SENSOR PLACEMENT FOR DAMAGE MONITORING IN CABLE STAYED BRIDGES

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1. Introduction

Damage Detection in flexible structures such as cable-stayed bridges requires a large number of sensors, but the number of sensors that can be used in real structures is limited by its cost and its useful information, sensor placement analysis must deal with *how many* sensors to use and *where* to place them in order to obtain the most information for damage detection. The purpose of this paper is the numerical implementation of the eigenvector sensitivity method for optimum sensor placement using the finite element model of the Bill Emerson Memorial cable-stayed bridge; different optimum sensors configurations will be analyzed using strain energy as indicator of damage.

2. Finite Element Model of the Bill Emerson Memorial Cable-Stayed Bridge

The cable-stayed bridge used for this numerical study is the Bill Emerson Memorial Bridge spanning the Mississippi River near Cape Girardeau, Missouri. The bridge is composed of two towers, 128 cables; it has a total width of 29.3 m and total length of 1205.8 m with a main span of 350.6 m and side spans of 142.7 m in length. The Finite Element Model of the bridge was developed by Caicedo [1]. It has 572 Nodes, 418 rigid links, 156 Beam Elements, 198 nodal masses and 128 cable elements. The deck is modeled as central mass less beam with two lumped masses joined to the beam element by a rigid links [1].

3. Optimum Sensor Placement Algorithm

The sensitivity matrix for the i^{th} element is defined as S_i. Eigenvector sensitivity method states that placing sensors at locations where F_i is maximized give the most information for damage detection [2] [4].

$$F_i = diag([S_i][[S_i]^t[S_i]]^{-1}[S_i]^t) \qquad (1)$$

4. Damage localization

The method used in this study was developed by Stubbs and Kim [3], this method can locate damage in structures given their characteristic mode shapes before and after damage; damage index is defined as the quotient squared of a structure's modal curvature in the undamaged state to the structure's corresponding modal curvature in its damaged state.

5. Degree of damage

Once damage is located and the damage region is clearly identified, the suspected damage elements are further analyzed to quantify damage using the following equation

$$\Delta\lambda = S_{Fi}(\Delta\alpha) \qquad (2)$$

where S_{Fi} is the sensitivity matrix of frequency of the element i^{th}, $\Delta\lambda$ is the difference between identified undamaged natural frequencies and damaged natural frequencies and $\Delta\alpha$ is the stiffness reduction in the element i^{th} [2] [4].

6. Results and Discussion

This study is focused on optimum sensor location for continuous damage monitoring of deck elements, only vertical mode shapes are considered, because ambient excitation is expected to be from traffic loads. Eleven vertical mode shapes were identified from the FEM [1], which correspond to mode shapes 1, 2, 5, 6, 7, 12, 17, 18, 19, 25 and 32. According to Hemez [4] mode selection for damage detection based on maximum modal strain energy produce more accurate results; using this concept modes 1, 2, 5 and 6 are selected. Optimum sensor placement is carried out using

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these four modes; in the FEM the total number of possible sensor locations is 67; in fig 1 four optimum set of sensors are compared, based on their ability to locate damage, eigenvector sensitivity analysis shows high concentration of sensors in the center of the spans, therefore geometric considerations where additionally used to distribute sensors uniformly. 10 deck elements, distributed over the length of the bridge, are selected to perform damage detection using damage index [3]; all damage cases are defined as 10% of stiffness reduction of the element. The y-axis shows the number of identified damage elements; damage is located when the damage element is identified within a resolution of either three or four elements. Finally, the degree of damage is computed for two damage elements and is shown in table 1.

6. Conclusions and Future Directions

The eigenvector sensitivity method cannot be directly applied to cable-stayed bridges for continuous damage monitoring, because the calculated optimum position of sensors are close to each other showing that higher sensitivity elements are dominant in the sensor placement analysis, therefore it will be impossible to locate damage if the sensors are not distributed over the length of the bridge due to the local nature of damage. The size of the damage element was 10.67 meters, which corresponds approximately to 1/60 times the length of the bridge; damage index analysis shows that it is possible to locate damage accurately using lower mode shapes, but dense array of sensors is necessary if damage is inflicted in elements near the piers, due to small vertical displacements of the deck in these regions. Another solution to these low sensitivity regions can be, the use of higher modes, but ambient vibration tests cannot excite these modes. This study shows that optimum location of sensors as well as damage detection in cable-stayed bridges using identified modal parameters from ambient vibration tests have some limitations due to the uncertain nature of damage in location, magnitude and size. Further studies are needed to determine the minimum length of the damage element that can be detected with the proposed analysis and the extraction of modal parameters using ambient excitation analysis.

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Figures and tables

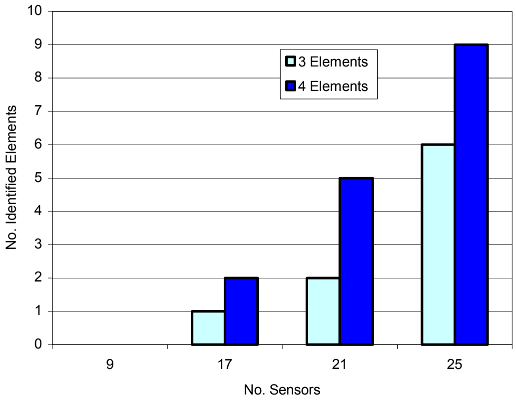

Fig. 1 Optimum Sensor Configurations

Real Damage Element	Possible Damage Element	True Damage Fraction	Computed Damage Fraction
8	6	0	0.0609
	7	0	0.0691
	8	0.1	0.1093
27	27	0.1	0.1085
	28	0	0.0678
	29	0	0.0477

Table 1 Degree of Damage