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Historical Study on the Development of Bridge Technology and Western Influence in Modern Japan *

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SUMMARY: With the opening of the country brought about by the Meiji Restoration of 1868 modern bridge building in Japan got off to start with a full assimilation of Western technology. In this paper with a comparison of bridge technologies between conventional and modern ones, the direction and the characteristics of modernization of Japanese bridge technology has been examined. The development of modern Japanese bridge technology was driven by changes in design concepts which occurred as a consequence of an awareness of the advanced state of western bridge technology, the superiority of iron as structural use and structural rationality against heavy load for railway bridges.

1 PURPOSE OF THE STUDY

The modernization of Japanese bridge technology began with the introduction of advanced Western technology during the years around the overthrow of the Tokugawa government and the Meiji Restoration of 1868. The way in which Japan handled the conventional technology and the advanced technology of the West introduced to Japan in those early years can be considered to be one of the significant factors in determining the direction and the character of the modernization of bridge technology.

In this study, the influence of the West and the development of bridge technology during the years before and after the Meiji Restoration have been focused on. The aim is to gain an understanding of the direction and the characteristics of the modernization of bridge technology in Japan.

2 EVOLUTION AND TRANSFER OF BRIDGE TECHNOLOGY

2.1 Evolution of Bridge Technology in the West

The two developments having the greatest impact on the evolution of bridge technology in the 19th century were the wide-spread of railway construction and the advancement of ironmaking technologies. From the early years of the century into its latter half U.K. and other advanced countries of the West experienced a boom in railway construction.

Advances in ironmaking provided bridge builders with large quantities of inexpensive structural materials. Specifically the development of the puddling process, a method of refining pig iron with coal brought about the industrial production of wrought iron in the first half of the century. In 1870s steel started to be produced in large quantities and at low prices by the Bessemer converter process a new method of pig iron refining discovered by Henry Bessemer (1813-1898). Wrought iron used in place of cast iron as a structural material, was itself pushed aside by steel in the second half of the century.

2.2 The Technology Transfer to Japan

The latter half of the 19th century marked the first era in which bridge technology was widely transferred on a global scale. The flow of the technology from the West spurred on by exports of iron girders and by the overseas dispatch of railway engineers.

In the 1850s a number of railways were built in India starting with a line constructed by the East India Company to connect Calcutta and Delhi. Exports of large girders for railway construction were brisk.[1]

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The boom in railway construction brought many British engineers to India and a number of these later found employment in Japan, in addition to such Commonwealth colonies as Australia and New Zealand. For example, among those British engineers who worked on the construction of the Shinbashi - Yokohama railway, completed in 1872 were Edmond Morel (1841-1871) and John England (1823-1877) both of whom had been involved in some railway construction projects in southern Australia and Richard. V. Boyle (1822-1908) and Thomas. R. Shervinton (1827-1903) both of whom in India.[2]

In this way, the latter half of the 19th century was an era of worldwide spread of bridge construction technology, developed in the European countries, especially U.K. propagated first through the colonies and from there out to the world at large. Japan, which had just opened its doors to the outside world in the 1860s is a country that was heavily influenced by the influx Western bridge technology.

3 BRIDGE TECHNOLOGY BEFORE AND AFTER THE MEIJI RESTORATION (1868)

3.1 Conventional Bridges before The Meiji Restoration

Most of the bridges constructed before the Meiji Restoration were made of wood and the structural type in widest use was a timber girder bridge (Fig. 1).[3] But there were several other types like timber arch and cantilever bridge (Fig. 2) for longer spans. Masonry arch bridges were constructed mainly in Kyushu and Okinawa.

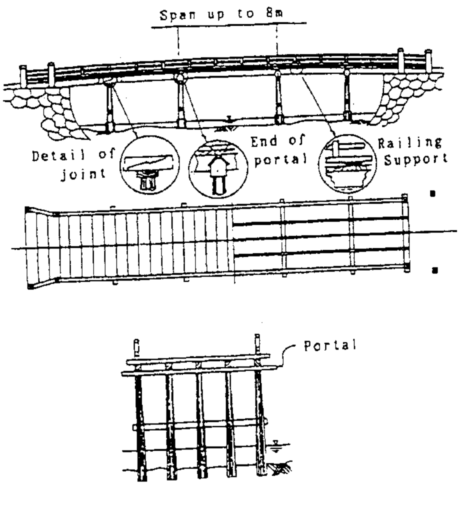

Figure 1 Conventional Timber Girder Bridge

This figure was drawn by the author according to "Teibou Kyouryou Kumitate no Zu (Drawings of Levee and Bridge)" 1871.[5]

The timber girder bridges feature a simple basic structure. Main girders consisting of exterior girders with a rectangular cross section and interior girders with either a rectangular or circular cross section are simply supported by timber piers.[4,5] The length of spans ranged from about 4 to 8m. The superstructure is not equipped with the lateral and sway bracings.

The pier was composed of 3 to 5 columns which supported a portal with a cross section width of about 40cm. This is so called pile bent type. Bracings were not equipped in many cases.[6]

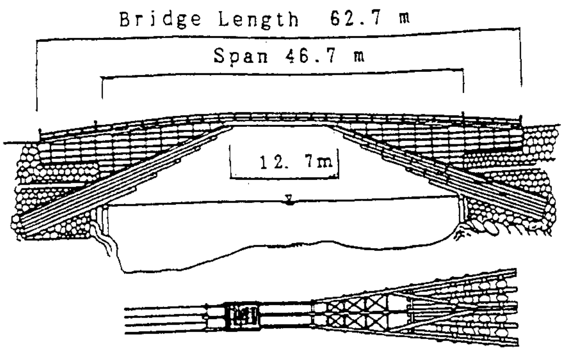

Figure 2 Conventional Timber Cantilever Bridge

This figure was drawn by the author according to "Ecchuu Aimotobashi", Takada. K., Proceedings of Japan Society of Eng., Vol.138.[24]

Overall, there was little resistance to horizontal forces and the materials (pine, cypress etc.) were not durable so it appears the bridges were not intended to last a long time.

The members of these timber bridges were usually connected by cutting and matching tenons on the joint surfaces and fastening them with wooden plugs or nails.

3.2 Modern Bridges after the Meiji Restoration

3.2.1 Examples from the early years of Meiji Era (1860s-1870s)

The first iron bridge in Japan was the Kurogane Bridge in Nagasaki wrought iron plate girder road bridge, constructed by a Dutch engineer in 1868. The second iron bridge was the Yoshida Bridge, wrought iron, truss road bridge. This bridge was constructed at the end of 1868 in Yokohama by R.H. Brunton (1841-1901), an engineer from the U.K. It was a through type, double warren truss bridge with a slab of planks on timber floor beams. The iron was imported from the U.K. and fabricated in Yokohama.[8] The abutments were masonry, its newel posts were also made of stone and light poles were installed in front of the newel posts.

The Korai Bridge, a wrought iron, plate girder, road bridge was constructed in 1870 at Higashi-Yokobori in Osaka (Fig. 3). This bridge had eight spans with each span length of 30 ft.(9.14m).[9] It was an imported bridge, designed and fabricated by A. Handyside & Co. of the U.K. Each pier consisted of 4 wrought iron screw piles. The piles were linked together with bracings in order to provide resistance against horizontal forces.

Japan's first railway bridge was the Rokugo River Bridge on the line of Shinbashi-Yokohama, opened in 1872. It was a queen post truss bridge made of cypress wood with spans of 55 ft. Because of excessive deflection during construction, queen posts were added on the outside of the warren truss initially constructed.[9]

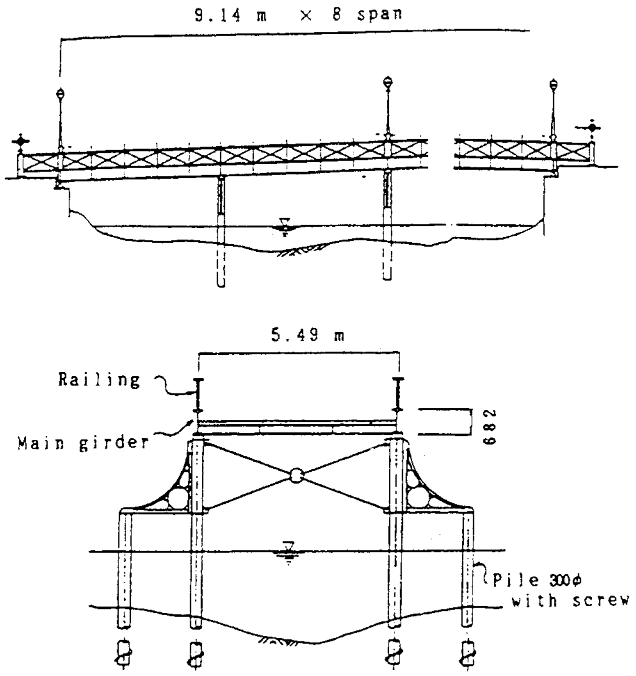

Figure 3 The Koraibashi Bridge, 1870, Osaka

This figure was drawn by the author refering to "Works in iron - bridge and roof structures" A. Handyside & Co., 1873.[8]

Next, several wooden truss bridges were constructed on the line of Osaka - Kobe, opened in 1874. One of these bridges were the Togagawa River Bridge shown in Fig. 4. It was a single track, pony, queen post, truss bridge with a span length of 32.5 ft.(9.91m). The joints were formed by tenons bolts and splice plates.

These timber railway truss bridges were replaced by iron truss bridges a few years later.

The first iron railway truss bridges were constructed between Osaka and Kobe in1874. They were the Mukogawa River Bridge (Fig. 5) Kanzakigawa River Bridge and the Jusougawa River Bridge. Those were trusses with span of 68 ft.8in. (20.93m) known as Seventy - Foot Truss. The bridges were fabricated at Darlington Iron Works Co. in U.K. and exported to Japan.[10]

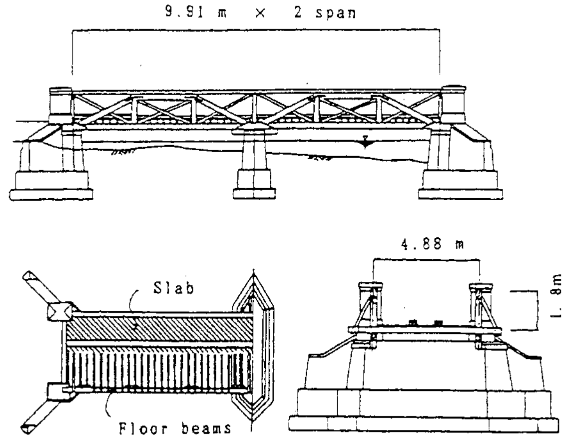

Figure 4 The Togagawa River Bridge (Osaka - Kobe, 1874)

This figure was drawn by the author according to "A History of the Railway Bridges in Japan, 1934.[11]

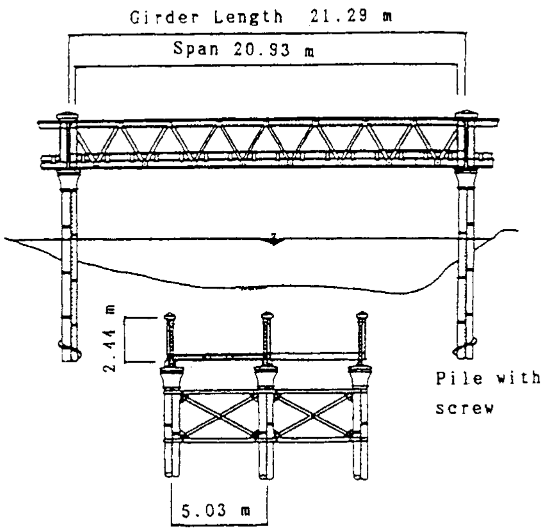

Figure 5 The Mukogawa River Bridge (Osaka - Kobe, 1874)

This figure was drawn by the author according to "A History of the Railway Bridges in Japan, 1934.[11]

3.2.2 Examples from the middle years of Meiji Era (1890s-1900s)

Fig. 6 shows a bridge designed by a Japanese engineer and erected in Gunma Prefecture in 1892(11). It was a pony type Howe Truss bridge with a span of 72 ft.(21.95m). The upper and lower chords and the diagonal members were made of wood but the hangers and the lateral bracings were made of wrought iron rods. The pier was made of wood, and bracings and diagonal piles were arranged to provide resistance to horizontal forces. Joints of the members were combination of tenons and bolts with iron splice plates.

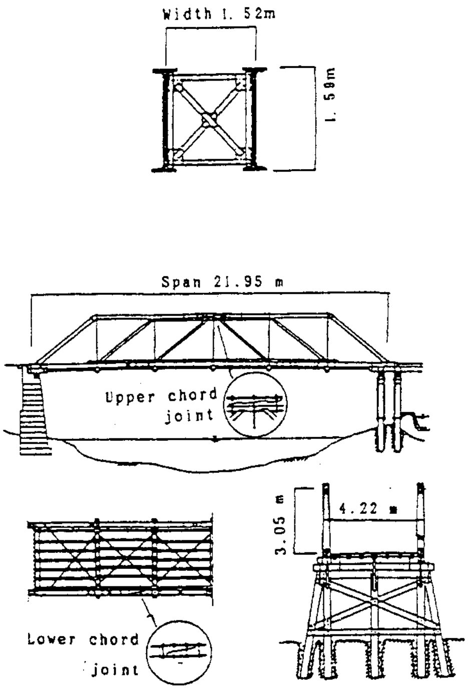

Figure 6 Timber Howe Truss (Gunma1892)

This figure was drawn by the author according to "Drawings of Timber Bridges, Vol.2", 1893.[12]

C. A. Pownall (1827-?) an engineer from the U.K., designed a standardized steel railway plate girder with a length that could range from 20 to 80ft. in 1893. But after he returned to the U.K. in 1896, the British type was replaced by American methods. In 1902, standardized steel plate girder bridges were designed by a Japanese engineer, Bunzo Sugi. These were of the American type and one of them, a 60ft plate girder, is shown in Fig. 7.[13]

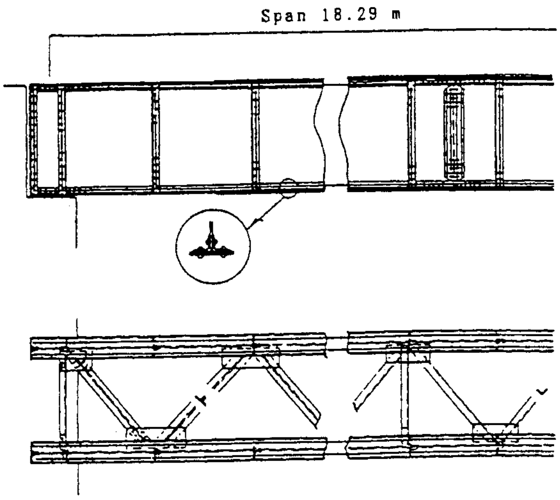

Figure 7 60-feet Standardized Steel Plate Girder (1902)

This figure was drawn by the author according to "A History of the Railway Bridges in Japan, 1934.[11]

4 CONSIDERATIONS

4.1 Comparison of Bridges Constructed before and after the Meiji Restoration

One of the biggest differences between conventional bridges and modern ones is in the material. Before the Meiji Restoration, iron was never used for structural purposes. The variety of structural types should also be mentioned as a difference.

The majority of conventional bridges were a simple timber girder and there were no structures like trusses before the Meiji Restoration. These differences show the most significant western influence on bridge technology in modern Japan.

There are also clear differences in details of structures. Fig. 8 shows the joint of timber bridges of conventional and modern bridges. Joints of the modern bridges are much complicated than the conventional ones.

Regarding substructure brick well foundation, brick abutment and iron pile with screw were never constructed before the Meiji Restoration.

Because of the above developments, the span length of modern bridges had increased even though the live load increased due to railways.

The following conclusions can be stated based on the results of the comparison:

- The Japanese modern bridges erected in the early years were basically constructed by carrying out a sweeping introduction of Western materials, structural technology and other areas of bridge technology. There was clear uncontinuity before and after the Meiji Restoration.
- The comparison of bridges in the early years and middle years of Meiji Era shows that, although there were several changes, such as the increase of domestic production ratio, tendency of practical aspect in design and increase of the scale of constructions, the development of the technology was basically a continuous process without any radical departures.
- The modernization process began with aggressive efforts to introduce advanced Western technology in all areas of bridge construction. This was followed by the development based on the same policy, that is the sweeping introduction and full assimilation of Western technology. This process determined the ultimate direction of modern Japanese bridge technology.

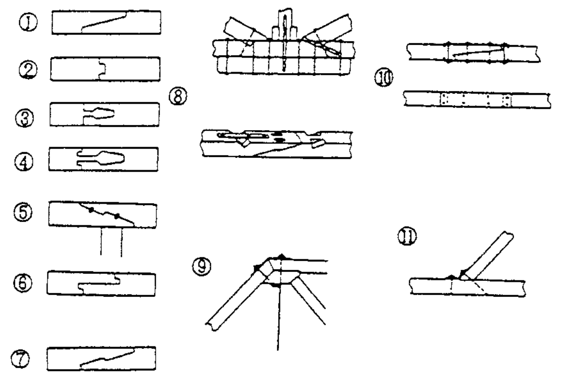

Figure 8 Joints of Timber Bridges

This figure was drawn by the author. 1 to 7 are joints of conventional bridges and 8 to 11 are joints of modern timber bridges.

4.2 Considerations

But why did the modernization of Japanese bridge technology take place in this way? The following attempts to answer this question.

4.2.1 Recognition of the Advanced Characteristics of Western Technology

The advanced characteristics of iron for structural purposes was widely understood and accepted very quickly in Japan.

Orihiko Ishibashi, one of the contemporary Japanese engineers, explained the benefits of using wrought iron as bridge construction material in his book.[14] The allowable stress of wrought iron which was applied for design at that time was five British tons per square in. (790kg/cm^2).[15] This is about 10 times of that of coniferous lumber, such as ceda,r widely used for conventional timber bridges, and if durability was considered it was obvious that iron was so much superior to wood.

As later evidence of the contemporary understanding of the advanced character of Western bridge technology, the shift in their focus from experiential judgments to scientific judgments can be named, which were reflected in the aggressive Japanese attitude toward the study and mastering of the theory of structures and other areas of Western engineering knowledge.

This appeared in the publication of engineering books in Japanese. Bridge engineering books had started to be published as early as in 1890s and the number and contents were sharply increased and widened afterward.[16]

4.2.2 Search for Rationality

The search for rational bridge structures began as a result of a significant increase in design live loads due to railways. The maximum applicable live load of conventional road bridges before the Meiji Restoration was assumed from the calculation based on span, width and cross section of a girders, shown by the reference.[17]

According to the calculation, applicable live load to conventional timber girder bridge was about 440kg/m^2.[18] Because this is almost equivalent to 400 kan per tsubo (455kg/m^2) the live load stipulated in an order issued by the Home Ministry in 1886,[19] it would be incorrect to conclude that the proof stress of the superstructure of a conventional road bridge was necessarily small in the vertical direction.

Turning to railway bridges, the situation was different. There was no such thing as a railway load before the Meiji Restoration. The locomotives running on the Yokohama - Shinbashi line that opened in 1872 weighed 23.08t, which was a unit length of 3.09 t/m^2.[19] Since the estimated maximum applicable live load of road bridges constructed before the Meiji Restoration was 440kg/m^2 as, shown above, if it is assumed that the width was 2 ken(3.6m), which was almost identical to the width of a single track railway bridge, then the applicable live load per unit length was 1.59 t/m^2.

This means that the live load of early railway bridges was equal to twice of the applicable live load of conventional road bridges. This clearly shows that to cope with the double live load was an extremely difficult task for the conventional bridge building method and it was essential to pursue structural rationality.

4.2.3 Durability and Economic Efficiency

It has been already pointed out that there were cases where bracings to resist horizontal forces were not provided in superstructures nor in substructures of conventional bridge technology. But when the Korai Bridge was constructed cast iron piles were braced together to resist horizontal forces such as the impact of boats. This is a clear indication of a new concern with design resistant to horizontal forces.

For other evidence it should be mentioned that contemporary bridge builders were abandoning the past view of bridges as temporary structures and beginning to treat them as highly durable structures for longer life time.

This can be seen in the replacement of wooden girder bridges with stone bridges as well as iron bridges in Tokyo to protect from fire, even though stone bridges were very rare in eastern part of Japan.

A total of 11 bridges including Mansei Bridge(1873), Kyobashi Bridge (1875) and Edobashi Bridge (1875) were rebuilt during a period of five years by skilled masons from Kyushu.

This shift from the long-established belief that bridges were temporary structures to the permanent structure view of bridges conformed with the principles of an economic society; one where the durability of structures is improved in order to increase economic efficiency.

4.2.4 Construction System

The direction of modernization was significantly influenced by bridge construction system. This system was based on the leadership of hired Western engineers as instructors the so-called "foreign experts system".[21]

R.H. Brunton, who designed the Yoshida Bridge, was one of the first Western civil engineers hired by the Japanese government.

During the early and middle years of the Meiji Era British engineers played key roles in the construction of bridges, mainly on Honshu. The engineers assigned work in Japan to others who remained back home, and fabricators in Britain formed an organic system to construct bridges in Japan.

This was similar pattern that was adopted in India, Australia, and other countries where railway construction was also influenced and developed by Britain.

During the period when the Muko River Bridge and other first generation modern railway bridges were erected, John England (1822-1877) served as a chief engineer and played a key role in British - Japanese bridge construction system. Based on England's basic designs, W. Pole (1814-1900), who had a contract to serve the Japanese Government as a consultant in 1871, prepared detail designs in U.K. The bridge members were then fabricated by British manufacturers and exported to Japan.

Other major British engineers hired by the Japanese Government and who helped compose the system were R. V.Boyle (1822-1908)[22] R. Shervinton (c1827-1903), W. F. Potter (1843-1907)[23] and C. A. Pownall (1827-?).

4.2.5 Engineering Education

Engineering education was also a proof of people's awareness of the advanced nature of Western technology. Engineering education, including bridge engineering, began shortly after the Meiji Restoration and institutes and schools were established accordingly.

One of the earliest ones was "Koubu-Daigaku" (the Imperial College of Engineering) established under the jurisdiction of the Ministry of Engineering. Henry Dyer (1848-1918) played a key role in the establishment of the curriculum of the college.[24] It was recognized that education in Western technology was supported by Japan's traditional respect for learning. Evidence of this tradition can be seen in the existence in the early Meiji Period of 230 Han (clan) schools, countless private schools and other institutions.

5 CONCLUSION

The modernization of Japanese bridge technology was not initiated by blending traditional bridge building methods with Western technology, but rather through the introduction of Western technology.

This process was clearly driven by changes in design concepts which occurred as a consequence of an awareness of the advanced state of Western bridge technology, the superiority of iron as a structural material and the rationality of structural methods. The approach which Japan followed for the development of bridge technology, and the wholesale introduction of Western bridge technology were part of the modernization efforts to increase national production and strengthen the nation by introducing the industrial strength of the Western countries.

Another factor was the ability of the people at that time to quickly assess Japan's conventional bridge building methods and gain an accurate understanding of the newly introduced Western bridge technology.

This ability owes a great deal to the positive attitude of the people of the early Meiji years, itself a product of their enterprising spirit and unfettered emphasis on practicality.

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18. $\overline{W} = 4bh^2\sigma / 3\ell^2 x \, 7/B \, x \, 7/n = 489 kg/m^2$,
$Weire = \overline{W} - Wdead = 489 - 50 \neq 440 kg/m^2$

    where, B: Road Width, 7.2m, n: Number of Girders, 5, b: Width of girder, 24.2cm, h: Depth of Girder 39.4cm, l: Span, 8.0m,: σ ; Allowable Stress, $90 kg/cm^2$.

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