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HISTORICAL STUDY ON THE DEVELOPMENT OF BRIDGE ERECTION TECHNOLOGY IN MODERN JAPAN

Hiroshi ISOHATA [1] and Yoshio HANZAWA [2]

[1]Member of JSCE, Dept. of Steel Structure, NKK Corporation (1-1-2,Marunouchi, Chiyoda-ku,Tokyo,100,Japan)
[2]Member of JSCE, Dr.of Eng.,Professor, Dept.of Transportation Eng.,Nihon Univ. (7-24-1, Narashinodai, Funabashi,Chiba,274,Japan)

With the opening of the country brought about by the Meiji Restoration (1868), modern bridge building in Japan got off to start with a full assimilation of Western technology.With a comparison of bridge-related technologies between Japan and other nations forming a contextual background, we examine in this paper the history of the establishment of bridge technologies -- or, more specifically, bridge erection technologies -- in modern (post-1868) Japan.

***Key Words** : structure, bridge, modern Japan, technology transfer*

1. WESTERN BRIDGE BUILDING TECHNOLOGY IN THE 19TH CENTURY

The two developments having the greatest impact on the development of bridge building technology in the 19th century were the wide-spread construction of railways and the advancement of ironmaking technologies. From the early years of the century into its latter half, Great Britain and other advanced nations 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 the second half, wrought iron, used in place of cast iron as a structural material, was itself pushed aside by steel,produced in large quantities and at low prices by the Bessemer convertor process, a new method of pig iron refining discovered by Henry Bessemer, and by other advancements in steelmaking technology.

Until the appearance of the first iron bridge in Great Britain at the end of the 18 th century[1], most relatively large bridges were comprised entirely of masonry arches and were erected utilizing falsework over their whole length. Some of the first generation of iron bridges too were constructed with this method. However, because of iron's relatively high strength-to-weight ratio,its ability to be fabricated into large erection blocks, the freedom it offers in terms of shape peripheral technologies, a variety of erection methods came to be developed. Indeed, the major methods of erection seen today were

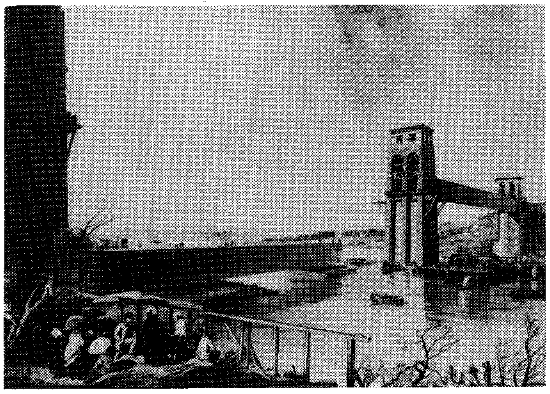

Fig.1 Construction of Britania Bridge (Completed in 1850)
(Presented by Mr C R Jones,Posford,Pavry & Partners,U.K.)

already in use by the time that Japan opened its doors to the outside world in the latter half of the 19th century.

The Britannia Bridge designed by Robert Stephenson(1803-1859), an early box girder bridge built in Wales and opened in 1850, was erected by raising blocks pre-assembled at near site²⁾. The blocks -- the heaviest of which weighed 1800 tons -- were composed of members sent by barge from a shipyard in London. This was done with hydraulic jacks(**Fig.1**). Similar tubler bridge had been built by Stephenson at Conway two years before the completion of the Britania Bridge. This bridge, still in service has a single span of 400 feet formed by two box girders weighting 1300 ton respectively³⁾. The Royal Albert Bridge, designed by Isambard Kingdom Brunel (1806-1859), a pipe arch structure completed in 1859, was erected using a similar method⁴⁾.

The whole arch spans were assembled at site and floated out by pontoons. The arch was positioned between piers and lowered to put on the piers by admitting the water to the pontoon. The archs were lifted in increments of 3 feet at each end, followed by the construction of masonry of the pier⁵⁾. For the erection of the Maria-Pia Bridge in Portugal in 1876 through 1877 and of the Garabit Viaduct in France in 1880 through 1885, Gustave Eiffel(1832-1923) used a large-scale implementation of the cable erection method⁶⁾. Already the method had been established to erect arches over deep valleys and inlets (**Fig.2**).

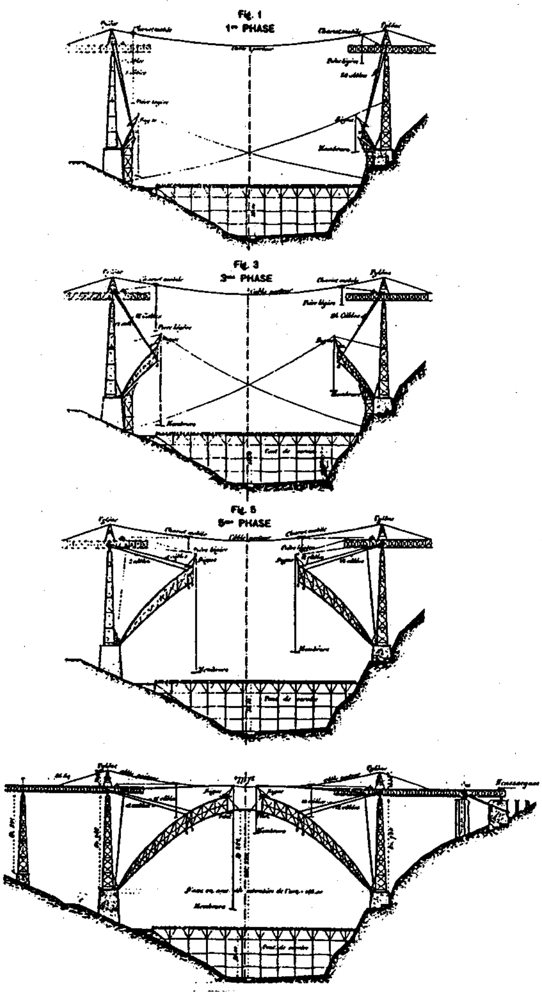

Fig.2 Construction of Garabit Viaduct (Completed in 1885)
(Source: "La Tour Eiffel - Un Message de 100 ans Architecture,Mode,Peinture⁶⁾ ",Tokyo Station Gallery,1990, p.53)

The Eads Bridge, completed by the American engineer James Buchanan Eads (1820-1887) in 1874, was the first to use steel. For its erection the cantilever method was used (**Photo.1**)⁷⁾. The cantilever method was also employed on a large scale in the erection of the Forth Railway Bridge

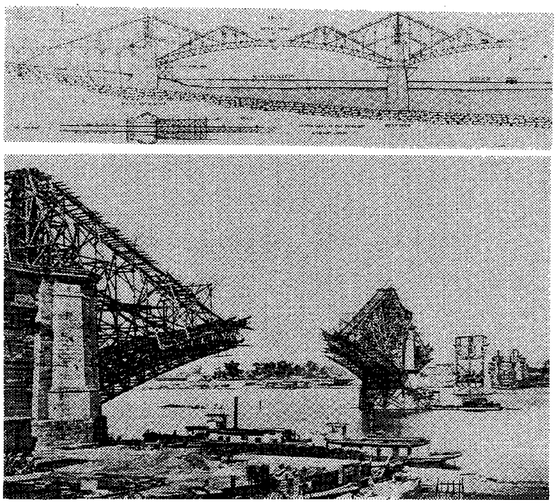

Photo.1 Construction of Eads Bridge (Completed in 1874)
(Source : "Civil Engineering(Special Issue)[7)] ASCE,1975-77,p.45)

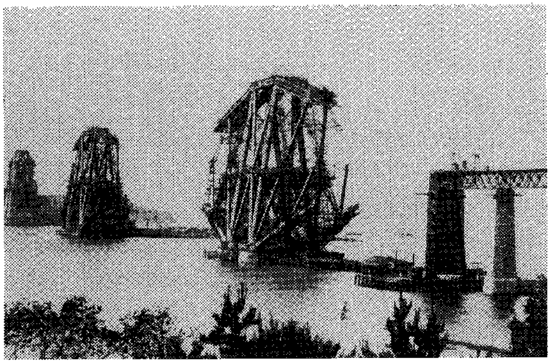

Photo.2 Construction of Forth Railway Bridge (Completed in 1890)
(Source: "Bridge Across the Century[9)] ", Moubray House Publishing Ltd,1985,p.25)

in Scotland from 1887 through 1889 (Photo 2)[8), 9)]. The construction of this bridge, designed by John Fowler(1817-1898) and Benjamin Baker(1840-1907), was commenced in 1883 and both central spans and side spans were extending out from central supports. It is interesting to note that a number of items indispensable for bridge building today -- including travelling platforms, an assortment of cranes, safety devices and an incredible number of fixtures -- were first developed for use in the construction of this bridge[10)]. Also, Kaichi Watanabe (1858-1932), who was studying in Scotland at the time, participated in the project as an assistant engineer. He graduated Imperial College of Engineering, Tokyo in 1883 and came to UK to study at Glasgow university after one year career of Railway Department of Japan[11)]. He was one of the early engineers who made great contribution to modern bridge engineering in Japan.

In Germany, Anton Rieppel(1852-1926) too utilized the cantilever method to erect the Müngstener Bridge, an arch bridge.

The work was carried out from 1894 through 1897[12)]. This method was first applied in Japan 16 years later in the construction of the Aganogawa-Kamanowaki Bridge in 1913 (**Photo.4** appeared later on)[13)].

2. THE TRANSFER OF BRIDGE ERECTION TECHNOLOGY TO JAPAN

The latter half of the 19th century marked the first era in which technology was widely transferred on a global scale. The flow of bridge technology from Great Britain, spurred on by exports of iron girders and by the overseas dispatch of railway engineers, had a large impact on bridge construction practices overseas. There were a number of factors behind this, including a desire to stimulate demand for railway-related equipment, an increase in export pressure brought about by heavy investments in related industrial facilities with a corresponding rise in production capacity back home, and imperialism policies.

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. For example, in 1856 W.G. Armstrong & Co. sent 4000 tons of 28 spans of 150-foot lattice girders for the East

India Railway: and British railway construction companies, setting up shop in such cities as Calcutta and Bombay, busily built bridges with iron sent from the home country[14). This 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[15).

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 Great Britain, 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 one country that was heavily influenced by the influx Western bridge technology. Indeed, this flow of technology into Japan can be considered as one of the most significant technology transfers from the West to the non - West that has occurred in modern times.

3. THE DEVELOPMENT OF BRIDGE ERECTION TECHNOLOGY IN JAPAN

(1) Bridge Erection in the Early Meiji Era

The early Meiji Era was a period in which efforts were made to quickly introduce these rapidly developing Western bridge erection technologies by implementing construction projects under the direction of large numbers of European and American engineers working on contract, by sending students to study overseas, and by filling out engineering education programs at home. In 1869, the Kurogane Bridge (wrought iron plate girder,span:21.8m), the first iron bridge in Japan, was erected in Nagasaki. This was followed in the same year by the Yoshida Bridge (wrought iron truss girder, span:23.6m) in Yokohama. No records remain that describe how either bridge was erected, although both of them were fabricated in Japan with imported wrought iron from Great Britain.

Work on the first railway bridge began in 1870. Back in those days, iron bridges were fabricated almost entirely from imported materials, which means that the introduction of bridge building technologies began with those related to assembling and erection.The Shinbashi - Yokohama railway, opened in 1872, had a bridge made entirely of wood over the Rokugo River (the Tama River). However, after three years in service, work began on the replacement of wooden girders, which had already begun to rot, with iron girders; and, from about this time, certain types of plate girders came to be manufactured domestically. R. Boyle, one of the British engineers who were involved in the project, wrote an paper about the project.[16) In it, he describes how the work, which extended over 17 months from 1875 to 1877, was carried out with 910 tons of wrought iron imported from Great Britain, including 24 spans of 40 - foot (12 m) girders and six spans of 100 - foot (30 m) warren trusses. These members were assembled by riveting at a yard near the site then erection work was done with goliath cranes.

William.F.Potter(1843 - 1907),another British engineer who participated in railway bridge construction projects, reported that, in the construction of a railway between Osaka and Kyoto begun in 1873, 100 - foot truss girders for a bridge near Sojiji, were assembled by riveting in a yard near Kanzaki River Bridge, about six miles distant, and transported to the site over a previously laid tracks¹⁷⁾. The trusses were then put into place with wooden erection girders. This is believed to indicate that a yard created for the assembling of the Kanzaki River Bridge was also used to assemble trusses for the bridge near Sojiji as well. According to K. Kubota's report¹⁸⁾, we have "...each truss was assembled off the bridge and erected into position by goliath crane." Truss girders were also erected over the Muko River and other sites on a railway between Osaka and Kobe begun three years earlier, but no records of the construction method remain. Even so, a photograph taken at the time¹⁹⁾ shows trusses girders being assembled on the ground next to the piers. We can infer that, just as with the bridges on the Osaka-Kyoto railway and the Rokugo River bridge on the Shinbashi-Yokohama railway, erection was done with goliath cranes and with the sliding-out method.

Road bridges of the early Meiji Era include, in addition to the Kurogane Bridge and the Yoshida Bridge, a suspension bridge built in 1870 at the Fukiage Gyoen section within the Imperial Palace. According to "Suspension Bridge in the Mikado's Pleasure Ground, Yedo," an article appearing in an 1873 issue of "Engineering"²⁰⁾, the bridge had a total length of 234 feet (70.2m), a breadth of 17 feet (5.1m), a clearance of 60 feet (18m), and a height of 64 feet (19.2m). The towers were made of brick, and the wires were of made of zinc-plated wrought iron. Storm cables were attached. It is said that the bridge was erected by Thomas. J. Waters, British engineer, although the details of the erection method are unclear (**Fig.3**).

346 ENGINEERING. [MAY 16, 1873.

SUSPENSION BRIDGE IN THE MIKADO'S PLEASURE GROUNDS, YEDO.

CONSTRUCTED FROM THE DESIGNS OF MR. T. J. WATERS, SURVEYOR-GENERAL TO THE JAPANESE GOVERNMENT.

(For Description, see Page [illegible].)

Fig.3 Yamazato Suspension Bridge (Completed in 1870)
(Source: "SUSPENSION BRIDGE IN THE MIKADO'S PLEASURE GROUND, YEDO", Engineering²⁰⁾ ", London, May 16, 1873, p.346)

(2) The Development of Erection Methods

In the early Meiji Era, bridge erection was done under the direction of Western engineers with Western technologies utilizing bridge members imported from the West. Yet, with subsequent efforts to train Japanese engineers and to expand the domestic infrastructure, various methods of erection began to be developed along Japanese lines. Outlined below is the history of the development of the major erection methods.

a) All Staging Method²¹⁾·²²⁾

The all staging method was commonly used to erect railway girder bridges. Staging (scaffolding) was built from the ground up over the entire length by positioning logs in an approximately 1.8 meter square crisscross pattern. Diagonal members were placed to provide rigidity, and the structure was secured with rope, bolt, wire or cramp. Bridge girders were either assembled in place on top of the staging or else pre-assembled in a yard and pushed into position. For the conditions of the Meiji Era -- namely, relatively shallow clearances and an inexpensive supply of logs -- this method was highly effective and economical. However, toward the end of the Meiji Era, railways began to extend out into more rugged, mountainous regions and advances in materials offered engineers a wider choice of erection methods. As a result, this method gradually fell into disuse. One large-scale application of the all staging method was the Amarube Viaduct on the Sanin Line. This bridge was completed in 1912[23].

b) Goliath Crane Method[24), 25), 26), 27)]

The goliath crane method was often used to erect railway trusses in the Meiji Era -- for example, it was employed in the construction of the bridge near Sojiji on the Osaka-Kyoto railway and in the girder replacement work for the Rokugo River Bridge on the Shinbashi - Yokohama railway in the early 1870s. This method was also employed in the construction of the Arakawa river bridge on the Tokyo-Takasaki railway in 1885[28]. **Fig.4** shows the erection of truss girders of the Arakawa river bridge by goliath cranes. When 200-foot trusses,designed by Charles A. W. Pownall, began to be erected later on, this method was usually employed for that too. In the early years, an assembly yard would usually be placed on the river flood plain directly underneath the bridge site. Tracks were laid alongside on the ground. Large cranes running along these tracks would then be used to lift the assemblies into place. The goliath cranes used for this had wooden frames; and the gears, racks and other parts were imported from Great Britain. Usually the cranes were assembled on-site.

Toward the end of the Meiji Era, the use of American-style pin connected trusses with eye-bars became more common. Here, the cranes would be run along tracks laid on top of the staging. The No. 1 Kiso River Bridge (span: 91.4 m.) on the Chuo Line was built in 1908 with this method (**Photo.3**)[29), 30)]. As the erection girder method came into use in the mid 1910s, goliath cranes were often run on top of the erection girders.

The goliath crane method was the most common for the erection of trusses in Japan for the period extending from approximately 1870 to 1920. Afterwards, however, the use of other methods became more common.

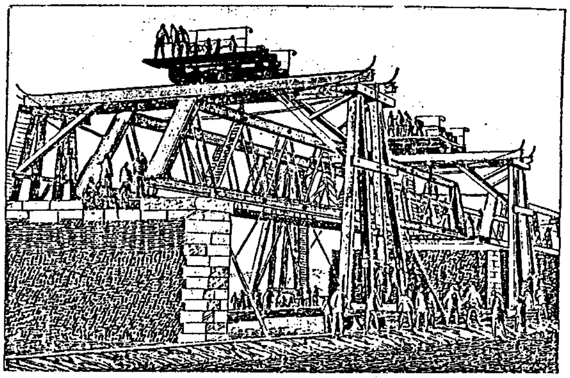

Fig.4 Goliath Crane Method.used in the Arakawa River Bridge in 1885
(Sourse:"Kougakukaishi(Journal of Japan Society of Engineering)[25] ",Vol.49, 1986, p.760)

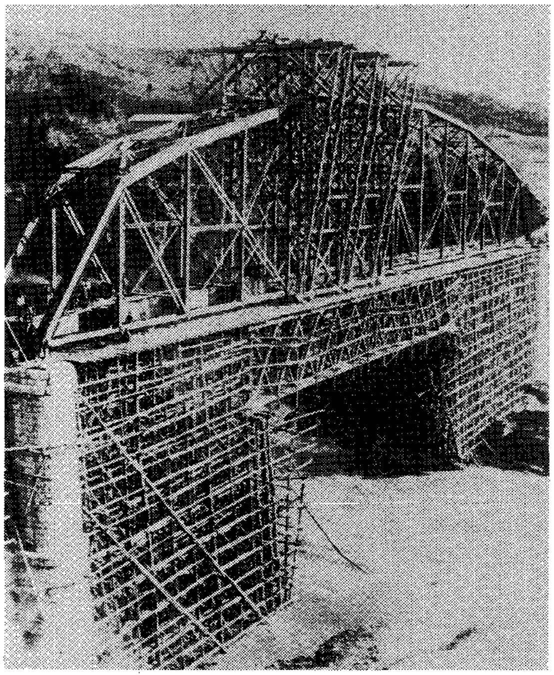

Photo.3 Construction of No.1 Kiso River Bridge (Completed in 1908)
(Source:"Nihon no Hashi(revised version)[29] ", JASBC,June 1994,p.77)

c) Sliding-out Method[31), 32)] **(including Launching Method and Mast Method)**

In the sliding-out method, girders assembled in a yard near the erection site are pushed or pulled into place on the bridge. There are several variations on this, including the launching nose method, the "jurenshiki" method--girders are connected temporarily while sliding out--, the erection girder method, and the mast method. In the Rokugo River Bridge girder replacement work, begun in 1875, trusses assembled on the south bank were projected over the river for the outer ends to be supported by boats and pulled into place to be erected by goliath crane[33). This is believed to mark the earliest application of the sliding-out method. The jurenshiki method was used in the 1908 construction of the Ohtaki River Bridge on the Chuo Line. Two spans of 18.3-meter plate girders were connected each other, fit with counterweights, and pushed into place with locomotives. Likewise, in the 1927 construction of the Arakawa Bridge on the Tohoku Line,seventeen spans of 60-foot (18.3 m) plate girders were erected after being pin-jointed and fit with a launching nose. The mast method was used to erect the No. 2 Takikawa Bridge (Joetsu Line) in 1920 and, in 1932, the Kanda River Bridge between Ochanomizu and Ryogoku in Tokyo.

d) Cantilever Method34), 35), 36)

From about 1910 onward, railway construction gradually shifted from the coast to the interior; as a result, more and more bridges had to be erected in mountainous areas. The cantilever method, along with the cable erection methods describe later, was adopted as a way to cope with these new conditions. The first application of the cantilever method to a railway bridge in Japan was in 1911 at the Aganogawa-Kamanowaki Bridge on the Gan-etsu Line completed in 1913 37). Traveller cranes were used to erect the 91 meter long central span using the side spans of trusses as anchors (**Photo.4**). In 1928, the method was used to erect the No. 1 Shirakawa Bridge on the Takamori Line, one of the first large scale steel arch bridges in Japan, a total length of 152.5 m. with three spans incliding a central span of 91.5m38).

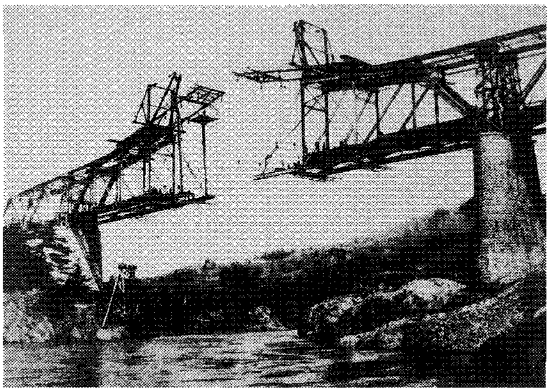

Photo.4 Construction of Aganogawa-Kamanowaki Bridge(Completed in 1913)
(Source: "Nihon no Hashi (revised version)35)", JASBC,June 1994,p.80)

e) Derrick Crane Car Method39), 40), 41), 42)

The derrick crane car method was first applied in 1919 as a means to continuously erect a number of deck plate girders for the construction of the Nippo Line. This was an improvement on an earlier method utilizing locomotive-mounted derrick cranes and first used on the Oita - Usuki section of the Nippo Line in 1913 by Mitsuo Nawa(1869-1960) who first developed the method43). In the derrick crane car method, each girder would be moved into place while suspended from a derrick crane. That is, the front end of the girder would be suspended in the air by the derrick boom, while the back end would rest on a cradle placed on the front of the derrick car. It is said that with this method, four spans of plate girders could be erected in a day. It should be also mentioned that the Shimoyodo River Bridge between Osaka and Tsukamoto was erected by launching method merged with this derrick crane car method in 193544).

f) Cable Erection Method45), 46)

The use of cable cranes in the construction of dams in Japan goes back to late 1800s, although it was not until the 1926 construction of the Ohta Bridge(highway

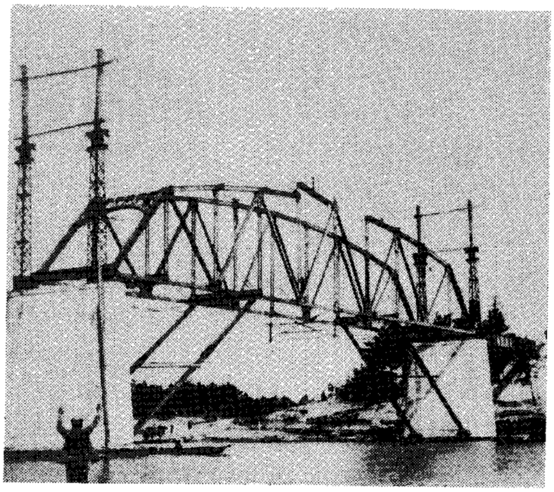

Photo.5 Construction of Ohta Bridge in Gifu (Completed in 1926)
(Source: "Nihon no Hashi(revised version)[45] ",JASBC,June 1994,p.81)

bridge) in Gifu Prefecture that they were first employed in bridge building (**Photo. 5**). This was followed in 1927 by the erection of the Shinanogawa Bridge on the Iiyama Line in Niigata Prefecture and in 1928 by the erection of the No. 3 Nagara River Bridge on the Takayama Line. These three bridges were comprised of truss girders. Cable erection method with vertical hanger cables was devised in Japan and first applied in 1933 to 77.5-meter trusses in the construction of the No.2 Yoshino River Bridge (Tosan Line)[47], [48].

g) Pontoon Erection Method[49], [50], [51], [52]

The pontoon erection method utilizes barges to lift the bridge sections into place by tidal action or to support one end of a bridge section as it is pushed into place. This method too has long been in use in the West for the erection of iron bridges. According to Kubota, in "A History of the Railway Bridge in Japan", construction of the Kiyosu Bridge and the Kototoi Bridge over the Sumida river in Tokyo was carried out in 1925 by placing the bridge sections on barges and lifting them into place with the tide. This was done in conjunction with work to rebuild Tokyo after the 1923 Great Kanto Earthquake. Kubota also claims in his work that the Kiyosu Bridge is the first -pontoon erected bridge in Japan. Other railway bridges built with this method include the Rokkaku River Bridge, a series of 46.9-meter trusses erected in 1929, and the Shiotagawa River Bridge, a series of 62.4-meter trusses erected in 1930. Both are on the Nagasaki Line. After assembling at a yard, the bridge sections were erected by placing one end on a barge, pulling it into place during high tide, and then waiting for the tide to ebb. The Chikugo River Bridge(1934) on the Sage Line[53] and the Nagahama Highway Bridge in Ehime(1935)[54], [55] were other examples erected by this method.

h) Side Removal Method and Flip Replacement Method[56]

These two methods were devised as means to replace bridge girders. The first, the side removal method, was used on the Chitosegawa(Chikugogawa) River Bridge (Kagoshima Line) and the Ogawa Bridge and the Natorigawa River Bridge(Tohoku Line) in the early 1910s[57]. Staging was placed alongside the old girders, and new girders were assembled on top.The old girders were then removed by shifting them sideways. Many bridges have since been rebuilt with this method.

To accommodate an increasing demand for girder replacement work on older bridges, the flip replacement method was devised in 1931 by an engineer working in the Nagoya District. New girders, attached with rails, would be moved into position upside down. Then, after being secured, the unit would be flipped over to drop the girders into place. After the war, this method was applied to girder replacement work on the Saruta River Bridge (Uetsu Line) in 1951 and, since then, to a number of other bridges.

4. CONCLUSION

Up until about the 1890, most bridges

built in Japan to accommodate the growing railway network were erected on relative flat land. For this, the goliath crane method was often employed. From the 1890s onward, it became not at all unusual for projects to be advanced by domestically educated Japanese engineers alone; and the bridge building technologies that they acquired through the implementation of the goliath crane method served them well in the subsequent development of other, more advanced erection methods, including some devised in Japan.

In the early Meiji until 1870s, almost all the bridge design works were carried out under the direction of western engineers and most of girders were imported from western countries. On the other hand, erection was the first modern bridge technologies experienced by Japanese. Erection of bridges as well as construction of railway needed a lot of local people and at the same time it presented chances of training through the works.

In 1878, Kyoto - Otsu railway construction was commenced by only Japanese. the Kamogawa Bridge on the line was the first railway plate girders designed and erected only by Japanese. After 1890s, graduate Japanese engineers educated by modern engineering system started to take important part.

From about 1910 onward, there was a general tendency to build bridges in mountainous regions in the interior. Required to handle the technical difficulties involved were more sophisticated methods, such as the sliding - out method, the cantilever method, the cable erection method, and the pontoon method. In testimony to the establishment of Japanese bridge building technology, it is interesting to note that the cable erection method with vertical hanger cables, the crane erection method, and the derrick car erection method were all modified in one way or another by Japanese engineers. They did not stop at simply applying developments in bridge technology thirty years or so after their Western originators, but instead worked to develop and improve the techniques to meet their own needs. These development of bridge technologies were dependent on various industries such as iron making, mechanics and others as well, which had been also developed by introduction western technologies.

The work done to replace road bridges damaged in the 1923 Great Kanto Earthquake could be called the culmination of the study and assimilation of technical knowledge acquired from the West from the 1870s onwards.

And, looking from the perspective of erection technologies, we can see that the latter half of the 1920s marked the period in which Japanese bridge technology became firmly established in its own right. In the background of this rapid development of erection technologies, we cannot ignore the will of independence of Japanese engineers from the western countries even though they relied on the western knowledge.

5. POSTSCRIPT

In studying the history of Japanese bridge technology, it is especially important to examine the connection with the West in how it relates to the introduction of technology. That is, the link with the West cannot be ignored in any treatment of the technological development of Japan.

When Japan open its door to western countries at the latter half of 19th century almost 80 years had past since iron started to be used for the purpose of structural members. Railway locomotive engines were also new as live load for bridges. Japan had chosen to introduce western technologies in order to catch up with forerunners. This was the common attitude towards the western advanced technologies in every field and recognized as national policy.

Therefore the western influence was very important factors for the establishment of the bridge technologies in modern Japan.

Here, to advance the historical study of Japanese bridges, we must continue to work with our fellow researchers overseas.

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近代日本における橋梁架設技術の発展について

五十畑弘・榛澤芳雄

本論文では近代日本における橋梁技術の確立の過程について特に架設技術の面から欧米からの技術導入の影響を考慮しつつ歴史的な考察をするものである．先ず我が国開国前後までの欧米における橋梁架設技術について述べ，これらがどの様に非欧米諸国に技術移転されていったかを論じる．次いで，これらの技術移転の一つである我が国の技術導入が橋梁架設技術についていかに行われたかを明らかにする．その後，各橋梁架設工法ごとに架設技術の発展について述べ，最後に近代日本の橋梁架設技術の経過について考察する．

3次元地質解析システム

未来設計企業
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GEORAMA

プログラムの概要

GEORAMAは、フィールド調査で得られたデータ（ボーリング等）を編集、それを基に推定を行い、**3次元地質モデル**を構築します。そして出来上がったモデルから図面（**地質・岩級・地下水位図等**）の出力、土工計画（**法面の設計、土量計算、斜面安定計算**）への利用、**地盤ＦＥＭ解析**（３Ｄメッシュジェネレート）のプレ処理を行う地盤のための総合的なシステムです。

プログラムの機能

- マルチウインドウでの図化表示、データの表形式入力（コピー・ペースト機能）、データ位置のマウス・デジタイザ入力等により３次元地質モデルの構築をグラフィカルな環境の下でインタラクティブに行うことができます。
- 出力図面としては、地形・地質・岩級・地下水位・柱状図等を水平・鉛直・任意断面または３次元的に図化できます。またブロックダイアグラムやパネルダイアグラム、**ルート沿いの地質断面図**出力も可能です。
- デジタイザを利用することにより地形図、地質断面図、平面図の形状をデータとして取り込むことが可能です。
- 節理データの処理として**ステレオネット投影**、図の作成及びクラスタリング計算による方位、分布の解析、任意断面での節理方向の表示が可能です。
- ボーリングで入力した各種物性値を任意断面図、または３次元のコンターとして表示し、その分布傾向を判断できます。

プログラムの特徴

- 地層面の推定では、地形の傾斜方向の考慮、走向・傾斜データの利用、データ分布が密な地域でのさらに詳細な推定等を行うことができます。
- 地質構造の表現として**不整合や貫入、断層、レンズ層**等を年代を考慮して表現できます。
- モデルの修正は、画面上の断面図で行うことができます。修正された断面は、３次元地質モデル全体に反映されるので**各断面図間の整合性を保つ**ことができます。

土工計画への利用

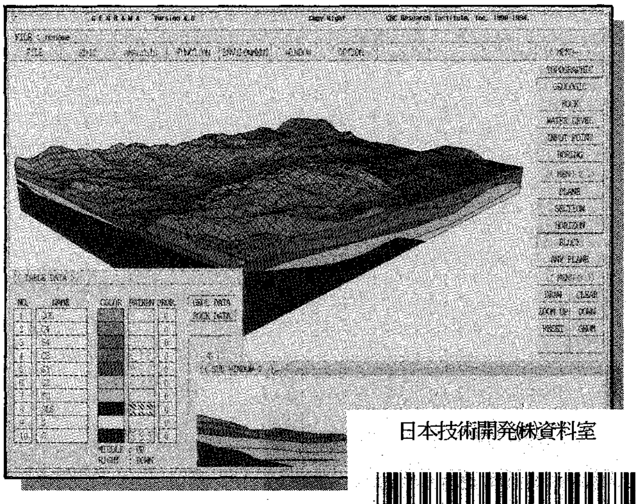
GEORAMA／V

- 複数の法面を**施工段階ごとに作成**し、その状態での地質図を確認することができます。
- 切り盛りした土量は、地質ごとに出力し、各種のグラフでみることができます。
- 作成した法面での**斜面安定計算**を行います。

ＦＥＭ解析への利用

GEORAMA／G

- 作成した地質モデルから３次元のＦＥＭ解析用の**地盤メッシュ**を地層の境界を考慮して作成することができます。
- トンネル等の構造物のメッシュを作成し、地盤のメッシュとリンクすることができます。



株式会社CRC総合研究所

- 西日本事業部　科学システム
〒541 大阪市中央区久太郎町
- 科学システム事業部　営業
〒136 東京都江東区南砂2-7-

土と水の連成逆解析プログラム

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応力解析と浸透解析がドッキングした！

軟弱地盤の解析に！

海洋開発・埋立

盛土・掘削

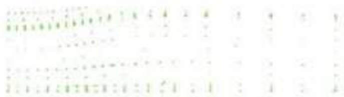
出力項目

- ●各節点での変位、各要素での応力
- ●各節点での全水頭・圧力水頭 他
- ●豊富な図化処理
  変位図、変位ベクトル図、応力ベクトル図、応力コンター図、安全率コンター図、水頭コンター図、圧力水頭コンター図

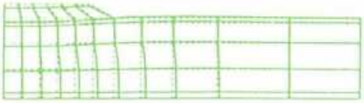
プログラムの特長

- ●応力と地下水の流れをカップルさせた問題が解析可能です。（圧密含む）
- ●地下水の流れは飽和・不飽和域を対象としています。
- ●多段掘削・盛土や降雨等が扱えます。
- ●梁や連結要素も扱え実用的です。
- ●経時観測記録（変位・水位）があれば、非線形最小二乗法に基づき変形係数や透水係数が逆解析できます。（順解析、逆解析がスイッチにて選択可能です。）
- ●弾性・非線形弾性・弾塑性・弾粘塑性を示す地盤が扱えます。
  非線形弾性（電中研式、ダンカン・チャンの双曲線モデル）
  弾塑性（ドラッガー・プラガー、モール・クーロン、カムクレイモデル、ハードニング、ソフトニング）
  弾粘塑性（関口・太田モデル）

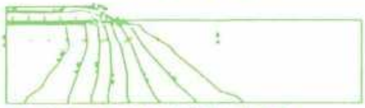
応力増分コンター（$\Delta\sigma$ V）
（10日後）



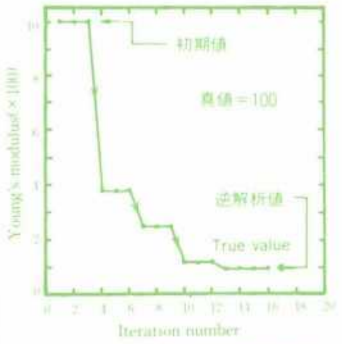
変位ベクトル図（40日後）



盛土（40日）後の地盤の変形



盛土（40日）後の地下水の流れと水頭コンターおよび自由水面



ヤング率と繰り返し回数の関係

逆解析によるパラメータの推定

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●西日本事業部　科学システム営業部／担当：岩崎
〒541 大阪市中央区久太郎町4-1-3 TEL:06- 241-4121

●科学システム事業部　営業第１部／担当：澤村
〒136 東京都江東区南砂2-7-5　TEL:03-5634-5790

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