Seismic Protection of Railway Bridges with Special Sliding Materials

M. Sartori
Alga S.p.A., Milan

SUMMARY:
The paper describes the application of special sliding materials with high performance in terms of resistance and friction, to the seismic isolation of railway bridges.
The seismic protection can be reached using spherical bearings with high resistance and low friction sliding material together with lock-up devices, viscous or hysteretic dampers. The application on the Rio Sado Bridge in Portugal is presented.
The application of the special sliding material for sliding pendulums is also presented; the paper describe the solutions applied for the Turkish high speed railway for assuring the correct behaviour both in seismic and service conditions.
Recovering of the braking force without movements in service is also very important. The application for the Spanish high speed railway, where a fuse restraint is coupled to the sliding pendulums, is also presented.
The presented solution is a mix of the most up-to-date technology in the field of bearings and seismic protection.

Keywords: Seismic Protection of Railway Bridges, Special Sliding Material, Sliding Pendulum

1. INTRODUCTION

The researches performed during the last years, like the one performed by Alga with the cooperation of Politecnico di Milano, carried to the development of new special sliding materials to be used for bearings and isolators. These materials have performances higher and higher, in particular they are able to resist to higher and higher pressure, reaching more than two times the characteristic resistance of the PTFE. Also these special sliding materials can assure a controlled friction coefficient, both when a low friction material or a high friction material is required. Moreover they have a great resistance to wear allowing the structure to increase its service life.

During the last years these materials have been widely applied in railway bridges, being applied as sliding materials for spherical bearings or sliding pendulums. Railway bridges, indeed, unlike in other types of bridges, have the distinctive feature to have high loads and, in case of large spans, the bearings present very high accumulated path.

This is the case of the Rio Sado bridge in Portugal, where the three steel arch bridges having 160 m span each one, carry to rotations on the bearings due live loads very high with consequent exceptional sliding movements. The daily traffic carries in a short time to the wear of the sliding material. Here the application of a special sliding material for spherical bearings allowed to increase a lot the service life of the installed devices. Lock-up devices, viscous and hysteretic dampers coupled to the spherical bearings complete the seismic protection of the bridge.

Even if in the case of the Rio Sado bridge the seismic protection was not directly provided by the special sliding materials, they can be applied in sliding pendulums. Indeed this is their typical application, where the friction coefficient is the most important design parameter. The special sliding material allows to calibrate and control the friction coefficient, even at different velocities.

A typical requirement of the designers, especially in very high seismic areas, is to increase the friction coefficient in order to dissipate as much energy as possible during the seismic event, limiting on the other hand the friction coefficient during service situations. This limitation has the double aim to have not too high reaction forces for thermal movements and to limit the wear of the sliding material. An application of this type was for the isolation of two viaducts of the Turkish High Speed Railway.

Another example of application of the special sliding material for the seismic isolation of railways bridges is the case of the Viaducto de Trasvase Tajo-Segura of the Orihuela-Colada de la Buena Vida High Speed Railway in Spain. These viaducts were isolated with sliding pendulums provided with fuse restraints in longitudinal direction, in order to recover rigidly the service loads like breaking and acceleration of the train, avoiding in this way any movement of the deck due to this kind of actions. During the earthquake, in order not to overload the piers having a limited longitudinal load capacity, the fuses break allowing the complete working of the sliding pendulums and dissipating energy making in this way the viaduct completely isolated.

2. THE RIO SADO BRIDGE

The Rio Sado bridge is composed by 2 approach steel-concrete ramps, each one 1.114 m length, and a central continuous span over the river made by 3 steel arches having 160 m span each one. The adopted solution is a mix of the most up-to-date technology in the field of bearings and seismic protection.

Figure 1. Rio Sado Bridge

The approach ramps are seismic isolated only in longitudinal direction by viscous dampers on abutments and steel hysteretic dampers on piers.

The isolators are composed by sliding guided pot bearings coupled with lock-up devices working together with the C-shaped hysteretic elements. In that way the bearing system is able to allow the slow movements during the service life with negligible resistance, while during the earthquake the lock-up devices stop the movements and transfer the forces to the C-shaped hysteretic elements that yield and dissipate energy through the plastic deformation if the forces exceed the design level. They are located on four piers and designed for maximum vertical load at SLS 14500 kN, maximum longitudinal seismic horizontal load 2500 kN (the yielding force of the C-shaped elements), service movement capacity of 260 mm, maximum seismic displacement ±90 mm.

At each abutment four viscous dampers of 2500 kN load capacity are increasing the damping capacity of the isolation system. Moreover, fixed pot bearings are located on each of the four central piers and designed for 14500 kN vertical load, 3000 kN transverse and longitudinal horizontal load.

The complete devices are easily replaceable with minimum deck lifting. The "C" shaped elements and lock-up devices can be individually removed for inspection and replaced without deck lifting. The supplied pot bearings comply with the requirements of European Standard EN1337 and are marked with CE European quality certification.

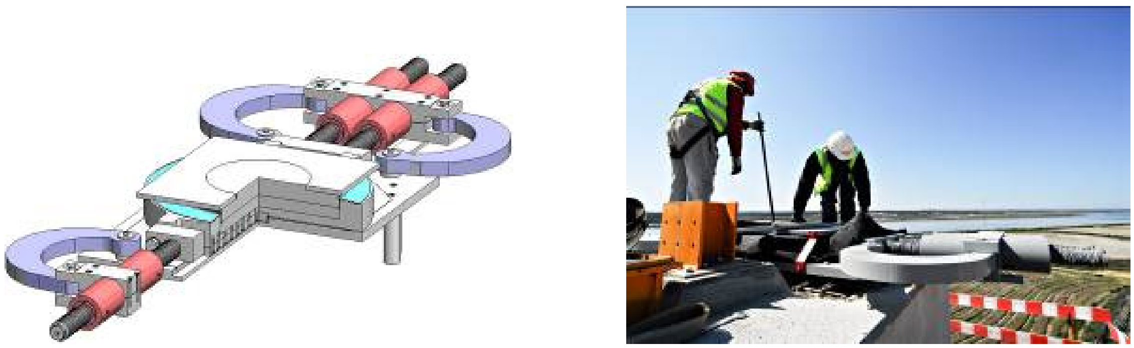

Figure 2. Guided pot bearing coupled with lock-up device and C-shaped hysteretic elements

The steel arches are supported by spherical bearings with 70000 kN vertical capacity. New special sliding material with low friction coefficient and high resistance has been used instead of PTFE due to the exceptional amount of sliding movement to grant a service life over 25 years. Lock-up devices grant seismic load distribution over the arch bridge piers. Spherical bearings have also been equipped with monitoring system to record and check loads and movements through remote control system.

Figure 3. Monitored fixed spherical bearing. Calibration and Installation phases.

The spherical bearings of the steel arch spans of the Rio Sado bridge are subjected to an exceptional sliding movement.

The sliding movement in the spherical bearings is mainly given by the addition of the thermal displacement due to the daily and seasonal temperature variations, of the flexural displacement due to the bending of the structure under the effect of the live loads and of the rotational displacement due to the bending of the structure under the effect of the live loads. The latter bending causes on the sliding surface a double movement due to the fact that the beam will return to its original shape.

As example, in the case of the bearings on the axis P4, we can consider the following like the daily displacements under the following assumptions:

- Daily temperature variation ± 10°C
- Flexural displacement caused by one train : 110 mm
- Flexural rotation given by one train 8.584 + 7.500 mrad
- Radius of the spherical surface equal to 4367 mm

The very high path accumulated in only one day shows the importance to have a sliding material with high performances, above all in terms of wear resistance. To improve the service life of the bearings, the special sliding material has been foreseen and it has been tested up to a sliding path of over 50000 m.

However this sliding path, with a daily traffic of 100 trains, would be reached in 1989 days only, that means in 5.4 years. The tests performed on the special sliding material however showed that, after 50000 m of slide path the material is not worn out but simply the lubricant is totally exhausted. Therefore the periodic lubrication would greatly amplify the service life of the bearings by a factor at least 5 so to a life of at least 25 years. For this reason it is strongly recommended to adopt the periodic lubrication of the bearings. To allow this the bearings of the Arch Bridge have been specially equipped for the lubrication. It has been recommended to lubricate the bearings at least every 5 years.

The lubrication is a very simple operation requiring a just special pump suitable to inject liquids up to a pressure of 70 MPa. The lubricant to be added shall conform to the requirements of EN 1337-2 Paragraph 5.8. The lubrication does not require the lifting of the bridge.
After 20 years and not more than 25 years it is recommended to replace at least one sheet of special sliding material in order to examine it and to verify if the service life of the bearings can be extended.
The inspection of the special sliding material extracted from the bridge shall be performed by the experts of ALGA.

3. THE SLIDING PENDULUM FOR THE TURKISH HIGH SPEED RAILWAY

The viaducts here described named VK12 and VK14A are located in the section Köseköy-Vezirhan of the Istanbul-Eskişehir line. This high-speed rail line is a part of the project of high speed railways development between the towns of Ankara and Istanbul. A large part of it is located near the southern branch of the North Anatolian Fault.

The viaducts, of 1020 m length, are composed by a total number of 31 spans, 33 m each.
The deck is composed by simply supported prestressed and precasted beams with a concrete slab of 12 m width. Each span is supported by 10 I-beams and the total height of the deck is about 3 meters. A typical section of the deck is shown in Figure 4.

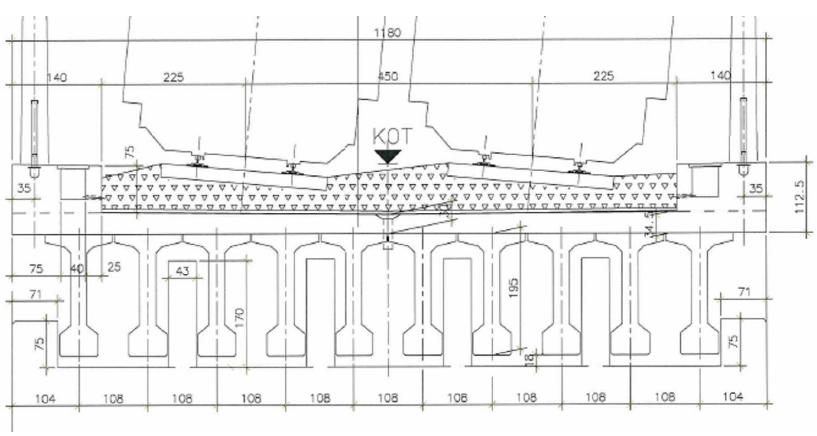

Figure 4. Typical cross-section of the viaduct

Every four or five spans, an expansion joint is installed in order not to concentrate the thermal expansions of a so long viaduct at the abutments, but lock up devices were foreseen in order to connect the entire viaduct under seismic conditions.

The proximity of the fault and the high base acceleration of 0.7 g cause the release of a very high quantity of seismic energy. This energy could cause high values of forces and moments transmitted to the foundations through the piers if a seismic isolation system is not adopted. The necessity of dissipating a very high quantity of energy moved the designer to apply a seismic isolation system using friction pendulum with high friction sliding material.

Friction pendulum with vertical load capacity up to 20000 kN and ±500 mm of displacement were designed, produced and tested by Alga according to the designer specifications. The Figure 5 shows the friction pendulum installed along with its behavior characteristic curve.

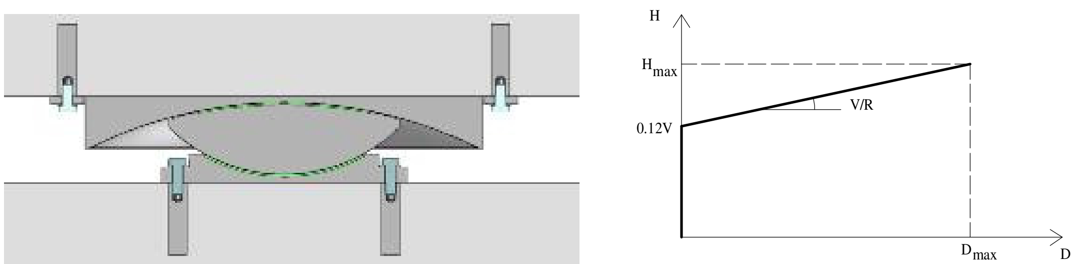

Figure 5. Friction pendulum and its characteristic curve

The designer requirements foresaw a different friction coefficient for seismic and service conditions, in particular for seismic conditions a friction coefficient of 12 % was required in order to dissipate a lot of seismic energy, while a friction coefficient of 6% was required in order to limit the force transmitted to the pier under service conditions.

Alga with the cooperation of Politecnico di Milano, developed a high friction special sliding material able to satisfy the designer requirements, having a friction coefficient depending on the applied velocity and stable to wear in order to grant the design life of the bridge.

Many tests were performed both on the material itself and on the entire bearing. Tests on the sliding material were performed at Politecnico di Milano in order to check the behavior at different velocities and demonstrate its suitability for the application on sliding pendulums. Further tests were performed at Eucentre laboratory in Pavia on the entire device in order to simulate the seismic behavior, up to velocity more than 1 m/s applying seismic displacements up to 340 mm with an applied vertical load of 5000 kN. Other tests were performed with the aim to demonstrate the suitability of the supplied friction pendulums to respect the designer specifications in terms of vertical capacity, horizontal force and displacement and in terms of effective stiffness and energy dissipated per cycle (EDC).

Figure 6. Friction pendulum with its high friction sliding material and tests performed

4. THE SLIDING PENDULUM WITH FUSE RESTRAINTS FOR THE SPANISH HIGH SPEED RAILWAY

The viaduct over the Trasvase Tajo-Segura of the Spanish High Speed Railway is located in the section Orihuela – Colada de la Buena Vida of the HSR line between Madrid and Castilla la Mancha, in the Valencian region. The viaduct was designed by K2 Ingegnería and is under construction by the Spanish contractor Sacyr.

The viaduct of about 1000 m length is composed by 28 simply supported beams with length between 28 and 36 m. The deck is 14 m wide accommodating two tracks and it is composed by a double precasted and prestressed box girder with variable height and cast-in-situ slab. The typical section is shown in picture 7.

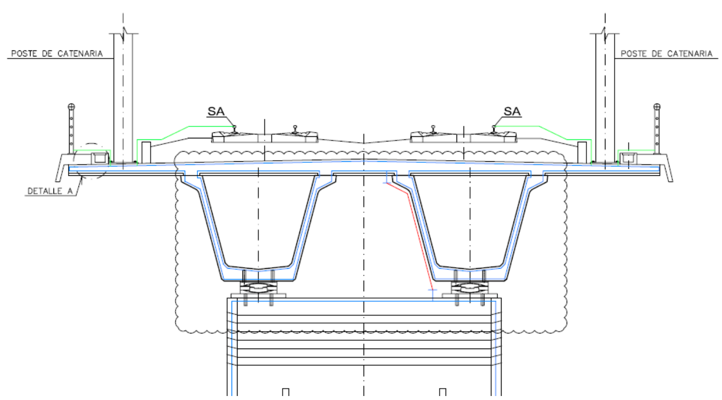

Figure 7. Typical cross-section of the viaduct

The ground characteristics are very unfavourable due to its great flexibility and poor load capacity. For this reason the designer adopted the seismic isolation of the viaduct, adopting the solution of friction pendulums able to dissipate a great quantity of energy, reducing at the same time the shear load on the top of the piers. Each span is supported by four devices, so that each pier accommodates four isolators, two of one span, and two of the following, like shown in picture 8. Each friction pendulum designed, tested and supplied by Alga is able to carry a vertical load of 6750 kN in service condition and 9500 kN at the Ultimate Limit State, has a displacement capacity of ±280 mm with a radius of 2000 mm. The special sliding material adopted is able to develop a friction coefficient of 6% in seismic conditions and a very low friction coefficient during service. It has been developed with a research promoted by Alga with the cooperation of Politecnico di Milano. The isolators were designed and tested according to the European Standard EN 15129 and are CE marked.

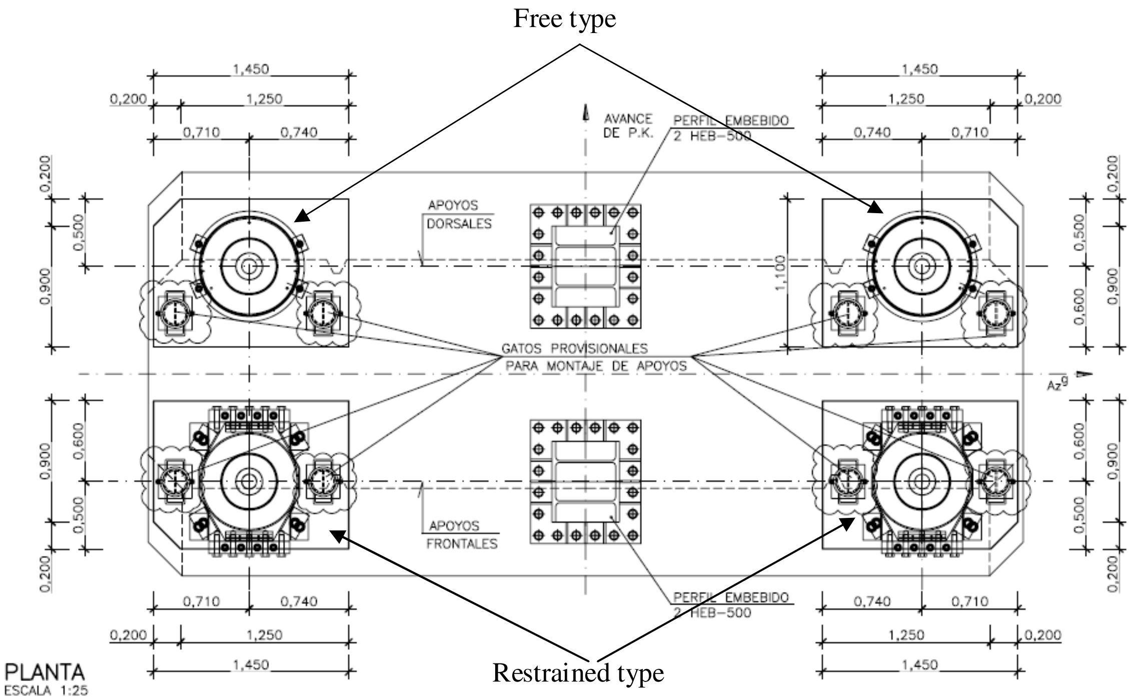

Figure 8. Typical plan of the top of the pier and isolators layout

In transversal direction the continuity of the deck is granted by shear bars into the slab able to carry the shear stress transmitted by each span, leaving each beam end free to move in longitudinal direction in order not to restrain the thermal expansion of each span. Longitudinally each span has a restraint given by the friction pendulum itself. Indeed they are not of the same type, on one side a free type is installed, while on the other side a restrained type is placed. This solution carry the deck to behave as independent beams in longitudinal direction and as a continuous deck in transversal direction restrained only at the abutments, so that no transversal deformations of the rails can occur also during the earthquake.

In longitudinal direction the restraint acts only in service conditions, carrying longitudinal service load mainly like breaking and acceleration. However, the restraint is composed by a fuse device calibrated so that it breaks for a force close to the maximum shear force carried by the piers. During the earthquake the restraint is not working allowing the friction pendulum to move dissipating the seismic energy. At the end of the earthquake the fuse restraint is replaced with a new one, but to do this is not necessary to remove the entire device from its place or to lift the deck. This operation can be simply done unscrewing the bolts that connect the plate containing the fuse device and replace it with a new one. The picture 9 shows the friction pendulum with fuse restraint and the part to replace after the seismic event.

The devices supplied are CE marked. The required prototype and routine tests were performed in 2012 at Politecnico di Milano for qualifying the adopted special sliding material and at the Eucentre laboratory in Pavia on the entire device in order to check the suitability of the friction pendulum to sustain the design loads and to simulate the seismic behaviour. At Eucentre also tests on the breakaway of the fuse devices installed on the friction pendulum were performed. All the routine tests required by the EN 15129 on the 10% of the supplied devices were performed in Eucentre and at AlgaLab in Montebello della Battaglia near Pavia. The picture 10 shows the tests performed in Eucentre on the entire device and on the fuse restraints.

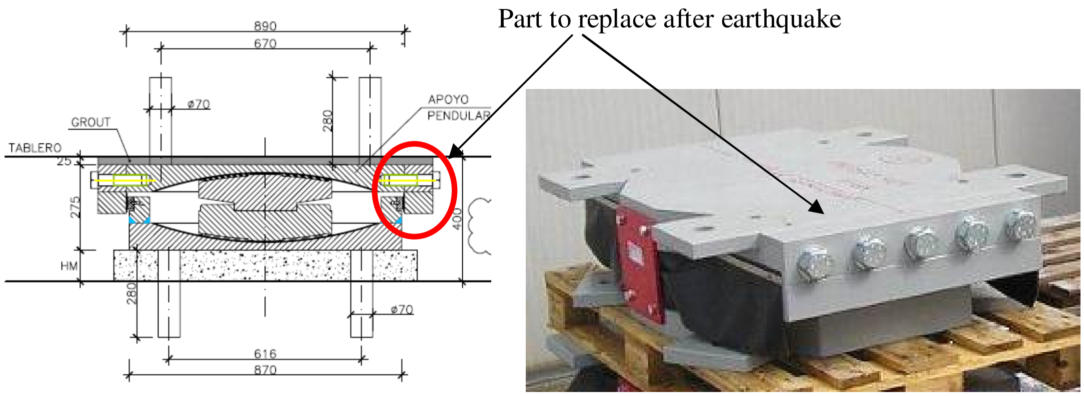

Figure 9. Friction pendulum with fuse restraint

Figure 10. Test on the fiction pendulum at Eucentre laboratory and breakaway of the fuse device

5. CONCLUSIONS

The paper describe the application of special sliding materials with high performance in terms of resistance and friction, to the seismic isolation of railway bridges.
During the last years these kinds of materials are widely used for many applications in bridge bearings, like in the case of spherical bearings or for sliding pendulums isolators.
The seismic protection can be reached coupling spherical bearings together with lock-up devices, viscous or hysteretic dampers. The spherical bearings if provided with special sliding material are able to withstand high vertical loads but at the same time to assure a very high service life, especially on railway bridges where important and frequent sliding movements can occur due to service conditions. The application on the Rio Sado Bridge in Portugal is presented where such kind of solution have been applied.
Another application of the special sliding material in seismic isolation is the sliding pendulums. The paper describe the solutions applied for assuring the correct behaviour both in seismic and service conditions.
In seismic conditions, especially in very high seismic zones, a very high friction coefficient is preferred, but, during service, low reaction forces are expected. The application for the Turkish high speed railway of friction pendulums with different friction coefficient at different velocity is presented.
Moreover, an important requirement is to recover the braking force without movements in service conditions. In these cases a fuse restraint can be coupled to the sliding pendulums. The application for the Spanish high speed railway is also presented.
The presented solutions are a mix of the most up-to-date technology in the field of bearings and seismic protection.

ACKNOWLEDGMENTS

The author wish to thank Prof. Reis of GRID, Lisbon, Portugal and the main contractor TEIXERA DUARTE, Portugal, respectively the designer and builder of the Rio Sado Bridge, for the technical information provided. Also he wish to thank Yuksel Proje and CCCI consortium respectively designer and Joint-Venture contractor of the VK12 and VK14A viaducts of the Turkish HSR and also K2 Ingeniería and SACYR, designer and main contractor of the Trasvase Tajo-Segura viaduct of the Spanish HSR.

REFERENCES

C. Özkaya, N. Celebi, F. Tulumtas , M. Dicleli (2010). Hybrid Seismic Isolation Design of Sakarya-II Viaduct in the Proximity of the North Anatolian Fault. IABMAS 2010 Conference-Philadelphia ABD

C. Özkaya, G. Çetin, F. Tulumtaş, M. Gerçek, A. Marioni, Y. Esat, S. Cam (2009). Sakarya II viyadüğünün sismik izolasyon teknolojisi kullanilarak depreme karşi tasarimi (Seismic isolation design of Sakarya II viaduct). Earthquake Engineering and Sysmology Conference , Ankara

C. Özkaya, Z. Harputoğlu, G. Çetin, F. Tulumtaş, A. Gıcır (2009). Eskişehir-Köseköy hızlı tren hattındaki köprü ve viyadüklerin performansa dayalı metotlar kullanılarak depreme karşı tasarlanması (Eskisehir-Köseköy high-speed railway seismic design of bridges and viaducts using performance-based methods). Earthquake Engineering and Sysmology Conference , Ankara