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Future Trans-Strait Road Projects and Technological Issues

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Summary

Creation of new traffic axes for regional revitalization and developments for the coming century requires the construction of super long-span bridges surpassing the Akashi Kaikyo Bridge by 20 to 30 percent. The studies were made so far to realize more economical and rational construction of super long-span bridges. The results have confirmed the possibility of reducing construction cost by developments of new structural types and introduction of new design concepts in place of the construction based on existing technologies. The studies also identified the technological issues to be resolved in the future.

1. Introduction

The Akashi Kaikyo Bridge was completed on April 5th 1998 as a part of the Honshu-Shikoku Bridges project, one of Japan's typical trans-strait road projects. In addition, the Kurushima Bridges and Tatara Bridge are scheduled for completion in the spring of 1999. Then the Honshu and Shikoku will be linked by the three routes as originally planned.

Furthermore, for the 21st century, the plans to develop new traffic axes are proposed in Japan with a view to making effective use of limited nation and building balanced national structure. In addition, a lesson from the Hyogoken-Nanbu Earthquake is the need to create a national structure that allows for certain redundancy. For such backgrounds, trans-strait road projects, as a part of new traffic axes, are being envisaged at such places as the Tokyo Bay Mouth, Ise Bay Mouth, Kitan Strait, Kanmon Strait and so on as shown in Fig.-1.

2. Toward the implementation of future trans-strait road projects

2.1 Need of technological developments

The various technologies were developed for the design and construction of the Akashi Kaikyo Bridge and other bridges on the Honshu-Shikoku Bridges project. The results have enabled safe and reliable construction of long-span bridges having a center span length in the order of 2,000m. Continued and sophisticated use of such technologies are important to the success of future trans-strait road projects.

The meteorological and oceanographic conditions in terms of topography, geology, water depth, wind speed and so on at planned sites in the future projects are, however, expected to be more severer than in the Seto Inland Sea area where the Honshu-Shikoku Bridges were built. Specifically, most future projects involve considerable widths and deep water levels. Therefore the bridge planning requires superstructures with longer spans and substructures appropriate for deeper water. The future projects, facing oceans, are highly vulnerable to typhoons and ocean waves. Some future projects are situated in areas prone to major earthquakes. These conditions may cause super long-span bridges, which are planned in future trans-strait road projects, to be 20 to 30 percent larger than the Akashi Kaikyo Bridge. The technologies used for the construction of the Honshu-Shikoku Bridges can certainly ensure the technological viability of the construction of super long-span bridges surpassing the Akashi Kaikyo Bridge. However, the developments of new technologies are essential to their more economical and rational design and construction.

2.2 Outline of technological developments

At present, the technological issues expected to reduce construction cost and period are being studied intensively as a top priority. The main technological developments are classified into two major categories, namely 1) developments of new structural types and 2) introduction of new design concepts. The technological developments are outlined in Table-1.

Table-1 Outline of technological developments

	Item	Outline of technological developments
Developments of new structural types	Bridge deck cross sections and cable systems with better aerodynamic stability	Slotted box girder and box girder with cross hangers are reviewed to increase aerodynamic stability without increasing dead weight.
	Underwater foundations with better earthquake resistance and economy	Twin-shaft type foundation is reviewed to increase earthquake resistance and economy.
Introduction of new design concepts	Wind resistant design	Fluctuation characteristics of natural wind are reviewed, and the possibility of wind load reduction is proposed. Flutter analysis is developed.
	Earthquake resistant design	Earthquakes considered in designs are defined in two levels, and earthquake resistant designs are proposed for each level.
	Design of superstructures	Safety balance in entire suspension bridge systems including cable safety factor is reviewed. Live loading methods considering actual passing of vehicles are studied.
	Design of substructures	Appropriate methods of evaluating bearing capacity and deformation of ground are studied.

(1) Review of new structural types

(i) Bridge deck cross sections and cable systems with better aerodynamic stability

Wind resistance is one of the most important themes in the design of super long-span bridges. Means of improving their wind resistance include increasing of stiffness of stiffening girders and innovation of bridge deck cross sections. While the stiffening truss girder was used for the Akashi Kaikyo Bridge, the box (one-box) girder was adopted on the Kurushima Bridges because of the center span length of about 1,000m.

Super long-span suspension bridges having a center span length exceeding 2,000m involves such problems as 1) the dead weight increase with enhancement of stiffening girders, and 2) high vulnerability to wind when truss girders are used which have great drag force. Therefore, slotted box (two-box) girders and box (one-box) girders are being examined based on the following assumption. The first is that the box girders can improve aerodynamic stability through enhancement of oscillation and aerodynamic characteristics of bridge deck cross sections. The second is that the hoisting erection method is applicable in which box girder blocks are hoisted directly from sea level right below installation points.

The slotted box girder has an opening at the center of girder (Fig.-2). The relationship between the opening pattern, location, width and other factors, and the critical flutter speed was examined. With the box girder, no critical flutter speed (assumed at around 80m/s) could be secured when the span was longer than 2,000m. Therefore, the improvement of oscillation characteristics by connecting girders and main cables with cross hangers was examined (Fig.-3).

As a result, it was confirmed that the both types were effective to improve the aerodynamic stability. At present, however, reviews are being continued for the slotted box girder. Because the box girder with cross hangers have a problem with the structure of connection between cross hangers and girders. The trial design confirmed that the adoption of the slotted box girder would require approximately 30 percent less weight than existing truss girders. Furthermore the ripple effects on main cables and main towers could make the entire suspension bridge more cost-effective.

(ii) Underwater foundations with better earthquake resistance and economy
The planned sites of the future projects, as compared to those of the Honshu-Shikoku Bridges, have such characteristics as 1) proximity to seismic center of large earthquakes, 2) large water depth at the planned points of their foundations and 3) poor bearing ground. Therefore, the cylindrical solid foundations for main towers, like foundations of the Akashi Kaikyo Bridge, cannot provide satisfactory earthquake resistance and economy.

So that twin-shaft type foundation shown in Fig.-4 is being studied. Some of the benefits of this type are 1) a small amount of concrete required leading to less cost and shorter construction period, 2) light weight applicable to relatively soft ground, and 3) light weight and low center of gravity which increase earthquake resistance. Further the studies are necessary about the structural details of the base of the shaft and the technologies of underwater reinforced concrete, etc. This type foundation, which is spread one, will be applied to individual future projects considering design conditions in terms of water depth and geology at the planned sites of those.

(2) Review of new design concepts
(i) Wind resistant design
As concerns wind resistant design of long-span suspension bridges, the various studies and experiments were practiced in the design of the Honshu-Shikoku Bridges. Besides the improvements were gradually made to increase accuracy. Based on the knowledge obtained in the full model wind tunnel studies, in particular, for examining the aerodynamic stability of the Akashi Kaikyo Bridge, a number of new concepts have been presented for information about future wind resistant design of super long-span bridges.

1) Review of wind fluctuation characteristics
With an increase of span, cross section of girders become more likely to be determined by wind load. More accurate wind load calculation, therefore, would contribute to greater economy. Wind load is calculated by adding an increment value based on wind fluctuation to static load calculated from mean wind speed. As a result of the full model wind tunnel studies at the Akashi Kaikyo Bridge, and of observation of natural wind, it was found that the effects

of wind fluctuation on long-span bridges were relatively small. The studies revealed the possibility of mitigating wind load in the design of long-span bridges, which was lighter than that calculated based on the existing standards.

2) Development of flutter analysis
In wind resistant design, static design against wind load is only insufficient. Measures to prevent flutter phenomenon at the wind speed not exceeding design level are also important. Past wind tunnel studies solely used a section model supported by spring. It was found that with increasing spans, a section model could not fully recreate actual oscillations of long-span bridges. In the wind resistant design for the Akashi Kaikyo Bridge, the full model having a total length of about 40m was adopted in the wind tunnel studies to recreate complex oscillations occurring on the actual bridge and to verify the aerodynamic stability. The results of the studies showed the effectiveness of flutter analysis as a more accurate means of grasping the aerodynamic stability of long-span bridges. For the new structural types such as the slotted box girder, however, the validity of the flutter analysis must be checked by the full model wind tunnel studies.

(ii) Earthquake resistant design
The planned sites of the future projects are close to the epicenters of plate boundary-type earthquakes, and the existence of active faults in the vicinity is also pointed out. In order to practice economical design while ensuring the safety of structures, appropriate input ground motions for design and corresponding analytical methods need to be adopted.

As a basis of earthquake resistant design, the ground motions assumed in the design and the corresponding safety of structures will be considered in two levels. At level-1, "damages which destroy transportation functions shall be prevented for moderate ground motions induced in the earthquakes with high probability to occur within the life time of structures". At level-2, "recoverable functional damages shall be allowed, but collapses shall be prevented for extreme ground motions induced in the earthquakes with low probability to occur". As level-2 earthquakes, two types of ground motions must be considered. The first is the ground motion which could be induced in the plate boundary-type earthquakes. The second is the ground motion developed in earthquakes at very short distance attributable to active faults.

For level-1, earthquake resistant design is made by response spectrum method with the non-linearity of ground. For level-2, check is made by elasto-plastic time history response analysis based on finite element methods. In the future, evaluation method for level-2 ground motion needs to be established.

(iii) Design of superstructures
Of the design standards for superstructures of the Honshu-Shikoku Bridges, those having great potential for reduction of construction cost and period were reviewed.

1) Allowable stress of main cable
On super long-span suspension bridges having a center span length exceeding 2,000m, the weight of main cable accounts for about 20 to 30 percent of total dead weight. Reduction of main cable weight may, therefore, make great contributions to reduction of construction cost and period. During the design of main cable for the Honshu-Shikoku Bridges, allowable stresses of 56kgf/mm2 and 64kgf/mm2 were adopted for the Innoshima Bridge (completed in 1983) and Seto Ohashi Bridge (completed in 1988), respectively. In the design of the Akashi Kaikyo Bridge, an allowable stress of 82kgf/mm2 was used by increasing the tensile strength

from 160kgf/mm2 to 180kgf/mm2 through the improvement of cable strand material.

In the design of super long-span suspension bridges, it was found that an allowable stress of main cable could be set at 100kgf/mm2 on such grounds as 1) sound quality of high-strength strands, 2) high erection accuracy, 3) prospect for enhanced rust-proofing technology and 4) room for further review of safety balance of the entire bridge system. The trial design confirmed that the allowable stress of 100kgf/mm2 in combination with the effects of less new type girder weight could reduce the weight of main cable by about 40 percent.

2) Methods of live loading
In the design of super long-span suspension bridges, live load is basically reduced according to a span as practiced in the design of the Honshu-Shikoku Bridges. In addition, live load is placed only on traffic lanes width unlike conventional loading on carriage way width, in view of the actual passing of vehicles.

In the design of main tower, influence line loading has been practiced in which live load was placed in the range where the load becomes the largest for a designing section. However, there is so little possibility of such loading in reality that it is now possible to increase an allowable stress.

(iv) Design of substructures
The future projects include the foundations which need to be laid on poor bearing grounds. For considering such cases, the studies are being made to grasp the non-linearity of ground based on soil investigations in laboratory using boring samples, and to evaluate the bearing capacity and deformation of ground accurately.

2.3 Technological issues to be resolved

The researches and studies have been made as to the various technological issues with a view to realizing super long-span bridges planned in future trans-strait road projects. As a result, as described above, it was found that the developments of the new technologies could substantially reduce construction cost by about 40 percent as compared to the use of existing technologies for the design and construction of super long-span bridges. The technologies to be developed, however, involve the technological elements, as shown in Table-2, which need to be established in the future. These technological elements will, therefore, be established to ensure the reduction of construction cost, and new technologies and structural types will also be studied which have not yet been given sufficient attention, toward further reduction of construction cost and period.

3. Conclusions

For the construction of super long-span suspension bridges, it was confirmed that the developments of the new structural types and introduction of the new design concepts could enable substantial cost reduction as compared to the use of existing technologies. In the future, the remaining technological issues will be tackled to ensure the reduction of construction cost, and new technologies and structural types will be studied toward further reduction of construction cost and period. For each project, the investigations of natural conditions at the planned sites will be continued and reinforced. Then based on their results, the studies will be made to make the design and construction plans more economical and rational in view of the unique local situation.

Table-2 Major technological issues to be resolved

Item	Technological issues
Wind resistant design	Full model wind tunnel studies for confirming the validity of flutter analysis
Earthquake resistant design	Evaluation method for level-2 ground motion
Design and construction of superstructures	Reviews of design methods which enable labor saving in work, and studies for further reduction of erection period
Design and construction of substructures	Establishment of large-scale underwater reinforced concrete technology Application to individual projects considering each conditions, and studies for reduction of construction period

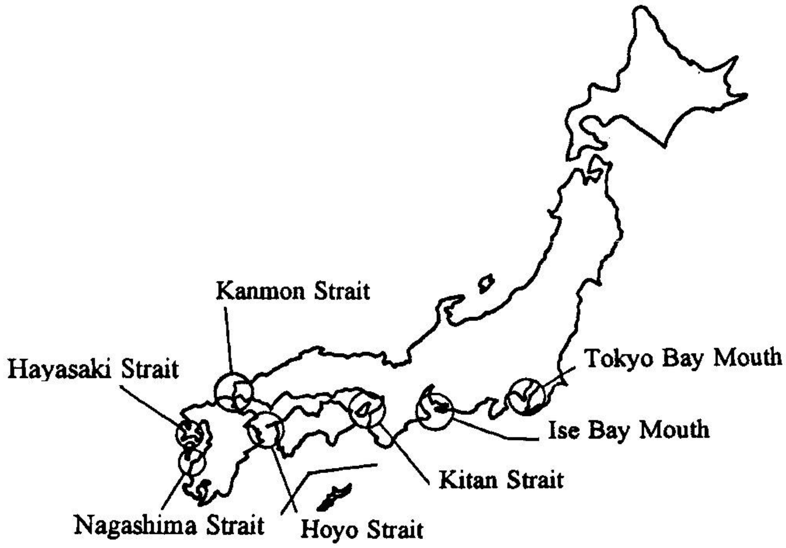

Fig.-1 Major Trans-Strait road projects

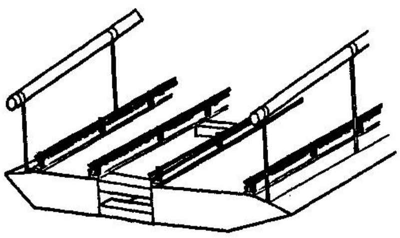

Fig.-2 Slotted box girder

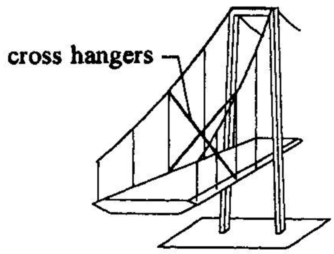

Fig.-3 Box girder with cross hangers

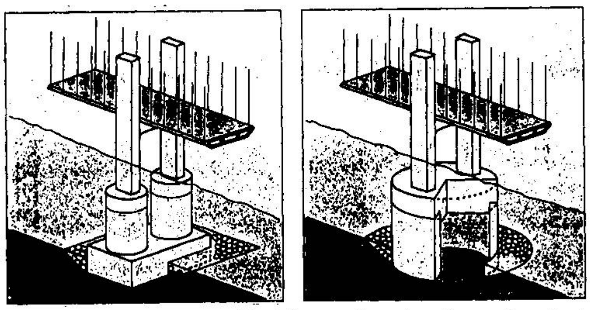

Fig.-4 Twin-shaft type foundation (left) and cylindrical solid foundation (right)

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