposed CEB fastener criteria. The basic factor for brittle failures (ϕ =

0.65) has been chosen based on the results of comprehensive probabilistic studies [1,2] which indicated that the use of ϕ = **0.65** for concrete controlled failures produced adequate safety levels. This ϕ factor should vary depending on the amount of reinforcing near the face, the state of stress in the concrete near the face, the life safety requirements of the attachment, and the redundancy of the connection. Such considerations may be reflected in future editions.

The strength reduction factor for fasteners subject to brittle failure under tension loads does reflect that the performance of post-installed fasteners can be sensitive to the installation procedures, that some fastening devices are more subject to installation tolerances and errors than others, and that some fasteners perform less satisfactorily in cracked concrete. The strength reduction factor, ϕ for tension loads, reflects this sensitivity.

The ASTM ZXXX installation safety tests determine the classification which is appropriate for a particular fastening device. The three classes of fasteners and their respective ϕ factors are as follows:

> ϕ = **1.0 x0.65** = **0.65** for systems with high installation safety, Class 1
> ϕ = **0.85 x0.65** ≈ **0.55** for systems with normal installation safety, Class 2
> ϕ = **0.70 x0.65** ≈ **0.45** for systems with low but still acceptable installation safety, Class 3.

For cast-in-place headed anchors this ϕ may be taken as **0.65**. For most undercut anchors this factor will also be **0.65**, while for most torque controlled expansion anchors this factor may be **0.55.**

The failure load of fasteners under shear loads is not as sensitive to installation errors and tolerances. Therefore, all fasteners use ϕ= **0.65** for shear calculations.

22.4.2 - The ACI 349 [3] approach for concrete breakout tensile and shear strength
design may meet the requirements of this section for many applications. The approach is not recommended overall because size effects are not clearly considered, the calculations involved in determining projected areas for overlapping cones and near edges are excessively complicated,

and the standard deviation is excessive for some applications [4].

The κ method [5,6] developed at the University of Stuttgart is considered to be generally acceptable for both tensile and shear strength calculations.

The method allowed under Section 22.4.5, the CCD Method, is an adaptation of the κ method and is considered to be accurate, relatively easy and transparent. The method predicts the load bearing capacity of a fastener or group of fasteners by using one basic equation for a single fastener in cracked concrete, and multiplying by factors which account for the number of fasteners, edge distance, spacing, eccentricity and absence of cracking.

The tensile strength calculations are based on the κ factor method for single fasteners which assumes a breakout prism angle of about 35 degrees (see Figure 22.4.2 (a)). Both the CCD and the κ methods include fracture mechanics theory, which indicates that in the case of brittle concrete failure the failure load increases at a rate less than the increase in the available surface and that the nominal stress at failure (peak load divided by failure area) decreases with increasing member size. The nominal stress at failure in tension decreases in proportion to $\mathbf{1/\sqrt{h_{ef}}}$, so the failure load increases with $\mathbf{h_{ef}}^{1.5}$.

Similarly, the shear strength calculations are also based on the κ factor method which assumes a breakout cone angle of about 35 degrees (see Figure 22.4.2(b)), and considers fracture mechanics theory. The nominal stress at failure in shear decreases in proportion to $\mathbf{1/\sqrt{c_1}}$, so the failure load increases with $\mathbf{c_1}^{1.5}$.

Test procedures may also be used to determine the basic single fastener shear and tensile breakout strength. However, the test results must be evaluated on an equivalent statistical basis to that used to select the values for the CCD Method. The 5% Fractile is used which requires that the basic capacity shall not be taken greater than the mean value less 2 standard deviations and the number of tests shall be sufficient for statistical validity.

22.5.2 - The basic fastener capacity equation is derived assuming a concrete failure prism with an angle of about 35 degrees, and considering fracture mechanics concepts, as follows:

$$N_b = k_1\sqrt{f_c'} \cdot k_2 h_{ef}^2 \cdot k_3 h_{ef}^{-0.5}$$

where $\mathbf{k_1 \sqrt{f_c'}}$ = Concrete tensile capacity,
$\mathbf{k_2 h_{ef}^2}$ = Activated load bearing area,
$\mathbf{k_3 h_{ef}^{-0.5}}$ = Size effect.

where $\mathbf{k_1}$, $\mathbf{k_2}$, and $\mathbf{k_3}$ are calibration factors.

If $\mathbf{k = k_1 * k_2 * k_3}$, then:

$$N_b = k \sqrt{f_c'}\, h_{ef}^{1.5}$$

For post-installed fasteners and cast-in-situ headed studs and headed anchor bolts, the mean values of **k** and the standard deviations were determined from a large database of test results[4]. The **k** value in the design equation is the mean value for specimens tested in cracked concrete less two standard deviations (one-sided 95% tolerance limit with 95% confidence for the appropriate sample size) [7], which is also the ICBO Acceptance Criteria Method B - 5% Fractile, [8].

For fasteners influenced by three or more edges where the edge distance is less than $\mathbf{1.5h_{ef}}$, it is possible that the concrete breakout capacity of the fasteners, which is calculated using the CCD Method, decreases for a constant edge distance and an increasing embedment depth, $\mathbf{h_{ef}}$. This always yields safe results, but it does not reflect actual behavior. These special cases have been studied for the κ-Method [9].

The anomaly can be remedied in two ways. The first is to use a fracture mechanics approach for the load reduction. The primary problems with this approach are the very complicated formulas and the loss of transparency in calculating ultimate loads. The second approach is more simple and user-friendly. An effective value for the embedment depth $\mathbf{h_{ef}^*}$ which predicts the highest capacity for the fastener arrangement may be used. The value may be calculated as:

$$\mathbf{h_{ef}^* = c_1 / 1.5.}$$

where $\mathbf{c_1}$ = the largest of the influencing edge distances.

22.5.3 - Figure 22.5.3(a) shows $\mathbf{A_{No}}$. $\mathbf{A_{No}}$ is the maximum projected area for a single fastener. Figure 22.5.3(b) shows examples of the projected areas for various single fastener and multiple fastener arrangements. Since $\mathbf{A_N}$ is the total projected area for a group of fasteners, and $\mathbf{A_{No}}$ is the area for a single fastener, there is no need to include the number of fasteners in the equation. If fastener groups are positioned in such a way that their projected areas overlap, the value of $\mathbf{A_N}$ must be reduced accordingly.

22.5.4 - Figure 22.5.4(a) shows dimension $\mathbf{e'_N}$ = $\mathbf{e_N}$ for a group of fasteners which are all in tension but the resultant force is eccentric with respect to the centroid of the fastener group. Groups of fasteners can be loaded in such a way that some of the fasteners are in tension while others are in compression, see Figure 22.5.4(b). In this case, only the fasteners in tension are to be considered in the determination of $\mathbf{e'_N}$. The loading shall be resolved to the resultant fastener tension at an eccentricity with respect to the center of gravity of the fasteners in tension. Eq 22-4 is limited to cases where $\mathbf{e'_N < s/2}$ after the determination which reflects the possibility of some fasteners being in compression. For cases in which $\mathbf{e'_N > s/2}$, a more rigorous analysis must be used.

22.5.5 - If fasteners are located so close to an edge that there is not enough space for a complete breakout prism to develop, the load bearing capacity of the fastener is further reduced beyond that reflected in $\mathbf{A_N/A_{No}}$. If the smallest side cover distance is greater than $\mathbf{c_{1crN}}$ = $\mathbf{1.5\ h_{ef}}$, a complete prism can form and there is no reduction ($\mathbf{\Psi_2 = 1}$). If the side cover is less than $\mathbf{c_{1crN}}$ = $\mathbf{1.5\ h_{ef}}$ the factor, Ψ_2 , is required to adjust for the disturbance of the radial symmetric stress distribution.

22.5.6 - Figure 22.5.6(a) shows the design equation for post-installed fasteners in uncracked concrete compared to test results. Figure 22.5.6(b) shows the design equation for cast-in-situ headed studs in uncracked concrete compared to test results.

Torque controlled expansion anchors which have not met the requirements for use in cracked concrete according to ASTM ZXXX and displacement controlled expansion anchors (anchors not able to re-expand under load) shall only be used in uncracked regions

22.5.7 - The fastener qualification tests of ASTM ZXXX require that fasteners in cracked concrete zones perform well in a base crack of 0.3mm. This is approximately the maximum crack size used to derive the flexural reinforcement distribution provisions of Section 10.6.4. If larger crack widths might be expected, confining reinforcement to control the crack width to about 0.3mm shall be provided.

22.6.2 - As with tensile loadings, the concrete breakout shear capacity does not increase with the failure surface, which is proportional to $\mathbf{c_1^2}$. Instead the capacity increases proportionally to $\mathbf{c_1^{1.5}}$, due to the size effect. The failure load is also influenced by the fastener stiffness and the fastener diameter.

The constant **6** in the shear strength equation was determined similarly to the **k** value in the tensile strength equation. It is also the mean value of the constant less two standard deviations (one-sided 95% tolerance limit with 95% confidence for the appropriate sample size) times a 0.7 factor to account for cracking. Test data used in this evaluation were obtained from shear tests performed with no grout pad between the surface of the concrete and the attachment. There may be a reduction in shear capacity if a grout pad is used.

For fasteners in a thin member influenced by three or more edges($\mathbf{c_2} < \mathbf{1.5c_1}$ and $\mathbf{h} < \mathbf{1.5c_1}$) , it is possible that the concrete breakout shear capacity of the fasteners, which is calculated using the CCD Method, decreases for a constant edge distance and an increasing distance to the edge of concrete, $\mathbf{c_1}$. This always yields safe results, but it does not reflect actual behavior. These special cases have been studied for the κ-Method [9].

The anomaly can be remedied in two ways. The first is to use a fracture mechanics approach for the load reduction. The primary problems with this approach
are the very complicated formulas and the loss of transparency in calculating ultimate loads. The second approach is more simple and user-friendly. An effective value for the distance to the concrete edge, $\mathbf{c_1^*}$ which predicts the highest capacity for the fastener arrangement may be used. The value may be calculated as:

the larger of: $c_1^* = c_2/1.5$,
or $c_1^* = h/1.5$.

22.6.3 Figure 22.6.3(a) shows $\mathbf{A_{Vo}}$. $\mathbf{A_{Vo}}$ is the maximum projected area for a single fastener, which approximates the surface area of the full breakout prism or cone for a fastener which is unaffected by edge distance or spacing or depth of member. Figure 22.6.3(b) shows examples of the projected areas for various single fastener and multiple fastener arrangements. Note that when there are multiple fasteners in the direction of the shear force, the edge distance of the fastener closest to the edge is used along with the shear on the fastener as determined by elastic analysis. $\mathbf{A_V}$ approximates the full surface area of the breakout cone for the particular arrangement of fasteners. Since $\mathbf{A_V}$ is the total projected area for a group of fasteners, and $\mathbf{A_{Vo}}$ is the area for a single fastener, there is no need to include the number of fasteners in the equation.

22.6.4 - Figure 22.6.4 shows the dimension $\mathbf{e'_V}$ for shear calculations.

22.6.5 - Figure 22.6.5 shows the dimension $\mathbf{c_2}$ for the Ψ_5 calculation.

22.6.6 - Figure 22.6.6 shows the design equation for fasteners in uncracked concrete compared to test results.

Torque controlled and displacement controlled expansion anchors are permitted in cracked concrete under pure shear loadings.

22.7 Traditionally, the shear-tension interaction expression has been expressed as:

$$\left(\frac{N}{N_n}\right)^x + \left(\frac{V}{V_n}\right)^x \leq 1.0$$

where x varies from 1 to 2. The current recommendation is a simplification of the expression where x = 2 (see Figure 22.7) with limits chosen to eliminate computation of interaction effects where very small quantities of the second force are present.

The interaction equation is valid even when the lowest shear capacity and lowest tension capacity are of different types, for example a tension capacity controlled by concrete breakout and a shear capacity controlled by the fastener steel.

22.8.3 - This minimum thickness requirement is not applicable to through bolts. Splitting failures are caused by the load transfer between the bolt and the concrete. Since through bolts transfer their load differently than cast-in-situ or post-installed expansion and undercut fasteners, they are not subject to the same member thickness.

22.9.3 - If multiple fasteners are used and the shear is applied in the direction of a series of fasteners, because of the limited shear deformability of fasteners, the failure load will be smaller than the number of fasteners times the individual fastener capacity. It is conservative to use the capacity of only the first fastener in the series. It is also possible to use the full capacity of the group multiplied by a reduction factor determined from realistic tests.

Bibliography

1. Farrow, C.B. and Klingner, R.E., "Tensile Capacity of Anchors with PArtial or Overlapping Failure Surfaces: Evaluation of Existing Formulas on an LRFD Basis," Draft for Internal use by ACI Technical Committees, March 14, 1992.

2. Farrow, C.B., Frigui, I., Klingner, R.E., "Tensile Capacity of Single Anchors in Concrete: Evaluation of Existing Formulas on an LRFD Basis," A Report to the Tennessee Valley Authority, March 13, 1992.

3. ACI Committee 349, "Appendix B - Steel Embedments," Manual of Concrete Practice.

4. Fuchs, W., Eligehausen, R., and Breen, J.E., "Fastening to Concrete: Design of Fastenings Using Steel Anchors or Headed Studs: Comparison of Procedures for Concrete Capacity," Report No. 12/14-91/10, Draft for ACI 318 SubCommittee B, Sept. 15, 1991.

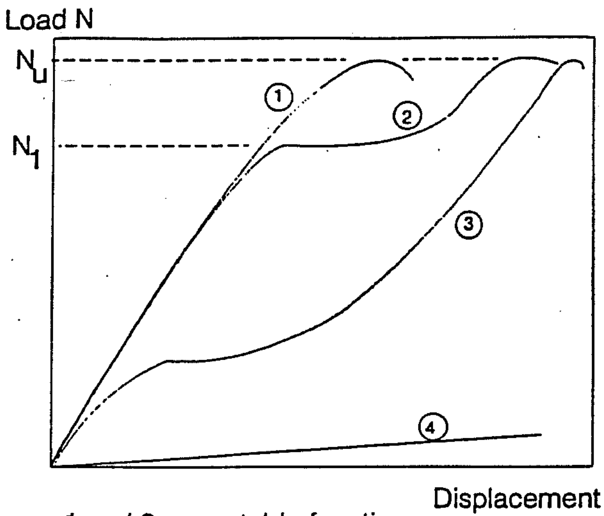
5. Eligehausen, R. and Fuchs, W., "Load Bearing Behavior of Anchor Fastenings Under Shear, Combined Tension and Shear or Flexural Loading," Betonwerk + Fertigteiltechnik, 2/1988, pp 48-56.

6. Eligehausen, R., Fuchs, W., and Mayer, B., "Load Bearing Behavior of Anchor Fastenings in Tension," Betonwerk + Fertigteiltechnik, 12/1987, pp 826-832, and 1/88, pp 29-35.

7. United States Department of Commerce, Experimental Statistics, Handbook 91.

8. ICBO Evaluation Service, Inc., "Acceptance Criteria for Expansion Anchors in Concrete and Masonry Elements," July 1991.

9. Eligehausen, R., Balogh, T., Fuchs, W., and Breen, J.E., "The CC-Method (Concrete Capacity-Method)," Report No. 12/15-92/1 prepared for ACI 318 SubCommittee B, March 6, 1992.



1 and 2 acceptable function
3 and 4 non-acceptable function

$N_1 = 0.7\ N_u$ (tests in cracked concrete)
$N_1 = 0.8\ N_u$ (tests in uncracked concrete)

Figure 22.2.1(a) Load-Displacement Curves for Fastener Tests.

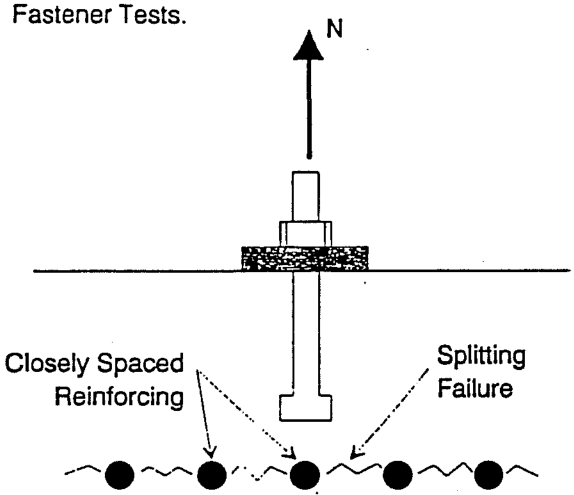


Figure 22.2.1(b) Splitting Failure Caused By Closely Spaced Reinforcing Below Fastener.

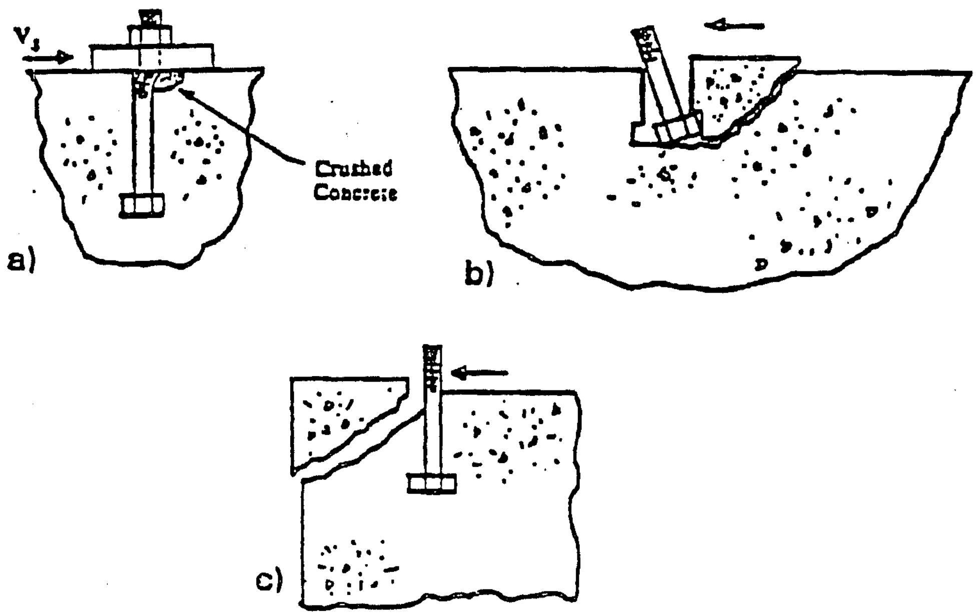


Figure 22.2.1(c) Typical failure modes for anchors in shear; a) shear failure of steel, b) pryout cone failure, c) edge concrete breakout failure.

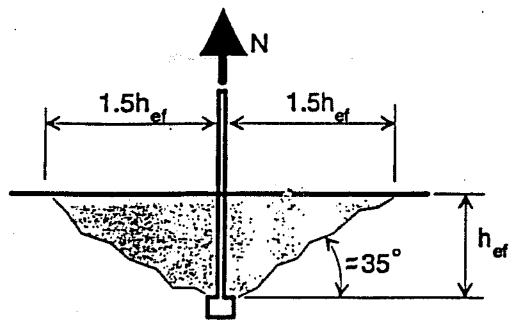


Figure 22.4.2(a) ≈35 Degree Breakout Cone for Tension.

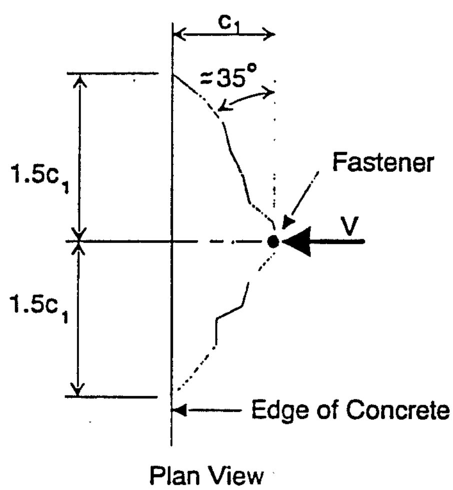
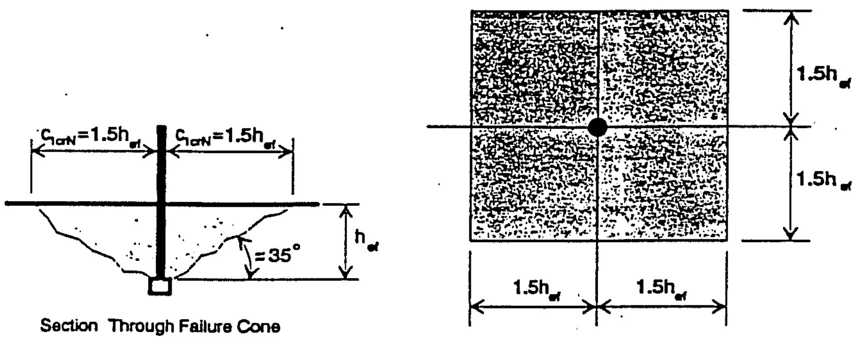
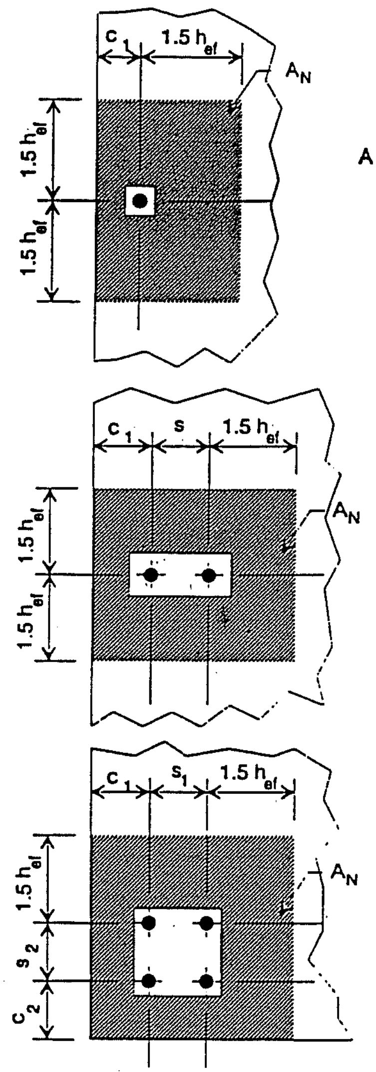


Figure 22.4.2(b) ≈35 Degree Breakout Cone for Shear.



$$A_{No} = 2c_{1crN} \times 2c_{1crN}$$
$$= 3h_{ef} \times 3h_{ef} = 9h_{ef}^2$$

Figure 22.5.3(a) Calculation of A_{No}



$A_N = (c_1 + 1.5h_{ef})(2 \times 1.5h_{ef})$

if $c_1 < 1.5h_{ef}$

$A_N = (c_1 + s + 1.5h_{ef})(2 \times 1.5h_{ef})$

if $c_1 < 1.5h_{ef}$

and $s < s_{crN} = 3h_{ef}$

$A_N = (c_1 + s_1 + 1.5h_{ef})(c_2 + s_2 + 1.5h_{ef})$

if c_1 and $c_2 < 1.5h_{ef}$

and s_1 and $s_2 < s_{crN} = 3h_{ef}$

Figure 22.5.3(b) Projected areas for single fasteners and groups of fasteners.

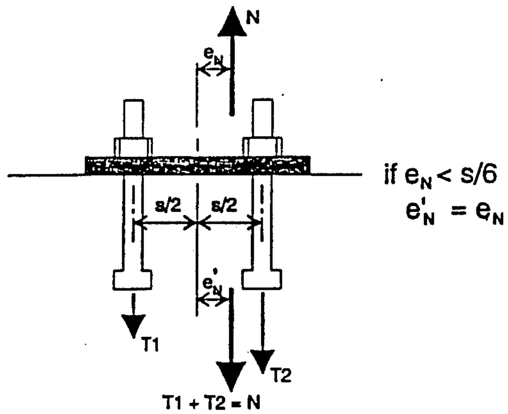
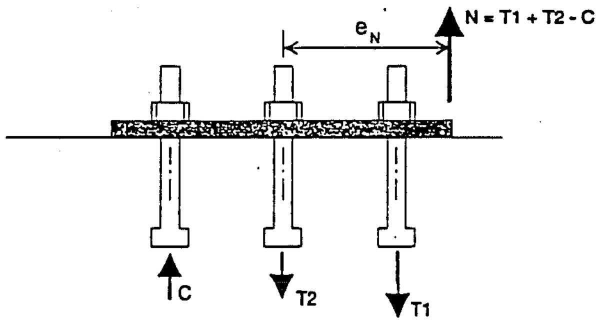


Figure 22.5.4(a) Definition of Dimension e_N when all fasteners in a group are in tension.



Actual Loading Condition

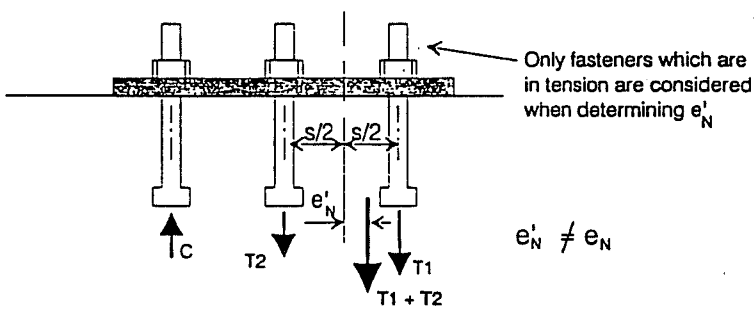
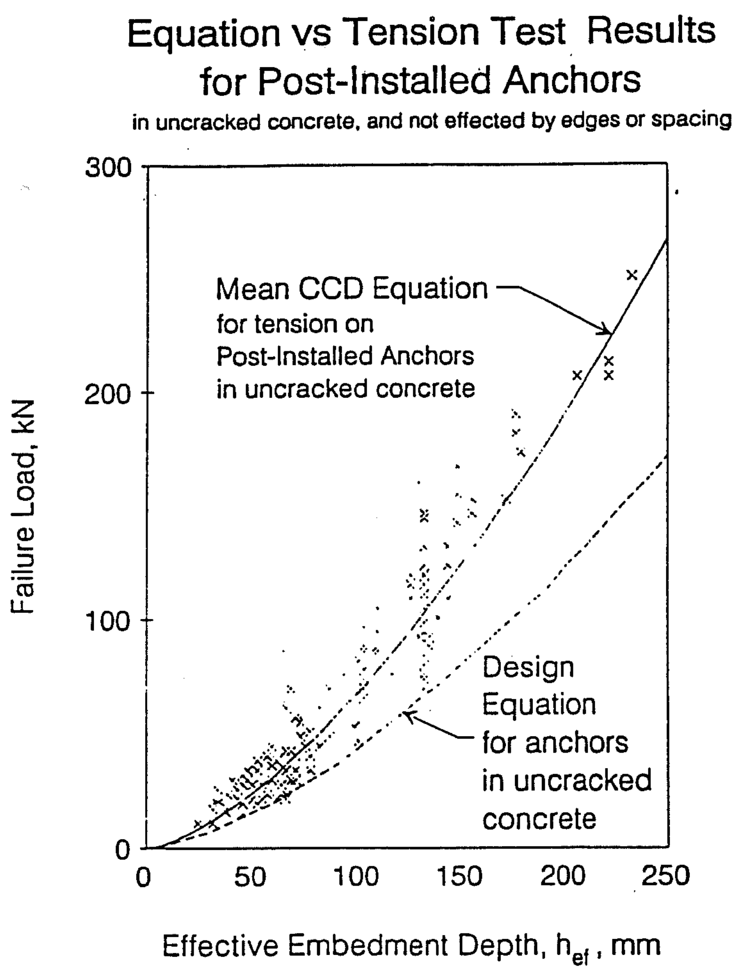
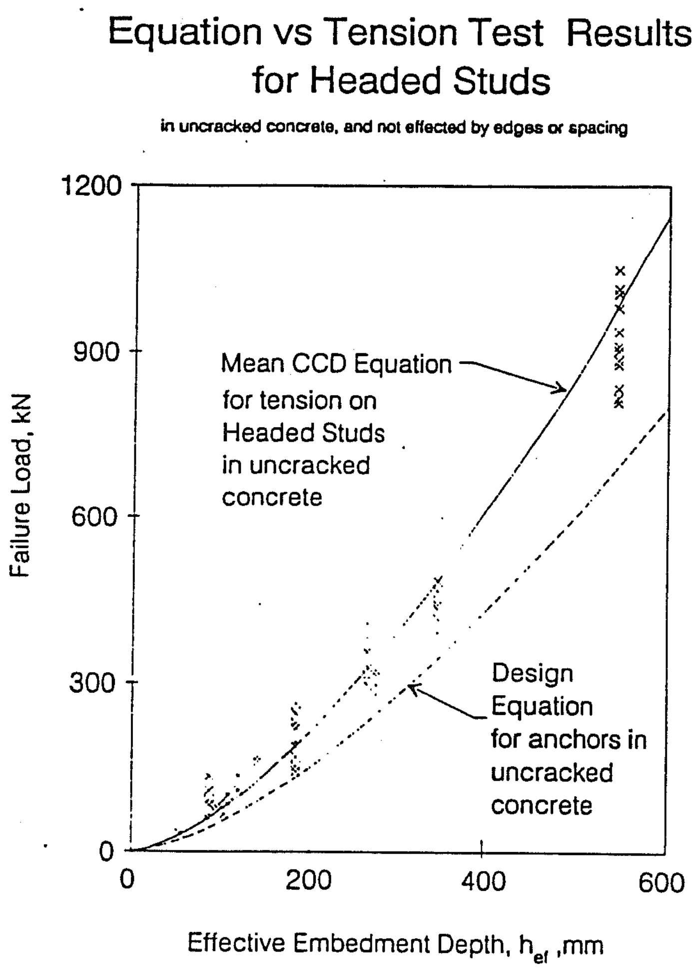


Figure 22.5.4(b) Determination of e'_N for fastener group with some fasteners in compression



22.5.6(a) Mean and Design CCD Equations for anchors in uncracked concrete compared to test data, for post-installed anchors.



22.5.6(b) Mean and Design CCD Equations compared to test data, for headed studs in uncracked concrete.

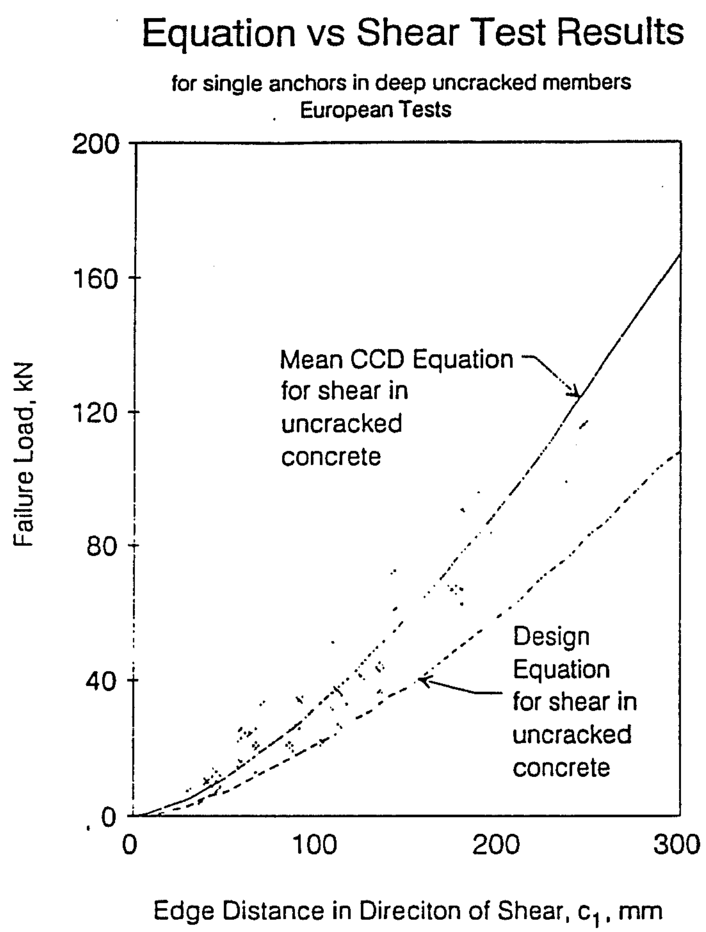


Figure 22.6.2 Mean and Design CCD Shear Equations for uncracked concrete compared to test data.

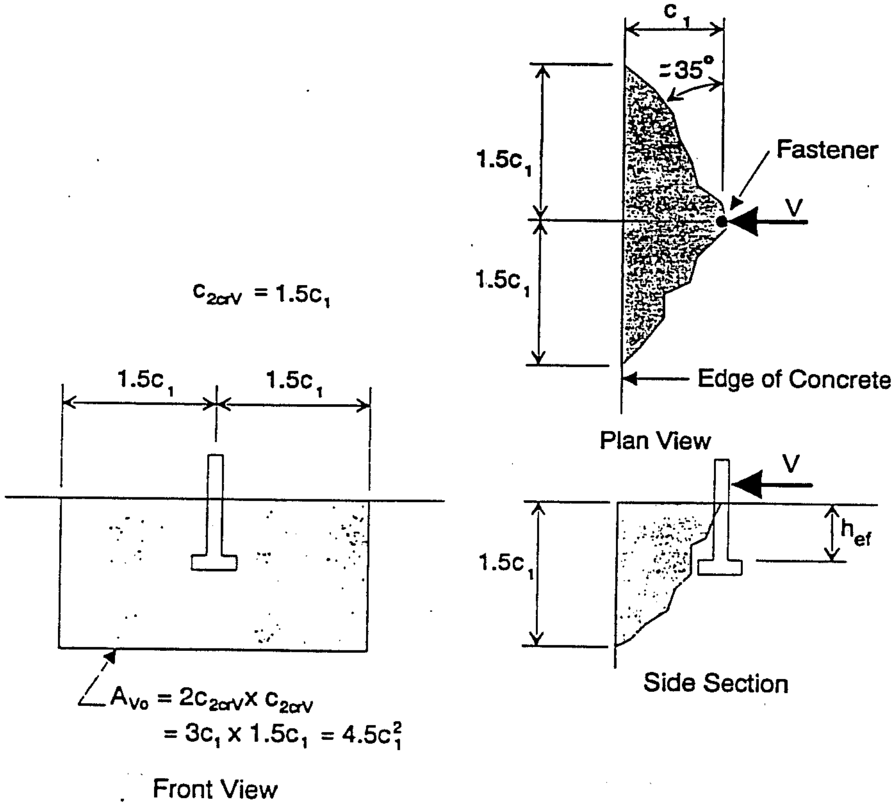


Figure 22.6.3(a) Calculation of A_{Vo}

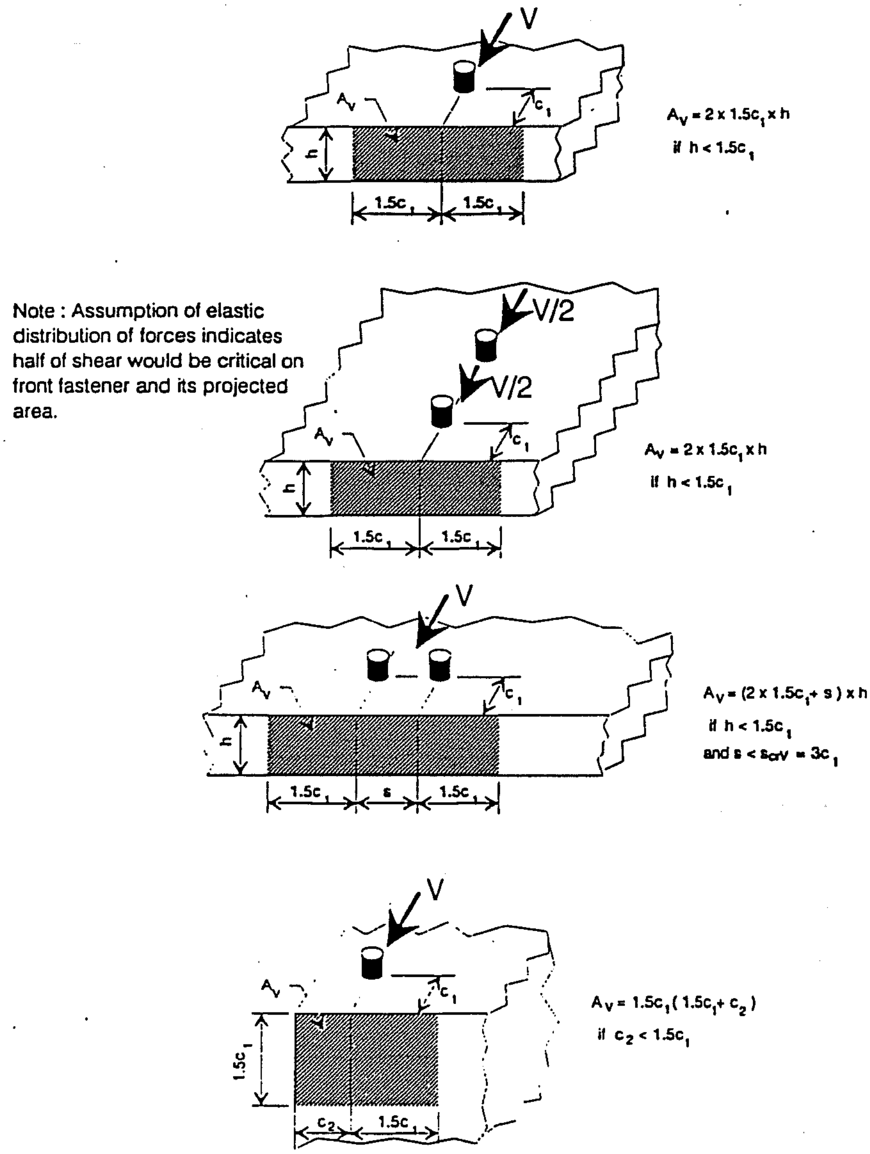


Figure 22.6.3(b) Projected areas for single fasteners and groups of fasteners

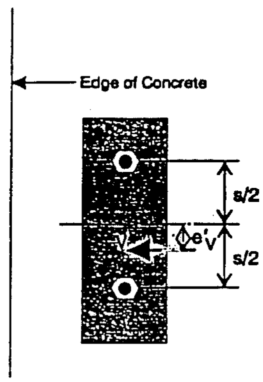
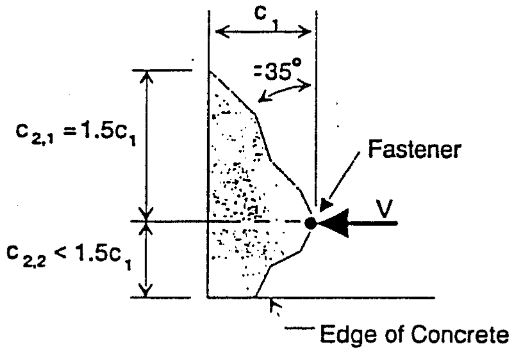


Figure 22.6.4 Definition of Dimension e'_V



Plan View

For calculation of Ψ_5 use smaller of $c_{2,1}$ and $c_{2,2}$

Figure 22.6.5 Dimension c_2 for Edge Proximity Modification Factor

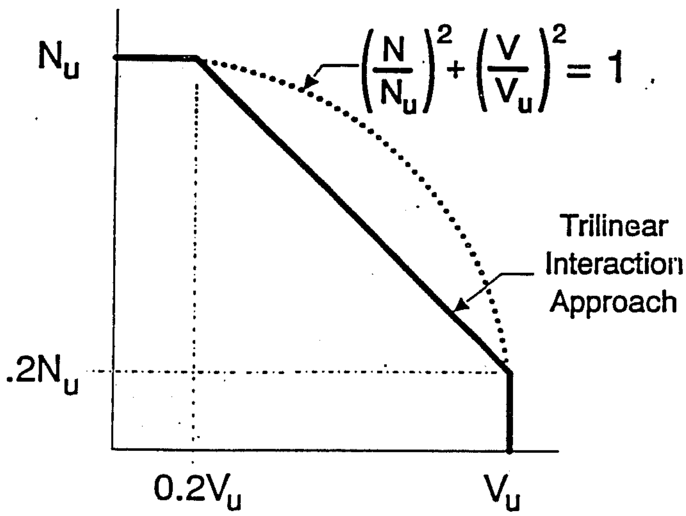


Figure 22.7 Shear and Tensile Load Interaction Equation

APPENDIX C

SAMPLE CALCULATIONS

The following calculations are examples of the equations provided in Ref. 6. These examples are typical of those used in this thesis to predict the nominal concrete breakout strength and anchor strength for oblique tension test, group tension tests, and group shear test. The notaton used in these examples are defined in Ref. 6.

Example 1

Nominal concrete breakout tensile strength of a single anchor

Anchor A

Diameter = 0.375in.

$$h_{ef} = 0.875 \text{ in.}$$

$$N_n = \frac{A_n}{A_{no}} \psi_1 \psi_2 \psi_3 N_b$$

$$N_b = \kappa \lambda \sqrt{f_c'} \left(h_{ef} \right)^{1.5}$$

$$A_n = (1.3125 \text{ in.} + 1.3125 \text{ in.})^2 + 6.89 \text{ in.}^2$$

$$A_{no} = 9 \left(h_{ef} \right)^2 = 9 (0.875 \text{ in.})^2 = 6.89 \text{ in.}^2$$

$$N_b = 17 (1) \sqrt{1926 \text{ psi}} (0.875 \text{ in.})^2 = 610.65 \text{ lb.}$$

$$\psi_1 = 1 , \psi_2 = 1 , \psi_3 = 1.4$$

$$N_u = \frac{6.89 \text{ in.}^2}{6.89 \text{ in.}^2} (1) (1) (1.4) (610.65 \text{ lb.}) = 855 \text{ lb.}$$

Example 2

Nominal concrete breakout shear strength of a single anchor

Anchor A

Diameter = 0.375 in.

ℓ = 1.25 in.

C_1 = 2.188 in.

$$V_n = \frac{A_v}{Avo} \psi_4 \psi_5 \psi_6 v_6$$

$$V_b = 6\left(\frac{\ell}{d_o}\right)^{0.2} \sqrt{do} \cdot \lambda \cdot \sqrt{f_c'} \cdot (c_1)^{1.5}$$

$$A_v = (2\ (1.5)\ (2.188)) \cdot (1.5\ (2.188)) = 21.543 \text{ in.}^2$$

$$A_{vo} = 4.5\ C_1^2 = 4.5\ (2.188 \text{ in.})^2 = 21.543 \text{ in.}^2$$

$$V_b = 6\left(\frac{1.25 \text{ in.}}{0.375 \text{ in.}}\right)^{0.2} \sqrt{0.375 \text{ in.}} \cdot \sqrt{1926 \text{ psi}} \cdot (2.188 \text{ in.})^{1.5} = 664 \text{ lb.}$$

$\psi_4 = 1$, $\psi_5 = 1$, $\psi_6 = 1.4$

$$V_n = \frac{21.543 \text{ in.}^2}{21.543 \text{ in.}^2} (1)\ (1)\ (1.4)\ (664 \text{ lb.}) = 930 \text{ lb.}$$

Example 3

Nominal concrete breakout tensile strength for a group of four anchors

Anchor C

Diameter = 0.625 in.

C_1 = 6 in.

h_{ef} = 7.313 in.

S = 12 in.

$$N_n = \frac{A_n}{A_{no}} \psi_1 \, \psi_2 \, \psi_3 \, N_b$$

$$N_b = \kappa \, \lambda \sqrt{f_c^{\prime}} \left(h_{ef} \right)^{1.5}$$

$$A_n = (\, 6 \text{ in.} + 12 \text{ in.} + 10.97 \text{ in.}\,) \cdot (\, 2\,(10.97 \text{ in.}\,) + 12 \text{ in.}\,) = 983.15 \text{ in.}^2$$

$$A_{no} = 9 \left(h_{ef} \right)^2 = 9\,(7.313 \text{ in.})^2 = 481.32 \text{ in.}^2$$

$$N_b = 17\,(\,1\,)\sqrt{2058 \text{ psi}}\,(\,7.313 \text{ in.}\,)^{1.5} = 15{,}251.58 \text{ lb.}$$

$$\psi_1 = 1\,,\ \psi_2 = 2\,,\ \psi_3 = 1.4$$

$$N_n = \frac{983.15 \text{ in.}^2}{481.32 \text{ in.}^2}\,(1.4)\,(15{,}251.58 \text{ lb.}) = 43{,}614 \text{ lb.}$$

Example 4

Nominal concrete breakout shear strength for a group of two anchors

Anchor B

$$\ell = 1.25 \text{ in.}$$

$$\text{Diameter} = do = 0.375 \text{ in.}$$

$$C_1 = 2.188 \text{ in.}$$

$$V_n = \frac{A_v}{A_{vo}} \psi_4 \psi_5 \psi_6$$

$$V_b = 6\left(\frac{\ell}{do}\right)^{0.2} \sqrt{do} \cdot \lambda \cdot \sqrt{f_c'} \cdot (C_1)^{1.5}$$

$$A_v = (2 + 1.5\,(2.188 \text{ in.}) + 2.188 \text{ in.}) \cdot (1.5\,(2.188 \text{ in.})) = 28.72 \text{ in.}^2$$

$$A_{vo} = 4.5\,(C_1)^2 = 4.5\,(2.188 \text{ in.})^2 = 21.54 \text{ in.}^2$$

$$\psi_4 = 1\,,\ \psi_5 = 1\,,\ \psi_6 = 1.4$$

$$V_b = 6\left(\frac{1.25 \text{ in.}}{0.375 \text{ in.}}\right)^{0.2} = \sqrt{0.375 \text{ in.}} \cdot 1 \cdot \sqrt{1497 \text{ psi}} \cdot (2.188 \text{ in.})^{1.5} = 585.36 \text{ lb.}$$

$$V_n = \frac{28.72 \text{ in.}^2}{21.54 \text{ in.}^2}\,(1)\,(1)\,(1.4)\,585.36 \text{ lb.} = 1093 \text{ lb.}$$

Example 5

Tensile strength of a fastener
Anchor A

$$\text{Diameter} = 0.500 \text{ in.}$$

$$f_{ut} = 120{,}000 \text{ psi}$$

$$N_y = A_{se}\,(0.8\, f_{ut})$$

$$A_{se} = \frac{\pi}{4}\left(do - \frac{0.9743}{n} \right)^2$$

n = number of threads per inch

$$A_{se} = \frac{\pi}{4}\left(0.500 \text{ in.} - \frac{0.9743}{13} \right)^2 = 0.1419 \text{ in.}^2$$

$$N_y = 0.1419 \text{ in.}^2 \left(0.8 \left(120{,}000 \frac{\text{lb}}{\text{in.}^2} \right) \right) = 13{,}622 \text{ lb.}$$

Shear strength of a fastener
Anchor A

$$\text{Diameter} = 0.500 \text{ in.}$$

$$f_{ut} = 120{,}000 \text{ psi}$$

$$V_y = 0.5\, A_{se}\,(0.8\, f_{ut})$$

$$V_y = 0.5\,(\,0.1419 \text{ in.}^2\,)\,(\,0.8\,(\,120{,}000 \text{ lb/in.}\,)\,) = 6{,}811 \text{ lb.})$$

REFERENCES

1. *Uniform Building Code* (UBC), International Conference of Building Officials, Whittier, CA, 1991.
2. "Accceptance Criteria for Expansion Anchors in Concrete and Masonry Elements," ICBO Evaluation Service, Inc., Whittier, CA, 1991.
3. *Fastenings to Reinforced Concrete and Masonry Structures: Part 1*, Bulletin D'Information No. 206, Euro-International Concrete Committee (CEB), August, 1991.
4. Pechillo, Thomas H., "Performance of Post-Installed Anchors in Uncracked Concrete Under Seismic, Fatigue and Shock Loads," Master's Thesis, The University of Texas at Austin, August, 1993.
5. ASTM E488-90: Standard Tests Methods for Strength of Anchors in Concrete and Masonry Elements," American Society for Testing and Materials, Philadelphia, PA, July, 1990.
6. ACI 318-95, Standard Building Code, Chapter 22, 1993.
7. ASTM C617-87, Standard Practice for Capping Cylindrical Concrete Specimens, American Society for Testing and Materials, Philadelphia, PA, 1988.
8. ASTM C39-86, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, American Society for Testing and Materials, Philadelphia, PA, 1986.

VITA

Winston Wayne Clendennen II was born in Waco, Texas, on September 6, 1960, the son of Winston Wayne Clendennen and Sandra Phillips Clendennen. He received a Bachelor of Science degree in Civil Engineering from The University of Arizona in August 1992. In September 1992 he entered Graduate School at The University of Texas at Austin.