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Design Supports for Wide Span Simply Supported Arch Bridge

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Abstract

This paper proposes the design of a scheme for a long span simple-supported arch bridge and its bracket. The design scheme is based on engineering examples and an actual engineering situation. In order to understand the design of the bracket of the long span simple-supported arch bridge, the feasibility of this design applied to construction is determined. MIDAS-Civil inite element software is used to establish the calculation model of a 144 m simply supported arch bridge bracket. After checking the stress and de lection of the bracket, the bracket system meets the strength and stiffness requirements of the standard design. The design scheme of long-span simple-supported arch bridge and its bracket proposed in this paper can provide references for similar projects.

Keywords: Wide span • Simply supported arch bridge • Bracket • Finite element method

Introduction

With the rapid development of modern road and bridge engineering in China, the structure of large-span simply-supported arch bridges is increasing. Simple supported arch bridge is a compression-bent structure, which has the advantages of high compressive bearing capacity, good flexibility, good dynamic stability, simple construction and short construction period. The arch rib section of a long-span simply supported arch bridge is often a steel tube concrete composite system with a spatially variable cross sectional shape. The structure of the concrete arch bridge is also relatively bulky. These factors have caused the construction of the simply supported arch bridge support system to be more complicated and difficult. To ensure the normal service life of long-span simply-supported arch bridges, some bridge researchers have conducted a series of investigations on the design, construction and materials of arch bridges. This paper combined with the actual project engineering, proposed a design scheme of 144 m simply supported arch bridge and used MIDAS-Civil software for establishing a calculation model of simply supported arch bridge. The empirical calculations were correlated with the rationality of the 144 m simply supported arch bridge support system [1].

Materials and Methods

Overview of railway engineering

The Weifang-Laixi high-speed railway, referred to as the Weilai high speed railway, is connected to the Qing rong intercity railway and the Rong lai high speed railway in the east and the Ji qing high-speed railway in the west Qingdao city China. It is a type III slab type double line ballast less track with a design speed of 350 km/h. The central passage of the three horizontal rapid railway network is located in Shandong province. The start stop mileage of the trans-haiqing-Qingdao railway bridge is DK57+132.6～DK59+989.08 and the bridge length is 2856.48 m. The bridge crosses the Rongwei express way at DK58+128.49, the line intersects the highway obliquely, the intersection angle is 149.42° and the spanning form adopts a 1 m-144 m simply-filled steel tube concrete arch structure [2].

Overview of simply supported arch project

The simply-supported arch of the Haihai-Qinghai railway extra-large bridge, with a total length of 144m, is the largest span of the entire Wei-Lai railway and one of the control projects on the entire line. BIM modeling effect diagram of 144 m simply-supported arch across Rongwei expressway, as shown in Figure 1 below.

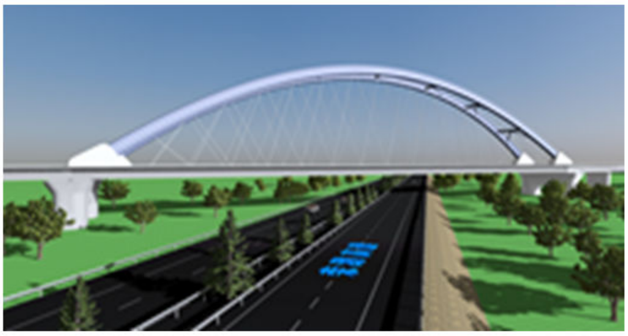

Figure 1. BIM effect of a 144 m simply-supported arch across Rongwei-Wei expressway.

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Simple supported arch and its support design

Design of simply supported arch: The upper and middle structures of the simply-supported arch bridge are simply supported arches and the lower foundations are all bored pile foundations and rectangular caps. The simply supported arch is constructed by the irst beam and later arch method. The calculated span is 144 m, the arch rib vector span ratio is 1:5, the arch rib projected vector height is 28.52 m, the arch rib is quadratic parabolic and the steel structure material is Q345qE steel.

The arch ribs are tilted inward at the bridge by 8 degrees in a basket style, using the Nielsen boom system. The center distance between the two arch ribs at the arch top is 8.884 m and the cross section of the arch ribs adopts a space-varying cross-section dumbbell-shaped concrete- illed steel tube concrete composite system with a cross-section height of 4 m, a steel tube diameter of 1.3 m and a wall thickness of 20 mm. Plates are connected and C55 is poured into the arch pipe to compensate the shrinkage of the concrete. One straight brace and six K braces are set between the arch ribs. The straight braces use a round steel pipe with an outer diameter of 1.5 m and the diagonal braces use a round steel pipe with an outer diameter of 0.9 m. The transverse bracing steel pipes are not illed with concrete [3].

The end of the tie beam is a solid rectangular section with a width of 19.3 m and a height of 3.0 m and a solid section at both ends with a length of 8.5 m. The common section is a single box three chamber section with a width of 18.5 m and a height of 3.0 m and a length of 131 m. The thickness of the box beam roof is 35 cm. The beam end is partially thickened to 85 cm; the bottom plate is 35 cm thick and the beam end is partially thickened to 85 cm; the transverse four webs are 35 cm thick and the beam end is locally thickened to 135 cm; the beam is set at the hanging point and the beam thickness is 40 cm-60 cm.

There are a total of 32 pairs of booms in the bridge, forming the Nielsen system. In the plane of the boom, the horizontal included angle of the boom is between 50.8° and 73.1° and the horizontal included angle of the transverse bridge is 82°. The distance between the booms is 8 m. The rods use 127 high strength, low-relaxation galvanized parallel steel wire bundles with a diameter of 0.7 cm. The cable body uses PES (FD) low stress anticorrosive cable body. Long-term monitoring of the stress of the boom during construction and later stages [4].

Design scheme of simply supported arch support: The 144 m simply supported arch bridge tie beam construction adopts a beam-column bracket construction scheme. The steel pipe columns differ in height. The maximum height of the bracket across the highway section is 8 m and the maximum height of the outer bracket on the highway is 12.5 m. The simply supported arch support foundation uses a strip foundation. According to design and construction requirements, a total of 14 rows of steel pipe columns are arranged in the entire bridge area, of which the No.1 and No.14 columns are located on the bases of No.327 and No.328. The 700 × 700 × 16 mm steel plate is embedded and the rest of the steel pipe column foundation is located on the strip foundation with replacement graded crushed stone +C30 reinforced concrete. The steel pipe columns are all φ 529 × 10 mm spiral welded pipes; the top of the steel pipe is welded and sealed with a 20 mm thick steel plate. The bottom is welded firmly with the embedded positioning steel plate. A sand cylinder is installed at the top of the steel pipe column to facilitate the removal of the bracket after the construction is completed.

The main beam is made of I56a double-steel, which is arranged close to the centerline of the column. A longitudinal beam is set above the beam. The bridge is located across the Rongwei expressway and 116 sets of beams are arranged vertically. On the outside of the expressway, a beret sheet is arranged along the bridge and the beret sheet across the expressway uses a special-shaped beret sheet to transition. In order to increase the lateral stiffness of the beret beam, the beret beam is uniformly stressed and it is set on the longitudinal beam. I12 I-beam distribution beams with a spacing of 0.6 m and a length of 20 m. A 10 × 10cm square wood is set on the distribution beam. Except for the bracket material, which uses 16Mn steel, the rest are all Q235 steel. Scissors and cross braces should be set between the horizontal columns and welded with L75 × 75 and other angle steel. The scissors supports are 3 meters high and the width is based on the distance between the columns. The vertical step between the two supports is 2 meters [5].

Checking load design of support

The load is the decisive factor in the design of the stent. The calculation of the stent system in this paper mainly considers the following loads:

- The vertical pressure and lateral pressure formed by the wet weight of the tie beam concrete are taken as 26 kN/m^3. The calculation of the bracket in this paper also consider the load of the arch rib steel pipe, the concrete in the arch rib and the arch rib bracket.
- The weight of the stent, the stent model is established according to the actual size, the corresponding material characteristics are defined and the software automatically calculates it.
- The formwork load is 2.5 kN/m^2 and the square wood load is 0.5 kN/m^2.
- The load of construction personnel and construction equipment is taken to be 1.5 kN/m^2 and the crane load is considered in this calculation.
- The load generated when vibrating the concrete is taken as 2.0 kN/m^2.
- The load generated when pouring concrete shall be 2.0 kN/m^2.
- When performing strength and internal force calculations, the basic combination is used. The partial factors of the dead weight of the support structure, the load of the tie beam concrete, the arch ribs, cast-in-place concrete, arch rib supports and formwork are taken as 1.2. The coefficient of the term is 1.4; the standard combination is used when the stiffness is checked and the sub-factors are all 1.0. When performing the stability analysis, according to the technical regulations for cast-in-place construction of the railway concrete beam support method, the partial coefficient of construction live load is 0.9 × 1.4.

Gravity calculation

Tie beam gravity calculation: The bridge girder of the bridge is a solid section at the arched ends of the two ends of the beam and the cross section of the remaining part of the beam is a single box three chamber section. A transverse partition is arranged every 8 m along the bridge longitudinal direction. At the centerline of the support, the beam height is 3 m. The beam height of the box girder section changes laterally. The height on both sides is 2.5 m and the middle height is 3 m. The model adopts the method of applying linear load on the distribution beam to apply the wet concrete load. The tie beams are divided into sections along the bridge direction and the concrete wet weight of each section is applied to the corresponding distribution beams and the spacing of the distribution beams along the bridge direction is 0.6 m. According to the design drawing, the net area of each section of the beam is extracted and calculated [6].

Calculation of self-weight of arch rib and its support: This bridge is a Nielsen tie-bar basket arch bridge. In addition to the weight of the tie beam, the influence of the weight of the arch rib steel pipe on the tie beam, the concrete in the arch rib and the weight of the arch rib bracket on the lower bracket must also be considered. The arch ribs are hoisted in sections and the lower part is provided with a bracket, which is supported on the tie beam. The weight of each arch rib is known and the total weight of the arch rib is calculated. The cross section of the arch rib is a dumbbell-shaped section. The length of the ribs is used to calculate the weight of the concrete poured into the arch ribs. The support is a steel tube lattice column support. Considering the length of each component in the support, the weight of the support is calculated based on the steel bulk weight of 7.85 t/m^3. The arch ribs, the concrete inside the arch ribs and the weight of the support are all transmitted to the beam through the support points at the lower part of the support.

Crane load calculation: The bridge needs to be hoisted during arch rib construction, so crane load should be considered. The bridge construction crane is an 80 T car crane with a weight of 68 T and four rows of 16 wheels.

Results

Check and calculation of bracket stress and de lection

Computational model: The inite element software MIDAS Civil is used to establish the calculation model of the bridge support. The steel pipe columns, beams, longitudinal beams and distribution beams are all simulated by beam elements. In the model, elastic and rigid connections are used to simulate the true connection relationship between the various components. The bottom of the steel pipe column is consolidated. The line load is applied to the distribution beam to simulate the dead load and live construction load. The calculation model of the simply supported arch bridge is divided into 12 spans and the 12 span supports are symmetrical about the bridge span centerline. Due to space limitations, this article only describes the irst span stress and de lection check calculation. The irst cross-stent model was divided into 8834 units and 7348 nodes. The inite element model of the irst span support is shown in Figure 2; the load distribution is shown in Figure 3 [7].

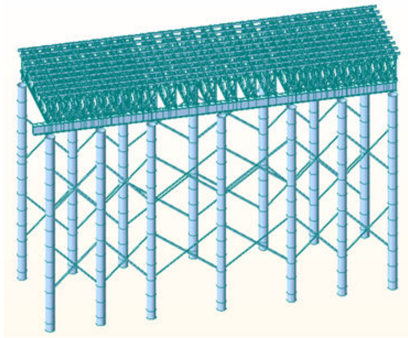

Figure 2. Finite element model of the first span support.

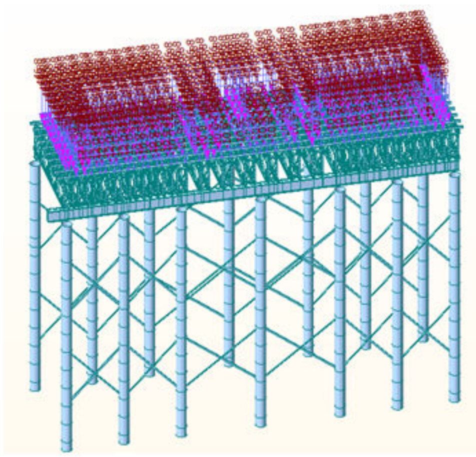

Figure 3. Schematic diagram of the first span support load.

Displacement analysis: Considering the wet weight of the concrete tie beam and the weight of the arch ribs, the concrete filled in the arch ribs and the arch rib brackets, these weights are collectively referred to as the weight of the tie beam. The maximum vertical displacement or deflection of each main component under the standard combined action (1.0 × trailer beam weight+1.0 × support and template structure weight) is shown in Table 1 below. The vertical displacement values, the deflection values of the transverse beam, longitudinal beam (beley beam) and distribution beam are all obtained by subtracting the corresponding fulcrum displacement value from the maximum displacement value in the figure.

Component	Compression or deflection（mm）	Torsion span ratio
Steel pipe column	-4.16	1/3005
Crossbeam	-1.45	1/2759
Stringer (Beley beam)	-2.24	1/2679
Distribution beam	-0.63	1/1810

Table 1. Summary table of vertical displacement check calculation of the first span support system.

With reference to the technical speci ications for construction of cast *in-situ* concrete of railway concrete beam bracket method, we can know the elastic de lection of the lexural members of the brace. Calculation of the span of the corresponding structure is 1/400 and the lex ratios of each component is less than 1/400 and meet the speci ications [8].

Stress analysis: Considering the wet weight of the concrete tie beam and the weight of the arch ribs, cast-in-place concrete and arch rib supports, under the basic combined action (1.2 × support structure constant load+1.4 × support structure construction load), the summary table of the combined bending stress and shear stress of the parts is shown in Tables 2 and 3 below.

Component	Maximum combined stress	Minimum combined stress	Design tolerance
Steel pipe column	49.57	-112.97	215
Crossbeam	124.64	-0.1	215
Stringer (Beley beam)	158.22	-165.88	310
Distribution beam	111.22	-120.5	215

Note: The combined stress refers to the stress generated by the axial force plus the stress generated by the bending moment

Table 2. Summary table of bending combined stress veri ication of the irst span support system (unit: MPa).

Component	Max	Minimum value	Design tolerance
Steel pipe column	2.87	-3.19	125
Crossbeam	68.78	-67.8	125
Stringer (Beley beam)	42.03	-39.98	180
Distribution beam	45.81	-46.16	125

Table 3. Summary table for checking and calculating shear stress of the first span support system.

Except for the materials of the main components and for the beret (bracket stringer), which is made of 16Mn steel, the rest are all Q235 steel. The design value of tensile, compression and bending strength of 16 Mn steel is 310 MPa (the thickness of the plate is less than 16 mm) and the design value of shear strength is 180 MPa. The design value of tensile, compression and bending strength of Q235 steel is 215 MPa (plate thickness is less than 16 mm) and the design value of shear strength is 125 MPa. The check results are as follows:

- The maximum bending combined stress of steel pipe columns is -112.97 MPa (compressive) and the maximum vertical shear stress is -3.19 MPa, which meets the strength requirements.
- The maximum bending combined stress of the beam is 124.64 MPa (tensile) and the maximum vertical shear stress is 68.78 MPa, which meets the strength requirements.
- The maximum bending combined stress of the longitudinal beam (Beley beam) is -165.88 MPa (compressive) and the maximum vertical shear stress is 42.03 MPa, which meets the strength requirements.
- The maximum bending combined stress of the distribution beam is -120.50 MPa (compressive) and the maximum vertical shear stress is -46.16 MPa, which meets the strength requirements.

Discussion

After checking the first span support system, the following conclusions were reached:

- For steel pipe columns, the maximum torsional span ratio is 1/3005, which is less than 1/400 of the specification; the maximum combined bending stress is -112.97 MPa (compressive), which is less than the design value of 235 MPa (tensile compression bending) of Q235 steel; the maximum shear stress is -3.19 MPa, which is less than the design value of the shear strength of 125 MPa.
- For beams, the maximum torsional span ratio is 1/2759, which is less than 1/400 as specified in the code; the maximum combined bending stress is 124.64 MPa (tensile), which is less than the design value of 235 MPa (tensile compressive bending) strength of Q235 steel; the maximum shear. The shear stress is 68.78 MPa, which is less than the design value of the shear strength of 125 MPa. The above calculations meet the requirements of the specification [9-11].
- For longitudinal beams (beret beams), the maximum torsional span ratio is 1/2679, which is less than 1/400 of the code; the maximum combined bending stress is -165.88 MPa (compressive), which is less than 16Mn steel (tensile compression). The design value of the strength is 310 MPa; the maximum shear stress is 42.03 MPa, which is less than the design value of the shear strength of 180 MPa. The above calculations meet the requirements of the specification [12].

- For distribution beams, the maximum torsional span ratio is 1/1810, which is less than 1/400 as specified in the code; the maximum bending combined stress is -120.50 MPa (compressive), which is less than the design value of 235 MPa (tensile compression bending) strength of Q235 steel; The maximum shear stress is -46.16 MPa, which is less than the design value of the shear strength of 125 MPa. The above calculations meet the requirements of the specification [13].

In summary, the first span support system meets the requirements of strength and stiffness. The stress and deflection of other spans meet the design requirements after verification [14,15].

Conclusion

Based on the actual engineering case, the engineering overview of a 144 m long span simply supported arch bridge, this paper comprehensively considers the factors such as the concrete filled steel tube composite system with a variable cross sectional shape of the arch rib section, the complex and difficult construction of the simply supported arch bridge bracket system and the bulky concrete arch bridge. The design scheme of long span simply supported arch bridge and its support is presented. Using MIDAS-Civil finite element software, the calculation model of the simply supported arch bridge bracket was established and through the stress and deflection check calculation of the bracket, it was determined that the deformation, stress and strain of each part of the bracket system meet the requirements of standard design strength and stiffness and further determined the rationality of the long-span simply-supported arch bridge support design provides a reference for similar engineering design.

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