Experiments on Dynamic Response of Submerged Floating Tunnel in a Steady Current

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Introduction: Japan is surrounded by sea on all sides and consists of four main islands and hundreds of smaller islands. The main islands are now well connected by bridges over the sea or tunnels on the bottom of the sea. But as the separation length as well as the depth increase, these types of connections are becoming extremely difficult for contruction both from technical and economical viewpoints. As the ocean development grows, it has become necessary to study alternate forms of channel-crossing concepts. In this regard, the underwater tunnels or the so-called submerged floating tunnels are attracting wide interest in the engineering and academic circles. It seems that the submerged floating tunnel concept may become a major part of the infrastructure of the 21th century.

When these tunnels are located in a region where current flow exists, they experience horizontal motion due to fluid drag force and vertical motion due to fluid lift force (vortex-induced motion). The vertical responses may be dangerously large if a hydroelastic resonance occurs between the eddy-shedding frequency and a structural mode of vibration of submerged floating tunnel. In the present research, experiments were carried out on tunnel models with different natural frequencies and their responses along horizontal and vertical directions due to the current flow were recorded and analyzed.

Experimental setup: PVC cylindrical pipes were used as experimental models. They were held in position by means of springs as shown in Fig. 1. Tests were carried out for various values of the ratio of horizontal and vertical stiffnesses. The natural periods of the models are tabulated in Table 1. As the horizontal stiffness increases the model becomes more rigid and the natural period is smaller. Forced vibration experiments were carried out for current velocities ranging from 0.1m/s to 1.2m/s at 0.1m/s intervals. Photo 1 is a shot of the model vibrating due to current loading. The responses were recorded by video camera, and then using video tracker, the traces of the responses were divided into horizontal and vertical components.

Results and discussions: Fig.2 shows the examples of the traces of response displacement of the center of gravity of the models. Larger values are observed for certain values of current velocities which may be due to the syncronization of the eddy shedding frequency at these velocities to the natural frequency of the models. The examples of the time histories of horizontal and vertical components of the traces are shown in Fig.3 for 20-second duration. The horizontal displacement increases with the increase in current veocity as expected due to the increase in fluid drag force. The variation in the vertical displacement is more complex and is influenced by eddies and other forms of turbulence. When there is not much interaction between the model and its wake, the eddy shedding frequency is directly proportional to the current velocity. In situations where the model is mostly stationary and the flow is laminar, regular number of vortices are generated on the downstream side of the model. However when the model is susceptible to movement or when the flow is turbulent, vortices are generated in a random fashion. For non-stationary models, these vortices influence the motion of the structure thus contributing a feed-back effect. This effect is particularly severe when the frequency of the eddy-shedding frequency is closer to the natural frequency of the structure. Also for larger current velocities, the flow becomes chaotic around the models with irregular eddy-shedding and the models show patterns of severe random vibration.

Fig.4 shows the rms displacements of the models plotted against the current velocities. Each value corresponds to the rms value of the displacement data for about 68-second duration. In general, the horizontal displacement grows with the increase in current velocity due to larger fluid drag forces. The values for the vertical component show a peak for certain values of current velocities which is due to the proximity of the eddy-shedding frequency to the natural frequency of the model. Also, as the model 2 is stiffer in the horizontal direction, the horizontal responses are smaller than that of model 1.

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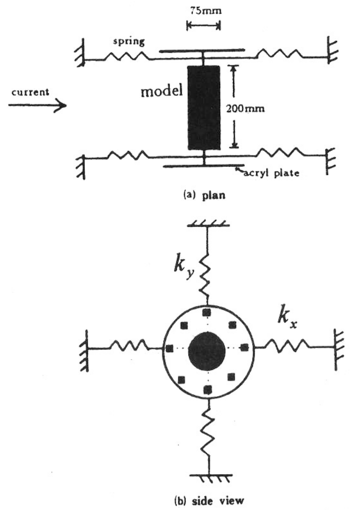

Fig.1 Schematic diagram of model

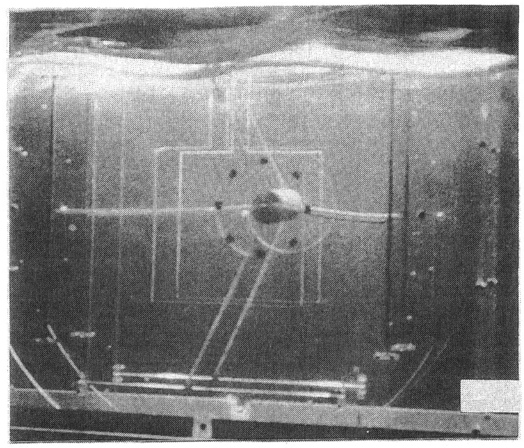

Photo 1 Steady response of a model in steady current

Table 1: stiffness ratios and the natural periods of the models

Model	Stiffness ratio (k_x / k_y)	Natural period (sec)	
		horizontal	vertical
Model 1	1	0.838	0.838
Model 2	2	0.665	0.741

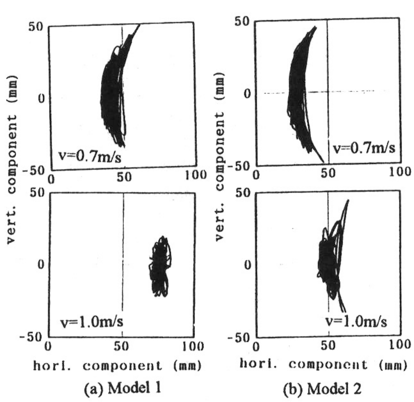

Fig.2 Examples of traces of response displacements

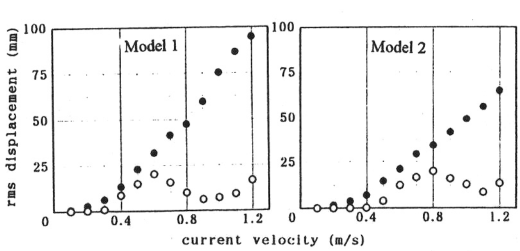

Fig.4 rms response displacements
(● hori. component; ○ vert. component)

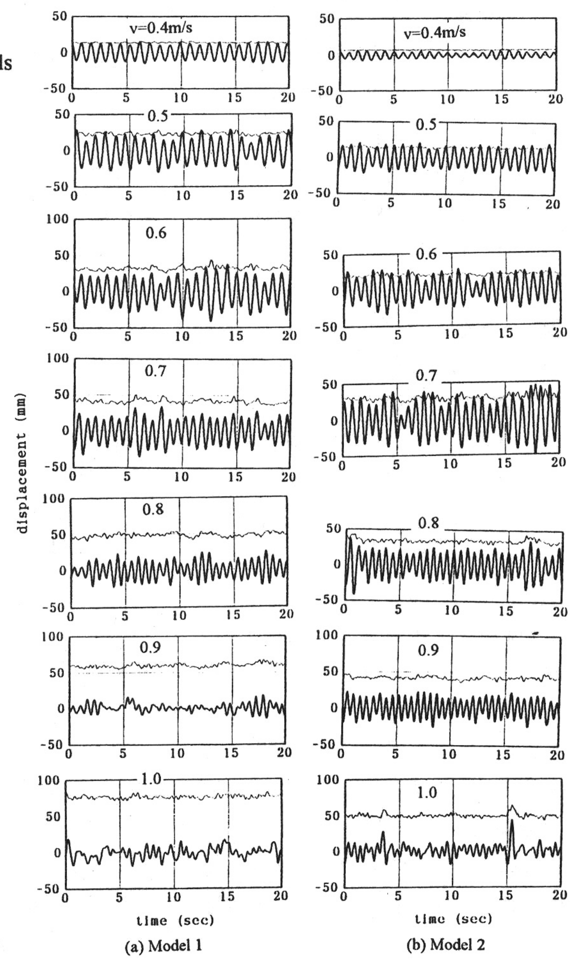

Fig.3 Examples of time histories of response displacements
(—— hori. component ; —— vert. component)