

Bearings in Structural Systems: Action and Reaction

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Specifications for modern high-load multirotational bridge bearings tend to create the impression that they can be used interchangeably on any structure. In general, bearings are specified and approved for use on the basis of three traditional parameters: maximum vertical load, maximum service rotation, and in the case of expansion bearings, maximum expected expansion and contraction. Although it is usually possible to design a pot bearing, a spherical bearing, or an unconfined elastomer pad (or disc) bearing to fit a given set of such parameters, it is important to understand that each of the three reacts differently within a structural system. Clues to differing reactions can be found by looking at how the three types of bearings carry load and absorb rotation. An examination of these behavior patterns relates them to typical structural systems and points out areas of incompatibility, which in extreme cases result in malfunction of the bearing. One such case is presented involving the leaking of elastomer from pot bearings at the end of a continuous span. A theory for the leakage mechanism is postulated. Increased awareness of the interaction of bearings and structural systems is indicated and research into certain aspects is suggested.

Modern high-load, multirotational bridge bearings fall into three categories: pot bearings, spherical bearings, and unconfined pad (or disc) bearings. State specifications, bid items, and project details seldom differentiate among the types and thus give the impression that they are interchangeable—and in some cases they are specified as being interchangeable.

Typically, project plans detail bearings on the basis of three parameters: bearing capacity, or maximum vertical load; maximum rotation; and in the case of expansion bearings, maximum expansion and contraction. Because bearings in all three categories use similar polytetrafluoroethylene/stainless steel slide systems for expansion and contraction, only loading and rotation data will be discussed here to draw attention to the widely different characteristics of the three types of bearings.

Given these limited data on maximum load and rotation plus a few dimensional requirements, it is possible to design a bearing from any of the categories to fit the requirements. However, it is important to understand that each of the three may react quite differently within a structural system. Further, any of the three may not react in one structural system as it does in another.

Clues to these differing reactions can be found by considering how the three types of bearing carry load and absorb rotation.

LOAD AND ROTATION CHARACTERISTICS

The pot bearing (Figure 1) transfers load from a circular plate (piston) onto a round rubber pad confined within a mating recess in a steel plate (pot). There is virtually no vertical deflection. When the bearing is loaded, rotation input causes the rubber within the pot to flow from beneath the downward-tilting side of the piston toward the upward-tilting side.

The spherical bearing (Figure 2) transfers load from a circular concave plate directly onto a mating convex plate; the actual curved interfaces are stainless steel and ptfe. Rotation input results in sliding at this interface.

Unconfined elastomer pad (or disc) bearings (Figure 3) transfer load through the pad onto a steel base plate. When the bearing is loaded, the pad compresses. Compression must be kept within acceptable limits, generally by steel laminates or by increased hardness of the elastomer. Rotation input further compresses one edge and relieves the opposite edge.

The pot bearing is basically a closed hydraulic system; under pressure, the rubber reacts like a fluid. When lightly loaded, however, this hydraulic system breaks down. The rubber strength dominates and rotation input may result in lift-off or separation at the piston-elastomer interface. Seal rings may be momentarily unloaded and a leakage mechanism may be started.

In the spherical system, effective rotation is available at any load (within the bearing's capacity) down to zero, but it is vital that this type of bearing not be subjected to a coincident horizontal force. Low vertical load together with high horizontal load could cause a critical dislocation of the concave and convex parts. This instability has been documented by Gilstad (1).

In the unconfined pad (or disc) system, there is an inherent conflict between the need to limit compression and the requirements for rotation. Design specifications limit strain at the compressed edge of a pad under rotation and dictate no lift-off at the relieved edge. This coupled with a maximum acceptable vertical compression clearly restricts rotation (Figure 4). Unconfined elastomers under load are subject to further deflection beyond the initial amount; this is due to creep of as much as 40 percent.

Consider the manner in which these bearing systems react to rotational input. Figure 5 shows a comparison of eccentricity and rotation characteristics for the principal types of structural bearing from a paper by Kauschke and Baigent (2). Curves *B*, *C*, and *D* relate to the bearings discussed here. Of these three, the pot bearing offers the lowest reaction to ro-

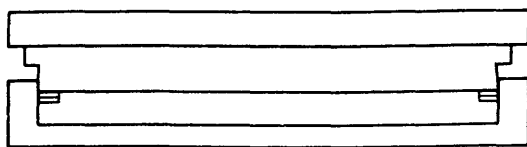


FIGURE 1 Diagram of pot bearing.

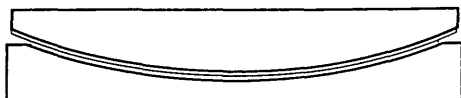


FIGURE 2 Diagram of spherical bearing.

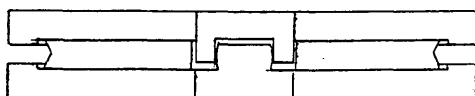


FIGURE 3 Diagram of unconfined elastomer pad (disc) bearing.

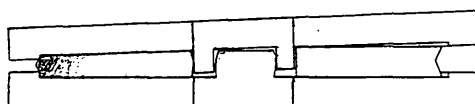
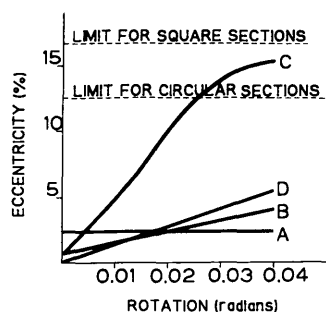


FIGURE 4 Diagram of unconfined pad bearing in rotated state.



- A SPHERICAL TYPE BEARING
 B RUBBER POT TYPE BEARING
 C DISC TYPE BEARING
 D ROCKER TYPE BEARING

FIGURE 5 Comparison of eccentricity and rotation characteristics for the principal types of structural bearings.

tation up to about 0.02 rad, beyond which the spherical bearing, with its constant rate resistance, gives the least eccentricity. The unconfined pad or disc unit has eccentricity several orders greater than the other two for all practicable rotation requirements.

Consider also the geometry. The pot bearing and unconfined pad bearing allow rotation about the approximate center of their upper elastomeric surfaces; the spherical bearing rotates about the center of the sphere. Obviously the orientation of the up curve or down curve will affect such structural details as the expansion joints, but it will also affect the amount of horizontal travel imposed on an expansion bearing by rotation (Figure 6). Wear characteristics of ptf on such bearings might warrant closer attention.

In general, pot bearings are best suited to high vertical loads, medium and high horizontal loads, and 0.02 to 0.03 rad rotation. Their strong feature is their low load eccentricity under rotation, and their weak feature is their limited ability to accept rotation at low vertical loads. Spherical bearings are best suited to high vertical loads, low and medium horizontal loads, and rotation above 0.02 rad. Their strong feature is their ability to accept high rotations at constant eccentricity under rotation, and their weak feature is their limited ability to sustain horizontal force at low vertical loads. Unconfined pad bearings are best suited to medium vertical loads, low and medium horizontal loads, and rotations up to 0.02 rad. Their strong feature is simplicity, and their weak features include amount and variability of compression deflection and a high resistance to rotation, which results in high edge loading on ptf when used. All types can be adapted to accept uplift loads.

RELATION OF BEARINGS TO STRUCTURES

Relating the reactions of the three types of bearings to various structural designs indicates that some structures are better suited to one bearing design than to another.

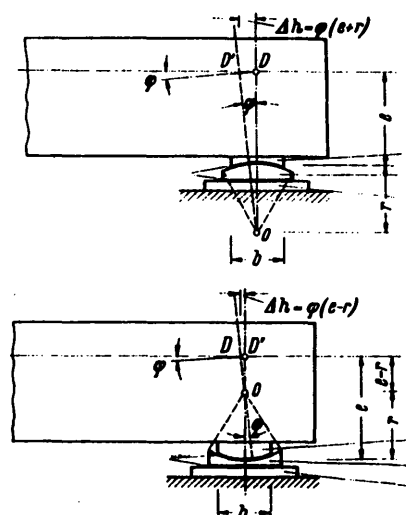


FIGURE 6 Comparison of the geometry of up-curved and down-curved spherical bearings.

The bridge in Figure 7 is well suited to pot bearings. It imposes a high permanent load and moderate rotation and requires the minimum of eccentricity to reduce bending moments in the tall piers. Spherical bearings, which require supplemental lateral restraint (the structure is vulnerable to hurricanes), would be less satisfactory. Unconfined pad bearings would be unsatisfactory because of the high bending moments induced in the tall piers and possibly because of the compression differential between the two bearings on any pier.

The bridge in Figure 8 makes excellent use of spherical bearings. The high rotation requirement and low load during initial construction make pot bearings less satisfactory for this structure. Unconfined pad bearings must be made thicker to accommodate higher rotation and this results in even more compression deflection. There also exists, under these loading conditions, the probability of lift-off and concomitant high edge loading of ptf.

Unconfined pad bearings would be satisfactory in the type of structure shown in Figure 9. Although the other two types of bearings would be serviceable here, their particular attributes would not be of significant advantage.

The compatibility of structural action and bearing reaction is so important that without it, bearing malfunction may result. It is possible, for example, that this incompatibility exists in the structure shown in Figure 10. This overpass has a two-span composite plate girder-concrete deck superstructure, fully continuous over the pier. Contract bearing notes indicate that pot, spherical, or unconfined disc bearings should be used. It may be, however, that because of the competitive bid system, the pots used were not the appropriate bearing for the structure.

Figure 11 shows a pot bearing with some elastomer leakage. This bearing, one of the abutment bearings on the structure, was made by a second manufacturer to replace one of the original lot that was leaking. It can safely be assumed that the replacement bearing was fabricated with particular care and diligently inspected and load-tested, yet it is leaking also. The reason for the leakage is postulated as follows: This superstructure is sufficiently stiff to transfer live loading of one span into uplift at the opposite abutment. Such uplift loading may result in widely fluctuating pressures within a pot bearing.

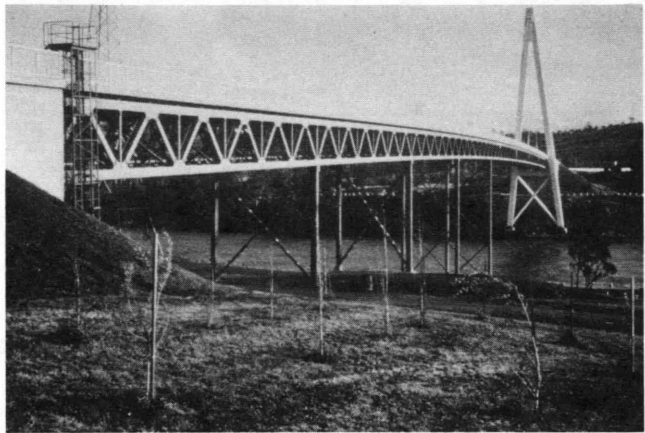


FIGURE 8 Typical structure suited to spherical bearings.

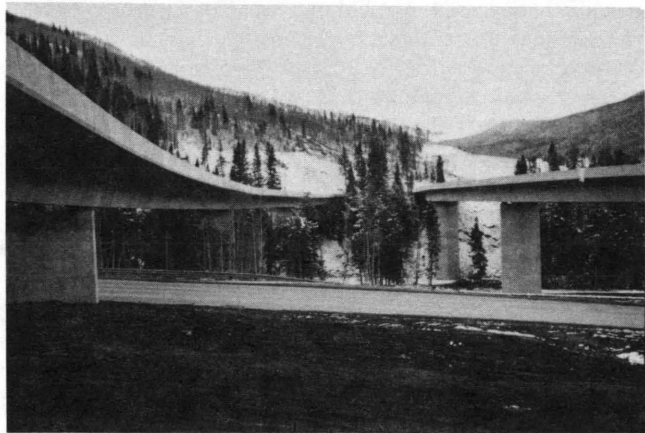


FIGURE 9 Typical structure suited to unconfined pad bearings.

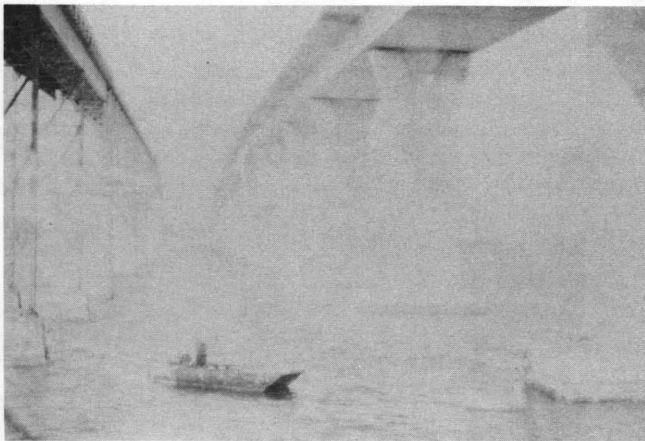


FIGURE 7 Typical structure suited to pot bearings.



FIGURE 10 Structure in which pot bearing leakage was found.

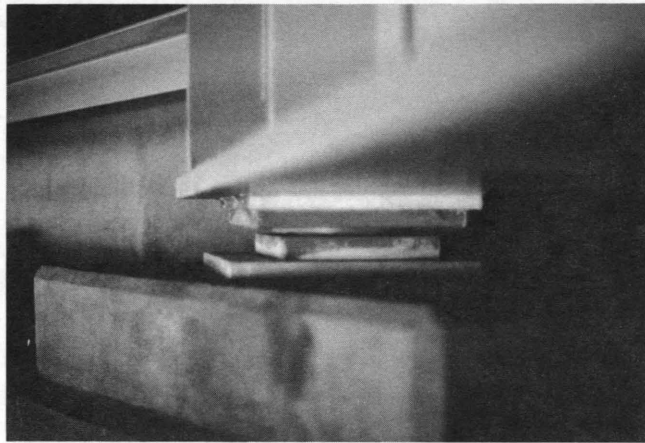


FIGURE 11 Abutment bearing on structure in Figure 10.

This “bounce-loading” would be of high frequency and, because of hysteresis in the elastomer, its reaction would be out of phase with the springier brass sealing rings. Thus, during each fluctuating load cycle, there could be an instant when the seal rings are not loaded against the pot wall, yet the elastomer is still loaded. At this moment, a small amount of elastomer would escape upward and be pinched between the seal ring and pot wall. Once there is elastomer in this area, pressure within the system would tend to equalize the loading on the inside and outside edges of the seal ring, reduce the ring’s effectiveness, and allow more elastomer to be pumped out during succeeding cycles. This leakage mechanism is consistent with the finely shredded appearance of the escaping elastomer.

There is also consistency between the design of this structure and that of the other few structures experiencing similar leakage. However, research into this theory is clearly needed.

CONCLUSION

This paper is not a damage report. The example presented is intended to emphasize to structural engineers the importance of awareness of the way different bearing designs react under given circumstances.

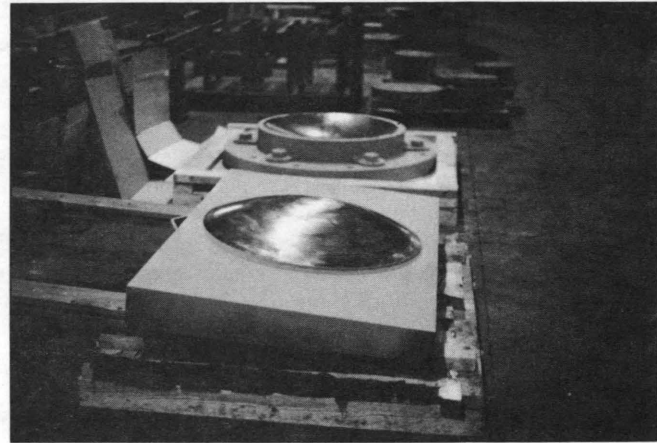


FIGURE 12 Typical modern spherical bearing.

In his paper on bridge deck joints, Burke (3) stated, “Poor performance and failures cannot be used as a general condemnation of the devices themselves. The success or failure of a design is directly related to the expertise of those responsible for its creation, development and application.” High-load multirotational bearings have achieved a refined state of development (Figure 12). Their creation is governed by a process of approval, specification, and inspection that, although onerous, goes a long way toward assuring the owners of good quality products. Problems will continue to arise, however, until due attention is given to the application.

The bearing industry and structural engineers must work together to ensure full understanding of the way these devices react in any particular structure.

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