

## **DAMAGE DETECTION OF FRAME STRUCTURES USING WAVELET THEORY**

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**Abstract—** The damage detection of civil and mechanical structures are drawing lot of interest from different fields. Damages cause changes in mass, stiffness, damping in the structures and subsequently change natural frequency and mode shapes of the structure. In this study, the damages are detected in a frame structure using wavelet theory along with natural frequency, mode shapes and curvature mode shapes.

**Keywords—** structural health monitoring, wavelet theory, MATLAB, SAP2000, damage detection

### **I. INTRODUCTION**

Damages occur in the civil, mechanical, aerospace and naval engineering structures in their life span [1 - 3]. Damage is induced either through sheer deterioration over time or owing to excessive structural loads such as winds, earthquakes, or traffic. So the improvement of public safety and maintainability of new and existing structures is necessary [4-7].

Damage detection of structures is gaining popularity and attention since failure of damaged structures under major hazard may be disastrous. Catastrophic bridge failures and aircraft crashes are some of the examples [8-11]. The field of structural health monitoring (SHM) has drawn the attention of the researchers mainly due to the security, reliability and economy aspects [12-13]. The data obtained from SHM is useful for structural safety evaluation, rapid evaluation of conditions of damaged structures, residual life estimation of structures, repair and retrofitting of structures, maintenance, management or rehabilitation of existing structures [14-15].

The objectives of this study are as follows:

- Damage detection of frame structure (Tables 1 - 4) using any wavelet (damage size 10%, 20% and 30%)
- Damage detection of frame structure using mode shape and natural frequency (damage size 10%, 20% and 30%)
- Damage detection of frame structure using mode shape curvature (damage size 10%, 20% and 30%)
- Comparison of results obtained by the above methods.

### **II. METHODOLOGY**

The following methodology is adopted for the study:

- A frame structure is modelled in SAP2000; this frame is divided into 400 elements along its length (Figures 1 - 4).
- Acquisition of modal parameter from SAP2000.
- These modal parameters are then imported to MATLAB for further analysis.
- Using Wavelet toolbox in MATLAB we generate 1D plot for variation of wavelet coefficient.
- By recording the sudden change in the wavelet coefficient in 1D plot, the location of damage can be predicted.

TABLE 1  
DESCRIPTION OF UNDAMAGED FRAME

|                                             |                |
|---------------------------------------------|----------------|
| <b>Length of the beam</b>                   | 6 m            |
| <b>Length of the column</b>                 | 3 m            |
| <b>Cross-section of the beam and column</b> | 500 mm x 300mm |
| <b>Material of the beam and column</b>      | M30 and Fe415  |
| <b>Loading on the beam</b>                  | 3 kN/m         |
| <b>Damage in the beam and column</b>        | No damage      |

TABLE 2  
 DESCRIPTION OF 10% DAMAGED FRAME

|                                             |                                                                                         |
|---------------------------------------------|-----------------------------------------------------------------------------------------|
| <b>Length of the beam</b>                   | 6 m                                                                                     |
| <b>Length of column</b>                     | 3 m                                                                                     |
| <b>Cross-section of the beam and column</b> | 500 mm x 300 mm                                                                         |
| <b>Material of the beam and column</b>      | M30 and Fe415                                                                           |
| <b>Loading on the beam</b>                  | 3 kN/m                                                                                  |
| <b>Damage in the frame</b>                  | Damage length = 200 mm and cross-section of frame at damaged location = 450 mm x 300 mm |

TABLE 3  
 DESCRIPTION OF 20% DAMAGED FRAME

|                                             |                                                                                        |
|---------------------------------------------|----------------------------------------------------------------------------------------|
| <b>Length of the beam</b>                   | 6 m                                                                                    |
| <b>Length of column</b>                     | 3 m                                                                                    |
| <b>Cross-section of the beam and column</b> | 500 mm x 300 mm                                                                        |
| <b>Material of the beam and column</b>      | M30 and Fe415                                                                          |
| <b>Loading on the beam</b>                  | 3 kN/m                                                                                 |
| <b>Damage in the frame</b>                  | Damage length = 200 mm and cross-section of frame at damaged location = 400 mm x 300mm |

TABLE 4  
 DESCRIPTION OF 30% DAMAGED FRAME

|                                             |                                                                                        |
|---------------------------------------------|----------------------------------------------------------------------------------------|
| <b>Length of the beam</b>                   | 6 m                                                                                    |
| <b>Length of column</b>                     | 3 m                                                                                    |
| <b>Cross-section of the beam and column</b> | 500 mm x 300 mm                                                                        |
| <b>Material of the beam and column</b>      | M 30 and Fe 415                                                                        |
| <b>Loading on the beam</b>                  | 3 kN/m                                                                                 |
| <b>Damage in the frame</b>                  | Damage length = 200mm and cross-section of frame at damaged location = 350 mm x 300 mm |

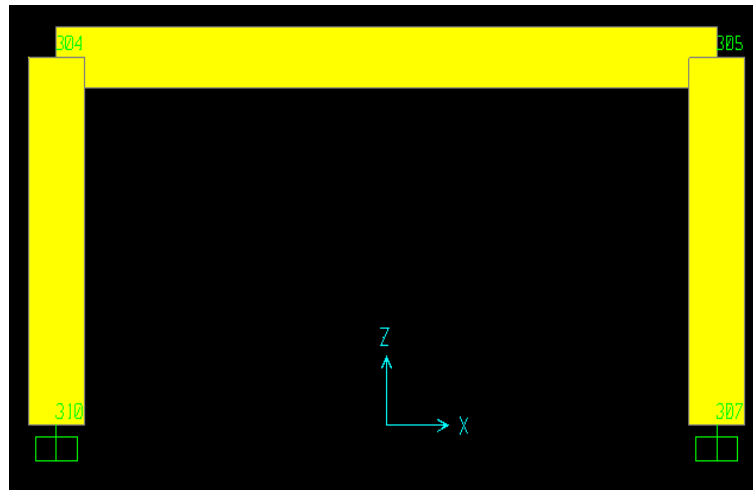


*Fig. 1 Model of undamaged frame*

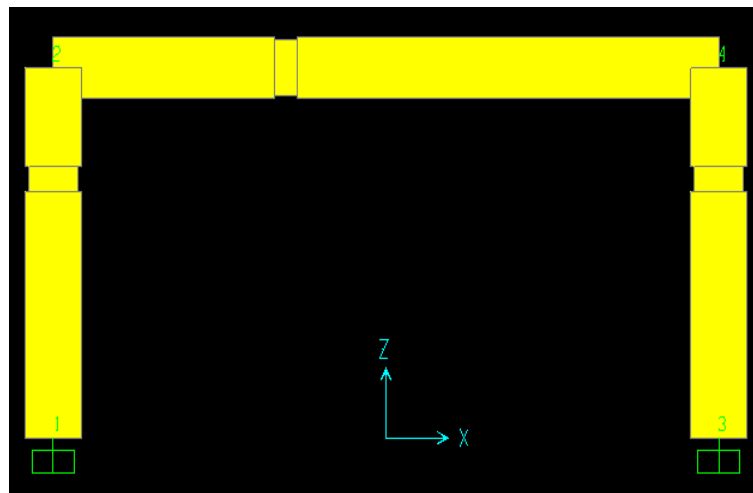


*Fig. 2 Model of 10% damaged frame*

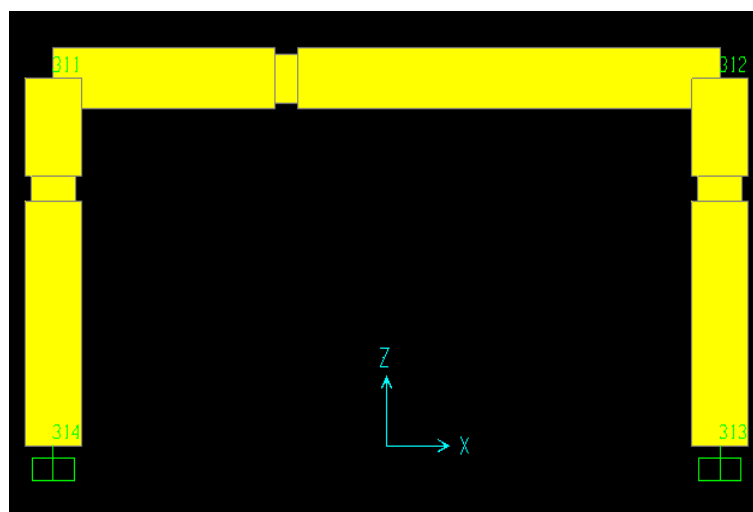


*Fig. 3 Model of 20% damaged frame*

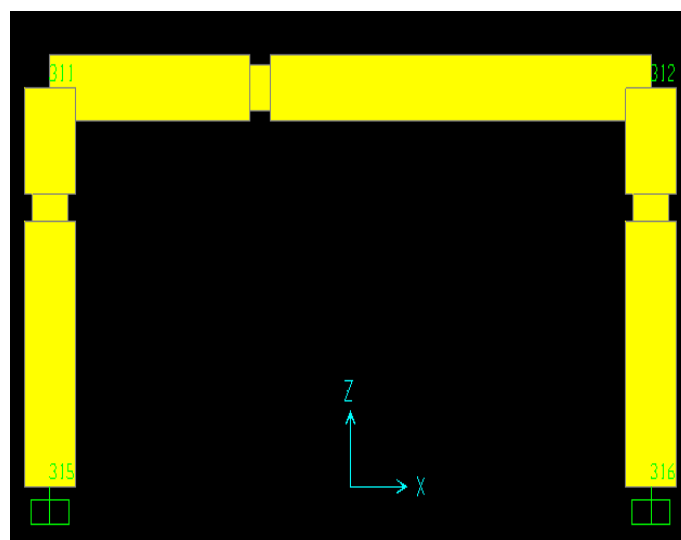


Fig. 4 Model of 30% damaged frame

### III. RESULTS AND DISCUSSIONS

The results obtained from the analysis of the wavelet coefficient, natural frequency, mode shape, mode shape curvature is presented in this section (Figures 5 - 17, and Table 5).

- From the wavelet coefficient diagram, we observed that a sudden change occurs in the wavelet coefficient at node no. 200 i.e. 2 m apart from the left support, which is the location of damage.
- It is found that mode shape curvature curve is discontinuous at 2 m from the left support this discontinuity in curvature curve defines the location of damage.
- Wavelets are very effective damage detecting tool. All types of cracks whether it is a minor crack i.e.10% or a major crack i.e.30% can be detected by wavelets.
- Mode shape curvature method can detect the damages only when the variation in the curvature is high. Sometimes variation in curvature is so small that discontinuity cannot be judged. Hence mode shape curvature method proves to be a good tool in detecting damages under higher modes.
- As we go for higher modes change in natural frequencies of undamaged and damaged structures increases this shows that damage can be detected very easily under higher modes.

TABLE 5  
COMPARISON BETWEEN FREQUENCIES OF DAMAGED AND UNDAMAGED STRUCTURES

| Mode No. | Natural Frequency (Hz) |                   |        |        |
|----------|------------------------|-------------------|--------|--------|
|          | Undamaged structure    | Damaged structure |        |        |
|          |                        | 10%               | 20%    | 30%    |
| 1        | 45.642                 | 45.613            | 45.467 | 45.205 |
| 2        | 173.85                 | 173.85            | 173.83 | 173.8  |
| 3        | 363.93                 | 363.76            | 362.5  | 361.35 |

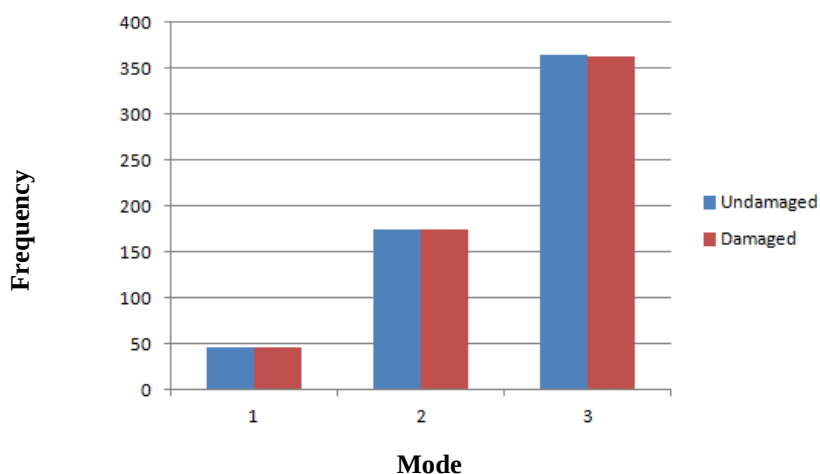


Fig. 5 Comparison of natural frequency (Hz) between 10% damaged frame and undamaged frame

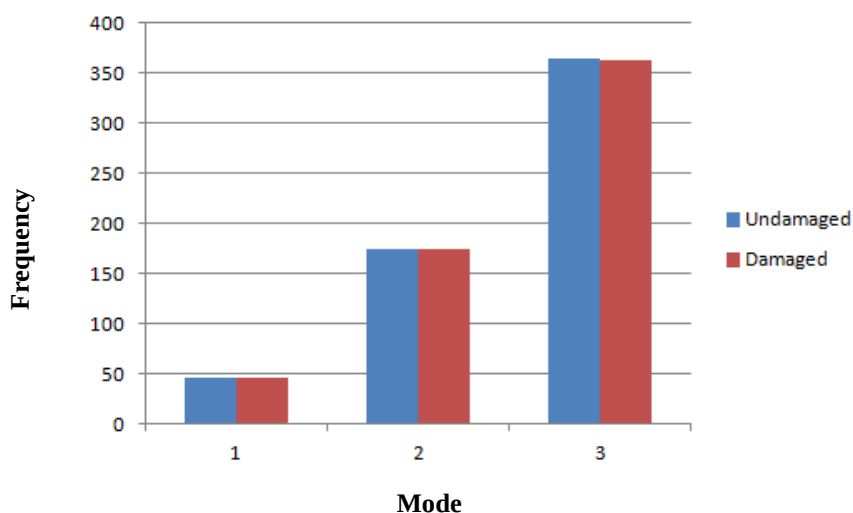


Fig. 6 Comparison of natural frequency (Hz) between 20% damaged frame and undamaged frame

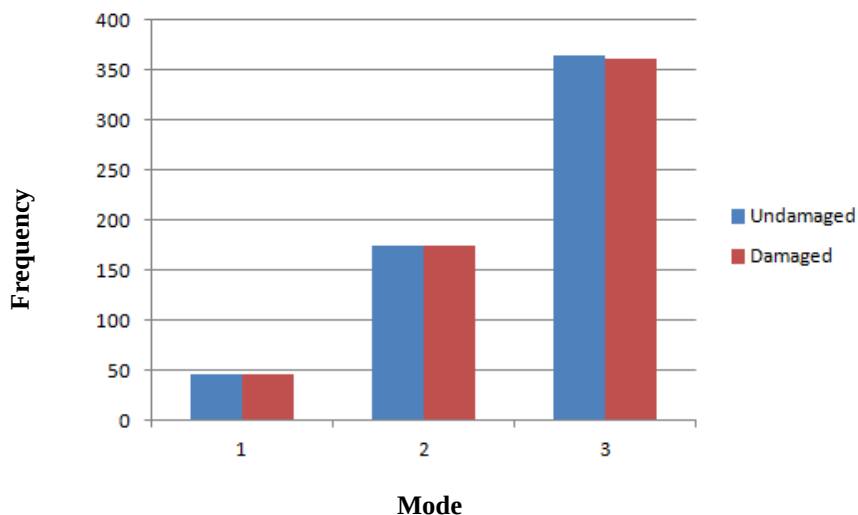


Fig. 7 Comparison of natural frequency (Hz) between 30% damaged frame and undamaged frame

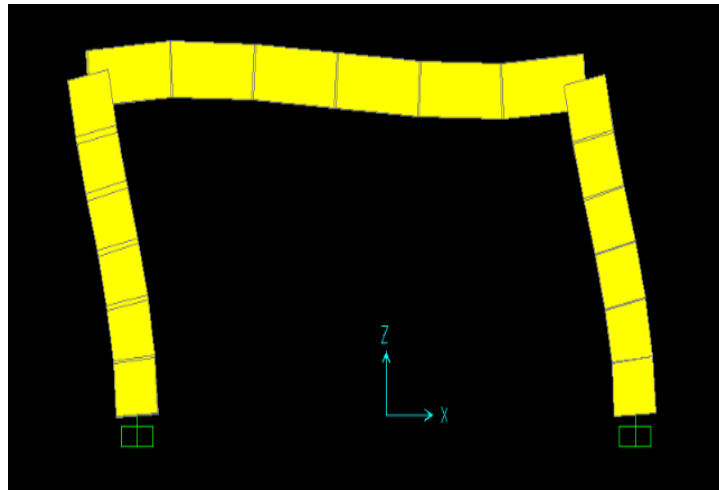


*Fig. 8 1<sup>st</sup> mode shape of undamaged frame*

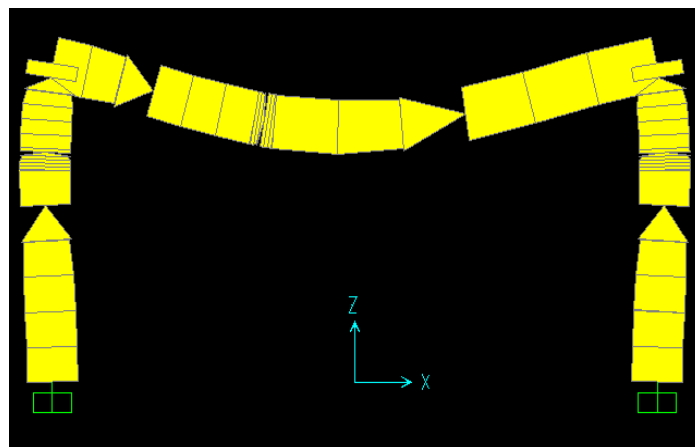


*Fig. 9 1<sup>st</sup> mode shape of 10%undamaged frame*

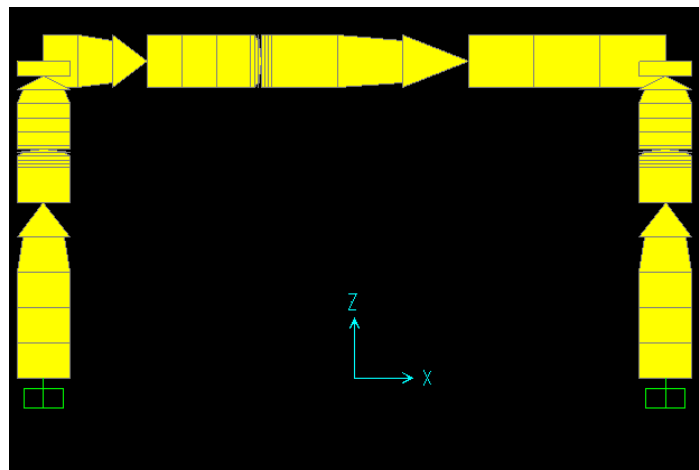


*Fig. 10 1<sup>st</sup> mode shape of 20% undamaged frame*

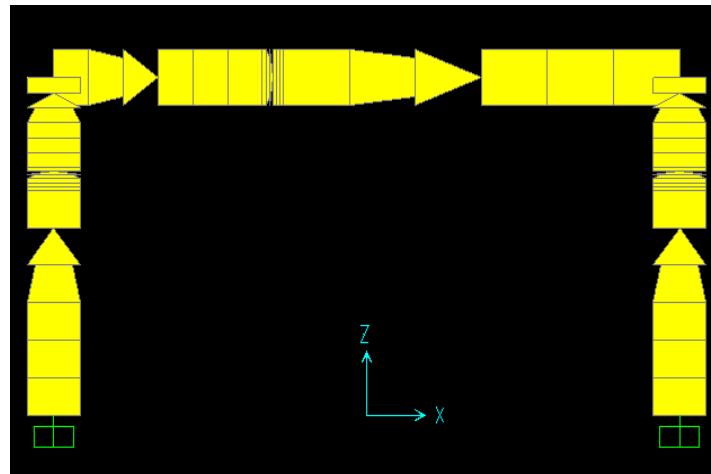


Fig. 11 1<sup>st</sup> mode shape of 20% undamaged frame

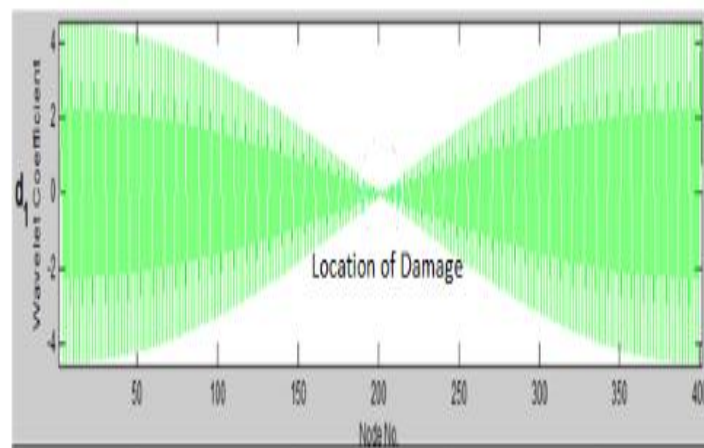


Fig. 12 Variation of wavelet coefficients along the length of 10 % damaged frame by using Haar wavelet

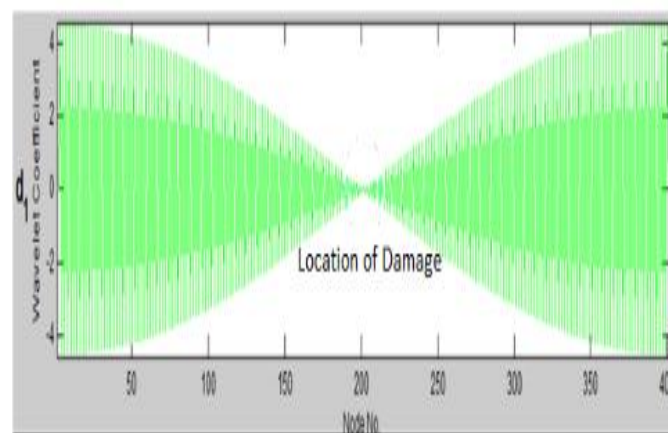


Fig. 13 Variation of wavelet coefficients along the length of 20 % damaged frame by using Haar wavelet

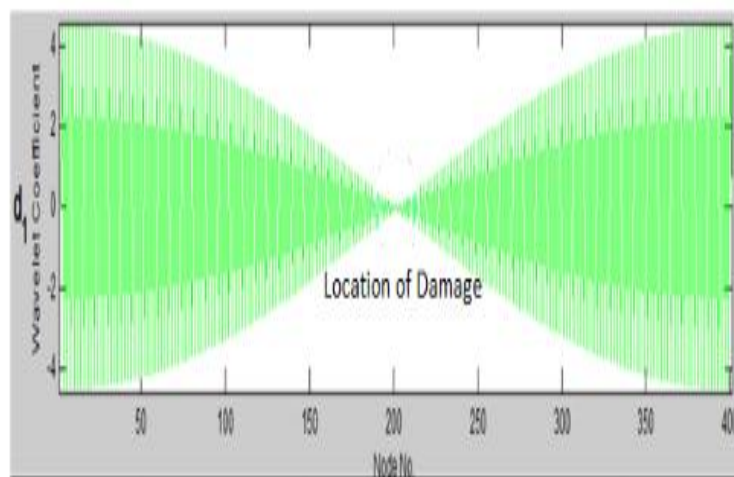


Fig. 14 Variation of wavelet coefficients along the length of 30 % damaged frame by using Haar wavelet

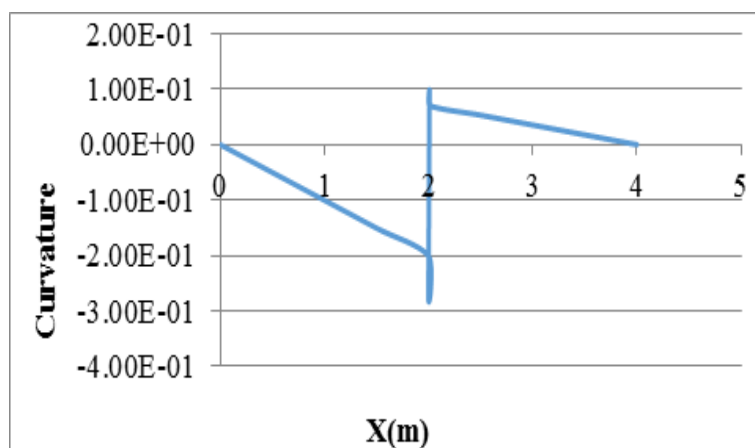


Fig. 15 Curvature( $m^{-1}$ ) of 1st mode shape of 10% damaged frame

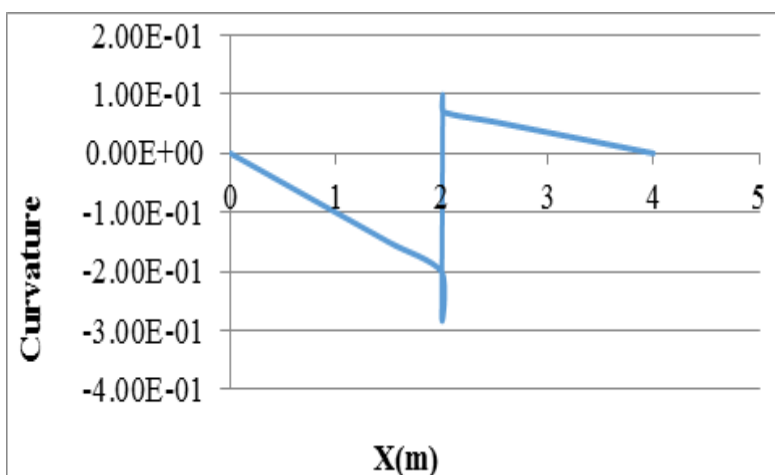


Fig. 16 Curvature ( $m^{-1}$ ) of 1st mode shape of 20% damaged frame

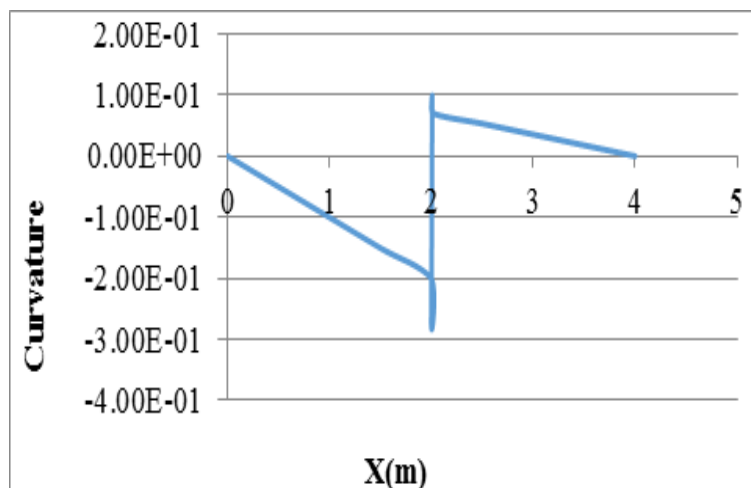


Fig. 17 Curvature ( $m^{-1}$ ) of 1st mode shape of 30% damaged frame

#### IV. CONCLUSIONS

It can be concluded from the present study that the wavelets are very effective damage detecting tool for all types of cracks whether it is a minor crack or major crack, whereas mode shape curvature method suitable for detecting the damages when the variation in the curvature is high. Natural frequency-based damage detection methods utilize change in the natural frequencies as the basic features for detecting damage. One of the main reasons for this is that natural frequencies are relatively simple and convenient to measure so as to arrive at a prompt diagnosis.

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