A COMPARATIVE STUDY OF ELASTOMERIC MATERIALS FOR BRIDGE BEARING PADS

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ABSTRACT

Elastomeric bearing pads of five different materials with shape factors ranging from one to six were subjected to a series of three specific tests to determine and compare their respective load-deformation characteristics. Compression-deflection tests were conducted to determine short-time load-deflection responses for solid pads and laminated pads placed between bearing surfaces of concrete-and-concrete, concrete-and-steel, and steel-and-steel. Additional vertical deflections due to creep in the pad material subjected to a constant static compressive stress were measured over periods ranging from one to three weeks. Investigations were made to determine the effects of repetitive reversed horizontal shear forces acting on a bearing pad while loaded under a constant vertical compressive stress. An objective comparison was made of the materials tested. Recommendations for a design procedure using curves from the experimental data are outlined. Recommendations are made for future research.

ACKNOWLEDGEMENTS

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Also the writers gratefully acknowledge the contributions of the graduate students Messrs. Pat Garner, B. Malhas, K. Salman, S. Suresh and Mehmet Bedestani an well as those of Mr. Gary Orr.

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SYMBOLS AND ABBREVIATIONS

A . . . . Area

AASHO . . . . American Association of State Highway Officials

ASTM . . . . . American Society for Testing and Materials

B . . . . butyl

C . . . . chlorobutyl

C-C . . . . . . concrete-and-concrete bearing surfaces

cpm . . . . . . cycles per minute

C-S . . . . . . concrete-and-steel bearing surfaces

E . . . . EPT (Trade name of an elastomeric compound)

°F. . . . . . . degrees Fahrenheit

H . . . . hypalon

in. . . . . inches

kip . . . . one thousand pounds

L . . . . length of pad in inches

N . . . . neoprene

P . . . . load in pounds

psi . . . . pounds per square inch

RRST . . . . . . repetitive reversed shear tests

S . . . . shearing stress

S.F. . . . . . . shape factor

SH . . . . Shore hardness

S-S . . . . steel-and-steel bearing surfaces

W . . . . width of pad in inches

T . . . . nominal or initial thickness of pad in inches

Note: Superscript numbers enclosed in parentheses refer to references listed in the Bibliography.

A COMPARATIVE STUDY OF ELASTOMERIC MATERIALS FOR BRIDGE BEARING PADS

CHAPTER I

INTRODUCTION

1.1 General

In recent years elastomeric materials have received considerable attention from bridge designers throughout the world. Their interest was generated by the development of a material with the engineering properties of "structural strength, together with flexibility, durability, versatility of form, and resistance to abrasion and to the destructive action of certain liquids and gases." (14) These mechanical properties can vary widely depending on the compound of the elastomeric material. Many of these elastomers appear to be well suited for use as a structural bearing. However, the material used primarily for such bearings has been neoprene. Neoprene has been widely accepted as an excellent engineering bearing material following over thirty years of laboratory testing and applications in the field.

The deformation and behavior of elastomeric bridge bearing pads are largely influenced by service loads and bridge conditions. While only a limited amount of information has been accumulated pertaining to the problems peculiar to elastomeric bridge bearings, research literature concerned with the general behavior of elastomers is voluminous and of long standing. However, this past research has contributed little information for the use of elastomeric bearing pads, and present knowledge has advanced primarily by empiricism.

Several new elastomeric materials are now being produced which have engineering properties comparable to, and in some cases superior to neoprene. However, very limited data are available which would indicate that these materials will function satisfactorily as bridge bearing pads. The limited number of researchers have avoided the testing of the newer elastomers, while investigating the specialized problems of elastomeric bearings made of neoprene. However, a limited number of studies have included some of the newer elastomers in conjunction with the primary investigation of neoprene. Therefore, comparative studies of the behavior of various elastomeric materials used for bearing pads are needed.

The use of elastomeric bearing pads appears to be of importance in view of the economic advantages to be gained by the use of these pads versus the use of the generally more expensive conventional pedestals and shoes, rollers, sliding plates, and fixed bearings. These economic advantages are generally due to the lower cost of elastomeric materials, ease of placement and positioning, and the elimination of lubrication, cleaning, painting, and replacement of bearing devices. In addition, some of the less obvious advantages are: the small size of bearing pads; the even distribution of loads to irregular contact surfaces; dampening of vibrations and a cushioning effect of the impact of moving loads (similar to a shock absorber) (25) which produces smoother riding qualities. (15)

1.2 Terminology

The following basic definitions for elastomeric materials which are used in this paper are generally accepted by the rubber industry and persons associated in this field. (3)

Abrasion Resistance. The ability of an elastomeric specimen to withstand mechanic action - such as rubbing, scraping, or erosion - which progressively tends to remove material from its surface.

Adhesion of Rubber to Metal. The strength of a bond formed between a metal surface and a rubber compound.

Aging. A progressive change in the chemical and physical properties of rubber usually marked by cracking and deterioration.

Anticracking Agent. A material which prevents or retards cracking in rubber vulcanizates in dynamic and static exposures.

Bonded Pads. Elastomeric bearing shapes made by glueing steel plates to the top and bottom bearing surfaces with an epoxy adhesive (Figure 1.5).

Compression-Deflection Characteristics. If a compressive force acts on rubber which is free to be displaced in any direction, it will undergo elastic deformation, storing up its applied energy and returning most of it when the force has been removed. The tests for compression-deflection characteristics constitute one kind of compression stiffness measurement. ASTM Method D 575 (b) requires that a specified compressive force be placed on a test pad and the resulting deflection should be measured and recorded. The parameters most generally plotted are applied stress versus deflection (thickness), percent.

Compression Set. The permanent decrease in a pad thickness measured 30 minutes after removal from a loading device, ASTM Method D 395.

Compression Stress. For elastomeric bearing pad, the calculated stress using the nominal unloaded bearing surface area.

Creep, Drift, or Strain Relaxation. The characteristic of elastomers to continue to deform after the initial short-time deformation resulting from a constant load. In this paper initial deflection is the amount of vertical deflection determined from compression-deflection tests. Time versus deflection and percent of initial deflection are plotted.

Cycle. The total movement of a pad from the initial compressed position to the forward deflection, back to center, to the backward deflection, and back to center (Figure 1.1).

Elastic Limit. The limiting stress to which a body may be deformed and return to its original shape after the force causing deformation has been removed. Elastomers have no real elastic limit and therefore receive some amount of "set" due to loading.

Elastomere Any rubber, synthetic rubber, or rubber-like material that will return to approximately its original shape with time after removal of external compression or tensile forces.

Epoxy. An adhesive compound consisting of an epoxy resin and a hardening agent. It is used to bond steel plates on opposite faces of elastomeric pads.

Fatigue. The molecular weakening of an elastic material resulting from repetitive shears or stresses.

GR-S. Government Rubber-Styrene used during World War II.

Flexinge The procedure of applying repetitive horizontal force cycles to an elastomeric pad. See also Cycle.

Hardnesse The relative resistance of rubber to the indention of a blunt point impressed on its surfacee The several methods being used are: ASTM Method D 314, D 531, D 676. ASTM Method D 676 was used to determine hardness values in this study.

Hooke's Lawe The capacity of a material to undergo strains that are directly proportional to the applied stress. Elastomers do not ordinarily obey Hooke's Law because there is not a constant relationship between stress and straine

Laminated Padse Elastomeric bearing shapes made by rubber fabricators by bonding steel plates to solid pads in multiple layers (Figure 1.4).

Shape Factore The shape factor of an elastomeric pad has been determined by Kimmich (11), of Goodyear Tire & Rubber Company, to be a significant parameter that influences the magnitude of vertical deflections resulting from applied stresses. Shape factor is the ratio of the nominal areas of one unloaded bearing surface to all nonrestrained surfaces that are free to expand laterally (Figure 1.2). It can be calculated using Equation (1-1).

$$S.F. = \frac{LW}{2(L+W)eT} \quad (1\text{-}1)$$

where: S.F. = shape factor
L = length of pad in inches
W = width of pad in inches
T = nominal or initial thickness of pad in inches

Shear Modulus. The ratio of the shearing stress to strain.

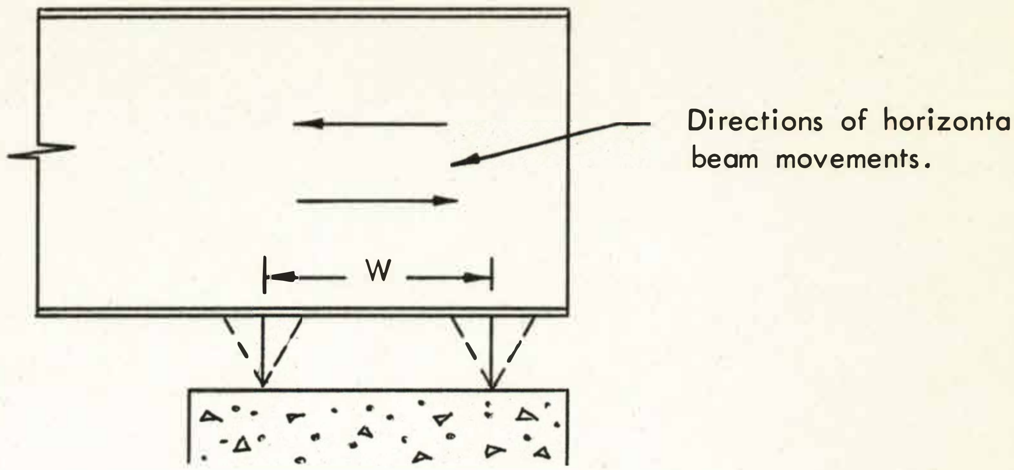


Figure 1.1 Horizontal displacement cycle of a pad due to temperature differential (rotations neglected).

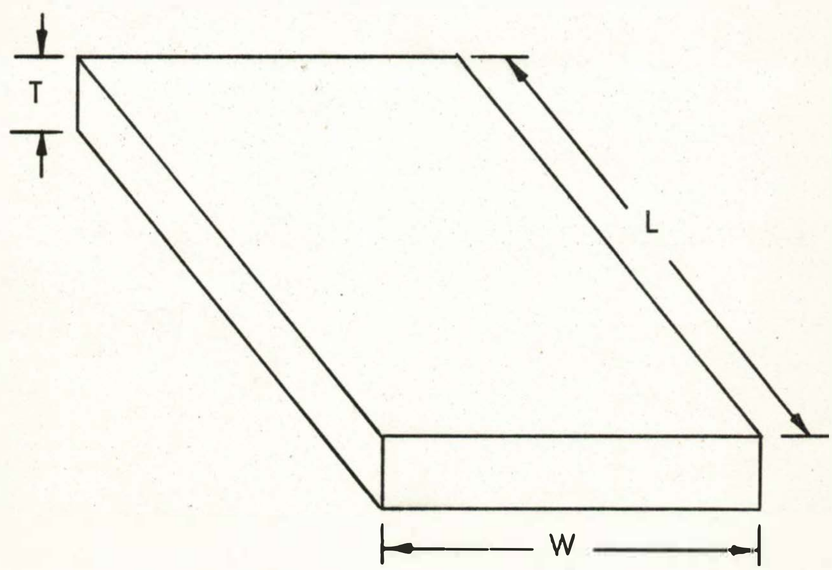


Figure 1.2 Basic dimensions used in calculations of the shape factor of a pad.

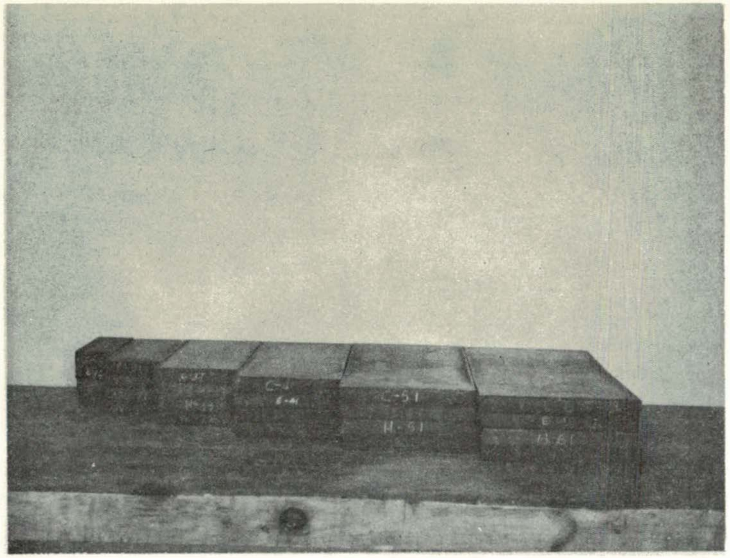


Figure 1.3 Solid pads.

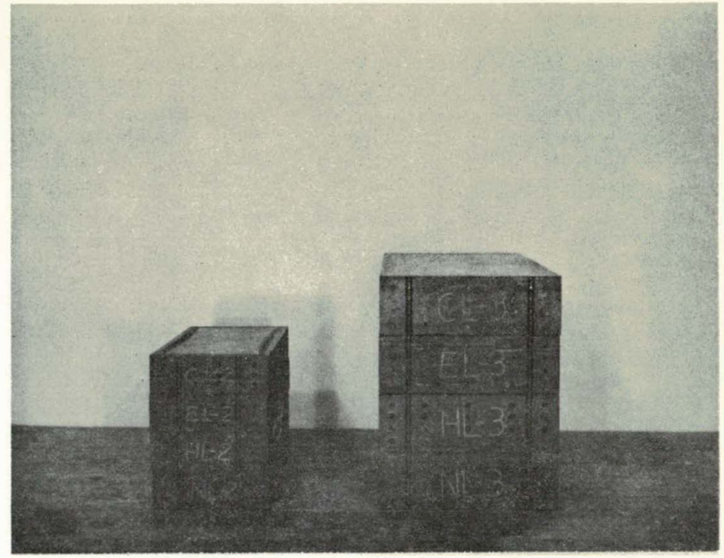


Figure 1.4 Laminated pads.

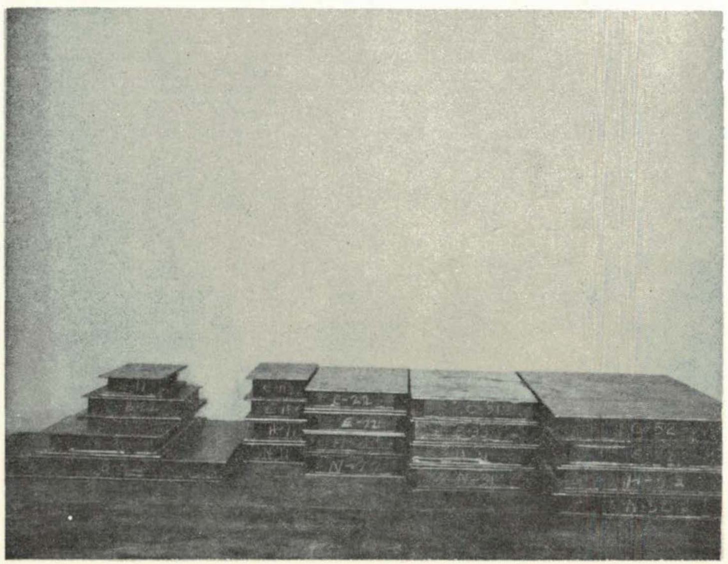


Figure 1.5 Bonded pads.

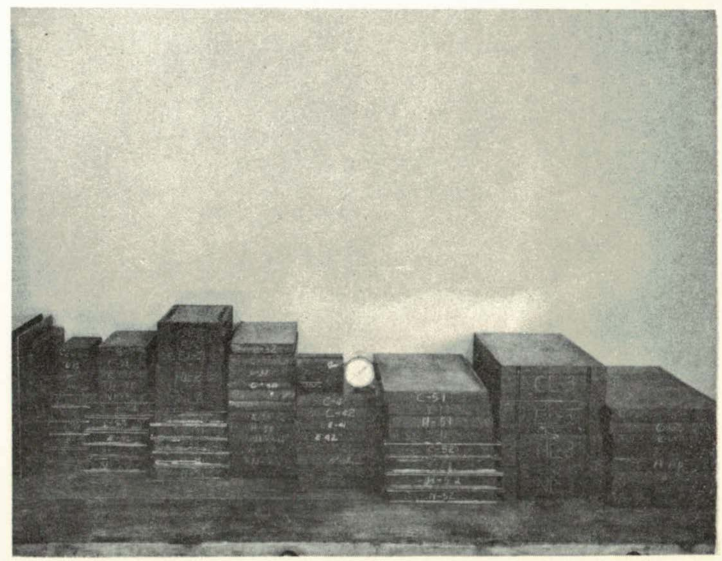


Figure 1.6 Assembly of all test pads.

Shearing Stress. Shearing stresses are developed by the application of an external force which causes two parts of a body to slide relative to each other in a direction parallel to their plane of contact. It can be expressed by Equation (1-2).

$$S = \frac{P}{LW} \qquad (1\text{-}2)$$

where: S = shearing stress
P = load in pounds
L and W = see Equation 1-1

Shore Hardness. The hardness value obtained by using a Shore Durometer, Type A-2 for ASTM Method D 676. It is a relative value on a scale of 100.

Solid Pads. Elastomeric bearing shapes comprised of a homogeneous material (Figure 1.3).

Strain. The deflection resulting from an applied force expressed as a percentage of original thickness.

Stress. Force per unit of original unloaded cross-sectional area.

Elastomeric Materials Tested

Butyl Rubber. A copolymer of isobutylene and isoprene.

Chlorobutyl. A chlorinated modification of the basic butyl rubber structure.

EPT. Ethylene-propylene terpolymer.

Hypalon. A chlorosulfonated polyethylene.

Neoprene. Synthetic rubber made by polymerizing 2-chloro-1, 3-butadiene.

1.3 Brief Historical Review

Elastomeric pads have been used for bridge bearing devices beginning shortly after World War II. The first elastomeric bridge bearing pads were used in France in the late 1940s. (6.1) Neoprene was selected for use as a load-transfer bearing device because of its proven serviceability as a covering for telephone lines. Neoprene was first introduced in 1932 by the E. I. duPont de Nemours & Co. (Inc.). Since its introduction thousands of bridges constructed with prestressed concrete beams have incorporated neoprene bearing pads because of the problems encountered in the seating of this type of beam.

In more recent years, elastomeric pads have been placed as supports for railway and highway bridges throughout the world. DuPont has reported (6.1):

> Among the most notable structures built with Neoprene bearings are: the Pensacola Bay Bridge in Florida; all the bridges on the Van Wyck Expressway extension built to serve the New York World's Fair; more than 300 bridges on the Autostrada system in Italy; the two-mile Champlain Bridge across the St. Lawrence River at Montreal; the Viaduc, an elevated expressway in Brussels, Belgium; grade separation bridges on highways in the Swiss Alps; . . . Recently, the Connecticut River bridge at East Haddam, Connecticut, was repaired, with Neoprene pads replacing worn out rollers under the two fixed spans, one of them 326 feet long.
>
> Among all the thousands of bridges built with Neoprene bearings, there has not been a single reported failure, or even a complaint.

Considerable economic savings were reported (15) with the use of 13,728 separate neoprene bearing devices in the construction of the Chesapeake Bay Bridge-Tunnel Crossing. This single item produced a saving in cost of over $0.5 million over the original estimate of slightly over $1 million for mechanical shoes and rollers.

In this country, the highway departments of California, Florida, Louisiana, New Hampshire, North Dakota, Oklahoma, Pennsylvania, Rhode Island, and Texas are just a few of those presently using elastomeric bearing pads. (Figures 1.7 through 1.10) Many other states are considering the use of these pads.

Past history of the successful use of neoprene bearing pads resulted in the adoption of the 1961 AASHO Standard Specifications for Highway Bridges Art. 1.6.47 - Expansion Bearings. Part (d) (1) states: "The pads shall be of the compound known as neoprene, . . .". A proposed revision of March 1, 1965, deleted the word neoprene in addition to other changes which would make it possible to use numerous elastomers that comply with the materials specification. This complete Proposed AASHO Specification on Expansion Bearings is included in Appendix A. However, due to the state of the knowledge, this proposed change was not accepted at the Spring 1966 meeting of the AASHO Expansion Bearing Sub Committee.

1.4 Summary of Previous Research

Reports of eight test programs have been made in this country since 1958. In addition, several reports of German research have been made in recent years. Numerous test methods were used in each program. The scope of the tests was quite varied. The parameters studied included: (1) compression-deflection characteristics, (2) shear-deflections, (3) static creep, (4) dynamic creep, (5) stress concentrations, (6) temperature, (7) repetitive loadings, (8) hole effects, and (9) bearing surface conditions. Due to the nature of the specific studies, various techniques were employed by different researchers. These tech-

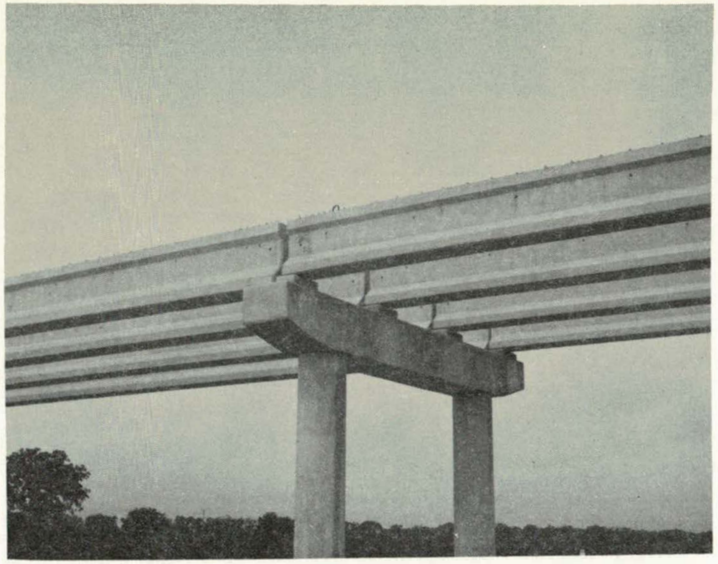


Figure 1.7

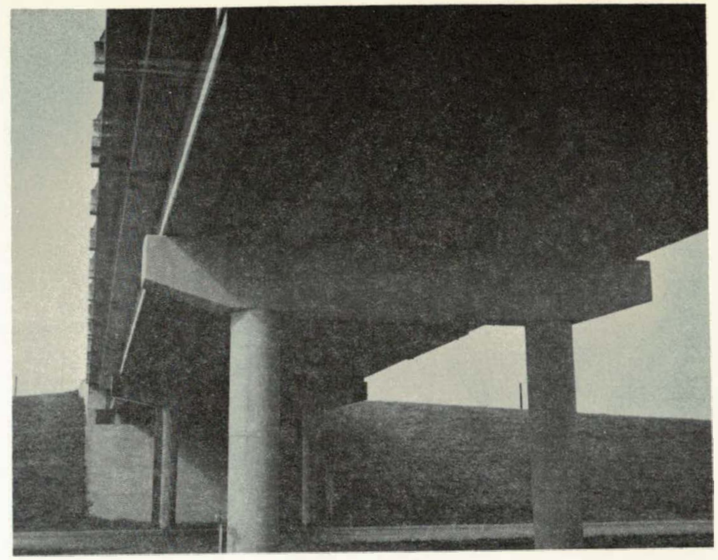


Figure 1.8

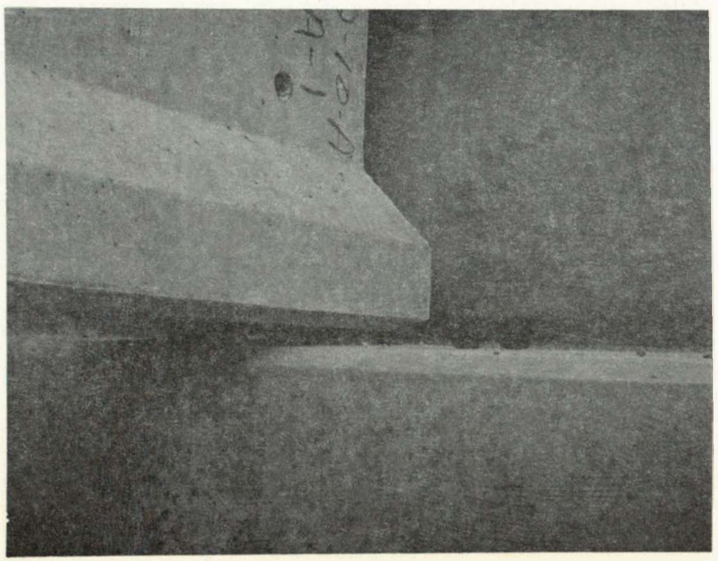


Figure 1.9

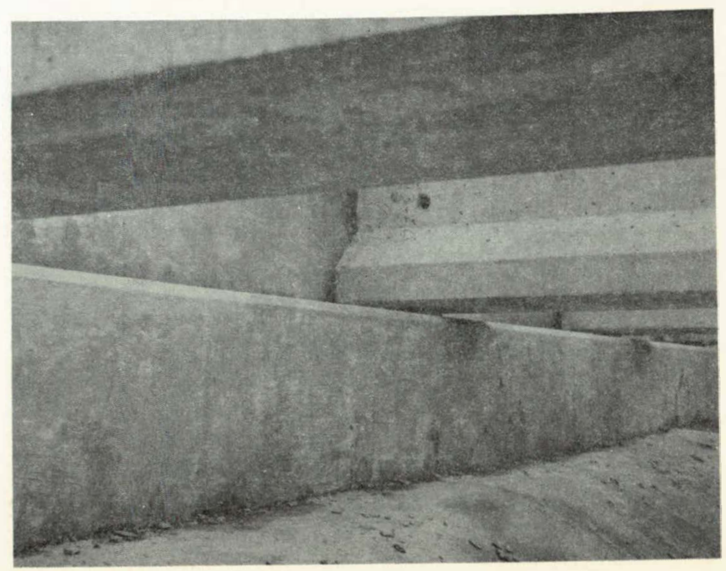


Figure 1.10

Neoprene bearing pads used with prestressed girders.

niques will be discussed in more detail (Section 1.8).

1.5 Objectives for this Study

The principal reason for this study is the lack of experimental data needed by designers to ascertain whether various elastomeric materials are suitable for use as bridge bearing pads. At present, neoprene has been the subject of most research, while very little information has been published about other elastomers. Several materials are now available which appear to have excellent mechanical and weathering properties. Therefore, the primary consideration for this study was a laboratory evaluation of the relative performances of different elastomers for use as bridge bearing pads. Finally, an important consideration of this study was to develop design criteria for bearing pads made from the materials studied.

1.6 Scope

The scope of this study was limited to the following:

1. All tests were conducted at room temperatures.

2. Butyl, chlorobutyl, EPT, hypalon, and neoprene were the materials under study. All pad samples had a nominal shore hardness of 60. Representative standard test results for these materials are included in Appendix D.

3. Compression-deflection characteristics were determined.

   (a) Solid, laminated, and bonded pads of each material were used (Figure 1.6).

   (b) All materials were tested between bearing surfaces of concrete-and-concrete (C-C), steel-and-steel (S-S), and concrete-and-steel (C-S).

(c) Shape factors ranging from one to six were investigated.

4. Static creep characteristics were determined during a period of three weeks and one week for solid pads and bonded pads respectively.

(a) Only pads with a shape factor (S.F.) of 1.5 were tested.

(b) C-S and S-S bearing surfaces were used for each pad.

5. Determinations were made due to the effects of repetitive reversed horizontal forces with a sustained constant vertical stress of 500 psi on 6 x 12 inch pads.

As mentioned above the materials for study were butyl, chlorobutyl, EPT, hypalon, and neoprene. Samples of butyl rubber were received gratis and were included in most of the tests. Since there was some variation between butyl and the four other materials in relation to type, number, and size of pads, general comments in this paper refer to the other four materials. Special comments about differences between butyl and the other four materials will be held to a minimum. Results of the tests on butyl will be presented where available.

1.7 Materials for Testing

The materials for testing included chlorobutyl, EPT, hypalon, and neoprene. Three types of pads (solid, bonded, and laminated) of each material were studied.

Although dimensions of elastomeric pads vary widely, the following procedure was used to determine representative test specimens. All solid pads were to be one inch thick, and the lengths were to be twice the width-where the width of the pad is generally placed parallel to the longitudinal axis of the member being supported. Figure 1.11 was plotted for one inch pads using Equation (1-3) which is obtained from Equation (1-1).

$$W = \frac{2\,L\,T\,(S.F.)}{(L-2\,T\,(S.F.))} \qquad (1\text{-}3)$$

Each material was labeled according to material, shape factor, and pad number and these designations are listed in Table 1.1.

Material	S.F.	Specimen Number	Nominal Size (in.)
Chlorobutyl - C	1	11 and 12	3x6x1
EPT - E	1.5	21 and 22	4.5x9x1
Hypalon - H	2	31,32,33, and 34	6x12x1
Neoprene - N	2.5	41 and 42	7.5x15x1
Butyl - B	3	51 and 52	9x18x1
	3.33	61 and 62	10x20x1
Laminated Only	5	L-2	6x12x2
	6	L-3	9x18x3

Table 1.1 Materials, shape factors, specimen number, and nominal size of pads tested in this study.

Actual pad measurements are included in Appendix B. Measurements of the length, width, and thickness were made of each pad with a steel rule graduated to 0.01 inche These measurements were obtained on both surfaces and the four faces and averaged to the nearest 0.01 inch. The hardness value was

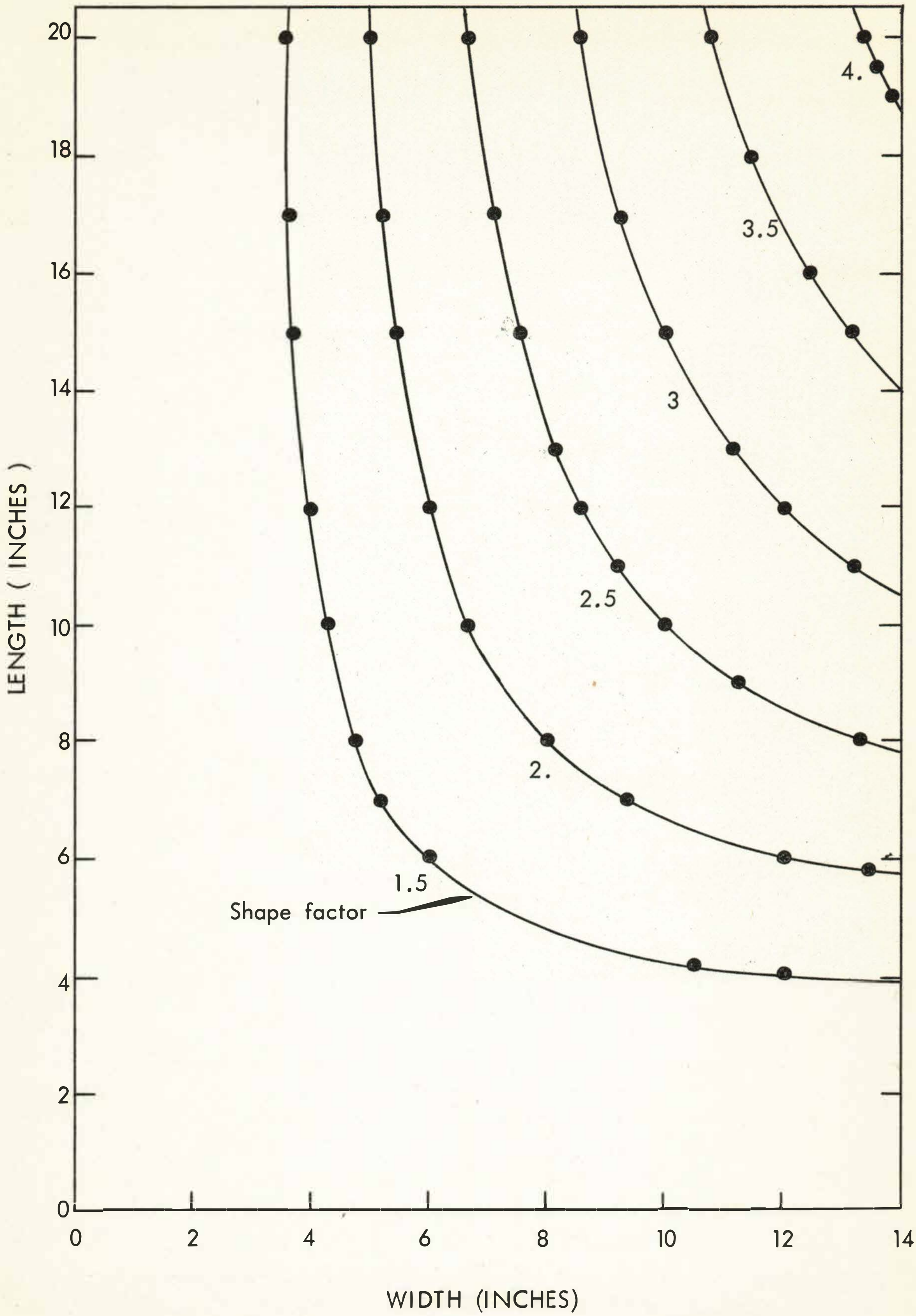


Figure 1.11 Length, width, and shape factor graph for one inch pads.

determined by means of a Shore A-2 durometer. A minimum of five readings was taken at different points on each surface to determine an average hardness value. The maximum instantaneous value was read to the nearest whole number. Hardness values on the same untested pad usually varied less than three units. The effects of loading generally reduced hardness values, and greater hardness variations occurred on opposite bearing surfaces.

The number of laminated pads was limited to eight due to their higher cost. Pads with nominal dimensions of 6 x 12 x 2 in. and 9 x 18 x 3 in. with three (Figure 1.12) and four laminations respectively were selected and ordered. The pads received were incorrectly fabricated with three (Figure 1.13) and four steel plates at even spaces instead of three and four laminations as ordered. Although the outside layers were somewhat thicker than the thickness generally used, the pads were considered as fully laminated in this study.e It will be shown that the discrepancy due to this assumption appears to be negligible.

After compression-deflection characteristics had been determined for all solid pads, approximately one-half of these pads were used to make bonded pads. An epoxy adhesive was applied to each roughened surface of two gage 11 steel plates which were bonded to each bearing surface of the solid pad. This unit was held under load for a curing time of two days. Although the bonded pads were assembled in the laboratory, these pads are quite similar in principle to the laminated pads molded by rubber fabricators. This bonding restrains the lateral movement of the bearing surface of the pad.

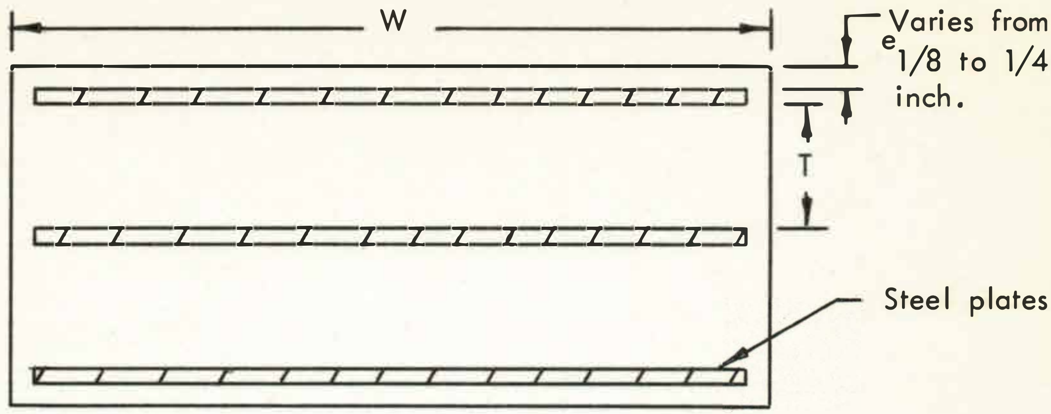


Figure 1.12 Typical laminated pad normally used in practice.

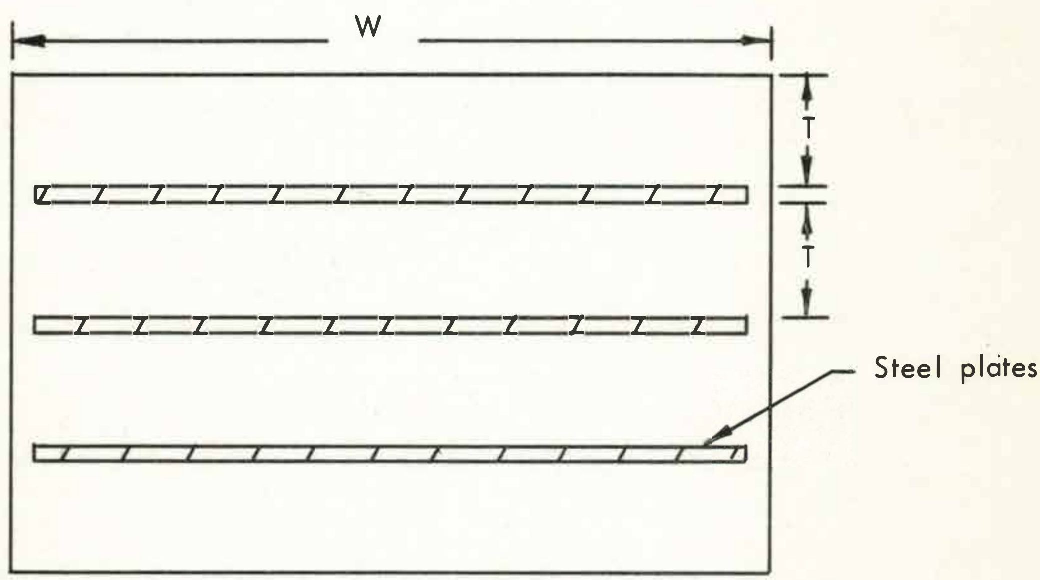


Figure 1.13 Laminated test pad used for this study.

1.8 Previous Research

A great number of tests of elastomers used for many engineering purposes has provided much information about the general engineering properties and characteristics of numerous elastomeric materials. However, published test results concerning problems peculiar to elastomeric bridge bearing pads are quite limited. This stems from the fact that interest has only recently developed toward this particular use of elastomers.

Pare and Keiner (16,21), early investigators concerned with the applications of elastomers for bridge bearing pads, studied the responses of numerous neoprene samples. An extensive number of tests were conducted in a study that included (1) vertical deflection under compressive loads, (2) horizontal and vertical deflection under combined compressive and shear loads, (3) creep effects due to static and dynamic loads, and (4) shape and hardness effects. Vertical deflections were found to increase inversely with hardness values, time under sustained loads, and dynamic shear loads. It is of interest to note that the authors discovered that shearing forces produced edge disturbances and a tendency for the pad to "roll" if the width of pad was less than four times the thickness.

Ozell and Diniz (20) have reported tests on neoprene pads conducted at the University of Florida of repeated shear loads with simultaneous compressive loads. Load-deformation characteristics of twenty-one pads were determined before and after repetitive shear loadings were conducted. Fatigue characteristics were determined from the results of numerous non-reversed repetitive shear cycles ranging from 35,000 to 1,090,000 at the rate of 120 cpme

The side cracks in nine test pads illustrated the damaging effects of shear forces on neoprene bearing pads, however, the pads were not unserviceable.

Fairbanks (8), in research for his Master's thesis at Texas A & M University, studied the behavior of neoprene bearing pads which supported steel beamse This investigation was concerned with the stresses induced in the beam and the neoprene pad due to the combined effects of a vertical reaction, beam rotation, and horizontal movements of the beam. Fairbanks reported that permanent deformations occurred in the beam flanges without bearing stiffeners, and higher beam stresses were developed when supported on thicker pads. Increase in the effects of beam rotation at the support produced non-uniform bearing pressures, and when the pad was as small as 1/2 and 1/4 inch in thickness the back edge of the flange did not remain in contact with the pad. Therefore, the author suggested the use of a minimum thickness of 3/4 inch pads for bearings, but he did not specify any maximum thickness since this is usually controlled by the shape factor.

An unpublished report (9) by the General Tire & Rubber Company deals specifically with laminated rubber bridge bearing pads. Compression-deflection characteristics, shear deflections, compressive creep, shear stress relaxation, and shear fatigue investigations were conducted at normal and low temperatures. A somewhat unique study was made regarding fatigue effects on samples containing holes that are positioned on pins for correct alignment on abutments. Several side cracks in test pads were noted, but due to the limited number of tests, the investigator did not conclude the reasons for these cracks.

Clark and Moultrop (5) reported the effects of simulated aging and load-deformation at low temperatures. Their investigation essentially followed the procedure of the work done by Pare and Keiner, but was extended to include butyl and chlorobutyl in addition to neoprene. The authors pointed out that although "all three bearing materials displayed the same dynamic and static creep properties", butyl and chlorobutyl were significantly more flexible than neoprene at low temperatures.

Enjay Laboratories (7) conducted a limited study of shear forces and deflections due to the effects of ambient temperature ranging from 78°F to -50°F. The butyl and neoprene samples exhibited a considerable increase in shear stiffness with decreasing temperatures. However, butyl pads stiffened considerably less than neoprene pads.

Nachtrab and Davidson (18) report investigations made at the Pennsylvania Department of Highways of load-deflection responses of test pads subjected to simultaneous compressive and shear loads. Testing rate, degree of strain, and previous deformation history of the sample were found to be significant parameters. The authors showed that the current straight line definition of shear modulus for elastomeric materials is not applicable.

Suter and Collins (24) have conducted one of the most extensive series of tests to date. This study was concerned with the effects of (1) load-deformation, (2) dynamic shear and vertical compression, (3) dynamic creep, and (4) temperatures. Test samples were neoprene, butyl and urethane. The most significant conclusion of this investigation was the absence of detrimental effects, fatigue, or any physical changes that would seriously affect the serviceability of these pads under actual service conditions.

CHAPTER II

COMPRESSION-DEFLECTION TESTS

2.1 General

Compression-deflection characteristics were determined by applying loads which were uniformly distributed over the bearing surfaces. Significant parameters of this study which influence the behavior of elastomeric pads are the composition of the material, shape factor, type of bearing surface, and level of compressive stress. The influences of these parameters are compared in Chapter V.

2.2 Test Equipment

The compressive loading force was applied with a 200 kip universal testing machine (Figure 2.1). At the outset of the research program the machine was calibrated by a factory representative, and the calibration was checked periodically during the test program with an eight SR-4 strain gage self compensating (temperature and bending) load cell and a hand operated hydraulic jack. Consequently, a three way static check was maintained.

The bearing blocks (Figure 2.2) were designed to utilize the platens of the testing machine. These bearing blocks were alternated using steel or concrete depending on the surface condition being studied. In those cases

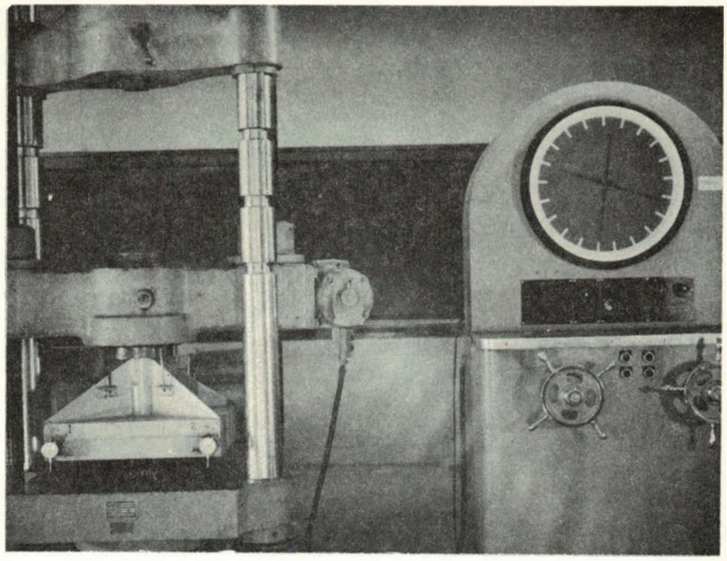


Figure 2.1 200 kip universal testing machine used for compression-deflection tests.

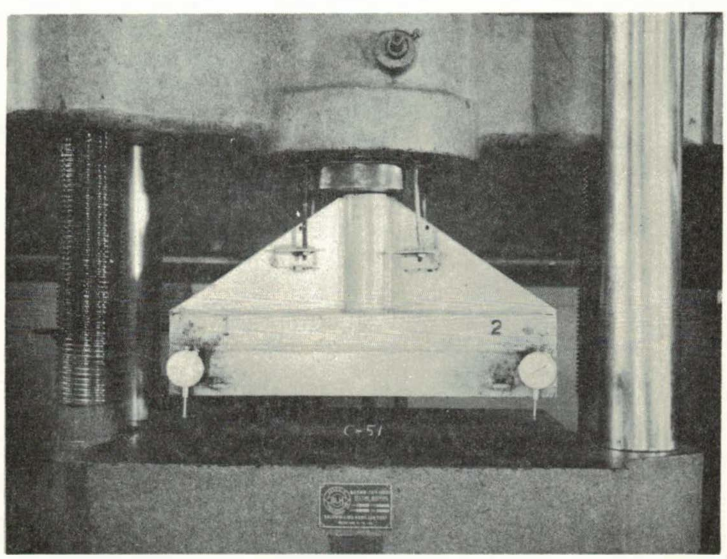


Figure 2.2 Concrete bearing block connected testing machine. Test pad and dial gages in typical position.

where the lower surfaces were steel, the lower platen of the test machine was used. The connection joining the upper block and testing machine was designed for easy installation, adjustment, and centering.

Deflections due to compressive forces were measured to the nearest 0.001 inch with four dial gages (Figure 2.2). They were bolted to brackets on the upper bearing blocks and positioned two each on opposite sides near the corners. The deflection range of these gages is 0.001 to 1.000 inch. The brackets were positioned in elevation to measure deflection of one inch thick pads. Spacer blocks of one and two inches were supplemented to measure deflections of two and three inch pads, respectively.

2.3 Test Procedure

Before actual testing was begun, calculations were made to determine loads which correspond to stresses ranging from 100 to 1000 psi in increments of 100 psi. Nominal dimensions of each size pad were used in these calculations. These load values were marked on the glass face of the load indicator of the testing machine with a grease pencil to insure that the correct load was read during each test.

The test pad was centrically positioned on the lower bearing surface. The upper bearing was lowered onto the pad and an initial stress of 10 psi was applied. This initial 10 psi was disregarded and not included in the net stress. All four deflection gages and the load indicator were then adjusted to a zero reading. A near constant rate of stressing was selected and adjusted such that each pad was loaded from zero to 1000 psi in approximately two minutes. As each 100 psi increment of load was reached, all deflection gages were read simultaneously. An average of the four deflection values was taken to be the deflection for each stress level. The maximum stress level of 1000 psi was held for times ranging from one to ten minutes. The pad was then unloaded with loads and deflections being recorded in the same manner as for the loading procedure. Measurements of each pad were taken after the specimen had been unloaded for approximately fifteen minutes.

A slight variation of this test procedure was used for pads tested between C-C and S-S. An initial stress of 20 psi was applied on the pads and only the deflection gages were zeroed. These tests were conducted during the earlier stages of the program.

2.4 Presentation and Discussion of Test Results

An index of the parameters studied in the static tests is shown in Figure 2.3. The physical dimensions and hardness values of each pad before and after testing are listed in Appendix B.

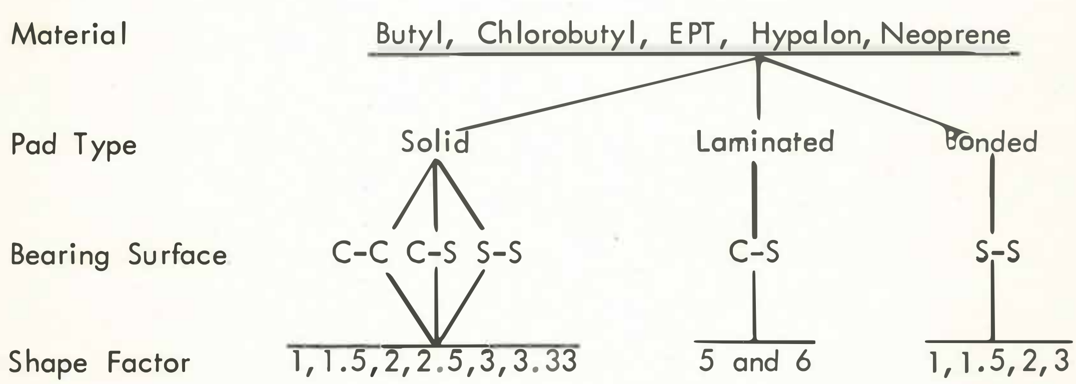


Figure 2.3 Compression-deflection test parameters

Compression stress values were based on the nominal area of the pad,

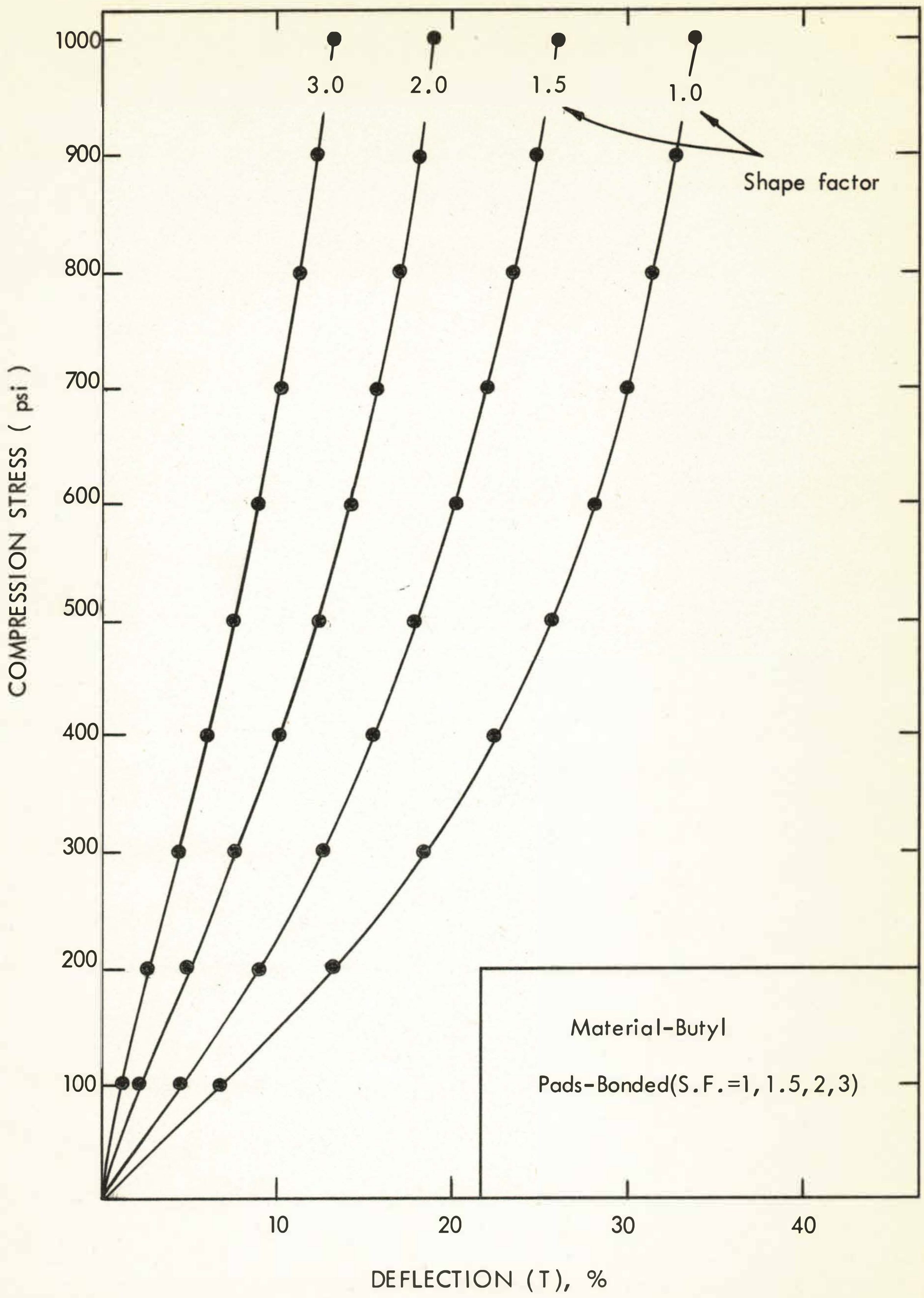


Figure 2.4 Compression stress versus deflection (T), % for bonded butyl pads.

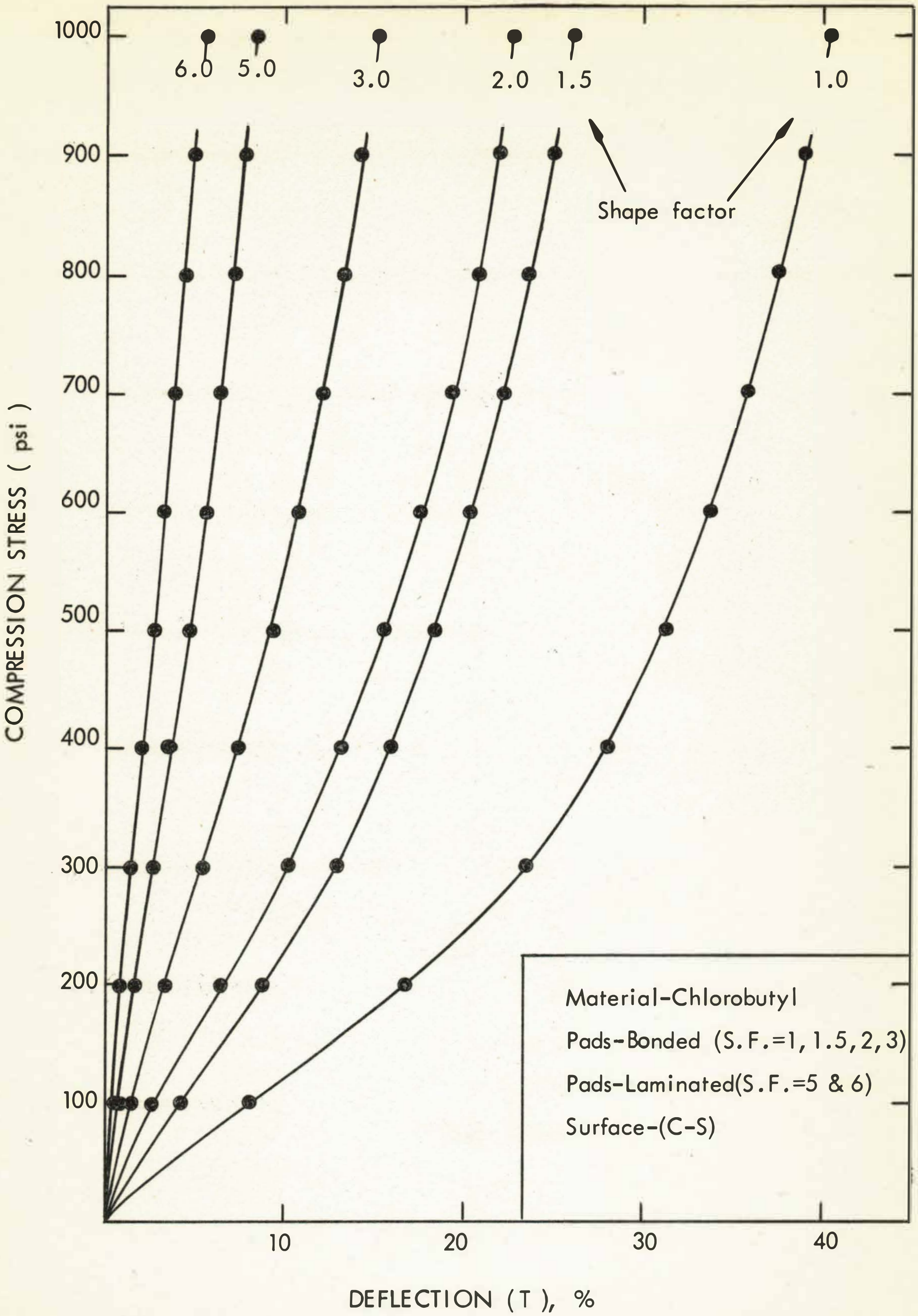


Figure 2.5 Compression stress versus deflection (T), % chlorobutyl bonded and laminated pads.

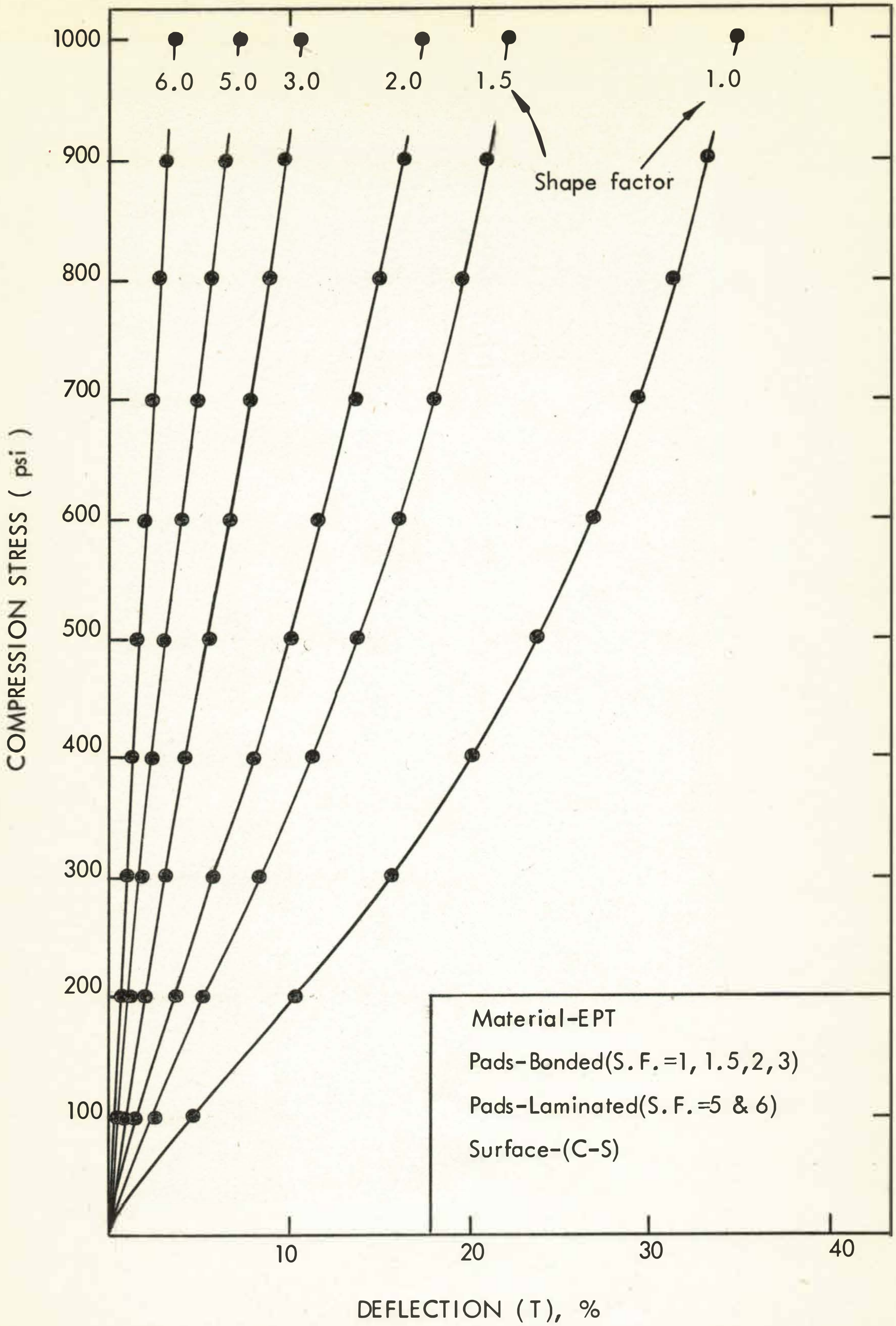


Figure 2.6 Compression stress versus deflection (T), % for EPT bonded and laminated pads.

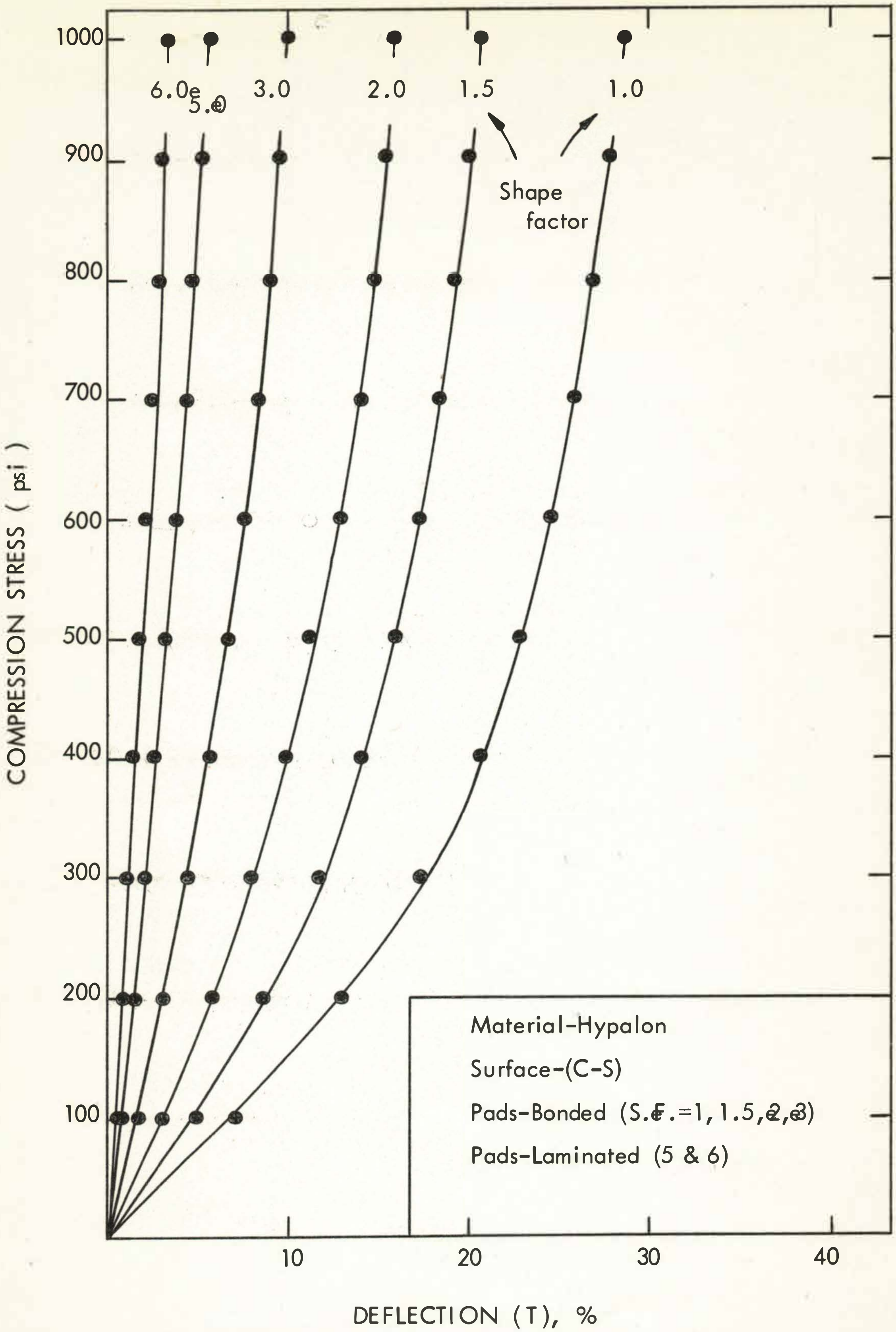


Figure 2.7 Compression stress versus deflection (T), % for hypalon bonded and laminated pads.

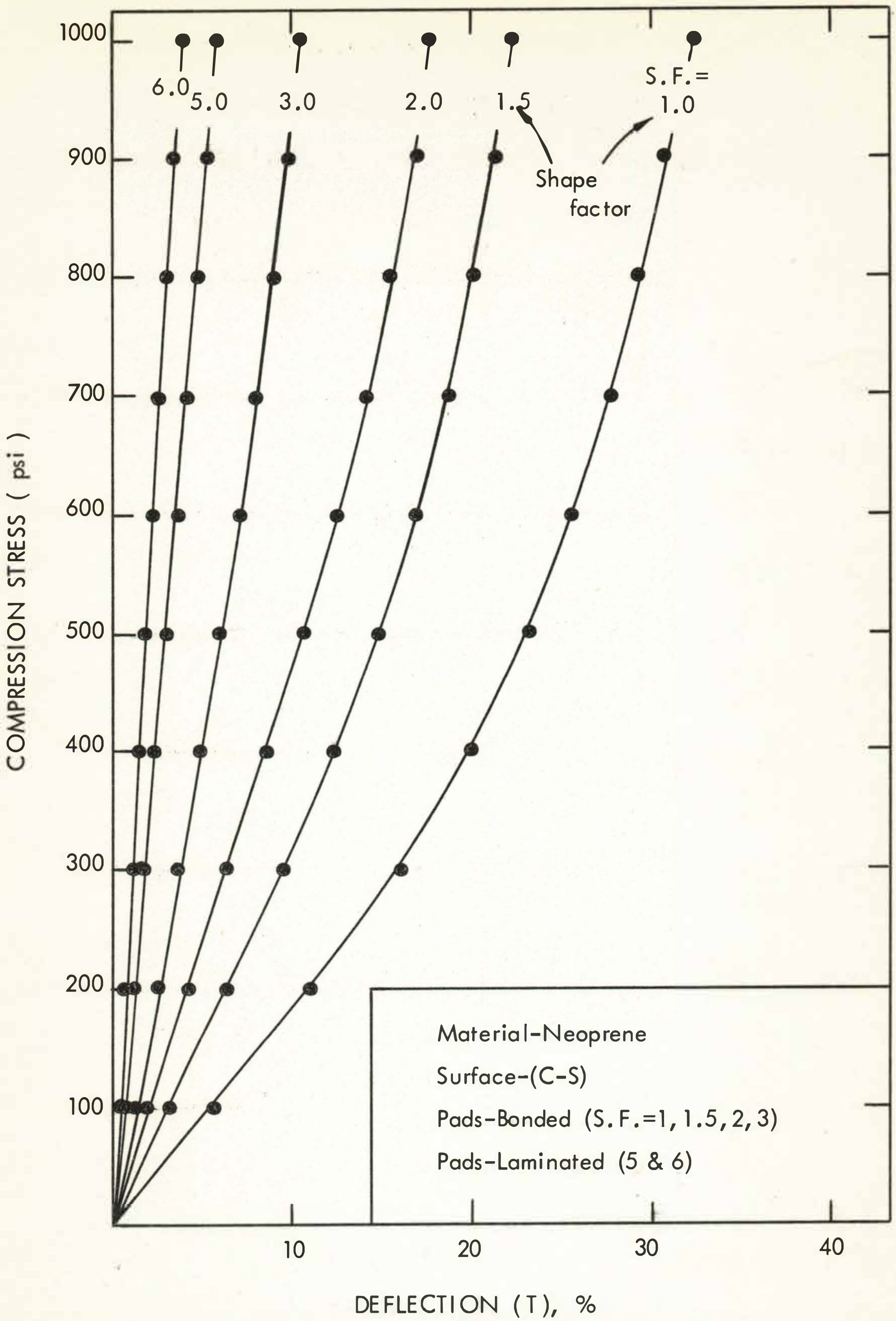


Figure 2.8 Compression stress versus deflection (T), % for neoprene bonded and laminated pads.

and deflection (T), % was calculated using the nominal pad thickness.

The curves produced from compression-deflection tests for bonded and laminated pads (Figures 2.4 through 2.8) were of the general form that was anticipated. However, the observations of tests conducted with S-S, C-C, and C-S quite often yielded dissimilar results (Figures 2.9 through 2.22).

Results were largely influenced by the rate of load application, and large variations of data were often recorded for pads of the same material, S.F., hardness, and bearing surfaces. The curves of Figures 2.9 through 2.22 were not highly reproducible, but are intended only to show the general response of bearing pads between the surfaces of C-S C-C, and S-S.

Figures 2.23 and 2.24 show the typical response of a solid pad before loading and in a loaded condition. The lateral expansion of the pad can be observed due to this vertical load. In Figure 2.25 the typical response of a laminated pad in the stressed condition is shown. Laminated pads do not noticeably expand laterally but bulge slightly between laminations. These pad edges were observed to "roll" away from the bearing surfaces with increasing loads.

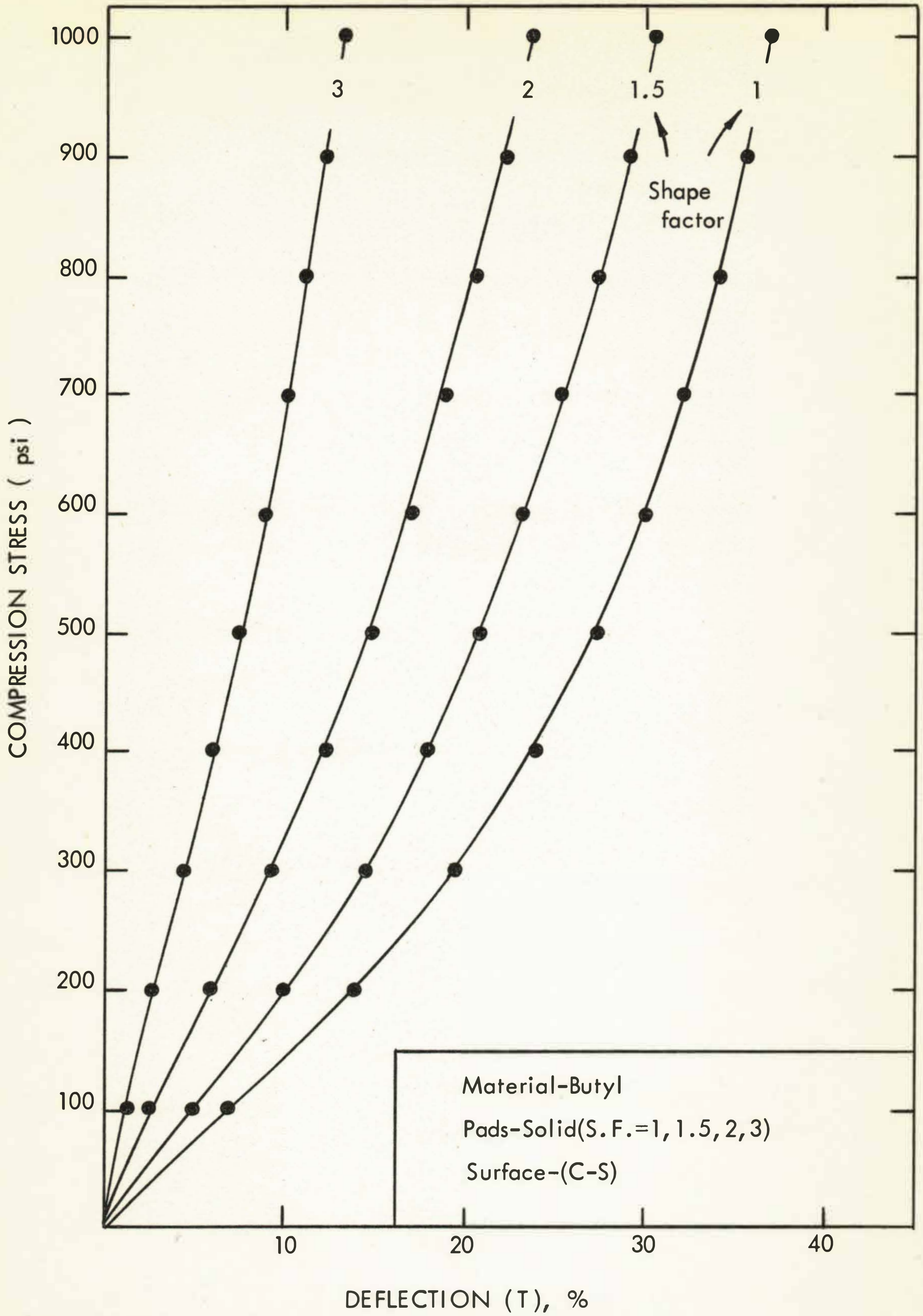


Figure 2.9 Compression stress versus deflection (T), % for butyl solid pads.

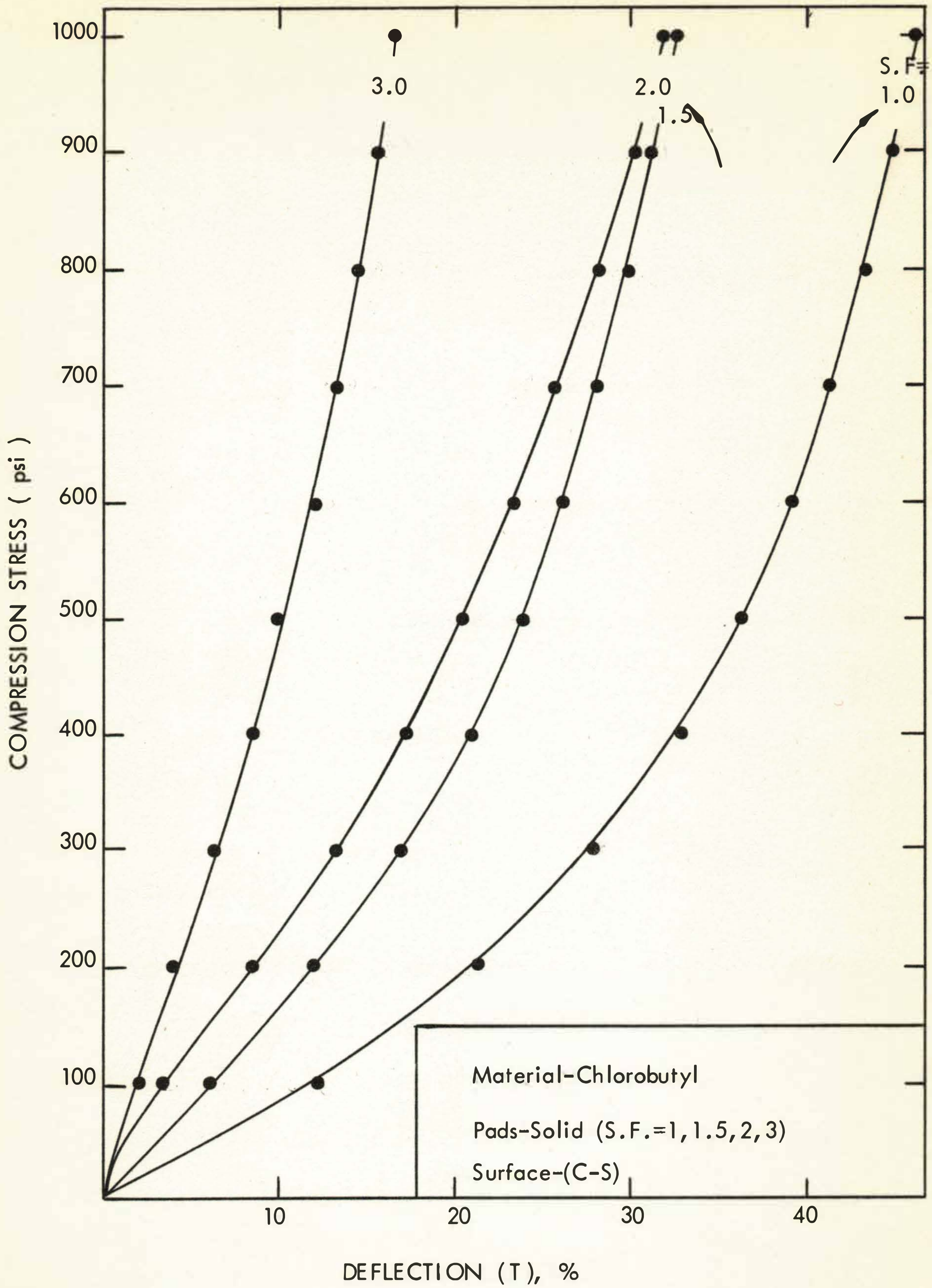


Figure 2.10 Compression stress versus deflection (T), % for chlorobutyl solid pads.

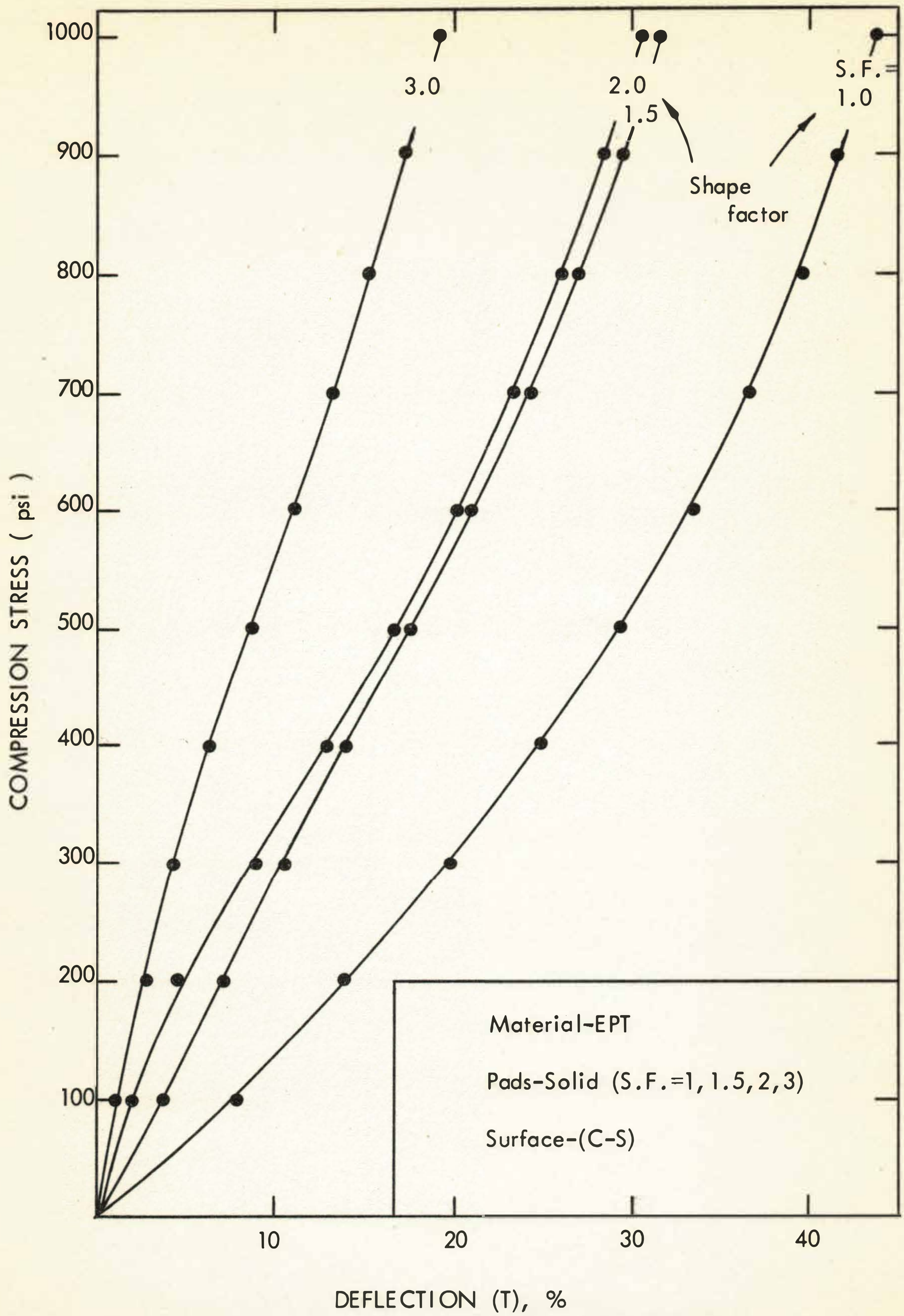


Figure 2.11 Compression stress versus deflection (T), % for EPT solid pads.

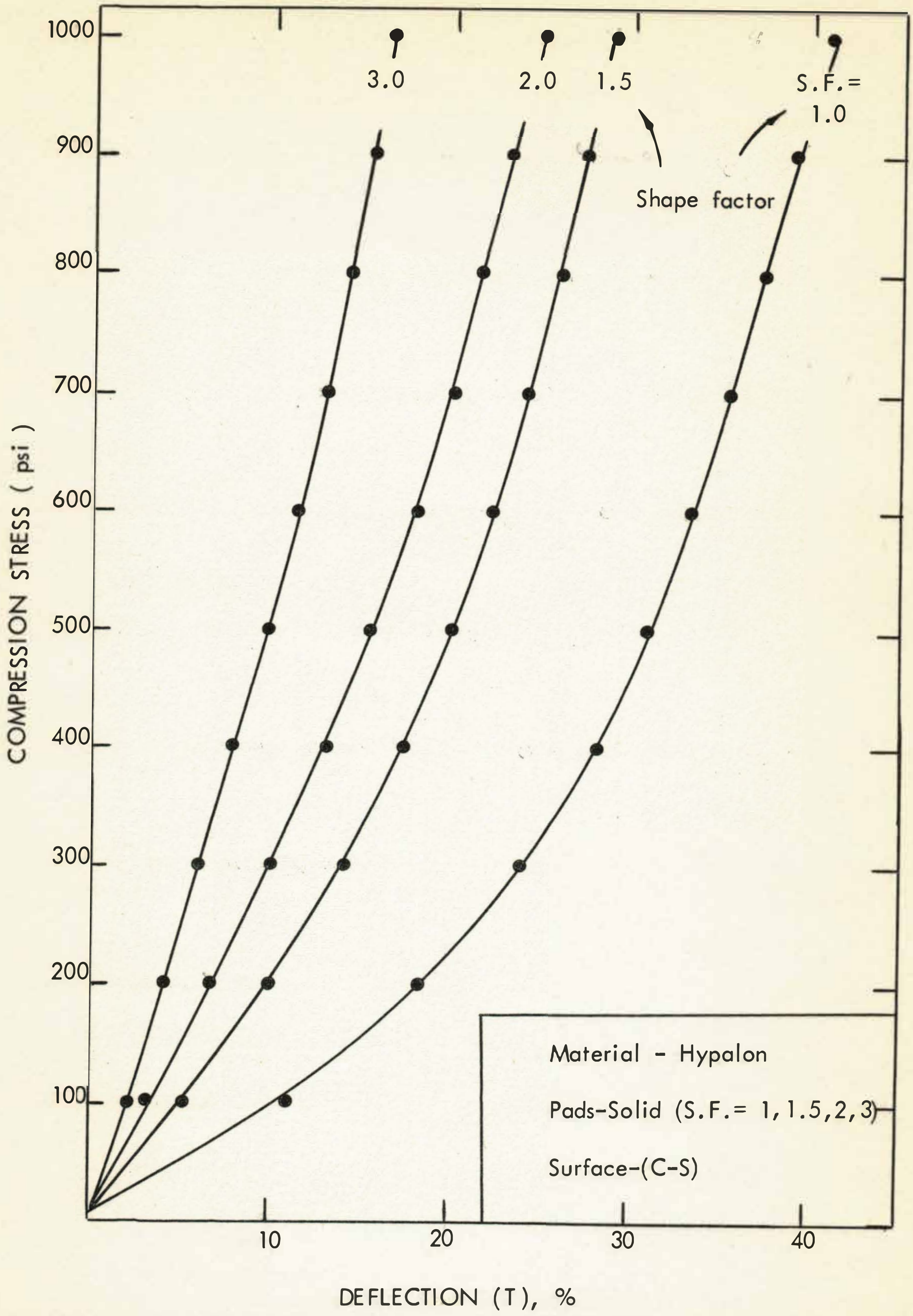


Figure 2.12 Compression stress versus deflection (T), % for hypalon solid pads.

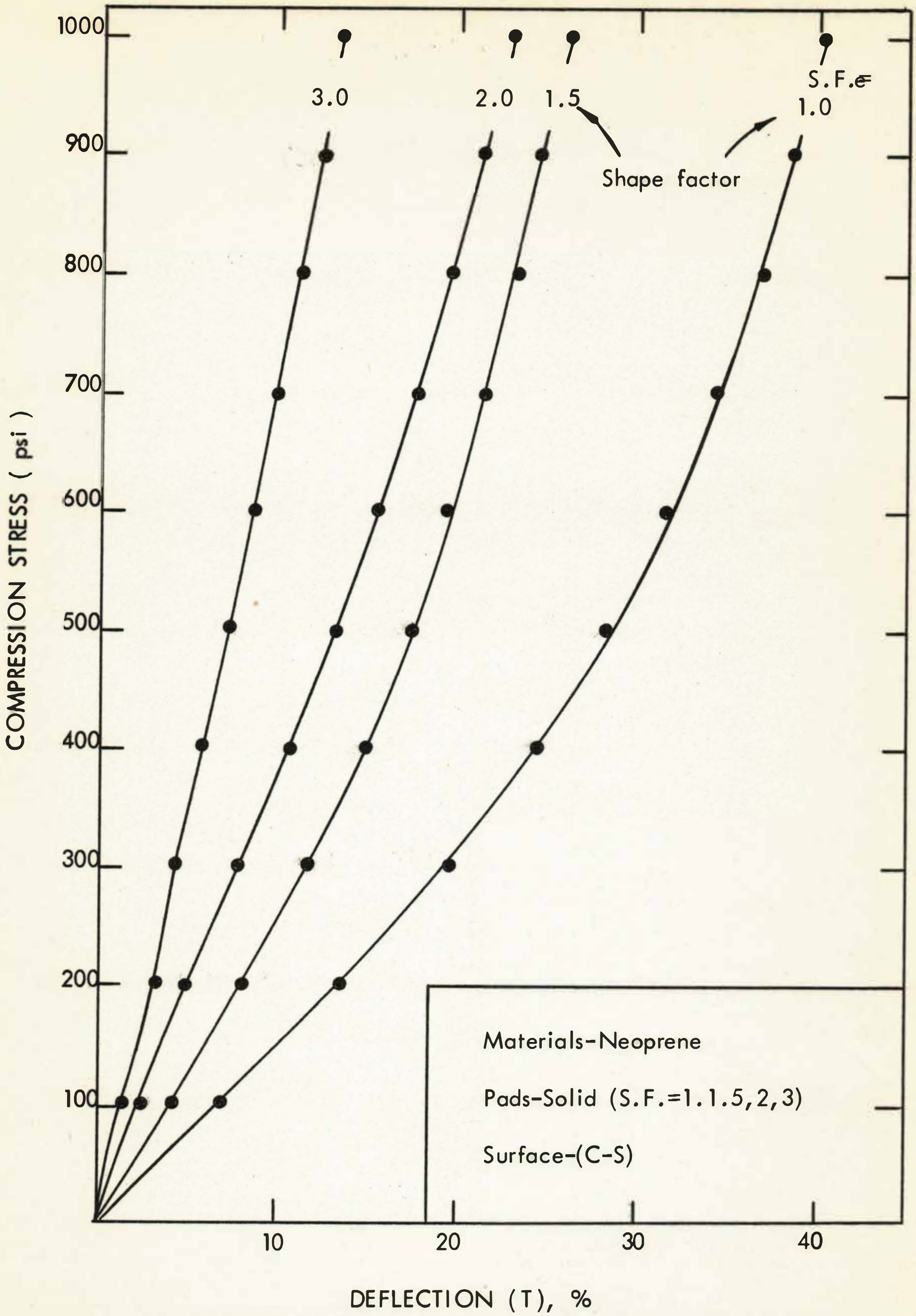


Figure 2.13 Compression stress versus deflection (T), % for Neoprene solid padse

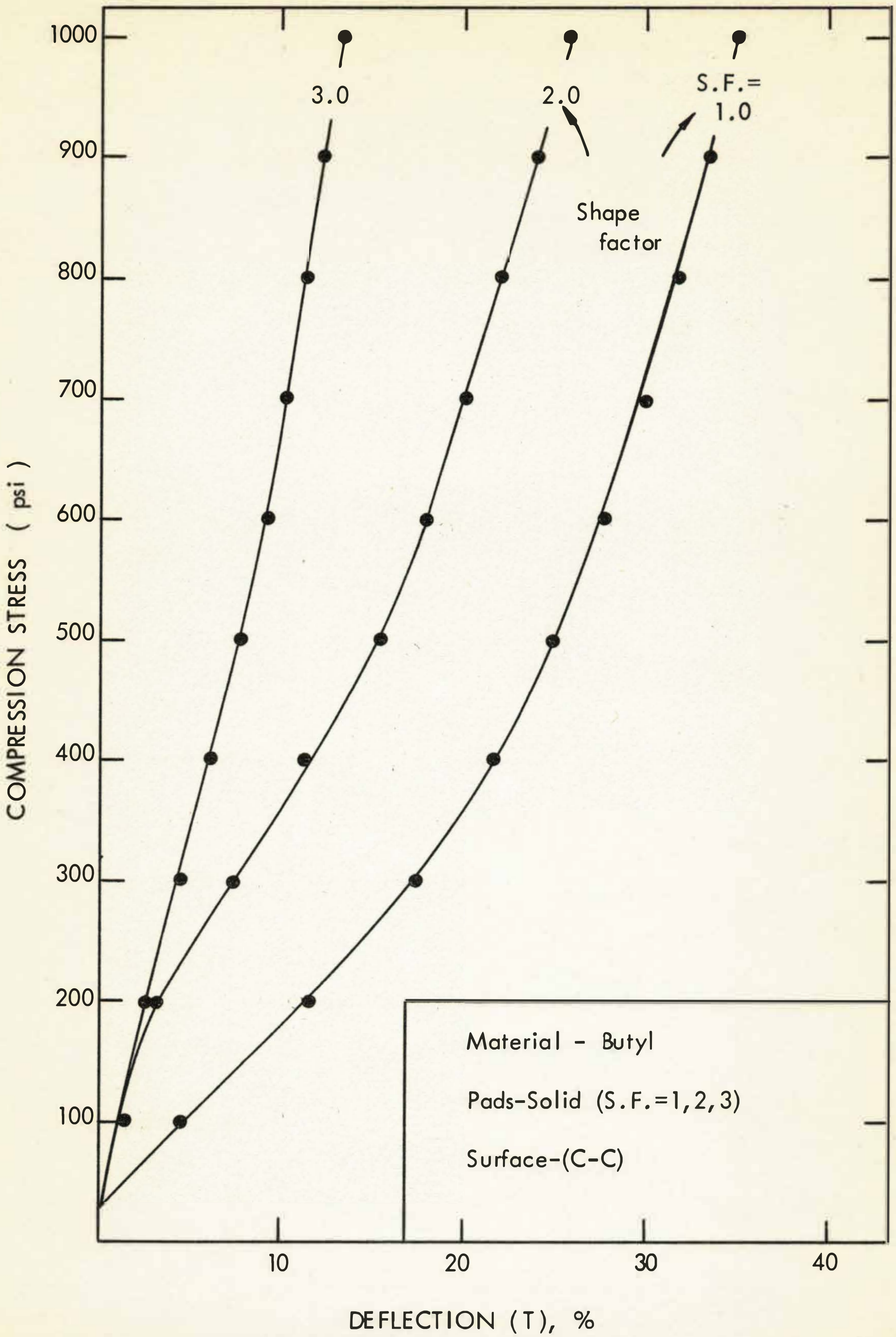


Figure 2.14 Compression stress versus deflection (T), % for butyl solid pads.

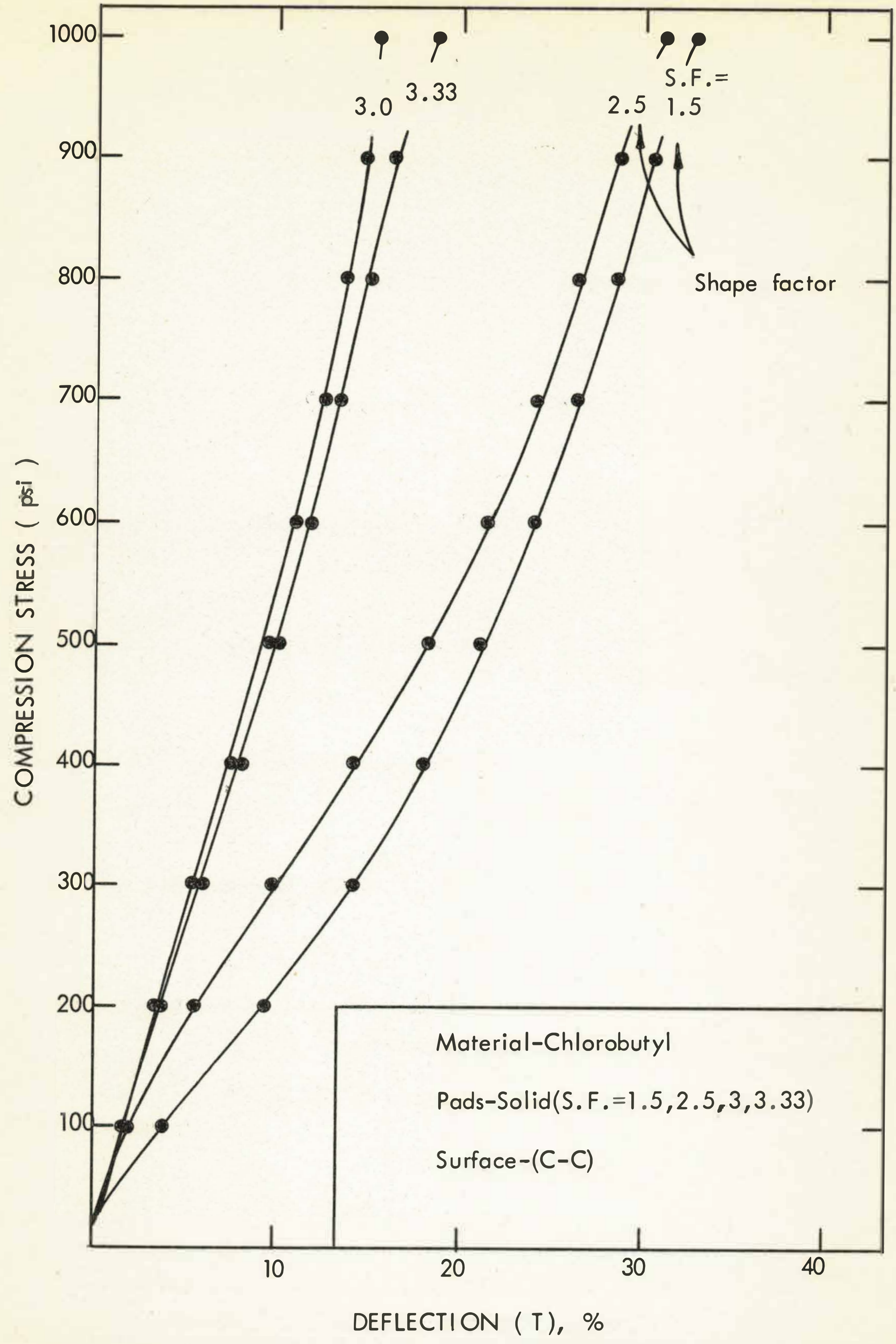


Figure 2.15 Compression stress versus deflection (T), % for chlorobutyl solid pads.

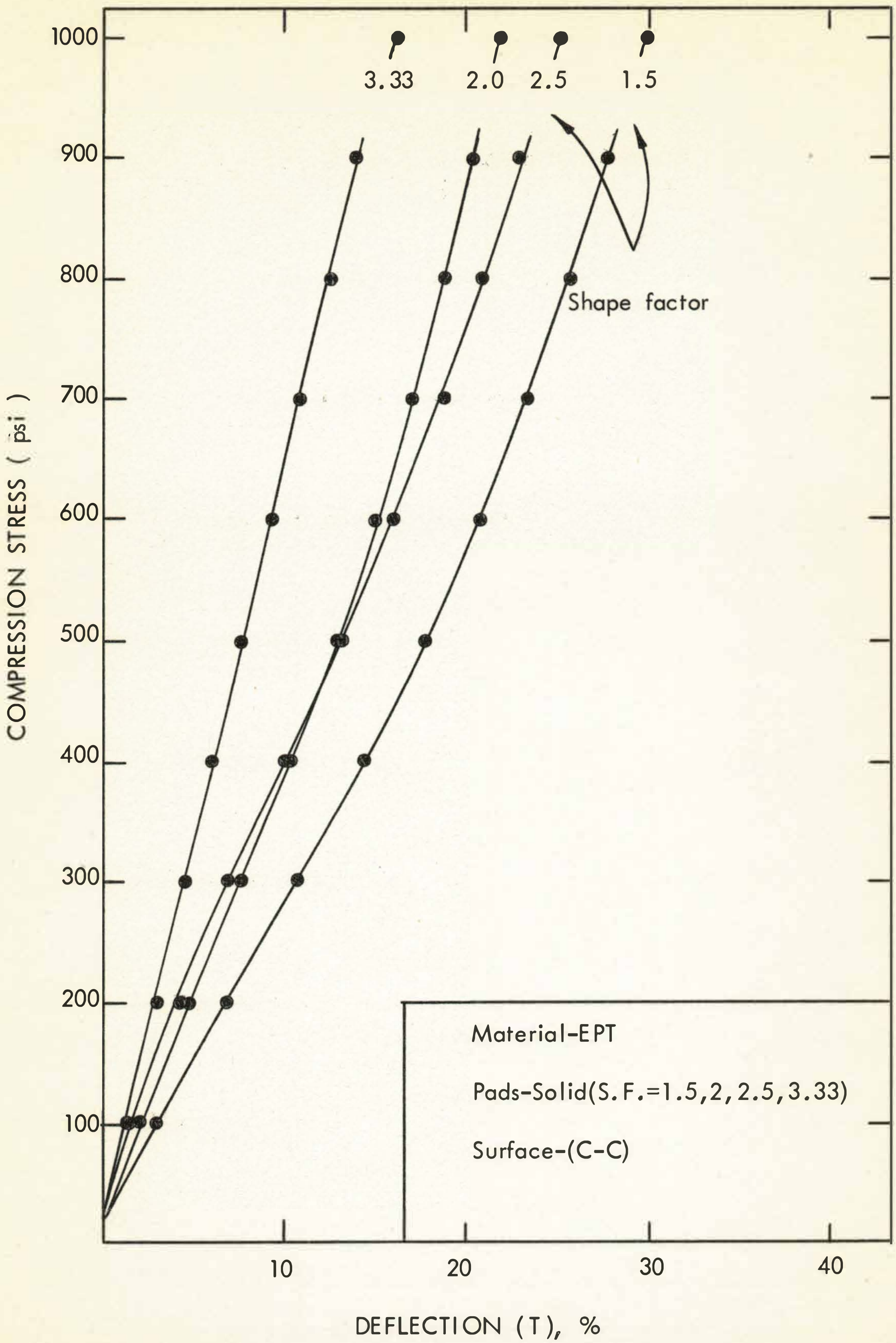


Figure 2.16 Compression stress versus deflection (T), % for EPT solid pads.

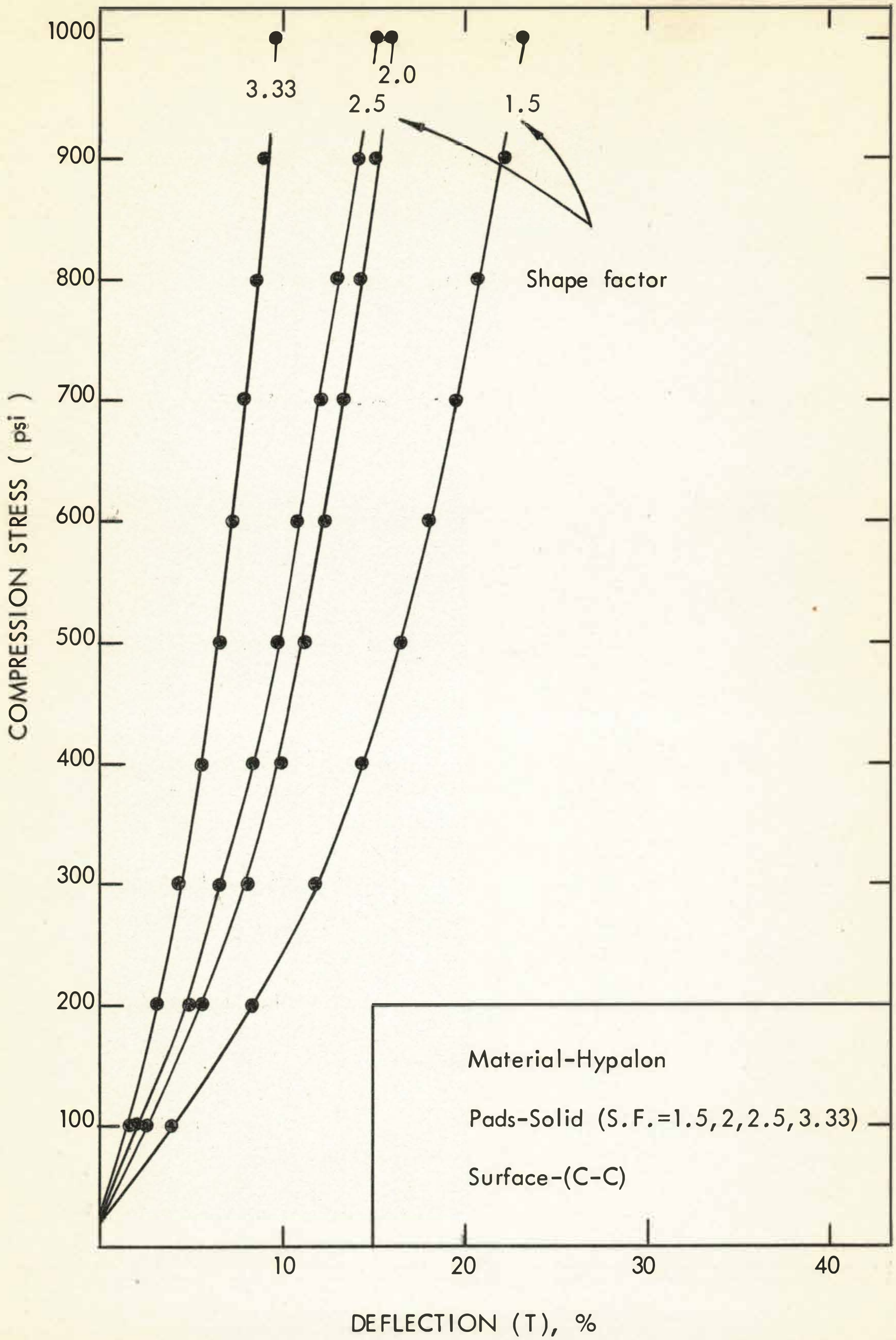


Figure 2.17 Compression stress versus deflection (T), % for hypalon solid pads.

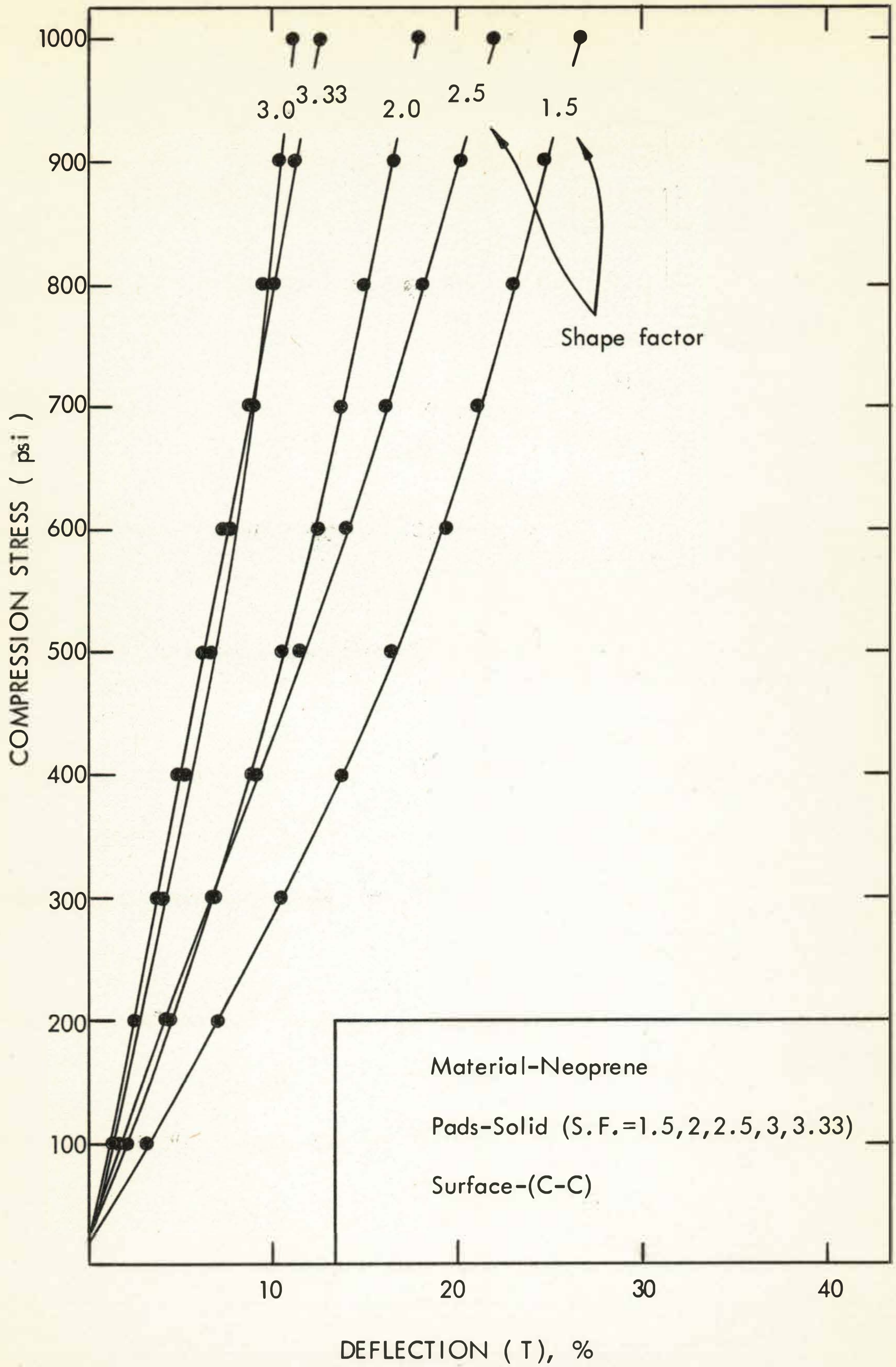


Figure 2.18 Compression stress versus deflection (T), % for Neoprene solid pads.

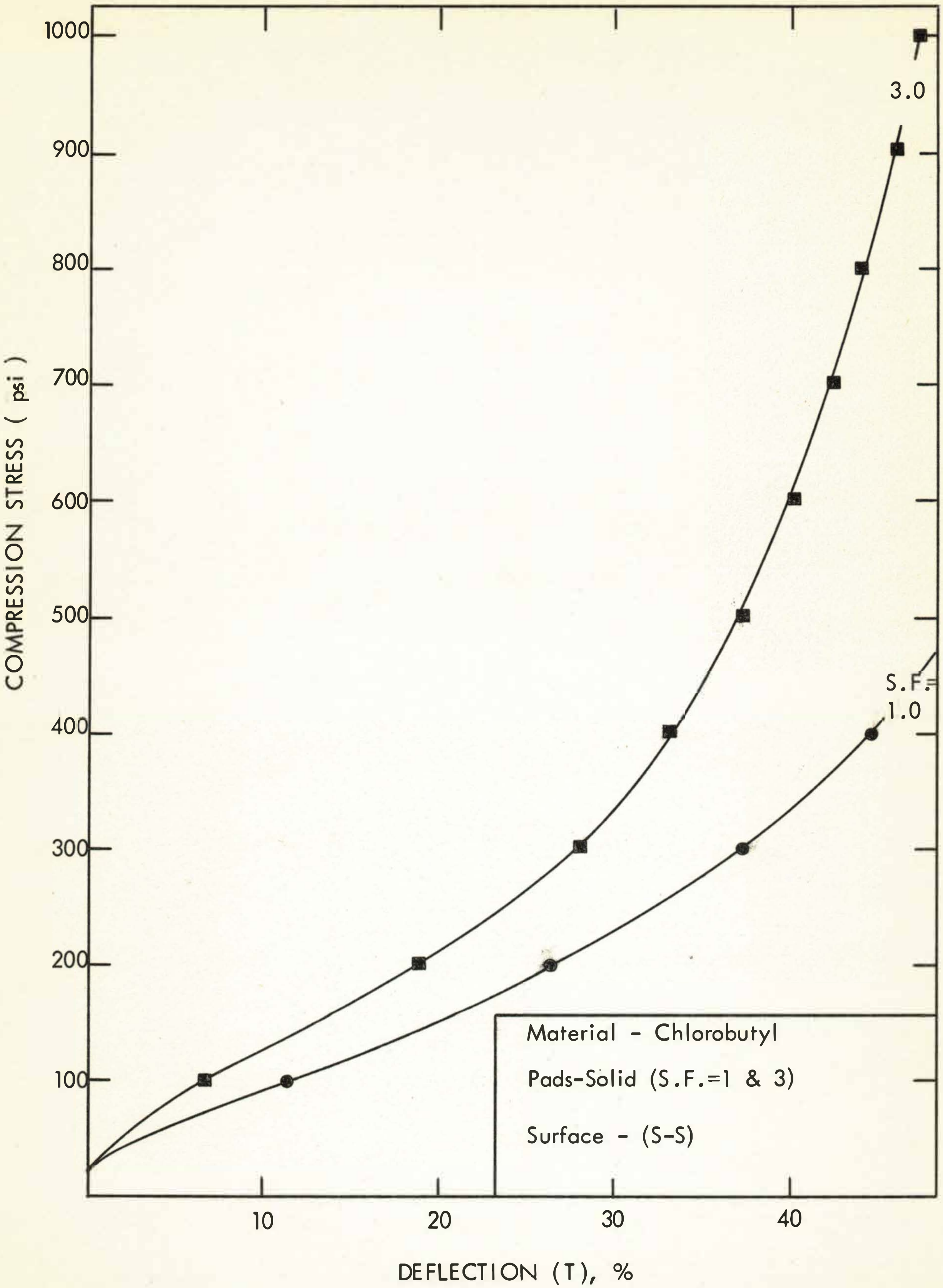


Figure 2.19 Compression stress versus deflection (T), % for chlorobutyl solid pads.

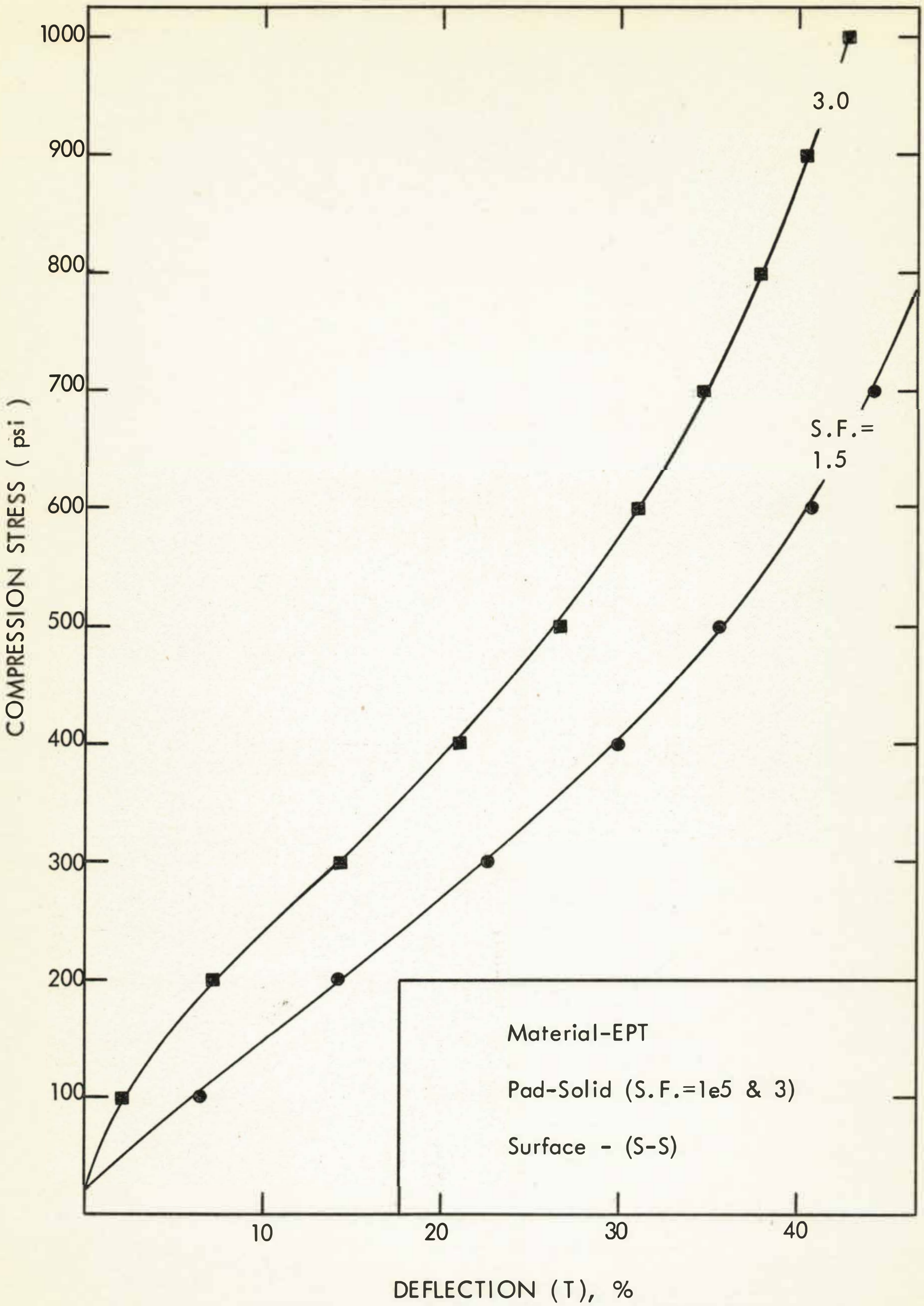


Figure 2.20 Compression stress versus deflection (T), % for EPT solid pads.

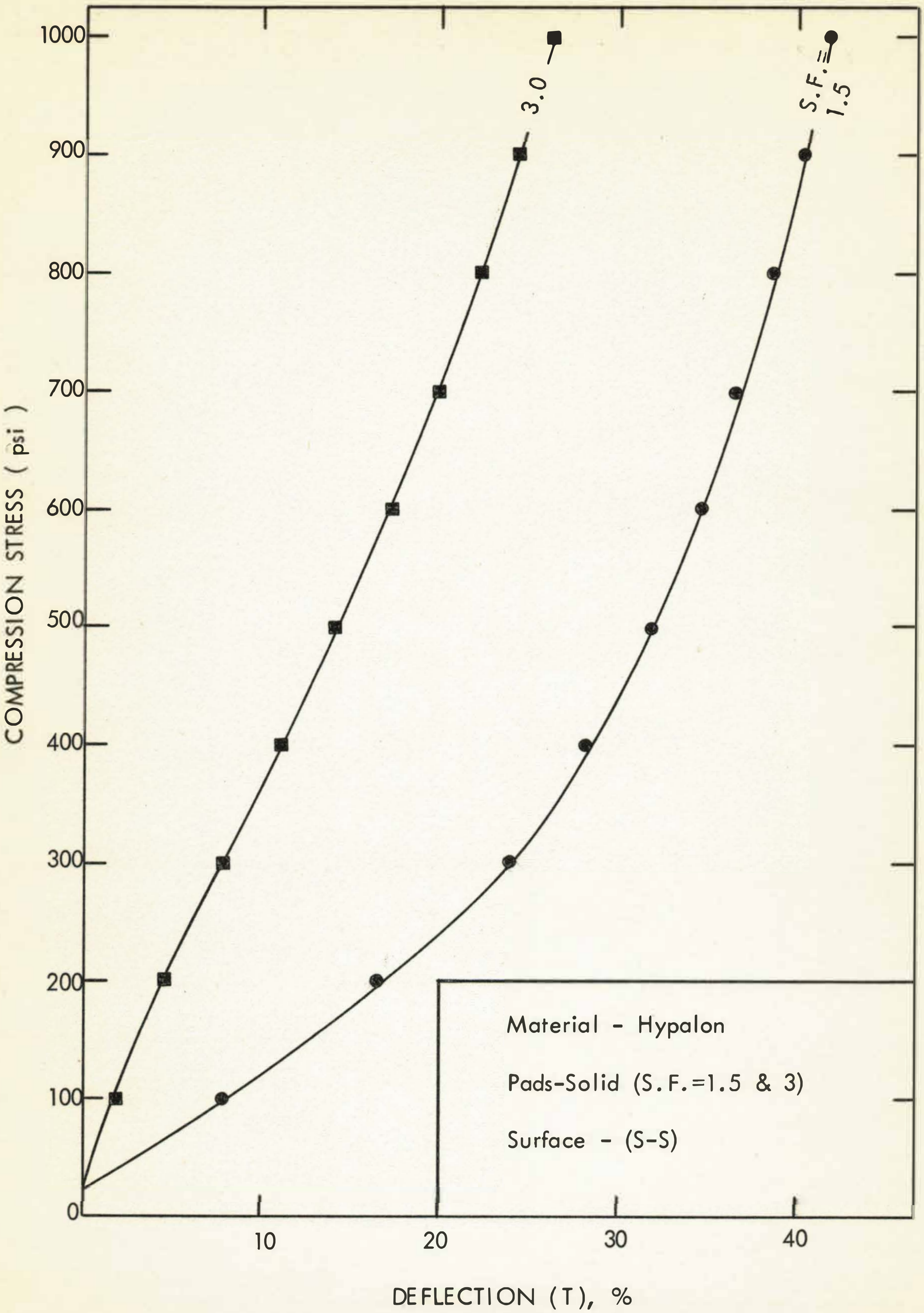


Figure 2.21 Compression stress versus deflection (T), % for hypalon solid pads

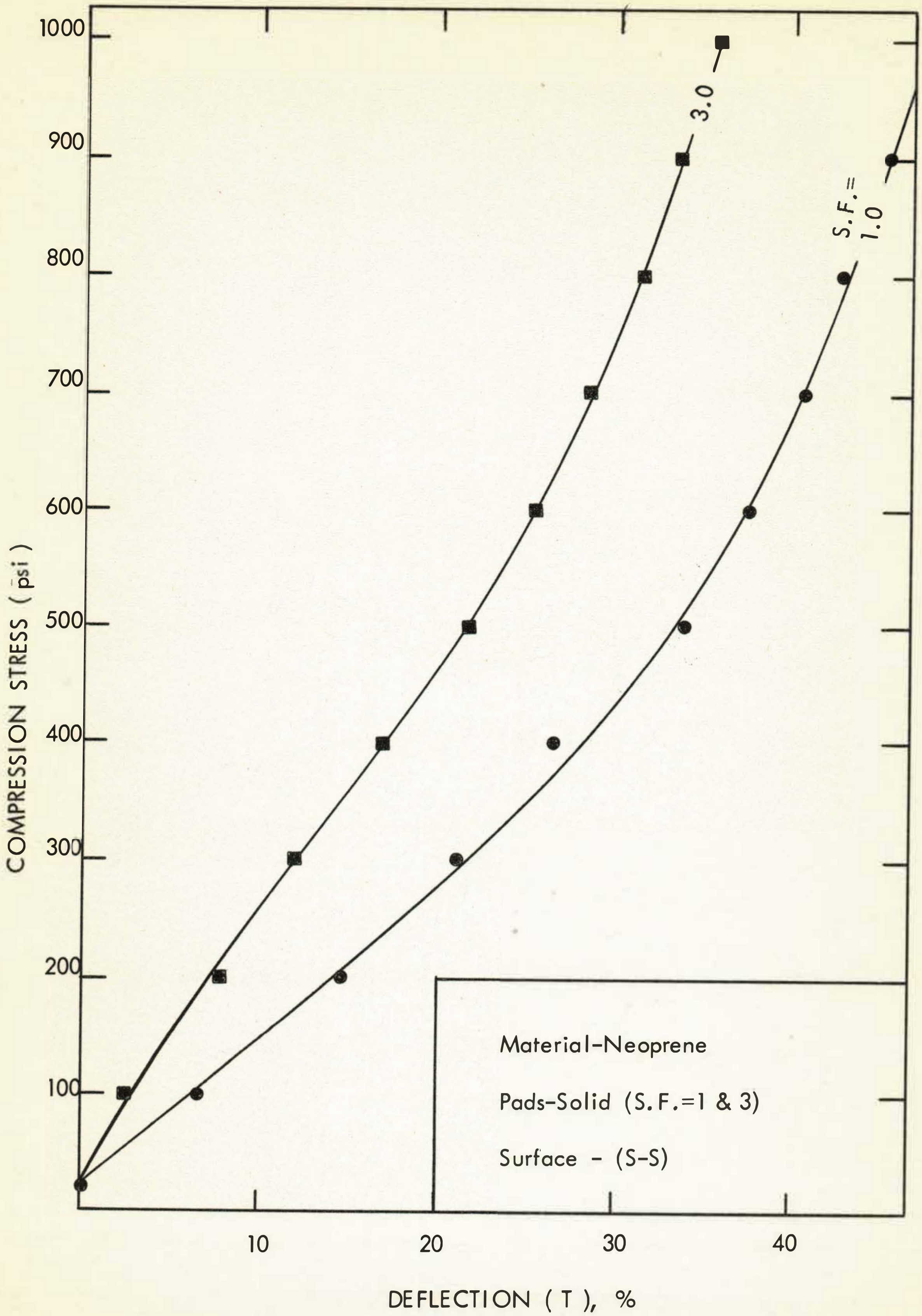
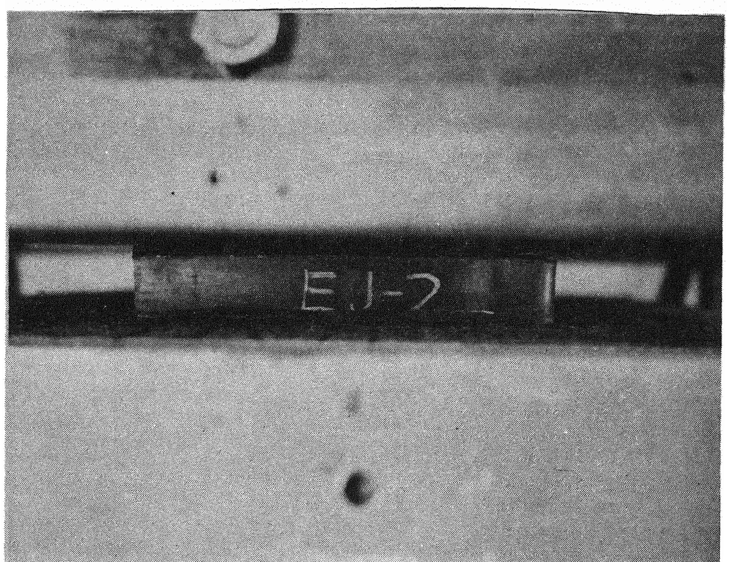


Figure 2.22 Compression stress versus deflection (T), % for neoprene solid pads.



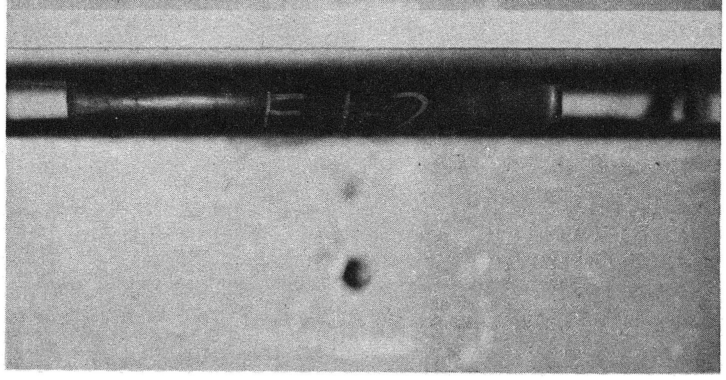


Figure 2.23 Butyl pad (6 x 12 inch) uncompressed (top).

Figure 2.24 Butyl pad under 1000 psi compression stress.

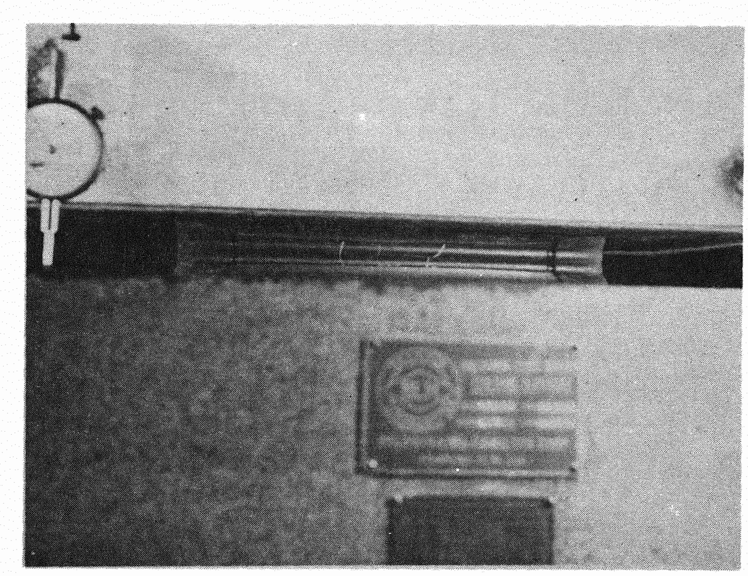


Figure 2.25 Laminated chlorobutyl pad under 1000 psi compression stress.

CHAPTER III

STATIC CREEP TESTS

3.1 General

Static creep characteristics were determined by maintaining a uniform bearing stress of 500 psi until the additional deflections appeared to be negligible. Bonded pads and solid pads of 1.5 S.F. were held at this stress level for one week and three weeks respectively. The surface effects of C-S, S-S, and bonding were each investigated and compared.

3.2 Test Equipment

The loading frame (Figure 3.1) measured 22 x 15 x 23 in. for the outside dimensions. Four dial gages mounted on the upper platen were used to measure vertical deflections. A 100 kip hydraulic jack, hand pump, and load gage with minimum divisions of 2 kips were used for loading. The equipment (Figure 4.1) described in Section 4.2 was also utilized for static creep tests.

3.3 Test Procedure

Each pad was centrically positioned on the lower platen. The upper platen was adjusted to be parallel to the pad surface, and an initial load corresponding to a pad stress of 10 psi was applied. The load indicator and each deflection gage was adjusted to a zero reading thus disregarding the small

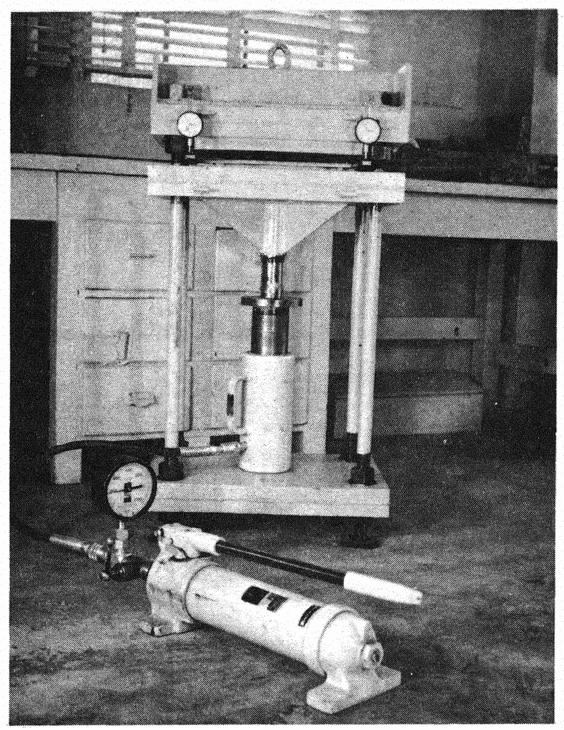


Figure 3.1 Static creep test equipment.

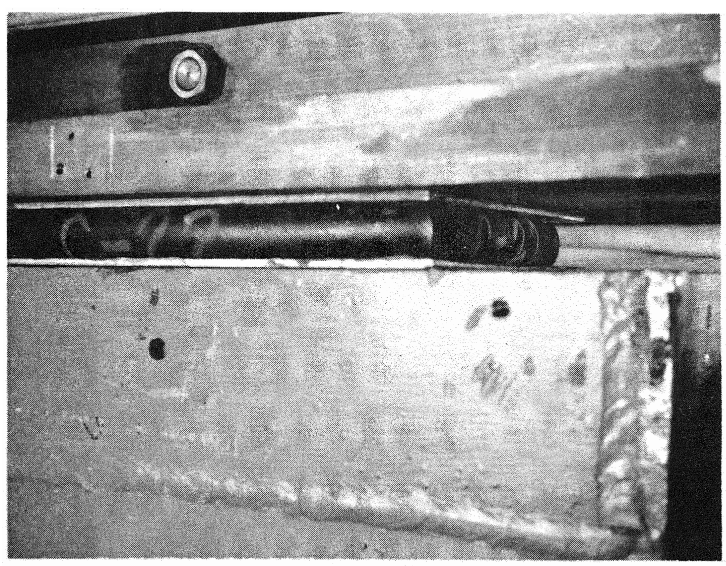


Figure 3.2 Bulging sides of bonded pad under load.

amount of initial stress and deflections. The time was recorded, and the total load was applied in one minute at an approximately uniform rate. The hydraulic hand pump was constantly attended during the following 15 minutes to maintain a near constant pad stress of 500 psi. Deflection readings were taken at 1, 2, 3, 5, 7, 10, 15 minutes after the initial load had been applied. Deflection occurring after the first 15 minutes of loading was at a much slower rate. Hence, constant attendance was not necessary, and loads and deflection were checked periodically during the first 24 hours. For the remaining test period, daily minor load adjustments were made and deflections were recorded.

3.4 Presentation of Test Results

An index to the parameters studied is shown in Figure 3.2.

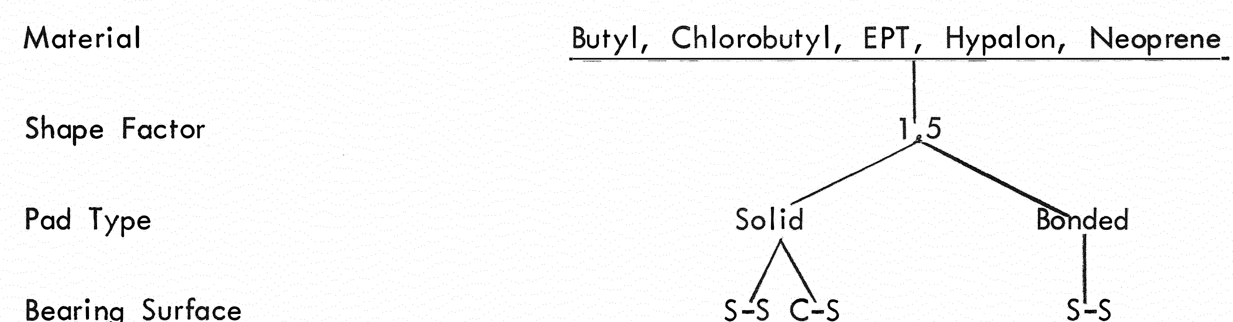


Figure 3.3 Static creep test parameters

Test results are reported in terms of deflection (T), %, percent of initial deflection, and time with the initial deflection values determined from compression-deflection data (Figures 3.4 through 3.11).

Bonded pads exhibited considerably less deflection than either pads

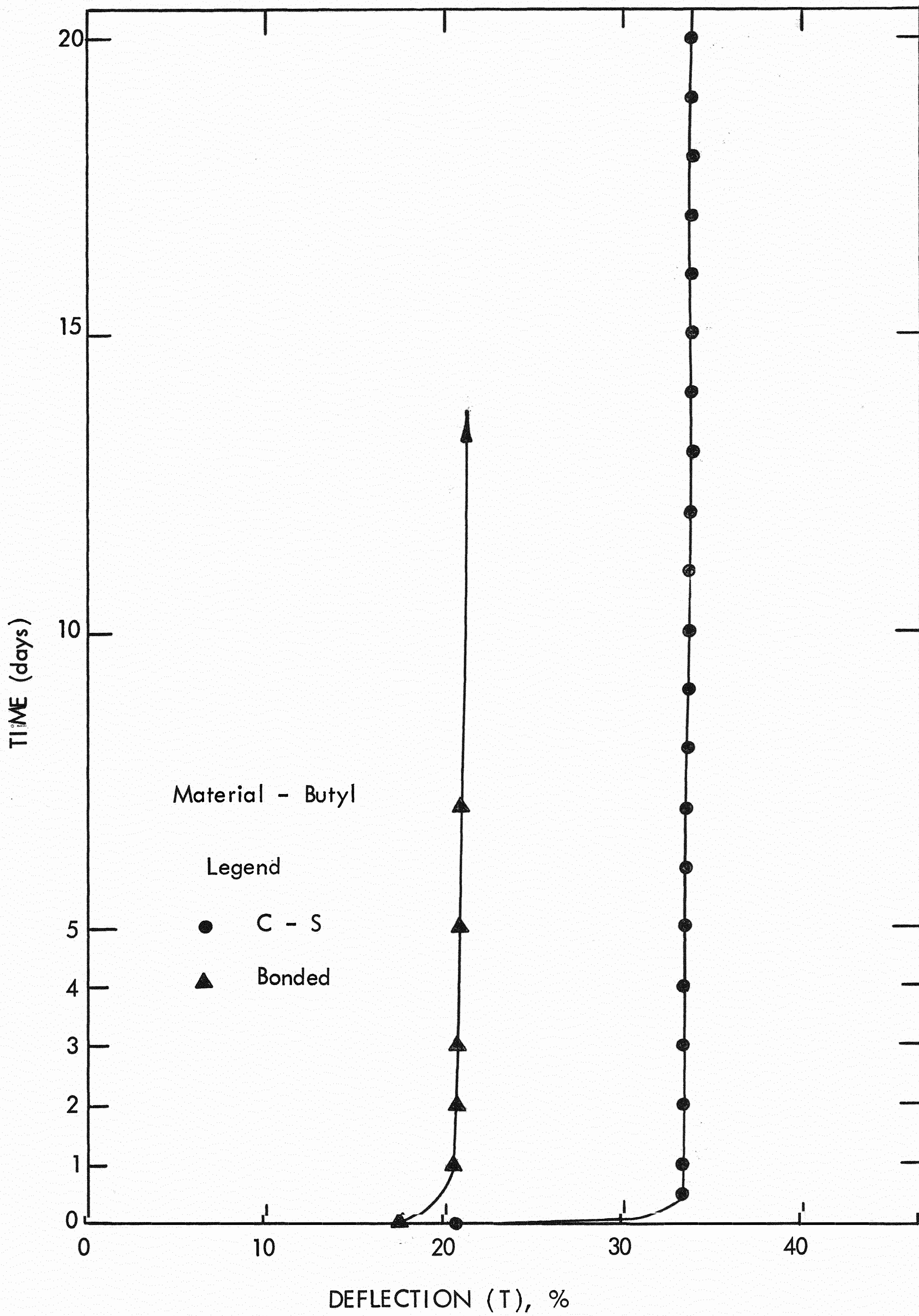


Figure 3.4 Static creep of butyl due to 500 psi constant stress.

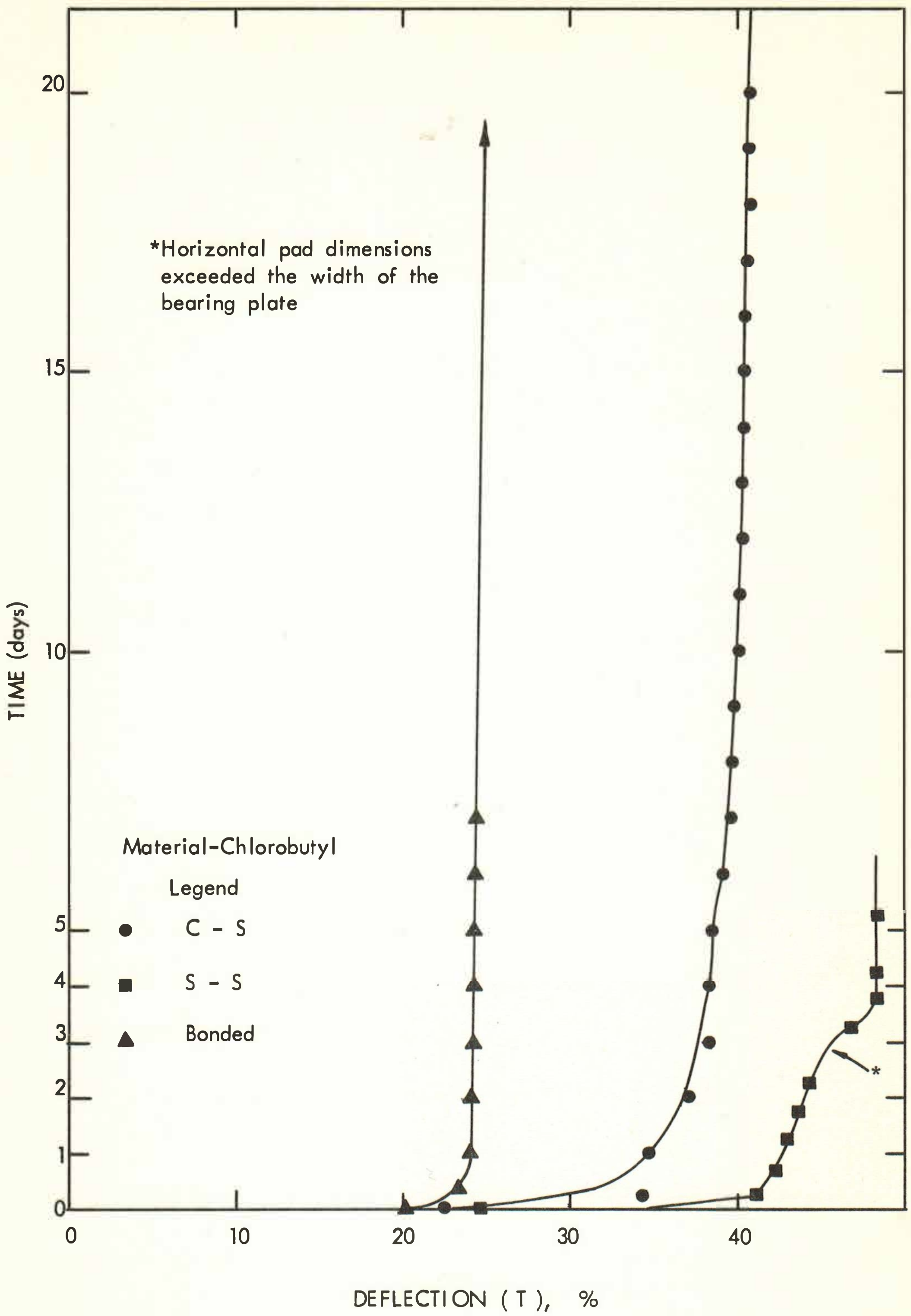


Figure 3.5 Static creep of chlorobutyl due to 500 psi constant stress.

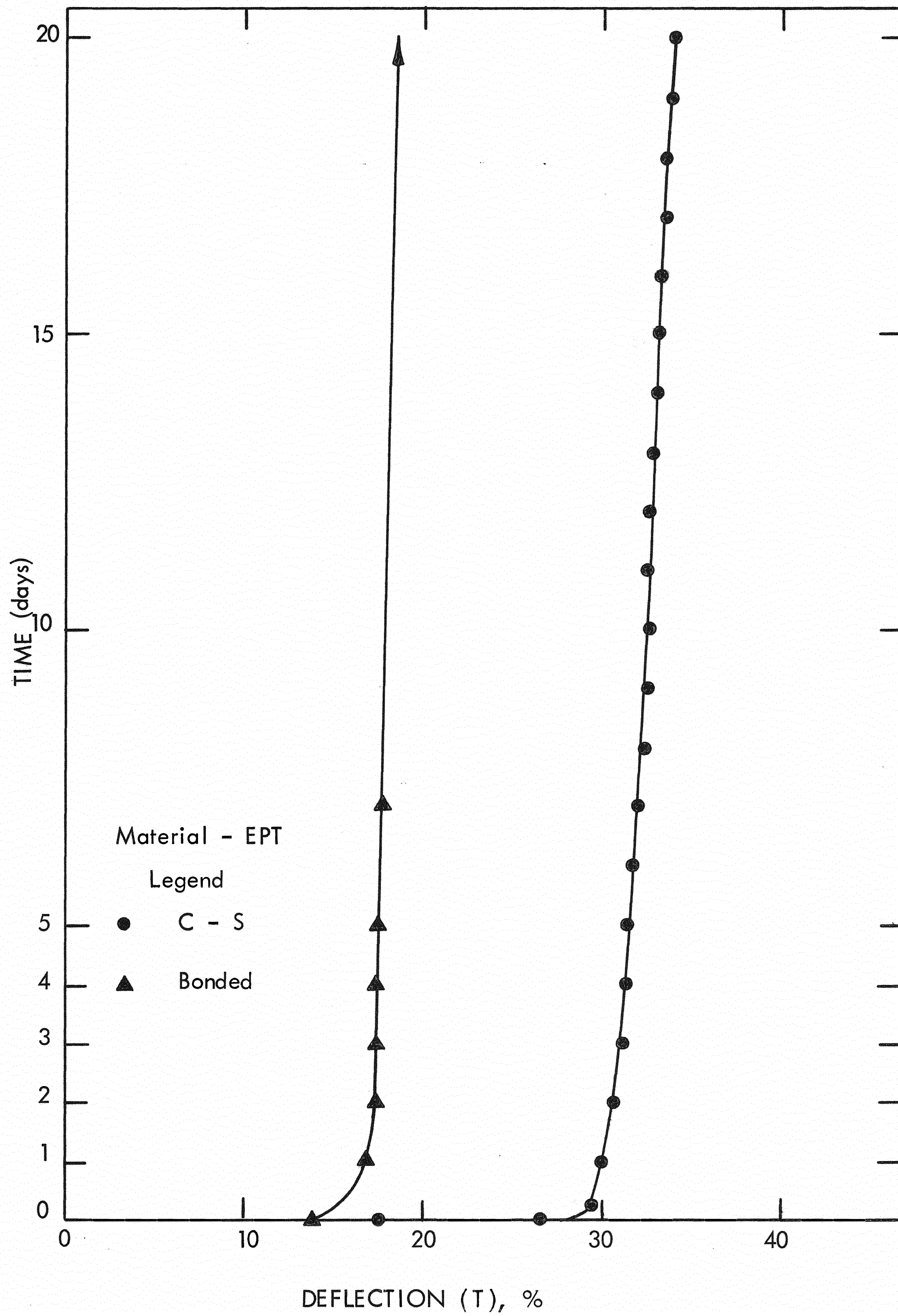


Figure 3.6 Static creep of EPT due to 500 psi constant stress.

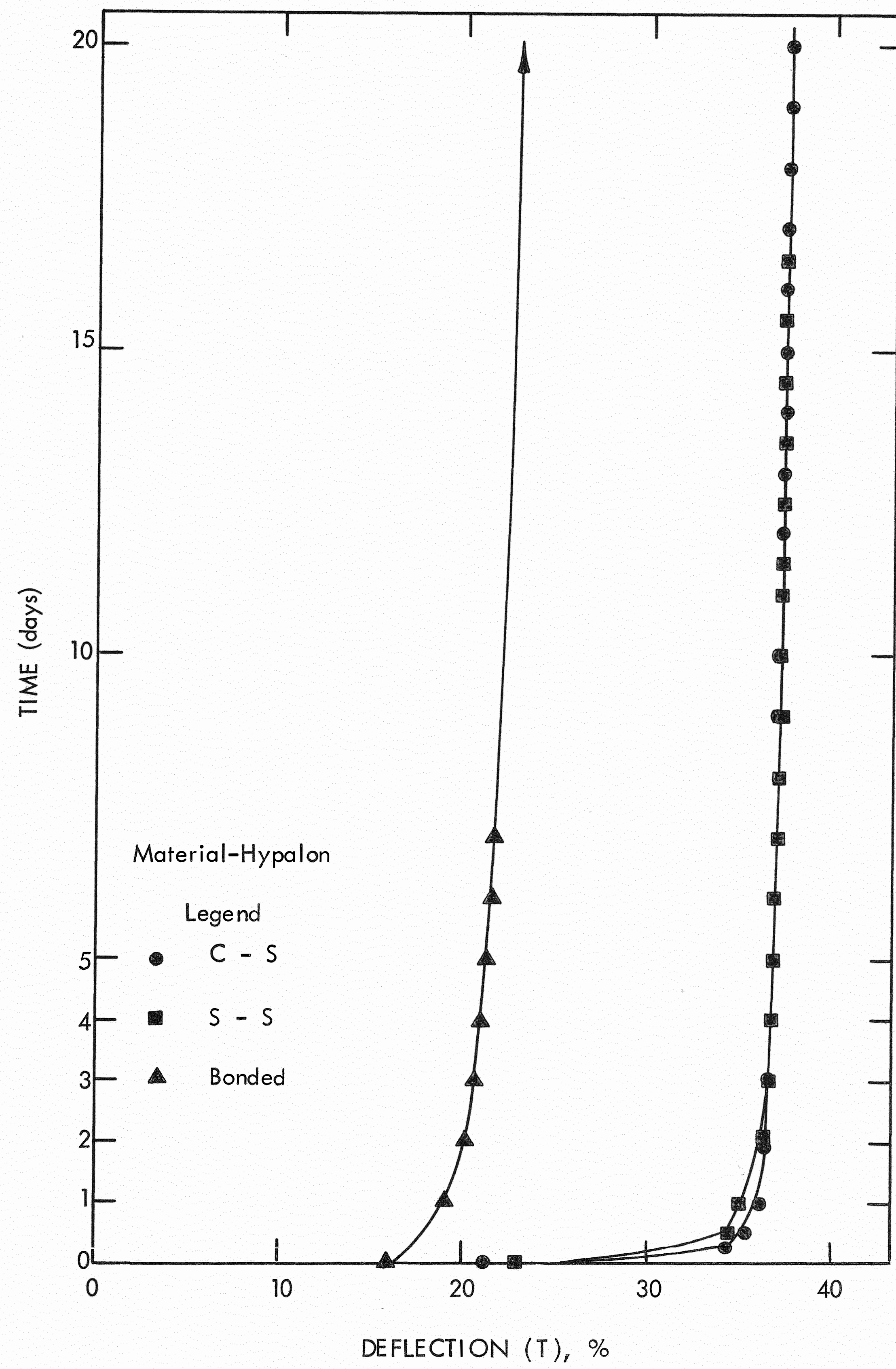


Figure 3.7 Static creep of hypalon due to 500 psi constant stress.

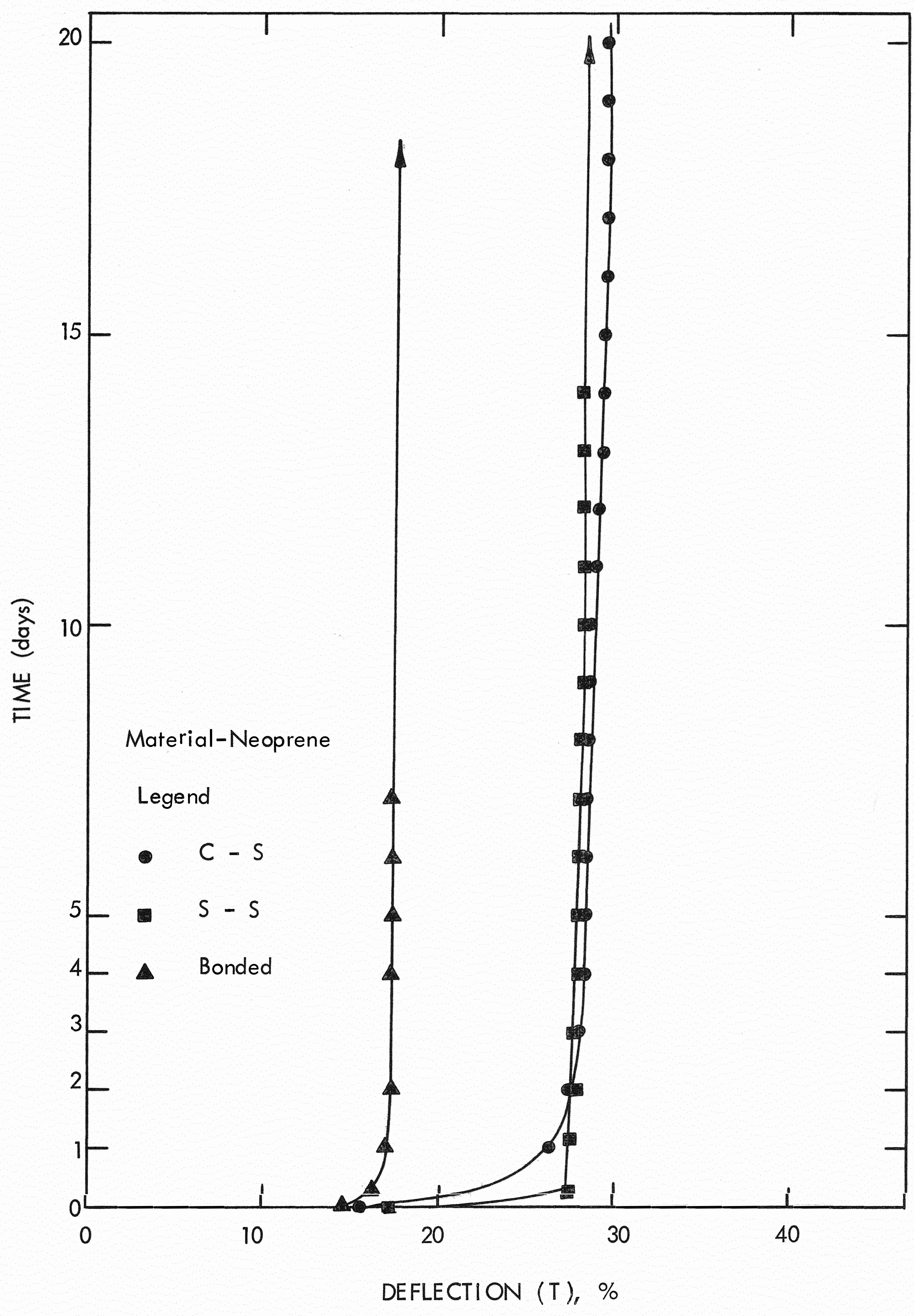


Figure 3.8 Static creep of neoprene due to 500 psi constant stress.

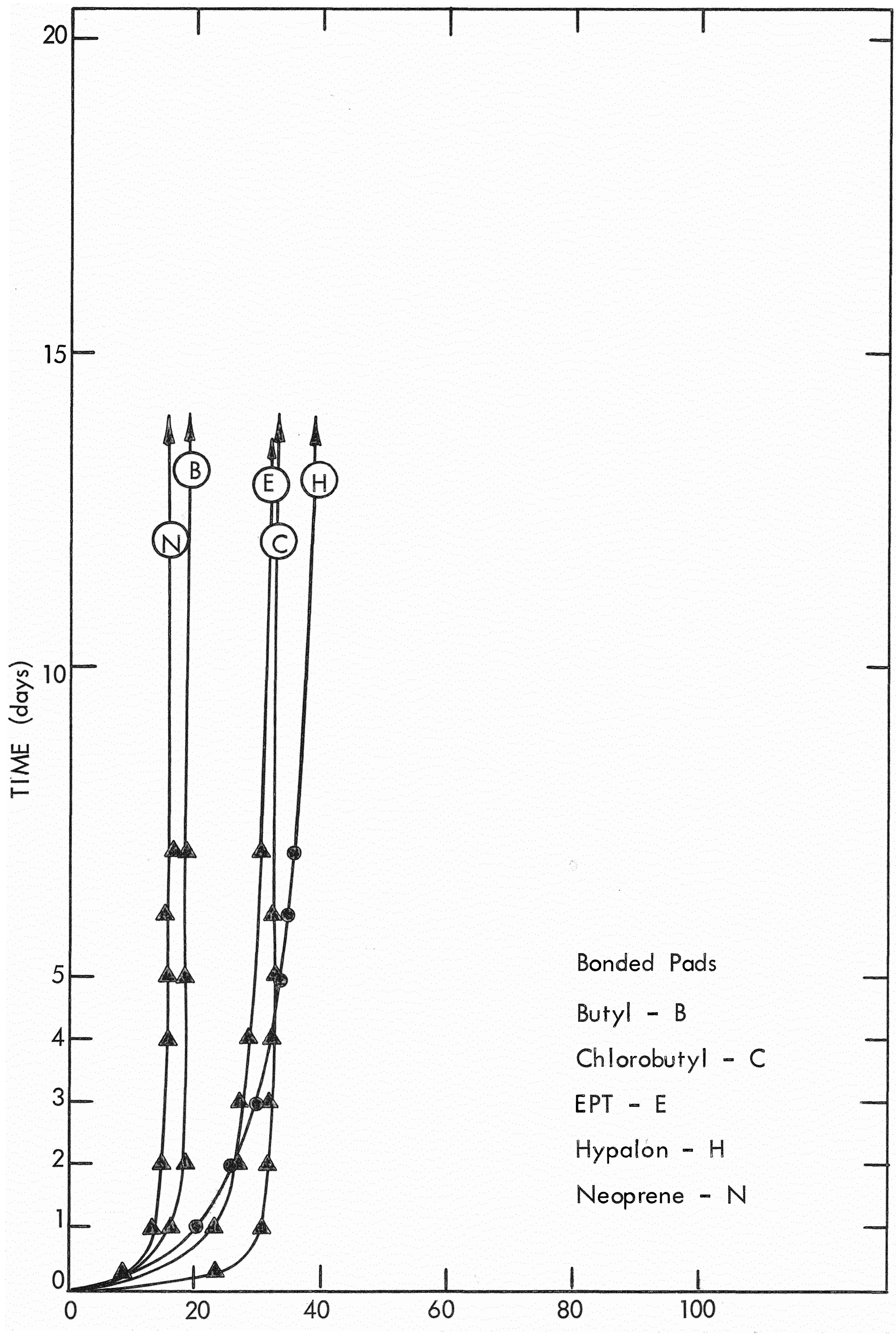


Figure 3.9 Static creep of bonded pads due to 500 psi constant stress.

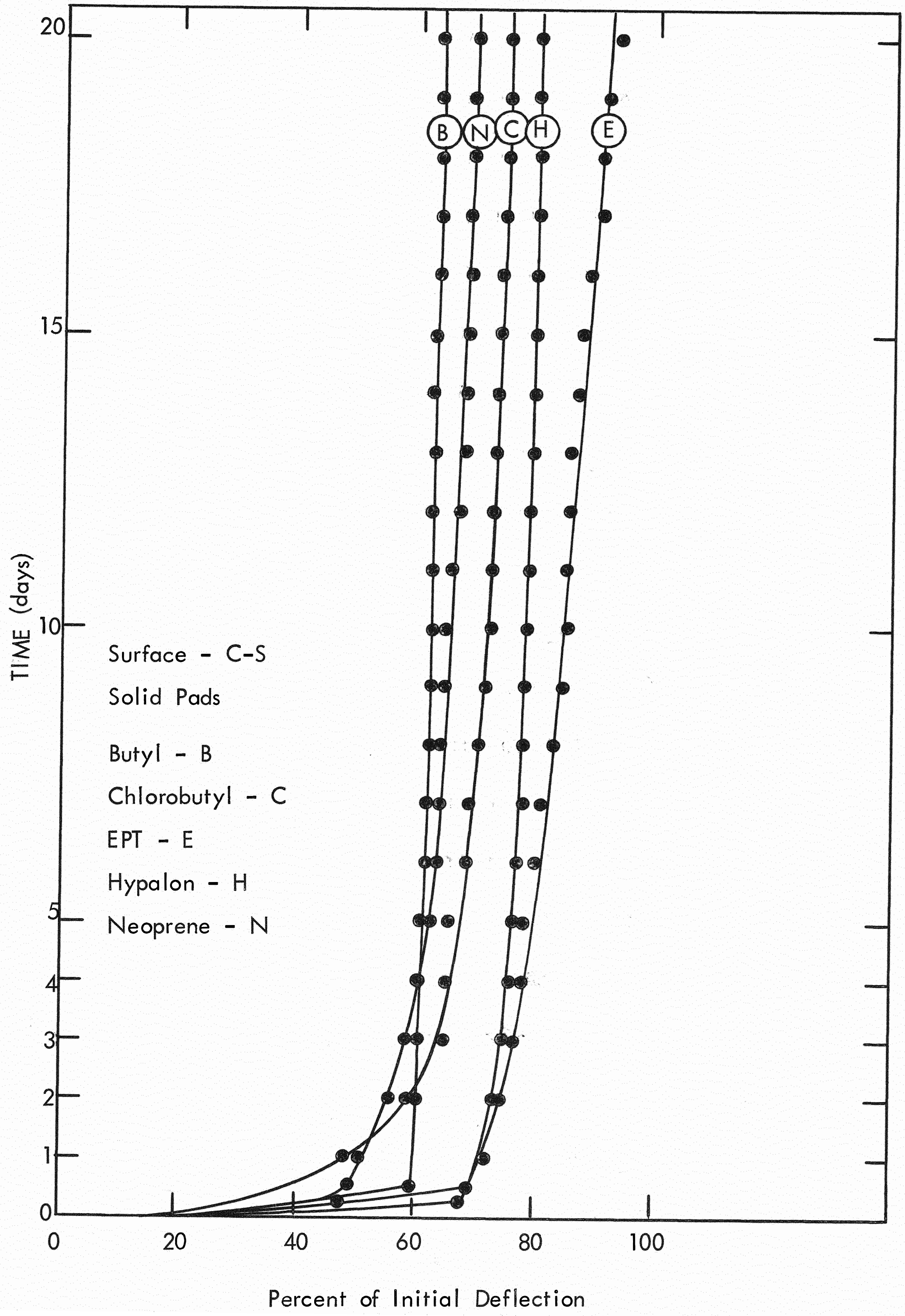


Figure 3.10 Static creep for pads between C-S due to 500 psi constant stress.

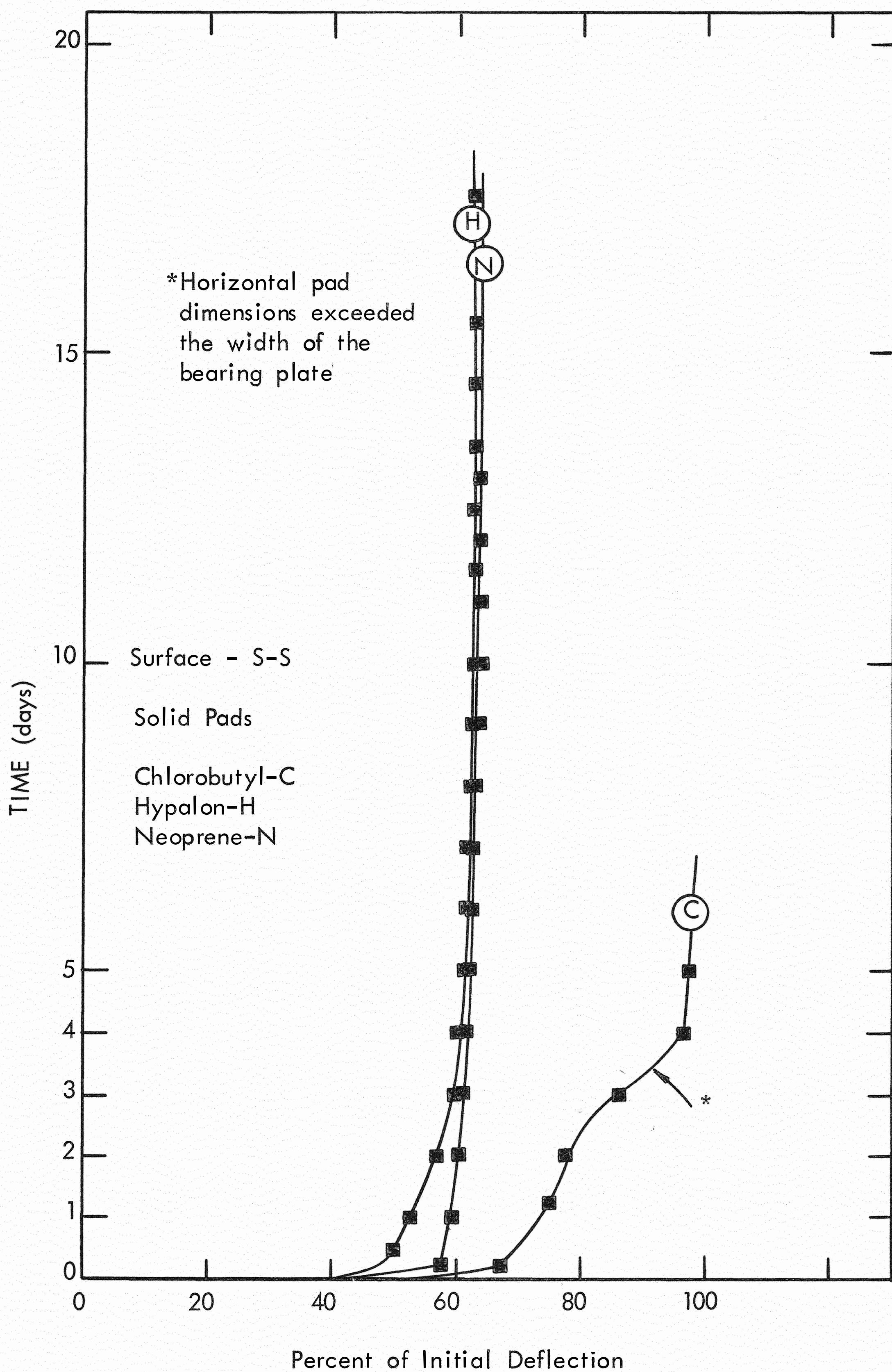


Figure 3.11 Static creep for solid pads between S-S due to 500 psi constant stress.

between C-S or S-S. Although pads between C-S deflected less than pads between S-S during the first few days under load, it was observed that the final deflection was approximately the same regardless of the bearing surface.

Increases of vertical deflections were negligible at the termination of the test. Variable hydraulic pressures due to daily temperature changes often caused deflection fluctuation more than the deflections due to creep in the material and did not warrant the continuation of the test for a longer time period. It should be noted the test for the chlorobutyl pad was terminated when the pad width exceeded the bearing surface width.

CHAPTER IV

REPETITIVE REVERSED SHEAR TESTS

4.1 General

One of the primary areas of interest regarding the uses of elastomeric bearing pads is the effects of horizontal shear forces resulting from bridge girder movements (primarily due to temperature changes). Repeated reversed horizontal shear forces were applied to 6 x 12 inch pads while maintaining a near constant vertical stress of 500 psi on the pads. Solid and laminated pads were individually subjected to constant reversed horizontal deflections equalling one-half the nominal pad thickness. These repetitive force applications caused an increase in vertical deflections. In addition, this repeated flexing resulted in abrasive wearing of the pad. These effects will be discussed later in more detail.

4.2 Test Equipment

4.2.1 Loading Frame

While designing the loading frame extensive reference was made to the plans of a similar device designed and built by the Materials and Research Department, California Division of Highways. However, reports of any tests conducted by the Materials and Research Department have not been published.

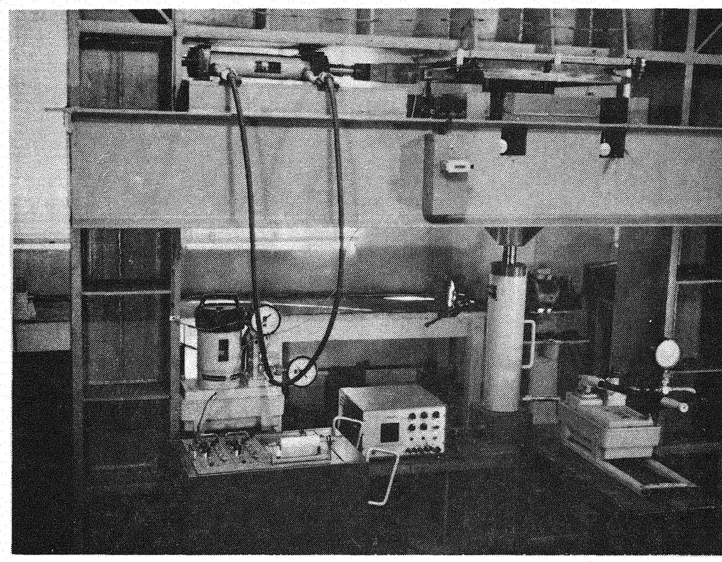


Figure 4.1 Loading frame and instrumentation used for repetitive reversed shear tests (RRST).

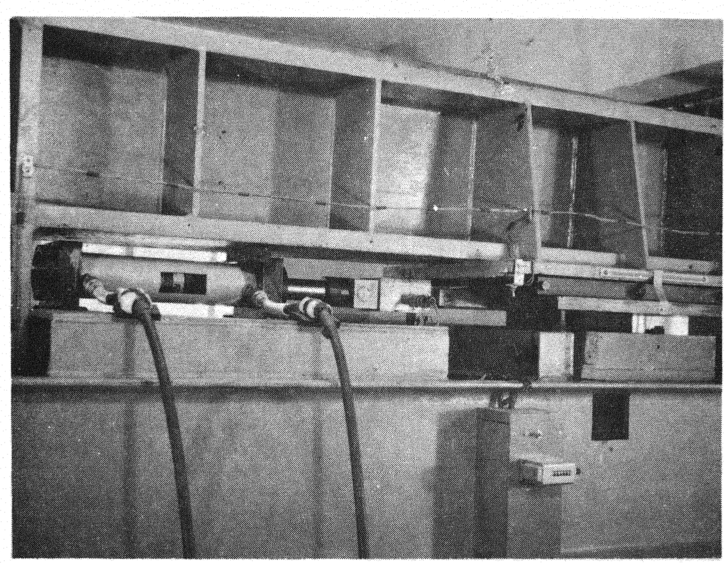


Figure 4.2 Horizontal loading assembly

The loading frame (Figure 4.1) was designed for the primary purpose of applying vertical loads and repetitive horizontal loads, and was built to withstand the full capacity of the 200 kip and 20 kip hydraulic jacks. The horizontal force was applied directly to the upper steel bearing surface. The lower bearing surface was constructed of concrete and secured in a fixed position by bearing bolts. All instrumentation and associated equipment were located on or near the frame.

4.2.2 Hydraulic System

The vertical compressive force was applied with a 200 kip hydraulic jack and hand operated pump. A 20 kip double acting jack (Figure 4.2) was regulated by a three-way electric pump and used for horizontal force applications. Hydraulic pressures were indicated on three dial pressure gages and were converted to actual load by multiplying by the effective ram areas of the hydraulic cylinders.

4.2.3 Instrumentation

The magnitude of vertical deflections was determined with four dial gages mounted near each corner of the concrete bearing block. Reversal of horizontal travel of the steel bearing plate was controlled by electrical limit switches. The amount of horizontal deflection was easily set by adjusting the position of these switches. The number of complete reversed horizontal force cycles was recorded by an automatic electric counter. Two safety switches were positioned to avoid the possibility of exceeding the allowable horizontal ram extension or withdrawal. An alternate check of the vertical compressive load was maintained with a calibrated load cell and strain indicator. A tension-compression load cell and electronic recorder were used to monitor the horizontal loads.

4.3 Test Procedure

Since the test procedure was both time consuming and complex a standard method of testing was developed and is included in Appendix C. In general, each pad was subjected to a vertical stress exceeding 500 psi for a 12 hour period preceding the test. This procedure of conditioning the pad was to eliminate--as much as possible--the continued vertical deflections due to static creep. However, during the test the vertical stress on each pad was maintained near a constant level of 500 psi. The horizontal movement of the top bearing plate was adjusted to cycle alternately in a forward and backward direction relative to the initial center position, a distance equal to one-half the nominal uncompressed pad thickness. The rate of horizontal load application was controlled by the electric pump and was not adjustable, but it appeared to remain constant at approximately 10 cpm. The test was continuous except for brief interruptions to record deflections.

4.4 Presentation and Discussion of Test Results

The results of this series of tests are shown as cycles of applied horizontal load versus deflection (T) % (Figuresr4.3 through 4.7). Total vertical deflection is described as being comprised of essentially three incremental parts shown typically in Figure 4.3. The first increment was designated the initial short-time deflection and was determined from compression-deflection data.

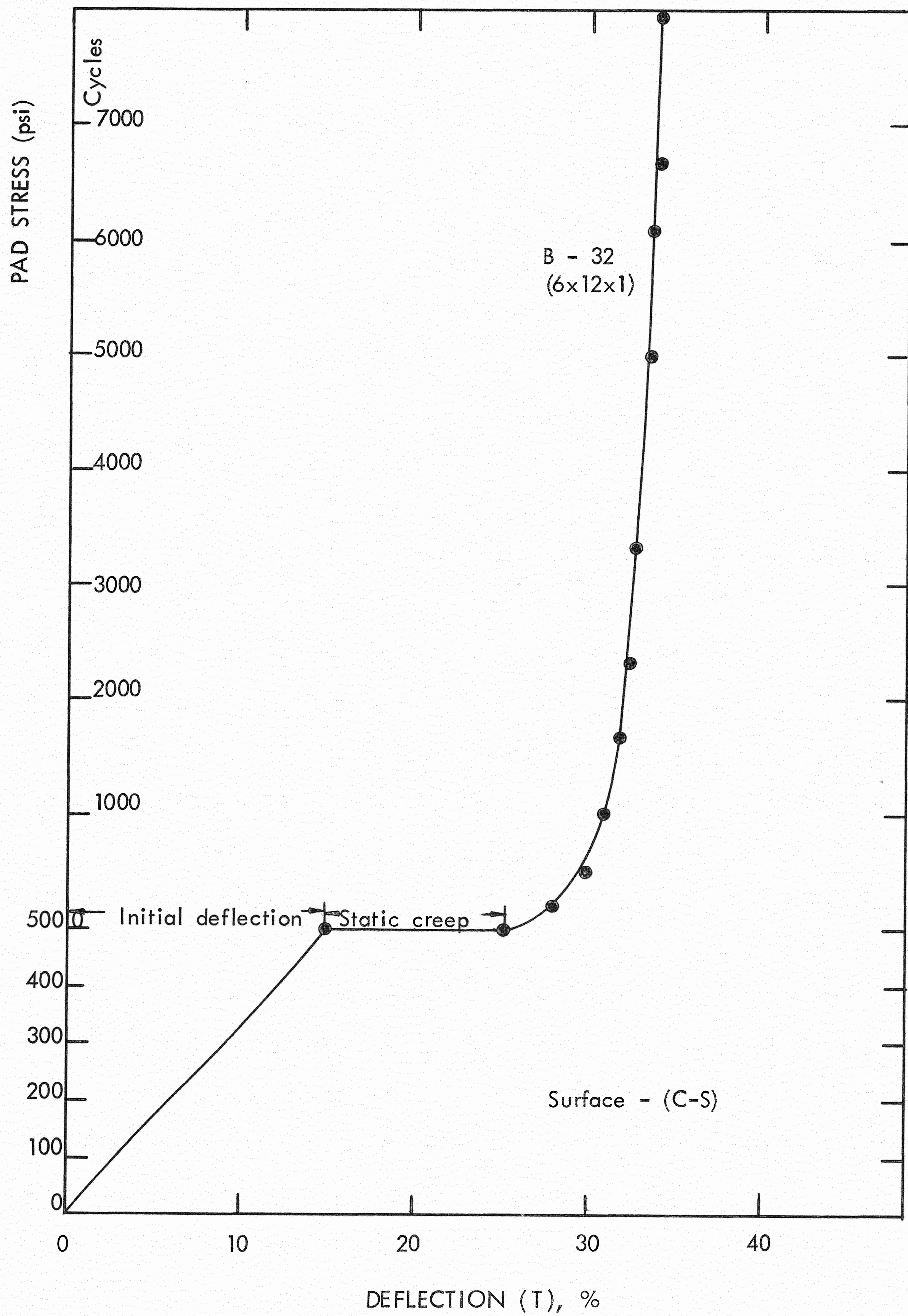


Figure 4.3 Total deflection of butyl pad due to RRST.

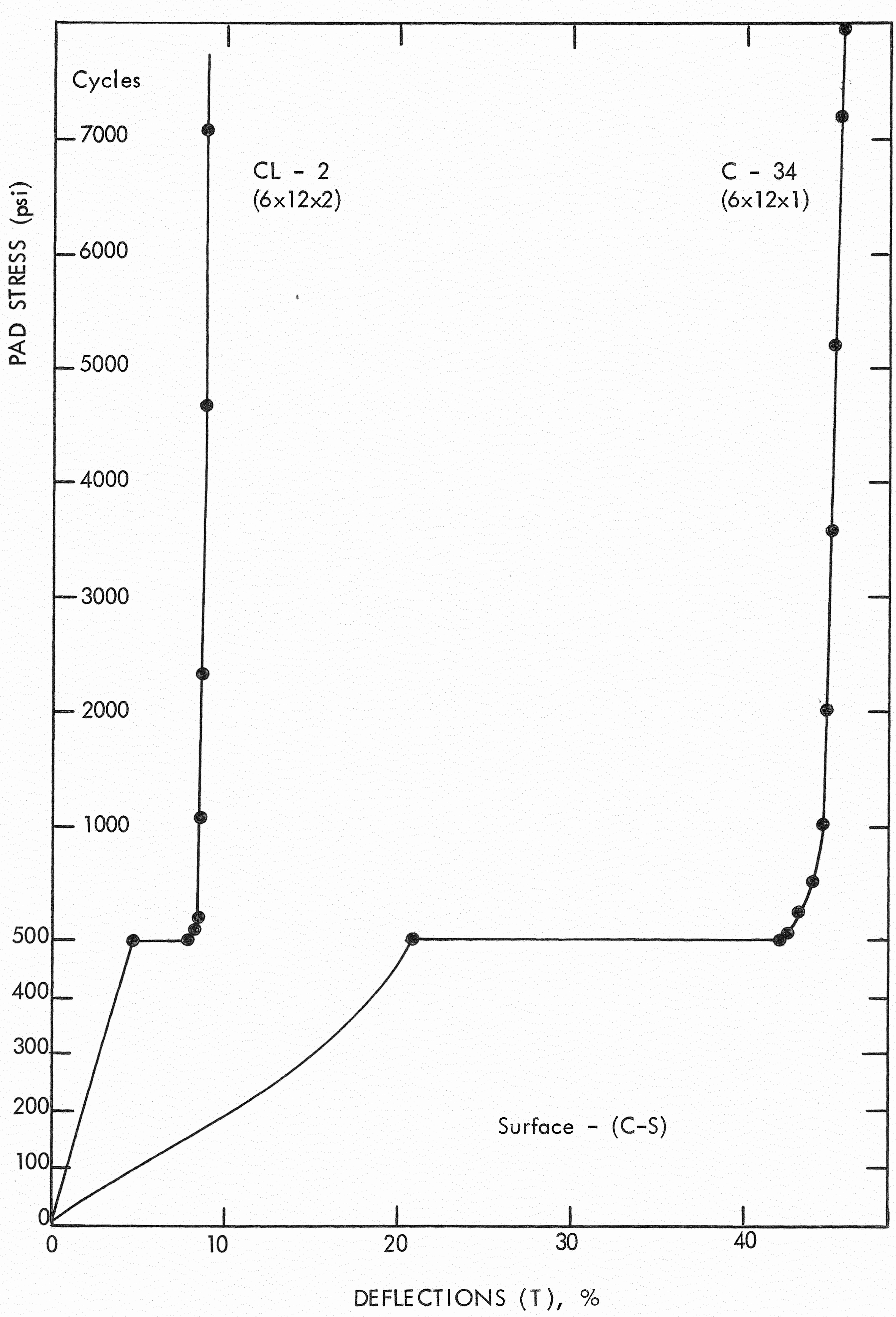


Figure 4.4 Total deflection of chlorobutyl pads due to RRST.

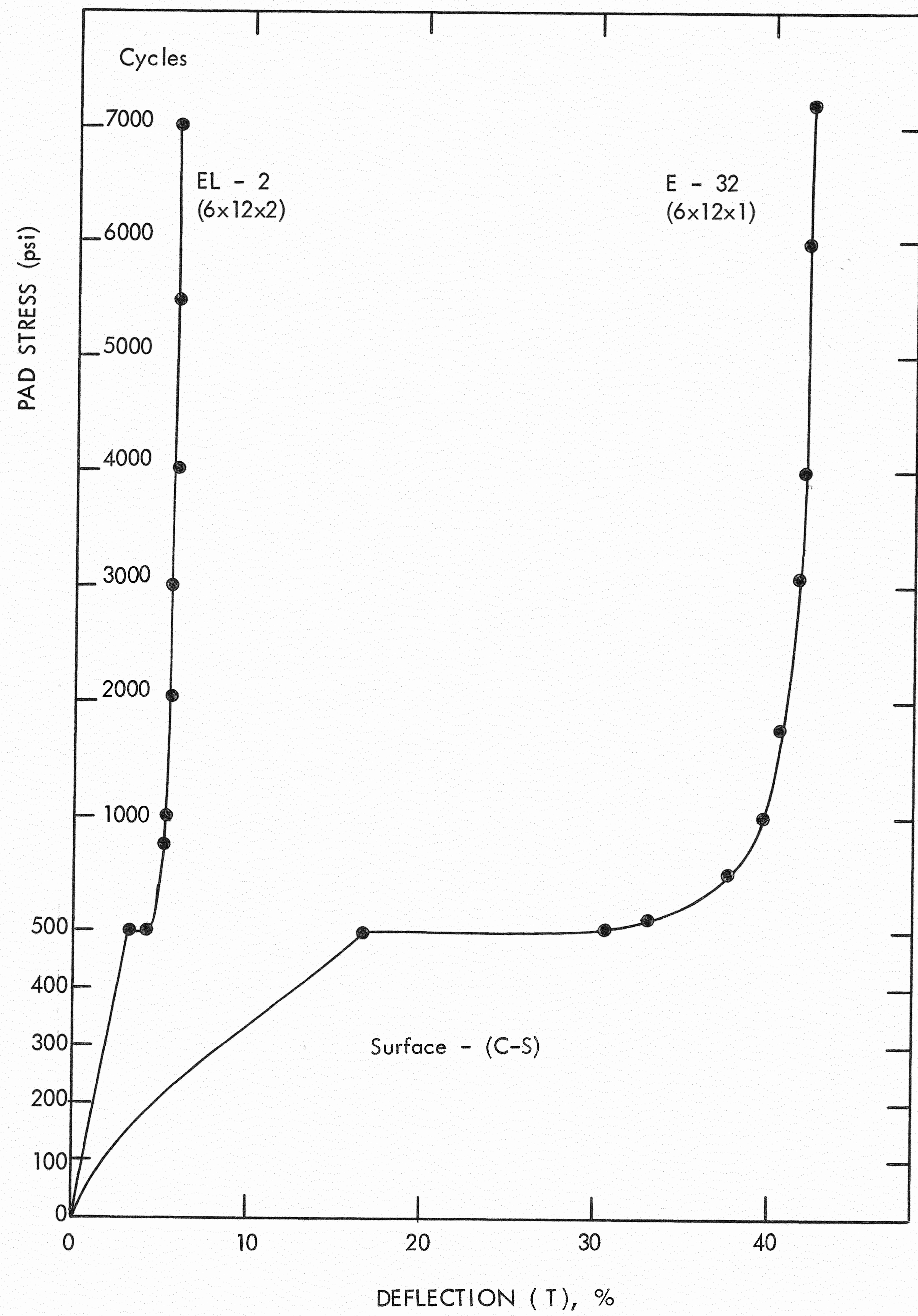


Figure 4.5 Total deflection of EPT pads due to RRST.

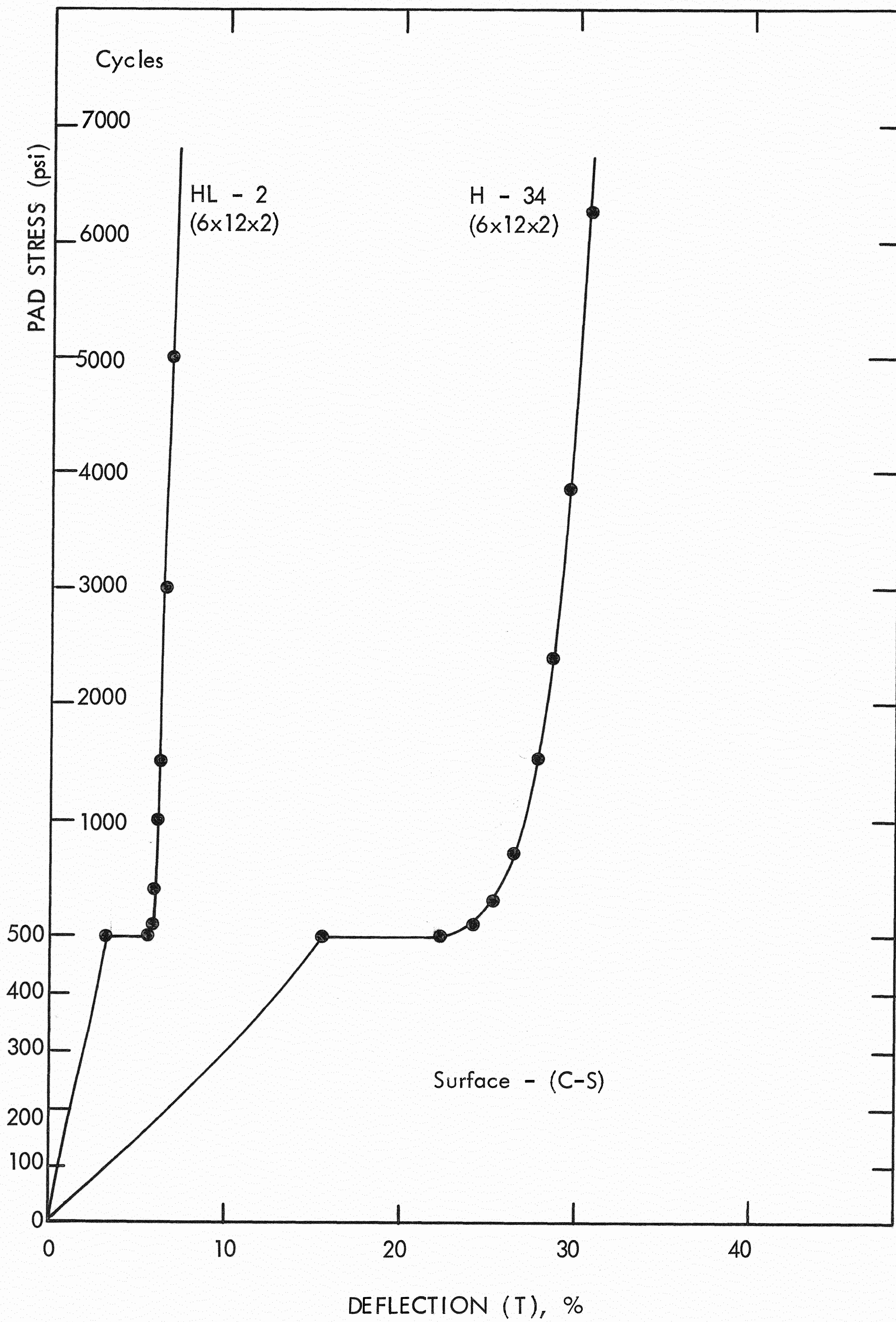


Figure 4.6 Total deflection of hypalon pads due to RRST.

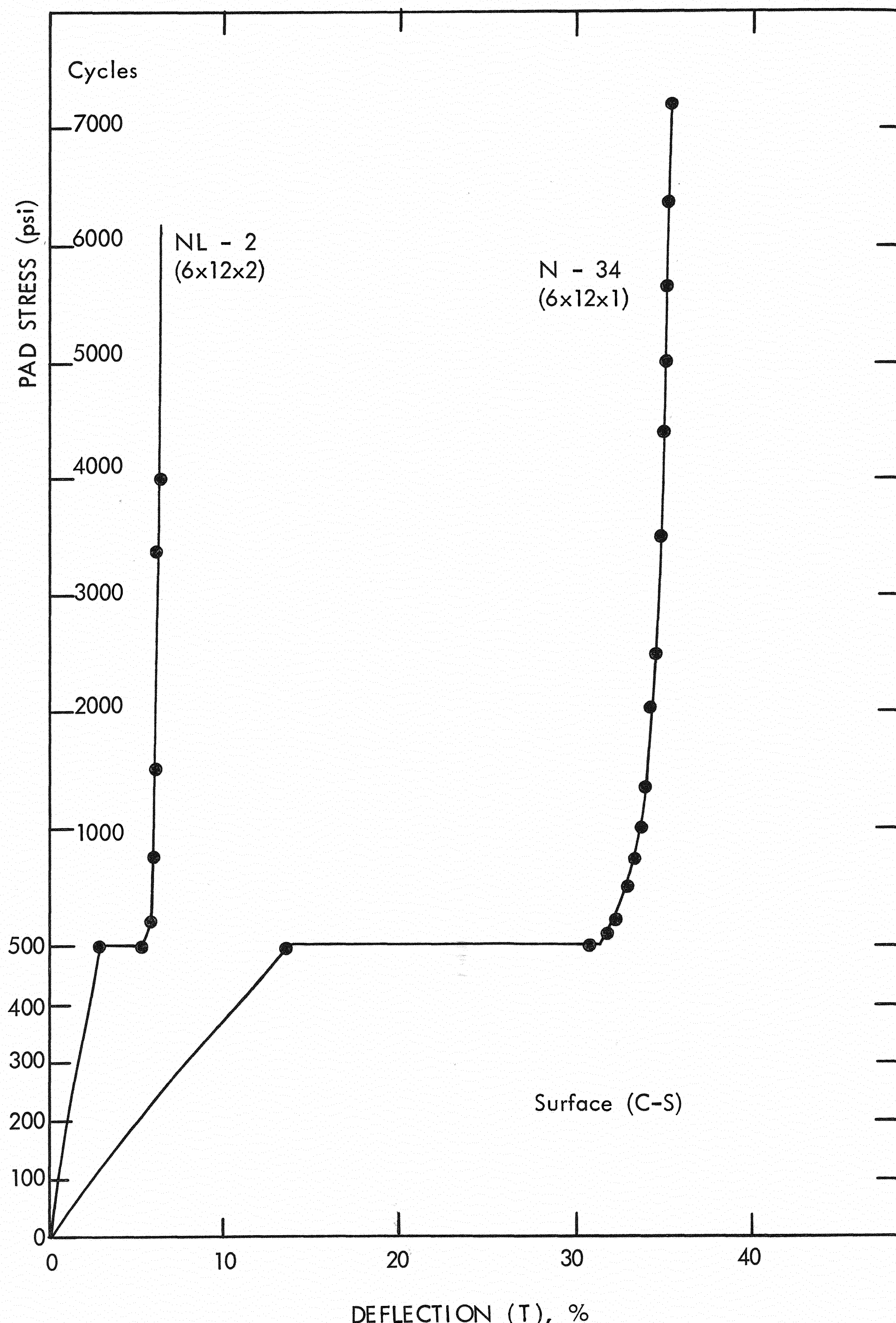


Figure 4.7 Total deflection of neoprene pads due to RRST.

The magnitude of static creep deflection resulted from the 12 hour preconditioning stress applied on the pad. The final increment of deflection was due primarily to the effects of repeated reversed horizontal movements of the pad.

During the time period just prior to the starting of the repetitive reversed shear tests (RRST), the rate of vertical deflection due to static creep had reduced to approximately 0.001 inch per hour for all pads. However, as the initial horizontal force cycles were applied, additional vertical deflections were rapidly produced. With continued horizontal flexing of the pad the rate of vertical deflections gradually reduced. It was also noted that surface temperatures of solid and laminated pads increased approximately 6 to 14°F above room temperatures which varied between 75 and 82°F. This temperature rise can be explained by the effects of the flexing rate and/or the friction generated by pad slippage.

Slippage between the pad and both bearing surfaces during each cycle was observed at the edges of the pads. No attempt was made to determine the actual point of slippage, but the relative amount of slippage was greater between the steel-pad interface than between the concrete-pad interface. It is interesting to note that the solid butyl pad was not correctly centered at the initial compressed position, and a greater horizontal deflection occurred in one direction during the initial cycles. The deflections soon equalized in each direction due to this slippage. Surface slippage produced two kinds of abrasion effects. Solid pads received noticeable abrasion on the pad sides (Figure 4.13) parallel to the horizontal movements. This action was due to the "rolling under" of the pad edges. Laminated pads received a bearing surface abrasion rather than on the sides. This bearing surface abrasion was more extensive where the contact surface was concrete.

The bearing surfaces also had a particularly noticeable effect on the loaded shape of solid pads. The concrete surface provided a restraining condition on the pad, while the steel surface allowed greater lateral pad movement.

This magnitude of the horizontal flexing force was found to increase slightly with the number of repetitive cycles on all solid pad tests. Conversely, this force decreased in magnitude on all laminated pad tests. Although all solid and laminated pads were each subjected to constant reversed deflections equalling one-half the nominal pad thickness, the magnitude of these forces varied with each material.

The damaging effects to the solid pads showed no correlation, except the various degrees of side abrasion to all pads. The neoprene pad exhibited only a slight crack on the width side, but a larger split was produced at an irregular pad trimming location on the length side. An extremely large split in the hypalon pad extended from the length edge into the center of the pad at an angle of approximately 30r°. This split could have possibly resulted when the horizontal movement exceeded one-half T due to a switch malfunction. Permanent deformation of the chlorobutyl pad bearing surfaces resulted in a slightly trapezoidal shape. The steel-pad surface resulted in a larger width dimension, while the concrete-pad surface width was reduced. The butyl and EPT pads were not noticeably effected or damaged.

Surface abrasion effects to laminated pads were quite similar as previously mentioned. However, chlorobutyl, EPT, and neoprene pads exhibited only slight surface wearing. The hypalon pad demonstrated much more surface wear and was the only laminated pad to develop side cracks (Figures 4.8 through 4.12, note the rubber "filings"). However, the development of these cracks did not lead to "pad failure," but in actual service conditions the presence of these cracks could seriously effect the pad life.

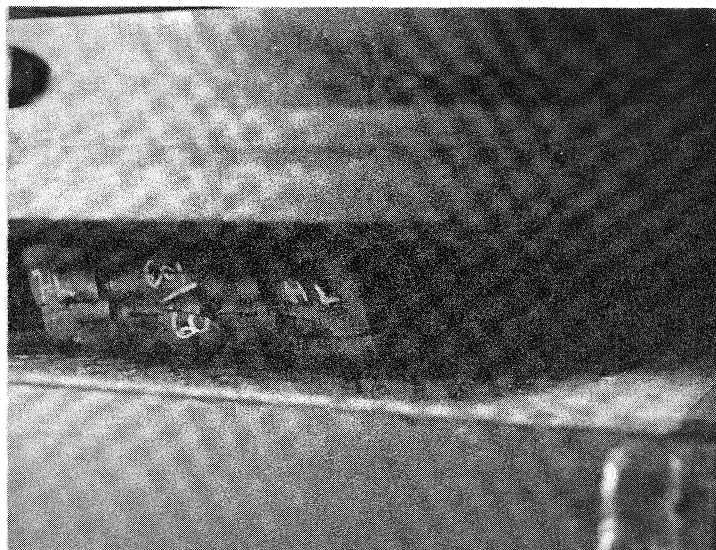


Figure 4.8

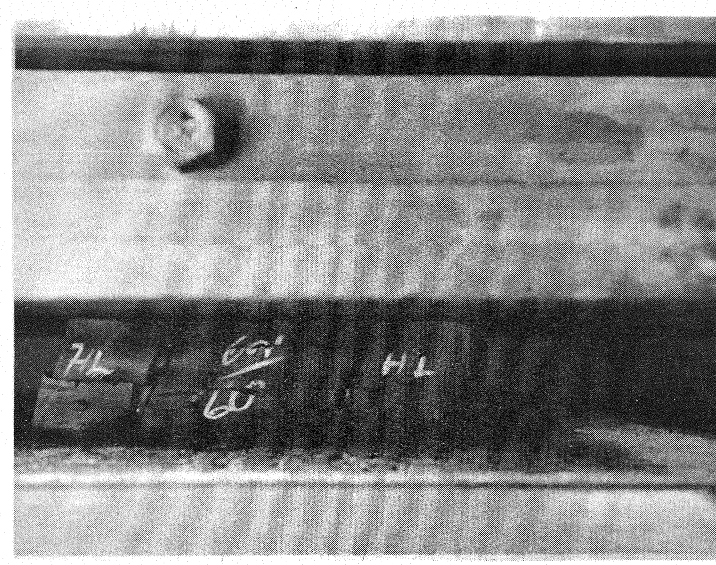


Figure 4.9

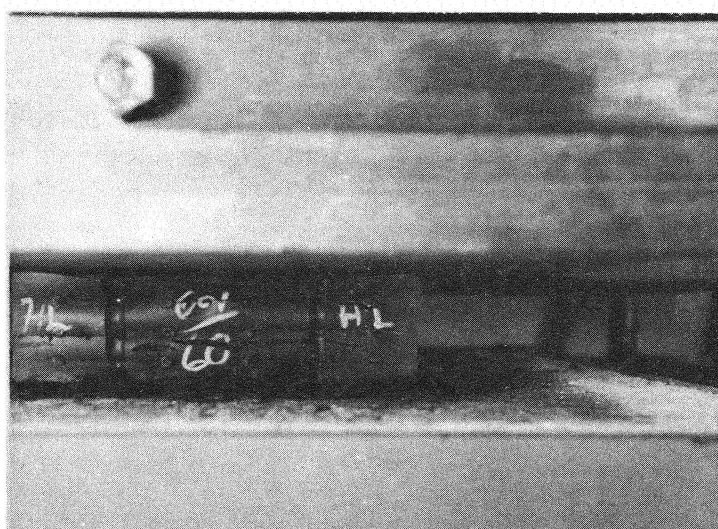


Figure 4.10

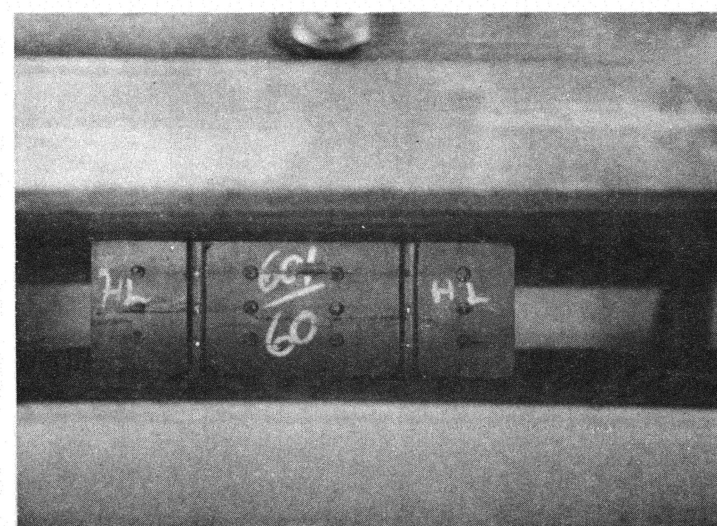


Figure 4.11

Views of side splits in the laminated hypalon pad.

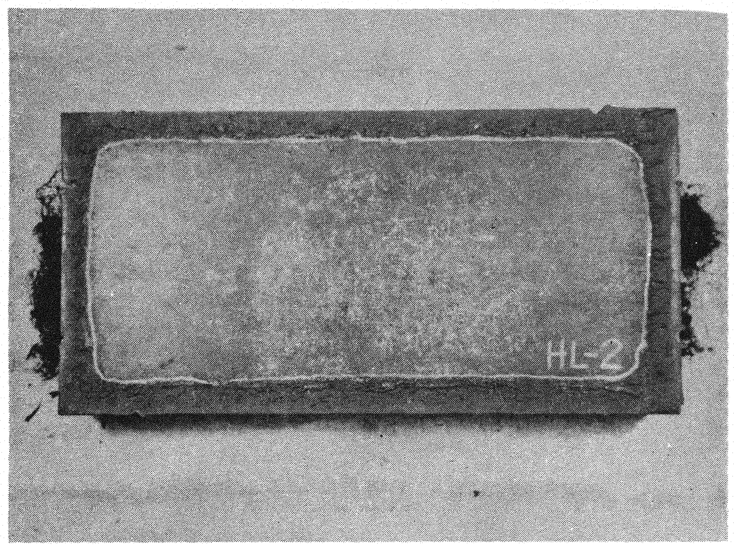


Figure 4.12 Surface abrasion effects due to the concrete bearing surface. The white line denotes the inner edge of the most severe abrasionr.

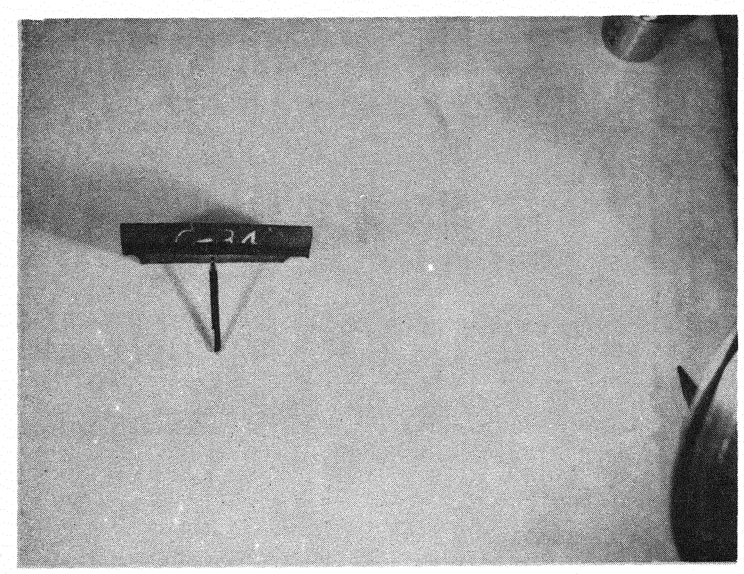


Figure 4.13 Chlorobutyl edge abrasion effects due to rubbing on the concrete bearing surface.

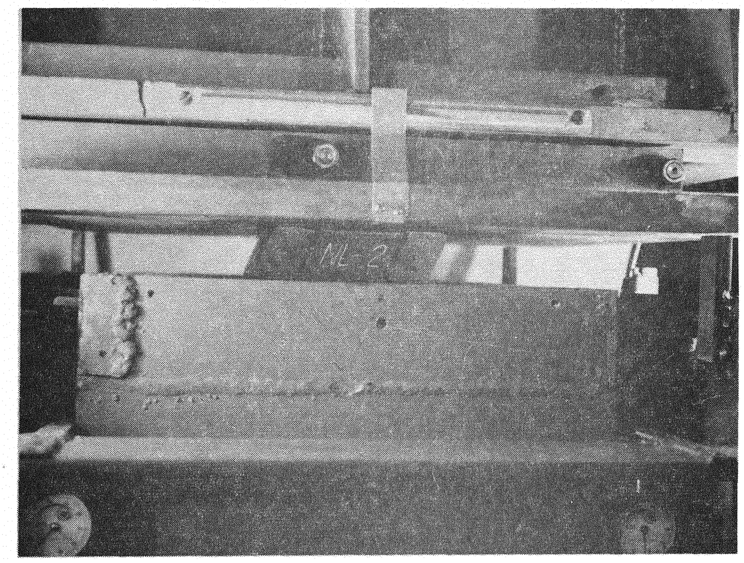


Figure 4.14 Neoprene pad in deflected position.

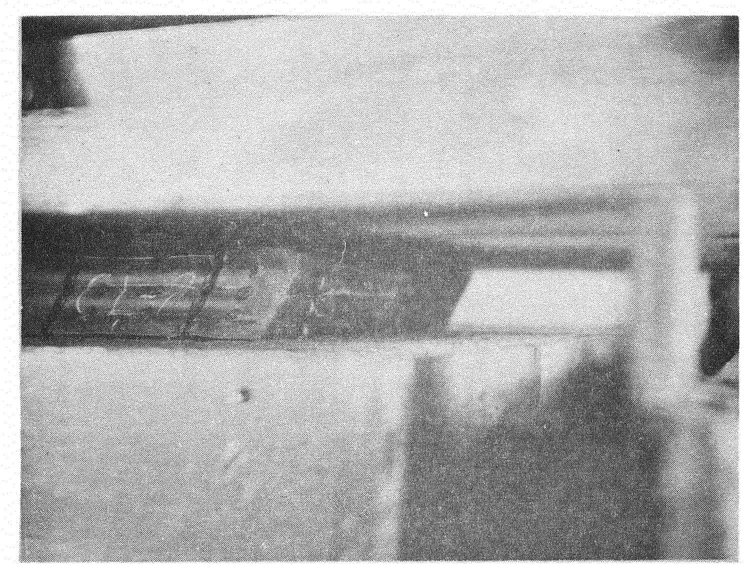


Figure 4.15 Chlorobutyl pad in deflected position.

CHAPTER V

LOAD-DEFLECTION COMPARISONS

5.1 Compression - Deflection

Probably more test data has been accumulated during previous research concerning compression-deflection characteristics than any other property of elastomeric bearings. This test is relatively easy to conduct but is unquestionably one of the least significant tests depicting pad behavior under actual service loads. However, the effects of such parameters as shape factor, hardness, material, compressive stress, testing rate, and bearing surfaces with respect to deflections are quite readily comparable.

Data from bonded and laminated pad--test results (Chapter II) were used to compare pad materials of three shape factors (Figure 5.1). Referring to this figure it can be observed that:

1. vertical deflections decrease as shape factors increase,

2. variations between individual material responses are a function of the shape factor, i.e., the deflection for pads of the low number shape factors demonstrate greater sensitivity to the material under load than the higher number shape factors which tend to more closely agree with the deflections of other materials.

3. an approximate linear compression-deflection relationship is ex-

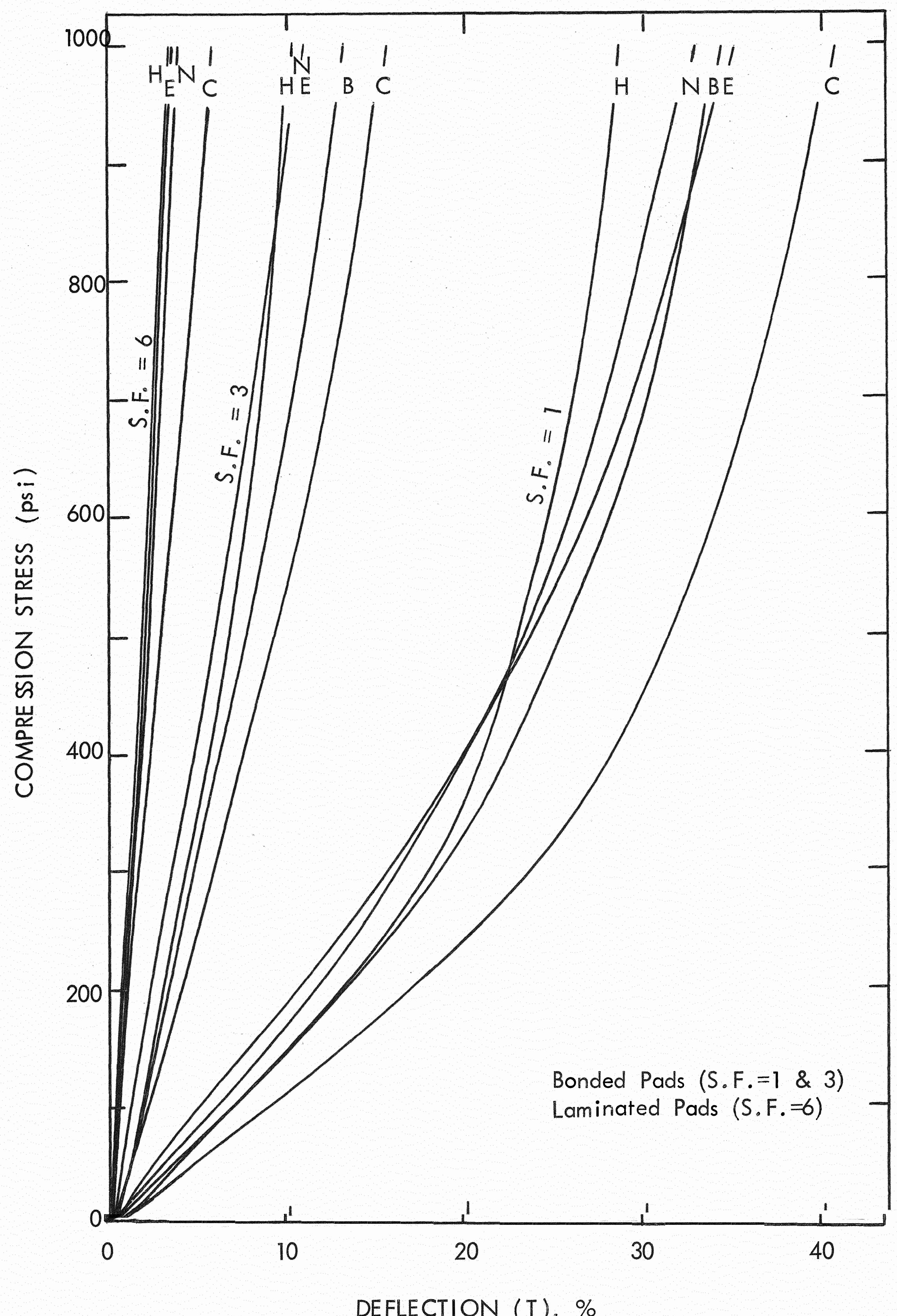


Figure 5.1 Comparison of compression-deflection characteristics for bonded and laminated pads of all materials.

hibited by the higher number shape factors while the relationship for pads with a shape factor of one is definitely nonlinear, and

4. chlorobutyl is more sensitive to load than the other materials regardless of shape factor.

A comparison for neoprene and butyl (Figures 5.2 and 5.3) demonstrates the effect of surface conditions on vertical deflections. From these two figures it can be noted that much larger deflections occur for pads between S-S, and deflections decrease in order when the surfaces are C-S, C-C, and bonded.

Since bearing pads may be used in conjunction with concrete or steel bridge girders and concrete abutments, it appears that very similar deflection responses will occur for either condition. However, if steel shims (for the elevation adjustments) are used on the pad surfaces, greater initial short-time deflections can be expected.

By reference to Figure 5.1 it can be observed that in changing from a shape factor of six to one there is approximately a six fold increase in deflection, from six to three a two fold increase, and from three to one less than a two fold increase. Since a pad with a shape factor of three is about the largest solid pad size that can be placed under a standard bridge girder, the engineer is faced with the problem of controlling deflections.

If the AASHO Specifications are followed, the engineer must not exceed the unit pressures of 500 psi under dead load nor 800 psi under a combination of dead and live load plus impact. In addition, the initial deflection under dead, live, and impact loads shall not exceed 15 percent of the pad thickness. Further, the pad dimensions must be less than the dimensions of the beam it

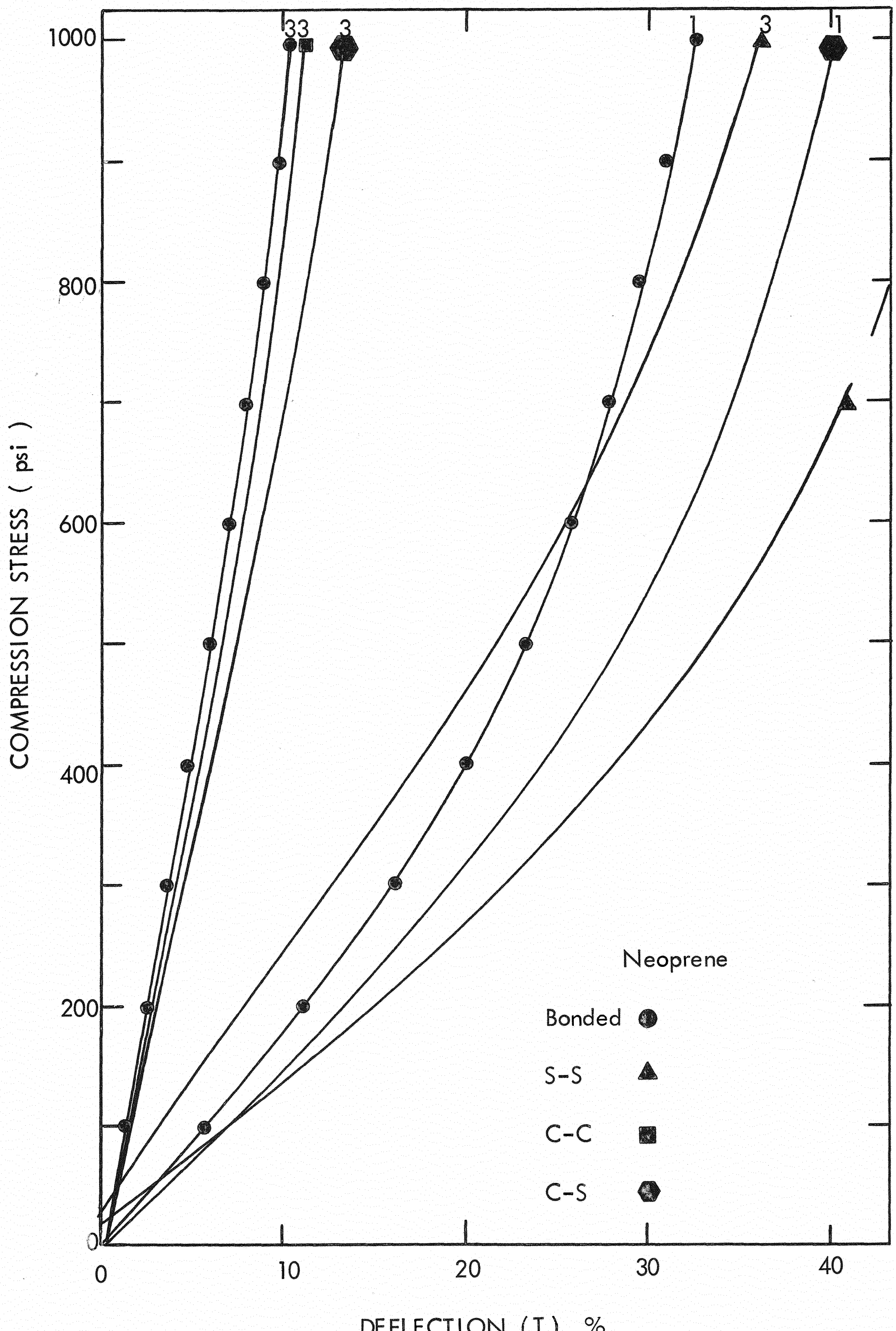


Figure 5.2 Comparison of neoprene pads for surface condtions of S-S, C-S, C-C, and bonded.

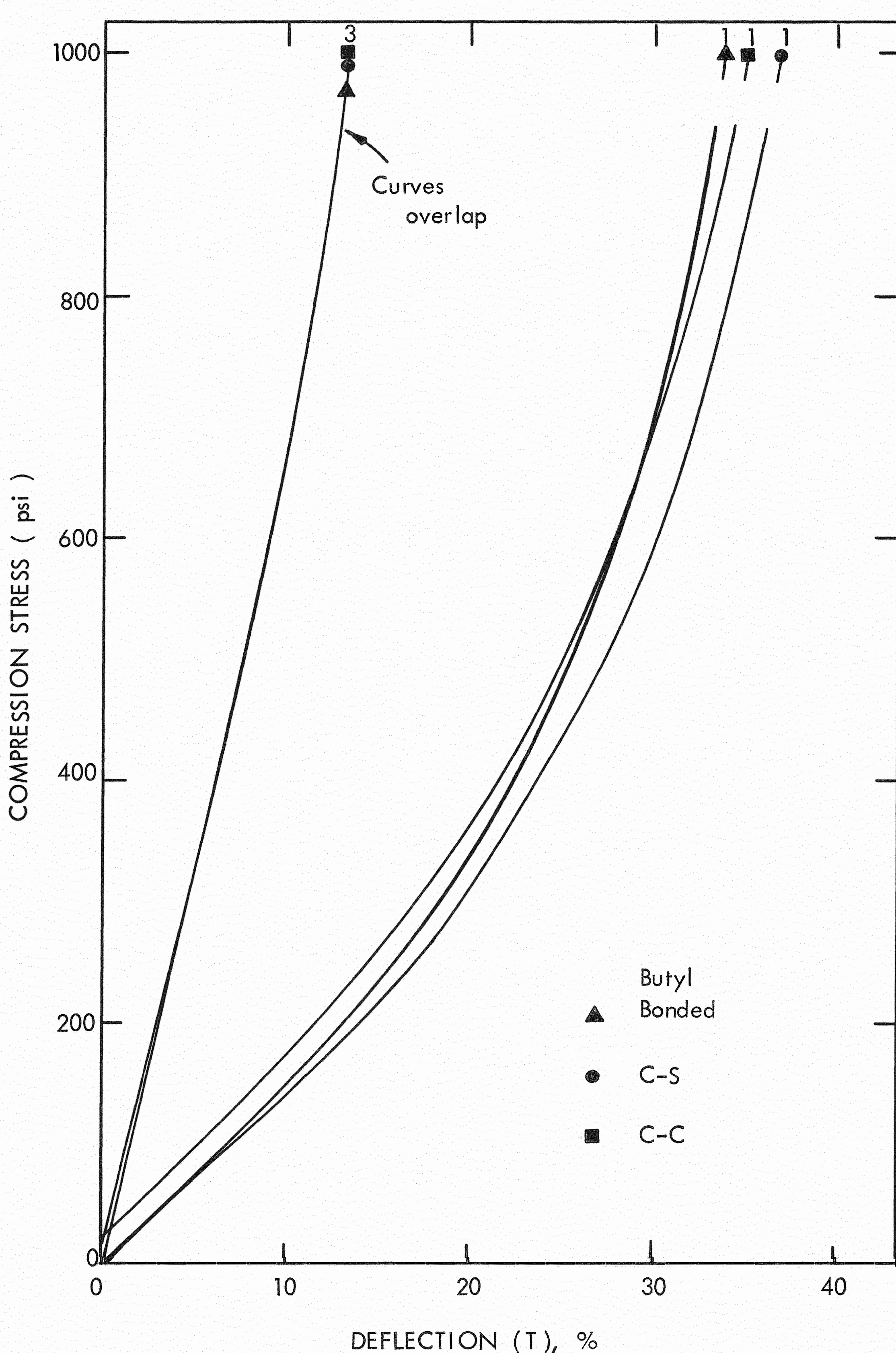


Figure 5.3 Comparison of butyl pads for surface conditions of C-S, C-C, and bonded.

supports.

Deflections are usually controlled by using larger shape factors. Increasing the shape factor is generally accomplished by (a) increasing the bearing area while maintaining the same pad thickness, or (b) decreasing the pad thickness and using more thicknesses with laminations if the bearing area is limited or is a maximum for the beam being supported. However, it should be noted that the introduction of laminations is expensive. For example, the use of a laminated unit containing three or four steel plates is approximately ten times more expensive than a one inch solid pad of the same plan dimensions. Therefore, the use of a solid pad (shape factor of three) would be more economical than a laminated unit (shape factor of six) even though the solid pad would exhibit greater deflections.

It has been noted (Section 1.3) that the 1961 AASHO Specification allows only neoprene to be used for expansion bearings. However, in view of the 15 percent initial deflection limitation which essentially necessitates the use of pads with a shape factor of three or larger (for reasonable design stress levels), these compression-deflection tests have shown that butyl, chlorobutyl, EPT, and hypalon are virtually equivalent to neoprene for shape factors greater than three in their responses to short-time loadings.

5.2 Static Creep

The Goodyear Tire and Rubber Company has written (11),

> Determination of creep has always been difficult because some creep is bound to occur while the initial or elastic deformation is being measured. It is customary to take the initial reading at some arbitrary time interval such as thirty seconds, one minute or five minutes after applying the load,

> and any creep occurring in this period is not charged against the compound. This practice is consistent with creep determinations in other fields of structural materials where the initial stage is usually discounted.

However, the nonconformity of elastomeric materials to the normal concepts of small deflection theory applicable for relatively rigid materials has been well established. Therefore, the greater sensitivity of elastomers to the time dependent phenomenon of creep should not be assumed consistent with creep of other structural materials. The practice of taking the initial reading at some arbitrary time interval can produce a wide range of the values for graphs showing percent of initial deflection since deflection changes rapidly during the first few minutes under load. In addition, this procedure does not account for total deflection and no relationship exists between compression-deflection and static creep. However, the percent of initial deflection creep curves presented in Chapter III are related to the compression-deflection curves determined in this study since initial deflection values were obtained from compression-deflection data. Thus, total deflection can be determined by using these two sets of graphs. It should be noted that only pads with 1.5 shape factors subjected to a constant 500 psi stress were studied.

The total deflection responses of the pads investigated were quite similar (Figures 5.4 through 5.6) except a noticeable difference in the rate of deflection was observed during the first three days under load (see specifically Figure 5.5). However, the deflection rate difference does not appear to be of significance since virtually all deflection should occur during the bridge construction period. In general, deflections increase at a very slow rate after the first

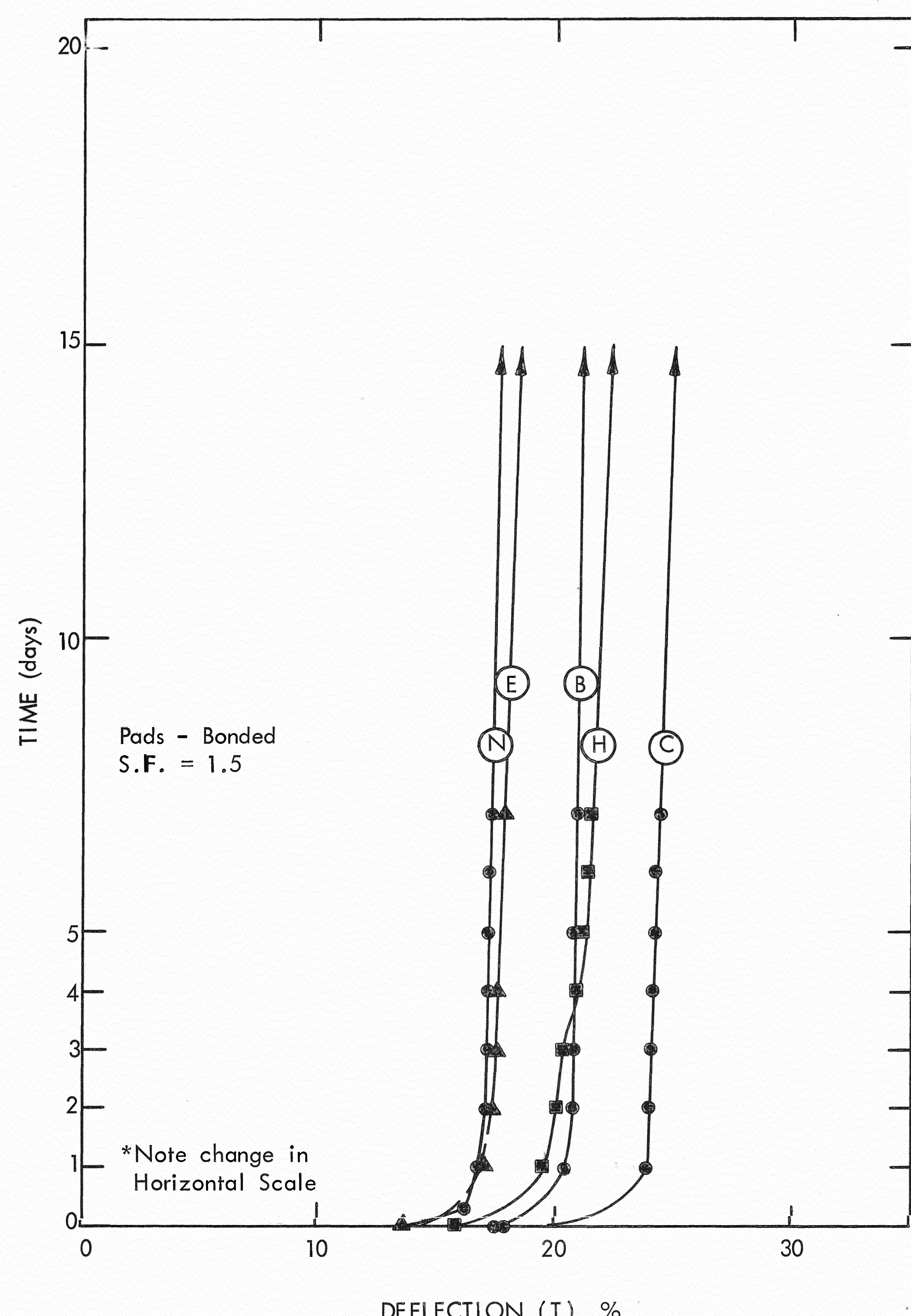


Figure 5.4 Comparison of total deflection for bonded pads due to 500 psi constant stress.

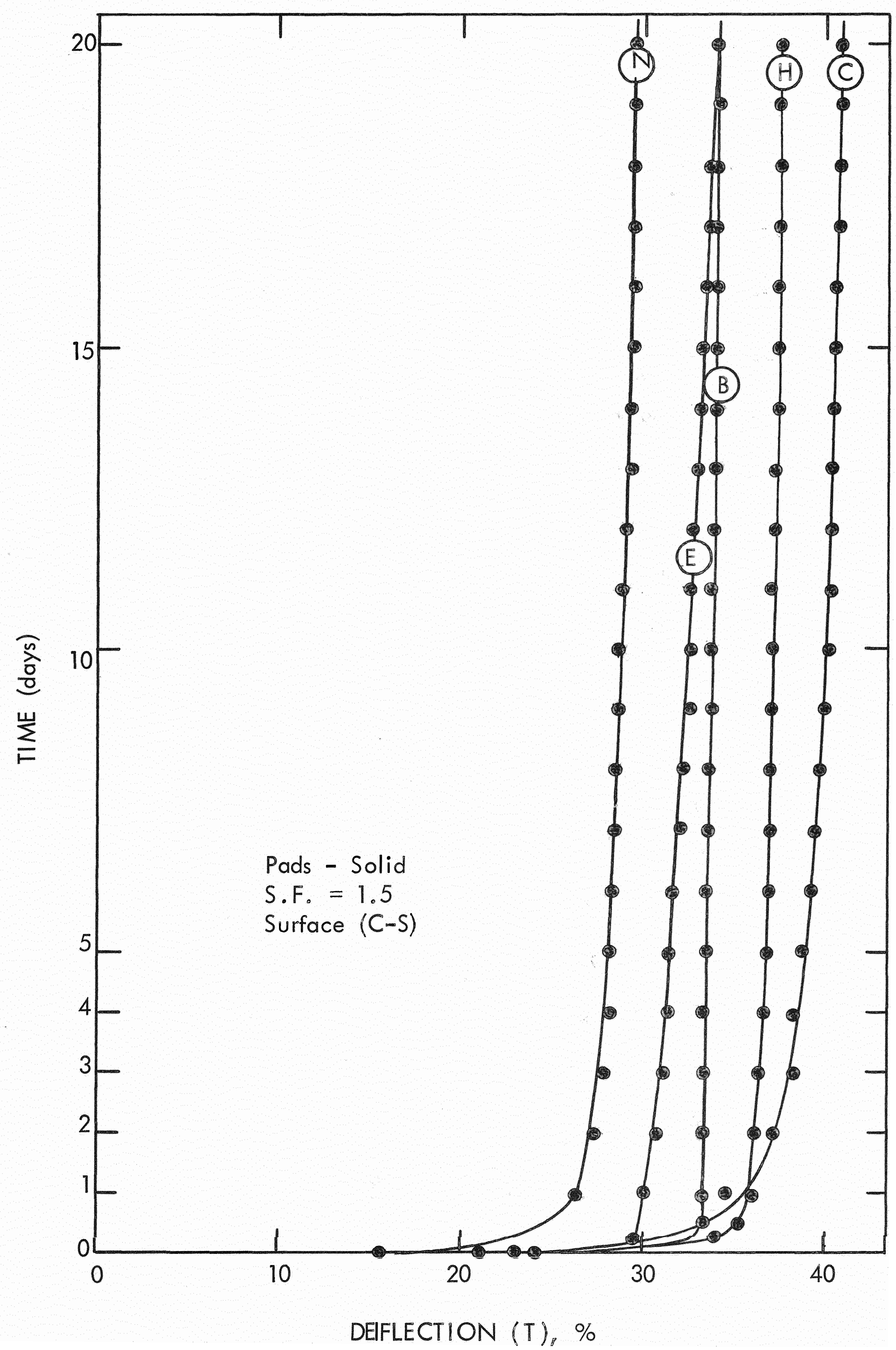


Figure 5.5 Comparison of total deflection for solid pads between C-S due to 500 psi constant stress.

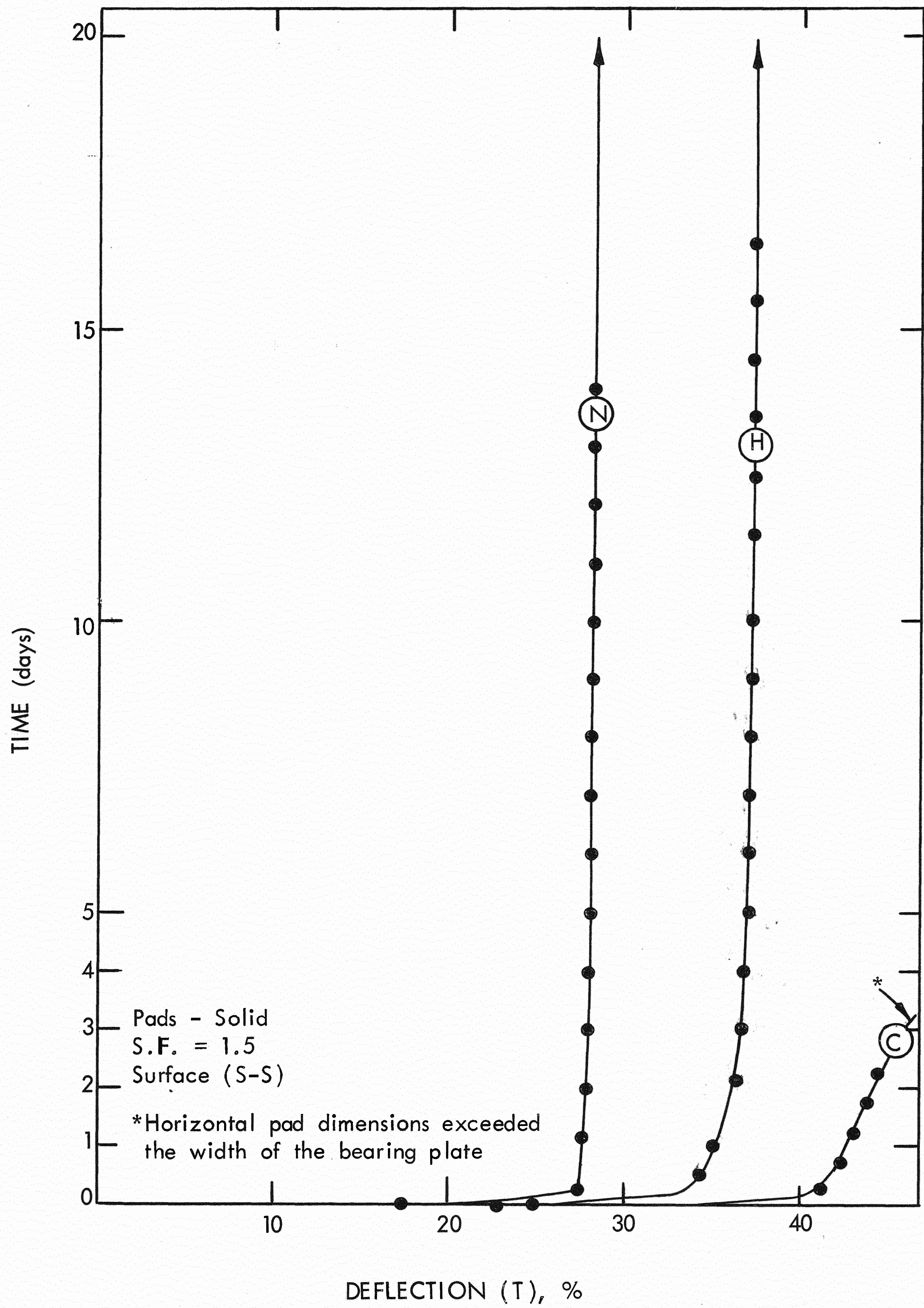


Figure 5.6 Comparison of total deflection for solid pads between S-S due to 500 psi constant stress.

several days under load. It has been reported (6.2) that this slow rate continues for approximately 100 days before approaching an asymptotic limit.

An unexpected total deflection response was observed for pads between S-S and C-S (see Figures 3.7 and 3.8). It was noted (Section 5.1) that larger short-time deflections occurred for pads between S-S than for pads between C-S. However, the roughness of concrete appears to affect only the short-time deflection since almost identical total deflection responses were observed for pads between S-S and C-S.

From Figure 3.9 it can be observed that deflections due to creep in the various materials for bonded pads resulted in a 15 to 35 percent increase above the short-time deflections. Comparatively, from Figure 3.10 unbonded solid pads between C-S exhibited a 65 to 95 percent increase above the short-time deflections.

Vertical deflections were significantly smaller for bonded pads than those occurring for solid pads. However, if this type of pad is required for field use, a laminated pad should be formed by a rubber fabricator, and field bonding is not recommended. An adequate bond of this type is difficult to obtain between steel plates , and the possibility of a bond failure would increase deflections appreciably (approximately 50 percent).

The relative order of the material deflections with reference to bonding, C-S, and S-S is listed in Table 5.1. In all tests neoprene was observed to deflect least while chlorobutyl incurred the largest deflections.

Rank	Bonded	C-S	S-S
1	N	N	N
2	E	E	H
3	B	B	C
4	H	H	
5	C	C	

Table 5.1 Increasing order of material deflections due to static creep (500 psi constant stress).

5.3 Repetitive Reversed Shear

A comparison of the vertical deflection responses for laminated and solid pads subjected to horizontal flexing is shown in Figure 5.7. Relative order of the material deflections is listed in Table 5.2. It should be noted that these observations were made with only one solid pad of each material. Similarly, the relative order of the deflections measured from the four laminated pads tested is listed in Table 5.3.

As previously mentioned, pad temperatures increased above room temperatures using a flexing rate of 10 cpm. Ozell and Diniz (20) used a non-reversed flexing rate of 120 cpm and noted the pads were warm to the touch, but never "hot". Suter and Collins (24) used a slower cycling speed of 2 cpm, and "completely prevented internal heat buildup". In discussing the Ozell and Diniz paper, McCready (13) commented, "it is safe to assume that considerable frictional heat developed which contributed to the failure of the neoprene pads. The rate of shear distortion of bearing pads in service would cause very little heat generation."

The writers feel that the temperature effects from the intermediate flexing rate (10 cpm) used for this study should not be disregarded. However, the rate

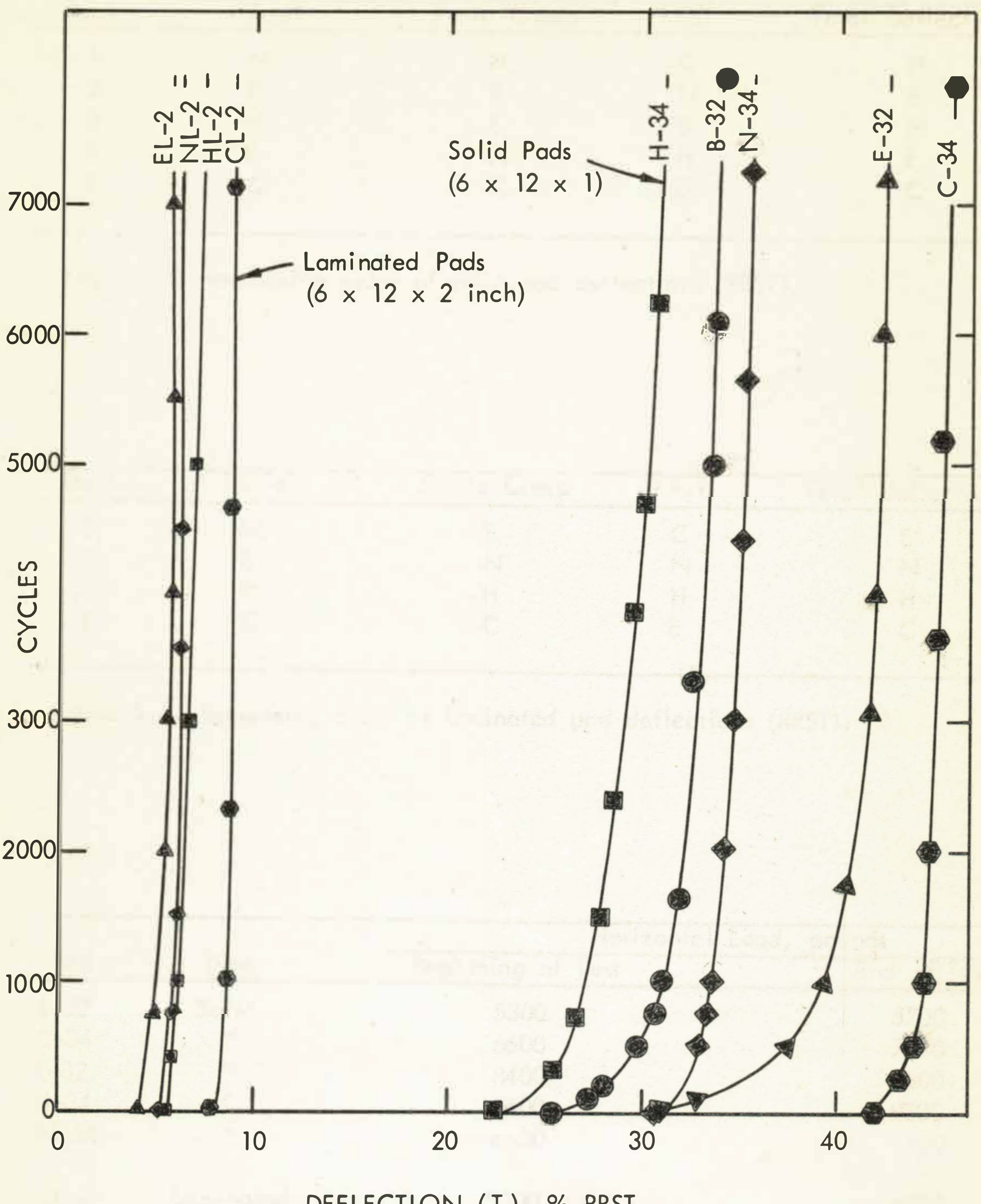


Figure 5.7 Comparison of vertical deflections measured during the application of horizontal load cycles.

Rank	Initial	Static Creep	RRST	Total Deflection
1	N	H	C	H
2	B	B	N	B
3	H	E	B	N
4	E	N	H	E
5	C	C	E	C

Table 5.2 Increasing order of solid pad deflections (RRST).

Rank	Initial	Static Creep	RRST	Total Deflection
1	N	E	C	E
2	E	N	N	N
3	H	H	H	H
4	C	C	E	C

Table 5.3 Increasing order of laminated pad deflections (RRST).

Pad	Type	Horizontal Load, pounds	
		Beginning of Test	End of Test
B-32	Solid	5300	5700
C-34	"	6600	7200
E-32	"	8400	9600
H-34	"	8400	9300
N-34	"	6600	7100
CL-2	Laminated	5300	4700
EL-2	"	7600	7200
HL-2	"	8600	7800
NL-2	"	7500	7000

Table 5.4 Repetitive reversed shear tests.

of flexing used in this study was selected in an effort to minimize the temperature effects and still complete the test in a reasonable length of time. By reference to Figure 5.7 it appears that significant vertical deflections were developed due to flexing (particularly for the solid pads). The writers are inclined to attribute these deflections to the method of test used, even though a relatively slow flexing rate was employede It should be noted further that fatigue tests for many structural materials are performed at high flexing rates, but fatigue results for elastomeric materials appear to be significantly biased by the rate of flexing.

The method of test employed in this study was to simulate the beam movement for a 120°F temperature change occurring daily during a 10 year period for 100 to 300 foot spanse Obviously, daily temperature differentials of this magnitude are not realistic, nor do the beam movements occur so rapidly. However, if a bearing pad can withstand the severity of this test, then it is not likely to fail under actual service conditions.

The abrasion of the sides of the solid pads resulted from the rubbing of the pad sides against the concrete bearing surface as the pad was subjected to horizontal flexing. This abrasion was generally negligible, and the chlorobutyl pad was most noticeably worn (Figure 4.13).

Some bearing surface abrasion was noted on all laminated pads. This abrasion was most prominent about one-half an inch inside the pad bearing surface edge (Figure 4.12). The hypalon pad received noticeably more surface abrasion than the other laminated pads and, in addition, exhibited extensive splits in the pad sides. Although this pad did not completely fail (become unserviceable), these side cracks potentially could be detrimental during the service life of the pad.

5.4 Summary

The results and comparisons of this study have shown that various materials exhibit virtually the same load-deflection responses. The current AASHO Specification sets design limitations based on initial deflections only. In Sections 5.1 and 2.4 it was shown that very little difference was observed in the deflection responses of butyl, EPT, hypalon, and neoprene (chlorobutyl exhibited greater deflections than all materials). In fact, if short-time initial deflections were the only design consideration, hypalon should be chosen for use because of the apparent smaller deflections. This rather obvious dichotomy is further emphasized in the conclusions to this report.

However, with reference to total deflection creep responses, (Figures 5.4, 5.5, and 5.6) neoprene exhibited the smallest deflection followed by EPT, butyl, hypalon, and chlorobutyl. It should be noted that these differences between material deflections were observed with a shape factor of 1.5 and less variation would occur with pads of a larger shape factor which would probably be used for field applications. To reiterate, virtually the same time-load-deflection responses were demonstrated by all of the materials tested (especially for the higher number shape factors).

The excessive horizontal deflections and the rate of flexing were undoubtedly much more severe than the conditions to be expected in the field. Therefore, it cannot be stated with certainty that hypalon could not serve satisfactorily as a bridge bearing pad. However, since the other materials were not noticeably damaged even due to the severity of the test, these materials appear more desirable than hypalon for pad usage.

In each series of tests chlorobutyl pads were observed to undergo larger vertical deflection than the pads of other materials. However, the low temperature flexibility of chlorobutyl as well as butyl (5) is a primary advantage over neoprene. If a bridge bearing will be subjected to extremely cold temperatures, this flexibility property gains significant importance over the slightly larger vertical deflections of butyl and chlorobutyl. No test results concerning the cold temperature behavior of EPT were available.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 General

The major objective of this study was to determine, analyze, and compare the load-deflection responses of five elastomeric pad materials. The conclusions and recommendations made herein are restricted to the scope of this study (Section 1.6), and no consideration was given to the probable effects of temperature and repetitive vertical load applications. However, the reader should be cognizant that these actual service condition parameters require further study.

Responses of the different materials were investigated using three basic methods of testing. Results of these tests were utilized to analyze and compare the overall behavior of the test pads (Chapter V). Comparison with published information was generally not possible due to various testing procedures employed and the sparse number of tests including materials other than neoprene.

6.2 Suggestion for Future Research

As mentioned in Section 5.2, the creep phenomenon of all elastomeric materials is lacking a common qualitative base or definition. Such a working qualitative definition is needed to correlate experimental work. Creep is highly responsive to stress level and temperature and needs further study.

The effects of millions of repetitive vertical loads applied during the life of bridge structure have only been tokenly studied (24). A definite problem exists in devising a representative test method since a considerable difference exists between a feasible method of test of reasonable time length and the rate of load application and beam movement under actual bridge conditions. Elastomers do not respond as typical structural materials and future test methods must closer approximate actual service conditions if test results are not to be highly biased.

Since no consistent mathematical relationship has been derived between shape factor, compressive stress, or any other parameters, present information is limited to empirical analysis. Work toward general analytical equations using the parameters mentioned above is needed for easier design of elastomeric bridge bearing pads.

6.3 Final Conclusions

The test data recorded herein is limited to room temperature studies. Noting the previous limitations (Section 1.7), the test results support the following conclusions:

1. The currently accepted relationship for compression-deflection characteristics that deflections increase with decreasing shape factors is valid for the materials and bearing surfaces studied.

2. All materials exhibit greater short-time deflections when the bearing condition is S-S and decrease in order when C-S, C-C, and bonding are employed. However, from static creep tests it is concluded that only the rate

of short-time deflections is greater for pads between S-S than between C-S, and combined pad deflection under load is approximately the same for both surfaces.

3. The effect of bonding greatly restrains lateral pad movement, and, as a result, short-time deflections and static creep deflections are significantly less than for unbonded solid pads subjected to similar stress conditions.

4. Static creep deflections increase significantly during the first few days under load.

5. Results of these tests have shown that static creep deflections are of considerable magnitude. Neither the current or Proposed AASHO Specifications stipulate any recognition for static creep effects, but it is obvious that these additional deflections are significant.

6. A limited number of rather severe horizontal flexing tests demonstrated that hypalon pads exhibited extensive bearing surface abrasion and splits in the pad sides. Since the other four materials were not noticeably damaged, hypalon is considered undesireable for bearing pad usage.

7. With the exception of pads compounded of hypalon, the effects of horizontal deflection movements will not cause concernable pad abrasion even if slippage occurs between the pad and the bearing surfacese

8. Solid pads as well as laminated pads (limitation for the use of laminated pads only in the Proposed AASHO Specification) can be used for bridge bearings. However, bonding solid pads to steel plates is not a recommended field procedure, but this process should be performed by a rubber fabricator.

9. Laminated pads exhibit more desirable load-deformation behavior than solid pads of the same plan dimensionse However, laminated pads are more

expensive than solid pads of the same volume.

10. The current and Proposed AASHO Specifications appear conservative for the limitations on vertical deflections. The initial deflection limit of 15 percent could reasonably be raised.

11. There appears to be no justification for the current stipulation made by AASHO that specifically bearing pads compounded of neoprene be used. Pads compounded of butyl, neoprene, EPT, and chlorobutyl (in order of preference) all demonstrate desirable load-deflection responses. The use of elastomeric bearing pads of these materials appears practicable.

6.4 Recommendation for Design Procedure

As discussed in Chapter V, the magnitude of vertical pad deflections is due primarily to short-time initial and static creep deflections. In order to determine total deflections for either solid or laminated pads, the engineer must use the appropriate design curves. Utilizing the test results and curves presented herein, the current AASHO Specifications, the Proposed 1965 AASHO Specifications, and suggestions from previous research, the following suggestions are made for a design procedure of elastomeric bridge bearing pads.

1. The maximum vertical compressive stress due to dead, live, and impact loads shall not exceed 800 psi.

2. Sustained vertical compressive stresses shall not exceed 500 psi due to dead load.

3. The minimum plan dimension of the pad shall be at least five times the thickness.

4. Solid pads shall be either 3/4 inch or one inch in thickness.

5. Individual laminations shall be at least 1/4 inch in thickness.

6. The maximum horizontal force developed from horizontal beam movement shall be calculated (see references 6.1 and 21).

7. Bearing stiffeners at the support shall be used with steel girders.

The selection of the pad dimensions can be determined by using the following procedure.

1. The pad dimensions should be a minimum of one inch less than the dimensions of the beam and the support.

2. The total pad area required is determined by the maximum loads to be carried by the bearing.

3. With the pad length, width, and compressive stress known, the required shape factor is determined from the appropriate compression-deflection curve by using a deflection less than 15 percent (T).

4. The required pad thickness is found by using Equation 1-1 rewritten as follows:

$$T = \frac{LW}{2(S.F.)\ (L + W)} \qquad (6\text{-}1)$$

5. The additional deflection due to static creep is calculated by assuming an asymptotic percent value from the appropriate static creep curve showing percent of initial deflection and multiplying this value times the short-time initial deflection.

BIBLIOGRAPHY

1. American Association of State Highway Officials. Standard Specification for Highway Bridges. American Association of State Highway Officials, pp. 81-83, 1961.

2. American Society for Testing and Materials. A. S. T. M. Standards. American Society for Testing and Materials, Part 28, 1965.

3. ASTM Committee D-11. Glossary of Terms relating to Rubber and Rubber-Like Materials. American Society for Testing Materials, Philadelphia, 1959.

4. Burton, W. E. Engineering With Rubber. New York: McGraw-Hill Book Company, Inc., 1949.

5. Clark, Earl V. and Kendall Moultrap. "Load Deformation Characteristics of Elastomeric Bridge Bearing Pads," Highway Research Record No. 34, pp. 90-116, 1963.

6. E. I. du Pont de Nemours & Co. (Inc.)
   6.1 Building with Elastomers, 1963.
   6.2 Design of Neoprene Bridge Bearing Pads (A-29619).
   6.3 Engineering Properties of Hypalon (A-23301).
   6.4 Engineering Properties of Urethane Elastomers (A-29569).
   6.5 Industrial Applications of Adiprene (A-28320).
   6.6 Nordel, An Engineering Profile (A-36228), 1964.
   Wilmington, Delaware, E. I. du Pont de Nemours & Co. (Inc.)

7. Enjay Laboratories. Shear Deflection of Elastomeric Bearing Pads as a Function of Ambient Temperature, ELD-40969, Enjay Laboratories Report, 1963.

8. Fairbanks, H. E. "Elastomeric Pads as Bearings for Steel Beams," Proc. American Society of Civil Engineers, Vol. 87, No. ST8, Journal of the Structural Division, pp. 73-85, December 1961. Highway Research Abstracts, Vol. 32, No. 3, p. 12, March 1962.

9. General Tire & Rubber Company. Laminated Rubber Bridge Bearing Design, Report No. 403 prepared by the General Tire and Rubber Company, Akron, 1960.

10. General Tire & Rubber Company. Standard Elastomeric Bridge Bearings-Design and Specifications, The General Tire & Rubber Company, Akron.

11. Goodyear Tire & Rubber Company. Handbook of Molded and Extruded Rubber, The Goodyear Tire & Rubber Company, 1959.

12. Lindley, P. B. Design and Use of Natural Rubber Bridge Bearings, Technical Bulletin No. 7, Natural Rubber Bureau, London, 1962.

13. McCready, S. D. Discussion of Report by Ozell and Diniz, Highway Research Board Bulletin 242, p. 26-27, 1960.

14. Engineering Uses of Rubber, Edited by A. T. McPherson and Alexander Klemin. New York: Reinhold Publishing Corporation, 1956.

15. Michner, P. Z. "Small Item Saves Big Money," Public Works, Vol. 96, No. 1-6, p. 143, June 1965.

16. Maguire, Charles A., and Assoc. Evaluation Tests of Elastomeric Bridge Bearings (Rubber-like materials - specifically "Neoprene" based). Providence, R. I., 1958, 67 p. (R. I. Highway Div. Study).

17. Ministry of Supply. Creep Phenomena - Natural and Synthetic Rubbers, Users' Memorandum No. U. 12, Ministry of Supply, Advisory Service on Plastics and Rubber (C. R. D. 4b), Berkeley Court, Glentworth Street, London, N. W. 1, 1945.

18. Nachtrab, William B. and Robert L. Davidson. "Behavior of Elastomeric Bearing Pads Under Simultaneous Compression and Shear Loads," Highway Research Record 76, 1965.

19. The Applied Science of Rubber, Edited by W. J. S. Naunton. London: Edward Arnold (Publishers) ltd., 1961.

20. Ozell, A. M. and J. F. Diniz (University of Fla.). "Reports on Tests of Neoprene Pads under Repeated Shear Loads," Highway Research Board Bulletin 242, p. 20-27, 1960.

21. Pare, R. L. and E. P. Keiner. "Elastomeric Bridge Bearing," Highway Research Board Bulletin 242, p. 1-19, 1960.

22. Proceeding of the Rubber in Engineering Conference. Natural Rubber Development Board. London, 1957.

23. Reécha, Charles. "Design of Elastomeric Bearing," Prestressed Concrete Institute Journal, Vol. 9, No. 5, p. 62-78, October 1964.

24. Sutter, G. T. and R. A. Collins (University of Toronto). Static and Dynamic Elastomeric Bridge Tests at Normal and Low Temperatures. Report No. 24 prepared as a part of the Ontario Joint Highway Research Programme, Toronto, 1964.

25. Zuk, Williams. "Bridge Vibrations as Influenced by Elastomeric Bearings," Highway Research Board Bulletin 315, p. 27-34, 1962.

APPENDIX A

PROPOSED AASHO "DESIGN" SPECIFICATION

1.6.47 - Expansion Bearings

Spans of less than 50 feet may be arranged to slide upon metal plates with smooth surfaces and no provisions for deflection of the spans need be made. Spans of 50 feet and greater shall be provided with rollers, rockers, or sliding plates for expansion purposes and shall also be provided with a type of bearing employing a hinge, curved bearing plates or pin arrangement for deflection purposes. Elastomeric bearings may also be used in agreement with the following definitions and criteria:

a) The relationship between the loaded face and the side areas is expressed as "Shape Factor". For rectangular shaped bearings with parallel loading surfaces

$$S = \frac{LW}{2t\ (L + W)}$$

Where S = Shape Factor
L = Length measured parallel to direction of travel
W = Width measured perpendicular to direction of travel
t = Functional rubber thickness - the thickness of one lamina or distance separating internal reinforcing plates

b) For non-reinforced bearings: Mine L = 5T, Min. W = 5T
For reinforced bearings: Min. L = 3T, Min. W = 2T

Where T = Total effective rubber thickness = Summation of "t's" plus the top and bottom skin thicknesses.

Bearings shall have built in taper when non-parallel load surfaces under dead load conditions produce 6% additional strain of "T". For bearings with built in taper (not over 5% slope to accomodate non-parallel load surfaces) "t" shall be the average thickness of the tapered lamina.

The average thickness of the top or bottom skin shall not be greater than "t".

c) The total of the positive and negative movements caused by anticipated temperature change shall not exceed one-half "T". Refer to TABLES A & B in "Material Specification for Elastomeric Bearings" for Shear Stress Values.

d) Average unit pressure on elastomeric bearings shall not exceed 800 psi under a combination of dead load plus live load, not including impact. The average unit dead load pressure shall not exceed 500 psi, nor be less than 200 psi. When dead load plus live load uplift reduce average unit pressure to less than 200 psi, the bearing shall be secured to the top and may be secured to the bottom surface; when secured to the bottom surface the bearing may take momentary light tension.

e) The initial deflection under dead load plus live load, not including impact, shall not exceed 7% "T", or including all deflection influences, such as impact, rotation and non-parallel load surfaces, the total strain shall not exceed a max. of 15% "T". The deflection can be determined by a plot of "Shape Factor" versus percent strain for the material of the hardness under consideration.

PROPOSED AASHO

"MATERIAL" SPECIFICATIONS FOR ELASTOMERIC BEARINGS

1. Elastomeric bearings shall be cast as a single unit including multiple layer bearings separated by non-elastic sheets to restrain deformation in thick bearingse

2. The elastomer compound shall meet the requirements as contained in either TABLE A or TABLE B.

TABLE A

ASTM Standard	Physical Properties	50 Duro	60 Duro
	Hardness ASTM-D676	50 ± 5	60 ± 5
	Tensile strength, min. psi ASTM-D412	2500	2500
	Ultimate elongation, min. %	400	400
	Heat Resistance		
A13 D573	Change in durometer hardness, max. points	+ 10	+ 10
70 Hr.	Change in tensile strength, max. %	- 25	- 25
@158°F	Change in ultimate elongation, max. %	- 25	- 25
B13 D395	**Compression Set**		
Method B	22 hours @ 158°F, max. %	25	25
C12	**Ozone**		
	25 pphm ozone in air by volume 20% strain	No cracks	No cracks
D1149	100°F ± 2°F, 48 hours, Mounting procedure D518, Procedure A.		
K21, D429, B	**Adhesion**		
	Bond made during vulcanization, lbs. per inch	40	40

Z_1	Low Temperature Test Bearing or sample preparation 96 hours @ -20°F ± 2°, axial load 500 psi and strain of 20% "T"*		
	Test Recorder shear resistance after (1) one hour (min.) at 25% shear strain psi shall not exceed	30	40

The above properties are equated to the ASTM Specification D2000-63T, Part 28 Line Call-Out, $4AA525A13B13C12K21Z_1$, for 50 durometer and $4AA625A13B13C12K21Z_1$, for 60 durometer.

TABLE B

ASTM Standard	Physical Properties	50 Duro	60 Duro
	Hardness ASTM-D676	50 ± 5	60 ± 5
	Tensile strength, min. psi ASTM-D412	2500	2500
	Ultimate elongation, min. %	450	400
	Heat Resistance		
A14 D573 70 hr. @212°F	Change in durometer hardness, max. points	+ 15	+ 15
	Change in tensile strength, max. %	- 15	- 15
	Change in ultimate elongation, max. %	- 40	- 40
B14 D395 Method B	Compression Set 22 hours @ 212°F, max. %	35	35
C12 D1149	Ozone 100 pphm ozone in air by volume 20 % strain 100°F + 2°F, 100 hours, Mounting procedure D518, Procedure A.	No cracks	No cracks
K21 D429, B	Adhesion Bond made during vulcanization, lbs. per inch	40	40

*Effective rubber thickness

Z_1 Low Temperature Test

Bearing or sample preparation
96 hours @ -20°F ± 2°, axial load 500 psi and strain of 20% "T".*

Test
Recorder shear resistance after (1) one hour (min.) at 25% shear strain, psi shall not exceed 50 75

The above properties are equated to the ASTM Specification D2000-63T, Part 28 Line Call-Out, 2BC525A14, B14, C12, K21, Z_1, for 50 durometer and 3BC625A14, B14, C12, K21, Z_1, for 60 durometer.

3. Each manufacturer shall qualify on the "Low Temperature Test" by submitting a curve or curves certified to the purchaser that the bearings meet the specified requirements.

4. Non-Elastic Laminations

The non-elastic laminations shall be rolled ASTM-A-36 mild steel or approved equivalent sheets of the thickness as shown on the plans.

5. Quality Assurance

The mechanical properties of the bearings shall conform to the following specifications under laboratory test conditions:

a) Compression strain of elastomeric bearings shall not exceed 5% effective rubber thickness at 500 psi nor 7% at 800 psi.

b) The shear resistance of the bearing shall not exceed 30 psi for 50 durometer or 40 psi for 60 durometer TABLE A compounds: nor 50 psi for 50 durometer or 75 psi for 60 durometer TABLE B compounds at 25% strain of the effective rubber thickness after an extended four-day ambient temperature of -20°F.

6. All tolerances, relative dimensions, finishes and appearance, flash, and rubber-to-metal bonding, shall meet the requirements as contained in TABLE C.

TABLE C

Symbol	Requirement
A3	Commercial dimensional tolerances, Table III, Page 15.

F3 Commercial finish, Table V, Page 20.

T.063 Tear trim tolerance no hand trimming required, Table VI, Page 23.

B2 Class 2, Method B. Minimum bond destructive value Table VII, Page 25.

Grade 2 Bond destructive value at 40 lbs. per inch Width, Table VIII, Page 25.

The above properties are equated to the Rubber Manufacturing Specification in the RMA Handbook 2nd Edition as follows: A3-F3-T.063-B2 Grade 2. RMA Association, Inc., 44 Madison Avenue. New York 22, New York, Price $1.50.

APPENDIX B

Static Tests

	Before Testing				After Testing			
Pad No.	L	W	T	SH	L	W	T	SH
11	6.02	3.04	1.05	60	6.04	3.01	1.07	58
12	6.04	3.00	1.05	60	6.04	3.01	1.05	62
21	9.10	4.54	1.02	60	9.13	4.56	1.05	56
22	9.14	4.60	1.04	60	9.15	4.65	1.05	56
31	12.08	5.99	1.04	61	12.32	6.12	1.02	54
32	12.02	6.01	1.03	60	12.31	6.07	1.03	54
33	11.98	6.01	1.05	60	12.24	6.13	1.02	55
34	12.08	6.05	1.03	59	12.28	6.15	1.02	55
41	15.08	7.53	1.05	58	15.12	7.55	1.05	56
42	14.99	7.60	1.04	58	15.02	7.63	1.06	55
51	17.99	9.00	1.09	60	17.98	8.97	1.11	58
52	17.97	9.01	1.08	60	17.97	9.00	1.10	57
61	20.13	10.11	1.05	59	20.17	10.14	1.10	57
62	20.10	10.10	1.07	60	20.07	10.07	1.08	58
L-2	12.02	6.00	1.90	56	12.05	6.03	1.95	53
L-3	18.06	9.00	2.95	57	18.07	9.02	2.95	55

Table B.1 Chlorobutyl pad properties.

Static Tests

	Before Testing				After Testing			
Pad No.	L	W	T	SH	L	W	T	SH
11	6.01	3.03	1.03	67	6.06	3.03	1.02	63
12	6.02	3.08	1.04	68	6.07	3.11	1.03	63
21	8.99	4.53	1.03	63	8.97	4.58	1.04	63
22	9.03	4.52	1.05	65	9.02	4.54	1.04	64
31	12.05	6.02	1.05	68	12.10	6.13	1.04	62
32	11.99	6.03	1.03	66	12.08	6.10	1.02	61
33	11.99	6.01	1.01	66	12.06	6.04	1.02	64
34	12.02	6.02	1.02	67	12.05	6.06	1.02	64
41	15.10	7.50	1.00	66	15.13	7.56	1.01	63
42	15.07	7.53	1.03	65	15.07	7.57	1.00	64
51	18.00	8.92	1.05	68	18.18	9.05	1.04	64
52	18.02	8.91	1.05	67	18.19	9.04	1.04	63
61	19.97	9.85	1.04	65	20.11	9.97	1.01	61
62	20.02	9.84	1.04	68	20.15	10.01	1.03	63
L-2	12.00	5.98	1.88	67	12.01	6.01	1.93	62
L-3	18.02	9.00	2.94	67	18.06	9.02	2.94	66

Table B.2 EPT pad properties.

Static Tests

	Before Testing				After Testing			
Pad No.	L	W	T	SH	L	W	T	SH
11	6.00	2.98	1.05	62	6.01	3.00	1.04	60
12	6.00	3.00	1.05	63	6.01	3.00	1.01	60
21	9.04	4.47	1.05	63	9.02	4.58	1.05	62
22	9.04	4.52	1.03	62	9.03	4.53	1.03	60
31	12.11	6.09	1.02	57	12.10	6.06	1.00	58
32	12.03	6.09	1.03	59	12.05	6.14	1.03	57
33	11.98	6.02	1.04	61	12.01	6.05	1.04	61
34	12.03	6.12	1.06	62	12.01	6.06	1.05	60
41	15.00	7.51	1.06	62	15.03	7.51	1.06	61
42	14.97	7.52	1.05	61	14.97	7.52	1.05	61
51	18.00	9.99	1.05	65	18.02	9.01	1.06	63
52	18.00	8.98	1.05	65	18.01	8.99	1.08	62
61	19.98	10.04	1.04	63	19.99	10.05	1.05	61
62	20.10	9.95	1.07	62	20.12	9.96	1.06	62
L-2	12.02	5.97	1.89	67	12.03	5.99	1.95	66
L-3	18.03	9.01	2.96	67	18.06	9.01	3.00	65

Table B.3 Hypalon pad properties.

Static Tests

	Before Testing				After Testing			
Pad Noe								
11	6.00	3.00	1.03	65	6.03	3.02	1.04	63
12	6.00	2.99	1.05	65	6.05	3.01	1.04	62
21	9.04	4.56	1.05	62	9.04	4.55	1.05	61
22	9.06	4.52	1.04	61	9.04	4.50	1.06	62
31	12.00	6.05	1.03	60	12.04	6.08	1.03	60
32	12.02	6.03	1.00	62	12.03	6.05	1.04	61
33	12.05	6.08	1.05	64	12.05	6.04	1.05	62
34	12.02	6.02	1.05	62	12.02	6.03	1.05	62
41	15.00	7.50	1.03	62	15.02	7.51	1.04	59
42	15.03	7.57	1.03	61	15.04	7.57	1.03	60
51	18.00	8.98	1.04	61	18.01	8.97	1.04	62
52	18.00	9.00	1.04	60	18.00	8.99	1.05	60
61	20.00	10.05	1.04	60	19.94	10.003	1.04	61
62	20.00	9.97	1.05	61	19.99	10.00	1.06	61
L-2	12.02	6.00	1.95	60	12.02	6.01	1.96	59
L-3	18.02	8.99	2.95	60	18.06	9.01	2.95	60

Table B.4 Neoprene pad properties.

Static Tests

	Before Testing				After Testing			
Pad No.								
11	6.03	3.0	1.00	62	6.03	3.01	1.02	57
21	9.00	4.50	1.03	60	9.00	4.47	1.05	55
22	5.90	5.85	1.00	60		Bonded		
31	11.85	5.96	1.00	56	11.87	5.97	1.01	55
32	11.80	5.80	1.02	63	11.88	5.80	1.03	58
51	11.88	11.80	1.00	61	11.90	11.82	1.02	60
52	11.78	11.81	1.00	59	11.83	11.87	1.02	57

Table B.5 Butyl pad properties.

APPENDIX C

Repetitive Reversed Shear

Standard Method of Test

1. Center steel bearing plate and roller assembly.
2. Adjust horizontal deflections to one-half the thickness of the pad used for the test.
3. Warm up strain indicator and set attenuator at 1.
4. Center 6 by 12 inch pad on lower concrete surface with plywood jig.
5. Apply a vertical load until the bearing plate and roller assembly is clear of support posts.
6. Adjust strain indicator for a reading of +25(10^{-6} in./in.).
7. Apply load until a strain of 000 is indicated.
8. Set vertical deflection dials at zero.
9. Apply a load of 36 kips in one minute; this corresponds to a strain indication of 700(10^{-6} in./in.), a pressure gage reading of 1830 psi, and a pad stress of 500 psi.
10. Record deflections at 1,2,3,5,10,15 and 30 minutes.
11. Increase the load for a pad stress of 700 psi for the overnight static creep.
12. After approximately 12 hours of creep, reduce the stress level to 500 psi and hold for an additional hour.
13. Warm up electronic recorder.
14. Check the zero setting on the following: recorder, cycle counter, and electrical pump pressure gages.

15. Tighten bearing block bolts in sequence.

16. Record time and begin horizontal cycling.

17. Record horizontal forces for ten seconds and maintain constant vertical stress.

18. Run 33 cycles, stop horizontal bearing plate in center position, loosen bearing block bolts, check vertical stress level, and read vertical deflection gages.

19. Repeat steps 16, 17, 18 and increase the number of cycles in step 19 to 67, 100, 200 . . . until the desired number of cycles are run.

20. Plot deflections during test.

A test run of 7200 complete reversed cycles on 6 x 12 x 1 inch solid pads generally required 12 hours of continuous running. An increase in the horizontal travel for 6 x 12 x 2 inch laminated pads increased the testing time only slightly.

APPENDIX D

Representative Standard

Test Results Supplied by Fabricators

Physical Properties	Material				
	Butyl	Chlorobutyl	EPT	Hypalon	Neoprene
Hardness, Shore, A	60	58	60	63	58
100% Modulus, psi	210	273	213	836	223
200% Modulus, psi	-	691	426	1819	463
300% Modulus, psi	1010	1163	853	-	962
Tensile Strength, psi	2930	1654	2667	1819	2555
Elongation, %	650	450	633	200	516
Compression Set B % 22 hours at 158°F	15	8.8	24.6	30.2	14.5