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# Integrated investigation of an incremental launching method for the construction of long-span bridges

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ABSTRACT

This paper conducts a combined experimental and numerical study of the effectiveness of the incremental launching method for the construction and erection of continuous hybrid arch-girder bridges. To verify construction safety for these bridges, the investigation focuses on the stress and deformation levels of the launched structures during the launching process. The stress fluctuation of structural members is analyzed at critical launching stages under the mechanical and wind loads. It is shown that the temporary connectors between steel arches and longitudinal girders are critical to the structures during the launching process, and that the front connector of the first launched span needs specific attention to avoid fatigue and buckling issues. It is further demonstrated that the wind load has a significant effect on both stress and deformation, especially during the critical launching stages. Stiffening the key components is recommended to ensure the safety of bridge structures during the erection process under severe weather and wind conditions.



## 1. Introduction

Since its first successful application on Austria's Ager Bridge in 1959, incremental launching construction technology has proved to be an economical and convenient method for the erection of long-span bridges. It is of particular advantage for bridge sites with deep valleys, long rivers, or nearby transportation systems that cannot be interrupted (such as railway and navigation channels), where conventional construction technologies are commonly restricted [1,2]. The incremental launching method has become particularly useful in recent years for the construction of bridges including the Millau Viaduct in France [2], the Ilsun Bridge in South Korea [3], the Vaux Viaduct in Switzerland [4], and the Yandangshan Bridge in China [5].

Although researchers and engineers have investigated the incremental launching method for concrete and steel girders [1,2,6–12], the stability and stress concentration issues raised by long-span hybrid arch-girder bridges when the integrated incremental launching technology is used are more prominent than those exhibited by routine girders during the launching process because of their thin plates, slender structural components, and complicated structural systems. Previous studies on the incremental launching method usually focused on isolated structural members such as slender plate girders [8], I-shaped steel girders [9,13], and others [10,11], conducting parametric analysis on the non-uniform distribution of support reaction of slide shoes and the ultimate load-bearing capacity [1,3,5,6,8,9,12,13]. However, few efforts have been made to apply incremental launching construction processes to large-scale hybrid structures that use long cantilever spans and that raise potentially complex questions of stress concentration and stability. One example is the construction of the Jiubao Bridge in Hangzhou, China, which posed challenges of this sort [2,14]. The main navigation span of the Jiubao Bridge is a continuous hybrid arch-girder structure with a span arrangement of $3 \times 210$ m; it is the largest river crossing project with composite structures in China (Fig. 1). This hybrid arch-girder bridge was constructed using a multi-point, simultaneously integrated incremental launching method, so as to avoid severe scouring and sediments as well as the extremely strong tidal force from the Qiantangjiang River, which has tidal height of up to 2.5 m and tidal speed of up to 6–9 m/s.

The construction risk derives not only from the long cantilever launching span, but also from the combined effects of the high-rise launched structure together with the potentially severe wind and weather conditions. Furthermore, the long launching distance of these integrated, three-span hybrid structures may lead to unexpected difficulties. Other problems affected the patch loading issue during the incremental launching for the Jiubao Bridge, such as the temporary connectors between arches and girders and the considerable weight of the launched structure, which leads to stress concentration and fluctuation. In order to reduce the stress concentration and failure risk, well-designed experiments and thorough analysis of the entire launching procedure should be carried out.

This paper presents a construction-process analysis including development of a scale-reduced experimental model that was used to study the safety and stress levels of the hybrid arch-girder structure of the Jiubao Bridge. The scale-reduced model permits reproducing the

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**Fig. 1.** Main navigational structure of the Jiubao Bridge, Hangzhou, China.

continuous change of the boundary conditions of the launched structure. The experimental results are compared with numerical models throughout the process. It is shown that the temporary connectors between steel arches are critical to the structures during the launching process. The wind load has a significant effect on both stress and deformation, especially during the critical launching stage.

## 2. Development and design processes

### 2.1. Description

The Jiubao Bridge, a navigational-channel bridge crossing the Qiantangjiang River in Hangzhou, China, is a three-span structure with each span measuring 210 m in length. The superstructure is continuous with a span arrangement of 608 m. Four V-shaped piers are used for the main bridge, and the pier contour profile is designed to have a smooth transition with the superstructure arch curve for aesthetic effect. Piers are designed to be separate from the superstructure with bearing connections in between. Sixteen bored piles, each of them 2 m in diameter, are used for the main pier foundation [2].

The arch-structure layout is shown in Fig. 2, which is composed of major arches and sub-arches linked by connecting ties. The major arch is the primary load-bearing structure, the central axis of which is a parabola located in the same plane but with 12° of externally inclined. The arch rise is 43.8 m high. A rectangular steel box (3.2 m high and 2.2 m wide) is used for the major arch, and the plate thickness is 22 mm at the deck level, declining along the span to 16 mm at the vault level. The central axis of the sub-arch is a spatial curve with a rise of 33 m while the cross-section of the sub-arch is 1.5 m × 1.5 m. The steel plate thickness is about 12–16 mm with some local parts at 18 mm. Transverse connection ties of 0.6–1 m diameter pipe at intervals of 8.5 m are used between the major arch and sub-arch. Three transverse ties at the arch top are specially strengthened to satisfy the stability requirement.

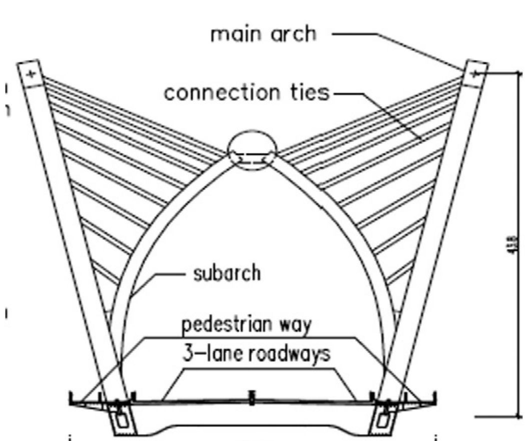


**Fig.2.** Cross section of hybrid arch-girder structure in main navigation span.

The typical cross-section of the bridge deck system is composed of an open steel box and concrete slab, with 37.7 m full width and 4.5 m height at the middle of the cross-section. Q345qD steel (Grade 50 in AASHTO) is used for the structure, and high-strength concrete is employed for the reinforced concrete deck, which is 260 mm thick. The steel part of the bridge deck system is composed of two main longitudinal girders, I-shaped transverse beams, and cantilever beams. The main longitudinal beam is the steel box structure with cross-section size of $2.25 \times 3.96$ m$^2$. The I-shaped transverse beams are longitudinally arranged at intervals of 4.25 m. The cantilevers are for the pedestrian lane. For ease of concrete slab fabrication, two smaller longitudinal beams are designed within the two main longitudinal girders. Hangers composed of 121-string, parallel wires, 7 mm each in diameter, are used at intervals of 8.5 m for the arch-girder connection. The bottom and top of the hanger are anchored in the main longitudinal girder and hanger connector at the major arch, respectively.

The launching process of the long-span arch bridge is complicated, with sensitive and frequently changing structure loading performance. Therefore, a set of tracked incremental launching systems is specially developed with highly modularized equipment and automatic controls. The fundamental principle is to use vertical jacks to lift the structure simultaneously in multiple locations, with horizontal jacks pushing the structure forward to achieve the launching purpose. The vertical jacks are then released and the entire structure is laid down on a temporary pad-beam to complete a launching cycle. The steps of lifting, launching, descending and withdrawing are then repeated to complete the entire bridge launching process. The total launching weight is as great as 14,500 tons and the maximum launching distance is 970 m, with a launching efficiency of 2.5 m/h. Moreover, only one temporary pier is used for each 210 m span during the launching process. The concrete deck slab is not cast until the steel hybrid arch-girder structure has been launched. Therefore, the steel structure of the hybrid arch-girder bridge has profound load-bearing capacity. Also, three types of temporary connectors, as shown in Fig. 3, are used to connect the steel arches and the longitudinal steel beams of the composite girder, thereby integrating the steel arch and steel longitudinal beam for joint load bearing and reducing the free length of this steel beam. This method also helps to effectively strengthen the overall load-bearing capacity of the entire structure.

### 2.2. Critical launching stage analysis

A finite-element-based structural model is developed to provide a reasonably high level of accuracy of structural deformation, which is useful for control and monitoring purposes with incrementally launched steel bridges. The steel structure of the main bridge, which includes the steel girder and steel arch, is first assembled on land and then launched to the design position by the multi-point simultaneous launching method. After that, the precast concrete deck slab is assembled. Construction of the three-span main bridge is divided into three steps. When one span's assembly has been completed, it is launched for the distance of one span towards the river. The second span is then assembled at the assembly yard, and the resulting two-span structure is accordingly launched forward. Upon the completion of the third span assembly, the entire three-span structure is then continuously launched, crossing the piers of the approach span towards the final designed position over the center of the river. Nose beams with a length of 45 m are designed at both the front and the back of the launched steel structures during the launching process. Therefore, only the three-span steel hybrid structures without hangers of the bridge need to be modeled for the incremental process analysis. Finally, shell elements are used to model major load-carrying members such as longitudinal girders, major arches, secondary arches,