Seismic Protection of Railway Bridges with Sliding Pendulum and High Friction Special Sliding Materials

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SUMMARY:
The paper describe the application of seismic protection of two railway viaducts for the Turkish high speed railway between Ankara and Istanbul.
The viaducts are simply supported beam structures very close to the Anatolian fault.
Each span is supported by sliding pendulums up to 20000 kN vertical capacity and ± 500 mm of displacement that provide the seismic isolation of the structure. Contiguous spans are also connected by lock-up devices forming in seismic conditions a multiple-span continuous viaduct.
A new material, able to guarantee a stable very high friction coefficient during seismic condition and low friction coefficient during service condition, was developed with Politecnico of Milano cooperation.
The results of material tests, in terms of resistance, friction and wearing are presented together with static and dynamic tests with applied velocity up more than 1 m/s on the assembled devices performed at Eucentre laboratory in Pavia.

Keywords: Seismic Protection of Railway Bridges, Sliding Pendulum, High Friction Material, Dynamic Tests

1. INTRODUCTION

The Eskişehir 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.

North Anatolian fault is about 1500 km long and crosses the country from east to west. The fault is a strike-slip fault similar to San Andreas fault. A lot of destructive earthquakes up to Mw= 7.5 occurred in the last years on the fault-line like the ones occurred in Izmit (1999, Mw=7.4) and Duzce (1999, Mw=7.2).

The fault cut the line in many points and a lot of bridges and viaducts on the line are positioned a few hundred meters away. In addition negative ground conditions make worse the situation.

The "near-fault-effect" cannot be disregarded. Near the fault a lot of earthquake energy is released in a very short time and in a limited number of cycles. These single or double wave pulses dominate the horizontal motion for strikeslip faults resulting in very high displacements and forces. Moreover the adverse ground conditions that occurs close to the fault, due to the presence of sand, gravel and water in the first 30 meters before the bedrock layer, could increase in case of higher earthquake acceleration the risk of potential liquefaction.

The viaducts here described named VK12 and VK14A are located in the section Köseköy-Vezirhan of the Istanbul-Eskişehir line, the Figure 1 shows the Istanbul-Ankara High Speed Railway and the location of the VK12 and VK14A viaducts. The picture 2 shows the seismicity of the Anatolian region.

The design of the viaducts was performed by Yüksel Proje from Ankara after the experience made on the Sakarya II highway viaduct in 2009. This viaduct, now completed and already opened to traffic, is located in the same region of the VK12 and VK14A HSR viaducts and, due to the presence of the fault, shows the same difficulties in terms of design. In the case of the Sakarya II viaduct the high performances granted by the installed Lead Rubber Bearings, with diameter up to 1400 mm and able to allow 1200 mm of displacement supplied by Alga, allowed to solve the problem due to the near-fault-effects, thanks to the special methods of seismic analysis adopted (Ozkaya et al, 2010).

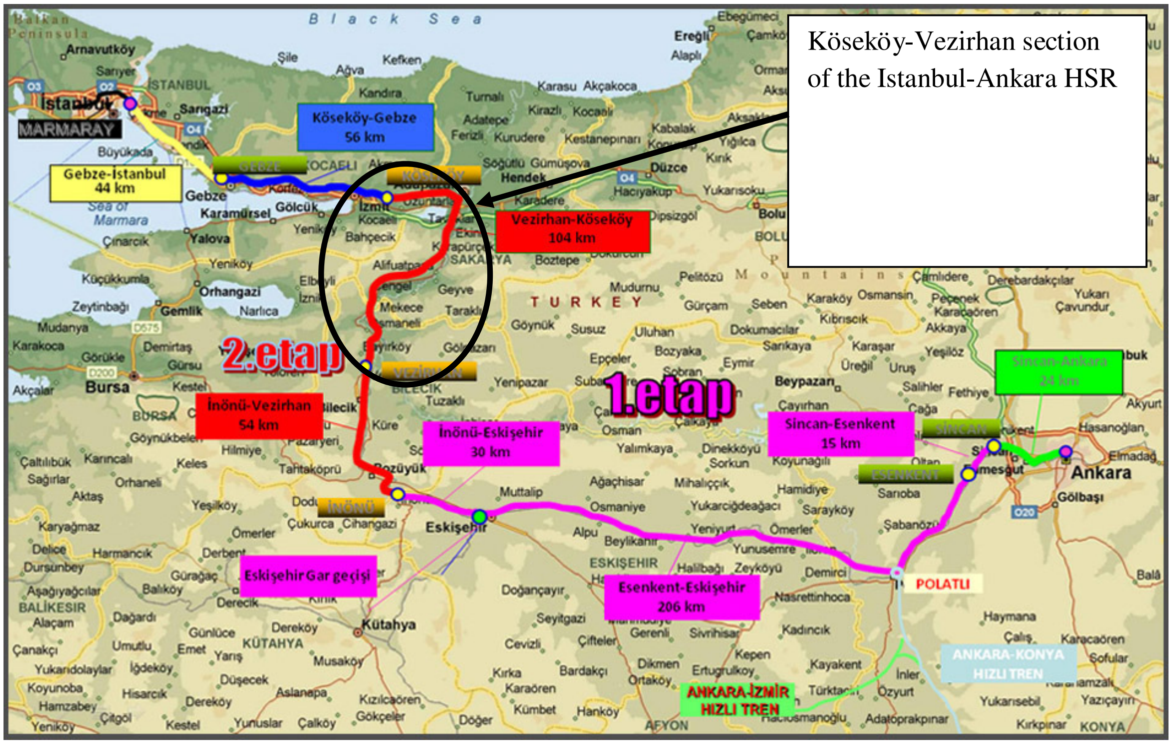

Figure 1. Istanbul_Ankara High Speed Railway and location of the VK12 and VK14 viaducts (http://www.ccciconsortium.com)

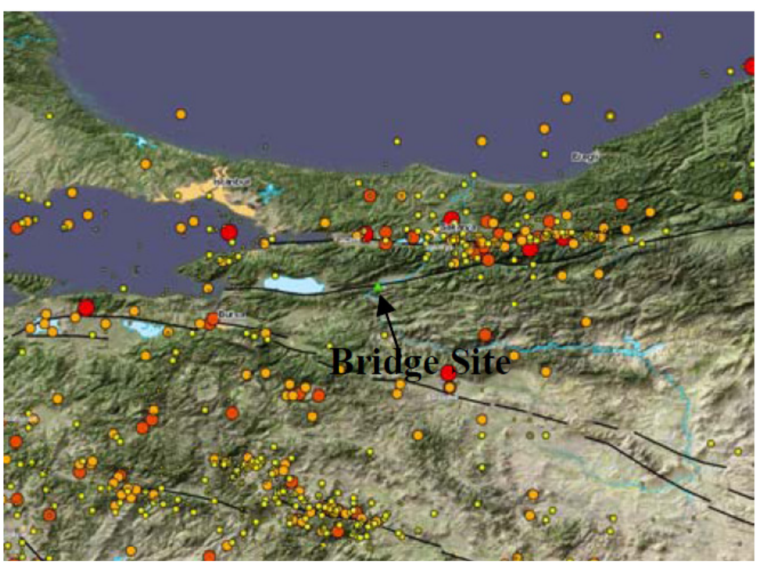

Figure 2. Seismicity of the Marmara Region and Bridge Site (1900-2006) [Cetin 2008]

2. DESCRIPTION OF THE VIADUCTS AND OF THE APPLIED ISOLATION SYSTEM

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 3.

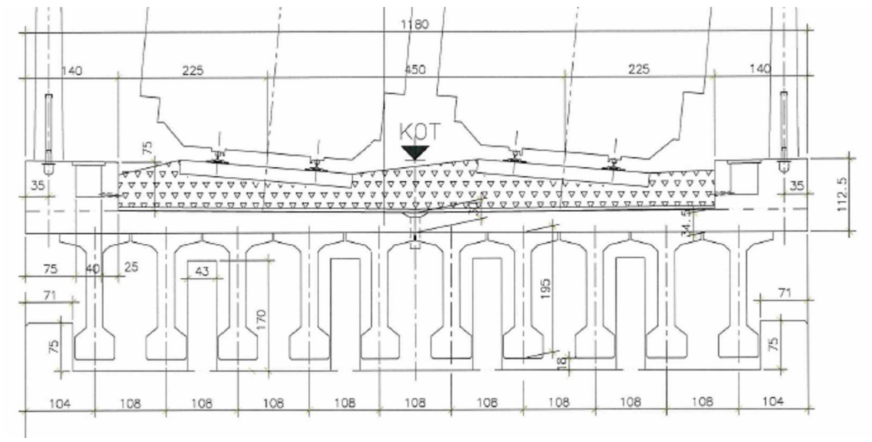

Figure 3. Typical cross-section of the viaduct

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 very hard seismic conditions are clearly represented by the response spectrum of the zone shown in the Figure 4, where the base accelerations is 0.7g.

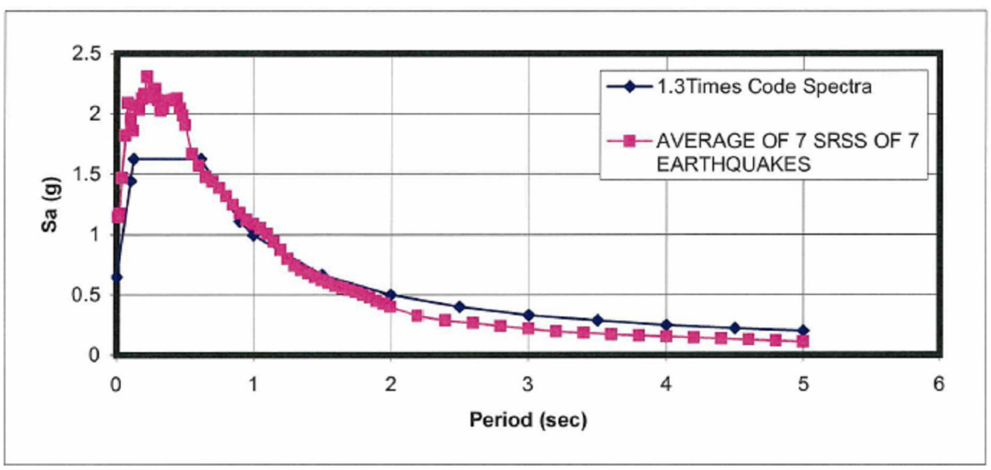

Figure 4. Response spectrum and scaling of the earthquake records

The proximity of the fault causes 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.

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.

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.

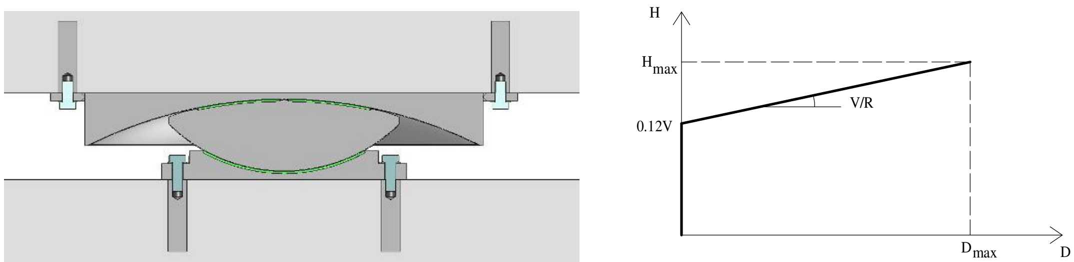

Figure 5. Friction pendulum and its characteristic curve

3. THE APPLIED SPECIAL SLIDING MATERIAL

The special sliding material named "TWELVESLIDE" applied on the friction pendulum for the VK12 and VK14A viaducts of the Istanbul – Ankara high speed railway is the result of a research conducted with the cooperation of Politecnico di Milano.

The aim of the research was to obtain a special sliding material able to develop two different friction coefficients for different working conditions. In particular for service condition, characterized by low values of the applied velocity, the material had to develop a friction coefficient not greater than 6%, while for seismic condition, characterized by greater applied velocity, the friction coefficient had to be of the order of 12%. The special sliding material is shown in Figure 6.

The most important property of such material is to have a great stability of the friction coefficient and a good wear resistance, in order to allow the developing of the design friction coefficient also after an accumulated path corresponding to the design lifetime.

Many tests were performed by Politecnico di Milano in order to check the behavior of the defined special sliding material in terms of friction. In particular tests at different velocities were performed on a friction pendulum of reduced dimensions. The main curved sliding surfaces consisted of a liner of Twelveslide as the convex surface and a highly polished stainless steel as the concave surface. Tests were conducted at different velocities in order to simulate both the situations of service conditions and typical seismic conditions.

The tests demonstrate that at low velocities, the dynamic friction coefficient is typically of the order of 6%, while at high velocities larger than 200 mm/s the twelveslide exhibits a dynamic coefficient of friction within the range of 0.12 ± 15%.

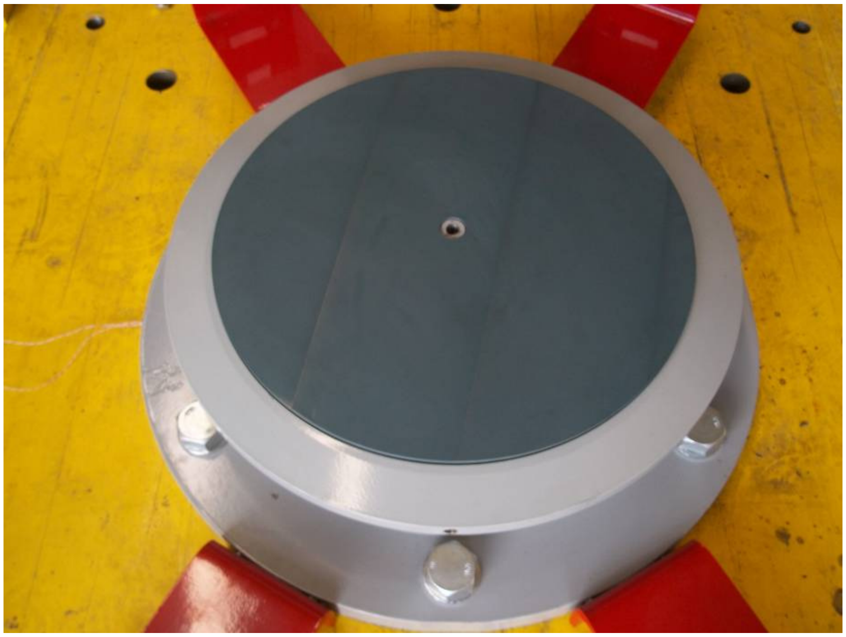

Figure 6. Special sliding material “TWELVESLIDE”

Figure 7. Test performed on Twelveslide special sliding material

In addition to the tests on the friction coefficient, tests on wear resistance were performed at Politecnico di Milano, in order to evaluate the wear of the special sliding material subjected to the movements resulting from imposed thermal displacements and live loads rotations on the viaduct structures corresponding to 30 years of lifetime. The long-term friction test performed confirms the serviceability of the special sliding material over the whole accumulated path of more than 2400 m.

4. THE PERFORMED TESTS

Besides to the tests performed on the special sliding material, tests on prototypes of the supplied friction pendulum were performed at Eucentre laboratory in Pavia.

The tests were performed on full scale friction pendulums. According to the designer specifications tests at different levels of displacement and at different velocities were performed. In particular tests at velocities typical of the service situation, like the case of the thermal expansion, and dynamic tests with a different number of fully reversed cycles at different seismic velocities up to more than 1 m/s were performed.

The most severe test performed on the prototype foresaw seven fully reversed cycles at displacement equal to the maximum test displacement of 340 mm at a velocity of more than 1 m/s, applying a vertical load of 5000 kN. The aim of all the prototype tests was 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).

The figures 8 and 9 show the testing machine and some test phases.

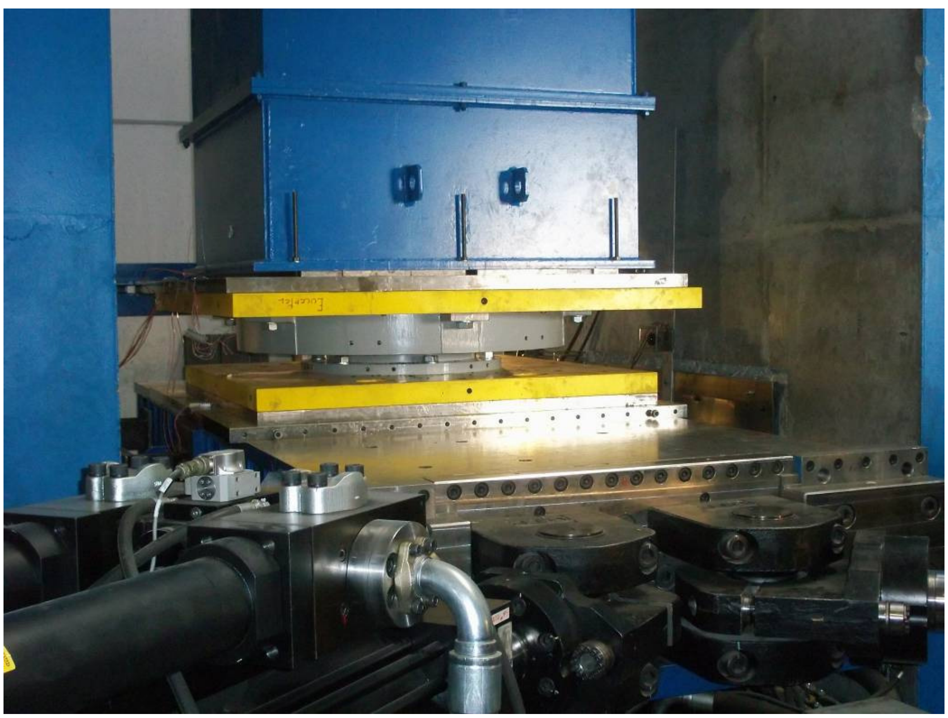

Figure 8. Test performed on the friction pendulum

Figure 9. Test performed on the friction pendulum

5. CONCLUSIONS

The paper describes the application of seismic protection to the viaducts VK12 and VK14A for the Turkish high speed railway between Ankara and Istanbul. The viaducts are placed very close to the North Anatolian fault and it induces very high acceleration on the structure besides to the necessity to dissipate a lot of seismic energy.

The isolation system applied on the viaduct consisting in friction pendulum up to 20000 kN vertical capacity and ± 500 mm of displacement. The friction pendulums equipped with high friction sliding material allow to dissipate a great amount of seismic energy being very stable for the service life of the structure. Service conditions are also very important, indeed the sliding material is able to develop a lower friction coefficient with respect to the one developed during seismic conditions. The friction coefficient of 6% during service allows the material not to wear excessively.

Tests both on the sliding material and on the friction pendulums were performed according to the designer specifications in order to demonstrate the suitability of the supplied devices for the application on the Turkish HSR viaducts.

ACKNOWLEDGMENTS

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