Cylindrical pendulum bearings for a record bridge span for rail traffic

Thomas Spuler, Carlos Mendez and Max Brüninghold

Biography: Thomas Spuler, born in 1956, received his civil engineering degree from the Polytechnic of Brugg, Switzerland and is today CEO and Chairman of Mageba Group. He is a member of the European expert team for Road Bridge Expansion Joints (EOTA), and Chair of IABSE's Working Group 5 on bridge bearings and expansion joints.

Carlos Mendez, born in 1981, received his civil engineering degree from Michoacana University in Mexico and his Ph.D. in earthquake engineering from Hokkaido University in Japan. Since joining Mageba in 2010, he has been responsible for the technical development of seismic devices, and is now general manager of the company's Mexican subsidiary.

Max Brüninghold, born in 1980, received his engineering degrees from the Technical University of Braunschweig, Germany and the University of Rhode Island, USA. He is currently responsible for research & development of structural bearings at Mageba Group.

ABSTRACT

The Third Bosphorus Bridge (3BB) is a hybrid cable-stayed / suspension bridge for road and rail traffic, currently under construction in Turkey. In order to carry freight railway traffic over its main span of 1408 meters – a record for a railway bridge – the design envisaged the use of pendulum isolator bearings with a sufficiently small radius of curvature to adequately stiffen the superstructure for railway traffic. For the given combination of very small curvature radius, load and displacement, standard (i.e. "spherical") pendulum bearings did not present a feasible solution. Therefore, a special "cylindrical" version was developed.

Keywords: pendulum isolator bearings; suspension bridge; railway; Bosphorus Bridge

INTRODUCTION

Officially named the Yavuz Sultan Selim Bridge, the third bridge to be built between Asia and Europe across the Bosphorus Strait (and thus also known as the Third Bosphorus Bridge, **Fig. 1**) is located just a few kilometers from the Black Sea. It has a main span of 1408 meters, tower height of 322 meters and a deck width 58 meters. Construction began in 2013 and opening to road traffic is scheduled for 2016.

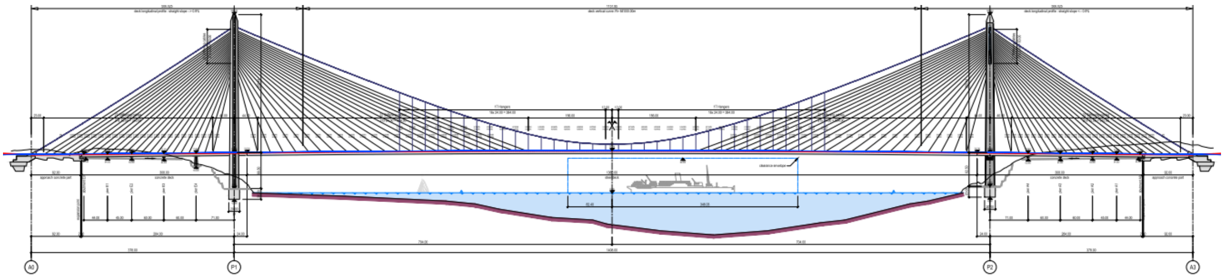


Fig. 1–Elevation of the Third Bosphorus Bridge (© T Engineering, Switzerland).

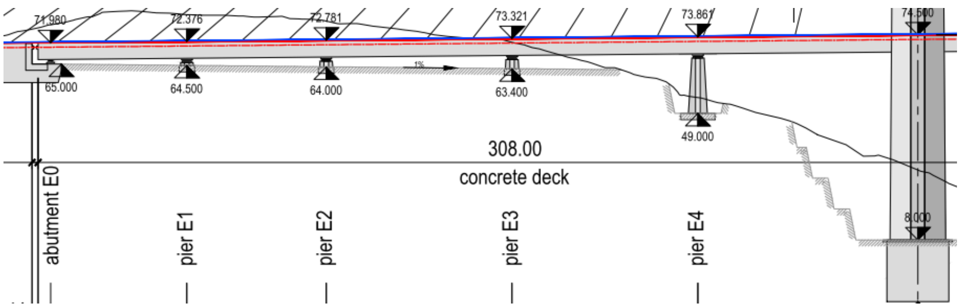
Of the one hundred suspension bridges with the longest main spans built to date[1], only four carry rail traffic, namely the Tsing Ma Bridge in Hong Kong and the Minami-Bisan-Seto, Kita-Bisan-Seto and Shimotsui-Seto Bridges in Japan. Although 3BB and Tsing Ma have a comparable main span, the loads are very different (see **Table 1**). Tsing Ma is equipped with "standard" spherical bearings and hydraulic dampers. In contrast, 3BB is equipped with pendulum isolator bearings and pot bearings only, with no additional damping devices.

Table 1–Comparison of key data of Tsing Ma and 3rd Bosphorus Bridges

Bridge	Completion	Main span [m]	Rail traffic / Load model
Tsing Ma	1997	1377	Commuter / 0.4 LM71
3rd Bosphorus	2016	1408	Freight/ 1.33 LM71

BRIDGE BEARING SCHEME

The bearing scheme at one end of the bridge is shown in **Fig. 2** (other end similar).At most piers, the deck is supported by pendulum isolator bearings (indicated by “PMC”), which are used, primarily, not for their seismic isolation function, but to reduce the longitudinal displacement of the deck and the tower bending under heavy railway traffic. distribute the very large longitudinal loading from railway traffic among a number of piers (avoiding excessive bending of the tower if these forces were resisted there instead). At the expansion joints at each end of the bridge section, free-sliding pot bearings (indicated by “TA-HP”) are used to resist vertical loads, since pendulum bearings would cause the deck to rise during longitudinal displacements (as described in the next section), which would not have been compatible with the railway tracks. Transverse forces (wind and seismic) are resisted by vertically oriented (wind shoe) pot bearings at the abutment and the tower.



© T Engineering, Switzerland

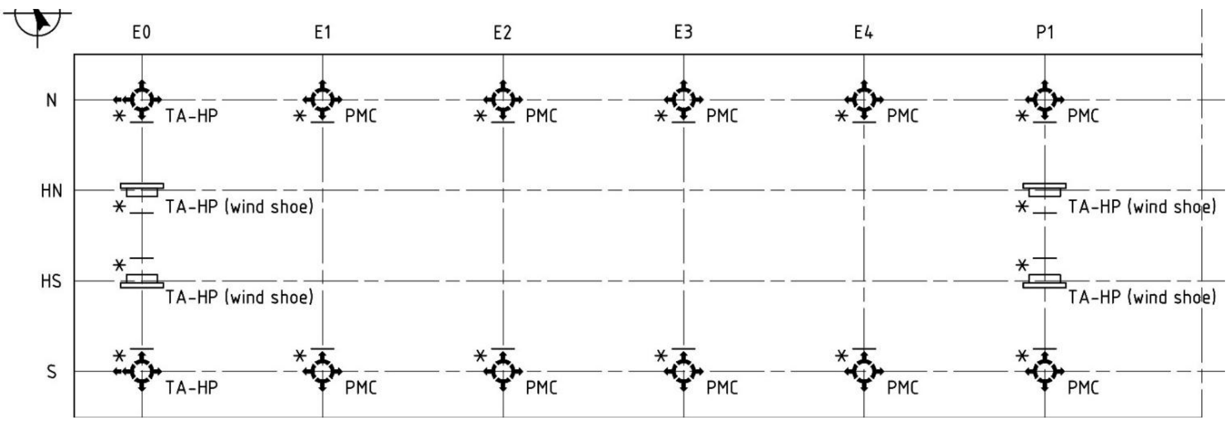


Fig. 2–Bearing scheme of a side span of the bridge (elevation and plan). PMC indicates a pendulum bearing, while TA-HP indicates a pot bearing.

PENDULUM ISOLATOR BEARINGS

Pendulum isolators, also known as *curved surface sliders*, are one type of seismic isolation bearing. Other types include *Lead Rubber Bearings* (LRB) and *High Damping Rubber Bearings* (HDRB). Each of these types protects the structures they support from violent seismic ground accelerations – isolating the structure from the ground and thus greatly reducing the movements/accelerations to which it is subjected. Further key functions of seismic isolators generally include controlled dissipation of destructive seismic energy, and recentering after the event (restoring the supported part of the structure back to its original location). In many countries, the design, fabrication and testing of each of these types is governed by European standard EN 15129[2], and strenuous testing is required in order to gain certification of compliance with the standard's demands[3,4].

Fig. 3 and **4** show the design of a typical pendulum isolator bearing. As can be seen, it has two spherically shaped sliding surfaces – a lower one to accommodate rotation of the superstructure about any axis, and an upper one to allow horizontal displacements during an earthquake (as illustrated in **Fig. 5**). The main components are the same as those of a typical free-sliding spherical bearing, except that a spherical bearing's upper sliding interface is flat rather than curved, designed just to accommodate service movements due to thermal expansion, etc.

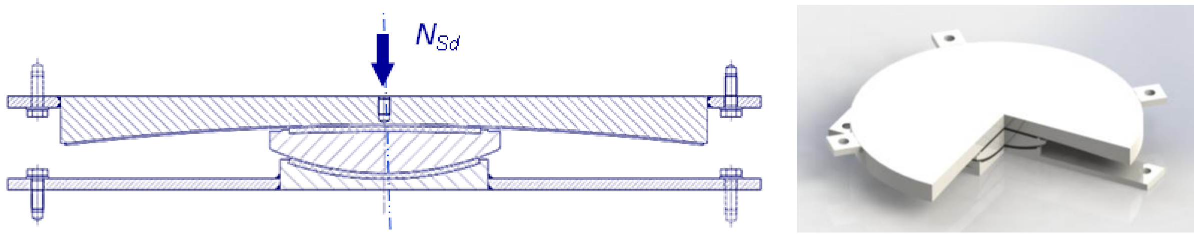


Fig. 3–Cross-section and cut-out view of a typical pendulum isolator bearing.

Fig. 4–A typical standard pendulum isolator bearing, viewed from below.

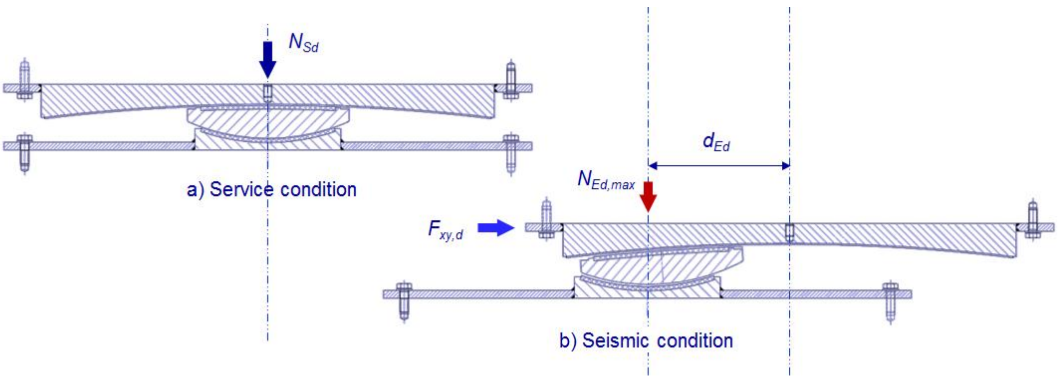


Fig. 5–Cross-sections of a typical pendulum isolator bearing showing how it accommodates horizontal ground movements (in any direction) during an earthquake.

As can be seen in Fig. 5, the height of the bearing increases as the upper plate (of varying thickness) is displaced from its central position during an earthquake. As a result, a great amount of work is performed in raising the superstructure, thereby dissipating much of the earthquake's energy in a non-destructive way.

The upper sliding plate of a standard pendulum isolator bearing is always circular in plan, making it equally well able to accommodate seismic ground movements in any horizontal direction – whether or not this may be required by the structure's design.

By selecting the radius of each sliding surface accordingly, the bearing can be designed for the appropriate period and damping ratio in any situation.

The dimensions of a pendulum bearing are primarily governed by two main parameters:

- The maximum load to be carried, which defines the minimum surface area of the sliding surfaces and thus the size of the calotte at the heart of the bearing.
- The displacements to be accommodated in service or in a seismic event

For this structure, the following parameters applied in the design of the largest bearings:

- strength limit state) load of 125 MN
- strength limit state displacement of 764 mm

FEASIBILITY OF DESIGNING AS A STANDARD PENDULUM BEARING

Fig. 6 shows how a standard pendulum isolator bearing, with a "spherical" calotte, would have looked based on the above project specifications (at maximum displacement of 764 mm). As can be seen, the upper sliding plate has a radius of 2000 mm and the lower sliding surface has a similar radius (2200 mm). With the diameter (on plan) of the central calotte being almost twice the radius of curvature, the calotte becomes enormous. Furthermore, the high load eccentricity of this design would be problematic for the spherical seating.

DESIGN AS A NON-STANDARD ("CYLINDRICAL") PENDULUM BEARING

To overcome these difficulties, and considering that the bearing's pendulum function is only required in the bridge's longitudinal direction, a cylindrical shape was investigated for the sliding surfaces. To accommodate rotations about a vertical axis, the calotte was split into a lower part and an upper part connected by a vertical pin as shown in **Fig. 7**.

Since the length of a cylinder can be increased as desired without affecting its radius – unlike a sphere, the dimensions of which must increase equally in all directions – the calotte can be designed to carry the specified load by adjusting the length only.

At a length of three meters, the calotte showed a reasonable ratio of width to curvature radius, as shown in **Fig. 8** (at maximum displacement of 764 mm).

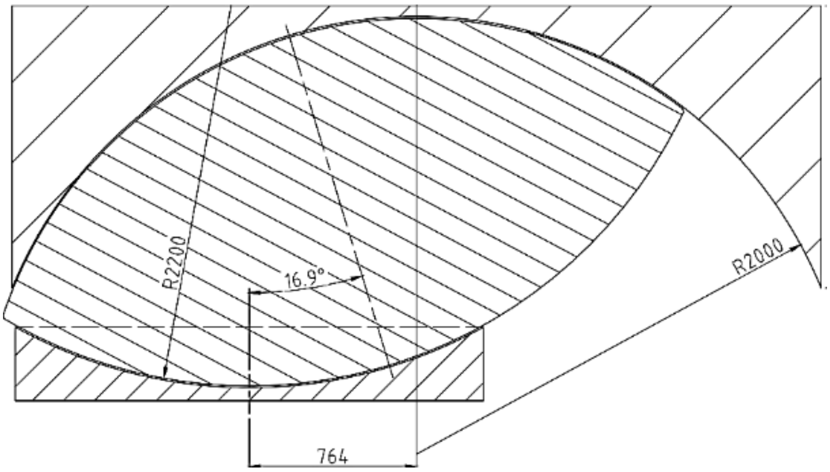


Fig. 6–Cross-section of possible solution if designed as a standard pendulum bearing – with the central calotte having spherically shaped upper and lower sliding surfaces.

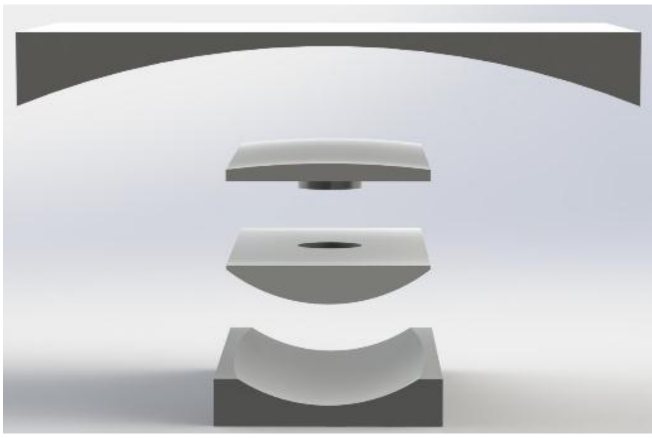


Fig. 7−Representation (exploded view) of designed pendulum bearing – with the central two-part calotte having cylindrically shaped upper and lower sliding surfaces.

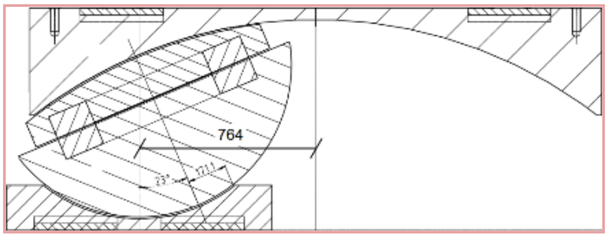


Fig. 8–Cross-section of designed non-standard pendulum bearing – with the two-part central calotte having cylindrically shaped upper and lower sliding surfaces.

This modification to the design, replacing spherical sliding surfaces with cylindrical ones and thus designing out the unnecessary ability of the bearing to accommodate transverse pendulum movements, greatly improved the efficiency of the design as can be seen by comparing the sections in Figures 6 and 8, which are drawn to the same scale.

The fabricated bearings (an example of which is shown in **Fig. 9**) are thus far lighter than they would otherwise be with a standard design. In fact, the largest of the bearings reduced in mass from over 100,000 kg to just 34,000 kg, offering great benefits during bridge construction, maintenance and renovation works.

Fig. 9−A "cylindrical" pendulum bearing, as fabricated.

CONCLUSIONS

The use of pendulum isolator bearings is an effective way of reducing the longitudinal deck displacements of suspension bridges under live loading, particularly in the case of heavy rail traffic loading. However, if the radius of curvature of the main sliding surface of a designed bearing is low relative to the vertical load to be supported, the design can become very inefficient and even unfeasible. In such cases, the "spherical" shape of the sliding surfaces of the bearing's calotte can be made "cylindrical", designing out unnecessary transverse pendulum movement capacity. The resulting rectangular plan shape is less prone to tilt and eccentric contact pressure problems, and the size and weight of each bearing can be significantly reduced – simplifying production, transportation, installation and future replacement.

REFERENCES

1. Continually updated list of longest suspension bridge spans, available at https://en.wikipedia.org/wiki/List_of_longest_suspension_bridge_spans

2. "EN 15129 – Anti-seismic devices", European Committee for Standardization, 2009.

3. Moor, G., Mendez, C. and O'Suilleabhain, C., "Measuring Up", *Bridge Design and Engineering - Issue 63,* London, 2011.

4. Mendez, C., Spuler, T., Moor, G. and Stirnimann, F., "Design, full-scale testing and CE certification of anti-seismic devices according to the new European norm EN 15129: Curved Surface Sliders". *Proc. 15th World Conference on Earthquake Engineering*, Lisbon, 2012.