Use of Spherical Bearings in Railway Bridges- Bogibeel Bridge Project

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Synopsis

Railways have traditionally used steel Rocker-Roller bearings for bridges with higher spans. They require high maintenance effort apart from being heavy and difficult to replace. With advancement of bearings technology new bearings like Pot-PTFE bearings and spherical bearings are now available. Spherical bearings are being provided for Bogibeel Bridge which is capable of taking high vertical and horizontal loads. The use of spherical bearings will result in savings in terms of low maintenance cost with enhanced life. With their ability to adapt to frequent high displacements under high vertical loads spherical bearings will prove to be the most suitable bearings for Railway bridges. The background behind the decision to adopt spherical bearings and the process of installation of the bearings in Bogibeel Bridge superstructure shall be the central theme of this paper.

1. Introduction :

The Bogibeel Bridge over the mighty River Brahmaputra near Dibrugarh in the state of Assam consists of 39 spans of 125 m and 2 shore spans of 32.75 m. With a length of 4.94 km, Bogibeel Bridge will be the longest bridge across the Brahmaputra and the longest Railway and Rail-cum-Road bridge in India.The superstructure of

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Bogibeel Bridge is fully welded Warren truss Open Web girder which will carry 2 Broad Gauge tracks and 3-lane Highway on the top deck. Unlike conventional rail-cum-road bridges on Indian Railways, this bridge is designed as a composite girder with the RCC deck acting as compression member. The design of the bridge has been inspired from the Ø resund link between Denmark and Sweden.

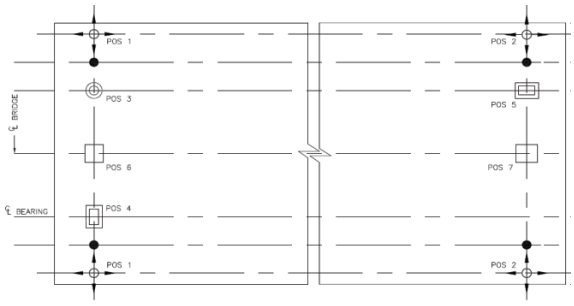

Fig. 1- Original bearing configuration

2. Bridge Bearings

The bearings for the bridge was originally conceived to be Pot-PTFE with Metallic pin and guide bearings. However, during design of the bearings by the agency executing the superstructure work, it was found that the size of bearing required for taking the designed loads cannot be accommodated in the pier cap. This was due to the limited capacity of elastomer and PTFE to take vertical loads. As per IRC-83 (Part II), the maximum compressive pressure permitted on the elastomer is 35 N/mm2. Similarly, the maximum permissible pressure on the PTFE shall not exceed 40 N/mm2.

In this juncture, the only option available for the bridge bearings was spherical bearings. Spherical Bearing is a structural bearing which consists of a set of concave & convex mating steel backing plate with a low friction sliding interface in between thereby permitting rotation by incurve sliding. For the purpose of providing the movement ability, the bearings are combined with flat sliding elements, guides and restraining rings. Spherical bearings with Ultra High Molecular Weight Polyethylene (UHMWPE) sliding material resulted in smaller bearing size that can be accommodated in the existing pier caps. The capacity of UHMPWE to take compressive stresses is double to that of PTFE. Apart from reduction in bearing size, this results in longer service life of the bearings.

Service life of 50 years or more is obtained. A comparison between Pot-PTFE bearings and Spherical bearings is shown in the table below.

Pot-PTFE Bearings	Spherical Bearings
Size of bearing is large due to limited capacity of elastomer.	The bearing components can be as small as half the size of Pot-PTFE resulting in savings in substructure.
Space requirement for Pot-PTFE and metallic bearings on pier caps can be large.	Minimum space on pier cap is required. In some cases, pier cap can be dispensed with.
Limited rotation capacity due to ageing of elastomer.	Allows greater rotation making it suitable for large turning angles.
Bulging or extrusion of elastomer is frequently encountered.	Does not have elastomer.
Requires high precision in installation.	They are easy to install and can be easily replaced.
Additional moment generated for guided bearings.	Little additional moment is generated on the bearings.
Requires metallic steel bearings for high horizontal loads.	Metallic bearings are not required. Capable of taking high horizontal loads.
Cost of Pot-PTFE bearings is high due to precision, accuracy and low tolerances in manufacturing.	Cost of Spherical bearings is marginally higher than Pot-PTFE bearings but gives more than twice the service life.

The revised bearing configuration after adoption of spherical bearings is shown in Fig. 2.

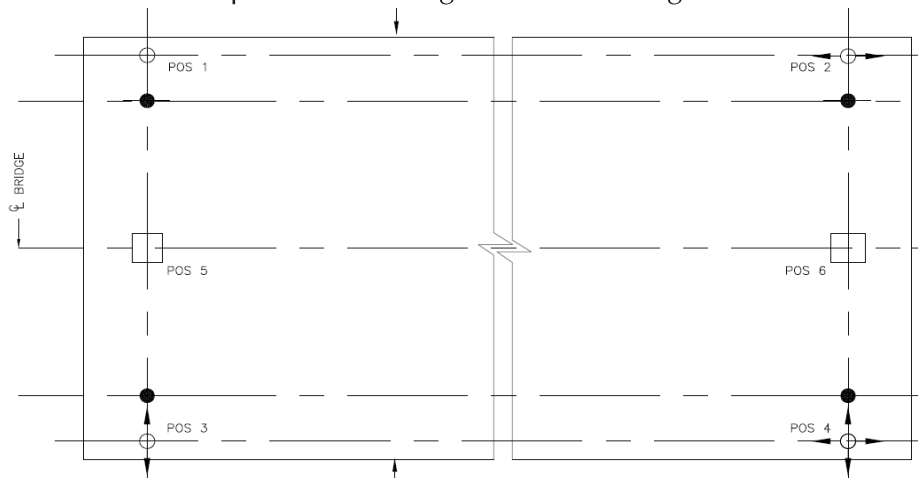

Fig. 2- Final bearing configuration

It can be seen that the total number of bearings have been reduced to four instead of seven. This has resulted in more space for future inspection and maintenance works of the bridge.

3. Specifications For Spherical Bearings

N F Railway (Construction) prepared the specifications for the spherical bearings in 2012 after due consultations with the designer, reputed manufacturers of spherical bearings and provisions of Draft Guidelines for design of Spherical and cylindrical bridge bearings published by RDSO.

As per the provisions of the specifications, the manufacturer shall submit the European Technical Approval (ETA) document for spherical bearings with special sliding material (UHMWPE) and shall ensure working life of bearings for not less than 50 years.

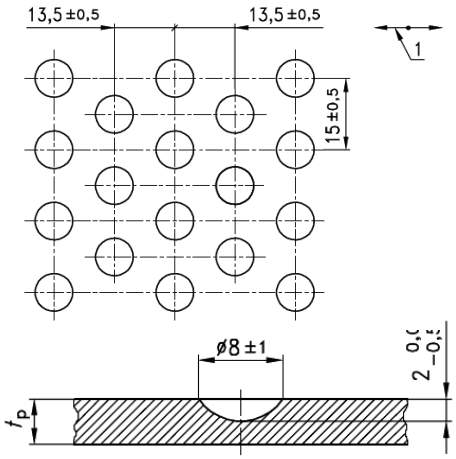

Fig. 3 - Dimple pattern of Sliding material

The standards for design of spherical bearings shall be EN 1337-7.

All main structural steel for fabrication of the bearings shall conform to requirements of S355J2+N of EN 10025 or EN 10137-1. Other steel accessories shall conform to S235JR or equivalent.

4. Special Sliding Material (UHMWPE)

Main sliding direction Special sliding material shall be Ultra High Molecular Weight Polyethylene (UHMWPE) of low friction and highly abrasion resistant and durable sliding material having European Technical Approval (ETA). The sliding material must have dimples for the main sliding surface. Flat UHMWPE shall not be allowed. The dimple pattern must be in a manner that in the main sliding direction there are no areas without dimples (dimples in one row shall not be permitted). The dimple pattern shall be in accordance with EN 1337-2.

All dimples have to be filled by silicon grease.

An independent material testing institute shall perform test to confirm the accordance of the requirements for the sliding material with respect to the physical and chemical properties as well as the tribological behaviour as per stipulation of EN 1337-2.

Sliding material in horizontal plane shall only be recessed and shall not be bonded into its steel substrate. Sliding material in vertical plane shall be bonded and recessed into or bonded to and mechanically fastened to its steel substrate. The recess into the steel substrate shall be designed in accordance to the technical approval of the bearing for the sliding material sheet thickness but shall be at least one half the thickness of the sliding material. The shoulders of the recesses shall be sharp and square.

5. Stainless Steel Sliding Surfaces

Sliding surface in contact with the sliding material shall be in accordance to specification given below.

The stainless steel sheets shall be attached to their backing plates by continuous welding along their edges so as to prevent ingress of

Austenitic Steel	1.4404+2B	EN 10088-2
Surface roughness	≤ 1μm	ISO 4287
Surface roughness	150 – 220 HV1	ISO 6507-2

moisture and shall be clean, sound, smooth, uniform without overlaps and ensure that the stainless steel sheet remains flat throughout its service life. Mechanical fastening of sheets without welding along edges is not permitted.

Minimum thickness of the stainless steel shall be 1.5 mm. The backing plates shall extend beyond the edge of the stainless steel sheets to accommodate the welds and the welds shall not protrude above the stainless steel sheets. The stainless steel sheets shall completely cover the sliding material in all operating positions, plus at least 25 mm in the direction of movement.

The curved sliding surface shall be hard chromium plated steel and conforming to EN ISO 6158. The steel substrate for hard chromium plated steel sliding surface shall be in accordance with EN 10025 Grade S355J2G3 or fine grained steel of the same or higher grade in accordance to EN 10113-1. The hard chromium plating shall be free from cracks and pores. The surface of the base material shall also be free from porosity, shrinkage cracks and inclusions. Alternatively, the curved sliding surface can be of special alloy which is having European Technical Approval with properties similar to that of hard chromium plated steel.

6. Guides

Guides are used to prevent movement in one direction such as in unidirectional bearings. They shall be designed to withstand the ultimate horizontal design loads of the structure as stated in the bridge bearings schedule. The top plate shall be restrained by guide bars. The guide bars which are located on the outer edges of the top plate and which use the bottom or base plate as the restraining device have limited rotational capabilities and may restrict the free

rotation of the bridge at the support where the axis of rotation of the bridge is parallel to the longitudinal axis of the guide bars. In such cases special adaptations to the side guides (such as by the addition of tilting bars) will need to be considered to accommodate the rotations of the bridge. Such details shall be subject to the approval prior to manufacture.

The guide bars shall be fabricated integral with the bearing base element when they are centrally located at the top of the convex spherical element in spherical bearings. Bolted down or welded guide bars shall not be permitted.

Guides which are located along the outer edges of the bearing may be welded to the bearing top sliding plate such that the transverse dimension of the top plate shall extend to the outer edges of the guides. The longitudinal dimension shall be determined by considering full movement range of deck superstructure and possible movement of the substructure. Full penetration shall be used for the connection between the guide and the top plate. The bearings manufacturer shall provide details of calculations and take into consideration long term durability of the bearing. Machining of the inside face of the top plate and guides and that of the top surface of the top plate shall preferably be done after welding is completed. The guides shall be self-aligning to ensure complete contact of the sliding material and the stainless steel surfaces along the entire length of the guide providing the lateral restraint.

The guides used for lateral restraint shall be faced with low friction material (UHMWPE) to ensure that the frictional resistance to the movement due to the guides is not significant. The total gap between guides and guided members shall be in accordance with EN 1337-2 and the ETA.

7. Free Sliding Bearings

Bearings which are not required to provide lateral restraint shall be attached to the structure by anchor bolts or other approved methods. The friction between the bearing and the superstructure

and substructure shall not be considered to assist in resulting horizontal forces.

8. Anchor Bolt Assembly

The anchor stud/ dowels welded to the underside of the bottom anchor plates shall be at least 16 mm in diameter. Anchor studs shall be welded by resistance welding method as per ISO 14555. Welding of anchor stud by GMAW/MMAW process shall not be permitted. The dowels shall be located in their sockets using high strength non-shrink grout applied strictly in accordance with the material recommendations and specifications. The grout shall be subject to the approval of the Engineer.

The anchor bolts shall be limited in length by the need to remove the anchor bolts during future bearing replacement. There shall be no obstruction which will impede the unfastening of the anchor bolts during bearing replacement.

The anchor bolts shall be designed to resist the full horizontal design loads from the bridge superstructure without reliance on the frictional forces developed from steel to steel contact between elements and the adapter plates.

9. Identification

All bearings must be clearly coded by the manufacturer. The coding must prevent mix-up and remain clearly visible on the bearings. Each bearing shall be stamped with the bearing number, direction of installation and the installed location which must correspond with the information contained on the approved drawings/ documentation for the bearings. The stamp shall be on a surface visible after installation.

10. Acceptance Criteria

Acceptance of the bearings shall be done on the basis of the material certificates, dimensional control cards, control for tolerance fit, corrosion protection, assembly control, material tests and load tests.

11. Lot Size

Minimum one bearings of each type from each lot shall be tested. A lot shall be defined as those bearings presented for inspection at a specified time and date. A lot shall not exceed 24 bearings. It shall consist of bearings of the same type.

The test and number of samples to perform tests shall be in accordance with the following.

Test	Samples required
Proof load test (vertical and horizontal as per design combination)	One production bearing per lot
Rotation	One production bearing per lot
Physical properties of sliding material	Six samples of 250 x 400 mm piece of sliding material for the project.

12. Proof Load Test

The bearing shall be simultaneously subjected to a load combination of 125% SLS design load and rotation of 0.02 radian or design rotation, whichever is greater, for a period of one hour. Note any distortions, cracks, or separation (lift off) of plates from each other or from the sliding material shall be made and the design of bearing system shall be improved.

13. Guide Horizontal Test

The aim of this test is to verify the capability of the bearing to withstand horizontal load. The bearing shall be subjected to a combination of vertical and horizontal load corresponding to 110% of their respective vertical and horizontal SLS design loads and held under load for a minimum period of 30 mins.

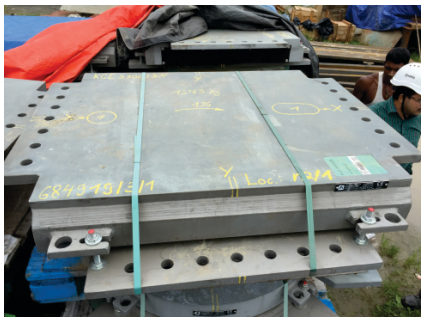

Fig. 4 - Spherical Bearings at project site.

14. Acceptance Of Bearings After Inspectionfig. 4- Spherical Bearings At Project Site.

If all tests performed on the selected bearing in a given load range and lot meet the specified requirements, all bearings within that load range will be accepted. In the event that any test on a bearing in a given load range and lot bearings does not meet the specified requirements, the tested bearings and all other bearings in that same load range and lot will be rejected unless each individual bearing is satisfactorily tested and accepted by the Engineer.

There shall be no lift-off or separation between plates during rotation. There shall be no separation between plates and sliding material under rotation. The sliding material shall not travel (cold flow). There shall be no cracks, separation or permanent deformation of the sliding material, stainless steel, other components, or welds. Properties of the material shall be within the limits of the specifications.

15. Installation Of Spherical Bearings

- Care shall be taken during installation of the bearings to permit their correct functioning in accordance with the design scheme.
- To prevent contaminations, dismantling of the bearings shall not be done at site except under expert supervision of the manufacturer's engineer.
- The load shall be transferred onto the bearings only when the bedding material has developed sufficient strength. The props for the framework shall only be removed after the lapse of appropriate time. In special cases, this can be ensured by suitable devices like jacks.
- Temporary clamps and shims (introduced to maintain working clearance) shall be removed at an appropriate time, before the bearing is required to permit movement.
- Permitted installation tolerance of the bearing from plane of sliding shall be maintained.

- Cement based non-shrink grout with air releasing additive and epoxy based grout, whichever is specified shall be first tried at the site. For the proprietary grout mixes, appropriate instruction from the manufacturer shall be followed especially with regard to the following
  - o Preparation- concrete cleaning, roughening, pre-soaking, etc.
  - o Forms- sturdiness, leak proofing, shape, header funnel vents, etc.
  - o Bearing base- cleaning, etc.
  - o Placement- mixing, consistency, time period, finishing, etc.
  - o Protection- curing, ambient temperature, etc.
- Bearings shall be installed in the structure as specified and shown in the drawings and directed by the bearing manufacturer. Installation procedure shall be subject to review and approval by the engineer. The manufacturer will have its technical representative present for the placement of all the bearings.
- Bearings shall be set to the dimensions and offsets prescribed by the manufacturer and the drawings. When placed, the bearings shall be dry and clean and free from dirt, oil, grease or other foreign substances.
- Bearings shall be adjusted as necessary to take into account the temperature at the time of installation and future movements of the bridge due to temperature changes, remaining creep and shrinkage of bridge deck, release of falsework and shortening due to pre-stressing (if any).
- Under no circumstances shall bearings be taken apart and reassembled on the site, except where it is an unavoidable feature of the installation procedure, in which case the dismantling, installation and reassembly shall be under the supervision of the manufacturer's technical representative and at the risk and responsibility of the Contractor.
- No rehabilitation, modification or repair work to the bearings shall be carried out on the bearings.

- Threaded fixings shall be uniformly tightened over their entire area to avoid overstressing any part of the bearing.
- Bearings shall be placed so as to have contact with the bedding surface over its entire area. Voids or hard spots after installation are not acceptable. Care shall be taken to ensure that no air pockets exist below the bearing bottom plate after installation.
- Bearings and their surrounding shall be left clean after installation. All temporary transit clamps shall be removed at a time to be agreed upon by the manufacturer and the engineer.
- Contractor/ manufacturer shall notify/ certify in writing to the engineer upon completion of the installation that the bearings have been correctly installed.

16. Installation Tolerances

Bearings shall be located true to line and levels such that

(a) their centrelines are within ±3 mm of their correct positions and

(b) bearings are set to their correct inclination to the horizontal within a tolerance of ±0.1º in any direction.

17. Seating

Seating shall be as per manufacturer's recommendations and in accordance to EN 1337-11.

18. Replacement Of Bearings

The bearing design shall be such that the given substructure and superstructure design permits the bearings to be removed for inspection or rehabilitation with minimal jacking of the structure. Sufficient space shall be ensured on top of bridge supports (at abutments and piers) and on the soffit of the bridge superstructures within the width of deck diaphragms to enable the location of jacks during bearing replacement.

The bearings shall be designed so that they can be replaced by lifting the deck no more than 15 mm or the distance specified.

19. Girder Lowering & Bearing Installation Works

The launching of Bogibeel Bridge superstructure is being done by Incremental Launching method in which 10 girders are joined together by temporary connection boxes and pulled by help of Freyssinet jacks installed at every 10th pier. After completion of launching, the temporary connection boxes are cut to separate the individual girders for lowering to its final level. The bearings are placed on the anchor plates which are already installed on the pedestals.

The bearings shall be affixed to the girder by means of wedge plates which shall be welded to the girder. The wedge plates have machined surfaces to ensure full contact with the girder and bearing top plate. The bottom of the girder, however, is not a machined surface. This is because machining of the girder's bottom surface after assembly/ launching is a difficult task owing to the lack of space and the difficult position on the pier. Machining of the girder bottom surface before component fabrication is also not advisable because there are distortions in the plate due to welding which will render the surface unsuitable for transfer of contact loads.

This called for an alternate solution for ensuring load transfer from the girder to the wedge plates. Contractor proposed use of DIAMANT Metallplastic grout which is a gap compensating material used in bridges and other civil engineering structures. The material known as MM1018 is a 2-component epoxy based reactive-resin-system grout used for filling up unevenness/ roughness between metal elements. The material is available in paste form (MM1018P) and fluid form (MM1018FL). The material has national technical approval from the German Approval Body (DIBt) and has been extensively used in various structures across Europe including Railway bridges and structures.

The use of the material was accepted by Railways after detailed discussion of various aspects with the Designer. The main aspect

that was considered was the stage at which the grout will be applied which will have a bearing on the weld design of the connection between the wedge plate and the girder. For spherical bearings of Bogibeel Bridge, modification of connection between the wedge plate and girder bottom was done due to the use of this material. Additional plate (profile plate) was introduced which will act as an interface between the girder bottom and the wedge plate as shown in the Fig-5. The welding of the profile plate shall be carried out by qualified welder and shall be done in such a manner as to reduce the effect of weld shrinkage and distortion.

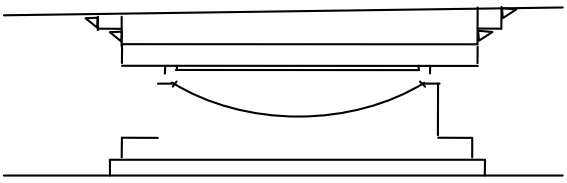

Fig. 5- Sketch showing the arrangement for wedge plate fixing

20. Inspection During Installation

The spherical bearings will be installed under the specialised supervision of the manufacturer (incorporated in the item of contract) because the manufacturer shall provide guarantee of 20 years for the bearings.

During the fixing of the bearings, the girder will be aligned by help of jacks. The levels of four corners shall be maintained at the same level by level instrument and the alignment shall be controlled by use of Total station instrument. For alignment of the girders, they will be supported on lifting jacks with sliding pads fitted with PTFE sheets which will allow smooth movement of the girder.

After fixing of the bearings, final line, levels and camber of the girder shall be checked and recorded. Gauge for measurement of girder movement shall be set to zero after installation.

21. Documentation

All test certificates of raw materials used in the manufacture of the

bearings shall be documented. The inspections carried out during the process of manufacturing of the bearings shall also be recorded. Reports of inspections carried out during and after installation of the bearings shall also form part of Spherical bearing documentation.

22. Cost Comparison & Conclusion

The cost comparison between Pot-PTFE bearings and Spherical bearings is shown in the table below. The costs are calculated based

Total cost of Spherical bearings with Price Escalation = Rs. 18,45,56,599 on the rates provided in the contract for Bogibeel Bridge superstructure.

It can be seen that there is only a marginal cost difference between the two types of bearings. Considering the additional life of spherical bearings and the technical superiority the bearing offers, it is greatly beneficial to use spherical bearings for Railway bridges. With the use of the first spherical bearings on Railway bridges in the New Jubilee Bridge and Bogibeel Bridge, it can be concluded that spherical bearings will become the most preferred choice of bearing on Indian Railways.

Type of Bearing	Cost of one bearing (Rs.)					Total cost in Rs. (w/o escalation)
	POS 1	POS 2	POS 3	POS 4	POS 5	
Pot-PTFE bearing	5,74,425	5,74,425	-	-	-	**13,29,33,600**
Metallic bearings	-	-	4,16,250	5,66,100	5,66,100	
Spherical bearings	10,88,168	9,21,678	13,07,059	5,40,274	-	**18,16,08,827**
Total cost of Pot-PTFE cum Metallic bearings with Price Escalation = Rs. 18,36,26,499 **Total cost of Spherical bearings with Price Escalation = Rs. 18,45,56,599**						