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Damage Detection in Frame Structure Using Frequency Response Measurements

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ABSTRACT

There is strong need and requirement for on-line damage detection and health-monitoring techniques on structures. This paper presents frequency response function (FRF) method to detect damage in frame structure. Vibration based methods with piezoelectric sensor and actuator integrated into structures is a promising option to fulfil such requirements. These methods utilize finite element analysis techniques, together with experimental results, to detect damage. They locate and estimate damage by comparing dynamic responses between damaged and undamaged structures. Frame structure is modelled using finite element software ABAQUS. Frame structure is coupled with piezoelectric transducer which will excite the structure for transient analysis. Acceleration responses are measured at various points in structure and this data is used to find out frequency response functions (FRF). The shifts in the natural frequencies of the structure will be observed for undamaged and damaged structure to detect the damage.

Keywords— **Damage detection, Dynamic responses, Frame structure, FRF, Piezoelectric transducer**

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I. Introduction

Space frame structures are widely used engineering structures and have been commonly used in the studies on structural damage detection. Typical damage in a space frame structure includes distortions of beam members and defects and degradations at its joints and boundaries. It is difficult to use the conventional non-destructive testing (NDT) methods, such as penetrant testing, ultrasonic testing, and electromagnetic testing, to detect damage in a space frame structure, since there is no obvious material loss associated with the damage, and the material of the structure is naturally discontinuous at its joints and boundaries. The topological complexity of a space frame structure also increases the difficulty of implementing conventional NDT methods since these methods often require local access to the test structure. As global damage detection methods, the vibration-based methods that use changes in vibration characteristics of a structure, such as natural frequencies, mode shapes, and frequency response functions (FRFs), to detect the locations and extent of damage in the structure can overcome the disadvantages of the conventional NDT methods. Because the vibration characteristics can be remotely measured at a few locations of the test structure, there is no need to locally inspect the test structure in vibration-based damage detection. Also, because the vibration-based damage detection methods utilize the relations between the vibration characteristics of a structure and the physical properties such as the mass density and the stiffness of the structure, they aim to detect the changes in the physical properties caused by damage, regardless of specific types of damage. Hence they can be used to detect various types of damage in a structure, including those that occur at its joints and boundaries.

Technique for detecting the loosening of the bolts in composite/metal bolted joints was presented by Vincent Caccese et al. [1]. He used three different techniques which are based on vibration measurements and also employed smart material like piezoelectric sensor for the same. Takeshi Nakahara et al. [2] proposed new bolt loosening detection sensor system using local mode vibration characteristics of thin plate.SaratChalumuri et al. [3] performed finite element analysis as well as experimental analysis to comprehend the behavior of the beam with progressively loosened bolted joint.Roxana Balc et al. [4] presented the analysis with finite elements of a steel joint with end plate and prestressed bolts, using the ABAQUS finite element software code. The results obtained after the numerical simulation were compared with the experimental data in order to validate the model.Y. Zou et al. [5]presented vibration based damage detection methods such as time domain, Frequency domain, Impedance domain, modal analysis methods. Delamination modelling techniques are also discussed along with the effects of delamination on dynamic modal parameters. Use of smart materials like piezoelectric transducer is also discussed in this study.S. Raja et al. [6]studied the effect of delamination or debonding on the static and dynamic characteristics of laminated piezoelectric beams and plates.IsrarUllah et al. [7] used apiezo-electric shaker to excite the composite plate and the acceleration responses were measured using the number of accelerometers. The dynamics of the delaminated composite plates were then compared with a healthy composite plate when the vibration experiments have been conducted at the lower modes.M. Meo et al. [8] presentedmodelling techniques able to predict a delamination failure mode in composite structures. Four different ways of modelling delamination growth of a double cantilever beam test (DCB) are proposed. The first two approaches were based on a cohesive zone model, the third approach was based on simulation of the interface with solid element and the last approach was based on the definition of a tiebreak contact.

II. METHODOLOGY

In this section the frame will be modelled in ABAQUS. Piezoelectric transducer is modelled using piezoelectric elements. Transient analysis is carried out to obtain dynamic responses of the structure using ABAQUS. From the dynamic responses frequency response functions (FRF) are obtained by using MATLAB code. The damaged and undamaged structure will be compared based on the FRF. The shift in the natural frequency will be obtained because of the damage, change in boundary conditions, delamination etc. In this study two different scenarios will be considered for the damage detection. In the first case bolted steel frame will be considered for the detection of the loosening of the bolt. In the second case delamination will be modelled in composite frame and FRF will be used to detect that delamination.

III. BOLT LOOSENING ANALYSIS

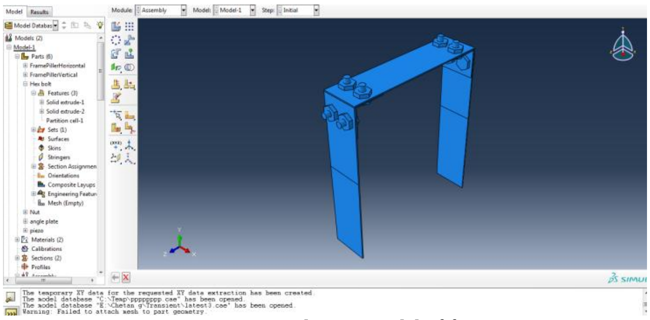

Fig.1 Finite element model of frame

For bolt loosening analysis, the FEM model of steel frame is developed in ABAQUS software. Twenty noded quadratic solid brick element C3D20R is used to model the frame structure. In the first step Modal analysis is carried out to find out the natural frequencies.

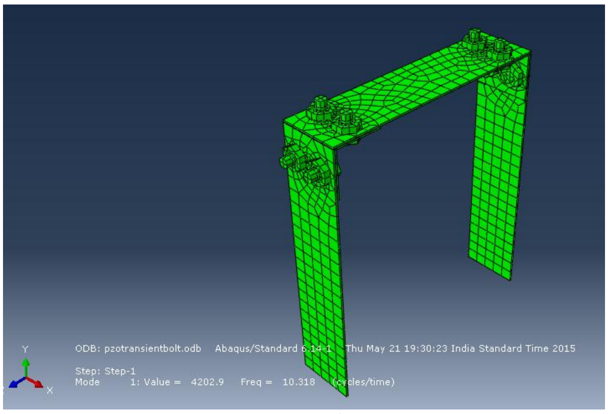

Fig.2 Modal analysis (Mode 1 frequency = 10.318 Hz)

In the second step transient analysis is performed to find out the dynamic responses of the structure. For transient analysis time step of one second was considered with the increment of 0.001 in each step. Load was applied at a point such that it will be applied at the time 0.002. Acceleration response of the structure is taken at a point on a structure.

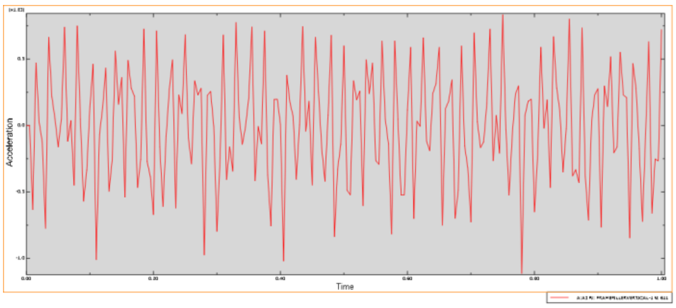

Fig.3Acceleration response of structure

The acceleration response of the structure is continuous signal. In order to obtain the frequency responses from this signal the discrete fourier transform of the signal is taken. MATLAB code is used to obtain the discrete fourier transform (DFT) of this signal. DFT converts time domain acceleration data into frequency domain. The peaks are obtained at the natural frequencies as follows.

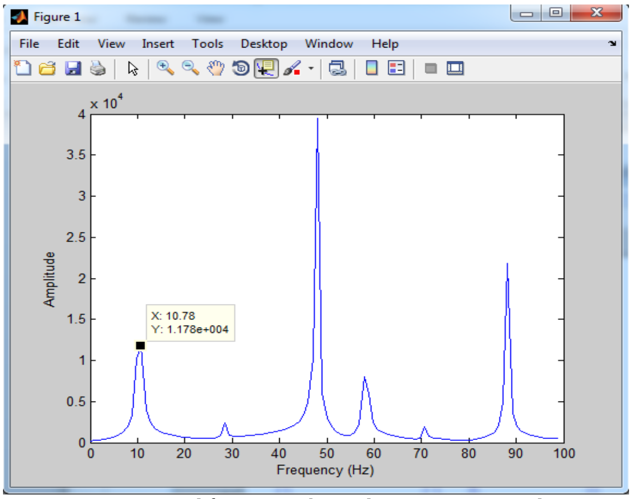

Fig.4Natural frequency obtained using transient analysis
(Mode 1 frequency 10.78 Hz)

From this study it is concluded that the transient analysis can be successfully used to obtain the natural frequencies.

The next step in the analysis is to couple the piezoelectric transducer to the frame structure. In this step transient analysis is performed using piezoelectric excitation which is given in the form of voltage signal. The piezoelectric element acts as an actuator in this case. It is modelled using the eight node piezoelectric linear brick element C3D20R. The study is first carried out for the simple frame model which does not have any bolted joints. Tie constraint is used to couple the piezoelectric transducer to the frame structure. Again modal and transient analysis is performed and the results are cross checked.

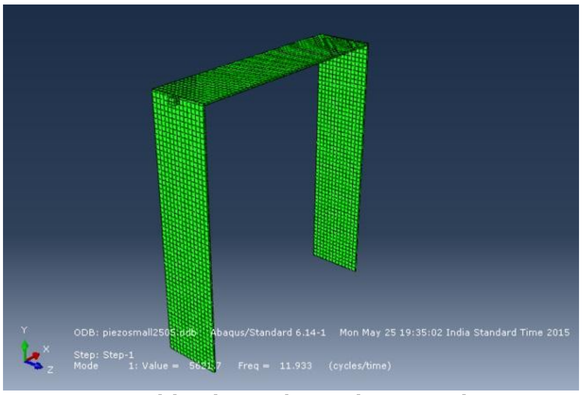

Fig.5Modal analysis with piezoelectric transducer
(Mode 1 frequency = 11.933 Hz)

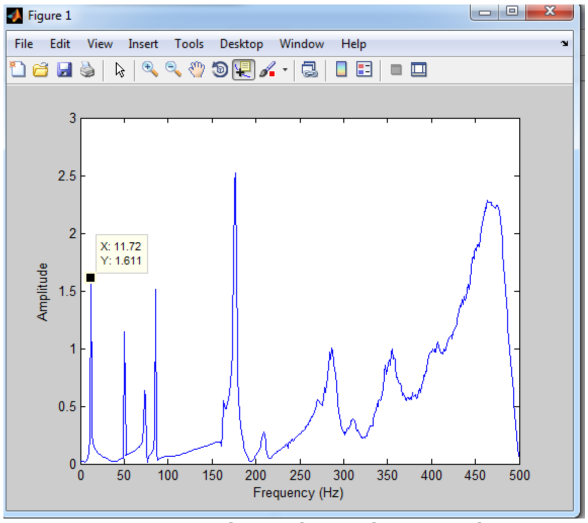

Fig.5Transient analysis with piezoelectric transducer
(Mode 1 frequency = 11.72 Hz)

It is found that the results for the simple frame are in agreement. The same study will be extended for the bolted frame for the bolt loosening analysis of the structure. The changes in the bolt preload will cause changes in the boundary conditions of the bolt and hence the natural frequency of the structure will be shifted. This shift in the natural frequency will be used to assess the damage.

IV. DELAMINATION MODELLING

Delamination is a frequent mode of failure affecting the structural performance of composite laminates. There are many methods available for the modeling of delamination. Out of these methods widely used methods are cohesive zone modeling and virtual crack closure technique. Both these methods are considered for the study and finally the best suitable method will be used.

Simple shell structure is taken and static analysis is performed. The delamination is modelled using virtual crack closure technique.

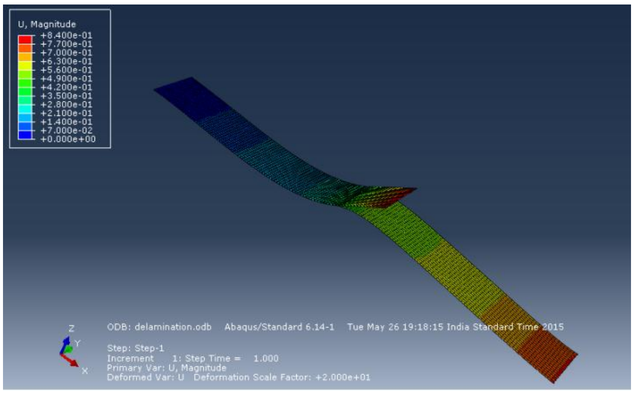

Fig.5Delamination modelling using virtual crack closure technique

V. RESULT DISCUSSION AND FUTURE WORK

In bolt loosening analysis the objective is to detect the damage using piezoelectric actuator. Till now the results are obtained for simple frame without bolted joints. Future work will be to obtain the results for the bolted steel frame and then the bolts will be loosened by varying the preload on the bolt and structural response will be evaluated. From this study the bolt loosening will be detected successfully.

In composite delamination the study is done on simple composite shell structure and static analysis is done the future work will consist of composite frame modelling and its modal and transient analysis for damage detection.

VI. CONCLUSION

Frequency response methods show good promise for detecting the damage in the structure. The modal frequencies were accurately predicted by the transient analysis of simple frame without bolted joints using piezoelectric transducer. Composite delamination is modelled in ABAQUS by virtual crack closure technique which can be extended to frame structure.

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