Effect on Tidal Current of Constructing the Akashi Kaikyo Bridge
Influence de la construction du Pont Akashi Kaikyo sur le courant de marée
Einfluss des Baus der Akashi-Kaikyo-Brücke auf die Gezeitenströmung

Takaya MORIMOTO
Gen. Manager
Honshu-Shikoku Bridge Auth.
Kobe, Japan

Tsutomu TAKAZAWA
Manager
Honshu-Shikoku Bridge Auth.
Onomichi, Japan

SUMMARY
The world' s longest suspension bridge, the Akashi Kaikyo Bridge, is now under construction. This paper reports on mathematical analysis and hydraulic model experiments conducted to estimate the effect on tidal flow in the surrounding sea of the reclaimed land for anchorages on each side of the Akashi Straits, and of the piers for the main towers in the middle of the Straits.

Influence de la construction du Pont Akashi Kaikyo sur le courant de marée

Résumé
Le pont suspendu le plus long du monde est actuellement en construction au Japon. Ce rapport présente l'analyse mathématique et les expériences de modèle hydraulique conduites pour estimer l'effet sur le courant de marée dans l'environnement marin modifié par la récupération de terrains sur la mer pour les butées et les pylônes du pont dans le détroit.

Einfluss des Baus der Akashi-Kaikyo-Brücke auf die Gezeitenströmung

Zusammenfassung
Die längste Hängebrücke der Welt, die Akashi-Kaikyo-Brücke, wird augenblicklich in Japan gebaut. Dieser Bericht präsentiert die mathematische Analyse und die ausgeführten hydraulischen Modellversuche, um die Wirkung auf die Gezeitenströmung in der Meeresumgebung abzuschätzen, die durch die Landgewinnung für die Ankerköpfe und die Brückenpfeiler in der Meerenge verändert wurde.

1. Outline

The Akashi Kaikyo Bridge, constructed on the Kobe- Naruto Route of the Honshu - Shikoku Bridges, is a 3- span, 2- hinged stiffening truss suspension bridge with a total length of 3,910m, and a center span of 1,990m. Construction work at the site was begun in May 1988, and is currently progressing on the substructures and on the fabrication of the main towers.

The Akashi Straits -- which this bridge spans -- links Osaka Bay with Harima Nada (the eastern section of the Inland Sea). The Straits are only 4km wide at the narrowest point, and are as deep as 110m in some parts. The tidal current at the Straits is well known as one of the fastest in Japan, reaching a maximum velocity of around 4m/sec. The sea in this area is heavily used. A width of 1,500m in the center of the Straits is designated as an international navigation channel, used by approximately 1,400 ships a day. Marine industries such as fishing and seaweed cultivation are also very active.

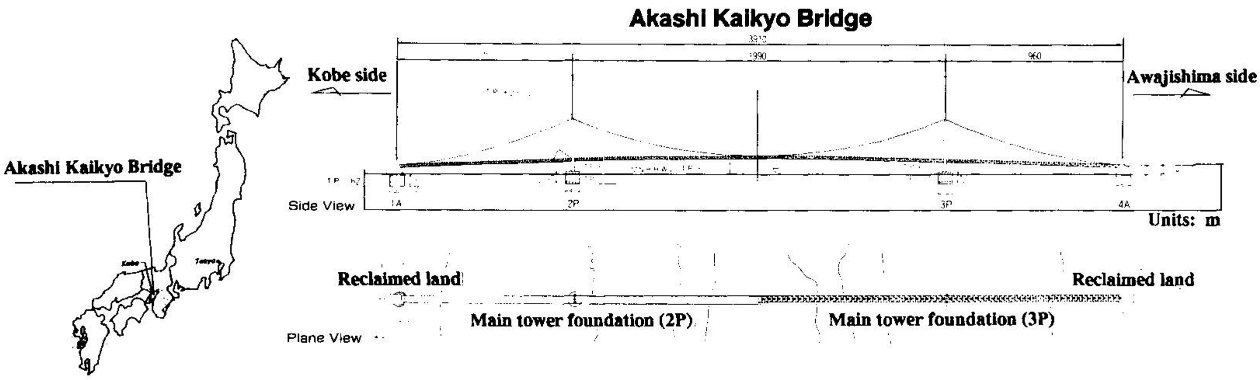

Figure 1 The Akashi Kaikyo Bridge

Figure 1 is a general view of the Akashi Kaikyo Bridge. This figure shows the relative positions and sizes of the two main piers for the towers in the middle of the Straits, and of the reclaimed land for the anchorages on each side (Approximately 6.2ha for anchorage 1A, 2.5ha for 4A).

The Honshu - Shikoku Bridge Authority carried out environmental impact assessments before construction of the bridge was started. The estimation of the effect on tidal current reported here was part of those assessments, and was conducted using two methods, mathematical analysis using a supercomputer, and hydraulic model experiments.

2. Investigation by mathematical analysis

2.1 Basic equations and mathematical analysis methods

Two mathematical models were used for the mathematical analysis. One was a wide area model (Osaka Bay model), and the other was a straits model (Akashi Straits model). These models were used for two- layer tidal current simulation to investigate the effect of the Akashi Kaikyo Bridge on tidal current. The two- layer model was considered to be most appropriate for mathematically estimating the tidal current conditions affected by the complex sea bed and shoreline shapes around the Akashi Straits because it can take vertical flow into consideration.

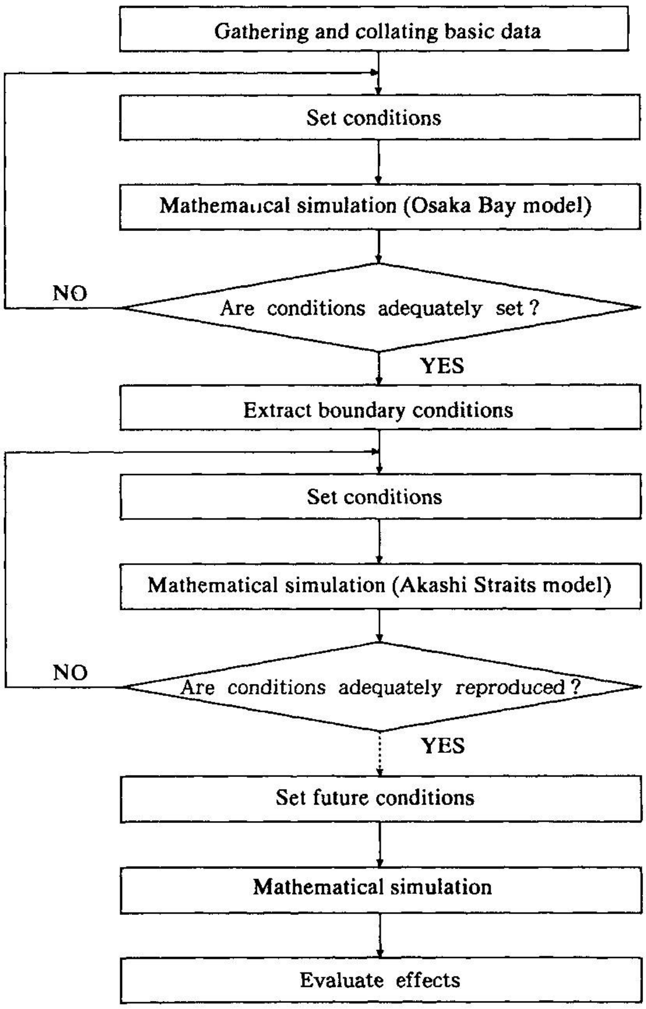

Figure 2 Procedure for predicting changes in tidal current

The procedure for the analysis is shown in Figure 2.

The mathematical models were based on the Navier- Stokes equation of motion and equation of continuity for incompressible fluids as shown in equations (1) to (4). Vertical movement was approximated using hydrostatic pressure, and the velocity of the vertical flow was obtained from the equation of continuity. The mean depth was used for the depth of each element.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=\frac{1}{\rho_o}\frac{\partial p}{\partial x}+\nu_H\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\nu_V\frac{\partial^2 u}{\partial z^2} \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+u\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}-fu=\frac{1}{\rho_o}\frac{\partial p}{\partial y}+\nu_H\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\nu_V\frac{\partial^2 v}{\partial z^2} \quad (2)$$

$$-g=-\frac{1}{\rho_o}\frac{\partial p}{\partial z} \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

Where:

x, y, z	:	coordinates with vertical axis upwards (cm)
t	:	time (sec)
u, v, w	:	flow velocity in x, y, z directions (cm/sec)
p	:	pressure (g/cm/sec2)
ρ_o	:	standard sea water density (g/cm3)
g	:	gravitational constant (cm/sec2)
f	:	Coriolis constant (sec- 1)
ν_H	:	horizontal eddy viscosity coefficient (cm2/sec)
ν_V	:	vertical eddy viscosity coefficient (cm2/sec)

In the mathematical analysis, these basic equations were used for two layers, and non-stationary analysis was performed using the finite differential method to obtain the flow velocity and water levels.

2.2 Calculation zone

The flow conditions (changes in velocity of tidal current and water level over time) were first obtained for the Osaka Bay model, using 1km square elements covering an area 78km from east to west, and 67km from north to south as shown in Figure 3. The results obtained were then used for calculations in the Akashi Straits model, with 250m square elements covering an area 30km from east to west, and 21km from north to south to clarify the detailed characteristics of tidal current in the area around the Akashi Straits. The range of the Akashi Straits model was decided by trial and error.

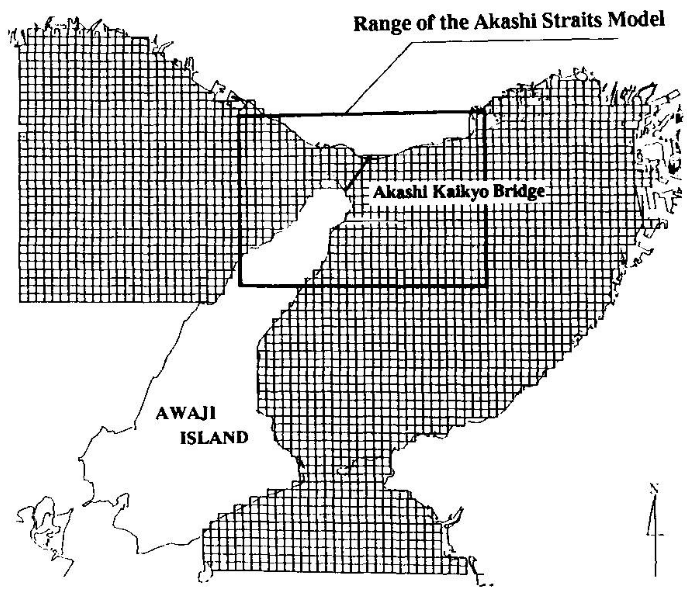

Figure 3 Mesh diagram for the Osaka Bay Model

2.3 Boundary conditions

The tides investigated were the annual mean tide and the annual mean highest tide.

The tide level oscillations to the open boundaries were applied as the boundary conditions for the Osaka Bay model. The tide level of the mean tide is considered to be the M2 partial tide, and the tide level of the mean highest tide is considered to be both the M_2 partial tide and S_2 partial tide. These tide level oscillations are given by equation (5). Measured data was used for the amplitude and delay angle, and the period was taken to be 12 hours.

$$\zeta = a\cos\left(\frac{2\pi}{T}t - \frac{\pi}{180}k\right) \tag{5}$$

Where:

ζ : tide level (cm)
a : amplitude of partial tide (cm)
k : delay angle of partial tide (degrees)
t : time (sec)
T : period of tide level oscillation (sec)

The boundary conditions for the Akashi Straits model were given by the flow velocity oscillations and tide level oscillations obtained from the mathematical analysis using the Osaka Bay model. These figures were obtained from harmonic analysis of the results from the Osaka Bay model over one cycle, and utilized in the calculations for the Akashi Straits model using equation (6). Linear interpolation was used spatially.

$$v = a_0 + a_1\cos\left(\frac{2\pi}{T}t - \frac{\pi}{180}k_1\right) + a_2\cos\left(\frac{2\pi}{T}t - \frac{\pi}{180}k_2\right) \tag{6}$$

Where:

v : flow velocity (cm/sec)
a_0 : flow velocity with residual tide flow (cm/sec)
a_1 : flow velocity for half day cycle (cm/sec)
k_1 : delay angle for half day cycle (degrees)
a_2 : flow velocity for quarter day cycle (cm/sec)
k_2 : delay angle for quarter day cycle (degrees)
t : time (sec)
T : period of flow velocity oscillations (sec)

Trials were conducted to decide whether to apply flow velocity oscillations or tide level oscillations to the open boundaries of the Akashi Straits model. The best representation of the flow characteristics of the Akashi Straits was obtained when flow velocity oscillations were applied to the eastern and southern boundaries and tide level oscillations were applied to the western boundary.

Calculations also took into consideration real data for outflows from the main rivers inside the zone, adjusted to the size of the model. The coefficients used in the calculations were determined by trial and error.

2.4 Accuracy

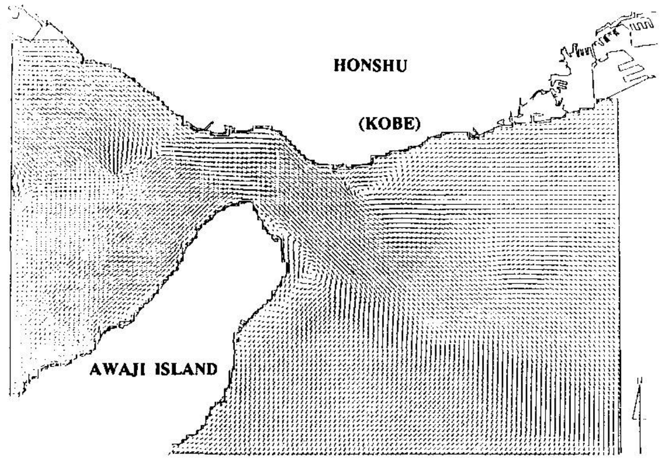

Figure 4
Flow conditions estimated using the Akashi Straits model (mean highest tide, eastern flow at maximum, upper layer)

One example of flow conditions around the Akashi Straits estimated using the Akashi Straits model is shown in Figure 4. The accuracy of this model in estimating the actual tidal current was considered in terms of flow patterns, flow levels (amplitude, delay angle), and tidal flow ellipse, comparing the calculated figures with real measurements. The model was found to be satisfactorily accurate.

2.5 The effect of the Akashi Kaikyo Bridge on tidal current in the Akashi Straits

The effect of the reclaimed land for anchorages and foundation for main towers of the Akashi Kaikyo Bridge on tidal current was analyzed using the Akashi Straits model. In this analysis, the proposed land shapes were represented as follows.

(1) The reclaimed land was handled as an equivalent land element.
(2) Section reduction was considered for the main piers. In other words, the transit section area in the continuous equation was reduced by the equivalent amount.

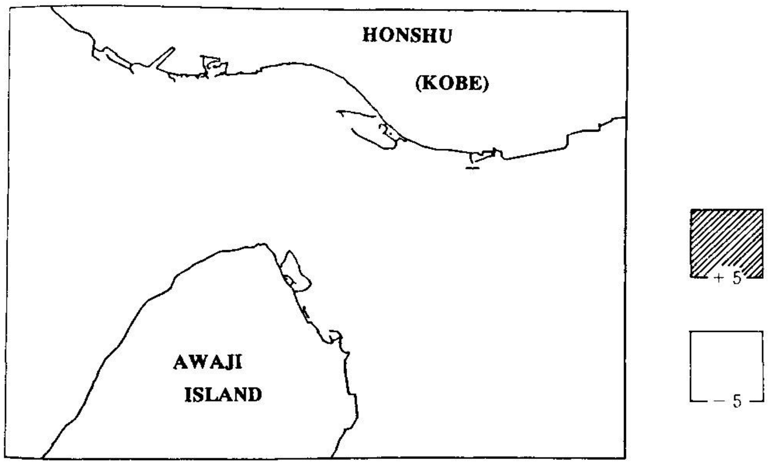

Figure 5 Flow velocity difference contours
(mean highest tide, west flow at maximum, upper layer)

One example of the flow velocity difference contours (future flow velocity minus present flow velocity) obtained by these methods is shown in Figure 5. As shown by the contours in Figure 5, the flow velocity becomes slower next to the reclaimed land of the Akashi Kaikyo Bridge, but this effect is relatively small. It can be considered that the effect of the bridge is small.

3. Investigation by hydraulic model experiments

3.1 Experimental zone

Mathematical analysis using the Akashi Straits model accurately estimated current flow conditions around the Akashi Straits, and it is considered to be a powerful means of prediction. However, it cannot provide a good estimation of phenomena smaller than the size of the mesh. Because the effects of the foundation of main towers are considered as section reduction, local effects close to the foundations are not obtained.

Flow structure and boundary conditions in hydraulic model experiments are often substantially different from true conditions, but the results still contain a lot of important information.

To examine the correlation with the mathematical analysis, two different hydraulic model experiments were conducted based on Froude's law. A wide area model experiment was conducted to examine the overall flow conditions, covering an area of sea around the Akashi Straits approximately 16km from east to west and 14km from north to south. The model was built with a horizontal scale of 1/1000 and a vertical scale of 1/500. A narrow area model experiment was also conducted with a scale of 1/100 in a flat vessel of 5m width to help understand the local flow conditions close to the main towers.

3.2 Results

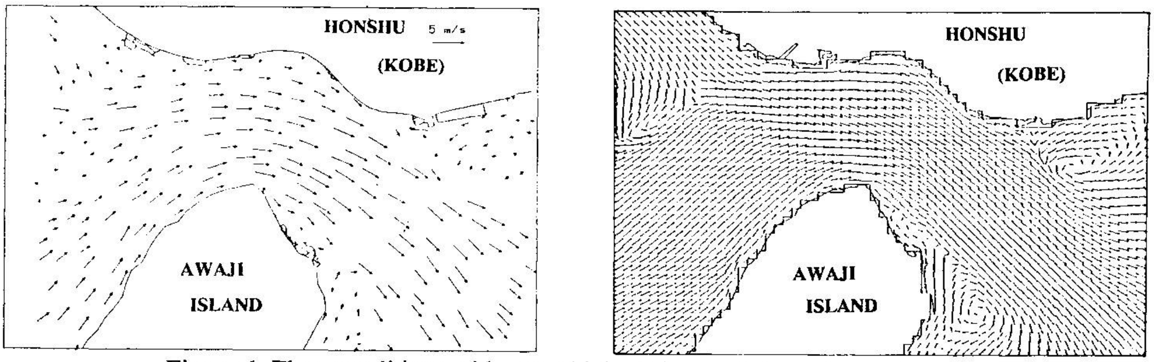

Figure 6 Flow conditions with mean highest tide, east flow at a maximum
(Left: Model experiment, Right: Mathematical analysis)

Figure 6 shows one example comparing the results of the wide area model experiment with the results of the mathematical analysis.
Examining flow direction, flow velocity, eddy areas, current rips, etc., it can be seen that there is a relatively good correlation between the two sets of results for flow characteristics.

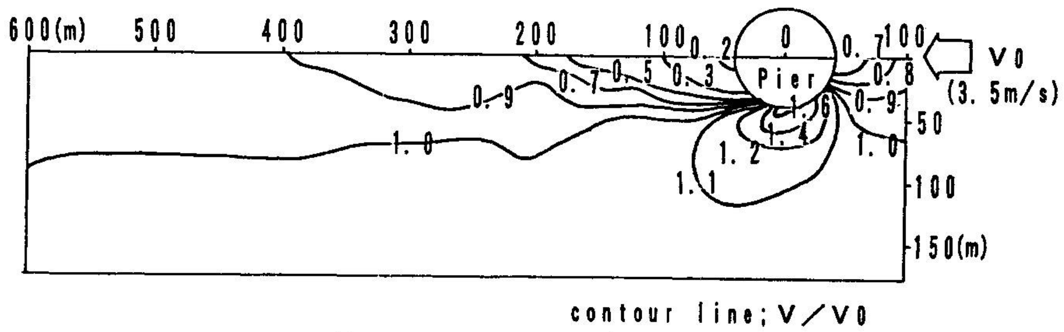

Figure 7 Flow around a circular pier

Figure 7 shows the mean surface flow velocity around a main pier as obtained from the narrow area model experiment. It can be seen that large changes in flow velocity are limited to a relatively small area around the pier.

Conclusion

Before constructing the Akashi Kaikyo Bridge, the Akashi Kaikyo Bridge Authority has conducted mathematical analysis and model experiments to investigate its effect on the tidal flow in the sea around the bridge. The investigations show that the effects will be relatively small, and restricted to the areas close to the actual structures.

Society now places a great importance on environmental impact assessments for large construction projects. Large construction projects have a variety of effects on the marine environment, and this is an important subject, but methods of prediction and evaluation have not been adequately established for many of the parameters involved. It is hoped that a great deal more progress will come from further study.