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Cable Force Identification based on Substructure Isolation Method

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ABSTRACT

Aiming at this characteristic that the cable force identification precision is influenced by factors such as stiffness, boundary conditions and length, especially when the length of cable is short, boundary conditions cannot be simplified as fixed or pinned directly. Therefore, the method of adding virtual supports on the structure was proposed for cable force identification. The method of adding virtual supports on cable is based on the Substructure Isolation, through the change rule of natural frequency realize the structure damage identification. The virtual supports were constructed by the Substructure Isolation method using the liner combination of responses. By adding virtual supports realized that the substructures of cable were constructed, using the method can be additional virtual support in different position of the cable and get more virtual structures, combined with the frequency variation law of all virtual structures, the damage identification of cable can be carried out quickly and accurately.

1. INTRODUCTION

In suspension bridge, cable-stayed bridge and arch bridge, cable is the main bearing components, and cable also is the most prone to damage, once the destruction of cable will directly lead to change of structural load transfer and distribution form. The performance of cable is relation to the safety and service life of the whole bridge, so the identification of cable force is very important. Cable force identification is not only the foundation for analysis of cable state, it also has a great significance for whole bridge structure health assessment (Qiao Y. 2009).

At this stage, cable force identification method there are resistance strain method, pressure gauge test method, hydraulic jack determination method, magnetic flux method and vibration frequency method, etc. The frequency method is a kind of economic cable force identification method, the way is through the hydrophone of high sensitivity, cable is vibrated by environmental or forced stimulation, recording the schedule data with acceleration sensor, through filtering amplifier to filter the noise and the signals are enlarged, again through the signal analyzer converts analog signals into digital signals, finally through the spectrum analysis, the natural frequency of vibration can be obtained through the spectrum diagram again by the cable force calculation formula gain cable force. (Wang X 2008) Cable frequency calculation is related to many factors, such as cable force, stiffness, boundary conditions, the length and sag, etc. Because the cable is part of the bridge structure, especially when the stiffness is bigger, the boundary conditions cannot be simplified as hinge or fixed, boundary conditions affect the identification precision of cable force at this time.

Based on the substructure isolation method additional virtual support on cable, the isolated substructure will be separated from cable, weaken the influence of boundary conditions, gain higher sensitivity index to improve the precision of cable force identification. The core principles of isolated substructure method are the response of liner combination to attach substructure boundary sensor into virtual support, the response of internal sensor as the isolated substructure acceleration response. Isolated substructure here is referred which is the virtual structure that using of numerical virtual support to separate from the overall structure, it is a complete structure model with fewer elements, so easier to identify the cable force.

At first, this paper introduces the cable identification method based on isolated substructure method, then joint modeling the suspension structure, at last, through the simulation of suspension bridge cable force identification verify the effectiveness of the proposed method.

2. CABLE FORCE IDENTIFICATION BASED ON ISOLATED SUBSTRUCTURE

The isolated substructure method (Hou J 2012) is used to identify the cable force purpose is to weaken the influence of unknown factors such as boundary conditions, and access to high sensitivity of cable force identification index. Through the isolated substructure method to isolate a length of cable form the isolated substructure, the response of the isolated substructure internal through isolated equation, as shown in Eq. (1). Including A is the response matrix that the incentive under the action of boundary sensor position on the substructure ("impulse excitation") of corresponding boundary sensor response, B is the response matrix under impulse excitation is corresponding to the response of the substructure internal sensor matrix, C is response matrix that the incentive is applied on substructure internal sensor position ('basic impulse') of corresponding boundary sensor position response, D is under the basic incentive which internal sensor form response matrix, the matrix D_S is calculated the response of substructure by isolated equation (Hou J 2009).

$$D_S = D - BA^{+}C \tag{1}$$

Constructing isolated substructure on cable, reaction of substructure boundary nodes in three degrees of freedom direction is exposed, so need to the boundary sensors construct to fix virtual support, need to measure the response of the boundary nodes in three directions, which is anything influence of the vertical degree of freedom can be ignored, and for the response of the rotational degree of freedom measurement is difficult, so set a length of local strengthening on cable, strengthening section is to point to increase rigidity, close to infinite stiffness, rotation response can avoid to acquire, hence only need to measure the response of the horizontal direction, as shown in Fig. 1.

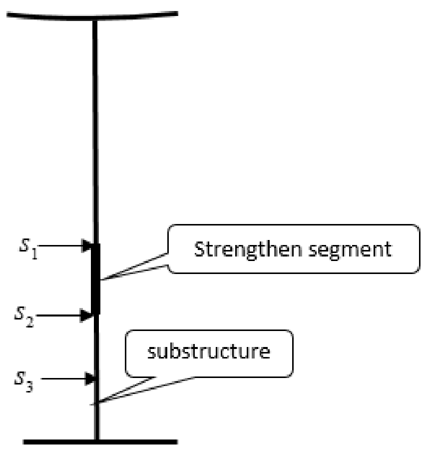

Fig. 1 Arrangement of sensors

In order to limit response of substructure boundary, requires to set two sensors in the substructural boundary, as shown in Fig. 2 to strengthen border *s1, s2* direction, a sensor in the substructure interior layout, namely the s3 direction. If *s1* and *s2* as the numerical supports and the substructure can be separated from the overall structure. Under basic motivation is to get the response of three sensors direction as the basic response, under the isolated incentive three sensors measured response as isolated response, according to the constraint equation construct isolated substructure response. Using constructed respond by ERA method to identify the isolated substructure frequency, the frequency of the substructure and cable force as the approximate linear relationship, can according to the change law of frequency to identify cable force.

3. SUSPENSION BRIDGE STRUCTURE JOINT MODELING

Because the Dofs of the FE model of suspension Bridges of is very large, the calculation efficiency is very low and time consuming, so the joint modeling method were proposed. First use of this group has established the finite element model of whole bridge structure, as shown in Fig. 2. Cable units of bridge structure are double cable model, as shown in Fig. 3, because the main research of the structure of the overall features, so according to the single cable establish model, overall and unit mass matrix and stiffness matrix were obtained by solving. This article is mainly to identify cable force, so by using the Guyan reduction (LIU J 2006) idea that cable Dofs as the master degrees of freedom, Dofs of the other parts as slave degrees of freedom, the global stiffness matrix and mass matrix of suspension bridge structure were reduced to the boundary of the degrees of freedom of the side cable. Fine single cable model was established after model reduction, then the horizontal and rotational freedom of two single cable boundary nodes freedom and coupling and isolation block location to assemble a new structure model with corresponding double cable.

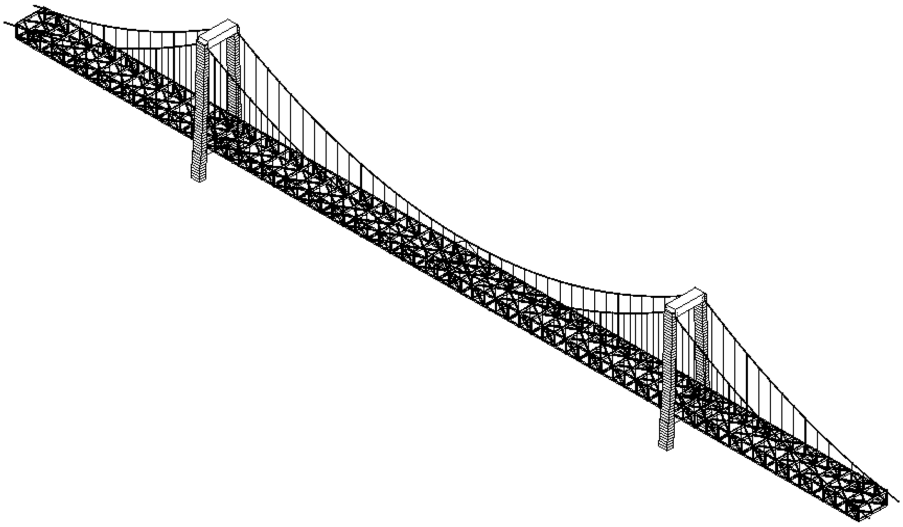

Fig. 2 The structure model of suspension Bridges

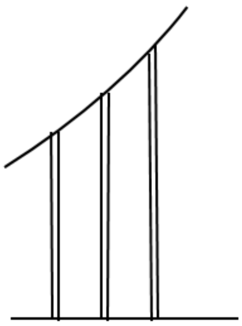

Fig. 4 Double cables model

4. CABLE FORCE IDENTIFICATION SIMULATION

4.1 *Cable model*

The basic parameters of the suspension bridge cable: cross-sectional area is *2.81e-3*, elastic modulus is *1.95e11*, density is $7850Kg/m^3$ and linear expansion coefficient is *1.0e-5*.

4.2 Construct isolated substructure response

Isolated substructure of double cable model is illustrated in Fig. 4. The length of substructure is set to 2.5*m*, the length of strengthen is 0.2*m*, increase its rigidity as 25 times of cable actual stiffness. When data acquisition in the actual environment, the influence of noise on response is inevitable, so the incentive and response of cable were considered the noise with 5%. Respectively construct isolated substructure and calculate the corresponding acceleration response for 33 cables, now draw one of the working condition corresponding response. Excitation is simulated by hammer, the sampling frequency is *10000Hz*, incentive time is *0.088s*. According to basic response and isolated response, isolated substructure responses are constructed

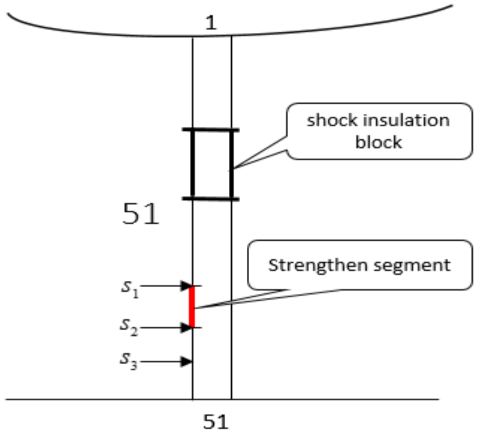

Fig. 4 Arrangement of sensors

4.3 Cable force identification

Assuming that took place damage in the 65th cable, damage factor is 0.95. Through isolated substructure method additional virtual support is constructed, and the substructure frequency is identified based on the EAR method. The frequency and cable force corresponding relation and are illustrated Fig. 5, the frequency of damage cable compared with other intact cable frequency is relatively low, again through the cable force and frequency of the basic relation between linear gain size of cable damage. For 65th damage cable according to the frequency of the substructure to identify cable force after change, and to calculate the damage factor, the results are shown in Tab. 1. The result shows that identified 65th cable damage factor and the damage factor of hypothesis are almost same.

Tab. 1 Damage identification result of the 65th suspender

actual cable force/ *N*	Identify frequency	Identify cable force/ *N*	Identify damage factor	Actual damage factor
289932.13	51.062296	290020.99	0.9502	0.95

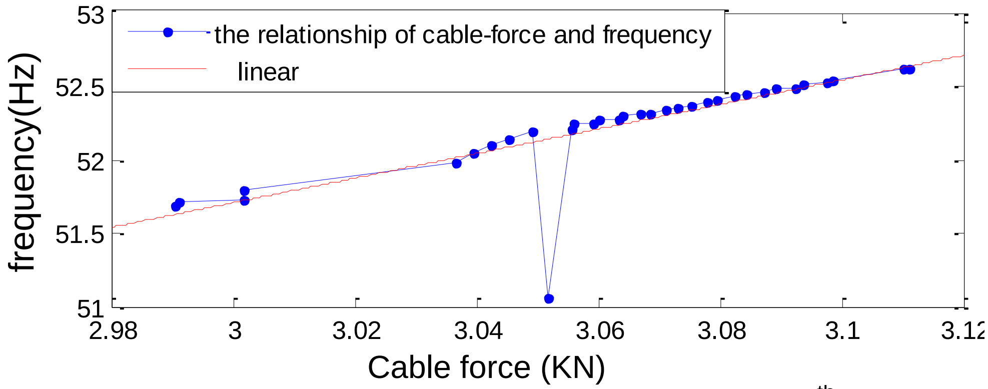

Fig. 5 Damage cable-force and frequency relation of the 65th suspender

5. CONCLUSIONS

This paper proposes to identify cable force based on isolated substructure method additional virtual support on the cable, and using the method to identify accurately cable force of suspension bridge model, and to get a recognition index of high sensitivity of in. The most important conclusion as follows.

(1) By means of suspension bridge structure joint modeling, taking into account the other parts of structure and cable interact, reduced the calculation degrees of freedom, get more accurate cable model, the acceleration response is more accurate.

(2) Using isolated substructure method can separate a part cable form of the isolated substructure, is used to identify cable force effectively reduce the effect with unknown factors such as boundary conditions, rigidity sag ect. and improve the precision of cable force identification.

(3) Isolated substructure method is used to identify the cable force, rapidly, simply, and easy to implement.

6. Acknowledgements

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