Comparison between Steel Arch Bridges in Japan and China

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1. Introduction

Arch bridge has a long history in the world. Lots of world-class achievements have been witnessed in the field of its design and construction. Steel arch bridges have been designed and constructed for about 140 years in Japan since the first cast iron bridge completed in 1872. The experiences and techniques for design and construction are well worth learning from. On the other hand, very few steel arch bridges had been built before 2000 in China, and more and more steel arch bridges have been built later on. Some of them have very long spans. However, considering its short history, more research and practice are necessary on the design and construction. In this context, a large amount of data about steel arch bridges in Japan and China is collected from websites[1] and references[2]-[5], and analyzed in terms of year of completion, main span length, structure type and construction method.

2. Main Span Length and Year of Completion

2.1 Main span length vs. completion year A total of 1509 and 82 steel arch bridges in Japan and China, respectively, were collected in this study. Among them, the main spans and completed years of 1467 bridges and 68 bridges are known. They are shown in Figs. 1 and 2, respectively, with a few representative bridges labelled. Fig. 1 shows that the distribution of steel arch bridge in Japan can be partitioned roughly into two stages by the year of 1955. Due to the limitation of steel production and backward technique, from the first cast iron bridge-Shinmachi Bridge completed in 1872, to 1955, only 112 bridges (7.6%) were built in this duration of 85 years. Only 4 bridges' main spans are 100m or longer. In the decades after 1955, 1355 bridges were constructed, which account for 92.4% of total. 531 bridges have the main spans of 100m or longer, and the average main span is 98.5m.

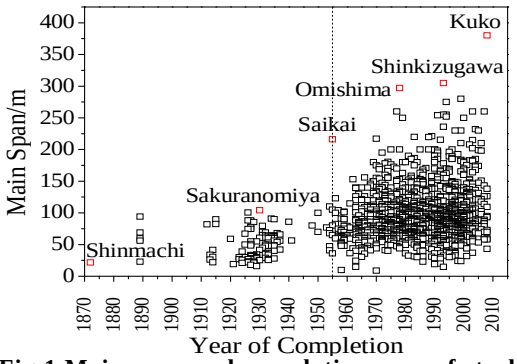

Fig.1 Main span and completion year of steel arch bridge in Japan

It can be seen from Fig. 2 that the distribution of steel arch bridges in China can be partitioned roughly into two stages by the year of 2000. From 1966 when the first steel arch bridge was completed, to 2000, only 10 bridges (13.2%) were built in this duration of 35 years. The one with the longest main span of 216m is the Jiujiang Yangtze River Bridge. In the decade after 2000, 66 bridges (86.8%) were built. Most of long span bridges were built in this period. 60 bridges with main spans of 100m or longer were built, and the average main span is 216m.

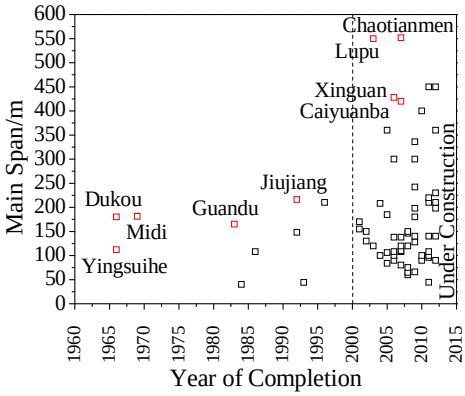

Fig.2 Main span and completion year of steel arch bridge in China

2.2 Number of bridges vs. completion year Fig. 3 compares the number of steel arch bridges in Japan and China. Fig.3 shows that the number of steel arch bridges in Japan has been increasing obviously since 1920, and almost stopped increasing between 1935 and 1955, later on, increased conspicuously between 1955 and 2004, then trend slowed down from 2004. Steel arch bridge in China seemed to lag much behind until 2000, and then the development accelerated, although the number of bridges is still quite fewer than that in Japan.

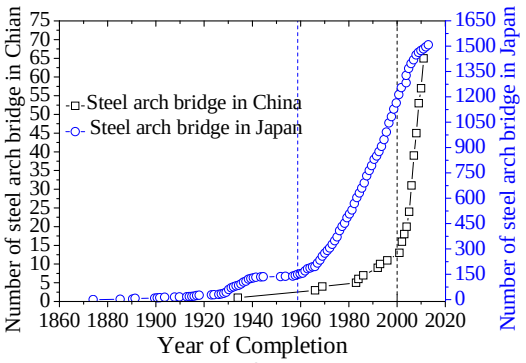

Fig. 3 Number of steel arch bridges

2.3 Distribution of main span length Figs. 4 and 5 show the distribution of main span length in Japan and China. The main spans of 932 bridges in Japan (63.5%) are smaller than 100m, and 400 bridges (27.3%) in the range of 100m-150m. Only 135 bridges (9.2%) have the main span larger than 150m. Therefore, most of steel arch bridges in Japan have the main span of 150m or smaller. On the other hand, the main spans of 16 bridges (21.0%) in China are smaller than 100m, 48 bridges (63.2%) are between 100m and 250m, 12 bridges (15.8%) are larger than 250m. Hence main spans of steel arch bridges in China are mostly between 100m and 250m.

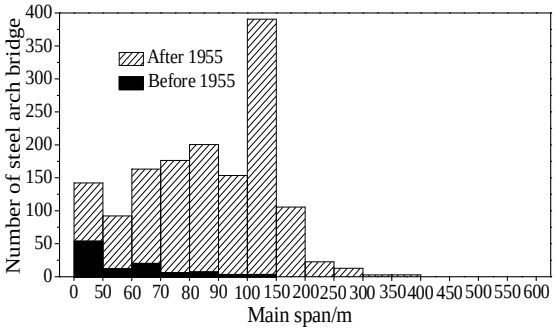

Fig. 4 Span distribution of bridge in Japan

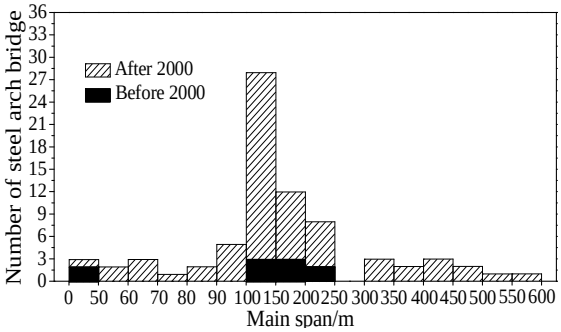

Fig. 5 Span distribution of bridge in China

3. Structure Type

3.1 Overall structural forms With respect to the relative position of bridge deck and arch rib, steel arch bridges can be categorized into deck, half-through, through and double-deck types. As shown in Table 1, in the 1165 steel arch bridges with structure types known in Japan, there are 369 (31.7%) deck bridges, 129 (11.1%) half-through bridges, 662 (56.8%) through bridges, and 5 (0.4%) double-deck bridges. In the 80 steel arch bridges in the list of China, there are 9 (11.3%) deck bridges, 32 (40.0%) half-through bridges, 35 (43.7%) through bridges, and 4 (5.0%) double-deck bridges.

With respect to the articulation of main arch, they can be classified into four categories, *i.e.*, three-hinged, two-hinged, single-hinged and hingeless types. Only one bridge selected-Shakuranomiya Bridge is three-hinged in Japan. Moreover, 7 asymmetry bridges were hinged at one arch springing and fixed at the other one. Two-hinged forms were adopted in majority of deck and half-through steel arch bridges, 286 bridges in total. However, all steel arch bridges selected in China are hingeless.

3.2 Main span rise-to-span ratio Rise-to-span ratio is an important parameter of steel arch bridges. The distribution of rise-to-span ratios used in existing steel arch bridges in Japan and China are illustrated in Figs. 6. The rise-to-span ratios of steel arch bridges in Japan are in the range of 1:9 to 1:3 and the commonly employed value are between 1:7 and 1:5, while those in China are in the range of 1:2 to 1:8, mostly between 1:4 and 1:6. The rise-to-span ratios of steel arch bridges in China are slightly greater than Japan's.

3.3 Arch axes The data about axes of arch ribs in Japan have not been collected. Hence just the axes of steel arch bridges in China are analyzed here. Among the selected 82 steel arch bridges, arch axes of 34 bridges except unknown or specific shape bridges are shown in Table 2. 23 (67.6%), 7 (20.6%) and 4 (11.8%) bridges adopt the parabolas, catenaries and other curves, respectively. It is obvious that the parabola is the most popular shape of arch axis because of the approximately uniform distribution of its dead loads.

3.4 Section of arch rib The type of arch ribs can be also classified into solid and truss types. All the 912 bridges in Japan and 76 bridges in China with section types known are analyzed here, as shown in Table 3. In Japan, solid ribs are employed in 899 bridges (98.6%) and truss ribs are only employed in 13 bridges (1.4%), while the solid and truss ribs are used in 57 (75.0%) and in 19 bridges (25.0%), respectively, in China. It means solid ribs are mainly adopted in both Japan and China. The box section is mainly employed in solid arch ribs and members of truss in both countries.

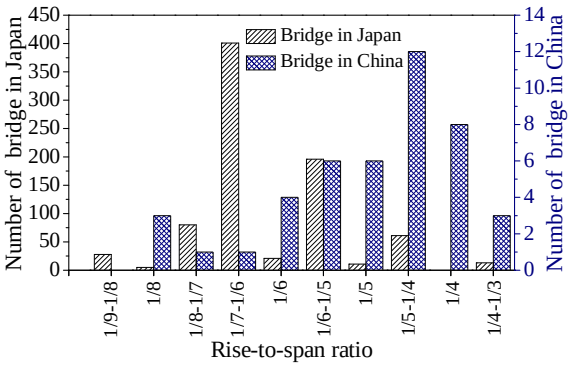

Fig. 6 Rise-to-span ratio of steel arch bridge

Table 1 Quantity of steel arch bridge classified by structure type

Type	Japan		China	
	Number	Percentage	Number	Percentage
Deck	369	31.7%	9	11.3%
Half- through	129	11.1%	32	40.0%
Through	662	56.8%	35	43.8%
Double deck	5	0.4%	4	5.0%

Table 2 Arch axes of steel arch bridges in China

Arch axial line	Number	Percentage
Parabola	23	67.6
Catenary	7	20.6
Others	4	11.8

Table 3 Section of arch rib

Type	Shape	Japan		China	
		Number	Percentage	Number	Percentage
Solid	Rectangle	870	95.4%	53	69.7%
	Tube	29	3.2%	0	0.0%
	Ellipse	0	0.0%	2	2.7%
	Octagon	0	0.0%	1	1.3%
	L shape	0	0.0%	1	1.3%
Truss	Rectangle	11	1.2%	19	25.0%
	Tube	2	0.2%	0	0.0%

Table 4 Construction methods for steel arch bridges

Construction method	Japan		China	
	Number	Percentage	Number	Percentage
cable method	231	50.0%	18	36.7%
scaffolding method	198	42.9%	21	42.9%
swing method	1	0.2%	3	6.1%
launching method	0	0.0%	2	4.1%
large block method	32	6.9%	5	10.2%

4. Construction Method

The construction methods used in selected steel arch bridges are shown in Table 4. The cable method and scaffolding method are the main construction methods, for 92.9% and 79.6% of the selected steel arch bridges in Japan and China employed these methods. The cable method can be adopted not only for small bridges but also for large bridges. Other methods are usually employed for bridges with spans less than 250m.

5. Conclusions

A result of comprehensive survey on steel arch bridges in Japan and China with respect to year of completion, main span length, structure type and construction method has been presented in this paper, and statistical comparison of them is also briefly addressed. The experiences and techniques of design and construction of steel arch bridges in Japan provide a good reference for worldwide engineers, especially in developing countries. Steel arch bridge still has prosperous future in this era of large scale transportation infrastructure construction in developing counties. The survey of steel arch bridges in Japan and China in this paper is expected to provide a base data and reference for its future research and construction.

References

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