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SEISMIC ISOLATION OF HIGHWAY VIADUCTS THROUGH PENDULUM ISOLATORS

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ABSTRACT

Three viaducts of the Salerno-Reggio Calabria Highway, located in one of the areas with highest seismicity in Italy, where retrofitted through seismic isolation. While the initial design called for the use of elastomeric isolators, the as built design here described has substituted pendulum isolators to elastomeric isolators, gaining big advantages for all the three viaducts, despite their differences. The "Piano della Menta" viaduct is 190 m long, with 32 m typical span. Thanks to the seismic isolation system comprising 28 pendulum isolators of two types, it has been possible to reuse the existing piers, despite they were originally designed without taking into account the seismic actions. The "Campo del Galdo" viaduct is 430 m long, with span from 30 to 50 m, is curved, has variable width, and includes an interchange. The use of 48 pendulum isolators allowed to avoid the expansion joint at mid length provided for in the initial design. The "Casale Civile" viaduct is a straight 380 m long viaduct, with typical span of 44 m. In this case the use of 40 pendulum isolators of three types has permitted to obtain a substantial saving in the length of the foundation piles. In total, 5 types of pendulum isolators have been employed, different for vertical load capacity, all of them characterized by equivalent radius of curvature of 3.1 m, friction coefficient higher than 5.5 %, displacement up to ± 350 mm.

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ABSTRACT

Three viaducts of the Salerno-Reggio Calabria Highway, located in one of the areas with highest seismicity in Italy, where retrofitted through seismic isolation. While the initial design called for the use of elastomeric isolators, the as built design here described has substituted pendulum isolators to elastomeric isolators, gaining big advantages for all the three viaducts, despite their differences. The "Piano della Menta" viaduct is 190 m long, with 32 m typical span. Thanks to the seismic isolation system comprising 28 pendulum isolators of two types, it has been possible to reuse the existing piers, despite they were originally designed without taking into account the seismic actions. The "Campo del Galdo" viaduct is 430 m long, with span from 30 to 50 m, is curved, has variable width, and includes an interchange. The use of 48 pendulum isolators allowed to avoid the expansion joint at mid length provided for in the initial design. The "Casale Civile" viaduct is a straight 380 m long viaduct, with typical span of 44 m. In this case the use of 40 pendulum isolators of three types has permitted to obtain a substantial saving in the length of the foundation piles. In total, 5 types of pendulum isolators have been employed, different for vertical load capacity, all of them characterized by equivalent radius of curvature of 3.1 m, friction coefficient higher than 5.5 %, displacement up to ± 350 mm.

Introduction

The reconstruction of the Salerno-Reggio Calabria Highway, a 500 km long highway in the South of Italy, includes the width increase, the seismic retrofit and sometimes a new layout for the too windings stretches. The paper describes the design of three viaducts of said highway, located at the border between the regions of Basilicata and Calabria, about 200 km south of Naples, one of the areas with highest seismicity in Italy. They are with dual carriageways and in composite structure.

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While the initial design called for the use of lead rubber bearings, the as built design here described has substituted pendulum isolators [1, 2] - named curved surface sliders according to the classification of the European Standard EN 15129 [3] to lead rubber bearing, gaining big advantages for all the three viaducts, despite their differences. In the following the design of the three viaducts is described in detail.

Pian della Menta viaduct

The existing viaduct (Figure 1), built in the late Sixties, was made of six simply supported spans in prestressed concrete (p.s.c.) with typical length of 32m. The deck of each carriageway was composed of four I-beam girders 1.6m tall, with a spacing of 2m, and a slab with a thickness of 20cm, 10m wide. Piers have a maximum height of 7m and are made of a pair of columns linked on top by a cap (Fig. 2).

Figure 1. Pian della Menta viaduct before retrofit.

Figure 2. Pian della Menta viaduct deck intrados before retrofit.

The initial design (Figure 3) allowed for the demolition of the whole existing viaduct and the construction of a new one with a continuous beam over five spans of different lengths (31+33+54+42+31m), fitted to avoid any interference with the existing foundations, with a composite steel-concrete deck made of three I-beam girders.

During the construction stage, poor stability of the slope discouraged the realization of new foundations, making it wiser to consider salvaging the existing consolidated foundations and the existing piers as well. The deck design has been therefore revised in order to fit the six existing substructures.

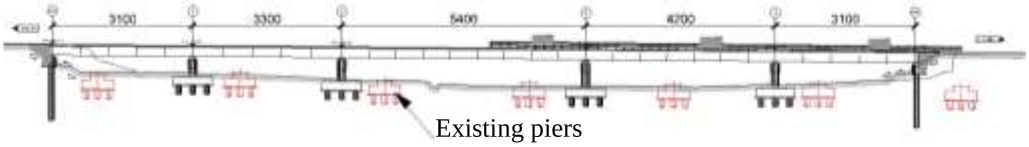

Figure 3. Pian della Menta viaduct initial project. Lateral view.

The new road section has a 12.6m wide slab and the number of steel girders has been reduced from three (2m tall, spaced 3.4m) to two, with a reduced height of 1.6m to fit the existing piers and a centre to centre space of 6.8m, linked with I-beam cross girders with typical spacing of 6m.

The box girder static scheme has been changed into a lattice girder scheme (Figure 4), eliminating the lower bracings for the benefit of easier construction.

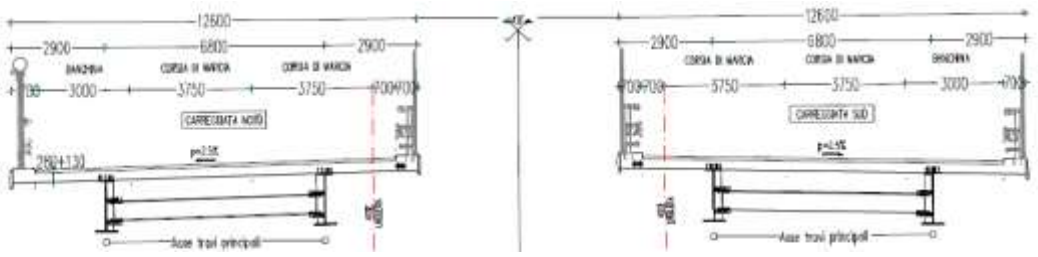

Figure 4. Pian della Menta viaduct new project. Transverse deck section.

The intent to lay the deck directly on existing piers, unloading the cap, entailed to move the bearings over the piers themselves, resulting in an eccentricity between bearings and girders' axis; over each pier there is an I cross beam as tall as the main girder.

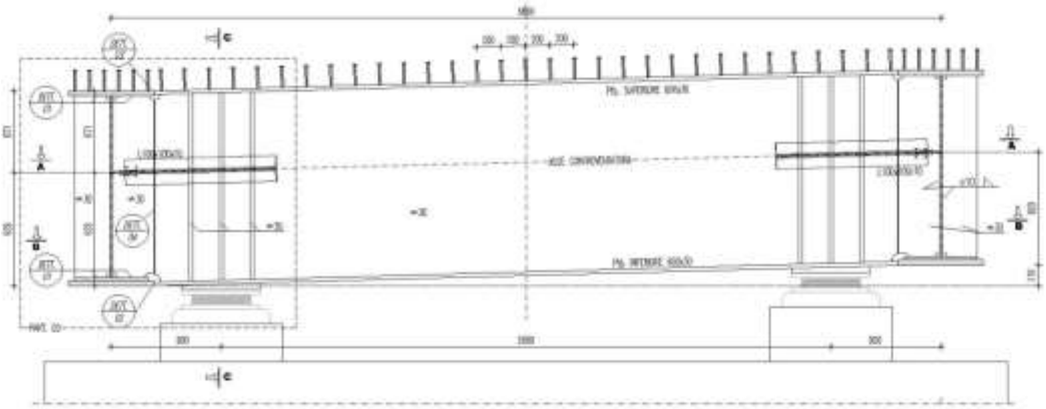

Fig. 5 Pian della Menta viaduct new project. Pier transverse cross-beam.

The opportunity to recover the existing substructures was subordinate to a significant reduction of seismic actions, therefore there was the need of a seismic isolation system very effective in such force reduction. In the initial project, the isolation system was made by 18 lead-rubber bearings (LRB) isolators for each carriageway, with an equivalent horizontal stiffness K=2.5 kN/mm. The single degree of freedom scheme of the viaduct with such isolation system led to a fundamental period T = 1.76 s.

In order to increase the fundamental period and thus reduce the forces transmitted to the substructures, the isolation system designed in the construction stage is based on pendulum isolators. In particular, it provides for 14 double concave curved surface sliders for each carriageway with the following characteristics:

- equivalent radius of curvature of 3.1 m;
- minimum friction coefficient 5.5 % (at maximum vertical load);
- maximum displacement of ±350mm;
- 4 isolators with maximum vertical load of 1700 kN on abutments (red in Figure 6) marked as FIP-D M 720/700 (3100);
- 10 isolators with maximum vertical load of 4300 kN on piers (blue in Figure 6) marked as FIP-D M 1300/700 (3100);

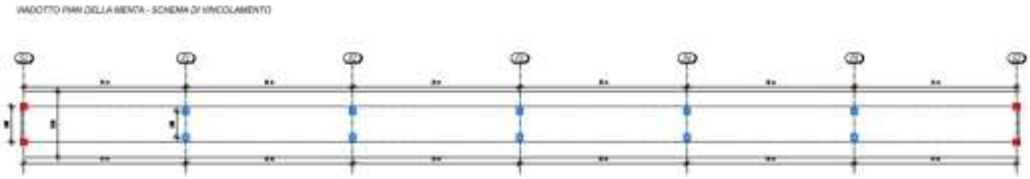

Figure 6. Pian della Menta viaduct new project. Isolators lay-out.

The equivalent horizontal stiffness of the pendulum isolators varies from 0.7 to 2.26 kN/mm with equivalent damping over 25%. The resulting fundamental period obtained through the finite element model (Figure 6) was of 2.54 s.

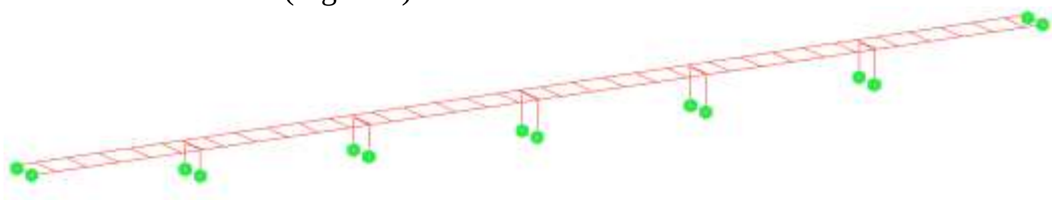

Figure 7. Pian della Menta viaduct new project. FEM model for static analysis.

The seismic analysis carried out with a non linear analysis and the adoption of 7 accelerograms compatible with the design spectrum provided maximum displacements at CLS (Collapse Limit State) of 217mm, with an average reduction of 14% in terms of forces on substructures compared to the initial design which made use of LRB isolators.

It is worth noting that the CLS is a specific Limit State introduced by the Italian Seismic Standard [4] for the isolators to take into account the “increased reliability” principle given by Eurocode 8. While in Eurocode 8 [5] and the product standard on Anti-seismic devices EN 15129 [3] such principle is realised through a magnification factor on the seismic displacement of the isolators, in the Italian Standard a specific CLS spectrum is introduced to verify the isolation system.

By virtue of the benefit attained with the new isolation system, despite a significant increase of total vertical load due to the new structure and modern design loads, it was possible to recover the existing piers through a modest encasing of shafts and foundation slab (Figure 6).

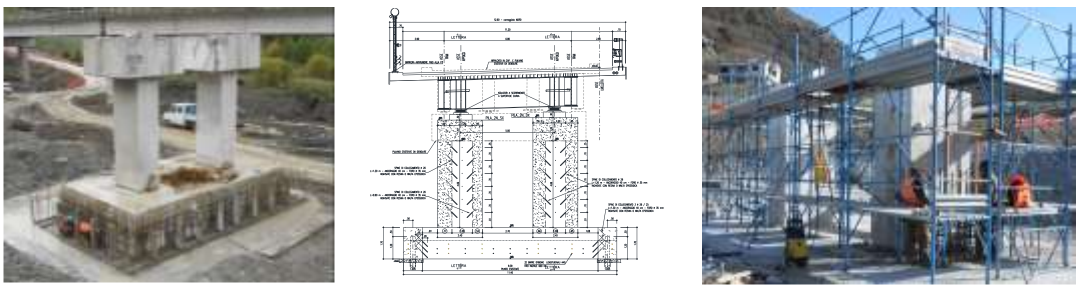

Figure 8. Pian della Menta viaduct new project. Reinforcement of piers.

Figure 9. Pian della Menta viaduct. New pendulum isolators as installed.

Campo del Galdo Viaduct

The existing viaduct (Fig. 10) crossed the plain of Galdo's industrial area, passing over state road SS19 with the first span; it was made of simply supported p.s.c. girders, eleven spans for the North carriageway, twelve for the South carriageway, with typical length of 32m each. Each deck was composed of four I-beam 1.6m tall with a spacing of 2m and a slab with a thickness of 20cm and a width of 10m. Piers were concrete frames made of two or three square-section columns linked on top with a cap, with a maximum height of 7m.

Figure 10. Campo del Galdo viaduct before retrofit.

The initial design allowed for the construction of a new deck with steel-concrete composite section which rested part on the existing plan and part on a new one with a quasi straight layout, with spans varying from 40 to 48m in order to avoid the existing foundations within the intersection with the old layout. This same design provided for the construction of the abutment on Salerno's side over a box underpass for the crossing of state road SS19. The deck section was provided for three girders (four in proximity of the ramp on the North carriage) 2m tall and spacing varying from 3.40 to 4.40m linked with truss cross-bracing respectful of the same geometry intended for Piano della Menta viaduct (

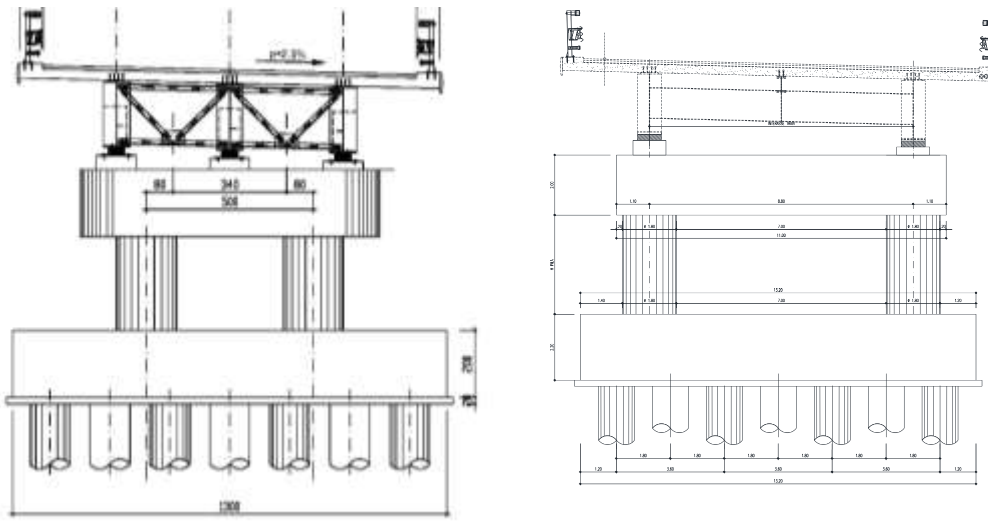

Figure 12, on the left). Because of the significant total length of the viaduct, each carriageway was divided in two segments with an expansion joint over the intermediate pier P6, limiting the length of each segment to a maximum of 250m in order to limit thermal expansion.

The seismic isolation system of the initial design included LRB isolators, with an equivalent horizontal stiffness K=1.8 kN/mm and a maximum displacement of 250mm, positioned under each girder for a grand total of 86 isolators (42 for South carriageway, 44 for North carriageway).

Figure 11. Campo del Galdo viaduct. Retrofit works aerial view.

During detail design a few notable modifications were introduced: the viaduct was lengthened, eliminating the box underpass beneath the abutment on Salerno’s side then directly overpassing SS19, changing the South carriageway from 12 spans (30+32+48+48+40+40+40+39+43+51+43+40m) to 10 (54.5+58+55+49+40+40+40+45+48+40m) for a grand total of 470m and the North carriageway from 11 spans (32+48+48+40+40+40+39+43+51+43+40) to 10 (51+48+48+49+40+40+40+45+48+40m) for a grand total of 450m. Current road section has a width of 12.6m, increasing up to 14.6m near the ramp, and considering the lengthening of the viaduct, an emergency stopping place was introduced on the South carriageway. The expansion joint was eliminated, so that the deck is continuous for each carriageway.The deck section has been simplified reducing the number of girders to two with a typical height of 2.2m, linked with a transverse I-beam girder (

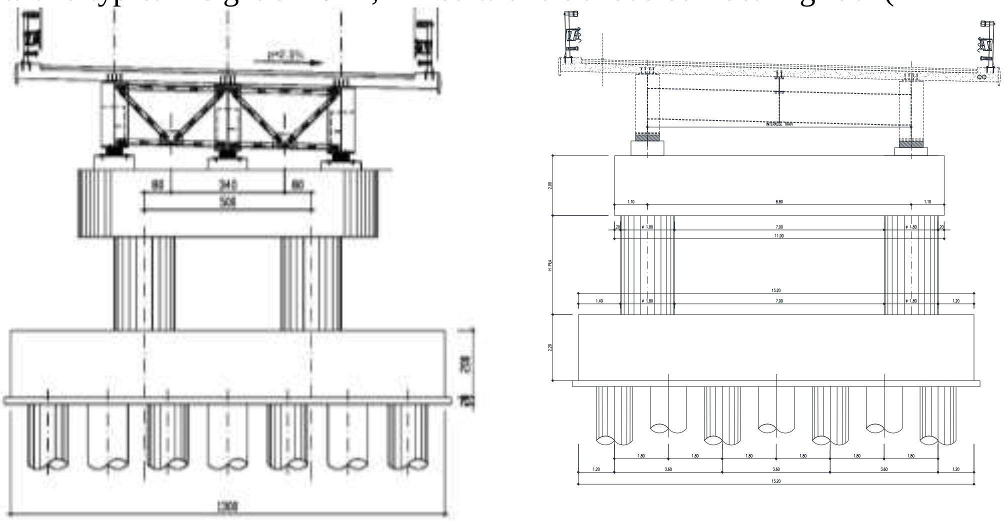

Figure 12, on the right). Such reduction allowed to reduce the number of isolators. The type of isolators has been changed as well, selecting pendulum isolators. The type of piers has remained unchanged, with a frame structure made of two circular columns linked with a cap, whose thickness has been reduced by virtue of positioning the columns underneath the main girders.

The new isolation system comprises 48 double concave curved surface sliders with the following characteristics:

- equivalent radius of curvature of 3.1 m;
- minimum friction coefficient 5.5 % (at maximum vertical load);
- maximum displacement of ±350mm;
- 38 isolators with maximum vertical load of 7700 kN on piers (blue in Figure 6) marked as FIP-D M 1900/700 (3100);
- 10 isolators with maximum vertical load of 2650 kN on abutments (red in Figure 6) marked as FIP-D M 960/700 (3100);

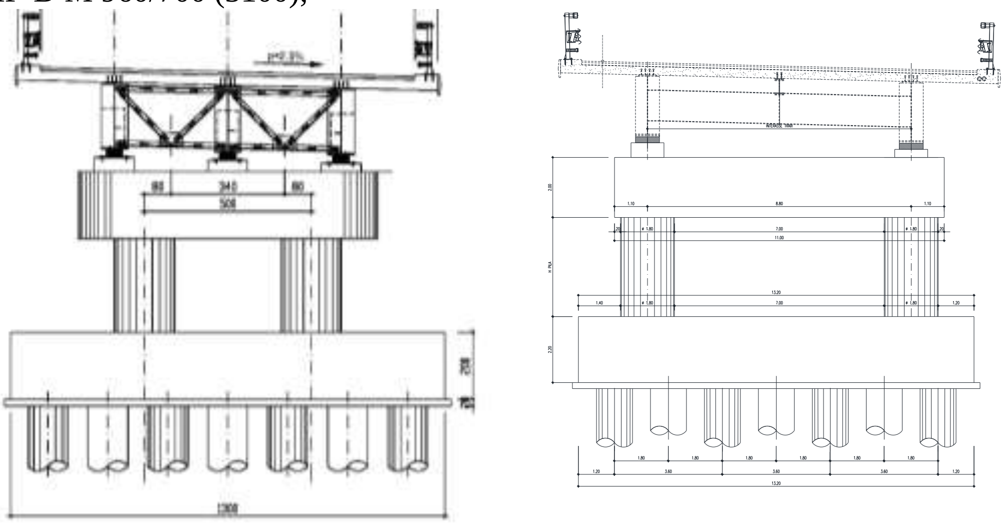

Figure 12. Campo del Galdo viaduct transverse sections. Initial project (left) and new project (right).

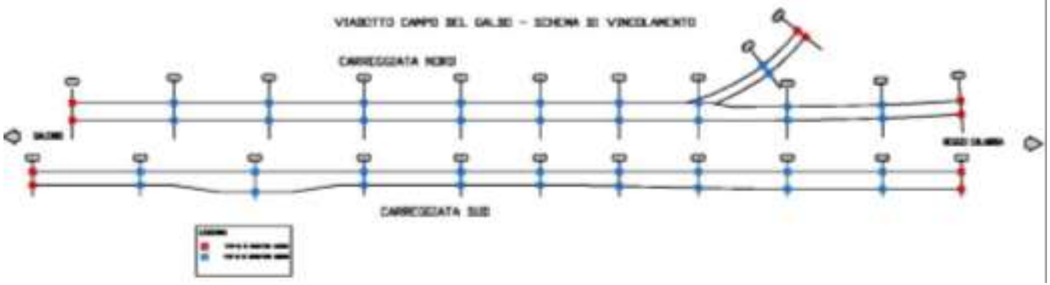

Figure 13. Campo del Galdo viaduct new project. Isolators lay-out.

The non linear dynamic analysis carried out with 7 sets of accelerograms compatible with the design spectrum (Figure 14) provided a maximum seismic displacement at CLS of 179mm, with an average reduction of 18% in terms of forces on substructures compared to the initial design which made use of LRB isolators.

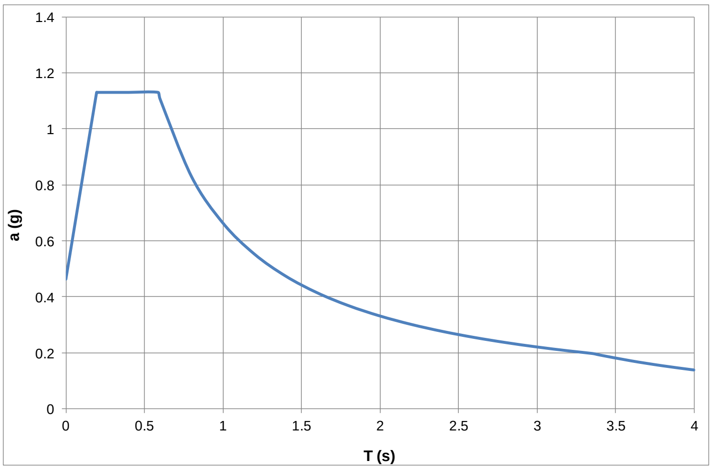

Figure 14. Design spectrum at CLS with equivalent damping $\xi eq = 5\%$.

Figure 15. Campo del Galdo viaduct. View of the new south carriageway.

Casale Civile Viaduct

Casale Civile viaduct is a new structure on the new layout, a variant to Salerno-Reggio

Calabria highway, located about 500m farther than Campo del Galdo viaduct The design initially provided for five spans (36+44x3+36m) for a total length of 204m. Similarly to other viaducts in the same lot, the deck was made with a steel-concrete composite section composed of three steel I-beam girders 2m tall spaced 3.4m (4.4m where the total section is 14.6m wide) linked by truss cross bracings and supported by LRB isolators.

During construction stage design, it was decided to lengthen the viaduct passing from five to nine spans (36+44x7+36m) for a total length of 380m. The road section on this viaduct, as well as the others, has a constant width of 12.6m on the North carriageway, and a width varying from 12.6 to 14.6m on the South carriageway. Modification on the deck followed the same principles adopted on the other viaducts, reducing the number of main steel girders from three to two, 2m tall.

The same isolation system of the other two viaducts has been used, with double concave curved surface sliders with the following characteristics:

- equivalent radius of curvature of 3.1 m;
- minimum friction coefficient 5.5 % (at maximum vertical load);
- maximum displacement of ±350mm;
- 20 isolators with maximum vertical load of 4300 kN on piers (blue in Figure 6 and Figure 6) marked as FIP-D M 1300/700 (3100);
- 12 isolators with maximum vertical load of 5000 kN on some piers of South Carriageway (green in Figure 6) marked as FIP-D M 1400/700 (3100);
- 8 isolators with maximum vertical load of 1700 kN on abutments (red in Figure 6 and Figure 6) marked as FIP-D M 720/700 (3100).

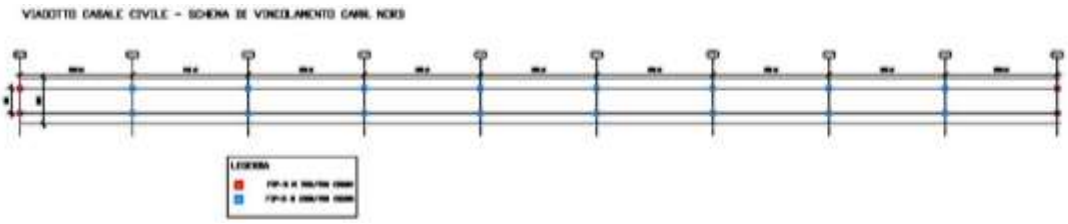

Figure 16. Casale Civile viaduct new project. North Carriageway isolators lay-out:
Red coloured: FIP-D M 720/700 (3100) – blu coloured FIP-D M 1300/700 (3100).

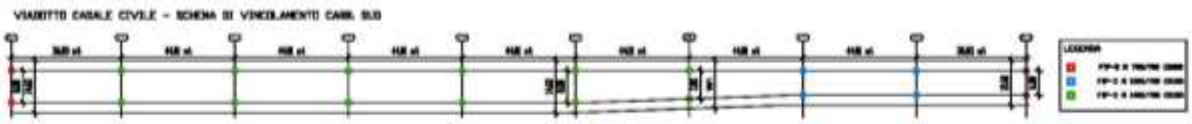

Figure 17. Casale Civile viaduct new project. South Carriageway isolators lay-out:
Red coloured: FIP-D M 720/700 (3100) – blu coloured FIP-D M 1300/700 (3100)
Green coloured FIP-D M 1400/700 (3100).

The non linear dynamic analysis carried out with the adoption of 7 sets of accelerograms compatible with the design spectrum provided a maximum seismic displacement at CLS of 207mm, with an average reduction of 15% in terms of forces on substructures compared to the initial design which made use of LRB isolators.

Such a decrease in force produced a reduction of length and number of foundation piles which allowed, at equal gross expense, to lengthen the viaduct. This modification of the viaduct was beneficial both for a reduction of embankments, founded over poorly consistent soils, and easing the access to the area surrounding the viaduct, one of the few industrial development areas located in the crossing zone.

Figure 18. Casale Civile viaduct. Deck intrados on new pendulum isolators.

Figure 19. Casale Civile viaduct. View of the new bridge.

Tests on pendulum isolators

Type tests and factory production control tests according to the European Standard on Anti-seismic devices [3] have been carried out on the pendulum isolators. Figure 6 shows one of the biggest isolators (FIP-D M 1900/700(3100)) under test in the Eucentre Laboratory in Pavia, Italy. The tests results confirmed the design properties of the isolators.

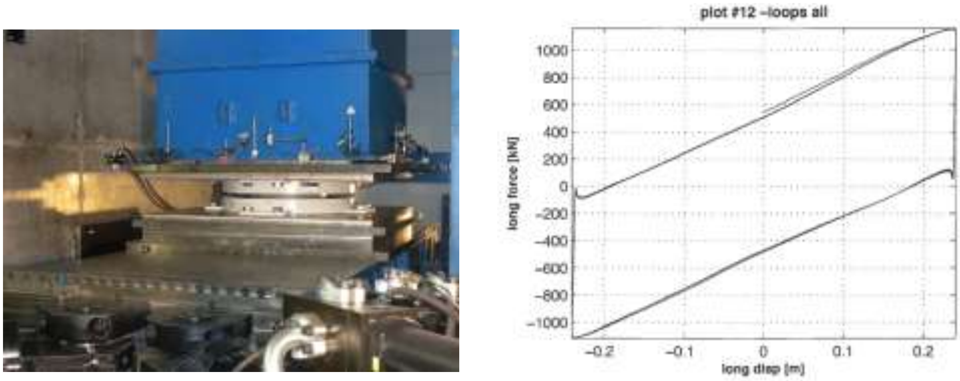

Figure 20. Type tests on isolator FIP-D M 1900/700(3100) at Eucentre Laboratory. The isolator in the testing rig (left) and hysteretic cycle measured in a benchmark test (right).

Conclusions

The selection of pendulum isolators has been optimized for the 3 viaducts. In total, 5 types of pendulum isolators have been employed, different for vertical load capacity (from

1700 kN to 7700 kN), all of them characterized by equivalent radius of curvature of 3.1 m, friction coefficient higher than 5.5 %, displacement up to ± 350 mm. In total, 116 double concave curved surface sliders were used in the three viaducts.

In every viaduct the substitution of lead rubber bearings in favour of pendulum isolators (double concave curved surface sliders) was the prominent reason for significant benefits in term of improved structural performance together with major construction economy. The average reduction in terms of forces on substructures given by the use of pendulum isolators instead of lead rubber bearings was of 14 % in the Pian della Menta viaduct, of 18 % in the Campo del Galdo viaduct and of 15 % in the Casale Civile viaduct.

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