Tests on Five Elastomeric Bridge Bearing Materials

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Solid, bonded, and laminated elastomeric bearing pads made of neoprene, butyl, HYPALON®, EPT, and chlorobutyl with shape factors ranging from one to six were subjected to a series of three specific tests to determine their respective load-deformation characteristics. Compression-deflection tests were conducted to determine short-time load-deflection responses for solid bonded and laminated pads placed between bearing surfaces of concrete-and-concrete, concrete-and-steel, and steel-and-steel. Additional vertical deflections due to static creep in the pad materials (loaded in compression) 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 bearing pads loaded by constant vertical compressive force. Neoprene, butyl, EPT, and chlorobutyl are recommended for use as bridge bearing pads. The only material rejected (HYPALON) as a result of the tests also failed to meet AASHO materials specifications. Bonded and laminated pads are recommended where economically practicable. The effect of contact surface type, in which friction provided the restraint, appeared to be insignificant for normal surface conditions except in the case of short-time deflections. Further suggestions include the need of allowance for static and dynamic creep.

•IN recent years elastomeric materials have become quite popular with bridge designers throughout the world (1). The obvious advantages of comparative low maintenance costs and simplicity of construction have been primary considerations in this change in design procedure. On the other hand, the individual designer has been faced with a shortage of reliable design guides and has been forced to resort to the findings of rubber producing companies. In this connection the research is voluminous and of long standing (2), but in general very little of this research has been directed toward the problems peculiar to bridge bearing applications. Further, it is not surprising that the development of reliable design guides has progressed almost cautiously when one considers the nonconformity of these synthetic rubbers to the normal concepts of small deflection theory applicable for common building materials. Significant variations include very high ultimate elongation, very low modulus of elasticity, and high modulus of resilience of elastomers as well as greater sensitivity to time dependent phenomena such as creep and aging.

SUMMARY OF PREVIOUS RESEARCH

Maguire (3) and Pare and Keiner (4) were early investigators concerned with the applications of elastomers as bridge bearing pads. These works were concerned with evaluations of the physical properties of the materials and the development of design criteria. Ozell and Diniz (5) conducted studies on the fatigue characteristics of neoprene subjected to repeated shear loadings. Lucas (6) tested laminated rubber and steel bridge bearings at temperatures down to -60 F, and Suter and Collins (7) have reported the results of tests carried out at the University to Toronto concerned with the stress-strain

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TABLE 1

CHEMICAL DESCRIPTIONS OF THE ELASTOMERIC MATERIALS

Material	Chemical Description
Butyl rubber	Copolymer of isobutylene and isoprene
Chlorobutyl	Chlorinated modification of the basic butyl rubber structures
EPT	Ethylene-propylene terpolymer
HYPALON	Chlorosulfonated polyethylene
Neoprene	Polymerized 2-chloro-1, 3-butadiene

behavior of various elastomers subjected to static and dynamic loading in compression and shear at temperatures down to -40 F. Recent reports in German have been concerned with various specialized applications (8, 9, 10, 11). Clark and Moultrop (1) reported the results of tests on the load-deformation characteristics of butyl, chlorobutyl, and neoprene at reduced temperatures. Nachtrab and Davidson (12) investigated the load-deflection responses of elastomers subjected to simultaneous compressive and shear loads.

In summary, the work cited has been concerned with investigations of the load-deformation responses of selected elastomers under compressive and cyclic shearing loadings for conditions of room temperature and at reduced temperatures. There is reason to doubt that the accelerated loading techniques employed in some of these tests are fully representative of the actual environment of the pads in the field due to the magnification of responses due to creep of the materials. Athough shape factor (ratio of one loaded area of pad to the total laterally unsupported area of pad) and hardness of pad have been studied widely, the maximum thickness investigated was 2 in. overall (7). Assuming a maximum usable lateral deformation of one-half the thickness, the investigations have in turn limited the applications (without extrapolation) to that of approximately a 100-ft span subjected to moderate temperature change.

MATERIALS TESTED

The bridge bearing materials tested for this study were neoprene, butyl, HYPALON,* EPT, and chlorobutyl. The chemical compositions and the physical properties of the materials tested are given in Tables 1 and 2, respectively. The physical properties were determined by the manufacturers using the applicable ASTM test methods. Pads were tested which were solid precut, bonded to thin steel shims, and laminated. The solid pads were supplied by the fabricators with the selected nominal dimensions. The bonded pads were formed in the laboratory by bonding oversize gage 11 steel plates to each preroughened bearing surface of a pad. Each unit was held under a light load for

TABLE 2

PHYSICAL PROPERTIES[a] OF THE ELASTOMERIC MATERIALS

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

[a] Supplied by manufacturers.

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*DuPont's registered trademark.

TABLE 3

INDEX OF PARAMETERS

Item	Compression-Deflection	Static Creep	Repetitive Reversed
Material	Butyl, HYPALON, Neoprene, Chlorobutyl, EPT	Butyl, HYPALON, Neoprene, Chlorobutyl, EPT	Butyl, HYPALON, Neoprene, Chlorobutyl, EPT
Pad type	Solid Bonded Laminated	Solid Bonded	Solid Bonded
Contact surfaces	Concrete-and-concrete Concrete-and-steel Steel-and-steel	Steel-and-steel Concrete-and-steel	Concrete-and-steel
Shape factor	1.0 2.5 5.0 1.5 3.0 6.0 2.0 3.3	1.5	1.0 2.0 6.0

48 hours to allow the epoxy adhesive to harden. The laminated pads were molded by the fabricators.

SCOPE

The test program for this study was developed in three phases: compression-deflection, static creep, and repetitive reversed shear. The parameters included in each phase (Table 3) were selected to represent a wide range of possible applications. All tests were performed at room temperature.

TEST PROGRAM

Compression-Deflection Tests

Compression-deflection characteristics were determined by applying loads which were approximately uniformly distributed over the bearing surfaces. The compressive loading force was applied with a 200-kip universal testing machine. The calibration of the test machine was checked periodically during the test program with an eight SR-4 strain gage self-compensating load cell and a hand operated hydraulic jack. Consequently, a three-way static check was maintained.

The bearing blocks were designed to utilize the platens of the testing machine. These bearing blocks were alternated using steel or concrete contact surfaces depending on the surface condition being studied. Deflections due to compressive forces were measured to the nearest 0.001 in. with four dial gages, which were bolted to brackets on the upper bearing blocks and positioned two each on opposite sides near the corners.

A near constant rate of stressing was selected and adjusted so that each pad was loaded from 0 to 1000 psi in approximately 2 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 1 to 10 minutes. The pad was then unloaded with loads and deflections being recorded in the same manner as for the loading procedure. Measurements of pad dimensions were taken after the specimen had been unloaded for approximately 15 minutes.

Static Creep Tests

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 with 1.5 shape factor were held at this stress level for 1 and 3 weeks, respectively. The loading frame was equipped with four dial gages mounted on the upper platen to measure vertical deflections.

An initial load corresponding to a pad stress of 10 psi was applied. The time was recorded, and the total load was applied in 1 minute at an approximately uniform rate. The hydraulic hand pump was constantly attended during the following 15 minutes to

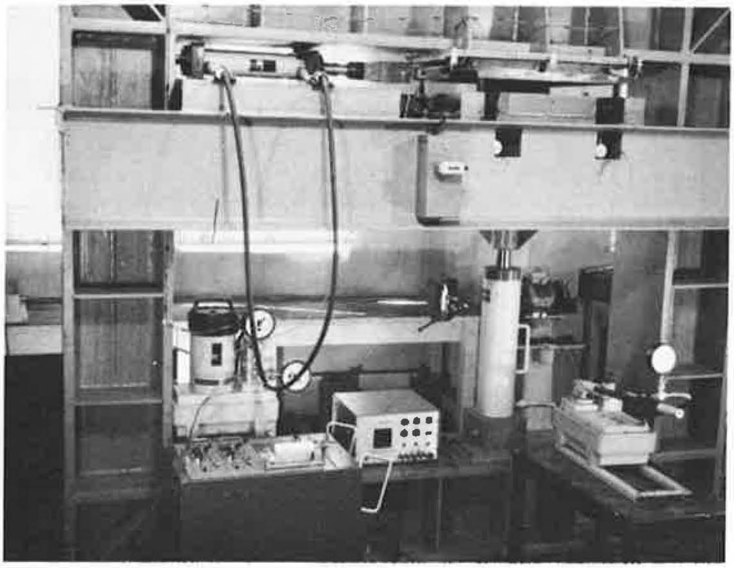


Figure 1. Loading frame and instrumentation used for repetitive reversed shear tests.

maintain a near constant pad stress of 500 psi. Deflection readings were taken at intervals of 1, 2, 3, 5, 7, 10, and 15 minutes. Deflection occurring after the first 15 minutes of loading proceeded at a much slower rate. Hence, constant attendance was not necessary, and loads and deflections were checked periodically during the first 24 hours. For the remainder of the test period, daily minor load adjustments were made and deflections were recorded.

Repetitive Reversed Shear

The loading frame (Fig. 1) was designed for the primary purpose of applying simultaneously vertical loads and repetitive reversed horizontal loads. Repeated reversed horizontal shear forces were applied to 6 by 12-in. 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. 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.

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 number of complete reversed horizontal force cycles was recorded by an automatic electric counter. An alternate check of the vertical compressive load was maintained with a calibrated load cell. A tension-compression load cell and electronic recorder were used to monitor the horizontal loads.

Since the test procedure was complex, a standard method of testing was developed (13). In general, each pad was subjected to a vertical stress slightly in excess of 500 psi for a 12-hr period preceding the test. This conditioning of the pad was done to eliminate—as much as possible—the continued vertical deflections due to static creep. During the test the vertical stress on each pad was monitored and maintained near a constant level of 500 psi. The horizontal movement of the top bearing plate was adjusted to cycle alternately forward and backward relative to the initial center position a distance equal to one-half the nominal uncompressed pad thickness. The rate of horizontal load application was timed at approximately 10 cpm. The test was continuous except for brief interruptions to record deflections.

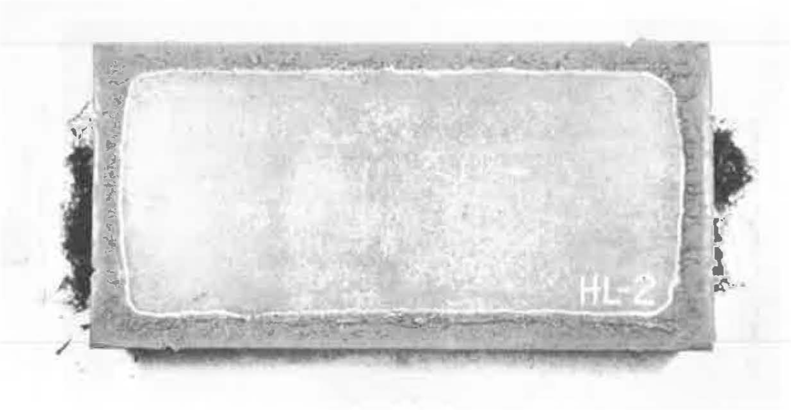


Figure 2. Surface abrasion effects due to the concrete bearing surface—chalked line denotes the inner edge of the most severe surface abrasion.

EFFECT OF SURFACE CONDITION FOR CYCLIC LOADING

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. 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 slippage.

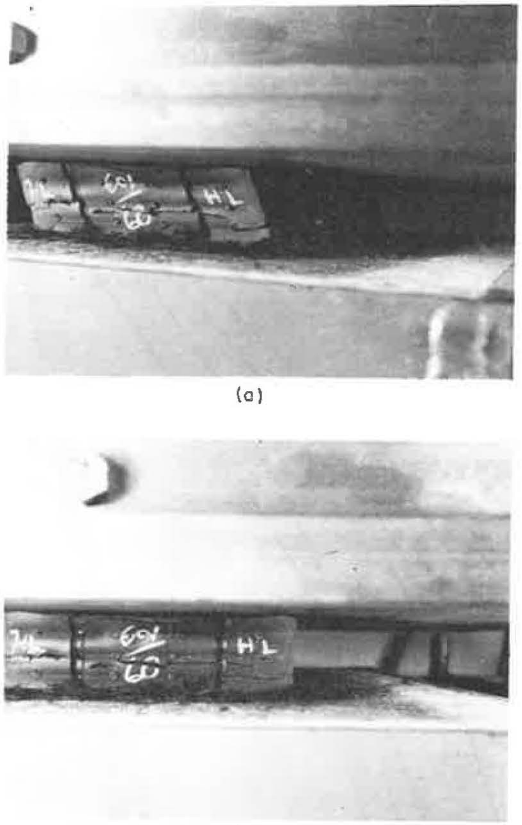
Surface slippage produced two kinds of abrasion effects. Solid pads received noticeable abrasion on the pad sides parallel to the horizontal movements. This action was due to the rolling under of the pad edges. Laminated pads exhibited a bearing surface abrasion rather than on the sides. This bearing surface abrasion was more extensive where the contact surface was concrete (Fig. 2).

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

The magnitude of the horizontal flexing force required to induce the fixed displacement was found to increase slightly with the number of repetitive cycles on all solid pads. Conversely, this force decreased in magnitude on all laminated pads. Although all solid and laminated pads were each subjected to constant reversed deflections equaling one-half the nominal pad thickness, the magnitude of the forces required varied with the different materials.

The damaging effects of the abrasion to the solid pads showed no correlation, except for varying degrees of side abrasion to all pads. The neoprene pad exhibited only a slight crack on the short side, but a larger split was produced at an irregular pad trimming location on the long side. An extremely large split in the HYPALON pad extended from the long edge into the center of the pad at an angle of approximately 30 degrees. Permanent deformation of the chlorobutyl pad bearing surfaces resulted in a slightly trapezoidal shape. The butyl and EPT pads were not noticeably affected 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 noticeable side cracks (Fig. 3). The development of these cracks did not lead to pad failure, but in actual service conditions, the presence of these cracks could seriously limit pad life.


(a)

(b)

Figure 3. Views of side splits in the laminated HYPALON pad: (a) loaded, and (b) unloaded.

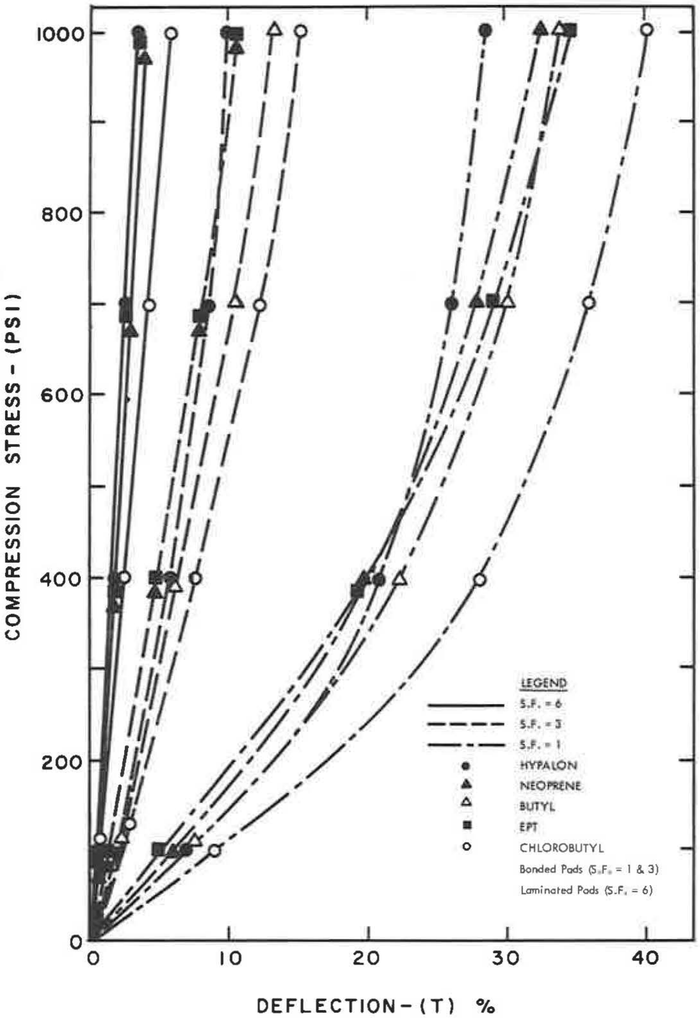


Figure 4. Comparison of compression-deflection characteristics for bonded and laminated pads of all materials.

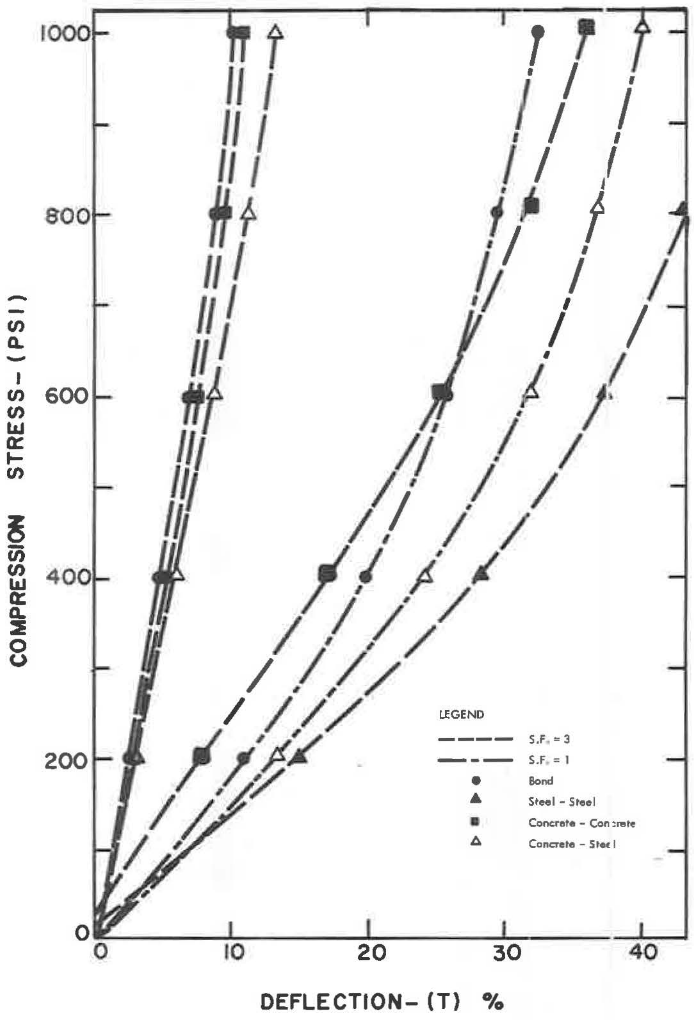


Figure 5. Comparison of neoprene pads for surface conditions of steel-and-steel, concrete-and-steel, concrete-and-concrete, and bonded.

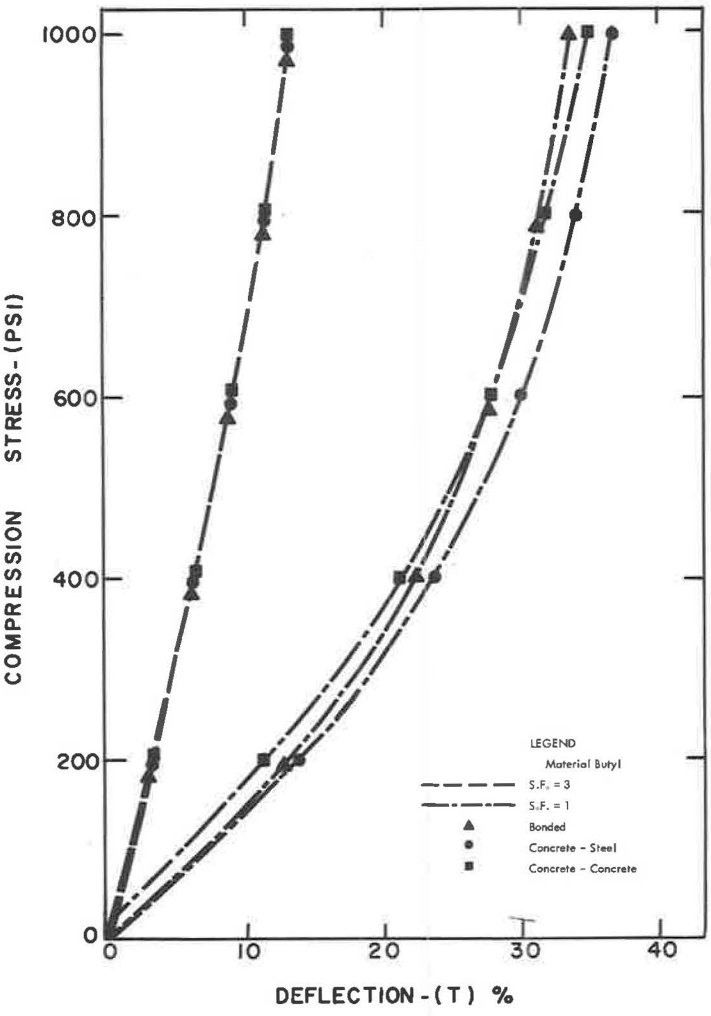


Figure 6. Comparison of butyl pads for surface conditions of concrete-and-steel, concrete-and-concrete, and bonded.

LOAD DEFORMATION RESPONSES

Compression-Deflection

The short-time load deformation responses of bonded and laminated pads were used to compare pad materials of three shape factors (Fig. 4). The following can be observed:

1. Vertical deflections decrease as shape factors increase;
2. Deflections for pads of the low number shape factors demonstrate greater sensitivity (more scatter) under load;
3. An approximate linear compression-deflection relationship is exhibited by the higher number shape factors, whereas the relationship for pads with a shape factor of one is definitely nonlinear;
4. Chlorobutyl is more sensitive to load than the other materials regardless of shape factor; and
5. In changing from a shape factor of 6 to 1 there is approximately a six-fold increase in deflection, from 6 to 3 a two-fold increase, and from 3 to 1 less than a two-fold increase. A shape factor of three is about the highest practicable for solid pads that can be placed under a standard bridge girder.

A comparison of neoprene and butyl (Figs. 5 and 6) demonstrates the effect of surface conditions on vertical deflections. Much larger deflections occur for pads between steel-and-steel, and deflections decrease in order when the surfaces are concrete-and-steel, concrete-and-concrete, and bonded. Since bearing pads may be used in conjuction with concrete or steel bridge girders and concrete abutments, it appears that very similar deflection responses will occur for either condition.

Finally it should be emphasized that these compression-deflection tests indicate that all materials tested exhibit virtually identical responses to short-time loadings for shape factors of 3 or greater.

Static Creep

The total deflection responses of the pads investigated for static creep are shown in Figures 7 and 8 where a difference in the rate of deflection was observed during the first 3 days under load. 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 several days under load. It has been reported (14) that this slow rate continues for approximately 100 days before approaching an asymptotic limit.

By eliminating the intial (short-time) deflections from the total deflections (Figs. 7 and 8) the additional deflections due to static creep may be obtained. For the bonded pads these additional deflections ranged from 15 to 35 percent of the initial deflections. Comparatively, for the unbonded solid pads the range is 65 to 95 percent. Therefore, the effects of static creep can be significant and should not be ignored; particularly for the case of unbonded pads.

Repetitive Reversed Shear

A comparison of the vertical deflection responses for laminated and solid pads subjected to horizontal flexing is shown in Figure 9. These deflections occurred as a result of the repetitive flexing (assuming that the short-time and the principal part of the static creep deflections had already taken place). Thus, the deflections are referred to as dynamic creep deflections.

During these tests the surface temperatures of the pads increased from 8 to 14 F. The authors feel that the temperature effects from the intermediate flexing rate (10 cpm) used for this study should not be totally disregarded. However, the rate of flexing was selected in an effort to minimize the temperature effects and complete the tests in a reasonable length of time. The method of test employed was designed to simulate beam movement for a 120 F temperature change occurring daily during a 10-yr period for 100 to 300-ft spans. Obviously, daily temperature differentials of this magnitude

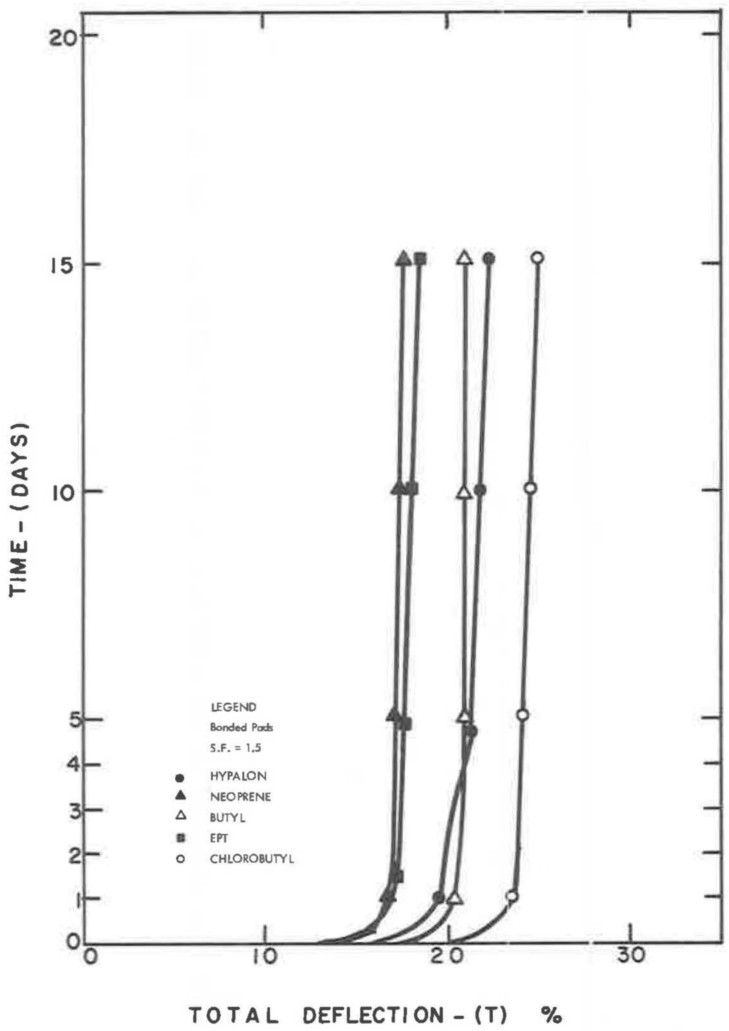


Figure 7. Comparison of total deflection for bonded pacs due to 500 psi constant stress.

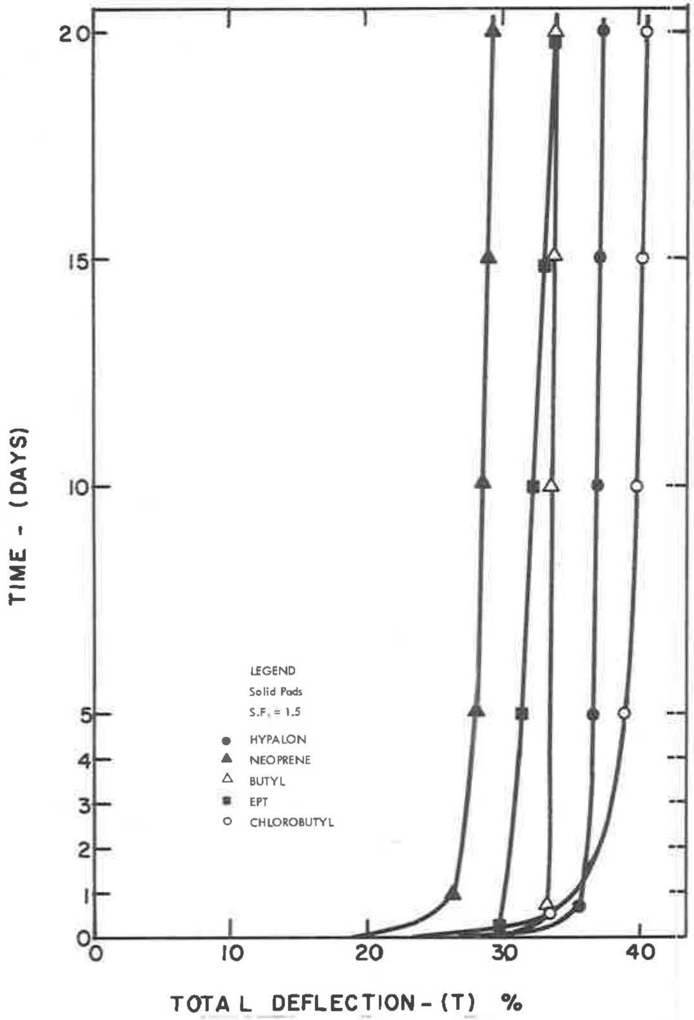


Figure 8. Comparison of total deflection for solid pads between concrete-and-steel due to 500 psi constant stress.

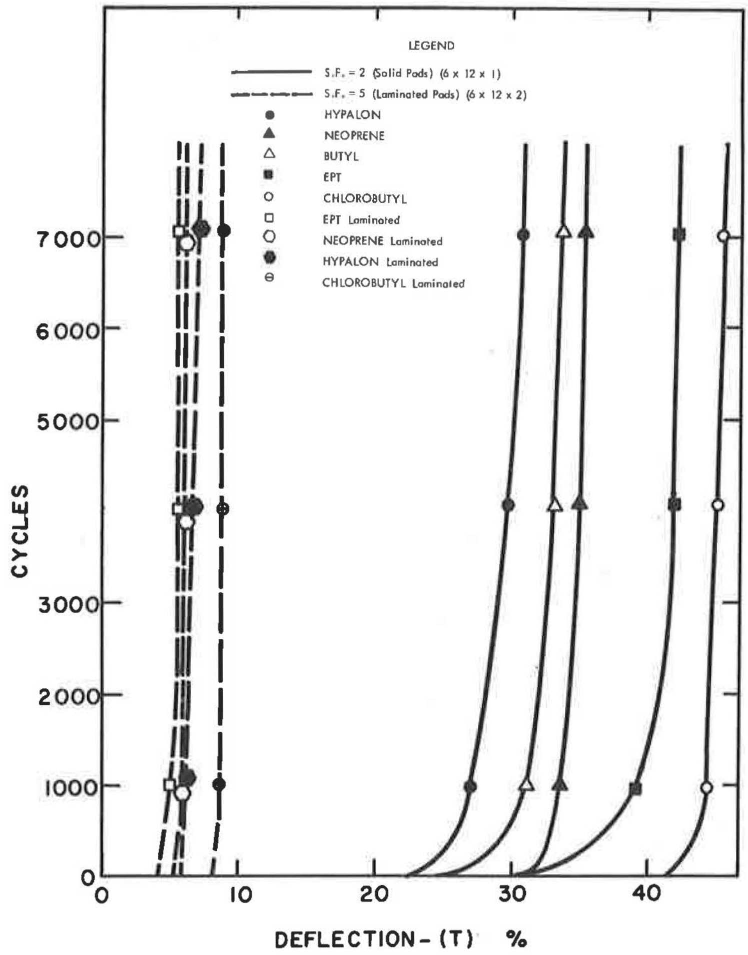


Figure 9. Comparison of vertical deflections measured during the application of horizontal load cycles.

are not realistic, nor do the beam movements occur as rapidly as in the simulation. However, it was assumed that, if a bearing pad could withstand the severity of this test, then failure was not likely under actual service conditions.

Finally, it should be noted that dynamic creep deflections, possibly extreme in this case, may be of considerable magnitude.

SUMMARY

The results and comparisons of this study have shown that the materials tested exhibit virtually the same load-deflection characteristics. 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 later in this report.

However, with reference to total deflection creep responses, neoprene exhibited the smallest deflection followed by EPT, butyl, HYPALON, and chlorobutyl. 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 under these severe test conditions, these materials appear more desirable for pad usage. HYPALON was the only material tested that did not meet the AASHO materials specification.

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 (14) is a primary advantage over neoprene. If a bridge bearing will be subjected to extremely cold temperatures, this flexibility property could be a definite asset.

CONCLUSIONS

Noting the limitations previously given, 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 steel-and-steel and decrease in order when concrete-and-steel, concrete-and-concrete, and bonding are employed.
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. Results of these tests have shown that static and dynamic creep deflections are of considerable magnitude; thus, these deflections should be considered by the designer.
5. With the exception of pads compounded of HYPALON, the effect of horizontal deflection movements will not cause concernible pad abrasion even if slippage occurs between the pad and the bearing surfaces.
6. Laminated pads exhibit more desirable load-deformation behavior than solid pads of the same plan dimensions. However, currently, laminated pads are considerably more expensive than solid pads of the same volume.
7. Pads compounded of butyl, neoprene, EPT, and chlorobutyl all demonstrate acceptable load-deflection and abrasion characteristics.

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