Damage Detection in Bowstring Girder Bridge using Dynamic Characteristics

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***Abstract* - Damage detection in civil infrastructure has gained greater attention for decades. Mode shape curvature method is a common damage detection technique based on Vibration based damage detection method. In this work we applied this method to a Bowstring girder bridge to locate the damage. Here we applied artificial damage to various members of the bridge model created using staad pro v8i.By changing damage severity at three different cases were also studied in this paper. The mode shape curvature for both intact and damaged structure were calculated. Damage location can be obtained with the help of central difference approximation. The absolute modal curvature was compared between the three damage cases. From the results, the absolute changes in modal curvature are localized in the region of damage and hence Mode shape curvature method is appeared to have potential in damage detection in this bridge.**

Keywords: Damage detection, mode shape curvature method, Bowstring Girder Bridge

I. INTRODUCTION

Civil engineering structures are prone to damage and deteriorations during their life time. Damage accumulates in structures due to environmental loadings such as wind, snow, and ice. These environmental factors can lead to fatigue, corrosion in structural steel and material deterioration in concrete .Damage existence in civil structures causes a reduction in their capacity to carry loads. Undetected damages can lead to catastrophic failure of the structure as a whole or some of its elements. Reliable nondestructive damage detection is crucial to maintain safety and integrity of these structures. The use of dynamic system parameters in damage detection has become an important topic. In the most general terms, damage can be defined as changes introduced into a system that adversely affects its current or future performance. Damage can be identified by making comparison between two different states of the system, one of which is assumed to represent the initial and often undamaged state (1). The idea of vibration based damage detection (VBDD) is to measure the dynamic characteristics of the structure such as natural frequencies, damping and mode shapes for comparing them with later measurements. Then comparing these characteristics, damages can be identified.

In recent years, many researchers were interested in developing methods that can detect the existence and location of damage. Some VBDD methods are based on changes in natural frequencies, curvature /strain modes, modal strain energy .Among the above said modal properties, natural frequency is widely used as it can be easily measurable. But they cannot provide sufficient information to locate the damage since they are global properties of the system.

To overcome this drawback mode shapes have been used for identifying the damage location (9). Changes in mode shapes are more sensitive to local damage when compared to changes in natural frequencies. However, using mode shapes also has some drawbacks. First, damage is a local phenomenon and may not significantly influence mode shapes of the lower modes that are measured from the vibration tests of a large structure. Second, the extracted mode shapes are affected by environmental noise from ambient loads or inconsistent sensor positions. Also, an accurate characterization of the damage location the displacement mode shapes requires measurements in many locations (10).

II. THEORETICAL BACKGROUND

A. Modal curvature based damage detection method Mode shape curvature for the bridge for both intact and damaged condition can be obtained from the displacement mode shapes. Derivative of mode shape is curvature.

Pandey, et al. (8) Stated that, the mode shapes of a damaged and the corresponding undamaged structure are identified, the curvature at each location i on the structure is numerically obtained by central difference approximation

$$\phi_{ij}'' = (\phi_{(i+1)j} - 2\phi_{ij} + \phi_{(i-1)j}) / h^2$$

Where, i is the node number, j is the mode shape number and h is the distance between the measurement points i+1and i-1.

The location of the damage is then identified by the largest computed absolute difference between the mode shape curvatures of the damaged and undamaged structure, as follows

$$\Delta \phi_{ij}'' = \phi_{ij\,d}'' - \phi_{ij\,ud}''$$

Where (ϕij,d) and (ϕij,ud) is the central difference approximation of damaged and undamaged structure respectively.

III. NUMERICAL ANALYSIS AND MODEL

A Bowstring girder bridge model is used in this work. The model was created using STAAD Prov8i. The modelled bow string girder bridge is shown in figure 1. It has a span of 53 m and width of 12m. The material considered is with Modulus of Elasticity, E = 2.17 X 10 ^{7}kN/m^{2}, Poisson's ratio = 0.17.

Both intact and damaged structure is created. Here one of the Dynamic characteristics i.e. mode shape is varied by changing the physical property stiffness. In this work damage is introduced all the structural elements of the bridge.

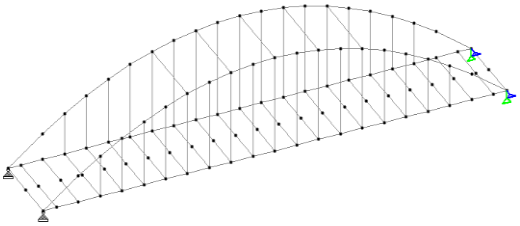

Fig 1: Bridge model created using STAAD Pro V8i

In the analysis, 48 mode shapes were obtained in the STAAD output. Both vertical and horizontal mode shapes can be used to locate the damage (11). In this work only vertical mode shapes is using for damage assessment.

Here three different damage severity cases were studied. By reducing young's modulus by 90%, 80% and 70%. These three different severity conditions were applied to all the elements i.e. arch rib, longitudinal girder, hangers, cross girder.

IV. RESULTS AND DISCUSSION

Mainly two mode shapes are considered for this study, mode 4 and mode 8.The following graph represents the curvature difference between different damage conditions. From that graph we can observe that 90% reduction in young's modulus has the highest peak followed by 80% and 70% respectively.

Table 1: Mode shape curvature difference at Arch rib element 10

Arch rib element 10			
mode shape curvature difference			
mode number	damage (E reduced by)		
	90%	80%	70%
4	0.00164	0.00099	0.00067
8	0.00425	0.00329	0.00241

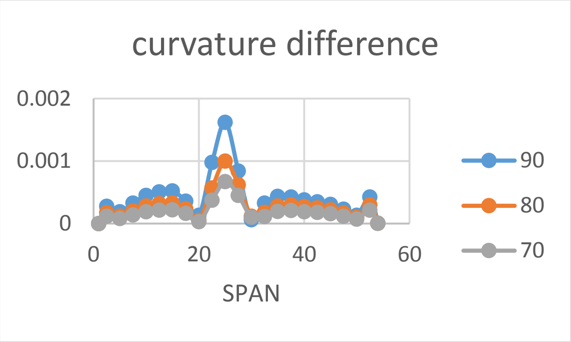

Fig 2: damage at arch rib element 10, mode 4

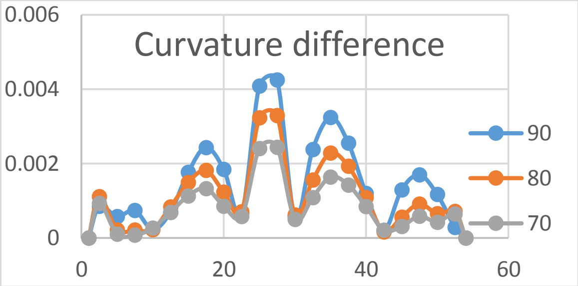

Fig 3: Damage at arch element 10, mode 8

Table 2: Mode shape curvature difference at longitudinal girder element 1

Longitudinal girder			
mode shape curvature difference			
mode number	damage (E reduced by)		
	90%	80%	70%
4	0.00522	0.0028	0.00184
8	0.00712	0.0038	0.00247

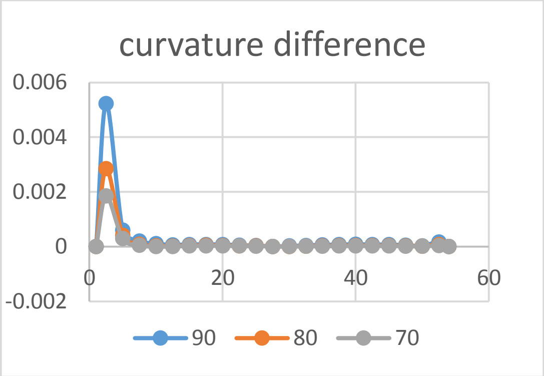

Fig 4: Damage at longitudinal girder element 1, mode 4

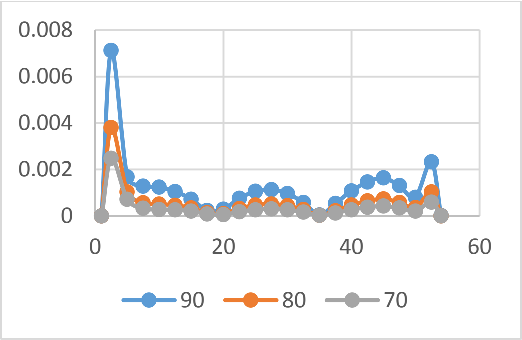

Fig 5: Damage at longitudinal girder element 1, mode 8

Table 3: mode shape curvature difference at cross girder element 8

Cross girder			
mode shape curvature difference			
mode number	damage (E reduced by)		
	90%	80%	70%
4	0.0255	0.0114	0.00678
8	0.0582	0.0207	0.01195

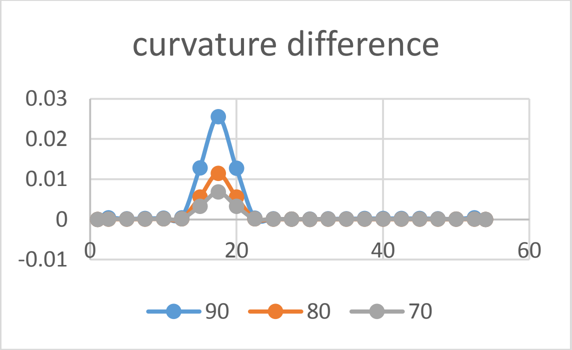

Fig 6: Damage at cross girder element 8, mode 4

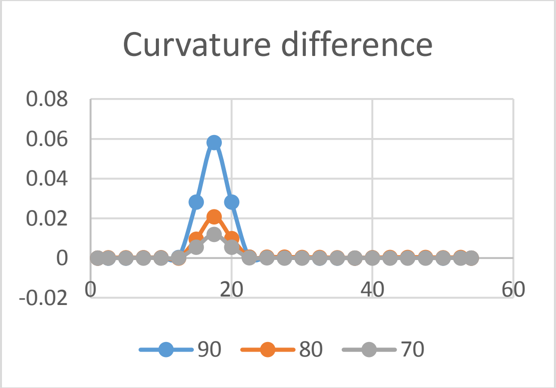

Fig 7: Damage at cross girder element 8, mode 8

Table 4: mode shape curvature difference at hanger element 1

Hanger			
mode shape curvature difference			
mode number	damage (E reduced by)		
	90%	80%	70%
4	0.00022	0.00018	0.00010
8	0.00082	0.00066	0.00052

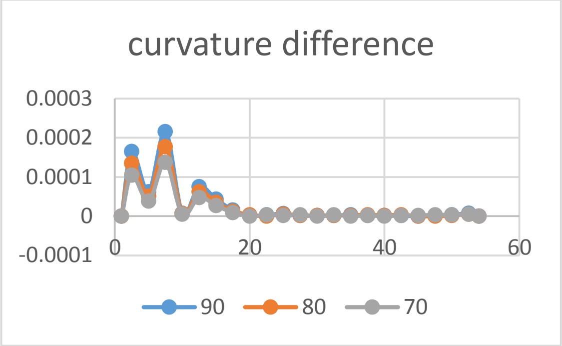

Fig 8: Damage at hanger element 1, mode 4

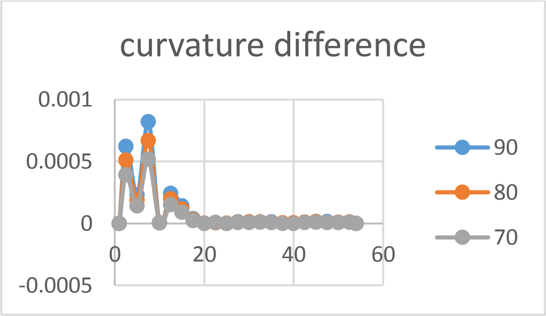

Fig 9: Damage at hanger element 1, mode 8

V. RESULT AND DISCUSSION

The method of mode shape curvature method is used in bowstring girder bridge to locate the damage. The main objective is to use the changes in the mode shapes curvature to detect the occurrence and location of structural damage. In this study, three cases were studied i.e. 90%, 80% and 70% reduction in young's modulus. Here mainly mode 4 and mode 8 are considered since these two modes was more capable for locating the damages. From the graph, we can conclude that highest peak point indicate the location of damage in the bridge. And also from the table, it is clear that higher the peak value means more severity in damage. All the elements were taken for the study, certain element's damage location is not accurate comparing to the other results. Further study is needed in damage location in certain elements, i.e. first element of hangers for this bridge.

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