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Structural Bearings for Monorail and Light Rail Bridges

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A few basic concepts

Bridges are quite often a very relevant part of Railway lines.

For Metro systems and Monorails the stress in the materials and the fatigue effects generated by the live loads in the structure are much more severe than in conventional Railway lines

	RAILWAYS	METRO LINES
TYPICAL TRAIN DAYLY FREQUENCY	240	360
TYPICAL RATIO FREQUENT LOAD/DESIGN LOAD	30%	80%

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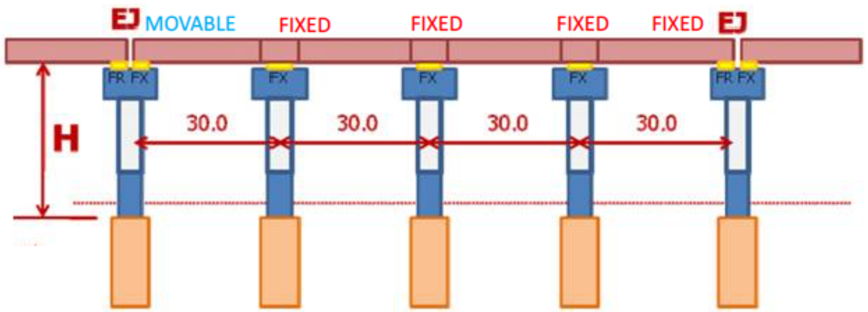
Typical Static Scheme of the Bridges

- Light rails frequently adopt simply supported spans. This is due to the fact that the rails are normally continuous and the simply supported spans can easily accommodate the different length variations of the rail and the beams with small relative displacements.
- For the monorail lines there is no rail and the expansion joints can be used without any negative effect. Therefore continuous beams with 3 or more spans are preferred.
- To support the beam of a monorail 2 possibilities are given

1. The beam is supported by columns to which is monolithically fixed
2. The beam is connected to the columns by structural bearings

Typical Static Scheme of the Bridges



Connecting the beams to the colums has some advantage:

- Maintenance of the bearings is avoided
- Undesirable relative movements between beam and columns are avoided

Nevertheless the adoption of structural bearings can bring several advantages:

- Twin columns in correspondence of the expansion joints are avoided
- Actions transmitted from the beam to the columns are reduced
- The displacement of the structure due to horizontal actions may be limited adopting stiffer columns
- The distance between expansion joints may be increased, reducing their number
- Foundation settlements may be easily compensated by adding shim plates between the bearings and the structure or adopting injectable bearings

The adoption of structural bearings however requires special attention and the fulfilling of particular requirements in order to assure the proper performance of the monorail throughout its entire service life.

Structural bearings

Structural bearings, as defined by EN 1337-1 are elements allowing **rotation** between two members of a structure and transmitting the loads defined in the relevant requirements as well as preventing displacement (fixed bearings), allowing **displacement** in one direction only (guided bearings) or in all directions of a plane (free bearings) as required.

The bearing system for a structure, as defined by EN 1337-1, is the combination of bearings and structural devices which together provide for the necessary movement capability and for the transmission of the forces.

Essential requirements of structural bearings

In addition to the rotation capability and the displacement capability when required, other essential requirements of the structural bearings are the following:

- bearings shall be designed to support the specified actions with the minimum possible deformation (mechanical plays shall be minimized).
- bearings shall be designed to allow the specified movements with the minimum possible reaction (friction shall be minimized).
- bearings and the relevant parts of the adjacent structures shall be designed to allow the easy inspection and the replacement of parts of them or the entire bearings. (replacement shall be allowed)

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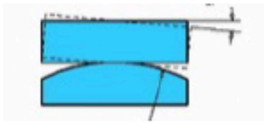
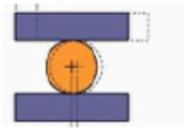
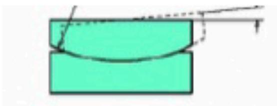
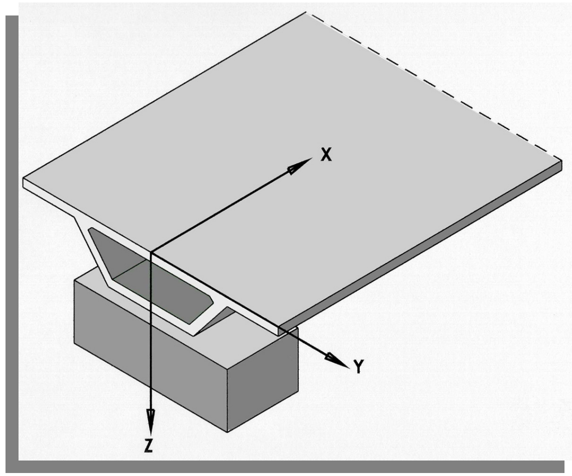
Functions and physical principles of the bearings

<table>
<tr><td colspan="2">FUNCTIONS</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Rotation</td><td>Displa-
cement</td></tr>
<tr><td></td><td></td><td>Rolling</td><td rowspan="3">PHYSICAL
PRINCIPLES</td></tr>
<tr><td></td><td></td><td>Elastic
Deformation</td></tr>
<tr><td></td><td></td><td>Sliding</td></tr>
</table>

BEARINGS CLASSIFICATION IN FUNCTION OF THEIR DEGREES OF FREEDOM

FORCES AND MOMENTS	F_z	F_x	F_y	M_y	M_x	M_z	**DOF**
Cylindrical fixed bearing							1
Spherical fixed bearing							3
Cylindrical sliding guided							2
Cylindrical free sliding							3
Spherical sliding guided							4
Spherical free sliding							5
Elastomeric bearing							5*
Restraint							3
Guide							4
DISPLACEMENTS AND ROTATIONS	**Z**	**X**	**Y**	β	α	γ	



(*) Degrees of freedom with limitations

Bearings for monorails

Performances of the bearings in service

We will consider the performances of the various types of bearings in service conditions considering the following aspects in particular:

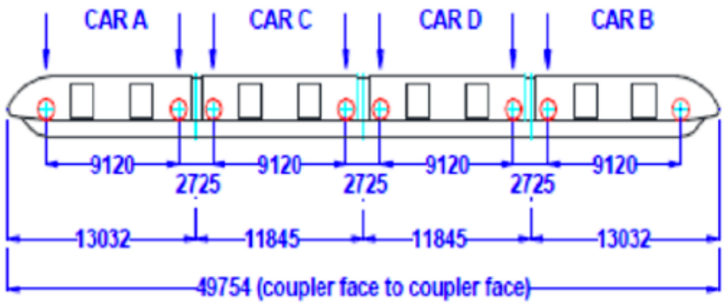
- Fatigue effects
- Wear of the materials
- Service life

We will base the analysis on the following data

- Frequent live loads
- Allowable structural deformations

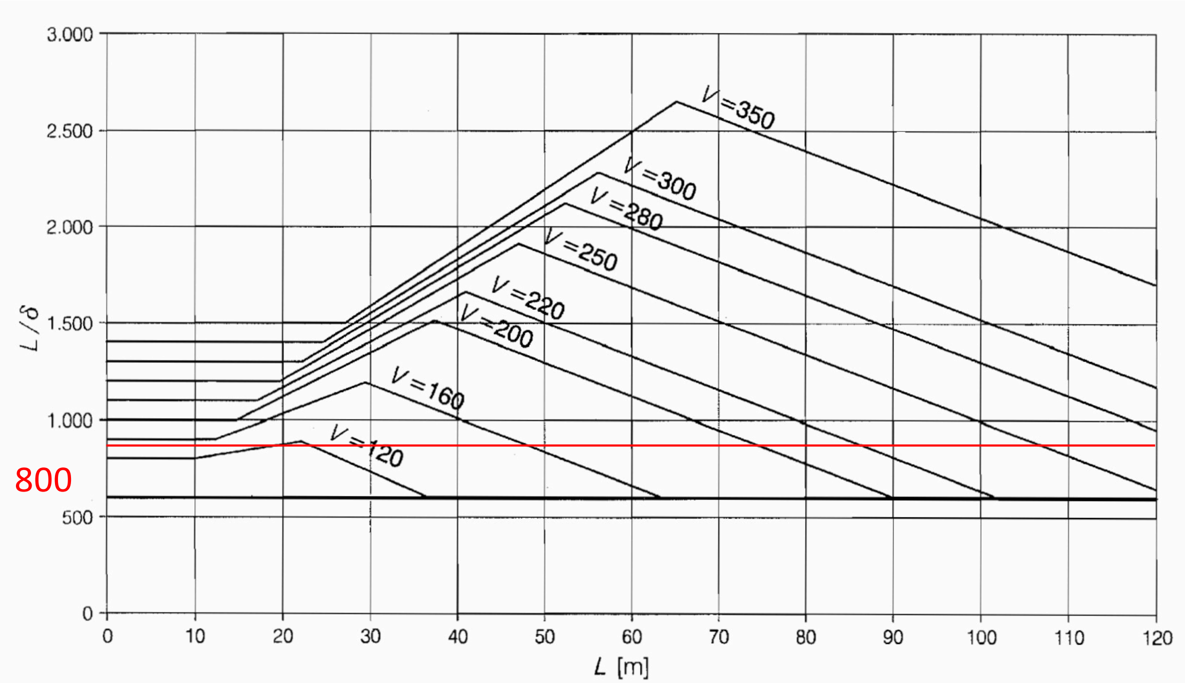
LIVE LOADS

Loading condition		Pax/car	Axle load (kN)
AW0	Empty	0	74.3
AW1	Seated	17	80.1
AW2	+ 4 pax/m^2	99	108.3
AW3	+ 6 pax/m^2	140	122.6
AW4	+ 8 pax/m^2	181	136.6
MAX	+ 10 pax/m^2	223	150.9



Typical live loads for a monorail train (in particular for Cairo Monorail)
AW3 is the frequent loading condition considered for the evaluation of fatigue effects

DEFLECTION LIMITATIONS



In the graph are given the deflection limitations for railway bridges according to EN 1990.

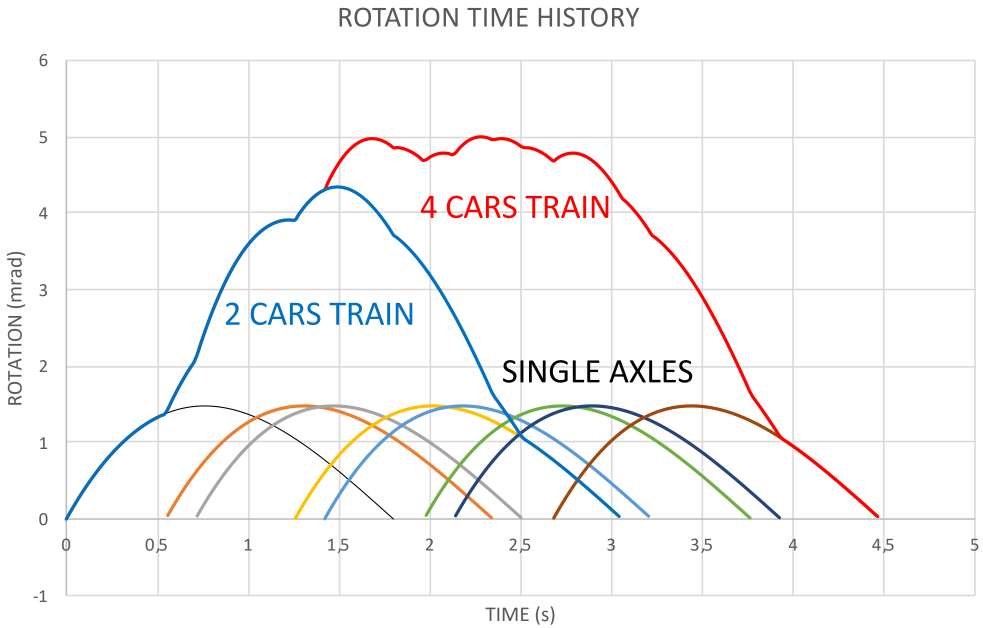
We assume for the following considerations

L/δ (span/deflection) = 800

This corresponds to a rotation of the bearings

$\alpha = 4\delta/L = 0.005$ rad

ACCUMULATED ROTATION



In the graph are given the rotation time histories for single axles, 2 and 4 cars trains scaled at 0.005 rad max rotation for the max design load train.

The accumulated rotation for the 4 cars train with max load transit is

α = 10.8 mrad

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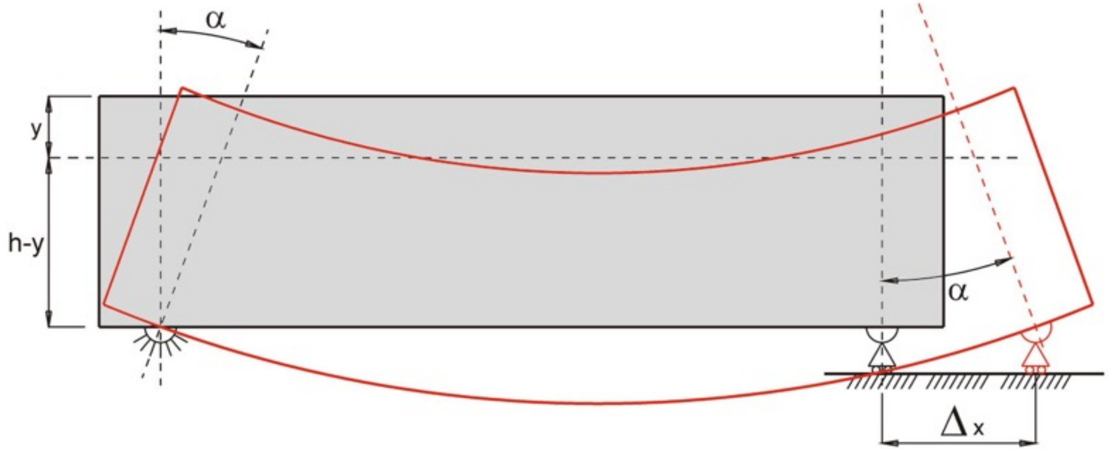
ACCUMULATED SLIDING PATH



The displacement in the sliding bearing given by the rotation α is: $\Delta x=2\alpha(h\text{-}y)$
With h-y =2300 mm as typical value for 30 m span bridges we get the displacement of the bearing for the transit of the 4 cars train at max load

$S=2x10.8x10^{-3}x2300=49.7mm$

ACCUMULATED ROTATION AND DISPLACEMENT

The accumulated rotation and displacement per day and per year have been computed assuming:

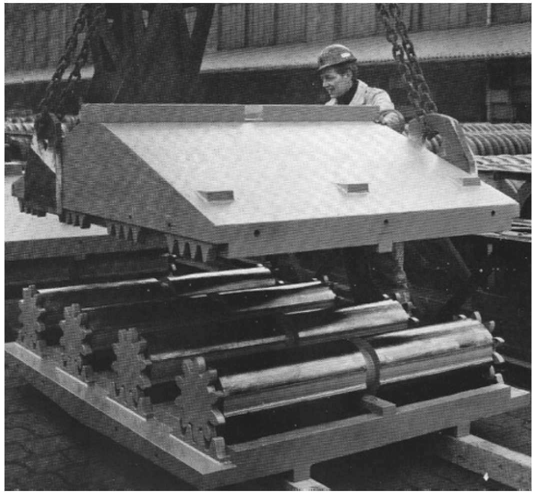
- Frequent load = 80% of the maximum design load
- Train frequency = 360/day

	Unit	Max Load	Frequent load	Day	Year
Rotation	rad	0.0108	0.00864	3.1104	1135
Displacement	m	0.0497	0.03976	14.31	5224

ROLLER BEARINGS

They were developped in early 1800

Roller bearing for a railway bridge. Germany late XIX century



Roller bearing for a steel bridge. Germany 1968

Relevant data of the giant roller bearing manufactured in 1968

- Vertical load 37320 kN
- Displacement ± 350 mm
- Mass: 28300 kg
- Ratio mass/vertical load: 0.76kg/kN

ROLLER BEARINGS

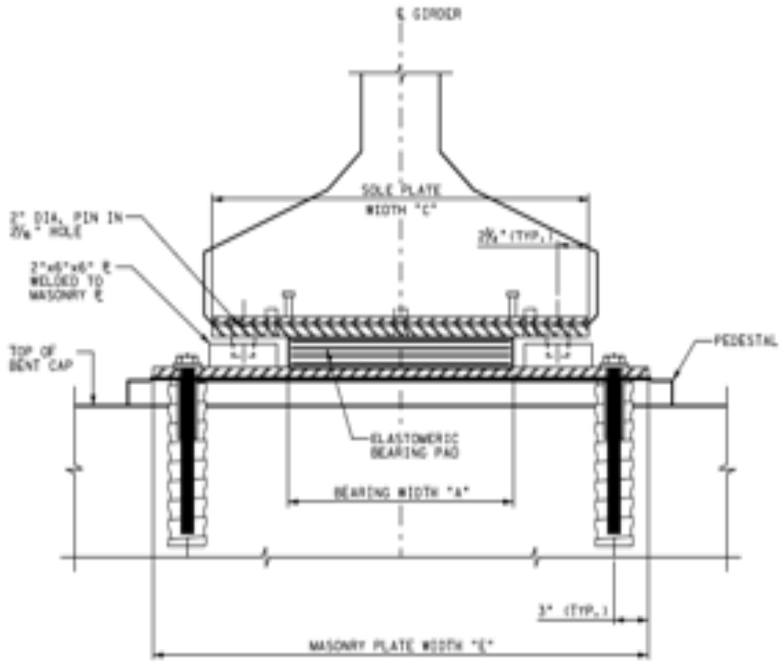
Roller bearings, although expensive in comparison with other types, are very robust and not subjected to wear.

The critical aspects of the roller bearings are the following:

- They don’t allow multidirectional movements
- They allow rotation around an axis perpendicular to the movement direction only. This may create a problem in curved or skew bridges.
- When subjected to uplift they cannot totally eliminate the vertical mechanical play.
- To reduce the roller diameter extremely high tensile steel is normally used (as for instance martensitic steel). This kinds of steel may became brittle al low temperature and under dynamic loads.

ELASTOMERIC BEARINGS

- Elastomeric bearings are utilized in bridge construction since late 19th century. Their use in railway bridges however is not recommended as they can resist horizontal actions with large horizontal deformations only.
- Elastomeric bearings, if utilized in railway bridges, should always be combined with rigid restraints



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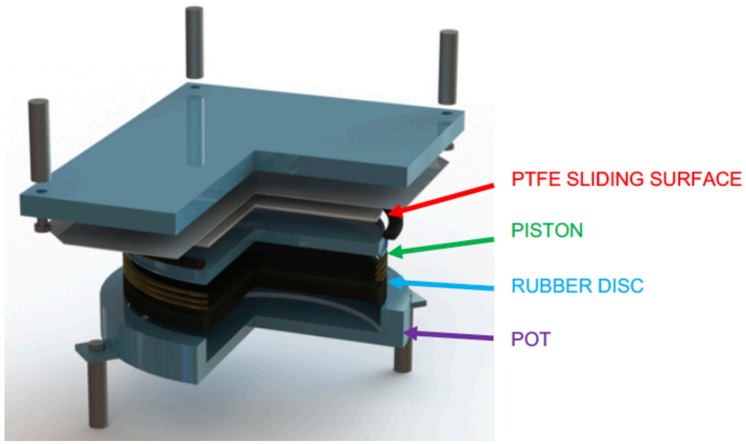
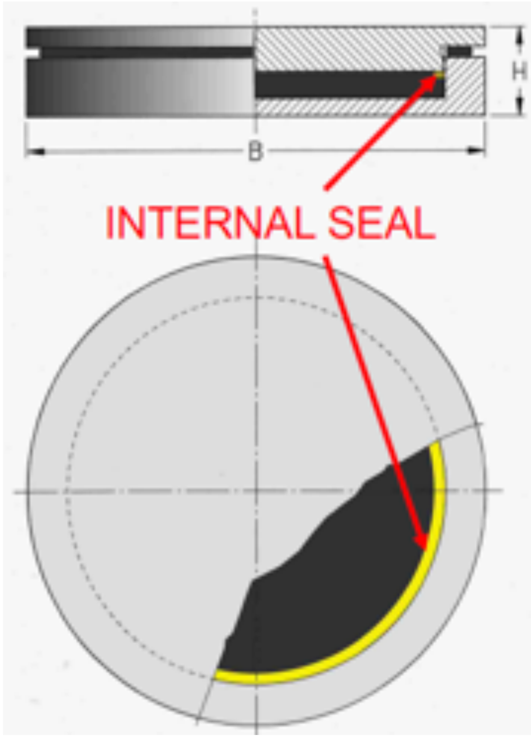
POT BEARINGS

- Pot bearings have been invented in Germany in 1960 and for sure, still today after more than 60 years, they are the most widely used structural bearings world-wide. They have been extensively used in High Speed Rail And Mass Transit Systems in all the world.
- In the pot bearing the rotation capability is given by the deformation of a rubber disc confined in a steel pot and a steel piston; the displacement capability, if required, is given by a PTFE sliding surface in combination with austenitic stainless



POT BEARINGS

- However their performance, due to the constant increase of requirements arising from the modern structures, in some cases is not more sufficient
- The most critical component of the pot bearing is the internal seal.



POT BEARINGS

In EN 1337-5 are foreseen 4 types of seals, characterized by different wear resistances. Wear resistance is expressed in terms of the accumulated sliding path of the seal against the pot wall generated by the rotation. The foreseen types of seals and their typical wear resistances are shown in the table

SEAL TYPE	WEAR RESISTANCE (m)	
	TEST	TRAFFIC (*)
Stainless steel	500	2500
Brass	1000	5000
POM	2000	10000
Filled PTFE	2000	10000

(*) According to EN 1337.5 the wear resistance for traffic is the test result amplified by 5 to correct the effect between the constant amplitude slide path used in the tests and the variable amplitude movements which actually occur due to traffic

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POT BEARINGS

For a pot bearing with 5000 kN bearing capacity at SLS the internal diameter of the pot, corresponding to the diameter of the seal will be:

D=460 mm

The accumulated sliding path in one year will be:

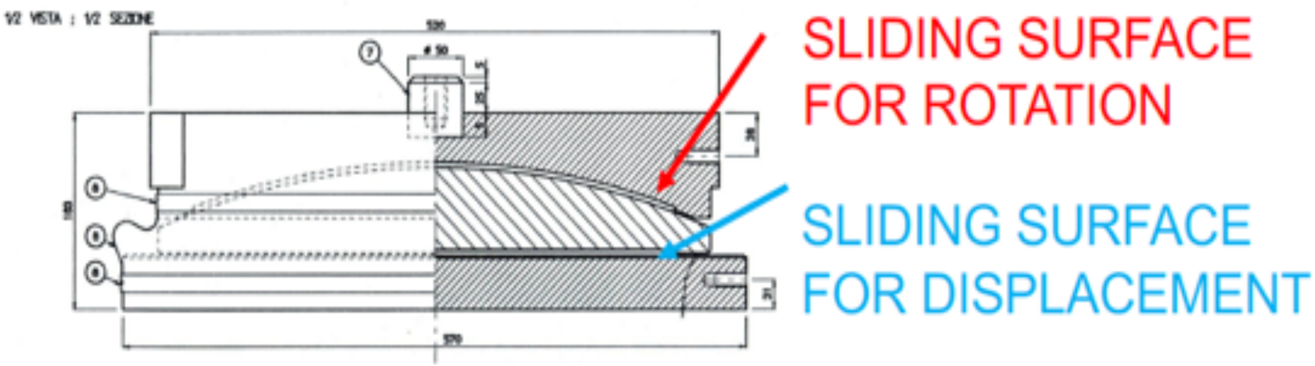
$$S_{\alpha year} = \alpha_{year} \times \frac{D}{2} = 1135 \times 0{,}46/2 = 261m$$

This means a service life of:

- 9.6 years for stainless steel seals
- 19.2 years for brass seals
- 38.4 years for POM and filled PTFE seals

SPHERICAL BEARINGS

- Spherical bearings have been developed in the years 60 of last century, after the introduction of the use of PTFE in structural bearings.
- In the spherical bearings the rotation capability is given by the sliding of a pair of spherical surfaces respectively plated with PTFE and austenitic stainless steel; the displacement capability, if required, is given by a PTFE sliding surface in combination with austenitic stainless steel



SPHERICAL BEARINGS

For the evaluation of the wear in the sliding surface for rotation we will consider a spherical bearing with 5000 kN bearing capacity at SLS and typical value of the radius of the spherical surface R = 700 mm.

The accumulated rotation implies the following sliding path in one year in the sliding material:

$$S_{\alpha year} = \alpha_{year} \times R = 1135 \times 0.7 = 795\ m$$

This means a service life of:

- 12.6 years for PTFE sliding material (wear resistance 10.000 m)
- 63 years or more for the innovative sliding materials (wear resistance 50.000 m or more)

WEAR OF THE SLIDING MATERIAL FOR DISPLACEMENT SPHERICAL & POT BEARINGS

- For the evaluation of the wear in the sliding material we consider the accumulated sliding path per year previously calculated
- $S_{year} = 5224\, m$
- This means a service life of:
- Less than 2 years for PTFE sliding material (wear resistance 10.000 m)
- Nearly 10 years for special sliding materials with 50.000 m wear resistance
- To grant a service life of 50 years or more without major maintenance the special sliding material should have a wearing resistance of approximately 250.000 m or more

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SLIDING MATERIALS

Sliding materials are the most important component of the bearing.
They shall provide 3 important performances:

- High compressive strength
- Long service life > 50 years without replacement
- Resistance to high temperatures

HIRUN developped innovative sliding materials for this kinds of applications with brand names HI3 and HIM

The main characteristics of these materials in comparison with the most common alternative sliding materials are shown in the following table

SLIDING MATERIALS DEVELOPPED BY HIRUN

- HIRUN developped innovative sliding materials:
  - HI-3 for use in spherical bearings
  - HI-M for use in sliding bearings and sliding pendulum isolators.
- Here below a comparison table with the most commonly used alternative sliding materials

PROPERTY	PTFE	HI-3	HI-M	UHMWPE
Compressive strength	90 MPa	180 MPa	270 MPa	180 MPa
Heat resistance (long term)	48°C	60°C	120°C	48°C
Heat resistance (short term)	48°C	120°C	180°C	80°C
Wear resistance	10,000 m	50,000 m	>>50,000 m	50,000 m
Static friction	$\leq$ 3%	$\leq$ 3%	3 ÷ 6%	$\leq$ 3%
Dynamic friction	$\leq$ 3%	$\leq$ 3%	3 ÷ 6%	$\leq$ 3%

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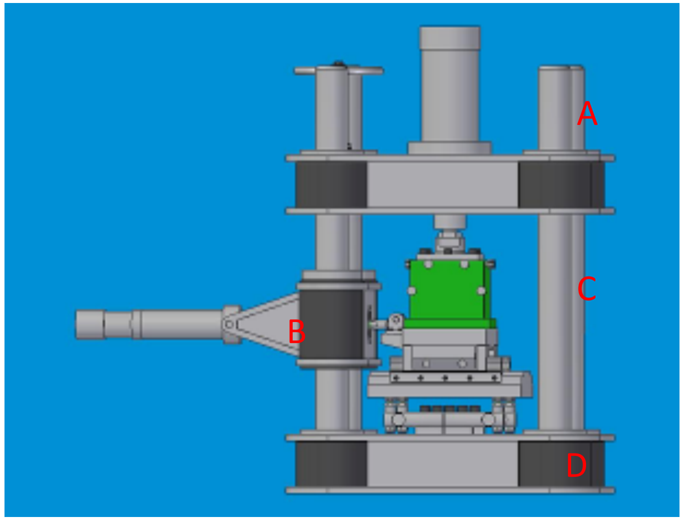
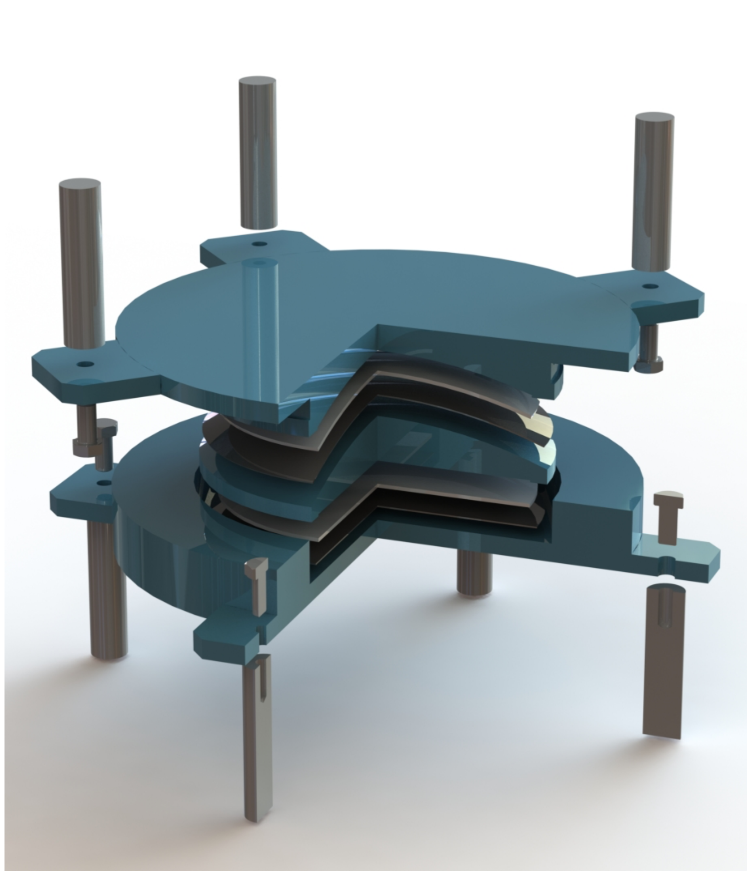
THE SLIDING MATERIAL TESTING MACHINE (SMTM)



A. Vertical actuator
B. Horizontal actuator
C. Climatic chamber
D. Reaction frame

SHERICAL BEARINGS



The most suitable bearing to take advantage from the new sliding materials and their increased compressive strength is the spherical bearing.

3 Rotation DOF $\alpha_x \alpha_y \alpha_z$

They can provide greater rotation than Pot Bearings

The increased compressive strength in comparison with PTFE allows to reduce the dimension of the bearing, greatly reducing its cost.

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EVOLUTION OF THE BRIDGE BEARINGS

TYPE OF BEARING	YEAR	MASS PER 1000 kN BEARING CAPACITY (kg)
Roller Bearing	1968	76
Pot Bearing	1990	15
Spherical Bearing with special sliding material	2008	5

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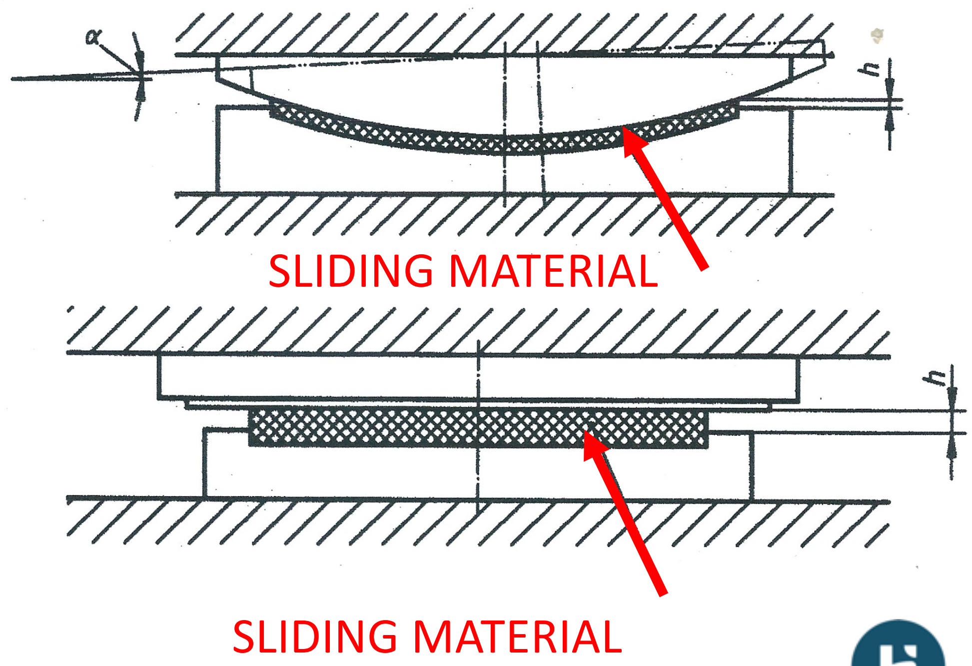
MAINTENANCE OF THE BEARINGS

- Maintenance of every kind of bearings is essential to grant the foreseen service life
- Every supply of bearings shall be provided with a specific maintenance manual
- The maintenance requirements of the bearings are quite limited: an inspection every 5 years is normally required
- For the sliding material it is very important to check the residual protrusion h
- The sliding material shall be replaced if the protrusion h is reduced to 1 mm or less
- The sliding material is normally not glued but simply recessed in order to make its replacemant easy



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The Bearings for the Bangkok Monorail

7626 spherical bearings currently under manufacturing and supply

Construction phases of the BKK Monorail

CONCLUSION

Light Railway bridges are peculiar structures where the actions of the repeated live loads on the bearings shall be evaluated carefully.

There are several bearing systems that is possible to apply and the designer shall select the right one in function of the performance required.

Roller bearings may require special attention in cold climates. The effects of the mechanical plays shall be carefully evaluated.

Pot bearings shall require special care in the selection of the internal seal and may be not suitable for some particular case.

Sliding materials shall have a very high wear resistance. PTFE should be avoided.

A proper maintenance is essential to grant the foreseen service life

Thanks for your attention!

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