

Dragon bridge - the world largest dragon-shaped (ARCH) steel bridge as element of smart city

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Abstract. Dragon Bridge - The world's largest dragon-shaped steel bridge, with an installation cost of \$85 million USD, features 6 lanes for two separate directions, 666 meters of undulating steel in the shape of a dragon in the Ly Dynasty, the symbol of prosperity in Vietnamese culture. This unique and beautifully lit bridge, which also breathes fire and sprays water. It's the purposeful integration of the lighting hardware articulates the dragon's form, and the fire-breathing dragon head. This project transcends the notion of monumental bridge with dynamic colour-changing lighting, creating an iconic sculpture in the skyline that is both reverent and whimsical. The signature feature of the bridge was the massive undulating support structure resembling a dragon flying over the river. The dragon is prominent in Vietnamese culture as a symbol of power and nobility. Dragon Bridge stands out as a model of innovation. It has received worldwide attention in the design community and from the global media for its unique arch support system. Dragon Bridge serves as an example of how aesthetic quality of a design can serve cultural, economic and functional purposes. The article presents design solutions of the object and the evaluation of the technical condition before putting the facility into service.

1 Introduction

To realise its full economic and tourism potential, Da Nang (the port city in south central Vietnam) needed a new bridge across the Han River to its developing eastern sectors, famed beach resorts and the route to the historic town of Hoi An. Charged with initiating a bridge plan, Da Nang sought a unique structure that would become an attraction unto itself. Da Nang is a transportation hub and important commercial and educational centre and Da Nang wanted a bridge that would complement and enhance its surroundings (Figure 1).



Figure 1. Picture of Dragon Bridge on the panorama of Da Nang city.

In 2005, Da Nang sponsored an international competition to find a bridge design fitting for Da Nang's imagination. Six entrants presented their concepts to the committee in a public meeting (Japan Bridge & Structure Institute, Inc., Nippon Engineering Consultants Co., Ltd, The Louis Berger Group (LBG) Inc., Egis Bceom International, Kraus & Nguyen

Architekten Ingenieure). And the team of Louis Berger and Ammann & Whitney won the competition with a design that caught the Da Nang's imagination (Figure 2). It also provided safe and seamless road access to the city centre on the west end with a low deck that did not block scenic views of the river and city. The signature feature of the bridge was the massive undulating support structure resembling a dragon flying over the river. The dragon is prominent in Vietnamese culture as a symbol of power and nobility.



Figure 2. Final design of Dragon Bridge by Louis Berger and Ammann & Whitney.

For this project Louis Berger and Ammann & Whitney, a Louis Berger company, won a Diamond Award for engineering excellence in the category of structural systems from the American Council of Engineering Companies (ACEC) of New York for the Dragon Bridge in Da Nang, Vietnam. The Diamond Award is the highest honour given for projects outside the state of New York.

Although the dragon shape was a factor in winning the design competition, other matters of a more practical

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nature also were important. One key consideration was that two prominent structures- the city's television and cultural museum- are located quite close to the bridge's western end. To avoid obstructing views of these edifices, the design team the navigation channel eastward so that the western end of the bridge would touch down at ground level at the water's edge. In this way the bridge designers achieved the minimum required vertical clearance over the navigation channel without having to construct a large embankment or a high-level approach structure on the bridge's western end.

Opened in March 2013, the 666-meter-long, multi-arch structure features [1]:

- Six 3.75-meter-wide vehicle lanes.
- Two 2.5-meter-wide sidewalks.
- 2,500 LED lights that illuminate the structure at night.
- The capability to "breathe" fire or water to mark special occasions (Figure 3,4)



Figure 3. Breathing fire of Dragon Bridge.



Figure 4. Breathing water of Dragon Bridge.

Dragon Bridge lights up the more than 900 LED luminaires. Great, golden dragon looks quite impressive, especially at night (Figure 5). Every year come to see it approx. 3 million tourists from all over the world. Additionally, it has improved the economic situation of the whole region, because tourism translates into increased revenue.

The intelligent LED lighting solution painted the iconic dragon with a myriad of colours that can

change in 5 different colours, customizable for any occasion, festival or holiday. The eye-catching design of this lighting solution clearly positions the Dragon Bridge as a gateway for Vietnam and the rest of the world to the city of Da Nang. Lighting solution brought to life the design of the dragon that seems to leap out of the Han River through a stunning display of colours, with lighting that is both environmentally sustainable and energy efficient [2].



Figure 5. Dragon Bridge at night.

2 The solutions

The main bridge is an arch structure consisting of the 5 major spans, the pylon from P0 to P5 $(64 + 128 + 200 + 128 + 72)m = 592m$ (Figure 6) [1]. Concrete extreme spans (64 m) on both sides have varying heights of 1,775m - 3.5 m. Centre span (200 m) is a steel structure with a fixed height of 3.5m. While the indirectly span of length 128 m (2 and 4) is a steel structure with a constant height of 3.5m. In places above supports and pylons there is prestressing concrete structure with a fixed height of 3.5m. On both sides there are flyovers leading to the main bridge. They are consisting of prestressed concrete beams with a length of 24m and 26 m [1].

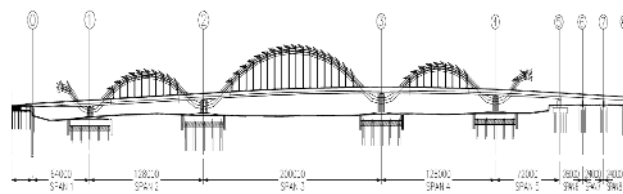


Figure 6. General plan of Dragon Bridge [1].

2.1 Main girders

Steel spans (Figure 7) of three consecutive spans between pylons 1 and 4 have a width of 14m and are supported on the concrete pylons and on a special lower arches which form in this way a framework support for the upper element. The main building spans are suspended by hangers to the main upper steel arcs. To enlarge the width of the roadway designed steel support (so-called. wings) on both sides of the main beams of steel with a width of 10.5 m. However, in the reinforced concrete beams further expanded width of 0.5m - 1.25m on both sides to create the changing width of the bridge along the sidewalks, which is an interesting element of design and aesthetic of bridge. Concrete spans (Figure 8) are supported on pylons by bearing neoprene (rubber-steel) which are also provide support for the upper arches and steel girders. Designed additional transverse prestressing strands of the bridge deck with the "wings" which increases the stiffness of the bridge

and also increases the capacity of the bridge particularly in terms of negative moments bending bridge deck.

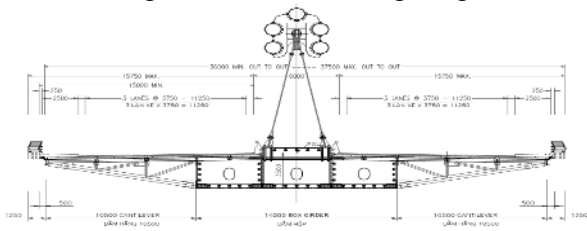


Figure 7. Cross section of steel girder.

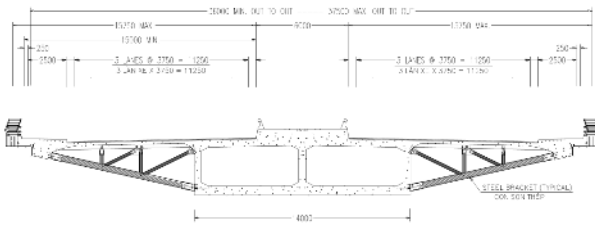


Figure 8. Cross section of concrete girder.

2.2 The bridge deck

The bridge deck is a hybrid structure, consisting of posttensioned concrete sections above the piers and steel box girders section in the suspended portions of the spans (Figure 9 and Figure 10). The two types of sections will be posttensioned together to form a continuous structure. The superstructure is 36m wide, accommodating ample shoulders and sidewalks in addition to three lanes of highway traffic in each direction. The arches have only one rib, but for aesthetic reasons that rib is made up of five steel tubes. Steel plates and connect the tubes, which measure 1.2m in diameter. The arch rib penetrates the bridge's superstructure in the centre of the roadway in the space provided by a 6 m wide median.



Figure 9. Prepare steel girder to transport.



Figure 10. Cable anchor at steel girder.

2.2.1 Joints between concrete and steel elements of span

In normal structures between the spans there is dilatation, but the Dragon Bridge has a rigid connection. It creates continuous and rigid manner hybrid span consisting of concrete and steel parts alternately. To create the connection to the cross-section designed 64 strand tendons between the structural elements (Figure 11 and Figure 12).



Figure 11. Cable tension in joints between sections.



Figure 12. Prestress cable between steel and concrete section.

2.3 Steel arches

The main arches are the steel structures of the five pipes with a diameter of 1200mm and a thickness of 19mm each. To the centre of the arch pulled a concrete to increase the stiffness of it. Steel pipes are fixed to each other by means of a specially designed steel fastener for every 8 m. In the areas of contact between the steel pipe and the connecting element is a layer of neoprene rubber to cushion the influence of spans transferred to arches by steel hangers (Figure 13). They are an added plus, i.e. reduce the bending moment in arches, which has been tested in the calculation. Each steel hanger consists of three steel bar having a diameter of 65mm type Hi-Am with a high capacity to fatigue. On both sides of the hanger there are special heads for attachment to the arches and to spans with a diameter of 350 mm. On the one side they are hung between tube connectors and on the other side are attached to spans by screws.



Figure 13. Steel hangers.

To provide high load capacity of arches, they were made by methods:

- CNC plasma cutting/Flame cutting (Figure 14)
- High frequency bending and welding.



Figure 14. CNC plasma cutting/Flame cutting - High frequency bending and welding.

To ensure the best protection for hangers against external influences and corrosion chosen the following solutions:

- Galvanizing and further applying a protective coating on the steel cables
- Hangers are made with external additional coating PE

The ratio of arch height to the length of the normal arch bridges are the values $1/4 \div 1/6$. For Dragon Bridge this ratio is $25/200 = 1/8$ through the use of a continuous bonding between the elements of the girders, which creates a continuous span. In addition, three steel arches are the main load-bearing element of the bridge with the framework support so be able to use the arch of small height (Figure 15). The ratio of height to length of the girder in the bridge is $1/57$ which much closer to the upper limit specified in the standard (normal, this ratio is between $1/30$ and $1/60$). Due to the above mentioned solution was able to firstly reduce the height of the bridge arches to fit in the designated areas on both sides of the river, but still could maintain adequate

clearance for maritime traffic under the bridge. Simultaneously raise the aesthetic value of the bridge.



Figure 15. Construction of steel arch [foto by Ehrin Macksey/Noi Pictures].

Concrete elements of girders were poured on site, later installed steel element after reaching the proper stiffness of concrete.

2.4 Pylons of bridge

The concrete pylons are connected with the lower arches (ie. the belly of the bridge) and are poured on site. Pylons 1, 2, 3 and 4 have a width of 7.5m which allows the structure to move lateral forces and large bending moments. To reduce the dead weight of the bridge part of the pylon are empty and have a partition in the middle, but the upper part of the pylon connecting with the lower arches concrete structure is compact.

The upper part of the bridge is relatively low, because a large height of girders enforces low height of pylons. Pylon of main bridge consists of an upper part and a lower portion at the base of the pylon, which is an element connecting pylon with piles drilled with a large diameter and a depth of 45m. Upper proper grade of pylon's base is lower than the lowest recorded water level of 1m. Loads from the top of the bridge are transmitted through the pylons to the foundation by means of neoprene bearings and by a rigid connection between the upper steel and lower concrete arches, which are able to bear not only the imposed loads and also loads due to external factors (such as wind, temperature, shrinkage of concrete and a seismic event).

To lessen the influence of the collision of vessels plying the river to the lower parts of the bridge, designed to separate the steel columns filled with sand and gravel in front of the pylons on both sides of the opposite directions of traffic. They also represent the prevent erosion elements of the bottom of the river bed at the base of the foundation of the bridge.

3 Assessment of structure state

Before putting the facility into service on March 29th, 2013. Da Nang Transport Department commissioned to independent design office to evaluate the technical condition of the object. Was found a lot of scratches with a width of 0.1 to 0.2mm mostly in places of contact technology at the base of arches and the main girders [3-5]. Perpendicular cracks are also present on the walls of the front of eastern abutment of the bridge (Figure 16). During the study engineers found that cracks are "normal" and accepted ranges of code, mainly there are cracks caused by concrete shrinkage [6,7]. But advocated monitor and regularly check the development of cracks in places prone, especially in connecting elements between the steel girder

and concrete, in the middle of the spans, in concrete arch to be possible to prevent unexpected symptom [7,8].

In addition to the above, the independent engineers claimed that:

- During the tests the bridge operates in the elastic, there is no abnormal deviations.
- The values of stress and stiffness of the object are accepted in intervals of code.
- Displacement peak of arch and its amplitude of the own vibrations are consistent with theoretical calculations.
- The bridge is able to bear the load utility provided in the standards.



Figure 16. Cracks appeared in the abutment after construction.

The final verdict is that the cracks caused by concrete shrinkage and temperature fluctuations during construction. During the study there were no changes in the created scratches and they do not influence the normal operation of the facility.



Figure 17. Injection epoxy glue to fill the cracks.

The object is still within the warranty period and the contractor of the bridge is intended to eliminate of scratches, monitor and supervise of development of the resulting cracks and the emergence of a new scratches. Simultaneously prevent the influence of refrigerants external on quality components and concrete construction of bridge. Adopted the following treatments:

- injecting epoxy adhesive Sikadur 572 high strength and low viscosity to visible scratches. Application

of epoxy mortar Sikadur 731 in places of small cracks (Figure 17)

- cracks occurring in concrete technology breaks at the base of arch and the abutment in the main spans will also be secured in a similar manner by means of epoxy adhesive Sikadur 572 and outer finishing mortar Sikadur 731.
- the contractor must forge outer layer of concrete and pour additional concrete layer with a capacity of 30MPa outside, near the joints to create a sloping prevent collecting water at the base of the abutment.
- in places of soaking water, workers must forge outer layer of concrete soaked with rainwater and apply a layer of special protective of Lemax 7WP (1 liter / 5m²).

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