

DESIGN CONSIDERATIONS FOR THE DESIGN OF POT-PTFE BEARINGS FOR RAILWAY BRIDGES

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Synopsis

The important design consideration involved in the design of Pot-PTFE bearing have been discussed in this paper and the limitations in design of these bearings for Railway Bridges have been illustrated. The design data of various standard spans has been shown and the need of making in-depth study of the implications of relaxing codal provisions has been stressed.

1.0 Introduction:

The pot bearing consists of circular, non-reinforced natural rubber or elastomer pad, totally enclosed in a steel pot with the load applied to the elastomer via a piston attached to the upper bearing plate. A seal is used to prevent rubber extruding between piston & pot. As the elastomer is fully confined within a metal cylinder, it provides a load carrying medium whilst at the same time providing the bearing with a multidirectional rotational capacity. By themselves, pot bearings do not permit translation. In order to permit translational movement in addition to rotation, plain sliding arrangement is provided over the top plate of pot bearing. PTFE (Poly tetrafluoroethylene) which is having very low coefficient of friction is generally used with stainless steel to design this sliding arrangement. The weight of Pot-PTFE bearing is about 50% of the weight of conventional rocker & roller bearing for the same span. Due to its less weight and due to almost no maintenance, it is desired to provide Pot-PTFE bearings instead of conventional rocker-roller bearings. However, due to certain design constraints these bearings cannot be designed for all type of spans. This paper describes in brief the design consideration involved and the limitations in the design of such bearings for railways bridges.

2.0 Material Specifications:

- | | | | |
|-------|-----------------|---|---|
| (i) | Mild Steel | : | IS: 2062 grade-B |
| (ii) | Stainless Steel | : | IS: 6911 |
| (iii) | Cast steel | : | IS:1030 grade 280-520W. |
| (iv) | Elastomer pad | : | a) IRC:83 (Part-II) Standard specifications and code of practice for Road Bridges-Elastomeric Bearings. |

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- b) IRC-83 (Part-III) Properties of confined elastomer.
- (v) PTFE : a) BS:3784 grade 'A'. Specification for poly tetrafluroethylene (PTFE) sheet.
- b) IRC:83 (Part-III) for permissible pressure on confined PTFE.
- c) BS:5350: Standard method of test for adhesives, Part-C9, Floating Roller Peel Test.
- (vi) Wiper seal & dust seal : RDSO/M&C/RP-194/94.

3.0 Codes Of Practice:

In absence of standard code of practice for Railway Bridges, the design of bearings to Railway Bridges is done in accordance with following documents:

- i) IRS Bridge Rules
- ii) IRS Steel Bridge Code
- iii) IRC-83 Standard specifications and code of practice for Road Bridges, Section:IX Bearings, Part-III: Pot, Pot-cum-PTFE, Pin and metallic guide bearings.

The relevant clauses for design are discussed as under:

3.1 Design of Elastomeric Pad Diameter and Thickness:

- 3.1.1 Average stress in confined elastomeric pressure pad of Pot bearing shall not exceed 35 Mpa and extreme fibre pressure shall not exceed 40 MPa.
- 3.1.2 The minimum thickness of the confined elastomeric pressure pad shall not be less than $\frac{1}{15}$ th of its diameter or 16mm, whichever is higher and the diameter shall not be less than 180mm.
- 3.1.3 Minimum average stress in confined elastomeric pressure pad of Pot bearing, under any critical combination of loads and forces that can coexist, shall in no case be less than 5 MPa.

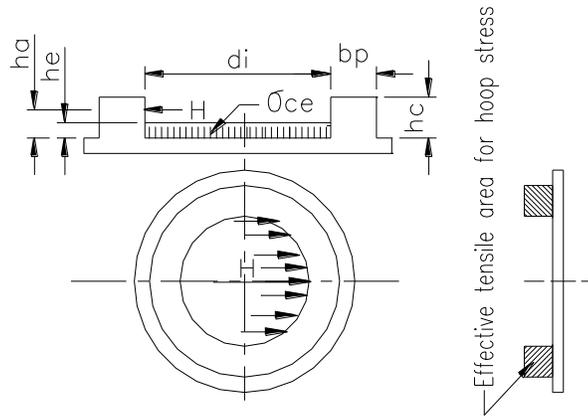


Fig. 1. DESIGN PRINCIPLE OF CYLINDER WALL

3.2 Design of Pot Wall:

3.2.1 The design of Pot wall is done with respect to the hoop tensile stresses in the cross section of the cylinder wall. Hoop tensile stress in the cross section of cylinder wall due to :

- i. Fluid pressure, $\sigma_{at1} = (di \times he \times \sigma_{ce}) / (2 \times bp \times hc)$
- ii. Horizontal force, $\sigma_{at2} = H / (2 \times bp \times hc)$,

Where,

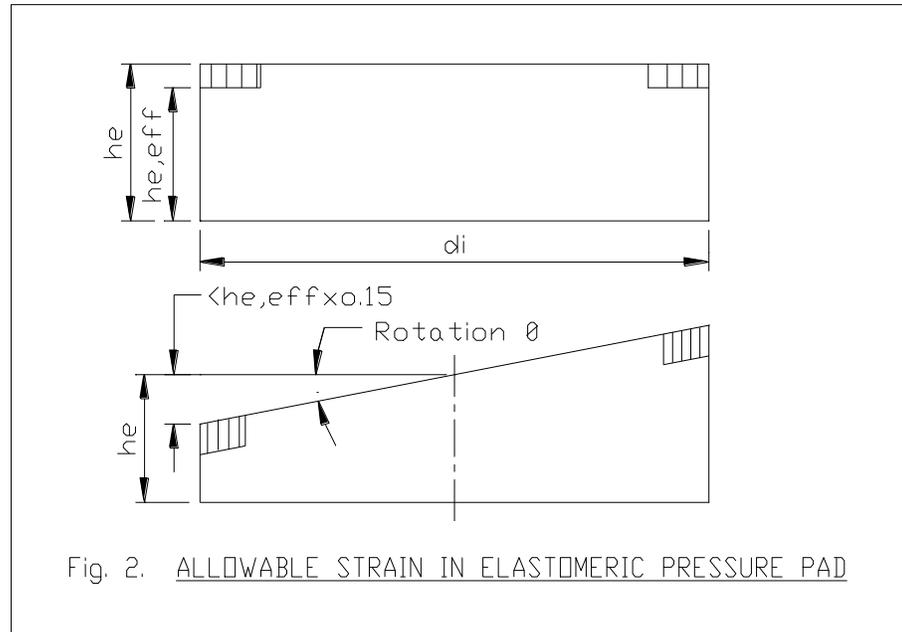
- di = diameter of confined elastomeric pressure pad in mm
 he = thickness of confined elastomeric pressure pad in mm,
 σ_{ce} = Fluid pressure in confined elastomeric pressure pad due to vertical load in MPa.
 bp = thickness of cylinder wall in mm
 hc = height of cylinder wall in mm

Total hoop tensile stress ($\sigma_{ats,cal}$) due to fluid pressure and horizontal force i.e. ($\sigma_{at1} + \sigma_{at2}$), shall not exceed the value of permissible stress in axial tension as specified.

3.3 Design of Sealing Ring:

3.3.1 For brass sealing ring type internal seal, 2mm thick and 20mm wide split rings made of metallic brass shall be provided in layers with staggered split positions. Minimum two layers of rings shall be provided for elastomeric pressure pad of diameter upto 480mm and minimum three layers of rings shall be provided for elastomeric pressure pad of diameters more than 480mm.

- 3.3.2 The dimension of the confined elastomeric pressure pad shall be such that at design rotation the deflection at the perimeter shall not exceed 15 percent of the pad thickness below the internal seal.



3.4 Design of PTFE Guided Sliding Assembly

- 3.4.1 PTFE shall be located into recess of a sufficiently rigid metal backing plate by confinement and shall either be dimpled large sheet(s) or an array of solid (i.e., without dimples) rectangular modules of size 80mm x 50mm. The dimpled large sheets shall be circular or rectangular in shape and may be subdivided into a maximum of four parts. For dimpled sheets with smallest dimension (diameter or smaller side) exceeding 100mm, contact area shall be taken as the gross area without deduction for the area of the dimples. In arrayed PTFE layout the distance between the individual modules shall not be more than 10mm. The shoulders of the recess should be sharp and square to restrict the flow of PTFE. The thickness of the PTFE and its protrusion from the recess should be related to its maximum plan dimension in accordance with Table 1.

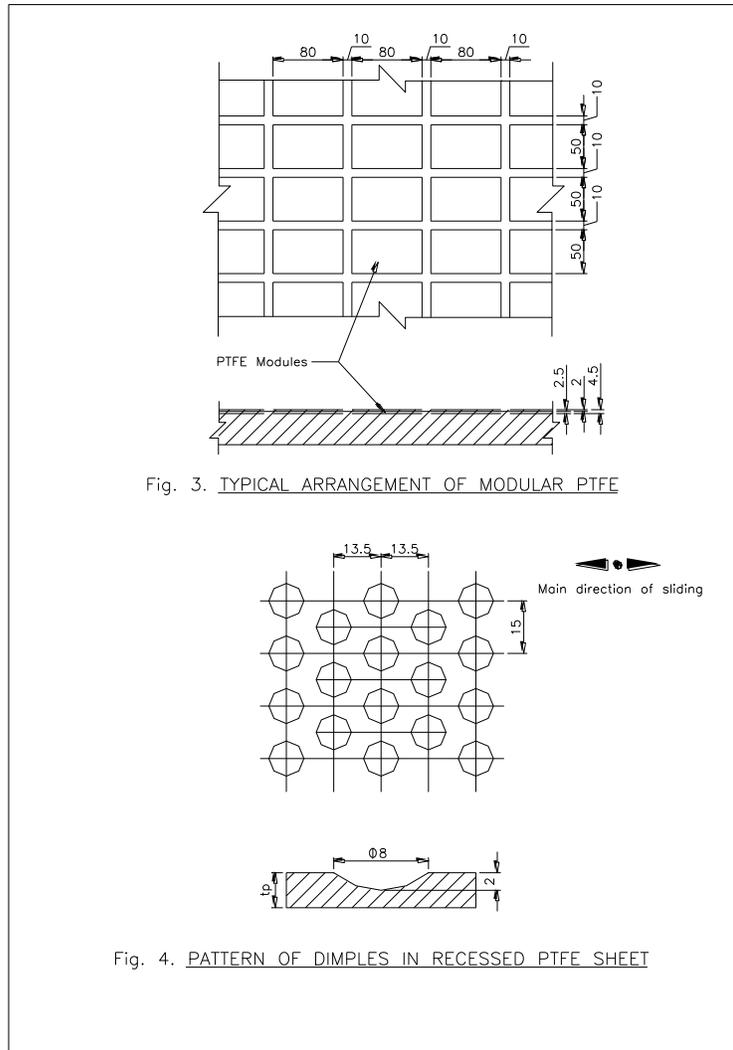


Table 1. Dimension of Confined PTFE

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

3.4.2 Average pressure on confined PTFE shall not exceed 40 MPa and extreme fibre pressure shall not exceed 45 Mpa.

- 3.4.3 The characteristic maximum coefficient of friction for steel sliding on uniformly lubricated PTFE shall be as per Table 2. Linear interpolation may be used for intermediate values. In absence of test data the coefficient of friction of unlubricated PTFE on stainless steel should be taken as twice the value as given in Table 2. For design purposes, induced horizontal force caused by the resistance to translational movement due to friction at the PTFE-stainless steel interface shall be determined considering the PTFE as unlubricated.

Table 2- Coefficient of Friction for Stainless Steel Sliding on Properly Lubricated PTFE

Average pressure on confined PTFE (MPa)	Maximum coefficient of friction
5	0.08
10	0.06
20	0.04
≥ 30	0.03

3.5 Design Horizontal Force:

- 3.5.1 For design of Pot bearings or part thereof the design horizontal force to be considered shall be the resultant of the coexisting active horizontal force, determined from global analysis, and included horizontal forces, generated due to friction at sliding interface (if any), but shall in no case be less than 10 percent and greater than 25 percent of the design vertical load.

3.6 Permissible stresses in steel

- 3.6.1 Permissible stress in axial tension σ_{at} shall not exceed $0.6 f_y$, where f_y = minimum yield stress of steel in MPa.
- 3.6.2 Maximum bending stress in tension (σ_{bt}) or in compression (σ_{bc}) in extreme fibre shall not exceed $0.66 f_y$.
- 3.6.3 Maximum shear stress (τ_{vm}) shall not exceed $0.45 f_y$.
- 3.6.4 Maximum bearing stress (σ_p) shall not exceed $0.75 f_y$.

- 3.6.5 Irrespective of any increase in the permissible stress specified the equivalent stress (σ_e) due to coexisting bending (tension or compression) and shear stress obtained from the following formula and shall not exceed $0.9f_y$.

$$\sigma_{e, cal} = \sqrt{(3 \times \tau_{vm, cal}^2 + \sigma_{bt, cal}^2)} \text{ or}$$
$$\sigma_{e, cal} = \sqrt{(3 \times \tau_{vm, cal}^2 + \sigma_{bc, cal}^2)}$$

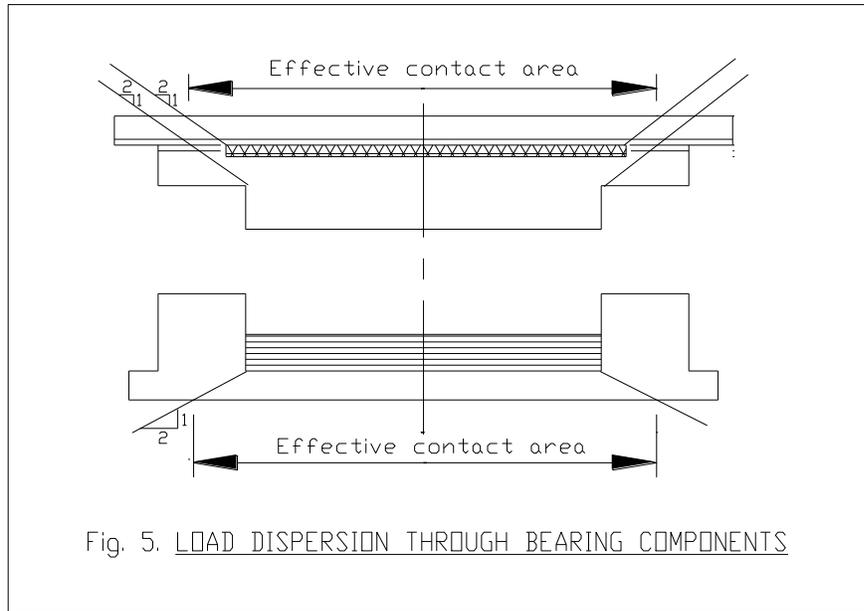
Where,

$\tau_{vm, cal}$	=	Calculated value of shear stress in MPa,
$\sigma_{bt, cal}$	=	Calculated value of bending stress in tension in MPa
$\sigma_{bc, cal}$	=	Calculated value of bending stress in compression in MPa
σ_e, cal	=	Calculated value of combined stress in MPa

- 3.6.6 When the effect of wind or earthquake is taken into account the above permissible stresses shall not be increased.
- 3.6.6 The above permissible values are also applicable for stresses on steel structure, adjacent to the bearing.

3.7 Distribution of Vertical Load

- 3.7.1 In absence of 3D FEM analysis, load distribution through the bearing component(s) and to the adjacent structure shall be calculated considering effective contact area after one vertical to two horizontal (IV:2H) distribution of confined elastomer stress as shown in Fig. 5. Flexural stress due to active and induced moments shall be calculated considering the section modulus of the effective contact area as shown in Fig. 5. Average contact stress, flexural stress and the combined effect shall not exceed the limiting values as specified. For dispersion through sliding components it should be ensured that the dispersed area is contained within the particular component, even when maximum design displacement occurs.



3.8 Shear Stress & Bending Stresses

3.8.1 Shear stress at cylinder wall and base interface calculated considering 1mm radial slice of the cylinder due to:

- (i) Fluid pressure, $\tau_{vm1} = (h_e \times \sigma_{ce})/b_p$
- (ii) Horizontal force, $\tau_{vm2} = 1.5 \times H/(d_i \times b_p)$

Where, Parabolic distribution factor is considered as 1.5.

3.8.2 Total shear stress (τ_{vm} , cal) due to fluid pressure and horizontal force, i.e. $\tau_{vm1} + \tau_{vm2}$, shall not exceed the value of permissible stress in shear as specified earlier in para 3.5.

3.8.3 Bending stress at cylinder and base interface calculated considering 1mm radial slice of the cylinder due to:

- (i) Fluid pressure, $\sigma_{bt1} = (6 \times \sigma_{ce} \times h_e^2)/(2 \times b_p^2)$
- (ii) Horizontal force, $\sigma_{bt2} = 1.5 \times 6 \times H \times h_a/(d_i \times b_p^2)$

Where,

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

- H = design horizontal force in N.
- h_e = thickness of confined elastomeric pressure pad in mm
- σ_{ce} = fluid pressure in confined elastomeric pressure pad due to vertical load in MPa
- b_p = thickness of cylinder wall in mm
- d_i = diameter of confined elastomeric pressure pad in mm.

Parabolic distribution factor is considered as 1.5.

- 3.8.4 Bending stress ($\sigma_{bt,cal}$) due to fluid pressure and horizontal force, i.e. $\sigma_{bt} + \sigma_{bt2}$, shall not exceed the value of permissible bending stress as specified in Para 3.5.
- 3.8.5 Equivalent stress (σ_e, cal) due to combined bending and shear shall be checked in accordance with Para 3.5.

Cantilever projection of guide shall be checked for shear, bending and combined stresses against permissible values specified in Para 3.5.

3.9 Average Permissible Direct Bearing Pressure on Pier/abutment

- 3.9.1 Average permissible direct bearing pressure σ_{cc} on the adjacent concrete structure shall be calculated using the following equation:

$$\sigma_{cc} = \sigma_{co} \sqrt{A_1/A_2}$$

σ_{co} = permissible direct compressive stress in concrete = 0.25 fck, where fck is the characteristic compressive strength of concrete.

A_1 = dispersed concentric area, which is geometrically similar to the loaded area A_2 and also the largest area that can be contained in a plane of A_1 (maximum width of dispersion beyond the loaded area face shall be limited to twice the height).

A_2 = loaded area and,

$$\sqrt{A_1/A_2} \leq 2$$

The projection of the adjacent structure beyond the loaded area shall not be less than 150mm. Adequate reinforcement for spalling and bursting tension shall be provided.

3.9.2 In case of coexisting direct and flexural compressive stresses on the adjacent concrete structure, the following criteria should be satisfied:

$$\sigma_{cc, cal}/\sigma_{cc} + \sigma_{c, cal}/\sigma_c \leq 1$$

Where,

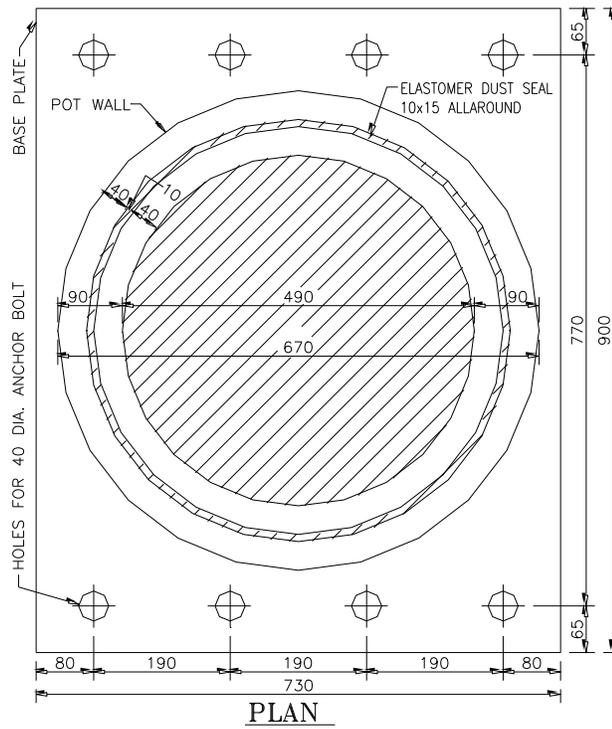
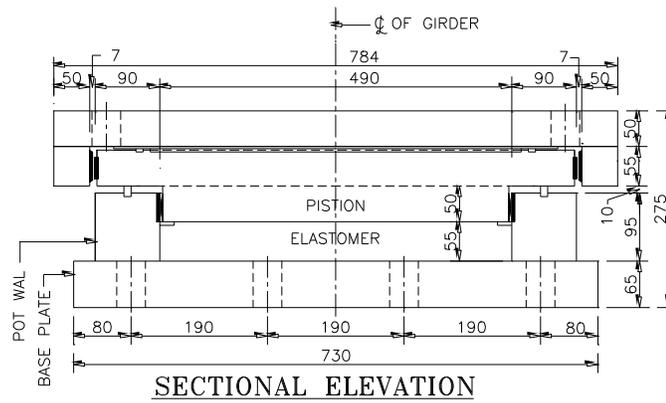
$\sigma_{cc, cal}$ = calculated direct compressive stress,

$\sigma_{c, cal}$ = calculated compressive flexural stress.

3.9.3 When the effect of wind or earthquake is taken into account, the above permissible stresses may be increased by 25 percent.

4.0 Design Of Pot-PTFE Bearings For Railway Bridges

4.1 The design of Pot-PTFE bearings has been done for large railway bridges based on above codal provisions and provisional drawings have been issued. The typical design data for 76.2m span is given in Annexure-I. The sectional elevation and plan of typical sliding bearing for 76.2 m span railway bridge girder is shown in Fig. 6. The values of critical design parameters in respect of minimum average stress, average stress and extreme fibre stress are tabulated in Table-3 for different spans.



**FIG.6 TYPICAL SECTIONAL ELEVATION AND PLAN
OF SLIDING BEARING FOR 76.2 m SPAN RAILWAY
OPEN WEB GIRDER FOR H.M. LOADING**

Table-3 Values of critical design parameters for different Spans for railway bridge girders

Span (m)	Drg.No.	Loading	Total weight of girder including track wt. etc. (t)	Perm. Str. \geq 5N/mm ²	Perm. Stress 35 N/mm ²		Perm. Stress 40 N/mm ²	
				Min. average stress (N/mm ²)	Average Stress		In Extreme fibre stress	
					Service condition (N/mm ²)	Seismic condition (N/mm ²)	Service condition (N/mm ²)	Seismic condition (N/mm ²)
76.2	B-11578	HM (OWG)	405	5.367	21.56	24.11	33.86	37.86
76.2	B-11577	MBG (OWG)	322	5.677	21.19	24.33	34.74	39.86
61.0	B-11576	HM (OWG)	286	5.038	22.75	25.15	35.58	39.32
61.0	BA-11575	MBG (OWG)	221	5.13	22.21	25.21	35.64	40.20
45.7	-	MBG (under slung)	140	5.084	26.32	30.68	41.96	48.87

4.2 It is observed that whereas it is possible to simultaneously meet the design criteria in respect of minimum average stress and maximum extreme fibre stress for larger spans, the same is not easy for lower spans e.g. for 45.7m span open web girder (under-slung type), the total weight of girder is so less (only 140t) that the diameter of elastomer pad has to be reduced substantially to achieve minimum average stress of 5N/mm². With this reduced diameter of elastomer pad, the extreme fibre stresses under service conditions as well with seismic effect are exceeding the permissible values (40 N/mm²).

4.3 The codal provision as given in BS-5400: Section 9.1 for design of Pot-PTFE bearing have been checked up and it is noted that no such limitation in respect of minimum average stress has been specified. However, keeping in view the stability of girders during seismic conditions the design of Pot-PTFE bearings for railway bridges has been done for ensuring minimum average stress 5N/mm².

5.0 Testing of Bearing

The actual stress in the elastomer in Pot bearing due to design load effects is limited by the effectiveness of the seal preventing it from extruding between the piston and the pot wall. Since the details of pot bearings vary considering and stress analysis is complex, the design

is invariably verified by testing. A sample test proforma is attached as Annexure-II.

6.0 Conclusions

Design of Pot-PTFE bearing is governed by the minimum average stress on the confined elastomer in the pot. For smaller spans it is not possible to simultaneously meet out the codal provisions for minimum average stress as well as for maximum extreme fibre stress in the elastomer pad. The design of Pot-PTFE bearing is therefore restricted due to the stipulated minimum average stress and can be feasible for railway bridge girders of spans 61.0 m and above.

7.0 Suggestion For Future Study

- 7.1 The implications of relaxing the existing codal provision for minimum average stress need to be studied further to take full advantage of Pot-PTFE bearings for all types of Railway Bridges.

8.0 References

- [1] IRC-83 (Part III), Standard Specifications and Code of Practice for Road Bridges, Section:IX, Bearings, Part-III:Pot, Pot cum PTFE, Pin and Metallic Guide Bearings.
- [2] BS-3784 Grade 'A', Specifications for Poly tetrafluoroethylene (PTFE) Sheet
- [3] BS-5400:Section 9.1, Design of Pot-PTFE Bearings.
- [4] LEE, DAVID J., Bridge Bearings and Expansion Joints, E & FN Spon London, UK.
- [5] IRS Steel Bridge Code, Research Design and Standard Organization, Ministry of Railways, Govt. of India, Lucknow (U.P.)
- [6] RDSO Design Documents for design of Pot-PTFE bearings for different spans and loadings.

ANNEXURE-I

Data for design of sliding and fixed pot PTFE bearing for 76.2m HM loading

1	Clear span	76.2 m
2	Effective span	78.8 m
3	D.L of girder including Track, gangway etc	405 t
4	L.L shear	980.024t
5	CDA	240.106 t
6	Vertical load due to wind/Bearing	16.84 t
7	Lateral load due to wind/Bearing	24.2 t
8	Lateral load due to seismic effect for zone-iv	25.18 t
9	Longitudinal force/Bearing	67.5 t
10	Max. horizontal movement -	63.5 mm
11	Total vertical load/bearing with wind = $\{(3)+(4)+(5)\}/4+16.84$	
	$\{(405+980.024+240.106)\}/4+16.84$	= 423.123t
12	Total vertical load/bearing with seismic effect for zone - iv	
	$\{(405+980.024+240.106)\}/4+35.09+13.24$	= 454.613t
13	Deflection at centre = 116mm	
14	THEETA = ATAN(116/39400)	0.0029 radians < 0.025 or 0.16869 Degree

CHECK LIST OF INSPECTION FOR FABRICATION OF POT PTFE BEARING

1.0 Raw Material

- | | | |
|----|----------------------------|---|
| 1. | M.S. Steel | As per IS 2062 Gr. B or C as mentioned in Drawing |
| 2. | Cast Steel | As per IS 1030 Gr. 280-520 W or As per IRC 83 (iii) as mentioned in drawing or contract agreement |
| 3. | PTFE | As per drawing or IRC 83 (iii) BS 3483 Gr. A |
| 4. | Elastomer | As per IRC 83 (Part II) |
| 5. | Stainless Steel Plate | IS-6911 |
| 6. | Internal seal (brass ring) | As per IS 410 |
| 7. | Wiper seal and dust seal | As per drawing and RDSO's Specification M&C/RP-194/94 |

2.0 Dimensional Test

2.1 Fixed Bearing (Pot Bearing)

Sl. No.	Item	Dimension (mm)		Whether within tolerance
		Nominal	Measured	
1.	Pot cylinder and elastomer			
	a) Inner dia of the Pot			
	b) Outer dia/size of the pot			
	c) Center to center distance of holes in the lugs of pot			
	d) Width of lugs (measure and record width of all lugs)			

- e) Thickness of the pot wall
- f) Thickness of the base of pot
- g) Thickness of lugs
- h) Thickness of the pot wall
- i) Inner height of the pot
- j) Thickness of elastomer

2.

Piston/top plate

- a) Thickness of the top plate in piston
- b) Thickness of the top plate above pot wall
- c) Dia of the top plates
- d) Center to center distance of holes in the lugs of top plate
- e) Thickness of lugs

3.

Sealing ring

- a) Thickness
- b) Width
- c) Inner diameter

4.

High tensile bolts and washers

- a) Dia of bolt sleeve with HT anchor
- b) Dia of bolt hole in bolt sleeve
- c) Dia of HT anchor
- d) Length of bolt sleeve
- e) Length of bolt sleeve with anchor

5. **Overall height of bearing
in assembled condition**

2.2 Free Bearings (Pot cum PTFE bearings)

Sl. No.	Item	Dimension (mm)		Whether within tolerance
		Nominal	Measured	
1.	Pot cylinder and elastomer			
	a) Inner dia of the Pot			
	b) Outer dia/size of the pot			
	c) Center to center distance of holes in the lugs of pot			
	d) Width of lugs (measure and record width of all lugs)			
	e) Thickness of the pot wall			
	f) Thickness of the base of pot			
	g) Thickness of lugs			
	h) Thickness of the pot wall			
	i) Inner height of the pot			
	j) Thickness of elastomer			
2.	Saddle Plate & PTFE			
	a) Size of the saddle plate			
	b) Size of PTFE sheet in plan			
	c) Thickness of PTFE sheet			
	d) Depth of dimples			

- e) Dia dimples
- f) Spacing of dimples
- g) Depth of groove in saddle plate for housing
- h) Thickness of saddle plate
- i) Thickness of the collar of saddle plate

3. Top Plate, Stainless Steel & Ear Plate

- a) Plan size of underside of top plate
- b) Thickness of top plate
- c) Plan size of steel plate
- d) Size of the lugs of top plate

4.

Sealing ring

- a) Thickness and no.
- b) Width
- c) Inner diameter

5.

High tensile bolts and washers

- a) Dia of bolt sleeve with HT anchor
- b) Dia of bolt hole in bolt sleeve
- c) Dia of HT anchor
- d) Length of bolt sleeve
- e) Length of bolt sleeve with anchor

6.

Overall height of bearing in assembled condition