

DAGU BRIDGE, TIANJIN, CHINA



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BIOGRAPHY

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SUMMARY

The Dagou Bridge is located in the center of the city of Tianjin. It has two slender steel arches, one large and one small, each with two planes of suspenders. The girder is a steel box with orthotropic deck. It carries six lanes of traffic and two pedestrian paths.

The main span is 106m to clear the river. The stable structural system of the bridge is an appropriate solution for this special site with very high seismicity and soft soil.

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by

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INTRODUCTION

The Dagu Bridge is located in the center of the City of Tianjin, which is about 120 kilometers east of the Chinese capital, Beijing. It is a part of the Downtown Redevelopment Plan to revitalize the old city. As one of the first parts of the Redevelopment, the City wanted to have a signature structure that would become the symbol of the city.

The bridge has a main span of 106 meters. It carries six lanes of traffic and two pedestrian paths, one on each side of the deck. The minimum width of each pedestrian path is 3.0m. Two of the traffic lanes are 3.75m wide and the other four are 3.50m wide. With a median divider, and barriers and railings, the minimum width of the deck is about 30m.

Design speed for this urban bridge is 60 km/h. The live load is the Chinese City Class A loading. Due to navigation requirements, the maximum girder depth is restricted to 1.38m at the center line of the bridge. The cross slope reduces this to 1.30m at the edge of the traffic lanes. Tianjin is very close to Tangshan City, where in 1976 a big earthquake caused very extensive damages and fatalities. Consequently, the bridge had to be designed for the highest seismic forces in China. Unfortunately, the soil in the upper layers is very soft. This eliminated all bridge types that required anchorage for any horizontal forces.

In the preliminary design stage, three alternatives were proposed: two self-anchored suspension bridges and a tied arch. All three of these alternatives would satisfy all navigation and design criteria. For a symbol of the city in the center of a major redevelopment area, the self-anchored suspension bridge, although very graceful, was not considered sufficiently visible due to its low profile. In addition, the city had already built some self-anchored suspension bridges and preferred a more exciting design. All these factors resulted in the selection of the tied-arch bridge.



Figure 1: Dagu Bridge Renderings

THE BRIDGE CONCEPT

The final configuration is a three-dimensional structure with two planes of suspenders attached to each arch rib, one at the edge of the roadway and the other one at the outside edge of the pedestrian paths. With two inclined planes of suspenders tying each arch rib to the deck, the arch ribs can be made very slender and still possess the required stability.

In this basic structural system, the arch ribs provide the vertical stiffness for the structure, the deck provides the lateral stiffness and the cables combine these two together into a compact system. The bridge itself is stable supported on piles.

For a 106m span, the rise of the arch ribs would usually be about 20m. To introduce some surprise and intrigue in its architecture, the two arch ribs are of un-equal heights and inclined outwards. The small arch is 19 meters high and the large arch is 39 meters high. Creating further architectural interest, the pedestrian paths are curved outward to offer additional space for the pedestrian to rest and to enjoy the surroundings.

STRUCTURAL ANALYSIS

A three-dimensional nonlinear analysis, for both static and dynamic loads, was carried out for the design of the structure. The bridge behaves basically linearly up to an overload equal to 370% of the total load on the bridge deck. This far exceeds the factor of safety required for such structures.

THE GIRDER

The bridge girder is divided into three parts, each of which is a steel box section. The center box is 24m wide and carries the six lanes of traffic. The other two boxes have variable width and carry only pedestrian loads. There are open spaces between the three boxes for aesthetic reasons. These three boxes are transversely connected by crossbeams that go through all three boxes horizontally. The suspenders are attached to the crossbeams directly.

The steel boxes all have orthotropic decks. Under the traffic lanes, the deck plate is increased to 16mm thickness with 8mm-thick U-ribs. The floor beams are spaced at 4.0m apart. The traffic lanes have a 50mm-thick epoxy asphalt pavement. The selection of a 16mm-thick deck plate for the traffic lanes was based on the fact that a large volume of heavy truck traffic may be expected on this bridge as the area is being rapidly developed. It is difficult to control the passage of overloaded trucks in a city. Extensive testing has shown that a thicker deck plate is very beneficial to the service life of the orthotropic deck and the pavement. Consequently, a thicker deck plate is believed to be more appropriate under this condition.

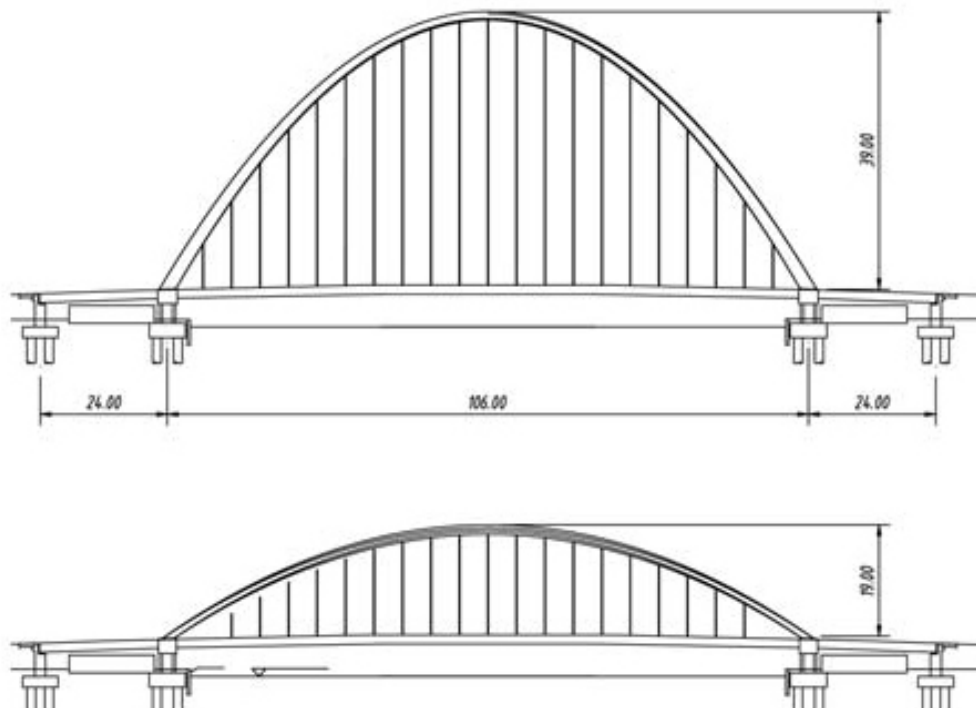


Figure 2A: Elevation

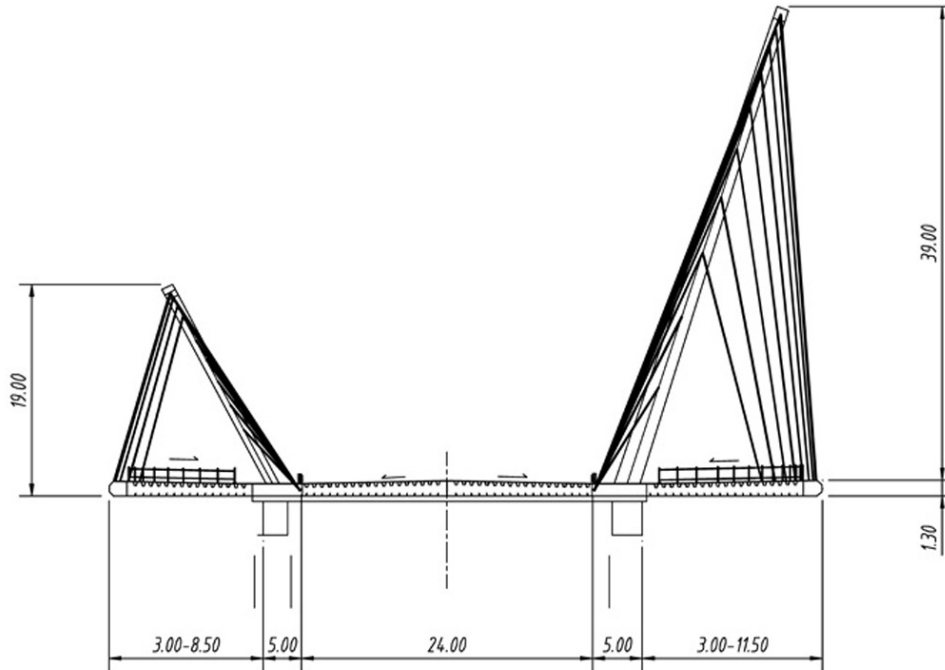


Figure 2B: Cross section

THE ARCH RIBS

The two arch ribs are not the same. They have different inclinations and different dimensions, except that they both are of trapezoidal cross section, with a constant soffit width of 0.9m. For the large rib, the width of the top plate varies from 1.3m at the crown to 2.2m at both ends and the depth varies proportionally from 1.3m to 2.2m. The slope of the side plates is constant to facilitate easy fabrication. For the small rib the trapezoid is 1.30m wide at the top, 0.9m at the soffit and is 1.30m deep constant along the entire length. Diaphragms inside the boxes are spaced at 4.00m horizontal intervals. The sloping web plates receive illumination from spot lights from the deck level to make them more visible in the night. No lights were installed onto the arch.



Figure 3: Pedestrian Path



Figure 4: View from Deck

Both arch ribs have a parabolic shape. Since a major portion of the load comes from the deck, and since this load is basically uniform, the parabola is an appropriate shape. In addition, the parabola is a more elegant form for this structure. The slightly non-uniform dead load causes a small bending moment in the arch ribs under permanent loading. However, the magnitude of this bending moment is not significant.

THE SUSPENDERS

Parallel wire strands with Hi-Am type sockets are used as suspenders. A white high density polyethylene sheath is extruded over the parallel wire bundle to provide protection and the desired color. The suspenders are designed in the same way as the stays in a cable-stayed bridge with the same safety factor and quality control requirements. The suspenders connect to the arch ribs at the diaphragm location and to the deck at the crossbeam location. Any one of the suspenders can be replaced without interruption of traffic.



THE TIES

The arch ribs are fully connected to the steel box girder, which can serve as the tie of the arch ribs. However, to increase the redundancy of the structural system, additional ties were provided. They were prestressed to predetermined forces so the horizontal components of the arch ribs are significantly balanced by the tie forces. The steel box girder will not experience high tension under the permanent load condition. Either the steel girder or the ties will be sufficient to resist the horizontal forces from the arch ribs, so the system is inherently redundant and safe.

Individually sheathed seven wire strand tendons are used as ties. They are placed inside a larger polyethylene duct located inside the middle steel box. The ties are anchored at a 2.0m deep transverse girder at both ends inside the box girder. The arch ribs are connected to the same transverse girder so the tie force will be transferred between the ties and the arch ribs. Due to the much higher stiffness of the steel box girder, the ties do not experience any noticeable stress variations under live loads and are therefore not susceptible to fatigue. Because the box girder alone can act as the tie, the strands can be replaced individually without interrupting traffic, if necessary.

AESTHETIC LIGHTING

There are three different sources of light illuminating the bridge. The first comes from the street lights on the bridge and along the river banks. The second light source comes from the spotlights on each suspender at a



Figure 6: Lighting of the Bridge

level slightly below the deck. There are two spotlights at each suspender location. The reason to install two spotlights at each cable is to obtain a more uniform reflection on the arch ribs. These lights will light up the arches and all of the cables. The third light source is a set of lights under the edge plates at the outer rim of the pedestrian paths. These lights reflect to the water underneath and horizontally through the holes in the edge plates. These three light sources are well coordinated in their intensity to express a gracefulness of the structure at night.

CONSTRUCTION

At the present time, the river is not being heavily navigated; therefore, temporary supports could be placed in the river for construction. The entire bridge was erected on traditional falsework. The lower tier of falsework was supported by piles driven into the river bed. The box girders were delivered to the site in sections and were welded together at the site on top of the temporary falsework. The steel beams connecting the three lines of box girders are made continuous after the box sections have been completed.



Figure 7: Construction

After the deck was finished, another set of falsework was erected on top of the deck girder to support the arch ribs. The falsework was comprised of patented universal elements which could be assembled rapidly. The arch ribs were divided into four-meter-long sections and welded together at the site on top of the falsework.

Suspenders were installed after the arch ribs had been completed. The inner layers of suspenders in each arch rib were partially stressed before the falsework was lowered and removed. They were stressed to a set of forces just sufficient to stabilize the arch ribs without falsework support. The final stressing was done in stages to attain the predetermined stress distribution in the structure.

The construction method using falsework is very simple and straight forward. The universal steel elements are reusable. They can be easily assembled and disassembled. The method also significantly simplified the geometry control during erection.

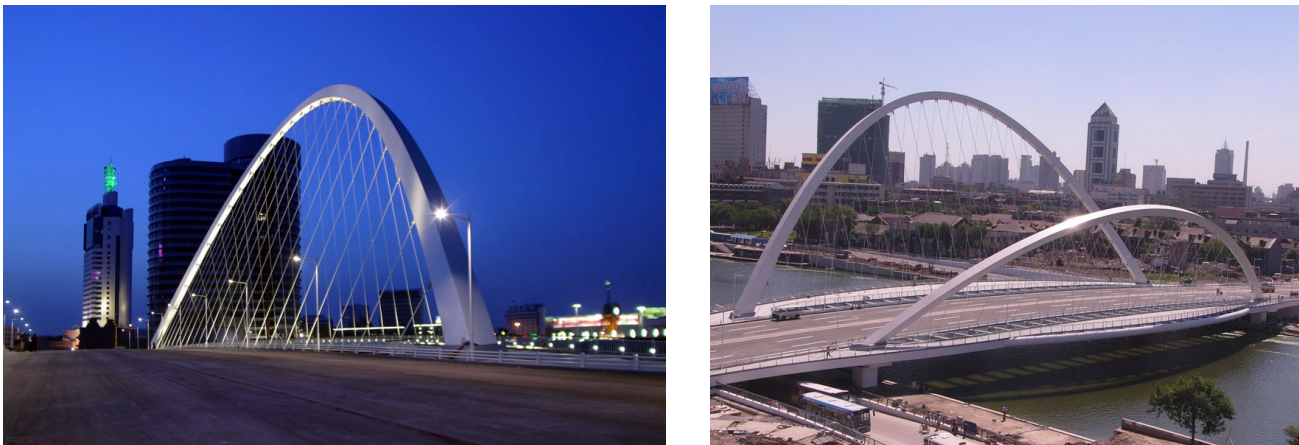


Figure 8: Completed Bridge

Lighting fixtures were installed after the bridge structure had been completed. The lighting was considered during the preliminary design stage so the locations of all light fixtures have been properly located during the design stage. Construction of the bridge started in the fall of 2003 and was complete by the end of 2004.

CONCLUSION

The design of the Dagou Bridge has been a unified process in which engineering, architecture, lighting and construction, including availability of materials and equipment, were all coordinated and considered simultaneously during the conceptual design stage. This is especially important in the design of a signature structure in a place like China, where cost efficiency is always a major consideration in a project.

CREDITS

Owner:

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