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# System Identification of a Beam Using Frequency Response Analysis

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***Abstract:*** *System identification is an emerging area in engineering fields. To assess the present health of important structures is necessary to know the status of the health of structure and subsequently to improve the health of the structure. In this work, using the finite element software, a simple structural member like beam is modeled. A simply supported beam is taken and crack is initiated at the bottom of the beam along it's width by reducing the cross section in different location. Free vibration analysis is performed using FEM software SAP2000. There is a difference between the frequencies of cracked and un-cracked beam. From this analysis it can be predicted that there is damage in the beam, but location of the damage cannot be detected. For this, mode shape to be found out. This concept can be used to know in the real life structure whether there is any damage or not using the non-destructive techniques.*

***Keywords***: FEM Software, SAP2000, System Identification.

## INTRODUCTION

System Identification (SI) is a emerging tool to assess the health of engineering structures and employed in different fields of engineering [1,2]. Using this tool, the dynamic characteristics – frequency, mode shaped, mass, damping coefficient, stiffness etc. of the structures are determined. Structural health monitoring has already gained a great attention to the engineers, scientists and academicians for assessment and evaluation the health status of the structures [3], [4] and [5] . The objective of the health monitoring is to give the present status of the structure so that precautionary measures can be taken to protect the structure from the further damage and repair the structure.

There are many reasons that cause early damage in the structures. Environmental actions cause deterioration in the concrete and steel. Lack in quality control at the construction stage is also the reason of damages in the structure. During manufacturing process there may be defects in the materials used in the structure. Natural hazards like earthquake and high wind also create defects in the structures. Due to load reversal in the structures, the cracks may be widened and there may be more cracks from the old cracks. Consequently, there may be loss of integrity in the structure leading to its failure. Structural health monitoring (SHM) gives the solution to avoid this problem. By using different methods of system identification, the early damages can detected with location. The structural parameters like stiffness, damping and mass can be evaluated and appropriate measures can be taken to avoid the catastrophic failure of the structure.

There are many non-destructive techniques for damage detection namely X-ray imaging, ultrasonic scans, infrared thermograph, and eddy current can identify damages. But those all are localized techniques and have many limitations. Besides, it is difficult to screen the whole structure locally to employ these techniques. These drawbacks of those techniques motivate engineer and researcher to search new techniques to overcome those difficulties. Evaluation of the dynamic response is very powerful techniques to get the global and integrated response of the structure. In this technique, the structure is excited with dynamic load to get the dynamic parameters like damping, natural frequency and mode shape. These parameters are compared with that of undamaged structures to detect the damage



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or defects in the structure. The damage can be estimated by comparing the parameters of damaged and undamaged structures.
Some methods in system identification are as follows:

- Conventional model-based approaches
- Biology based approach - Neural network and genetic algorithm
- Signal processing-based approach- wavelets
- Chaos theory
- Multi-paradigm approaches

In conventional model-based approaches of system identification, some physical parameters are evaluated from model developed in FEM software [6] and [7]. In this approach, the parameters are evaluated in the model and compared between the parameters of damaged and virgin structures. This is the advantage of the approach. The disadvantage of the approach is that it cannot accurately predict the physical parameters of complex and life line structure. But it forms a basis for other methods.

## LITERATURE REVIEW

Most beams and 2D frame structures can be modelled with reasonable accuracy using a model-based approach. Liu [8] used measured natural frequencies and mode shapes for system identification and damage detection of an aluminium 2D truss with 21 members. The damage was defined as a reduction in the axial stiffness which was determined by identifying changes to the natural frequencies and mode shapes of the truss.

J. Kosmatka, M. Ricles [9] presented for detecting structure damage in elastic structure by non-destructive means. The current approach is unique as it accounts for:

1. Variation in system mass, system stiffness and mass centered locations.
2. Perturbation of both the natural frequency and modal vectors.
3. Statical confidence factors for the structural parameters and potential experimental instrumentation error.

It used modal vibration characterization for detecting stiffness changes in a ten-bay aluminium space truss.

Kim and Stubbs [10] investigate how model uncertainty affects accuracy when identifying structural degradation of a two-span aluminium plate girder, especially when only a few modal response parameters are used. The authors point out the potential shortcomings of the model-based approach especially when the model is too idealized and not a good representation of the actual structure.

Modelling error-effects on model-based systems are also investigated by Sanayei et al. [11] with respect to the error functions used. The authors compare the performance of two stiffness-based and two flexibility-based error functions in terms of model error propagation rate and the quality of the final parameter estimates. They conclude that stiffness-based error functions are better than flexibility-based functions in terms of modelling error.

Damage identification in beams is a common theme in system identification research. Kim and Stubbs [12] discuss damage identification of a two-span continuous beam using modal information.

U. Lee, J. Shin [13] developed a frequency response function-based structural damage identification method. They detect changes in the stiffness of beams based on a frequency-based response function by varying the cross sections of beam sections at different locations. J. Kim, N. Stubbs [14] presented improved damage identification method based on modal information. This paper introduces a FRF based structural damage identification method for beam structures. The damage within the beam structures are characterized by introducing a damage distribution function.

Z.R. Lu, J.K. Liu, M. Huang, W.H. Xu [15] identified of local damages in coupled beam systems from measured dynamic responses. They used a Finite Element (FE) model updating method to detect changes in flexural stiffness in coupled beam systems (two beams connected by a set of linear and rotational springs). This investigation investigated the non-linear free vibration of a cantilever beam containing an open crack under large vibration amplitudes and a semi-analytical solution about the beam of non-linear vibrations was proposed. K. Liew, Q. Wang [16] applied wavelet theory for crack identification in structures. They used wavelets to identify cracks in simply supported beams. This paper presents the first attempt of an application of the wavelet theory for the crack identification of the systems. In this case study, crack identification is considered using the wavelet theory for a simply supported beam with a transverse on-edge non-propagating open crack.

T. Pan, C. Lee[17] applied wavelet theory to identify yielding in seismic response of bi-linear structures. They used wavelets to identify yielding of lumped mass Single-Degree-Of-Freedom (SDOF) and Multi-Degree-Of-Freedom (MDOF) systems subjected to seismic loading.

Jeong-Tae Kim; Yeon-Sun Ryu; Hyun-Man Cho; Norris Stubbs [18] presented damage identification in beam-type structures: frequency-based method vs mode-shape-based method. They presented a methodology to nondestructively locate and estimate the size of damage in structures for which a few natural frequencies or a few mode shapes are available. First, a frequency-based damage detection (FBDD) method is outlined. A damage-localization algorithm to locate damage from changes in natural frequencies and a damage-sizing algorithm to estimate crack-size from natural frequency perturbation are formulated. Next, a mode-shape-based damage detection (MBDD) method is outlined. A damage index algorithm to localize and estimate the severity of damage from monitoring changes in modal strain energy is formulated. The FBDD method and the MBDD method are evaluated for several damage scenarios by locating and sizing damage in numerically simulated prestressed concrete beams for which two natural frequencies and mode shapes are generated from finite element models. The result of the analyses indicates that the FBDD method and the MBDD method correctly localize the damage and accurately estimate the sizes of the cracks simulated in the test beam.
X.Q. Zhu, S.S. Law [19] developed Wavelet-based crack identification of bridge beam from operational deflection time history. They suggested a new method for crack identification of bridge beam structures under a moving load based on wavelet analysis is presented. Crack is modelled through rotational springs whose compliance is evaluated using linear elastic fracture mechanics. Dynamic behavior of the cracked beam subject to moving load is analyzed using mode superposition. The response obtained at a single measuring point is analyzed using continuous wavelet transform and the location of the cracks is estimated. The locations of the cracks are determined from the sudden changes in the spatial variation of the transform responses. To estimate the relative depth of the cracks, a damage factor is established which relates the size of the cracks to the coefficients of the wavelet transform. The proposed method is validated by both simulation and experiment. Locations of multiple damages can be located accurately, and the results are not sensitive to measurement noise, speed and magnitude of moving load, measuring location, etc.

## DAMAGE DETECTION TECHNIQUES

In this section, two mostly used damaged detection techniques are described.

### Frequency based damage detection

Natural frequency based method is the easiest method of system identification. In this method, natural frequency is measured experimentally in one or two locations of the structure be placing the sensors. The frequency of damaged structure will be less than that of undamaged structure as the stiffness is reduced. This method can easily be verified in the laboratory by employing on simple structures. Analytically or computationally, natural frequency can be determined using different methods. Using FEM software, the model of the structure is made and either stiffness or cross section is reduced at the damaged location. Then natural frequency is determined. This is the simplest method, but it cannot be applied for complex and big structure. By this method, only one structure is damaged or not can be detected. The location, shape and size of the damage cannot be determined as several combinations of these variables can yield similar or identical frequency change.

### Mode shape-based damage detection

A more robust application of dynamic-based approach for damage detecting is based on mode shapes. This method has been developed to assess damage directly using the measured displacement mode shapes or curvature mode shapes. A more effective method of damage detection based on the mode shapes is the use of curvature mode shapes. From Euler-Bernoulli beam theory, the curvature mode shape is related to the Young's modulus of beam and the beam cross sectional geometric properties. The use of curvature mode shapes in damage identification is based on the assumptions that the curvature of an undamaged structure is smooth and continuous and the irregularity of the curvature can thus determine the location of the damaged for a homogeneous structure. The change in the curvature mode shapes is highly localized to the region of damages, and they are more pronounced than the changes in the displacement mode shapes. The curvature is often calculated from the measured displacement mode shapes by using a central difference approximation.

## FEM MODELLING

SAP2000 is used in present analysis. Description of these softwares and their participation in analysis is mentioned below.
Modelling and frequency response analysis is done in SAP2000
SAP 2000 is used to model plain concrete beams. The analysis of beams is based on Euler-beam theory, i.e., shear deformations are not considered. Area section is used to model beam. Element type is selected such that assumptions of Euler-beam theory are satisfied. Therefore 'thin shell' is used to model the beam.
Simply supported beam is selected for the purpose of analysis.
'Grid only' option is used to create beam models. For all three beams specified above grid is created such that sectional view along the longitudinal axis of beam is divided into 'n' number of rectangle representing minimum size of crack to be provided.

### DIMENSIONS OF BEAM

For all three cases same cross-section and span length is considered.
Cross section - 230 x 300 mm
Span length - 3000 mm

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**DIMENSION OF CRACK AND CRACK LOCATION**

***CRACK SIZES-***

Crack sizes were used mentioned below,
30mm x 20mm x 230mm
60mm x 40mm x 230mm

***CRACK LOCATION-***

| **BEAM TYPE** | **LOCATION** |
|---|---|
| Simply supported beam | At L/4 |

## RESULTS AND DISCUSSION

As discussed above two damage detection techniques can be studied in this analysis, Here frequency based analysis is carried out in order to detect damage in simply supported beam.

Comparative results obtained, are discussed below:

Results of frequency and natural frequency are arranged in tabular form.

**FREQUENCY**

Comparison between frequencies at different modes is given in the following table (table 1):

TABLE 1
NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

| NATURAL FREQUENCY (Rad/sec) | | | | |
|---|---|---|---|---|
| Crack size (mm) | Crack location | Mode1 | Mode2 | Mode3 |
| UNCRACKED | | 2215.7 | 4432.6 | 6645.7 |
| 30 X 20 | L/4 | 2215.1 | 4434.1 | 6644.5 |
| 60 x 40 | L/4 | 2213.6 | 4442 | 6639.4 |

## CONCLUSION

In this study, using damage localization technique frequency based the natural frequency of damaged and undamaged simply supported beam is determined as an assessment of state of the health of structures. By this method, only detection of damage can be carried out. For detecting location of damage, other methods like mode shape based methods to be employed.

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