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It is concluded that polyester reinforcement is undesirable for bearing pads much over one inch in thickness because of its relative flexibility and tendency to creep substantially under sustained loads. compressive stress/strain data is presented for pads with shape factors up to 15.0. Shear modulus data is presented for various sizes of pads and angles of translation. Data from creep and cycling tests simulating dead load and live load conditions demonstrate the desirability of steel or fiberglass reinforced pads.

The report includes recommended design data, basic elements of current California specifications for bearing pads, and suggestions for further research.

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A LABORATORY EVALUATION OF FULL SIZE ELASTOMERIC BRIDGE BEARING PADS

75-01

CA-DOT-TL-6574-1-75-01

Presented at the 54th Annual Meeting of the Transportation Research Board
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A LABORATORY EVALUATION
OF FULL SIZE
ELASTOMERIC BRIDGE BEARING PADS

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INTRODUCTION

Elastomeric pads were first used as bridge bearings in the United States in the late 1950's largely due to the need to find a satisfactory bearing device to accommodate the relatively severe end rotation and translation associated with prestressed concrete structures and to utilize a more economical and maintenance free bearing concept than those used previously. At that time the State of California initiated a research project titled "Laboratory and Field Performance of Elastomeric Bridge Bearing Pads"(1) to establish design guidelines and specifications for these pads. That study revealed that neoprene pads reinforced at 1/2 inch intervals with steel sheet or polyester fabric performed very satisfactorily in the bridges constructed during that period. The polyester fabric became the most commonly used reinforcement in California since it was less expensive than the steel because large pads could be fabricated, stockpiled, and then, sliced into custom sizes upon demand. Steel reinforced pads must be individually fabricated to the desired size because of the necessity to cover the edges of the steel with elastomer for corrosion protection.

During the 1960's the use of prestressed concrete bridges became more common and typical span lengths became longer due to the designer's interest in economy, safety, and aesthetics.

Consequently, the bearing pads became larger in both plan area and thickness to accommodate the increased loads, translations, and rotations. As pad sizes increased, construction personnel began to notice pad deflections that were considerably different than those anticipated. At that time pad deflections were predicted on the basis of tests performed on relatively small pads. Design data such as that published by E. I. duPont de Nemours and Company(2) was extrapolated to estimate the behavior of the pads being used. When it became apparent that extrapolation of data from small pads would not assure satisfactory performance of large pads, this research project was initiated to evaluate the physical characteristics of full size bearing pads, and to modify the pertinent specifications and design criteria if necessary.

The objective of this research was to evaluate the performance of full size bearing pads under test conditions which simulate the physical environment they are subjected to in actual field use. Various shapes and sizes of pads up to seven square feet in plan area and 5 inches in thickness were subjected to compressive, cycling, creep, translation, rotation, and ultimate strength tests. Typical pads consisted of 55 durometer neoprene reinforced at 1/2 inch intervals with steel, polyester, or fiberglass reinforcement.

This report is a condensed version of Reference 3 which presents a more detailed description of the research effort described herein.

CONCLUSIONS

The following conclusions are based upon laboratory testing at approximately 70°F., and apply to pads fabricated in accordance with the California specifications presented in the Reference 3. Among the requirements of these specifications are: 55 ± 5 durometer hardness (ASTM D1149, Type A); reinforcement at 1/2 ± 1/8 inch intervals; 20 gage mild steel reinforcement or fabric reinforcement possessing a minimum ultimate tensile strength of 700 pounds per inch at top and bottom of pad and 1400 pounds per inch within the pad.

Polyester Reinforced Pads

1. The compressive deflection of polyester reinforced pads is difficult to predict accurately because:

   a. The magnitude of deflections is much greater than that of steel or fiberglass reinforced pads because of the relative tensile flexibility of the polyester fabric.

   b. The compressive stiffness decreases as the overall pad thickness increases.

c. The compressive creep under sustained dead load stresses is two to three times that of steel or fiberglass reinforced pads because of the creep of the polyester fabric.

d. Compressive deflections due to live load cycling tend to remain in the pad after the live load is removed.

2. The translation and ultimate strength properties of polyester reinforced pads are very similar to those of fiberglass reinforced pads.

Fiberglass Reinforced and Steel Reinforced Pads

1. The compressive deflections of fiberglass or steel reinforced pads can be reliably predicted within the normal range of construction tolerances.

2. The compressive stiffness of fiberglass or steel reinforced pads is not significantly dependent on the overall pad thickness.

3. The compressive creep of fiberglass or steel reinforced pads under sustained dead load stresses is approximately 25 percent of initial deflection after ten years of service.

4. Compressive deflections of fiberglass or steel reinforced pads due to live load cycling tend to diminish after the live load is removed.

5. The ultimate compressive strength of fiberglass or steel reinforced pads is more than 1600 psi. The mode of failure is fabric tearing or steel yielding.

6. Under a nominal compressive load of 800 psi, fiberglass or steel reinforced pads may be subjected to rotational forces until the compressive strain at an extreme edge is zero without damaging the pad.

7. The shear modulus of fiberglass or steel reinforced pads is approximately 100 psi at 70°F. This value is not significantly dependent on pad size, shape, skew angle, or compressive stress.

RECOMMENDATIONS

1. Polyester reinforced pads over one inch in thickness should not be used in bridge bearings because of the difficulty in predicting compressive deflection.

2. For pad thicknesses normally used in bridge construction, steel or fiberglass reinforced pads should be specified in accordance with the specifications presented in Reference 3.

3. Compressive deflections for steel or fiberglass reinforced pads should be predicted using Figure 1. The accuracy of these curves is considered to be well within the range of normal construction tolerances. If long term compressive creep is to be included in the prediction, the values obtained from Figure 1 should be increased by 25 percent. For special situations where extreme accuracy is desired, sample pads should be tested to determine the stress/strain behavior of each lot of pads.

4. Further research is needed to improve specifications and test methods used to assure the quality of bridge bearing pads. Based on field performance to date, current specifications and test methods result in high quality pads, but these requirements vary considerably throughout the nation; some tests are

difficult and/or expensive to perform; and in some cases, the requirements may be unnecessarily conservative and restrictive. Research is needed to develop simple, inexpensive test methods which are related to performance requirements.

5. If further research is contemplated for large bearing pads, careful consideration must be given to test method details. Recommendations regarding such details are included in Reference 3.

Recommendations 1 and 2 were implemented by the California Department of Transportation, CALTRANS, in late 1972 by way of a revised specification. Since that time, there have been no reports of adverse performance of fiberglass reinforced pads.

TECHNICAL DISCUSSION

General Discussion of Testing Program

The basic objective of this research was to evaluate the physical characteristics of elastomeric bridge bearing pads commonly used in highway construction under loading conditions which simulate their in-service environment. The overall pad dimensions were selected to represent the range of sizes to be expected in modern bridge construction. Pads were purchased out of production runs from several manufacturers and complied with all the specifications presented in Reference 3 which substantially affect the physical properties.

The material properties which were most pertinent to the physical properties are listed below:

1. The sole polymer in the elastomeric compound was neoprene and said polymer was at least 60 percent by volume of the total compound.

2. The Shore durometer hardness (Type A) was 55 ± 5.

3. The reinforcement was at 1/2 ± 1/8 inch intervals.

4. The steel reinforcement was 20 gage mild steel.

5. The fabric reinforcement was single ply at the top and bottom surfaces of the pads, and double ply within the pads.

6. Each ply of fabric reinforcement possessed a breaking strength of at least 700 pounds per inch.

For the reader who is interested in more detailed information on any particular test pad, the pad details are listed in Reference 3. All tests were run at a temperature of approximately 70°F.

Compressive Stress/Strain Behavior

Test Procedure

Accurate prediction of the deflection of a bearing pad under compressive loads is necessary in order to assure that the bridge deck elevations on either side of an expansion joint will match within reasonable tolerance. Therefore, a large number of compressive tests were performed on pads with various reinforcement, overall dimensions, and shape factor to determine the compressive stress/strain behavior.

Shape factor is a commonly used parameter which is used to predict compressive stress/strain behavior and is defined as the loaded area divided by the total free area(2,4). In other words, for a pad of width, w, length, l, and distance between layers of reinforcement, t, the shape factor, sf, would be:

$$sf = \frac{wl}{2t(w+l)}$$

Compressive stress/strain tests were performed on pads possessing shape factors from about 3 to 15. In order to minimize the cost of purchasing pads, larger pads were first tested and then cut into smaller pads for subsequent tests. The typical testing and cutting sequence is illustrated in Figure 2.

Figure 3 illustrates the test set-up for pads whose greatest dimension was larger than 24 inches. For these large pads the C12x30 steel channels were needed to distribute the load uniformly to the pad. The composite concrete and steel plates shown in Figure 3 were fabricated to provide a relatively rigid bearing against the test pads while simulating the frictional characteristics between concrete and pads in an actual installation. The concrete was heavily reinforced and attached to the steel plates by shear connectors. The testing machine used in all tests was a 1,000,000 pound capacity, electro-hydraulic, universal testing machine with a remote console for programming loading schedules.

For pads whose greatest dimension was less than 10 inches, deflections were measured by a linear variable differential transformer which is an integral part of the testing machine. For larger pads, deflection was measured by a minimum of four dial gages, reading to the nearest 0.001 inch. Deflections were typically read at several intervals up to 100 psi and then at intervals of 100 psi for the remainder of the test. The smaller intervals were used to define the lower portion of the stress/strain curve, particularly to define the point of zero stress and zero strain.

Test Results

Figure 4 illustrates the substantial difference between the compressive stress/strain characteristics of polyester reinforced pads versus steel or fiberglass reinforced pads. Regardless of shape factor or stress level, the polyester reinforced pads undergo more strain than equivalent steel or fiberglass reinforced pads. This characteristic makes them less desirable than steel or fiberglass reinforced pads when a relatively thick pad is needed for an expansion joint. Because of their relative tensile flexibility, variations in dead load or the pad's stress/strain curve from that expected can yield relatively large unexpected deflections.

Figures 5 and 6 present the compressive stress/strain curves obtained from steel and fiberglass reinforced pads with shape factors ranging from 3 to 15. Regardless of shape factor, the compressive stress/strain characteristics of fiberglass reinforced pads are very similar to steel reinforced pads up to compressive stress levels of 1000 psi. Under these stress conditions the tensile stiffness of the fiberglass fabric is comparable to the 20 gage steel sheet.

Development of Recommended Stress/Strain Curves

In order to convert the data such as that shown in Figures 5 and 6 into usable form for design purposes, a technique employed by the Battelle researchers was selected(4). At various compressive stress levels, the values of compressive strain are plotted versus shape factor on a log-log plot. Straight lines are fitted to this data and appropriate values from these straight lines are plotted to establish stress versus strain curves for various shape factors. Figure 7 illustrates the compressive strain versus shape factor curve at 800 psi. The straight line in this figure was used with others at other stress levels to establish the recommended stress/strain curves of Figure 1.

By studying Figure 7 one can see that the steel reinforced pads tend to be slightly stiffer in compression than fiberglass reinforced pads but not substantially stiffer. Therefore, to simplify design procedures, a single set of compressive stress/ strain curves are recommended to represent both steel and fiberglass reinforced pads.

Figure 7 also illustrates, via the data scatter, the amount of variation one might expect between the predicted compressive deflection and the actual deflection obtained. This data indicates that for most installations this variation would not be critical. For instance, if the variation from predicted strain was one percent for a 5 inch thick pad, the variation in pad deflection would be only 0.05 inch - not a substantial amount in light of normal construction tolerances.

Effect of Pad Thickness on Compressive Stress/Strain Behavior

Test Procedure

The structural system of a reinforced elastomeric bearing pad is such that as the overall pad thickness is increased, the compressive stiffness of the pad tends to decrease although the shape factor is held constant. This tendency increases as the tensile stiffness of the reinforcement decreases as illustrated in Figure 8. The more flexible the reinforcement, the more the pad bulges laterally with resultant increase in compressive deflection. This characteristic in itself is not undesirable as long as the dependency of compressive strain upon pad thickness is quantified such that compressive deflections could be accurately predicted. Laboratory testing by California and others has revealed that the compressive strain of polyester reinforced pads is significantly dependent on the overall pad thickness(4).

Early in this research project, a testing program was planned to quantify this effect of thickness on polyester reinforced pads. As it became apparent that polyester reinforced pads would no longer be used in thicknesses exceeding one inch, this testing program was abandoned, and the emphasis was shifted to assuring that the compressive strain of fiberglass or steel reinforced pads was not significantly dependent upon overall pad thickness.

Pads with varying overall thicknessess were loaded in compression as described earlier. The different thicknesses were achieved by successively stacking identical pads on top of each other. The pads were considered identical since they were cut from the same original larger pad.

Test Results

Figure 9 illustrates the substantial effect overall pad thickness has on the compressive stress/strain behavior of polyester reinforced pads. No effort has been made to quantify this effect because it appears that such pads will not be used in thicknesses exceeding one inch.

Figure 9 also shows that the compressive stress/strain behavior of fiberglass or steel reinforced pads is not significantly dependent upon overall pad thickness. Therefore, the recommended compressive stress/strain curves of Figure 1 apply to all fiberglass or steel reinforced pads regardless of overall pad thickness.

For a bridge bearing pad to creep excessively under sustained compressive loads would be highly undesirable because of the resulting differential elevation of the two sides of the expansion joint, i.e. - a bump in the roadway which would vary in magnitude as long as the bearing pad continued to creep. Therefore, several test pads were subjected to compressive loading conditions simulating sustained dead load and repetitive live load to assess the amount of creep to be expected.

Current CALTRANS design practice limits the nominal compressive stress on a pad to 800 psi due to dead load, live load, and impact load. For testing purposes a dead load stress of 575 to 600 psi was selected to represent typical dead load stresses in a bridge bearing pad. Test pads were subjected to these stress levels using the compressive test apparatus described earlier. The test machine was set to automatically hold a constant load throughout the test. Compressive deflections were recorded versus time and creep was defined as the increase in deflection with time divided by the initial deflection when the pad was first loaded(4). The dead load was sustained on the test pads for periods up to several days or until it appeared that creep was progressing at a very slow rate.

Following the static creep tests, the compressive stress was cycled from the simulated dead load stress to 800 psi to simulate a live load environment. The testing machine automatically controlled the sawtooth function at a rate of 100 cycles per hour. After 200 cycles the compressive stress was returned to the dead load stress level and the pad deflection was measured to determine the amount of strain caused by the simulated live loading. The compressive stress was then held at the dead load stress level to determine whether or not the pad would tend to recover from the strain caused by the live loading. The test was terminated when the data indicated whether or not this recovery was occurring.

A few pads were also subjected to static creep tests at 1000 psi to assure that current design practice possessed a factor of safety against excessive creep.

Test Results

Creep test results are summarized in Figure 10. This figure clearly illustrates the unsatisfactory performance of polyester reinforced pads relative to the performance of fiberglass or steel reinforced pads. The creep of polyester reinforced pads can exceed 30 percent of their initial deflection after 24 hours under dead load conditions while the corresponding creep for fiberglass and steel reinforced pads is approximately 10 percent.

Figure 10 also illustrates the relative performance of different reinforcement materials under simulated live load conditions. Although all pads experienced creep due to the 200 cycles of live load, the fiberglass reinforced and steel reinforced pads tended to recover from this dynamic creep when the load was returned to the dead load condition while the polyester reinforced pads failed to make this recovery. This indicates that over a long period of service that the deflection of polyester reinforced pads would tend to increase due to creep caused by live loads.

Figure 11 presents data from creep tests on a logarithmic scale in order to make long term projections of creep. This figure again illustrates the undesirable creep characteristics of polyester reinforced pads, and also supplies an estimate of creep after a number of years. Based on this data, creep of about 20 percent would be realized after ten years of sustained dead load on fiberglass or steel reinforced pads. This is in agreement with the DuPont ten year test data which indicates creep of 25 percent after ten years(2). Therefore, current California design criteria which estimate creep to be 25 percent over the lifetime of a bridge appear to be reasonable.

Curves similar to Figure 11 were also established to estimate the creep of fiberglass reinforced and steel reinforced pads under a static load of 1000 psi. As would be expected the creep at 1000 psi tends to be higher than that at 600 psi but it is not considered excessive. This indicates that steel or fiberglass reinforced pads designed for dead load stresses of approximately 600 psi possess a substantial factor of safety against excessive creep.

Ultimate Strength in Compression

Test Procedure

Current CALTRANS design practice limits the nominal compressive stress to 800 psi. In order to estimate the factor of safety against pad failure in compression, several pads were subjected to ultimate strength tests. Because of the 1,000,000 pound capacity of the testing machine, the size of the test pads were limited.

The pads were loaded and data acquired as described earlier for compressive tests except that the load was increased in 100 psi increments until the pad had failed or yielded.

Test Results

Figure 12 presents the stress/strain curves for typical ultimate strength tests. At a compressive stress level of 2400 to 2800 psi in the steel reinforced pads the slopes of the curves decreased indicating that the steel reinforcement was yielding. Based on the theoretical equations of Rejcha, the tensile stress in the 20 gage mild steel reinforcement is about 36,000 psi at this compressive stress level(5). After yielding, the pads could carry much more load although their compressive stiffness was substantially diminished. The yielded shape of reinforced pads was such that the maximum amount of bulging was at the center of the long side of the pad. Inspection of such pads indicated that no loss of bond between the elastomer and the steel reinforcement occurred until the compressive stress exceeded 4000 psi.

Figure 12 also presents the stress/strain curves for fiberglass reinforced pads. At a compressive stress level of 1700 to 1900 psi the sound of tearing fabric was heard and the pads could carry no further increase in load. According to the Rejcha equations the theoretical tensile load in each ply of the fiberglass reinforcement at this point is about 450 pounds per inch(5). The ultimate tensile strength of each ply of fiberglass in the test pads was about 700 pounds per inch as determined by a unidirectional tensile test. Based on inspection of the center layer of fiberglass following ultimate strength tests, it appears that tearing initiates at the geometric center of the pad and progresses outward toward one edge. Following this initial tear, the pad becomes, in effect, two smaller pads which attempt to carry the imposed load. These two smaller pads in turn tear resulting in a cross-hatched pattern. Following the ultimate strength tests, there was no appearance of loss of bond between the elastomer and the fiberglass reinforcement.

Figure 12 also presents a stress/strain curve for a polyester reinforced pad. The pad behaved very much like the fiberglass reinforced pads except for the obvious difference in compressive stiffness. As with the fiberglass reinforced pads, failure occurred suddenly and was well defined at about 2000 psi compression.

Based on these tests, one can see that fiberglass or steel reinforced pads possess a substantial factor of safety against compressive failure when designed for a compressive stress of 800 psi.

Compression and Rotation

Test Procedure

Although current design criteria limit the maximum nominal compressive stress to 800 psi, local compressive stresses can be substantially higher due to the amount of rotation allowed. To simulate extreme conditions of compression combined with rotation, a series of tests were performed on fiberglass and steel reinforced pads under the conditions illustrated in Figure 13.

These conditions were achieved by moving the test pad off the centerline of the testing machine and allowing the gimbal joint of the testing machine to accommodate the rotation. The test apparatus was the same as that discussed earlier for compression tests, but no deflections were measured. The amount of eccentricity was increased until a feeler gage could be placed between the loading plate and the top surface of the pad at one edge while applying a nominal compressive load of 800 psi. Under this condition, the opposite edge is undergoing the maximum compressive strain to be expected in an actual installation.

Test Results

As expected the pad edge under maximum compressive strain, bulged considerably. This area was closely inspected visually but there was no appearance of any pad failure. After releasing the load, the pads always returned to their original shape. This indicates that fiberglass and steel reinforced pads can accept the maximum rotations allowed by current design criteria without damage to the pad. CALTRANS design criteria limit the amount of rotation by requiring that bearing be maintained throughout the plan area of a pad.

To determine the distribution of compressive stresses experimentally would require extensive instrumentation and testing. Although the above tests show that the pads are capable of sustaining large rotations without failure, designers are encouraged to minimize rotational stresses by specifying the smallest pad width possible within the limits of the particular application.

Compression and Translation

Test Procedure

Current CALTRANS design criteria for bearing pads limit the amount of lateral translation to 1/2 the pad thickness while using a shear modulus value, G, of 135 psi to compute lateral loads. The shear modulus, G, is defined as the shear stress times the ratio of pad thickness over pad translation.

These same criteria are used regardless of the size or shape of the pad, skew angle, compressive stress, or type of reinforcement. The skew angle is defined as the angle between the direction of translation and the axis of the pad running across the pad width. A series of combined compression and translation tests were performed to determine whether or not variations in these parameters had any substantial effect on the shear modulus, vertical deflection, or overall pad behavior. Translation tests were also performed on pads which were stacked on top each other to determine if such pads could be translated without slippage between the pads.

The test apparatus used for the combined compression and translation.tests is illustrated in Figure 14. The one-inch thick steel plate was sandwiched between two identical test specimens and a compressive stress of 400, 600, or 800 psi was applied via the concrete and steel plates. The testing machine was set such that the compressive load remained constant throughout the translation test. Horizontal loads were applied by a 120,000 pound capacity hydraulic jack through a rather complex apparatus which is best illustrated by the photographs presented in Reference 3. In order to keep the two concrete and steel plates parallel throughout the translation tests, braces were placed between these plates and the testing machine after the compressive load had been applied. The horizontal loads were measured by a strain gage load cell mounted on the hydraulic jack and the horizontal deflections were measured by two dial gages mounted to read relative deflection between the one-inch steel plate and the concrete and steel plates.

After applying the compressive load, translation was applied in increments of ten percent of pad thickness. At each increment the vertical load and horizontal load and deflection were measured as quickly as possible - within 30 seconds of obtaining the desired translation. The maximum translation for most of the tests was 100 percent of the pad thickness.

Because the shear modulus is highly dependent upon the hardness of the neoprene, the pads used for these tests possessed almost identical hardness. The shore durometer hardness of the steel reinforced pads was 53 while that of the fiberglass reinforced pads was 54.

Test Results

One of the obvious visual differences between steel and fabric reinforced pads when translated laterally is illustrated in Figure 15. The fabric reinforced pads tend to curl at their edges and actually separate from the loading plates at translations between 25 and 50 percent of pad thickness. Field service of fabric reinforced pads has not shown this phenomenon to be detrimental. Because of the bending stiffness of the steel sheet, the steel reinforced pads do not curl at their edges until the translation exceeds the design maximum of one-half the pad thickness. Such behavior might be detrimental under cyclic conditions where the steel would be bent back and forth beyond its yield point.

Figure 16 compares the shear stress/strain behavior of steel reinforced pads versus fiberglass reinforced pads, and also illustrates typical data points obtained in the translation tests. It can be seen that there is no significant difference between the shear moduli of steel or fiberglass reinforced pads. Figures 17 and 18 show that this is true regardless of size or shape of the pad, skew angle, or compressive stress.

Figure 17 illustrates the effect of varying the compressive stress on the shear modulus. The shear modulus values presented represent the shear stress required to translate the pad 100 percent of its thickness. This figure shows that the shear modulus is not significantly dependent on the magnitude of compressive stress. Visual observation of the pads during these tests revealed no difference in physical behavior due to differences in compressive stress.

Figure 18 illustrates the effect of varying the skew angle on the shear modulus. This figure shows that the skew angle does not significantly affect the shear modulus. As expected, the corners of the pads tend to curl more as the skew angle is increased to 45 degrees, but this curling does not damage the pad.

In all the translation tests described above, the highest value of shear modulus obtained was 109 psi while the lowest was 95 psi. This indicates that the shear modulus of 135 psi used to predict lateral loads is adequate regardless of size or shape of the pad, skew angle, compressive stress, or type of reinforcement.

In all the translation tests, the vertical deflection was monitored to determine whether the translation would result in any significant vertical deflection. The vertical deflections measured at translations of 50 percent of pad thickness were small enough to be considered insignificant. For example, the largest compressive strain realized was 0.31 percent for an 8" x 16" steel reinforced pad. For a four-inch thick pad, this would amount to an 0.01 inch deflection - not enough to be concerned about in normal bridge construction.

One other parameter was investigated during the translation tests - that of stacking individual pads on top each other. At a translation of about 25 percent of the pad thickness, the pads began to slip at their interface. Despite a compressive stress of 400 psi, the friction between the pads was not high enough to prevent slippage. This indicates that pads which are stacked to form a thicker pad must be bonded together to assure that the pad remain intact throughout its service life.

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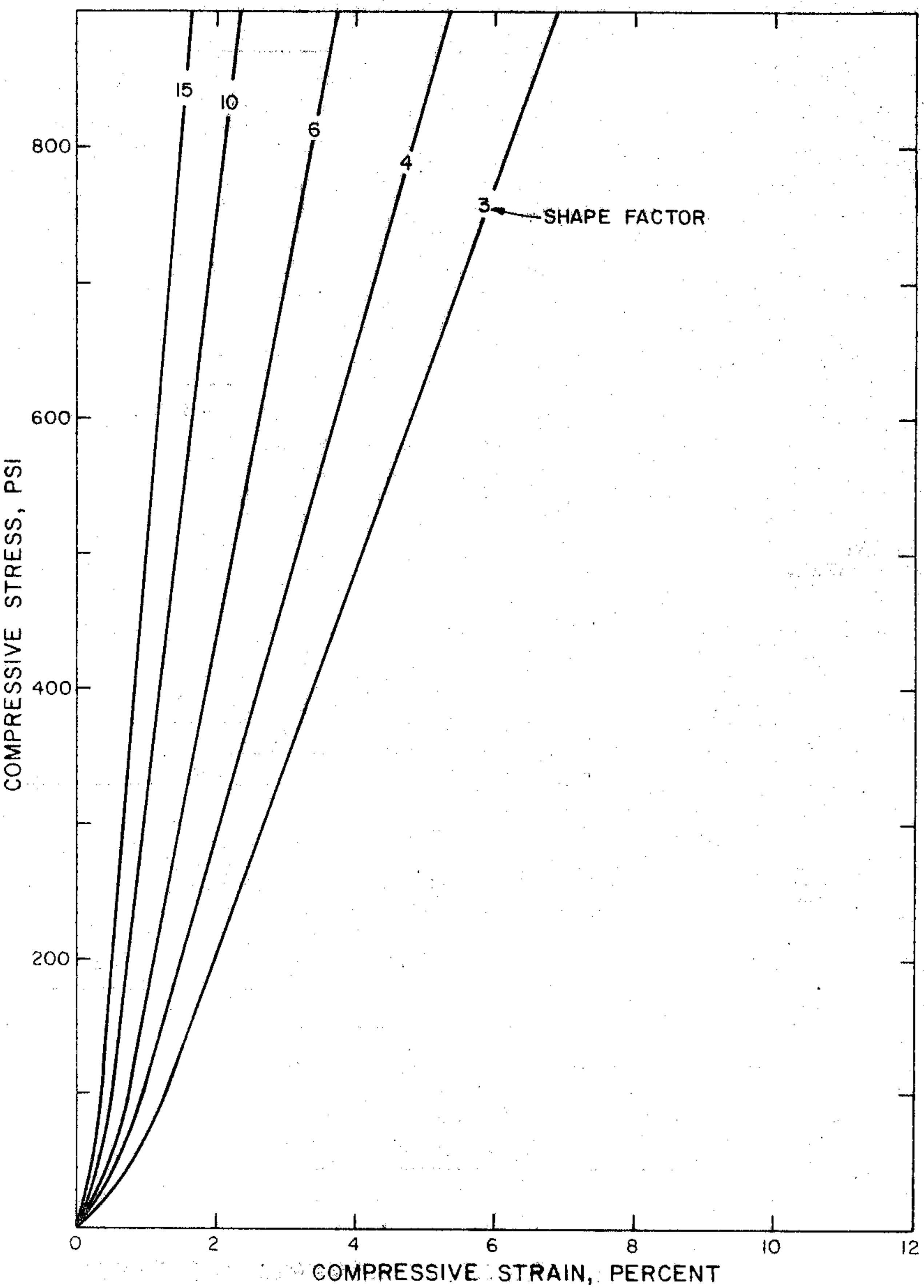


Fig. 1 RECOMMENDED COMPRESSIVE STRESS/STRAIN CURVES FOR STEEL OR FIBERGLASS REINFORCED PAD, 55 DUROMETER NEOPRENE

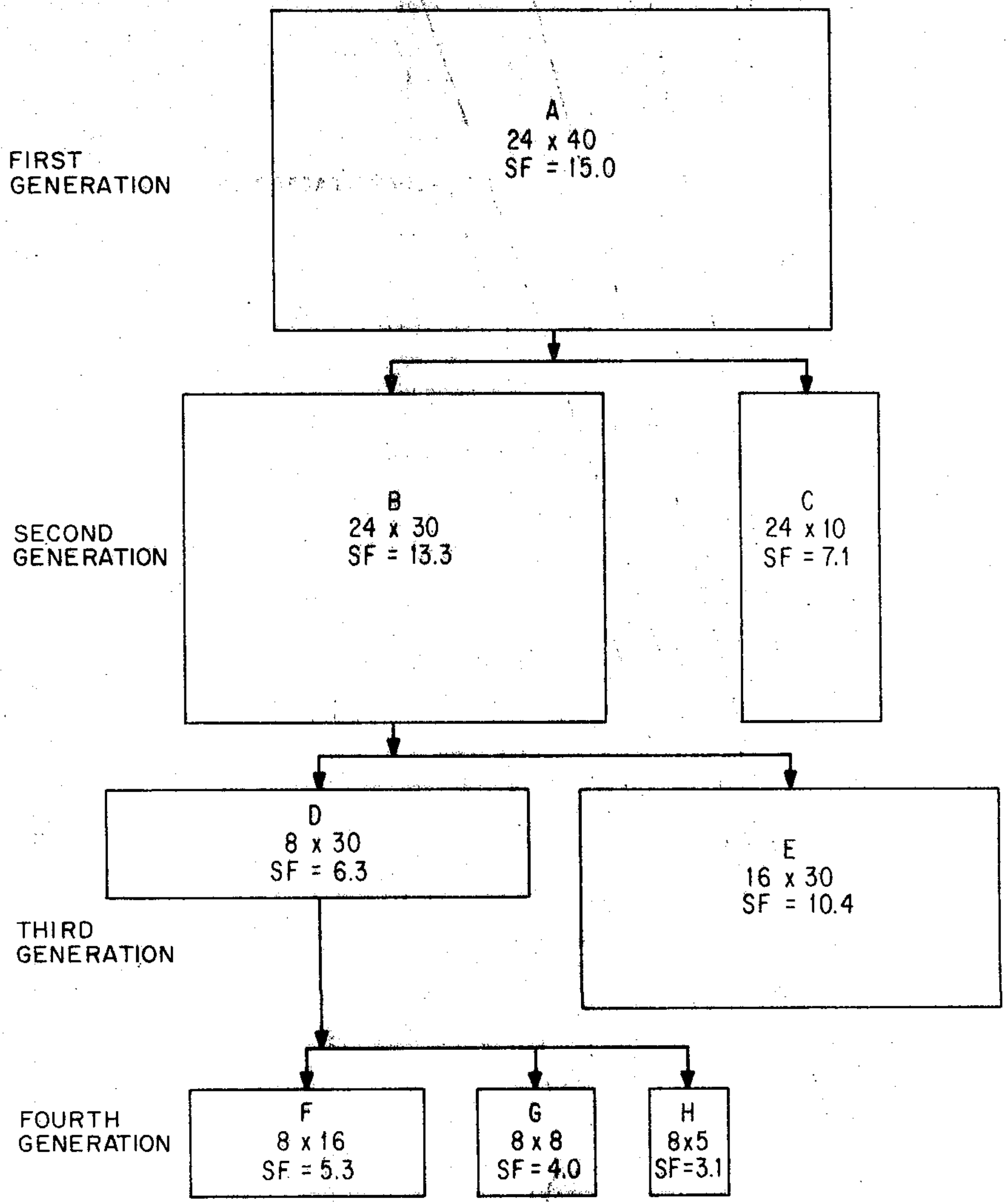


Figure 2, TYPICAL SEQUENCE OF COMPRESSIVE TESTS

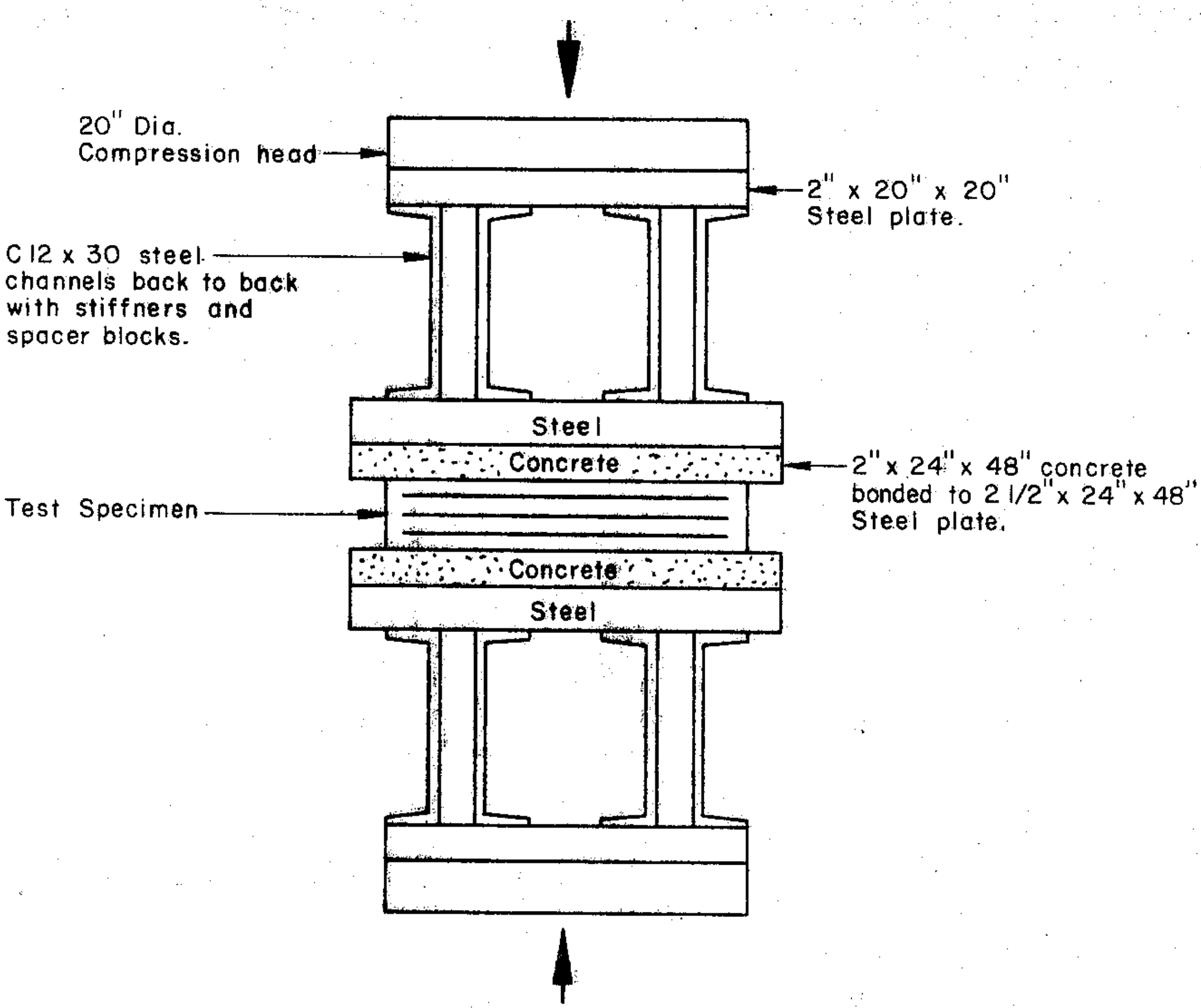


Figure 3 TYPICAL COMPRESSION TEST APPARATUS

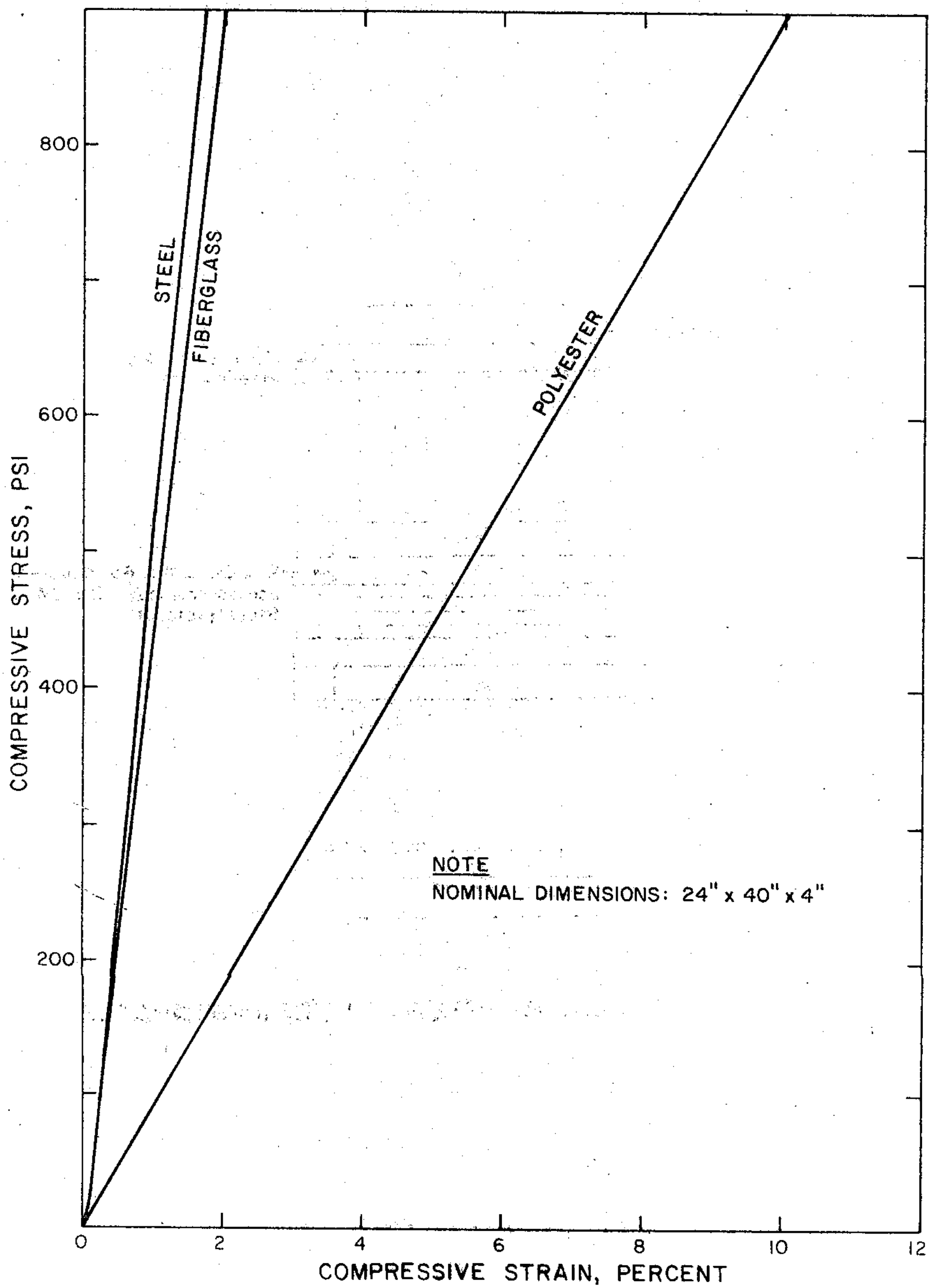


Fig.4 STRESS VS. STRAIN WITH VARIOUS REINFORCEMENT, SHAPE FACTOR= 15.0

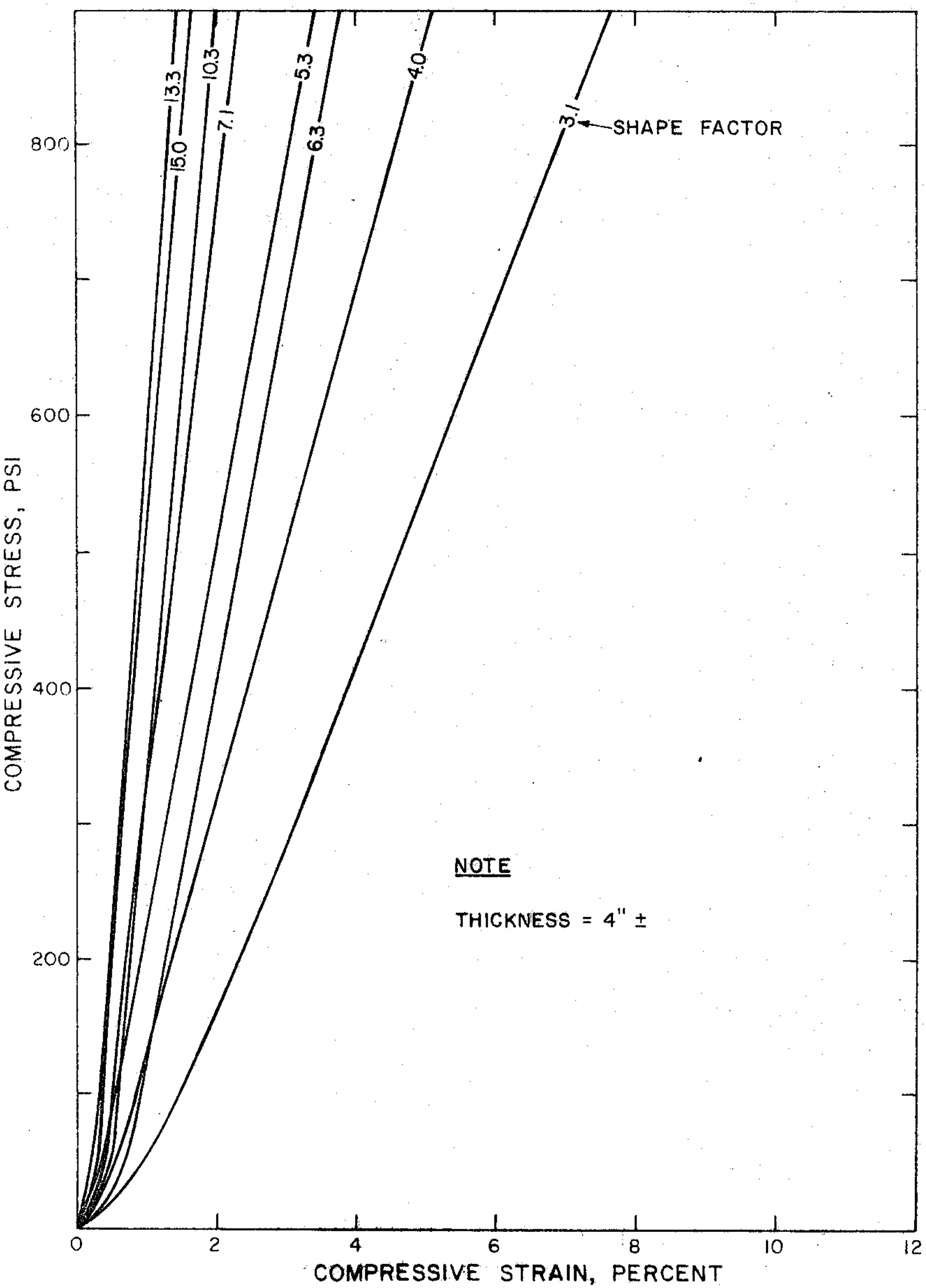


Fig. 5 COMPRESSIVE STRESS / STRAIN DATA FOR STEEL REINFORCED PADS

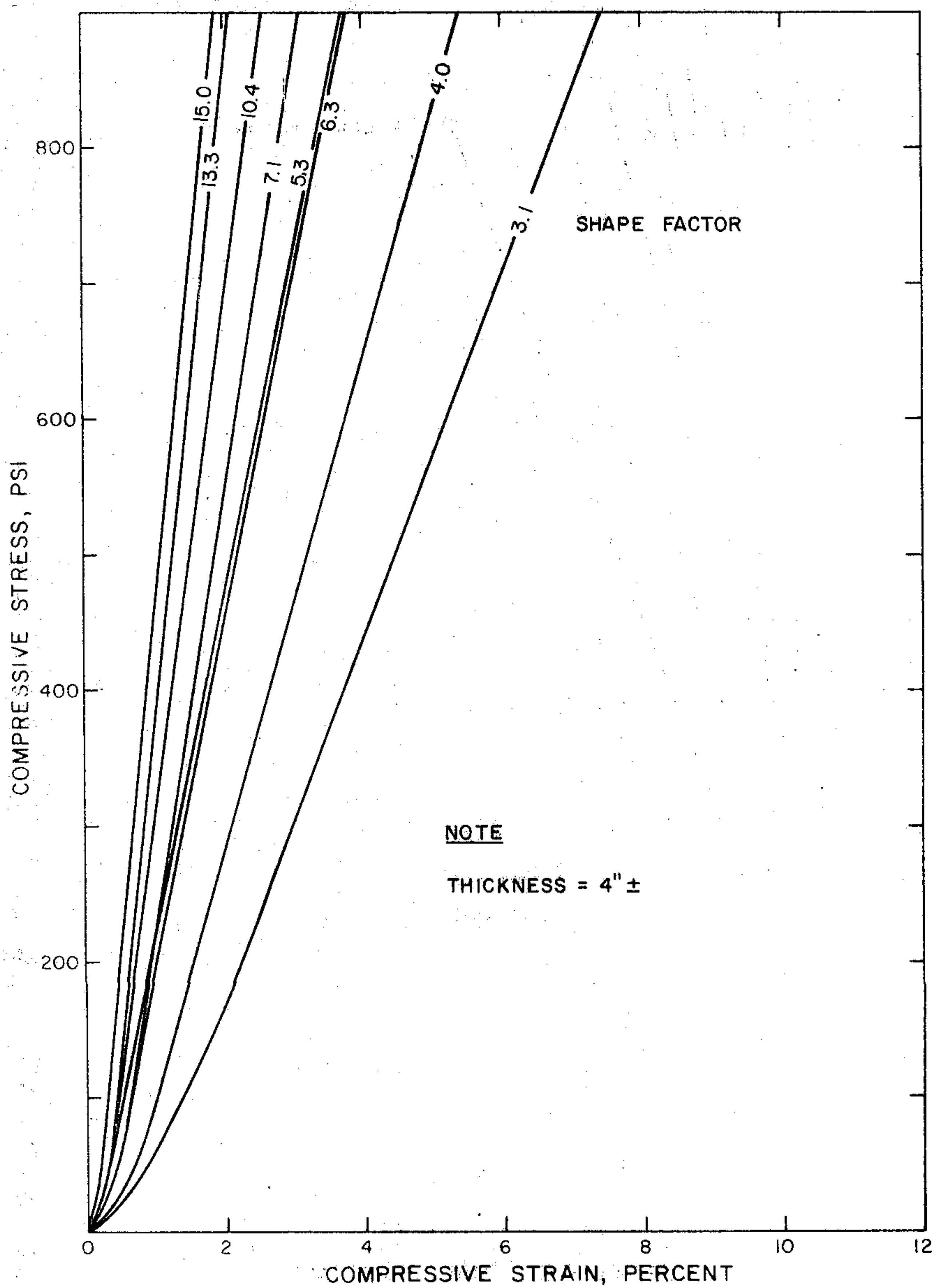


Fig.6 COMPRESSIVE STRESS/STRAIN DATA FOR FIBERGLASS REINFORCED PADS

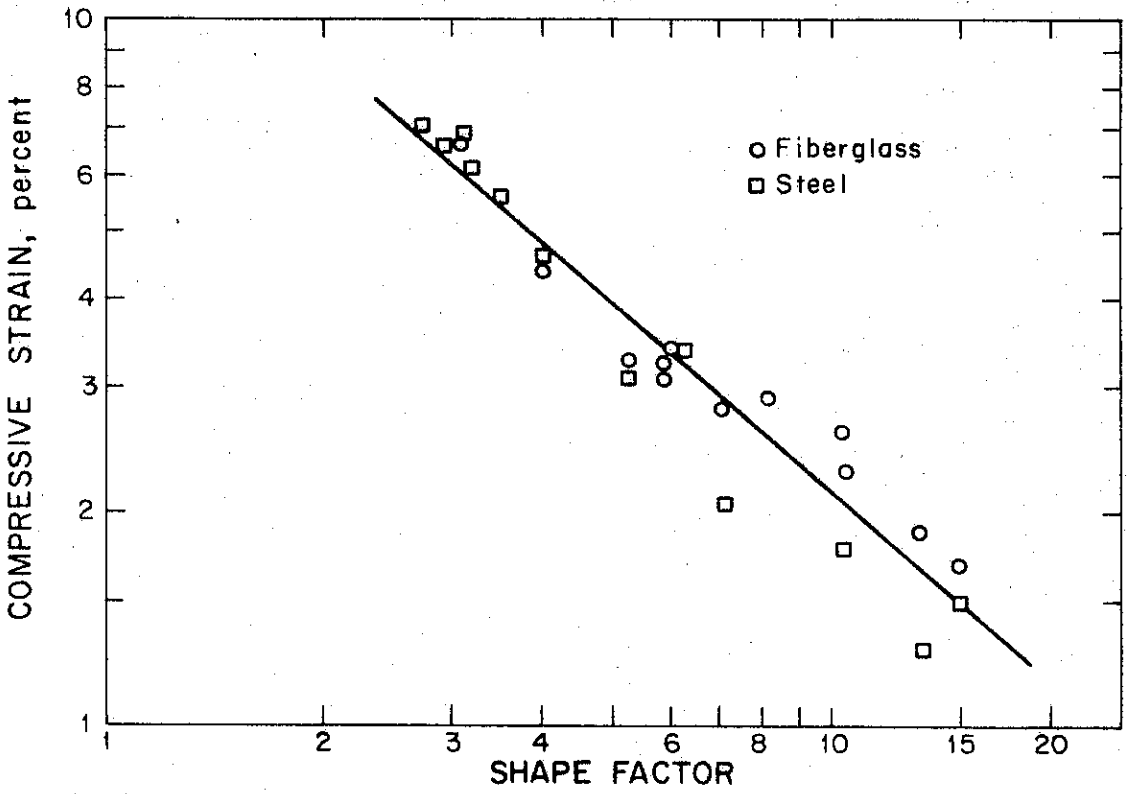
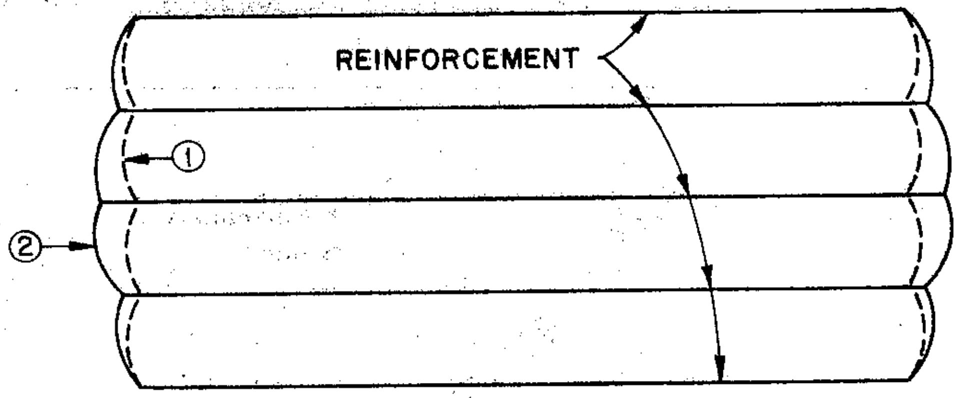


Figure 7 COMPRESSIVE STRAIN VERSUS SHAPE FACTOR AT 800 PSI COMPRESSIVE STRESS



① STEEL OR FIBERGLASS REINFORCED PAD.

② POLYESTER REINFORCED PAD.

Figure 8 COMPARISON OF PAD CONFIGURATIONS UNDER 1000 PSI COMPRESSIVE LOAD

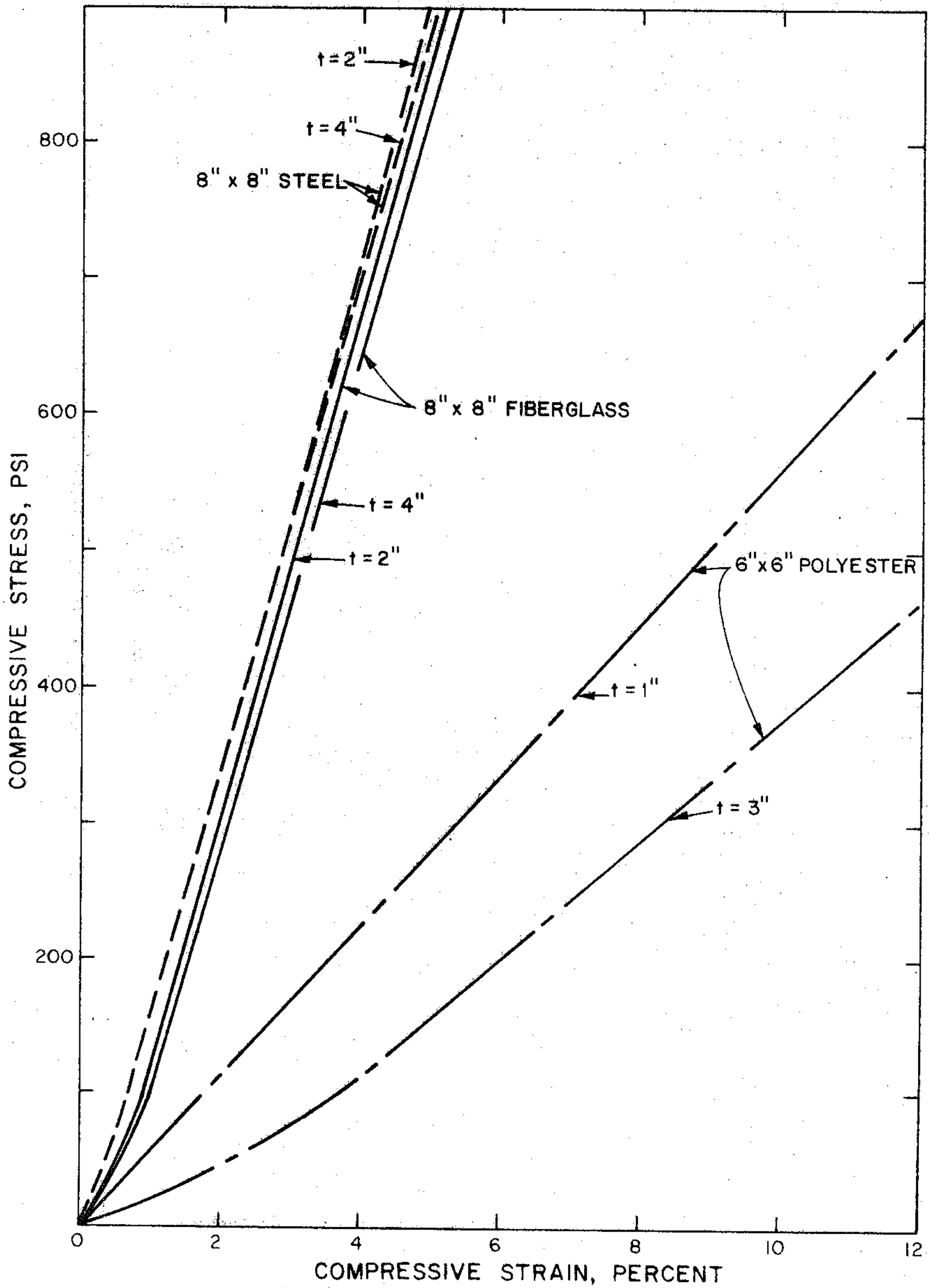


Fig. 9 EFFECT OF OVERALL PAD THICKNESS ON COMPRESSIVE STRESS/STRAIN BEHAVIOR WITH CONSTANT SHAPE FACTOR

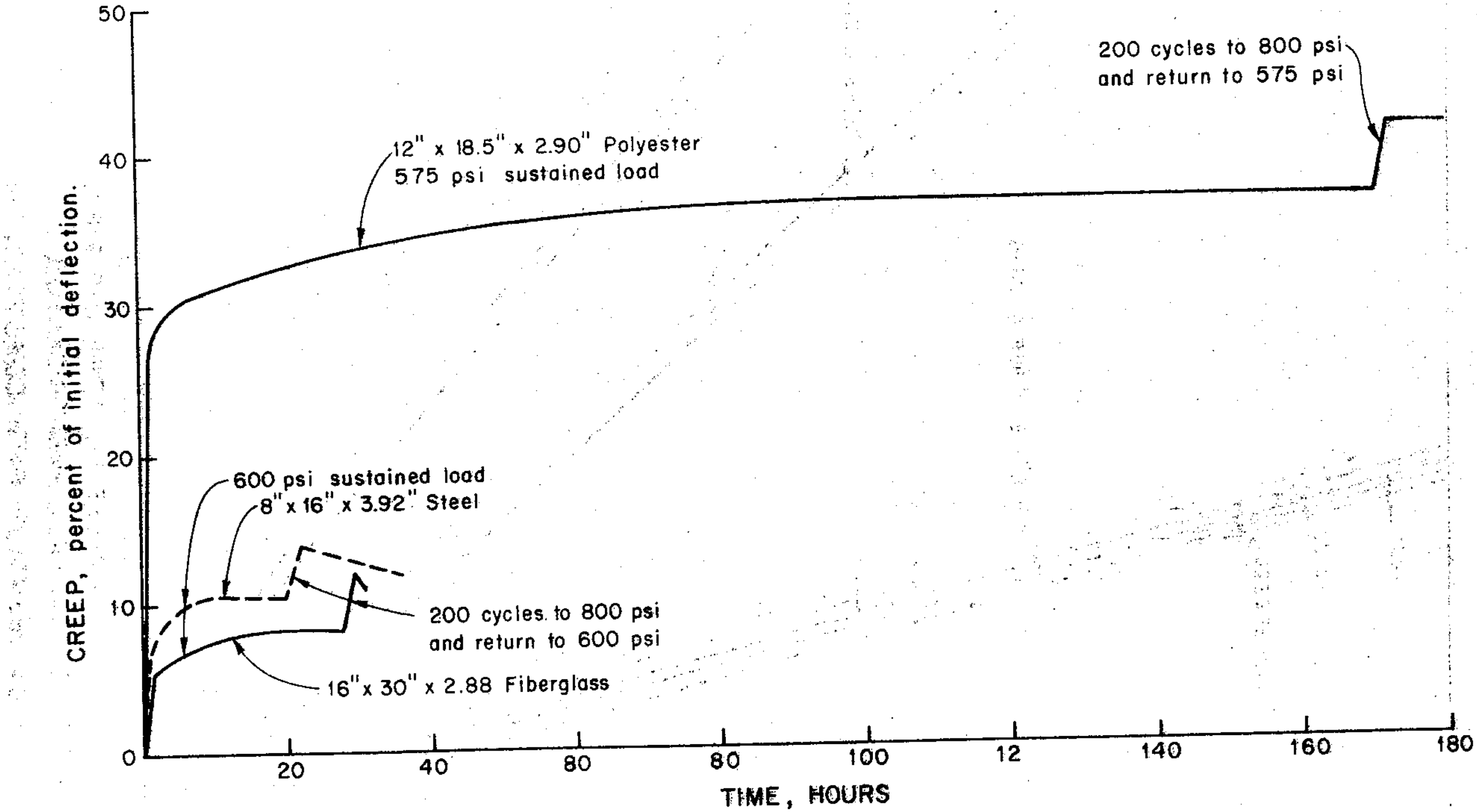


Figure 10 TYPICAL COMPRESSIVE CREEP CURVES UNDER SIMULATED DESIGN LOADS

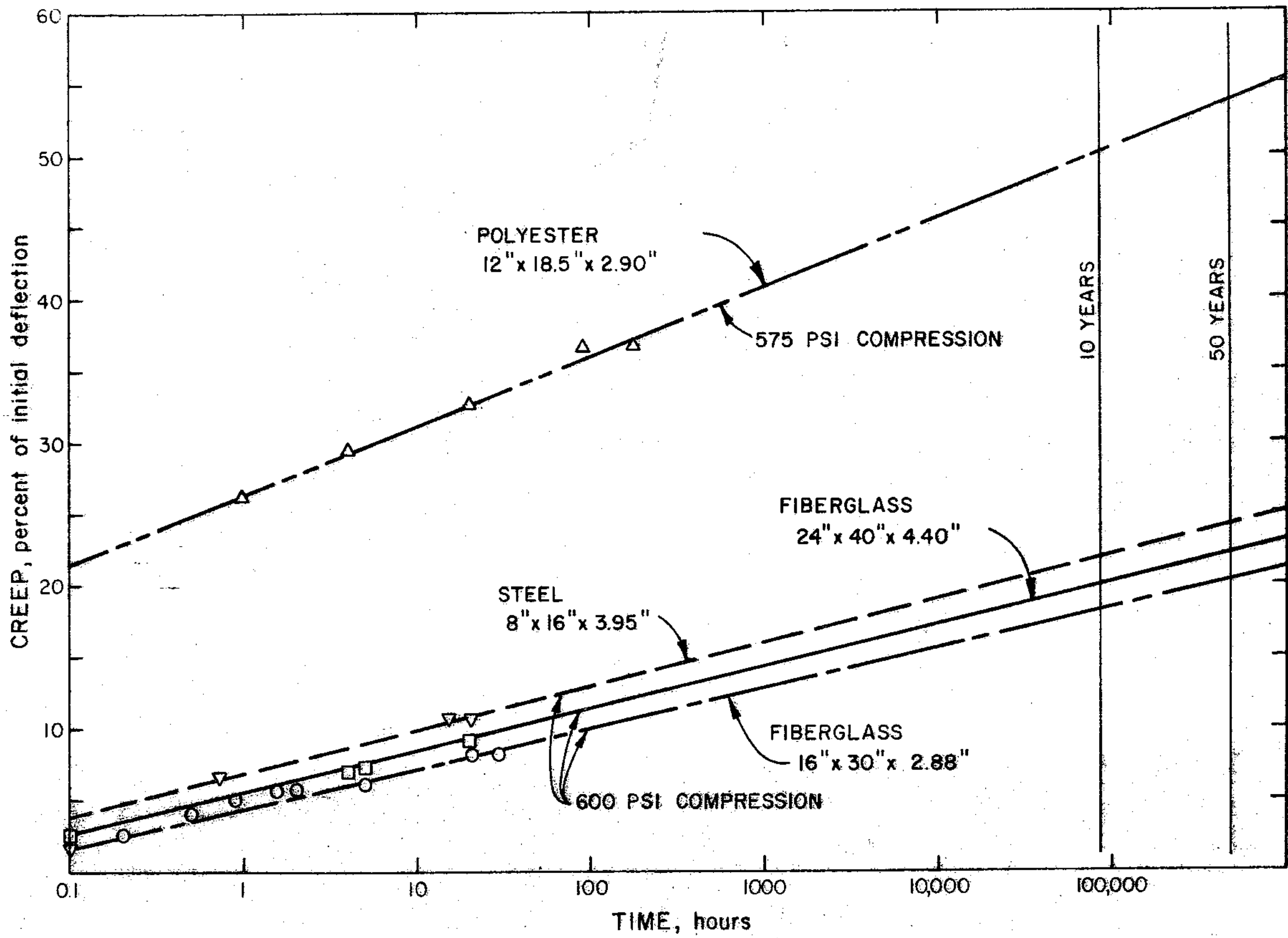


Figure 11 CREEP UNDER SIMULATED DEAD LOAD COMPRESSIVE STRESS

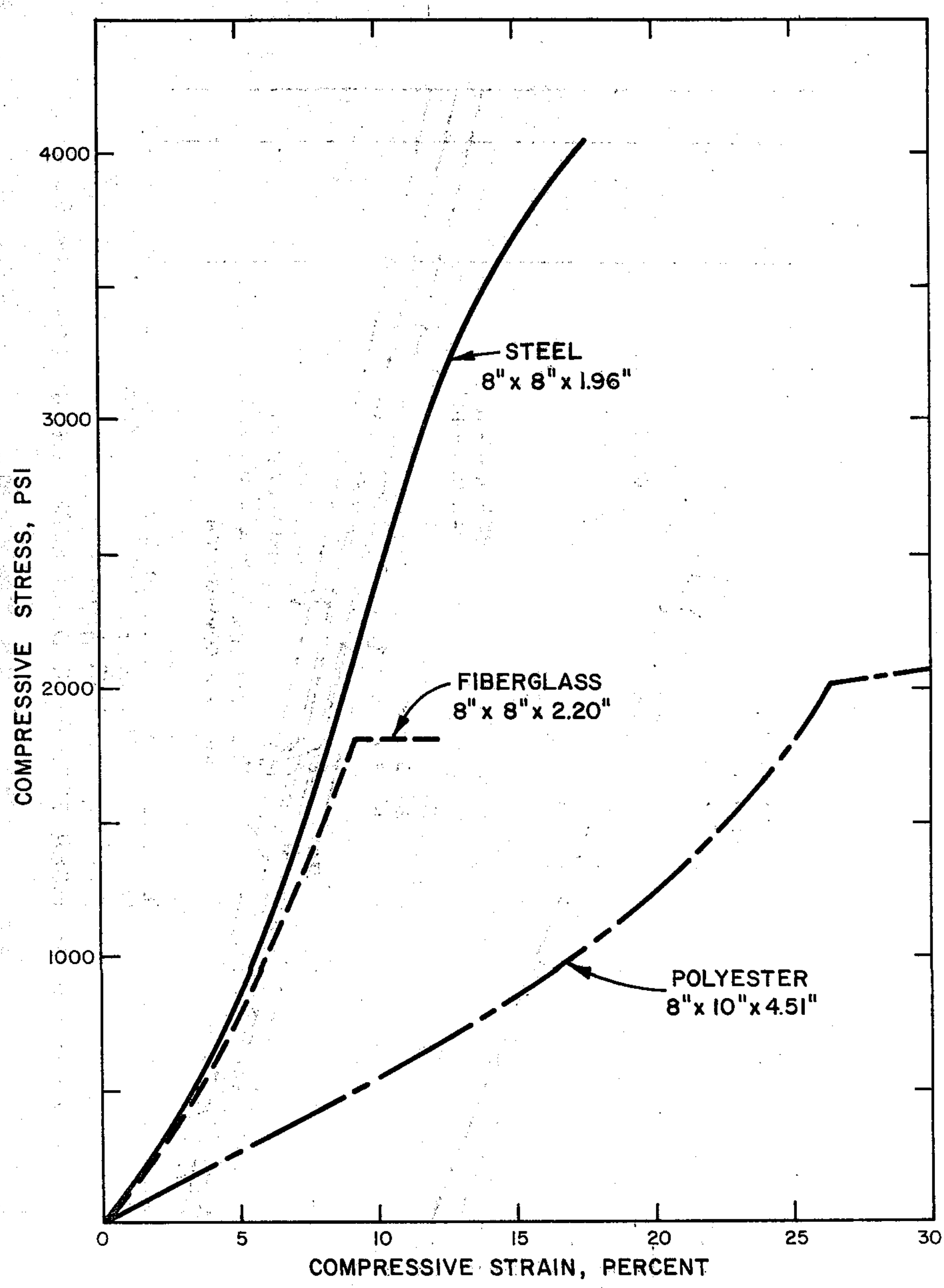
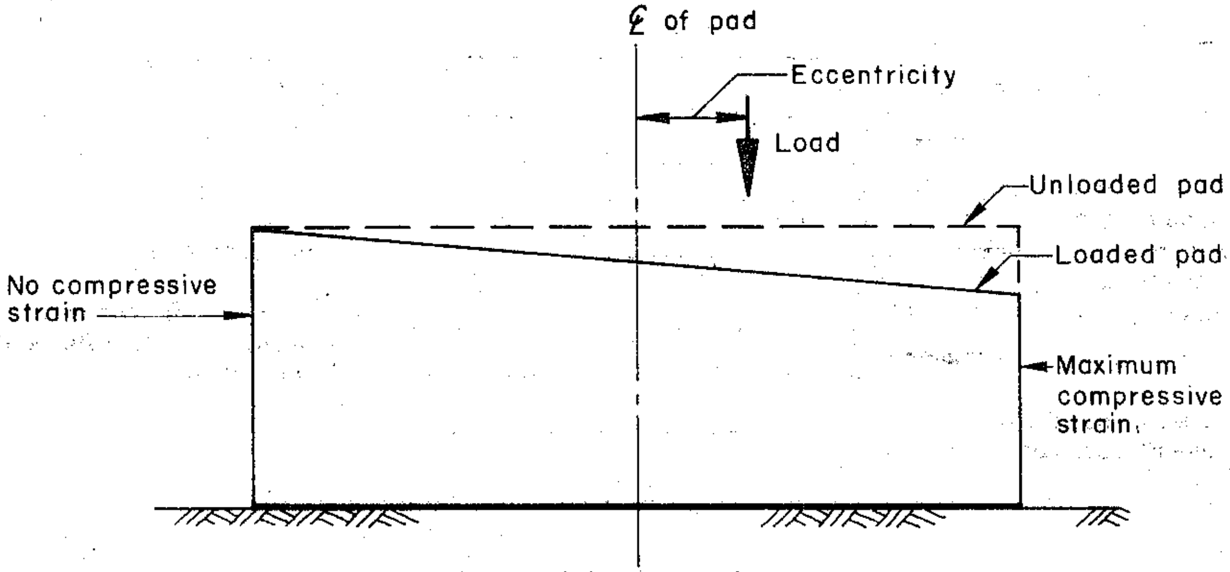


Fig. 12 TYPICAL RESULTS OF ULTIMATE STRENGTH TESTS



Note: The load is that which causes an average compressive stress of 800 psi.

Figure 13 CONDITIONS OF ROTATION TESTS

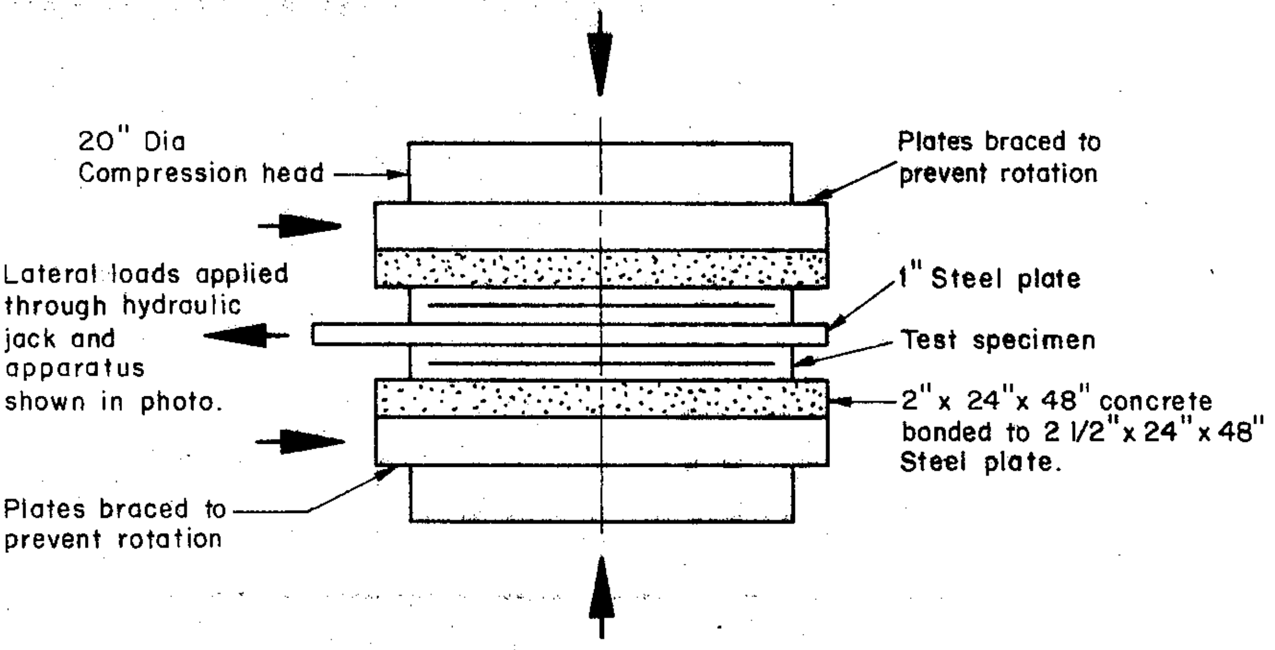


Figure 14 TYPICAL TRANSLATION TEST APPARATUS

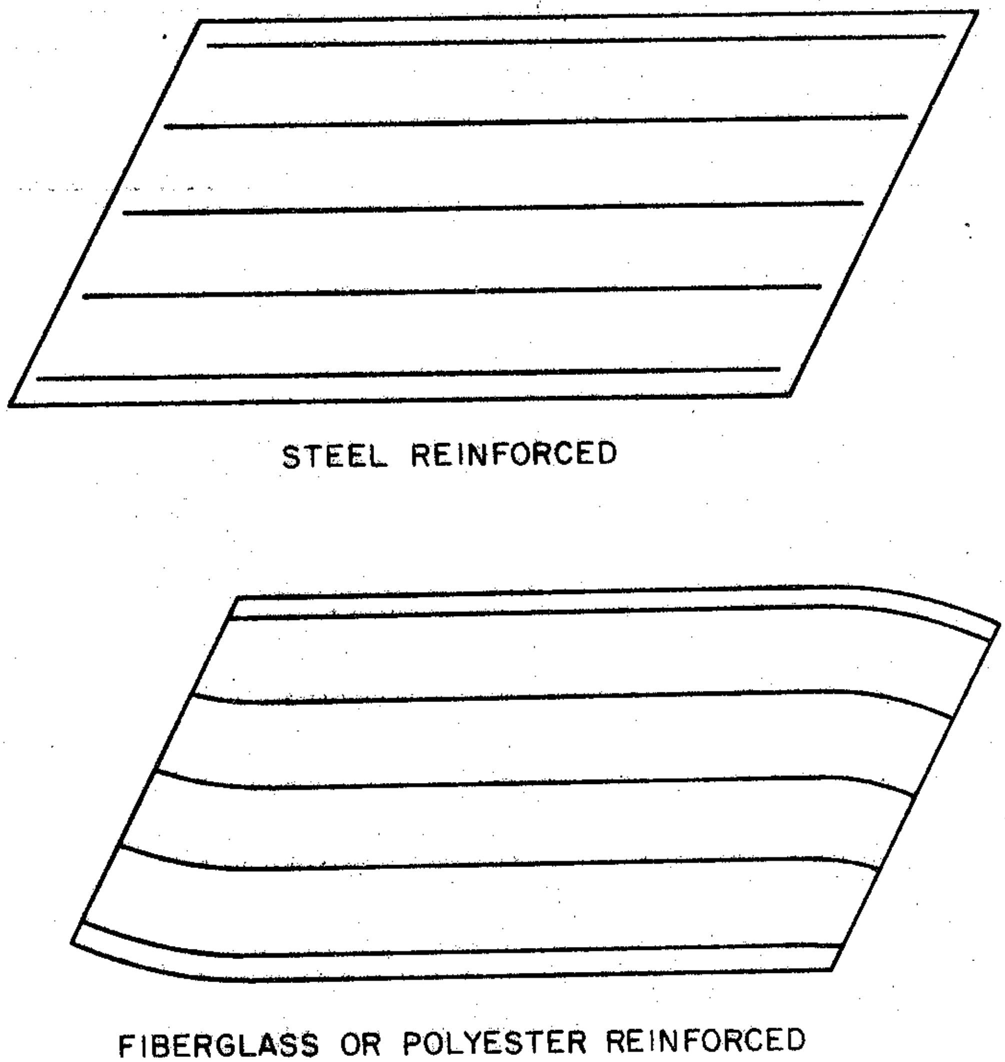


Figure 15 COMPARISON OF PAD CONFIGURATIONS WHEN TRANSLATED 50 PERCENT OF THICKNESS

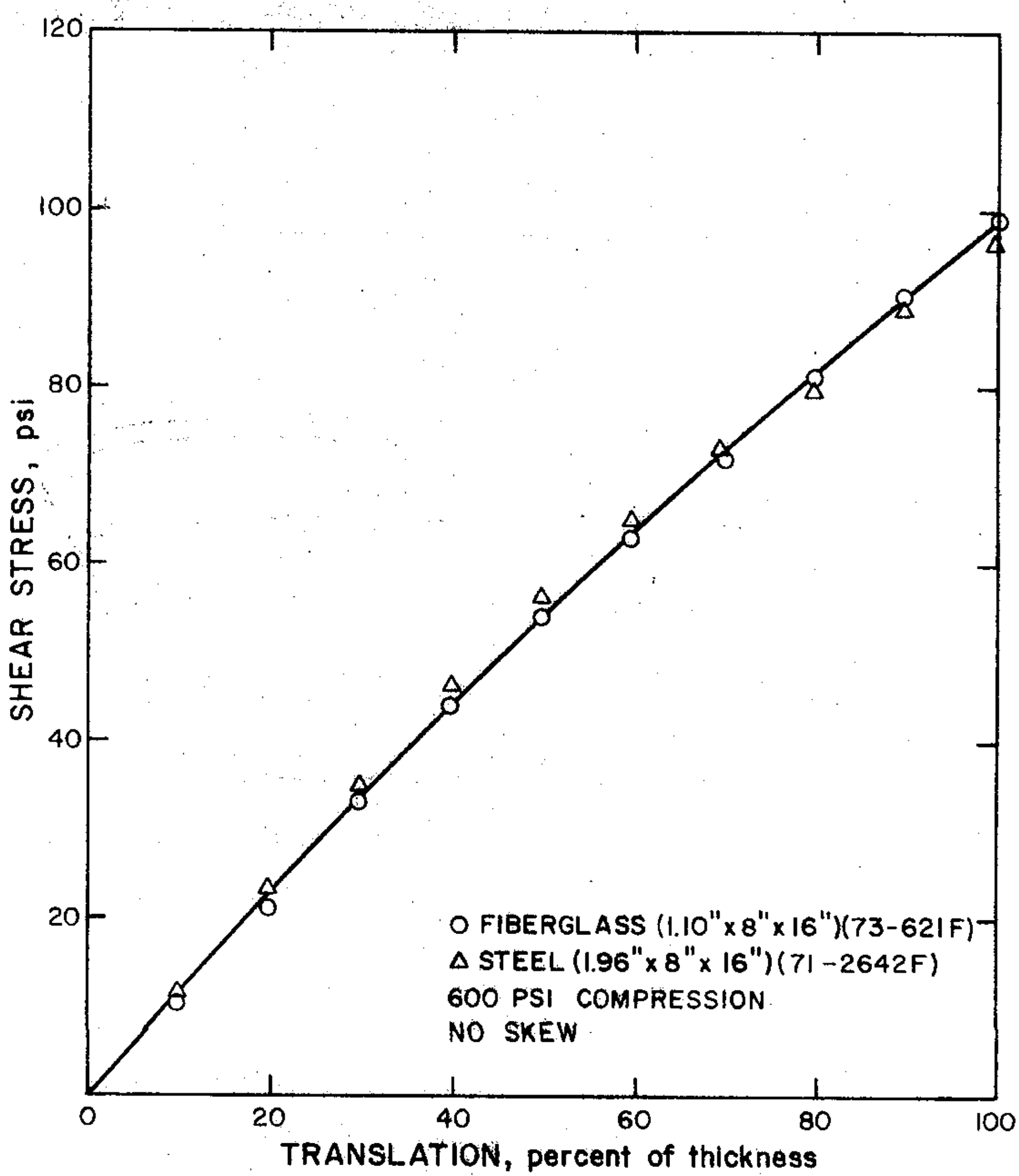


Figure 16 SHEAR STRESS VERSUS TRANSLATION FOR STEEL OR FIBERGLASS REINFORCED PADS

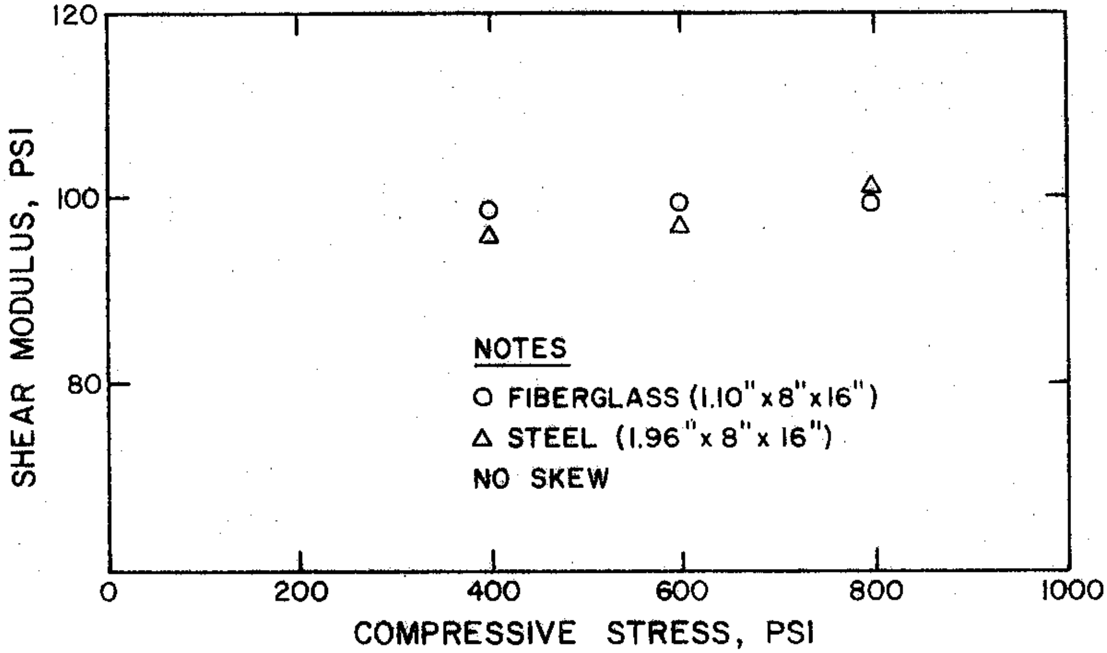


Figure 17 SHEAR MODULUS VERSUS COMPRESSIVE STRESS

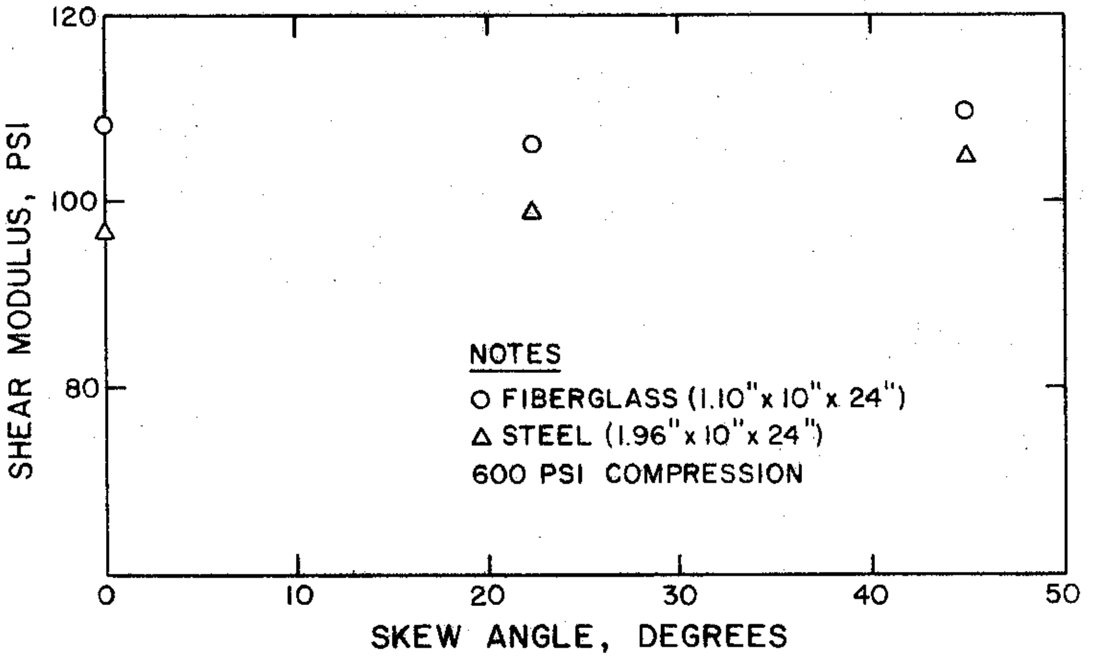


Figure 18 SHEAR MODULUS VERSUS SKEW ANGLE