A new arch bridge in Georgia: a high-seismicity area

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ABSTRACT

The North-South Corridor is a strategic project in the efforts of Georgia's Government in transforming the country into a transport and logistics hub for trade. Connecting to the main border crossing points is becoming a critical part to enhance its role as a transit country along the Silk Road. A new arch bridge has been designed for this matter in the Khada Valley (Georgia) by IDOM and Arenas & Asociados. This has been a challenging project, which has simultaneously achieved a high-quality result for erection process and service life of the bridge, in a high-seismicity area.

KEYWORDS: concrete arch bridge, temporary diagonals, aerodynamic behavior, high seismicity.

1. Introduction

The North-South Corridor Project is a strategic project in the Georgian Government's effort of transforming Georgia into a transport and logistics hub, emphasizing trade between Central Asia and the Far East on one hand, and Turkey and Europe on the other. Connecting to the main border crossing points is becoming a critical part of Georgia to enhance its role as a transit country along the Silk Road.

The future road will connect, in the central section of the route, the towns of Kvesheti and Kobi, reducing the route's length from 35 km to 22 km, and travel time from one hour to approximately 20 minutes. It will also suppose an important improvement in road safety conditions.

To achieve this, a 432 m long challenging arch bridge, spanning 285 m over Khada Valley has been designed by IDOM and Arenas & Asociados.

Figure 1. The Khada valley with the designed bridge.

2. Geometry of the structure

The adopted solution for crossing the deep valley with difficult access and steep slopes is a concrete arch bridge, erected through a cantilever method with temporary diagonals.

The arch has been designed with a main span of 285 meters and the complete length of the bridge is 432 meters. There are two symmetrical access viaducts of 73.5 meters at both sides of the main span.

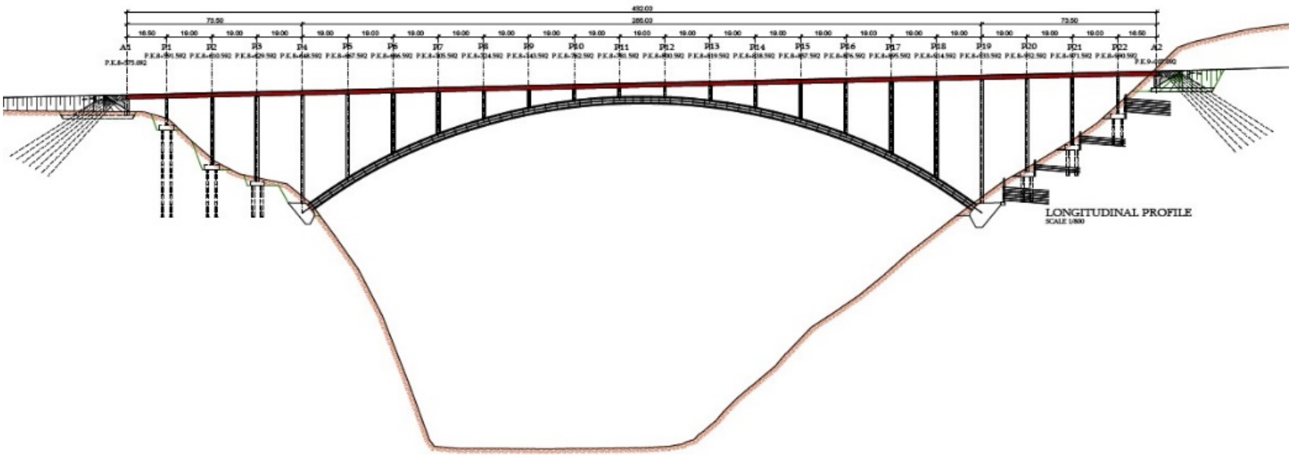

Figure 2. General elevation.

The arch gives support, by means of spandrel columns, to the upper deck. Its rise is 51.5m; therefore, the span/rise ratio is 5.5. The deck is supported on a set of pillars spaced 19 meters, being the length of the spans the same, both in the approach stretches and in the main stretch.

The deck is formed by a continuous composite steel-concrete structure simply supported on piers resting whether on the ground or the arch.

The deck has been designed in steel for two reasons: during construction, the deck mainly works on tension, transmitting tension force to the abutment, as the deck constitutes the upper member of a truss of great depth.

Also, the use of steel as the material for the deck makes possible to minimize weight, which is very important during cantilever construction and contributes to reduce the seismic effect in the final configuration.

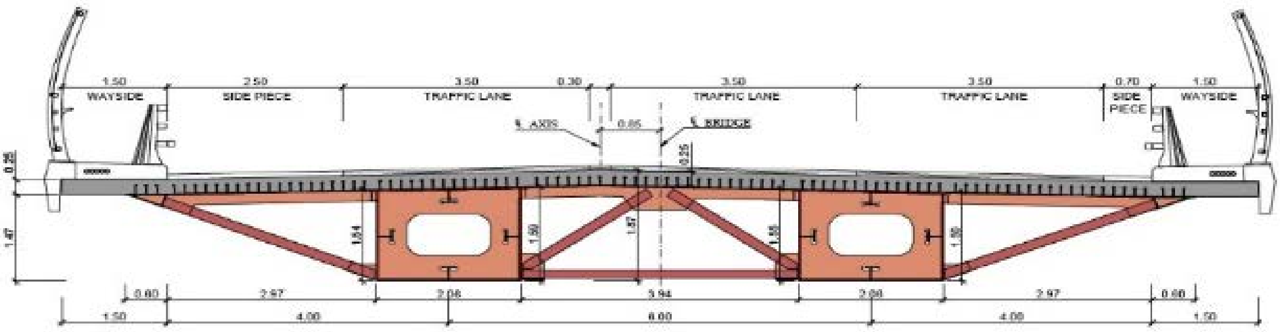

Figure 3. Deck typical section.

The arch is formed by two parallel elements with a chamfered hexagonal box section, linked together by means of diaphragms under the arch pillars.

This configuration improves, with a fixed amount of used material, the behavior of the bridge under transversal actions (both static and seismic) and its response to out-of-plane instability phenomena.

In structures of this magnitude, the behavior of the structure against wind loads is a key factor in the design. The edge of the arch should be as small as possible to present a smaller surface exposed to wind, and the shape of the cross section should be optimized based on the knowledge of the properties of wind flow with an effective profiling to establish a compact and opaque arch to wind.

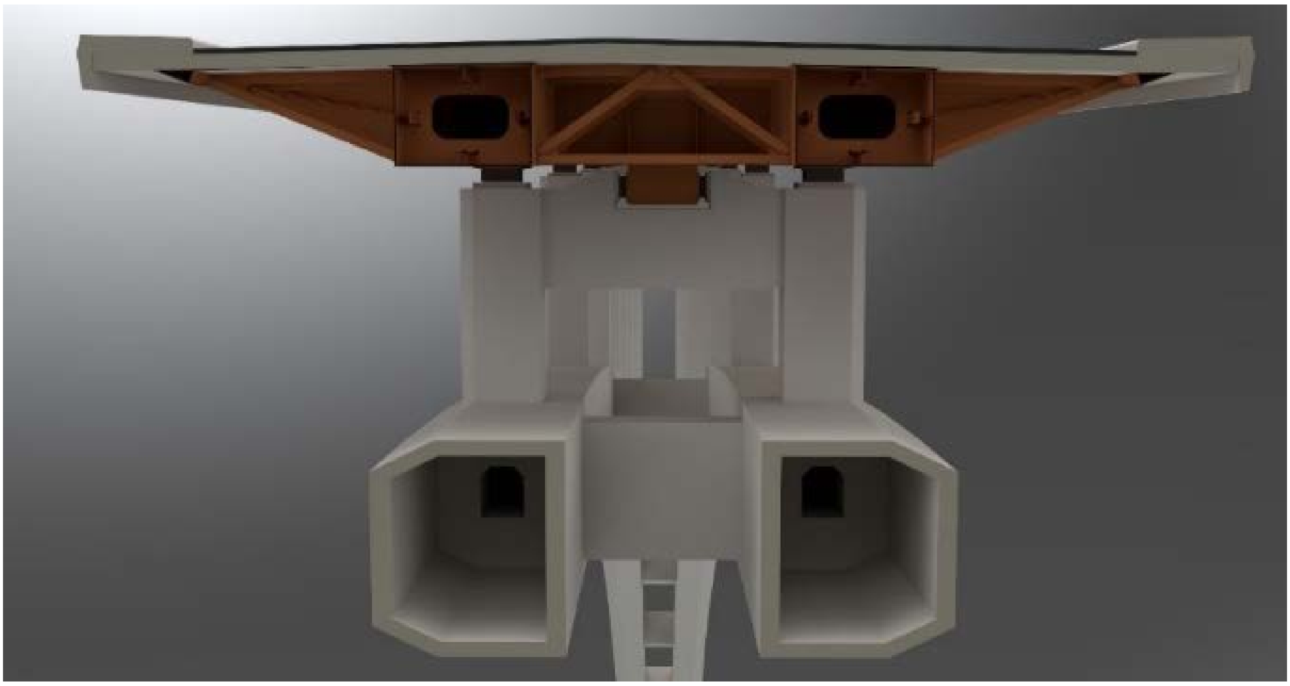

Figure 4. Typical section of the bridge.

The design of the arch section is the result of previous experiences in arch bridges developed by Arenas & Asociados, as it can be seen by comparing the section designed for this viaduct with the one constructed on the viaduct over the Almonte River [1].

The irregular hexagonal section of the arch derives from the search for an appropriate aerodynamic behavior, designing external section chamfers that will reduce its drag coefficient, a fundamental parameter in long-span bridges. This section will cause minimal disturbance to the airflow, reducing and optimizing their depth, but also with an adequate inertia to deal with concurrent bending moment. The section of the "legs" of the arch is a single cell bow with constant depth of 3.5 m and width of 3.0 m, being the horizontal distance between outside faces being 9.0 m.

The arch has been designed with high-strength high-performance concrete (C80/95). The cross-section of the arch thus designed has many advantages in terms of construction and makes it possible to use low weight cantilever formwork travelers. Both piers and pillars have a hexagonal section shape, contributing to the good aerodynamics of the bridge. Abutments are U-type with wing walls and shallow foundation on rock. The cantilever construction system, with temporary diagonals, requires temporary rock anchors under the two spread footings of the abutments, in order to transmit the tension that comes from the deck during cantilever construction.

3. Erection process

The selected erection process is cantilever construction method with temporary diagonals, that uses the arch as the lower chord of two great truss cantilevers and the deck of the bridge is the top chord.

The procedure involves progressing in cantilever from both sides with temporary steel cable diagonals, using the steel deck section as a tie.

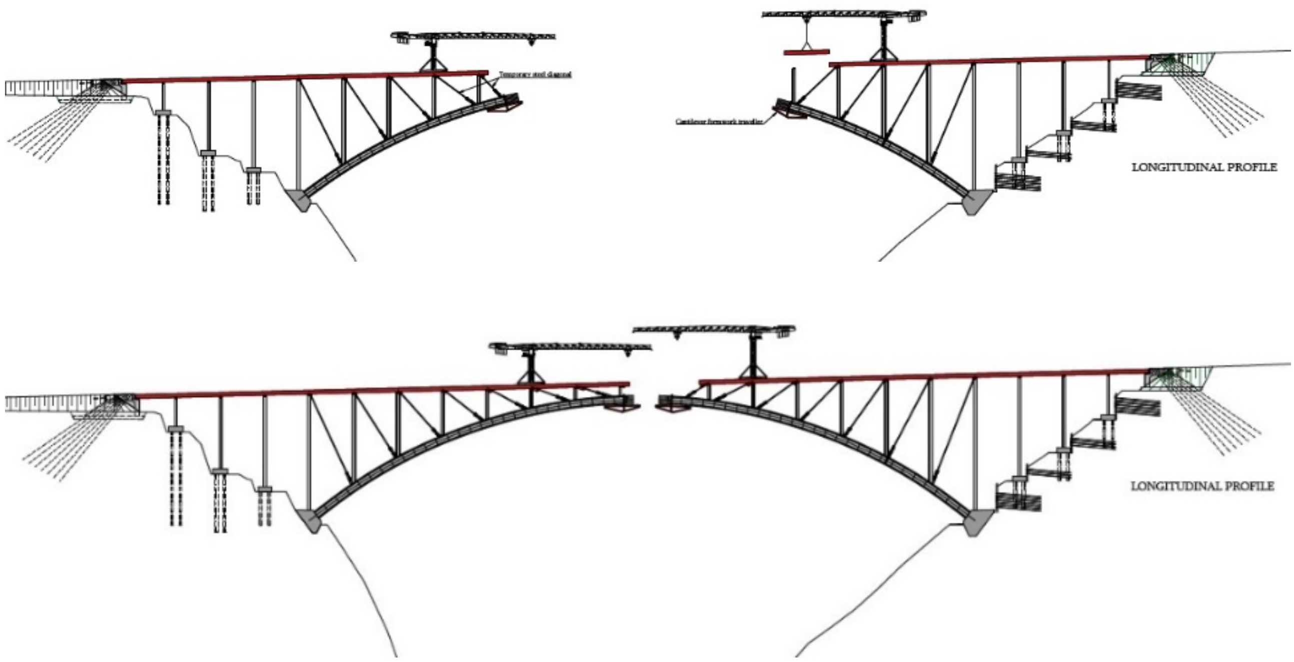

Figure 5. Different stages of the cantilever erection process.

When the two cantilevers reach the center of the span, the arch is closed with a crown segment that is executed after "opening" the two semi-arches with jacks of sufficient strength.

Once the construction of the arch is finished, the deck will be completed with the concreting of the top slab.

The length of the spans (19 meters) and the two-steel box-girder type scheme adopted for the transversal section of the deck, derive from the construction process considered, consisting in a crane rolling over the beams that allow erecting the next span beams.

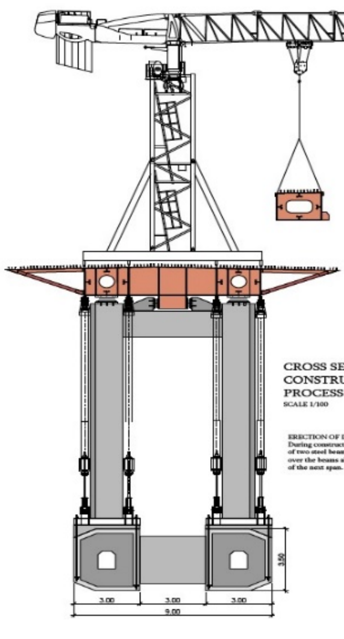

Figure 6. Detail of the rolling crane.

4. Seismic behavior

To determine the seismic demand, horizontal and vertical spectra are used.

The acceleration coefficient from the national map, Georgian Building Code Earthquake Engineering (PN 01.01-09), is taken to use the core philosophy developed in the European standards.

A key point in the bridge design is the longitudinal stiffness of each element and the consequent force distribution.

The study of the longitudinal behavior has permitted the design of the structure without dampers, which supposes a great advantage from economical and maintenance considerations.

Longitudinally, deck is restrained at piers 2 to 8 and, symmetrically, at piers 15 to 21. In abutments and the remaining piers (1, 9 to 14 and 22) sliding elastomeric bearings are placed.

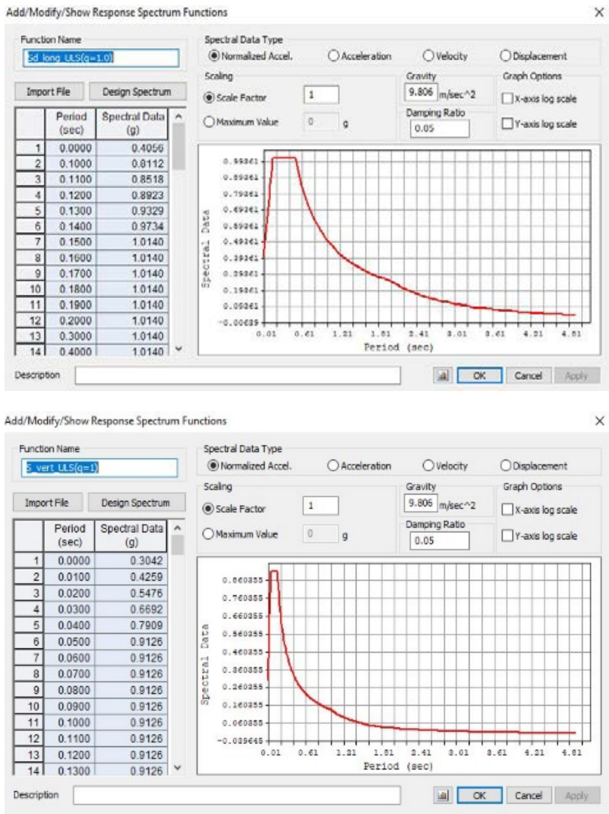

Figure 7. Horizontal and vertical spectrum.

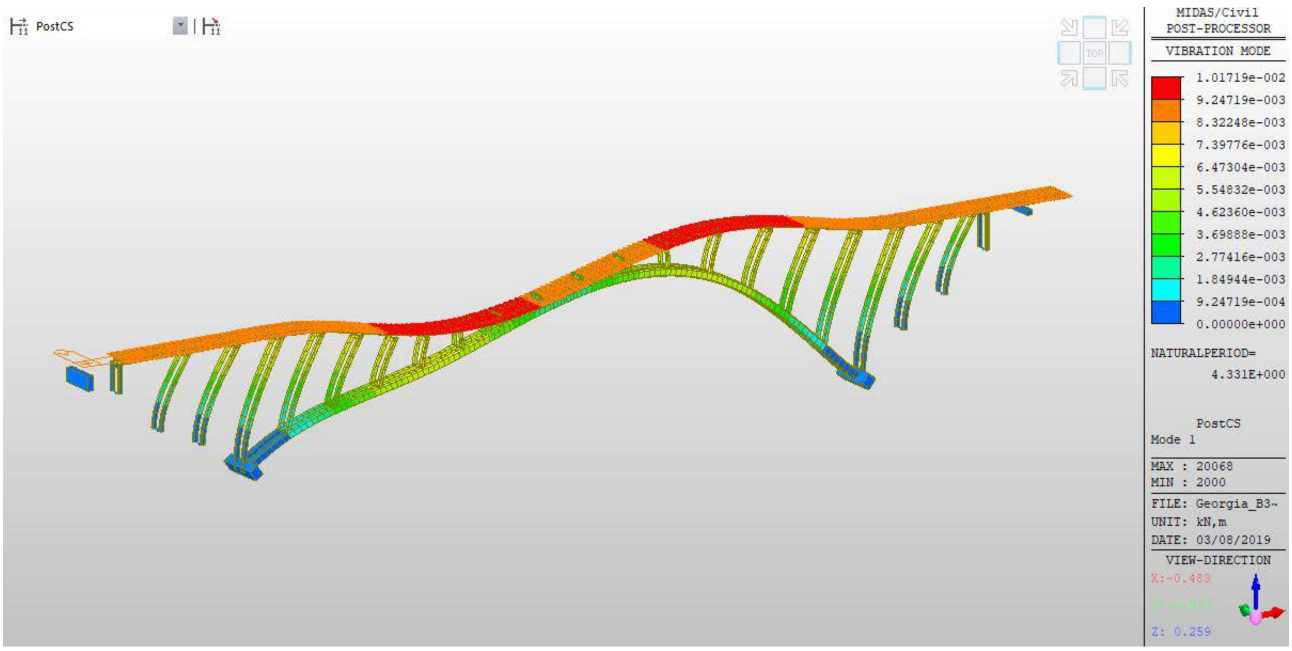

Figure 8. First vibration mode.

Due to the seismic isolation of the deck, the structural acceleration during seismic event to consider in analysis decreases as the natural structural period increases.

Piers linked with the deck re-center the deck automatically after the seismic event.

To support transversal seismic actions, the deck is restrained by transverse shear keys placed at the top of piers.

The bridge is designed so that its behavior under the design seismic action is essentially elastic, according to EN 1998-2, i.e. no plastic hinges will appear in the structure and q=1 is assumed for all elements.

5. Non-linear effects

Material and geometrical non-linearity are to be considered in the analysis of the arch, this has been performed through an incremental-iterative process, where initially sections are assumed un-cracked, and it is verified, with the beam forces obtained for each phase and the moment-curvature diagrams of each section, if this hypothesis is correct.

The stiffness values are corrected, adapting to the stress-strain diagram of the EC-2, and the stresses are calculated again, checking whether the rigidities considered correspond to the tension levels reached.

This process is repeated until the variation in stiffness between the value considered for the calculation of stresses and that which would be obtained from the moment-curvature diagram is negligible.

The non-linearity in the real behavior of the bridge makes it necessary to rule out the possibility of calculating the structure with the classical superposition of states, so it is necessary to develop a non-linear analysis.

With this propose, it was required to establish the calculation hypotheses to be analyzed and their combinations. In this case and taking into account the beam forces of the first order, a wide, although limited, number of critical sections was defined in the arch and for each of them the combination of loads for which the maximum and minimum bending moment are reached is determined.

In the combinations considered, the usual loads included in the Eurocode have been taken into account: Self-weight and permanent loads, rheological actions (creep and shrinkage), bearing friction, temperature loads, traffic loads, snow loads and longitudinal and transversal wind.

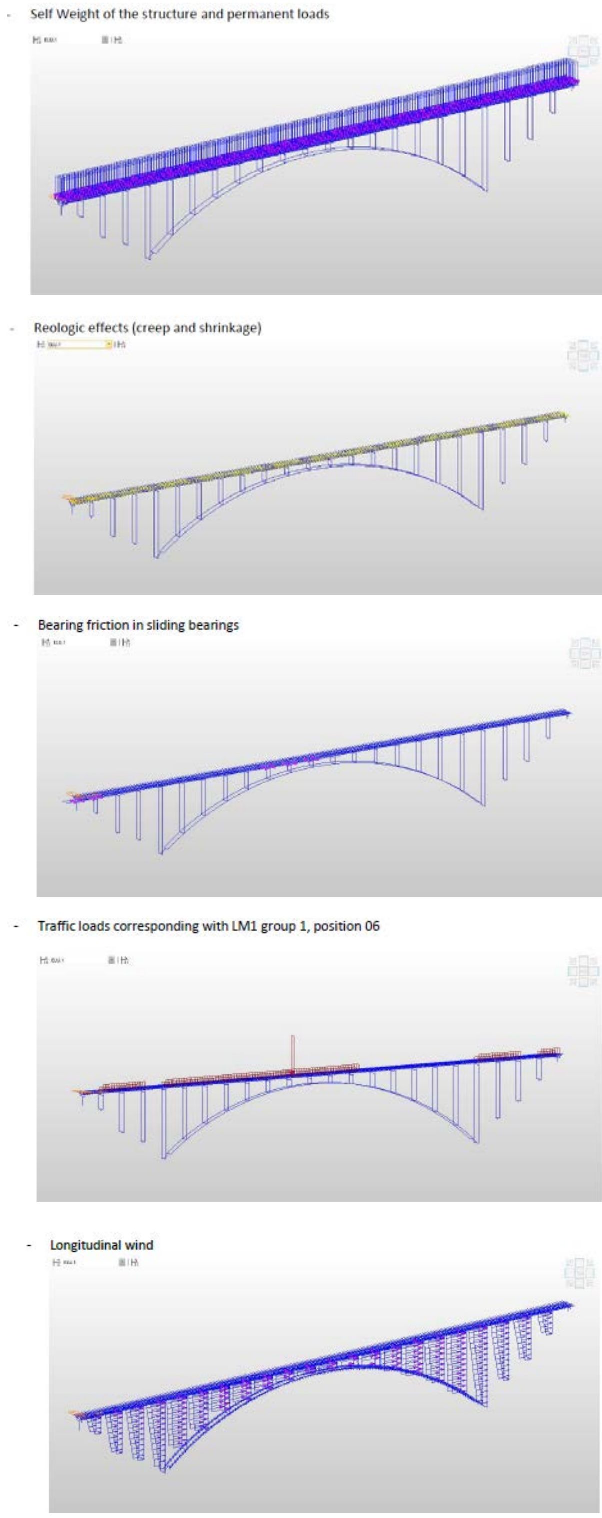

Figure 9. Loads combination considered.

In the following graph, bending moments in different analysis steps are represented. The variation from the linear analysis to the non-linear analysis with geometrical imperfection is represented.

Coming up next, based on the load combinations analysis, an envelope of efforts is generated and used for section analysis of the arch.

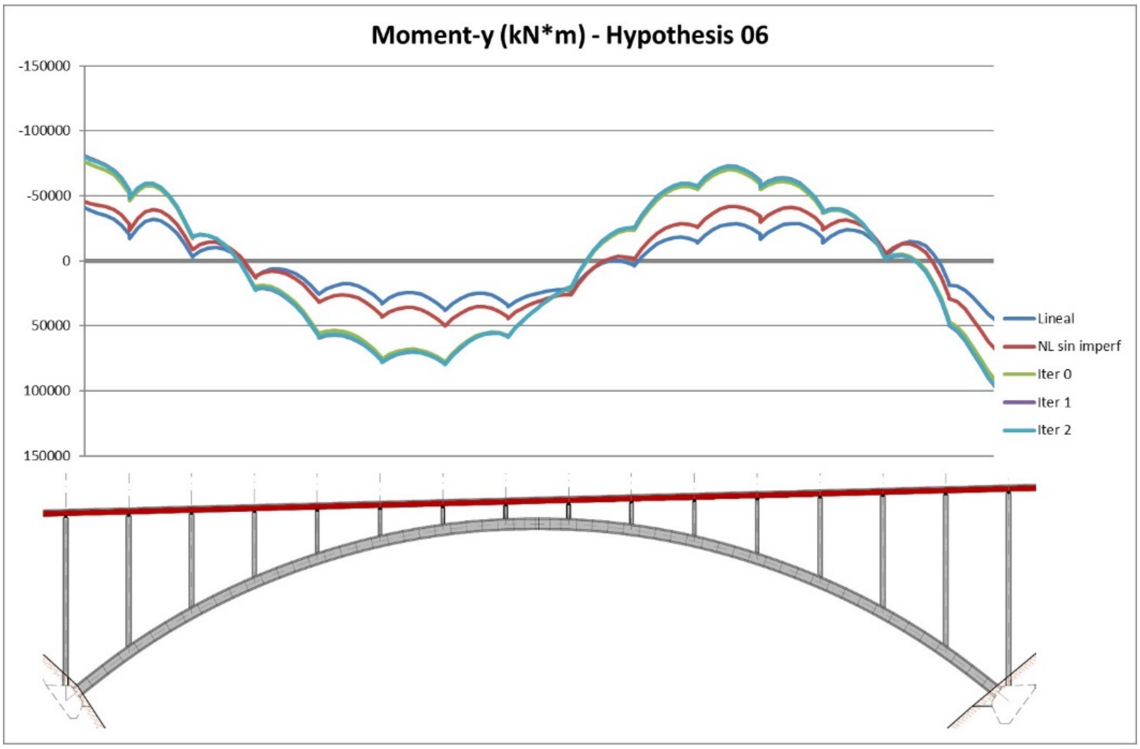

Figure 10. Arch bending moments for Hypothesis 06.

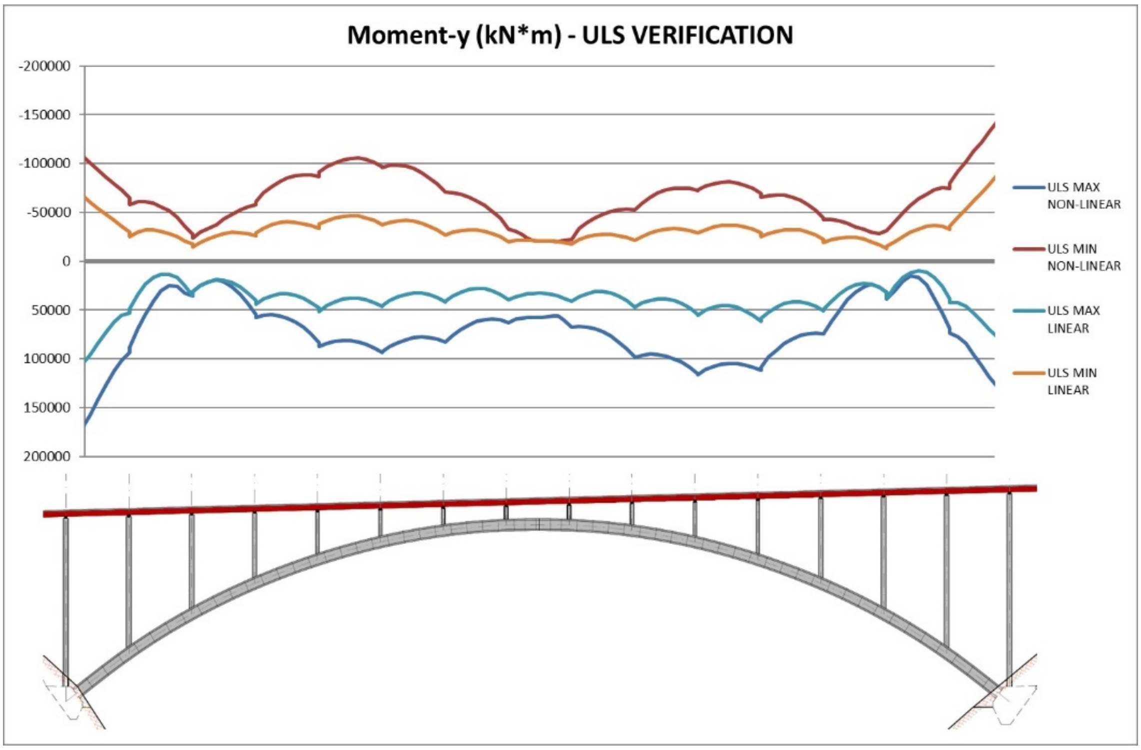

Figure 11. Arch ULS bending moments (envelopes).

6. Conclusions

This paper introduces the design considerations that have allowed to overcome the crossing of the road over the valley of the Khada with an efficient structure in an area of high seismicity.

The designed bridge arises as the most advantageous solution from the point of view of durability, maintenance, behavior under seismic loads and comfort and functionality due to the small deformability of the structure compared to other solutions.

Figure 12. Render image of the Bridge over Khada Valley.

Acknowledgment

First of all, we must acknowledge the technical professionals of the Roads Department of Georgia who gave the team the opportunity to work in this challenging project, whose construction will become true soon thank to the involvement of international financial institutions (World Bank, Asian Development Bank and European Bank for Reconstruction and Development).

Developing such a project would not have been possible without the invaluable work of all team members from Arenas & Asociados and Idom involved in the project despite the paper authors.

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