ज्ञान ज्योति से मार्गदर्शन

BRIDGE BEARINGS

March 2006

(Corrected & Reprinted January 2014)

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING
PUNE 411001

Bridge Bearings

March 2006
(Corrected & Reprinted : January 2014)

PREFACE TO THE SECOND EDITION

The book 'Bearings for Railway Bridges' was first published in 1996. The book had been well taken by the field engineers as this was perhaps the first book exclusively devoted on bridge bearings.

A need was felt to revise the book thoroughly in view of the fact that numerous developments have taken place in the field of bearings. New types of bearings are being conceived and tried on the bridges. These are aimed at mitigating the problems arising out of increased seismic activities and longitudinal forces. On existing bridges, these types of bearings have proved to be a boon because the substructure can be retained merely by replacing the conventional bearings with these new bearings in order to cater for the higher longitudinal forces on account of introduction of higher axle loads.

A revised & enlarged edition of the book has been compiled by Shri Ghansham Bansal, Professor/Bridges. A new chapter on 'Emerging trends in bearings' has been added which incorporates the new types of bearings which are being used in advanced countries. Sample design problems have been incorporated in the chapters of 'Elastomeric Bearings' & 'POT-PTFE Bearings' for better understanding of the subject.

Although every effort has been made to bring out the latest and present the book in error free manner, yet if there is any suggestion or discrepancy, kindly do write to us.

Shiv Kumar
Director

ACKNOWLEDGEMENTS TO THE SECOND EDITION

The first edition of the book 'Bearings for Railway Bridges' published in 1996 was very popular among the field engineers probably because this was the first book available exclusively on bearings for railway bridges. Shri S.M. Vaidya, Ex. Professor/Bridges, IRICEN had made great efforts in publishing the first edition. Nevertheless, with numerous developments taking place in this field, there was a crying need to bring out the latest on the subject.

In this second enlarged and revised edition, a new chapter on 'Emerging trends in bearings' has been added to incorporate the new types of bearings. In addition to this, design of POT-PTFE bearings has been dealt in greater detail with one sample design problem for better understanding. Likewise, one sample design problem has also been included for Elastomeric bearings. The critical steps have been explained with the help of sketches and derivation of formulae.

Many a times, due to increased longitudinal loads on account of traffic as well as seismic activities, the bridge substructures constructed in the past with conventional bearings are found to be inadequate. New types of bearings like 'Shock Transmission Units' and 'Seismic Isolation Bearings' have come to the rescue of bridge engineers and the same old substructures, thus, can be retained by provision of these new bearings.

Efforts have been made to make the book more useful for the field as well as the design engineers. In this effort, the IRICEN faculty and staff have contributed immensely, notably among them are Mrs. Lata Sridhar, Mr. Ganesh and Mr. Sunil Pophale. In fact, Shri Ajit Pandit, Ex. Dean/IRICEN had initiated the idea of updating this book, which was taken to its logical end. I am also thankful to Shri A.K. Yadav, Senior Professor Bridges for proof-checking and valuable suggestions.

Above all, the author is grateful to Shri Shiv Kumar, Director/ IRICEN for his initiative, encouragement and necessary guidance for the publication.

Ghansham Bansal
Professor Bridges

ACKNOWLEDGEMENTS TO THE FIRST EDITION

While covering the subject of Bridge Bearings during various courses at IRICEN the absence of a document covering all aspects of different types of bridge bearings was acutely felt. Information on bridge bearings is available in various technical literatures but it is scattered.

This IRICEN publication is a result of the desire to fill the gap and produce a documentation which would be useful for all practicing civil engineers on Indian Railways. Even though the publication is primarily aimed at Railway engineers, the basic concepts are equally applicable to road bridges also.

It would not be out of place to acknowledge the support and assistance rendered by IRICEN faculty and staff in the above efforts. Shri N.L. Nadgouda, Associate Professor has contributed immensely by his experience of handling steel bridges. Word processing of the manuscript and numerous editings thereof has been done by Mrs. Lata Sridhar. The drawing staff of IRICEN have assisted in preparation of the drawings.

Above all the author is greatful to Shri Vinod Kumar, Director IRICEN for his encouragement and guidance for improving the document.

S.M. VAIDYA
PROF. BRIDGES 1

FOREWORD TO THE FIRST EDITION

The subject of bridge bearing is of considerable importance to the field engineers who are engaged in construction and maintenance of railway bridges. Trainee officers have often expressed the need for a comprehensive documentation on this subject. It is hoped that this booklet will fulfil this need and disseminate the knowledge and experience on this subject to the field officials.

This book has been prepared by **Professor S.M. Vaidya** of this Institute. If there are any suggestions for improving the book or if any error/discrepancy is noticed in its contents, kindly write to the undersigned.

Vinod Kumar
Director
IRICEN/Pune

PREFACE TO THE FIRST EDITION

Indian Railways are custodians of one of the largest bridge stock under one management with more than 1,15,000 bridges on the rail network. It is important to construct new bridges with highest standard of quality and to maintain them for smooth movement of railway traffic. Bridge bearings play a very important role in keeping the bridge structure in good health. Tradionally, Indian Railways have been using steel girder bridges and steel bearings. With the advent of new technology, RCC and PSC bridges along with elastomeric and PTFE bearings are gradually replacing steel bridges and conventional bearings.

The bridge engineers require a comprehensive document dealing with all facets of bridge bearings to facilitate procurement, installation and maintenance of the same. I am glad that IRICEN is bringing out this book exclusively dealing with bridge bearings. I hope that this publication will be very useful to all civil engineers with the objective of maintaining the bridges in good condition.

V. K. AGNIHOTRI
MEMBER ENGINEERING
RAILWAY BOARD
NEW DELHI

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
BM	Bending Movement
BS	British Standard
BSC	Bridge Standards Committee
CDA	Coefficient of Dynamic Augment
DL	Dead Load
EUDL	Equivalent Uniformly Distributed Load
HMLS	Heavy Mineral Loading Standards
IIBE	Indian Institute of Bridge Engineers
IRC	Indian Road Congress
IRHD	International Rubber Hardness Degrees
IRS	Indian Railways Specification
IS	Indian Standards
KN	Kilo Newton
LF	Longitudinal Force
LL	Live Load
LUD	Lock Up Device
LWR	Long Welded Rail
MBG	Modified Broad Gauge
MPa	Mega Pascal
MS	Mild Steel
ORE	Office of Research and Experimentation
PSC	Pre-stressed Concrete
PTFE	Poly Tetra Fluoro Ethylene
RBG	Revised Broad Gauge
RCC	Reinforced Cement Concrete
RDSO	Research Design and Standards Organisation
SEJ	Switch Expansion Joint

SIB	Seismic Isolation Bearing
STU	Shock Transmission Unit
UIC	International Union of Railways (Translated from French)

LIST OF SYMBOLS

ζ_α = Shear stress in elastomer due to rotation

ζ_h = Shear stress in elastomer due to horizontal force

ζ_p = Shear stress in elastomer due to compressive force

σ_b = Permissible bearing pressure in Bed block material

σ_m = Max. Permissible pressure in elastomer

σ_s = Permissible tensile stress in the steel plate

σ_{min} = Minimum stress in elastomer

σ_{max} = Maximum stress in elastomer

α_c = Rotation under effect of slow acting loads

α_s = Rotation under effect of quick acting loads

a = length of the bearing along the span

b = width of the bearing across the span

B = width of the girder/beam

E_a = Modulus of elasticity of elastomer

e_i = Compression of elastomeric layer

f_{ck} = Grade of concrete

G = Shear modulus of elastomer

H_c = Slowly applied horizontal load

H_s = Quickly applied horizontal load

n = number of layers of elastomer

P_c = Slowly applied normal (vertical) load

P_s = Quickly applied normal (vertical) load

S = Shape factor of elastomer

h_i = thickness of each layer of elastomer

h = Total thickness of elastomer

t_s = Thickness of steel plate in the elastomeric bearing

U_c = Horizontal movement due to slow acting load

U_s = Horizontal movement due to quick acting load

$D_{1,}$ D_2 = Diameter of contact surfaces in roller bearings

CHAPTER 1

GENERAL

1.1 INTRODUCTION

A bridge is assumed to be made up of two major parts namely, superstructure and substructure. Superstructure consists of track structure, girder/ truss and bearing. Substructure consists of bed block, pier or abutment and foundation as shown in **Fig. 1.1.**

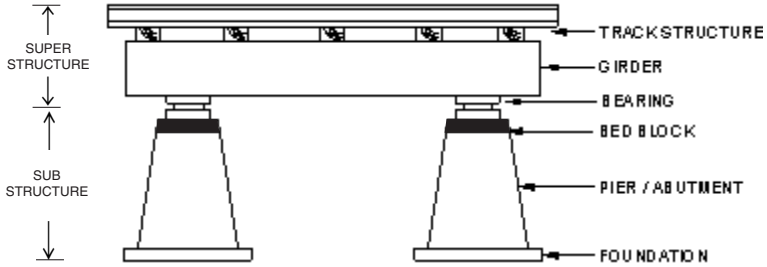


FIG. 1.1 PARTS OF BRIDGE

Thus, a bridge bearing is an element of superstructure which provides an interface between the superstructure and substructure. This interface is vital because superstructure undergoes dimensional changes and deformations due to various factors which are listed as follows:

a) Thermal expansion/contraction
b) Elastic deformation under live load
c) Seismic forces
d) Creep and shrinkage of concrete
e) Settlement of supports
f) Longitudinal forces - tractive/ breaking
g) Wind loads.

Most of these movements are bi-directional but some, like creep of concrete may result in irreversible unidirectional movement. The magnitude of these movements depends upon a number of factors like span of the bridge, magnitude of loads, extent of temperature variation etc.

If the movement between the superstructure and substructure are not allowed to take place freely, large amount of forces may develop in the girder or the substructure. If the ability to move is not built into the bridge (span), it will push the supports until it achieves the freedom required and in the process causing damage to the supports. It is, therefore, necessary to permit relative movement between the girders and the substructure.

Since the bearing is introduced between superstructure and substructure for accommodating the various permitted movements, it has to transfer the entire load from superstructure to the substructure of bridge. We can say that 'Bearings' assume the functionality of a bridge by allowing translation and rotation to occur while supporting the vertical loads. In

nutshell, the various functions of bearings can be summarised as given below:

(1) To allow the permitted' movements. (longitudinal & rotational)
(2) To prevent the 'not permitted' undesirable movements.
(3) To transfer the load from superstructure to substructure.

The 'permitted' and 'not permitted' movements in the bridge in relation to bearing can be better appreciated if we analyse the degree of freedom in 3-D as shown in **Fig. 1.2.**

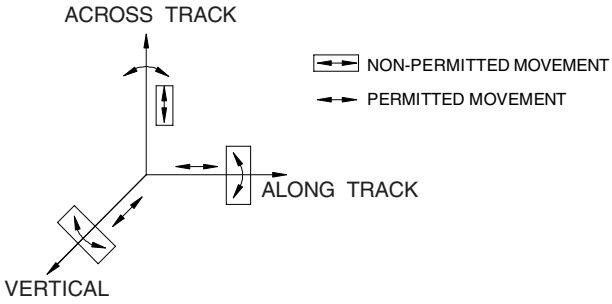


FIG. 1.2 DEGREE OF FREEDOM IN 3-D

In the era of stone and brick masonry bridges, the spans were limited and the superstructures used to be massive, primarily developing only compressive stresses under the loading conditions. Such bridges did not need special bearings since the movements were very small.

With the advent of steel, RCC and PSC for construction of bridges, the spans became large and the girders longer. The longer spans coupled with higher elastic deformations led to the need for and development of various forms of bridge bearings.

1.2 CLASSIFICATION OF BEARINGS

Bearings can be classified depending upon

a) Degree of freedom

b) Material used

These are discussed below.

1.2.1 *Degree of freedom :* There are possible 6 degrees of freedom at any support as described earlier. These are translation in three directions and rotation about these three axes. A bearing may permit movement in any of these 6 degrees of freedom or in none. During the structural design of the bridge girders, each support point is idealised in a specific manner by the design engineer. The bearing has to fulfill this assumption.

Translation can be permitted by the following modes of action :

i) by sliding action
ii) by rolling action
iii) by shearing strain
iv) by racker and pinion devices (gears)

Rotation can be permitted by the following modes:

i) by rocking/hinge action
ii) by differential compression (as in elastomeric pads)
iii) by bending/ flexure (as in tall piers, portals)

Therefore based upon degree of freedom requirements, different degree of freedom can be given at the support point and bearings may be classified as:

(1) Fixed (Hinged) - Translation not permitted, Rotation permitted
(2) Free - Translation permitted, Rotation permitted
(3) Rocker & Roller - Roller end free, Rocker end fixed

1.2.2 *Material used :* A number of different materials have been used for making bearings such as steel of various types, phosphor bronze, synthetic material like rubber (elastomer) and PTFE etc. Out of these materials steel, rubber and PTFE are the most commonly used materials, today, for bearings. In certain forms of bearings, a combination of two materials is also used. **Table 1.1** lists various materials used in fabrication and installation of bridge bearings.

TABLE 1.1 MATERIALS USED IN BRIDGE BEARINGS

Material	Components of bearing where material used
1) Steel	a) Plates-MS, HTS, Stainless steel b) Cast and forged products c) Gears d) Anchor bolts, rivets, pins etc.
2) Bronze	a) Sliding plates b) Bushings
3) Synthetic materials	a) Elastomer b) PTFE (Poly Tetra Fluoro Ethylene)
4) Other materials	a) Concrete b) Wood and timber
5) Lubricants	a) Graphite b) Grease, oils and silicones
6) Packing and levelling materials	a) Lead sheets b) Bitumen impregnated felt pads c) Cement / Epoxy grouts

1.2.3 *Types of bearings :* Based upon degree of freedom and types of materials used, the various types of bearings used on bridges are shown in **Fig. 1.3** to **1.13.**

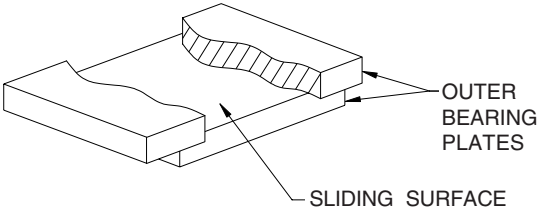


FIG. 1.3 PLAIN SLIDING BEARING

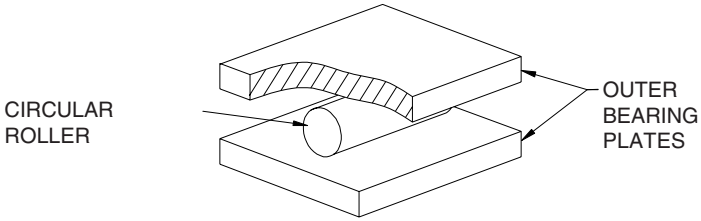


FIG. 1.4 SINGLE ROLLER BEARING

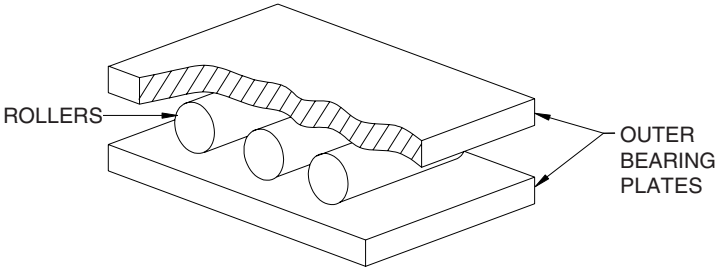


FIG. 1.5 MULTIPLE ROLLER BEARING

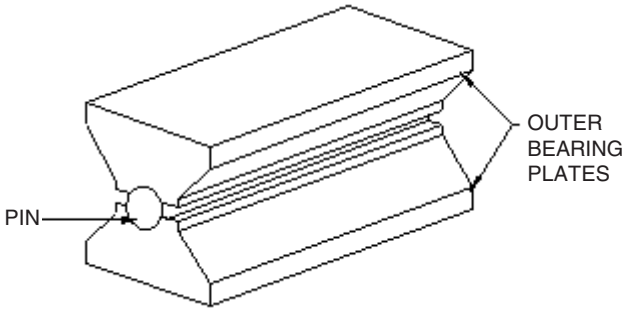


FIG. 1.6 KNUCKLE PIN BEARING

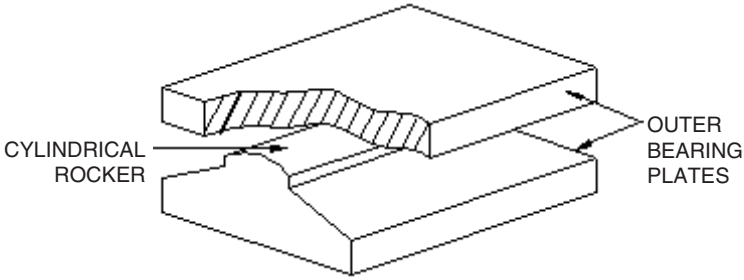


FIG. 1.7 LINEAR ROCKER BEARING

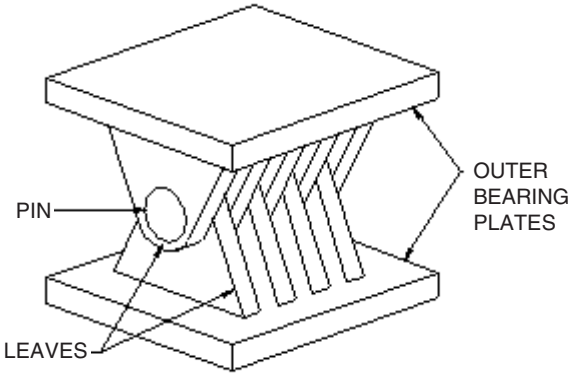


FIG. 1.8 KNUCKLE LEAF BEARING

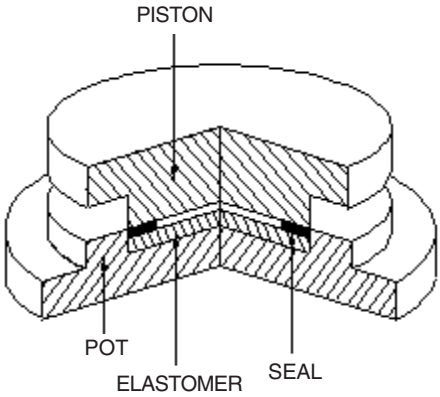


FIG. 1.9 POT BEARING

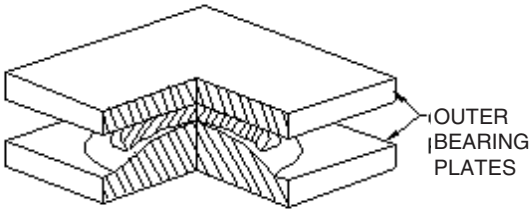


FIG. 1.10 SPHERICAL KNUCKLE BEARING

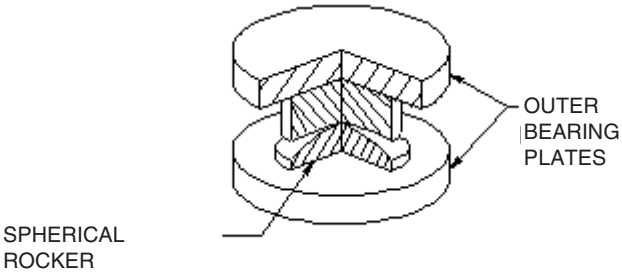


FIG. 1.11 POINT ROCKER BEARING

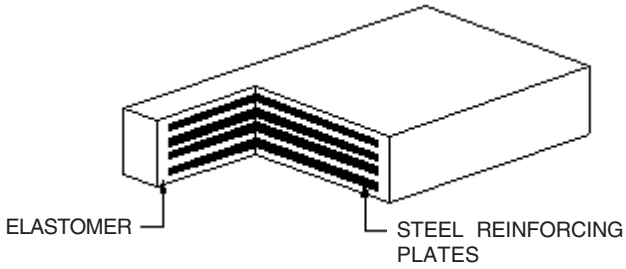


FIG. 1.12 REINFORCED ELASTOMER BEARING

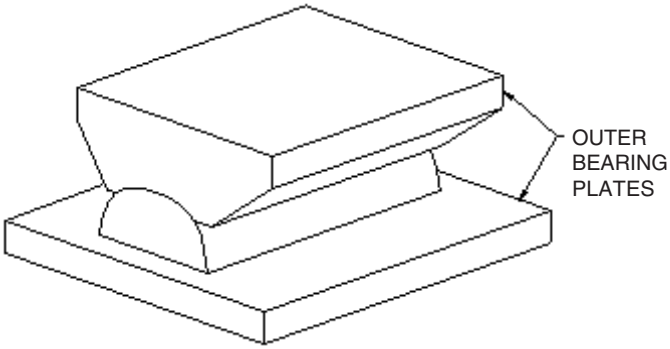


FIG. 1.13 CYLINDRICAL KNUCKLE BEARING

1.3 SELECTION OF BEARINGS

For a given bridge structure there could be a number of different solutions for providing bearings. However, in each case there will be one most appropriate choice of the bearing. The selection will depend on a number of factors. These are listed and discussed below:

1.3.1 *Functional Requirement :* The bearing must fulfill the functional requirement in terms of permitted movements, load bearing and load transmission. The various functions performed by different types of bearings are reproduced in **Table 1.2** from BS: 5400 part-IX. **Table 1.3** may also be referred for selection of bearings as this table gives load ranges and movement capacities of various types of bearings.

1.3.2 *Expected life :* An attempt should be made to select a bearing whose expected life is compatible with that of the bridge itself. Failing this, replacement of the bearing will have to be planned for during the life of the bridge. It should however be acknowledged that any scheme for replacement of bearings will invariably require suspension of traffic, which is very costly and troublesome.

1.3.3 *Maintenance efforts :* The importance of proper functioning of the bearing for the health of bridge can not be overemphasized. In many cases, the bearing is not in a easily accessible position. It is, therefore, preferable to opt for a bearing which requires minimum maintenance effort. Bearings

TABLE 1.2 FUNCTIONS PERFORMED BY DIFFERENT TYPES OF BRIDGE BERAINGS

Type of bearing	Translation permitted		Rotation permitted			Loading resisted		
	Longitudinal	Transverse	Longitudinal[1]	Transverse[2]	Plan	Vertical	Longitudinal	Transverse
Roller								
Single cylindrical	✓	X	✓	X	X	✓	X	S
Multiple cylindrical	✓	X	X	X	X	✓	X	S
Non-cylindrical	✓	X	✓	X	X	✓	X	S
Rocker								
Linear	X	X	✓	X	X	✓	✓	S
Point	X	X	✓	✓	✓	✓	✓	✓
Knuckle								
Pin	X	X	✓	X	X	✓	✓	S
Leaf	X	X	✓	X	X	✓	✓	✓
Cylindrical	X	S	✓	X	X	✓	✓	S
Spherical	X	X	✓	✓	✓	✓	✓	✓
Plane Sliding	✓	✓	X	X	X	✓	✓	S
Elastomeric								
Unreinforced	✓	✓	✓	✓	✓	✓	✓	✓
laminated	✓	✓	✓	✓	✓	✓	✓	✓
Pot	X	X	✓	✓	S	✓	✓	✓
Guide								
Longitudinal	✓	X	✓	S	X	X	X	✓
Transverse	X	✓	S	✓	X	X	✓	X

Key : ✓ suitable
X not suitable
S Special consideration required

Note : 1. Rotation about transverse axis.
2. Rotation about longitudinal axis.

TABLE 1.3 GUIDELINES FOR SELECTION OF BRIDGE BEARINGS

SN	Type of bearing	Vertical load recomended range (KN)	Movement capacity "One Way" (mm)	Rotation in radians	Seismic perfor-mance	Horizontal* force on supports (% of superstructure dead load)	Maintenance requirement	Bearing height approx. range (mm)	Typical application			
									Straight	Curved	Steel	Conc.
1	Steel roller	600 to 2660	100	0.19	Poor	3	Maximum	360 to 660	✓	-	✓	-
2	Steel Sliding	200 to 1330	25	0.08	Poor	15	Maximum	50 to 100	✓	-	✓	-
3	Pot	200 to 17800	No limit	0.04	Good	3 to 5	Minimum	60 to 180	✓	✓	✓	✓
4	Disc	400 to 17800	No limit	0.04	Good	3 to 5	Minimum	60 to 180	✓	✓	✓	✓
5	Spherical	800 to 26700	No limit		Good	5 to 10	Minimum	125 to 250	✓	✓	✓	✓
6	Plain Elastomeric	100 to 450	10	Negligible	Good	3 to 12	None	10 to 209	✓	✓	-	✓
7	Laminated elastomeric	300 to 2200	60	0.025	Good	3 to 12	None	10 to 20	✓	✓	-	✓

with moveable parts require greater maintenance effort as well as those made of steel due to the possibility of corrosion, and consequent freezing of the bearing.

1.3.4. *Cost :* The capital cost includes cost of design, fabrication and installation of bearing. Generally, this will be a fraction of the cost of the bridge. As such, the initial cost alone should not be a consideration in choice of the bearing. Many bearings which had attractive initial cost proved to be a liability later on during maintainance. Therefore, life cycle cost should be the criteria for selection of bearing.

1.3.5 *Other factors :* Factors which may be relevant in our quest for the most suitable bearing are:

a) *Height of the bearing :* This may be critical in case of regirdering works where maintaining existing rail / road level is the main constraint .

b) *Management of horizontal force transferred to the substructure :* This is an important consideration while upgrading the load carrying capacity/gauge conversion works. The bridge rule stipulates that with properly designed elastomeric bearings, the dispersion of the longitudinal forces to the approaches can be increased from 25% to 35%.

c) *Performance under seismic loads :* Sometimes seismic consideration may alter the choice of bearing particularly in zone IV & V.

Having chosen the type of bearing for a given structure, the following guidelines may be followed in order to minimize the life cycle cost.

i) Choose larger size of rollers in rocker & roller bearing, since smaller components are more prone to accumulating dust and moisture. A larger roller will overcome debris more easily than smaller roller. Larger components also facilitate inspection and maintenance.

ii) For the material selected, specify the highest grade of mechanical properties and the strictest tolerance that can be practically attained. Maintenance efforts, thus, can be greatly reduced.

These recommendations only underscore the fact that the initial cost is not a consideration for good bearing design and specification.

1.4 MINIMIZING THE REQUIREMENT OF BEARINGS

Bearings are unavoidable evils. In bridges of very small spans, however, the bearings are not required e.g. in slab bridges. Here, the interface between the slab and the abutment-top or bed block functions as a 'bearing'. The coefficient of friction between concrete and concrete can be taken as 0.50 to 0.60 depending upon the surface condition. Generally speaking, spans shorter than 9 m do not need bearings.

The various ways, which can be used to minimize the number of bearings are given below:

1. Adopt continuous construction through a number of spans. Superstructure is supported on the intermediate piers with one bearing on each pier. Thus the number of bearings on each pier is reduced by one half.

2. On long and tall piers, the bridge movement can be accommodated by flexible piers and thereby using fixed bearings only. The fixed bearings are relatively less problematic as compared to free bearings.

3. The superstructure and substructure can be made monolithic, thus totally eliminating the need for any bearings. In such type of multispan structures, the entire movement is accommodated at the abutments, where bearings capable of providing large movements are required.As per AASHTO specifications, in sliding bearings up to span 50 feet, no provision for deflection of the spans need be made.

Excluding these special cases, all other forms of bridges require bearings. Though bearing is a tiny part of the bridge, both physically as well as costwise, the entire load is transmitted through it. Therefore, great attention must be paid on selection, design, fabrication, installation and maintenance of the bridge bearings.

Theoretically, the bearings can be avoided for any type of bridge, but the design of substructure

will have to be modified to bear the entire loads. This modification will result into high cost of substructure. Therefore, provision of bearings is the economical solution.

A bearing is a negligibly small part of a bridge and unfortunately the attention it receives from the engineers is also negligibly small. In fact, the importance of this small part should have been inversely proportional to its size, as the entire load is transmitted through this tiny component and any mis-behaviour of bearing may lead to catastrofic results both for substructure as well as superstructure. Therefore, selection, fabrication, installation and maintenance of bearings should be on the top of list as far as the bridges are concerned.

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CHAPTER 2

SLIDING BEARINGS

2.1 GENERAL

A system of two plates, one sliding over the other makes one of the simplest type of bearings. These bearings permit translation in longitudinal and transverse directions, unless specifically restrained in any of these directions. No rotation is permitted unless specially provided in the form of articulation and only vertical loads are resisted /transmitted by these bearings.

Common materials that have been used as sliding surfaces and their coefficients of friction are:

a) Mild steel over mild steel - 0.2 to 0.3
b) Mild steel over phosphor bronze - 0.15
c) PTFE over stainless steel - less than 0.08

Generally, plain sliding bearings are provided where span is less than 30 m, because the movement capacity of these bearings is generally small.

2.2 DIFFERENT TYPES OF SLIDING BEARINGS

There has always been an endeavor to reduce the coefficient of friction. The longitudinal force transmitted to substructure depends upon coefficient of friction. In an effort to reduce the

coefficient of friction, different materials have been tried and different types of sliding bearings have been created. These are as given below:

(a) *Steel over steel :* Steel over steel sliding bearings transmit considerable horizontal force to the substructure because coefficient of friction is very large. In addition to the type of material the coefficient of friction also depends upon the condition of the contact surface. Bridge Rules stipulate that the coefficient of friction should be taken as 0.25 for the lubricated steel surface. Entrapment of dirt, debris and corrosion of steel plates can increase the coefficient of friction considerably, and in the limiting case it may cause the bearings to freeze. These bearings, therefore, require periodic cleaning and greasing so that the superstructure is allowed to expand/ contract freely without transmitting excessive longitudinal force to the substructure.

(b) *Steel and phosphor bronze :* Since the coefficient of friction between steel and phosphor bronze is considerably low, it is advantageous to provide these in lieu of steel sliding bearings. Phosphor bronze bearings also require lesser maintenance than steel bearings as no greasing is required. This eliminates the need to jack up the girders for greasing operation. Moreover, use of the grease which attracts dust and sand particles is avoided. Only outside area (other than the contact area) needs to be cleaned.

(c) *Steel and PTFE :* Use of PTFE (Poly Tetra Fluoro Ethylene) more widely known as Teflon

also offers many advantages. The coefficient of friction between PTFE and stainless steel is the lowest between any two materials within the normal temperature range. A peculiar feature of PTFE is that the coefficient of friction reduces as the applied load increases. The value of coefficient of friction at 5 MPa is 0.08 where as at 30 MPa the value reduces to 0.03, which is very close to rolling friction. Thus we are able to achieve near-rolling friction without having to maintain the rolling arrangements. PTFE is also hard, durable and possesses high chemical resistance. It is routinely used in POT bearings where very large translational movements, required for large span bridges can be achieved.

2.3 PARTS

Stopper plates : When both ends of a span are supported on such sliding bearings, the girder may have a tendency to creep under the influence of predominantly unidirectional movement. To prevent the girders from falling off the bearings, stopper plates are provided. These plates are also known as Locking strips

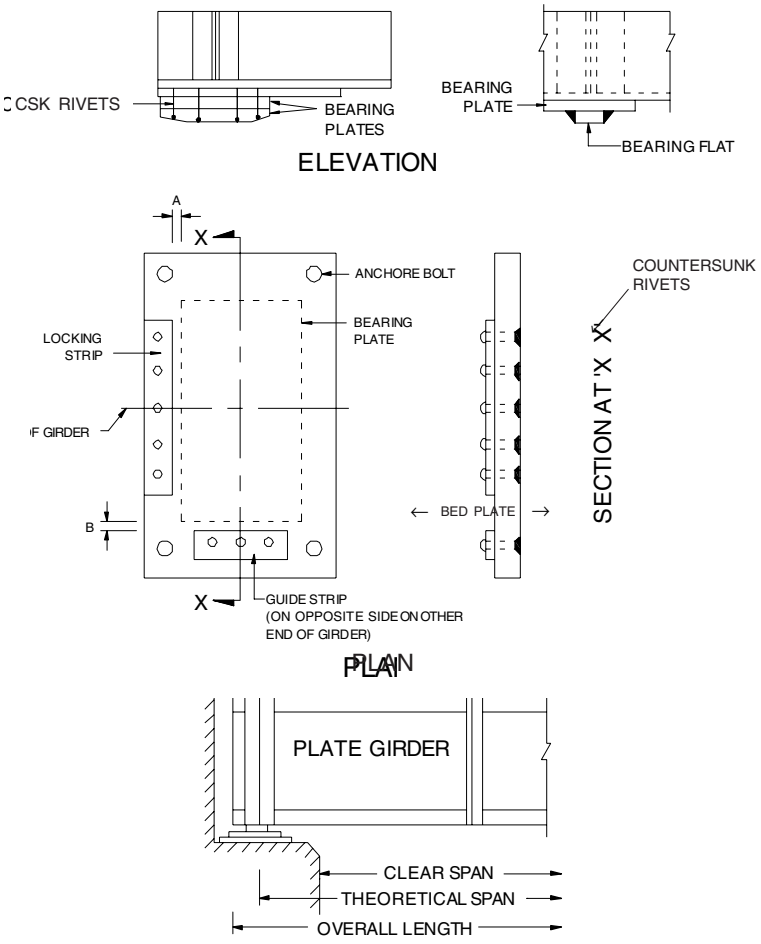
Guide strip : To regulate the movement of the girder in the correct alignment, guide strips are provided parallel to the span.

Size of bearing plate : The size of the bearing plate is governed by the total vertical load (DL + LL + CDA) on the bearing and the allowable bearing stress in the bed block material. The sole plate of the bearing is directly connected to the girder by welding or countersunk rivets / bolts.

The base or bed plate is held in position on the bed block by anchor bolts. Since the sliding bearings do not allow free rotation, unequal distribution of load takes place due to the rotation/ deflection of the girder. This leads to stress concentration under the bearing towards inside of the span. There have been instances of failure of the bed block material due to this deflection. In order to overcome this deficiency, the inside edge of the top plate of the sliding bearing is chamfered. This is commonly known as the centralised articulated bearing. **Fig. 2.1** shows a typical sketch of the standard centralised articulated bearing adopted on Indian Railways, These bearings are used in steel plate girders, composite girders and underslung girders.

On a reference made by RDSO to British Railways it was learnt that the PTFE bearings are in use on British Railways since middle of seventies without any maintenance problems. The British Railways have provided these bearings in through type girder bridges of spans upto 40 m and concrete bridges of various types upto 90 m spans.

Sliding bearings are the simplest type of bearings, used up to 30.5 m span girders. Their regular maintenance is very important, to keep a tab on friction otherwise the value of horizontal force transmitted to sub-structure will increase tremendously. It may so happen that the value of horizontal force becomes so large that cracks may develop at the bottom of bed block. Therefore, the frequency of lubrication has been prescribed as once in three years. It may be increased to once in two years in case track consisting of long welded rails is provided over the bridge.



GENERAL ARRANGEMENT

A - EXPANSION GAP 12 TO 20 mm B - INSTALLATION GAP 1.5 TO 2 mm

NOTE: FOR ENSURING THESE GAPS, THE ANCHOR BOLTS SHOULD BE INSTALLED ACCURATELY IN PROPER POSITION.

FIG. 2.1 CENTRALISED ARTICULATED BEARING

CHAPTER 3

ROCKER & ROLLER BEARINGS

3.1 GENERAL

For railway bridges with spans in excess of 30.5m, where open web through girders are generally provided, the amount of movement needed and the vertical load transmitted through each bearing is too large to be catered by the sliding bearings. It is common, on Indian Railways, to provide rocker & roller bearings at the free end of open web through girders, and rocker bearings at the fixed end.

A typical rocker and roller bearing for open web girders of 45.7 m span is shown in **Fig. 3.1 & 3.2**. The roller bearing consists of a base plate, two or more rollers and a top plate. The rocker & roller end is made by providing a saddle and knuckle plate on top of the rollers whereas the same arrangement except rollers is at the rocker end. The rocker & roller end of bearing permits translation as well as rotation, whereas the rocker end permits only rotation.

3.1.1 **Parts :**

(a) *Roller :* The rollers are made of forged steel of Class-3, as per IS:2004 and basic raw material is as per IS:1875. The rollers may, alternatively, be turned from approved C&W axles manufactured after 1931. USFD test shall be conducted to ensure that there are no internal flaws. These have machined surface to permit smooth rolling action.

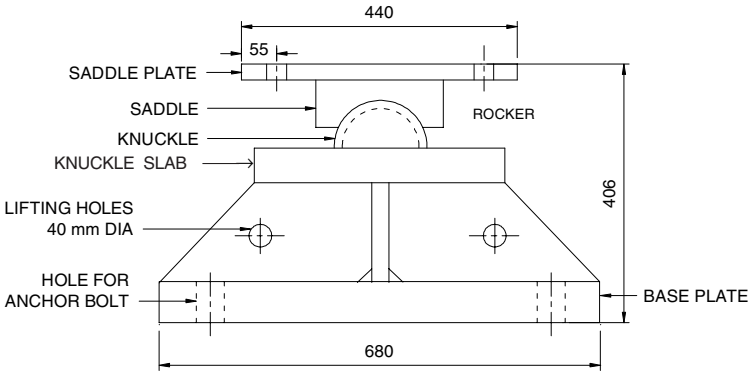


FIG. 3.1 ROCKER BEARING AT FIXED END

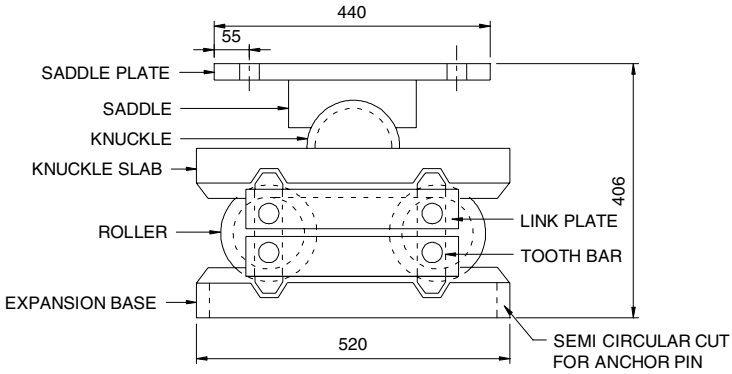


FIG. 3.2 ROLLER BEARING AT FREE END

(b) *Link Bar :* All the rollers are connected to each other with a link bar to ensure that they always move together and maintain the clear gap between rollers.

(c) *Tooth Bars :* Rollers on the extreme end of a group of rollers are provided with tooth bars. The tooth bars rest into grooves provided in the knuckle plate on top and base plate at bottom. The purpose of tooth bars is to arrest movement of the rollers beyond a point (depending upon the design movement). Tooth bar in rocker-roller bearing can be assumed to be equivalent to 'stopper plate' in sliding bearing.

(d) *Rib and Notch :* To arrest transverse movement between the roller and the base or knuckle plate, a longitudinal notch can be provided in the middle of the roller and a matching rib in the base and top plate. The rib thus guides the rollers to roll only in the longitudinal direction and prevents any transverse movement. Rib and notch arrangement in rocker-roller bearing can be assumed to be equivalent to 'Guide strip' in the sliding bearings.

3.1.2 *Connections :* The top plate or saddle plate is connected to the end of the bottom chord. Since this connection is crucial for transmitting the horizontal thrust from the bottom chord to the bed block, it must be made tight fit. The top plate is generally installed to the underside of the bottom chord in-situ. However, the joint is not amenable for riveting for want of adequate space. The number of rivets required and their lengths will also be very large. The joint is therefore made with turned and fitted bolts. The reaming of the

holes in bottom chord and the saddle plate is, therefore, required to be done by assembling them together. The tolerances in the hole and shank diameter of turned bolts as per clause 28.6 of IRS :B1 -2001 are as under :

Limit of tolerance	Shank of bolt (mm)	Diameter of hole (mm)
Upper	0.000	+ 0.125
Lower	- 0.125	0.000

Such tolerances are prescribed to ensure adequate contact area between the hole and shank, which is presumed while allowing higher permissible bearing stress for the design of turned bolt connections.

The rocker-cum-roller bearings require periodic greasing of rolling contact surfaces. This requires the girder to be jacked up and the contact surfaces are cleaned to remove all entrapped dirt/ dust etc. and a fresh layer of grease is applied. A frequency of once in 3 years has been prescribed for greasing of bearings on Indian Railways. The oiling and greasing of roller bearings must be done under traffic block. The maintenance details of rocker-roller bearing will be discussed in subsequent paras.

3.1.3 *Segmental Rollers :* For large span bridges (Span > 45.7 m) more than two roller are required. The size of the base plate required is large when number of rollers are more. It should be realized that the full periphery of a circular roller is never utilised during the rolling action. It is, therefore,

prudent to cut the sides of the roller to save not only in the weight of roller, but also to reduce the size of the base plate. A smaller base plate will require smaller pier top, thus, resulting in economy. These cut rollers are called segmental rollers as shown in **Fig. 3.3**.

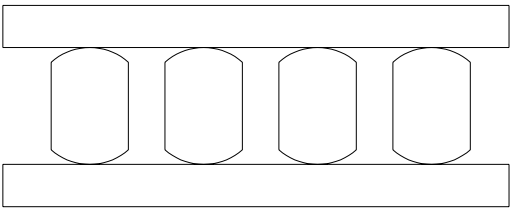


FIG. 3.3 SEGMENTAL ROLLER BEARING

Size of the base plate is reduced without compromising the rolling action of the rollers.

Generally, the height of the segmental rollers is made more than its diameter so as to permit a larger effective diameter. Thus the centre of the curved surfaces at top and bottom do not coincide. This imparts a tendency of lifting of the girder during the rolling action but this is negligibly small. IRC:83 Part-I cautions designers while proposing use of segmental roller bearing in seismic areas as there have been instances of the bearing collapsing under excessive longitudinal movements, which may occur during an earthquake.

3.1.4 *Oil Baths :* Roller bearings function smoothly as long as the contact surfaces are clean. However,

there is always a tendency to accumulate dirt and debris as well as rusting of steel. Very quickly, it leads to freezing of the bearing. The smaller the size of the rollers, more are the chances to freeze.

There have been instances where after a few years, a small nest of rollers has corroded so much that it is difficult to count the number of rollers. The Indian Railways have rightly gone in for large size of roller in the standard designs. The minimum size of roller to be provided is 102 mm as per Para 3.1.2.3 of IRS: Steel Bridge Code.

Therefore, in order to overcome this problem for spans of 76.2 m and above, an oil bath is provided around the rollers as shown in **Fig. 3.4.**

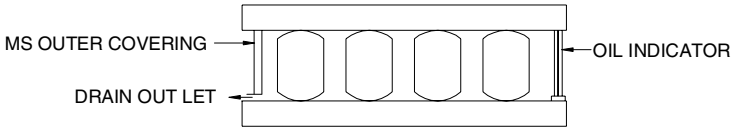


FIG. 3.4 SEGMENTAL ROLLER WITH OIL BATH

The reason for providing oil bath for such large spans is that mostly these bridges are rail-cum-road bridges and lifting of the girders is very difficult due to the very heavy dead load. Since the rollers are completely submerged in oil, they are effectively protected against corrosion.

The oil bath is fabricated from MS plate and is provided with oil seals. A gauge or an oil level indicator is provided to enable periodical check of oil level in the box. A drain outlet is provided at the bottom to drain out and replace the oil without the need to open out the oil bath. The necessity of such replacement may be due to contamination of the oil, which should be periodically sampled. Once in five years the oil bath is to be opened out after draining the oil, the rollers inspected and the oil changed. The oil baths have performed very well on Indian Railways and have contributed to the success and longevity of roller bearings. The use of oil bath should be extended to all roller bearings of through spans and more so in aggressive environments.

3.2 DESIGN ASPECTS

The design of rocker & roller bearing involves selection of roller length, its diameter, radius of the contact surface of saddle/knuckle, thickness and plan size of the base plate and number and size of anchor bolts. Simple design rules are provided in IRS: Steel Bridge Code to obtain these values, The excerpts are given below :

a) Allowable load P for rollers

Roller on curved surface

i) For single and double roller

$$P = 0.8 \frac{1}{(1/D_1 - 1/D_2)} \text{ kg/mm length of roller}$$

ii) For multiple rollers i.e. more than two rollers

$$P = 0.5 \frac{1}{(1/D_1 - 1/D_2)} \text{ kg/mm length of roller}$$

where D_1 and D_2 are diameters of convex and concave contact surface respectively as shown in **Fig. 3.5**.

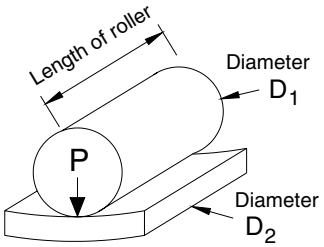


FIG. 3.5 ROLLER ON CURVED SURFACE

Roller on flat surface

For a flat surface the diameter is infinity. Substituting $D_2 = \infty$, the above two equations reduce to -

i) For single and double rollers-

$P = 0.8\ D_1$ kg/mm length of roller

ii) For multiple rollers

$P = 0.5\ D_1$ kg/mm. length of roller

A lower value of P for multiple rollers is taken due to the possibility of unequal load sharing among various rollers when number of rollers are more than two. When more than two rollers are in contact with rigid plates at top and bottom, any small difference in diameter of rollers will result into unequal load distribution. This possibility is not there where only two roller are used.

Therefore the tolerance in roller diameter is an important aspect to be considered in fabricaton of rollers. In recognition of the importance of variation in diameters, a very close tolerance of +0.04mm is prescribed in IRS: B1-2001, Appendix-VI.

A positive variation in diameter of one roller is more damaging than negative variation. In a set of rollers, a smaller diameter roller will only become ineffective, whereas the larger diameter roller in the same set will make many other rollers ineffective depending upon its location as shown in **Fig. 3.6 & 3.7.**

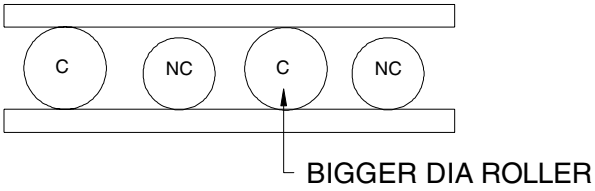
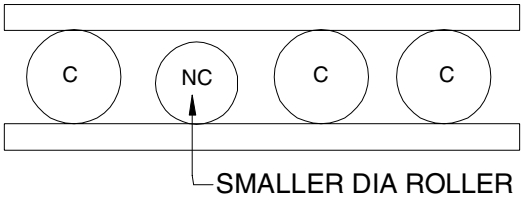


FIG. 3.6 POSITIVE VARIATION IN DIAMETER



C - CONTACT NC - NO CONTACT

FIG. 3.7 NEGATIVE VARIATION IN DIAMETER

b) Allowable load on spherical bearing

$$P = \frac{1}{127} \frac{1}{(1/D_1 - 1/D_2)^2} \text{ kg}$$

c) Size of base plate:

The length and width of the base plate will be governed by the following three factors -

i) Total vertical load and horizontal thrust to be transmitted by the bearing to the bed block.

ii) The length and number of the rollers and the total movement to be accommodated. The length of the rollers will be governed by allowable load per roller and maximum vertical load.

iii) The permissible bearing stresses in the bed-block material.

As per clause 3.16 of IRS : Steel Bridge Code the allowable bearing pressure for different materials is as under:

i) Stone Masonry = 36 kg/cm^2
ii) PCC (1:2:4) = 31.6 kg/cm^2
iii) RCC = 0.2 * fck (average pressure)
= 0.3 * fck (local max. pressure)

Where fck is the characteristic strength of concrete.

The base plate size can be reduced by adopting concretes of grade higher than M-20, provided a larger size of base plate is not required from other considerations.

d) Thickness of base plate :

The thickness of base plate should be adequate to withstand the bending moment (B.M.) caused by line load of rollers as shown in **Fig. 3.8.**

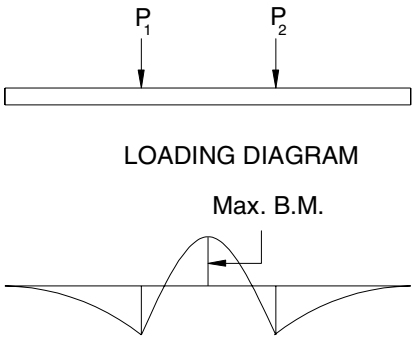


FIG. 3.8 BENDING MOMENT DIAGRAM

Thickness of base plate can be calculated from bending moment crietria as given below.

Permissible value of bending stress = M / Z

M = Max. Bending Moment

$Z = bt^2 / 6$

where b = width,

t = thickness of base plate

A very thin plate may be adequate from max. B.M. crieteria but it has a tendency to develop a curvature resulting into a non uniform load distribution. Therefore a minimum thickness of 20 mm is recommended even if it is not required from B.M. point of view.

e) *Saddle/knuckle block :* The saddle plate can also be designed as a cantilever with uniform load from top and a line load reaction from the knuckle plate. Quite often the saddle plate/ knuckle blocks are made of cast steel.

In such cases the cast steel should conform to the appropriate grade of the cast steel, the permissible stresses are same as that for mild steel conforming to IS:226/IS:2062 Gr. A.

f) *Anchor bolt :* All the longitudinal force from the girder is transmitted to the piers through the fixed end of bearing. Any friction between the bed block and base plate or saddle plate and bottom chord is completely ignored and the entire horizontal force is assumed to be transmitted by the connecting bolts/rivets. The bolts are thus checked against shear failure and also for safe bearing stresses. The permissible shear or bearing stresses for different grades of steel should be as per IRS: Steel Bridge Code.

3.3. INSTALLATION

For proper transmission of loads, the bearing should have uniform seating on the bed block. It is a common practice to provide a felt packing dipped in coaltar under the base plate. This is done with a view to provide uniform and even seating of the bearing. It has the added advantage of damping the vibrations and impact forces and thus increasing the life of the bed block. Cement or cement epoxy grout are also used as an alternative for levelling the bed block top surface.

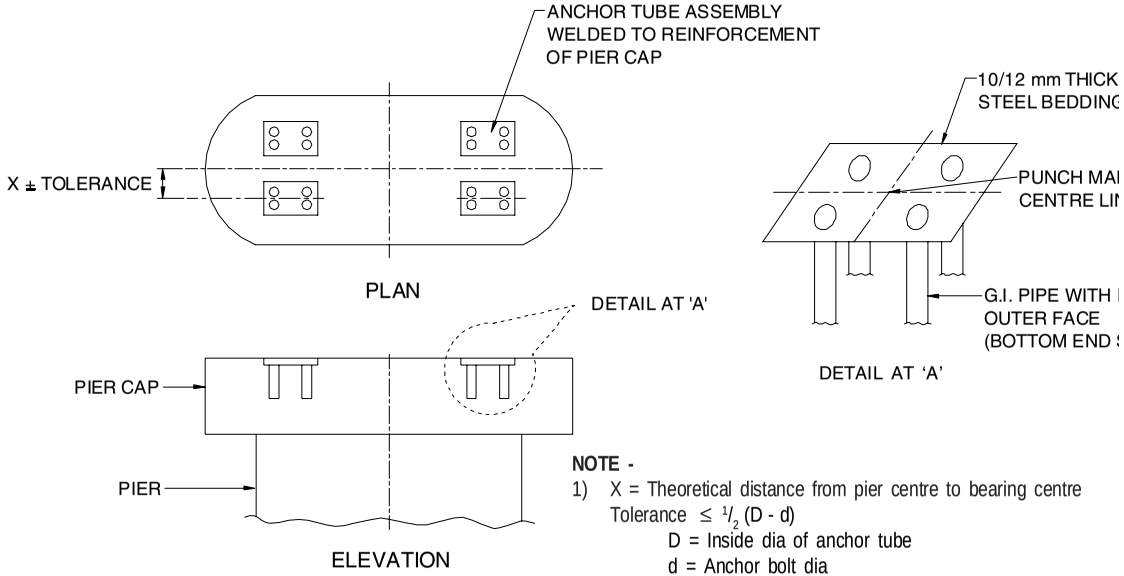
Use of materials such as lead sheets which tend to flow under loads in not recommended.

Mean position of rollers : In order that the bearing provides the full designed movement, it should be ensured that the rollers are in mean position (vertical in case of segmental rollers) at the specified mean temperature and loading condition. It is common to prescribe that the rollers are in mean position at the specified mean temperature and under (DL + LL + impact). In such a case, the rollers will take a position towards the inside of span at mean temperature when only DL is acting. Since there is no scope for adjusting the position of base plate, positioning of the anchor bolts must be done with a very high level of accuracy.

If mean position is not ensured, the bearing movement may be limited in one direction whereas unusable surplus movement will be available in other direction. The saving grace against an error during installation of the anchor bolts is the fact that the thermal movements specified in most cases is quite conservative.

A typical scheme of installation of anchor bolts is illustrated in **Fig. 3.9.**

If the correct position of the roller at mean temperature and DL condition is known it will be a very useful reference point for monitoring proper functioning of the roller bearing. It is very easy to check the bearing position by measuring the gap between the top and bottom contact



NOTE -

1) X = Theoretical distance from pier centre to bearing centre
   Tolerance $\leq {}^{1}/_{2}$ (D - d)
   D = Inside dia of anchor tube
   d = Anchor bolt dia
2) Anchor tube to be sealed from top during concreting of pier cap.
3) Anchor bolts to be grouted in position after positioning of the bearing.
4) A thin layer of mortar may be used between the bearing and bedding plate for making uniform contact.

FIG. 3.9 SCHEME FOR INSTALLATION OF ANCHOR BOLTS

points of the rollers in longitudinal direction. Alternatively, for full/segmental bearings, the movement may be measured by the position of the contact point of the tooth bar on top and bottom plate respectively. In case oil bath is provided, a movement gauge should be provided so as to directly read the roller position from outside without the need of opening the oil bath.

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CHAPTER 4

MAINTENANCE OF STEEL BEARINGS

4.1 GENERAL

Cleaning and greasing of bearings is one of the important maintenance works to avoid premature failure of bearings and reduce recurring heavy repair cost of bed block and masonary below bed block. Steel bearing strip resting on steel base plate has a tendency to stick together on account of corrosion, and cease the movement of bearings. This is called as Frozen Bearing. Sliding bearings of plate girders are generally designed keeping both ends free. When bearings are frozen, a large amount of longitudinal force is transferred to the substructure for which the substructure may not have been designed. Upon introduction of RBG, MBG and HM loadings on the Indian Railway, longitudinal forces have increased considerably whereas the old substructures had been designed without considering such large longitudinal forces. Sometimes, even repairs will not hold good if cause of frozen bearings is not eliminated by greasing. It has been laid down that the steel bearings of all girder bridges should be greased once in 3 years to ensure proper movement of bearing plates. This should be done once every two years when track consisting of LWR is continued over bridge span.

4.1.1 *Lifting of girders :* For greasing the bearings girders are required to be lifted. But the gap between the bottom flange of plate girders and

the bed block generally varies from 100 mm to 150 mm. The standard jacks normally available have a closed height of at least 300 mm. These jacks, therefore, can't be used for lifting the girders without making special jacking arrangements.

Following jacking arrangement can be adopted for different types of girders:

1. For plate girders upto 6.1 m span, jacks can be directly applied below end sleeper ensuring firm hook bolt connection, since load to be lifted is about 4 to 5 ton only.
2. Jacking arrangement for span 9.15 m plate girder requires provision of a hard wood beam below inner top flange as shown in **Fig. 4.1** for lifting the girder.
3. Jacking arrangement for span 12.2, 18.3, 24.4 and 30.5 m plate girder requires provision of a steel beam as shown in **Fig 4.2.**

The provision of jacking steel beam and its removal is difficult. It requires more man power and also it is time-consuming on account of heavy weight of the beam and limited working space on bridge piers. Field officials, many times, apply jack to the end cross frame angle (diagonal) to avoid provision of the jacking beam, to lift the girder. This may cause bending of the angle on account of its slender size, which results in lifting of bearing strips inside when lowered on base plate. This improper seating of the bearing strip will cause hammering action during subsequent passage of train resulting in damage

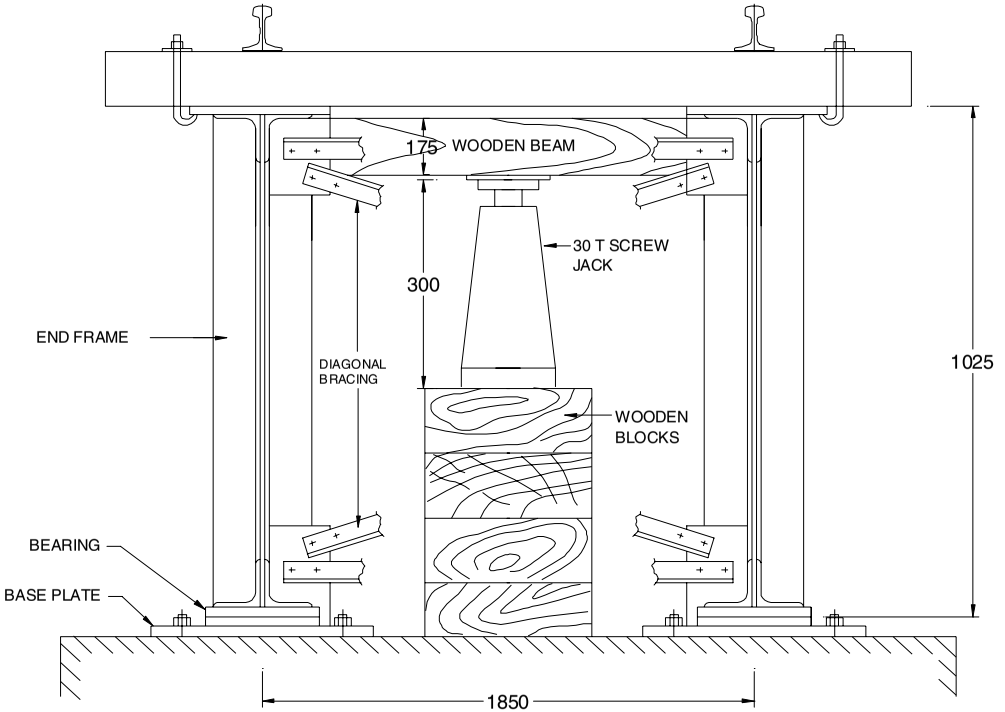


FIG. 4.1 JACKING ARRANGEMENT FOR 9.15 m SPAN

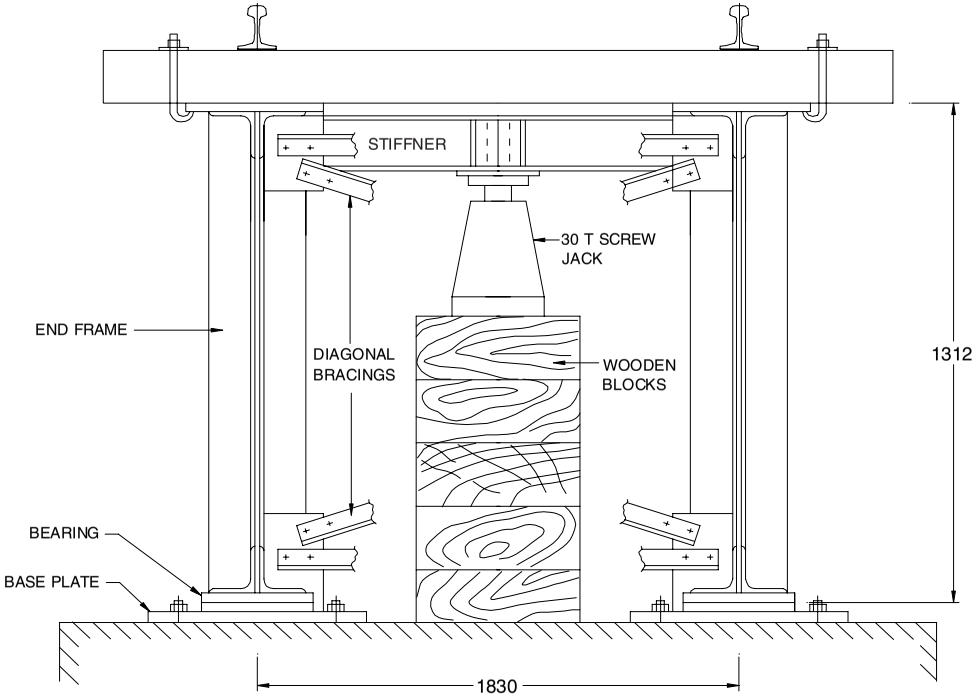


FIG. 4.2 JACKING ARRANGEMENT FOR 12.2 m, 18.3 m & 24.4 m SPANS

to the bed block and masonry of the substructure.

Therefore the method of provision of jacking beam to outside girder as shown in **Fig 4.3** is preferable. This requires less manpower and less time for lifting of the girder.

4.1.2 *Cleaning and greasing of steel sliding bearings :*

Following equipments are required for greasing of steel sliding bearings:

1. Jacks (50 ton capacity) - 2 nos.
2. Hard wooden packing below and above jack
3. Grease graphite Grade 3 conforming to IS:508
4. Kerosene or released black oil for cleaning
5. 6 mm thick steel scrapers
6. Mortar pan
7. Cotton waste

Greasing of sliding bearings can be undertaken under traffic with issue of caution order and line protection for temporary works as per provision of IRPWM.

Lifting of girder should be restricted to 8 to 10 mm only, ensuring that the bearing strip does not get lifted over locking strip and guide strip to avoid creep of girder in logitudinal and lateral direction. For lifting, it is not necessary to break the track. Only loosening of fish bolts and dog spikes over a small length on both sides of the pier is sufficient. Only one end of the girder should be lifted at a time and steel scraper inserted between bearing strip and base plate to remove old grease dust and dirt. The contact surface is cleaned with oil and grease applied. Girder is then lowered back over the base plate.

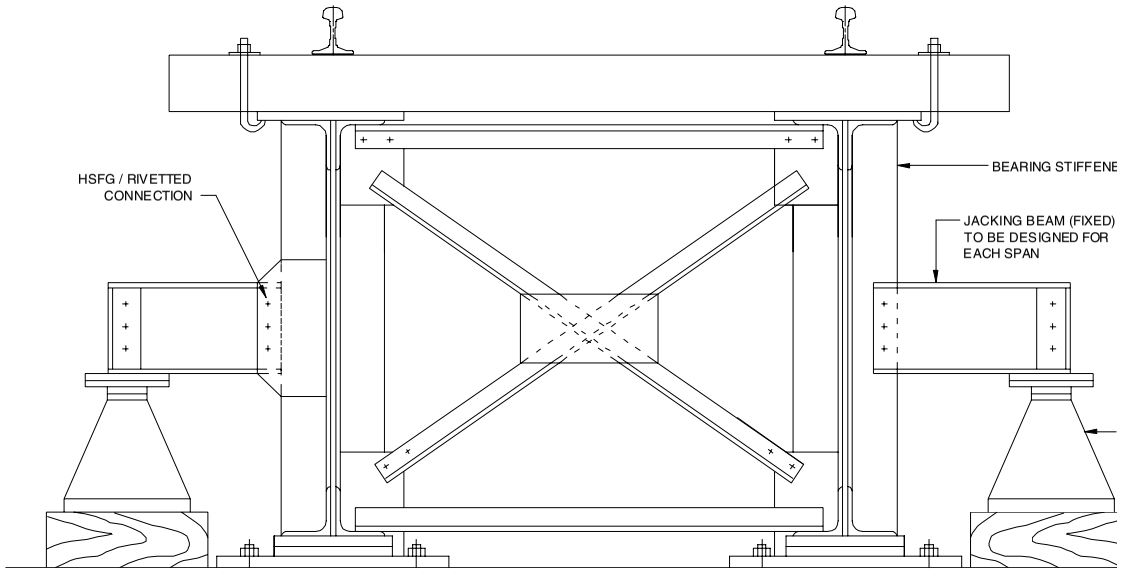


FIG. 4.3 PROPOSED JACKING ARRANGEMENT FOR 12.2 m, 18.3 m & 24.4 m SPANS

Time required for all these activities is approximately 15 to 20 minutes.

4.1.3 *Cleaning and greasing of Rocker & Roller bearings of open web through girders :* In case of standard open web through girders, no separate jacking arrangement is required as the end cross girders are designed and provided with stiffener and pad plate for provision of jack for lifting. Gap between bottom of cross girder and top of bed block is about 600 mm, hence any type of jack of 100 ton to 200 ton capacity can easily be used for lifting. In case of non standard spans, the end cross girder requires adequate strengthening or special jacking beam below the bottom boom.

The equipments required in this case are same as for sliding bearing except that the jacks of higher capacity (100 ton to 200 ton) and wire rope with turn buckle arrangement for holding the free end are required.

Greasing of rocker and roller bearing should be carried out under traffic block under the supervision of an official not below the rank of ADEN/ABE.

Following precautions and preliminary arrangements are required:

1. Ensure tightness of rivets connecting end cross girder and end panel point of truss.
2. Provide hard wooden packing below the end cross girder to support the girder in case of failure of jacks. This should be done at three places to prevent tilting of this girder.

3. Remove fish plates and loosen dog spikes of rail over adjacent spans to avoid overloading the jack on account of weight of adjoining span and stiffness of the track.

4. If trolley refuge is connected to both spans on any pier, loosen the bolted connection of adjoining span to avoid overloading of jack and damage to the trolley refuge.

5. While lifting the fixed end, the other end being free, the girder is likely to creep longitudinally. To prevent this, provide hard wood packing between the ends of girder on pier and between girder and the ballast wall on abutment.

6. Jacks should be kept in working order and tested to 1.5 times the load they are expected to lift. Keep one spare jack as stand by.

7. During lifting of girder, precaution should be taken to prevent creep of rail.

4.1.4 *Method of Greasing :* Greasing of fixed end requires 20 to 25 minutes. The lifting is hardly 10 mm, ensuring that the gap is created between saddle block and knuckle pin. Saddle is not lifted above collar to prevent lateral creep of the girder. Steel scraper is used to remove old grease, dust and dirt. The contact area is cleaned with oil. Grease is applied and then girder is lowered back.

Greasing of free end requires 45 to 50 minutes. Knuckle plate is tied to the saddle plate with wire rope having turn buckle arrangement to release the load from roller when the girder is lifted.

When the girder is lifted about 10 mm and rollers are free, link plate and tooth bar are removed after opening the stud connections. All rollers should be taken out and cleaned with scraper and these are sand-papered with a fine sand-paper of zero grade. Rollers should be examined for any possible signs of flattening or minute cracks with a magnifying glass. Grease graphite grade 3 conforming to IS 508 is applied over the base plate evenly below the roller contact area. The rollers are then placed in position and grease applied at the top contact surface. Link plate and tooth bars are connected with care so that tooth bar is placed in the same inclination as per the drawing.

With the help of turn buckle of wire rope sling, the knuckle plate is lowered over the rollers. This will create gap between the saddle block and knuckle plate. Cleaning and greasing of this area is then carried out similar to the fixed end and girder is lowered back.

> While taking out rollers for examination and greasing, take special precautions to prevent the rollers from falling-off the bed block.

❍ ❍ ❍

CHAPTER 5

ELASTOMERIC BEARINGS

5.1 GENERAL

Steel bearings are good but suffer from problems of corrosion and high level of maintenance. Due to these problems of steel bearings, engineers were on the lookout for a bearing which could accomodate large movements and at the same time being relatively maintenance free. Elastomer as a material for making bridge bearing has been found to satisfy these requirements so much so that many engineers believe that the search for an ideal material for bridge bearing has come to an end. Further developments in future may involve refining the use of elastomer and enhancing its properties.

To summarise, the elastomeric bearings offer number of advantage as listed below:

1. Requires minimum maintenance compared to all other bearings.
2. Installation is easy.
3. Permits movement of the structure in all directions, depending upon the applied forces.
4. Occupies small space.
5. Serves as a shock absorber due to anti-vibration properties of elastomer.
6. Acts as an aid to better dispersion of longitudinal forces to the approaches.

5.2 PROPERTIES OF ELASTOMER

An elastomer is a polymeric substance obtained after vulcanization of rubber. Vulcanization is the process of improving the properties of rubber by heating with sulphur. A normal rubber is not useable as it becomes brittle at low temperature and sticky at high temperature. Charles Goodyear had been trying to 'cure' the rubber so that it could be used in all seasons. He tried to mix all kinds of things such as ink, black pepper, cheese and what not. But he couldn't succeed until he dropped a piece of rubber on stove accidentally. To his surprise, he found that instead of melting the rubber piece hardened and remained pliable. It was found in the lab that it contained traces of sulphur. Goodyear perfected the process and named it 'vulcanization' after the Roman God of fire, 'Vulcan'.

As a result of vulcanization, rubber molecules are cross-linked with sulphur. This cross-linking makes the rubber stronger. It allows the rubber to keep its shape better even when it is stretched over and over again. But there is a drawback of cross-linking also. Vulcanized rubber doesn't flow when it gets hot, therefore one has to mould it into whatever shape one wants before cross linking. Due to the same reason, it can't be recycled – a big environment problem. The tyres of the vehicles also use the same material, and we are not able to recycle the cross-linked rubber used in tyres.

One of the most well known natural rubber is **'Poly-isoprene'** which is harvested from the sap of 'Hevea' tree. Natural rubber have all the

excellent properties making it extremely suitable to many engineering applications, except for its relatively high reactivity with environment particularly ozone. Ozone causes surface cracking that can rapidly penetrate even at very low tensile stress.

To obviate this drawback many synthetic rubbers were developed, most popular among those is **'Poly-chloroprene'**. Thus, we have -

1. Natural rubber - Poly-isoprene
2. Synthetic rubber - Poly-chloroprene

There is often a confusion between the words elastomer and neoprene. While elastomer refers to the generic name of the rubber, neoprene refers to the trade name of the elastomer of one of the leading rubber manufacturers.

Engineers are more familiar with materials which obey Hooke's Law i.e. behaving in a linear elastic manner. We understand elastomers less well than we do concrete or steel because elastomers do not obey Hooke's Law. They are very flexible in shear but very stiff in bulk compression. The simple theory of mechanics characterizing the behaviour of rubber is quite different from that used for conventional materials, and quite complex for the liking of the practical engineers.

It is therefore not surprising that most of the codal provisions for design, fabrication, installation and maintenance of elastomeric bearings are based on extensive studies and laboratory trials conducted by ORE (Office for Research and Experiment) of UIC. These are documented in ORE Report D-60. Important

specifications which can be referred to for elastomeric bearings are listed below:

1. UIC 772-2R 1989
2. BS:5400 Part 9.1
3. IRC 83 Part II
4. AASHTO specifications
5. IS:3400 Part I to XXIV

Some of the important findings of the studies conducted by ORE, which are relevant to the design of elastomeric bearings are enumerated below :

1. Elastomers do not follow Hooke's Law and, therefore, the modulus of elasticity 'E' is not constant.
2. The shear modulus 'G', however, is fairly constant and is more relevant for the design of elastomeric bearings than 'E'.
3. The coefficient of friction between elastomer and the base material is unaffected by the nature of the contact surface i.e steel, concrete, painted or unpainted surfaces.
4. The coefficient of friction between the elastomer and the base material reduces with increase in normal load on the bearing. It is expressed by the formula $\mu = 0.15 + \frac{0.6}{N}$

   where N = normal pressure in MPa
5. Except under extremely low temperatures (less than -15^0C), performance of the elastomeric bearing is not affected by temperature variation. These have also been tested satisfactorily up to + 50^0C.

6. Under the effect of cyclic loading the bearings become more flexible.

7. In some of the tests conducted on elastomeric bearings, there was a distinct tendency of the elastomer to slip when the minimum normal pressure was less than 2 MPa. This observation has important ramifications for use of elastomeric bearings in railway steel bridges of smaller spans where normal pressure may be less than 2 MPa. The elastomeric bearings in such small bridges can be used alongwith anti creep devices as explained in subsequent paras.

5.3 BEHAVIOUR OF ELASTOMERIC BEARINGS

In order to carry out successful design and installation of elastomeric bearings, it is necessary to understand the behaviour of elastomeric bearings against various imposed loads. The elastomer being practically incompressible, the total volume of the pad in loaded and unloaded conditions remains unchanged. Therefore, under the action of a compressive load, a plain elastomeric pad with no friction on its top and bottom surfaces, flattens and expands laterally as shown in **Fig. 5.1.**

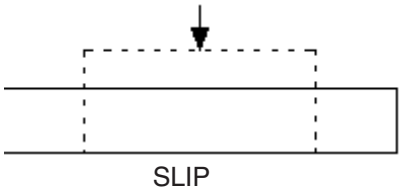


FIG. 5.1 PLAIN ELASTOMERIC PAD WITHOUT FRICTION AT CONTACT PLANE

Since a frictionless contact surface does not exist in practice, the deformation of the pad will be part flattening and part bulging and the behaviour of plain elastomeric pad will be as shown in **Fig. 5.2.**

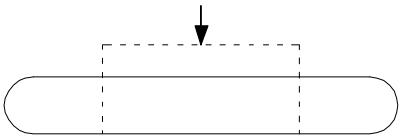


FIG. 5.2 PLAIN ELASTOMERIC PAD WITH FRICTION AT CONTACT PLANE

The lateral expansion of plain elastomeric pad is too much for practical purposes and it can not be used as it is without making arrangements for reducing the lateral expansion. If the elastomer is bonded between two layers, the lateral expansion is prevented at the interfaces and bulging is controlled.

The compressive stiffness of the bearing, therefore, depends upon the ratio of loaded area to the area of the bearing free to bulge. This is essentially quantified by Shape Factor 'S' which is a dimensionless parameter defined as under:

$$S = \frac{\text{Plan area loaded in compression}}{\text{Perimeter area free to bulge}}$$

Greater compressive stiffness is, therefore, obtained by dividing elastomer into many layers by introducing very thin, usually 1 to 3 mm, steel reinforcement plates between the elastomer layers and bonding the plates firmly with the elastomer to prevent any relative movement. This

has the effect of decreasing the area free to bulge without any change in the loaded area. Hence, higher the Shape Factor, stiffer is the bearing under compressive load. Since the elastomer expands laterally, shear stresses are set up in the elastomer by the bond forces. The steel plate, in turn, is subjected to pure tensile stresses as shown in **Fig. 5.3.**

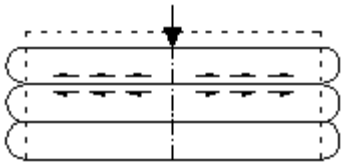


FIG. 5.3 REINFORCED ELASTOMERIC PAD

The elastomeric bearing provides horizontal translation by shear strains as shown in **Fig. 5.4** and rotation by differential compression as shown in **Fig. 5.5.**

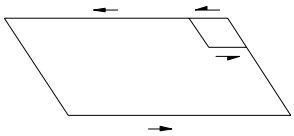


FIG. 5.4 SHEAR STRAIN DUE TO SHEAR

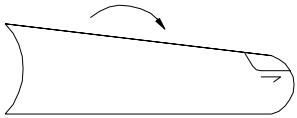


FIG. 5.5 SHEAR STRAIN DUE TO ROTATION

Elastomeric bearings can accomodate horizontal movements to an extent of 125 mm while it is claimed that each 13 mm thickness of the pad could accomodate one degree of rotation.

In fact, horizontal translation is being provided by elastomeric bearing without loosing the contact either with superstructure or with substructure. Therefore, the movements are allowed without any relative movement of parts.

The shear deformation depends upon the height of the elastomeric pad as shown in **Fig. 5.6.**

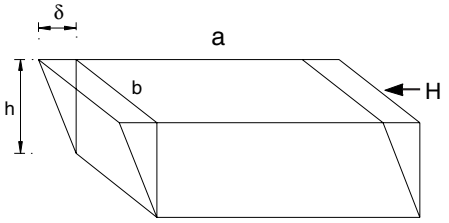


FIG. 5.6 DEFORMATION OF ELASTOMERIC PAD

$$\text{Shear stress} = \frac{\text{shear force}}{\text{plan area}}$$

$$= \frac{H}{a \times b}$$

$$\text{Shear strain} = \frac{\delta}{h}$$

where δ = deformation
h = thickness of elastomeric pad
H = horizontal force

a = length of elastomeric pad
b = width of elastomeric pad

$$\text{Shear Modulus } G = \frac{\text{shear stress}}{\text{shear strain}}$$

$$G = \frac{H}{a \times b} \times \frac{h}{\delta}$$

$$\therefore \delta = \frac{H \times h}{G\ (a \times b)}$$

Thus for a given size of bearing, the shear deformation will depend upon thickness of elastometric pad, value of horizontal force and value of 'G'. Since horizontal force and 'G' can not be altered, deformation 'δ' will be proportional to thickness of elastomeric pad.

$$\delta \propto h$$

Under the influence of rotation, the compressive loads on the inner edge is magnified and it is relieved on the outer edge. In the design it is, therefore, ensured that, under the combined effect of normal loads and rotations, the outer edge of the elastomer does not get off-loaded completely.

5.4 TYPES OF ELASTOMERIC BEARINGS

Three basic types of elastomeric bearings are used.

1. Plain elastomeric pads
2. Steel reinforced elastomeric pads
3. Fibre reinforced pads

Plain pads are used for light or moderate

loadings. Plain pads have a tendency to bulge under heavy loadings. In order to reduce the tendency of bulging, the elastomer pads are reinforced with steel plates. The steel sheets separating the layers of elastomer are completely encased within the elastomeric material. For vertical load, each layer of elastomer behaves like an individual pad, while horizontal strain on each layer is additive. Therefore, adding steel laminations is a convient way to accommodate larger lateral movements for the same compressive loads. Fibre reinforced pads are usually reinforced with fibre glass.

5.5 DESIGN OF ELASTOMERIC BEARINGS

The standard drawings of bridge bearings issued by RDSO are on the basis of UIC 772-R. To maintain uniformity of approach, the design of elastomeric bearing discussed in the following paragraphs is only as per UIC 772-R.

5.5.1. *Flow Table of Design :* The flow table of design given at **Table 5.1** has been prepared to simplify the design process and eliminate trial and error approach. It is expected that the number of iterations required for successful design will be minimum if this sequence of steps is followed.

TABLE 5.1 FLOW TABLE OF DESIGN

SN	Sequence of steps	Remarks
1.	Collect input data	Dead load, live load, horizontal slow load, horizontal quick load, span length, rotation at ends, etc. as given in next paragraph.
2.	Select width 'b' of bearing	Generally equal to width of girder & larger than 'a' due to better rotational stability in lateral direction.
3.	Calculate net plan area of bearing	Depends upon max. vertical load including impact and permissible bearing pressure on bed-block.
4.	Calculate length 'a' of bearing along girder	Net plan area divided by 'b'.
5.	Calculate Shape Factor 'S'	It should be between 6 and 12.
6.	Calculate min. vertical pressure	Dead load / plan area of bearing.
	a) If it is < 2 MPa	Bearing may slip. Revise plan dimensions so that vertical pressure is min. 2 MPa or provide 'Anti Creep Device'.
	b) If it is ≥ 2 MPA	O.K. Proceed further.
7.	Calculate max. vertical pressure	Total vertical load including impact / plan area of bearing.
	a) If it is ≤ 10 MPa	O.K.
	b) If it is > 10 MPA	Revise plan dimension, keeping a watch on step 6 a).
8.	To ensure 'No slip condition'	
	a) Calculate μ_1 when only D.L. is acting $\mu_1 = 0.10 + 0.6/N_1$ where N_1 = vertical pressure due to DL only	μ_1 x DL should be more than slow acting horizontal force.

	b) Calculate μ_2 when both DL + LL (including impact) are acting. $\mu_2 = 0.10 + 0.6/N_2$ where N_2 = vertical pressure due to DL + LL	μ_2 x (DL + LL) should be more than total horizontal force.
9.	Calculate % distortion in shearincrease 'h' to limit % distortion = $\frac{\delta}{h} x\ 100$	It should be max 70%, otherwise this % age.
10.	To ensure no uplift condition	
	a) Under Dead Load Permissible rotation = $\frac{\text{Comp. of all layers under DL}}{a/6}$	It should be more than actual rotation of span under dead load only.
	b) Under Total Load Permissible rotation = $\frac{\text{Comp. of all layers under TL}}{a/6}$	It should be more than actual rotation of span under total load including impact.
11.	Total shear in elastomer includeslimited to 5 x G or 5 MPa a) Due to compression b) Due to horizontal load c) Due to rotation	Addition of all three should be (considering G = 1 MPa).
12.	Thickness of steel lamination plate required $= \frac{2\ (h_i + h_{i+1})(\ P_c + 1.5\ P_s)}{a\ x\ b\ x\ \sigma_s}$	This should be more than actually provided.

5.5.2 *Input data required :* The input data required for carrying out the design is as under:

P_c = D L or slowly applied vertical loads
P_s = L L or quickly applied vertical loads
H_c = Slow acting horizontal forces
H_s = Quick acting horizontal forces
U_C = Horizontal (shear) movement due to H_c
U_s = Horizontal (shear) movement due to H_s
α_C = Rotation under effect of slow acting loads
α_s = Rotation under effect of quick acting loads
G = Static shear modulus of elastomer
σ_b = Permissible bearing pressure in bed block material
σ_m = Max. Permissible pressure in the elastomer
- 10 MPa (as per IRC : 83)
- 5 MPa or 5G, whichever is less (as per RDSO)
- 11 MPa (as per UIC 772 - 2R)

B = width of the girder/beam

5.5.3 *Output Expected :* The output expected at the end of design of the elastomeric bearing is as under :

a = length of the bearing along the span
b = width of the bearing across the span
n = number of layers of elastomer
h_i = thickness of each layer of elastomer
h = total thickness of elastomer.

5.6 MANUFACTURE AND QUALITY CONTROL

5.6.1 *Properties of Elastomer :* Though elastomeric bearings offer a number of advantages as compared to steel bearings, many failures have been reported pertaining to these bearings. A majority of these failures can be attributed to improper quality of elastomer and/or faulty installation. These two aspects, therefore, need very careful attention by the construction engineer in the field. The properties of the elastomer are detailed in IRC:83 Part-II and are reproduced in **Table 5.2.**

The shear modulus of the elastomer depend upon the hardness of the rubber. The relation between shore hardness and shear modulus G as indicated in UIC-772-2R is as under:

Shore hardness	50	60	70	80
Modulus G	0.5	0.8	1.1	1.4

Therefore with age, hardness increases, which in turn increases the value of 'G'. For the adopted dimension of the elastomeric bearing, the horizontal movement 'δ' reduces with the increase in value of 'G'. Therefore with age, the movement capacity reduces.

5.6.2 *Dimensional Tolerance :* The bearing should be fabricated to the dimensional tolerances stipulated in IRC:83 which are reproduced in **Table 5.3.**

TABLE 5.2 PROPERTIES OF ELASTOMER

Name of test	Reference code for testing	Permissible limits	Methodology of testing and remarks
1) Chemical composition			
i) Poly-chloroprene content test	ASTM- D297	Not less than 60%	Use of fillers to be minimized.
ii) Identification of polymer	ASTM- D3677	No reclaimed rubber or natural rubber to be used.	Test involves use of infra red spectrophotometry
iii) Ash content	IS 3400 PART-XXII	Not more than 5%	
2) Hardness	IS 3400 PART- II	60$\pm$ 5 IRHD	IRHD stands for International Rubber Hardness Degree. The hardness scale is similar to the Shore or Durometer hardness.
3) Ultimate tensile strength	IS 3400 PART-I	Min. 17 MPa	
4) Elongation at break	-do-	Min. 400%	
5) Accelerated aging test	IS 3400 PART- IV	Variation in i) Hardness - not more than 5 ii) UTS - not more than 15% iii) Elongation at break - not more than 30%	The elastomer sample is subjected to a temperature of 100^{0}C for a period of 70 h and then allowed to cool to room temperature. The variation in physical properties is subsequently measured.
6) Compression set test	IS 3400 PART- X	Compression set not to exceed 35%	The elastomer sample is subjected to a compressive strain of 25% at a temperature of 100^{0}C for 24 hours. Subsequently, the sample is cooled and the residual strain is measured. The residual strain called the "set" should not exceed 35% of the initial strain.
7) Ozone test	IS 3400 PART- XX	No cracking or disintegration of the sample.	The sample is subjected to a tensile strain of 20% in a chamber where the temperature is maintained at 40^{0}C and Ozone concentration kept at 50 pphm(parts per hundred million)

TABLE 5.3 DIMENSIONAL TOLERANCES

SN	ITEMS	TOLERANCES
1.	Overall plan dimensions	-0, + 6 mm
2.	Total bearing thickness	-0, + 5%
3.	Parallelism A. Of top surface of bearing with repect to the bottom surface as datum B. Of one side surface with respect to the other as datum	 1 in 200 1 in 100
4.	A. Thickness of individual internal layer of elastomer B. Thickness of individual outer layer	$\pm$ 20% (max. of 2mm) -0, +1 mm
5.	A. Plan dimensions of laminates B. Thickness of laminate C. Parallelism of laminate with respect to bearing base as datum	-3 mm, +0 $\pm$ 10% 1 in 100

5.7 INSPECTION AND TESTING

The inspection and tests on elastomer and the finished bearings are very important aspects of ensuring a satisfactory performance of the bearing. IRC:83 has laid down detailed testing plan and acceptance criteria for elastomeric bearings. The important aspects are highlighted in the following paragraphs.

5.7.1 *Lot size :* Testing and acceptance of elastomeric bearings should be done lot-wise. A 'lot' of bearings shall comprise of all bearings of equal or near equal size produced under identical conditions of manufacture to be supplied for a particular project. For the purpose of grading the

levels of acceptance test, the lots are classified as under :

1. A lot size of 24 or larger number of bearings is defined as **large lot**.

2. A lot size with less than 24 bearings is defined as **small lot**.

When the number of bearings for a bridge project is large and phased production is permitted, bearings supplied in any one phase will be considered as a large lot. The levels of acceptance test applicable will be as under :

Large lot - 'Level 1' Acceptance testing
Small lot - 'Level 2' Acceptance testing.

5.7.2 *Level 1 Accpetance Testing :* This will include the following tests:

A. General inspection
B. Test on specially moulded test piece
C. Test on complete bearings.

A. General inspection

1. All bearings of the lot shall be visually inspected for absence of any defects in surface finish, shape or any discernible superficial defects.

2. All bearings of the lot shall be checked for dimensional tolerances.

3. All bearings shall be subjected to an axial load corresponding to normal pressure of 15 MPa applied in stages and held constant while visual examination is made for:

a. Misalignment of reinforcing plates
b. Poor bond at interface
c. Variation in elastomer thickness
d. Surface defects
e. Low stiffness.

The deflection under loads between 5 MPa and 15 MPa should be measured with sufficient accuracy. Variation in stiffness of any individual bearing from the mean of all such bearings should not be more than 20% of the mean value.

B. Test on specially moulded test piece

The test piece shall be moulded by the manufacturer with identical compound and under identical vulcanizing conditions as used in manufacture of the bearings. The test pieces should be suitably identified and certified. The test pieces will be subjected to the following tests:

- Test for chemical composition, specific gravity, ash content etc.

- Test for physical properties such as

(i) Hardness

(ii) Ultimate tensile strength

(iii) Elongation at break

(iv) Accelerated aging test

(v) Compression set test

(vi) Ozone test

The details of these tests are given in **Table 5.2**.

C. Test on complete bearings

Two bearings should be selected at random from the 'lot'. Various tests should be conducted on these 'test bearings'. These bearings should be excluded from the accepted lot because all the tests given below except 'Shear Modulus test' are destructive tests.

1. Shear Modulus
2. Elastic Modulus
3. Adhesion strength
4. Ultimate compressive strength.

In addition to above tests, the ash content (%) and specific gravity of elastomer of test pieces from test bearing shall be compared with those of corresponding specially moulded test pieces and maximum acceptable variation will be as given below:

Ash content $\pm$ 0.5%
Specific gravity $\pm$ 0.2

The test specifications and acceptance criteria should be as per Appendix II of IRC 83 Part II. The excerpts are given below:

General about tests

1. All testing shall be done at room temperature.
2. No bearing shall be tested earlier than a week after vulcanization.
3. Bearing sections shall be cut from test bearings without overheating the rubber and

with smooth cut square edges.

4. Test for determination of 'E' may precede that of 'G' when both tests are conducted on the same pair of test bearings.

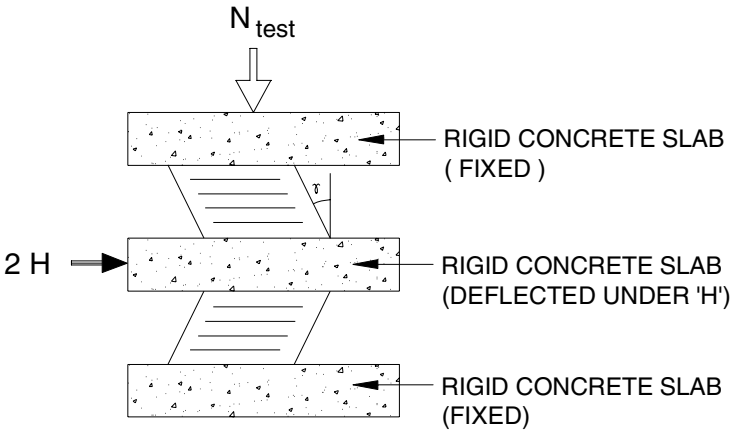
Test for determination of Shear Modulus

- *Conditioning load :* Bearings shall be preloaded with maximum horizontal load H_{test} (with N_{test} or vertical load held constant) and unloaded before test loading.
- *Rate of loading :* N_{test} corresponding to σ_m = 5 MPa shall be held constant during test and the horizontal loading H shall be gradually increased to yield a shear stress rate of approximately 0.05 to 0.1 MPa per minute.
- *Maximum test loading N_{test} :* The horizontal loading H shall be increased upto a maximum H_{test} which corresponds to horizontal deflection equal to 'h' (total elastomer thickness).
- *Measurement :* Load and deflection measurements shall be calculated at approximately equal intervals not less than 5.

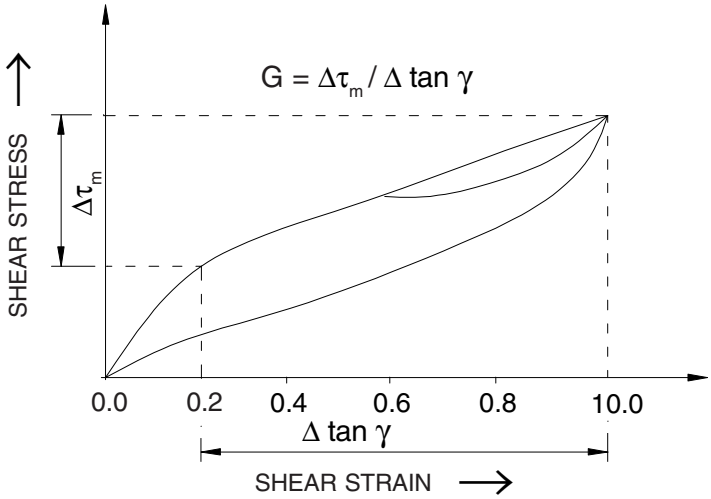
Evaluation

A shear stress strain curve shall be plotted and the value of shear modulus G determined as shown in **Fig. 5.7.**

The test result shall be deemed satisfactory if value of G is within $\pm$ 20% of 1 MPa and provided there is no evidence of instability, defect or damage detected by close inspection during the test.



a) TEST ASSEMBLY



b) SHEAR STRESS STRAIN CURVE

FIG. 5.7 DETERMINATION OF SHEAR MODULUS

Test for determination of Elastic Modulus

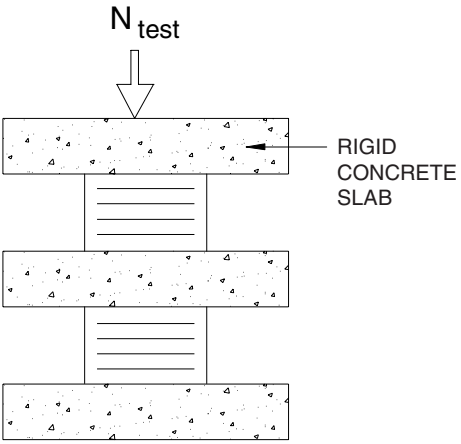
- *Conditioning load :* Bearing shall be preloaded upto N_{test}. The load shall be retained for 10 minutes and unloaded upto σ_m = 2 MPa before test loading.
- *Rate of loading :* The axial load 'N' is increased gradually at a rate yielding approximately σ_m = 0.5 MPa to 1 MPa per minute
- Maximum test loading N_{test} corresponds to σ_m = 20 MPa.
- *Measurement :* Load and deflection measurements shall be made in approximately equal load intervals not less than 5. Deflection shall be measured at four edges and mean value accounted for.

Evaluation

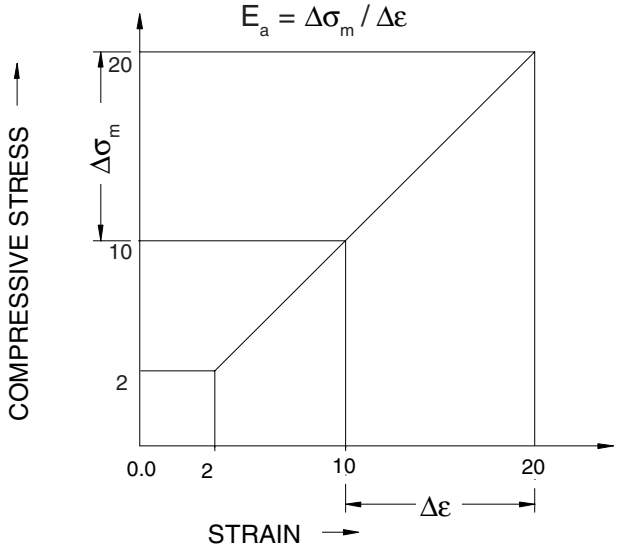
A compressive stress strain curve shall be plotted and the value of apparent elastic modudus 'Ea' shall be defermined as shown in **Fig. 5.8.**

Acceptance Criteria

Test result shall be deemed satisfactory if value of 'Ea' is within $\pm$ 20 percent of $1(0.2/S^2 + 0.0005)$ and provided, there is no evidence of any defect or damage discerned by close visual inspection during the test.



a) TEST ASSEMBLY



b) COMPRESSIVE STRESS STRAIN CURVE

FIG. 5.8 DETERMINATION OF ELASTIC MODULUS

Test for determination of Stripping Strength

Two identical test pieces shall be cut from the test bearing. The plan dimensions of each test piece shall not be less than 100 mm x 200 mm as shown in **Fig.5.9.**

Two opposite ends of each test piece shall bevelled to an angle of 45^0

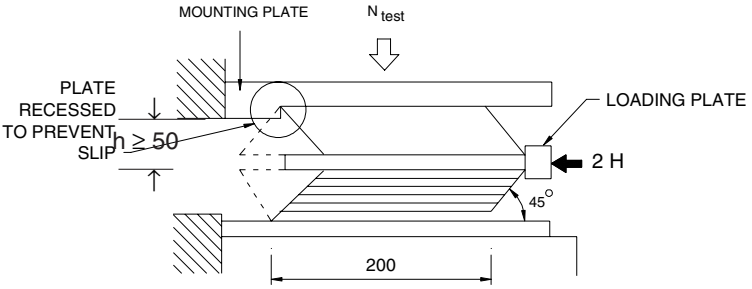


FIG. 5.9 DETERMINATION OF ADHESION STRENGTH

Test Procedure

- Maximum test loading: N_{test} corresponding to σ_m = 4 MPa is to be held constant during the test.
- The horizontal loading H shall be increased upto a maximum yielding τ_m = 3 MPa

Evaluation

Examine the test pieces for evidence of cracking or peeling both in the strained and unstrained state.

Acceptance criteria

If neither test piece shows evidence of

peeling or separation at or near the interface between rubber and reinforcement layers, the bearing shall be deemed to have satisfactory adhesion.

Test for determination of Ultimate Compressive Strength

The test pieces are to be loaded either till the failure of the steel laiminate or till the irreversible squeezing out of elastomer whichever is earlier. The test assembly and the test pieces may be identical to those for 'E' test. However, a small section (not less than 100 x 200 mm) shall be cut from test bearing and testing to failure by placing directly between the plates of the testing machine shall also be performed. The rate of loading shall not exceed 10 MPa per minute. The result of the test shall be deemed satisfactory if the σ_m at failure is not less than 69 MPa.

5.7.3 *Level 2 Acceptance Testing :* This will also include the same tests as in Level 1

A. General inspection
B. Test on specially moulded test piece
C. Test on complete bearings.

But here, the test 'C' is little different as only one test i.e. 'test for shear modulus' is conducted. Since this is not a destructive test, the test bearings can be used in the bridge and these shall become the part of the accepted 'lot'.

5.7.4 *Inspection and Quality Control Certificate :* A 'lot' under inspection should be accepted by the inspector when no defect is found in the acceptance level tests and so certified. In case of any defect in the bearing, the whole 'lot' shall be

rejected by the inspector and certified accordingly.

The bearings shall be transported to the bridge site after final acceptance and should be accompanied by an authenticated copy of the test certificate. An information card giving the following details should be appended to the test cerftificate:

1. Name of manufacturer
2. Date of manufacture
3. Grade of elastomer
4. Bearing dimensions
5. Production Batch No.
6. Accpetance lot No.
7. Date of testing
8. Specific bridge location
9. Explanation of markings on the bearing, if any.

A commentary on various tests conducted on specially moulded test piece

Elastomeric bearings have had an extraordinary performance record over the past 50 years as some of these have been used since 1950 satisfactorily. A number of tests are required to be performed on elastomers in order to ensure the good performance. But still it is not very clear whether all these tests are necessary or not. In this commentary, it has been discussed that some of the tests are not related to the actual performance of an elastomeric bearing and thus may be either scrapped or the prescribed tolerances should be diluted. These are based upon the studies undertaken by AASHTO.

1. Ozone Test

Some research and studies determined that the ozone test was unnecessary as this affects only the surface layer. In un-stretched rubber, ozone degradation is confined to a thin surface layer, typically 0.5 μ. Ozone cracks develop at right angles to the tensile strain and they degrade rubber's tensile strength and may also initiate fatigue growth that ultimately leads to failure of rubber products. Because cracks only occur in regions where tensile stresses are induced, they are unable to penetrate very far into objects, which are under compression. In bearings, the growth of cracks ceases close to the surface because cracks quickly encounter compressive rather than tensile stresses. Therefore, it has been contended that ozone damage is a serious concern in thin-walled products, but not in those bulky products like bearings. Contrarily there is a harmful effect because the manufacturers use anti ozanant waxes to protect against ozone attack. This viscous layer of wax is responsible for a significant number of serious slipping problems where the bearings 'walked-out' of the support area.

2. Accelerated Aging

Accelerated ageing tests are conducted at elevated temperature of 100°C to know the variation in hardness, UTS and elongation at break. The research showed that the size of sample was very important in establishing the significance of aging. Current test methods use very thin specimen and the results generally show significant changes due to aging. The

actual bearing, however, is not a thin specimen and effect of aging is not so pronounced. It was found that it would take hundreds of years of service to change the bearing stiffness by 10%. Given that the correlation between the test and the real situation is not known, it seems that the test is just a quality control test, not a performance test.

3. Hardness

Hardness has been believed to be related to shear modulus but studies have shown that hardness is a surface measurement and it only crudely represents the stress strain relationship in shear.

5.8 INSTALLATION

5.8.1 *General guidelines*: Some of the important provisions of UIC-772-2R and IRC:83 Part-II pertaining to installation of elastomeric bearings are given below:

1. Elastomeric bearings must not be placed one behind the other along the longitudinal axis of the girder on a single line of support under any circumstances.
2. Bearings of different plan size must not be installed next to each other (on the same pier) under the same girder/span.

Different plan area will lead to different value of 'δ' for given values of H, h and G as under:

$$\delta = \frac{H \times h}{G(a \times b)}$$

3. The contact surface between the bearing and

the bed block must be horizontal to avoid tangential force due to gravity coming on to the bearing (maximum tolerance 0.2% perpendicular to load). In case of sloping girders, this may be achieved by providing shims under the girder or by creating a recess with a horizontal surface on the underside of the girder.

4. The bearings must be placed on a contact surface which is free from local irregularities, maximum tolerance being $\pm$1 mm in height.

5. The bearings must be placed at true plan position with a maximum tolerance of $\pm$3 mm (along and across the bridge axis).

6. As a measure of ample safety against accidental displacement, the bearings should be placed in a recess. This is specially necessary for bridges with low DL/(DL+LL) ratio or bridges with larger horizontal displacements. This is typical in railway bridges with steel girders.

7. Where shrinkage and creep are likely to produce excessive horizontal movements, it is advisable to raise the girders before commissioning the bridge, allowing release of this unidirectional displacement.

8. Care should be taken in storage, handling and installation of the bearing to avoid any mechanical damage, contamination with oil, grease, dirt and undue exposure to sunlight and weather.

9. It is preferable to install the elastomeric bearing on a pedestal to permit jacking of the

girders for future replacements and for proper drainage.

10. The area around elastomeric bearings should be inspected and scrupulously cleaned after the installation is complete. Railway bridges with ballasted decks should be provided with suitable expansion joints to prevent ballast from fouling the breathing space between girders, or between end span girder and ballast wall.

5.8.2 *Process of installation :* The process of installation of elastomeric bearing differs in case of precast vis-a-vis cast-in-situ girders. For precast girders, the bearing may be fixed to the underside of the girder by application of epoxy resin adhesives after specified surface preparation. Care should be taken to guard against faulty application and consequent behaviour of the adhesive layer as a lubricant. The adhesive is considered merely as an installation device and is not an adequate anti-creep measure.

The process of installation of elastomeric bearing in a cast-in-situ girder is more complex. It involves the following stages:

1. Placing and adjusting the bearings on the bed block with required accuracy.
2. Preparation of a formwork sideframe all around the bearing.
3. Filling up the space between the bearing and the formwork frame by clean sand.

4. Placement of top forms over the side frame and sand with an opening matching the size and position of the bearing.
5. Sealing of the gaps between the opening in top form and the bearing by adhesive tape.
6. Execution of soffit formwork of the girder.
7. Concreting of the girder.
8. Removal of side forms and sand from around the bearing and cleaning up the spaces.

5.9 PERIODICAL INSPECTION AND MAINTENANCE

The elastomeric bearings are considered largely to be maintenance free. However due to possible deficiencies in manufacture and installation, these bearings may show signs of distress or develop malfunctioning. Before any malfunctioning of the bearings leads to distress in the girders or substructure, it should be detected and preventive actions taken. It is, therefore, necessary to undertake periodical inspection of elastomeric bearings. The inspecting official should look for the following aspects:

- Correct position
- Excessive shear
- Excessive bulging
- Separation of rubber from steel lamination
- Cracking and tearing of elastomer
- Flattening out
- Off-loading of one edge due to excessive rotation

Under the effect of loads and induced movements, the elastomeric bearing will

a) compress (flatten),

b) bulge and

c) shear.

These are signs of normal functioning of the bearing and judgement regarding distress can be formed only on the basis of personal experience of the inspecting engineer. As a general guide, however, the following movements can be considered to be excessive:

a) Shear deformation more than 50% of height of elastomeric pad

b) Rotation leading to off-loading of an edge

c) Compression more than 5% of height of the pad.

Generally, malfunctioning of the elastomeric pad would result in distress either in the girder or in bed block and the area close to the bearing should be examined for cracking or spalling of concrete.

5.10 ELASTOMERIC BEARINGS IN AID OF OLD SUBSTRUCTURES

There are very large number of railway bridges constructed before 1926. The significance of the year 1926 is that it was in that year the IRS : Bridge Rules first incorporated provision of longitudinal force i.e. tractive effort and braking force. Prior to 1926 the bridges were designed only for the vertical effects of axle loads.

With the technological improvements, the bridge rules have also undergone changes primarily to reflect introduction of diesel and electric traction. RBG loading standard - 1975, MBG loading standard - 1987 and HM loading standard - 1995 are characterised by large increase in longitudinal force as compared to the increase in axle loads. In addition, due to the "Policy of Uni-gauge", many MG and NG sections have been upgraded to BG. It is therefore not surprising that a large number of railway bridge substructures are called upon to bear much larger horizontal forces than their original design values.

A check on design calculations of substructure of such bridges indicates unacceptable level of stresses in the bridge substructure. Thus many piers are required to be strengthened or rebuilt even though they happen to be otherwise physically in sound condition. Apart from being costly and time consuming, strengthening measures like jacketing may not inspire full confidence in the load carrying capability of the substructure. Complete rebuilding of bridge, in many cases is far too time consuming to fit within the tight time schedules laid down for gauge conversion works.

A better and cheaper solution to the above problem is possible by way of better management of the longitudinal force on bridges. The longitudinal force is generated at the rail wheel contact surface and it can either be passed on to the substructure through the bearings or can be dispersed onto the approaches. The sharing of the longitudinal force

depends upon the relative stiffness of the "girder-bearings-pier-soil" system or "rail - track - ballast - approach embankment" system. While the derivation of the load sharing is quite complex, it is certain that introduction of a flexible bearing under the girder can disperse more longitudinal force on the approaches, thereby relieving the piers of the horizontal forces. A number of experiments have been conducted in India and abroad on this aspect and rules laid down for dispersion of longitudinal force to approaches. Surprisingly, there is considerable variation in the rules adopted by various countries in this regard. The provision of IRS : Bridge Rules in force on Indian Railways are explained below:

1. The quantum of longitudinal force is laid down in appropriate EUDL tables in the appendix to the IRS : Bridge Rules.
2. Subject to proper standard and condition of track on bridge approaches and provision of rail free fastening on the girders, 25% of the longitudinal force subjected to a minimum of 16t for BG, can be considered to be dispersed on to the bridge approaches.
3. In case, suitably designed elastomeric bearings are used, the above dispersion can be further increased by 40%. Thus use of elastomeric bearings results in 35% of longitudinal force being thrown on to the approaches.
4. In case of a span having free-fixed bearing combination, the full longitudinal force (net after dispersion) is transmitted to the pier with fixed bearing.

5. In case of a span having sliding bearing or elastomeric bearings at both ends the net longitudinal force is shared @ 40% at either support point, the remaining being shared by the piers beyond the loaded span.

Though the above provisions are considered to be conservative by many, it still shows a clear cut benefit of replacing steel sliding bearings or rocker & roller bearings by elastomeric bearings. A note of caution is however necessary that the amount of dispersion will also depend upon the capacity of the rails, joints and approach track to transmit and absorb the longitudinal force. It is however beyond doubt that more studies are necessary in this area and there is scope for retaining old substructures by use of elastomeric bearings.

While replacing other bearings especially rocker & roller by elastomeric, the correction slip no. 6 to Concrete Bridge Code dated 30.7.2002 should be kept in mind, which states that "use of elastomeric bearings in prestressed concrete bridges should preferably be restricted up to maximum clear span of 30 m."

5.11 ANTI-SLIP DEVICES

It has been explained earlier that elastomeric bearings have a tendency to slip if the minimum normal pressure is less than 2 MPa. Such a situation is likely to occur when elastomeric bearings are used in steel plate girders having less self weight. UIC code 772-2R cautions against the use of elastomeric bearings if they are required to undergo simultaneously light

loading and large longitudinal movements.

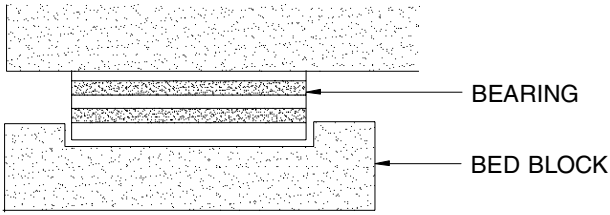
For steel girders of spans ranging from 12.2 m to 30.5 m the minimum bearing pressure is less than 2 MPa. All such bearings, therefore, require some anti-creep or anti-slip device.

There are number of possible ways of providing the anti-slip device as given below:

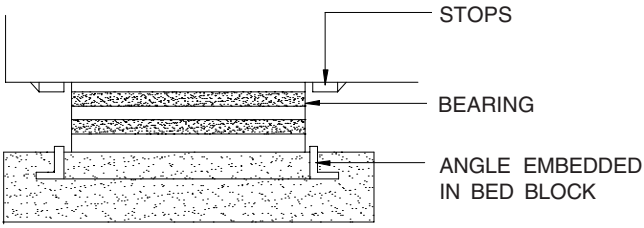
1. *By stops :* In this method stopper plates or angles are welded to the underside of the girder and embedded in the bed block. It should be ensured that the thickness of the elastomer butting against the stops is not considered in the design since this thickness will not take part in the shearing action. A typical anti-slip device using stops is shown in **Fig. 5.10 a.**

2. *By embedment :* A recess can be created in the bed block in which the elastomeric pad will be placed. The functioning of the recess as an anti-slip device is same as that of the stopper plate. The bearing is usually glued to the girder with an epoxy resin. A typical detail is shown at **Fig. 5.10 b.**

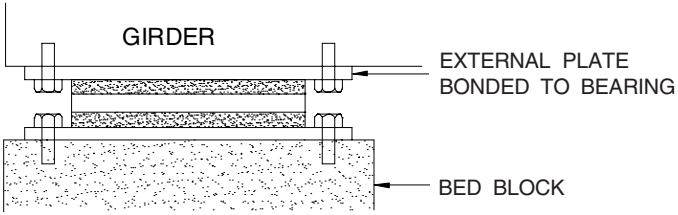
3. *By bolting :* The elastomeric bearing can be vulcanised with a stainless steel outer plate. The stainless steel plate is provided with holes through which anchor bolts can be used for attachment of the bearing to the girder and to the bed block. This method however requires either anchor bolts to be cast along with the girder or dowel holes left in position in the concrete at correct locations. A typical detail of this scheme is shown in **Fig. 5.10 c.**



a) PLACEMENT IN RECESS



b) BY STOPPER PLATE



c) BY BOLTING

FIG. 5.10 ANTI-SLIP DEVICES

5.12 SAMPLE DESIGN PROBLEM FOR ELASTOMERIC BEARINGS

Problem

Check the design of bearing as shown in **Fig. 5.11,** of size 650 x 450 x 120 mm, for 18.3 m span PSC I - girder section as per HMLS 1995. Assume suitable related data and refer IRS : Bridge Rules and IRC-83 Pt.- II.

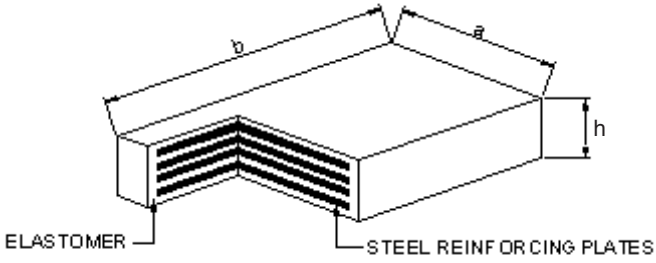


FIG. 5.11 CUT SECTION OF ELASTOMERIC BEARING

Guiding considerations

1. Dimensioning
   (i) $b \leq 2a$ where 'b' is across the traffic and 'a' is along the traffic

   The longer dimension across the girder ensures rotational stability in lateral direction.

   (ii) $a/10 \leq h \leq a/5$

   $a/10 \leq h$ so that it should ride over the irregularities of bed block in a better way.
   $h \leq a/5$ so that there is no buckling condition.

   (iii) Shape Factor $6 \leq S \leq 12$

   $6 \leq S$ so that high vertical stiffness can be given and bulging is controlled.
   $S \leq 12$ not required from design considerations and thus uneconomical.

2. Limits of vertical pressure

   i) Minimum vertical pressure = 2MPa

      Otherwise bearing is likely to 'walk-out'

   ii) Maximum vertical pressure =10 MPa
      Otherwise bearing is likely to get crushed

3. No Slip condition

   a) when only DL is acting.

      μ_1 X DL > slow acting horizontal force

   b) when (DL + LL) both acting.

      μ_2 X (DL + LL) > Total horizontal force

4. Plan dimensions of bearing should be sufficient such that bearing pressure on bed-block should be within permissible limit for the material of bed block.

5. Distortion limit in shear = 70 % of height of bearing

   or δ_{max} = 0.7 x h

6. No uplift condition

   The bridge span rotates at ends due to dead and live load deflections. Due to this rotation, there should be no loss of contact of the far end of the bearing with bed block. To ensure this

   i) $\frac{\sum ei}{a/6} > \tan\alpha_c$ when only dead load is acting.

   ii) $\frac{\sum ei}{a/6} > \tan\alpha_c + 1.5\tan\alpha_s$ when dead load and live load both are acting.

7. Total shear stress in elastomer should be within limit of 5 x G.

Total shear stress includes
a) due to compression
b) due to horizontal load
c) due to rotation

8. Thickness of steel lamination

$$h_s = \frac{2(hi_i + h_{i+1})(P_c + 1.5P_s)}{a \times b \times \sigma_s}$$

Solution:

Thickness of top and bottom rubber pad covers = 6 mm

Steel plates = 8 nos @ 3 mm thick, total = 24 mm

Intermediate elastomer pads = 7 nos @12 mm thick

Thickness of elastomer = 7 x 12 + 2 x 6 = 96 mm

Thickness of bearing (h) = 96 + 24 = 120 mm

1. Dimensioning

(a) Considering 6 mm cover on all sides,

a = 450 - 2 x 6 = 438 mm

b = 650 - 2 x 6 = 638 mm

2a = 438 x 2 = 876

b < 2a ..... Hence OK

(b) a/10 = 43.8 and a/5 = 87

h should be between 43.8 mm & 87 mm

h provided = 96 mm .....almost satisfied.

(c) $S = \frac{a \times b}{2(a+b)h_i} = \frac{438 \times 638}{2(438+638)12} = 10.82$

(It is calculated for individual layer)

Since, $6 \leq S \leq 12$ ..... Hence OK

2. Limits of vertical pressure

Data for 18.3 m span (HMLS)

Dead load of span = 226 t

Weight of ballast and track per span = 96 t (say)

Slowly applied vert. load = 226 + 96 = 322 t

Slowly applied vert. load per bearing P_c = 322/4
= **80.5 t**

For a girder of 18.3 m clear span
overall length of girder = 20 m

L (m)	Total load for BM	Total load for SF	CDA=0.15+8/6+L
20	261.8 t	286.2 t	0.458

Total load for shear =286.2 t (excluding CDA)

Total load including CDA = 286.2 x 1.458

Quick acting vertical load per bearing

$$Ps = \frac{286.2 \times 1.458}{4} = 104.32 \text{ t}$$

σ_{min} (only due to DL)

$$= \frac{80.5 \times 1000 \times 10}{438 \times 638} = 2.88 \text{ MPa} > 2 \text{ MPa} \quad \text{... O.K.}$$

…hence no slip condition

σ_{max} (due to both DL & LL)

$$= \frac{(80.5 + 104.32) \times 1000 \times 10}{438 \times 638} = 6.61 \text{ MPa} < 10 \text{ ... O.K.}$$

3. No slip condition

L	Tractive Effort	Braking force
20.0 m	75.0 t	50.6 t

Horizontal load adopted = 75.0 t. (higher of TE & BF)

∴ Quick acting horizontal load per bearing

$$H_S = \frac{75 \times 1000 \times 0.4}{2} kg = 15\,t$$

(Considering 40% horizontal load on one support)

Assuming value of G = 1 MPa

Shear strain = shear stress/G

$$\text{Shear Strain} = \frac{15 \times 1000 \times 10}{638 \times 438 \times 1} = 0.54$$

Movement corresponding to above strain

= 0.54 x 96 = **51.84 mm**

Slow movements due to temperature effect

(Assuming temp. change of 30^0C with other end fixed)
Temperature movement = $\propto$ t l

= 1.17 x 10^{-5} x 30 x 20 x 1000 = 7 mm

Adding 3 mm for creep and shrinkage

Total movement = **10 mm**

Slow acting horizontal force H_c corresponding to movement of 10 mm
= 638 x 438 x 1 x 10/96 = 2.9

Check for no slip condition

μ = coefficient of fraction = 0.10 + 0.6/N

for DL only μ_1 = 0.10 + 0.6/2.88 = 0.31

for DL + LL μ_2 = 0.10 + 0.6/6.61 = 0.19

When only DL is acting

Slow acting horizontal force = 2.9 t

Resisting frictional force = 0.31 x 80.5 t

= 24.96 t > 2.9.....safe

When (DL + LL) both are acting

Total horizontal force = 2.9 + 15 = 17.9 t

Resisting force = 0.19 x (80.5+104.32)

= 35.1 > 17.9 t .....safe

4. Bed block concrete

σ_{max} = 6.61 MPa

use M30 grade concrete for bed block

Permissible stress in bearing = 0.25 x 30

= 7.5 MPa ..... safe

5. Limit of distortion

$$\text{Shear strain} = \frac{51.84 + 10}{96}$$

= 64.4% .....safe

6. Check for no uplift condition at most lightly loaded edge of bearing

Assumptions:

Let the vertical defection under DL + LL = 25 mm

Rotation at bearing = 25 x 2 / 20000

= 0.0025 radians

Rotation due to only DL

$$= 0.0025 \text{ x } \frac{80.5}{80.5 + 104.32} = 0.0011 \text{ radians}$$

Rotation due to LL

$$= 0.0025 \text{ x } \frac{104.32}{80.5 + 104.32} = 0.0014 \text{ radians}$$

a) For D.L. condition

$$\frac{\sum ei}{a/6} > \tan\alpha_c$$

$$\text{where } ei = \frac{hi \times N}{4GS^2 + 3N}$$

Compression of individual layer

$$= \frac{12 \times 2.88}{4 \times 1 \times (10.82)^2 + 3 \times 2.88} = 0.072 \text{ mm}$$

Compression of 7 layers = 7 x 0.072 = 0.504

$$\frac{\sum ei}{a/6} = \frac{0.504}{438/6} = 0.007 \text{ radian}$$

Rotation under DL = tan α_c = 0.0011 radian

Hence $\frac{\sum ei}{b/6}$ > tan α_c ..... hence safe.

b) For DL + L. L. Condition

$$\frac{\sum ei}{a/6} > \tan\alpha_c + 1.5\tan\alpha_s$$

Compression of individual layer

$$= \frac{12 \times 6.61}{4 \times 1 \times (10.82)^2 + 3 \times 6.61} = 0.162 \text{ mm}$$

Compression of 7 layer = 7 x 0.16 = 1.14 mm

$$\frac{\sum ei}{a/6} = \frac{1.14}{438/6} = 0.016 \text{ radians}$$

tan α_c +1.5 tan α_s = 0.0011+1.5 x 0.0014

= 0.003 radians

Hence $\frac{\sum ei}{a/6} > \tan \alpha_c + 1.5 \tan \alpha_s$ ..... hence safe.

7. Check for total sheer stress

a) Sheer stress due to compression load

$$= \frac{1.5}{S}\left(\frac{P_C + 1.5P_S}{axb}\right)$$

Factor 1.5 with P_s makes allowance for severe effect of vertical vibratory railway loads observed during test.

$$= \frac{1.5}{10.82} \times \frac{80.5 + 1.5 \times 104.32}{438 \times 638} \times 10^3 \times 10 = 1.18 \text{ MPa}$$

b) Shear stress due to horizontal load

$$= \frac{(15 + 2.9) \times 10^3 \times 10}{438 \times 638} = 0.64 \text{ MPa}$$

c) Shear stress due to rotation

$$= \frac{Ga^2}{2 \times hi \times H}(\tan \alpha_c + 1.5 \tan \alpha_s)$$

The factor 1.5 for tan α_s makes allowance for the fatigue effects produced by rapid variation of vertical vibrators railway loading.

$$= \frac{1 \times 438^2}{2 \times 12 \times 96}(0.0011 + 1.5 \times 0.0014) = 0.27 \text{ MPa}$$

Total shear stress = 1.18 + 0.64 + 0.27

= 2.09 MPa < 5 MPa ..... safe

8. Check suitability of 3 mm thick steel plates

$$hs > \frac{2(h_i + h_{i+1})(P_c + 1.5P_s)}{a \times b \times \sigma_s}$$

σ_s = allowable stress in steel = 140 MPa

$$> \frac{2(12+12)(80.5 + 1.5 \times 104.32)}{638 \times 438 \times 140}$$

> 2.9 mm

Therefore, adopted size of 3 mm is safe.

❍ ❍ ❍

CHAPTER 6

POT BEARINGS

6.1 GENERAL

POT bearing was developed in 1959 as an alternative to heavy steel sliding bearings. It consists of a circular non-reinforced rubber-pad fully enclosed in a steel pot. The rubber is prevented from bulging by the pot walls and it acts similar to a fluid under high pressure.

From the discussion on various bearings, it has been observed that most of the bearings have the limitation of either load or movement capacity. The load range and movement capacity of various types of bearings are given in **Table 6.1**.

TABLE 6.1 Load and Movement Ranges

	Load (T)	Movement
Sliding	20 – 133	± 25 mm
Rocker & roller	60 – 266	100 mm
Elastomeric	30 – 220	60 mm

The above bearings are adequate for smaller spans having the requirement of load and movement, within the range prescribed in the above table. But what to do for the larger spans having more load and more movements? In fact the problem of load can be solved by providing more bearing area or providing more number of bearings so that load is shared by many bearings. However this idea of 'sharing' can't be extended to movement because the number of ends can't be more than two.

Therefore, it is the requirement of movement which is more critical than the load requirement and we require some other type of bearing where the horizontal movement should not be the limiting factor. Since necessity is the mother of invention, a special category of bridge bearing was developed known as 'POT and PTFE'. PTFE is a short form of Poly Tetra Fluoro Ethylene.

6.2 POT-PTFE BEARING vs ELASTOMERIC BEARING

In POT bearing, two most important synthetic materials i.e. Elastomer & PTFE are utilised. Elastomer has an excellent property of providing translation and rotation without any moving parts. In POT-PTFE bearing, the latter part is utilised by completely encasing the elastomer pad in steel casing or POT. PTFE has an excellent property of having very low coefficient of friction and in the free end, a sliding component is added on top of POT, comprising stainless steel and PTFE for translation. The rotation, therefore, is provided by elastomer due to differential compression and translation by steel and PTFE.

Elastomeric bearing, otherwise, considered to be an ideal bearing, could not be used in larger spans because of some drawbacks. These drawbacks of elastomeric bearing which lead to development of POT – PTFE bearing are given below:

(1) The ordinary elastomeric bearing can't be used as a fixed bearing.

(2) The translation allowed by the elastomeric bearing is restricted by its thickness.

$$\delta = \frac{H \times h}{G(a \times b)} \quad \text{or} \quad \delta \propto h$$

'δ' is generally restricted to 50-60% of total thickeness of the elastomer.

(3) In order to have more value of 'δ', the thickeness of the elastomer pads will have to be increased but the same can't be increased beyond a limit as thicker elastomer pads are rather unstable.

(4) There is a limit to the vertical load also which the elastomeric pad can safely withstand. Large vertical loads result in greater amount of compression and bulging.

(5) Large rotation create the danger of off-loading of one edge and overstressing the other.

Fig. 6.1 to 6.4 show typical details of various types of POT-PTFE bearings.

6.3 PROPERTIES OF PTFE

PTFE is a linear chain polymer of great molecular strength, known for its chemical inertness and low coefficient of friction. PTFE is not oxidised easily, it is resistant to all common solvents and remains stable at extremes of atmospheric temperatures.

It was earlier thought that lowest coefficient of friction could be obtained with PTFE sliding against PTFE. But on the basis of tests conducted on several frictional interfaces, it has been conclusively proved that the frictional coefficient of PTFE sliding against grounded stainless steel surface is lower than PTFE on

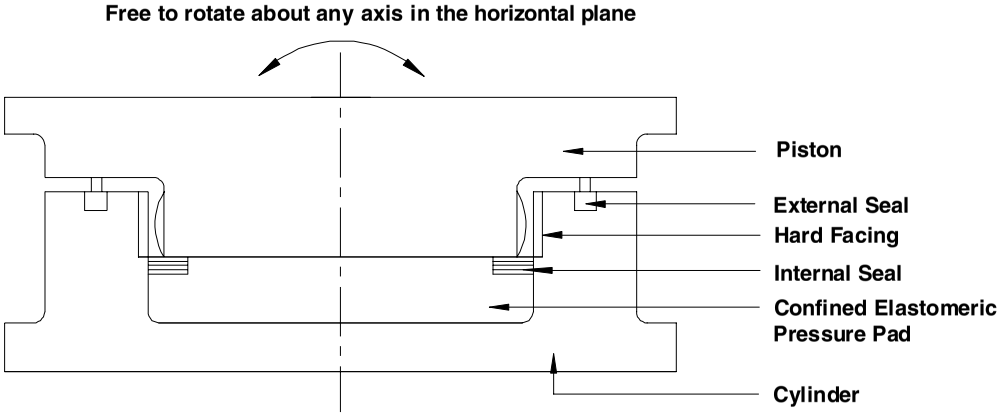


FIG. 6.1 FIXED TYPE POT BEARING

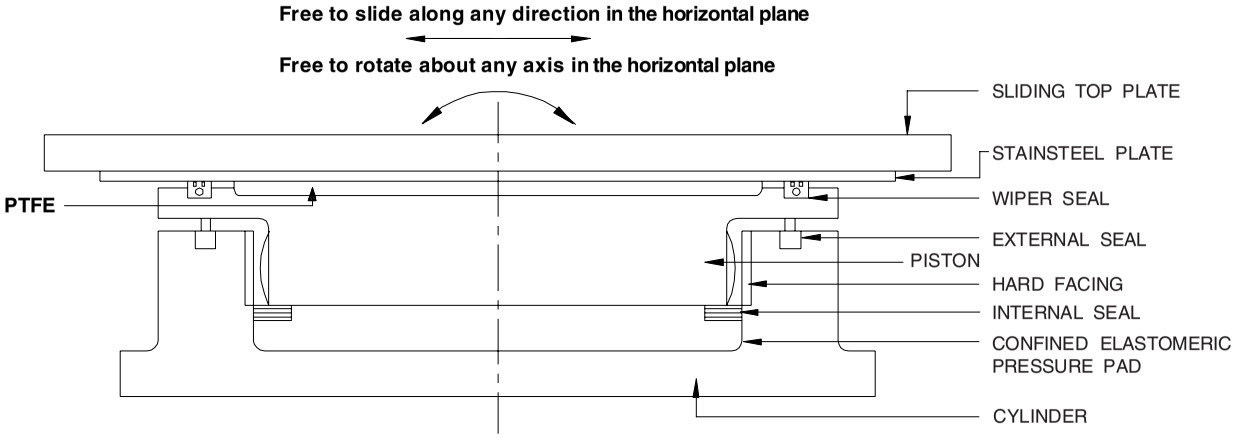


FIG. 6.2 FREE SLIDING TYPE POT-CUM-PTFE BEARING

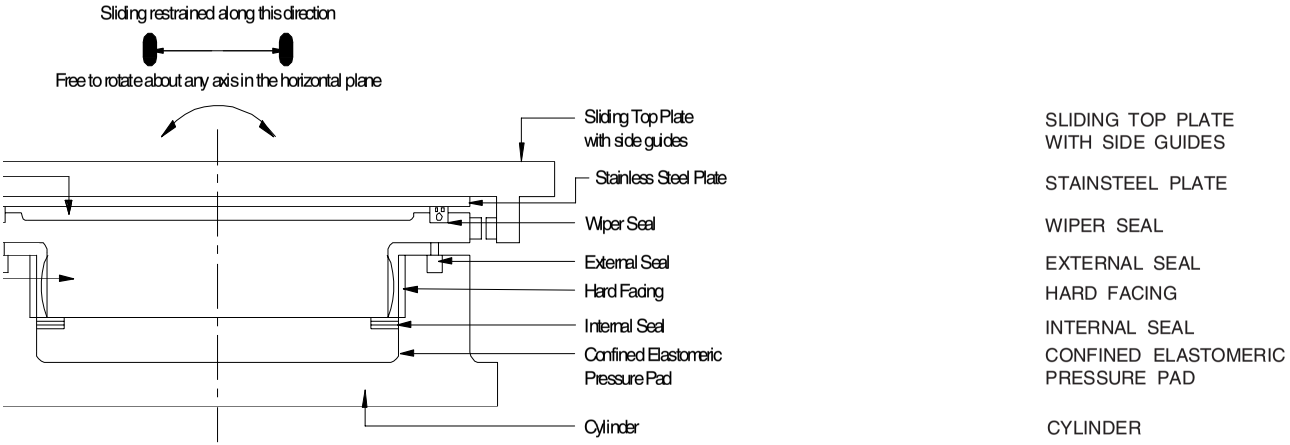


FIG. 6.3 POT-PTFE BEARING WITH SLIDING GUIDES

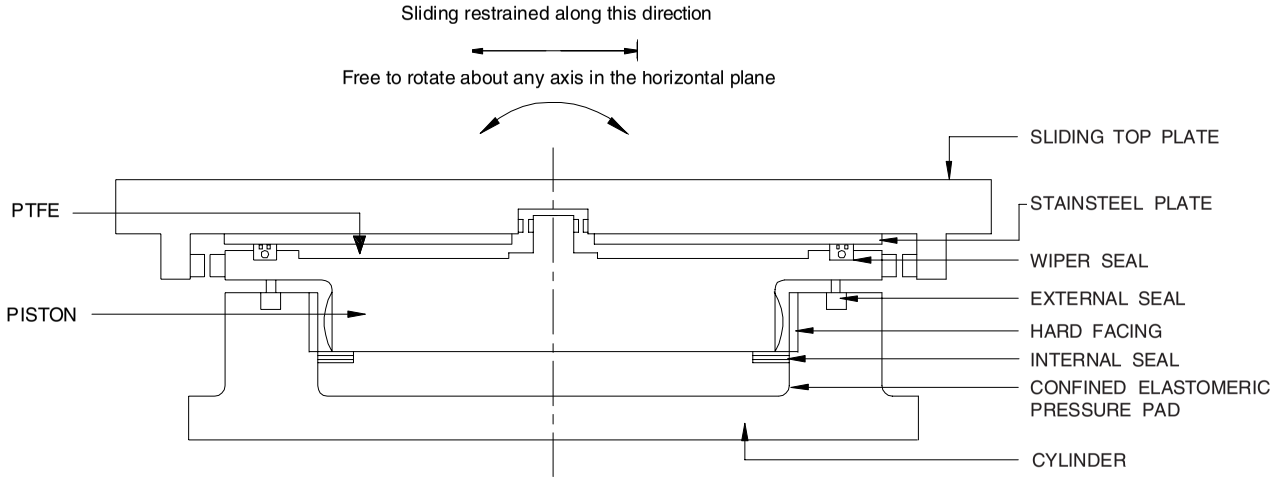


FIG. 6.4 POT-PTFE BEARING WITH CENTRAL GUIDE

PTFE. However PTFE has poor creep properties i.e. it exhibits permanent compression under loads. It also has poor bonding properties, and therefore, always used in thin sheets (upto 3 mm) recessed in a steel plate with half the thickness of PTFE embedded. Addition of certain fillers such as glass fibre, graphite or bronze to PTFE increases the wear resistance and creep properties but it also increases the frictional resistance. Fillers of molybdenum sulphide or silica though improves wear and creep properties without appreciable increase in friction. In bridge bearings, pure PTFE is therefore rarely used.

Although, friction between steel and PTFE is the minimum, yet it is highly susceptible to intrusion of dust. Elaborate arrangements are, therefore, must to prevent entry of dust particles on the sliding surface. Silicon grease is generally used as a lubricant for PTFE surfaces. Dust seals are also recommended around PTFE bearings to prevent the ingress of dust.

6.4 PERMISSIBLE BEARING PRESSURE ON PTFE

For the purpose of design, it is important to lay down permissible bearing pressure on PTFE sliding surfaces. There is no code of practice available in India for this purpose. Reference may be made to BS:5400 Section 9.1 and AASHTO specifications of USA for this purpose. The values as given in **Table 6.2** obtained from various technical literature give an idea about the range of the permissible stress in various types of PTFE.

TABLE 6.2 PERMISSIBLE BEARING PRESSURE

Type of PTFE	Average bearing pressure (MPa)	Max. edge pressure (MPa)
Filled PTFE or unfilled recessed PTFE	24.5	35
Unfilled PTFE (not recessed)	14	35
PTFE with bronze	42	70
PTFE perforated metal composite	35	35

BS:5400 limits the average pressure on PTFE with glass fibres to 45 MPa and PTFE in a metal matrix to 60 MPa. For any material other than the above, permissible values should either be established by tests or the values recommended for unfilled PTFE should be adopted.

6.5 OTHER RECOMMENDATIONS FOR DESIGN OF PTFE SLIDING BEARING

1. Expansion bearings having sliding surfaces of PTFE shall have a provision for minimum 0.01 radians of rotation. This is to prevent excessive local stresses on the PTFE sliding surface.
2. The minimum and maximum thicknesss of PTFE sliding surface shall be as given in **Table 6.3**.

TABLE 6.3 THICKNESS OF PTFE SURFACES

Type of PTFE	Minimum thickness	Maximum thickness
Filled PTFE	0.8mm	2.4mm
Unfilled PTFE	0.8mm	2.4mm
PTFE with bronze	0.8mm	3.0mm
PTFE perforated metal composite	1.6mm	3.0mm

3. The contact surface of PTFE shall have a minimum Brinell hardness of 125 and surface finish of less than 20 microns.
4. Holes or slots shall not be made in the sliding surfaces.
5. For calculating the pressure on PTFE, the contact surface area may be taken as the gross area of the PTFE without making any deduction for lubricating cavities, if any.
6. The stresses in the elastomer are limited by the effectiveness of the seal preventing it from squeezing out. However, they should not exceed 40 N/mm^2.
7. The lateral pressure exerted on the cylinder (POT) can be considered to be that produced by the pad acting as a fluid. The stress analysis in the pot is very complex and should be verified by testing.

6.6 DESIGN ASPECTS

Basic elements of a POT bearing are:

- POT or a shallow cylinder
- an elastomeric pad
- a set of sealing rings
- a piston

POT bearings are fixed against all translation unless they are used with a PTFE sliding surface.

The POT may either be one piece construction shaped by machining or fabricated by welding ring on to the base plate. The elastomer pad inserted into the POT is restrained from being squeezed out of the annular gap between the side wall and the piston by means of a set of two or three flat brass rings. The circular rings have traditionally been brazed into a closed circle, whereas the flat ones are usually bent from a strip and the ends are not joined. Brass rings are placed in a recess on the top of the elastomeric pad. PTFE rings have been tried, but have been abandoned because of their poor performance. The cover piston which fits into the POT is placed in contact with the elastomer pad. In the POT type sliding bearing the cover/piston is mounted by a sliding assembly. The upper surface of the piston is recessed and filled with the PTFE disc. The upper sliding plate is provided with a sheet of stainless steel or chrome nickel alloy steel. The PTFE disc is provided with small cavities (lubrication pockets) containing a special lubricant which ensure life long lubrication of the sliding surface. An all around seal is

provided to prevent ingress of moisture and dust on the contact surface as well as inside the POT. Generally four holes are drilled in the top plate as well as the plate on which POT is mounted to facilitate attachment of the POT bearings to the girders and bed block.

The PTFE-steel contact surface can also be in the form of two hemispheres in which case the bearing provides for rotation as well as translation. The following types of actions are there in POT bearings.

a) *Compression :* Vertical load is carried through the piston of the bearing and it is resisted by the elastomeric pad. Elastomer is incompressible, though deformable. Due to this property, elastomer exerts pressure on the POT wall like a fluid. Deformation of the POT wall is a concern since this deformation changes the clearances between the POT and the piston. Similarly in the downward direction, the base plate deformation causes the POT wall to rotate inward.

b) *Rotation :* POT bearings are associated with large rotations which are accomodated by the deformation of elastomeric pad. Large cyclic rotations can be very damaging to POT bearings due to abrasion and wear of the sealing rings and elastomeric pad. In fact, during rotation, the elastomeric pad compresses on one side and expands on the other, so the elastomer is in contact with the POT wall and slips against it. This causes elastomer abrasion and sometimes contributes to elastomer leakage. To mitigate this problem, silicon grease is generally used.

c) *Lateral load :* Lateral load is transferred from the piston to the POT by contact between the rim of the piston and the wall of the POT. The contact stresses are generally very high. Lateral loads may also contribute to increased wear of the elastomeric pads and greater potential for wear and fracture of the sealing rings.

The damage observed in tests suggests that the lateral load should be carried through an independent mechanism wherever possible.

Design aspects will become clear in design problem at the end of chapter.

6.7 INSTALLATION OF POT BEARINGS

In a sliding POT bearing, positive fixing to the main structure may not be required if the bearing is always subjected to adequate vertical loading which is the case in most of the concrete bridges. In such a case, any horizontal movement will always occur on the plane of least resistance which is of course the sliding surface of bearing. However, it is prudent to provide some fixing to guard against displacement during installation, impact, vibrations and accidental loading.

Malfunctioning in a bridge bearing, in majority of cases, can be traced to faulty installation and much of damage usually occurs during installation, handling or storage. Careless handling on site and ingress of dirt can easily lead to abnormally high frictional resistance. The sliding POT bearings are, therefore, normally delivered at site with the top and bottom parts bolted together. The bearings should not be dismantled at site. The bearings should be

transported and unloaded carefully and stored under cover in clean, dry conditions.

The seating provided under the bearing should be perfectly levelled. It is common to use a mortar bedding composed of sand-cement mortar with or without epoxy resin. A cube crushing strength of 35 N/mm^2 is usually recommended for the bedding mortar. While installing the bearing, the transit bolts must be in position and these should be removed after the mortar has set and before the bearing is called upon to slide or rotate.

POT bearings have been used in many important bridges on Indian Railways. It was used, in addition to many other bridges, in the construction of 3rd Godavari Bridge at Rajamundry having bow string arch girders of 90 m span, on Zuari and Mandovi bridges on the KRCL having 120m span open web steel girders. Recently these have also been used on a number of bridges on Jammu-Udhampur Rail Link Project (JURL) e.g. Tansi bridge (71.4+102+71.4m), Dudhar bridge (64+92+64m) and E-18 viaduct (40+29.68m) etc. POT-PTFE bearings are being used on Udhampur-Srinagar section also. POT bearings, both fixed and sliding type can be used to advantage in all situations where there is a limitation on overall height of the bridge girder coupled with large force/movements involved. This is so because the POT bearings are substantially thinner as compared to roller bearings. PTFE sliding sheets have also been used for the launching of superstructures of bridges in Konkan Railway and JURL with great

advantage.

6.71 Placement of Expansion End

For placement of expansion end of the bearing at a particular ambient temperature, other than the mean temperature, necessary correction has to be applied. The drawings of Pot-PTFE bearings, generally specify the values of the movement of the point of inter section (of bottom chord and end raker) with reference to center line of base slab under combined effect of temperature and loading. At the mean temperature, the center line of the bearing and the point of intersection shall match under full live load with impact. Therefore, under the dead load alone, the point of intersection of girder shall be towards the span with respect to the centerline of the bearing. Mean temperature is to be taken as Tmin + (Tmax-Tmin)/2, where Tmin & Tmax are the specified values of the minimum and maximum temperatures for the location.

6.72 Fixing of Bearings

1 To cater for vibration and accidental impact, some anchorage should be provided. Anchorage should be accurately set into recesses cast into the structure using templates and the remaining voids in the recesses should be filled with material capable of withstanding the loads involved.

2 Bearings that are to be installed on temporary supports should be firmly fixed to the substructure by anchorage or other means to prevent disturbance during

subsequent operations. Finally, voids beneath the bearings should be completely filled with bedding material using the appropriate method.

3 Bearings may be fixed directly to metal bedding plates that may be cast in or bedded on top of the supporting structure to the correct level and location.

4 If the structure is of steel, the bearings may be bolted directly to it. Proper care shall be taken to ensure that there are no mismatch in the bolt holes of the structure and the bearing.

5 .Threaded fasteners shall be tightened uniformly to avoid overstressing of any part of the bearing.

6.8 DESIGN SPECIFICATIONS FOR POT-PTFE BEARINGS

General Guidelines

- Provisions apply for temperature ranges of -10°C to +50°C.
- POT bearing of dia. up to 1500 mm are within scope of these specifications.
- Tensile load can't be applied to bearings.
- Rotation up to 0.025 radians only considered.

Confined elastomer used in metal POT is unreinforced. It allows only rotation by virtue of differential compression. The popular property of elastomer i.e. translation due to shearing strain is not used here in POT-PTFE bearings due to confinement.

Specifications

1. Design horizontal force generated due to friction at sliding surface shall in no case be less than 10% and greater than 25% of design vertical load i.e. μ = 0.10 to 0.25.

   Moment will be induced due to stiffness of elastomer and friction at piston-cylinder contact. This may be computed as under:

a) Induced moment resulting from resistance to rotation due to effect of tilting stiffness of elastomeric pressure, is given as

$M_{e,d} = di^3 \times (k_1 \, q_p + K_2 \, q_v)$

di = dia of elastomer pad in mm

k_1, k_2 = constants depending upon di/he as given in **Table 6.4**

he = thickness of elastomer pad in mm

q_p = rotation angle in radian due to long term effect
q_v = rotation angle in radian due to short term effect

TABLE 6.4 Values of constant k_1 and k_2

di/he	k_1	k_2
15.0	2.2	101.0
12.5	1.8	58.8
10.0	1.5	30.5
7.5	1.1	13.2

b) Induced moment will also result due to friction at piston-cylinder contact which is given by
$M_{R,d} = 0.2 \times C \times H$

C = perpendicular distance from point of action of horizontal force on cylinder wall to the axis of rotation (mm) as shown in **Fig 6.5**.
H = Design Horizontal force (N)

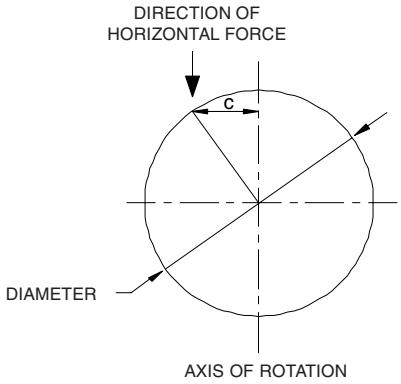


FIG. 6.5 MOMENT ARM FOR ROTATION RESISTANCE

c) Total induced moment

$$M_{T,d} = M_{e,d} + M_{R,d}$$

For pin bearings $M_{e,d} = 0$

Therefore, $M_{T,d} = M_{R,d}$

Design values of rotation and translation movement will be multiplied by a factor of 1.3.

2. Recommendations for confined elastomeric pad

(a) Permissible limits for confined pressure on elastomer pad depends upon effectiveness of internal seal preventing it from extruding. Therefore, it shall be verified by load testing of assembled bearing.

(b) Dimensioning of pad should be such that at design rotation, the deflection at perimeter shall not exceed 15% of pad thickness (he,eff) below internal seal, as shown in **Fig. 6.6.**

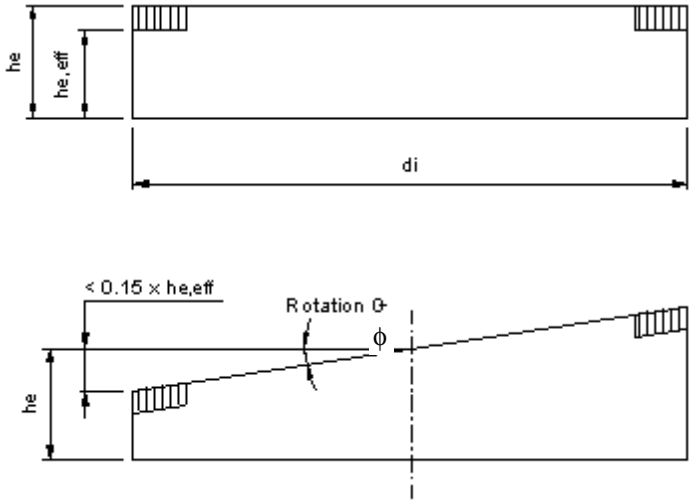


FIG. 6.6 DEFLECTION IN ELASTOMERIC PRESSURE PAD

(c) Even then average stress in pad shall not exceed 35 MPa and extreme fibre stress shall not exceed 40 MPa. However minimum value, under any critical combination of loads, shall not be less than 5 MPa.

(d) The thickness of confined elastomeric pad shall not be less than 1/5th of its diameter or 16 mm whichever is higher. Its diameter shall not be less than 180 mm.

3. Recommendations for PTFE

(a) It can be either of the two forms given below:

(i) Dimpled large sheet

It may be circular or rectangular divided maximum into four parts. For dimpled sheets with smallest dimension exceeding 100 mm (dia. or smaller side of rectangle), the contact area shall be taken as gross area without deduction for the area of the dimples.

(ii) Arrayed (without dimples)

Distance between individual modules shall not be greater than 10 mm. Thickness of PTFE and its protrusion from recess depends upon maximum plan dimension as given in **Table 6.5**.

TABLE 6.5 Thickness of PTFE and its Protrusion

Max. dimension of PTFE (mm) (Diameter or diagonal)	Minimum thickness (mm)	Max.protrusion above recess (mm)
≤ 600	4.5	2.0
> 600, ≤ 1200	5.0	2.5
> 1200, ≤ 1500	6.0	3.0

(b) The coefficient of friction between stainless steel and uniformly lubricated PTFE will be as given in **Table 6.6**.

TABLE 6.6 Coefficient of friction between PTFE and Stainless steel

Average pressure on confined PTFE (MPa)	Max. value of 'μ' for lubricated PTFE	'μ' for unlubricated PTFE
5	0.08	Double the
10	0.06	values for
20	0.04	lubricated PTFE
≥ 30	0.03	

For design purpose, the value of 'μ' corresponding to unlubricated PTFE is taken into account.

(c) Average pressure on confined PTFE shall not exceed 40 MPa and extreme fibre pressure shall not exceed 45 MPa.

Corresponding values for confined elastomeric pad are 35 MPa and 40 MPa

5. Permissible limits in bolt and screws for Class 4.6 (Ref IS : 1367).

(a) Permissible stress in axial tension ≤ 120 MPa
Permissible stress in shear ≤ 80 MPa
Permissible stress in bearing ≤ 250 MPa
For higher class than 4.6, the above values shall be multiplied by factor 'x'

$$\text{Where } x = \frac{\text{yield stress or 0.2\% proof stress or 0.7 x UTS (whichever is greater)}}{235 \text{ MPa}}$$

(b) For bolts and screws subjected to both shear and axial tension.

$$\frac{\text{Calculated shear stress}}{\text{Permissible stress in shear}} + \frac{\text{Calculated tensile stress}}{\text{Permissible stress in tension}} \leq 1.4$$

6. Permissible stress for welds

(a) Permissible stress in fillet weld based on its throat area shall be 110 MPa.

(b) Permissible shear stress on plug welds shall be 110 MPa.

No increase in permissible stresses is allowed for seismic, wind or any other load combination for elastomer pad, PTFE, bolt and screws or welds.

6.9 DESIGN OF POT- PTFE BEARINGS

In absence of 3D - FEM analysis, simplified design can be adopted. For POT bearings of vertical load capacity 7500 KN or higher, the analysis should always be done using 3D–FEM with authentic software.

Design steps

1. Effective contact area shall be calculated with load distribution of confined elastomer stress as 1V : 2 H, as shown in **Fig. 6.7.**

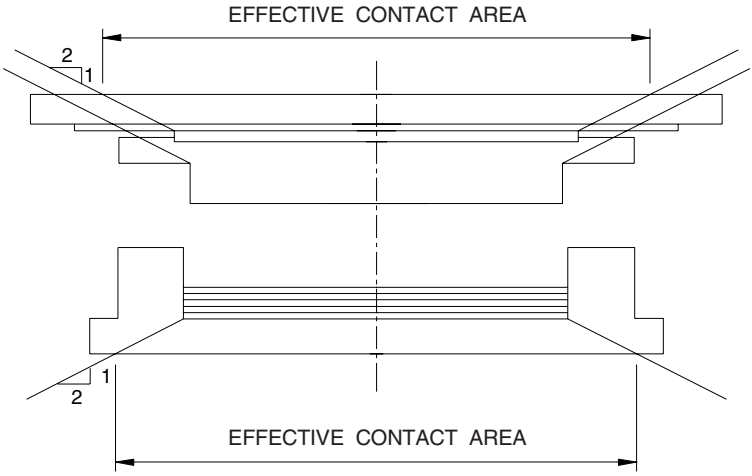


FIG. 6.7 LOAD DISPERSION THROUGH BEARING COMPONENTS

2. The confined elastomer pad is considered to act as fluid exerting fluid pressure under vertical load.

3. Total hoop tensile stress on cross section of cylinder wall will be due to -

(a) Fluid pressure due to elastomer
(b) Horizontal force

The sum of both shall not exceed the permissible stress value in axial tension.

(i) The hoop tensile stress due to elastomeric bearing = $\frac{d_i \times h_e \times \sigma_{ce}}{2 \times b_p \times h_c}$

where;
d_i = Dia of elastomer pad (mm)
h_e = thickness of elastomer pad (mm)
σ_{ce} = fluid pressure in elastomer due to vertical load
b_p = thickness of cylinder wall (mm)
h_c = Height of cylinder wall (mm)

Total force on cylinder wall = projected area x σ_{ce}

Projected area = $d_i \times h_e$

From **Fig. 6.8** $2T = \frac{d_i \times h_e \times \sigma_{ce}}{b_p \times h_c}$

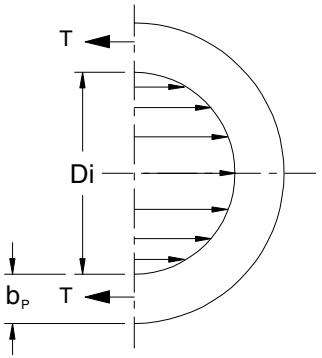


FIG. 6.8 HOOP TENSION

Therefore, Hoop tension (T) = $\frac{d_i \times h_e \times \sigma_{ce}}{2 \times b_p \times h_c}$

(ii) The hoop tensile stress due to horizontal force

$$= \frac{H}{2 \times b_p \times h_c}$$

4. Shear stress at cylinder wall and base interface will be due to

   (a) Fluid pressure

   (b) Horizontal force

   and the total shall not exceed the permissible value in shear.

(i) Shear stress due to fluid pressure

$= \frac{h_e \times \sigma_{ce}}{b_p}$ for 1 mm radial slice as shown in **Fig. 6.9.**

Radial shear on 1mm radial slice = $h_e \times 1 \times \sigma_{ce}$

Resisted by a section = $b_p \times 1$ at interface

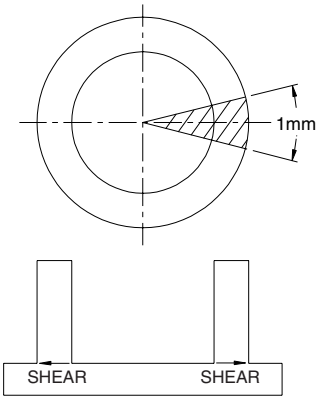


FIG. 6.9 CALCULATION OF SHEAR STRESS

therefore shear stress = $\frac{h_e \times \sigma_{ce}}{b_p}$

(ii) Shear stress due to horizontal force

$$= \frac{1.5 \times H}{b_p \times d_i}$$

Factor 1.5 has been taken due to parabolic distribution

5. Bending stress at cylinder and base interface shall also be due to -

(a) Fluid pressure

(b) Horizontal force

The total shall not exceed the permissible value of bending stress.

(i) Bending stress due to fluid pressure

$$= \frac{6 \times \sigma_{ce} \times h_e^2}{2 \times b_p}$$

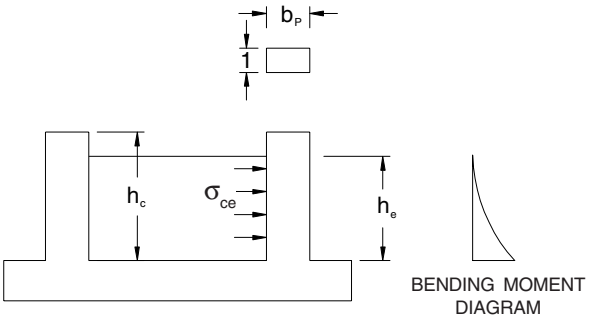


FIG. 6.10 CALCULATION OF BENDING STRESS

M at interface = $\frac{\sigma_{ce} \times h_e^2}{2}$ as shown in **Fig. 6.10**

Bending stress at interface

$$f = \frac{\sigma_{ce} \times he^2}{2} \times \frac{y}{I}$$

$$I = \frac{1 \times b_p^3}{12}$$

$$y = \frac{b_p}{2}$$

Therefore,

$$f = \frac{\sigma_{ce} . h_e^2}{2} \times \frac{b_p}{2} \times \frac{12}{b_p^3}$$

$$= \frac{6 \times \sigma_{ce} \times h_e^2}{2 \times b_p^2}$$

(ii) Bending stress due to horizontal force

$$= \frac{1.5 \times 6 \times H \times ha}{d_i \times b_p^2}$$

Where, ha = Height of application of design horizontal force 'H' in N from cylinder wall above base interface in mm.

Force H is acting on entire section width of d_i

Therefore, force per unit length = $\frac{H}{d_i}$

Max force per unit length = $1.5 \frac{H}{d_i}$ (considering parabolic distribution)

Therefore, M at interface = $1.5 \frac{H}{d_i}$ x ha

$$\text{Bending stress} = \frac{M.y}{I} = 1.5\frac{H}{d_i} \times ha \times \frac{b_p}{2} \times \frac{12}{1 \times b_p^3}$$

$$= \frac{1.5 \times 6 \times H \times ha}{d_i \times b_p^2}$$

6. Combined bending and shear shall also be checked such that the equivalent stress due to co-existing bending and shear stress shall not exceed 0.9 fy.

   Equivalent stress when bending is in tension

   $$= \sqrt{3 \times (\text{Calculated shear stress})^2 + (\text{Calculated bending tension})^2}$$

   or

   Equivalent stress when bending is in compression

   $$= \sqrt{3 \times (\text{Calculated shear stress})^2 + (\text{Calculated bending stress in comp})^2}$$

7. Minimum dimensions in POT bearing

   (a) Minimum thickness of cylinder base shall not be less than 2.5% of inner diameter of POT cylinder.

   (b) Minimum thickness of sliding component of stainless steel shall not be less than 2.5% of max. dimension (dia. or diagonal) in plan.

   (c) Min. thickness of any steel component shall in no case be less than 12 mm.

8. Other minimum dimensions

   (a) Minimum theoretical depth of effective contact width of piston at design rotation shall not be less than 5 mm.

   (b) Minimum theoretical clearance between the top edge of cylinder and the bottom edge of piston at design rotation shall not be less than 5 mm.

(c) For sliding component, the stainless steel surface always overlap the PTFE even when the extreme movement occurs. The welded connection with backing plate should be designed to withstand only the force generated at sliding interface due to friction. The thickness of stainless steel plate shall be guided by the requirement of proper welding and in no case shall be less than the thickness of weld or 3 mm (whichever is higher).

6.10 DESIGN OF GUIDES

1. Sliding surface for guides and sliding assemblies shall be made of one of the following:

   (a) Stainless steel sliding on confined PTFE
   (i) 'μ' to be taken for unlubricated PTFE
   (ii) Average pressure on PTFE should not be > 40 MPa
   Extreme fibre pressure should not be > 45 MPa

   (b) Stainless steel sliding on stainless steel
   (i) 'μ' = 0.2
   (ii) Bearing pressure should not be >150 MPa
   But it may be increased by 33.33% when effect of wind or EQ is taken into account.

   (c) Stainless sliding on composite material
   (i) 'μ' = 0.05
   (ii) The pressure on composite material shall not exceed 70 MPa.

2. Guide shall be in the form of one guide bar located centrally or two guide bars attached side wise to the sliding plate. But one thing is certain that it shall be monolithic to the component to which it is connected, thickness of which shall not be less than thickness of guide along direction of horizontal force acting on the guide.

3. For central guides
(a) The thickness of the recessed portion of sliding plate shall not be less than

0.3 x thickness of sliding plate or
0.3 x width of recess or
12 mm

(b) The vertical clearance between the guide and the recessed sliding plate shall not be less than

0.2 % of length of recess or
2 mm

6.11 DESIGN OF ANCHORING ARRANGEMENT

Aim : Bearings should be replaceable with minimum lifting of the superstructure

1. The horizontal force transmission capacity of the anchorage shall be considered as the sum of friction force developed at the interface and the capacity of the anchorage to resist shear force. Here 'μ' will be taken as 0.2

2. (a) The diameter of anchor sleeves should not be < 2 x nominal diameter of bolts/screws.
(b) The length of sleeve should not be > 5 x diameter.

3. Peak stress on concrete adjacent to the anchor sleeve shall be calculated using the following expression.

$$\sigma_{cpu} = \frac{3 \times A \times \delta}{D \times L}$$

σ_{cpu} = peak stress in concrete behind anchor sleeve (MPa)
A = Effective tensile area of bolt/screw (mm^2)
δ = permissible shear stress in bolt / screw
D = Diameter of sleeve (mm)
L = Length of sleeve (mm)

4. Specifications for bolt / screws

(i) The threaded fastening length of bolt / screw (of class 4.6) should not be < 0.8 x nominal dia.
For higher class, it will be proportionately adjusted.

(ii) Edge distance should not be < 1.5 x dia. of hole.

(iii) Centre to centre distance of bolt/screw should not be < 1.5 x dia. of hole.

(iv) a) Anchor studs shall be made of forged steel.

For adjacent structure made of concrete of grade M35 and above -
- Length of stud should not be < 6 x dia. of stud
- Dia of stud head should not be < 2.5 x dia. of stud
- Thickness of stud head should not be < 0.4 x dia. of stud
- Stud head shall be always monolithic to the studs.

b) Centre to centre distance between studs should not be < 3 x dia. of studs.

For manufacturing tolerances, manufacturing methods, finishing, acceptance specifications, installation and maintenance, IRC-83 (Pt.III) may be referred.

6.12 SAMPLE DESIGN PROBLEM FOR POT-PTFE BEARINGS

Problem

Design the bearing for 76.2 m open web girder. Assume suitable related data and refer IRS : Bridge Rules and IRC-83 Pt.- III. Assume seismic zone-IV.

Effective span = 78.8 m
D.L. of girder + track + gangway etc = 405 t
Live load for shear = 980.024 t

From Bridge Rule Appendix- XII (H M Loading standards)
EUDL for shear = 980.024 t (corresponding to Span 78.8 m)

Assumed data :

Vertical load due to wind / bearing	=	16.84 t
Lateral load due to wind / bearing	=	24.2 t
Lateral load due to seismic effect	=	25.18 t
Longitudinal force / bearing	=	67.5 t
Max. horizontal movement	=	63.5 mm
Total vertical load including wind only	=	423.123 t
Total vertical load including seismic effect only	=	454.613 t
Deflection at center	=	116 mm

Rotation = 116/39400 = 0.0029 radian < 0.025, therefore all provisions of IRC 83 - (Pt-III) can be applied.

A. Design of elastomeric pad

Guiding considerations :

- Minimum dia. should be 180 mm. Also the area should be sufficient such that average vertical permissible stress should not be > 35 N/mm^2
- Min. average pressue should not be < 5 N/mm^2
- Extreme fibre stress should not be > 40 N/mm^2
- Thickness of elastomeric pad should be minimum of

(a) Dia. / 15
(b) 16 mm

Add 6 mm for brass ring and 25% provision for creep.

- Deflection at perimeter should not be > 15% of pad thickness.

1. Maximum vertical load = 454.61 t (including seismic effect)
   Average permissible stress = 35 N/mm^2

$$\frac{P}{\pi/4 \times d^2} = 35$$

   d = 406.77 mm

   Provide d = 490 mm.

2. P_{min} = 405/4 = 101.25 t

   Min. Avg. Stress = 101.25 x 10000 / π/4 x 490^2
   = 5.36 N/mm^2 > 5 N/mm^2 ..... OK

3. Max. horizontal movement = 63.5 mm at guided sliding end
   Max. eccentricity = 63.5/2 + 10% for unserviceable service condition
   Moment due to this eccentricity = 454.61 X 0.035
   = 15.91 tm

   Extreme fibre stress = P/A + M/Z

$$= \frac{454.61 \times 10^4}{\pi/4 \times 490^2} + \frac{15.91 \times 10^7}{\pi/32 \times 490^3}$$

   = 37.86 N/mm^2 < 40 N/mm^2 O.K.

4. Thickness should be greater of

a. Dia of elastomer/15 = 490/15 = 32.67 say 35 mm.
b. 16 mm (minimum)
c. Extra 6 mm for brass ring – 3 Nos. and 25% for creep

$\therefore$ Minimum thickness = (35 + 6) 1.25
= 51.25 mm
Say 55 mm

5. Deflection at perimeter = Max. 15% of pad thickness
= 0.15 x 55 = 8.25 mm
Actual rotation = 0.16869 degrees
Actual deflection at perimeter = 490/2 x tan 0.16869
= 0.7213 < 8.25 … OK

B. Design of confined PTFE

- Average pressure on confined PTFE should not be > 40 MPa, and
- Extreme fibre pressure should not be > 45 MPa

There are two alternative for shape of PTFE:

Alternative 1 Square shape of sheet

Considering square sheet of 450 x 450 mm^2

$$\text{Average pressure} = \frac{454.61 \times 10000}{450 \times 450}$$

= 22.45 N/mm^2 < 40 MPa ……. OK

Extreme fibre stress = P/A + M/Z

$$= \frac{454.61 \times 10^4}{450 \times 450} + \frac{15.91 \times 10^7}{450^3/6}$$

= 32.93 N/mm^2 < 45 N/mm^2 ....OK

For max. dimension of PTFE < 600 mm

Min. thickness = 4.5 mm Adopt 5.0 mm

Max. protrusion above recess = 2.0 mm
Adopt = 2.0 mm

Alternative 2 Round shape of sheet

Consider dia. = 520 mm

$$\text{Av. pressure} = \frac{454.61 \times 10^4}{\pi/4 \times 520^2} = 21.40 \text{ N/mm}^2$$

< 40 N/mm^2 …… OK

Extreme fibre stress = P/A + M/Z

$$= \frac{454.61X10^4}{\frac{\pi}{4}X520^2} + \frac{15.91X10^7}{\frac{\pi}{32}X520^2}$$

= 21.40 + 11.525 = 32.925 < 45 MPa … OK

Adopt 4.5 mm thick pad with max. protrusion as 2.0 mm.

C. Design of POT cylinder

Guiding considerations :

- Resultant force due to longitudinal and lateral force should not be less than 10% and greater than 25% of design vertical load.
- Permissible axial tension due to hoop shall not exceed 0.6 x fy.

1. Longitudinal force per bearing = 67.5 t
   Lateral force due to wind = 24.2 t
   Horizontall seismic force = 25.18 t

   Resultant with wind pressure = $\sqrt{67.5^2 + 24.2^2}$
   = 71.71 t

   Resultant with seismic force = $\sqrt{67.5^2 + 25.18^2}$
   = 72.26 t

   Out of wind and seismic force, only one is assumed to act at one time. (greater of above two adopted).

   Design horizontal force H = 72.26 t (adopted)

   72.26 should be < 25% of 454.61 = 113.65 t

   and also,

   72.26 should be > 10% of 454.61 = 45.46 t

   Both satisfied .....OK

2. Axial tension in cross section of cylinder wall will be due to -

a. Fluid pressure
b. Horizontal force of 72.26 t

a. Fluid pressure = $\dfrac{d_i \times h_e \times \sigma_{ce}}{2b_p \times h_c}$

d_i = dia of confined elastomer pad = 490 mm
h_e = thickness of confined elastomer pad = 55 mm
σ_{ce} = fluid pressure in elastomer due to vertical load

$= \dfrac{454.61 \times 10^4}{\pi / 4 \times 490^2} = 24.12$ N/mm^2

b_p = thickness of cylinder wall
h_c = height of cylinder wall

fluid pressure = $\dfrac{490 \times 55 \times 24.12}{2 \times b_p \times h_c}$ ..... (I)

b. Axial or hoop tensile stress due to H = $\dfrac{H}{2 \times b_p \times h_c}$

$= \dfrac{72.26 \times 10^4}{2b_p \times h_c}$ ..... (II)

Total (I) + (II) = $\dfrac{104.76 \times 10^4}{b_p \times h_c}$ N/mm^2

This value should not exceed 0.6 fy or 0.6 x 280 = 168 Mpa

Therefore $\dfrac{104.76 \times 10^4}{b_p \times h_c} = 168$

$\therefore$ $b_p \times h_c = \dfrac{104.76 \times 10^4}{168} = 6235.72$

taking $b_p = h_c = \sqrt{6235.72}$

= 78.9 mm Adopt $b_p = h_c = 90$ mm

D. Design of base plate of POT

Assume base plate thickness = 65 mm

Dispersion of stress through 65 mm plate at 1V : 2 H

Dia. at base resisting pressure = 490 + 2 x 2 x 65 = 750 mm

Max. pressure = P/A + M/Z

Min. pressure = P/A – M/Z

$$\text{Max. pressure} = \frac{454.61x10^4}{\pi/_4\, x750^2} + \frac{15.91x10^7}{\pi/_{32}\, x750^3}$$

= 10.29 + 3.84 = 14.13 N/mm²

Min. pressure = 10.29 – 3.84 = 6.45 N/mm²

Moment at XX due to upward force as shown in **Fig. 6.11**

$$= 12.80x130x\frac{130}{2} + \left(\frac{14.13 - 12.80}{2}\right)x130x2/3x130$$

= 108160 + 7492.33 = 115652 N-mm

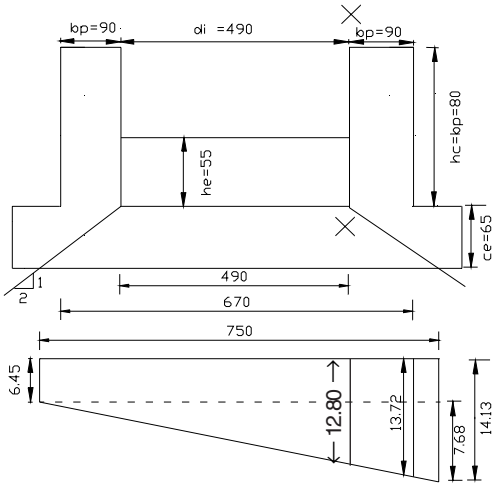


FIG. 6.11 MOMENT DUE TO UPWARD FORCE

Thickness of plate required:

Taking 1 mm width, $Z = \frac{1xt^2}{6}$ or $t = \sqrt{6Z}$

M/Z = f = 0.66 fy (fy = 280 MPa)

= 184.8 N/mm ^{2}

Z = M / 184.8 = 115652 / 184.8 = 625.822

$t = \sqrt{6Z}$

= 61.277 mm Adopt = 65 mm

E. Checks for cylinder

(a) Check for shear stress

Shear stress at interface of cylinder wall and base will be due to fluid pressure and horizontal force. Considering 1 mm slice of cylinder.

(i) fluid pressure = $\frac{h_e \times \sigma_{ce} \times 1}{b_p \times 1}$

$= \frac{55 \times 24.12}{90}$

= 14.74 N/mm^2

(ii) Horizontal force = $\frac{1.5 \times H}{d_i \times b_p}$

(Factor 1.5 for parabolic distribution and total H will be resisted by $d_i \times b_p$)

$= \frac{1.5 \times 72.26 \times 10^4}{490 \times 90}$ = 24.58 N/mm^2

Total shear stress = 14.74 + 24.58 = 39.32 N/mm^2

< 0.45 fy or 126 N/mm^2 ..... OK

(b) Check for bending stress

Bending stress at cylinder and base interface considering 1 mm radial slice of cylinder due to

(i) fluid pressure $= \frac{M}{Z} = \frac{\sigma_{ce} \times h_e \frac{h_e}{2}}{b_p^2/6}$

$$= \frac{24.12 \times 55^2}{2 \times 90^2/6} = 27.02 \text{ N/mm}^2$$

(ii) Horizontal force $= \frac{\frac{1.5H}{d_i} \times h_a}{b_p^2/6}$

ha = height of line of application of design horizontal force from cylinder wall above base interface in = 75mm

$$= \frac{1.5 \times 72.26 \times 10^4 \times 75}{490 \times 90^2/6}$$

$= 122.891 \text{ N/mm}^2$

Total bending stress = (i) + (ii) = 149.914 N/mm^2

< 0.66 x fy or 184.8 N/mm^2 …….. OK

(c) Check for combined bending & shear

$$= \sqrt{\text{Shear.stress}^2 + \text{bending.stress}^2}$$

$$= \sqrt{39.32^2 + 149.91^2}$$

= 164.655 N/mm^2 < 0.9 fy or 252 …….. OK

F. Design of side guides for sliding of POT – PTFE bearing

Size of side guide = 350 x 50 x 30

1. Lateral load due to wind = 24.2 t

2. Horizontal seismic force = 25.18 t

   Greater of the two i.e. 25.18 t is adopted

   (a) Check for shear stress

   Shear Stress < 0.45 fy

$$\frac{25.18x10^4}{350x50} < 0.45 \times 230$$

14.39 N/mm^2 < 103.5 N/mm^2 …….. OK

(b) Check for bending stress

Moment at - XX

M = 25.18 x 10^4 x 30

$$Z = \frac{350 \times 50^2}{6}$$

$$\frac{M}{Z} = 51.8 \text{ N/mm}^2 < 0.66 \text{ fy}$$

< 151.8 N/mm^2 ……..OK

(c) Check for combined bending and shear

$$\text{Total stress} = \sqrt{3 \times \text{shear.stress}^2 + \text{bending.stress}^2}$$

$$= \sqrt{3 \times 14.39^2 + 51.8^2}$$

= 57.4844 N/mm^2 < 0.9 fy or 207 N/mm^2

…… Hence OK

6.13 Common problems with Pot-cum-PTFE bearings

1. The concept of pot bearing is based on effectively confining the elastomer within a metallic piston-cylinder arrangement so that the elastomer remains in a state of uniform strain and no tension is produced while subjected to very large compressive stress. Unlike traditional laminated elastomeric bearing, such a perfectly confined elastomer, while subjected to large compressive stress, behaves like a viscous fluid and therefore is capable to cater for high degree of multi directional rotational movement. Extremely tight tolerance of manufacturing is required to be maintained together with properly detailed effective sealing system to confine the elastomer effectively. If the steel piston is manufactured with high tolerance relative to the base pot, a condition of steel-to-steel contact develops which inhibits the rotational capacity of the bearing device. When the piston is manufactured with a low tolerance relative to the base pot, the sealing ring has difficulty in containing the elastomer, which acts like a fluid under pressure.

2. There have been a number of problems with pot bearings, due to inadequate design, incorrect selection of raw material and improper production technique. Leakage of the elastomer has been noted, even with bearings, considered well manufactured. Abrasion or wear of the elastomeric pad has also been noted in some cases. A number of reasons have been postulated for these problems including inadequate clearances or tolerances between the piston and cylinder, excessive rotation, number of rotational cycles or lateral loads, abrasion of the sealing ring, deformation of the Pot due to excess lateral load or gravity load, inadequate surface finish of the portion of piston/cylinder in contact with elastomer pad etc.

3. The other problems include inability of the steel pot to withstand the transverse loadings, combined with the pressure developed from the elastomer. Another is

the fact that satisfactory rotational distribution is not achieved until a load of atleast 25% of the bearing capacity, is applied. The rotational resistance of the confined elastomer pad, though not negligible, is often ignored due to lack of understanding of behavior of the pad and in some cases due to absence of data. Another problem has been experienced with the pot concept in cold climates. This deals with the rotational element being typically manufactured from synthetic rubber (chloroprene rubber) as in India. During extreme cold temperatures, coupled with high-design pressures, the rotational element has been known to crystallize, which in turn eliminates the rotational capacity of the device. Many cases of such types of failures have forced the design authorities to revert back to traditional steel bearings. However, in India no such failure has been reported so far.

4. All these defects/deficiencies in the confined elastomeric pad element in a pot bearing cannot be detected after installation and transfer of full load, unless the bearings are removed and elastomeric pressure pad is taken out for inspection of the elastomeric element, metallic cylinder and piston. For the same reason, the behaviour of the elastomeric rotational element cannot be checked visually during proof load and movement testing at manufacturer's works. Therefore, a lot of care has to be exercised at the manufacturing and inspection stage.

6.14 Maintenance of Pot-cum-PTFE bearings

1. The Pot-cum-PTFE bearings are designed and manufactured so as to make it almost maintenance free. However, the surrounding area of the bearings shall always be kept clean and dry to avoid damage to the bearings.

2. Suitable easy access to the bearing shall be provided for inspection and maintenance. Provision shall be made for jacking up the superstructure so as to allow repair/replacement of the bearings.

3. Inspection of bearing at site is required from time to time to ascertain the performance of the bearings. Periodic nominal maintenance of bearing shall be carried out in order to ensure better performance and longer life. The bearings are required to be inspected at an interval of one year for the first five years and at an interval of two years thereafter. However, the bearings shall also be examined carefully after unusual occurrences, like movement of abnormal heavy traffic, earthquakes, cyclones and battering from debris in high floods.

4. The inspection shall be preceded by careful cleaning of the bearings and its surrounding space, depending on the actual conditions around the bearings, e.g., deposit of salt, debris, dust or other foreign material.

6.15 Elements of Inspection

1. Measurement of movement - During inspection at site, measurements are required to be taken and documented to compute its movement and rotation values in relation to their design values to ascertain whether the performance of the bearings are satisfactory. To ascertain maximum movement, measurement should be taken once during peak winter (early morning) and once during peak summer (after noon) and corresponding atmospheric temperature should be recorded. The recoded value of movement shall be compared with the design values.

2. Measurement of dimensions - Overall dimensions of the bearings is required to be measured and compared with the actual dimensions to ascertain any excessive stress or strain on the bearing.

3. Evidence of lock in condition- If any moveable or rotating part of a bearing is found to be in locked-in/ jammed condition, necessary rectification measures shall be taken immediately.

4. Evidence of corrosion - If corrosion of any part of exterior exposed steel surface of the bearing is detected the following measures may be taken.

i. Detect affected part

ii. Wire brush the affected portion to clean the rust.

iii. Apply protective coating as per manufacturer's specifications.

5. Condition of the adjacent bridge structure - The adjacent structure of the bearings are also required to be inspected for any damage and necessary actions to repair the same, should be initiated. The root cause of defect should be searched and remedial actions should be planned to avoid recurrence of the problem.

6.16 RESULTS AND ACTIONS

The results of every inspection to be recorded in the inspection report and shall be classified in each case into the following types of action:

i) No action

ii) Further measures/long-term monitoring or design analysis needed (e.g., considering extreme temperatures/ exposures, variation of loads, etc.).

iii) Minor repair works e.g. cleaning, repainting etc.

iv) Repair or replacement of entire bearing or parts of the bearing.

In case of defects where the cause of necessary actions cannot be determined by the inspecting person or the responsible bridge engineer, the design engineers/ manufacturer should be consulted.

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CHAPTER 7

EMERGING TRENDS IN BEARINGS

7.1 GENERAL

New innovations have taken place in the area of bridge bearings, notable among them are:

(1) Shock Transmission Unit (STU) or Lock Up Device (LUD)

(2) Seismic Isolation Bearings (SIB)

7.2 SHOCK TRANSMISSION UNIT

Ever since engineers have started designing multi span simply supported bridges, they have been dreaming of connecting all the spans together to distribute seismic loads to more than one pier during an earthquake or other sudden loadings. Thus, the peaks due to sudden force is considerably reduced.

One possible solution to this requirement could be continuous construction of bridges so that a large number of piers can participate in load sharing during earthquake. But the requirement of size of expansion joint in such an arrangement would be extraordinarily large and thus not feasible.

The other solution has been provided by Shock Transmission Unit (STU) or Lock Up Device (LUD). It is a simple device which is designed to

be connected between superstructure and substructure of a bridge to form a temporary rigid link as shown in **Fig. 7.1**. The peculiar feature of this device is that it forms a rigid link only under rapidly applied loads such as braking and seismic forces whereas under slowly applied loads such as temperature, creep, shrinkage etc, it allows the free movement.



FIG. 7.1 CONNECTION OF STU

STU, thus, allows load sharing in case of suddenly applied short duration horizontal loads. The unit is connected near the bearing between the superstructure and substructure. It works on principle that rapid passage of viscous fluid through a narrow gap generates considerable resistance while slow passage through the same gap only minor resistance as shown in **Fig. 7.2.**

In this figure e_1 and e_2 are the movements accomodated in STU due to superstructure and substructure respectively.

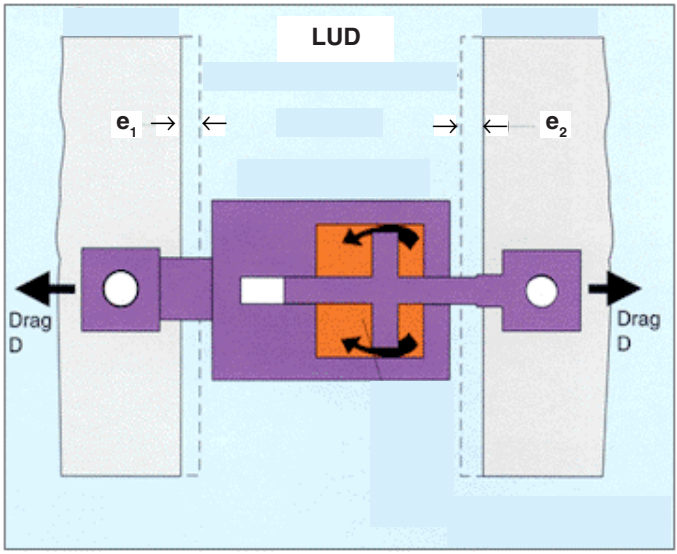


FIG. 7.2 PRINCIPLE OF WORKING OF STU

Use of an STU was first made by Steinman, the designer of Carquinez Bridge in California in 1927 and thereafter it was used in many bridges in US, Europe, Netherlands and UK. In India STU has been used for the first time in the Second Bassein Creek Road Bridge, Mumbai. It has not yet been tried on Indian Railways.

7.2.1 *Description :* The STU as shown in the **Fig. 7.2** consists of a machined cylinder with a transmission rod that is connected at one end to the structure and at the other end to the piston of the cylinder. Inside the cylinder a specially formulated Silicone compound is filled in an unpressurized condition

instead of normally used hydraulic oil.

The compound doesn't adjust quickly to accommodate the movement and therefore locks up under the action of a sudden load. Under slow acting thermal, creep or shrinkage movements, the liquefied compound gradually migrates from one side of piston to the other and allowing the piston and cylinder to expand or contract with the structure.

7.2.2 *Advantages :*

(a) STU is simple to install with minimal traffic disruption.

(b) STU can be used for strengthening of existing bridges also. This option of strengthening is more economical and feasible than structural methods.

(c) Efficient design of new continuous bridges due to reduction in structural component sizes.

(d) STU can also be used advantageously for expansion joints as shown in **Fig. 7.3**

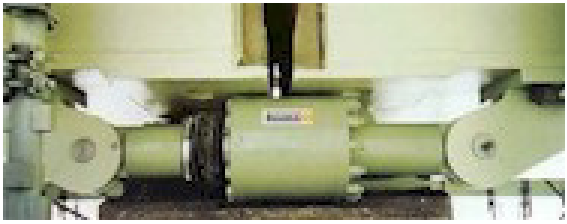


FIG. 7.3 STU FOR EXPANSION JOINTS

7.2.3 *Limitations :* STUs are not intended for energy/ shock absorption. They simply transmit load from one part of the structure to another thus sharing

the load among various spans.

7.2.4 *STU on second Bassein Creek Road Bridge, Mumbai :* In India, the Second Bassein Creek Bridge is a good example of a new multi span continuous bridge where installation of STUs have saved time and money in construction of caisson foundations.

The bridge is located 25 m upstream of existing bridge on Mumbai-Ahmedabad NH-8 near Ghodbunder at the confluence of Ulhas river and the Arabian Sea. Being a creek area with two low and high tides, the site is very difficult for construction of caissons. Average daily tidal variation is of the order of 4.25 m with an average velocity of 2.4 m/s. All these conditions at site made the caissons construction a risky and difficult task.

The bridge was designed for vessel collision for an impact force of 5000 KN at well cap, horizontal seismic coefficient of 0.075 and importance factor of 1.5. The central navigational span being 114.7 m and earthquake shock as a function of the deck mass, the caisson foundation with fixed pot bearing was to be designed for 9300 KN seismic horizontal loading. During preliminary design it was found that for the above loading of 9300 KN, the size of caisson required was 16.5 m for P4.

The engineers immediately realized the difficulty in constructing such a large 16.5 m caisson in this difficult creek conditions combined with very high cost. This was the situation where it was decided to incorporate Shock Transmission Unit on P3 and P5 to create temporary fixity at these

piers during seismic loading. The STU on piers P3 and P5 would lock up during an earthquake thereby distributing the seismic loading of about 9300 KN among P3, P4 and P5 according to their stiffness.

This resulted into a massive reduction of the diameter of Caisson for pier P4 from16.5 m to 12.5 m This not only made the Caisson construction manageable but also resulted into considerable cost saving.

7.2.4.1 *Type :* Presently two types of STUs are available in the overseas market:

(a) Silicon putty based from UK and USA

(b) Oil based from some countries in Europe

The disadvantage of oil STU is that oil is more likely to leak out rapidly from the cylinder than Silicon putty, which is like dough.

7.2.4.2 *Cost :* There is a keen competition among the few STU manufacturers. For the second Bassein Creek Bridge, the average cost of two STUs of capacity 3100 KN was US $100,000 including supply at site, specified tests at UK, brackets holding down bolts airlifted from UK to the site and assistance of a qualified supervisor for the installation of STUs at the site.

7.2.4.3 *Basic requirement of Design :* The STU must withstand the specified design load. The stroke of the piston must be bigger than the movement of deck due to temperature, shrinkage & creep in each direction of the deck's longitudinal movement. Just to give an idea about the movement of deck to the readers, the movement of the deck was for +40 mm to –90 mm.

The maximum life expected for an STU is around 75 years subject to appropriate maintenance being performed by the user.

7.2.4.4 *Critical factors in Design :* (a) STUs are unidirectional devices for load transmission. If out of plane forces will be acting on the STU, the angular limits of these loads must be determined to assure that the STU can withstand them. Generally ball joints and or additional devices can be incorporated to properly transfer these forces.

(b) For rail road bridges, the traction forces may equal or exceed seismic forces in magnitude and applied many times over the life of the structure.

(c) The corrosion protection for STU is very important. The position rod, in particular, should be protected from environment by a scaled cover able to accommodate the full stroke of the STU.

7.2.5 *Load testing of STUs* :

a) Seal wear
b) Fatigue load
c) Drag load
d) Dynamic force transfer
e) Cyclic load

a) *Seal wear test :* Seal prevents the leakage of silicon putty in the cylinder. The test is conducted for 30000 cycles assuming that the piston of STU moved for the full design range in 24 hrs. 30,000 cycles equals 82 years which is more than the expected life of STU which is 75 years.

b) *Fatigue load test :* This test was carried out for 100,000 cycles for maximum capacity of STU, assuming the worst case that the 'Lock Up Load'

is applied to STU due to braking load four times a day for specified design life of 75 years.

c) *Drag load :* This test ensures that excessive load should not be transmitted to the structure by the STU. As per the test the STU shall have an impressed deflection of '0 mm – 40 mm – 0 mm – 40 mm – 0' mm in not less than 10 hrs and not more than 24 hrs. During the impressed deflection cycle the STU shall develop no more drag force than 10% of the maximum design capacity of 3100 KN.

d) *Dynamic force transfer test :* This test mainly prove the lock up capability of the device.The STU shall be loaded in tension from zero to the full design load in less than 0.50 seconds and the force sustained for 5 seconds.

Then the load shall be reversed to the full design load in less than 0.50 seconds and held again for 5 seconds. The acceptance criteria for the above test shall be that the deflection during the loading of the positive force and the negative force shall be no greater than 6 mm and the deflection during sustained load portion shall not exceed 3 mm.

e) *Cyclic force transfer test :* This test is specified to prove that the STU would function as intended during a seismic event. The STU shall be tested by applying 50 sinusoidal cycles of load ranging between the maximum design tension and compression forces at a frequency of 1 Hz. There shall be no visible signs of distress or degradation as a result of 50 cycles of loading.

7.2.6 *Installation of STU :* It is not always necessary to

install STUs while a structure is under construction but the holding down anchor bolts and the brackets are required to be fixed in structure during construction. There are two ways of connecting STUs to a structure.

a) One way is to connect the superstructure element together normally at the expansion joints.

b) The other way is to connect superstructure elements to substructure elements.

The first type of connection may be more helpful for railway bridges where excessive longitudinal traction and braking load is applied to one particular viaduct and the same is required to be transmitted through STUs connected across the expansion joints for sharing the load with adjacent unloaded viaducts.

The second type of connection is used for load distribution in continuous bridges.

7.3 SEISMIC ISOLATION BEARINGS

Many bridges had been built before the proper seismic design specifications were known to us. These bridges require strengthening and enhancing the ductility of substructures in order to sustain the earthquake forces. Conventional retrofitting methods are costlier (more than 3 times) than providing 'Seismic Isolation Bearings' (SIB). The studies have shown that:

(a) The SIB eliminated the in-plane torsional rotation of the bridge and resulted in a more uniform distribution of seismic forces among substructures in the transverse direction.

(b) The modifications in the response of the bridge resulted as a result of use of SIB because the effective fundamental period of the bridge get elongated due to the flexibility provided by the SIB.

(c) Average retrofitting cost using SIB is calculated as only 30% of that using conventional retrofitting methods.

An isolation bearing induce sufficient lateral flexibility in a bridge structure and increase the period of vibration, resulting in a reduced force response. The increased lateral flexibility is associated with larger horizontal displacements at the bearing level.

In the longitudinal direction, the stiffness of a bridge with isolation bearings is the sum of the stiffness of all piers and abutments including the bearings. In a bridge with conventional bearings. However, the longitudinal stiffness incorporates the stiffness of a fixed support alone.

The isolation bearings should also include a restoring force to return the superstructure to its pre-earthquake position.

7.3.1 *Types of seismic isolation bearing :* Seismic isolation is obtained by two types of isolation bearings.

a) Rubber bearings

b) Friction pendulum bearings

Rubber bearings are composed of a lead case and natural or synthesized rubber with embedded

layers of steel plates as shown in **Fig. 7.4**.

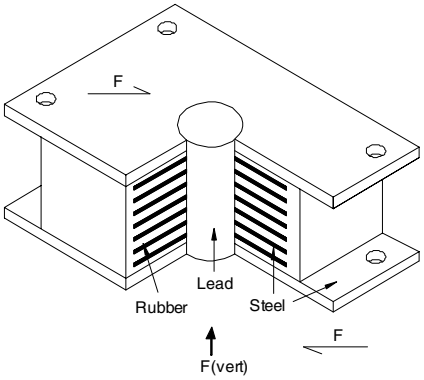


FIG. 7.4 RUBBER BEARING

The force-displacement behaviour of this bearing is elastic under service load and inelastic during an earthquake when the lead case deforms beyond its elastic limits. In fact, the bearing distribute the inertial forces from the deck level to all supporting substructures on the basis of their relative stiffness.

Rubber bearings are meant to shift the vibrational period of the structure so as to avoid resonance with the excitations. These are usually combined with high damping material to prevent the isolated structures from over-displacing.

In friction pendulum bearings, the lateral displacement is permitted at the interface of the bearing element between the superstructure and the substructure. Lateral movement at a sliding surface is associated with friction forces that

oppose movement as shown in **FIG. 7.5**

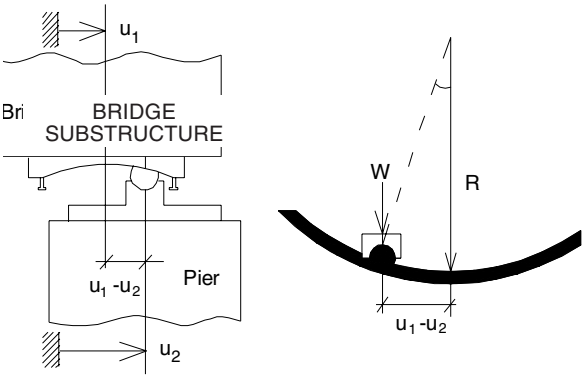


FIG. 7.5 FRICTION PENDULUM BEARING

The value of the friction force depends on variation factors, including the vertical reaction at the sliding surface, contact pressure, ambient temperature, speed of the movement and the condition of the sliding surface.

As shown in **Fig. 7.5**, the relative displacement between the sliding interfaces is $u_1 - u_2$ and the potential energy V_g due to gravity accumulated during the lift-up is

$$V_g = WR\left[1-\sqrt{\left(u_1-u_2\right)^2/R^2}\right]$$

where W is the weight supported by the bearing, R is the radius of curvature of the sliding surface as depicted in **Fig. 7.5**.

The friction force between the sliding interfaces plays the roll of energy dissipation during the sliding motion.

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