Fluid Viscous Dampers and Flat Surface Sliders for Seismic Isolation of the Bridge over Po River in Piacenza, Italy

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SUMMARY:
The new bridge over the Po river in the city of Piacenza has been built in substitution of the previous bridge partially destroyed by the flood of the Po river on April 30, 2009. The main bridge has a continuous deck of 11 spans for a total length of 815 m; the approach viaduct on the Piacenza side is subdivided in three portions, for a total length of 270 m. Both the main bridge and the approach viaduct are seismically isolated with an isolation system comprising free-sliding flat surface sliders and non-linear fluid viscous dampers, the latter both in the longitudinal and transverse direction. Most of the sliders are combined with fluid viscous dampers installed within the same device, thus realising an isolator with very high energy dissipation capacity; said compact configuration makes easier the installation of the devices. The paper describes said seismic isolation system, focusing on the main bridge.

Keywords: fluid viscous damper, seismic isolation, energy dissipation, bridge

1. INTRODUCTION

The new bridge over the Po river in the city of Piacenza, in the North of Italy, spanning 1.1 km, has been built in substitution of the previous bridge partially destroyed by the flood of the Po river on April 30, 2009. This bridge, located on state road 9 ”Via Emilia”, is one of the most important infrastructures in Piacenza’s economy logistics, with a traffic estimate of 18000 ÷ 20000 vehicles/day. Thus, the replacement of the old bridge had to be provided on fast-track basis [Bonomo & Casazza, 2010; Mele, 2012].

The main bridge has a continuous deck of 11 spans for a total length of 814.5 m (Figure 1), being minimum span length of about 62 m, maximum span length of about 76 m, and the deck 14.5 m wide. The approach viaduct on the Piacenza side is subdivided in three portions, respectively of about 86 m (4 spans), 31 m (single span), and 153 m (7 spans). The paper focus on the main bridge.

Due to the historic value of the old bridge, one of the design driving principles was to maintain the architecture of the old bridge, and keep part of its elements. For example, seven of the piers of the new main bridge are the old masonry piers, even though properly reinforced; some portion of the one century-old arch bridge on the Piacenza approach side, classified as cultural heritage, was refurbished and strengthened, even though is structurally independent from the new viaduct [Mele, 2012].

The choice of a steel deck truss allowed for the desired architecture, appropriate load-carrying capacity and fast erection [Mele, 2012]. Despite the low mass of this type of deck allows to reduce the seismic loads on the substructure, in particular the old piers and foundations, a seismic isolation system was also employed, and it is described in the following. Particular care in the design was devoted to the construction method, to respect the requirement of fast-track construction [Contin *et al.*, 2011].

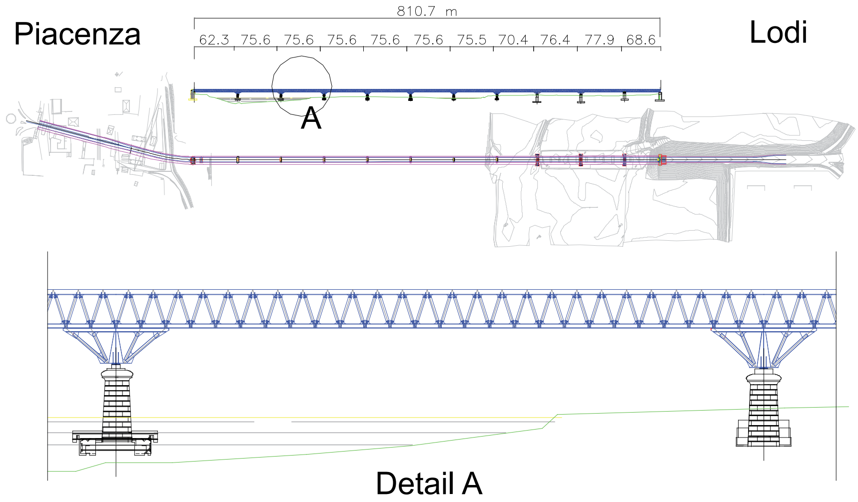

Figure 1. Elevation of the main bridge, alignment and span detail (Unit: m).

2. THE SEISMIC ISOLATION SYSTEM

Both the main bridge and the approach viaduct are seismically isolated with an isolation system comprising free-sliding flat surface sliders and fluid viscous dampers. This isolation system, characterised by high energy dissipation capacity, is able to strongly reduce horizontal forces on the substructures (piers and foundation) as well as to reduce the horizontal displacements. The design ground acceleration for the structure is 0.189 g corresponding to an earthquake with 712 years return period and the type D soil. The design ground acceleration for the seismic isolation system is higher than that for the structure, according to the Italian Standard: it is 0.242 g, corresponding to an earthquake with 1462 years return period. Figure 2 shows the elastic response spectra corresponding to the two levels of design earthquakes, for the structure (limit state for life protection, reported as SLV in the figure) and for the seismic isolation system (collapse limit statem, reported as SLC in the figure). In effects, the Italian Standard's approach to the "Increased reliability" required by the Eurocode 8 [EN 1998:1, § 10.3(2) P] for the seismic isolation system is the introduction of an additional Ultimate Limit State specific for the seismic isolation system, with a return period higher than that of the design earthquake for the structure. Conversely, the European Standard approach to obtain said increased reliability consists of applying a magnification factor on the seismic displacements of the isolating devices [EN 1998:1; EN 1998:2; EN 15129]. The suggested value for said magnification factor is 1.2 for buildings and 1.5 for bridges.

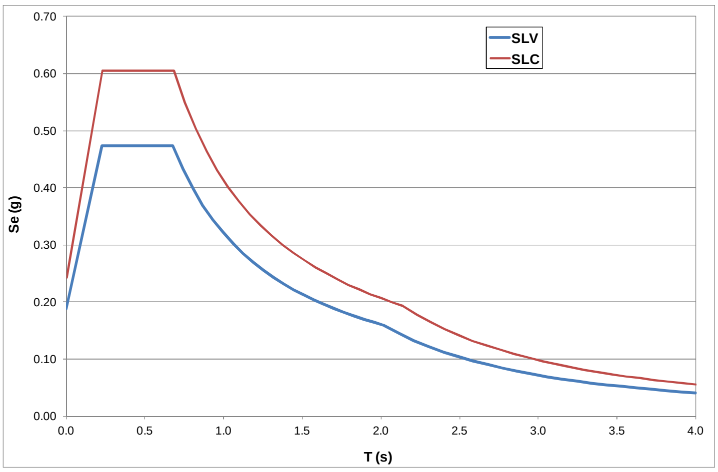

Figure 2. Comparison of elastic response spectrum for the structure (SLV)
and for the seismic isolation system (SLC) of the Bridge over the Po river in Piacenza.

Figure 3 shows the bearing layout of the main bridge. On the new reinforced concrete piers (P8, P9 and P10) as well as on the new abutment on the Lodi side (SP2), the fluid viscous dampers are both along the longitudinal and transverse axis of the bridge, while on the new abutment-pier on the Piacenza side (SP3) and in particular on the seven existing masonry piers (from P1 to P7) they are only along the transverse axis. This choice is due to the need of reducing as much as possible the horizontal forces transmitted to the existing piers, in particular in the longitudinal direction in which the pier strenght is limited, despite the strengthening.

The sliding bearings on SP3, P8, P9, P10 and SP2 are combined with fluid viscous dampers in the same device, thus realising an isolator with very high energy dissipation capacity; each isolator comprises a free sliding bearing and two viscous dampers (Figure 4). Said combination makes easier the installation of the devices and is often used in Italy in bridges.

The fluid viscous dampers are highly non-linear, i.e. with a constitutive law $F=C \cdot v^{\alpha}$, where F is the force, C is the viscous constant, v is the velocity and $\alpha \leq 0.15$. This non-linear behaviour guarantees a very high energy dissipation and a low variation of the reaction force with the velocity. The technology of FIP Industriale’s non-linear fluid viscous dampers has been widely tested in last years [Infanti & Castellano, 2001; Infanti, Papanikolas & Theodossopoulos, 2003] and applied worldwide in important structures such as the Rion-Antirion bridge in Greece, that recently was subjected to an earthquake [Infanti, Papanikolas & Castellano, 2003; Infanti *et al.* 2010]. Two different types of viscous dampers are used in the Po river bridge, FIP’s OP and OTP series (Figure 3). OP series viscous dampers are devices equipped with relief valves designed to open at pressures (loads) higher than those induced by service load conditions. OP series dampers are used on all piers in transverse direction, so that transverse movements of the bridge due to non-seismic loads are not allowed; the dampers installation details allow the bridge movements in the longitudinal direction (Figure 5) and actually constitute a guiding system for the bridge under service movements. OTP series viscous dampers are devices that can accommodate longitudinal displacements induced by both thermal deformations (providing a very low reaction) as well as earthquake actions. Viscous dampers on piers P8, P9 and P10 in longitudinal direction are of the OTP series. Under service conditions, longitudinal horizontal loads (*i.e.*, wind, braking actions, etc.) at the fixed point (SP2) are resisted by OP series viscous dampers. Figure 6 shows the bearing system of the bridge under service conditions. Under seismic conditions, the behavior of OP and OTP series viscous dampers is the same: owing to their non-linear constitutive law, they dissipate a large amount of the energy transmitted by the earthquake in both longitudinal and transverse directions.

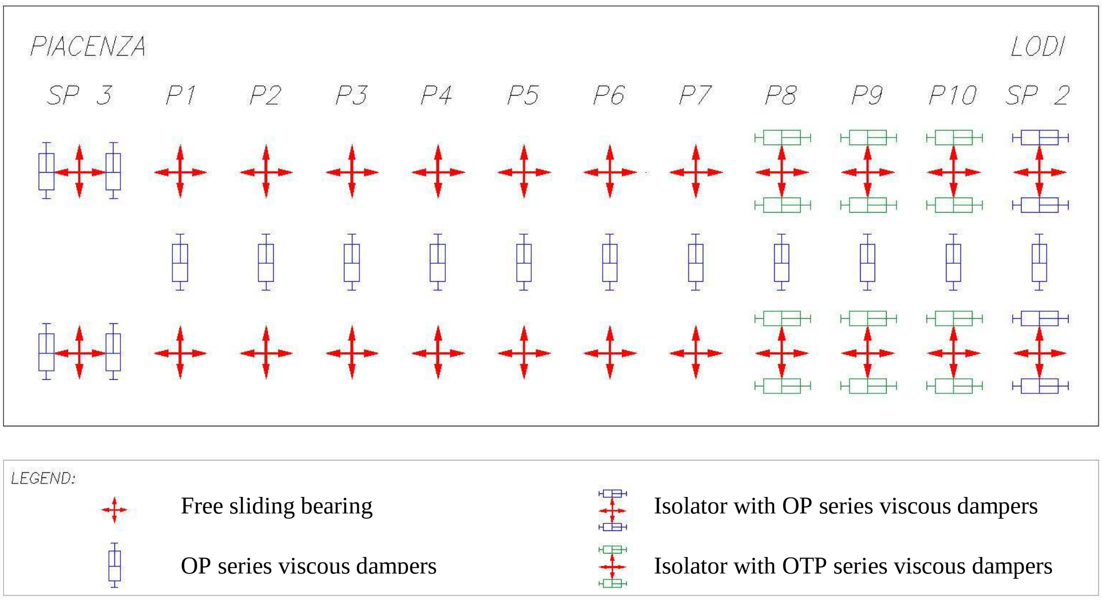

Figure 3. Seismic isolation system layout of the main bridge over Po river in Piacenza**.**

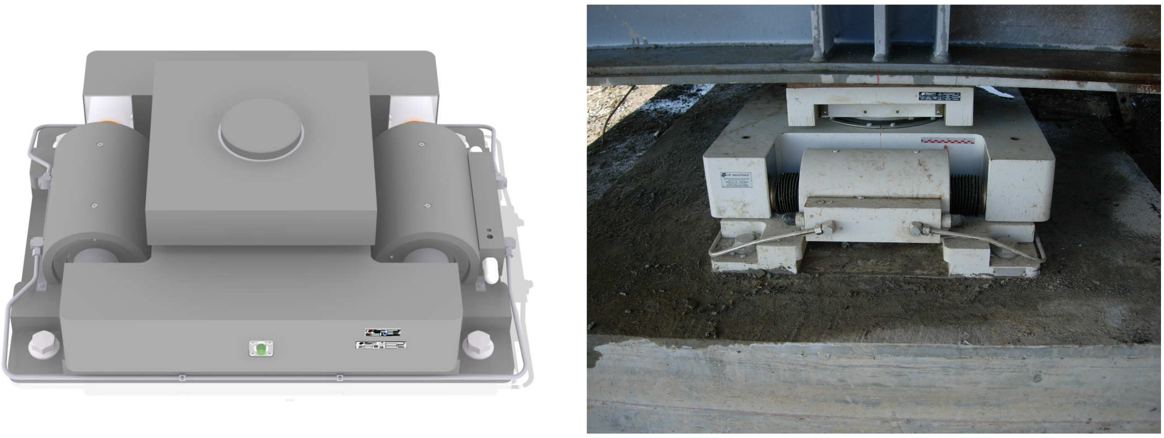

Figure 4. Isolator comprising a free sliding bearing and two OP series viscous dampers: rendering (left) and isolator as installed on SP2 (right)**.**

Figure 5. OP series viscous dampers installed in transverse direction of the bridge (on P1 ÷ P10 and SP2 positions, see Figure 3)**.**

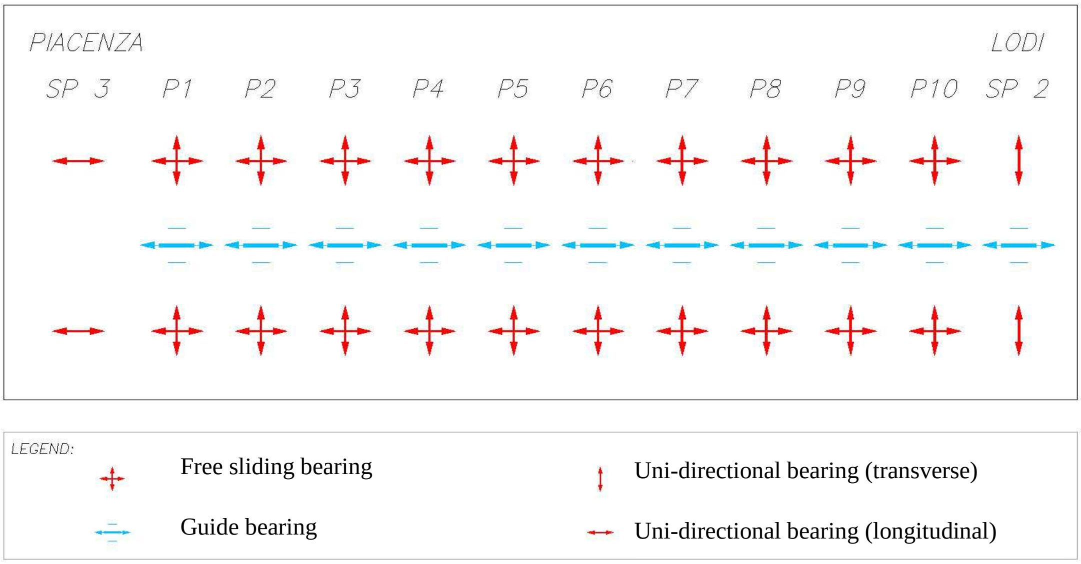

Figure 6. Bearing layout of the main bridge over Po river in Piacenza under service movements**.**

The isolators on piers P8, P9 and P10 comprise fluid viscous dampers characterised by a maximum force (total, i.e. on the couple of viscous dampers) of 1250 kN. The isolator on the abutment on the Lodi side (SP2) comprise fluid viscous dampers characterised by a maximum force of 2750 kN. The stroke of the longitudinal viscous dampers is different in the different positions, due to different thermal displacements and to the additional displacement imposed by the installation phase as well. The OP series fluid viscous dampers installed in transverse direction are characterised by a maximum force in the range 600÷1200 kN and a maximum displacement of ±60 mm.

Both the free sliding bearings and the isolators (bearing & viscous dampers combined in the same device) are equipped with a patented built-in measuring system aimed at measuring the vertical load [Colato *et al*., 2001]. Maximum vertical load is 15000 kN on piers P1 ÷ P10 and 500 kN on abutments (SP2 and SP3).

In total, the seismic isolation systems of both the main bridge over the Po river and the viaduct access on the Piacenza side, comprise 38 isolators, each combining a free sliding bearing with two fluid viscous dampers, 14 free sliding bearings and 37 fluid viscous dampers.

3. FACTORY PRODUCTION CONTROL TESTS

Fluid viscous dampers of different sizes were subjected to factory production control tests (FPCT) according to the procedures required by the Italian Standard. Here below the results of tests on viscous dampers type OTP, used on the approach viaduct on the Piacenza side, are presented. On this type of dampers, FPCT were carried out on 18 devices, thus it is possible to observe the statistical variation of the behaviour of the dampers within the supply.

The tested dampers are characterised by maximum force of 250 kN corresponding to a maximum design velocity of 200 mm/s, and different strokes, from ± 50 mm to ± 125 mm. The tests have been carried out imposing displacement with sinusoidal input, at a frequency corresponding to a maximum velocity of 150 mm/s, and with amplitude of about ± 20 mm. Two series of tests have been carried out, of 5 cyles each. Figure 7 shows the force vs. displacement curve measured in one of these tests. For each series, the maximum force has been calculated as average of the measured force values on the 5 cycles; Figure 8 shows such force values for all the devices, compared to the theoretical value (239.4 kN) and the tolerance of ±15% given by the Italian Standard. All the values are fully within the tolerance: the maximum difference from the theoretical value is 5.9 %. The energy dissipated per cycle (EDC) has been calculated for each cycle of both series, as required by the Italian Standard to check its variation during cycling. According to the Italian Standard, the variation of the EDC in each cycle apart the 1st in comparison with the 3rd cycle, shall be lower than 10 %. The tests results showed that the maximum EDC variation was 2.6 %, thus confirming the very high stability of this technology.

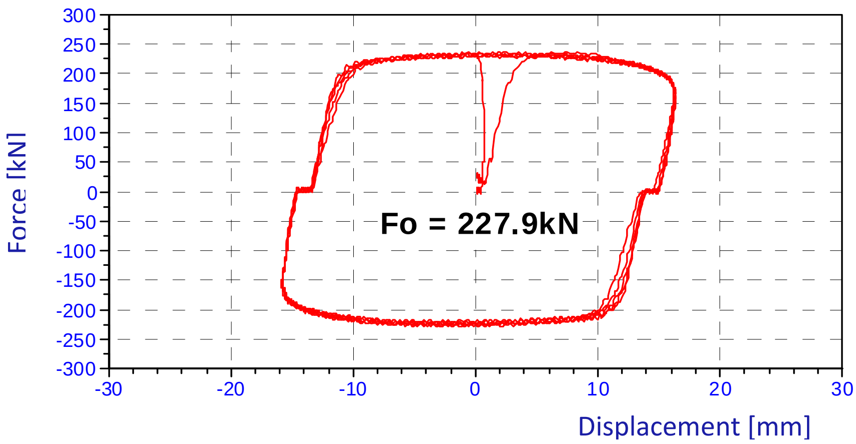

Figure 7. Force vs. displacement graph obtained in dynamic test on a viscous damper characterised by maximum force 250 kN and maximum stroke ± 75 mm (maximum velocity 150 mm/s)**.**

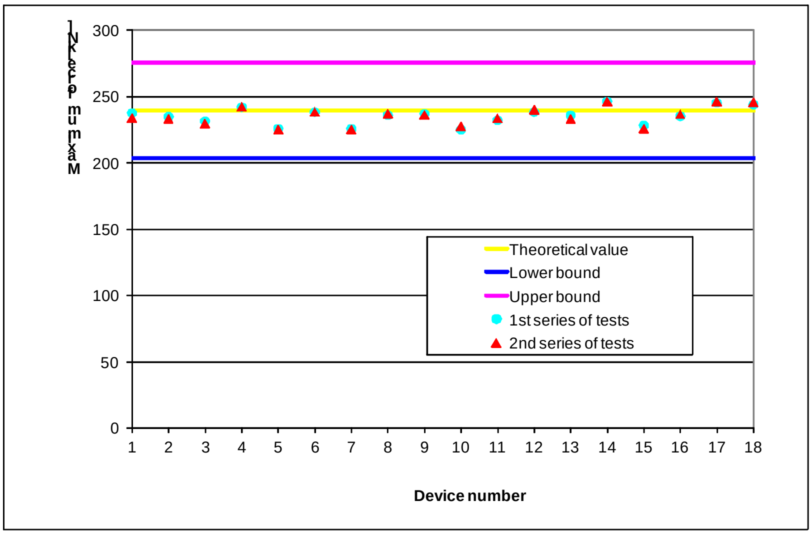

Figure 8. Maximum force (average of the 5 cyles of each series of tests) for the 18 viscous dampers subjected to FPCT.

5. CONCLUSIONS

The Bridge over the Po River in Piacenza has been designed and built on fast-track basis, after the partial collapse of the previous bridge during the flood of the Po river on April 30, 2009. This paper describes the seismic isolation system of the bridge, comprising a combination of free sliding bearings and non-linear fluid viscous dampers. In some positions, the bearings and the viscous dampers are combined within the same device, in order to make easier their installation.
The results of the factory production tests on the viscous dampers confirm their stable behaviour with cycling, as well as an experimental behaviour very close to the theoretical one.

Figure 9. The new bridge over the Po river in the city of Piacenza.

Figure 10. Details of the deck of the new bridge over the Po river in the city of Piacenza.

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