IABSE-JSCE Joint Conference on Advances in Bridge Engineering-III, August 21-22, 2015, Dhaka, Bangladesh. ISBN: 978-984-33-9313-5
Amin, Okui, Bhuiyan, Ueda (eds.) www.iabse-bd.org

Cylindrical bearings as a superior option for railway bridges in the subcontinent

G. Moor
Mageba USA, New York, USA

C. Ghosh & K. Gupta
Mageba India, Kolkata, India

ABSTRACT: Although long been outdated in other parts of world, metallic bearings of roller-rocker type have still found application in railway structures in the subcontinent, primarily from the inclination of adhering to an orthodox solution. Cylindrical bearing is a modern bearing system which provides appropriate technical solution for railway spans of conventional open web girders. This paper will discuss in detail the working principle of the Cylindrical bearing system and its suitability of application under railway spans, both new and old, with a couple of case studies.

1 INTRODUCTION

Traditionally metallic roller-rocker bearings have been used under open web steel spans of railway bridges in the Indian subcontinent. As the length of bridge spans increases, so do the demands on the bearings for accommodating greater movements and rotations, for resisting larger horizontal forces and perhaps being subjected to more severe vibrations, dynamic loading or uplift forces. Meeting such demand with conventional roller-rocker bearing poses a difficult challenge as the solution becomes unnecessarily cumbersome with inefficient use of steel and involves extensive maintenance throughout its service life.

2 DEVELOPMENT OF RAILWAY BEARINGS

Railways operation in the Indian subcontinent started in 1853 and gradually became an integral part of the region with the present networks encompassing a population well over a billion. The railway played a pivotal role in the development of the subcontinent changing the way in which people and cargo were transported across the vast expanse. The region is criss-crossed with numerous major and minor rivers, necessitating construction of thousands of bridges from early on. Railway engineers of the British Raj soon felt the necessity to standardize the railway spans aimed at rapid and efficient construction. Thus spans ranging from 40ft (12.2m) to 250ft (76.2m) got standardized with uniform deign and details including the support bearing systems.

2.1 *Roller-Rocker Bearings*

Metallic rocker and roller-cum-rocker bearings, adopted mostly for the larger (100ft i.e. 30.5m and above) standard spans, have been installed in thousands of bridges since pre-independence India and are still being used in large numbers. While roller-rocker bearings system can allow longitudinal movements and rotations about the transverse axis, they are quite unsuitable for other movements/rotations that often arise in modern day long-span bridges. Moreover, these types of bearings work on metal to metal line contacts causing a lot of wear and tear and also stress concentration on the adjacent structure. The working (i.e. moving/rotating) parts of these bearings are exposed steel surfaces which are highly prone to corrosion and thus huge maintenance is required during its service life. In addition, the movement of rollers induces eccentricity on the pier and substructure, requiring more steel and concrete to build them. Point of action of horizontal force is also quite high compared to other modern bearing systems which results in high flexural stress on the adjacent structure. Lastly due to inefficient use of huge quantity steel these bearings are quite expensive. Roller-Rocker type bearing system thus has long become obsolete throughout the world due to its several disadvantages.

2.2 *Pot Bearings*

Since its inception in the 1960s, Pot bearings became extremely successful in road bridges as engineers found it ideally suited to implement different degrees of freedom and restraint envisaged in the analysis of the structure. In fact the versatility of the Pot bearings ushered in a whole range of new opportunities to experiment with the architecture and design of the structure which were not possible to conceive earlier. Thousands of road bridges around the world, with varying sizes, types and complexities got equipped with Pot bearings over last 5 decades.

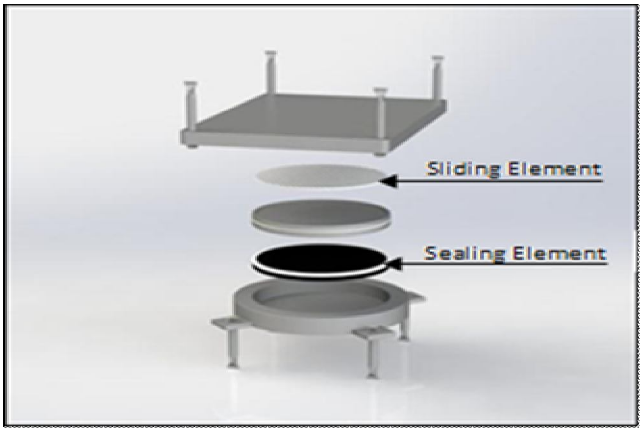

Figure 1. Components of a Pot bearing with the weakest parts labelled.

Inspired by the success of Pot bearings in the road bridges, attempts were made to introduce it in railway bridges as well. However it was soon realised that for application in Railway Bridges, particularly those with steel superstructures having a disproportionate ratio of dead load and design load, Pot bearing is not the ideal candidate. Bearings in such bridges experience very large accumulated movements, cyclical rotation and dynamic loading, which might cause wearing of the weaker components viz. sliding element and sealing element of the elastomeric pressure pads.The above concerns have led the 'American Railway Engineering and Maintenance-of-Way Association (AREMA)' to restrict the use of Pot bearings. Many countries in Europe also discourage Pot bearings from general use in railway bridges.

2.3 *Spherical Bearings*

Engineers were in search of an alternate solution to overcome the durability issues of Pot bearings. One of the primary factors determining the service life of a Pot bearings is the effectiveness of the sealing material for elastomeric pressure pads, which have been found particularly unsuitable for railway bridges. Although the issue has been partly addressed with the introduction POM sealing chain, which being integrally moulded with the elastomeric pressure pad nearly doubles the expected service life of the bearing over those fitted with metallic brass seals, the sealing element, irrespective of its type, still remains a critical part of the pot bearing.

Figure 2. Components of a Spherical Bearings - without any requirement of sealing element.

In the case of the spherical bearing, the rotation is allowed by a hard-chromed steel spherical calotte that slides on top of a matching concave lower element fitted with sliding element. Rotation in a spherical bearing are taken through sliding between components without involvement of any elastomeric pad and thus avoids any sealing issues as in Pot bearing.

3 SPECIFIC PROBLEM WITH OPEN WEB GIRDERS

In addition to the general concerns about use of Pot bearings in railway bridges described above, there is a specific problem when Pot or Spherical bearing is used under standard open web steel truss bridges, quite common in the subcontinent. These structures usually have bottom chords consisting of two parallel webs, at a distance apart, with a thin gusset plate connecting them at the bottom with the cross-girder and the bearings are placed underneath. Bottom chord design is done considering it only as an axially loaded member and localised bending is not considered.

In their book 'Structural Bearings' Dr-Ing Helmut Eggert and Dipl-Ing Wolfgang Kauschke clearly express their view - "A bearing will only work properly if the connected parts of the structure are rigid enough. This is usually no problem for massive parts, but in steel superstructures an increased level of stiffness in the bottom girder above the bearings may become necessary."

In absence of any additional stiffening at the bearing seating of bottom chords of a typical standard open web steel bridge, the parallel webs impart two lines of load over the top plate of the bearing. This loading pattern is not a problem for the roller-rocker bearing, as the entire load transfer takes place from the two bottom chord webs through all bearing components to the substructure below and the entire path is fully supported.

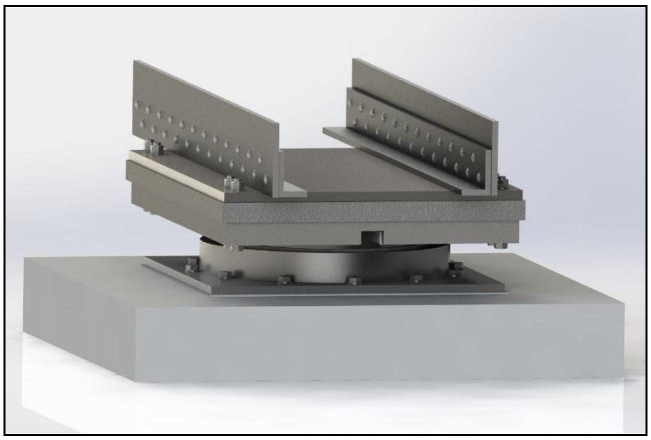

Figure 3. Placement of a Pot bearing under the bottom chord of a typical steel open web girder

However, Pot or Spherical bearings are designed assuming the structure adjacent to the bearing, to which reaction is transferred, would behave like a rigid plane. Absence of adequate stiffening of the bottom chord at the bearing seating will result in localised line contacts at two sides of the bearing top plate, while the reactive force from the elastomeric pressure pad below, akin to fluid pressure, is planar and near-uniform in nature.

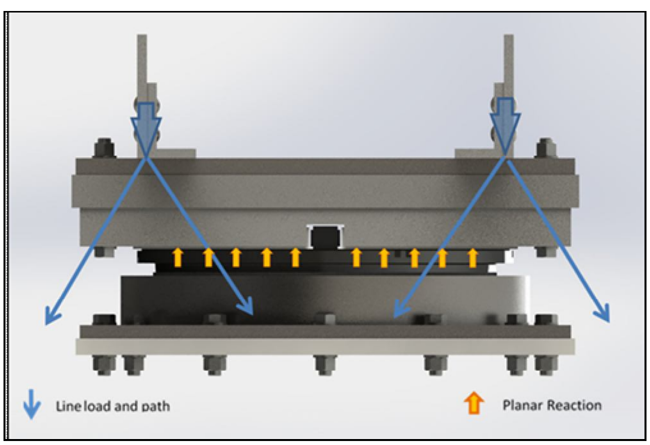

Figure 4. Line loads from the webs of an unstiffened bottom chord and planar reaction from elastomeric pressure pad

This nature of load transfer through line contact at two sides on top and near-uniform, planar and centric reaction at bottom, as depicted in figure 4, will result in hogging of the top plate in the transverse direction. Such phenomena has been observed in several steel truss bridges where Pot bearings have been used without due consideration of strengthening the bearing seating.

4 SOLUTION USING CYLINDRICAL BEARINGS WITH HIGH PERFORMANCE SLIDING MATERIAL

Cylindrical Bearings, with high performance sliding element, addresses the issues described above. The principle of load transfer from unstiffened girders remains more or less similar as that of the roller-rocker bearing system and at the same time it provides extended service life and little requirement of maintenance due to absence of any weaker components viz. PTFE or elastomeric pad as are present in Pot bearing. The specific advantages of the cylindrical bearings with advanced sliding interface for open web steel truss railway bridges are listed below.

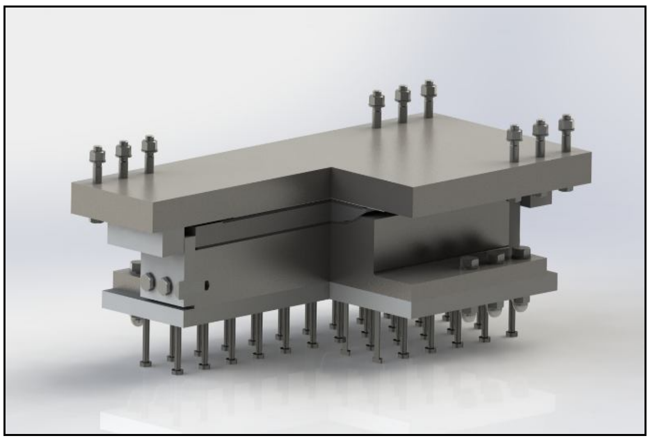

Figure 5. Isometric 3D-sectional view of a Cylindrical Bearing showing internal components

4.1 *Compatibility with Open Web Girders*

Cylindrical bearing, in contrast to Pot bearings, is suitable to sort out the problem of open web through girders with unstiffened bottom chord as it provides adequate dimensions of all components across the girder to disperse the line loading from the bottom chord webs.

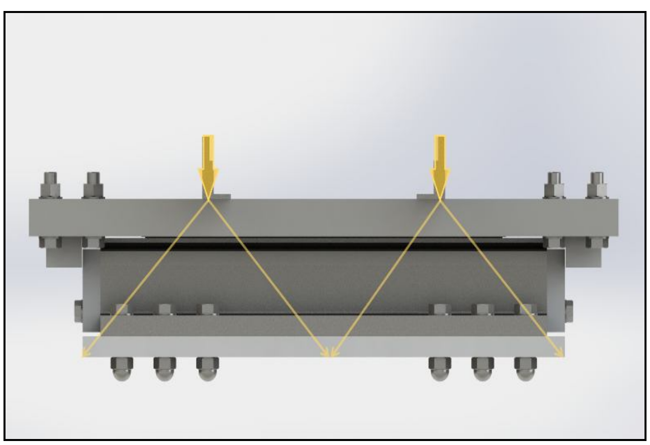

Figure 6. Line loads from the webs of an unstiffened bottom chord passes through all components of a Cylindrical Bearing

The load dispersion path looks remarkably similar to that of roller-rocker bearings; the entire load transfer path from the bottom chord webs through all the bearing components to the substructure below is fully supported, unlike Pot/Spherical bearings.

While cylindrical bearing is capable to cope with line load like roller-rocker bearings by virtue of its geometry, the sliding interface has to be equipped with specially developed high performance and approved sliding material having high bearing capacity. Since line load application points are very close to the sliding interface, there would be high localised stress concentration on the sliding material and the material generally used in Pot bearing i.e. PTFE would be inadequate for such high level of localised stress concentration.

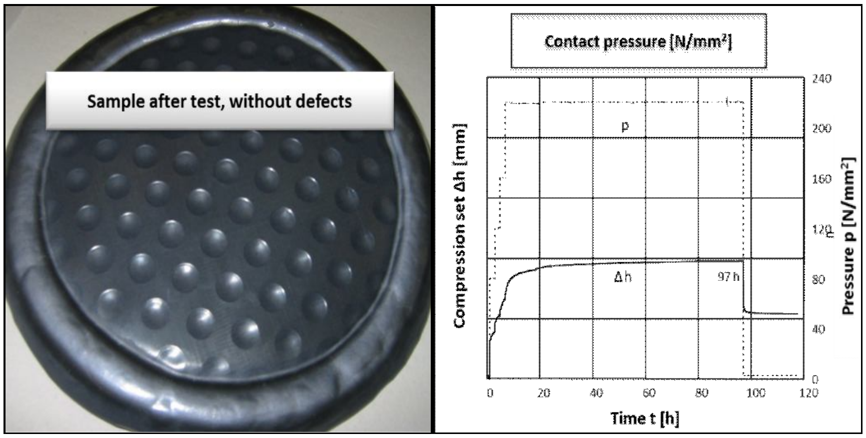

Figure 7. Special sliding material has very high resistance to pressure Characteristic load capacity of 180 N/mm2 – double that of PTFE.

4.2 *Enhanced Life*

Specially developed and approved sliding material, made of Ultra High Molecular Weight Polyethylene, should also have low frictional properties for very large accumulative movements, rotation and dynamic loading. PTFE is inadequate for high abrasion resistance, whereas the special sliding material demonstrates reduced abrasion and thereby almost no wear and tear, ensuring maintenance free operational life of more than 50 years.

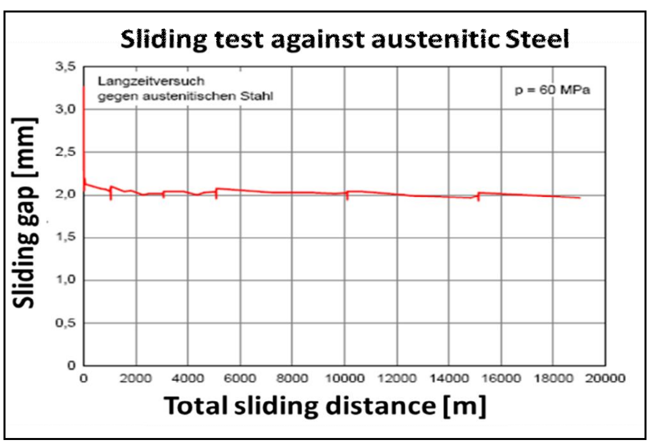

Figure 8. Special Sliding Material is highly durable and abrasion resistant material. Virtually no abrasion after sliding distance of 50 km where PTFE shows significant loss after just 10 km.

The lower friction values of the Special Sliding Material are even more pronounced when it is considered that it is designed to be used at double the pressure of PTFE, due to its higher compressive strength. In the example shown, the friction value of Special Sliding Material at 60 N/mm2 is nearly 50% less than that of the value of PTFE at its corresponding pressure of 30N/mm2.

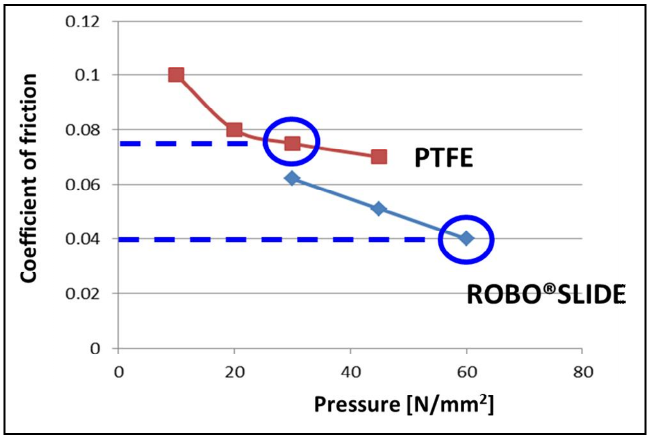

Figure 9. Comparison of friction coefficients of PTFE and Special Sliding Material, at -35°C and after 20 km of sliding

4.3 *Special Protection of Rotating Interface*

The Convex upper element (calotte) of the Cylindrical bearing has a polished hard chrome surface of minimum thickness 100 micron to provide a smooth rotating interface as well as to protect the working surface from corrosion. The hard chromium plating process shall comply with the requirements of EN1337.

4.4 *Corrosion Protection of Exposed Steel Parts*

All exposed steel parts of bearings are protected against corrosion by designed paint system. The protective coating has Environmental Classification C4 with Expected durability H (high i.e. > 15 years) according to ISO 12944-5:1998 or even higher, depending the degree of severity of exposure.

4.5 *Protection from Dust/Debris*

By basic design concept, the working parts (i.e. moving/rotating parts) of a cylindrical bearing are well protected, preventing contamination by dirt/debris for smooth functioning. Additional features like dust-skirt all around the cylindrical bearings also contributes towards enhancement of life of the bearings.

4.6 *Safer Substructure*

In case of Roller-Rocker bearings the movement of the span is accommodated by ‘rolling displacement’ of the rollers which always produced an eccentricity on the pier and substructure as the load transfer points shifts. Whereas, in case of the cylindrical bearings the bottom part of the bearing connected to the pier remains static and only the top sliding plate moves, thus the load transfer point remains unchanged and no eccentricity is generated with respect to the substructure. As such the design of the pier and substructure can take advantage of such reduced eccentricity, i.e. reduced moment. Moreover the metal to metal line contact in case of Roller-Rocker bearings causes stress concentration on the adjacent structure, whereas cylindrical bearings with plane sliding interface ensures better stress distribution. In case the pier/substructure has already been designed/constructed considering metallic roller-rocker bearings, e.g. for a rehabilitation project, the application of Cylindrical bearings will ensure safer substructure.

4.7 *Easier Installation*

In case of Roller-Rocker bearings the anchoring is generally done by means pf holding down pins/ bolts which are quite long and sometime infringe into the pier cap. The problem gets aggravated for higher horizontal force. For cylindrical bearings the installation becomes much easier due to use of anchor plates with shear studs, which are contained within the pedestal.

5 CASE STUDIES OF USING CYLINDRICAL BEARINGS WITH HIGH PERFORMANCE SLIDING MATERIAL

Cylindrical bearings are being used successfully in railway projects in the Indian subcontinent in both old and new bridges. Here we present two case studies one each for a rehabilitation project and a new project under construction.

5.1 *Case Study 1: Bridge No. 20 (Revised Br. No. 186) across Jhajjar Khad, India*

The bridge across Jhajjar Khad on the Jammu-Udhampur rail link corridor under India's Northern Railway division has the largest simply supported through type open web steel girder span (2x150m) and the tallest pier on Indian Railways so far. The bridge was supposed to get opened to traffic in 2013 but had to be postponed after inspection of the bridge bearings which revealed a problem.

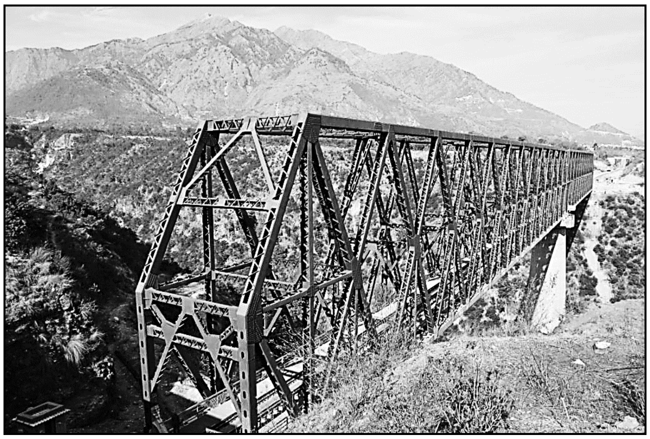

Figure 10. Bridge No. 20 at a height of 85 metres, Asia's tallest steel railway bridge

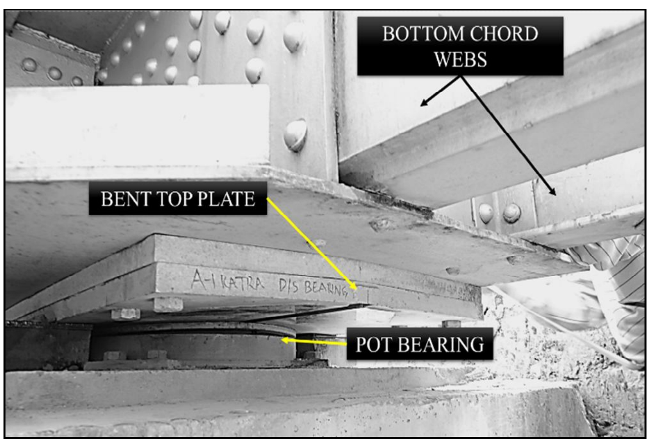

Figure 11. Photograph of bent top plate of a Pot bearing placed under unstiffened girder

The spans were supported on Pot bearings at both Pier and abutments. However, adequate stiffening of the girder at the bearing location, absolutely necessary for proper load transfer to the Pot bearings as explained above, was missing, which resulted in bending of the bearing top plate. From some quarters it was suggested to insert an additional plate in-between the girder bottom chord and the bearing top plate, which however, would not have addressed the basic issue i.e. the absence of a rigid plane for load transfer. On the other hand carrying out in-situ stiffening of the bottom chord at the bearing location was not practically possible.

Finally an innovative solution was introduced to address the issue. The existing Pot bearings at both Pier and abutments were replaced with Cylindrical bearings and this happened to be the most suited option for such application. The height of the replacement bearings were a little higher than that of the existing ones, which required slight raising of the bridge and the Railway Authority pragmatically agreed to match the gradient of the rails in spite of a tunnel ahead. Total 8 nos. Cylindrical bearings equipped with high performance sliding interface and 2 nos. Metallic Pin bearings were installed replacing the existing bearings. After successful installation, the bridge was subsequently opened to traffic in 2014 all the bearings are performing satisfactorily.

5.2 *Case Study 2: 2nd Bhairab Railway Bridge over river Meghna, Bangladesh*

Second railway bridge at Bhairab over the Meghna River, which will establish link between Kishoreganj and Brahmanbaria districts, covering a stretch of 982.2 m, consists of 9 nos. span of 102.40 m each and 3 nos. span of 20.2 m each. The spans with length of 102.4 m are open web through type steel truss and the smaller spans of 20.2 m are composite girders.

In the original design Roller- Rocker or Pot bearing system was proposed for the bridge. The arrangement was subsequently changed with Cylindrical Bearings for the longer spans of 102.4 m and Spherical Bearings for shorter spans of 20.2 m in view of the several advantages those would bring in.

One of the primary reasons of selecting Cylindrical Bearings for the open web girders over any other modern bearing system was to keep the compatibility of the structure vis-à-vis the bearing system. The structure originally designed with Roller-Rocker bearings had rotational freedom only about transverse axis of the bridge and no rotation was considered about the longitudinal axis; that remains unchanged in case of Cylindrical bearings. For any other types, viz. Pot/Spherical bearings which allow rotation about all axes the same would not have been true.

In the original design, the entire longitudinal horizontal force had to be taken by the Rocker Bearings and movement in longitudinal direction was allowed at the roller end. The transverse forces were however could be shared by bearings at both end of the spans. The same load sharing arrangement and degrees of freedom and restraint could be provided by fixed Cylindrical bearings in place of Rocker bearings and Longitudinally Guided Sliding Cylindrical bearings in place of the Roller-cum-Rocker bearings. Thus the basic philosophy of the structural design remains unaffected due to the change in the bearing system.

6 CONCLUSIONS

Cylindrical Bearings, equipped with advanced sliding material, can offer optimal solution in many situations. Use of the bearing system could be particularly advantageous in construction of new bridges with open web through type trusses as well as in rehabilitation of numerous such bridges, supported on roller-rocker bearings, constructed earlier in the Indian subcontinent. For open web steel truss bridges the bearing system would retain the principle of existing idealization of structure and would have the closest resemblance to the anticipated roller-rocker bearing system, while ensuring maintenance free service life for more than 50 years.

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