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Design of long span steel pipe tied arch bridge with integral hoisting offshore

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Abstract. taking an 84m span offshore all steel tied arch bridge of a port as an example, this paper introduces the application of steel tied arch bridge in Wharf approach bridge. The bridge is welded as a whole in the factory and hoisted as a whole on site by large floating crane. In this paper, by comparing the static, dynamic, seismic and wind resistance of concrete-filled steel tube arch rib and all steel arch rib, it is concluded that the steel arch rib is more suitable for the bridge. Through the comparison between flexible suspender and steel suspender, it is proposed that steel suspender is used in this bridge. The optimized design of all steel tied arch bridge reduces the process of pouring arch rib concrete and tensioning steel suspender, which has great economic significance and application value.

Key words:steel pipe tied arch bridge；offshore； integral hoisting； design optimization； steel suspender

1. Introduction

In the wharf approach bridge, especially in the large tonnage deep-water wharf approach bridge project, the use of conventional small and medium-sized 20 ~ 30m span approach bridge will lead to excessive number of lower foundations and excessive investment. Proper use of long-span approach bridge can not only reduce the number of substructures and reduce the construction difficulty, but also reduce the impact of piers on ocean currents. The use of long-span integral steel bridges at sea has the advantages of factory prefabrication, convenient transportation and hoisting, and is widely used in the construction of sea crossing bridges [1,2]. Under the influence of water level and wharf elevation, the steel approach bridge of long-span wharf generally adopts through steel bridge. Compared with the steel truss [3] wharf approach bridge, the tied arch bridge has the advantages of less parts and nodes and simple facade, which reduces the workload of anti-corrosion maintenance of the bridge girder of the wharf operator.

The suspender of the conventional tied arch bridge adopts flexible sling. Generally, the construction sequence of arch before beam [4] or beam before arch [5] is adopted to meet the requirements of dead load and live load. The project is a wharf approach bridge, which is dominated by pipeline load. The tied arch bridge is hoisted above the pier as a whole. According to these two characteristics, the design of tied arch bridge is optimized to reduce the construction process and facilitate the later maintenance and use.

2. Project overview

The project is the approach bridge of a 300000 ton crude oil wharf project. The overburden in the proposed site area is made up of about 3 ~ 8m thick silt mixed sand and silty fine sand,and the lower layer is strongly weathered rock stratum. The foundation has high bearing capacity and good physical and mechanical indexes. It is suitable for gravity structure, and the water depth in the proposed area is 12~25m, which meets the water depth requirements of large floating crane. In the early stage, the long-span approach bridge scheme with Gravity Caisson Foundation and small-span beam slab bridge scheme with pile foundation are compared. Due to the water depth, thin overburden, high cost and difficult construction of pile foundation, the substructure adopts Gravity

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Caisson Foundation after comprehensive comparison. The foundation adopts caisson structure, and the approach bridge adopts long-span, which not only has advantages in construction and cost, but also has high value in landscape. The whole project includes two tied arch bridges with a span of 84m. The function of the bridge is to pass through pipelines and repair vehicles. The pipeline area is 6.2m, the lane area is 4.15m, and the structural width of the whole bridge is 13.15m, as shown in Figure 1.The tied arch bridge adopts all steel structure, which is welded and installed in the factory,

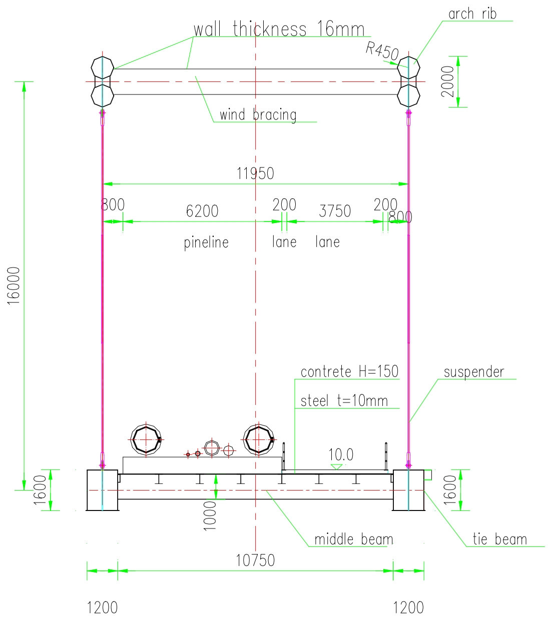

Figure 1. cross section of bridge midspan(mm)

Figure 2. site hoisting picture of steel arch bridge

and then hung on the caisson, as shown in Figure 2.

3. Original arch bridge design scheme

The total length of the arch bridge is 84m, the calculated span is 80m, the arch rib adopts parabolic arch, the rise span ratio is 1 / 5, and the arch rib is 16m high. The single arch rib adopts dumbbell section, which is made up of two single circle and the total height of rib is 2000mm. The circle's diameter is 900mm, with wall thickness of 16mm,See Figure 3. The spacing between the arch rib axes in the transverse direction of the bridge is 11.95m. Wind bracing is set between the arch ribs. The wind bracing adopts steel pipe with diameter of 1000mm and wall thickness of 16mm. C40 micro expansive concrete is poured into the arch ring to make the arch rib, arch seat and tie rod firmly connected. Before the arch rib is poured with concrete, the arch rib is in compression, so the overall stability and local stability of the arch rib must be guaranteed. Longitudinal and circumferential stiffeners are set in the steel pipe to ensure the local stability of the steel pipe.

The tie beam adopts box section, with section height of 1600mm and web thickness of 14mm; 1200mm wide, 16mm thick top and bottom plate. The stress of the arch seat is complex, and the concrete is poured after hoisting to enhance the integrity of the springing. The suspender adopts a flexible suspender composed of 55 ∅ 7 steel strand in diameter. The side beam adopts box section, with section height of 1840mm and web thickness of 14mm; 1200mm wide, 16mm thick top and bottom plate.The middle cross beam adopts box section, with section height of 1000mm and web thickness of 12mm; 600mm wide, 16mm thick top and bottom plate.

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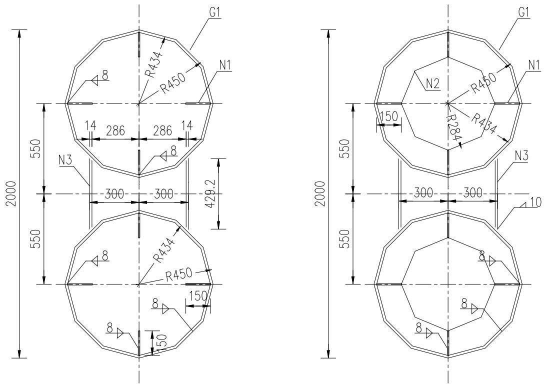

Figure 3. cross section of arch rib

Steel tubular bridge section filled with concrete combines the advantages of steel and concrete, and is widely used in bridges. Steel pipe can be used as the formwork of concrete, and form a composite beam section with concrete. It has large stiffness and good mechanical performance. In this project, the concrete shall be poured after the steel pipe is hoisted. The water depth of the sea area is more than 10m, so it is unrealistic to use temporary support; and using the bridge formed by hoisting to pour concrete into the arch rib has certain risk and complex process. Therefore, it is proposed whether the concrete-filled steel tube can be directly replaced by steel tube without pouring concrete and whether the suspender tension process can be cancel.

4. The scheme of replacing the original concrete-filled steel tube with steel tube

4.1 Stress analysis of dead load + live load

The approach bridge is a pipeline bridge, mainly with dead load. The load of pipeline is 4.71t/m. Lane load: 16t tire crane and 20t fire truck; The first-class Lane load of the highway is used for design. The basic combination: 1.2 dead load + 1.4 live load.

Midas Civil is used for three-dimensional finite element calculation. The basic combined internal forces of each component are shown in Table 1.

Table 1. basic combination results of arch rib under different working conditions

Work condition	Arch rib without concrete	Arch rib with concrete
arch rib	N=-7199KN M=2050KN.m	N=-9813KN M=3044KN.m
Tie beam	N=3260KN M=2601KN.m	N=4861KN M=2170KN.m
Middle beam	M=2023KN.m	M=2024KN.m
Side beam	M=3662KN.m	M=3615KN.m
Suspender	N=602KN	N=611KN

It can be concluded from table 1: 1) whether concrete is poured into the steel pipe has little impact on the stress of the beam and suspender; 2) After pouring concrete, the axial force and bending moment of arch rib become larger, the tension of tie beam becomes larger, and the bending moment decreases slightly. It shows that the increase of the stiffness of the arch rib reduces the bending moment of the tie beam.

Table 2. deflection of arch rib under load under different working conditions (m)

Work condition	Arch rib without concrete	Arch rib with concrete
dead load deflection	0.083	0.102
live load deflection	0.027	0.020

It can be concluded from table 2 that although the pouring concrete increases the stiffness of the arch rib, the dead load deflection increases and the live load deflection decreases.

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4.2 Wind resistance analysis

Wind load: considering the 100 year cycle, the maximum basic wind pressure is 0.6kpa.The wind load is applied to the arch rib according to the code for wind resistance design of highway bridges (JTG / T 3360-01-2018). The calculation results are shown in Table 3.

Table 3 horizontal deformation of arch rib under different wind load conditions (m)

working condition	Arch rib without concrete	Arch rib with concrete
Along the bridge	0.004	0.003
Transverse bridge direction	0.054	0.048

It can be concluded from table 3 that pouring concrete increases the stiffness of arch rib and reduces the displacement under the same wind load.

4.3 Seismic analysis

The area where the arch bridge is located is an 8-degree area, and the site where the approach bridge is located is a grade I site. Considering the earthquakes in two directions, the X direction along the bridge and the Y direction across the bridge.

Using Midas for response spectrum analysis, the stress of each component of steel structure caused by seismic force is small, but it produces a certain horizontal force on the support.

This bridge is a pipeline bridge, and the flow of pipeline fluid also has a certain horizontal force on the bridge, which is provided by the pipeline technology specialty.

Table 4. seismic reaction of bearing under different working conditions(KN)

working condition	Arch rib without concrete		Arch rib with concrete	
Reaction force	FX	FY	FX	FY
Pipe rack	736	332	736	332
X-direction earthquake	196	0	495	0
Y-direction earthquake	0	317	0	401
Summary	932	649	1201	833

Table 5. seismic horizontal displacement of arch rib under different working conditions (m)

working condition	Arch rib without concrete	Arch rib with concrete
X-direction earthquake	0.012	0.020
Y-direction earthquake	0.040	0.068

It can be concluded from tables 4 and 5 that pouring concrete increases the mass stiffness of arch rib and the horizontal reaction force and horizontal displacement produced by earthquake, which is not conducive to earthquake resistance.

4.4 Overall stability analysis

Midas is used to analyze the overall stability of the arch bridge. The modes and critical coefficients of the first three steps are as follows:

Table 6. overall stability analysis results (critical coefficient)

	modality	Arch rib without concrete	Arch rib with concrete
1	First order lateral instability (Figure 4)	16.22	10.36
2	Second order longitudinal antisymmetric torsion (Figure 5)	23.43	18.14
3	Second order lateral instability (Figure 6)	32.57	25.17

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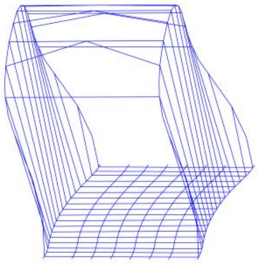

Figure 4. first order lateral instability mode

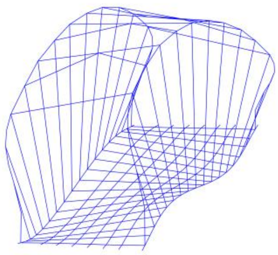

Figure 5. second order longitudinal antisymmetric torsional mode

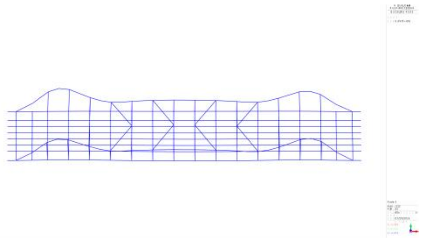

Figure6. second order lateral instability mode

It can be concluded from table 6 that whether the arch rib is poured with concrete or not meets the requirements of the overall stability of the arch rib.The working condition of pouring concrete is less than that of the arch rib without pouring concrete at each stage of stability calculation. The arch rib without pouring concrete is better for the overall stability of the arch rib.

5. Steel suspender is used to replace the original steel strand suspender

5.1 Characteristics of steel strand suspender and steel suspender

The strength of steel strand is up to 1860MPa, which is widely used in prestressed steel strand or suspender of bridge.The steel strand can be tensioned and applied in the suspender, which can regulate the deck elevation and facilitate the adjustment.

The maximum strength of steel suspender is 650mpa, which is widely used in buildings or small-span bridges.The steel suspender cannot be tensioned to adjust the stress on the bridge deck.

The details of steel strand suspender, tie beam and arch rib joints are complex, and the tensioning end is often set below the bridge deck, which requires professional maintenance. There have been accidents of fracture due to internal corrosion of steel strand at home and abroad [6]. Steel suspender joints are relatively simple and easy to maintain.

5.2 Application of steel suspender in the project

The project is a pipeline bridge, and the load is mainly dead load.The internal force of the suspender under dead load is 319kn and the live load is 165kn.The bridge deck displacement caused by live load is 2.73cm (as Figure 7). Without cable adjustment, the bridge deck can meet the requirements of 1 / 600 deflection in the specification.

The project is a wharf approach bridge which is in the marine environment. In order to make the steel bridge easier to maintain, the suspender adopts 70mm diameter steel tie rod, which is connected with the arch rib tie beam through the lifting lug, as shown in Figure 8.The lifting lug is exposed above the bridge deck, which is convenient for maintenance personnel to check, repair and replace.

6. conclusion

The design of offshore bridges should fully consider reducing construction procedures.This paper makes an all-round comparison between the two working conditions of the arch rib without pouring concrete and pouring concrete in the dead live load analysis, wind resistance analysis, seismic analysis and overall stability analysis. Except the wind resistance deformation, the arch rib without pouring concrete is better for the dead live load stress, earthquake resistance and overall stability of the structure.

According to the characteristics that the project is a pipeline bridge dominated by dead load and little live load deformation, the use of 650mpa steel tie rod instead of high-strength steel cable can

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not only reduce the process of cable tensioning, but also the connection structure of steel tie rod is easier to maintain and replace than that of steel cable.

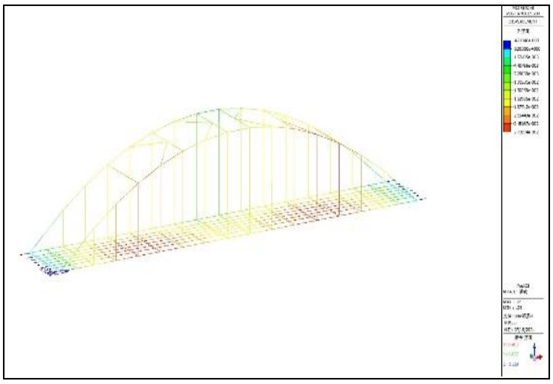

Figure 7 displacement under live load condition

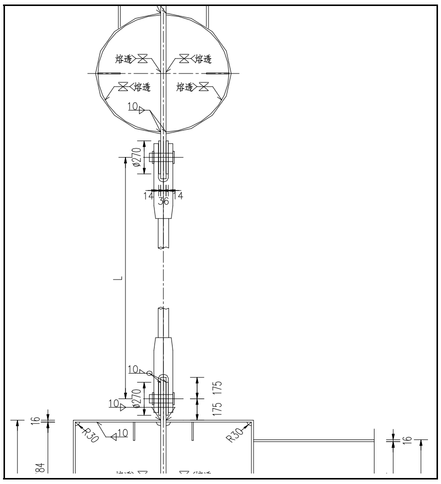

Figure 8. Joint of tie beam and suspender

In the design of long-span wharf approach bridge, the overall hoisting process can be adopted to minimize the offshore operation process on the premise of ensuring the safety of arch bridge.The scheme of using long-span all steel tied arch bridge is economical and reasonable, with strong landscape, which greatly reduces the workload at sea, and has certain popularization value.

Acknowledgments

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