“Pedro Gómez del Bosque” Pedestrian Footbridge over the Pisuerga River in Valladolid (Spain)

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Summary

This urban pedestrian and bicycle bridge crosses the River Pisuerga in the historic city of Valladolid. A marked difference in the ground elevations between the riverbanks enabled a stress-ribbon type suspended footbridge. The total footbridge length is 110 m including the two anchor abutments and the central 90 m long suspended deck with a sag of only 1.72 m (1/50L).

To simplify the erection and the marked geometrical and material non-linear response, the supporting tensile force in this work is provided exclusively by means of a continuous 3600x35 mm S355 weathering-steel plate. This arrangement enabled us to place the concrete platform directly over the plate without a longitudinal collaboration between the two elements.

Due to the flexible response of these structures, special attention was paid to the dynamic analysis under pedestrian-and wind variable loads. Detailed dynamic tests were carried out to verify that real accelerations matched the estimated analytical values.

Keywords: suspension structure, stress-ribbon, light concrete, precast slab, weathering steel, pedestrian-induced vibrations, dynamic behavior, dynamic test, careful equipment design.

1. Introduction

The new “Pedro Gómez Bosque” footbridge is part of a new pedestrian itinerary commissioned by the Valladolid City Council to connect the neighborhoods of Arturo Eyries and La Rubia, heretofore connected by bridges located 2 km apart.

Fig. 1 Lateral view and general elevation
The footbridge spans the Pisuerga River at a location where the left river bank lies on high and steep slopes, while the other bank lies in a lower flat floodplain currently protected by a flood protection concrete wall. Such crossing configuration, where one of the ends is in a relatively high position over the river, provided an adequate height over the water level to adopt a suspended stress-ribbon type solution that neatly spans the riverbed from one bank to the other with no intermediate supports, tracing a very gentle curve. The crossing length amounts to about 100 m, with the abutments moved slightly forward into the riverbed. As a result, the final main span of the structure is reduced to 85 m.

2. **General comments on stress-ribbon structures**

Generally speaking, one of the main problems of any hanging type structure is its potential great deformability under variable loads due to the fact that the structural stiffness greatly depends on its main element, the suspension cable. There are different options to control this.

- One is to increase the flexural rigidity of the suspended elements, solution used in suspension bridges. The load-bearing element -the cable- is separated from the platform –the deck- so the deformation under live loads is mainly controlled by the flexural stiffness of the deck. Depending on whether the deck is self-anchored or free, the resulting normal sag/span ratios of the cable fall within the interval of 1/6-1/10.

- Another option is to increase the initial tension load of the cable in order to increase the nonlinear recovering effect which is due to the cable elongation. This is the system used in stress-ribbons structures, where there is no separation between the load-bearing element and the platform. The stiffness of the system is achieved mostly through the great tension to which the structure is subjected. Vertical deflection under live loads is thus controlled by the markedly nonlinear structural behavior of the stressed cable. Such a large force on the suspension cable therefore leads to a very low sag/span ratio, of about 1/50. Additional stiffness can be achieved by increasing the deck flexural rigidity. However, high values, in their turn, introduce problems of concentration of local bendings moments near rigid supports, thus complicating the section design.

3. **Main structural and distinctive features**

The 1/50 sag/span ratio adopted for this structure provided a maximum sag of 1.72 m in the 85 m long span. This allowed us to keep the lowest point of the footbridge at a sufficient distance from the water level of this 500 years old passage, and at the same time guaranteed a sufficient clearance for the tourist boat that sails the Pisuerga River in normal water volume conditions.

![Fig. 1. General view of the bridge](image)

The cross section width is 5.0 m to allow for a 2.50 m pedestrian walkway and a 1.50 bicycle lane.
In order to improve the structure both constructively and formally, two variations have been introduced in this project as compared to the most commonly used solutions in stress-ribbons bridges:

On the one hand, tension is not obtained using prestressing cables, typically applied as tension elements in stressed ribbons. The hanging element used instead is a continuous steel plate. The concrete platform placed over it does not collaborate in the longitudinal work of the catenary. Precast light concrete slabs placed directly on the plates with nonstructural transverse joints between them were used for this purpose. Two of the main problems of the prestressed stressed ribbons are thus avoided: the deformation due to creep and shrinkage, and the appearance of parasite bending moments in the support areas due to the imposed curvatures.

The plate is made of conventional structural S355 grade steel. This is a continuous plate, 94 m long, 30 mm thick and 3.60 m wide. For the protection and durability of the structure, weathering steel type was used. Theoretical final loads on the plate were achieved in a passive way, that is, applying due geometry control during construction.

The steel plate is attached to the abutments at both ends in carefully designed concrete saddles. Smooth and gradual load transfer is achieved through fillet weldings of longitudinal cuts of the plates to three vertical steel strips which are embedded in the abutment and connected to the concrete by shear studs. Saddle curvature (R=50 m) was designed to assure that additional bending stresses on the plate fall within admissible values.

The second distinctive feature has to do with the formal aspect of the cross section. Due to the low strength demands, the traditional solution is a constant depth slab with small thickness. Instead of that, a U-shaped cross section with slightly lifted curved arms on either side was designed with the aim of increasing the apparent depth, so that pedestrians may enjoy a greater sensation of comfort and security during the crossing, and in order to achieve a more consistent lateral view of the footbridge from the outside.
4. Foundations

The transmission of the reactions to the ground is carried out through tubular reinforcement micropiles of a 125 T capacity, duly anchored in the substratum by repetitive grouting. Given that the reaction of the band has a mainly horizontal component, the micropiles are placed in a slanting angle to the vertical, in order to decompose the reaction of the tension-compression forces in the piles.

The rear micropiles are arranged in two rows of 8 with an average slant angle of 45°. The rear ones are arranged in two rows of 7 with a 25° slant angle. The maximum horizontal stress transmitted by the plate amounts to 20,000 kN.

5. Erection process

The installation of the steel plate was a very interesting aspect of this project. It was carried out by hanging it from auxiliary cables arranged to provide the plate with adequate geometry before subjecting it to the weight of the concrete platform.

The whole plate was completely assembled beforehand on one riverbank placing it on provisional supports with rollers. Once the auxiliary cables, made of prestressed steel chords, were extended and duly loaded between the abutments, the plate was hanged from transverse beams supported over the auxiliary cables with the rollers.

The plate was then dragged from the opposite abutment with pulling cables using two hydraulic jacks. Once it was anchored, the 0.75 m prefabricated slabs were placed directly on top and then connected by means of shear studs. The joints between slabs were then grouted and the equipment and paving laid.

The launching operation lasted about 12 hours. The state of the plate and its geometry were object of thorough control and monitoring throughout the operation, due to their high sensibility to thermal conditions. Once in place, the plate was lowered and welded to the three vertical anchorage plates placed on the abutments.
The whole structure was monitored during launching; it was essential to control that the progressive load increase of the structure be kept within the predicted values. Two additional auxiliary 800 T jacks were ready on either end in case the need arose to adjust the bridge geometry, but finally did not have to be used.

6. Dynamic behavior

Natural frequencies of structures as lightweight as this footbridge are normally values close to the pedestrian path (frequency ranging from 1 to 3 Hz depending on the pace speed). In this structure the first vertical mode value is about 1 Hz. The coupling effect of the pedestrian passage -known and characterized with precision after the problems aroused in some recent footbridges-, made the footbridge potentially vulnerable to resonance and vibration problems.

The great tensile force provides the necessary stiffness to control the deformations resulting from static loads in stress-ribbon structures with steel plates as the sole load bearing element. However, this may be insufficient to control live loads coming from pedestrian or wind actions:

- On the one hand, the structure’s dynamic behaviour is affected by a low effective stiffness value of the resistant cross sections, that is of the steel cross section of the plate in which there is no collaboration from concrete.
- On the other hand, the damping intrinsic to the structure is scarce since it is made of a steel plate.

Dynamic amplifications may therefore not be under control when the structure is subjected to certain loads. For that reason, careful analyses of variations under live loads were carried out during the design stage. Vibration levels under live loads of pedestrians were carefully analyzed throughout the design phase, following the specifications included in the Eurocode 1. Annex X. Model of dynamic actions in footbridges, in order to ensure that the resulting accelerations did not produce discomfort to the users.

In practice, as reported in the Eurocode and other studies, this consists of keeping vertical vibrations under 0.5-0.7 m/s² vertically and the horizontal ones under 0.10-0.15 m/s².

Additional damping systems were contemplated during the design stage in case greater vibration control was required. These finally proved unnecessary. The only detail we modified consisted of providing a certain transverse continuity through the precast segments joints to give additional torsional stiffness to the cross section. Low-shrinkage grout was used for this purpose instead of the initially planned flexible mastic.

Once completed, the work was subjected to a static and dynamic load tests. The footbridge behavior was concluded to be perfectly satisfactory and no additional damping elements, –initially planned to be installed in the handrail if necessary-, were required to comply with users comfort requirements.
7. Equipment

Given the uniqueness of the footbridge and the interest of the Valladolid City Council in obtaining an outstanding work for their city, the whole was complemented using exquisitely designed finishing: glazed, stainless steel railings and wall cladding using white limestone from the area. The bridge was paved using a flexible colored rubber-based solution -similar to the material used for athletic tracks with partially recycled components- extremely comfortable to walk on.

The lighting solution used RGB LED light strips, arranged along the railing banisters and programmed to gradually change color shades. Its striking visual effect has become a new vibrant nighttime landmark of the city.

Fig 8. View of the abutment

Fig 9. LED RGB lighting from the handrail

8. Conclusions

Very few stressed ribbon structures where suspension system is provided by steel plates have been built during the last few years (Pforzheim and Börstel pedestrian bridges in Germany designed by the firm Schlaich,Bergermann und Partner, Suransuns footbridge in Switzerland designed by Conzett, Bronzini Grantmann AG).

The “Pedro Gómez Bosque” footbridge is a recent work with this kind of arrangement and it currently holds the record for span length in stress-ribbon structures made out of steel plates (85 m). It also features some distinctive elements: full section steel plate, wide U-shaped precast light-weight concrete slabs and a detailed erection process with auxiliary cables avoiding any contact with the riverbed. No jacking was required for the ribbon stressing; final loads were reached by providing adequate geometry to the steel plate during erection.

9. Sei Data Block

Owner: Valladolid City Council

Structural design and construction supervision:
Carlos Fernández Casado S.L. Oficina de Proyectos (Madrid)
Consulting de Ingeniería Civil S.L. (Valladolid)

Main Contractor: Construcciones Llorente S.A.
Specialized subcontractors: Construgomes (concrete works)/ CIMTRA (foundations)/JOAMA (structural steel)

*Main plate steel:* 76 T (S355W)

*Concrete* (light precast concrete slab): 59 m³

*Total cost:* 0.95 M€

*Service date:* 2011