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AESTHETICS OF URBAN STEEL BRIDGES

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Bridge engineers should take responsibility for the structure's appearance, as well as ensuring that it carries the load.

Fig. 1. Girona pedestrian bridge.

THE AESTHETICS of a bridge play a role as important as efficiency, economy, sustainability and constructability. Bridges, as long-lasting structures, modify the landscape and their influence in the life of various generations is something we cannot forget in their planning and design. Good architects and engineers have this concept—"the significance of the appearance"—always present when they conceive a house, a building or a transportation infrastructure.

There are many bridges out of context that have irreversibly damaged natural and urban landscapes. Too many bridges are devoid of any creativity, unattractive, and both badly conceived and built. These anodyne works have caused civil engineering to lose its good reputation.

Unfortunately, the design of most modern bridges is based only on cost and efficiency. Cost and value have long been confused in bridge design. This is a strange contradiction, because the communities feel linked to and proud of their city, if public spaces are taken care of, if aesthetics are present, if history and culture form part of the city's tradition, along with other intangible values related to beauty.

In the last decade, poor bridge designs have resulted in the construction of landmark bridges that want to be different, usually out of scale, and neither efficient nor economic. Political demagogy has also had its consequences, and manifests itself in some leaders that, unable to decide or to accept technical advice in such matters, transfer those decisions to lay people. These spectacular landmark bridges are creating confusion in both the public and bridge owners. There is a feeling that aesthetics cost more money, but this is not true. Luxury costs more money, but that is not necessarily true of aesthetics.

Fortunately, there are many tools and resources to help in designing expressive, attractive bridges. We engineers are conscious of the importance of properly selecting the structural type, the shape, the dimensions, the relationship between the bridge and the site as well as among different bridge elements, the design of details, the color and the textures. All of these aspects, combined with a technical approach to analyzing the efficiency and the economy on a life-cycle cost basis, plus using CAD and virtual simulation techniques, allow bridge engineers to make the right decisions.

Urban bridges with small or medium spans offer an opportunity to explore new forms and construction methods, because the cost of construction depends mainly on the free span and the material, as long as they can be built using conventional methods. In urban zones the cost of the finishes, the restrictions of the site, the services affected, and the traffic disruption can approach the cost of the structure itself. The limit is an ethical matter. We work with taxpayer money

➤ Fig. 2. Andoain pedestrian bridge.

and the engineer's duty is to make responsible use of these public resources. An engineer's real challenge is to conceive aesthetic bridges with no cost increase.

Steel bridges offer great aesthetic possibilities to bridge designers in addition to the advantages in erection, rapid construction and sustainability. If each bridge is unique, why not explore the enormous opportunities in steel construction now open to us with the use of CAD/CAM and numerical control techniques?

Pedestrian Bridges with Structural Railings

Railings are important elements of a bridge, as pedestrians are close and can touch them. The form, color and materials selected for railings are crucial for the appearance of the bridge.

An interesting idea is to design railings, which are always present, as structural components to increase stiffness and to reduce the visual depth of the deck. This concept has been used in several pedestrian bridges we designed in Spain.

The pedestrian bridge designed in Girona, from 1996, crosses the Onyar River 60 miles north of Barcelona. This structure is a frame with one span of 190 ft that is supported on reinforced concrete blocks integrated into the existing embankments. The main part of the bridge deck is a weathering steel box girder made up of stiffened steel plates with a 50 ksi yield strength (Figure 1). The typical cross-section is a unicellular box girder with a top flange 7.9-ft wide with its depth varying between 2-ft (*L*/97) at mid-span and 5.6-ft (*L*/34) at supports. The girder is very slender thanks to the structural railings, which are connected to the box girder. The presence of the ribs creates shadows on the web surface creating an attractive 3D effect. The final result, a sober and simple shape, conceals a complex process of searching for the optimum design, but is at the same time exciting. The weight of steel girder is only 46 tons.

The same concept used at Girona was applied in 2005 to a longer pedestrian bridge in Andoain, in Spain's Basque Country. The main span is 223 ft and the box girder depth varies between 3.1ft (*L*/71.6) at center span and 5.6 ft (*L*/40) over the supports (Figure 2). The overall weight of steel is only 103 tons.

This idea of using the railing as a part of the structural system was pushed to the limit at the pedestrian bridge in Matadapera, which is in the Barcelona Province, Spain. The solution consists of a very slender steel box girder with a length of 571 ft. The typical cross-section is a unicellular box girder at the extremes that is transformed into an extremely slender multicellular box girder of only 8.3 in. at mid-span (Figure 3).

▲ Fig. 3. Matadepera pedestrian bridge.

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Innovative Bridges with Stainless Steel

Fundamental advances in structural engineering have clearly been related to the use of new materials along the history of construction. The increase in the use of advanced materials in bridge design can partially be attributed to the growth in awareness of owners about the use of materials that require reduced maintenance in addition to having greater mechanical resistance and capacity to be reused.

In 2005, we designed the first European road bridge with a complete duplex stainless-steel structure at Cala Galdana, in Minorca, Spain. Minorca is a Mediterranean island that was declared a reserve of the biosphere by UNESCO and Cala Galdana is one of its most beautiful beaches. The surroundings are only partially urbanized, and they contribute to the island's attractiveness to tourists.

The bridge had to replace an existing concrete bridge that was only 30 years old but exhibited significant degradation due to the corrosive marine environment. The new bridge had to meet four explicit owner requirements. It had to be environmentally friendly, have high durability, require minimum maintenance and be a symbol of innovation. For these reasons duplex stainless steel was selected.

The structural systems consist of two parallel arches with a free span of 147.6-ft and an intermediate deck (Figure 4). The main structure is made of Grade 1.4462 duplex stainless steel, which exhibits a high resistance to corrosion by chlorides. The arches, with a total rise of 19.7-ft, have a triangular cross-section with a central web. Its 2.3-ft depth is constant throughout its overall length. However, the width of the section varies between 2.3-ft and 3.3-ft. The use of a triangular cross-section produces a very apparent slenderness. The deck is made of reinforced concrete connected to a series of transverse floor beams. The use of stainless steel introduced some difficulties, in particular in the treatment of the surfaces, and some specific rules had to be applied.

▲ Fig. 4. Stainless-steel road bridge in Minorca.

▼ Fig. 5. Stainless-steel pedestrian bridge in Sant Fruitós.

One of the main concerns when using stainless steel is the increase of construction cost. In this particular case, we estimated that the increase of cost will be offset in 80 years due to the minimum maintenance required.

In 2009, a pedestrian bridge combining stainless-steel and glass fiber reinforced polymer (GFRP) panels for the floor was built in Sant Fruitós, near Barcelona. In this pedestrian bridge we combined a traditional structural type, the arch, with advanced materials. The arch is connected to the deck to avoid horizontal forces at the supports. The deck is very slender and has a triangular cross-section with transverse ribs supporting the GFRP planks. This structure is very light and transparent and very easy to maintain.

The inclined arch is designed to generate a more expressive structure without significantly increasing the cost of the structure. The structural system is very effective, which was confirmed in the static and dynamic tests. The lighting system is also crucial to achieving a warm atmosphere during the night (Figure 5).

Abetxuko Bridge

The Abetxuko Bridge, completed in 2006, crosses the Zadorra River in Vitoria, Spain. It is intended as a vindication of an open and creative engineering design, which meanwhile does not exclude the traditional engineering approach. New forms have intentionally been sought in an attempt to escape from standard geometry (Figure 6).

The bridge replaced an old and very narrow (19.7-ft-wide) bridge with a poor hydraulic capacity. Crossing the old bridge was risky for pedestrians and the municipality decided to improve the mobility of the users.

However although the bridge is intended to be a landmark, its structural system is very simple. The bridge is a continuous structure with three spans of 85 ft, 131 ft and 85 ft and with a total deck width of 103 ft, carrying four road traffic lanes, a central light rail line with two tracks, and two pedestrian walkways. The structural system consists of two parallel trusses with organic forms, their dimensions adjusted according to the structural analysis. The flow of the Zadorra River is safeguarded because the structure has two longitudinal steel trusses and a steel-concrete deck supporting the traffic. The trusses, which ultimately support the deck and the traffic, are arranged with a large part of their structure above the deck. This allows the level of the new road to be raised to meet the hydraulic requirements.

The uncomfortable experience felt by pedestrians on the old bridge was reversed so that they are in a privileged situation on the new bridge. Pedestrians cross the river on external walkways of the bridge, protected from the traffic by the organic structure and enjoying the best views of the river.

The irregular, curvaceous forms of this bridge are in defiance of the traditional use of symmetry, purity and order in engineering design. The chosen material, weathering steel, is intended to show the expressivity of the structure and the choice of weathering steel is also a reference to the history of the Basque country. The color of this steel alters over time; together with the irregular shadows generated by the curves of the structure, it is intended to create the idea of a "living" bridge.

The total weight of steel used in the bridge is about 671 tons (43 lb/ft^2). The total cost of the structure was approximately \$150 per ft^2, which is only about 10% to 15% more than a standard composite bridge of the same dimensions.

Fabrication of the complex steel structure was carried out at one steel yard in Vitoria. The process included preparation of drawings, definition of the pieces, cutting, preparation of plate edges, bending of curved plates, pre-assembling, welding of stiffeners, assembling of the segments, and transport to the site and the erection of the sections and welding of the rest of the steel members. The process of fabrication illustrates the enormous possibilities available through CAD/NC techniques. As the inner surfaces of the steel structure will be inaccessible, the members were made completely watertight.

Conclusion

Bridge engineers have a very creative profession, but we should improve our designs through adopting an open and flexible view, providing not only cost-effective bridges but also caring about their aesthetic aspects. An open and creative engineering design does not exclude a traditional engineering approach.

Steel provides excellent possibilities for bridge designers to create innovative structures that transmit beauty and goodness at a reasonable cost. We just have to explore how to do it. MSC

The author of this article will present additional international perspectives in session B6, "Ideas From Abroad," at the World Steel Bridge Symposium, April 18-20 in Dallas. Learn more about the World Steel Bridge Symposium and NASCC: The Steel Conference at ***www.aisc.org/nascc****.*

◄ Fig. 6. Abetxuko Bridge in Vitoria.