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DETECTION OF DAMAGE IN A BEAM USING VIBRATIONAL SIGNATURES

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Abstract: It is required that structures must work safely during its service life. But damages initiate a breakdown period on the structures. Damage in the form of cracks may be dangerous due to static or dynamic loadings on the structure and so crack detection plays an important role for Structural Health Monitoring applications. The presence of cracks causes changes in the physical properties of a structure which in turn alter its dynamic response characteristics. The change in the physical properties is characterized by changes in the Eigen parameters, i.e. natural frequency, damping values and the mode shapes associated with each natural frequency. Due to presence of crack the local flexibility due strain energy concentrates at the crack location. So it is important to detect the damages in a beam at the initial stage of the crack. For detection of damages, free vibrations are applied on a simply supported steel beam in undamaged and damaged condition, the instrumentation for which is carried out using strain gauge and accelerometer on wireless data acquisition system. The results of strains and natural frequency which were obtained from experiment are then compared with modal analysis by preparing a finite element model in ABAQUS and checking its significance with theoretical calculations. It is verified from both experimental and simulation analysis that presence of cracks decreases natural frequency of structure. It is observed that as the crack size and number of cracks increase, the natural frequency of the structure decreases. The significance of this study is to detect the damage in vibrating structure by observing the change in natural frequency, which may prove helpful for structural health monitoring of the various structures.

Keywords: Beams, Vibration, Damage

I. INTRODUCTION

The importance of inspection in the quality assurance of manufactured products is well understood. Several methods, such as non-destructive tests, can be used to monitor the condition of a structure. It is clear that new reliable and inexpensive methods to monitor structural defects such as cracks should be explored. The procedures that are often used for detection are called direct procedures such as ultrasonic, X-rays, etc. However, these methods have proven to be inoperative and unsuitable in some particular cases, since they require expensive and minutely detailed inspections. To avoid these disadvantages, researchers have focused on more efficient procedures in crack detection based on the changes of modal parameters likes natural frequencies, mode shapes and modal damping values that the crack introduces. Dynamic response, natural frequencies and mode shapes of a structure depend on the mass and stiffness distributions of the structure, and any changes in these parameters should affect the dynamic behavior of the structure. The stiffness of a structure containing a breathing crack changes continuously with time during the vibration which causes the dynamic behavior of the structure to be significantly nonlinear and the level of nonlinearity is sensitive to the crack parameters (depth and location). In this paper, a new parameter called curvature mode shape is investigated by introducing free vibrations on a simply supported steel beam.

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II. METHODOLOGY AND EXPERIMENTAL SETUP

A. Methodology

Detection of the damage before structural failure of a structure is an important need for structural health monitoring. Various methods have been known for damage detection but we will be using change in natural frequency and change in mode shape patterns for the same. There has been research work already done using nondestructive detection method via changes in the dynamic responses, i.e. modal parameters of the structure. Changes in modal parameters often indicate the appearance of damage in a structure. In this thesis, change in natural frequency between damage and undamaged case depicts that there is certain amount of damage in the structure. Analytical as well as experimental modal analysis is performed on simply supported steel I section beam of length 6m. First, the natural frequency of the beam in undamaged condition is noted. The beam is then damaged by introducing cracks in bottom flange and web portions. Again the natural frequency of the beam is obtained in damaged conditions. The same procedure is repeated in finite element software ABAQUS. Finally, the comparison between analytical and experimental results is shown.

B. Experimental Setup

The experimental setup consists of a steel beam spanning 6m. The beam is supported on a simply supported boundary condition. The steel section here used is ISLB 100. The wireless data acquisition system along with different sensors used in the experiment is shown in the figure. The sensors and data acquisition system used in the research belongs to the Indian Railways. The data acquisition uses WinSTS 3480 and WinGraf applications for noting the response.

Figure 1: - ISLB 100 spanning 6m on which experiment is performed

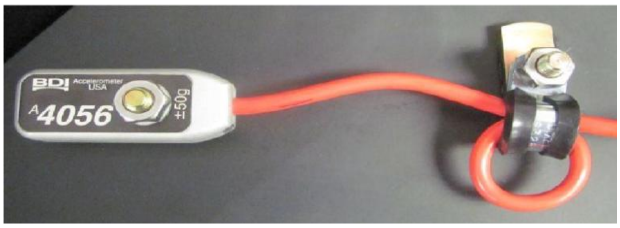

Figure 2: - Accelerometer and strain gauges used in Experiment

III. EXPERIMENTAL PROCEDURE

A. For an undamaged beam :

1. An ISLB 100 steel beam of span 6m is used with no damages.
2. It is simply supported on two roller supports.
3. The connections i.e. Accelerometer (A 4056), Data acquisition system (WinSTS-3480 and WinGraf) and other power connections were made.
4. The surface of the beam was cleaned for proper contact with the accelerometer.
5. The accelerometer was then attached to the surface of the beam.
6. The analyzer and the accelerometer record the responses.
7. An initial vibration is given to the simply supported beam with the help of a hammer and allowed to oscillate on its own.
8. The data obtained from the chosen transducer are recorded in the form of graph (variation of the vibration response with time).
9. The procedure is repeated for 5 to 10 times to check the repeatability of the experimentation.
10. The Curvature Mode Shapes are obtained from the data obtained from transducer.
11. Now a Three dimensional finite elements modelling of I-beam having same specification is generated in ABAQUS software which is a general purpose finite element modelling software for numerically solving a wide variety of mechanical problems.
12. The comparison of Experimental and Analytical calculation is done.

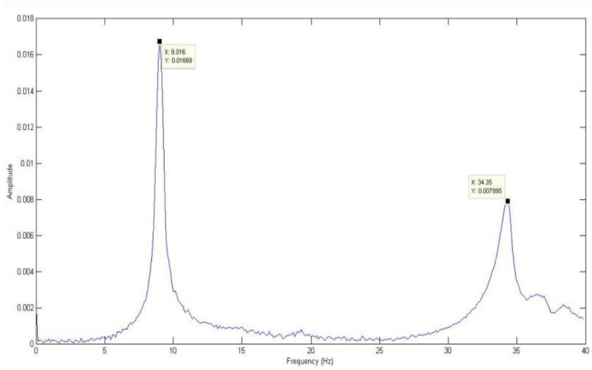

Figure 3: - FFT Plot for Mode 1 and Mode 2 in Undamaged Condition

B. For a damaged beam

1. We will take ISLB 100 steel beam of 6m span which is simply supported on two roller supports
2. The whole experiment was repeated by creating damages at different locations.

a. Damage 1: 50mm cut on bottom flange at the center (i.e. at 3000mm).
b. Damage 2: 100 mm cut on bottom flange at the center (i.e. at 3000mm).
c. Damage 3: Web hole crack of 50mm x 50mm at (L/4) (i.e. at 1500mm).
d. Damage 4: Crack at the intersection of flange and web of 200mm.

e. Damage 5: Web hole of 100mm x 100mm at a distance of 400mm from simply supported end.
3. The whole set of data was recorded.
4. A 3D model of the same beam is modelled in the ABAQUS software.
5. Damages in the beam are modelled referring to the actual experiment performed.
6. The modal analyses will be performed to calculate the natural frequencies of the beam and the curvature mode shapes are obtained from it.
7. The comparison of Experimental and Analytical calculation is done.
8.

IV. RESULTS AND DISCUSSION

a. Case 1: Undamaged condition

	MODE 1	MODE 2	MODE 3
THEORETICAL (Hz)	8.94	35.76	80.47
ANALYTICAL (Hz)	8.83	35.069	77.855
EXPERIMENTAL (Hz)	9.016	34.355	-

Case 2: Damaged 1

	MODE 1	MODE 2	MODE 3
ANALYTICAL (Hz)	8.73	35.068	77.136
EXPERIMENTAL (Hz)	8.659	33.68	67.73

b. Case 3: Damaged 2

	MODE 1	MODE 2	MODE 3
ANALYTICAL (Hz)	8.703	35.067	76.993
EXPERIMENTAL (Hz)	8.600	33.33	66.27

c. Case 4: Damaged 3

	MODE 1	MODE 2	MODE 3
ANALYTICAL (Hz)	8.729	35.23	77.134
EXPERIMENTAL (Hz)	8.614	33.39	66.79

d. Case 5: Damaged 4

	MODE 1	MODE 2	MODE 3
EXPERIMENTAL (Hz)	8.647	33.60	65.74

e. Case 6: Damaged 5

	MODE 1	MODE 2	MODE 3
EXPERIMENTAL (Hz)	8.657	33.63	67.41

IV. OBSERVATION AND DISCUSSION

1. Firstly, it is observed that all the theortical and analytival calculations are in good agreement with each other. The percentage error between theorerical and experimental results is not more than 2.5%.
2. It is also observed that as the amount of damage increases, the natural frequency goes on decreasing. That means we can predict the change in natural frequency of a structure depicts the presence of damage.

V. SUMMARY

This study is mainly focused on damage detection in beams. The change in natural frequency parameter is used for detection of damage in the structure. In this study, experimental investigation was conducted on free vibration analysis of a simply supported beam in damaged and undamaged conditions. The damages were introduced at different locations by varying crack sizes. The FE Analysis has been carried out using ABAQUS. The experimental investigation was validated using finite element modelling.

VI. CONCLUSION

The experimental and analytical results show good agreement for damaged and undamaged condition both. There is significance decrease in stiffness and natural frequency due to presence of cracks. The change in frequency depends on the crack depth as well as the location.

VII. RECOMMENDATIONS FOR FUTURE RESEARCH

- The Curvature mode shape can be plotted directly from the experimental data. Since curvature is proportional to the bending strain, in experimental test curvature modes shape can be obtained directly by measuring strain instead of displacement or acceleration.
- Once the detection of damage is done experimentally, one can work in calculating the remaining life of the structure.
- The simply supported beam in Undamaged and damaged condition can be analyzed under the influence of forced vibration.
- The dynamic response of the cracked beams can be analyzed for different crack orientations.

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