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Railway bridge seismic protection with the Isosism® range

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Abstract
Algeria is extending the railway infrastructure in a seismic zone. In order to meet as well the seismic design criteria and the railway serviceability criteria, an innovative seismic protection system has been recently used for some new viaducts, using Prestressed Spring Dampers (PDS). These seismic devices have three functions: blocking axial displacements as long as forces are smaller than a preload, viscous damping for higher loads than the preload, bringing back the bridge in initial position after the earthquake. The preload has been set above service loads. For longitudinal PDS, the preload is set above thermal expansion, shrinkage and breaking loads. For transversal PDS, the preload is set above wind loads. Additional damping is provided by traditional viscous dampers. Vertical load is supported by sliding pot bearings. This innovative seismic protection system has been used because it efficiently reduces seismic demand on the piers and foundations. Devices have been intensively tested to demonstrate their reliability.
Keywords: Railway bridge; seismic isolation; Eurocode 8; viscous dampers; time history analysis

1. Introduction

A 21 km long railway line is being constructed west of Algiers, to connect five cities to the national railway network. Trains will have a speed of 140 km/h. This project is hold in the highest seismic risk area of Algeria. There are four viaducts along the line, which are required to remain operational after they have undergone ultimate seismic action. Thus, they shall be designed to remain elastic. In order to prevent from any derailment, their curvature shall not be excessively modified during an earthquake. This leads to stiff piers. Lateral deformation shall remain limited at their extremities to not exceed rails deformation, which leads to high forces on guiding systems. The Fig. 1 shows one of the four bridges during launching.

Conventionally designed railway bridges usually have massive abutments, piers and foundations. Like an increasing number of railway bridges around the world, the four Algerian viaducts have been equipped with prestressed damping springs (hereinafter “PDS”) that lead to optimized designs and to a global cost reduction. These seismic devices act as fixed points during service operation, they dissipate energy during an earthquake, and they recentre the structure to its initial position after the seismic event.

Fig. 1 – SR06 bridge during launching

2. Overview of BTZ project

Seismic protection is being installed on four new railway viaducts in Algeria for national railway company Agence Nationale d’Etudes et de Suivi de la Réalisation des Investissements Ferroviaires (ANESRIF). The railway line is just west of Algiers, between the cities Bir Touta and Zeralda, which gave its name to the project. It is being built by main contractor Yapi Merkezi and is in Algeria's maximum earthquake risk area. The four bridges range in length from 334 m to 660 m, with 9 to 17 spans and central spans of 40 m, as presented on Table 1. The Fig. 2 shows the location of the four bridges along the line. The cross-section is a post-tensioned concrete box girder. The challenge of the project was to limit the impact of the seismic design on the total cost of the four viaducts on the so called BTZ line.

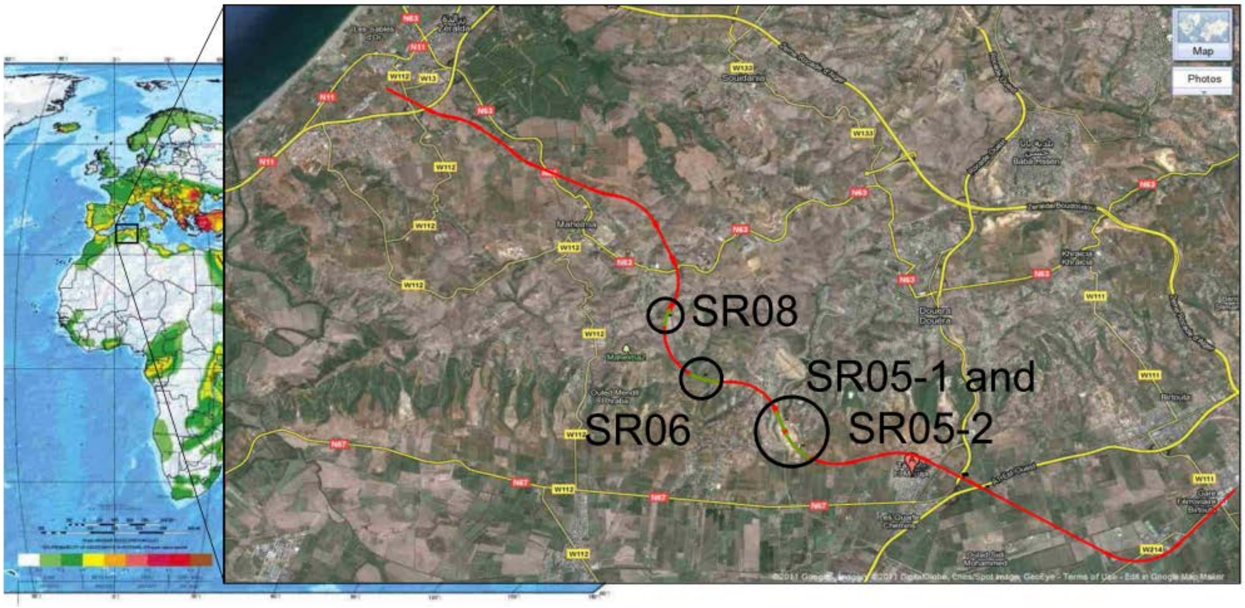


Fig. 2 – Localization of the four bridges

Table 1 – Main characteristics of the four bridges

Name	Length	Slope	Span	Launching system
SR05-1	660 m	-1.9%	17	Push pull system
SR05-2	380 m	+1.9%	10	Strand jack system
SR06	540 m	-0.7%	14	Strand jack system
SR08	334 m	-3.0%	09	Push pull system

These railways bridge are required to remain operational after they have undergone ultimate seismic action, hence the structure's behaviour must remain in the elastic field. This means that seismic energy cannot be dissipated by plastic hinges, which impose significant forces on the bearings, piers and foundations. Furthermore, the soil is poor quality, with layers of weak friable sandstone, silty clay and shelly clay. As a result, the initial design resulted in massive piers and foundations.

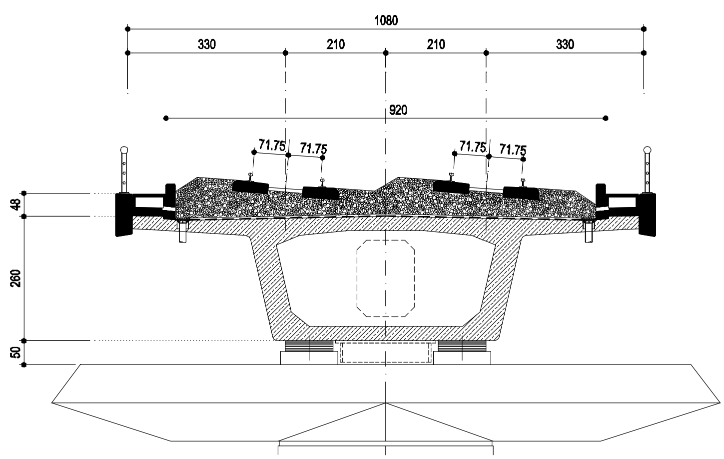


Fig. 3 – Deck's cross section (dimensions are in cm)

Freyssinet, as a subcontractor of Yapi Merkezi, is responsible for supplying the earthquake protection on the civil engineering structures and the launching. The Fig. 4 shows one of the four bridges during launching and the location of transversal seismic devices, which are installed after launching. A solution was developed to optimize the initial design using seismic devices. The structures on the BTZ line are designed to be fitted with longitudinal and transverse devices. The high damping provided by these devices lead to a drastic force reduction at the connection between the deck and the pier's head.

Fig. 4 – SR05-01 bridge during launching and location of transversal seismic devices, highlighted with circles

As a result, all the loads transmitted down to the piers and piles are much lower with the seismic devices. It eventually conducted to a few reinforcement ratio in the piers and to lower piles.

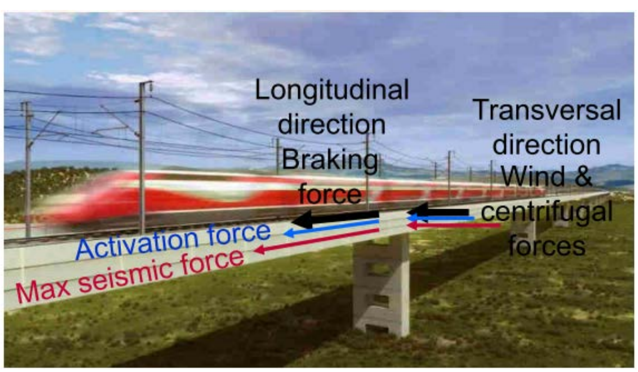
A beam finite element model was produced for each of the four structures and non-linear elements were added between the piers and the deck, representing dissipation devices. Non-linear temporal analyses were performed to check the seismic design of the structures and the size of the fluid dampers was determined in such a way as to reduce the seismic forces by a factor of four in the structure and foundations.

3. Seismic devices

Most commonly used seismic devices are isolators, such as rubber bearings and sliding pendulums. These devices are very useful during seismic events because they efficiently reduce the acceleration. However, isolators cannot be used as fixed point during service conditions, for environmental loads (thermal and wind loads) and for rolling stock loads (braking and centrifugal loads). This is the reason why other types of devices have been chosen for this project.

Among the Isosism® range of seismic devices developed by Freyssinet, two types of dissipation device are being used: fluid dampers (FD), and prestressed damping springs (PDS). As shown on Fig. 5, the PDS perform three functions; during normal operation, they act as fixed points; during an earthquake, they dissipate energy, and after an earthquake, they return the structure to its initial position.

The FD provide some additional damping during the seismic conditions. They are free to move during operation conditions. The behaviour laws of both devices are presented on Fig. 6.



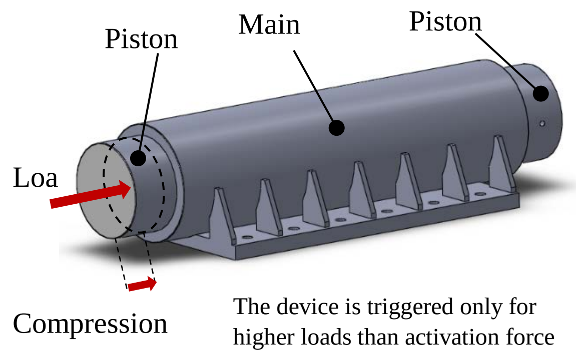


Fig. 5 – Loads on railway bridges and behaviour of a prestressed damping springs

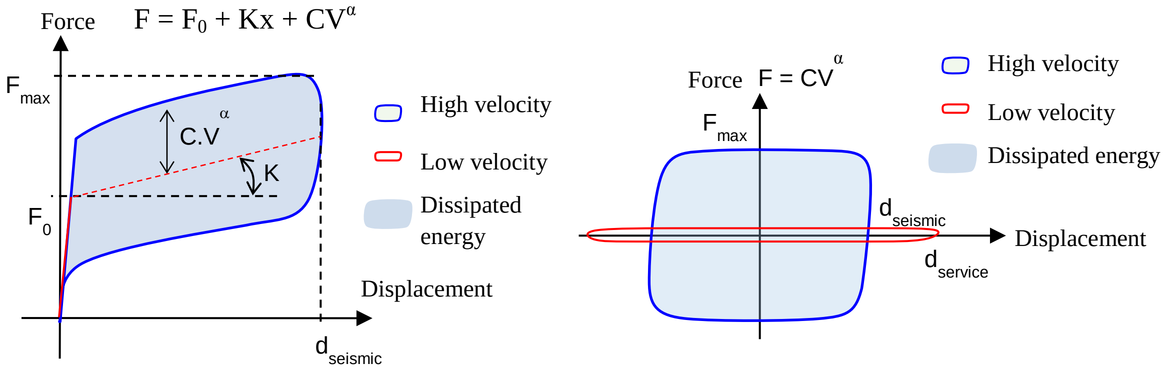


Fig. 6 – Behaviour law of prestressed damping springs (left) and of fluid dampers (right)

These both devices work along their axial axis. Their body is fixed to the pier, while their pistons are sliding onto plates attached to the deck. FD stored at the Factory are shown on Fig. 7, with green parts being the sliding material. A pier that should be dampened in both longitudinal and transversal directions should be equipped with a longitudinal device and a transversal device.

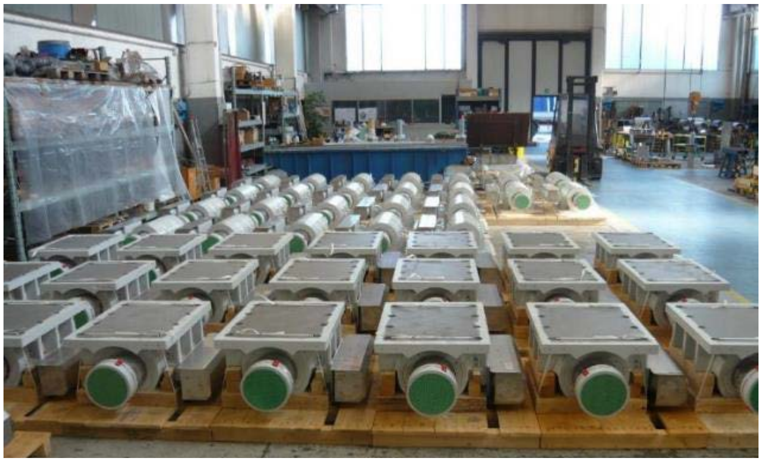


Fig. 7 – Fluid dampers at the factory

These devices are installed as detailed on Fig. 8 and will provide longitudinal and transverse protection for all four structures. Longitudinal prestressed damping springs are installed on the abutments, and all of the central piers are fitted with transverse prestressed damping springs, providing stability on the railway tracks during operation and earthquake. The Fig. 9 shows some piers before installation of transversal PDS. Longitudinal and transverse dampers were added to increase the total amount of damping. All of the bearings on the central piers are free sliding pot bearings and the end piers, which do not have the damping springs, are fitted with guided elastomeric bearings, which restrict transverse displacement.

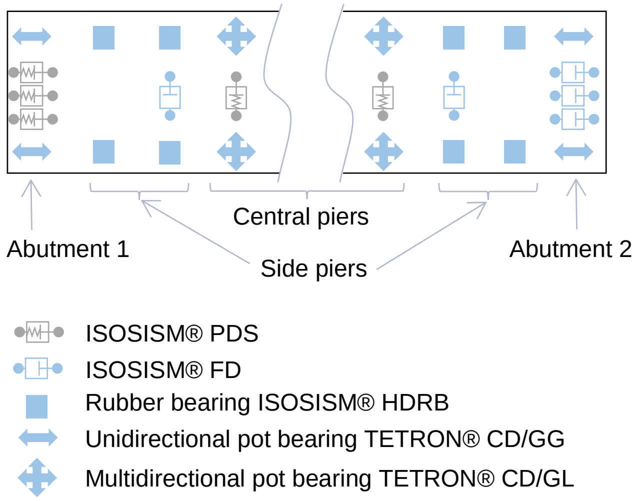


Fig. 8 – Layout of the four bidges

Fig. 9 – Location of transversal PDS and FD on piers' head

The Table 2 and Table 3 show the benefits of this solution compared to the initial conventional design.

Table 2 – Main results comparison for the 1st viaduct, in longitudinal direction

Design	Without seismic devices	With seismic devices	Gain
Total force (MN)	418	41	-90%
Max displacement at abutment (mm)	0	105	

Table 3 – Main results comparison for the 1st viaduct, in transversal direction

Design	Without seismic devices	With seismic devices	Gain
Total force (MN)	469	316	-33%
Max displacement at piers head (mm)	270	66	-76%

Seismic dampers lower the piers' head displacement and thus the forces in piers and piles. The devices get compressed during an earthquake, which creates a relative displacement between the piers' head and the deck, as shown on Fig. 10. The total transversal displacement of the deck is actually lower with the seismic dampers than with the conventional design. This is because the relative displacement is compensated with the reduction of the piers' head displacement.

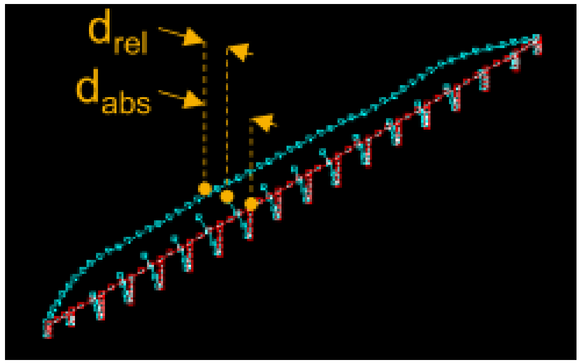


Fig. 10 – Typical transversal deformation during an earthquake. The total transversal deck displacement ("d_{abs}" on the picture) is due to piers deformation and devices compression ("d_{rel}" on the picture)

The overall earthquake protection system was designed iteratively, and this led to the use of a reduced number of types of device and other structural accessories. These included one type of prestressed damping spring with a range of strokes; one type of longitudinal fluid dampers with a range of damping levels; two types of transverse fluid dampers, with a range of damping levels; four types of pot bearing with different strokes; one type of laminated elastomeric bearing with different sliding plates; two types of fuse element and two types of expansion joint.

4. Seismic devices tests

A comprehensive test procedure was established to certify the earthquake protection devices, based on NF EN 15129 [3]. This included pressure tests, where the strength of the devices was checked at 125 % of nominal capacity; low-speed tests to ensure that they met the behaviour requirements under slow movements such as those caused by thermal expansion; and behaviour law tests at a velocity up to 300 mm/s as shown on Fig. 11 for FD and on Fig. 12 for PDS. In addition, the devices were tested for their ability to dissipate energy during repeated loading cycles; the strength of the seals throughout the service life of the devices was tested, and the total stroke of the devices was tested. These tests were performed at Freyssinet's Isolab laboratory and, for the higher speeds, at the laboratory of European Centre for Training & Research in Earthquake Engineering (Eucentre) in Italy. The tests were successful and confirmed the reliability of the product range. The Fig. 13 shows that dynamical constitutive law test results of PDS are within the standard acceptance criteria.

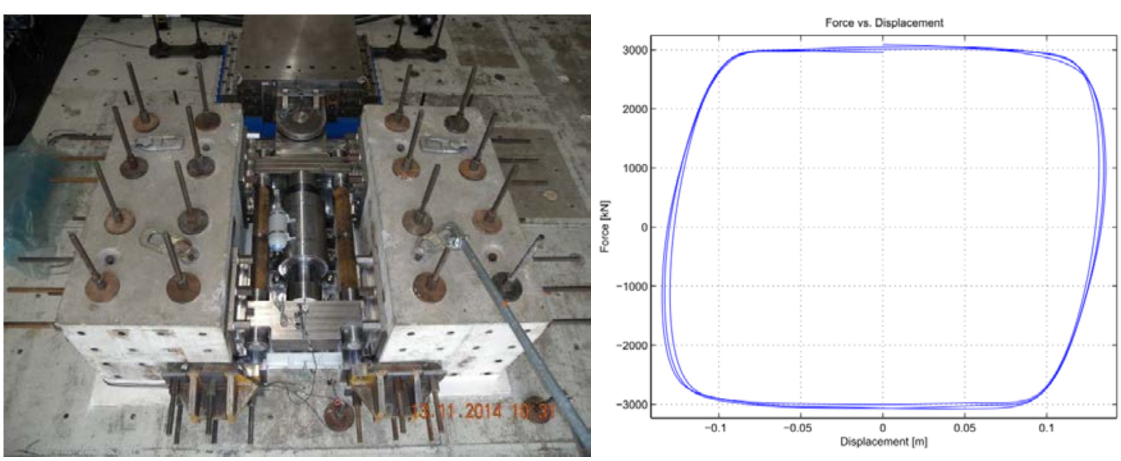


Fig. 11 – Test setup of fluid dampers for the dynamic tests (left) and test result of fluid dampers (right)

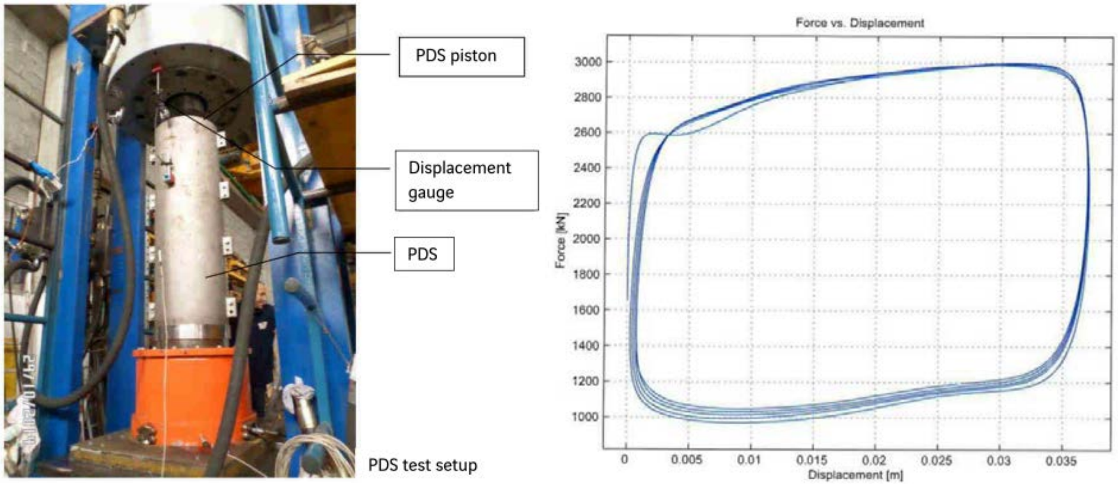


Fig. 12 – Test setup of prestressed damping springs at Freyssinet laboratory (left) and test result of prestressed damping springs (right)

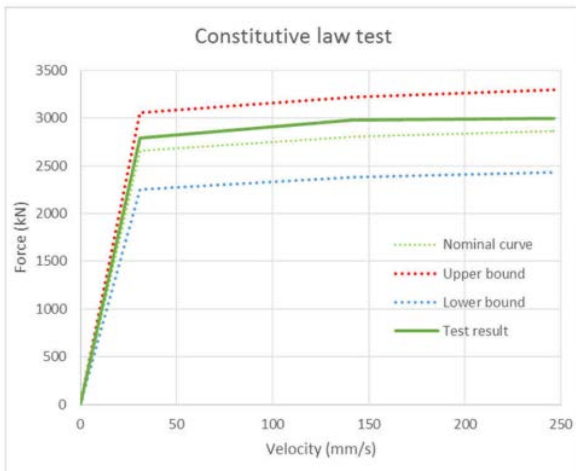


Fig. 13 – Test results of prestressed damping springs used to validate the CV^{α} part of the behavior law $F_0 + Kx + CV^{\alpha}$

5. Launching and installation

Decks are precast on the ground. Each pouring stage is followed by a launching. Translation is done by sliding on the abutment and on the piers, at an average speed of 6 m/h. This launching procedure is repeated, as shown on Fig. 14, until the deck is fully launched in final position.

No prop works are needed under the bridge and all the main tasks are performed in a restricted area behind the launching abutment, improving both the construction quality and the safety. This method only require simple tools (steel works, strand jacks, crane and concrete plant) that are easy to supply and use. However, a strong geometry control of the casting yard and of the piers is necessary in order to reduce as much as possible the parasite forces during the sliding of the deck. Launching generates some additional loads on the piers due to friction on the bearings and the temporary guides, which are generally not critical considering the reduced weight of the deck during launching (no superstructures, ballast, etc.).

The position of the casting yards was decided by the general contractor, taking into account the site environmental requirements and the road access to the site. As shown on Fig. 15.The viaducts were either pulled upwards with a pair of strand-jacks (pulling force: 800 t) or pushed downwards with double acting hydraulic jacks, capable to prevent any uncontrolled sliding (pushing force: 500 t – retaining force: 250 t).

The average cycle (setting of formwork, reinforcement installation, concreting, curing, post-tensioning and launching) of a 350 m^3 span was of 10 days.

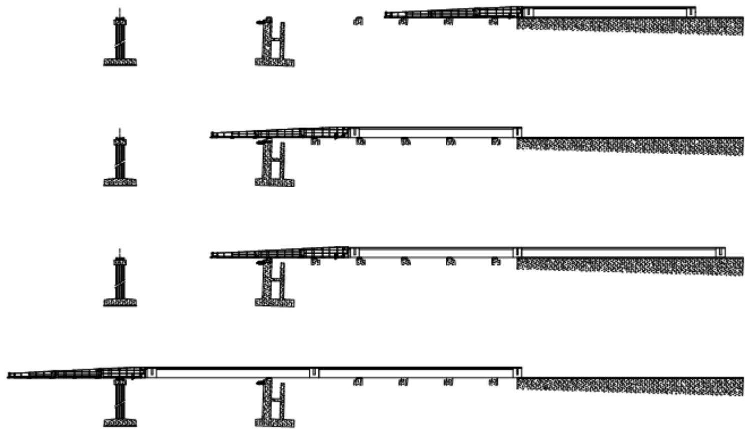


Fig. 14 – First four steps of the launching process

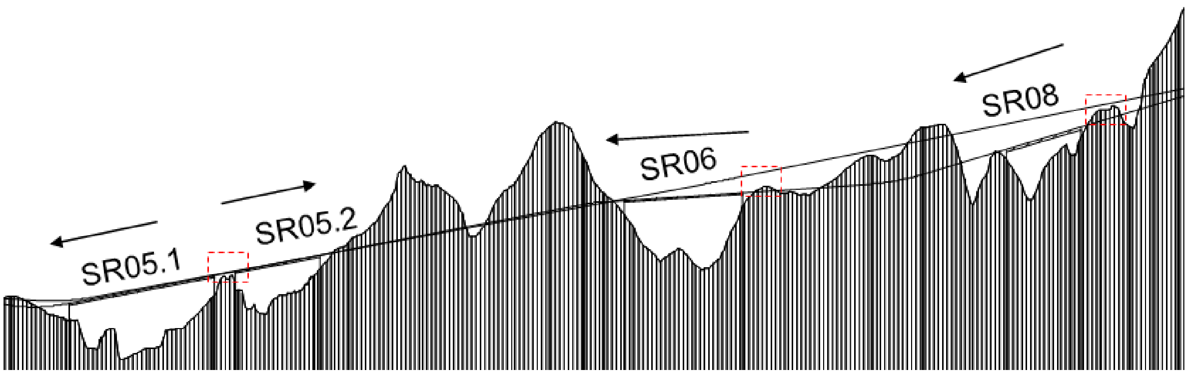


Fig. 15 – Launching directions of the four bridges

Fig. 16 – Prestressed damping spring installed under the deck

6. Conclusion

Four structures on the BTZ line have been fitted with earthquake protection devices of the Isosism® range, enabling a reduction in the reinforcement of the piers and size of the piles. This led to reduce the overall cost of the project. The construction method optimization done in parallel resulted in lowering the total duration of the project. The devices were produced and tested while the initial construction work was being completed, and were installed on the structure after the launching operation. A PDS installed on one of the bridges is illustrated on Fig. 16. The line is expected to come into operation end 2016, increasing services to the West Algiers region.

7. References

[1] RPOA (2008): Paraseismic rules for civil engineering works. *Document Technique Réglementaire*, Algeria.

[2] AFNOR (2005): Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings. *NF EN 1998-1*.

[3] AFNOR (2010): Anti-seismic devices. *NF EN 15129*.