I - B166 On Interaction Among Cables in A Cable System

Saitama University Student M Md. Alauddin
Saitama University Member H. Yamaguchi

1. Introduction

Prediction of response of a structural system requires adequate knowledge not only about the characteristics of individual member or component but on the interaction among various members of the system. Now a days, cable is an important component in structural systems and a number of interconnected cable elements are sometimes used to form a component of large civil engineering structures. In the past, many researches have been done to investigate both the static and dynamic behavior of single cable while the research on dynamic behavior of cable system is not sufficient. In this study, therefore, efforts have been made to interpret the dynamic behavior of cable system from the dynamic characteristics of individual member by paying much attention to the interaction.

2. Formulation

The substructural formulation with modal synthesis [1-2] is applied to solve the dynamic interaction problem of cable systems. This is because it is convenient to explain the effect of one element on the other on the basis of substructural response solution. Since cables are inherently geometrically nonlinear, some modifications have been incorporated in the substructural formulation in this study.

For r-th substructure, using modal synthesis method, the dynamic displacement vector $\{U\}_r$ relative to the static configuration can be expressed as

$$\{U\}_r = [\Phi_C \quad \Phi_N]_r \{p\}_r \tag{1}$$

where submatrices $[\Phi_C]$ and $[\Phi_N]$ are constraint mode matrix and truncated normal mode matrix [2] respectively. $\{p\}_r$ is the substructural generalized coordinate vector. If $\{q\}$ is the independent system generalized coordinate vector then, unlike other formulations, using kinematic compatibility at joints, at first, the substructural displacements of Eq.(1) is expressed in terms of independent system generalized coordinates vector $\{q\}$ as follows

$$\{U\}_r = [\overline{\Phi}]_r \{q\} \tag{2}$$

Using nonlinear strain-displacement relation [3] for cable element, the substructural kinetic energy, elastic potential energy and potential of applied loading can be computed in terms of system generalized coordinates. Substructural kinetic and potential energies are added for all the substructures to get the total energies of the system. Then energy expressions are introduced in to the Lagrange equation and a coupled set of nonlinear equations in terms of system generalized coordinates are obtained.

A damping matrix is formulated assuming modal damping for different cable element separately. In this case, proportional damping matrix is formulated for each cable element using finite element mass and stiffness matrices corresponding to equilibrium configuration of individual cable. Substructural damping matrices are assembled to form the system damping matrix taking in to account the common degrees of freedom among different substructures.

3. Numerical Analysis and Discussions

A cable system consisting of two main cables and one secondary cable shown in Fig.1, which is a model of catwalk system studied for the control performance of the secondary cable [4], is analyzed as an example by using only the linear part of coupled equation of motion. In this analysis, 2% and 4 % modal damping is assumed for the main cable and secondary cable respectively and the cable system is analyzed with all the three cables having same sag of 5.0 cm. Fig.2 shows the frequency-response curves for both the main and secondary cable computed at the mid-span. Unlike single cable, the main cable response shows two peak responses. On the other hand, secondary cable frequency-response curve has only one peak at the frequency of around 7.1 Hz while at the frequency of around 7.6 Hz its response is cosiderably smaller at which main cable approaches the maximum

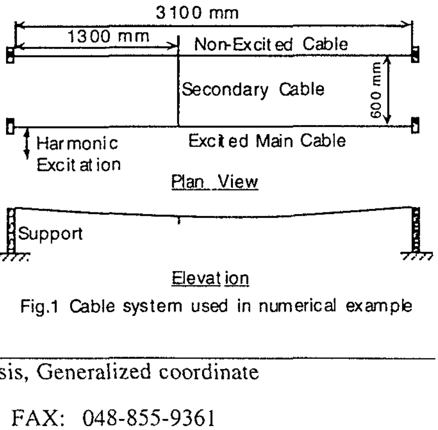

Fig.1 Cable system used in numerical example

Keywords: Interaction, Cable system, Substructure, Modal synthesis, Generalized coordinate
Dept. of Civil & Environmental Eng., Saitama University
255 Shimo-ohkubo, Urawa, Saitama, 338 TEL: 048-858-3552 FAX: 048-855-9361

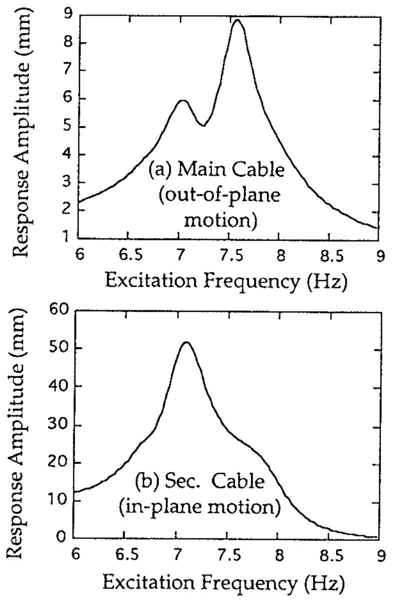

Fig. 2 Frequency-Response curve at mid-span with 2% main cable modal damping and 4% secondary cable modal damping

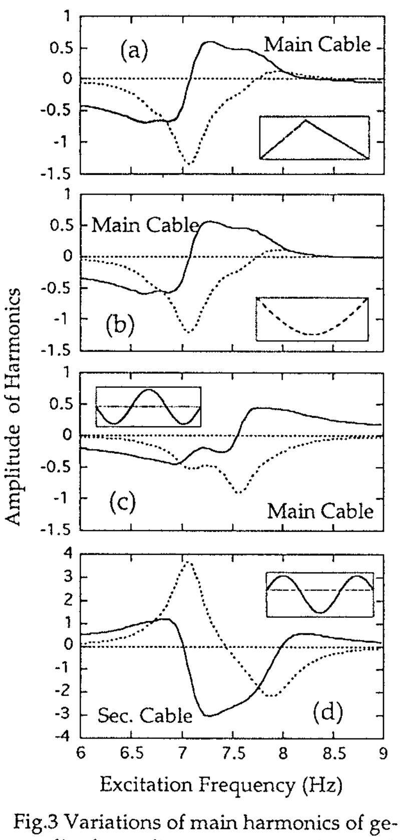

Fig.3 Variations of main harmonics of generalised coordinates corresponding to the mode shapes shown in figure (dotted line for 'sin' & solid line for 'cos' component)

response. This phenomena can be explained on the basis of the variation of different generalized coordinates with excitation frequency, which is shown in Fig.3. In Fig.3a, Fig.3b and Fig.3c the generalized coordinates corresponding to dominant modes associated with out-of-plane response of excited main cable are shown. In all the cases, each generalized coordinates has both "cosine" and "sine" harmonic components with frequency equal to that of excitation frequency and it is obvious that maximum magnitude of "sine" component is associated with peak response of main cable. Out-of-plane constraint mode and first out-of-plane normal mode of main cable are dominant , but their total effect is negligible as the two modes are of opposite sign. From this observation it is clear that the net effect in total response of main cable is due to the third out-of-plane normal mode. It is expected because the range of excitation frequency considered here is the third mode frequency region of single main cable (around 7.5 Hz corresponding to 5.0 cm sag). At this point, it can be assumed that the additional peak (at 7.1 Hz) in the main cable response curve is the effect of secondary cable at which frequency secondary cable shows the highest response as mentioned earlier.

Fig.4d shows the variation of harmonic components of generalized coordinates corresponding to dominant mode associated with in-plane motion of secondary cable. Maximum magnitude of "sine" component of generalized coordinate is also associated with peak response of secondary cable. Since secondary cable has the same sag as main cable peak response of secondary cable should be at the frequency of around 7.6 Hz which is not true here. This may be due to the fact that secondary cable is more flexible in comparison to that of main cable. As a result, secondary cable can undergo nonlinear motion more easily. But in our investigation only linear part of equation of motion is considered. Interaction among main cables and secondary cable may also be related to this fact

4. Concluding Remarks

Main cable behavior in cable system is greatly dependent on the single main cable characteristics. But addition of secondary cable modify the response behavior of main cable in cable system to some extent. Total response of a substructure or element in system is dependent on the harmonic composition of generalized coordinates. Existence of maximum "sine" harmonic component with smaller "cosine" component in a generalized coordinate indicate greater contribution of that mode in the total response.

References

[1] Hurty, W. C., "Dynamic Analysis of Structural Systems Using Component Modes," *AIAA Journal*, Vol.3, April 1965, pp. 678-685.

[2] Craig, R. R. Jr. and Bampton, M. C. C., "Coupling of Substructures for Dynamic Analysis," *AIAA Journal*, Vol.6, July 1968, pp. 1313-1319.

[3] Yamaguchi, H. and Ito, M., "Linear Theory of Free Vibrations of an Inclined Cable in Three Dimensions," *Proc. of Japan Society of Civil Engineers*, June 1979, 286, pp. 29-36.

[4] Alauddin, Md. and Yamaguchi, H., "Nonlinear Effects of Secondary Cable on its Control Performance," *Proc. of 3rd Int. Conf. on Motion and Vibration Control*, Vol.2, Chiba, 1996, pp. 36-41.