Summary Report

Bearing Pads for Precast Concrete Buildings

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Bearing pads are essential in constructing precast concrete buildings.

They provide two functions:

- To obtain uniform distribution of concentrated loads.
- To allow horizontal and rotational movement and hence minimize the detrimental effects from shrinkage, creep and temperature.

While bearing pad problems and failures have occurred due to poor materials or improper use of certain bearing pads, the majority of experience has demonstrated their beneficial effects.

Elastomeric bearing pads can be divided into two general groups: unreinforced or plain pads and reinforced pads made of elastomer reinforced with various materials such as steel, fabric or fibers. Large, steel reinforced, laminated pads are used in bridge bearings. This type is not used in building construction and is not discussed in this paper.

A number of other materials such as plastic, steel, bituminous joint filler and wood have also been used as bearing pads and Teflon or TFE (polytetrafluoroethylene) is used in combination with other materials to provide a low-friction bearing.

One of the difficulties in designing small elastomeric bearing pads for buildings is trying to generalize the properties of pads which are made by a large number of companies producing similar appearing products but which often have different physical properties.

NOTE: This Summary Report is a condensation of Technical Report No. 4, "Criteria for Design of Bearing Pads," a study sponsored by the Prestressed Concrete Institute. The investigation was conducted by Wiss, Janney, Elstner Associates, Inc., Northbrook, Illinois. The full report (118 pp.) is available from PCI Headquarters upon request at a cost of $30 per copy; $15 to PCI members.

Generally, a few large chemical companies produce the basic raw elastomer, but they do not produce the final product. The actual manufacturing is performed by the pad producers, who buy the raw material, formulate it with fillers and enhancers, vulcanize it with or without reinforcement, and cut the final pad. This company may in turn sell the pads to suppliers or distributors and the designer may find it difficult to determine the actual composition and mechanical properties.

The work reported in this summary report was accomplished as a research project for the Prestressed Concrete Institute. The complete project included surveys of selected PCI producer members and bearing pad producers for information; visits to five cities to investigate pad problems; review of current design information on pads; limited laboratory testing; and preparation of recommended pad design procedures for inclusion in the Third Edition of the PCI Design Handbook. The full length report is available from PCI Headquarters (see Note on opposite page).

REVIEW OF CURRENT PRACTICE AND PROBLEMS

Materials

Chloroprene or styrene-butadiene or a combination of these two elastomers are used in the majority of pads. The elastomer is combined with inert filler materials, such as carbon black and clay and other materials may be added for color or ozone resistance.

The AASHTO Specifications, Section 25, requires that "the elastomer portion of the elastomeric compound shall be 100 percent virgin natural polyisoprene (natural rubber), meeting . . . , or 100 percent virgin man-made chloroprene (Neoprene) meeting . . . " Natural rubber is not commonly used in the United States. Chloroprene is the only man-

SUMMARY AND CONCLUSIONS

A study of elastomeric bearing pads for use in precast concrete building construction was undertaken. This work included a survey of PCI producers to identify problems and practices, and a review of recent literature. Limited laboratory testing on unreinforced chloroprene (Neoprene) pads, and on random oriented fiber and duck layer reinforced elastomeric pads was undertaken with respect to long-term compressive creep, shear-compression, and uniform and nonuniform compression. Parking structures in five cities were inspected to determine actual field performance of bearing pads under out-of-door conditions. As a result of this work, new design recommendations have been provided for use in PCI literature.

Bearing pad thickness design has been modified to allow thinner pads with subsequently larger shape factors, generally based upon allowing the pad thickness to be 1.4 times the anticipated movement of the end of the precast member. Previous design concepts generally required 2.0 times the end-of-member movement for the pad thickness.

A design chart, based on laboratory tests, for estimating maximum friction forces on small pads is presented. These values are based on the work that illustrates that at compressive stresses over 400 psi (2.8 MPa), slippage of the unreinforced chloroprene and random fiber reinforced pads will occur at lower shear forces than assumed in design practice in the past.

A simple fire test to give a preliminary indication that a Neoprene pad contains only chloroprene as its elastomer has been identified.

made elastomer allowed by the AASHTO Specifications. Chloroprene or polychloroprene is a generic name for a material manufactured and patented by DuPont under the trade name Neoprene. With normal use of fillers and other additives the chloroprene will account for about 50 percent of the volume of an AASHTO-grade chloroprene pad.

The use of styrene butadiene (SBR) elastomer results in a less expensive and generally a less resilient and durable plain pad. Pads are also produced that contain a combination of chloroprene and other elastomers, most often SBR, and the properties and durability of these combination pads can vary. Unreinforced pads manufactured with other than 100 percent chloroprene elastomer are commonly called commercial grade pads and these have often exhibited problems.

The action of compressive load on unreinforced elastomeric pads will cause them to enlarge or bulge as shown in Fig. 1. This phenomenon leads to the use of a "shape factor" in determining the pad load capacity. The shape factor is defined as the loaded area divided by the area of the unconfined edge or the total area free to bulge. This ability of the elastomer to flow or act similarly to an inflated inner tube leads to many of its desirable qualities.

Such pads can accommodate small irregularities in the loading surfaces, absorb small amounts of rotation and horizontal movement and support high compression loads. This flowability can also contribute to slippage problems. The designer's task is to choose a pad that will take the loads and movements without excessive deformation, gross slippage or cracking.

Duck layer, fabric reinforced pads are generally produced with chloroprene or nitrile elastomers used to bond closely spaced horizontal layers of duck fabric material. These pads are more costly and have much higher compressive load capacities than unreinforced pads since the fabric reinforcing minimizes bulging and deformation. Shear, rotation and irregularities are less easily accommodated than with unreinforced chloroprene pads.

Random oriented fiber reinforced pads are generally produced from excess virgin tire material. The material is processed by chopping the tire reinforcing fibers, adding ozone retardant and then, vulcanizing into sheets which are cut to size. The random fiber reinforcement reduces the bulging characteristic and allows higher compressive loads, but the material is somewhat stiffer and accommodates irregularities, rotation and shear movements somewhat less easily. Variability as to fiber type (nylon, rayon, etc.), fiber distribution and elastomer composition occurs with this type of pad.

Plastic is not commonly used for bearing pads except under concrete slabs and planks. It is used for shims under precast panels and columns. This material is considered advantageous for shims because it does creep slightly and will transfer load to the grout bed. This material does not bulge and has extremely high compressive load capability. It is relatively hard and has little ability to conform to surface irregularities, rotations or shear movements.

Steel pads are used in heated buildings where movements will be a minimum and where little surface irregularity is encountered. They also are used for shims. The steel has very high compressive load capability, but no ability to accommodate surface irregularities, rotation or horizontal shear. If used as shims it does not creep to allow transfer of load to grout, and spalling at the shims may result.

TFE or Teflon is often used with stainless steel to provide an extremely low friction surface that can slip to accommodate horizontal movement and still transfer high vertical loads. This

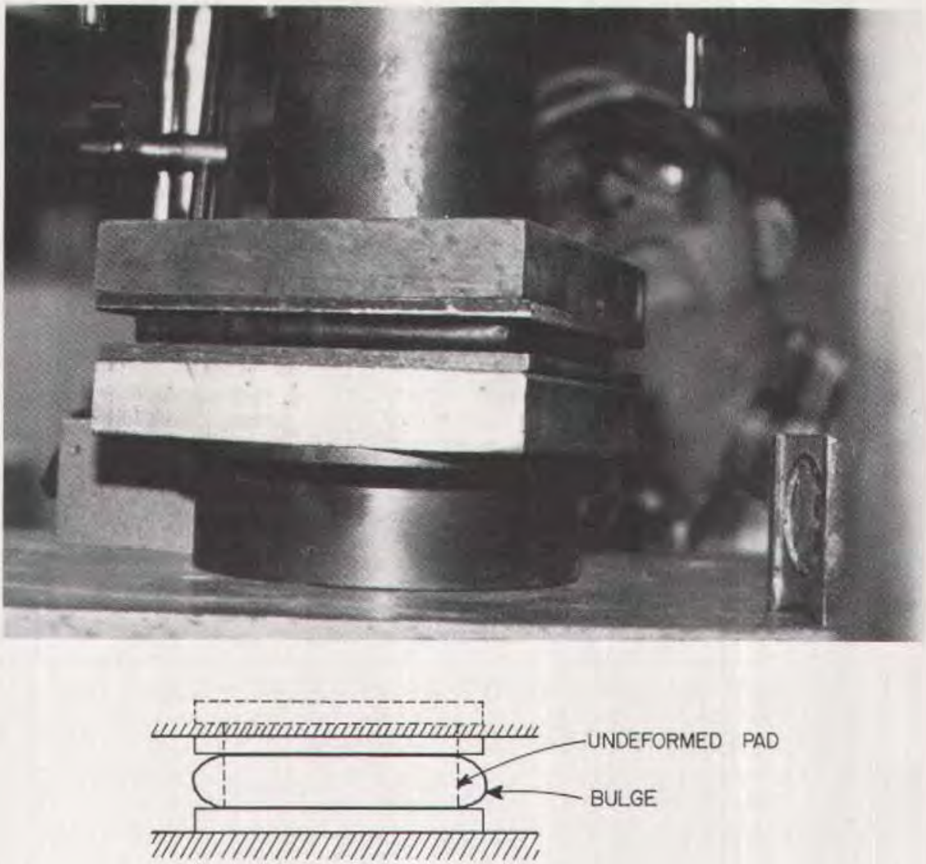

Fig. 1. Bulging of unreinforced elastomeric pad under compressive load.

low friction material has also been coated on other bearing pad materials such as duck layer fabric reinforced pads.

Finally, a number of miscellaneous materials, such as hardboard or wood have been used and have caused problems through collapse, staining or spalling of the concrete.

The failure criteria for bearing pads is not clearly defined. This problem is exemplified by a consideration of the pad functions previously discussed which clearly relate to protection of the concrete members from undesirable forces. Presumably if these functions are not accomplished, the pad has failed. However, there are numerous cases where pads were either not installed, or have slipped, crumbled or disintegrated and the concrete members are functioning with little or no distress.

Most commonly stated failure criteria are based on the condition of the pad. With this point of view, several conditions can lead to failure. However, excessive deformation created by bulging, crumbling, cracking, splitting or delamination of the pad or gross slippage of the pad from between the two bearing surfaces are probably the most commonly observed types of failure.

Design and Specification Guidance

Current AASHTO Specifications are a commonly used design reference. They are considered outdated and are under study[1,2,3] for revision. The AASHTO guidelines are clearly directed toward large steel laminated reinforced pads. AASHTO provides a material specification for chloroprene and natural rubber for pads in Section 25 of their Standard Specifications.[4]

Article 2.10.3(l) also provides a brief description of duck layer reinforced pads. Military specification MIL-C-882C also covers duck layer reinforced pads. A number of State Highway Departments have sections in their standard specifications dealing with bearing pads.

The design of small pads for buildings is discussed in the PCI Design Handbooks[5,6,7] or various pad manufacturers' brochures. The manufacturers' brochures are limited to their particular material and often do not provide sufficiently broad design data or recommendations. One notable exception is the design information for plain chloroprene or Neoprene pads published by DuPont in 1959.[8]

The first part of a study to update the AASHTO Specification is covered in NCHRP Report 248.[1] This 1982 report summarizes foreign design requirements and discusses European research. Table 1 (see full length PCI report), which summarizes AASHTO and European design requirements for large, plain chloroprene pads for bridges, is taken directly from this NCHRP report.

The UIC 772R Specification[9] is used in Europe by railway and highway authorities. The BE 1/76 report[10] is a British specification and the BS5400[11] is a current draft British Standard and it represents a combination of BE 1/76 and UIC 772R. These foreign codes are based on considerable testing and theory and tend to be more complex than AASHTO or PCI. When European design procedures are used with bearing conditions having minimum movements, much higher compressive stresses are allowed when compared to AASHTO.

German practice is of interest. Design calculations are simplified, and only a few standardized sizes and shapes with a single elastomer are allowed. All pads are proof tested and each manufacturer must pass rigorous certification. The results from using this concept have apparently been very satisfactory but pads are costly and the concept tends to restrain new developments.

SURVEYS AND SITE VISITS

Survey of PCI Member Companies

Twenty-one member companies were contacted across the United States and Canada. Significant comments from the survey were:

1. Twenty percent felt they had bearing pad problems. However, the problems were related to only a few projects.

2. Thirty percent felt that they experienced limited bearing pad problems.

3. Sixty percent use the PCI or slightly modified PCI criteria for pad design. The remaining respondents used rule of thumb design procedures, relied on the designer or used pad manufacturers' data.

4. AASHTO-grade plain chloroprene and random oriented fiber pads were the most commonly used pad materials (60 percent). Two respondents with no problems used AASHTO-grade exclusively. Twenty percent use random fiber pads as their primary material, while others use it as a secondary material. One producer has recently switched totally to the use of plastic pads. Commercial-grade neoprene was used by 20 percent, primarily under double tee legs. Duck layer reinforced pads are generally only used if specified, al-

though one producer uses it under large beams on a regular basis.

5. Ten percent perform limited regular inspections of the pad performance in parking garages. All others do not perform inspections or only on a casual basis.

6. None of the PCI producers test the pads that they use. Most rely on the pad manufacturer's certification.

7. Three respondents mentioned that the PCI design practices made no provisions for consideration of rotation in the bearing surfaces. Two felt that the design for full concrete creep and shrinkage movement with a horizontal shear displacement limit of 50 percent of the pad thickness was too conservative.

This survey indicates that a bearing pad problem exists, but is not widespread. A number of comments indicated that individual companies changed their practice with regard to plain pads about 10 years ago. This change generally involved closer specification of materials, which resulted in increased use of AASHTO-grade chloroprene and increased care in pad design and installation. They felt that performance since then has been more satisfactory.

It is significant that one type of structure, parking garages, seems to be the problem area, although the authors are familiar with other types (cooling towers and storage tanks), that have experienced significant pad problems. Whether this is due to the out-of-door exposure conditions or to the small pad sizes used was not clear and probably both items contribute to the problems.

Five geographic areas were then selected for site trips to review bearing pad performance in parking garages, since no significant problems were reported in other types of buildings.

Site Visits

Five urban areas were visited:

- Chicago, Illinois
- Washington, D.C.
- Minneapolis, Minnesota
- Denver, Colorado
- Phoenix, Arizona

In each area, from four to six garages were visited, and conditions noted. Garages with poor to excellent performance of the pads were encountered. Problems noted consistently in all areas were:

- Poor pad materials
- Nonuniform bearing
- Mislocated pads

Other problem areas were noted although on a more local basis:

- Delamination of elastomeric pads
- Excessive shimming and multi-pieced beam pads
- Moving pads
- Total disintegration of pad material in loaded area

Testing for durometer hardness (Shore A) was undertaken with no clear correlation between hardness and pad performance. A cigarette lighter fire test to determine relative chloroprene content was also made and correlation with poor pad performance and burnability of the pad was clear.

An important observation was that none of the garages were experiencing significant damage to the concrete members because of the pad problems. If significant problems were found, it was from unusual bearing conditions, usually relating to insufficient bearing area. Even when pads had crumbled and practically disappeared, concrete damage was minimal. The average age of the garages was about 5 years, so distress might develop in the future.

TESTING PROGRAM

A limited laboratory testing phase was undertaken. Pads made of AASHTO-grade chloroprene, random oriented fiber reinforced materials (ROF) and duck layer fabric reinforced materials (DLR) were tested as follows:

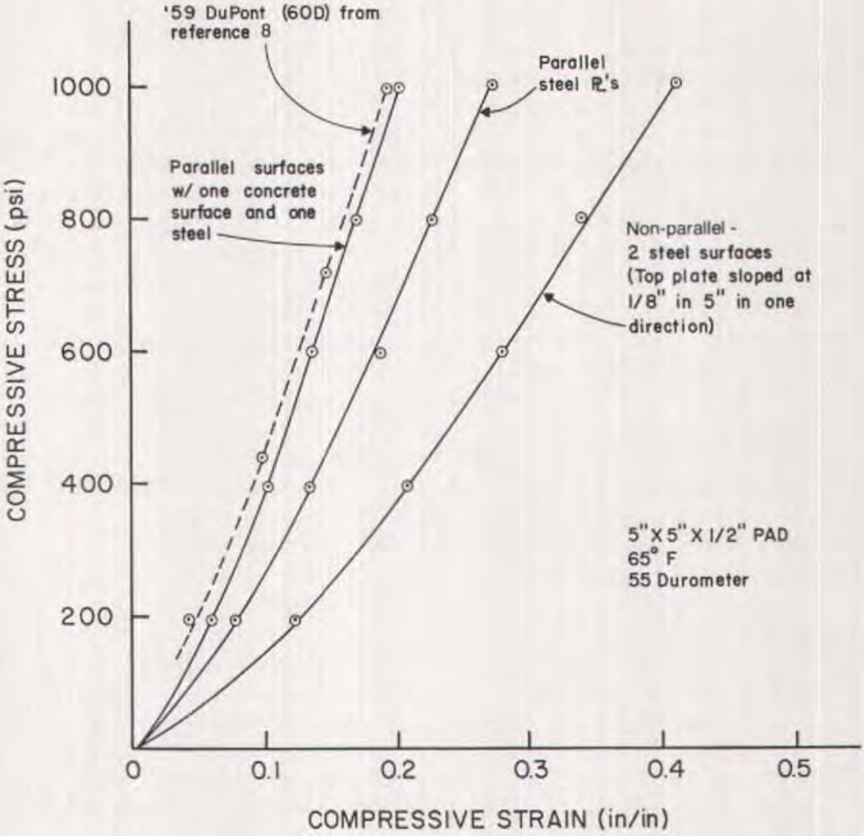

Fig. 2. Effect of bearing plate slope and surface on compression behavior of AASHTO chloroprene pads.

1. Compression testing; with nonparallel steel bearing plates; with one concrete bearing surface and a parallel steel plate; and with two parallel steel plates for all three materials, a total of five tests.

2. A simple in-plant burnability test for chloroprene content.

3. Horizontal shear with accompanying perpendicular compression, two tests for each material or six tests total.

4. Compression creep under typical maximum design stresses using two tests for each material or a total of six tests.

All test materials were obtained from Chicago area pad suppliers. The pads were 5 x 5 x ½ in. (127 x 127 x 13 mm) or ⅜ in. (9.5 mm) nominal size with shape factors of 2.5 or 3.3, respectively.

Compression Tests

A series of direct compression tests were undertaken with all three materials to study the effect of using a sloped bearing surface which simulated normal tolerances for steel bearing plate installation as well as the usual geometry at the end of a cambered member. The slope of one steel plate was set at ⅛ in. (3.2 mm) in 5 in. (127 mm) in one direction relative to the mating plate. Companion tests were also made using

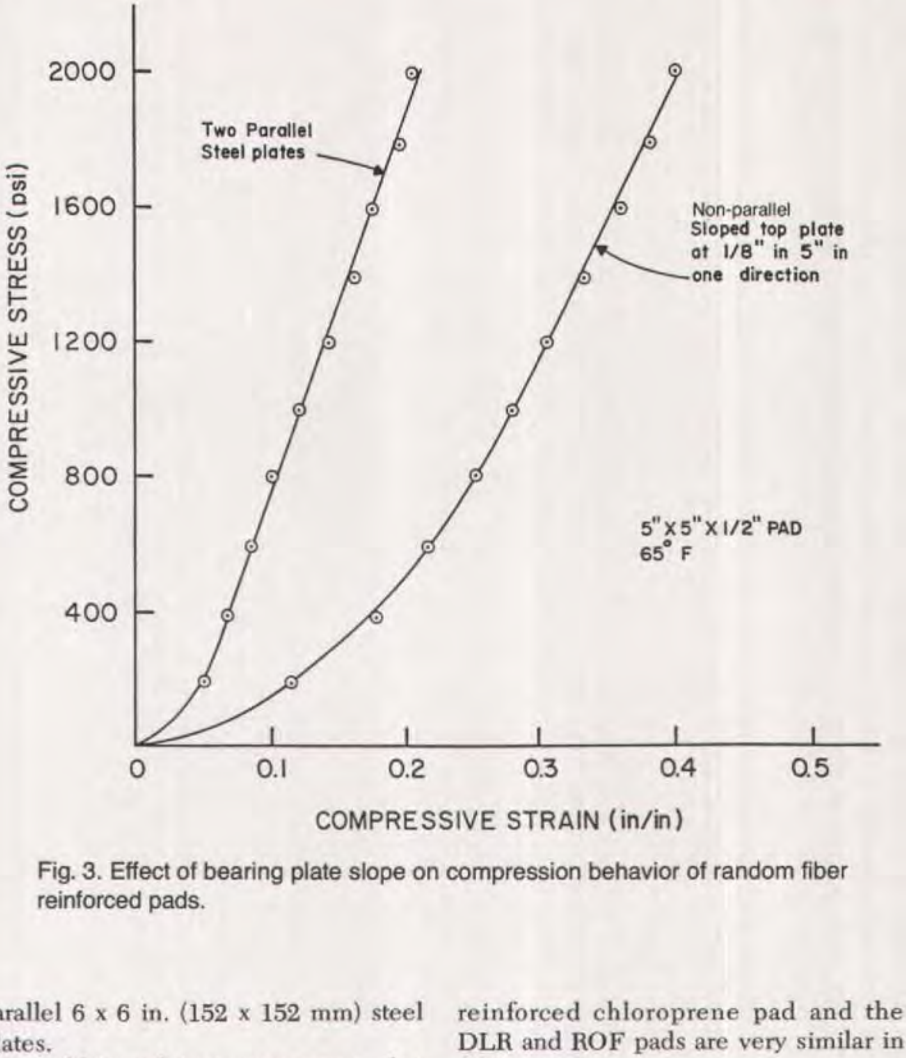

Fig. 3. Effect of bearing plate slope on compression behavior of random fiber reinforced pads.

parallel 6 x 6 in. (152 x 152 mm) steel plates.

An additional test series was also undertaken with the chloroprene pad material using a parallel steel plate and concrete plate with a normal floated finish. Figs. 2, 3 and 4 show the test results. Fig. 5 shows the superimposed data for the parallel steel plate testing for the three pad materials. For comparison purposes, a stress-strain curve from the commonly used 1959 DuPont publication is also shown in Figs. 2 and 5. The tests with parallel surfaces indicate the following:

1. The reinforced pads are much stiffer in compression than the plain unreinforced chloroprene pad and the DLR and ROF pads are very similar in this property.

2. When a concrete surface is substituted for one of the steel plates the average vertical strain of an unreinforced chloroprene pad was reduced by about 30 percent, apparently from the increased friction effect from the concrete.

3. Significant bulging of the AASHTO-grade chloroprene pads occurred at stresses of 400 to 600 psi (2.8 to 4.1 MPa) even though oversized steel plates were used.

Fig. 6 shows the data for all types from the nonparallel steel plate testing series. These tests indicate the following:

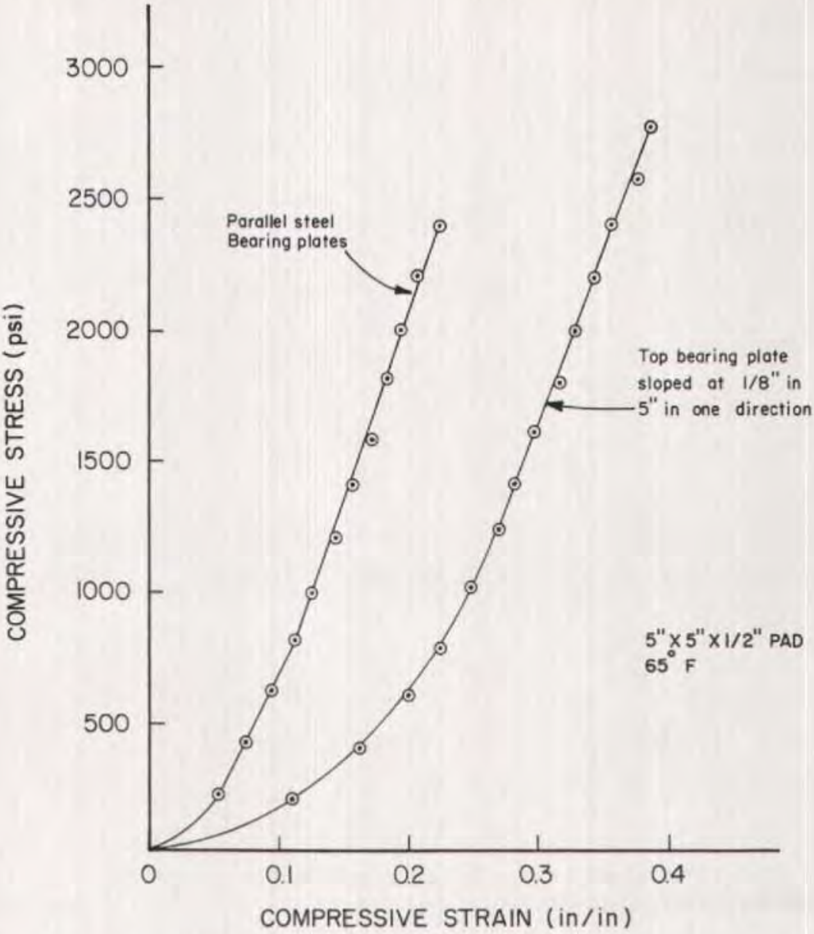

Fig. 4. Effect of bearing plate slope in compression behavior of duck layer reinforced pads.

1. At a stress of 1000 psi (6.9 MPa), the chloroprene, ROF and DLR pads exhibited average compressive strains which were about 50, 130 and 95 percent greater, respectively, than when a parallel steel plate loading system was used.

2. At stresses up to about 200 psi (1.4 MPa), little difference in compressive stress-strain behavior exists between these three materials.

During these compression tests, none of the pads showed evidence of pad failure from cracking or delamination.

Recent testing by Raths, Raths and Johnson[12] on a ROF pad with a slightly different formulation, has shown 100 percent greater compressive strains at 2000 psi (13.8 MPa) than those noted in this testing under similar uniform parallel plate conditions.

Chloroprene Material Verification Test

A simple burning test was made throughout the site visits and in the laboratory to indicate whether the pads

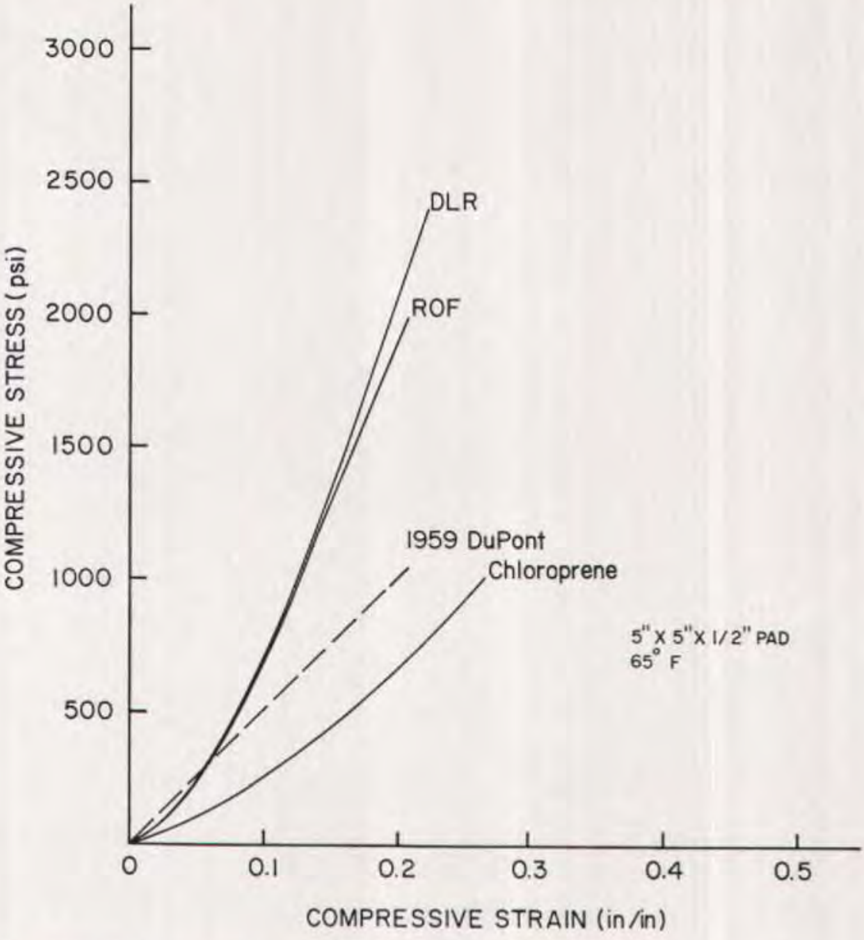

Fig. 5. Uniform compression tests with parallel plates comparing chloroprene, ROF and DLR pads.

contained chloroprene as their only elastomer. Chloroprene (Neoprene) apparently does not support combustion and neither do most of the fillers used in AASHTO-grade pads. Therefore, if the pad is ignited and the source of flame removed, AASHTO-grade pads will self extinguish. A commercial-grade chloroprene pad often will not.

Buring tests in the field were somewhat imprecise because of varying wind, flame sources, etc., although many pads would easily support combustion. Generally, if the sustained flame in the field was intense, so were the problems with the pads.

A suggested test procedure was conducted in the laboratory to verify field observations. The test procedure is:

1. Use a draft-free room.

2. Use a bunsen burner or other constant flame.

3. Hold a sample of the pad in the flame for 5 seconds.

4. Remove pad from flame. If pad continues to burn after 15 to 20 seconds out of the flame, the pad is probably not an AASHTO-grade chloroprene pad.

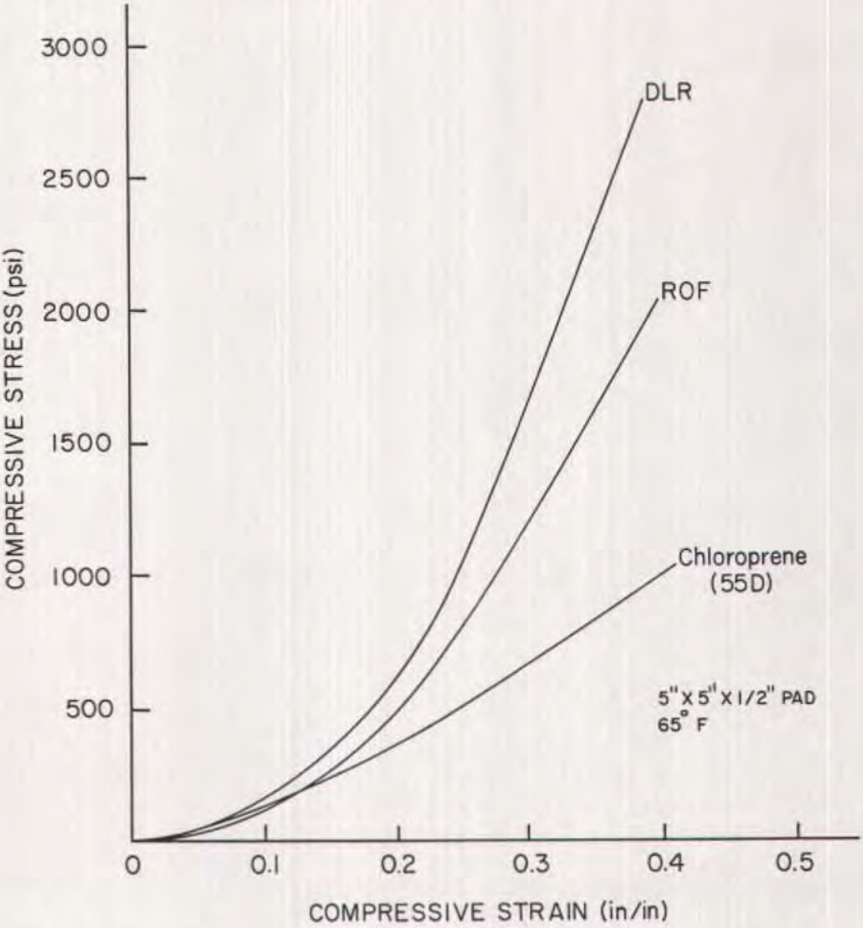

Fig. 6. Comparison of compression behavior of materials for testing with one bearing plate sloped.

To confirm this simple fire test, spectrophotometer analysis was made on a number of pad samples. Spectra for approximately 25 vulcanized elastomers, including five types of Neoprene were obtained from DuPont. Five pad samples from the field were then selected and were subjected to spectrophotometer analysis. Two pads (Nos. 4 and 5) were found to be AASHTO-grade, three were not.

The five samples were then given the simplified burn test. Samples 1, 2 and 3 burned continuously after being removed from the flame. Samples 4 and 5 burned for less than 15 seconds after being removed from the flame.

The simple flame test can be a useful tool for preliminary verification of AASHTO-grade chloroprene pads and the spectrophotometer analysis is a valid method for more certain verification.

Shear Tests

A limited number of vertical compression/horizontal shear tests were made with three pad types as shown in Fig. 7.

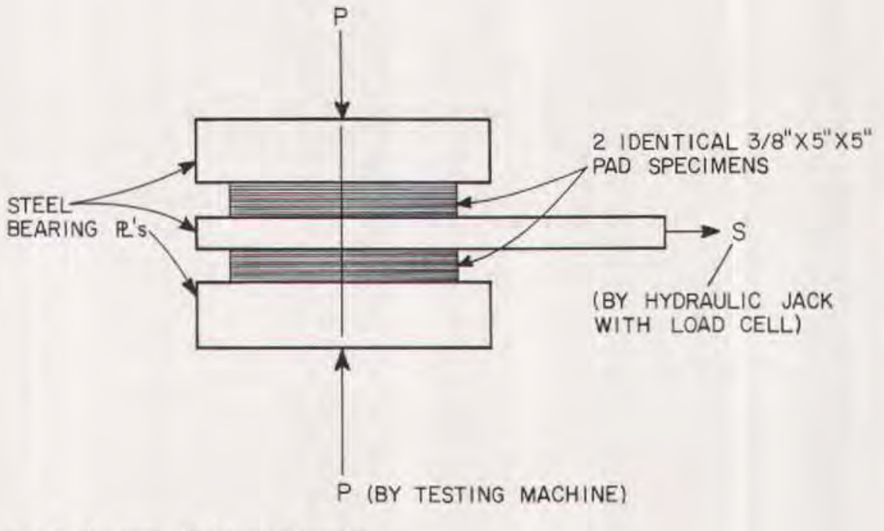

Fig. 7. Diagram of shear test setup.

Mill quality steel bearing surfaces, free of heavy rust, were used and the pads were not glued to the steel surfaces. It should be emphasized that the results relate to an apparent shear and friction performance that one might expect from a pad acting on steel surfaces under the conditions noted. These tests do not represent a true material shear modulus, or coefficient of friction obtained under ASTM laboratory conditions.

Identical pad specimens, 5 in. x 5 in. x ⅜ in. (127 x 127 x 9.5 mm), were used. The results are reported in terms of shear stress, i.e., horizontal force divided by the undeformed pad area, and shear strain, i.e., horizontal pad displacement divided by original pad thickness. Each test required about 10 to 15 minutes.

The compression stresses were 800 psi (5.5 MPa) for chloroprene, 1500 psi (10.3 MPa) for ROF and 2000 psi (13.8 MPa) for DLR, i.e., generally equal to the maximum design stresses allowed. Test results are shown in Figs. 8 and 9. The chloroprene test result is not plotted because of early slipping at a shear stress of about 27 psi (0.19 MPa), or a shear stress to compressive stress ratio of about 0.03.

The two tests with ROF pads showed slippage at shear stresses of about 75 psi and 125 psi (0.52 and 0.86 MPa), which are at a shear to compression stress ratio of 0.05 to 0.08. The ROF pads exhibited an apparent shear modulus of elasticity (*G*) of about 700 psi (4.8 MPa) up to a shear stress of 75 psi (0.52 MPa). At higher stresses, the shear modulus reduced to about 50 percent of the original.

The duck layered reinforced (DLR) pad test showed no apparent slippage up to the minimum applied shear stress of 200 psi (1.38 MPa). The shear strain at that stress was 10 percent. The DLR pads exhibited an initial shear modulus of elasticity (*G*) of about 4700 psi (32.4 MPa) and a secant modulus from 0 to 170 psi (0 to 1.2 MPa) of about 3000 psi (20.7 MPa).

These limited shear-compression tests show that the measured friction coefficients (at slippage) for the chloroprene and ROF pads on steel plate and under high compressive loads were only 3 to 8 percent of the applied compressive stress.

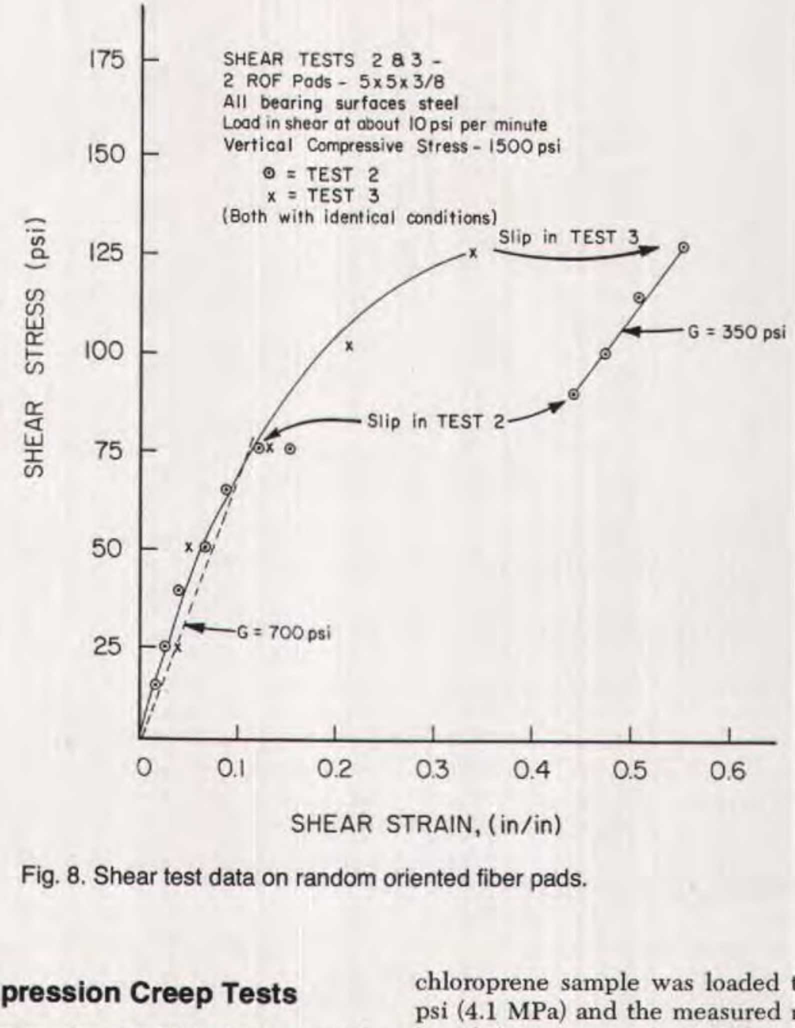

Fig. 8. Shear test data on random oriented fiber pads.

Compression Creep Tests

Compression creep tests were made on two samples of each material in a controlled temperature and relative humidity room [73°F (23°C), 50 percent RH] as shown in Fig. 10. All tests were on nominal 5 x 5 x ½ in. (127 x 127 x 13 mm) pads and oversized 6 x 6 in. (152 x 152 mm) steel plates were used. The vertical deformations were measured immediately after the initial loading, after 4 hours under load, and then at appropriate intervals during the 120-day test period. Again, maximum design compressive stresses were used. The test results are presented in Fig. 11.

Chloroprene Material — The No. 2 chloroprene sample was loaded to 600 psi (4.1 MPa) and the measured modulus of elasticity was about 3000 psi (20.7 MPa). The measured instantaneous and creep strains were 18.8 and 17.6 percent, respectively, of the original pad thickness. As a result, the total deformation was 36.4 percent of the pad thickness and the 0.5 in. (13 mm) thick pad reduced in thickness down to 0.32 in. (8 mm) in 120 days. The shape of the creep curve suggests that additional creep shortening will occur after 120 days. These data show that at a stress of 600 psi (4.1 MPa) the creep shortening may equal or exceed the instantaneous shortening.

Random Oriented Fiber Material —

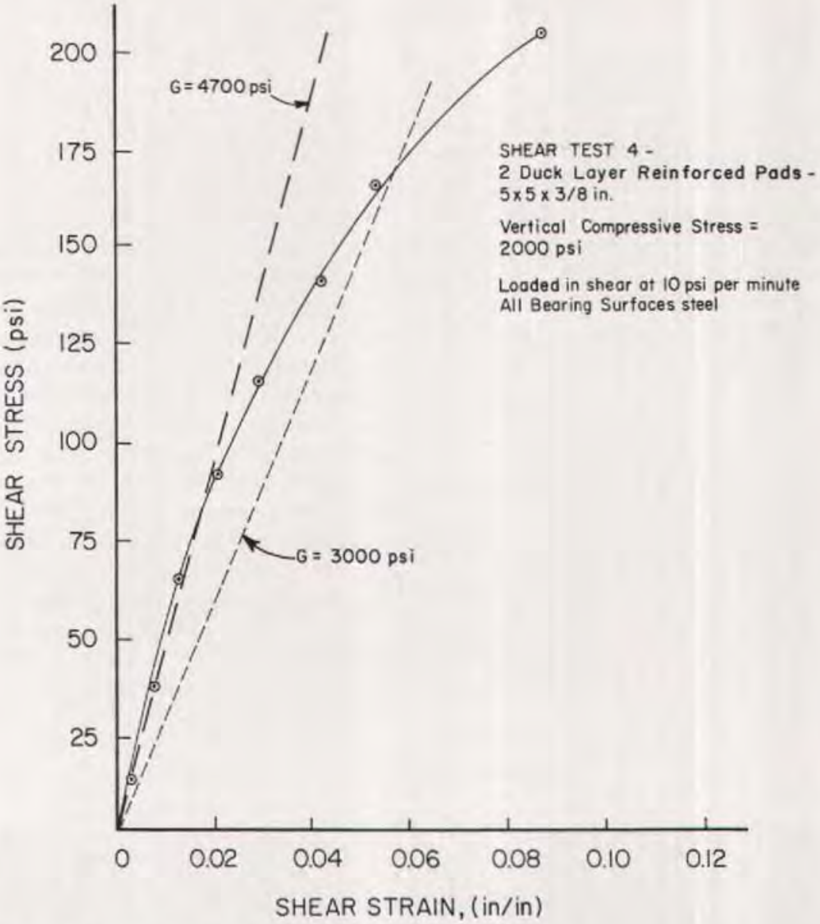

Fig. 9. Shear test data on duck layer reinforced pads.

The ROF pads were loaded to 1500 psi (10.3 MPa) and the modulus of elasticity measured during the initial loading was about 9000 psi (62.1 MPa). The measured instantaneous and creep strains were 16.1 and 7.8 percent, respectively, of the original pad thickness. As a result, the total deformation was 23.9 percent of the pad thickness and the 0.5 in. (13 mm) thick pads reduced in thickness to 0.38 in. (10 mm) in 120 days. The shape of the creep curves suggests that the continuing rate of creep is significantly less than that of the chloroprene pad even though the applied stress on the ROF pad was 2½ times greater.

Duck Layered Reinforced Material — The DLR pads were loaded to 2000 psi (13.8 MPa) and the measured average modulus of elasticity during the initial loading was about 17,000 psi (117 MPa). The measured instantaneous and creep strains were 11.9 and 8.4 percent, respectively, of the original pad thickness. As a result, the total deformation was 20.3 percent of the pad thickness and the 0.5 in. (13 mm) thick pads reduced in thickness to 0.40 in. (10 mm) in 120 days. The shape of the creep curves suggest that the DLR pads exhibit the least rate of creep of all three materials at age 120 days.

Discussion — The creep testing was run at typical maximum design compressive stresses. The measured creep strains after 120 days ranged from 48 to 94 percent of the initial shortening and averaged 70 percent for the three pad materials. These values are much greater than the 20 to 40 percent values discussed in the NCHRP 248 report or the creep values shown in the 1983 DuPont brochure.

REVIEW OF DESIGN ASPECTS

Plain Chloroprene Pads

Recent publications by Stanton and Roeder[1,2,3] introduce a simple formula limiting nominal compressive stress for plain unreinforced AASHTO chloroprene pads, f_c, to:

$$f_c \leq \frac{GS}{\beta} \quad \text{but less than 800 psi for nonrestrained plain pads}$$

where

G = shear modulus, psi
S = shape factor
β = material factor (= 1.8)

This formula is straightforward, but it does depend on the laboratory measured shear modulus. While this is an important property, it is not information that is commonly available. In addition, this property is difficult to measure consistently, and it varies widely with temperature. The formula essentially linearizes the allowable compressive stress as a function of shape factor. This simplification makes it appealing and since pad mechanical properties and behavior are not as accurately known as many other engineering materials, this linear formula is probably as accurate as our present state of knowledge warrants.

The material factor of 1.8 is applied slightly differently in the recent DuPont

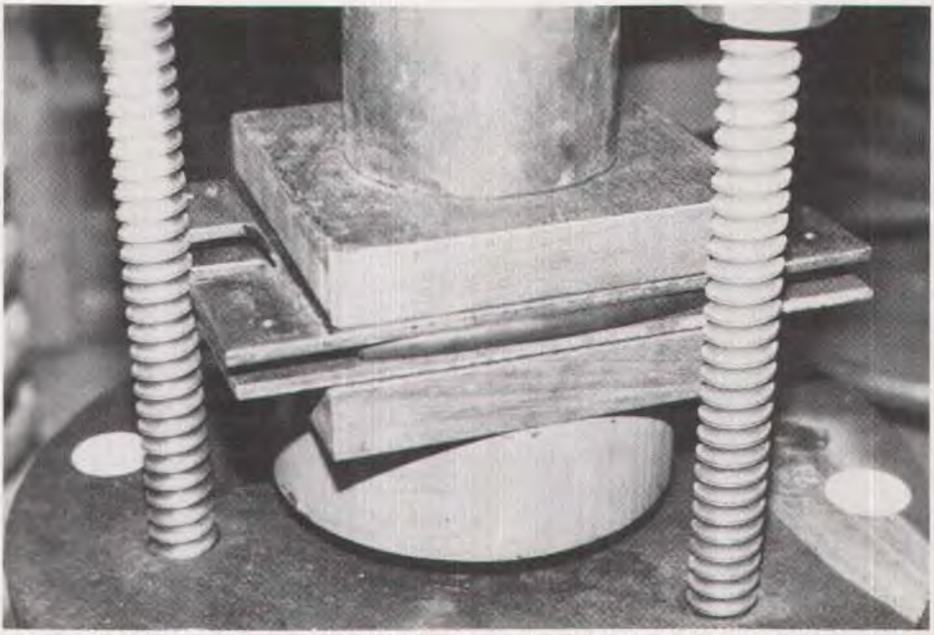

Fig. 10. Typical creep specimen with chloroprene pad at 600 psi (4.1 MPa).

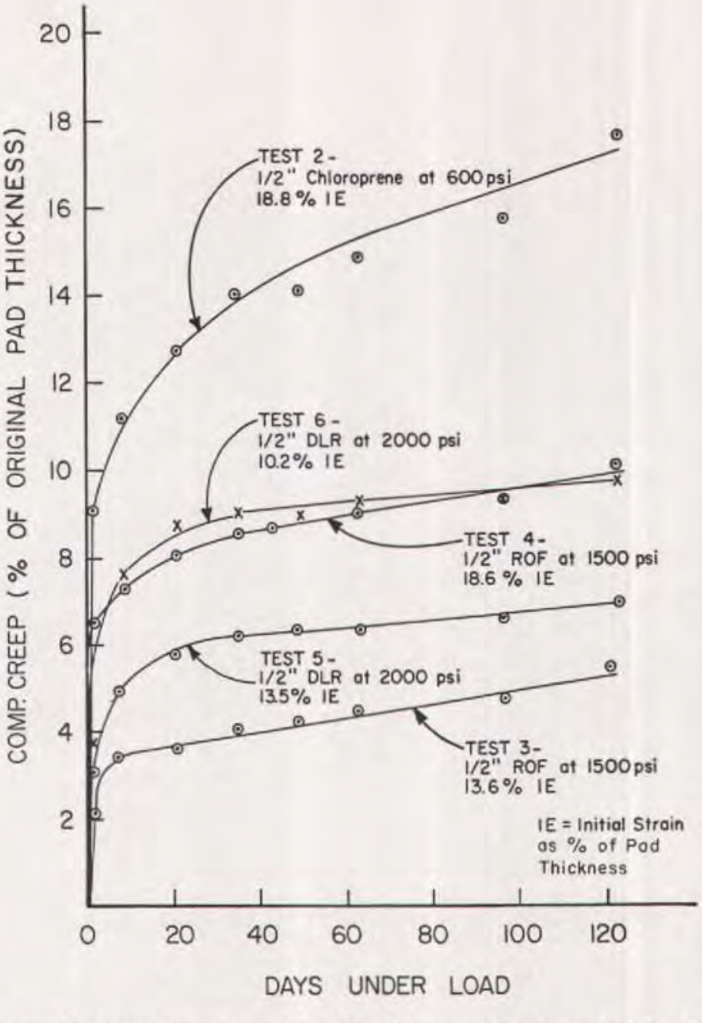

Fig. 11. Creep data on chloroprene (Neoprene), random oriented fiber reinforced and duck layered reinforced pads.

publication[13] and European codes. In these documents the material factor is divided into the shape factor and this reduced equivalent shape factor is used to determine the allowable compressive stress. Fig. 12 summarizes these NCHRP and DuPont recommendations and superimposes the previous PCI design values. The new NCHRP[1] recommendations when applied to small shape factors of five or less, as typically used in precast building construction, result in very conservative design stresses when compared to previous PCI recommendations.

It should be noted that most codes recommend a maximum compressive stress on unreinforced chloroprene pads. AASHTO recommends 800 psi (5.5 MPa) and the PCI has previously recommended 1000 psi (6.9 MPa). The shape factors commonly encountered in building construction are considerably lower than in bridges, typically ranging

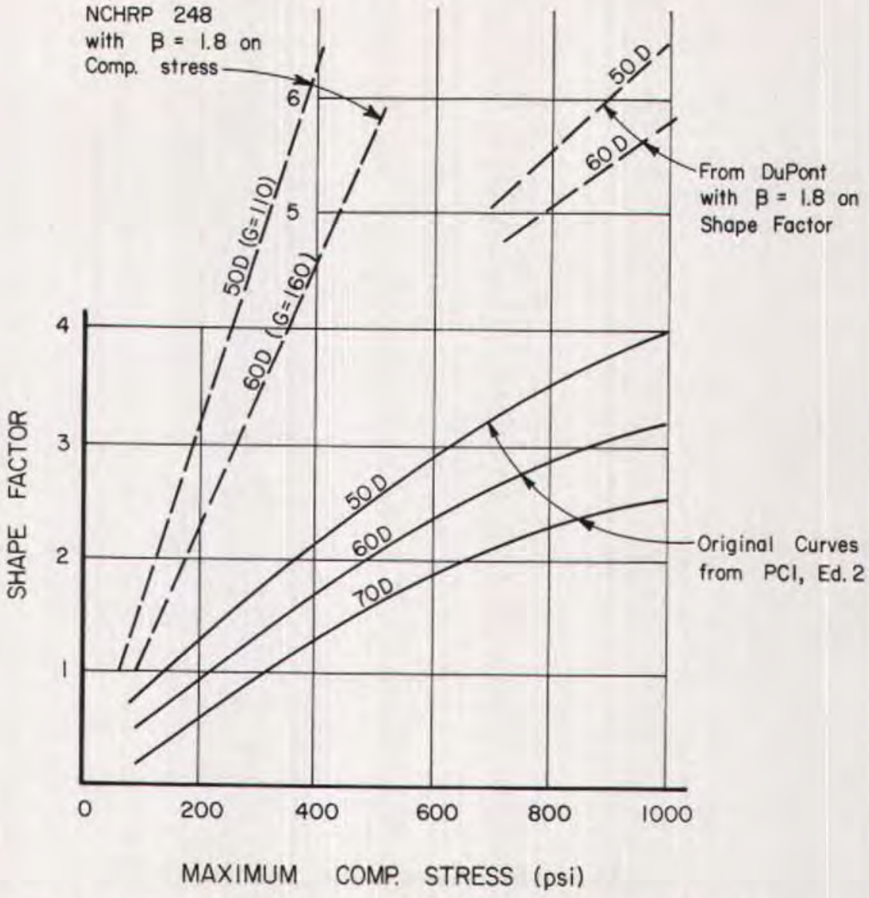

Fig. 12. Recent design recommendations for plain chloroprene pads.

from 2 to 5. Testing has indicated that more severe behavioral conditions occur in the low SF pads.

Excessive lateral flow of a chloroprene pad can be detrimental to its bearing capacity. The large vertical displacement caused by the lateral flow of the chloroprene material is one of its best and yet most troublesome properties. The flow allows accommodation for large irregularities and horizontal shear or rotations in the bearing surfaces. The present PCI and AASHTO pad design procedures call for a limit on pad compressive strains. Based on the variations discussed above, this is not a consistent approach. The use of a design procedure based on limiting stresses seems more consistent, when considered in the light of the variations encountered in different compression testing.

Compressive Stress-Strain Properties of Different Pad Materials

While the number of tests to measure the compressive stress-strain characteristics of small-sized chloroprene, ROF and DLR pads have been limited, the following observations appear warranted:

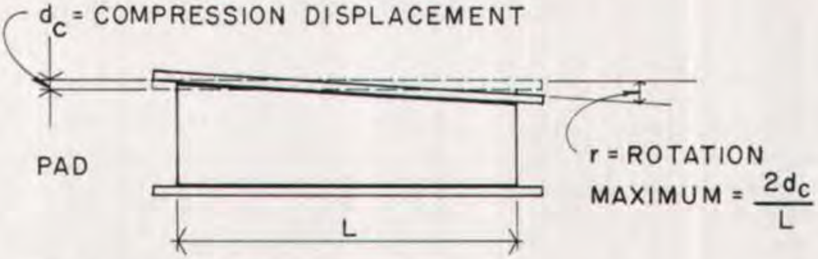

Fig. 13. Limitation on rotation.

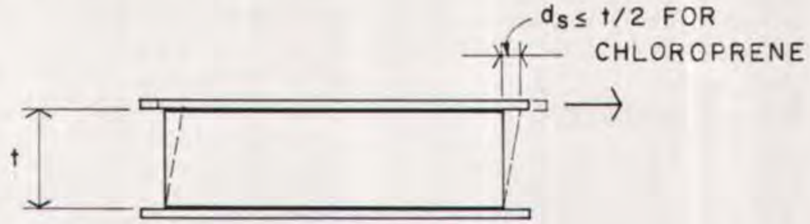

Fig. 14. Shear movement limits.

1. The compressive stress-strain curve for chloroprene and ROF is sensitive to the shape factor.

2. Two different ROF materials can exhibit widely different stress-strain behavior when tested under similar conditions.

3. The stress-strain characteristics may be dramatically influenced by the type of bearing materials that contact the pad (i.e., concrete versus steel) as well as the bearing surface geometry.

4. The review of product literature and information on ROF and DLR pads generally found little data available for their design or specification. While this lack of definitive specifications may be a detriment, many producers are using the ROF pads which are economical and take higher compressive loads with low shape factors, a definite advantage for building with precast concrete.

5. While oversized pads are commonly used to allow holding the pad while the precast concrete member is being erected, the design of the pad should consider only the loaded area.

Rotation and Shear Deformations

The consideration of rotation, i.e., nonparallel bearing surfaces, is not made in either the PCI or AASHTO design procedures. A common rule of thumb[6] has been to limit such rotation, as shown in Fig. 13 to:

$$r = \frac{2\,d_c}{L}$$

where

d_c = compression displacement
L = length of bearing in direction of rotation
r = maximum rotation in radians

Lateral shear displacement has also commonly been limited to 0.5 of the pad thickness as illustrated in Fig. 14, while European practice has allowed 0.7.

It is actually the combination of compressive strain, shear strain and rotation strain that leads to failure (cracking) in the critical toe region of the bearing pad. The present limits on rotation and shear deformation were set so as to be sufficiently conservative that design compression stresses are not significantly affected by deformations within the limits.

The European codes attempt to model these combinations, either through stress or strain statements. However, the resulting expressions are often complex and the wide variety of properties for pads used in the United States negate the usefulness of such detailed analysis. Also, as discussed below, slippage probably makes such lateral strain limits physically unrealistic.

Friction and Slippage

Design for the "classical" shear deformation of elastomeric pads as outlined above has generally been used by the design profession based upon the assumption that the horizontally loaded pads can deform in shear to 50 percent of the pad thickness while under perpendicular design compressive stresses and that friction will prevent the nonfixed pad from slipping. The upper limit on the frictional force which could be developed between elastomeric pads and steel or concrete surfaces was commonly assumed to be 0.6 to 0.7 of the normal force, based upon static friction coefficient, determined by tilting the bearing surface until the unloaded pad slipped down the incline.

The 1982 NCHRP 248 report[1] discusses cases of troublesome slipping of elastomeric pads when loaded in shear while under perpendicular compression. This slipping or "walking out from under loads" is a commonly noted problem. The NCHRP report discusses European research in 1965 which showed that the friction coefficient for concrete or steel surfaces in contact with plain rubber pads decreased dramatically as compressive stress increased. This study suggested the following equation for the coefficient of friction for concrete or steel surfaces as a function of compressive stress.

$$\mu \geqslant 0.10 + \frac{29}{\sigma_c}$$

where

μ = friction coefficient = σ_s / σ_c

σ_c = compressive stress on pad, psi

σ_s = shear stress on pad, psi

The coefficient approaches 0.7 at compressive stress levels of 50 psi (0.34 MPa) while it decreases rapidly as compressive stress levels increase. This dramatic decrease in friction coefficient for elastomeric pads has not been accounted for in American design practice.

Another European research paper on pad friction was published in ACI SP-70[14] in 1981. This paper discussed numerous tests on plain chloroprene pads under shear and compression against concrete and steel surfaces. The tests utilized compressive stresses of 72, 725 and 2900 psi (0.5, 5.0 and 20.0 MPa). The pad shape factor was generally 2.0. These tests applied the shear loads at constant displacement rates of 1.97, 0.02 and 0.0004 in. per sec (50, 0.51 and 0.01 mm per sec) to a maximum horizontal displacement of 0.7, 1.4 and 2.1 times the pad thickness.

The typical unrestrained displacement rate for the end of a 60 ft (18.3 m) long double-tee member experiencing a 50°F (28°C) temperature change uniformly over a 6-hour period would be about 0.000005 in. per sec (0.00013 mm per sec) at each end of the tee. Thus, the lowest rate of shear loading used in these tests [0.0004 in. per sec (0.01 mm per sec)] was most typical of daily temperature effects and long-term creep and shrinkage effects.

Significant observations and conclusions from these 1981 tests are as follows:

1. Minor slip occurs at even low shear stresses.

2. Plain chloroprene pads under low vertical compression stresses tend to move under horizontal load by pure slippage.

3. Plain chloroprene pads exhibit

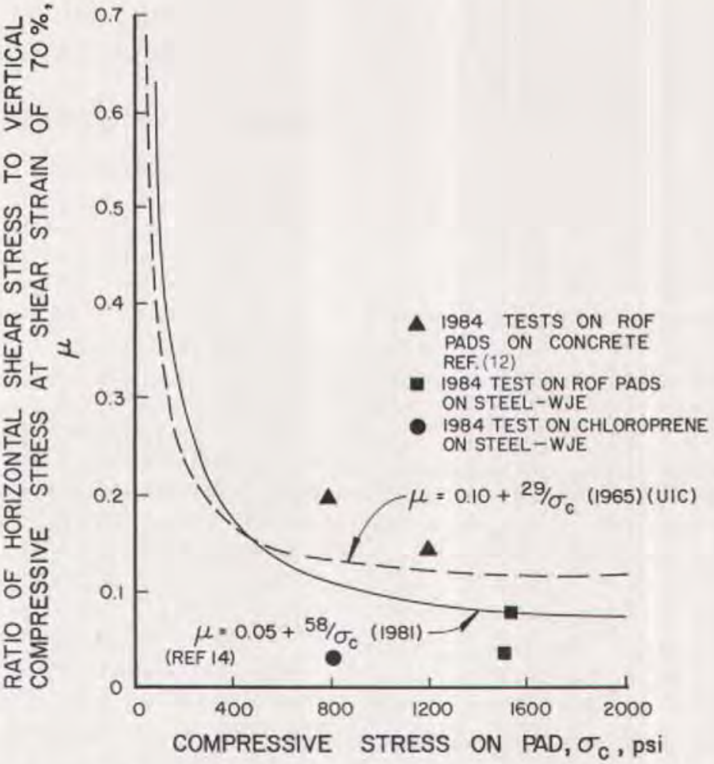

Fig. 15. Comparison of friction coefficient from 1965 and 1981 West German reports and United States test results.

"rolling" and slipping when under high compressive stresses and subjected to horizontal shear loads.

4. The apparent coefficient of friction is decreased dramatically as compressive stress increases.

5. The coefficient of friction is dependent on the shear loading rate.

6. For the very slow shear loading rate, the tests on steel and concrete surfaces produced different coefficients of friction.

This paper presents an equation for relating friction dependance on compressive stress:

$$\mu = 0.05 + \frac{58}{\sigma_c}$$

A similar study[12] of the shear-compression strength of specially formulated, small, random oriented fiber pads was undertaken in 1983-84 by a pad manufacturer in the United States. Sixteen shear tests were made using pads ranging in size from 2 x 2 to 6 x 6 in. (51 x 51 to 152 x 152 mm) (square pads) and 1½ x 3 to 3 x 6 in. (38 x 76 to 76 x 152 mm) (rectangular pads). The thicknesses were ¼, ½ and ¾ in. (6, 13 and 19 mm). The compressive stress levels used were 800 and 1200 psi (5.5 and 8.3 MPa). The shear test method is the same as shown in Fig. 7. These tests were on uniform, float finished concrete surfaces. Significant test results from this 1984 American study are summarized below:

1. The static friction coefficient using only gravity loading during an inclined

plane test, where the angle of the inclined plane was measured when sliding or slipping initiated, varied from 0.7 to 0.9. The 0.7 value was the most common.

2. The friction coefficient measured during the shear-compression tests varied from 0.2 to 0.5, depending upon the applied compression stress and the attained shear displacement.

3. For compressive stress levels of 800 and 1200 psi (5.5 and 8.3 MPa), the average friction coefficients were about 0.20 and 0.15 at shear plus slippage strains of 75 percent.

4. The leading edge of the pad tended to roll at shear plus slip deformations of about three-quarters of the pad thickness. (This same type of behavior was noted in the tests by Schrage on chloroprene pads and at similar geometries.)

Fig. 15 shows the 1965 UIC equation and the equation proposed by Schrage and the test results for ROF and chloroprene pads from the American work.

The tests conducted in the United States substantiate the European data and show that the shear-compression friction coefficients of chloroprene and the ROF pads decrease well below the static coefficient of 0.7 that has been commonly used in design.

While the shear-compression friction coefficient decreases dramatically as the compressive steel level increases, the available or allowable shear stress on the pad under the same conditions does not decrease. The data from the European tests and the American tests were calculated and plotted in Fig. 16 to compare the shear stress versus compressive stress on the pad at shear plus slippage strains of 70 percent. These four curves show increasing shear stress capacity as compressive stress increases. They are based on slow loading rates such as caused by temperature change and are not appropriate for seismic loadings.

DESIGN RECOMMENDATIONS

Plain Chloroprene Pads

These recommendations are intended for plain chloroprene pads of 50 to 70 durometer, under normal exposure conditions, for precast concrete building construction, and for materials meeting AASHTO Section 25 Specifications.

Allowable Compressive Stress — The allowable compressive stress is the most appropriate and straightforward design parameters for chloroprene pad design. The simplified formula proposed by Stanton and Roeder[1] (NCHRP 248) has appeal. However, the use of the shear modulus has the weaknesses of being difficult to measure consistently and this material property is extremely temperature sensitive. Hardness, on the other hand, is still the most widely employed measure of the physical properties of rubber materials and hardness is related to shear modulus and compression modulus.

The following design formula for unfactored service load is recommended:

$$f_c = KDS$$

where

f_c = allowable compressive stress, psi

K = empirical constant, psi

D = Shore A hardness of the material (durometer)

S = shape factor

The incorporation of the durometer factor, D, allows for consideration of the improved stiffness and compressive strength of harder elastomeric materials. This same consideration is accomplished in the NCHRP 248 formula through the use of the shear modulus. The empirical constant, K, accounts for conversions of units. The proposed formula when equated to the previous PCI design recommendations results in a "K" factor of about 4. A plot of this proposed equation with $K = 4$ is shown in

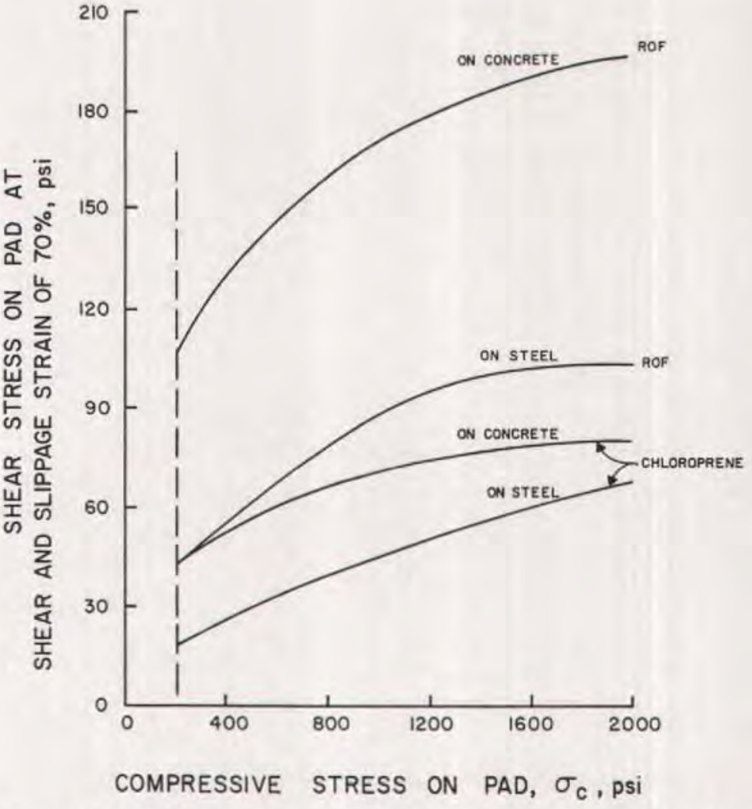

Fig. 16. Shear stress versus compressive stress for chloroprene (Neoprene) and random oriented fiber pads on steel and concrete surfaces.

Fig. 17 along with the present PCI recommendations and the NCHRP 248 bridge pad recommendations and 1983 DuPont recommendations for bridge pads.

The proposed formula matches closely with the current PCI recommendations and is considerably less conservative than either of the recent bridge recommendations for plain pads. This is appropriate since the present PCI recommendations are considered well tested and most of the problems encountered in the field were clearly related to poor materials.

Since plain pads do not contain any reinforcement, the elastomer itself must resist internal tensile stresses from bulging caused by the compressive loading. Friction along the loaded surfaces also acts to restrain bulging. Since the friction coefficient at moderate to high compression stresses is very low and potentially unreliable due to long-term creep effects, plain chloroprene pads should be designed for relatively low compressive stresses, particularly under unfactored working dead loads.

A 1000 psi (6.9 MPa) maximum design compressive stress when supporting unfactored design loads has been used for many years. However, the results of the testing in this project illustrate that significant bulging and creep deformation occur when high compressive stresses [i.e., 600 psi (4.1 MPa)] are held constant for long periods. It is recommended that the maximum design com-

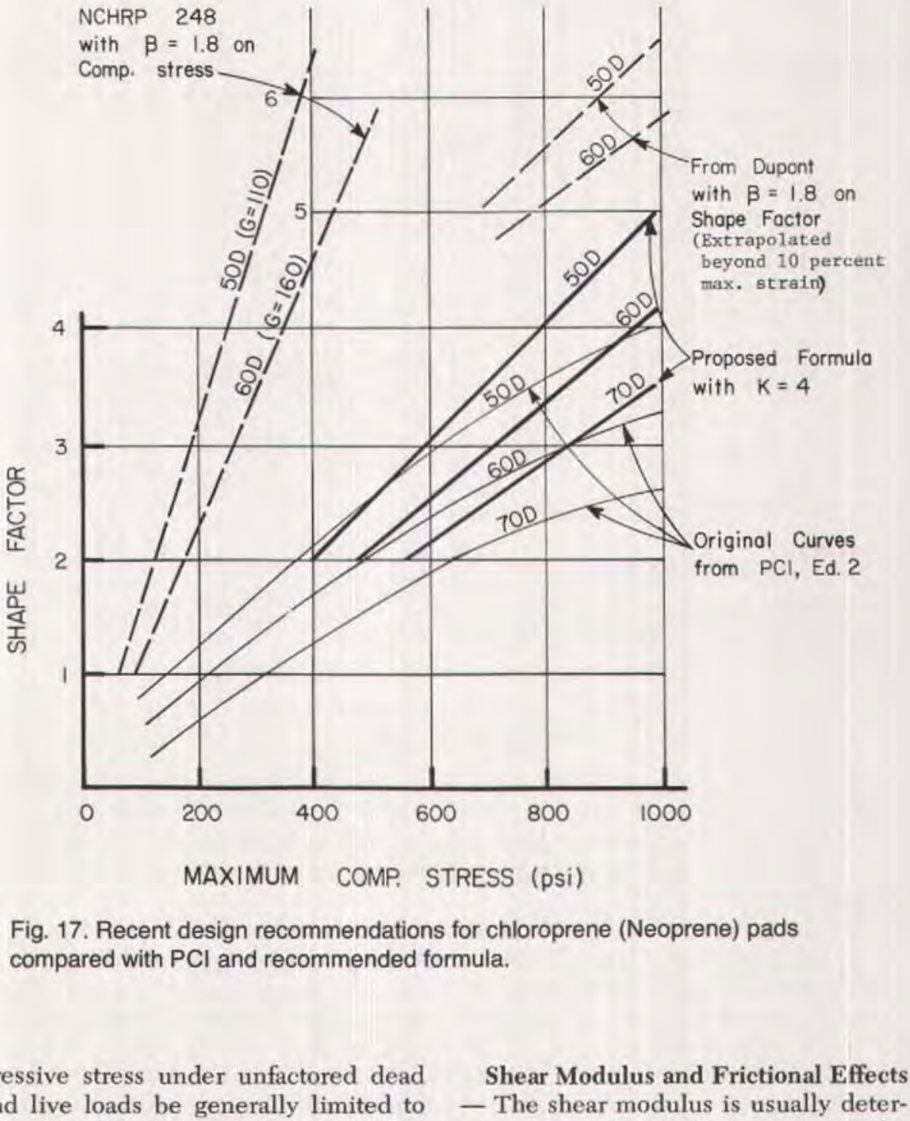

Fig. 17. Recent design recommendations for chloroprene (Neoprene) pads compared with PCI and recommended formula.

pressive stress under unfactored dead and live loads be generally limited to 800 psi (5.5 MPa) and that the unfactored sustained dead load stress be limited to 500 psi (3.4 MPa).

Further limitations are recommended that under double-tee stems pads with a shape factor smaller than 2 be avoided and under beams a shape factor less than 3 be avoided. This implies that small, tall pads should not be used. The choice of SF = 2 as a limit is based on observed results and problems. These recommendations are based on properties of the loaded area of the pad.

Shear Modulus and Frictional Effects — The shear modulus is usually determined by pad manufacturers using the ASTM D4014-81 test and slipping is not permitted. Since bearing pads in precast building construction are not glued or fixed in-place, slippage occurs, and shear deformation calculations using a shear modulus are unrealistic, even when a long-term shear modulus of 0.5 *G* is assumed. The use of normal short-term shear modulus values of 110, 150 and 215 psi (0.8, 1.0 and 1.5 MPa) for 50, 60 and 70 durometer chloroprene pads [at 70°F (21°C)] will significantly under-estimate the measured pad deformation from actual test data.

The recent shear-compression testing discussed in the previous section suggests that pads slip appreciably and that this slip can play a significant role in reducing forces transmitted to the ends of precast members by frictional forces. While the amount of testing has been limited, the data in the previous section suggest that Fig. 16 represents an alternative and improved design aid to estimate frictional forces at ends of members. The use of the data in Fig. 16 as an upper limit is conservative since long-term creep effects are not included.

Shear Deformation and Movement Limitations — Present design practice has been to limit the shear strain of the pad to 50 percent of the pad thickness. This design practice did not totally recognize the effect of slippage. This limitation results in a pad thicknesses of two times the calculated deformation of the end of the precast member and a resulting high shape factor since thick pads are often necessary.

Current testing and other practice in European codes leads to the approach of limiting pad shear and slip to 70 percent of the pad thickness since rolling and severe slipping is noted at this point. Based upon this limit, the pad thickness can be selected as 1.4 times the calculated deformation of the end of the precast member. This leads to a lower and more favorable shape factor.

Rotation — Rotation is not presently covered in the PCI pad design recommendations. Nonparallel bearing surfaces are a common problem and were noted in many instances during the site visits. A method to consider rotation of bearing surfaces in pad design procedures by using the following formula is suggested:

$$\text{Maximum rotation} \leq \frac{0.3\,t}{L}$$

where

t = pad thickness

L = dimension of pad

This would be taken in either one of the principal dimensions of the pad in which the maximum rotation occurs. This formula is based on the assumption that a minimum compressive displacement of 0.15 t occurs under design loads and then applying the rule of thumb discussed previously:

$$r \leq \frac{2\,d_c}{L} = \frac{2\,(0.15\,t)}{L} = \frac{0.3\,t}{L}$$

Since nonparallel bearing surfaces do exist, it must be recognized that such nonuniform loading can double the 15 percent strain often assumed in design. Thus, 30 percent instantaneous compressive strain can occur in highly stressed, nonparallel situations and this may cause larger vertical deformations as was noted in the testing.

Random Fiber Reinforced Pads

Allowable Compressive Stress — The PCI Design Manuals previously suggested a maximum design compressive stress of 1500 psi (10.3 MPa) for ROF pads. This suggested level of stress was not influenced by the shape factor.

Few problems were noted in the site inspections, although limited cracking of the exposed surfaces was observed. As such, there is little evidence to suggest significant problems when ROF is used at or below this level.

Since ROF pads have a more limited experience record than chloroprene pads, and since recent testing[12] suggests that pad performance is sensitive to low shape factor, the above recommendation may be too liberal for small shape factors. Testing has shown that ROF pads can have widely different compression and shear modulus values depending on the elastomer type, fiber type and orientation; and as such design conservation is warranted. Recognition of shape factor is recommended in design. Based upon the data available, the following maximum design compressive stresses are recommended for unfactored dead and live loads:

Shape factor	Uniform compressive stress (psi)
1	1100
2	1200
3	1300
4	1400
5	1500
> 5	1500

Or stated as a formula; $f_c = 1000 + 100(SF)$, in psi, to a maximum of 1500 psi (10.3 MPa). The compressibility of ROF pads must be calculated or estimated from test data from the actual pad material since stiffness of the ROF pads varies significantly from one manufacturer to another. As an example, for a SF of 2.5, one pad material under a uniform compressive stress of 1250 psi (8.6 MPa) compressed about 15 percent while a different manufacturer's pad compressed about 30 percent. Pads from various manufacturers have been subjected to uniform compressive stresses of 5000 psi (34.5 MPa) without exhibiting any evidence of pad failure, other than large vertical deformation.

Shear Modulus and Friction — The shear modulus of ROF pads is higher than chloroprene pads and values in the range of 300 to 700 psi (2.1 to 4.8 MPa) have been measured at room temperature. High or low temperature data are not available.

The shear-compression testing discussed previously has shown significant slippage and rolling at apparent shear strains of 15 to 75 percent. These tests show similar slippage and rolling behavior as was noted in the chloroprene tests from Europe which showed severe slippage and rolling at or near 70 percent apparent shear strain.

Since pad slippage does occur it is recommended that the pad thickness be selected as 1.4 times the calculated deformation of the end of the precast member, the same as the chloroprene recommendation.

The maximum friction force which can be produced at the ends of members can be estimated by the shear stress versus compressive stress curves shown in Fig. 16.

Rotation — The same recommendations would be suggested here as were used in chloroprene pads. The recommendations there are based on a minimum 15 percent vertical strain in the pad and rotations limited to avoid lift-off or tension in the high side. These criteria also seem appropriate for ROF pads.

Duck Layer Reinforced Pads

Allowable Compressive Stress — Present PCI criteria and a number of manufacturers suggest an allowable maximum compressive stress of 2000 psi (13.8 MPa) for DLR pads. This value appears appropriate and should be continued in the PCI literature. These pads are seldom used in smaller shape factors and little apparent need exists to limit stresses on smaller pads.

Shear Modulus — The shear modulus is much higher than for the other pads. A recommended range of shear modulus is suggested with a lower limit of 500 psi (3.4 MPa), taken from present PCI recommendations, and an upper limit of 3000 psi (20.7 MPa), as noted in our testing.

Shear Deformation — The high shear modulus leads to very small shear deformation during shear-compression testing. While the single test in this research is far from conclusive it is recommended that a limit of $0.2\,t$ be considered for the maximum shear deformation. In this single test a shear deformation of about $0.10\,t$ required a shear stress of over 200 psi (1.38 MPa) and no observable slipping had occurred. This area warrants future testing to confirm upper limits on shear deformation and slippage behavior.

Rotation — The same recommendations for rotation limits are suggested, based on a minimum vertical strain of 0.15 and designing against lift-off or tension on the high side.

Chloroprene Identification Test

The simple burning test developed in this study apparently provides a ready means of preliminary identification of those pads in a Bunsen burner flame for 5 seconds and then withdrawn. If the flame dies in less than 15 to 20 seconds, the pad is probably composed of chloroprene elastomer. More certain analysis can be accomplished using spectrometer analysis, with the availability of spectra of various materials to be identified. These spectra tests are more expensive and time consuming.

Future Research

The general scarcity of test data relating to random oriented fiber and duck layer reinforced pads suggests a serious need for future research with these pad types, and need for definitive specifications for these materials.

The slipping noted in the shear-compression testing at moderate to high compressive stress in Europe and the United States suggests that further testing and correlation with field performance would perhaps yield a different outlook on the performance of plain bearing pads. Tests should be undertaken on actual long-span structures to determine if the member deformation results in pad shear strains, slippage or a combination of these two mechanisms.

Further correlation of the "*K*" factor in the simplified compressive stress formula proposed here for chloroprene pads should be considered to provide the designer with safe yet economical designs.

The use of plastic shim material as bearing pads is an interesting development that also needs future review, study and evaluation.

* * *

NOTE: Discussion of this paper (or the full length report) is invited. Please submit your comments to PCI Headquarters by May 1, 1986.

REFERENCES

1. Stanton, J. F., and Roeder, C. W., "Elastomeric Bearings, Design, Construction, Materials," NCHRP Report No. 248, Transportation Research Board, Washington, D.C., August 1982, 82 pp.
2. Stanton, J. F., and Roeder, C. W., "Elastomeric Bridge Bearings Specification: Review of the Present and Proposals for the Future," *ACI Journal*, Proceedings V. 80, No. 6, November-December 1983, pp. 514-525.
3. Roeder, C. W., and Stanton, J. F., "Elastomeric Bearings: State-of-the-Art," *Journal of Structural Engineering*, ASCE, V. 109, No. 12, September 1983, p. 2853.
4. *Standard Specifications for Highway Bridges*, American Association of State Highway and Transportation Officials, Washington, D.C.
5. *PCI Design Handbook – Precast Prestressed Concrete*, Second Edition, 1978, Prestressed Concrete Institute, Chicago, Illinois, pp. 5-3 — 5-5.
6. *PCI Manual for Structural Design of Architectural Concrete*, Prestressed Concrete Institute, Chicago, Illinois, 1977.
7. *PCI Design Handbook – Precast and Prestressed Concrete*, Third Edition, 1985, Prestressed Concrete Institute, Chicago, Illinois, pp. 6-14 — 6-16.
8. "Design of Neoprene Bearing Pads," E. I. DuPont de Nemours and Company, Wilmington, Delaware, April 1959, 20 pp.
9. "Code for the Use of Rubber Bearings for Rail Bridges," Union Internationale des Chemin de Fer (UIC), Code 772R, France, 1973.
10. "Design Requirements for Elastomeric Bridge Bearings," Technical Memorandum BE 1/76, Highways Directorate, Department of Environment, Great Britain, February 1976.
11. British Standards Institution, "Draft British Standard BS5400: Steel Concrete and Composite Bridges: Part 9A: Code of Practice for Design of Bearing and Part 9B: Specifications for Materials, Manufacture and Installation of Bearings," Document 81/10184, February 25, 1981.
12. "Masticord Design Guide JVI Inc.," Raths, Raths and Johnson, 1984, Willowbrook, Illinois.
13. "Engineering Properties of Neoprene Bridge Bearings," DuPont Company, Elastomers Division, Wilmington, Delaware, 1983, 13 pp.
14. Schrage, Ingo, "Anchoring of Bearings by Friction," Publication SP-70, *Joint Sealing and Bearing Systems for Concrete Structures*, V. 1, American Concrete Institute, Detroit, Michigan, 1981, p. 197.

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