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The seismic retrofitting of the Viaduc de Chillon, Switzerland

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ABSTRACT: This paper describes the seismic retrofitting of an important highway viaduct in Switzerland. The viaduct has a length of 2,100 m, and consists of two structures, side by side, each 12 m wide. It has a total of 23 spans of prefabricated concrete deck, each of approximately 100 m length. The concrete hinges which form the deck connections to the piers below allow rotations, but no sliding movements. As a consequence of this, the horizontal movements of the decks are facilitated by deflection of the piers alone. A review of the design of the viaduct concluded that substantial changes would be required in order to bring the structure up to the safety standard defined by today's standards. To address this deficiency, it was determined that the concrete hinge connections between pier and deck should be replaced with elastomeric isolators which would facilitate the design movements of up to 40 mm in each direction in most cases while providing damping, hysteretic energy dissipation and re-centering capacity. Strengthening of the piers was also deemed necessary, to enable them to withstand the forces from the new bearings. The implementation of this project, and in particular the design and installation of the seismic isolators, are described.

1 INTRODUCTION

This paper describes the seismic retrofitting of an important highway viaduct in Switzerland. When constructed between 1966 and 1969, the structure was designed in accordance with the Swiss design standards of the day, but significant advances have been made in these standards in the intervening period – most notably in relation to the seismic safety of the structure. The current Swiss design code SIA 262, published in 2003, defines the effects and influences for which structures must be designed, and includes details of the seismic actions and the braking forces that structures must be designed to withstand, depending on geographical location and intensity of traffic. A review of the design of the viaduct concluded that substantial changes would be required in order to bring the structure up to the safety standard defined by the code. The longitudinal and transverse movements of the deck that would arise in a design earthquake could not be facilitated by deflection of the piers alone, especially considering their greatly varying stiffnesses, both longitudinal and transverse, causing the smaller ones to fail. A solution which would apply modern seismic engineering methods to this decades-old structure was required.

2 THE VIADUCT'S EXISTING DESIGN FOR MOVEMENTS AND ROTATIONS

The Viaduc de Chillon forms part of the A9 highway, which traverses south-western Switzerland from the French border (Geneva) in the west to the city of Brig in the south. The viaduct has a length of 2,100 m, and consists of two structures, side by side, each 12 m wide. It has a total of 23 spans of prefabricated concrete, each of approximately 100 m length. Views of the structure are presented in Figures 1 to 3.

Figure 1. View of the viaduct, showing its location on the side of a hill.

Figure 2. View of twin structures of viaduct from beneath

Figure 3. View of twin structures of viaduct, showing typical arrangement of two slender pillars per structure at each end of each span.

The concrete hinges which form the deck connections to the piers below allow small rotations, but no sliding movements. As a consequence of this, the horizontal movements of the decks are facilitated by deflection of the piers alone. The piers beneath each carriageway are 0.8 m wide and 5 m long, and vary greatly in height, from 1 m to 45 m, resulting in greatly differing stiffnesses. See Figures 4 to 7.

Figure 4. The simple existing connections of the deck to the support pillars, without any type of mechanical bearing.

Figure 5. A concrete hinge, which prevents horizontal movement of the deck but permits small longitudinal rotations.

Figure 6. Some pillars, with lengths of up to 45 m, can facilitate significant longitudinal deck movements through pillar deflection.

Figure 7. Some pillars, with a length of just one metre, are too short and stiff to facilitate any deck movements by deflection.

3 THE SOLUTION

In order to make the viaduct capable of withstanding a seismic event as defined by current design standards, it was determined that the concrete hinge connections between pier and deck at the short piers and the abutments should be replaced by seismic isolation devices. The main objective of a seismic isolation system is to increase the natural period of a structure. However, rather than simply increasing the natural period to a high value, an efficient seismic design also considers how energy dissipation capability can be increased and how lateral forces can be distributed to as many substructures as possible. Bridges, and viaducts in particular, are ideal candidates for the adoption of such a seismic isolation approach due to the ability to distribute lateral forces among multiple supports, and thanks also to the general ease of installation and inspection of isolation devices.

An isolation system placed between the bridge superstructure and its supporting substructure is generally capable of increasing both flexibility and energy dissipation. Flexibility in the horizontal plane will lower the frequency of the bridge, decreasing earthquake-induced acceleration, while the energy-dissipating capacity of the seismic isolators will considerably reduce the damaging energy exerted to the bridge piers. Moreover, when isolation devices are installed at the tops of a bridge's piers, the lateral force from the superstructure during a seismic event can be distributed among all piers, avoiding the concentration of lateral forces at specific locations.

Among the different seismic isolation devices available, elastomeric isolators have found wide application in bridge structures. This is due to their simplicity and their combining of isolation and energy dissipation functions in a single compact unit. They provide a high level of damping - a crucial aspect of seismic protection - to minimise the seismic energy flow to the superstructure and to limit the horizontal displacements of the isolators.

The isolators required for this project would be required to fulfill the following requirements:

- (i) facilitate movements of up to 40 mm in each direction in most cases (or 80 mm in the longitudinal direction at the abutments) - thus countering the relative stiffness of the short piers and preventing them from failing;
- (ii) provide damping of up to 28%;
- (iii) dissipate hysteretic energy;
- (iv) ensure re-centering following an earthquake;
- (v) increase the period of the deck of the bridge to more than 2 seconds; and
- (vi) be able to transmit horizontal loads of up to 400 kN.

Lead rubber bearings (LRB), a popular type of elastomeric isolator, were chosen to fulfil these needs. As shown by Figures 8 and 9, an LRB is similar to a normal elastomeric bearing (round or rectangular) with anchor plates, but made using specially chosen elastomer and with a lead plug at its centre (see Figure 10). The lead plug deforms plastically during an earthquake, dissipating energy through hysteretic damping as indicated by the hysteresis loop graph in Figure 11.

The effective secant stiffness and equivalent damping ratio are two of the most important characteristics of an LRB for use in the design of a seismic isolation system. Examples are shown in Figures 12 and 13, in respect of the type of LRB used for this project.

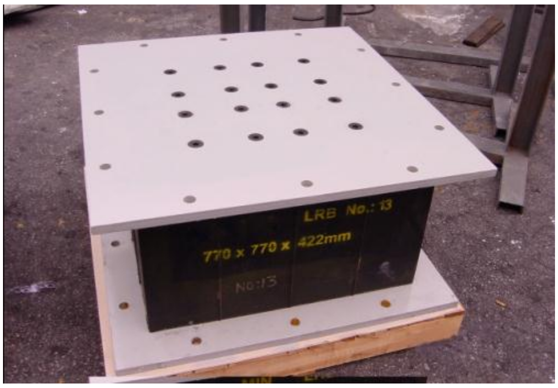

Figure 8. A typical rectangular Lead Rubber Bearing, ready for installation.

Figure 9. A rectangular Lead Rubber Bearing, following installation in a typical bridge.

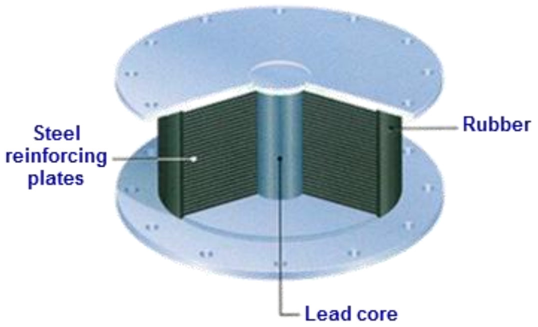

Figure 10. Cut-out view of a typical round Lead Rubber Bearing (LRB), showing lead core.

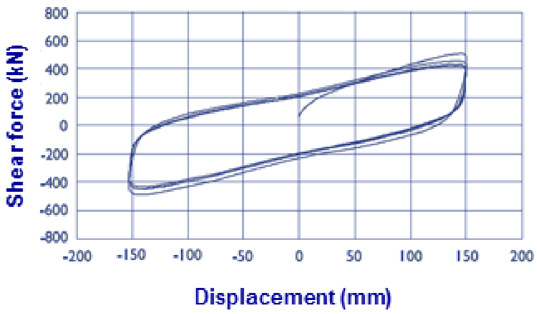

Figure 11. Force – Displacement hysteresis loop of a LASTO®LRB Lead Rubber Bearing.

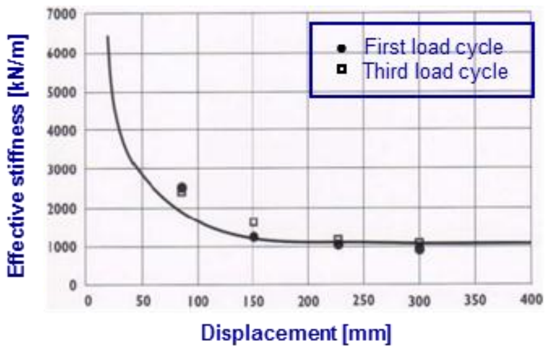

Figure 12. Effective secant stiffness of a LASTO®LRB Lead Rubber Bearing.

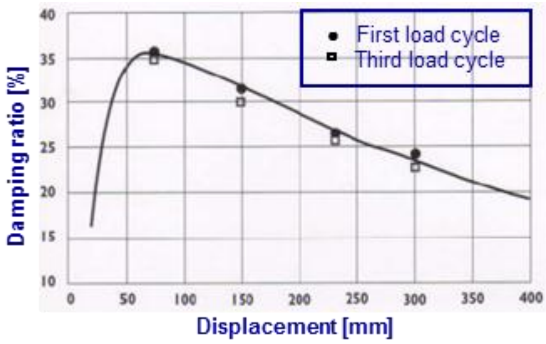

Figure 13. Equivalent damping ratio of a LASTO®LRB Lead Rubber Bearing.

This type of seismic isolator was among the first to be tested in accordance with the new European standard for anti-seismic devices, EN 15129 [CEN (2009), Moor et al (2011)], see Figure 14. The testing, carried out at the European Centre for Training and Research in Earthquake Engineering (EUCENTRE) in Pavia, Italy, paved the way for certification with the CE label, verifying conformance with the standard.

Figure 14. Testing of LRB in accordance with EN 15129, with displacements of +/- 250 mm at speeds of up to 1.634 m/s, while subjected to vertical loads of between - 3,450 kN (uplift) and 1,150 kN.

In addition to determining the exact properties required of the LRBs at each pier and abutment, and replacing the existing concrete hinges with the new seismic bearings, it was also necessary to adapt the main structure to suit the new isolators. In particular, the individual pillars which would support the new bearings had to be extended, to enable them to support the hydraulic jacks used to hold the bridge during the installation of the new isolator bearings. Since the works have not yet been completed, the approach is illustrated below by details from the design drawings. Figures 15 and 16 show the first and final stages respectively of the extending of individual pillars and the installation of a new LRB to replace each existing concrete hinge.

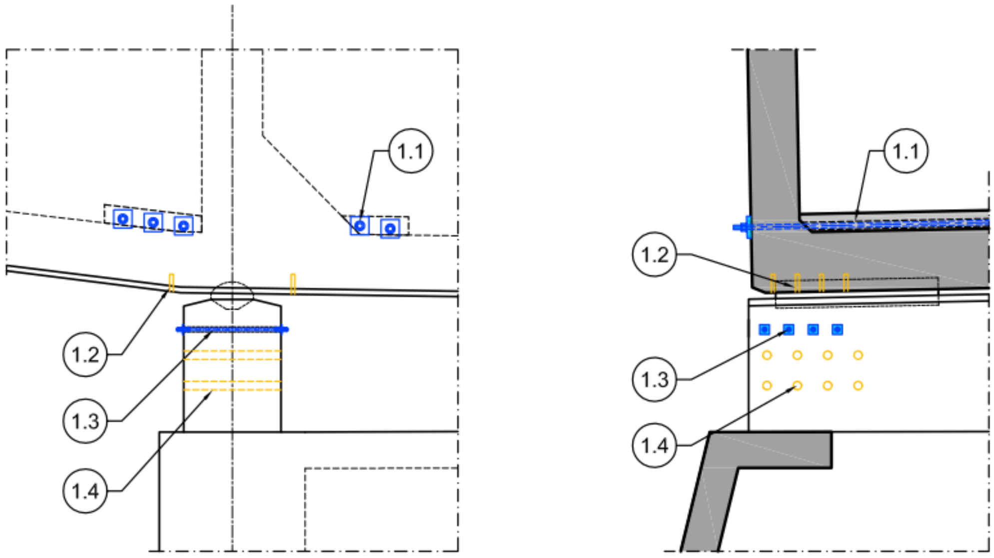

Figure 15. Sections through pillar (parallel (left) and transverse (right) to span of bridge), showing first stage of pier extension and bearing replacement works. The existing concrete hinge can be seen in each section. Holes are drilled through the pillar for the connection of concrete extensions at each side.

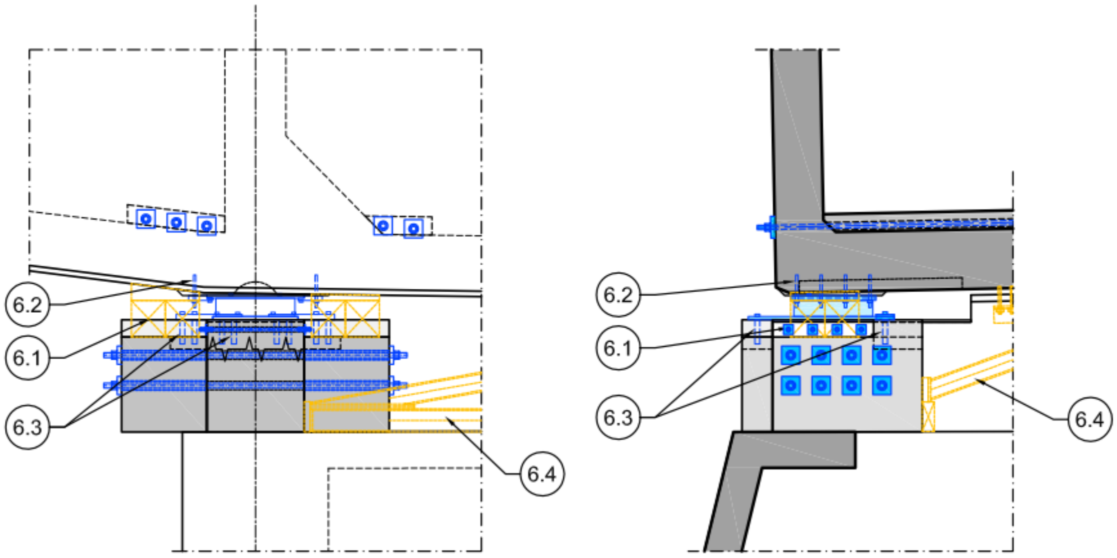

Figure 16. Sections through pillar (parallel (left) and transverse (right) to span of bridge), showing final stage of extension and bearing replacement works. After cutting off the top of the pillar to make space for the new bearing, the pillar has been extended with new concrete at each side, and a new Lead Rubber Bearing has been placed with the aid of hydraulic jacks placed on the new concrete extensions.

The strengthening of the entire pier, with new bracing installed between the individual pillars, is illustrated by Figures 17 and 18.

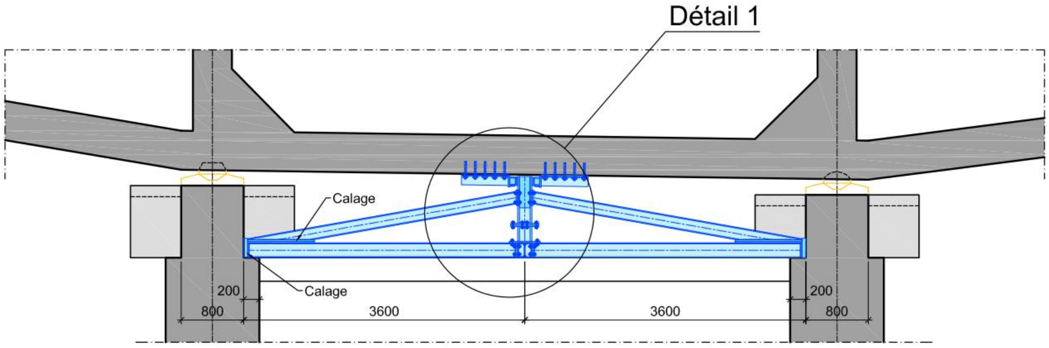

Figure 17. Section (parallel to span of bridge, Section 1 in Figure 18) through both pillars of one structure at one pier location, showing steel bracing placed between the pillars.

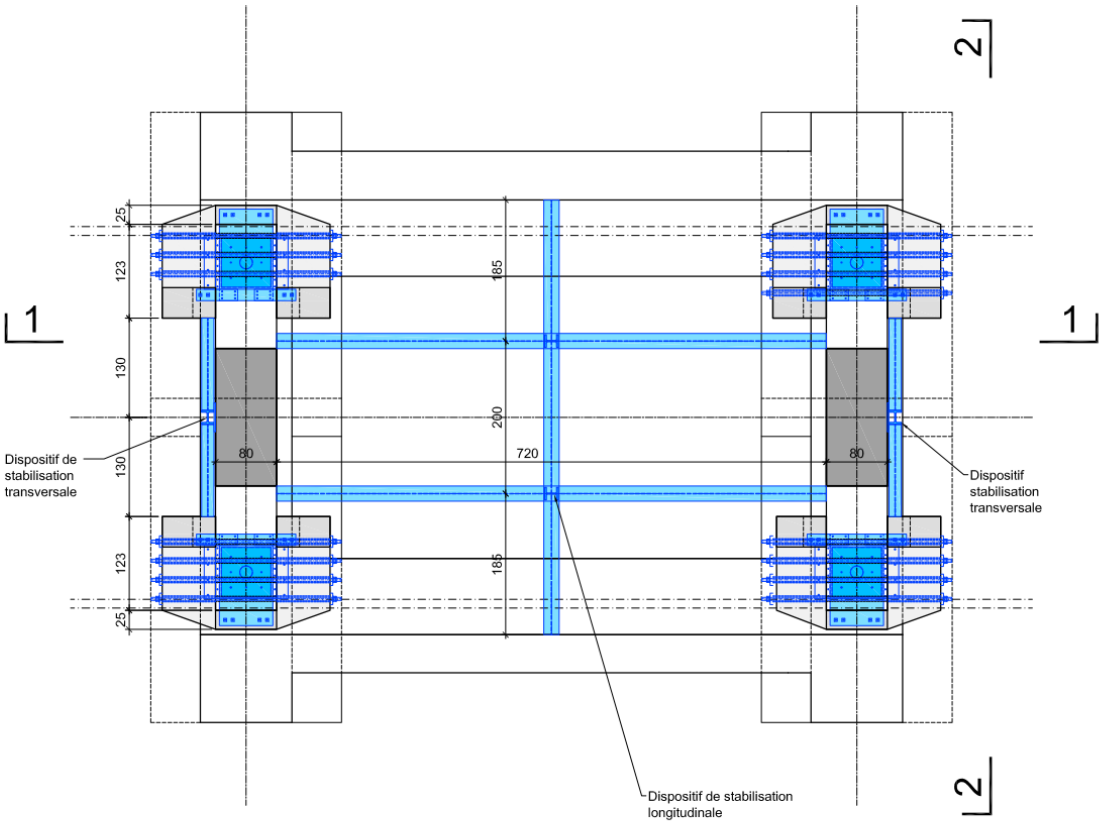

Figure 18. Plan view of both pillars of one structure at one pier location, showing steel bracing placed between the pillars.

Initial images from the ongoing construction work on site are presented in Figures 19 and 20. The project is scheduled to be completed in 2014.

Figure 19. One pillar at one location after drilling of holes for connection of concrete extensions.

Figure 20. Addition of reinforcing steel for new concrete extensions

4 CONCLUSIONS

The use of a seismic isolation strategy in this case - and in particular, one based on Lead Rubber Bearings - has already proven to be a sensible approach to the challenge presented by the need to make this important highway viaduct seismically safe in accordance with current seismic design standards. By providing an alternative to conventional earthquake resistance design measures, it saves the major strengthening works which would otherwise be required, if the benefits of energy dissipation and damping were not incorporated in the design. The project thus demonstrates the potential such an approach, and such devices, have to significantly reduce seismic risk without compromising the safety, reliability, and economy of bridge structures.

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