Heavy Movable Structures, Inc.

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Guidelines for Selection of Large Sized Spherical Plain Bearings for Heavy Movable Structures

by

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Introduction:

Bearing used in heavy movable structures such as bascule or swing type bridges, during operation are subject to high internal specific pressure loads combined with slow velocities at the sliding interfaces. The bearings also need to be resistant to the effects of constant or periodically induced micro-movements, shock loading, false brinelling or other forms of damage to their sliding interface surfaces over their design service life. In many cases this can be 50 years or more. Increases in span lengths and newer bridge designs often require the structural support systems to be more elastic. This requires the trunnion, counterweight or cylinder bearings to accommodate greater imposed deflections and/or misalignments, while maintaining a high safety factor.

Manufacturing methods for associated bearing components, on-site installation methods and field conditions can also require a mounted bearing to accommodate high misalignments. These conditions may seriously affect the bearings performance after installation. Increasing costs associated with long term maintenance, labor and materials also create a need to provide a reliable low maintenance, highly wear resistant, compact but simple bearing design. Spherical Plain Bearings having either low maintenance or maintenance-free materials as their sliding interface surfaces fill this need.

This paper will present the advantages provided by Spherical Plain Bearings (SPB's) for large movable structures. The following parameters will be used: 1.) Static and dynamic load carrying capacities; 2.) Speed limitations; 3.) Frictional moments; 4.) Misalignment capabilities; 5.) False brinelling; 6.) Maintenance; 7.) Cost & availability; 8.) Current AASHTO specifications.

Selecting Spherical Plain Bearings

1. **Static & Dynamic Load Capacities:** The load carrying capacity for SPB's, unlike other bearing types having line or point contact within the load zone, is based upon surface contact area. Dynamic load capacity is the allowable load capability of the bearing during any type of motion, such as rotation, oscillation or tilting, when well lubricated. Static load capacity is more a function of the bearing design and material properties than their coefficients of friction while lubricated.

Depending on bearing design and component material properties, very high dynamic (C) and static (C_o) load carrying capacities in both a radial and axial direction are possible. Large size SPB's conform to the boundary dimensions set by ISO 6124/3 except for the width of the outer ring which follows dimensions found in Series 59 of ISO 15 for roller bearings.

Table 1 lists load carrying capacities for several large size SPB's having different sliding materials and sliding velocities. Under a unidirectional load condition, the highest area of stress is within either the upper or lower portion of the bearing, depending upon the direction of the applied load, in an approximate arc of 150°. Since loading in a SPB is based on surface contact, the internal specific bearing load is distributed over a much greater area than other bearing type with the same bore dimensions.. This produces less load per square area within the SPB compared to other bearing types. Under static load conditions or long periods of non-movement, SPB's having the special bronzes sliding materials offer a slightly higher load carrying capacity than composite plastic materials.

Bearing Load Capacity Relative to Speed				
Property	**Sliding Velocity** m/sec (fps)	**Load Designation**	**FS Type**(1) N/mm^2 (PSI)	**P4S Type**(2) N/mm^2 (PSI)
Dynamic Rating	None	C	80 (11,600)	80 (11,600)
Static Capacity		C_o	100 (14,500)	140 (20,300)
Dynamic Rating	<0.025 (4.92) (3)	C	50 (5,800)	50 (5,800)
Static Capacity		C_o	100 (14,500)	140 20,300)

(1) FS designation is for a SPB having a full shell liner of a high performance thermoplastic (HPTP) composite liner within the bearing. See Figure 1.
(2) P4S designation is for a SPB having special bronze insert pads within the bearing. See Figure 2.
(3) Most applications have a sliding velocity below this value. For higher speeds consult the bearing supplier.

Table 1

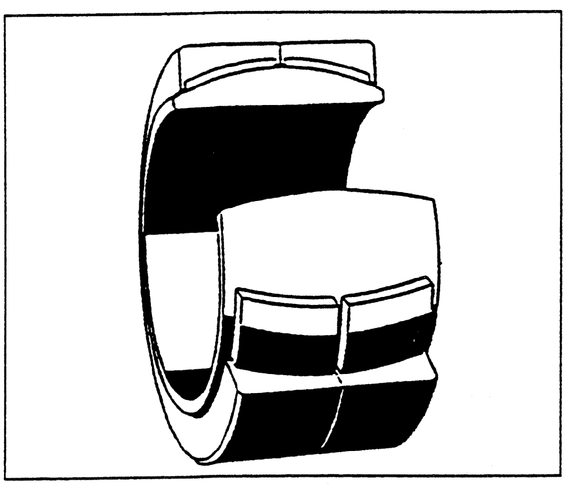

Figure 1 Type "FS" Large Size Spherical Plain bearing with a full HPTP composite plastic liner between the inner and outer rings.

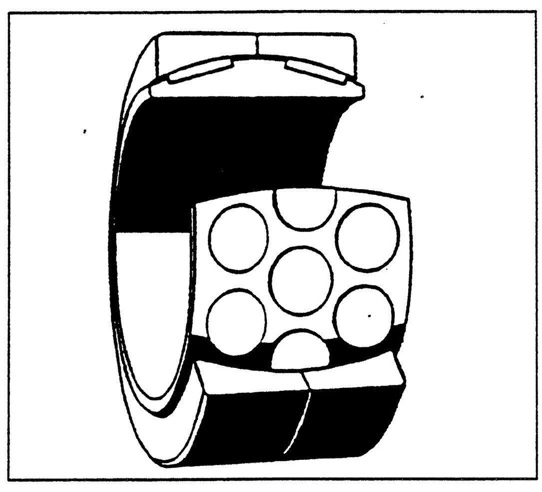

Figure 2 Type "P4S" Large Size Spherical Plain bearing with a sliding discs of special bronze materials between the inner and outer rings.

In bridge designs, if bearing size is based solely upon its dynamic and static load capacities, and not other parameters such as bending in the trunnions, the size of a SPB is significantly smaller then other bearing types under the same conditions. This reduction is size leads to increased savings when the entire trunnion or cylinder assembly is considered. Smaller housings, smaller shafts & seals, smaller mounting pads are required thereby reducing both assembly and construction costs.

For most design applications, to provide for long trouble free operation, it is desirable to keep the specific bearing load (dynamic conditions only) at a level of 40 N/mm^2 (5,800 psi) or lower. When looking strictly at the static loading, the full capacity of the bearing materials can be utilized, see Table 1. Due to the damping capabilities of the materials within SPB's shock or impact loading does not normally cause damage to the sliding materials. Therefore SPB type bearings do not exhibit a Fatigue Load Limit like other bearing types.

Table II lists various load capacities for some of the more common sizes of FS and P4S type bearings with both HPTP composite liners and special bronze sliding materials.

Static and Dynamic Bearing Capacities			
Bearing	**Size** (bore/OD/width) See Note 1	**Dynamic Capacity** kN (x10^3 Lb.)	**Static Capacity** kN (x10^3 Lb.)
GEP 420 FS	420x600x280	10,600 (2,382)	16,000 (3,595.5)
GEP 440 FS	440x630x300	12,200 (2,741.5)	18,600 (4,179.7)
GEP 480 FS	480x680x320	14,300 (3,213.5)	21,200 (4,764)
GEP 500 FS	500x710x335	15,300 (3,438.2)	23,200 (5,213.4)
GEP 560 FS	560x800x380	19,600 (4,404.5)	29,000 (6,516.8)
GEP 600 FS	600x850x400	22,000 (4,943.8)	33,500 (7,528)
GEP 750 FS	750x1060x500	34,500 (7,752.8)	52,000 (11,685.4)
GEP 420 P4S	420x600x280	8,300 (1,865.1)	20,800 (4,674.1)
GEP 440 P4S	440x630x300	9,650 (2,168.5)	24,000 (5,393.2)
GEP 480 P4S	480x680x320	11,000 (2,471.9)	27,500 (6,179.7)
GEP 500 P4S	500x710x335	12,000 (2,696.6)	30,000 (6,741.5)
GEP 560 P4S	560x800x380	15,300 (3,438.2)	38,800 (8,719.1)
GEP 600 P4S	600x850x400	17,000 (3,820.2)	43,000 (9,662.9)
GEP 750 P4S	750x1060x500	27,000 (6,067.4)	68,000 (15,280.9)

Table II

Note 1: GEP—FS type bearings can be provided in sizes ranging from 100 mm to over 1,000 mm bore. Special sizes can also be accommodated if required by design parameters. GEP type bearings are also available with special bronze sliding discs. These bearings have a suffix P4S and are available in sizes from 320 mm to over 1,000 mm bore dimensions.

Service Life: Unlike roller type bearings which have a service life based upon an L_{10} value a SPB in a bridge application, has its life based upon wear of the sliding material over the distance the bearing will travel during its specified operational service life. These values will differ greatly. Typically the lifetime sliding distances required by design, in these types of applications, can be in a range of 450-600 Km (280-375 miles). A range easily within the capability of either sliding material combination with proper maintenance and lubrication. Typically wear, in a unidirectional load condition, is in one specific area of the bearing. Should wear be higher than expected the bearing can be rotated 180° so as to produce a fresh set of sliding materials within the SPB.

HPTP type bearings:
The current calculation used in determining the service life of a large size SPB with HPTP composite sliding materials is noted below. This calculation is based upon the distance of travel to cause 1 mm (0.039") of wear. The distance required to cause this amount of wear is determined by substitution of values for the specific bearing load "p" and a factor for the HPTP composite material based upon the bore of the bearing in the following formula:

$$S = A*1150*p^{-1}$$

where S = Distance traveled to cause 1 mm wear, meters
p = specific bearing load, N/mm^2
A = 3.3 for dia up to 180 mm bore
3.8 for dia 180 to 440 mm bore
4.5 for dia larger than 440 mm bore

Knowing the: 1.) allowable wear of the HPTP composite materials within the bearing; 2.) the sliding distance to cause 1 mm of wear; 3.) the approximate sliding distance in one year of operation of the bearing; the service life in years can be now determined.

This formula is valid for sliding velocities below 0.025 m/sec (4.92 fpm) at a specific load up to 50 N/mm^2 (7,250 psi). For speeds and specific loads higher than this it is recommended that the bearing supplier be contacted for a complete review.

Special Bronze type bearings:
Likewise service life for similar GEP type bearings having special bronze sliding materials is based upon the amount of wear over the life of the bearing. The actual or assumed load conditions as defined in DIN 19704 are used in determining the correct size of the bearing. the DIN standard load conditions are: Normal operating loads (NB); Special operating loads (BB); and Exceptional loads (AL). For applications where the life time sliding distance is less than 1000 meters this is considered as a quasi-static condition and the static load rating of the bearing is compared to the actual load place on the bearing during use. The actual load is a combination of the radial load (Fr) and the axial load (Fa). For longer sliding distances it is recommended that the bearing supplier be contacted for correct sizing of the bearing.

The following is the current method for selecting a special bronze sliding bearing based on the DIN 17904 conditions. Using the following equation the "equivalent bearing load" (P_{perm}) is determined.

$$P_{perm} = x_1 * x_2 \text{ or } x_3 * C_o$$

values for x_1, x_2, x_3 are dependent on the load cases NB, BB & AL as previously defined in DIN 19704 (see table III below)

Permissible equivalent load for trunnion bearings

$P_{perm} = x_1 * x_2$ or $x_3 * C_o$

Bearing type	Design load (DIN19704) Normal operating load NB/BB[3]	Exceptional Load AL
GEP...FS[1]	$x_1 = 0.75$	$x_2 = 1$
GEP...P4S[2]	$x_1 = 0.75$	$x_3 = 1.2$

1. C_o based on $p_m = 120$ N/mm^2
2. C_o based on $p_m = 200$ N/mm^2
3. If special operating loads (BB) occur, these higher loads should be used instead of NB

Table III

In order to determine the corresponding bearing size, when the shaft diameter is not yet set, Figure 3 below should be used along with the value of F_a/F_r is required along with the applicable x-factor. F_a/F_r needs to be determined for each separate load condition (NB. BB or AL). Having the correct value for F_a/F_r for the load condition the correct "y" value, from Figure 3, can be found. This value is used in the equation:

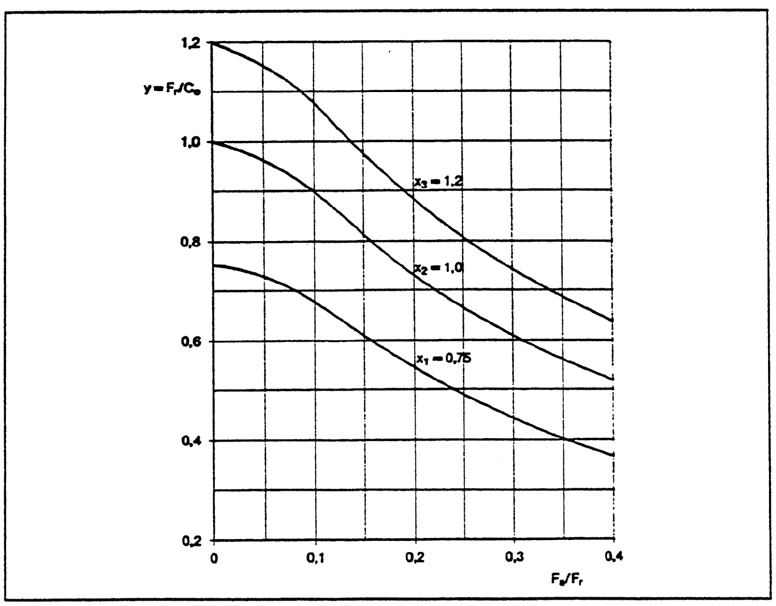

Figure 3

$$\mathbf{C_o = F_r/y}$$ where

C_0 = bearings static load rating
F_r = radial load on bearing
y = value from Figure 3

The value of this calculated C_o is then compared to the listed values for the P4S bearings to determine the correct size for the application.

2. Speed Limits: The mean sliding velocity of motion for a SPB, in swing or bascule bridge applications, is not normally problematic. If SPB's are to be considered for use on rolling bascule bridges or center lift type bridges it is suggested that the application be reviewed by the bearing suppliers Engineering Department for acceptability.

At low sliding velocities less frictional heat is generated between the inner ring and the sliding materials and is easily removed through the bearing housing or via the lubricant greases or oils. Higher rotational velocities, several revolutions per minute, the amount of heat generated could be a problem if the motion were continuous. This is not normally the case for bridges. Infrequent high rotational speeds may be allowed but such applications would need to be considered on a case by case basis.

Typically SPB's, of any sliding combination, are used for high load low speed applications. As in the case of a bascule bridge a 750 mm (29.527") bore bearing opening through an arc of 75° in a two minute period produces a rotational speed of about 0.005 m/sec (0.1 rpm) which is very low.

3. Bearing Frictional Moment: As previously noted SPB's are a surface sliding condition unlike other bearings which may be either point or line contact. This difference in contact area leads to differences in the amount of bearing frictional moment required for movement of each bearing type. As an example, a 600 mm (29.527") bore diameter bearing with a radial load of 9,875,300 N (2,217,000 Lb.) on a well greased SPB, having either a HPTP composite or the special bronzes sliding materials, produces a frictional moment of approximately 400,000 Nm (295,000 Ft-Lbs.) This value is based upon a mean coefficient of friction (μ) of 0.10 (the full range for this material is 0.05 to 0.20). This figure is large when compared to a frictional moment of other bearing types but in comparison to the overall motor requirements for moving the bascule or swing span this value may be insignificant. For SPB's the frictional moment is a function of: 1.) the equivalent dynamic bearing load at the sliding surface (see our product literature for determining this value); 2.) the coefficient of friction for the sliding material combination; and 3.) the mean diameter of the spherical ball of the bearing.

These values are substituted into the following equation:

$$\mathbf{M = 0.5x10^{-3}\mu P d_m}$$ Where:

M = Frictional moment, Nm
P = equivalent dynamic bearing load, N/mm^2
d_m = mean diameter of the spherical surface, mm
μ = coefficient of friction of the sliding materials
Composite Plastic = 0.05 to 0.20
Special Bronzes = 0.07 to 0.15

The higher value of frictional moment may beneficial in smoothing out the motion of the moving structure (reducing the chatter sometimes seen during operation) as the coefficient is constant and the sliding surface is not subject to permanent deformations, as may be the case in bearings with false brinelling, damage to the sliding surfaces or components.

Typically large size SPB's are not provided with any external side face seals which would add to the frictional moment. If required, they can be provided. Seals are normally suggested to be provided in the bearing housings for contaminant and moisture exclusion. A full grease seal along the side faces of the bearing and the inner surface is best. This amount of grease along the side faces is not considered in the determination of the frictional moments for these bearings. Typically SKF would recommend for use our lithium based LGEP2 grease with extreme pressure (EP) additives for such applications.

4. <u>Misalignment Capabilities:</u> Typically large size spherical plain bearings have a misalignment/deflection (dynamic or static) capability up to 2½°. The angular limit is defined as when the inner ring tilts under the side face of the outer ring. Higher than normal misalignments capabilities can be provided, if required by design. Misalignment/deflection is taken up within the bearings internal spherical surfaces and does not reduce the safety factor of the design or the stress distribution across the sliding interface surface. In other words the outer ring is always supporting the full width of the inner ring.

Misalignment/deflection can be due to any of several causes, such as: 1.) elastic deformations of the structure under load (trunnion shaft, support girders, housings, foundations; 2.) Changes in length due to temperature variations; 3.) position changes over time due to settling of piers, overloading, ground movements; 4.) differences in bearings due to improper mounting, and differential settling of piers.

5. <u>False Brinelling:</u> Small micro-movements within other bearing types, during transportation, installation or during use, can eliminate all lubrication at the sliding surface interface. Loss of lubrication and constant movement, combined with high loads and shock loads, can cause dull depressions in the mating surfaces even without rotation being present. The surfaces may appear polished or show staining characteristic of fretting. This is known as false brinelling. If the surfaces are permanently deformed due overloading, shock or, impacting during mounting, which causes plastic flow of the material is true brinelling.

SPB's having either the special bronze or the HPTP composite materials do not exhibit this conditions. The maintenance-free material compositions are excellent in damping these small movements. They are absorbed and dissipated by the materials and therefore do not present any problems in providing smooth motion during movement. Shock loads imposed on the bearings do not normally present any problems due to the nature of the sliding materials.

6. <u>Maintenance:</u> It is normally recommended that the bearing housing be supplied with good external seals to reduce the ingress of any moisture or other contaminants. It is possible to provide external seals on the SPB's if required by the application. This is not possible or practical for other large bearing types. Bearing seals used in conjunction with seals in the bearing housing this provides a very effective means of keeping lubrication in and excluding contaminants from entering the bearings sliding surface area. The means of providing lubrication to the bearing and the seal areas should be considered in the early stages of any design and should be reviewed by the bearing supplier for any recommendations concerning frequency and lubrication types for the application.

Relubrication for both the special bronzes and the HPTP composites, in most applications, is on an annual basis, unless there is extremely frequent movement of the bearing. Lubrication of the sliding surfaces is provided by lubrication holes and grooves in the outer ring and sliding surfaces. These groove allow to excellent distribution of the lubricant within the load zone of the bearing. In some applications special bronzes only, oil may also be used as a lubricant. Oil lubrication may require special sealing considerations for the housings. For both the special bronzes and HPTP composite our lithium based LGEP2 grease with extreme pressure (EP) additives, without molybdenum disulphide additives, is suggested. Other additives for corrosion and moisture protection may be used. Only a very small amount of lubricant is required to maintain a positive pressure against the seals so that they may function properly.

Installation of spherical plain bearings is less involved than procedures required for other bearings. Unlike other types of bearings which may require the internal clearances to be measured prior to, during and after mounting SPB's do not. The internal clearance of the bearing is a function of the machined inner and outer rings and the fits between the bearing, shaft and housings. It is possible, if considered in the early design stages, to provide for periodic measurement of the wear within the bearing which is either difficult or impossible with other bearing types.

7. **Cost & Availability:** The cost associated with the use of a SPB needs to be considered in an overall scheme. Due it its high load carrying capacity and compact design smaller SPB's can be utilized in many designs where typically a larger bearing would be required, depending upon the type of the bearing being considered for use. This allows an overall reduction in the cost of the associated assembly components: i.e.: housings, shafts, seals, support structures etc. Use of a SPB also allows for the use of a less expensive grade of steel for the shafting as rotation is between the inner and outer rings of the bearing and not between the bore and the shaft unless dictated by design criteria.

Assembly of the bearing, on to the shaft or in to a housings, is another area of cost reduction. SPB's can be, and often are, preassembled to a trunnion shaft or other type of shafting and installed in the housing in a shop environment. This provides for reductions in field assembly costs (time, materials and labor). It must be remembered that cost of the bearing is a relative. It must be consider in relation to many factors, such as: 1.) how well the bearing will function over the life of the project; 2.) safety of the people using the bridge or whatever other structure it is under consideration; 3.) project labor and associated component assembly costs; 4.) periodic relubrication costs and equipment, if required; 5.) future replacement costs for damaged or worn bearings.

Large size SPB's currently are manufactured at our facilities in Europe. Therefore cost and delivery of large size spherical plain bearings is based upon several factors. These include current production scheduling, availability of large size castings or forgings, manufacturing requirements, shipping means and project scheduling by the customer. Delivery times need to be considered in relation to the project scheduling as most large sizes are manufactured on a demand basis although some stock sizes for GEP/GEC bearings are available.

8. <u>AASHTO Specifications:</u> Currently the 1988 AASHTO specifications have no provision for use of Spherical Plain Bearings included within it. To date only journal bearings (lined and unlined), step bearings, anti-friction bearings and roller bearings are specified. Spherical plain bearings should be considered for inclusion in the soon to be rewritten AASHTO specifications. Spherical plain bearings can be supplied in sizes and load capacities to meet the requirements of the specifications while maintaining a high degree of safety under varying load and operating conditions.

<u>Conclusions:</u> Large size Spherical Plain Bearings offer the designer of Heavy Movable Structures the ability to downsize the complete assembly area of the trunnion shaft on bascule type bridges. While providing a very cost effective bearing having a constant safety factor and smooth trouble free operation in the presence of vibratory motion or micro-movements. They also allow for additional cost saving in reductions in both shop and field assembly costs by their simplicity of design and their tight machining tolerances.

Once a preliminary selection has been made a complete review is suggested by the bearing supplier to provide additional input and guidance in obtaining the best trouble free service life. It is hoped that this paper presents the structures designer with adequate information to make a determination as to the use of large size Spherical Plain Bearings in bridge applications.