

The Construction and Components Analysis of The Aizhai Bridge

Feiyao Cai^{1, †}, Tianwei Lu^{2, †}, Shihui Xie^{3, †}, Wuxian Zhu^{4, *, †}

¹ New Oriental Nanjing, Nanjing, China

² Dulwich College, London, UK

³ Civil Engineering, Taiyuan University of Technology, Taiyuan, China

⁴ Civil Engineering, Central South University, Changsha, China

*Corresponding author Email: 8406180124@csu.edu.cn

† These authors contributed equally

Abstract. The Aizhai bridge was constructed in a mountainous area and across a large canyon, a bridge that bears immense importance to the development of the nearby areas, according to the China Hunan Roads Development III Project. This study analyzes the structure, construction, materials, and components of the Aizhai Bridge, and discusses their advantages and drawbacks. Some novel construction techniques for the suspension bridge include aerial spinning and steel truss gliding method. Results show that the structural design is unique to the project, adapting to specific conditions such as complex geology, extreme weather, and large interval by implementing the design of tower-girder separation for the bridge alongside the design of the suspender cables and the materials implemented in the bridge, comparisons of carbon emissions due to materials are made with other bridges demonstrate the high effectiveness of the bridge design. Although the essence of the structure follows that of a traditional suspension bridge, the new design of the tower-girder separation structure has made the bridge much more environmentally friendly and safe.

Keywords: Aizhai Bridge; Suspension bridge; Construction, Design; Modeling.

1. Introduction

The suspension bridge is the most antique type of bridge in the history of humanity, defined by a bridge structure that uses the main cable to bear the load. In the 7th century in Yaxchilan, Central America, the Mayan people built a simple suspension bridge. Then one of their first evolved structures is the Menai suspension bridge which uses chains for the main cables and was built in 1826. The modern technique of using parallel wires for the main cable was implemented in 1930. In the mid-20th century, the aerial-spinning technique was developed, allowing an alternative method to using prefabricated main cables, hence beginning the modern popularisation of suspension bridges.

The suspension bridge is an excellent choice for large interval bridges, due to the requirement of fewer materials and less cross-sectional area of supporting structures with an increment of the span compared to other types of bridge structures. The suspension bridge also allows for easier construction, where the catwalk can be set up after the mounting of the main cable, allowing easier access for the construction workers, furthermore, the maintenance of the bridge structure is inexpensive compared to other bridge structures.

The Aizhai bridge was constructed in a mountainous area and across a large canyon, a bridge that bears immense importance to the development of the nearby areas, according to the China Hunan Roads Development III Project. The structural design is unique, adapting to specific conditions such as complex geology, extreme weather, and large interval by implementing the design of tower-girder separation for the bridge alongside the design of the suspender cables and the materials implemented in the bridge. This study analyzes the structure, construction, materials, and components of the Aizhai Bridge, and discusses their advantages and drawbacks.

2. Basic background of aizhai bridge

The Aizhai suspension bridge was constructed in Aizhai town, Jishou city, Xiangxi area, Hunan Province about 20 kilometers away from Jishou city, one of the eight national key planned expressways for targeted poverty alleviation projects. It has a double-decking structure, a four-lane highway, and a sightseeing tunnel below. The bridge model is steel truss stiffened beam single span suspension bridge, with a main span of 1176 m and a rise/span ratio of 1/9.6. In addition, the pylon at the Jishou bank has a height of 129 m and the pylon at the Chadong bank has a height of 62 m.

3. Structure and construction

3.1 Structure

Aizhai Bridge is a double-pylon steel truss stiffened beam single-span suspension bridge, which adopts tower beams separated structure layout, the steel truss beam is supported on both sides of the rock mass, the bridge is directly connected with the tunnel, and Chadong bank tower footing is found above the tunnel. The main beam abutment is provided with vertical support, horizontal elastic support and transverse wind bearing.

3.2 Construction

3.2.1. Difficulties During The Construction Of The Aizhai Bridge

There are five main difficulties during the construction of the Aizhai Bridge.

First is the dangerous terrain. The height from the bridge deck to the canyon floor is 355 meters, and the height of cable towers on both sides of the cliff edge is only 70 to 100 meters.

The second is complex geology. There are bad geological phenomena such as rock piles, karst, fissure, and dangerous rock mass at the bridge site

The third is the changeable weather, foggy canyon, and extreme instantaneous maximum wind speed seriously affecting the construction survey and main cable erection.

Fourth, it is difficult to lift. The main cable and steel truss beam are 355 to 400 meters above the bottom of the valley.

Finally, transport is difficult, civil engineering transport volume, only steel, cement, sand and other materials and construction.

3.2.2. Solutions

3.2.2.1. Solutions for Dangerous Terrain

To overcome these difficulties, the construction team takes a series of solutions. First of all, on the basis of the local terrain conditions, new suspension bridge structures, the tower and beam bridge construction are proposed in the mountain areas, providing a safe and reliable bridge layout scheme. It not only combines structure with nature, but displays a beautiful atmosphere with highly ornamental value. Secondly, as for the problems of deeply buried depth and poor durability of the traditional rock anchor, a high-performance rock anchor system of new materials is developed to solve the big tonnage carbon fibre anchor reinforcement problems at a stroke. Meanwhile, given the complex mountain, and difficulties in mountain suspension bridge girder erection, the construction team develops the related technologies for real-time monitoring of the mountain according to the local actual situation and proposes the new suspension bridge girder erection as the first innovation process. The new equipment, rail cable slip method, provides a Chinese solution for the erection of the main girder of suspension Bridges worldwide.

3.2.2.2. Solutions for Complex Geology

As for corrosion cracks under the base of the Jishou shore cable tower, they need to be filled and grouted. The scale of the cave needs to be further exposed after foundation excavation.

As for dissolution fissures with joint structural development in Chadong shore cable tower and some of which extend to the highway tunnel below, they could affect the highway tunnel. The cliff

slope in front of the main tower of Jishou Bank has karst caves and water holes, and the cutting depth is large, part of the rock has been in an unstable state, easy to collapse. Filling of the fissures is necessary, and the supporting structure of the highway tunnel should be strengthened.

In addition, Chadong shore cable tower and loose cable saddle are affected by a strong dissolution zone, and after excavation by blasting, rocks easily fall out, which should be removed or partially protected. At the Chadong shore bridge and tunnel connection, the excavation depth of the tunnel entrance is 46m, and the height of the upward slope is 62m. Due to unloading and dissolution, the unloading zone and the range of 15-20m at the bridge and tunnel connection are developed zones of dissolution cracks.

As for water holes and upper sinkholes, they also need to be backfilled by grouting. There is a highway tunnel under the foundation, and the cable tower loading has a certain influence on the highway tunnel, so the support of the tunnel roof should be strengthened.

3.2.3. Construction Processes

The main construction processes of Aizhai Bridge include the following steps.

Construction of the anchorage (excavation of foundation pit. Positioning bracket, Prestressed pipe installation, and the Concrete is poured in layers. On Chadong bank and Jishou bank build distinct kinds of anchorages, Figures 1, 2);



Figure 1. Construction of concrete anchorages

Figure 2. Construction of concrete anchorages

The main tower construction (Expand foundation concrete construction. Digging caves, cleaning, backfilling. Tower pouring construction. Pillar construction. Template installation. Concrete placement and maintenance. Horizontal braces. Beam casting. Main cable saddle and Bulk cable saddle installation. Anchoring system installation, Figures 3, 4);

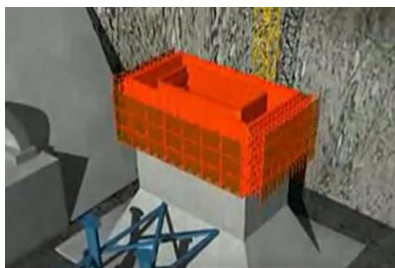


Figure 3. Foundation of the tower



Figure 4. Erection of the bridge tower

Cable system installation (Pilot cable installation. Erection of traction rope. The cat way's installation. Cable racks, slings and central clasp stay cables' installation and construction, Figure 5);



Figure 5. Installation of the main cable

Erection of steel truss beam (Rail cable moving beam erection, Figure 6);

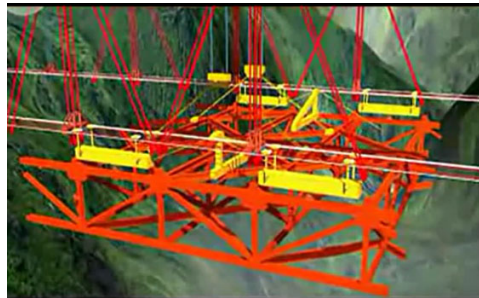


Figure 6. Transportation of a steel truss beam section

Deck installation (Figure 7);

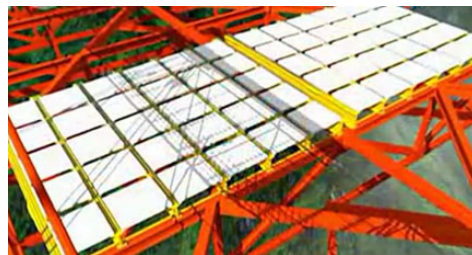


Figure 7. A decking section

Main cable protection and coating (Figure 8).

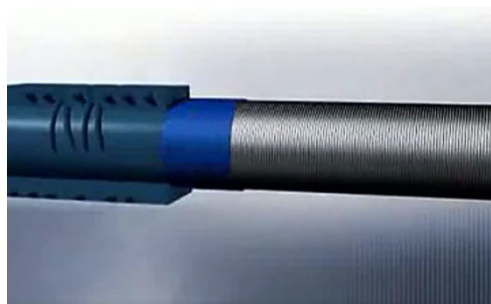


Figure 8. Coating of the main cable

4. Compositions and Materials

Aizhai Bridge consists of the main bridge, two towers, cables, anchorages, booms and junction tunnels. It is a single-span suspension bridge with double towers and steel trusses, using a tower and beam separation structure layout, with the ends of the steel trusses supported on both banks of the rock, and the bridge is directly connected to the tunnel, with the tower base of the Cha-dong bank located above the tunnel. The main bridge section is arranged in a northwest to southeast direction.

4.1 Main beam

The main beam is made of permeable joist structure and the steel joist stiffener consists of a main joist, an upper and lower flat joist, and transverse joist. The upper and lower flat joist adopt the K-

shape system, the upper and lower chords of the main joist, the upper and lower chords of the crossbeam adopt the box section, web and upper and lower flat joist adopt the I-beam section. The orthogonal anisotropic steel bridge deck adopts the combination form of longitudinal I-beam and orthogonal anisotropic bridge deck plate. The concrete bridge panel adopts the combination form of longitudinal I-beam and concrete bridge panel. The longer steel beam is simply supported on the upper chord of the main truss beam, and the bridge panel adopts the precast concrete plate. The bridge panel is combined with the longer beam through the shear nail on the longer beam at the joint.

4.1.2. Pylon (Bridge Tower)

The pylon adopts the main structural form of a portal frame hurried concrete hollow room, which consists of a separated expanded foundation, tower base, tower column, upper crossbeam and middle crossbeam. Cha-dong bank adopts a reinforced concrete structure, the tower column cross-bridge is vertical from top to bottom, the tower column is equipped with an upper cross-beam, and the tower column bottom is equipped with a towering seat and located on the separated expanded foundation; Jishou bank cable tower adopts steel and mixed soil combination structure, the tower column cross-bridge is inclined from top to bottom, the tower column is equipped with upper and middle cross-beam, the tower column bottom is equipped with tower seat. The towering column adopts a prestressed concrete crossbeam, the steel strands are arranged in a straight line, and the cross ground is arched; the expanded foundation is a C30 hurry concrete structure, the tower base and tower column are C55 reinforced concrete structures, and the upper and middle crossbeams are C55 prestressed concrete structure.

4.1.3. Main Cable

The main cable adopts a parallel steel wire strand, single strand consists of galvanized parallel steel wire, the cross-section of the strand is positive six deformations, tied with tying tape, with a hot cast anchor head at both ends. The rope is made of special span type steel wire rope (8X36SW+IWR, nominal tensile strength 1870MPa).

4.1.4. Cable Saddle

The main rope saddle adopts the structure of a cast-welded combination, and the loose rope saddle body adopts the structure scheme of a cast-welded combination. The saddle groove is cast in cast steel. For the main cable maintenance personnel to pass, the main cable maintenance channel (catwalk) is set up on the top surface of the main cable; the loose cable saddle is of swing shaft type, and the saddle body adopts the structure of cast-welded combination. The sling is made of straddling steel wire rope, the anchor head at both ends of the sling is made of fork-shaped hot-casting anchor, the sling clamp is made of cast steel, the left and right pairs are combined, and the two halves of the clamp are connected and clamped with screws, and the joints are filled with rubber waterproof strips.

4.1.5. Anchor

In response to the problem of a tower and girder suspension bridge without a sling area, three pairs of ground slings were added to the bridge, and the durability of the ground rod is crucial to the safety and normal operation of the opposite project. The traditional ground fault system generally faces structural durability problems due to steel corrosion and concrete aging. The traditional ground fault system generally faces structural durability problems due to steel corrosion and concrete aging, affecting the overall structure's safety and durability.

To improve the durability of the ground system, a high-performance ground fault system consisting of advanced composite material CFRP (carbon fibre reinforced plastic) rod and ultra-high-performance concrete RPC (reactive powder concrete) bonded solid system was developed. After the systematic study of the carbon fibre ground system, it was applied to the sling C00 of the bridge. The new system on the ground solid section uses bonded with (RPC as bonding medium) solid CFCC (carbon fibre stranded wire) rod; underground solid section infusion RPC material to CFRP rod solid in the rock and tensioning the cable to the design load; free section infusion of ordinary cement mortar seal.

The rod of the new system is made of CFCC material, with a tensile strength of 2620 MPa, and a modulus of elasticity is 180 GPa; after the slurry ratio test and theoretical analysis, the 7d standard curing strength of RPC material is greater than 120 MPa.

5. Novel designs and materials

5.1 Tower-Girder Separated Design

5.1.1. Problems With The Conventional Design

According to the construction conditions, two schemes have been proposed Initially, the one is a low alignment site, and the other is a high alignment site. Affected by the landform, the low alignment site has a huge amount of excavation on both sides' mountains. The excavation of the Jishou bank including dangerous rock masses is about $4 \times 10^5 \text{ m}^3$, and the excavation of the Chadong bank is about $8 \times 10^5 \text{ m}^3$, which has serious damage to the mountains and the environment, and more engineering materials are used.

In order to reduce the excavation of the mountains, a high alignment site is proposed: on the Jishou Bank, the Aizhai No. 3 tunnel is not used, and the bridge is connected to the bank through an approach bridge. The tower height, span, and length of the bridge also have been greatly increased. The tower height is adjusted from 94.4m to 159.8m, the span is adjusted from 145m to 200m, and the bridge length is also increased by 110m. and at the Chadong Bank, the clear distance between the bottom of the anchorage and the top of the tunnel has been reduced from 23m to 17m. These not only increase the project cost but also reduce the safety of the structure.

To sum up, regular suspension bridges have three disadvantages, mass destruction of the environment due to excavation, expensive construction cost, and the structural design is not elegant and unstable. Although the conventional suspension bridge layout scheme is possible, it is difficult to meet the two conditions of protecting the environment and saving the project cost at the same time.

5.1.2. Tower-Girder Separated Design

A simple force analysis is carried out on the bridge tower, which is simplified as a plane problem. The top of the tower is subjected to tension in two directions of the mid-span main cable and the side-span main cable. If the live load is considered, the live load acting on the main span causes the linear change of the side span main cable, thus causing the tower top displacement. The axial force on the bridge tower is composed of its weight and the vertical part of two tension forces. If the bending moment at the bottom of the tower caused by its weight is ignored, the bending moment at the bottom of the tower is the sum of the moment caused by the displacement of the tower top and the bending moment caused by the vertical tension of the main cable.

The previous studies show that the maximum longitudinal and lateral displacements of Model 1 are smaller than those of Model 2 under various loads. The lateral maximum displacement of model 1 is 34.9% smaller than that of model 2 under the most unfavorable load combination.

The comparative analysis of the two models shows that the internal force of the tower-girder separation suspension bridge is the same as that of the conventional suspension bridge. However, the longitudinal and lateral static stiffness of the tower-girder separated suspension bridge structure system is large, and the wind resistance performance is better.

5.1.3. Advantages of tower-girder separated design

The excavation of the mountain is reduced by $6.7 \times 10^5 \text{ m}^3$ m. The length is shortened by 175.5 m, and the height of the bridge tower in Chadong is reduced by 74m. These three indicators save about 130 million RMB in construction costs. The vertical, horizontal, and longitudinal overall stiffness are larger than those of conventional suspension bridges. The longitudinal displacement of the end of the stiffening beam is greatly reduced, which can greatly reduce the scale of the expansion joint.

The tower-girder separated suspension bridge has three major advantages, the construction process is more environmentally friendly, the project cost is reduced significantly and the stiffening beam provides high stiffness and better wind resistance.

5.2 Steel Reinforced Concrete

The reinforced concrete structure has many advantages. Firstly, it is easier to acquire and implement concrete. Concrete sand, gravel is generally easy to use local materials. In addition, can also effectively use slag, fly ash and other industrial waste. Secondly, it is much more economical to use reinforced concrete when compared to a traditional steel structure. Furthermore, concrete has high strength under compression, ranging from 30 MPa to 80 MPa, which is comparable to that of steel which is around 250 MPa, also by wrapping steel using concrete, rusting can be mitigated. Additionally, concrete provides an insulating layer for the steel sections, steel bars cannot reach the softening temperature as quickly leading to the overall destruction of the structure compared to traditional steel structures. Compared with exposed wood structures and steel structures, fire/heat resistance is better in reinforced concrete structures. According to the need, concrete can be easily poured into a variety of shapes and sizes of the reinforced concrete structure. Finally, reinforced concrete structures have better integrity, and are conducive to earthquake resistance, vibration, and explosion shock wave resistance.

5.3 Main Cable And Suspender Cable Designs

5.3.1. Main Cable Design

The main cables are the main load-carrying components of the bridge structure, these cables are assumed to only carry tension (tension members), which do not resist bending or compression. In other words, they do not take these deformations, steel truss girders provide the resistance to bending and compression. Because of the load of its weight, the main cable can provide great rigidity against Y-axial forces such as the weight of cars in traffic.

5.3.2. Suspender Cable Design

The suspender cables are tension members, which transfer the weight of bridge decking to the main cable. They are normally designed in two ways, slanted or perpendicular to the decking (Figure 9). Both designs have their advantages. The slanted cable design allows for greater rigidity of the bridge structure by providing more damping to vibrations due to, for example, wind forces, because the wires provide support on the Y plane and the x plane. However, during vibration in the x plane, we can observe that some of the suspender cables can go slack (assuming that the two ends of the main cable are fixed), with a constant loading and unloading of the wire ropes, this will cause the suspender cables to unwind and thus become a safety hazard. So, the perpendicular design is implemented, and its drawback of less damping is complemented using steel truss girders.

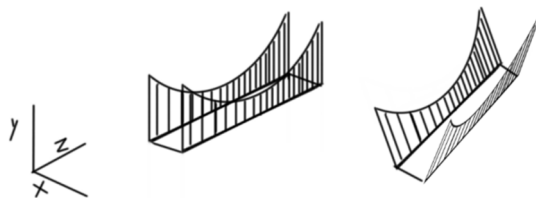


Figure 9. Perpendicular vs. slanted design

5.3.3. Global Warming Potentials Of Main Cables And Suspender Cables

Based on calculations, the total impact of the main and suspension cables is about 23600000 kg CO₂e. The steel truss is estimated to weigh 69x125000kg, $8625000 \cdot 1.157 = 9979125$ kg CO₂e, adding the two up, giving about 33600000 kg CO₂e emission for the steel part of the bridge. It is safe to assume that this is the largest component of the bridge's global warming factor. Dividing it by the

deck length, which is 1534, gives about 21900 kg CO₂e/m for the bridge, then dividing it by the width of 27m, gives 811 kg CO₂e/m².

Compared to the Okinawa footbridge, the Okinawa beam bridge has a width of 4.3m and a length of 37.8m, giving about 615 kgCO₂e/m², compared to 811 kgCO₂e/m² of the Aizhai Bridge's steel parts. Considering that the Aizhai Bridge requires more reinforcement and uses galvanised steel wire, and the beam bridge has a much simpler structure and is made mostly of reinforced concrete, the environmental impact of the Aizhai bridge is greater within a reasonable range.

Compared to the new Dyfi viaduct, the viaduct has a length of 1200 m and a width of 9.3 m, giving (with contingency), 1163 kgCO₂e/m², net, 830.6 kgCO₂e/m², compared to Aizhai suspension bridge 811 kgCO₂e/m². Even with an underestimation (excluding concrete), it is quite safe to assume that the Aizhai suspension bridge has quite an effective design according to environmental factors.

6. Conclusion

A range of novel construction techniques were used for the bridge to meet the challenges. The bridge is a well-designed structure, as many specific requirements were met, such as construction on dangerous terrain, complex geology, and transportation across the canyon.

The bridge uses not only traditional materials but also innovative materials to support the suspension bridge. Although the essence of the structure follows that of a traditional suspension bridge, the new design of tower-girder separation structure has made the bridge much more environmentally friendly and safe. Despite all the limitations, the bridge has proven to be quite environmentally friendly according to the carbon dioxide equivalent emission due to the steel sections used.

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