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Pot Bearings and PTFE Surfaces

An NCHRP digest of the essential findings from a report prepared under NCHRP Project 10-20, "Elastomeric Bearings Design, Construction, and Materials--Phase III," by the University of Washington, Seattle, Washington

INTRODUCTION

NCHRP Project 10-20, "Elastomeric Bearings Design, Construction, and Materials," was initiated in the early 1980s in order to develop specifications for unconfined, plain and reinforced elastomeric bridge bearings. The first phase of the project resulted in recommended specifications for improved bearing design. The specifications were adopted by AASHTO in 1985, completely revising the provisions for unconfined bearings in the AASHTO *Standard Specifications for Highway Bridges.*

The second and third phases of research were initiated to develop more sophisticated specifications for special bearing applications and to improve the provisions adopted by AASHTO. The second phase included a comprehensive test program to evaluate the physical properties of elastomeric bearings under compression, shear, rotation, and fatigue forces. The third phase concentrated on the low temperature behavior of elastomeric bearings and on bearing prequalification and acceptance requirements. A secondary objective for the third phase of research was to perform a critical state-of-the-art review of design and construction procedures for pot bearings and PTFE sliding surfaces.The first phase research was reported in *NCHRP Report 248*, "Elastomeric Bearings Design, Construction, and Materials." The second phase findings were published in *NCHRP Report 298*, "Performance of Elastomeric Bearings." The research on Phase III, concerning low temperature bearing behavior and prequalification and acceptance testing, will be documented in an upcoming NCHRP Report. This digest provides a summary of the pot bearing synthesis that was performed in Phase III. The synthesis was prepared by the principal investigators on NCHRP Project 10-20, Drs. John Stanton and Charles Roeder, of the University of Washington.

THE PROBLEM AND ITS SOLUTION

Pot bearings and bearings with PTFE (polytetraflourethylene) sliding surfaces are widely used in bridge construction. They support heavy compressive loads while permitting large movements or rotations. Despite their wide use, they are typically designed and constructed on a highly empirical foundation based on guidelines proposed by the manufacturer. Not

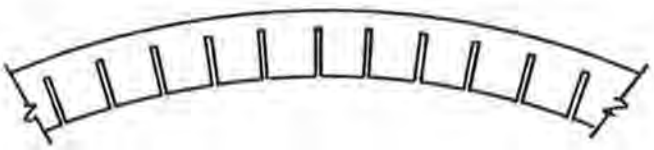

FIGURE 2. Saw Cutting of Flat Brass Sealing Ring

depending on cost and, to some extent, on the machine tools available. Large high-speed computer-controlled lathes can remove metal rapidly and make bearings machined from plate economical up to a larger size. Cast steel pots require an extra operation (casting) but reduce the amount of machining needed. When they are used, stiffeners are often incorporated between the base plate and the pot wall. Welded assemblies are seldom used because of the problems of reliability and difficulty with distortion when the weld cools. Welding can be economical for big bearings. Several problems with the use of welded pots were mentioned by respondents from the U.S.

Neoprene is the elastomer most commonly used for the pads in pot bearings in the U.S., Germany, and France, with hardness values in the range of 50 to 60 durometer. Natural rubber is commonly used in Britain and Switzerland. It has been noted that the pad was sometimes severely abraded and worn in pot bearings that had been replaced after a few years in service. The abrasion may be associated with the squeezing of the elastomer past the seal, which has been observed in a number of cases. To avoid this potential problem, some manufacturers apply grease or powdered lubricant to the pad before it is placed in the cylinder, for which purpose silicon lubricant was sometimes mentioned. However, this practice was questioned by some respondents because some elastomer compounds deteriorate over time when in contact with oil. Others suggested that the lubricant migrates from the areas where it is needed, and so a better solution would be to line the pot with smooth stainless steel or PTFE.

The seal is a critical element in the bearing. Three flat brass rings are commonly used, with cross-sectional dimensions of approximately 3/8 in. by 1/8 in. (USA) or 20 mm by 2 mm (Europe). The rings are split, like automobile piston rings, and are placed in the pot so the splits are out of phase. Brass rings with a circular cross section are also used. They are made from straight brass rods bent into a circle and brazed. PTFE rings were used in a number of early bearings in the U.S. because they are cheaper than brass and create less frictional resistance to rotation of the piston. However, the elastomer leaked past them relatively easily and this caused widespread problems. Several different cross-sectional shapes have been tried, which in some cases resulted in an unsuitable shape that may have contributed to bearing failure. PTFE seals are no longer used in this country.

In Europe, the sealing ring is sometimes made from straight strips bent round into a circle; in which case, they may be saw-cut as shown in Figure 2. This facilitates bending to a smooth circular shape without buckling. The rings are not bonded to the elastomeric pad, but are set into a recess in the pads top surface. In Australia, this seal design has been modified, and a single closed brass ring is sometimes vulcanized to the elastomeric pad during molding. The attachment is claimed to provide superior resistance to escape of the elastomer.

One major European bearing manufacturer uses a patented sealing ring made of polyoxymethylene (POM), a hard, durable, and somewhat slippery plastic. The ring is made from individual beads that snap together to form a closed chain, which is then vulcanized to the elastomeric pad. The number of beads is chosen to suit the diameter of any pot, which adds versatility during manufacturing. There is enough slack in the joints between the beads so that the chain can expand under pressure from the elastomer to form a tight seal against the pot wall. For this reason, and because it is deeper than the brass rings used by others, it is thought to provide an effective fail-safe seal. Friction between the seal and the pot wall is also claimed to be lower than that with brass rings, reducing resistance to rotation.

Design. Most manufacturers in the U.S. and abroad choose the pot diameter so that, under the maximum compressive load, the compressive stress on the PTFE is approximately 3500 psi and that on the elastomeric pad is somewhat less. The 3500-psi stress limit appears to be based on the bearing capacity of concretes available in the 1960s rather than rational consideration of pot bearing behavior. Some countries use higher stress limits.

Excessive rotation appears to have caused some pot bearings to fail because of metal-to-metal contact. Concern has been expressed over the selection of proper design criteria to prevent this. Most manufacturers use an elastomeric pad thickness and pot depth that are chosen to meet the geometric requirement shown in Figure 3. The rotation of the bearing is limited by bottoming out of the piston on the base of the pot, or by lifting of the piston out of the pot, if the pad is too thin or the cylinder is too shallow. The rotational capacity of the bearing may also be limited by the piston contacting the top of the wall of the cylinder or by uplift of the piston from the elastomer. Pot bearings are typically designed for a rotation capacity of 0.015 to 0.02

radians, but several cases were reported of measured rotations larger than this. The excessive rotation may have been caused by underestimated bridge movements or by improper installation of the bearing. The bearing has to accommodate rotations due to initial lack of parallelism between the bearing parts as well as those due to live load. Misalignment may, in many cases, be the larger of these two components. Damage was reported to a few of the pot bearings because, at large rotations, the piston began to bind on the cylinder or the guide bars began to bind on the bearing. At least one European manufacturer has developed a computer program for checking these clearance requirements.

The design of the pot wall thickness often is based on a simple hoop stress calculation, ignoring the restraining effects of the base. More sophisticated calculations might result in slightly thinner walls, but the material savings they offer may not justify the extra expenditure on analysis. Few states require that pot bearings be designed for replacement. Engineers with extensive experience with pot bearings note that these bearings occasionally need replacing, and this can be extremely difficult and expensive if provisions are not made in the initial design.

Some concern was expressed about the effect of horizontal forces on the pot bearing. These horizontal forces may be transmitted by the piston into the wall of the cylinder and distort the pot. Deformation due to lateral loads is usually ignored in design today. Some manufacturers indicated that the guide bars of movable pot bearings should be equipped with strips of PTFE to permit easy movement of the bearing. This is done in some cases, but there appear to have been some problems with attachment. PTFE strips bonded with epoxy have come unbonded. This has been attributed to bond deterioration caused by ultraviolet light.

Fabrication. Generally, manufacturers preferred to cast the pot as a single piece, or machine it from plate, rather than weld it. In some cases, however, bearings have been manufactured in the U.S. by welding a formed cylinder to a thin base plate. It appears that bearings can be successfully fabricated by welding if the base plate and cylinder wall are thick enough and if the cylinder is welded on both the inside and outside. Distortions due to welding have resulted in poor tolerance control. Thin cylinder walls have also deformed because of internal pressure from the rubber. At least one bearing in the U.S. failed because the cylinder wall twisted outwards, as the pot walls were fillet welded to the outside of the base plate only.

There is some variation in the values recommended for manufacturing tolerances and piston clearances. Typically, it is recommended that the diameter of the piston should be 0.03 in. to 0.05 in. smaller than the inside diameter of the cylinder. Out-of-round tolerances, on the order of several thousandths of an inch, are acceptable for guide bars and sliding mechanism. Clearances on the order of 1/16 in. to 1/8 in. appear to be common for straight right bridges, with larger clearances for curved or skewed bridges.

Installation. Several problems have been reported in the U.S. and Europe with pot bearing installations. The bedding tolerances during installation have a significant impact on the rotation capacity of the bearing. A maximum allowable out-of-level of about 0.01 radians was recommended by one manufacturer. As a result, the pot bearing could be designed for a total rotation capacity of at least 0.02 radians. To minimize the out-of-level, a bedding material is sometimes placed below the base plate. The bedding material may be grout or epoxy or, in some cases, a thin, soft membrane such as lead or fabric that may be inserted.

Leveling nuts on hold-down bolts, instead of shim stacks, were strongly recommended by some European manufacturers. Shim plates may be dislodged or provide a hard spot in the support, which could deform the bearing. The

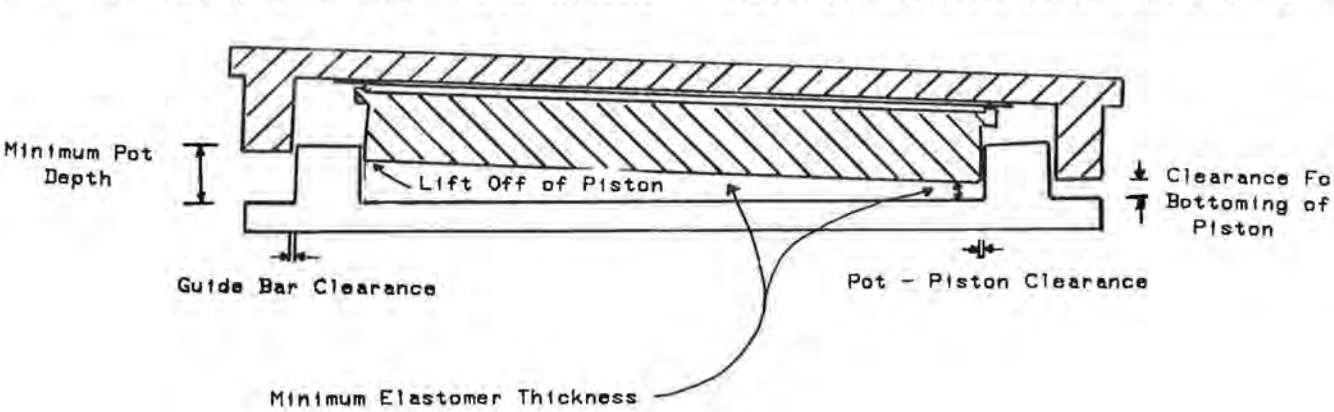

FIGURE 3. Geometric Requirements for Rotation Control of Pot Bearings

grout bed thickness is also of concern. If the bed is too thin, it is difficult to install the bearing without air pockets. If the bed is too thick, it becomes an undesirably flexible support for the bearing. A bed thickness of 2 in. is recommended in Germany. Tapered grout beds provide the possibility of uneven compressive deformation under the bearing, causing difficulties with rotation capacity, and so are avoided whenever possible. It has been noted that bearings were occasionally installed with the guide bars oriented in the wrong direction.

Replacement capability depends on the method of installation, and this appears to vary with manufacturer and from state to state. It is common for a base plate and a sole plate to be anchored, respectively, to the pier and bridge superstructure. This may be accomplished by casting anchors into the concrete and attaching the plates to the anchors after providing a level bedding surface, or by grouting or epoxy injection. The base of the pot and sliding plate arrangement may then be welded to the base and sole plates with fillet welds on the outside edges. Alternatively, the base of the pot may be set into a recess in the base plate, so that the bridge needs to be lifted only to a height equal to the depth of the recess in order to remove and replace the bearing. In one case, the recess was made with a bolted, removable shoulder on one side, allowing the bearing to slide out after the load was removed. Some bearings have been installed as a single unit.

Certification. Testing methods and acceptance criteria vary widely in the U.S. In Europe, standards for both initial approval and ongoing quality assurance testing are more uniform and are extremely high. In Germany, the process of gaining initial approval to manufacture pot bearings is sufficiently time-consuming and expensive that very few companies make bearings. Those that do, apparently make high quality products. This has the effect that the initial cost of bridge bearings may be higher than it would be in a more competitive market such as in the U.S., but problems occur less often. Most of the problems in Europe appear to be related to faulty installation.

Problems. There have been numerous failures of pot bearings in the United States. They have caused considerable economic loss, but have not led to any known cases of structural collapse. The cost of replacing a failed bearing generally far exceeds the initial bearing cost. Loss of elastomer through poor seals and tolerances has been noted. This may reduce the rotation capacity of the piston. Some of these failures can be pin-pointed to poor quality control, while others have occurred in seemingly well-made bearings.

PTFE Sliding Surfaces

The survey revealed that PTFE sliding surfaces are widely used in both the U.S. and Europe, but again the general understanding of its behavior appears to be stronger in Europe. Some states use PTFE extensively, even though they seldom use pot bearings. Other states use PTFE as the key element in a number of different bearing types, such as those shown in Figure 4. A PTFE slider is often used in conjunction with pot bearings and disk bearings to provide horizontal movement capacity. Similar horizontal sliders are also used on top of elastomeric bearings where the PTFE is bonded to the top cover layer of the elastomer on a steel top plate. The slip surface limits the maximum strain on the elastomeric bearing. The elastomer is designed to withstand limited shear strain from daily superstructure movements, but the PTFE sliding surface permits larger movements caused by extreme temperatures, creep, and shrinkage. With this type of bearing, the PTFE slider and the elastomeric bearing must be designed as a unit, and the stiffness of the bearing must be balanced with the friction on the PTFE.

PTFE is also being used today in situations where a metal bearing would have been used previously. For example, flat PTFE sliding surfaces are being used in place of sintered bronze bearings. PTFE is also used on cylindrical or spherical surfaces to provide rotation about one or two axes. These bearings develop large contact stresses at the stainless steel/PTFE interface, so friction is low. They have a resistance to rotation that is both relatively small and nearly independent of rotation angle. This is in contrast to pot bearings, in which the moment increases with rotation. However, pot bearings are believed to have less rotational resistance than many other bearing systems.

In Europe, there is wide use of PTFE in combination with different bearing systems. Greased and dimpled PTFE are primarily used rather than the dry, flat PTFE commonly used in this country. Their use leads to smaller and more consistent coefficients of friction.

Materials. PTFE friction was the major material property of concern. In the U.S., it was generally noted that the friction obtained in acceptance testing of PTFE sliding surfaces was invariably larger (as much as 200 percent larger) than anticipated in the initial design. Part of the difficulty is related to the friction values published in the *Standard Specifications for Highway Bridges.* The AASHTO values may be somewhat misleading, in that they do not clearly indicate how the friction changes with lubrication, contamination, variations in surface condi-

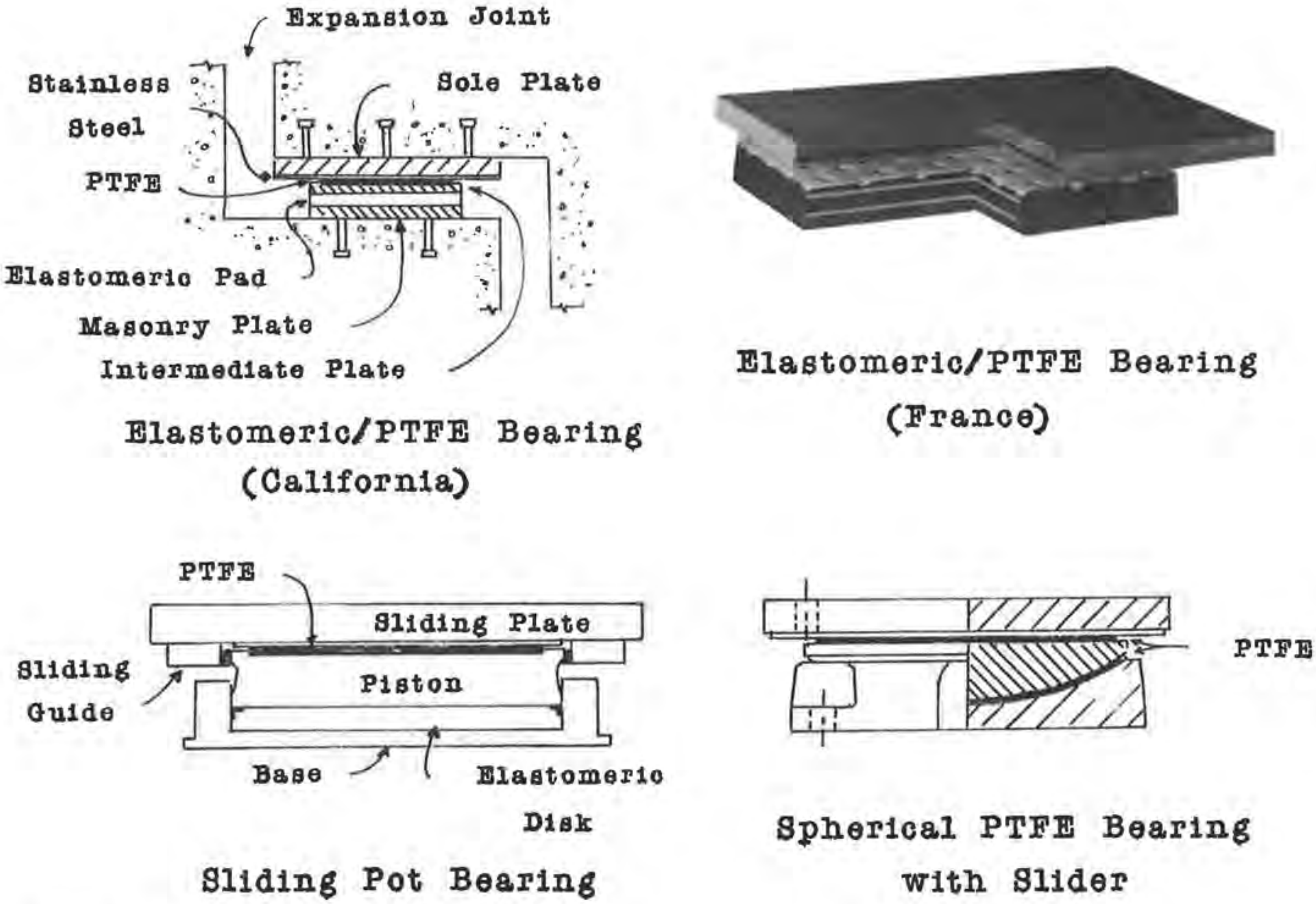

FIGURE 4. Typical Bearing Applications for PTFE Sliding Surfaces

tion, time, or the conditions to which they are supposed to apply. It was noted that contractors sometimes inadvertently contaminate the slip surfaces by separating them during construction, and sand, dust, and dirt get between the contact surfaces causing a significant increase in the friction factor. There is also concern that lubricated surfaces may accumulate dust more readily than unlubricated surfaces. If this is the case, precautions should be taken against entry of dirt.

Lubrication reduces the friction, but in many cases it is not specified and in some cases not permitted. There is a concern that the lubrication will wear off the flat surface and that friction will increase later in the life of the bridge.

PTFE can be provided in a filled and unfilled form and the friction factor can be very different for the two different forms. This is not commonly recognized in the U.S. The majority of PTFE used in the United States is unfilled with no specified lubrication.

The friction factor also depends on the mating surface material. Manufacturers in the U.S. and Europe generally agree that the mating surface should be a very smooth stainless steel, and ASTM 240 Type 304 stainless is commonly used in the U.S. The surface finish appears to be less precisely defined, but finishes such as 10 micro-inch RMS or less are sometimes specified. In Germany and England the surface roughness has to meet limiting values in design specifications, but in France and Italy no such limits exist. A chrome surface on structural steel was tried in Germany and found to give excellent results until small pockets of rust caused by pinholes in the chrome broke up the surface. It is no longer used in bridges. The curved surfaces in cylindrical and spherical bearings are often made from aluminum in both the U.S. and abroad. This is because it is difficult to attain a high degree of curvature accuracy when attaching a stainless steel sheet to a spherical surface. Solid stainless is occasionally called for in special applications, but is too expensive and difficult to machine for common situations.

PTFE is defined by its chemistry and is available from a number of manufacturers. It may be produced either by sintering into sheets or by peeling a block into foil in a manner similar to that in which veneer is peeled from logs. The foil is said to be more resistant to creep. However, it may have a higher friction coefficient and be more susceptible to wear. Therefore, only the sintered material is used as a mating surface in Europe. Foil is sometimes used under the elastomeric disk in pot bearings in the U.S. and Europe. PTFE is generally accepted on the basis of the certificate of its chemical composition in France, Italy, and England. In Germany, each batch destined for use in bearings also has to be laboratory tested for friction against standard grease and stainless steel samples. The reason given is that the crystal structure of the material depends on the sintering process, and it may influence the friction coefficient.

All PTFE/stainless steel sliding bearings in Europe are greased. Dimples in the PTFE act both as grease reservoirs and as a means to reduce the surface area and increase the contact stress. However, the reduction in area generally is not considered in the design calculations. If the surfaces are not greased, the pressure on the PTFE causes the dimples to flatten out because of cold flow. Virtually any grease reduces friction at the first movement, but experiments in Germany have found that a lithium soap in a silicone grease is particularly effective. It maintains good sliding properties at low temperature and the ingredients separate only very slowly with time. As with the PTFE, the testing requirements for grease are more rigorous in Germany than elsewhere, since each individual material must be tested. This practice apparently produces a lower and more consistent coefficient of friction.

Design. PTFE may wear but replacement has seldom been considered in U.S. design practice. It does appear that this issue is being given more attention in new bridge designs, because several cases of wear were recently reported by U.S. bridge engineers.

Contact stresses are the limiting design factor, but edge bearing also must be considered. The most important number used in design of sliding bearings is the coefficient of friction. Most bearings are designed so that the contact stress is as high as permitted to take advantage of the lowest possible friction value. European specifications use a design friction coefficient of 3 percent for dimpled, lubricated PTFE at high vertical pressure and higher coefficients for lower pressures. Coefficients about ten times smaller than this have been obtained in the laboratory with virgin materials. The 3 percent coefficient is understood to include a reasonable margin of safety to allow for adverse effects in the field such as low temperature and worn surfaces.

Unfilled PTFE should be recessed into the steel plate to avoid plastic flow under compressive load. The usual depth of the recess is approximately 1/2 the thickness of the PTFE layer. Most manufacturers use a PTFE thickness of 1/16 in. to 1/8 in. for common applications. A PTFE thickness of 1/32 in. has been used on occasions in the U.S., but there have been reports of excessive wear with this thinner material. European practice commonly employs somewhat thicker material (5 mm is common). The PTFE is typically bonded to the steel with an epoxy adhesive whether or not it is also recessed.

The friction factor at first movement is significantly higher than it is for subsequent cycles. However, the values quoted by most manufacturers in the U.S. are typically based on performance after initial slip has taken place. This may cause confusion in the interpretation of test results.

In curved bearings, the contact stress is assumed to be uniform, which would be the case if the PTFE acted like a fluid. A larger radius of curvature leads to a more even contact stress distribution, but higher resistance to rotation for a given coefficient of friction. The choice of curvature is, therefore, a compromise between conflicting criteria. For any curvature, it is assumed that cold flow of the PTFE will help to even out the contact stresses.

Fabrication. The PTFE should fit well and remain in place. In the U.S., separation of the PTFE from the bonding surface has been reported. The causes of these separation failures may include poor bonding methods and the use of unrecessed PTFE. Because PTFE may experience creep or cold flow under compressive load, this deformation may contribute to separation by applying large shear stresses to the bonding agent at the edge of the PTFE.

PTFE has a much higher coefficient of thermal expansion than steel. If the bearing is subjected simultaneously to low temperature and light vertical load, it is possible that the PTFE may become loose in the recess and become damaged at its edge. In Germany, the PTFE is precooled before it is inserted into the recess, so that normal temperatures result in a tight fit. In a curved bearing, the PTFE has to be sprung into place, and once it is set in the recess, it cannot be removed without damage. However, if it is also precooled, the in-plane stresses can become high enough for the PTFE to buckle upwards in a snap-through mode if the two parts of the bearing are separated.

The stainless steel mating surface must be as flat as possible and thick enough to avoid wrinkling up in waves under friction load, to prevent local stress concentrations in the PTFE. The most sophisticated method found was to weld the stainless steel all around, with the sequence chosen so as to introduce as much tension due to cooling stresses in the sheet as possible. This method has the added advantage of drying out the air trapped behind the stainless steel to minimize corrosion of the structural steel. Attaching the sheet by means of countersunk screws was seen as the least desirable method in European practice, and usually requires a greater thickness to deal with possible local distortions at the screws.

Installation. Manufacturers are very concerned about contamination of the sliding surfaces in the field. The different parts of bearings are usually fixed together in the fabrication plant with special temporary bolts that act as physical protection for the sliding interface. These temporary fixtures also maintain the initial offset, if any, of the components. In Europe, horizontal sliding bearings are often equipped with an external pointer to indicate horizontal movement. This enables sliding movements to be checked quickly and easily without having close access to the bearing; if no slip has taken place since the last inspection, a closer examination is warranted.

Some problems were reported with unidirectional sliding bearings. Damage has been caused by guide bars that were set with too tight a tolerance against the body of the bearing. The guide bars locked up and imposed large forces on the piers. About 0.2 in. (5 mm) of clearance on each side is recommended to avoid this problem. The problem can be worse if the bridge is curved, because the thermal movements are harder to predict.

Other problems with installation were primarily concerned with gross errors, such as installing the bearing with the guide bars perpendicular to the bridge axis, and with inaccurate leveling.

Certification. Quality control and acceptance procedures vary in the U.S. Bearings should achieve the friction factors quoted in the AASHTO *Standard Specifications for Highway Bridges*, on which the design has been based. The AASHTO Specifications outline a test method for determining the friction coefficient, but some of the details are open to interpretation. Testing large bearings in combined compression and shear is difficult and requires large equipment. Tests are often performed on a scaled version of the actual bearing, on the assumption that the same friction coefficient will be achieved in the prototype. Manufacturers expressed frustration over the differences among the testing requirements of the states, and it was clear that a common procedure would benefit all parties.

In France and Germany a manufacturer has to receive approval just to be allowed to produce bearings. In England and Italy, the process is less formal and depends more on the past experience of the fabricator. Once this approval is obtained, three levels of quality control are exercised for a particular batch of bearings. The first consists of certificates covering the component materials from their suppliers (e.g., mill certificates for the steel, and chemical analyses and viscosity measurements for the grease). The second is the in-house quality assurance program exercised by the fabricator, which typically consists of at least regular testing of material samples (e.g., for surface roughness of the stainless steel, friction coefficient of the mating materials). The third consists of random checking of the finished bearings by the purchaser. Guidelines for how this should be done are laid out in many specifications, but the details are decided on a job-by-job basis. Testing of the finished bearings requires large test machines, and several manufacturers have installed their own.

In Germany an extra level of quality control exists. Each manufacturer must submit material samples, once a year or from each batch, for testing by a state testing laboratory. Each of the three component materials (PTFE, stainless steel, and grease) is tested for friction against standard virgin samples of the other two. Three test programs are run; one at room temperature, one at constant low temperature, and one at variable temperature. Only when each material has passed all the tests may the batch from which it came be used for production.

Problems. One failure occurred in Italy, during an earthquake, because the slider was too short to accommodate the combined thermal and seismic displacements. This caused damage to the PTFE as it scraped over the end of the stainless steel. Other cases of misaligned unidirectional sliding bearings have been noted, including cases where the bearing was installed with the initial offset reversed. Separation of PTFE from the backing surface has been reported in a number of cases where the PTFE was not recessed.

In Europe, a knuckle bearing with a slider on top had a large radius to control the contact stresses. However, this created a large eccentricity and the stainless steel lifted off the PTFE on one side of the bearing, allowing it to come out of its recess. It squeezed out further as more cycles of rotation occurred, and with each cycle it was cut by the lip of the recess. A related experience was reported in Italy, where a bridge had risen off its elastomeric bearings at several places.

Concern has been expressed over wear of PTFE and the change in friction coefficient with time and slide path. Field data suggest that the many small movements due to traffic contribute more towards the total slide path than do thermal displacements, so the sliding surfaces might be expected to wear out much faster in a bridge that carries heavy traffic. A bearing from a 15-year old highway bridge in Germany was recently inspected and found to have more PTFE wear after an estimated 1-km total slide path than had occurred in 20 km in laboratory tests. This suggests that time may be a more important criterion than total slide path. Considerable uncertainty remains on this point. Wear and migration of the lubrication in PTFE sliding surfaces are also a common concern.

APPLICATIONS

A significant amount of research has been performed on pot bearings and PTFE in the United States and Europe. The result of much of this research has worked its way into various codes and specifications throughout the country and abroad. However, there are significant differences in the various specification requirements from state to state and between countries. Tables 1 through 6 provide a comparison among the specification requirements from four states (Ohio, Oregon, New York, and Washington), three countries (the U.S.–AASHTO, Canada–Ontario Ministry of Transportation draft recommendations, and the United Kingdom–BS 5400), and draft recommendations from an ad-hoc group composed of the FHWA Region 3 States and bearings manufacturers (the Structures Committee for Economical Fabrication–SCEF).

Table 1 summarizes the various pot bearing specifications for allowable stress and rotation limits. A compressive stress limit of 3500 psi is primarily used in the U.S. and Germany. However, research has shown that confined elastomers can withstand hydrostatic stresses well in excess of 3500 psi under static load. Increased stresses have been recommended for the BS and Ontario specifications.

TABLE 1. Pot Bearing Stress and Rotation Limits

	Ohio DOT	Oregon DOT	New York DOT	Washington DOT	SCEF Draft	BS5400	Ontario Draft
Maximum Compressive Stress (psi)	---	3675 psi	---	---	3500 psi	5800 psi	5800 psi
Minimum Rotation (Radians)	0.02	0.02	0.02	0.02	.02 + .015	---	---
Depth of Pot (Inch)	.02*D/2 + .1 + te	(.02+R)*D/2 + .1 + te	---	(.02+R)*D/2 + .1 + te	(.02+R)*D/2 + .1 + k + te	---	---
Minimum Elastomer Thickness (Inches)	.067 * D	D/25 if R<.011 D/20 if .011 < R < .017 D/15 if R>.017	---	D/25 if R<.011 D/20 if .011 < R < .017 D/15 if R>.017	R*D/.3	15% Strain in Elastomer due to Rotation	15% Strain in Elastomer due to Rotation
Rotation Clearance Between Side Plate and Pot (Inches)	---	.01*D+.12	---	---	---	---	---
Maximum Eccentricity Induced by Rotation	---	---	---	---	---	< 3 % of D	< 3 % of D

Note - D = Diameter of Elastomer; R = Design Rotation of the Bearing in Radians; te = Thickness of the Elastomer; and k = constant dependent upon the type of sealing ring.

TABLE 2. Pot Bearing Clearances, Tolerances, and Manufacturing Methods

	Ohio DOT	Oregon DOT	New York DOT	Washington DOT	SCEF Draft	BS5400	Ontario Draft
Method of Manufacture	Machined	----	---	Fabricated One Piece	Machined or Welded	---	Machined
Sealing Rings	2 Flat Brass Rings	2 or 3 Flat Brass Rings	Brass	2 or 3 Flat Brass Rings	Flat Brass or Round	---	Brass ASTM B36 Half Hard
Piston Clearance (Inch)	.03 - .05	.03 - .05	.03 - .05	.03 - .05	.03 - .05	.03 - .05	.03 - .05
Out of Round Tolerance (Inches)	.005 D<20 .007 D>20	.005 D<20 .007 D>20	---	---	.005 D<20 .007 D>20	---	-O +.01" D<20 +.014 D.20
Lubrication of Elastomer	PTFE Disks	Yes	---	---	Yes or PTFE Disks	---	Silicon Grease

Note - D = Diameter of Elastomer and Piston.

The rotation limit is related to the average elastomer compressive stress. Rotation is also related to the diameter and thickness of the elastomeric pad, height of the pot cylinder, required clearance to avoid contact between the slide-plate and top of pot wall, and by lift-off of the piston from the elastomer. U.S. specifications typically require minimum rotations on the order of 0.02 radians. Foreign specifications require computed design rotations rather than minimum rotations. As the required elastomer thickness is a function of design rotation, a number of thickness calculations are presented in the specifications.

Table 2 summarizes the requirements for sealing rings, piston clearance, pot tolerance, and manufacturing methods. Some pot bearings have failed because of extrusion of the elastomer between the walls of the cylinder and the piston. Therefore, the manufacturing methods, clearances, and types of sealing rings are all relevant to this element of quality control. The specification requirements are quite consistent between the states and foreign countries.

Table 3 summarizes the typical pot bearing material requirements and component thicknesses. The cylinder wall, piston, sole plate, and base plate must all be thick enough to retain the hydrostatic stresses imposed by the elastomer, while preventing excessive distortion. Many specifications require the cylinder wall thickness to be thick enough to withstand the internal pressure. However, none of the specifications appear to address possible deformation of the wall. Deformation of the pot and piston may reduce the rotational capacity of the pot bearing. Deformation may also cause a variation in the gap between the piston and pot cylinder walls, leading to elastomer leakage.

Corrosion protection requirements are also noted in Table 3. Pot bearings are frequently installed in relatively protected locations. Therefore, it is not clear how much corrosion protection is actually required. Deformation of the elastomeric disk and abrasion of the piston and sealing rings on the cylinder walls may reduce the effectiveness of the various internal corrosion protection systems.

Table 4 summarizes the design friction coefficients for PTFE at three levels of compressive stress. The table indicates that the recommended friction factors decrease with increasing compressive stress. In addition, the factors are smaller for unfilled PTFE as compared to filled PTFE. AASHTO recommends that PTFE be used with stainless steel as a mating surface. AASHTO does not recognize differences, however, between the friction factors for the following: lubricated versus unlubricated PTFE; dimpled versus flat PTFE; or static versus dynamic friction. Foreign specifications do account for some of these parameters, but still have friction factors higher than AASHTO. This is a concern that still requires investigation for the AASHTO specifications.

TABLE 3. Pot Bearing Steel Thickness Limits and Material Requirements

	Ohio DOT	Oregon DOT	New York DOT	Washington DOT	SCEF Draft	BS5400	Ontario Draft
Type of Steel	A572 or A588	A36, A572 or A588	---	M183, M222 or M223	M183, M222 or M223	---	---
Minimum Thickness of Cylinder Wall	---	.75 "	.75 "	.75 "	.12"D A36 .11"D A588	---	---
Minimum Thickness of Piston	.02"D + 0.12"	.06 * D	---	.75 "	Rotation Clearance	---	---
Minimum Thickness of Base of Pot	.045 * D but > .5"	.045 * D but > .5"	---	---	.045"D w/MP .06"D w/o	---	---
Minimum Thickness of Sole Plate	.75 "	---	---	---	---	---	---
Corrosion Protection	Prime Coat	Painted	---	Metalize or Paint	---	---	Coating System 2

Note - D = Diameter of Elastomer and Piston, and MP is an abbreviation for Masonry Plate.

TABLE 4. Typical Design Coefficients of Friction with PTFE

	AVERAGE COMPRESSIVE STRESS		
	500 psi	2000 psi	3500 psi
AASHTO Unfilled	0.08	0.06	0.04
AASHTO Filled	0.12	0.1	0.08
SCEF Draft Specification	---	---	---
BS5400 with Continuous Lubrication	---	0.065	0.052
Ontario Unfilled	---	0.065	0.052
Ontario Filled	---	0.13	0.104

Table 5 summarizes the allowable design compressive stresses on PTFE. The table notes the average allowable bearing stresses and the maximum edge bearing stresses. PTFE is subject to creep under high compressive stress and nearly all specifications account for this by requiring filled or woven PTFE or by recessing unfilled PTFE into a steel plate for one-half its thickness.

Other factors also affect the performance of PTFE. The distance and speed of travel may affect both the friction factor and the wear and deterioration of the PTFE. Neither variable is addressed in the present specifications. Temperature may have an impact on the properties and behavior of the material. This is only recognized in the BS specifications where tabular friction factors are provided but are limited to temperatures above −24°C. Nearly all specifications recognize that contamination increases friction and wear in PTFE and attempt to minimize it through appropriate fabrication details.

Table 6 summarizes the various State design parameters for guide bars. There is significant variation in the specified design force, but close agreement on the required clearances.

CONCLUSIONS

This research has shown that pot bearings can perform well if they are properly manufactured and installed. It appears that the selection of a good manufacturer is one of the best ways of assuring a good quality bearing. However, occasional problems still occur even with the best manufacturers bearings. Further, there have still been problems with pot bearings in Germany, where extremely tight manufacturing standards are employed. These observations lead one to an unavoidable conclusion that even well-made bearings have a small probability of failure under normal service conditions. This observation is entirely consistent with recent statistically based design philosophies, such as Load and Resistance Factor Design (in other words, every structural component has a small probability of failure). The design objective is to keep the probability of failure acceptably small. It appears that bearings have a larger probability of failure than most other structural elements in bridges. A careful examination of some of the failures noted in U.S. practice would suggest that pot bearings may have a larger probability of failure than many other types of bearing. This does not mean that pot bearings should not be used, but it does mean that they should be used carefully. It is possible that some of the current applications of pot bearings would be better served by other systems, and that inappropriate usage may lead to some of the problems observed with pot bearings. One way of reducing the number of failures of pot bearings would be to develop a bearing selection guide to provide sufficient information on the proper selection and use of appropriate bearings. (This will be done in NCHRP Project 10-20A,

TABLE 5. Design Compressive Stresses for PTFE Sliding Surfaces

	Average Bearing Stress	Maximum Edge Bearing Stress
AASHTO Unfilled	3500 psi	5000 psi
AASHTO Filled and Recessed	3500 psi	5000 psi
AASHTO Filled and Not Recessed	2500 psi	5000 psi
SCEF Draft Specification Sheet	3500 psi	5000 psi
SCEF Draft Specification Fabric	6000 psi	---
BS5400 Recessed w/ Permanent Loads	7750 psi	9650 psi
BS5400 Unrecessed w/ Permanent Loads	5150 psi	6450 psi
BS5400 Recessed w/ All Loads	11600 psi	14200 psi
BS5400 Unrecessed w/ All Loads	7750 psi	9650 psi
Ontario Draft Specification w/ Permanent Loads	7750 psi	9300 psi
Ontario Draft Specification w/ All Loads	9650 psi	11580 psi

which was initiated in mid-1989.) Such a guide should make clear the characteristics of different bearing types so that the engineer can have realistic expectations of the device he chooses.

A second general cause of problems related to both pot bearings and other bearings with PTFE sliding surfaces may be the computed bridge movements. Bridge movements and rotations can be caused by thermal contraction and expansion, creep and shrinkage of concrete, and traffic loading. Inaccuracies in construction and fabrication, and manufacturing tolerances must also be accommodated by the bearing. However, it appears that some of these effects are frequently neglected, and the calculated components of movement (i.e., longitudinal and transverse displacement, rotation and so on) are often very simplified. If these movements are not properly determined, the bearing experiences greater load, increased wear, and possible deterioration. Improved performance of pot bearings could be achieved if these movements and rotations were estimated with greater accuracy and reliability, and were properly accounted for in the design of the bearings.

TABLE 6. Guide Bar Design Parameters for PTFE Sliding Surfaces

	Ohio DOT	Oregon DOT	New York DOT	Washington DOT	SCEF Draft
Horizontal Force as a % of the Vertical Load	20 %	10 %	---	---	10 %
Minimum Sliding Clearance (Inches)	3/16	3/16	---	3/16	1/8
Sliding Clearance Tolerance (Inches)	1/16	1/16	---	1/16	1/16
Tolerance on Length (Inches)	1/8	1/8	---	1/8	1/8
Tolerance on Cross Section (Inches)	1/16	1/16	---	1/16	1/16
Maximum Out of Parallel (Inches)	1/32	1/32	---	1/32	1/32
PTFE Required	No	No	If Required	Yes	No