CRITERIA FOR DESIGN OF BEARING PADS

James K. Iverson and Donald W. Pfeifer
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CRITERIA FOR DESIGN OF BEARING PADS

INTRODUCTION

General:

Bearing pads are essential in construction with precast concrete. They provide two primary design functions both intended to minimize undesirable stresses in the adjacent concrete:

1) To obtain more uniform distribution of concentrated loads.

2) To allow movement and minimize the effects of loads due to volume changes from shrinkage, creep and temperature.

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

In the past, the most commonly used elastomeric bearing pads could be divided into two general groups; unreinforced plain pads made of elastomer, and laminated pads made of elastomer reinforced with parallel horizontal steel plates. Small size plain pads are used throughout the construction industry, whereas the larger, more expensive, reinforced, laminated pads are used primarily for bridge bearings.

Pads reinforced with both random oriented fibers and layered fiber material are available and their use is increasing in building construction. These newer pads bridge the gap between the large steel laminated pads and the plain unreinforced pads.

One of the difficulties in designing bearing pads stems from the large number of companies producing similar competing products which often have different physical properties and capabilities. Generally, a few large chemical companies produce the
basic raw elastomer, but they do not produce the final bearing pad product. This operation is left to the numerous pad producers, who buy the raw material, formulate it with a number of fillers and enhancers, vulcanize it with or without reinforcement, and cut the final pad. This company may in turn sell the bearing pads to other suppliers or distributors and the final user or designer finds it difficult to determine the actual composition and mechanical properties for the pad.

Types of Pads

The most common types of bearing pads used today are:
- Chloroprene (Neoprene) is probably the most commonly used pad.
- Random oriented fiber (ROF) reinforced elastomeric pads are made from excess materials from the tire industry, with short fibers randomly oriented throughout the material.
- Duck layer reinforced (DLR) pads are generally of chloroprene or similar elastomer with horizontal layers of woven duck fiber reinforcing at extremely close spacing.
- Laminated elastomeric pads with reinforcing layers of steel or fiberglass are commonly used for bridge bearings.
- Natural rubber is commonly used in Europe but seldom used in the United States.
- Plastic pads
- Steel plate
- Low friction materials such as teflon or TFE (polytetrafluoroethylene) are most often used in conjunction with other bearing materials, to provide a slip surface.
- A number of materials, such as bituminous joint filler, hardboard, wood and similar filler materials have been used, but these materials are not generally considered as reliable structural bearing materials.
Material and Design Specifications

At present, the design guidance for these various pads comes primarily from the American Association of State Highway and Transportation Officials (AASHTO) Specification, (1) State Highway Departments, and the Prestressed Concrete Institute (PCI) Handbooks. (2, 3) Most of the design information and material on plain chloroprene pads is based on Du Pont research and design recommendations published in 1959. (4)

AASHTO provides a material specification for chloroprene and natural rubber bearing pads in Section 25 of their Standard Specifications. (1) Article 2.10.3(L) also provides a brief description of duck layer reinforced pads that falls short of being a complete specification. MIL-C-882C also covers duck layer reinforced pads and a number of State Highway Departments have sections in their standard specifications dealing with bridge bearing pads.

Design information and specifications for the numerous types of small pads used in building construction are not covered to any extent by standard specifications. The general sources of design guidance for small pads are the PCI handbooks (2, 3) and manufacturers brochures which apply to a particular product.

Purpose and Direction for this Study

The purpose of this study is to better understand pad behavior and development of appropriate design criteria for bearing pads to be included in the PCI Design Handbook. This study has been accomplished in accordance with the following five tasks outlined in the PCI request for proposals and detailed in further directions from the following advisory committee appointed by PCI:

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*References at end of report*
Advisory Committee

<table>
<thead>
<tr>
<th>Member</th>
<th>Affiliation</th>
</tr>
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<tbody>
<tr>
<td>Daniel P. Jenny</td>
<td>Technical Director, P.C.I.</td>
</tr>
<tr>
<td>Anthony L. Schloss</td>
<td>E. I. duPont deNemours &amp; Company, Elastomers Division</td>
</tr>
<tr>
<td>T.J. Gutt</td>
<td>TPAC Division of the Tanner Companies</td>
</tr>
<tr>
<td>Kenneth Vick</td>
<td>Spancrete Industries, Inc.</td>
</tr>
<tr>
<td>Thomas J. Lechner</td>
<td>Voss Engineering, Inc.</td>
</tr>
<tr>
<td>James R. Voss</td>
<td>JVI, Inc.</td>
</tr>
<tr>
<td>John M. Hanson</td>
<td>Wiss, Janney, Elstner Associates, Inc.</td>
</tr>
</tbody>
</table>

Research Tasks

Task 1 - "Conduct a survey of the membership of the Institute to obtain information on problems that have been encountered with use of bearing pads in buildings."

Task 2 - "Investigate a selected number of the problems identified in Task 1, by making site visits and carrying out analyses to determine conditions that caused these problems."

Task 3 - "Collect and synthesize all current information on pads that are suitable for bearings of precast members."

Task 4 - "To the extent that resources are available, conduct tests to evaluate the performance of selected bearing pad materials."

Task 5 - "Using the information collected in Tasks 1 through 4 develop appropriate design criteria for precast concrete construction. These criteria along with supplemental design aids are to be developed in a form suitable for inclusion in the Industry Design Handbook."

A primary direction emerged during the early committee discussions. Since the PCI Design Handbook is currently under revision, the Industry Handbook Committee determined that the new edition would be clearly directed to serve design of precast and prestressed concrete in buildings and it would not attempt to serve the bridge construction industry. As a result, the orientation of this study was directed toward buildings. The primary
Fig. 1 - Bulging of unreinforced elastomeric pad under compressive load
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 between the two loading surfaces and still support and transfer 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 or gross slippage. An example of an unreinforced chloroprene pad is shown in the center of Fig. 2.

Duck layer reinforced pads are generally produced with chloroprene or nitrile elastomers used to bond closely spaced horizontal layers of woven duck fiber material together. The resulting pads are more costly and have much higher compressive load capacities than unreinforced pads since the reinforcing minimizes bulging and deformation. However, shear, rotation and irregularities are less easily accommodated than with the unreinforced chloroprene pads. A sample of this pad type is shown on the right in Fig. 2.

The random oriented fiber reinforced pads are a recently introduced pad type. They are generally produced from excess virgin tire production material. The material is processed by chopping the tire fibers, adding ozone retardant and then vulcanizing into sheets. These sheets are then cut to size. Again, the random fiber reinforcement reduces the usual pad bulging characteristic and allows higher compressive loads, but the material is somewhat stiffer and accommodates irregularities, rotation and shear movements less easily. A sample of this type of pad is shown on the left in Fig. 2. Some variability is noted in these pads, such as, fiber type (nylon, rayon, etc.), fiber distribution, and elastomeric composition.

Plastic is not commonly used for bearing pads except under solid or hollow-core concrete slabs. It is used for shims under precast wall panels and columns. Two companies manufacture such
Fig. 2 - Samples of random-fiber reinforced, chloroprene and duck layer reinforced pads
a product. The material is considered advantageous for shims because it creeps slightly and transfers some load to the grout bed. The material essentially does not bulge, and it has high compressive load capability. It is relatively hard and has more limited ability to conform to surface irregularities, rotations or shear movements than the elastomeric pads. No standard industry specifications are known to exist for this material.

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 similarly to the plastic material discussed above. 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.

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. These low friction materials have also been coated on other bearing pad materials such as duck layer reinforced pads.

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

**Design Guidance**

Current AASHTO Specifications, although often used, are now considered outdated and are currently under study for revision. Most State Highway Departments use these guidelines which are clearly directed toward large pads with heavy loads. Bridge pad design is conservative since these pads will be used in extreme environmental conditions with heavy moving loads and generally provided little or no maintenance.
The design of pads for buildings are covered in the PCI Design Handbooks or various pad manufacturers' brochures. The manufacturers' brochures are limited to each manufacturer's data and often do not provide sufficiently broad design values for the designers use.

The first part of the study to update the AASHTO bridge pad design specification is covered in NCHRP Report 248(5). This comprehensive report is of interest as it also summarizes the most commonly used foreign design requirements. It appears that significant research has been undertaken on bearing pads in Europe. Table 1, which summarizes these design requirements and notation for large, plain chloroprene pads for bridges, is taken directly from this NCHRP report. The three foreign bridge codes and the AASHTO specifications that are summarized are representative of current world practice. The UIC 772R Specification(8) is developed by the International Union of Railways and is used in Europe and some other parts of the world by both railway and highway authorities. The BE 1/76(9) is a British code and is stated to be the most widely used elastomeric bearing specification in the world. It is used in Britain, Australia and in countries in Europe and Asia. The design methods were particularly developed for reinforced-laminated bearings of natural rubber but they are widely used with chloroprene. BS5400(10) is a draft British Standard and represents current thought on this subject in Britain. It represents a combination of BE 1/76 and UIC 772R. These foreign codes are generally based on considerable testing or theory and tend to be more complex than AASHTO Specifications. However, if favorable design conditions with minimum movements are encountered, much higher compressive stresses are allowed when compared with AASHTO particularly on pads with large shape factors. It is useful to note again that these codes all are dealing with large bridge bearing pads, where small plain pads tend to be relegated to a secondary position.

A discussion on German practice is warranted. Design calculations are simplified, and only a few standardized sizes and
<table>
<thead>
<tr>
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<th>BS 5400</th>
<th>BE 1/76</th>
<th>AASHTO</th>
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<tr>
<td><strong>ALLOWABLE SHEAR DISPLACEMENT</strong></td>
<td>$\delta_s \leq 0.7$ T</td>
<td>$\delta_s \leq 0.7$ T</td>
<td>$\delta_s \leq 0.5$ T</td>
<td>$</td>
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<tr>
<td><strong>ALLOWABLE VERTICAL DISPLACEMENT</strong></td>
<td>$\delta_c \leq 0.15$ T</td>
<td>To be specified by engineer</td>
<td>$\delta_c \leq 0.1$ T</td>
<td>$\delta_c \leq 0.07$ T</td>
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<td><strong>VERTICAL DEFLECTION EQUATION</strong></td>
<td>$\delta_c = \frac{Pc}{A_{re}} \left( \frac{1}{5d^2} + \frac{1}{T} \right)$</td>
<td>$\delta_c = \frac{Pc}{A_{re}} \left( \frac{1}{5d^2} + \frac{1}{T} \right)$</td>
<td>$\delta_c = 1.8pT_{re} \left( \frac{1}{E_c} + \frac{1}{1.2k} \right)$</td>
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<td><strong>SHAPE FACTOR</strong></td>
<td>$S = \frac{Pw}{2T(L+W)}$</td>
<td>$S = \frac{3.67L(L+W)}{W}$</td>
<td>$S = 3.67(L+W)$</td>
<td>$S = \frac{Pw}{2T(L+W)}$</td>
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<td><strong>LIMITING CRITERIA FOR ALLOWABLE LOAD $P$</strong></td>
<td>$\bar{\sigma}_c &lt; 20S$</td>
<td>$\bar{\sigma}_c &lt; 20S$</td>
<td>$\bar{\sigma}_c &lt; 0.07$ T</td>
<td>$\bar{\sigma}_c = \frac{P}{A} \leq 800$ psi</td>
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<tr>
<td><strong>STABILITY REQUIREMENTS</strong></td>
<td>$T \leq \frac{L}{5}$</td>
<td>$T \leq \frac{L}{4}$</td>
<td>$T \leq \frac{L}{6}$</td>
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<tr>
<td><strong>SLIP REQUIREMENT</strong></td>
<td>$\bar{\sigma}_c &gt; 145 \left( 1 + \frac{1}{W} \right)$ psi</td>
<td>$\bar{\sigma}_c &gt; 145 \left( 1 + \frac{1}{W} \right)$ psi</td>
<td>$\bar{\sigma}<em>c &gt; 3H \frac{A}{A</em>{re}}$ (concrete)</td>
<td>$\bar{\sigma}_c &gt; 200$ psi due to D.L</td>
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**NOTATION:**
- $A \cdot LW$  
- $A_{re} = (L - \delta_s)W$  
- $\delta_s$ = Shear Deflection  
- $\delta_c$ = Compressive Deflection  
- $T$ = Total pad thickness  
- $L$ = Length (Parallel to Beam Centerline)  
- $E$ = Young's Modulus with unrestrained lateral displacement  
- $E_c$ = Compressive modulus with lateral displacement restrained  
- $k$ = Material constant depending on hardness  
- $K$ = Material bulk modulus in compression  
- $F_{pl}$ = Allowable Load  
- $Y_{pl}$ = Compressive strain as per subscript  
- $F_{pl}$ = Shear strain as per subscript  
- $B = \text{Ratio of max. comp. load in BE 1/76}$  
- $W = \text{Width (perpendicular to Beam Centerline)}$  
- $S = \text{Shape Factor}$  
- $H = \text{Horizontal Force}$  
- $P = \text{Allowable Load}$  
- $\gamma = \text{Shear strain as per subscript}$  
- $\bar{\sigma}_c = \text{Average Compressive Stress}$  
- $T = \text{Average compressive strain}$
shapes of pad using a single elastomer are used. All pads are proof tested and each manufacturer must pass a rigorous certification procedure. The results from this concept have apparently been very satisfactory but pads are quite costly and the concept tends to restrain new developments.

SURVEYS AND SITE VISITS

The survey work involved in Tasks 1, 2 and 3 involved:

- PCI Membership Survey
- Site Visits
- Collection of Data and Information

PCI Membership Survey

This work was performed with a controlled combination letter and telephone survey of selected producer members. Twenty-one PCI member companies were selected across the U.S.A. and Canada. An initial letter outlining the followup telephone survey was sent to each company. Following their study of this letter questionnaire, telephone contact was made and their responses were noted as outlined in Appendix 1.

Significant comments on responses from the Survey are:

1. Four respondents or about 20 percent felt they had bearing pad problems. However, these problems were related to only a few projects.

2. Six respondents or about 30 percent felt that they experienced limited bearing pad problems.

3. About 60 percent of the respondents used the PCI or slightly modified PCI criteria for their pad design.

4. The remaining respondents used rule-of-thumb procedures to select pads, relied on the building designer to provide pad design, or used pad manufacturer's data.

5. AASHTO-grade plain chloroprene (neoprene) was the most commonly used pad material (60 percent used it as a primary material). Two respondents with no problems used AASHTO-grade exclusively, whenever possible.
Random-oriented fiber pads were also used by 60 percent. Four producers, or 20 percent, use random fiber pads as their primary material, while others use it as a secondary material. One producer has recently switched to the use of plastic bearing pads for all projects. This change being fairly recent, judgment of the success of this choice is still pending, but the producer is enthusiastic. Commercial-grade neoprene is used by four producers, or 20 percent, primarily under double tee legs. Duck layer reinforced pads are generally only used if specified, although one producer uses it under beams on a regular basis.

6. Two producers, or 10 percent, perform limited regular inspections of the pad performance in parking garages. All others do not perform inspections or only on a casual basis.

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

This survey indicates that a bearing pad problem does exist, but it is not wide spread. A number of comments from individuals indicated that their practices with regard to plain bearing pads had changed about seven to ten years ago. These changes 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. Three respondents mentioned that the PCI design practices made no provisions for consideration of rotation in the bearing surfaces. Two respondents felt that design for full concrete creep and shrinkage movement with a shear displacement limit of half the pad depth was too conservative.

It is significant that one type of structure, parking garages, seems to be the problem area. All significant problem projects noted in the producer survey were parking garages.
Whether this is due to the larger volume changes due to the exposure conditions, or to the very small pad sizes used, was not clear and probably both items contribute to the problem. The writers are also familiar with other types of structures (cooling towers and storage tanks) that have experienced significant pad problems.

After reviewing this data, five geographic areas were selected for site trips to review bearing pad performance. A decision was made to concentrate on parking garages, since no significant problems were reported in other types of buildings and garages are easily available for inspection.

Site Visits

Five urban areas were visited:
1) Chicago, Illinois
2) Washington, D.C.
3) Minneapolis, Minnesota
4) Denver, Colorado
5) Phoenix, Arizona

Comments from these inspections are summarized in Appendix 2.

Individual projects were also reviewed from several other states including Washington, Tennessee and Ohio.

In each of the five areas, from four to six garages were visited, conditions noted, and photographs taken. The inspection team generally consisted of an Engineer from a local PCI producer, a representative of a pad producer and one of the writers. Garages with poor to excellent performance of the pads were encountered.

When problems occurred, the following were noted consistently in all areas:

1) Poor pad materials
2) Nonuniform bearing
3) Mislocated pads
Other problem areas were noted although on a more local basis:

1) Delamination of elastomeric pads
2) Excessive shimming and multi-pieced beam pads
3) Moving pads
4) Total disintegration of pad material in loaded area.

Testing of individual pads for durometer hardness (Shore A) was undertaken at most locations. There was no clear correlation between hardness and pad performance. A cigarette lighter fire test to determine chloroprene content was also used and correlation with poor performance and burnability was clear.

An important observation was that none of the garages viewed were experiencing significant damage to the concrete because of these numerous bearing pad problems. If significant problems were evident it generally was from unusual bearing conditions that a bearing pad could not solve. Even when pads had crumbled and practically disappeared concrete damage was minimal. The average age of the garages inspected was about five years, so distress might develop in the future.

Collection of Information from Pad Manufacturers

A survey letter was mailed to seventeen bearing pad manufacturers and nine responses were received. The responses generally consisted of a letter with company literature or data on physical tests on their pads. A list of the responding companies is given in Table 2. These responding companies generally provide design aids although design recommendations vary widely. Some companies have developed pads of combined materials for specialized functions.

The information was reviewed and is felt to be limited in scope and is often duplicative of PCI recommendations. It is primarily related to proprietary materials. No attempt was made to summarize the data, but it was referred to in the development of design aids discussed later in this report.
### TABLE 2
RESPONDING PAD MANUFACTURERS

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Address</th>
<th>Phone</th>
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<tbody>
<tr>
<td>Alert Manufacturing</td>
<td>1848 Wilmot Avenue</td>
<td>312-452-6480</td>
</tr>
<tr>
<td></td>
<td>Chicago, Illinois 60647</td>
<td></td>
</tr>
<tr>
<td>Jack Blackburn</td>
<td></td>
<td></td>
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<tr>
<td>Con-Serv Inc.</td>
<td>600 Forest Ave</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P.O. Box 404</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E. Hanover, New Jersey 07936</td>
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<tr>
<td>General Tire &amp; Rubber Co.</td>
<td>Wabash, Indiana</td>
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<tr>
<td></td>
<td>219-563-1121</td>
<td></td>
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<tr>
<td>Don Dean</td>
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<tr>
<td>JVI, Inc.</td>
<td>7315 N. Monticello Avenue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skokie, Illinois 60076</td>
<td></td>
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<tr>
<td></td>
<td>312-675-1560</td>
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<tr>
<td>James Voss</td>
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<tr>
<td>Oil States Rubber Co.</td>
<td>Farm Rd. 2495 at Progress Way</td>
<td></td>
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<tr>
<td></td>
<td>Athens, Texas 73751</td>
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<td>Walter Adler</td>
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<tr>
<td>Structural Bearing Co.</td>
<td>189 Arkansas</td>
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<td>San Francisco, California 94107</td>
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<tr>
<td>Spencer Dynamics</td>
<td>8-235 Promenade St.</td>
<td>401-274-6202</td>
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TESTING PROGRAM

Pads made of AASHTO-grade chloroprene, random oriented fiber reinforced materials (ROF) and duck layer reinforced materials (DLR) were tested as follows:

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


3. Horizontal shear with accompanying perpendicular compression, a total of four tests.

4. Compression creep under typical maximum design stresses on each material, a total of six tests.

All test materials were obtained from Chicago area pad suppliers. The test pads were 5 in. x 5 in. x 1/2 in. or 3/8 in. nominal size. The shape factors were 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 simulates normal tolerances for steel bearing plate installation as well as the usual geometry at the end of a cambered prestressed concrete element. The slope of one steel plate was set at 1/8 inch in 5 inches in one direction relative to the mating plate.

Companion tests were also made with all three pad materials using parallel 6 x 6 in. 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.

Average stress was determined as the applied load divided by the initial pad area. For all testing, vertical displacements were measured at the four corners of the pad and the average strain was calculated as the average vertical displacement of the pad divided by the initial average pad thickness.
Figures 3, 4, and 5 show various views of these tests in progress. Figures 6, 7 and 8 show the test results for these various test methods and materials. Fig. 9 shows the superimposed data for the parallel steel plate testing for the three materials. For comparison purposes, a stress/strain curve from the commonly used 1959 DuPont publication is also shown in Figs. 6 and 9. It is probable that DuPont testing utilized parallel steel plates.

The parallel surfaces tests indicate the following:

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

2. Compressive strains at 1000 psi were about 0.12 for the reinforced pads and about 0.27 for the chloroprene. For the reinforced pads strains increased to about 0.2 at 2000 psi.

3. The chloroprene test indicated somewhat similar slope to the 1959 DuPont data but showed considerably higher initial nonlinear displacement. The pads in this test were somewhat softer than DuPont's (55 vs 60).

4. When a concrete surface is substituted for one of the two steel plates in the parallel plate loading system using chloroprene, as shown in Fig. 6, the average vertical strain was reduced by about 30 percent, apparently from the increased friction effect from the concrete.

5. Significant bulging of the chloroprene pads occurred at stresses of 400 to 600 psi.

Figure 10 shows the superimposed data for the nonparallel plate testing. These data indicate the following:

1. At an average stress of 1000 psi, the chloroprene, ROF and DLR exhibited compressive strains which were about 50, 130 and 95 percent greater, respectively, than when a parallel steel plate loading system was used.
Fig. 3 - Typical parallel plate compression test

Fig. 4 - Typical non-parallel plate compression test
Fig. 5 - Extrusion of chloroprene during non-parallel plate test
Fig. 6 - Effect of bearing plate slope and surface on compression behavior of AASHTO chloroprene pads
Two Parallel Steel plates

Non-Parallel Sloped top plate at 1/8" in 5" in one direction

5" X 5" X 1/2" PAD
65° F

Fig. 7 - Effect of bearing slope on compression behavior of random fiber reinforced pad
Fig. 8 - Effect of bearing plate slope on compression behavior of duck layer reinforced pad
Fig. 9 - Uniform compression tests with parallel plates comparing chloroprene, ROF and DLR pads
Fig. 10 - Comparison of compression behavior of materials for testing with one bearing plate sloped.
2. At stresses up to about 200 psi, little difference in stress/strain behavior exists between these three materials.

3. Increased bulging of the chloroprene pad occurred at a stress of about 400 psi as shown in Fig. 5.

During all of these various compression tests, none of these pads showed evidence of pad failure from cracking or delamination. At stresses above 200 to 400 psi, all pads apparently had full contact.

Recent testing by Raths, Raths and Johnson(11) on a ROF pad with a different formulation than that used here, shows 100 percent greater compressive strain at 2000 psi than noted in this test. Their research resulted in recommending design based on a compressive strain limit of 30 percent of the pad thickness.

Simple Chloroprene Verification Test

A simple burning test was tried several times throughout the site visits and in the laboratory to indicate whether the pads contained chloroprene as their only elastomer. Chloroprene (or neoprene) does not support combustion and neither do most of the fillers used in the AASHTO-grade pad manufacture. As such, if the pad is ignited and the source of flame removed, an AASHTO-grade chloroprene pad will quickly extinguish. A commercial-grade chloroprene pad will not.

During the site visits to five urban areas, many elastomeric pads would easily support combustion after being exposed to a cigarette lighter flame. Generally if the sustained flame was intense, so were the problems with the pads.

A suggested test procedure was developed in the laboratory to verify field observations. This same test could be easily made by PCI producers in their plants. The test procedure is as follows:

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, as shown in Fig. 11, for 5 seconds.

4. Remove pad from flame and if the pad continues to burn after 15 to 20 seconds out of the flame, the pad is probably not an AASHTO-grade chloroprene pad. Fig. 12 shows a commercial-grade pad burning after being removed from the flame.

To confirm the validity of this simple test, spectrophotometer analysis was used on a number of pad samples. Spectra for approximately 25 vulcanized elastomers, including five types of Neoprene, were obtained from DuPont. Five random samples were then selected from the pad samples obtained in the field trips as shown in Fig. 13. Samples from all areas of the country were used. These five samples (Nos. 1 to 5) were subjected to spectrophotometer analysis, which is reported in Appendix 3. Two pads (Nos. 4 and 5) were of AASHTO-grade chloroprene (neoprene), three were not. The remaining portion of these 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. Both Samples 4 and 5 were retested with similar results. Sample 5 is shown in Fig. 14 after two seconds out of the flame and the flame has extinguished.

These tests show that the simple flame test should be a useful tool for preliminary verification of AASHTO-grade chloroprene pads and that spectrophotometer analysis is a valid method for more certain verification.

Shear Tests

A limited number of shear tests were made. A diagram and photograph of the test set-up are shown in Figs. 15 and 16. These four tests were set-up to attempt to emulate field conditions for pads and not necessarily to maximize the accurate measurement of the static friction coefficient of the material. It
Fig. 11 - Pad sample held in Bunsen burner flame

Fig. 12 - Pad burning out of flame
Fig. 14 - Sample No. 5 after two seconds out of flame
Fig. 15 - Diagram of shear test setup

STEEL BEARING P's

P (BY TESTING MACHINE)

2 IDENTICAL 3/8"X5"X5" PAD SPECIMENS

(BY HYDRAULIC JACK WITH LOAD CELL)
Fig. 16 - Photograph of shear test
was decided to test for shear properties under approximately maximum compression shear loading conditions. 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 all results relate to an apparent shear and friction performance that one might expect from pads of these materials and size acting on steel bearing surfaces under the conditions noted. These data do not represent a true material shear modulus, or coefficient of friction obtained under ideal laboratory conditions.

Identical pad specimens, 5 in. x 5 in. x 3/8 in., 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 displacement divided by original pad thickness. Each test required about 10 to 15 minutes.

The normal compression stresses were 800 psi for chloroprene, 1500 psi for ROF and 2000 psi for DLR. These stress levels are generally equal to the maximum design stresses allowed. Test results are shown in Figs. 17 and 18. The chloroprene test result is not plotted because of early slipping. Slipping of the chloroprene pads occurred at an extremely low shear stress of about 27 psi which is approximately a shear stress to compressive stress ratio of 0.03. The two tests with ROF pads showed slippage at shear stresses of about 75 psi and 125 psi, which are at shear to compression stress ratios of 0.05 to 0.08. The ROF pads exhibit a shear modulus of elasticity (G) of about 700 psi up to a shear stress of 75 psi. 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 maximum applied shear stress of 200 psi while under a normal compression stress of 2000 psi. The shear strain of the pad at a shear stress of 200 psi was about 10 percent. The DLR pads exhibited an initial shear modulus of elasticity (G) of about 4700 psi and a secant modulus from 0 to 170 psi of about 3000 psi.
SHEAR TESTS 2 & 3 -
2 ROF Pads - 5x5x3/B
All bearing surfaces steel
Load in shear at about 10 psi per minute
Vertical Compressive Stress - 1500 psi

○ = TEST 2
x = TEST 3
(Both with identical conditions)

Fig. 17 - Shear test data on random oriented fiber pads
SHEAR TEST 4 -
2 Duck Layer Reinforced Pads -
5x5 x 3/8 in.
Vertical Compressive Stress =
2000 psi

Loaded in shear at 10 psi per minute
All Bearing Surfaces steel

Fig. 18 - Shear test data on duck layer reinforced pads
These limited shear-compression tests show that the measured friction coefficients (at slippage) for the chloroprene and ROP pads on steel plate were only 3 to 8 percent of the applied compressive stress.

Creep Tests

The creep tests were made in standard creep frames in a controlled temperature and relative humidity room (73°F, 50% R.H.) as shown in Fig. 19. Six creep tests were made on two samples of each of the three materials. All tests were on nominal 1/2 in. thick pads. As shown in Fig. 19, the steel plates extended over the sides of the pads. During testing the separation of the four corners of these projecting steel plates was measured with a micrometer and averaged to indicate the initial vertical deformation of the pad during loading and the subsequent time-dependent creep deformation of the pad for over 120 days while under constant loading. The vertical deformations were measured immediately after the initial loading, after 4 hours under load, and then at appropriate intervals during the test period. Again, maximum compressive stresses were used. The test results are presented in Fig. 20. Discussion of test results follow.

Chloroprene Material - The chloroprene sample No. 2 was loaded to 600 psi uniform compressive stress. The average measured modulus of elasticity was about 3000 psi. The measured initial and creep strains with pad No. 2 were 18.8 and 17.6 percent of the original pad thickness as shown in Fig. 20. As a result, the total deformation was 36.4 per-cent of the pad thickness or 0.18 inches. Thus, the 0.5 inch thick pad reduced in thickness down to 0.32 inches in 120 days. The shape of the creep curve in Fig. 20 suggests that additional creep shortening will occur in the future. These data show that at a stress of 600 psi the creep shortening may equal or exceed the instantaneous shortening.
Fig. 19 - Typical creep specimen with chloroprene pad at 600 psi
Fig. 20 - Creep data on chloroprene (Neoprene), random oriented fiber reinforced and duck layered reinforced pads

TEST 2 -
1/2" Chloroprene at 600 psi
18.8% IE

TEST 5 -
1/2" DLR at 2000 psi
13.5% IE

TEST 4 -
1/2" ROF at 1500 psi
18.6% IE

TEST 3 -
1/2" ROF at 1500 psi
13.6% IE

IE = Initial Strain as % of Pad Thickness
Chloroprene test pad No. 1 was preloaded to 800 psi for two minutes and then unloaded down to 600 psi and held at 600 psi for the duration of the testing. Results of testing of pad No. 1 were not conclusive and are not plotted. Creep was approximately 2 percent of original pad thickness.

The chloroprene pads showed significant bulging at 600 psi as shown in Fig. 19 and even more severe bulging at 800 psi. Extension outside the loading plates was not considered significant in the reported specimens.

**Random Oriented Fiber Material** - The ROF pads were loaded to 1500 psi. The average modulus of elasticity measured during the initial loading was about 9000 psi. The measured average initial and creep strains were 16.1 and 7.8 percent of the original pad thickness as shown in Fig. 20. As a result, the total deformation was 23.9 percent of the pad thickness or 0.12 inches. The 0.5 inch thick pad reduced in thickness to 0.38 inches in 120 days. The shape of the creep curves suggest that the continuing rate of creep and amount of creep are significantly less than that of the chloroprene pad No. 2 even though the applied stress on the ROF pad is 2 1/2 times greater.

**Duck Layered Reinforced Material** - The DLR pads were loaded to 2000 psi. The average measured modulus of elasticity during the initial loading was about 17,000 psi. The measured average initial and creep strains were 11.9 and 8.4 percent of the original pad thickness as shown in Fig. 20. As a result, the total deformation was 20.3 percent of the pad thickness or 0.10 inches. Thus, this 0.5 inch thick pad reduced in thickness down to 0.40 inches 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.

These limited tests at maximum design stresses illustrate that additional creep tests are required to better understand these various engineering factors.
DISCUSSION

General

There is a need for simple, straightforward design criteria for chloroprene, random oriented fiber and duck layer reinforced pads for building construction. The present PCI bearing pad design criteria are widely used, and these criteria appear to provide adequate field performance when proper bearing pad materials are used. Some pad problems have occurred and often can be related to poor materials. The remainder of this section deals with conclusions and observations obtained during this study.

Current Recommendations on Compression of Chloroprene Bridge Bearing Pads

The recent publications by Stanton and Roeder(5,6,7) introduce a simple formula limiting nominal compressive stress for plain chloroprene pads, $f_c$, to:

$$f_c = \frac{G_S}{\beta} \text{ psi}$$

but less than 800 psi for non-restrained, plain pads

$G$ = Shear Modulus, psi

$S$ = Shape Factor

$\beta$ = Material Factor (= 1.8)

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

The material factor of 1.8 is applied slightly differently in the recent DuPont publication(12) and European codes (Table
NCHRP 248(5)
with β = 1.8 on Comp. stress

50 D  (G = 10)
60 D  (G = 60)

From DuPont (12)
with β = 1.8 on Shape Factor

Original Curves from PCI, Ed. 2

Fig. 21 - Recent design recommendations for plain chloroprene pads
3. As shown in Fig. 6, the stress-strain characteristic may be influenced by the type of bearing materials that contact the pad (i.e., concrete vs steel).

4. The compression testing with nonparallel plates as undertaken in this study (Figs. 6, 7 and 8) clearly illustrated an increased compressive strain when compared to parallel steel plates.

The review of information on ROF and DLR pads finds limited data available for their design or specification. The lack of definitive specifications for ROF is a detriment to their use. However, many producers are using the ROF pads which are less expensive and take higher compressive loads than plain pads.

The design of a bearing pad must relate to the loaded area. It was noted in the site inspections that many pads were used that extend some distance outside of the loaded area. The oversized pad is commonly used to allow holding the pad while the precast member is being placed. Design should consider only the loaded area.

The lateral flow of a pad as illustrated in Fig. 19 is detrimental to its bearing capacity. Bonding the pad to the bearing surfaces, or between reinforcing steel plates, as in the laminated steel plate reinforced bearing, is beneficial. Both NCHRP 248 and Dupont suggest much higher allowable compressive stresses for these conditions. Such confined pads are not presently used in building construction but may be a future development worth study.

The large vertical displacement caused by the lateral flow of the chloroprene is one of its best and yet most troublesome properties. The flow allows accommodation for large irregularities and shears 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.
3. As shown in Fig. 6, the stress-strain characteristic may be influenced by the type of bearing materials that contact the pad (i.e., concrete vs steel).

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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\(^3\) has been to limit such rotation to:

\[
r = \frac{2d_c}{L}
\]

\(d_c\) = compression displacement

\(L\) = length of bearing in direction of rotation

\(r\) = maximum rotation in radians

This is intended to prevent lift-off at the low-stress end of the nonparallel plates. This geometry is illustrated in Fig. 22.

Lateral shear displacement has also commonly been limited to 0.5 of the pad thickness as illustrated in Fig. 23. European practice has allowed up to 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 to be sufficiently conservative so that design compression stresses are not significantly affected by deformations within the limits. The European Codes (Table 1) attempt to model these combinations, either through stress or strain limitations. However, the resulting expressions are often complex and the wide variety of properties for pads used in the U.S. negate the usefulness of such detailed analysis. Also, as discussed below, slippage probably makes such limits physically unrealistic.

Friction and Slippage

Design for the shear deformation of elastomeric pads as outlined above has generally been 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 pad from slipping. The
Fig. 22 - Limitation on rotation

Fig. 23 - Shear movement limits
upper limit on the frictional force which could be developed between elastomeric pads and steel or concrete surfaces was assumed to be 0.7 of the normal force, based upon static friction coefficient test data.

The 1982 NCHRP 248 report\(^{(5)}\) discusses the apparently troublesome slipping characteristic of plain elastomeric pads when loaded in shear while under perpendicular compression loads. This slipping or "walking out from under loads" is a commonly noted pad problem. The NCHRP report discusses research reported in Europe in 1965 which showed that the friction coefficient for concrete or steel surfaces in contact with plain rubber pads decreased dramatically as the compressive stress level on the rubber pad was increased. This European study suggested the following equation for a conservative estimate of the coefficient of friction for concrete or steel surfaces as a function of compressive stress on the pad:

\[
\mu \geq 0.10 + \frac{29}{\sigma_c}
\]

where \( \mu \) = friction coefficient, \( \frac{\sigma_s}{\sigma_c} \) = compressive stress on pad, psi \( \sigma_c \) = shear stress on pad, psi

A plot of this equation is shown in Fig. 24 covering a range in compressive stress from 50 to 2,000 psi. It is noted that the value approaches 0.7 at compressive stress levels of 50 psi while it decreases rapidly to values of only 0.17 to 0.12 for compressive stress levels of 400 psi to 2,000 psi, respectively.

A similar reduction effect on \( \mu \) for teflon pads is shown in the PCI Architectural Design Manual\(^{(3)}\) in Fig. 2.81. The friction coefficient for TFE reduces from about 0.09 to 0.04 as the compressive stress level increases from 10 to 2,000 psi.

These dramatic decreases in friction coefficients have not been previously accounted for in design practice. The NCHRP 248 report discusses other test data which substantiate this decrease
Fig. 24 - Friction coefficient versus normal stress for rubber pads

\[ \mu = 0.10 + \frac{29}{\sigma_c} \]
and certain comments taken directly from this report are as follows:

- "Friction is thus seen to be imperfectly understood and the possibility of slipping merits conservative consideration."

- "Further, the unreliability of the friction results in the increased probability of a plain pad 'walking' from under the load."

- "The lower values of $\mu$ found by others, combined with the effects of dynamic live load which further reduce them, make some slip almost inevitable for pads of practical shape factors."

A significant research paper on this subject is from West Germany and was published in A.C.I. Publication SP-70(14) in 1981. This paper by I. Schrage presented and discussed numerous tests on plain chloroprene pads undergoing shear/compression tests against concrete and steel surfaces. The tests utilized nominal compressive stresses of 72, 725 and 2,900 psi on the plain chloroprene pads. The pad shape factor was generally 2.0. These tests applied the shear loads at constant horizontal displacement rates of 1.97 in./sec, 0.02 in./sec and 0.0004 in./sec to a maximum 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 long double-tee member experiencing a 50°F temperature change uniformly over a six hour period would be about 0.000005 in./sec at each end of the tee. Thus, the lowest rate of shear loading used in these tests (0.0004 in./sec) was most typical of daily temperature effects and long-term creep and shrinkage effects.

Their data are presented and discussed in terms of "slip resistance" at the different maximum shear deformations for the pad. The German building regulations assume that nonanchored bearings are appropriate to transfer short-term tangential loads.
However, service performance is limited to a maximum shear deformation for the pad of 0.7 times the pad thickness and the friction coefficient, $\mu$, was previously assumed at 0.20.

Significant observations and conclusions from these tests are as follows:

- Minor slip occurs at even low shear stresses.
- Plain chloroprene pads under low vertical stresses tend to move under horizontal load by pure slippage.
- Plain chloroprene pads exhibit "rolling" and slipping when under high compressive stresses and subjected to horizontal shear loads.
- The coefficient of friction is dependent on the shear loading rate.
- For the very slow shear loading rate, the tests on steel and concrete surfaces produced different coefficients of friction.

Figures 25 and 26 show the average relationship between $\mu$ and compressive stress on the pad at a "shear plus slippage" strain of 70 percent using concrete and steel surfaces. Figure 27 shows the range of the data for their multiple tests on chloroprene pads on concrete surfaces using the shear load rate of 0.02 in./sec.

In the conclusion portion of his 1981 ACI paper, Mr. Schrage suggests a "rough" equation for relating friction dependence on compressive stress as follows:

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

He further comments that the present German regulation of using $\mu = 0.20$ is realistic at very low compressive stresses but the pad will slip before reaching shear strains of 70 percent.
Fig. 25 - Compressive stress versus apparent friction factor - concrete surfaces
FROM REFERENCE 14
CHLOROPRENE PADS ON
STEEL SURFACES

SHEAR LOADING RATE

Fig. 26 - Compressive stress versus apparent friction factor - steel surfaces
FROM REFERENCE 14
CHLOROPRENE PADS ON
CONCRETE SURFACES
SHEAR LOADING RATE, 0.02"/sec.

Fig. 27 - Range of data - concrete surfaces
He also pointed out that at high compressive stresses, the $\mu$ value will be well below 0.20. Figure 28 shows the above suggested equation and compares it with the 1965 UIC equation previously discussed.

A study of the shear-compression strength of specially formulated random oriented fiber pads was undertaken in 1983-84 by a pad manufacturer in the United States (11). This data was submitted during this study for review. Sixteen shear tests were made using pads ranging in size from 2 x 2 to 6 x 6 in. (square pads) and 1-1/2 x 3 to 3 x 6 in. (rectangular pads). The thicknesses were 1/4, 1/2 and 3/4 in. The compressive stress levels used were 800 psi and 1,200 psi. The shear test method is the same as used by WJE as shown in Fig. 15. These tests were on uniform float finished concrete surfaces. Significant test results from this U.S. study are discussed below:

- The ROF pad static friction coefficient on a concrete surface using only gravity loading during an inclined plane test, where the angle of the inclined plane was measured at which sliding or slipping initiated, varied from 0.7 to 0.9, while the 0.7 value was the most usual.

- The friction coefficient measured during the 16 shear-compression tests varied from 0.2 to 0.5, depending upon the compression stress and shear displacement.

- The leading edge of the pad tended to roll at shear plus slip deformations of about 3/4 of the pad thickness. (This same type of behavior was noted in the tests by Schrage on chloroprene pads with similar geometries.)

- For compressive stress levels of 800 psi and 1,200 psi on the ROF pads, the average friction coefficient was about 0.20 and 0.15, at shear plus slippage strains of 75 percent. These coefficients gradually increased to about 0.30 and 0.27, at
Fig. 28 - Comparison of friction coefficients from 1965 and 1981 West German reports

\[ \mu = 0.10 + \frac{29}{\sigma_c} \] (1965)

\[ \mu = 0.05 + \frac{58}{\sigma_c} \] (1981)
shear plus slippage displacements of twice the pad thickness. At that time significant slippage had occurred.

These recently acquired shear test data on ROF pads on concrete are shown in Fig. 29 superimposed on the L. Schrage results for chloroprene on concrete.

The previously discussed WJE shear-compression tests on chloroprene and ROF pads on steel surfaces exhibited extremely low friction coefficients. These tests used a shear loading rate of about 0.00002 in./sec. which is slower than the lowest rate used in the Schrage tests on chloroprene. The chloroprene pad test for PCl utilized a compressive stress of 800 psi and slip occurred at a friction coefficient of approximately 0.03 at a very low shear strain. The ROF on steel tests both utilized a compressive stress of 1500 psi and friction coefficients 0.05 and 0.08 resulted. These data are plotted in Fig. 30 which also shows the Schrage data for chloroprene pads on steel surfaces for comparison.

Fig. 31 shows the 1965 UIC equation and the 1981 equation proposed by Schrage for rubber or chloroprene pads on either concrete or steel surfaces and all the 1984 U.S. test results for both ROF and chloroprene pads.

The DLX pad test for PCl did not show any apparent slippage while being subjected to a shear stress of 200 psi and under a compressive stress of 2,000 psi. The shear strain was only 10 percent and the friction coefficient, \( \mu \), at the end of the test was about 0.10. This test was terminated due to equipment capacity.

These 20 shear-compression tests in the U.S. during 1983-84 substantiate the European data and show that the shear-compression friction coefficients for chloroprene and the specially formulated and standard ROF pads decrease well below a static coefficient of 0.7 that is commonly used in design, under commonly used compression loads.
Fig. 29 - Compressive stress versus friction for ROF and chloroprene on concrete surfaces
Fig. 30 - Stress ratios on steel surfaces
Fig. 31 - Comparison of friction coefficient from 1965 and 1981 West German reports and U.S. test results
While the shear-compression friction coefficient, $\mu$, at slippage or pad rolling decreases dramatically as the compressive stress level increases, the available or allowable shear stress on the pad under the same conditions does not decrease. The data from the 24 European tests and the 20 U.S. tests on plain pads were calculated and plotted in Fig. 32 to compare the shear stress on the pad versus compressive stress on the pad at shear plus slippage strains of 70 percent. These plots are for chloroprene and ROF pads on concrete or steel surfaces. These four curves show increasing shear stress capacity as compressive stress increases. These curves are based on a slow loading rate, such as occurs due to temperature changes, and are not appropriate for seismic loading.

The European equations for $\mu$ are of the form:

$$\mu = \frac{A + B}{\sigma_c}$$

where $A$ and $B = \text{Constants}$

$\sigma_s = \text{shear stress on pad}$
$\sigma_c = \text{compressive stress on pad}$
$\mu = \text{friction coefficient } (\sigma_s / \sigma_c)$

This equation is equivalent to

$$\sigma_s = A + \frac{B}{\sigma_c}$$

This linear equation with an intercept on the shear stress axis can then be used to approximate the curves in Fig. 32 and can be solved for the $A$ and $B$ constants. Approximate values for these constants are as follows:

<table>
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<tr>
<th>Pad Type</th>
<th>Surface</th>
<th>$A$</th>
<th>$B$</th>
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<tbody>
<tr>
<td>Chloroprene</td>
<td>Steel</td>
<td>0.03</td>
<td>14</td>
</tr>
<tr>
<td>Chloroprene</td>
<td>Concrete</td>
<td>0.04</td>
<td>38</td>
</tr>
<tr>
<td>ROF</td>
<td>Steel</td>
<td>0.05</td>
<td>36</td>
</tr>
<tr>
<td>ROF</td>
<td>Concrete</td>
<td>0.09</td>
<td>90</td>
</tr>
</tbody>
</table>
Fig. 32 - Shear stress versus compressive stress for chloroprene (Neoprene) and random oriented fiber pads on steel and concrete surfaces
These constants would produce equations for $\psi$ as follows for the above four combinations:

$$\psi = 0.03 + \frac{14}{C_{\text{Chloroprene - Steel}}}$$

$$\psi = 0.04 + \frac{38}{C_{\text{Chloroprene - Concrete}}}$$

$$\psi = 0.05 + \frac{36}{C_{\text{ROF Steel}}}$$

$$\psi = 0.09 + \frac{90}{C_{\text{ROF Concrete}}}$$

The form of this equation suggests that the allowable shear stress at slippage increases linearly as the compressive stress increases. Considering Fig. 32, it can be noted that when the linearity ceases, it is probably evidence of unnoticed slippage during the testing. The constants suggest that only 3 to 9 psi added shear stress is achieved for each 100 psi added compressive stress on the pad.

The above four equations are shown plotted in Fig. 33 along with the 1981 German equation suggested by Schrage for chloroprene on steel or concrete surfaces.

Creep Characteristics

The creep testing indicated that the creep strains after 120 days of loading ranged from 48 to 94 percent of the initial shortening and averaged 70 percent for these three materials. These values are much greater than the 20 to 40 percent values discussed in the NCHRP 248 report based on large size bridge bearings. They are also much greater than the creep values shown in the 1983 DuPont brochure on chloroprene. These creep tests on small pads were undertaken using maximum design compressive stresses and for a reasonably long period and certainly represent rigorous conditions although nonparallel plates were not included. The additional vertical deflection of the pad from the creep in the bearing pads probably has little effect in the building. It might have to be accounted for in certain joint details, but the majority of the pad deflection has often occurred by the time the toppings are cast and connections are made.
Fig. 33 - Friction coefficient variation for chloroprene (Neoprene) and random oriented pads on concrete and steel surfaces
DESIGN RECOMMENDATIONS

Appendix 4 contains a recommended Section for the PCI Design Handbook which incorporates the following 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 parameter for chloroprene pad design. The simplified formula proposed by Stanton and Roder (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 loads is recommended:

\[ f_c = KDS \]

\( f_c \) = 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. 34 along
Fig. 34 - Recent design recommendations for chloroprene (Neoprene) pads compared with PCI and recom­mended formula.
with the present PCI recommendations and the NCHRP 248 bridge pad recommendations which were given in Fig. 21. 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 reinforcing, the elastomer itself must resist internal tensile stresses from bulging caused by the compression 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 1,000 psi maximum design compressive stress for 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) are held constant for long periods. It is recommended that the maximum design compressive stress under unfactored dead and live loads be generally limited to 800 psi and that the unfactored sustained dead load stress be limited to 300 to 500 psi.

Further limitations are recommended that under double tee stems pads with a shape factor less than 2 be avoided and under beams a shape factor less than 3 be avoided. This implies that small, thick pads should not be used. For example, a 1/4 x 2 x 2 in. or a 1/2 x 4 x 4 in. pad have a shape factor (SF) of 2. Plain chloroprene pads of these sizes that are any thicker should be used only with extreme care. Such small pads may sometimes be required, and if so, reinforced material is recommended. The choice of SF = 2 as a limit is based on observed results and
problems. It is noted that these recommendations are based on properties for 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 procedures. These procedures utilize pads bonded to steel plates 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(3) for 50, 60 and 70 durometer chloroprene pads (at 70°F) will significantly underestimate the measured pad deformation in actual tests.

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. 32 represents an alternative and improved design aid to estimate frictional forces at ends of members. The use of the data in Fig. 32 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 thickness of two times the calculated deformation of the end of the precast member and a resulting low 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 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 in the site visits. A method to consider rotation of bearing surfaces in pad design procedures by using the following formula is suggested:

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

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 $0.15t$ occurs under design loads and then applying the rule of thumb discussed previously:

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

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 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 1,500 psi 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 stress level.

Since ROF pads have a more limited experience record than chloroprene pads, and since recent testing\(^{(11)}\) suggests that pad performance is sensitive to low shape factor, the above recommendation may be too liberal for small shape factors and design conservatism may be warranted. Also, testing has shown that ROF pads can have widely different compression and shear modulus values depending on the elastomer type, and fiber type and orientation. Recognition of shape factor is recommended in their design. Based upon the data available, the following maximum design compressive stresses are recommended for unfactored dead and live loads:

<table>
<thead>
<tr>
<th>Shape Factor</th>
<th>Uniform Compressive Stress, (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1100</td>
</tr>
<tr>
<td>2</td>
<td>1200</td>
</tr>
<tr>
<td>3</td>
<td>1300</td>
</tr>
<tr>
<td>4</td>
<td>1400</td>
</tr>
<tr>
<td>5</td>
<td>1500</td>
</tr>
<tr>
<td>&gt;5</td>
<td>1500</td>
</tr>
</tbody>
</table>

Or stated as a formula; \( f_c = 1000 + 100(SF) \leq 1500 \) psi.

The compressibility of ROF pads must be calculated or estimated from test data from the actual pad material used since stiffness of the ROF pads varies significantly from one manufacturer to another. As an example, for a S.F. of 2.5, one pad material under a uniform compressive stress of 1250 psi 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 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 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, similarly to 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. 32.

Rotation - The same recommendations would be suggested here as were used in chloroprene pads. The recommendations 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 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, taken from present PCI recommendations, and an upper limit of 3000 psi, as noted in our testing.

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

Rotation - Essentially the same recommendations for rotation limits would be used as for other pads, 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 containing only chloroprene as an elastomer. The small pad is inserted 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 much 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 U.S.A. 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.

Summary and Conclusions

A broad 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 chloroprene (neoprene), 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 different cities in various U.S. locations were inspected to determine actual field performance of bearing pads under out-of-door conditions.

As a result of this work, new design recommendations are suggested for use in the PCI literature. A simple method to
identify AASHTO-grade chloroprene (neoprene) pads and a new method to estimate frictional forces on pads were developed.

Noteworthy conclusions or observations from these various tasks are discussed in the following sections:

**Surveys and Site Visits**

1. Bearing pad problems exist, but not on a broad scale.

2. The use of commercial-grade chloroprene pads has created numerous problems in the past such as excessive bulging, disintegration, etc.

3. Chloroprene, random fiber reinforced and duck layer reinforced pads are most prevalent in building construction.

4. Nonuniform bearing due to nonparallel surfaces is a commonly noted problem and excessive deformation of the pad does occur.

5. Mislocated pads were observed. These mislocations can be caused by improper installation or by gradual pad slippage due to low frictional resistance.

6. Pertinent generalized design information based upon appropriate testing of pads used for building construction are not available, particularly for reinforced pads.

7. AASHTO-grade chloroprene pads exhibited excellent performance in the field survey. Commercial-grade chloroprene pads exhibited widely different performance in the field from total disintegration to good performance. A simple burnability test was used during this work to help identity if a chloroprene pad is AASHTO-grade, i.e., if it contains only chloroprene as the elastomer.

8. Pads which are supposedly deformed in horizontal shear as assumed in design were not observed in that deformed shape during the site visits.
Laboratory Testing

1. The long-term compressive creep testing on chloroprene pads at 600 psi showed high creep strain of almost 90 percent of the initial pad strain. This is greater than the 30 percent creep strain versus initial strain data shown in the 1983 DuPont literature for 55 Durometer material.

2. The creep tests show the beneficial effect of internal reinforcing in the ROF and DLR pads on compression modulus, rate of creep, total creep and total deformation.

3. Extremely low friction coefficients of from 0.03 to 0.08 times the applied compressive stresses were measured.

4. Typical tolerances for precast construction lead to nonparallel bearing surfaces and tests to simulate this condition show an increase in the average instantaneous compressive strain in the pad by as much as 100 percent over uniform bearing conditions.

Literature Review

1. A number of companies manufacture pads which can be generically the same but which can have widely different engineering properties.

2. NCHRP Report No. 248 suggests a simplified equation for design of compression strength of plain bearing pads. This equation utilizes the shape factor and shear modulus as variables.

3. The 1983 DuPont brochure "Engineering Properties of Neoprene Bridge Bearings" suggests that plain (non-reinforced) chloroprene pads be generally limited to design compressive stresses of 400 to 500 psi.
This compares with the present AASHO design value of 800 psi for plain, unrestrained chloroprene bearings.

4. European design utilizes an allowable shear displacement of 0.5 to 0.7 times the pad thickness. Testing has shown that at an apparent shear strain of 70 percent severe slippage and rolling of the pad occurs. The shear-compression stress ratio at slipping may be extremely low (0.2 to 0.05) when moderate to high compressive stresses are applied to chloroprene materials.

5. The use of the traditional shear modulus equation to estimate the horizontal force that the pad can develop, even using the long-term value of 50 percent of the shear modulus, appears to be inappropriate. This traditional design approach does not recognize the slippage that occurs at all levels of shear stress and the shear modulus values used in these equations were usually determined from glued pads which do not reflect realistic field conditions. An alternative design procedure is suggested.

Recommendations

Simplified formulas for compression design of chloroprene pads are suggested. A method of considering plate rotation in bearing pad design is suggested. Revisions in maximum recommended compression values for chloroprene are suggested.

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

A design chart, based on laboratory tests, suggesting revised friction forces is presented. These values are based on test work that illustrates that at compressive stresses over
400 psi slippage of the chloroprene and random-fiber reinforced pads will occur at low shear forces.

A simple fire test to give a preliminary indication that a pad contains only chloroprene as its elastomer is also suggested.
REFERENCES


APPENDIX 1

SUMMARY OF PCI PRODUCERS SURVEY
## APPENDIX 1
SUMMARY OF PCI PRODUCERS SURVEY

<table>
<thead>
<tr>
<th>Response No.</th>
<th>Problem</th>
<th>Design methods</th>
<th>Materials used</th>
<th>Inspect jobs</th>
<th>Building types with problems</th>
<th>Test packs</th>
<th>Types of members with problem</th>
<th>Unusual practices</th>
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<tbody>
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<td>1</td>
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<td>PCI</td>
<td>AASHTO, RBF - limited Plastic, shims</td>
<td>No</td>
<td>Garage</td>
<td>No</td>
<td>DT's primarily</td>
<td></td>
</tr>
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<td>2</td>
<td>Limited</td>
<td>PCI</td>
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<td>No</td>
<td>Garage and bridge</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>No</td>
<td>PCI</td>
<td>AASHTO, Beam - DT's</td>
<td>No</td>
<td></td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td></td>
<td>All plastic</td>
<td>No</td>
<td>Garages</td>
<td>No</td>
<td></td>
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</tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bearing pads</td>
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<td>Comm. grade only if vert. stress</td>
<td>No</td>
<td>Garages</td>
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<td>Garages</td>
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<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
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<td>PCI + Mfg. for RBF</td>
<td>AASHTO, RBF Plastic, shims</td>
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<td>Garage</td>
<td>No</td>
<td>DT</td>
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<td>Only make hollow core plank</td>
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<td>AASHTO</td>
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## SUMMARY OF PCI PRODUCERS SURVEY

<table>
<thead>
<tr>
<th>Response No.</th>
<th>Problems</th>
<th>Design method</th>
<th>Materials used</th>
<th>Inspect jobs</th>
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<th>Test pads</th>
<th>Types of members with problems</th>
<th>Unusual practices</th>
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<tr>
<td>14</td>
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<td>PCI</td>
<td>RGF, Plastic shims</td>
<td>Limited - garages</td>
<td>--</td>
<td>No</td>
<td>--</td>
<td>Had a job with steel L's top and bottom of pad. Pads slipped out like a bar of soap</td>
</tr>
<tr>
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<td>Limited</td>
<td>PCI +</td>
<td>RGF - beams, Comm. - DR's, Limited AASHTO</td>
<td>Limited - garages</td>
<td>Garages</td>
<td>No</td>
<td>DT's - placement beams</td>
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<td>16</td>
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<td>PCI</td>
<td>AASHTO</td>
<td>No</td>
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<td>Mfg.</td>
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<td>--</td>
<td>No</td>
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<tr>
<td>18</td>
<td>No</td>
<td>R of T</td>
<td>AASHTO, Comm. - Plastic shims</td>
<td>Limited - garages</td>
<td>--</td>
<td>No</td>
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<td>--</td>
<td>No</td>
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<td>Limited</td>
<td>PCI</td>
<td>RGF, Comm. grade AASHTO</td>
<td>No</td>
<td>Garage</td>
<td>No</td>
<td>DT</td>
<td></td>
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APPENDIX 2

SUMMARY OF SITE VISIT INFORMATION AND TESTS
# APPENDIX 2

## SUMMARY OF SITE VISIT INFORMATION AND TESTS

<table>
<thead>
<tr>
<th>Location</th>
<th>Structure type</th>
<th>Approx. age in years</th>
<th>Problem</th>
<th>Damage</th>
<th>Description</th>
<th>Diagnosis</th>
<th>Photographs (Fig. No.)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Garage</td>
<td>Phoenix</td>
<td>?</td>
<td>None</td>
<td>Pads have turned to rubble under load</td>
<td>Some spalling</td>
<td>Poor material</td>
</tr>
<tr>
<td>2</td>
<td>Garage</td>
<td>Phoenix</td>
<td>?</td>
<td>None</td>
<td>1/4&quot; x 4 (\times) 3 3/8&quot; x 500-burns</td>
<td>--</td>
<td>A2-2</td>
</tr>
<tr>
<td>3</td>
<td>Garage</td>
<td>Phoenix</td>
<td>1</td>
<td>None</td>
<td>1/4&quot; x 55B - no burn</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>Garage</td>
<td>Phoenix</td>
<td>1/2</td>
<td>None</td>
<td>3/8&quot; ROF - glued to stem</td>
<td>--</td>
<td>--</td>
</tr>
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<td>5</td>
<td>Garage</td>
<td>Phoenix</td>
<td>6</td>
<td>None</td>
<td>1/4&quot; x 65B burns</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>Garage</td>
<td>Phoenix</td>
<td>?</td>
<td>Spalling</td>
<td>Pads totally gone in loaded area</td>
<td>3/8&quot; x 603</td>
<td>Poor material</td>
</tr>
<tr>
<td>7</td>
<td>Garage</td>
<td>Minneapolis</td>
<td>5 &amp; 10</td>
<td>Limited to E under tees, crumbling layered</td>
<td>Limited to expansion joint</td>
<td>1/2&quot; E - no burn</td>
<td>--</td>
</tr>
<tr>
<td>8</td>
<td>Garage</td>
<td>Minneapolis</td>
<td>1 &amp; 10</td>
<td>Limited to E under tees, crumbling layered</td>
<td>Limited-spalling</td>
<td>Old portion (3/8&quot; x 5 \times 2/3&quot; x 6) under tees-burns.</td>
<td>Poor material</td>
</tr>
<tr>
<td>9</td>
<td>Garage</td>
<td>Denver</td>
<td>8+</td>
<td>Bulging, layering of pads under beams. Crushing, cracking of tees pads</td>
<td>None</td>
<td>1/2&quot; x 7&quot; x 24&quot; E-beams</td>
<td>Poor material</td>
</tr>
<tr>
<td>10</td>
<td>Garage</td>
<td>Denver</td>
<td>2</td>
<td>Limited, cracking in tees pads</td>
<td>None</td>
<td>1/2&quot; x 24&quot; E-beams</td>
<td>Poor material</td>
</tr>
<tr>
<td>11</td>
<td>Garage</td>
<td>Denver</td>
<td>2</td>
<td>Bulging, layering of beam pads. Non-uniform bearing</td>
<td>None</td>
<td>1/2&quot; x 24&quot; E-beams</td>
<td>Poor material</td>
</tr>
<tr>
<td>12</td>
<td>Garage</td>
<td>Denver</td>
<td>2</td>
<td>Bulging, layering of beam pads. Non-uniform bearing</td>
<td>None</td>
<td>1/2&quot; x 4&quot; x 5&quot; E-beams</td>
<td>Poor material</td>
</tr>
<tr>
<td>Location</td>
<td>Structure type</td>
<td>Location</td>
<td>Approx. age in years</td>
<td>Problem</td>
<td>Damage</td>
<td>Description</td>
<td>Diagnosis</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>----------</td>
<td>----------------------</td>
<td>---------</td>
<td>--------</td>
<td>-------------</td>
<td>-----------</td>
</tr>
<tr>
<td>14</td>
<td>Garage</td>
<td>Denver</td>
<td>6</td>
<td>Fades cracking at edge of loaded area</td>
<td>None</td>
<td>1/2&quot; x 7&quot; x 1/4&quot; E-beams, 1/4&quot; x 6&quot; x 9&quot; E-tee</td>
<td>Poor material</td>
</tr>
<tr>
<td>15</td>
<td>Garage</td>
<td>Denver</td>
<td>7</td>
<td>Beam pads cracking on edge of ROF and bulging E</td>
<td>Very limited</td>
<td>5/8&quot; E and 1/2&quot; ROF under beams, 1/4&quot; x 4&quot; x 5&quot; E-tee</td>
<td>Poor material</td>
</tr>
<tr>
<td>16</td>
<td>Garage</td>
<td>Washington</td>
<td>1+</td>
<td>Mislocated pads, Pad tearing</td>
<td>Very limited</td>
<td>1/2&quot; ROF beams, 1/4&quot; E-tee</td>
<td>Poor geometry in building + fair material</td>
</tr>
<tr>
<td>17</td>
<td>Garage</td>
<td>Washington</td>
<td>7</td>
<td>None</td>
<td>None, except design damage at expansion joint</td>
<td>3/4&quot; DLR-beams, 1/4&quot; E-tee</td>
<td>--</td>
</tr>
<tr>
<td>18</td>
<td>Garage</td>
<td>Washington</td>
<td>6</td>
<td>None</td>
<td>None</td>
<td>1/4&quot; E</td>
<td>Not a pad problem</td>
</tr>
<tr>
<td>19</td>
<td>Garage</td>
<td>Washington</td>
<td>7</td>
<td>None</td>
<td>None</td>
<td>1/4&quot; E</td>
<td>Not a pad problem</td>
</tr>
<tr>
<td>20</td>
<td>Garage</td>
<td>Chicago</td>
<td>10</td>
<td>Beam pads moving, tearing</td>
<td>None</td>
<td>1/4&quot; x 6&quot; x 6&quot; E-tee, 1/2&quot; DLR-beams</td>
<td>Non-parallel bearing, Tension coated without tie-down</td>
</tr>
<tr>
<td>21</td>
<td>Garage</td>
<td>Chicago</td>
<td>8</td>
<td>None</td>
<td>None</td>
<td>1/4&quot; E-tee, 1/2&quot; E-beams</td>
<td>No burn test</td>
</tr>
<tr>
<td>22</td>
<td>Garage</td>
<td>Chicago</td>
<td>2-3</td>
<td>None</td>
<td>None</td>
<td>1 and DLR-tees</td>
<td>No burn test</td>
</tr>
<tr>
<td>23</td>
<td>Garage</td>
<td>Chicago</td>
<td>2</td>
<td>None</td>
<td>None</td>
<td>1/2&quot; DLR-beams, 1/2&quot; E-tee</td>
<td>No burn test</td>
</tr>
</tbody>
</table>
Fig. A2-3 - Compressed pad
fig. A2-4. - Remains of deteriorated pads, material in loaded area totally deteriorated.
Fig. A2-7 - Excessive bulging of pad
Fig. A2-13 - Pad moving
APPENDIX 3

SPECTROPHOTOMETER ANALYSIS OF BEARING PAD SAMPLES
This report presents the results of an examination of five samples. The samples were submitted for laboratory investigation by J. K. Iverson, Consultant for Wiss, Janney, Elstner Associates, Inc. (WJE) on September 22, 1983. The samples were identified as Nos. 1 through 5. Each sample consisted of one small piece of black rubber-like material. We were requested to determine the composition of the material. An analytical procedure and reference spectra prepared by the DuPont Chemical Company were submitted for comparison.

Each sample was analyzed using the Beckman spectrophotometer. The best spectra were obtained when samples were treated with O-dichlorbenzene and recorded using cast-film techniques. The spectra obtained were compared to the supplied reference spectra and identified as follows:

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Identification of the base polymer</th>
<th>Reference spectra (page)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Styrene butadiene copolymer (SBR)</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>Styrene butadiene copolymer (SBR)</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>Nortel 1560 hydrocarbon rubber</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>Neoprene GN</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>Neoprene AH</td>
<td>8</td>
</tr>
</tbody>
</table>

Sample Nos. 1 and 2 contained significant amounts of a clay and silicate-type filler. They are a mixture of styrene butadiene rubber and hydrocarbon oils which probably gave the elastic properties to the final product. It is believed a small amount of silicate-type filler is also in Sample Nos. 4 and 5. All samples contained carbon black. The spectra of No. 1 through No. 5 are enclosed.
Fig. A3-1 - The infrared spectra of Sample No. 1
Fig. A3-2 - The infrared spectra of Sample No. 2
Fig. A3-4 - The infrared spectra of Sample No. 4
Fig. A3-5 - The infrared spectra of Sample No. 5
Bearing pads are used to distribute localized vertical loads over the bearing area and to provide freedom for limited horizontal or rotational movement without creating large undesirable tangential forces from effects of time-dependent volume or load change. Their use has proven beneficial and often may be necessary in precast concrete construction. Design is accomplished based on unfactored service loads.

Several materials are commonly used for bearing pads.

1. AASHTO-grade chloroprene pads are made with 100 percent chloroprene (neoprene) as the only elastomer and conform to the requirements of the AASHTO Standard Specifications for Highway Bridges (1977), Section 25. Inert fillers are used with the chloroprene and the resulting pad is black in color and of a smooth uniform texture. While allowable compressive stresses are somewhat lower than other pad types, these pads allow the greatest freedom in movement at the bearing.

2. Commercial-grade chloroprene pads have no defined specification and often represent a given manufacturer's attempt to provide a less expensive yet functional material. These are plain pads with no reinforcing and properties vary widely. They should be used only if satisfactory long-term performance has been achieved with the same material. Many commercial-grade chloroprene pads have led to problems in field service.

3. Random oriented fiber reinforced pads are a more recently introduced material. These pads are usually black and contain short reinforcing fibers located randomly throughout the body of the pad.
Vertical load capacity is enhanced by the reinforcement, but tolerance of rotations and horizontal movement may be somewhat less than the chloroprene pads. No national standard specifications are available for this material.

4. Duck fiber reinforced pads are generally used where higher compression stresses are encountered. These pads are often yellow-orange in color and are reinforced with closely spaced, horizontal layers of woven duck material, bonded in the elastomer. The horizontal reinforcement layers are easily observed at the edge of the pad. Section 2.10.3(L) of the AASHTO Standard Specifications for Bridges and Military Specification MIL-C-882C discuss this material.

5. Laminated pads utilizing chloroprene material reinforced with alternate layers of bonded steel or fiberglass are often used in bridges but seldom if ever used in building construction. The AASHTO Specification, Section 25 covers these pads.

6. Miscellaneous materials such as plastic, steel, joint filler, or hardboard are used as bearing materials in specialized situations, but are not considered as structural materials and are not discussed in this section.

A situation in pad design occurs occasionally when larger horizontal movements exceed the capacity of any reasonably sized elastomeric bearing pad, as at a slip or expansion joint. Teflon or TFE coated materials are often used in this situation, to provide a low friction slip surface. Stainless steel mated with teflon at the slip surface has been found to provide the most reliable and durable joint. The teflon or TFE must be reinforced by bonding to an appropriate backing material. Figure 4-1 shows typical details and a range of friction coefficients for use in this type of design situation.
Friction coefficient of TFE as function of compression stresses

Typical TFE bearing pad detail

Fig. 4-1 - TFE slip bearing
The following are simple, design criteria for nonrestrained elastomeric bearing pads. These criteria recognize the presence of slippage in pad shear movements and are stated in terms of maximum allowable one-way horizontal movement expressed in terms of pad thickness.

Design Recommendations

1. Use unfactored service loads for design.

2. At the suggested maximum uniform compressive stresses, instantaneous vertical strains of 10 to 20 percent in the pad will generally result. The instantaneous compressive strains may double when nonparallel bearing surfaces are present. In addition, these uniform and nonuniform instantaneous strains may increase approximately 25 to 100 percent from long-term creep effects. The higher creep values are associated with high sustained design load stresses on the pads. These instantaneous and creep movements should be accounted for in design and detailing.

3. Length of unreinforced pad \( \geq 5 \times \text{thickness} \) for stability. Width of pad \( \geq 5 \times \text{thickness} \) for stability.

4. \( t \geq 1/4 \text{ in.} \) for stemmed members and \( 3/8 \text{ in.} \) for beams.

5. Shear force has been shown to be a function of slip in the chloroprene or random oriented fiber pad and Fig. 4-2 should be used to estimate these forces.

6. The portion of a pad outside of the covering bearing surface is not considered in these recommendations. If additional pad area is provided for ease in placement, it should be ignored in calculating pad stresses, stability and movements.

7. Unreinforced pads with shape factor \((S)\) less than 2 should be avoided under tees and pads with shape factor less than 3 should be avoided under beams.

8. The sustained dead load compressive stress on an unreinforced chloroprene bearing pad should be limited to 500 psi.

9. In checking long-term slowly applied pad shear deformation due to creep and shrinkage of concrete members, the long-term concrete movement may be reduced by one-half because of compensating creep and slip in the bearing pad.
SINGLE LAYER BEARING PADS
FREE TO SLIP

\[ D = \text{Durometer (Shore A Hardness)} \]
\[ S = \text{Shape Factor} = \frac{L \times W}{2(L+W)t} \]
\[ \Delta = \frac{\text{Loaded area}}{\text{Area Free to bulge}} \]
\[ t = \text{pad thickness (in.)} \]
\[ \Delta = \text{Design Horizontal Movement at End of Member in one direction (in.)} \]

<table>
<thead>
<tr>
<th>Type of Pad Material</th>
<th>Allowable compressive stress (psi)</th>
<th>Hardness Range (D)</th>
<th>Minimum pad thickness for horizontal movement of ( \Delta ) (in.)</th>
<th>Maximum allowable rotation (in critical direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced Chloroprene or Rubber (AASHTO Sec. 25)</td>
<td>= 40S (1) ( \leq 800 )</td>
<td>50 through 70</td>
<td>1.4( \Delta ) (3)</td>
<td>( \frac{0.3t(2)}{L \text{ or } W} )</td>
</tr>
<tr>
<td>Random fiber Reinforced Elastomeric</td>
<td>1000 + 100S ( \leq 1500 )</td>
<td>80+10 ( \leq 90+10 )</td>
<td>Data not available</td>
<td>( \frac{0.3t(2)}{L \text{ or } W} )</td>
</tr>
<tr>
<td>Duck Layer Reinforced Elastomeric (AASHTO 2.10.3(L) &amp; MIL-C-882)</td>
<td>( \leq 2000 )</td>
<td>90+10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) See 7 and 8.

(2) The maximum rotation angle in either the L or W direction should be compared with the appropriate limit.

(3) If the pad is sheared in two directions, the maximum of the two horizontal movements should be used. The values in the table are based on sliding criteria. If sliding is not critical or testing indicates more advantageous conditions, thinner pads may be used.
Fig. 4-2 - Design chart for estimating shear stress or force on member ends (for small pads)