AESTHETIC DESIGN OF LONG SPAN ARCH BRIDGE

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This paper refers to the aesthetic design of long span arch bridge reviewing the historical development of concrete arch bridge design and construction method in Europe and Japan. Getting the inspiration from ideas of historical engineers like Josef Melan (1853-1935), Robert Maillart (1872-1940) and Urich Finsterwalder (1897-1988), the balanced cantileverering method was firstly applied to the Iked Hesokko bridge with a center span of 200m in Tokushima prefecture. Through the real design process, the coraboration of bridge designer and engineer is reviewed..

Keyword: history, aesthetic design, longspan arch bridge, collaboration

1. Introduction

The history of engineering is not a set of facts, dates, and phenomena, but a process of human thought and challenges by engineers and architects. Reviewing the process of development of materials and structures, there appears to be a cause and effect relationship between the newer and the older stages. The development of each stage is the result of an organic chain reaction with the former stage. This relationship was revealed by Charles Darwin who presented a theory of evolution in his book "On the origin of species". But it is not always true that evolution is absolute progress of the former, and that the new is always better than the old. A new form of bridge is the result of human thought and challenges by engineers and architects, and then the value of the bridge design is always the same. The form of bridge does not evolve, but metamorphoses (changes gradually) according to human thought. We can thus review historical bridges and the concepts of bridge engineers equally. This will be a useful approach for engineers and architects who are seeking a new and aesthetic bridge form [1)]

２. History of arch bridges in Europe

In the early 20th century, the design of concrete arches was strongly influenced by stone bridges, where the arch rib supports the entire upper load. Much timber was required for the scaffolding in order to support the weight of the arch rib **(Fig. 1)**. The design of concrete arch bridges evolved from the need to reduce the quantity of scaffolding and to use effectively both the arch deck and the arch rib. There were two excellent engineers whose structural concepts were indispensable for the development of new forms of concrete arch bridges.

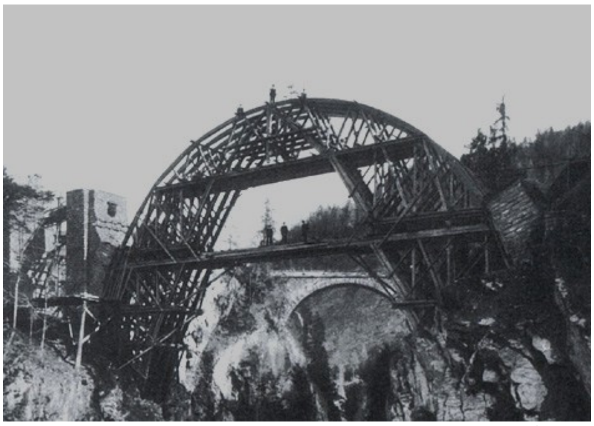


Fig.1 Solis Bridge during construction (Rhaetische Bahn) 1902[2)]

In 1902, Robert Maillart (1872-1940), a bridge engineer in Switzerland, patented the idea of a box girder section that consists of deck-slab, web and arch rib. These three members were built as a framework and resist loads. This approach enables the total weight of the concrete arch bridge to be reduced, he tried to build the three members separately, firstly the arch rib, then the web and finally the deck. This phased construction method greatly reduced the total amount of timber scaffolding compared to that of stone bridges, because the scaffolding must support only the weight of the arch rib **(Fig. 2)**. After the arch rib is completed, it helps to support the following member, the web and the deck-slab. The second approach is the deck-stiffened arch, in which the deck-slab and the arch rib act simultaneously. If the stiffness of the deck-slab is large enough to resist the live load, the arch rib can be made thinner, as evidenced by the Valtscielbach Bridge with an arch span of 43.2 m in 1924 **(Fig. 3).**
This was the beginning of a new type of arch bridge that offered transparency and lightness among the massive concrete bridges.

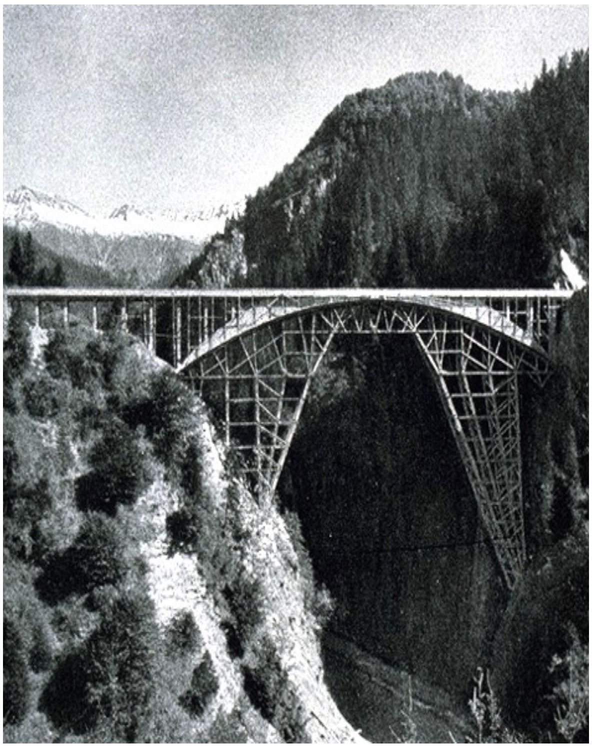


Fig.2 Salginatobel Bridge during construction 1930 [3)]

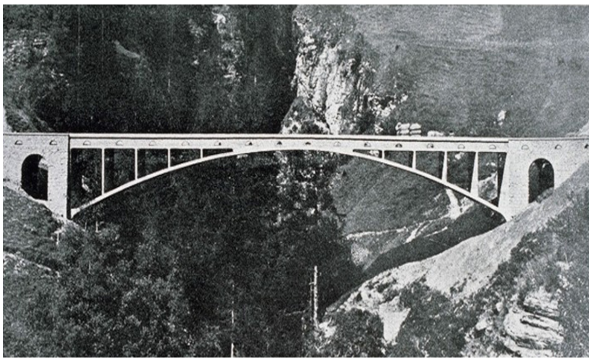


Fig. 3 Valtschielbach Bridge 1924 [3)]

In 1892, Joseph Melan (1853-1935), a professor of Vienna University, invented the Melan construction method that enabled the non-scaffolding. The idea came from steel bridge construction. Firstly, steel truss beams are set between the abutments, then the formwork is hang from them, then concrete is placed around the steel truss beams. This approach produced the flattest arch bridge, Schwimmschul Bridge in Steyr, with an arch span of 42.8 m in 1898. The Melan construction method contributed to longer arch bridges and higher construction efficiency.

The prestressing technique firstly invented by Eugene Freyssinet (1879-1962) and the balanced cantilevering method invented by Urich Finsterwalder (1897-1988) also contributed to longer arch spans and more efficient bridge construction.

4. History of arch bridges in Japan

In Japan, the first prestressed concrete bridge with a bridge length of 11.6 m was constructed in 1951. In the 50`s and 60`s, Japanese bridge engineers devoted themselves to rebuilding the Japanese economy and learned much about modern bridge design and construction methods from Europe. For example, the balanced cantilevering method using the Dywidag system was first applied to the Ranzan Bridge with a bridge length of 75 m in 1959.

In 1970`s, flourishing of new ideas, such as various prestressed concrete bridge types and construction methods; railroad bridges with prestressed concrete stays, concrete truss bridges and stress ribbon bridges for roads were realized.

As for the development of concrete arch bridges, application of the balanced cantilevering method to arch bridge construction played a major role. In 1974, the Hokawazu Bridge with an arch span of 170 m was constructed using the balanced cantilevering method **(Fig. 4)**, this was the first application in the world. In 1979, this construction method was applied to deck-stiffened arch bridge for railroads, Akayagawa Bridge with an arch span of 116 m. In 1978, the Pylon and Melan construction method was invented and applied to the Taishaku Bridge with an arch span of 145 m. The characteristics of this construction method are that it reduces temporary stay cables and improves the stability against earthquake during construction. This construction method greatly enlarged the possibility of arch bridge design in Japan, such as the Beppu-myoban bridge with an arch span of 235 m which was constructed in 1990 by using the Pylon and Melan construction method **(Fig. 5)**. This bridge form is harmonized with the surroundings and the aesthetic design was evaluated at the FIP congress in Hamburg in 1991. The Ikeda Hesokko Ohashi bridge, which is the main topic of this report, is a three-span continuous deck-stiffened arch bridge. The design of this bridge is based on application of the balanced cantilevering method where two form-travelers are cantilevered from the pier head in two directions simultaneously.

Fig. 4 Hokawazu Bridge 1974

Fig. 5 Beppu-myoban Bridge 1990

5. The aesthetic design of the Ikeda Hesokko Ohashi bridge

5.1 Conditions and first comparison of bridge types

The Ikeda Hesokko Ohashi Bridge **(Fig. 6) (Fig. 7)** is located in Ikeda town in Tokushima prefecture. The bridge is located in the final section of the Tokushima Expressway, and crosses over the Ikeda dam lake of the Yoshino river, Yoshino river park, a railway line, a national highway, and a prefectural road. The bridge is surrounded by steep mountains and the bridge length is 705 m. The road level is about 60 m above the water level. The scenery of the bridge changes quickly, because viewing points are situated on the winding national highway under the bridge. The three main conditions in the planning were as follows:

1) In the future, the same bridge will be constructed along to the bridge of this time.
2) As the bridge is located between two tunnels, the erection area is restricted.
3) The bridge form should be transparent so that the view of the surroundings is not disturbed.

In the first comparison of bridge types, cost effectiveness and transparency were most important factors. Five types of bridgewere compared: 1) a cable stayed bridge, 2) an extradosed bridge, 3) a steel arch bridge, 4) a prestressed concrete continuous box girder bridge and 5) a four-span continuous deck-stiffened arch bridge **(Fig. 8)**. Types 1) and 2) were discarded because of the higher cost and the structure above the bridge deck would obscure the natural view. Type 3) is a combination of a steel arch bridge, steel box girders and beams, which would be extremely difficult to construct due to the limited erection space, and then realizing the continuity of the bridge girder is also difficult. The maintenance cost of steel bridges is higher than that of concrete bridges. Type 4) has a center span of 200 m and the height of the girder on the pier is 11 m, which would look oppressive. Type 5) is a combination of concrete deck-stiffened arch for the longest span section and box girder bridge for other sections where the clearance from the national highway is about 30 m. With this bridge type, the height of the girder in the arch span section can be constant, so the thin vertical walls make the arch more transparent. Finally, type 5 was selected in view of the above conditions. In the second stage, analysis of bridge form, the continuity of the two structures, the deck-stiffened arch and box girder sections, was examined as follows.

Fig.7 Ikeda Hesokko Ohashi bridge

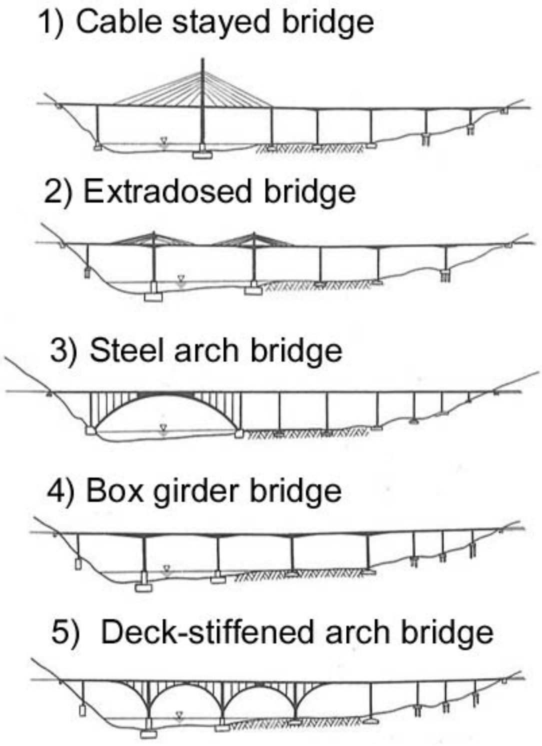


Fig. 8 Comparison of 5 bridge types

5.2 Aesthetic analysis

The position of Pier 1 and Pier 2 in the Yoshino river is decided according to river usage. The main span

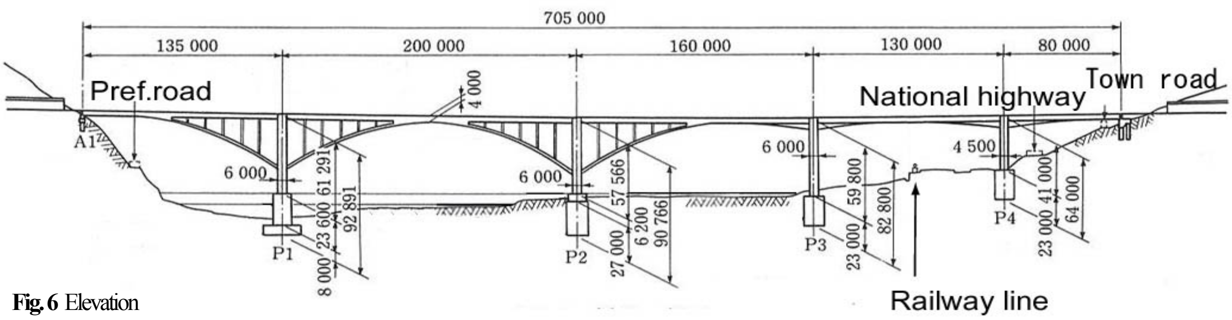


Fig. 6 Elevation

lengths of other spans varied according to the crossing conditions of the national road and railway. Span lengths of the bridge were decided as 135 m + 200 m + 160 m + 130 m + 80 m. These irregular span lengths are unfavorable for a continuous arch bridge, so the aesthetic investigation played a major role in the design of this bridge. In order to check the whole bridge form, firstly the viewing points were selected to identify aesthetic characteristics. Three points were selected as shown in（**Fig. 9**）. The aesthetic characteristics were checked from each view points **(Fig.10)**.

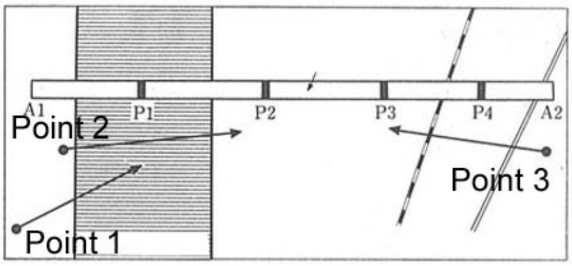


Fig. 9 Aesthetic problems from viewing points

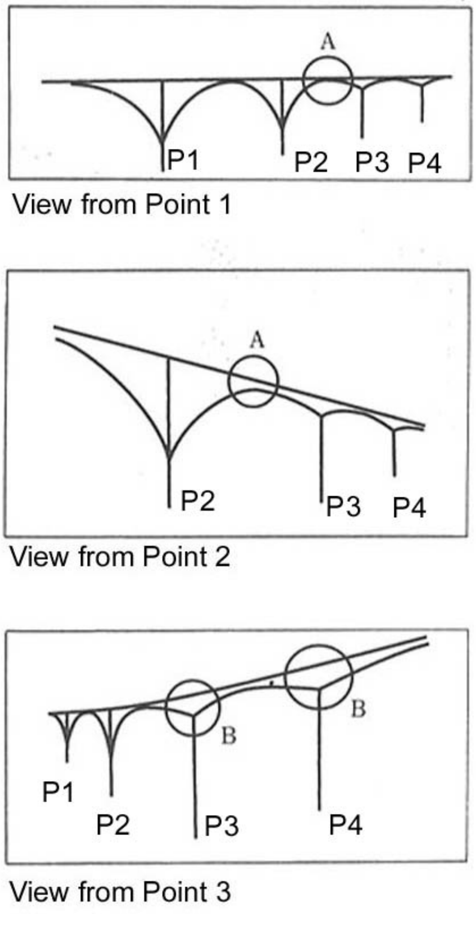


Fig. 10 Aesthetic problems from viewing points

Point 1: For the whole bridge, check the continuity of the whole bridge form.

Point 2: Check the discontinuity between P2 and P3, where the deck-stiffened arch bridge connects to the box girder bridge.

Point 3:Check the oppression of the pier heads of the box girder.

The aesthetically important parts of the whole bridge were then investigated by using the Psycho-vectors method (Fig. 11). In this method, the visually important members of the bridge can be ranked from aesthetic points of view.

In the case of the Ikeda Hesokko Ohashi bridge, the continuity of the girder is the most important factor, then the vertical vectors of the piers which support the girder, then the curved line of the arch and girder, and finally the vertical thin vectors of the vertical walls on the arch rib. In order to clearly understand of the bridge form, it is important to ensure that the vectors are recognized in this order.

5.3 The continuity between P2 and P3

In order to check the continuity between Pier 2 and Pier 3, three types of bridge design were compared (Fig. 12). Type A is a basic plan ; it looks simple and the aesthetic disorder is not strongly disturbed, but the difference of curvatures of the deck-stiffened arch section and box girder section prevents rhythmical movement as shown by Psycho-vector C in Fig. 11. Type B is a five-span continuous deck-stiffened arch bridge. The curvatures of P3 and P4 change gradually, and the difference of arch forms might cause some perspective disorder. Type C is designed to strengthen the continuity of the girder throughout the bridge where the height of the girder in both the arch section and box girder section is constantly 4 m. In the box girder section, the inclined web is applied to the part lower than 4 m below the deck-level. Comparing these three types, type C was selected because the visually important part of the bridge was strengthened according to the Psycho-vectors concept, because the sense of oppression over the national highway is reduced.

5.4 Detail Design

After the basic bridge form is decided, attention must be paid to the erection of the protection wall, drainage pipes, electric boards for traffic information and emergency telephones. In order to keep the continuity of the girder, the outside face of the concrete handrail

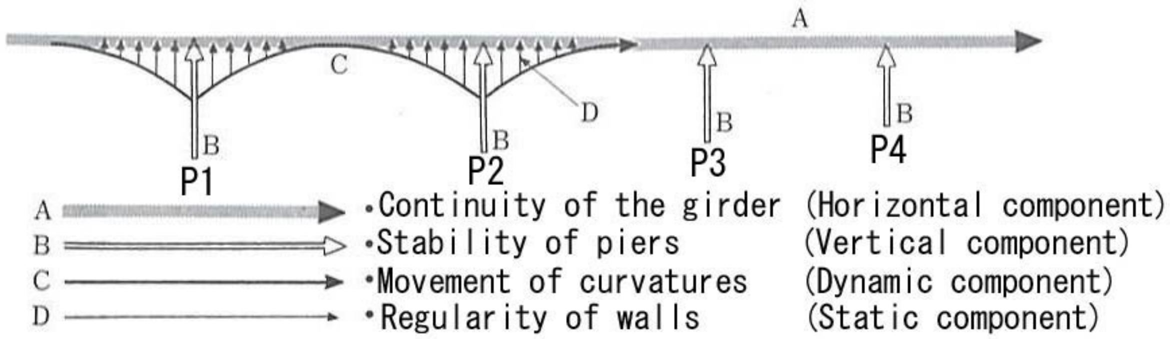
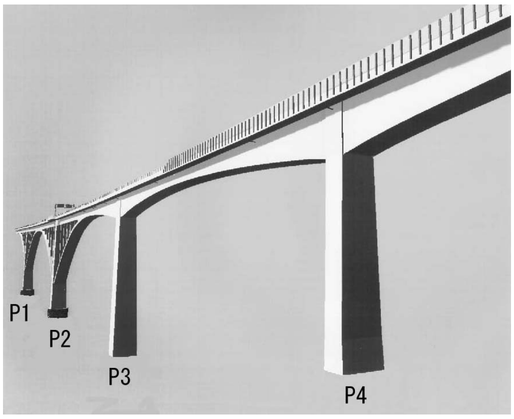
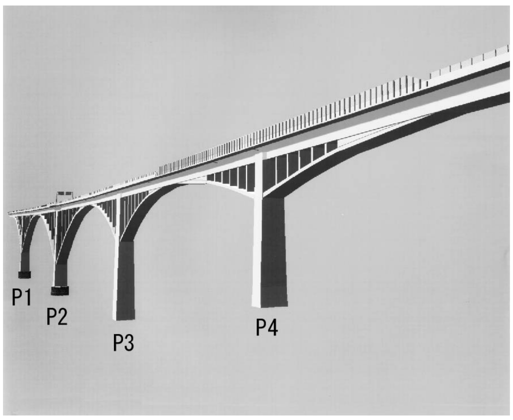


Fig. 11 Psycho-vectors of the basic plan

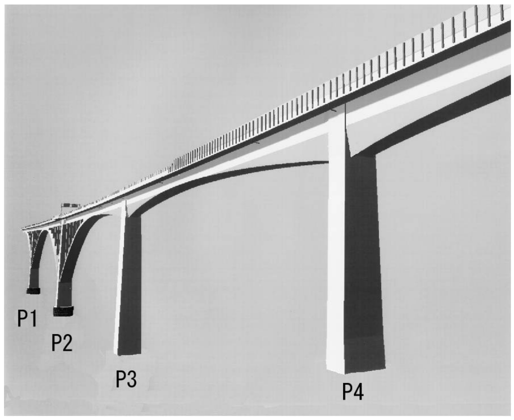
must not be disturbed by the attachments for electric boards and emergency telephones, so these instruments were concentrated in an emergency area. Also, the protection wall was set on the top of it. The drainage pipes were arranged as follows. From the inlet on the deck edge, a L-shaped pipe hangs under the deck and then goes through the web into the main drainage pipe inside the box girder. The drainage pipe is hardly visible from outside, because the pipe is concealed within the shadow of the cantilevered deck.



Type A : Basic plan



Type B : Continuous deck-stiffened arch



Type C : Type A with inclined web

Fig. 12 Comparison of three bridges **types**

6. Conclusion

The completion of the X-shaped highway network through the four prefectures in Shikoku Island will contribute to the development of the economy and flows of transportation in and outside of Shikoku Island. It is very important to study aesthetic characteristics of a large-scale bridge like the Ikeda Hesokko Ohashi Bridge and we should consider whether the bridge should play a major role in the landscape or should be harmonized with the landscape in the early stage of the planning,. The bridge design is based on the new construction method and required close collaboration between skilled engineers and designers. I hope this paper will contribute to the evolution of of new bridge

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