Key Construction Steps of A Half-Through Basket-Type Tied-Arch Bridge with Unequal Spans and Multiple Arches

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Abstract. Half-through tied-arch bridges feature complex structures and are constructed via numerous processes. As these bridges are designed more neoteric, their construction is also becoming more complex. The research takes a novel half-through basket-type tied-arch bridge with unequal spans and multiple arches over Sishui River, in Yanzhou, Shandong Province, China as the engineering background. On this basis, the structural characteristics and key construction steps of this type of bridges are analyzed. It is proposed to install triangular areas first and then arch ribs, and to assemble side spans before the middle span, followed by tensioning of hangers. Key construction steps are elaborated, which provides practical and technical reference for similar engineering.

1. Introduction
Half-through tied-arch bridges are a type of self-balanced arch bridge structures, which are applicable to plains areas, and particularly they show typical advantages in areas under poor geological conditions. The horizontal thrust at the arch foot, internal force in arched girders, and structural displacement can be adjusted by adjusting tensile force of tie bars, thus ensuring successful construction of the structure. Under general conditions, half-through tied-arch bridges feature arch ribs of large stiffness, and it is economic to balance the bending moment by arch ribs in the case that tie bars provide sufficient horizontal pull. Besides, flexible hangers can reduce structural internal force arising due to deformation of hangers [1]. In terms of the appearance, half-through tied-arch bridges are characterized by a graceful structural form and exquisite profile, and are visually appealing. For this reason, it has been widely favored by designers. To further meet the requirements for span capacity and appearance, designers have innovatively developed some novel structural forms on the basis of half-through tied-arch bridges. A novel type among them is half-through basket-type tied-arch bridges with unequal spans and multiple arches.

Half-through tied-arch bridges have large capacity and graceful profile, and are highly expressive, and especially they play a significant role in application in areas crossing rivers and lakes where demands of landscape construction are set. Despite these advantages, this type of bridges have complex structures and are constructed via numerous steps, and their construction complicates with the increasingly neoteric design [2]. This is especially true for half-through basket-type tied-arch bridge with unequal spans and multiple arches. Due to effects of unequal spans and multiple arches, these bridges are under special stress during construction. If their assembling and tension processes are not considered according to the structural form, it is very likely to give rise to problems influencing
construction quality, and even trigger accidents, which causes an immeasurable loss to projects [3-5]. Existing research into half-through basket-type tied-arch bridges with unequal spans and multiple arches mainly focuses on the overall stress analysis of the structure while seldom studies key construction technologies [6-9]. Therefore, it is a pressing need to carry out relevant studies based on practical engineering.

The research takes the novel half-through basket-type tied-arch bridge with unequal spans and multiple arches over Sishui River (hereinafter referred to as Sishui Bridge) as the background engineering. On this basis, the stress characteristics and key construction steps of the bridge are analyzed, providing practical and technical reference for similar engineering.

2. Engineering overview and structural stress system
The half-through basket-type tied-arch bridge with unequal spans and multiple arches is adopted as the main bridge of Sishui Bridge, with a span of 30 m + 95 m + 130 m + 95 m + 30 m = 380 m. The main girder is a steel structure, with the standard beam depth at the designed center line of the road to be 2.0 m. Steel boxes are used as arch ribs, and the main arch rib tilts inward by 10°. The vector height and rise-to-span ratio of the main arch are 38.078 m and 1/3.4, while those of the secondary arch are 26.401 m and 1/3.6, respectively. The bridge deck system in the cable region is a system of longitudinal and transverse beams, consisting of stiffening girders, beams, small stringers, and bridge deck slabs, all of which are steel structures. The bridge deck slabs are orthotropic plates. The cross section is arranged as follows: as the arch ribs (cable region) occupy a certain width of the bridge, the full width (34.5 m) of the cross section of the main girder comprises: 2.5 m (sidewalk) + 3.0 m (bicycleway) + 3.5 m (hanger region) + 8 m (motorway) + 0.5 m (medial strip) + 8 m (motorway) + 3.5 m (hanger region) + 3.0 m (bicycleway) + 2.5 m (sidewalk) = 34.5 m. The overall effect of the main bridge of Sishui Bridge is shown in Figure 1.

![Figure 1. Overall effect of the main bridge of Sishui Bridge](image_url)

3. Classification of arch rib segments and layout of hangers
Two arch ribs are arranged in the transverse direction of the main bridge, and classified into arch ribs in the main, secondary, and side spans according to their specific locations. Arch ribs are placed in the cable region, with their spacing along the transverse direction of the bridge at the arch foot being 25 m, and the arch ribs tilt inward by 10° as a whole. The main arch has a span of 130 m and the arch axis is a quadratic parabola, with the vector height of 38.078 m and the rise-to-span ratio of 1/3.4. The secondary arches span 95 m and the arch axis is a quadratic parabola. The vector height and the rise-to-span ratio of the secondary arches are 26.401 m and 1/3.6, separately. The side span is 30 m and the arch axis is composed of a straight line and a parabola. The straight line is 6.5 m long and the parabola is a curve of a 1.5-order equation, with the in-plane vector height and rise-to-span ratio of 9.545 m and 1/4.9.
4. Key construction steps

The key construction steps of the main bridge of Sishui Bridge are as follows:

1. Providing power and water supply as well as access to roads, leveling the ground, and constructing builders’ road;
2. Constructing the foundation of main piers, bearing platforms, and pier bodies;
3. Erecting construction brackets for the secondary and side spans of the main bridge;
4. Prefabricating arch ribs and steel girders in factories, as shown in Figure 3;
5. Installing steel arch ribs in the triangular areas in the side and middle;
6. Segmental assembling of steel girders in the secondary and side spans;
7. Erecting brackets for arch rings, segmental assembling of steel arch ribs, and installing wind braces, all in the secondary spans, as shown in Figure 4;
8. Tensioning hangers of the secondary spans and temporary tie bars of the side spans;
9. Dismantling brackets in the side and secondary spans, triangular areas, and under girders.
10. Erecting brackets for the main arch ring, segmental assembling of steel arch ribs of the main span, closure of arch ribs, installing wind braces in the main span, and dismantling brackets above the bridge deck, as shown in Figure 5;
11. Erecting brackets for the main span and assembling the main girders, and installing permanent short tie bars in the main span which are used as temporary cables, followed by tensioning of hangers and temporary cables in the main span;
12. Installing permanent long tie bars, tensioning and then dismantling temporary cables in the side spans, to complete the transformation of the tie bar–cable system, as displayed in Figure 6;
13. Removing brackets below the bottom of the main girders of the main span;
14. Constructing the phase-two and accessory structures in the bridge deck system;
15. Adjusting hangers and tensile force of tie bars to the corresponding pre-set values;
16. Completing construction and opening to traffic, as shown in Figure 7.
5. Conclusions
1) The half-through basket-type tied arch bridge with unequal spans and multiple arches is a system in which flexible steel arch beams hang girders. In the bridge, arch ribs are the main bearing structure. The horizontal thrust produced by the main arch is partially balanced by the main, secondary, and side spans, and partially borne by tie bars that are anchored inside tie beams of side spans.

2) Two arch ribs are arranged in the transverse direction of the main bridge and classified into arch ribs in the main, secondary, and side spans according to their specific locations. Arch ribs are arranged in the cable region. The spacing of arch ribs in the transverse direction of the bridge at the arch foot is 25 m and the arch ribs tilt inward by 10° as a whole.

3) Twelve pairs of hangers are arranged in the main span and eight pairs are set in each secondary span. The hangers are spaced 8 m in the longitudinal direction of the bridge and double cable planes are used in the transverse direction. Steel anchor boxes are set in both the arch ribs and the steel box girders for anchoring the hangers, with the fixed end in the arch and the tensioned end in the box girders.

4) It is proposed to construct the bridge according to the following steps: installing the triangular areas first and then the arch ribs, and assembling side spans before the middle span, followed by tensioning of hangers are proposed. The key construction steps are elaborated, which provides practical and technical reference for similar engineering.

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