PLAN AND DESIGN OF 'THE RINKAI OHASHI BRIDGE' IN TOKYO PORT

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ABSTRACT

'The Rinkai Ohashi Bridge' is a 440m span bridge crossing the shipping lane at the entrance to Tokyo Port, the largest container port in Japan. The bridge type is a truss bridge, which is uncommon among recent long span bridges, and the bridge has a unique form that is different from that of truss bridges of the past. This paper introduces the features of this bridge, which has created the modern appearance of a truss bridge, including the new technologies used in its planning and designing.

INTRODUCTION

Tokyo port is the largest container port in Japan with a throughput of around 4 million Teus. To enhance hinterland transportation, one axis freeway across the heart of the port has been developed from early 1990's. At present, construction phase 1, crossing the western fairway by underwater tunnel, was already completed and phase 2, crossing the eastern fairway by long-span bridge, is under construction to be opened in the middle of 2011. (See Fig.1)

Fig. 1: Location map

This long-span bridge, tentatively called 'the Rinkai Ohashi Bridge' meaning harbor-front main bridge, was planned and designed deliberately to overcome many technical difficulties.

As a result of many studies in both structural and aesthetic fields, 'the Rinkai Ohashi Bridge' was decided to be truss box-girder hybrid-bridge of steel structure.The whole length of this unique bridge is 760m, with main span of 440m and two side spans of 160m respectively.

BRIDGE TYPE OF THE RINKAI OHASHI BRIDGE

Table 1 shows the structure of the Rinkai Ohashi Bridge.

Tab.1: Structure of the Rinkai Ohashi Bridge

Total width	21.1m (4 vehicle lanes + 3m sidewalk on one side)
Bridge length (span lengths)	760m (160m+440m+160m)
Superstructure type	3 span continuous steel truss box-girder hybrid-bridge
Substructure type	RC wall type pier (intermediate piers) RC double column pier (end piers)
Foundation type	Steel pipe-piled well foundation

As shown in Table 2, in 1890 the Forth Railway Bridge (UK) was constructed as the world's longest span truss bridge, and in 1917 the Quebec Bridge (Canada) was constructed which is still the world's longest span truss bridge. However, after the construction of the Ikitsuki Ohashi Bridge (Japan) in 1997, there are no more examples of truss bridges in the world. Recent long span bridges are structures using towers and cables, such as cable-stayed bridges and suspension bridges, etc.

Tab.2: The world's longest truss bridges

	Bridge name	Span length (m)	Year completed	Use	Country	Notes
1	Quebec Bridge	549	1917	Combined	Canada	Gerber
2	Forth Bridge	521	1890	Railway	UK	Gerber
3	Minato Ohashi Bridge	510	1974	Road	Japan	Gerber
4	Commodore John J.Barry Bridge	501	1974	Road	USA	Gerber
5	Greater New Orleans Bridge (East)	482	1958	Road	USA	Gerber
6	Greater New Orleans Bridge (West)	482	1988	Road	USA	Gerber
7	Howrah Bridge	460	1943	Combined	India	Gerber
8	Veterans Memorial Bridge	445	1995	Road	USA	Gerber
9	The Rinkai Ohashi Bridge (tentative name)	440	2011 scheduled	Road	Japan	Continuous
10	San Francisco Oakland East Bay Bridge	427	1936	Road	USA	Gerber
11	Ikitsuki Ohashi Bridge	400	1997	Road	Japan	Continuous
12	Columbia River Bridge (Astria Bridge)	376	1966	Road	USA	Continuous
13	Baton rouge Bridge	376	1968	Road	USA	Gerber
14	Tappan Zee Bridge	369	1956	Road	USA	Gerber
15	Long View Bridge	366	1930	Road	USA	Gerber
16	Patapsco Bridge	366	1976	Road	USA	Continuous

It was against this background that the bridge type adopted for this bridge was the truss bridge, which could be described as an old-fashioned bridge type. This was selected not only for landscape, but structural reasons also inevitably led to its selection. Firstly there are very deep weak soils at the site of the bridge, so it would be difficult to locate the anchorages of a suspension bridge there. Next, the site of the bridge is near Tokyo International Airport, located directly below the aircraft flight path, so the height of the structure was limited to less than 98.1m, and on the other hand it was necessary to maintain a 300m wide × 54.6m high shipping lane as a clearance. As a result there was a restriction on high towers, so a cable-stayed bridge was not suitable. Also, to keep the bridge pier foundations to a practical size, it was necessary to adopt a seismic isolation structure that separated the substructure and the superstructure. To properly utilize the seismic isolation mechanism, it is effective to keep the position of the center of gravity of the superstructure as low as possible, so a truss bridge with deck-type side spans was ideal.

Assuming a truss bridge, a new type of truss bridge was studied in the Working Group for Landscape, based on the basic policy that the structural characteristics should be expressed in its form, with the aim of providing a modern truss bridge. Also, based on the basic themes of "presence as a global gateway" and "symbol of development of the area", a novel design was adopted that combined both the impression of Tokyo Port's gate to the world as well as that of being a landmark.

OUTLINE OF THE STUDY ON LANDSCAPE

Normally the appearance of a truss bridge is massive and complex compared with bridges with other types, so it does not have a modern image, and this is the very opposite of the design image required for this bridge. The main task of the study on landscape was how to design a new truss bridge. From this point of view also it was very desirable to positively incorporate new technologies and materials. The new technologies introduced to create this bridge are described later, but in this section an outline of the study on the landscape of the bridge is presented.

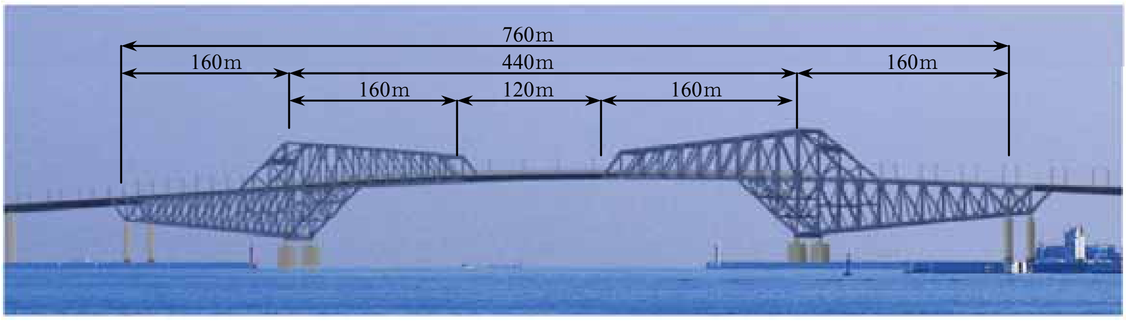

Fig. 2: CG image perspective

In the study on landscape, first as a basic policy it was decided to express a rhythmical and light image, by using the inherent beauty of the truss structure. Therefore gentle curves were avoided, and the bridge was composed completely of straight lines. Also, to express the mechanical characteristics of a continuous truss bridge in its shape, the central piers supporting the central span and the side spans were given a weighty feeling to emphasize the openness of the central span. The end piers were given the image of slender members being pulled down, to express the equilibrium of forces. In the actual structure the truss and the piers are connected by cables at the end supports, as a structure to prevent lifting during an earthquake, so the feelings of stability and tension are skilfully expressed.

In addition, the 120m central section is a box-girder structure, given an open feeling by making it continuous, and the truss structure arranged symmetrically on both sides create the image of a gate. Also, if you zoom out, the straight line connecting the reclaimed islands are emphasized, and various measures are taken such as changing the paint color of the truss members and the girder.

Although there are some people that say that the image of the bridge is that of a dinosaur, there are also those that say it appears to be a bird or a propeller, so it can be said that an excellent design has been produced that embraces symbolism that can evoke various associations, not just that of a gate.

NEW TECHNOLOGIES TO ACHIEVE THE LONG SPAN CONTINUOUS TRUSS BRIDGE

Many new technologies were adopted for the design of this bridge, but firstly to realize this new long span truss bridge it was necessary to reduce the size of the foundations. Since the type of this bridge is a truss bridge, the self weight is large, and the support reaction of the intermediate pier of the bridge per a main truss amounts to 90,000kN. Also, the local ground consisted of deep weak soils, so the structural scale of the pier foundations were impractical. Therefore a seismic isolation structure was adopted, to reduce the forces acting on the pier foundations. However, the scale of the seismic isolation bearings exceeded that which has been achieved in the past, so the structure was made more compact with bearings in which the functions of the vertical load bearings and the horizontal load buffers were separated. Also, the damping effect of the friction force occurring at the sliding surface (teflon plate and stainless steel) of the vertical bearings was included in the design as a damping effect of the seismic isolation mechanism.

Since the coefficient of friction at the sliding surface has the characteristic that it depends on the surface pressure and the velocity, the variation in the coefficient was determined through repeated loading tests, and the results were used in a time history response analysis. Also, by using checkered steel plate in the junction pipes connecting the steel tubular piles of the steel pipe-piled well foundations, the stiffness and strength of the junctions were increased, so the size of the foundations was reduced.

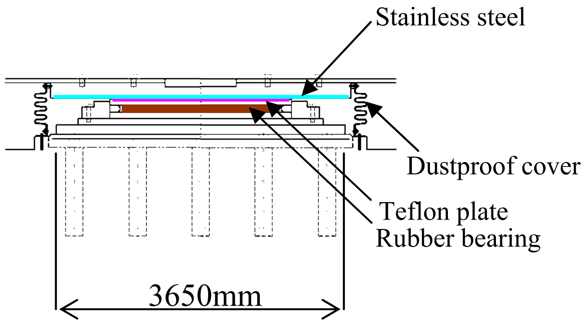

Fig. 3: Vertical load bearing

NEW TECHNOLOGIES TO RATIONALIZE THE TRUSS BRIDGE DESIGN

To design the truss bridge with an economical and sound structure, new technologies were introduced, such as simplification of the superstructure, adoption of rational design methods and use of high performance steel. In addition to these, other new technologies such as compact connections at the nodes of the trusses and adoption of a fully welded structure, which also contributed to the improved appearance of the truss bridge, were introduced.

Simplification of the superstructure

In a conventional truss bridge, the floor system is incorporated above or in the main structure. In this bridge, based on experience with truss main girders of cable-stayed bridges, etc., the floor system was made a steel deck full box cross-section, and a hybrid truss box-girder structure was adopted by combining the floor system and the chord members of the truss. In this way it was possible to omit the bearings for the floor system, and by improving the torsional stiffness of the main structure as a whole, part of the upper lateral bracing and sway bracing could be omitted, so the overall weight was reduced.

Adoption of rational design methods

Almost all civil engineering structures in Japan are designed by the allowable stress design method. In the near future this is due to change to the partial safety factor design method, but it is expected that some time will be required before the changeover is completed. Against this background a design method was adopted that incorporated at least partially the concept of the partial safety factor design method, to arrive at a design that will be compliant with future design criteria, and to achieve a rational design for a long span bridge in which the dead load is a large proportion of the total load. Specifically, by reference to the research results of the Japan Society of Civil Engineers and Load and Resistance Factor Design (LRFD) in the USA, etc., the safety factor for dead load was set at 1.05, and for live load 1.70 in the case of design of a truss superstructure, in other words different safety factors are set depending on the characteristics of the load. The load factor design method would be an appropriate response, but by adopting in advance the future design criteria, a rational design as well as a 13% cost saving were achieved in main truss.

Adoption of high performance steel

By using the newly developed bridge steel BHS500 (Bridge High-Performance Steel) in about 1/2 of the total number of members in stead of usual steel, there was improved welding quality in the high tensile steel, also reduction of steel member weight and facilitation of fabrication process, so a cost reduction in excess of 10% was achieved in truss members. BHS500 is steel similar to HPS485 in the USA, but its yield point is higher at 500MPa, and it is expected that in the future it will become the main steel used for bridges.

Compact truss node connections

Many members intersect at the nodes of trusses, so it is difficult to determine the stress state, so conventionally they were designed very much on the safe side using bolted gusset plates on two sides. As a result the appearance of truss bridges suffered. The dimensions of the box members in this bridge are large, so a structure in which members were joined by welding on 4 sides was adopted, which kept the nodes compact. To adopt this method, the stress distribution was checked by FEM analysis, and the fabricability was checked by a full size fabrication test. Also, by changing from bolted connections to welded connections, the durability of the paint was improved, which contributed to reducing the maintenance.

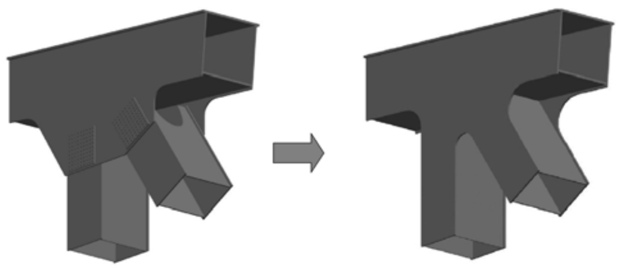

Fig. 4: Structure of the truss nodes

Adoption of fully welded structure

The impression of massiveness of truss bridges comes from the unsophisticated looking bolted joints, so besides making the nodes compact, the joints in almost all the members were welded joints. By adopting BHS steel, the welding operability and the welding quality was improved, but also appropriate detailing was carried out at the design stage to improve the fatigue endurance, such as Z-joints were used for bending members so that the positions of the flange and web welds were shifted, etc., and proper construction controls were implemented to ensure welding quality.

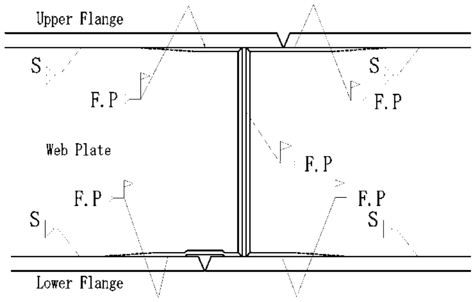

Fig.5: Z-joint

CONCLUDING REMARKS

At present installation of the side spans of the Rinkai Ohashi Bridge has been completed, and installation of the central span is commencing. Fig.6 shows a side span truss girder (lifting load: about 6,000 tons) being lifted into place in one operation with the 3 largest floating cranes in Japan. In August when this conference is being held joining of the central box-girder is scheduled to be carried out, and the bridge is scheduled to be opened 1 year later in summer 2011. It is expected that the new bridge design technology used on this bridge will be used in various ways in bridge construction in the future.

Fig. 6: On-site installation

BRIEF BIOGRAPHY OF PRESENTER

Toru Shigihara

Born	January 14, 1956 (age 54)
March 1980	Completed Master’s course in Construction Engineering at Graduate School of Science and Engineering, Waseda University
April 1980	Joined Central Consultant Inc., mainly engaged on bridge design

At present he is Head of the Bridges Department at the Tokyo Headquarters and Chairman of the Bridges Specialist Committee within the company.