CFC

CONCEPTUAL DESIGN & STRUCTURAL ENGINEERING

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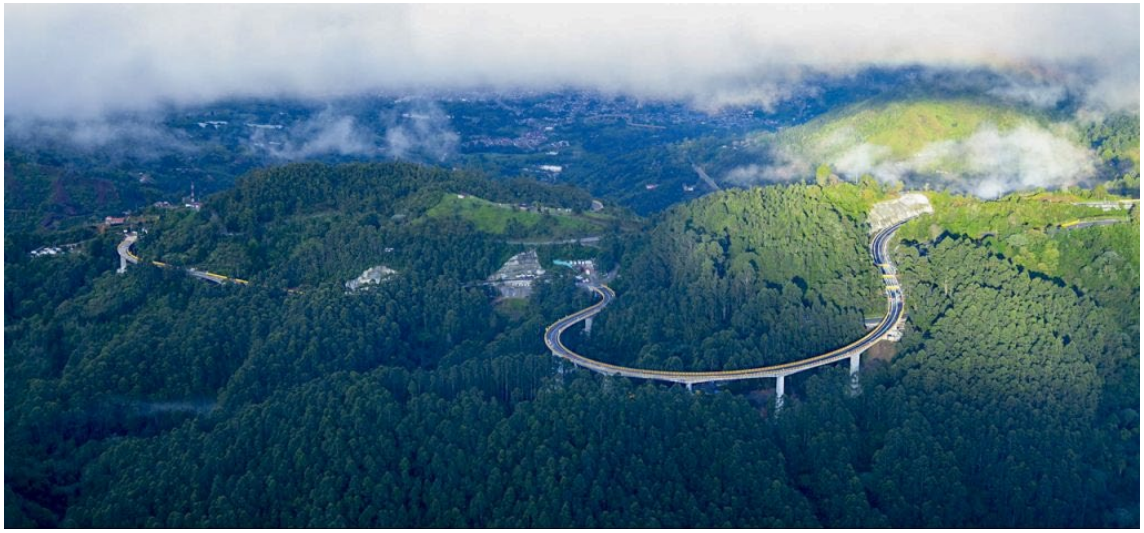

The La Herradura Viaduct is located on the road that crosses the Central Mountain Range of Colombia to communicate Calarcá and Cajamarca. It is a structure whose works began more than ten years ago and that for various unfortunate circumstances had to be paralyzed -like the rest of the actions of the road of which it was part- leaving the viaduct only partially built.

This situation has since been a huge problem for communications in this area of the country, causing great controversy, as well as strong social pressure to resolve it.

The INVIAS of the Ministry of Public Works, the body responsible for the country's road network, responding to this need, relaunched the works as soon as it had the opportunity. After a first phase in which the works were assumed by another contractor, the tender for the final project for the completion of the works - called *"Completion of the short tunnels, the open-air road and the bridges in the sector between km 7 + 895 and the Americas Interchange - Second Quindío Causeway-Central Cordillera Crossing Project"* - was awarded to the proposal made by the Vías América Consortium formed by the groups OHL and FTAA.

This consortium in turn commissioned CFC Sucursal Colombia the Technical Assistance services for the works of the most unique structure of the action, the aforementioned Viaduct of the Herradura.

The name of the viaduct comes from its particular geometry as the whole work is in a strongly curved section in plan. The total length of the structure is 640 m, divided into two independent sections by a joint at approximately half the length on axis called 6 resulting in two structures of 300 m (axes 1 to 6) and 340 m (axes 6 to 12). The first section has a distribution of five spans of spans 37.5m-3x75 m-37.5 m. The second presents 6 with lights 34m-3x68 m-34 m).

The deck is a longitudinally constructed prestressed concrete caisson section built by cantilever advance. It has a width of 11.30 m wide, and variable edge between 2.00 in key and 4.20 m on piles with vertical souls.

The work was partially executed. Superstructure and substructure completely between axes 6 and 12, and only the substructure as well as some sections of the deck between axes 1 and 6. The foundations were made on "caissons" (wells) of variable depths, many of them executed halfway up the slope in areas of steep slopes. The pillars were made of reinforced concrete with rectangular section of variable dimensions with height.

After analyzing the documentation of the original project, the available research that had served to draft the original repowering project based on the tender as well as the results of a new reconnaissance campaign, it was detected that the repowering project presented several aspects that should be reconsidered to guarantee the safety of the structure in light of the current regulations and the development of the seismic design of structures. In coordination with OHL's technical services, an adjustment proposal was made to solve various problems:

1. The initial seismic configuration inadequate when resorting to solutions of monolithic links between board and piles in all the pillars -except in which the expansion joint was located between the two sections- being the height of these - and therefore their rigidity- very unequal throughout the work, and particularly reduced in the piles near the abutments
2. The structural checks showed that large reactions in the shorter pillars that logically occurred as a result of the great difference in relative rigidities with the high piles, caused a seismic demand that far exceeded their capacity. Likewise, many of the foundations were vulnerable because they did not have the capacity to resist the reactions they had to resist, both vertical and horizontal.
3. In parallel to this problem of conception the executed work also presented deficiencies in the qualities of the concrete in many areas and of the execution in general, with a great dispersion and lack of homogeneity.
4. To this was added the change of regulations and the development of the seismic calculation methodology that has generally occurred in structural engineering since the date of the first project of this work.

The reception by INVIAS and the work audit, the Integral signature of these new considerations was at all times receptive and proactive to coordinate update the solution so that the intervention guaranteed the most appropriate levels of security.

In summary, this has resulted in the following adjustments:

- The modification of the longitudinal configuration of the work, seismically isolating the shorter piles. For this, the bases of these piles have been cut and interspersed between them and the encepado group of four pendulum insulators of friction by pile. These special devices were supplied by the Maurer house, which was also actively involved in the design and adjustment of the solution.
- The reinforcement of practically all the foundations that presented deficiencies of various types, leading to the addition of new caissons, regrowth of encepados to connect them, treatments of the terrain, reinforcement of the caissons with interior micropiles ... etc.
- Reinforcement of the pillars with interior and exterior section regrowths, carbon fiber reinforcements, transverse reinforcements to guarantee a design of capacity against seismic action, connection with prestressing to the new base dice supported on the insulators ....etc.
- Redesign of the links of the board in stirrups and with the pile of the axis-6 where the expansion joint is located.
- Completion of the cantilevered deck sections with some adjustments in the distribution of the prestressing and the reinforcement details
- Finally, and with the work practically about to be inaugurated, it was detected that a large part of the prestressing pods of the board of section 1 executed prior to the new works were not injected. The time elapsed without protection -more than 5 years- as well as the verification of the presence of water in many of the pods logically made it impossible to have guarantees on the durability of these elements. This led on the one hand to replace all the cords of the cables of the lower slab that were accessible from internal boxes and the restitution of the strength of the cables of the upper slab inaccessible by means of external prestressing combined with carbon fiber reinforcements in specific areas.

The challenges of this project have been many and intense given the urgency with which the work had to be addressed. On the one hand the structural calculations for the design of the repowering have resorted to a multitude of complex linear analysis models and some evolutionary ones collecting the interaction of the soil-structure, effect of the slopes, differences in the vertical rigidity of the caissons, the non-linear behavior of cracked and confined concrete, of nonlinear behavior of the insulators .....etc. In these analyses, the ABAQUS program has been used, with the aim of being able to limit the behavior of the structure to the maximum, making sensitivity studies to check the robustness of the solution against the uncertainties of the real state of the structure. A crucial aspect in this study has been the development of accelerograms from real earthquakes and the site threat study, for which we had the collaboration of OHL's technical services.

On the other hand, during the work, continuous and intense support had to be given, both from the CFC offices in Madrid and with the presence of resident engineers,

having to adapt in a dynamic and agile way the details and planned designs to the conditions of execution and materials that were found as the works were carried out. A particularly special action was the cutting of the bases of the batteries and the subsequent transmission of the charge from these to the insulators.

The efforts of all the participants in this action have happily led to be able to open this work, and to develop an innovative solution and to our knowledge, completely new in the context of bridge engineering with solutions with seismic isolation.