Urban Cable Stayed Bridge in Envigado (Colombia)

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Summary

A new cable-stayed bridge has been recently built in the city of Envigado (Colombia), being the second largest bridge of this type in the country. A strong personality is required for the bridge to become a new distinctive local landmark of a totally consolidated urban area.

The paper presents the alternatives studied for this bridge and the final characteristics of the constructed structure, describing the most relevant aspects due to the implicit interaction between design and construction.

A brief summary of load static and dynamic test results are also presented.

Keywords: Design, construction, cable-stayed bridge, static and dynamic tests

1. Introduction

Envigado is a Colombian municipality of 180,000 inhabitants, with the higher level of rent in the country, located in the Department of Antioquia next to the beautiful city of Medellín. It is not easy for the visitor to figure out where are the limits between Envigado and its neighbouring city. The Municipality faced with the challenge to build a road connection in the Las Vegas Avenue, decided to design a bridge of exceptional character. Personality and optimization of costs would need to be combined in a sober structure.

In the 90's, a Colombian engineering firm JLdM raises a first draft of 3 spans cable-stayed bridge, with a central span-length of 240 m, that is later reduced to a two spans asymmetric bridge, with a main span of 121 m length, in order to reduce its cost. When beginning the construction, the authors of this paper were asked to put forward the final construction project.

The requirements of the client and the nature of the communication that is created with the bridge would not allow establishing an authentic, honest, real structure, if the spirit of the designers did not comprise of the essence of the work. It is for that reason that the innovation and creativity and the optimization of economic resources have impregnated each idea and detail of the design.

In one first stage of the project a study of dimensional alternatives for the bridge was developed. As final objective, the cost of construction had to be optimized, staying the basic requirements of the existing first design: spans and location of pylon. Two possible pylon heights (40 or 50 m), three alternatives of pylon inclination (0º, 5º and 10º) and two different depths of the deck (1.7 and 2.4 m) were analyzed. The solution that better integrated the aesthetic appearance and the constructive and economic aspects is the structure that is described hereinafter.

2. Conceptual design and description of the bridge

The fruit of the intellectual tension to integrate all these conditions in only one unit is presented hereinafter: an asymmetric cable-stayed bridge with only one pylon and two stayed-cable spans of 121 and 60 m lengths.

Four fundamental aspects have conditioned the design of the structure: aesthetic, optimization of the final cost of the work, earthquake behaviour, and erection process of a bridge of great dimensions in a consolidated urban area. To build in urban zones is always a dare, due to the difficulties originated by possible restrictions in the accesses, the existing traffic, the next presence of buildings and residential zones, etc (Figure 1). The bridge allows the crossing at different levels of two routes with heavy road traffic, being located a public square in the inferior level that allows creating a connection with Avenue 37 South.

The bridge presents three approached spans of 20.2 m length and two cable-stayed spans of 121 and 60 m. The two main spans are supported by central stays continuous through a steel saddle on top of the pylon. All stays converge at the top of the pylon as a fan type stay configuration and are spaced at the deck between 10 and 12 m (Figure 2). This stay configuration results in an optimization of stays and also in a significant increase of superstructure stiffness.

Fig. 1 View during construction

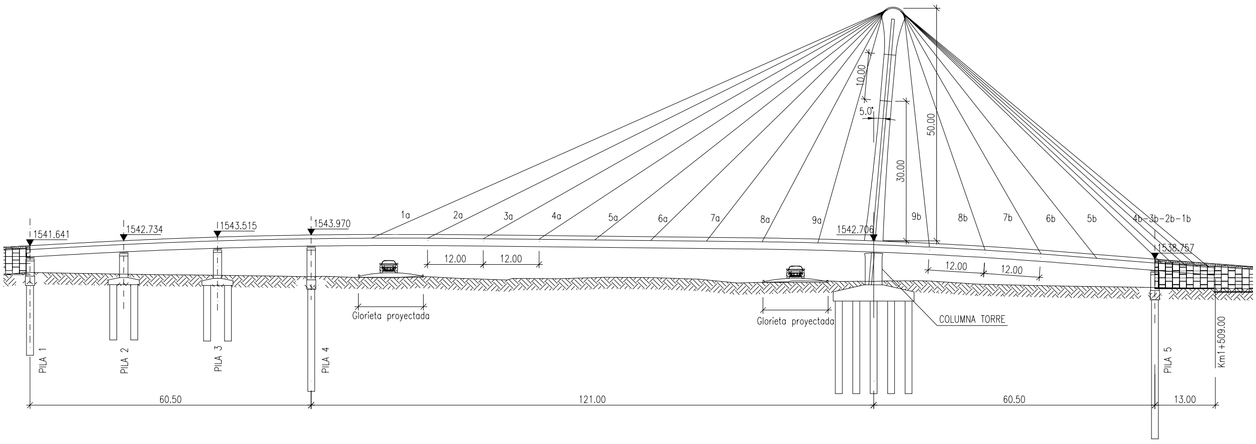

Fig. 2 Elevation

The poor bearing capacity of alluvial and non-consolidated soils of the plain of the Medellín River calls for the design of foundations by means of piles that must be embedded in the granular substratum to avoid inadmissible vertical settlements for the superstructure. All the foundations are made of piles 1.5 m of diameter, reaching, some of them, 30 m depth. More than 1200 m length of piles has been excavated.

The pier under pylon presents a circular cross-section, of variable diameter in height between 3.6 and 6 m supported by 30 piles of 1.5 ms of diameter. The pile cap presents a rectangular plant of 21x17 m2 and a maximum depth of 4.5 m. This pier is the fixed point of the superstructure against earthquake or other longitudinal horizontal forces. The superstructure rests at this pier on two POT bearings with 4600 T and 1250 T of vertical and horizontal capacities.

The north abutment works as a counterweight, supporting the retaining stays, having to resist a vertical force of 3000 T (Figure 3). In his zone, the deck rests on PTFE-elastomeric bearings that allow longitudinal horizontal sliding. The abutment consists of a slab of 15.6 m by 18.25 m and 2.2 m thick resting on 16 piles. The footing slab supports a reinforced concrete box, allowing the access for the tensioning of cable stays and the suspension of the vertical force using sixteen looped 12 T 0.6” cables. The great mass generates important efforts on the piles under the earthquake hypothesis that had conditioned the pile design. Prefabricated concrete walls in the approach ramps to the bridge are constructed by means of earth retaining walls in an approximated amount of 2000 m2.

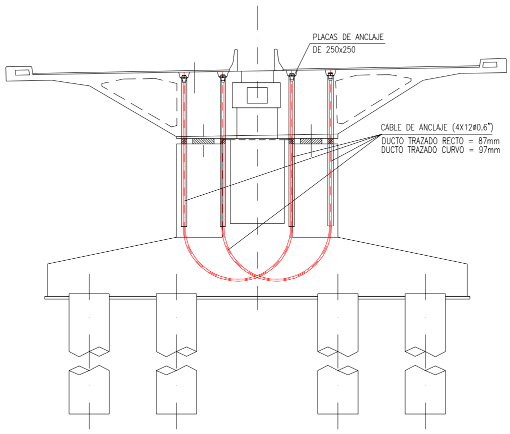

Fig. 3 Cross-Section of the counterweight and view during its construction

The most singular element of the bridge is the 50 m high pylon that, as a landmark, is a new reference of the city. The significantly slender pylon consist of a single element rigidly connected with the deck, designed as a prestressed and reinforced concrete element with a rectangular cross-section of variable depth in both directions (dimension in the base of 4 by 2 m). The pylon has been slightly inclined, to generate an impression of movement, 5º with respect to the vertical axis.

The deck has practically a straight alignment in the horizontal plane except the final stretch with a circular transition of 820 m. The width of the platform is constant of 18.6 ms and it has been designed with a cross-section of the great inertia to torsion constituted by a concrete tri-cellular box girder of 2.40 m depth. The deck has been post-tensioned with longitudinal and transverse cables. The longitudinal prestressing consists of straight 12 T 0.6” tendons. The transverse prestressing has been placed in the zones of cable stay anchorages and in some of the diaphragms over supports. Longitudinal prestressing has been designed to remove temporary supports when needed due to traffic requirements under the bridge. The final amount of post-tensioning steel is 75 T.

The stays are constituted by parallel strands (0.6” diameter) with galvanized, waxed and PE coated with an outer co-extruded HDPE stay pipe of white color, varying the number of strands between 33 and 91 units. The total stay weight is 112 T. VSL type SSI 2000 anchorages have been used. These anchorages allow for future retensioning and replacing of the stays.

The bridge is located in a seismic zone of average degree in Colombia, having calculated for an earthquake spectrum with a maxima acceleration of 5m/s2. The design has been made in agreement with the specifications of the Colombian Bridge Design Code, similar in many aspects to AASTHO Code, and the recommendations of the PTI (the U.S.A.) and the CIP (France) were used for the dimensioning of the stays.

Two different structural models, using three dimensional bar elements, have been carried out for the general structural analysis. Both models are elastic and take into account the non-linear behaviour of cable stays. One of the models also considers the concrete time-dependant mechanical properties that clearly conditioned the design of longitudinal prestressing, in particular, at the main span. Maximum deflection due to creep is expected to be about 10.6 cm (L/1130). Adjustment of stay forces has been recommended after creep deformation occurs and continuous monitoring has also been installed on the bridge to control general behaviour of the structure.

Other more sophisticated calculations, using finite element models, have also been carried out to analyse the behaviour of diaphragms at the anchorages, longitudinal distribution of normal stresses at the anchorages and other special local zones of the structure (Figure 4). These models have also been calibrated using simplified strut-and-tie models. In general, good agreement between both options has been obtained, but results coming from the finite element models have been preferred for the design of reinforcement, as they are more precise, in particular, for the cracking control.

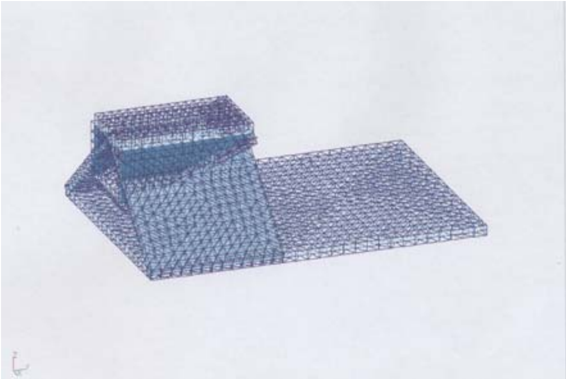

Fig. 4 View of diaphragm at stay anchorages and numerical model using finite element techniques

The President of the Colombia Republic, Mr. Álvaro Uribe, and the Mayor of the Municipality of Envigado, Mr. Álvaro Velásquez, held the opening ceremony in July of 2003. The total budget of the work ascends to 7.3 million euros (1500 €/m2).

3. Erection process

An always-present aspect in the bridge design is the judicious analysis of contractor's means. In Colombia the cost of the labour is lower than in other countries but imported materials, as prestressing steel, stay technology and bridge accessories are very expensive. For this reason, the design of the diverse structural elements of the bridge pretends, as main objective, the optimization of materials, although the execution was more complex.

The height of the deck on the natural land is of approximately 6 m, being possible a construction of the deck using classical false work. The construction of the deck has been made by segments that have not been built consecutively to prevent interferences with the existing traffic under the bridge. The conventional false work was, in some sections, replaced by a temporary concrete frame structure (Figure 5).

Fig. 5 Views of the bridge deck under construction

Pylon has been constructed by means of a climb-form, in modules of 5 m high, with a variable rectangular geometry in its two dimensions with the height. The construction of pylon has been developed in parallel with the construction of the deck. Once reached the top of pylon, the deviation saddle was placed. The saddle is constituted by a series of steel tubes that guide each cable on pylon (Figure 6).

The installation of the cable stays has been made strand to strand, guaranteeing its parallelism during the tensioning. The cables are deviated on pylon head in a steel saddle and all of them are anchored in the deck. The saddle has been pre-assembled at the site and positioned in a single operation. The strand HDPE cover as well as wax is removed in the saddle surface and, later, it has been grouted with resin mortar to increase their friction and to avoid relative displacements between stays and pylon. Once inserted, cable stays have been tensioned, using single-strand jacks from both ends at the same time to prevent horizontal forces at the top of pylon. Two tension stages have been necessary to adjust the final specified force. Finally, the assembly of centring devices, shock absorbers and protective caps is made, filling up the guides of the saddle with a resin mortar and mounting the cover of the saddle. The installation of the stay cables was made in less than three months.

Fig. 6 View of the steel saddle during its construction

4. Static and dynamic load tests

Static and dynamic load test have been carried out after the completion of the bridge. Although these tests are not mandatory in Colombia, they were suggested to verify the correct structural behaviour of the bridge.

Live load applied during test was about 60% of the design traffic load. Three different cases of static load were considered, two of them to obtain maximum displacement in each cable stayed span and the last one to measure the deck behaviour under maximum torsion effect. Regarding the static load test, excellent agreement has been observed between theoretical and experimental results of displacements, but remaining deformations were close to 20% in the first case of load and practically with no remaining displacement for the two other cases.

Regarding the dynamic test, accelerations, displacements and stresses were measured at several points of the deck or stays for one or two trucks crossing the bridge at different speeds (5, 35 and 60 km/h). The impact factor obtained, in terms of deflection, was about 1.02 and 1.04 due to vehicles crossing over an obstacle to induce an impact effect on the superstructure. Peak accelerations measured in these tests were lower than 0.09 g and the critical damping varied between 1 % and 1.93 %.

Additionally, in order to control the behaviour of the structure throughout its life, a continuous monitory system has been installed, constituted by load cells in stay anchorages, accelerometers in stays and deck and other sensors to measure temperature and displacements in certain points.

5. Conclusions

The bridge is the second largest concrete cable-stayed bridge in Colombia and has become a work of reference in the country thanks to its design and construction quality as well as improvement and enhancing of the urban facilities of its surroundings (Figure 7).

Fig. 7 General view of the bridge

This example clearly illustrates the aesthetics and formal possibilities of cable stayed bridges in urban areas to act as an icon or landmark. This bridge is conceived as representation of the effort and persistence of the community to surpass the convulsed situation that lives the country. This explicit desire of overcoming has been shaped in a bridge whose costs and type would not be understood without considering these circumstances before. An optimization of construction cost has been achieved taking into account the particular conditions of the country, trying to minimize the use of materials in spite of increase in labour time required.