PS I -12 EXPERIMENTAL INVESTIGATION ON DYNAMIC COUPLING OF CABLE-STAYED BRIDGE

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SUMMARY : The cable-stayed bridge potentially possesses various kinds of dynamic coupling phenomena. An experimental study using a simple cable-stayed beam model was carried out to investigate the mechanisms and characteristics of these coupling phenomena. Linear coupling, auto-parametric coupling of cable and beam, and the swirling of cable were three major types seen in the experiment. Saturation phenomenon of auto-parametric coupling was also observed.

THE EXPERIMENTAL APPARATUS : The model(Fig.1) is a cantilever cable-stayed beam of 2 meters length. Stainless wire rope with distributed lump masses simulates the dynamic characteristics of the stay cable. Turnbuckle is used to adjust the natural frequency of cable. The damping of cable is adjusted by proper size of rubber cover at the anchorages, while viscous damper, a rod immersed in glycerine, is attached to the beam to adjust its damping. In some experimental cases, tie thread is applied to restrain in-plane motion of cable. Hand-made electro-magnetic excitor, in the form of electrical coil immersed in fixed magnetic field, provides an accurate harmonic induced force proportional to the driving electrical current.

Both in-plane and out-of-plane motions of cable are detected by video type position sensor system. In-plane (vertical) and out-of-plane (lateral) motions of beam are detected by strain-gages circuits.

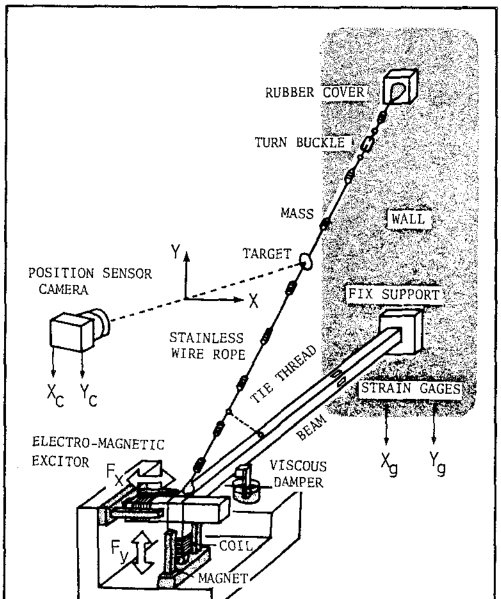

Fig.1 The experimental apparatus

SIMILITUDE : Dimensionless parameters of the model are given in Table 1.

"Beam lateral" and "Beam vertical" in Table 1 mean out-of-plane 1st mode (Fig.2(**A**)) and in-plane 2nd mode of cable-stayed beam (Fig.2(**F**)), respectively. The definition of mode, here, is based on non-coupling condition. When the natural frequency and damping of cable-stayed beam mode are measured, the cable is restrained in order not to oscillate relative to beam. On the other hand, when those of cable mode are measured, the beam is fixed to the reference frame.

Frequency ratios are selected here in such a way that linear coupling and auto parametric coupling of cable-beam can be anticipated either separately or jointly. The other dimensionless parameters, necessary for dynamic similarities, are set in reasonable range of normal cable-stayed bridge.

There are six main experimental cases corresponding to six natural frequencies of cable. For each case **frequency sweep test** is conducted with fixed amplitude of force, but in some cases the amplitude of excitation force is varied.

Table 1. Dimensionless parameters of model

Dimensionless parameters	Value
(1) Frequency ratios	
(Beam vertical)/(Beam lateral)	2.1
(Cable 1st mode)/(Beam lateral)	0.85, 0.94, 1.00 1.02, 1.05, 1.06
(2) Logarithmic decrement	
Cable 1st mode	0.007
Beam lateral	0.012
Beam vertical	0.018
(3) Effective mass ratios	
(Beam vertical)/(Beam lateral)	1.0
(Cable 1st mode)/(Beam lateral)	0.01
(4) Geometrical ratio θ (cable / beam)	26.6°
(5) Pre-strain of cable	$3700\sim6200\times10^{-6}$ (stress 3800~6500ksc)
(6) Stiffness ratio (longitudinal stiffness of cable) / (equivalent stiffness of Beam vertical)	0.15

RESULTS AND DISCUSSION : Only qualitative results and discussion will be given here. Variety of observed dynamic response pattern of model can be summarized into (A)-(I) types shown in Fig. 2.

When the natural frequencies of beam mode and cable were closely spaced, **linear coupling** was clearly observed (B or G in Fig. 2), like a system of structure and tuned dynamic absorber. When these frequencies were well separated, the linear coupling disappeared, resulting in motion **A** or **F**.

For a certain case, in-plane motion of cable was added to the motion **B**, due to tension-induced nonlinear coupling. This led to motion **C**, named **swirling** (see Miles).

The remaining motion types (D),(E),(H) and (I) have one common feature of nonlinear coupling referred to as **auto-parametric interaction**. Vertically excited beam can act as a parametric excitation for in-plane or out-of-plane cable mode. On the other hand, oscillated cable can also act as double frequency vertical force to the beam. This type of nonlinear coupling usually combined with linear coupling previously mentioned, and the coupling was most pronounced when the ratio of natural frequency of parametrically excited mode to the exciting mode equals **1:2**.

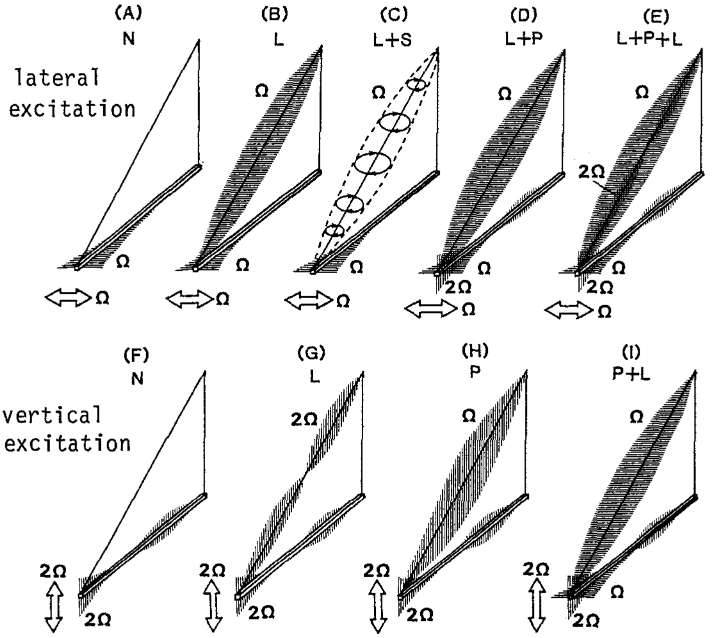

Fig.2 The observed dynamic response pattern
N: non coupling S: swirling(nonlinear coupling)
L: linear coupling P: auto-parametric(nonlinear)coupling

The result of test by varying the force amplitude while fixing the frequency is presented in fig. 3. Note that, in this case, the tie thread was installed in the cable to prevent in-plane cable motion. Type (F) of response was changed from stable to unstable steady-state condition when the force amplitude was increased beyond the critical value Fa. The new stable steady-state was (I) type, which has a saturation phenomenon of beam vertical mode;i.e, amplitude of beam oscillation does not increase when the force increases. This is one of the clear non-linear response characteristics possessed by **auto-parametric system** (see Nayfeh sec. 6.5).

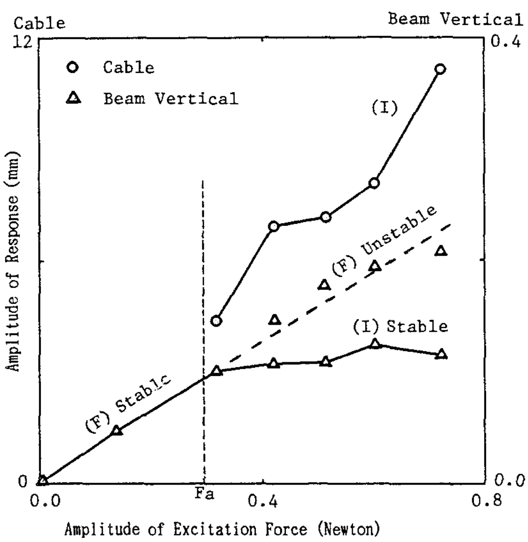

Fig.3 Saturation phenomenon

Analytical study based on nonlinear vibration theory is in progress, to explain the governing mechanisms. Clear understanding of the various dynamic coupling phenomena is helpful in the proper design of vibration control.

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