THE DESIGN AND CONSTRUCTION OF A LARGE PLANE STRAIN APPARATUS FOR TESTING REINFORCED SOIL SPECIMENS

by

Joseph Edwin Dove

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J.M. Duncan, Chairman

G.W. Clough R.D. Krebs

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(ABSTRACT)

The increased popularity of using reinforcement in embankment fills and slopes has created a need for studies of the interaction between the reinforcement and surrounding soil to provide an improved basis for limit equilibrium design methods. The purpose of this study was to develop a plane strain triaxial apparatus and associated equipment to study the interaction of soil and reinforcement.

The plane strain apparatus was designed to model an element of soil situated along a slip surface in a reinforced embankment. The device constructed is capable of testing a sample 9.4 inches square and 23 inches high with full size reinforcing materials included. A 30,000 pound capacity load frame and a 20,000 pound capacity electric load cell were also constructed during this study. Drawings of the equipment constructed and a design method for the load cell are included.

Preliminary tests on unreinforced and reinforced samples under a confining pressure of 10 psi were performed to check the equipment operation. These tests show that the equipment functions as planned. Modifications desirable to improve the performance of the equipment are given.

Acknowledgements

I would like to express my thanks to my advisor and friend, Professor J.M. Duncan, for his support, generosity and many thoughtful suggestions. I would also like to thank Glenn Thomas and Brett Farmer of the Virginia Tech civil engineering shop for their outstanding work in the construction of all the equipment.

Lastly, but most importantly, I would like to thank my wife and best friend Patricia, for her undying support, encouragement, and help throughout this endeavor.

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Introduction

With the increased use of soil reinforcement in embankment fills, the need has developed for reliable and soundly based methods for their design. Presently, most procedures for design are based on conventional limit equilibrium methods of slope stability analysis, modified to account for the stabilizing effects of the reinforcement. Examples of current design procedures are given by Jewell (1982), Milligan and La rochelle (1982), Fowler (1982), Jewell et al. (1982), Low (1985), and Leshchinsky et al. (1985). These procedures use various assumptions concerning the interaction between the soil and the reinforcement, particularly where a slip surface crosses the reinforcement. However at present, our knowledge of the interaction between the reinforcement and adjacent soil is limited. There is thus a need for studies to determine the mechanisms involved in this interaction, to provide an improved basis for the assumptions necessary for limit equilibrium analyses of reinforced slopes and embankments.

A question of considerable practical importance in this regard involves the orientation of the tensile force developed in the reinforcement in the condition of impending failure. For example, consider the case of an embankment containing a single layer of reinforcement built upon a soft clay foundation, as shown in Figure 1. If the embankment failed, a slip surface would form through the embankment and into the clay, crossing the reinforcement. As movement along the slip surface begins, the outer portion of the embankment moves down, carrying the outer part of the reinforcement with it. If the reinforcement is flexi-

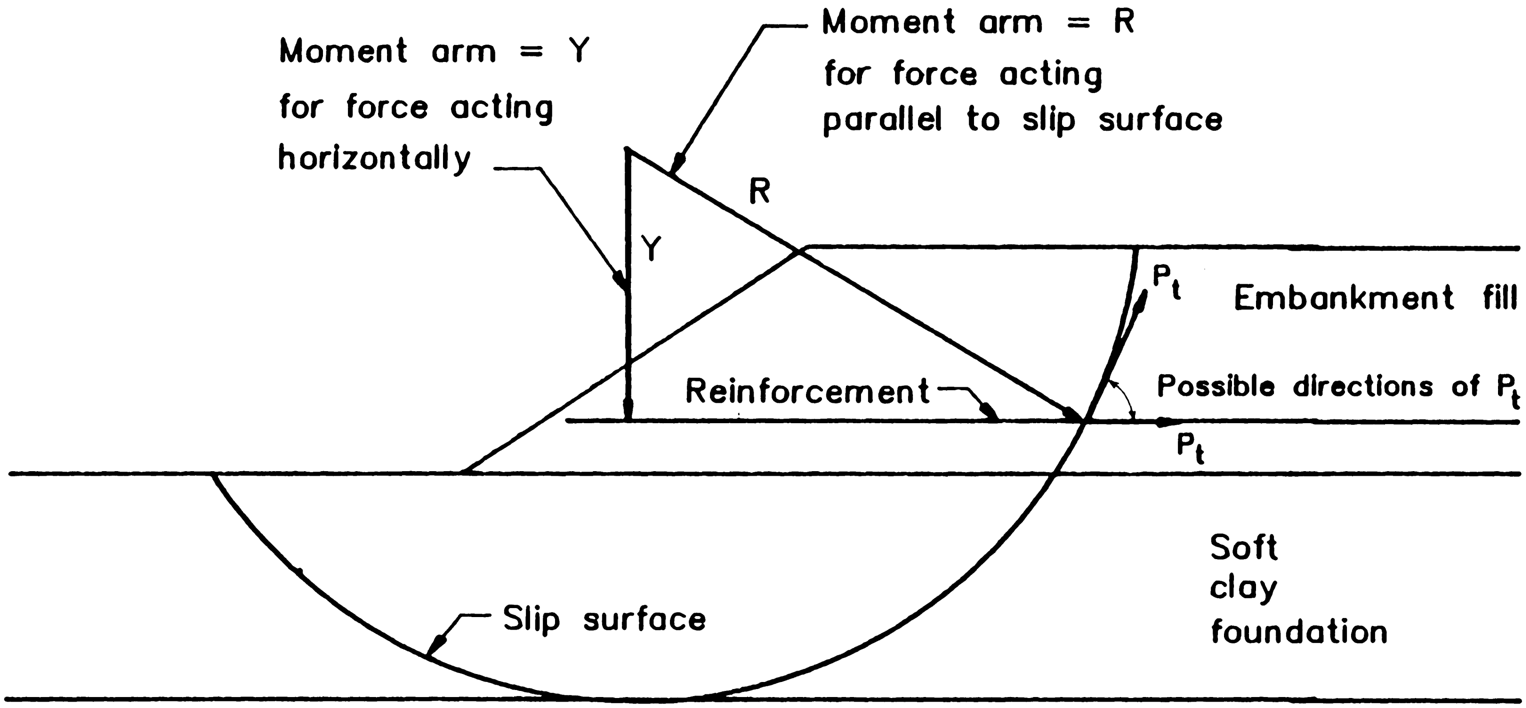


Figure 1. Possible Orientations of Reinforcement Force

ble in bending and fully conforms to the slip surface, the resulting tensile force will be oriented tangent to the slip circle. If the reinforcement is stiffer and does not conform to the slip surface, the tensile force will be oriented horizontally or at some angle above horizontal.

The direction of the tensile force influences the magnitude of the contribution of the reinforcement to the stability of the embankment. Possible orientations of the tensile force are shown in Figure 1. If the tensile force is oriented tangent to the slip circle, its contribution to the resisting moment will be P_t*R, where P_t is the tensile force developed in the reinforcement and R is the radius of the slip circle. However, if the tensile force is oriented at some other angle, the moment arm will be smaller, and the stabilizing influence of the reinforcement will be less. If the tensile force is oriented horizontally, the resisting moment will be P_t*Y, where Y is the vertical distance from the circle center to the reinforcement. It is thus important to determine how various types of reinforcing materials behave when they are intercepted by slip surfaces, in order that their stabilizing effects can be evaluated more accurately.

Because most embankments deform in a condition of plane strain, it is desirable that studies of embankments be performed under these same conditions. Plane strain is a condition in which strains and movements in one direction are prevented. Thus in the plane strain condition, strain occurs in a single plane only. In embankments, plane strain is a natural consequence of the fact that the lengths of most embankments are very great compared to their widths. If such an embankment fails, movement takes place in planes perpendicular to the long axis of the embankment, with little or no movement parallel to the axis.

The condition of plane strain may be modeled in the laboratory by using lubricated end plates to prevent deformation of a rectangular soil specimen in one direction, as described by Cornforth (1964) and Marachi et. al. (1969).

The purpose of this study was to develop an apparatus capable of simulating conditions in an element of soil like the one shown in Figure 2. This element of embankment soil, located along the slip circle and containing a section of reinforcement, can be modeled experimentally by a plane strain triaxial specimen containing a layer of reinforcement. End plates can be used to restrain the sample to deform in plane strain. If full sized reinforcing material is to be used in the experiments, the plane strain specimen must be large enough to accommodate a representative section. The apparatus designed and built in this study can be used to test a 9.4 inch by 9.4 inch by 23 inch high specimen.

This report describes the considerations involved in the design and construction of a plane strain apparatus for study of the behavior of reinforced soil, and associated equipment needed for this study. Results are given for preliminary tests performed using the new equipment.

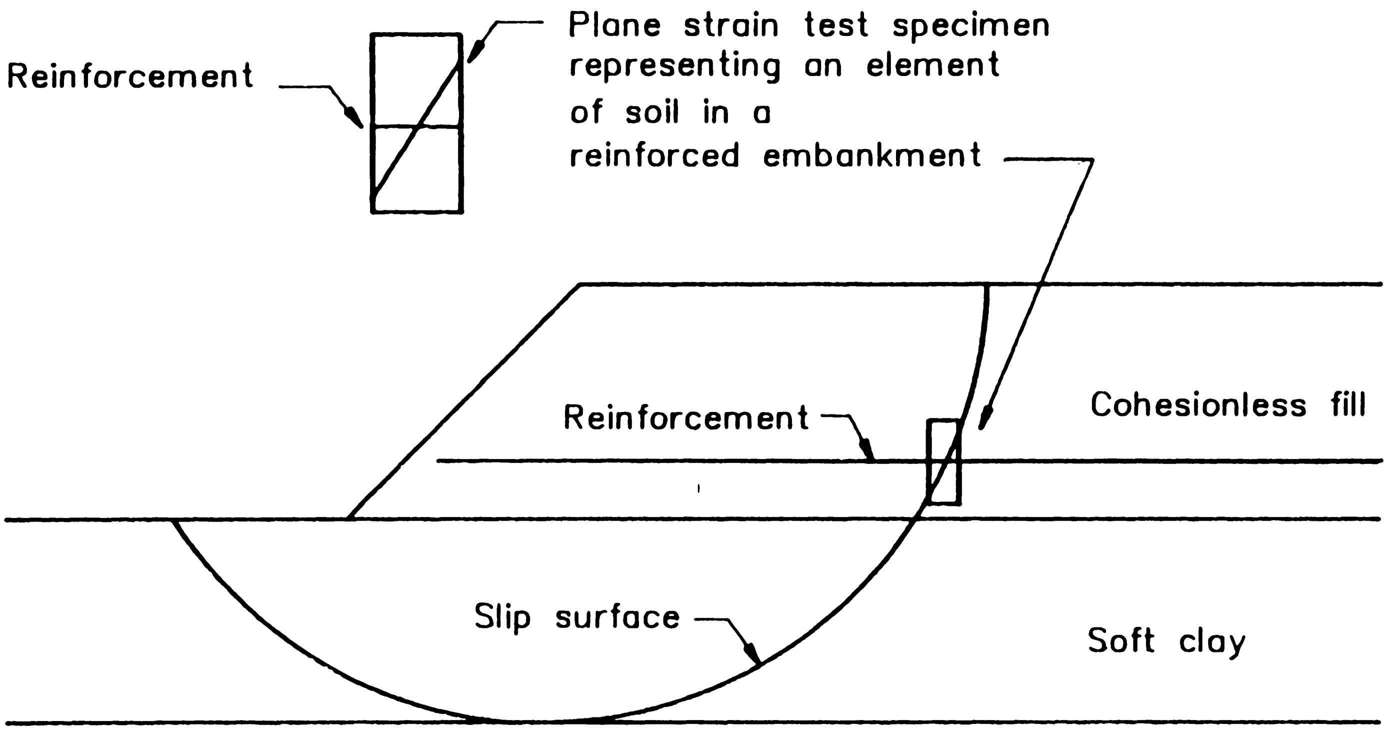


Figure 2. Element of Soil Modeled in Laboratory Study

Design and Construction of Equipment

This study involved the design and construction of three pieces of equipment; a large plane strain triaxial apparatus, a load frame and a load cell. Their characteristics and the considerations involved in their design are described in subsequent sections.

Large Vacuum Plane Strain Apparatus

The plane strain apparatus was developed to model an element of soil in a reinforced embankment, using full size reinforcing materials in the laboratory specimens. The equipment was constructed in the machine shop of the Department of Civil Engineering at Virginia Tech. The apparatus consists of a cap and base, two end plates to restrain the sample, and a forming jacket. The base is shown in Figure 3 and in Plate 1, the cap in Figure 4 and Plate 1 and the end plates in Figure 5 and Plate 2.

The apparatus is designed to accommodate a 9.4 inch square sample 23 inches in height. This gives a specimen large enough to test many full-sized reinforcing materials and a ratio of height to width of about 2.4. The height to width ratio is slightly larger than the the minimum 2:1 ratio needed to minimize the effects of end restraint (Bishop and Green, 1965). The choice of a 9.4 inch square specimen was convenient because it has the same perimeter as a 12 inch diameter specimen, and membranes for this diameter are available commercially.

The design used for the cap and base was closely modeled after those used in an extensive program of plane strain testing at the

University of California at Berkeley (Marachi et al, 1969, Becker, et. al. 1972). The cap and base each consist of a 9.4 inch square section in contact with the specimen, a zone of transition, and a circular section to which the membrane is sealed. They were constructed of 6061 aluminum by first machining each of the three pieces to the required shape and then laminating them using 1/2x13 socket head cap screws. The square section and the circular section are of the same perimeter, which permits the membrane to fit over the square section and, at the same time, allows it to seal around the circular base.

The transition section is necessary to provide a gradual change in shape to prevent puncturing of the membrane by sharp edges and corners. It was constructed from a 12 inch square plate that was first machined to a 12 inch diameter on one side, and a 13.3 inch diagonal dimension on the other side. It was then placed on a milling machine where the 9.4 inch square sides were formed by cutting the sides at a 49 degree angle, as shown in Figures 3, 4 and Plate 1.

The base has a vacuum port in the center of the square section in contact with the sample. A porous stone covers the vacuum duct which runs from the center of the sample to a 3/8 NPT fitting on the round base, as shown in Figure 3. The cap has no ports to the sample but has a spherical ball seat to permit application of the axial load through a one-inch diameter steel ball, as shown in Figure 4.

To achieve the plane strain condition in the test specimen, it is necessary to provide lateral restraint in one direction. This is accomplished by using two rigid end plates which fit on opposite sides of the sample. The end plates are maintained at constant spacing by four

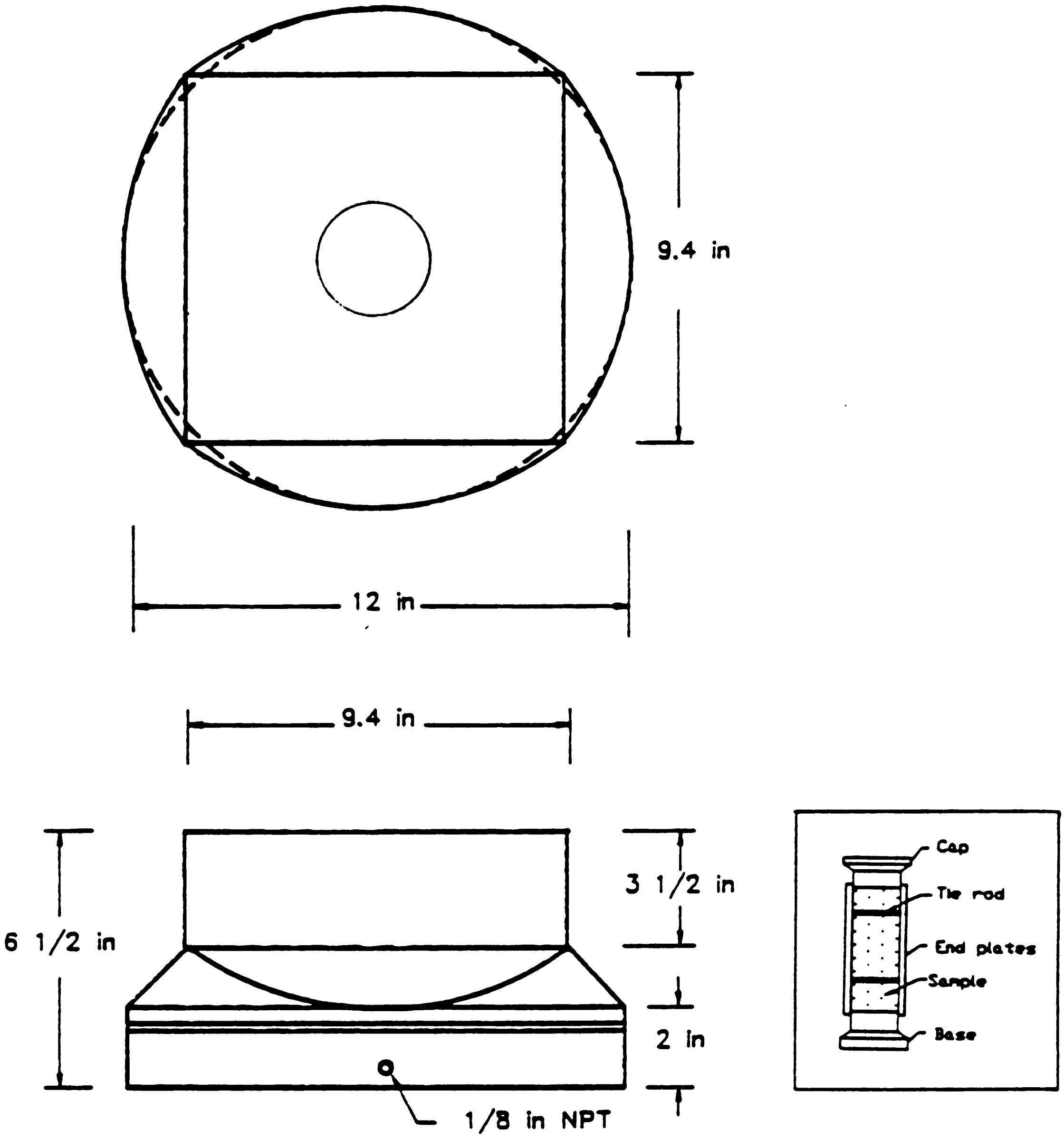


Figure 3. Specimen Base

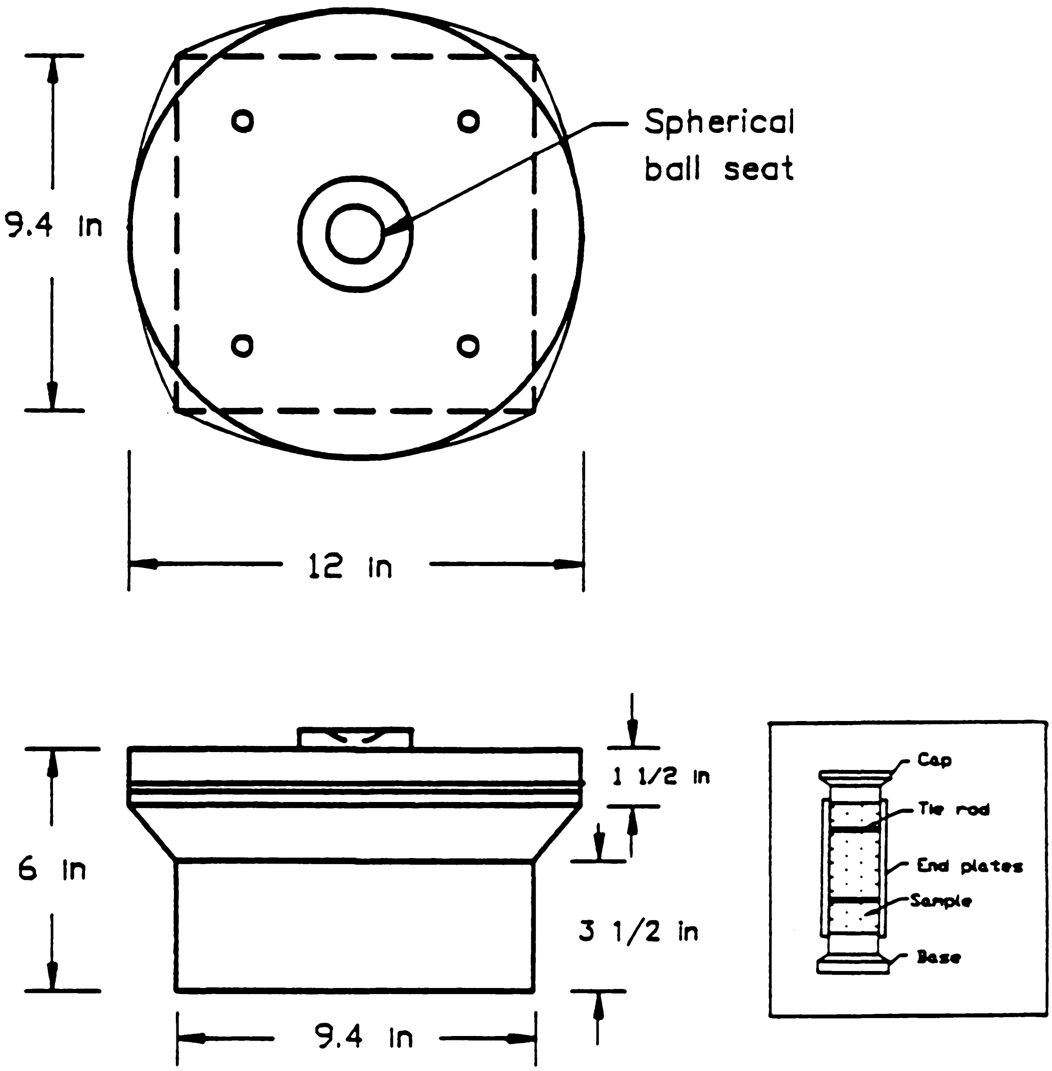
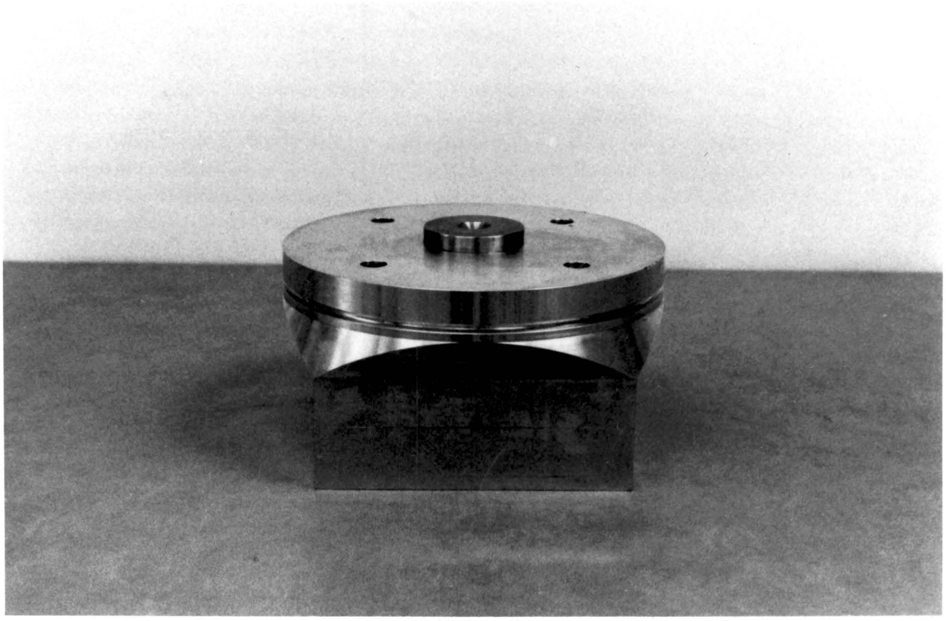


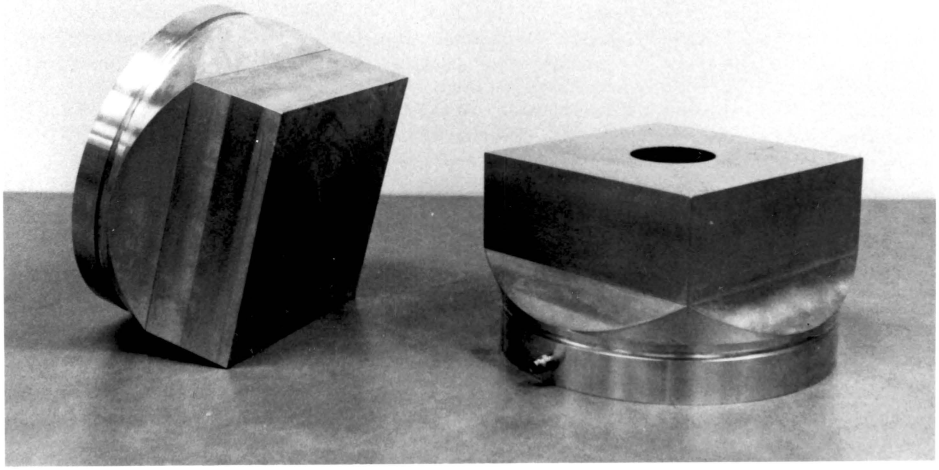
Figure 4. Specimen Cap

Plate 1. (a) Cap of plane strain specimen

(b) Cap (left) and base



(a)



(b)

stainless steel tie rods, as shown in Figure 5. The design of the end plates and tie rods was based on the results of the work done by Marachi et al (1969), who studied the stiffness of end plates and tie rods needed to achieve plane strain conditions in laboratory tests. Since it was desired to be able to view the plane across which a shear plane would develop, a clear material, cast acrylic, was used for the end plates. No material properties were available for the cast acrylic, so strength and stiffness values were taken from manufacturers literature on similar materials. The values used were thought to be conservative for the cast acrylic. Using these figures a thickness of 1-1/2 inch was determined to be needed.

The forming jacket was constructed from four pieces of 3/8 inch thick 6061 aluminum plate, as shown in Figures 6 and 7. The inside of the jacket is lined with a porous plastic material which distributes the vacuum and helps to draw the membrane tightly against the inside of the forming jacket, thus forming a sample with a square cross section. The mold itself is supported by two cast acrylic supports which prevent it from damaging the membrane by pinching it between the forming jacket and the sharp corners of the base.

The estimated total cost for the construction of the cap, base, end plates and forming jacket, excluding costs of machining time, is about $1300.00 (1985). Approximately 200 hours of machinist's time were spent in the construction, due to the large sizes of aluminum pieces that were used, and the shapes that were required.

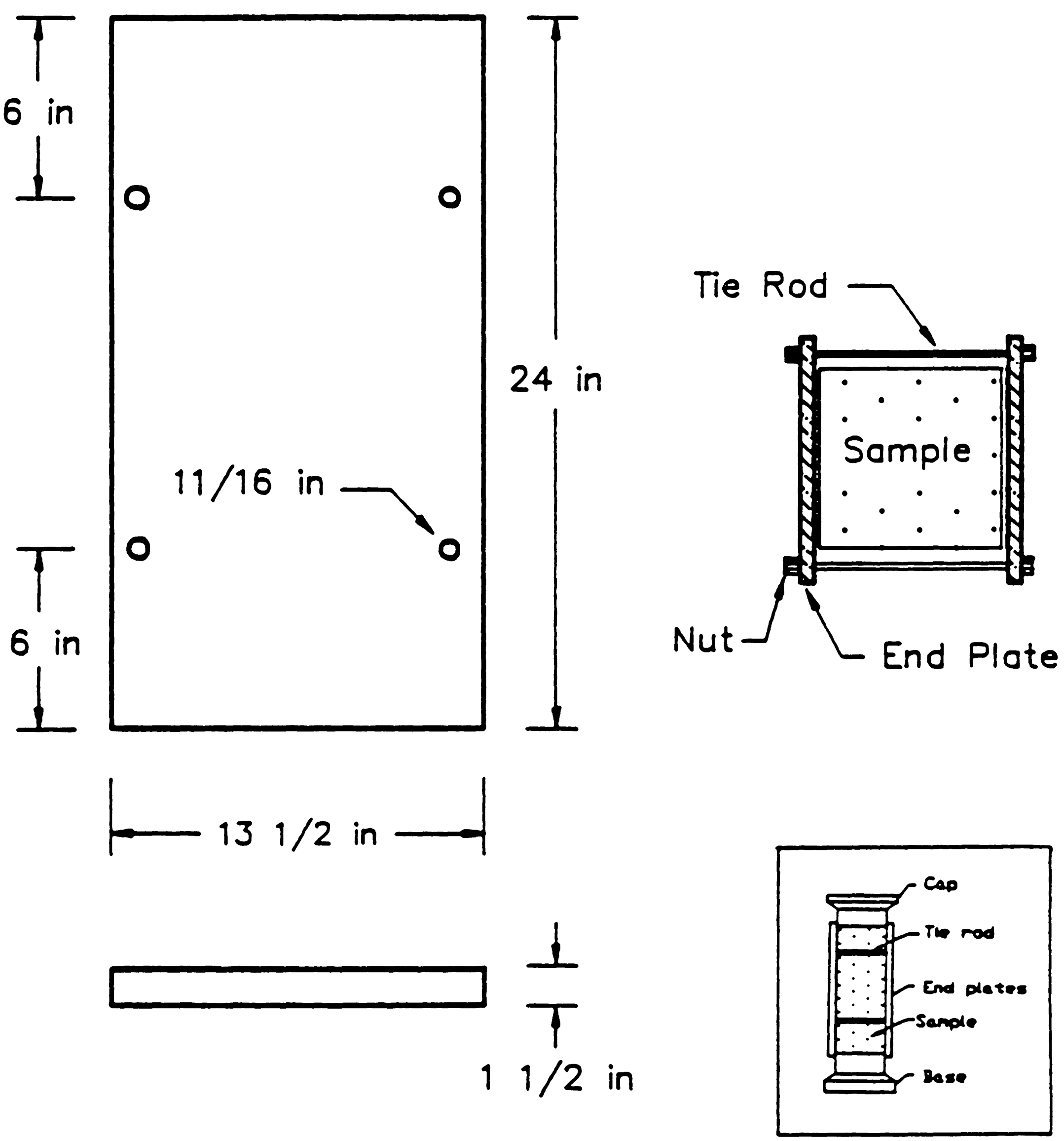


Figure 5. End Plates

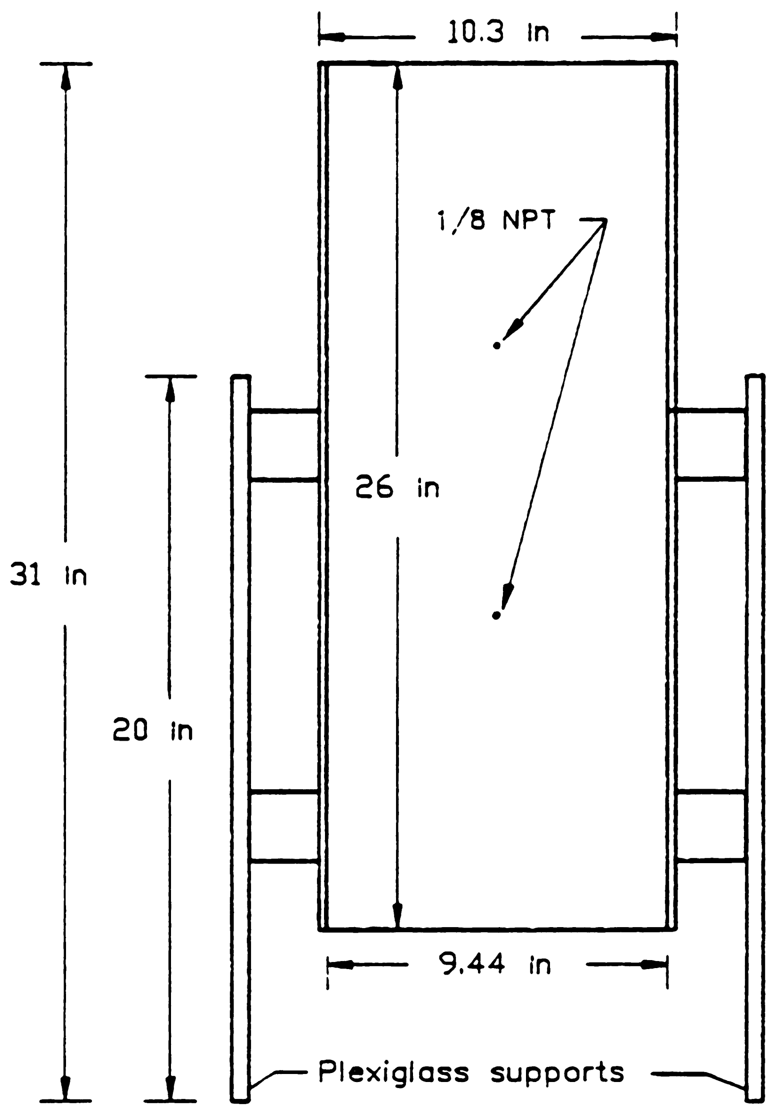


Figure 6. Side View of Forming Jacket

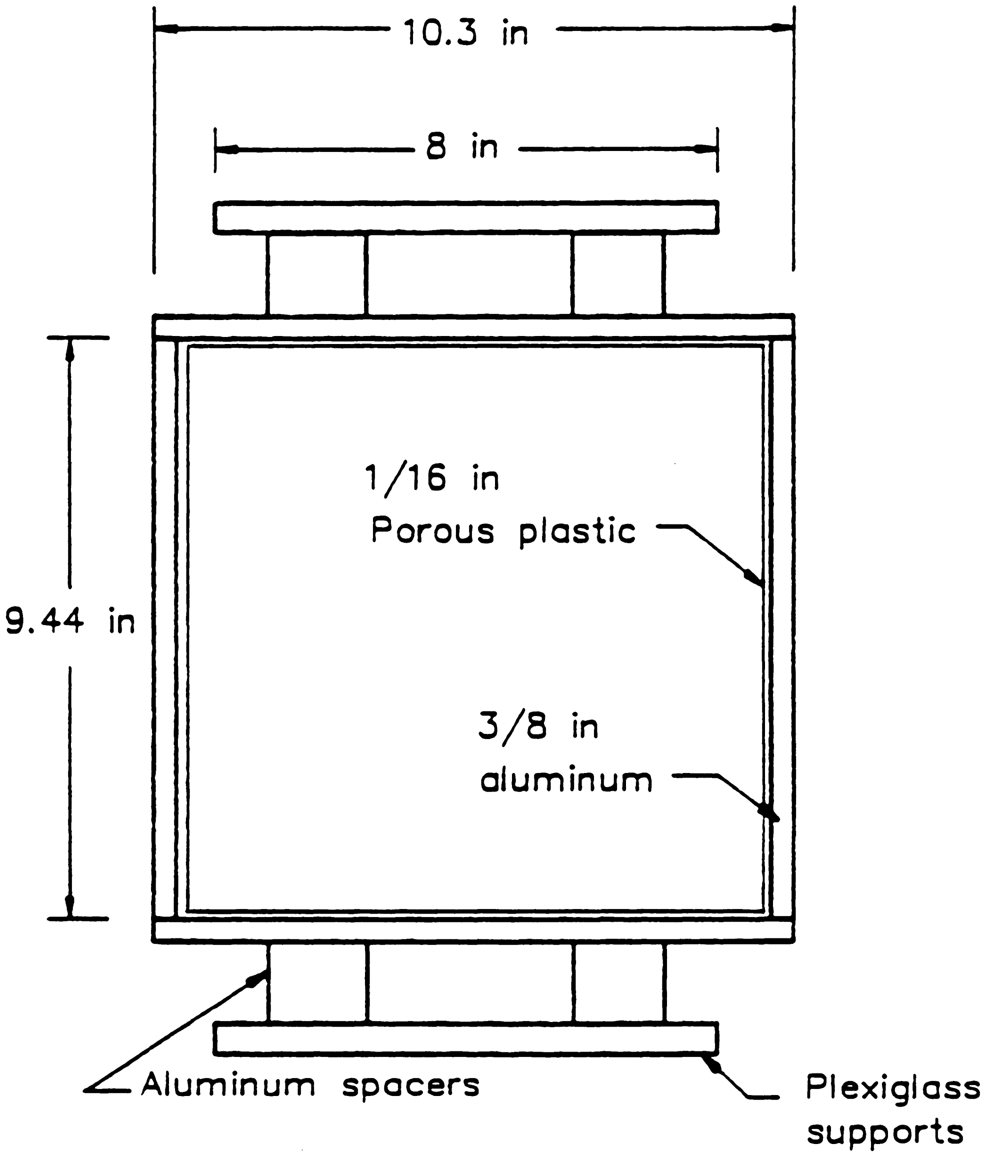


Figure 7. Top View of Forming Jacket

Load Frame

Testing of the large size reinforced specimens required construction of a loading frame with a capacity of about 10,000 pounds and a stroke of about six inches. The load frame built during this study has a capacity of 30,000 pounds and a 14 inch stroke. It can be driven by a hand pump or an electric pump and is capable of a wide range of strain rates. Drawings of the load frame as constructed are given in Figures 8, 9 and 10.

The frame consists of a base support, upper and lower crossbeams connected by tie rods, and a loading platform. The base assembly, shown in Figure 8, is constructed of C 5x6.1 channel sections, butt welded together to form the feet, the legs and the support for the lower crossbeam.

The lower crossbeam, shown in Figure 9, contains the ram, guide bushings and the loading platform. This unit consists of two 5X19 wide flange beams, 3 3/4 inches apart, welded to 3/8 inch structural steel plates on the top and bottom. A six inch outside diameter ring was threaded for the ram, and welded to the lower unit over a centrally located hole cut in the plates for the ram body. Holes in both the upper and lower plates are located on either side of the ram mount for the loading platform guide rods and bushings. This load frame features four-one inch Thompson roller bushings, two on each rod, to prevent any change in alignment of the loading platform under load. The guide rods are 30 inch long pieces of Thompson case 60 hardened steel, tapped on the ends to mount to the loading platform. These rods were used because

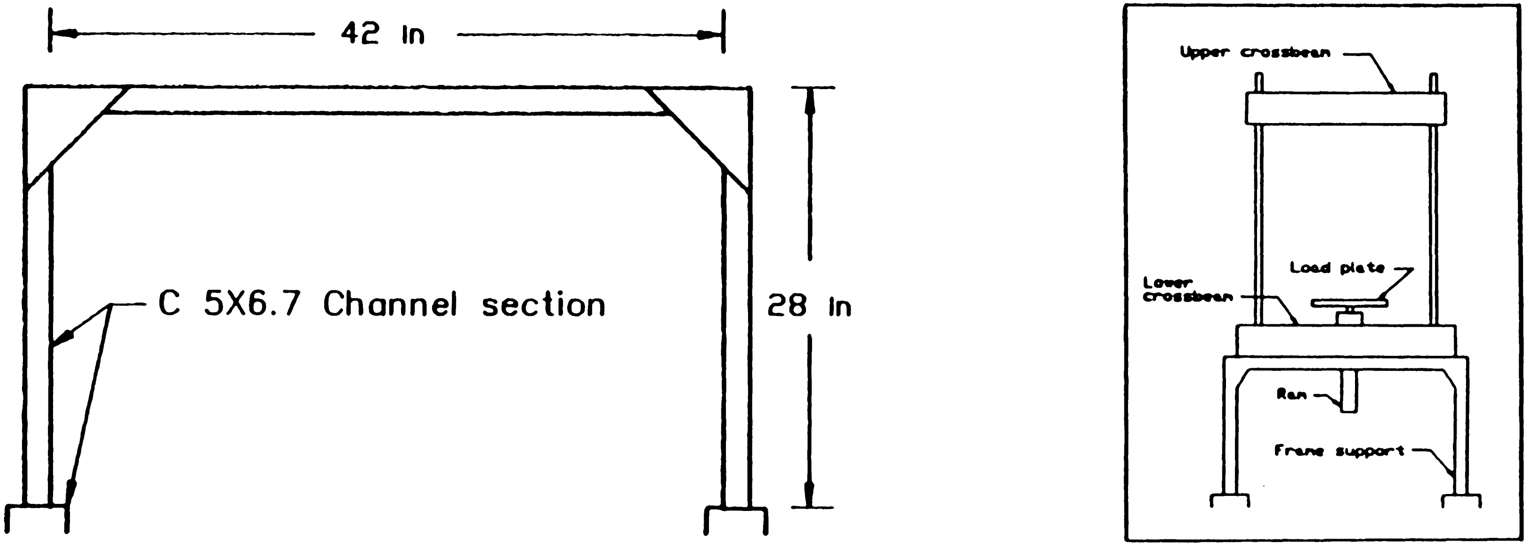


Figure 8. Load Frame Support

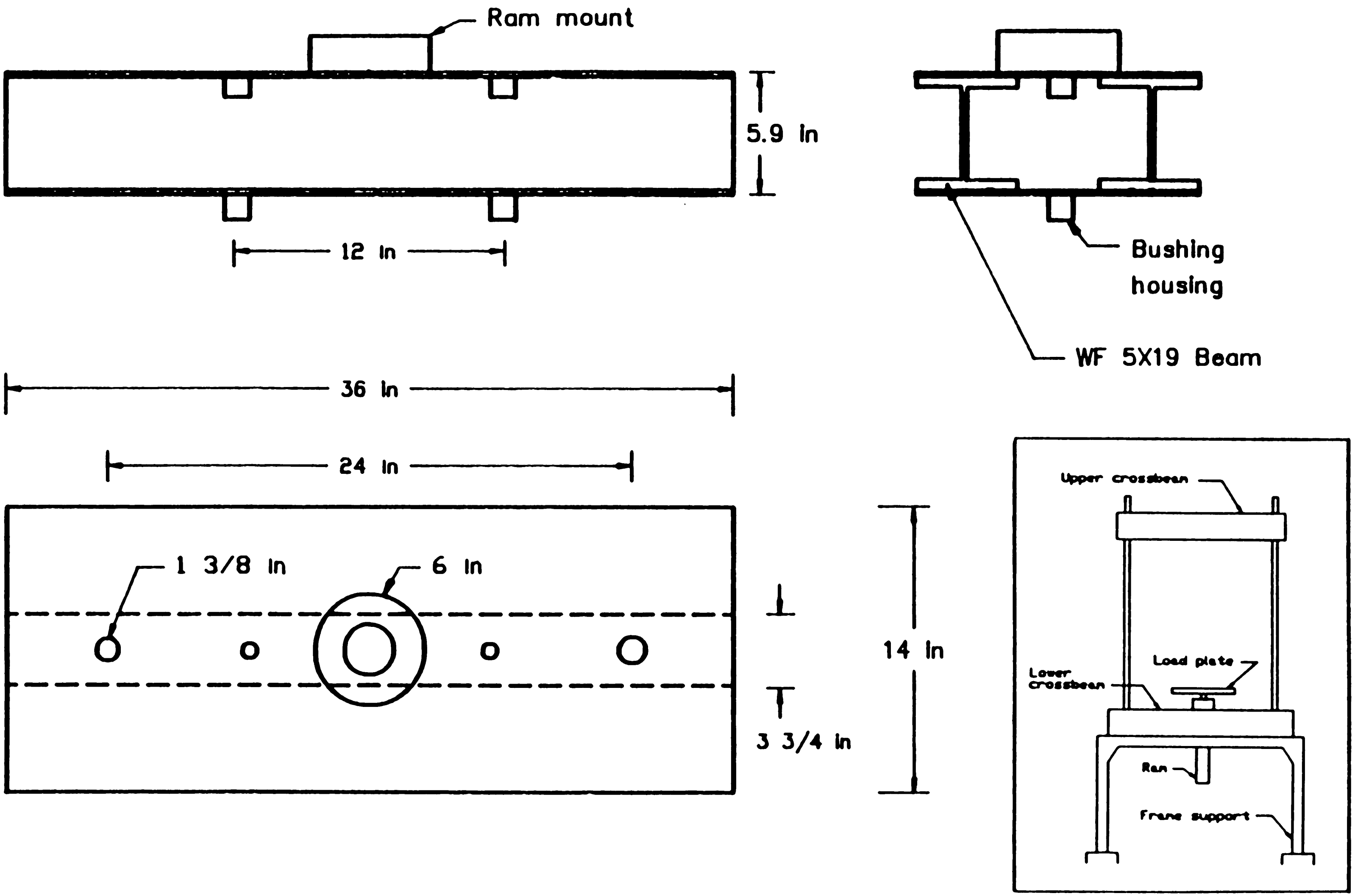


Figure 9. Lower Crossbeam

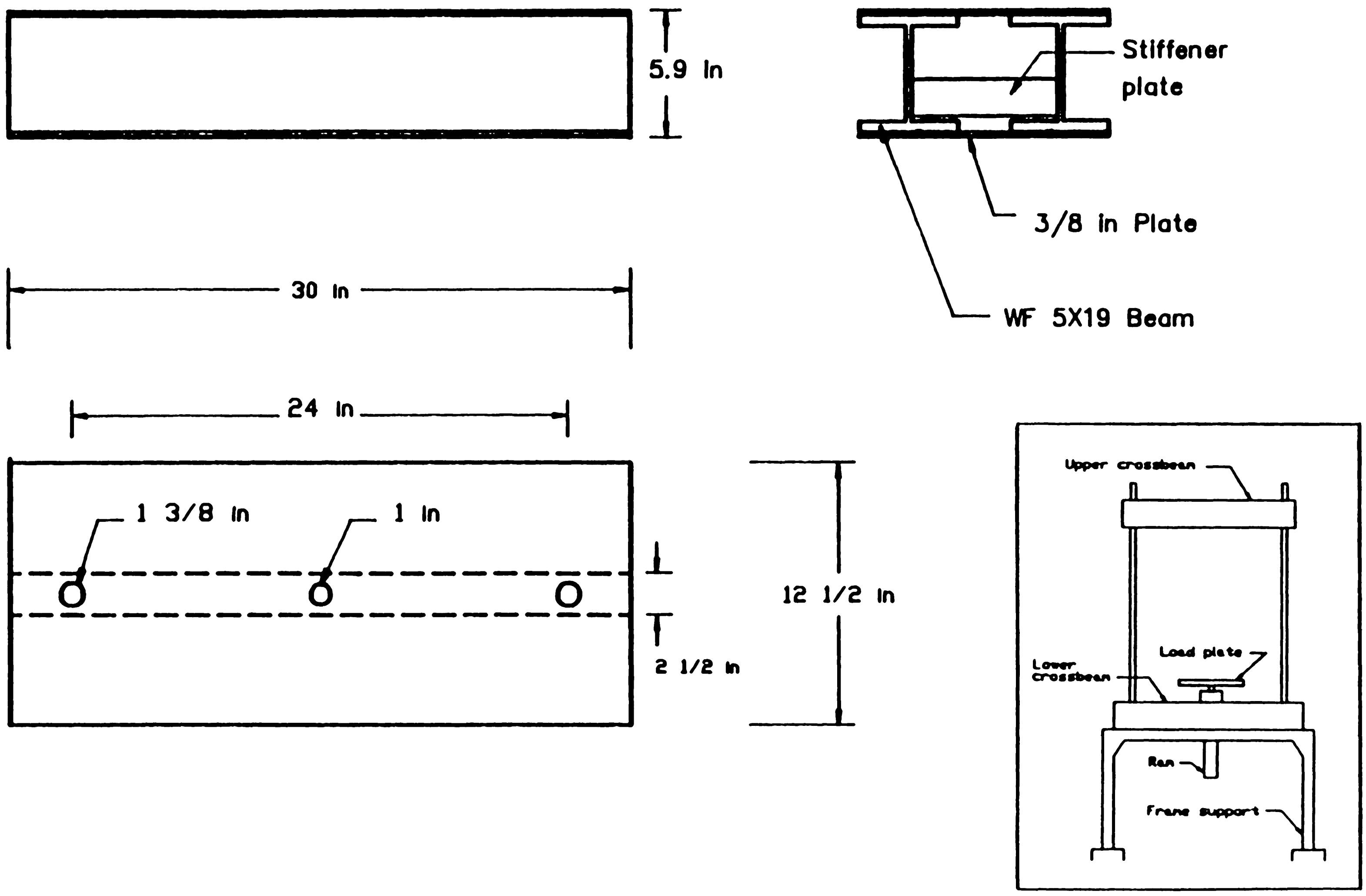


Figure 10. Upper Crossbeam

of their hardness and resistance to wear. Dust boots were added to the ends of the bushings to protect them from grit. The bushings fit into four specially made aluminum housings which bolt onto the 3/8 inch plates, two inside and two under the base unit, as shown in Figure 9. On the ends of the base unit, two 1-1/4 inch grade 8 threaded rods, six feet long, are bolted onto the upper and lower plates with grade 8 nuts. These threaded rods serve as the uprights to which the crossbeam is attached.

The upper crossbeam, shown in Figure 10, was constructed in the same manner as the lower crossbeam, with two 5X19 wide flange beams connected with 3/8 inch structural steel plate. The upper crossbeam has holes at either end where the threaded rods are inserted and a centrally located hole for the load cell mount (see next section).

The loading system of the frame utilizes an OTC brand single acting ram with a 50,000 pound capacity and a 14 inch stroke. It can be driven by either a hand pump or an electric hydraulic pump. The latter has a built-in flow control valve that permits constant rate of strain testing with a wide range of speeds possible.

The cost of the frame, the guide rods, the bushings, the ram and the hand pump was approximately $1780. The cost of the electric hydraulic pump, the flow control valve and the hoses was approximately another $1700. Thus the total cost for the load frame was about $3500.

Load Cell

A low cost electric load cell was constructed so that a computer based data acquisition system could be utilized to record loads during testing. Its design was based on a method developed by Duncan (1985). The design method and drawings of the cell are given in Appendix I.

The load cell, shown in Figure 11, has a 20,000 pound capacity. It is constructed of a high strength hollow bar tool steel and includes a four arm bridge of strain gages mounted in the three, six, nine and twelve o'clock positions, as shown in Figure 11. The strain gauges are driven by a 10 volt DC power supply and the output is read in millivolts on a voltmeter. A spherical ball seat is located on the bottom of the load cell, where a steel ball fits to transfer load to the cap on the top of sample. A threaded hole an top of the load cell is used to bolt it to the upper crossbeam on the loading frame.

The hollow bar tool steel was chosen for the load cell because of its high strength, its easy machinability, and its shape, which required very little machining. The material has a yield strength of about 70 ksi and is rated as easily machinable. Hollow bar steel is manufactured by extruding steel into doughnut shapes, in which various internal and external diameters are available. Thus, for construction of this load cell, machine time was reduced considerably by using a shape which had external and internal diameters close to that required for the capacity desired.

Calibration of the load cell was carried out on a 20 kip capacity Instron machine in the Engineering Science and Mechanics Department. The calibration curve for a cycle of loading and unloading is shown in Appendix I, Figure A1.1. It may be seen that the hysteresis effects upon loading and unloading are extremely small compared to those experienced in thin proving rings (Lambe, 1951, Bishop and Henkel, 1962). It

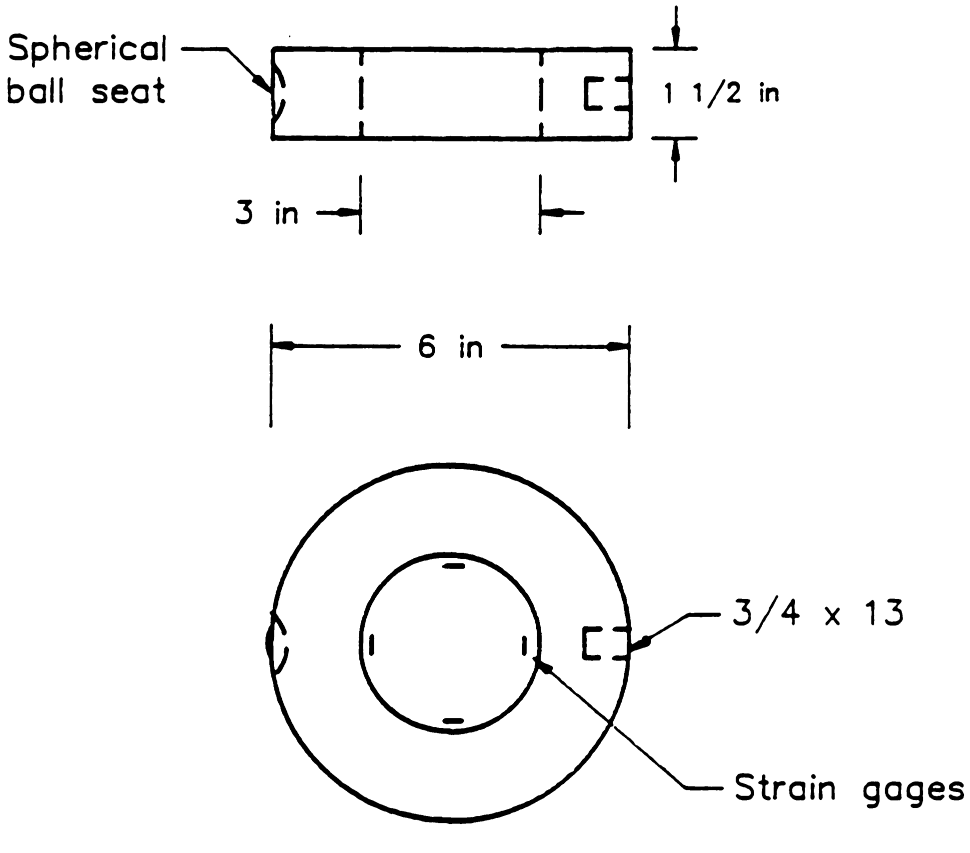


Figure 11. Load Cell

may also be seen that the calibration curve is a straight line, indicating a linear response. The slope of the line is 1160 pounds per millivolt. Thus, with a voltmeter that reads to the hundredth of a millivolt, the minimum resolution of the load cell is 11.6 pounds. This corresponds to a 0.13 psi accuracy in stresses for the 9.4 inch square sample, which results in a negligible change in the measured value of phi, and which appears to be sufficiently accurate for tests at confining pressures above about 4 psi.

The cost of constructing the load cell was about $50. This includes $30 for the steel and $20 for five strain gauges (four of which were used). This is an exceptionally low cost for a load cell with its response and sensitivity; comparable commercial load cells cost approximately 20 times as much.

Preliminary Testing

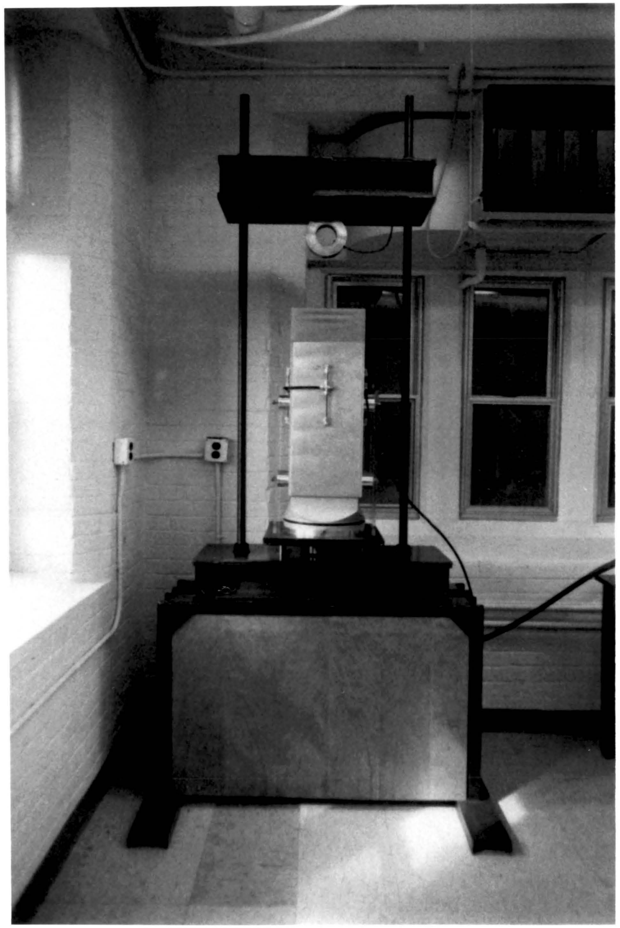
A series of tests was performed to check the equipment operation and to obtain preliminary data on the behavior of reinforced and unreinforced specimens. This part of the study was also concerned with developing a method of sample construction. Since the specimens are so large, considerable effort was required to develop a safe and effective procedure for preparing specimens for testing.

Samples were prepared by first placing a membrane around the base and sealing it with an O-ring. Then the sample forming jacket was lowered over the base while drawing the membrane tightly against it by means of a vacuum applied through the base port. The vacuum was then released and the membrane was pulled up through the forming jacket and lapped over the sides at the top. A vacuum then was applied through the ports of the forming jacket, which caused the membrane to be pulled tightly against its sides, forming a square cross section. Plate 2(a) shows the forming jacket placed over the specimen base with the membrane pulled over the top. Monterey # 0/30 sand was then poured into the membrane-lined forming jacket from a bucket. In these preliminary tests, no attempt was made to densify the sand or to achieve a uniform sample density. Pouring the sand into the membrane from a bucket resulted in a sample with a density that was close to the minimum density for this sand. For the specimen that contained a reinforcing grid, sand was first poured to midheight of the forming jacket. The grid was then placed and the remainder of the sand was poured into the jacket. After reaching the 23 inch height desired for the specimens the top cap was

Plate 2. (a) Load frame with forming jacket

(b) Assembled apparatus

(a)



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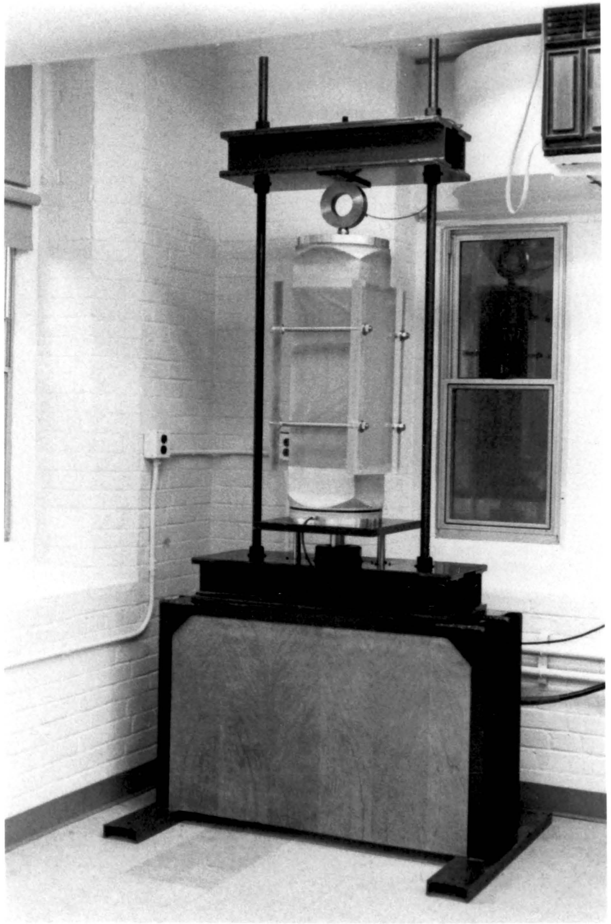

placed on the sample, the membrane pulled up and sealed to it with an O-ring, and confining pressure was applied to the specimen by evacuating the inside of the sample with the forming jacket still in position. After attaining the required confining pressure, the forming jacket was removed.

With the sample placed in the load frame, the end plates were put in place on the specimen. Before placing the end plates, a liberal coating of silicone grease was applied to the sides of the sample to eliminate friction between the sample and the end plates. With the sample now ready for testing, the ram was used to raise the loading platform and seat the load cell on the cap. Plate 2(b) shows the completed specimen seated in the load frame and ready for load application.

Tests on an unreinforced sample and a sample reinforced with one layer of Tensar SS-1 polymer grid were performed using a confining pressure of 10 psi. The stress-strain curves for these tests are shown in Figure 12.

Several observations can be made on the basis of the results shown in Figure 12. First, in the initial part of the tests, the stress-strain curves are essentially the same up to a deviator stress of about 8 psi. This is because insufficient lateral expansion has occurred in the early stages of the test to develop a significant tensile force in the geogrid in the reinforced specimen. Without tensile force in the reinforcement, the sample behaves as if it were unreinforced. As the test proceeds, the stress-strain curve for the reinforced sample eventually shows an increase in strength and stiffness as compared with the unreinforced sample. At the later stages of the tests the reinforcement

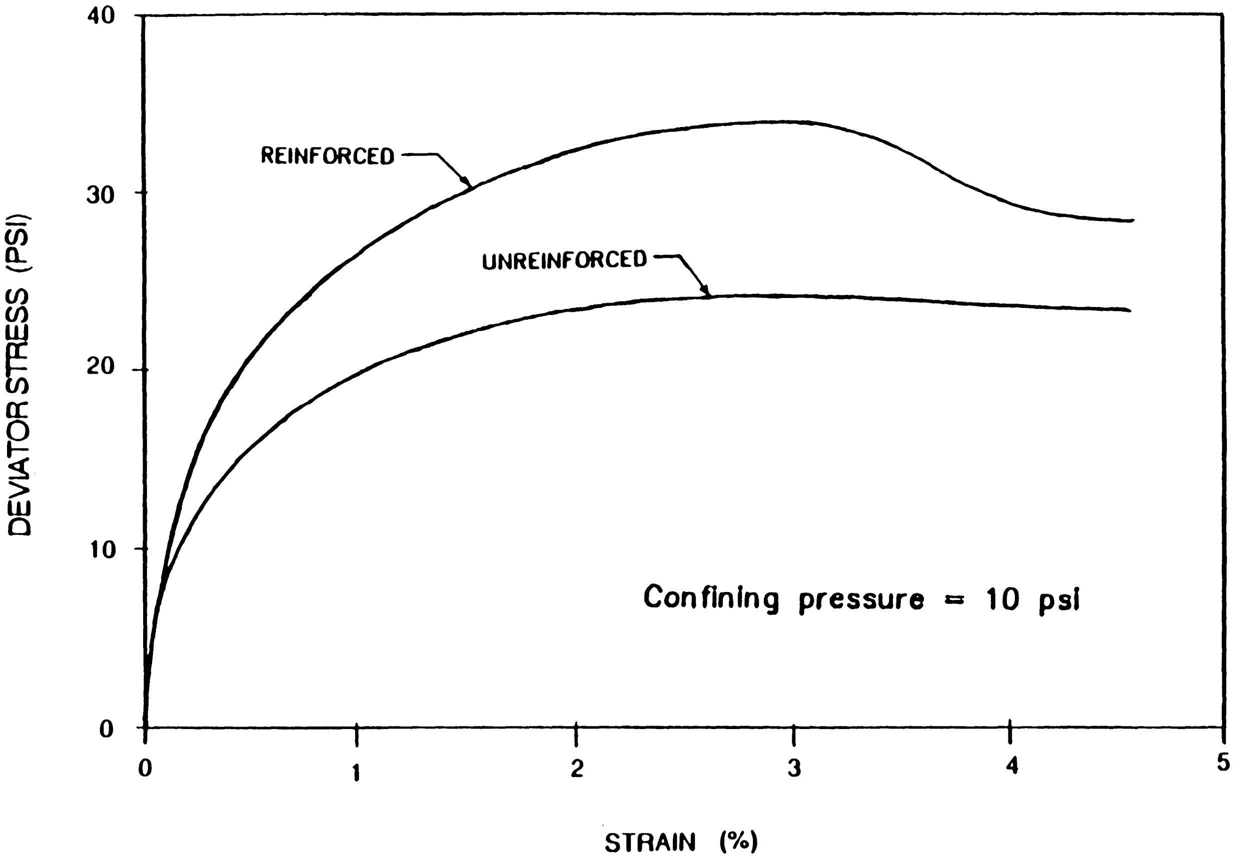

Figure 12. Comparison of Stress–Strain Curves

develops internal tensile stress due to the tendency of the specimen to expand laterally as it is compressed axially. This tensile stress in the reinforcement results in added confinement in the specimen. This increased confining stress produces the increased strength and stiffness.

At about 3 percent strain, the deviator stress in the reinforced specimen decreased noticeably. This coincided with development of a shear plane in the lower half of the specimen, between the grid (which is in the center of the sample) and the base. The failure plane did not cross the reinforcement, and it was thus not possible to learn anything about the mode of deformation of reinforcement at a slip surface. In future tests it may be necessary to change the test conditions in some way to force development of a failure plane crossing the reinforcement.

The development of the failure plane below the grid may have been due in part to the loose condition of the sand and to the nonuniform density that resulted when the sand was placed by pouring it from a bucket. It is expected that when the sand is placed in a dense uniform state a failure plane may develop across the reinforcement, since the sand on either side of the grid will be uniform with respect to density.

These results show that the equipment functions as planned. However, some modifications of the equipment are desirable, and these are discussed in the next section.

Comments and Conclusions

The plane strain cap, base, forming jacket and membrane are all well-suited for the research studies planned. They can be used to study the plane strain strength and stress-deformation behavior of reinforced and unreinforced dry sands at confining pressures between about 2 psi and 14 psi, applied by vacuum. If a pressure chamber of sufficient size was available, the cap and base could be used for tests at considerably higher pressures, although the end plates might need replacement for higher pressure tests. The loading frame and load cell are suitable for these and other types of compression tests, for axial loads as high as 20,000 pounds for this load cell and 30,000 pounds for this load frame. Considering that the total cost of the equipment was only $4900., this developmental project is considered to be highly successful.

After working with the equipment during the initial testing, it was recognized that some modifications are desirable to improve its performance. These modifications are discussed in the following paragraphs.

In designing the load frame, it was found that 1 1/4 inch rods had sufficient tensile strength for the expected loads. However these rods are so thin that they permit excessive lateral deflection under lateral loads, and the upper crossbeam sways undesirably when subjected to lateral loads. Therefore, these rods should be replaced with two inch diameter grade 8 threaded rods to eliminate this undesirable lateral motion.

Since the expected loads during this testing program are below 10,000 pounds, a new load cell with a capacity of 10 kips would be more suitable than the 20 kip cell that was constructed. The new load cell could be constructed from the same tool steel stock used for the first load cell.

In order to obtain a uniform density in the specimens, a better method of placement is needed. Pluviation of the sand through an orifice has been successfully used in many similar cases, and would seem to be the most logical choice of placement technique. Therefore a sample raining system should be developed for forming the plane strain specimens.

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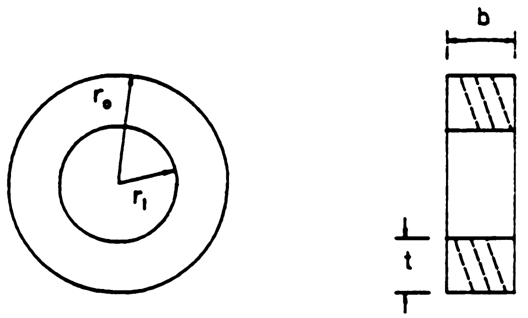
Appendix I

Design, Construction and Calibration of the Load Cell

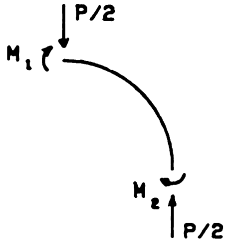
This appendix describes the methods by which the load cell used in this study was designed and constructed. The method of design was developed by Duncan (1985).

Derivation of Design Equation

Below is shown a circular ring with outside radius r_o, inside radius r_i, thickness b and width t. The stresses and strains in the ring can be analyzed approximately by using equilibrium equations.



To simplify the analysis, the thickness of the ring is ignored. The thick ring is represented by a thin ring with a radius r_a, where $r_a = 1/2(r_o+r_i)$. A freebody diagram for a quarter of the thin ring is shown below.



For moment equilibrium, $M_1+M_2 = P/2\ (r_a)$. If it is assumed that $M_1=M_2$ then,

$$M_1 = M_2 = M \tag{1}$$

and

$$2M = P/2\ (r_a) \tag{2}$$

or

$$M = P/4\ (r_a). \tag{3}$$

Stresses at the top of the ring (point 1) can be calculated by using equation (4):

$$f_1 = MC/I. \tag{4}$$

Substituting the expression of equation (3) for M and $I=bt^3/12$ for a rectangular cross section, f_1 may be expressed as,

$$f_1 = 3P(r_a)\ /\ t^2(b)\ . \tag{5}$$

Likewise at the side of the ring (point 2), the stresses can be calculated using equation (6),

$$f_2 = MC/I + P/2A \tag{6}$$

or

$$f_2 = 3P(r_a)/t^2b + P/2bt\ . \tag{7}$$

Because point 2 has the highest stress and thus controls the design, equation (7) can be rewritten as follows:

$$K = \frac{f_2 b d_o}{P} = \frac{3(1+D)}{(1-D)^2} + \frac{1}{(1-D)} \qquad (8)$$

where $D = d_i/d_o$.

This equation can be rewritten to give the design equation:

$$f_2 = KP/bd_o \qquad (9)$$

where: f_2 = maximum stress

P = design load

K = as given above

b = thickness

d_o = outside diameter

Equation (9) can be used to determine the size of the ring needed for any design load and allowable forces. For given values of P and f_2, suitable dimensions for the load cell can be established. The values of K tabulated below facilitate the calculations.

D	K
0.1	5.19
0.2	6.88
0.3	9.59
0.4	13.33
0.5	20.00
0.6	32.50
0.7	60.00

Using this method of design a 20 kip load cell was constructed and tested. Figure 11 shows a drawing of the load cell. Figure A1.1 shows the calibration curve for the load cell expressed as millivolt output versus applied load. This figure shows that the hysteresis effects are negligible and the response is linear.

Figure A1.2 shows a comparison of the actual and theoretical strain versus load for the load cell. It can be seen that the actual strain is less than that calculated from $\varepsilon = 2(f_1+f_2)/E$. The slope of the theoretical curve is $1.45(10^{-7})$ (in/in/Lb) whereas the slope of the experimental curve is $4.16(10^{-8})$ (in/in/Lb), a difference of 3.5. This is probably due to the fact that the thick ring constructed deviates significantly from the thin ring assumed in the development of the design equation.

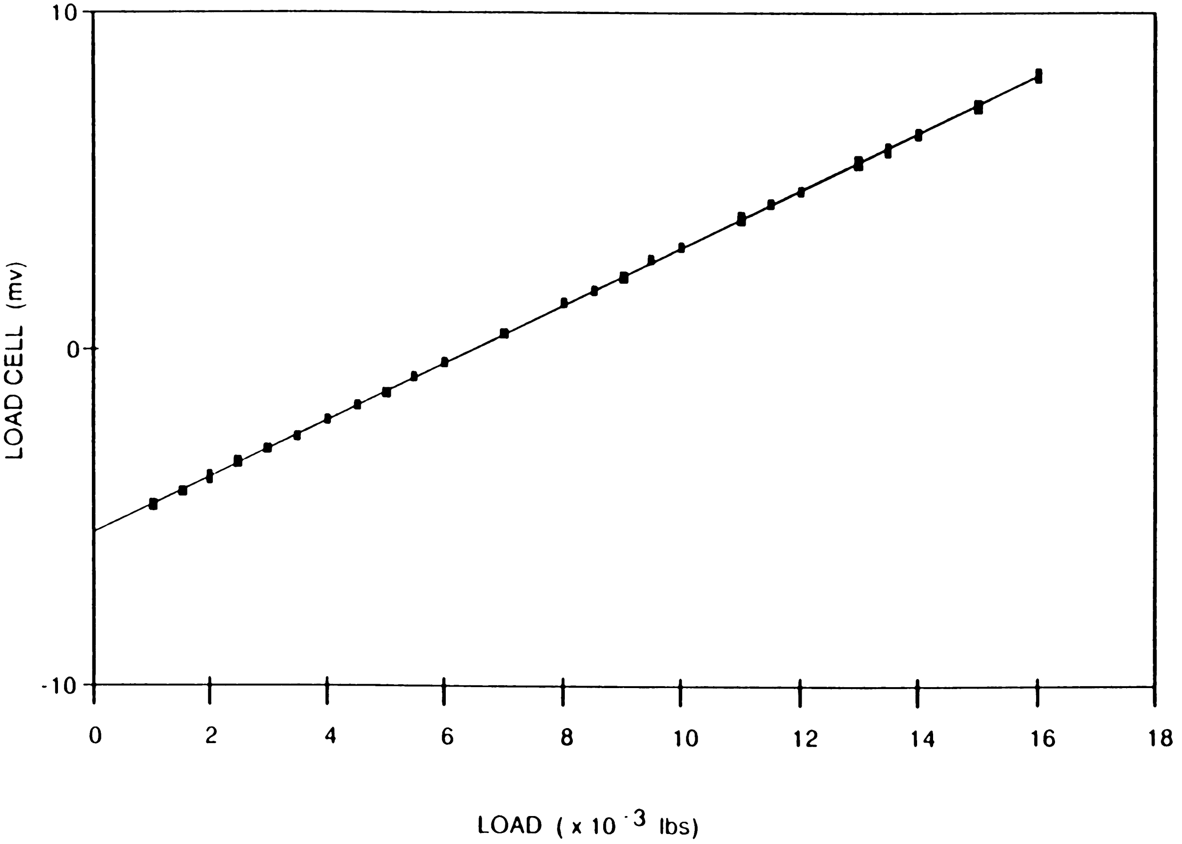


Figure A1.1. Load Cell Calibration Curve

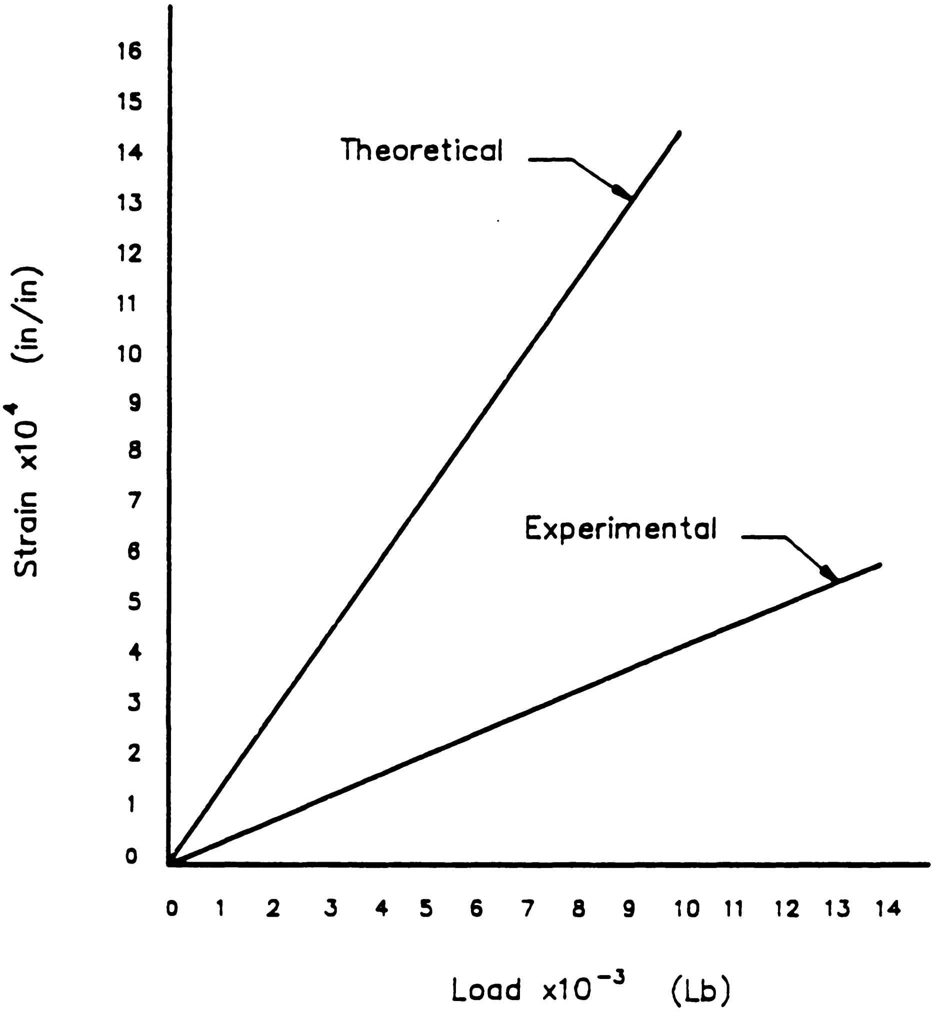


Figure A1.2 Comparison of Theoretical Versus Observed Load Cell Strains

Appendix II

List of Material Suppliers and Materials Used

List of Material Suppliers

A large part of the effort required to construct a piece of equipment is in the location of material suppliers. A listing of the sources utilized in this study is given here.

Rubber Membranes

3-D Polymer
13026 South Normandy
Gardena, CA 90249
(213) 321-2235

Cast Acrylic

Atlantic Plastics
Kimball Ave.
Roanoke, VA
(800)-572-3027

Porous Plastic

General Polymeric Corp.
621 Franklin St.
West Reading, PA 19611
(215) 374-5171

Aluminum

Virginia Metal Services
2501 Green St.
P.O. Box 10141
Lynchburg, VA 24506
(804) 846-4039

Steel

Steel Service, Inc.
5025 Starkey Rd.
Roanoke, VA
(703) 989-4930

Carolina Steel
P.O. Box 13386
Botetourt Industrial Park
Roanoke, VA 24033-3386

Tool Steel for Load Cell:

Time Steel, Inc.
Charlotte, NC
(704) 523-88920

Threaded Rod and Nuts

Valley Fasteners
902 Shenandoah Ave. SW
Roanoke, VA
(703) 981-1435

Load ram, hydraulic pump, roller bushings, rods and O-rings

Dixie Bearing Co.
3025 Wintworth Ave NW
Roanoke, VA
(703) 352-3741

Strain gages

Measurements Group, Inc.
P.O. Box 27777
Raliegh, NC 27611
(919) 365-3800

List of Materials Used

The following is a listing of the materials used in each piece of equipment constructed in this study. Note that all dimensions are in inches.

Plane Strain Apparatus

Base:

1pc. 12 X 2 6061 aluminum round
1pc. 12 X 12 X 11/2 6061 aluminum plate
2pc. 10 X 10 X 2 6061 aluminum plate
4pc. 1/2 X 13 X 41/2 socket head cap screws

Cap:

1pc. 12 X 2 6061 aluminum round
1pc. 12 X 12 X 11/2 6061 aluminum plate
2pc. 10 X 10 X 2 aluminum plate
4pc. 1/2 X 13 X 4 1/2 socket head cap screws

End Plates

2pc. 14 X 24 X 1 1/2 cast acrylic sheet

Sample forming jacket

4pc. 10 1/2 X 26 1/2 X 3/8 6061 aluminum
2pc. 8 X 20 cast acrylic sheet
4pc. 1/4 Swagelock tee
8pc. 1/8 NPT to 1/4 Swagelock elbow

Porous Plastic:

1 sheet 48 X 36 X 1/16 20 to 50 micron polypropylene.

Tie rods

4pc. 3/4 X 14 stainless steel rods

Load frame

Lower crossbeam:

2pc. WF5X19 beams, 36 long
2pc. 14 X 36 X 3/8 A-36 plate
2pc. 9 X 2 1/2 X 3/8 A-36 plate
1pc. 6 X 2 A-36 round

Upper crossbeam:

2pc. WF 5X19 beams, 30 long
2pc. 12 1/2 X 30 X 3/8 A-36 plate
2pc. 2 1/2 X 8 X 3/8 A-36 plate

Base:

2pc. C5X6.7 channel, 42 long
2pc. C5X6.7 channel, 34 long
4pc. C5X6.7 channel, 28 long
4pc. 6 X 6 X 1/4 A-36 plate

Bushing housings:

4pc. 3 X 3 6061 aluminum round
16pc. #10 X 1 1/4 socket head cap screws
8pc. External retaining rings

Loading plate:

1pc. 16 1/2 X 16 1/2 X 1 A-36 plate

Load cell

1pc. 6 outside diameter hollow bar tool steel
1 pack CEA-06-250UW-350 strain gages.

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