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Comparison of Damage and Undamaged Mechanical Structure using Free Vibration Analysis

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Abstract

The current paper presents free vibration analysis of a steel frame structure using experimental Technique. The comparison is drawn by showing the free vibration response of an undamaged and damaged mechanical structure. Vibration pattern of a damaged and undamaged structure is recorded and analyzed to find out the intensity of damage caused by vibration. Three crack depth cases (10mm, 20mm, and 30mm) considered during analysis. It is found Vibration patterns of a damaged structure are different from the undamaged structure. It is also found that the natural frequency of the structure tends to get decrease as the crack depth increases. This decrease in natural frequency can be used for damage detection. The frequency of a damaged structure is lowered due to reduction of stiffness and material degradation. With the help of vibration patterns and change in natural frequencies, it is easy to monitor the health of the structure and to detect the damage at the right time, in order to take safety precautions before the structure goes to failure.

.***Keywords***: *Free Vibration, Structural Health Monitoring, Undamaged, Damaged Structure.*

1. Introduction:

Beams and columns are a basic structural component of any mechanical structure. Beams and Columns are joined together to form a large mechanical structure. The damage present in any mechanical structural member causes changes in mechanical properties and structure health. In recent years, work has been done to monitor the health of the structure using different techniques. However, less study can be found using vibrational analysis to monitor the health of a structure. Hearn et al. [1] concluded that location of damage in the structure is determined using changes in natural frequency derived from the equation of motion. He also found that damage to the structure can influence the natural frequency and mode shapes of the structure. The modal parameters required for the inspection is obtained from the free vibrational response of structures. Kashirsagar et al. [2] experimentally investigated the vibration patterns of a damaged cantilever beam. They compared vibrational patterns of a cracked and uncracked cantilever beam. Their experimental study concluded that natural frequencies are reduced due to the presence of a crack. They also found that for a particular mode, the decrease in frequency and change in mode shape become noticeable as the crack grew bigger. Ramos et al. [3] showed that the

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crack appears then the modular properties of the structure are delicate to the damage. The estimations of the recurrence essentially diminish as the crack in the structure advances. Khoa Viet Nguyen et al. [4] showed that distinguished mode shapes and their unexpected changes at the break condition can be identified clearly between the damage and undamaged structure. The projections of the mode shapes can be utilized to observe the damage and presence of cracks. The crack location can be dictated by the scene at which the projections of the mode shapes have serious variations.

JT Kim et al. [5] exhibited a method to nondestructively find and gauge; the degree of destruction in structures for which two frequencies were reachable. A damage confinement algorithmic program discovers damage from natural frequencies and a damage measuring calculation that assesses crack size from regular recurrence were made. KH Barad et al. [6] showed that crack with more prominent depth causes bigger reductions in modal frequencies than that of the minor crack. Damage present near fixed point causes more decrease in modal frequency than the damage presents away from the restrained end. D.K. Agarwal et al. [7] showed the modal properties and mode shapes of the vibrating structures are vulnerable to change under the influence of crack depth and also to the crack location. Mode shapes in magnifying view allow the scholars to get knowledge of the major variations at the crack site. Therefore, position and level of crack can be determined by evaluating these changes.

DKB Waghulde et al. [8] found that the effect of a crack is more pronounced near the restrained end compared to the free end. The first natural frequency decreases with the increase in the number of cracks. The natural frequency decreases with the increase in relative crack depth. IA Khan et al. [9] contemplated vibration examples of the harmed composite pillar which demonstrates a difference in modular properties and normal frequencies for the damaged and undamaged bar. The results of the numerical investigation are compared with the experimental case. This system was utilized as a health monitoring apparatus for vibrating damaged dynamic constructions.

Baruh et al. [10] established a system for the identification of the position of a damage. The detection is done in two portions. First, the Eigensolution is identified using a modal identification technique. Then, the identified Eigensolution is used together with the properties of eigenvalue problem to sense the damage components.

W. Zhou et al. [11] added that vibration-based monitoring techniques (VBMT) have proved useful for the detection and localization of structural damages. Sudath C. et al. [12] developed a technique that mainly depends on plots of variation of the model parameter with respect to the location of damage. The validated FE model, which signifies more reasonably the actual static and dynamic behavior of the structure at the time of validation, was obtained by comparing the measured responses with FE model. The author concluded that this measurement can be inexpensively acquired and the proposed method provides a damage locating technique.

Antunes et al. [13] established the feasibility of dynamic SHM of high structures using optical technology sensor. There work presented that it as possible to obtain the natural frequencies for two orthogonal directions, which could be used to calculate the response of this type of structures along his lifetime. Foti et al. [14] suggested two methods for damage identification for bridges using a simulated data for a simply supported structure. The change in the mode shape method is not properly sensitive to the damage since the change in displacement mode shapes is mostly too small.

Wahab et al. [15] inspected that the modal curvatures of the lower modes are more accurate than those of higher ones. He added that attention should be taken when using the modal curvatures of higher modes for the damage detection.

Presedent studies is limited to the analysis on the square frame structure where damage i.e cracks are created at one joint. Cracks are created at three different depts i.e 3mm, 20mm and 30mm. In this study the free vibration of a damaged and undamaged steel frame structure is investigated utilizing experimental study. This damaged frame structure is analyzed experimentally and damage is detected using natural frequencies and vibrational patterns.

2. Experimental Setup

The mechanical model is a single story steel structure. Three squared beams are welded together to form square type structure. The dimensions of the beam constitutes 1000mm of length and a cross-sectional area of 31mm. A weight of 93 kg is welded onto the top of the squared beam to keep the time period of the structure at 0.1s.

The whole structure is instrumented with one accelerometers. One accelerometer is attached to the top end of the structure where the two beams are joined together by a welded joint. The mechanical structure is mounted on the vibration shake table. Accelerometers convert the vibrational signal into a voltage signal that is further analyzed by the data acquisition systems to show the response of the structure. Free vibration analysis of an undamaged structure is recorded by striking the structure with the help of a hammer. The structure is allowed to vibrate and the accelerometers record the data. The structure is damaged at three different depths ranging from 10mm to 30mm. For each damage created in the structure, the free vibrational analysis is carried out to extract mode shapes or vibration patterns. The vibration pattern of both damaged and undamaged structure is compared. This research deals with the comparison of vibration patterns of damaged and undamaged structure to monitor the health of the structure. Figure 1 shows the diagram of a frame structure with accelerometer attached to data acquisition system and display screen.

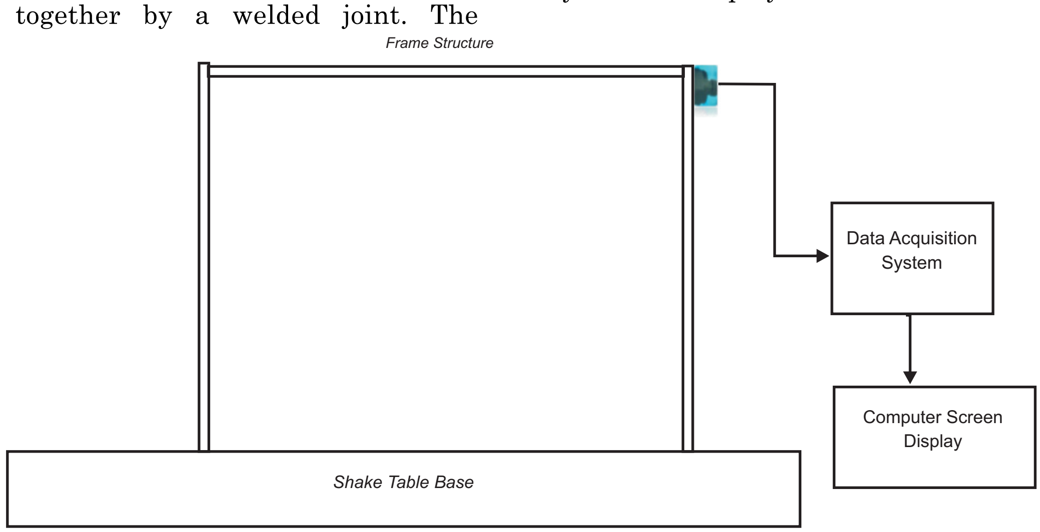

Figure 1: *Steel Frame Structure.*

3. Results And Discussion

3.1 Undamaged Structure response

The seismic signal software was used to manage the data collected from the accelerometers and to plot the data. First of all, the data of an undamaged structure was recorded and plotted. The data from the accelerometer number one is plotted in Figure 2 & 3. The peaks in the graph represent the natural frequencies and the first natural frequency for the undamaged structure occurs at 0.16272 Hz.

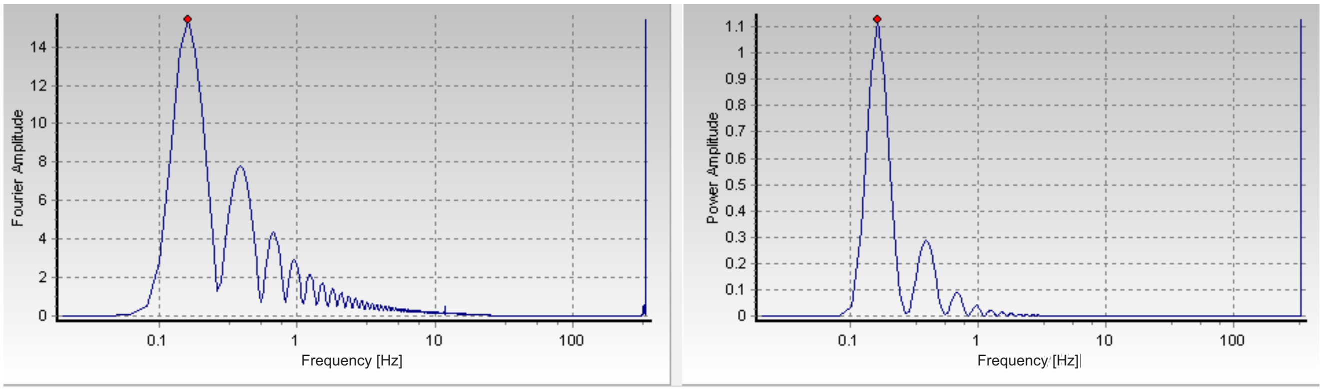

Figure 2: *Undamaged structure data showing Fourier Amplitude & Frequency*

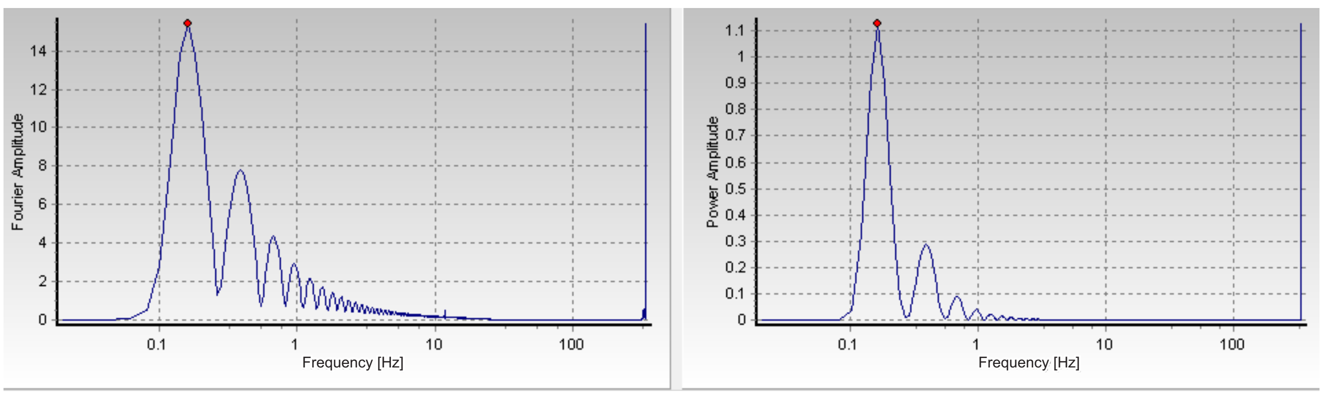

Figure 3: *Undamaged structure data showing Power Amplitude & Frequency*

3.2 Damaged Structure response

The structure was damaged at three depths of a crack size of 10mm, 20mm, and 30mm. the response of a 10mm crack depth is noted. The data from accelerometer one for the 10mm depth case is depicted in Figure 4 & 5.

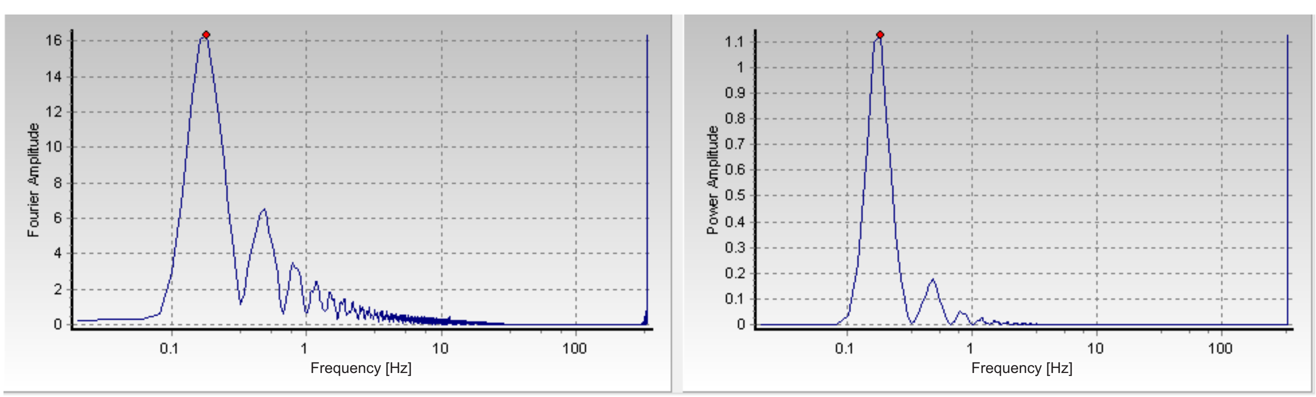

Figure 4: *Damaged structure data Showing Fourier Amplitude & Frequency at 10mm crack depth*

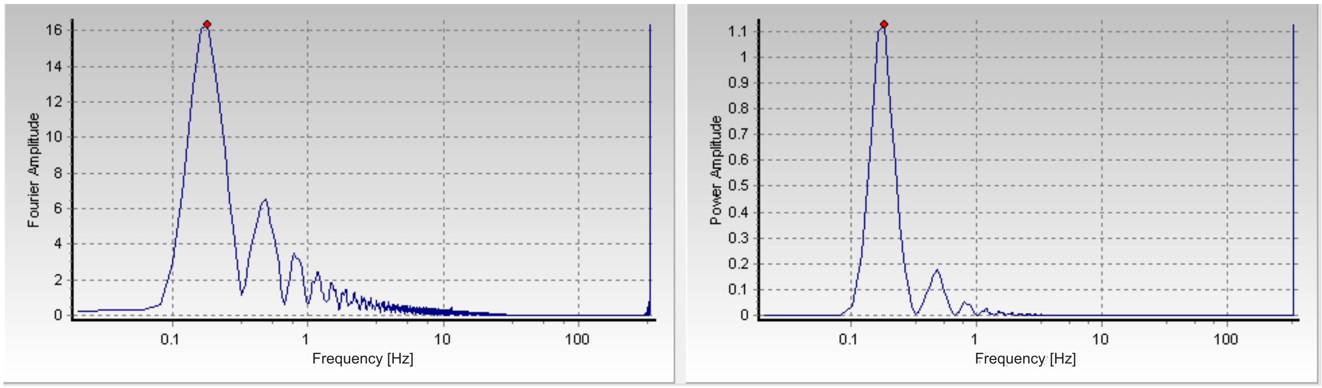

Figure5: *Damaged structure data showing Power Amplitude & Frequency at 10mm crack depth*

The structure was damaged at the joint and a crack of 10mm depth was created intentionally by hand saw. From the figure 4, the first natural frequency comes out to be 0.15011 Hz. The natural frequency of the structure changed from 0.16272 to 0.15011 Hz. This change in the natural frequency possibly suggests that the structure is damaged.

The structure crack depth is increased from 10mm to 20mm without changing the location of the damage. The frequency from accelerometer 1 is plotted in Figure 6 &7.

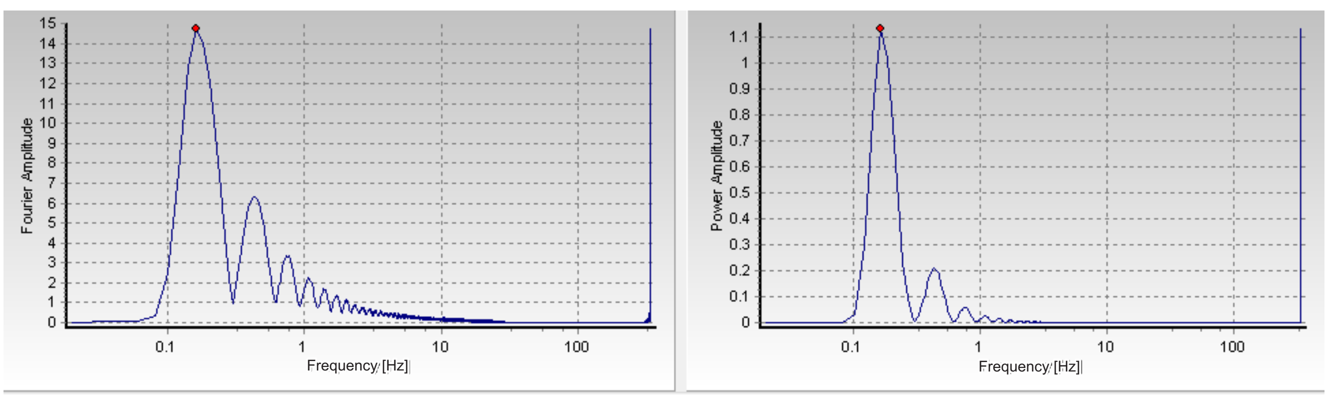

Figure 6: *Damaged structure data showing Fourier Amplitude & Frequency at 20mm crack depth.p*

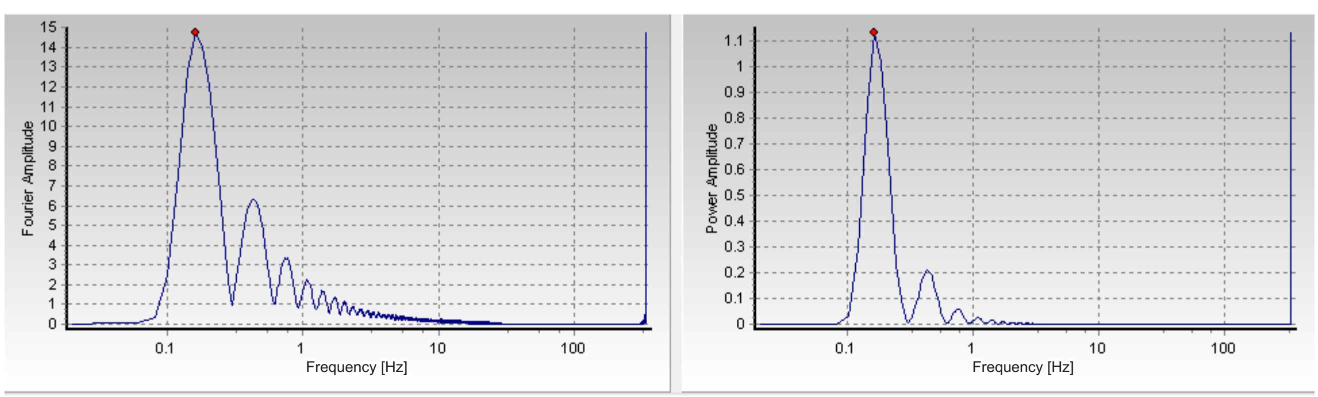

Figure 7: *Damaged structure data showing Power Amplitude & Frequency at 20mm crack depth.*

From the plotted data the natural frequency of the structure reduced from 0.15011 to 0.14272 Hz. when the crack depth is increased the corresponding natural frequency also decreased of the structure. The structure crack depth is increased further from 20mm to 30mm, keeping the location of the damage unchanged. The frequency from accelerometer 1 is plotted in Figure 8 & 9.

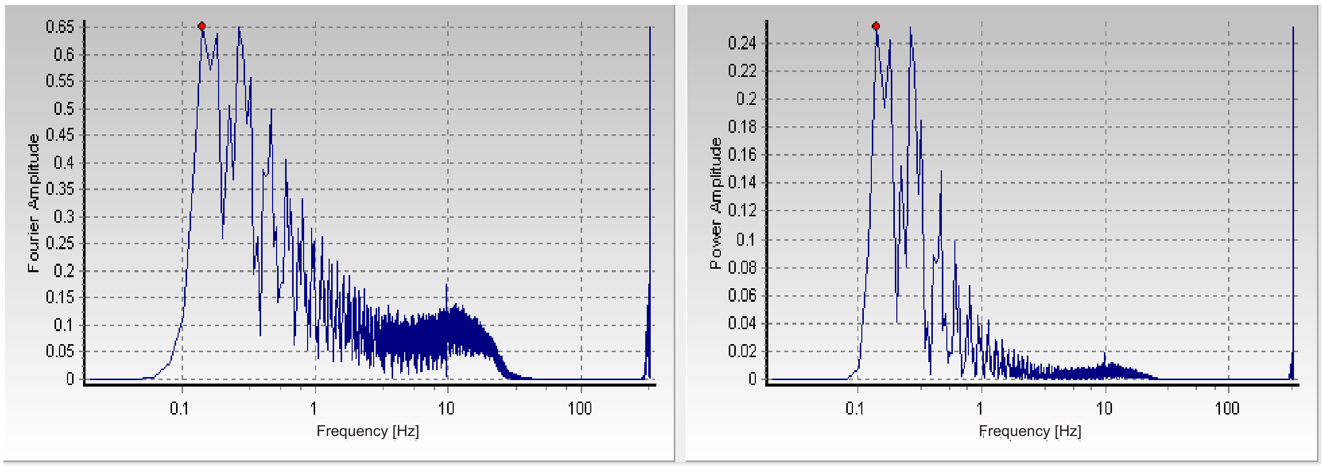

Figure 8: *Damaged structure data showing Fourier Amplitude & frequency at 30mm crack depth.*

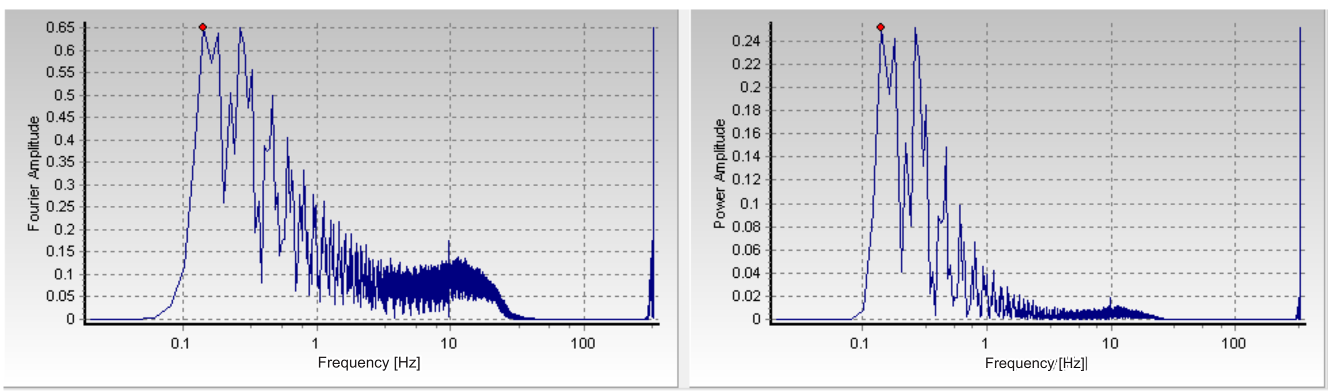

Figure 9: *Damaged structure data showing Power Amplitude & Frequency at 30mm crack depth.*

The frequency from accelerometer 1 is 0.13762 Hz. This frequency is reduced from the previous frequency at 20mm crack depth. This reduction in the natural frequency indicates that the structure stiffness is kept on decreasing so that its natural frequency.

4. Discussion

Free vibrational analysis is performed for a single story steel structure with dimensions of 1000mm height and a cross-sectional area of 31mm. Free vibration analysis is carried out by striking the structure by a hammer. The transducers pick up the signal. This signal is analyzed in the software and is plotted. The Fourier frequency is plotted on the X-axis while the Fourier amplitude is plotted on the Y-axis.

The data from accelerometers entered into the software in the form of a text file. The time step is kept at 0.005s for the analysis. The data is manipulated by its multiplier which is the sensitivity of the accelerometer. In my case the transducer, I choose, its sensitivity is 490.1mm/g. After manipulating the data, we get the acceleration valves. These valves are then introduced to the software to get the response of the structure. The software plots the data of frequency vs amplitude. The crests in the plot indicate the modal frequencies of the steel structure.

The examination of an undamaged structure is done to extricate the characteristic frequencies of the structure. The model is damaged at three unique profundities and again free vibration investigation completed. From the finding of both investigations for the undamaged and harmed structure we can see an adjustment in the regular frequencies for every single case.

The frequency of the structure decreases as the damage in the structure increases. From the experimental data, we can notice that when the damage is introduced in the structure the natural frequency starts decreasing. By looking at the three damaged cases it is clear that the frequency of the structure decreased from 0.15011 Hz to 0.13762 Hz. When the first crack of 10mm depth is introduced in the structure, the frequency is reduced from 0.16272 Hz to 015011 Hz and when we keep on increasing the crack depth the corresponding natural frequency keep on decreasing to 0.13762 Hz. The overall summary of the decrease in the natural frequencies is tabulated in Table I.

Table I: Summary of Natural Frequencies for various crack Depths.

Damage Level	Natural Frequencies
No Damage (No Crack)	0.16272 Hz
10mm crack depth	0.15011 Hz
20mm crack depth	0.14272 Hz
30mm crack depth	0. 13762 Hz

5. Conclusion:

Free vibration analysis of a mechanical steel structure is presented in this paper. Free vibration investigation is completed to extract the natural frequencies of the Damage and undamaged structure. The structure is damaged at three different crack depths to discover the response of the structure. The change in the vibration patterns is observed as damage in the structure appears. From the results, it is concluded that the natural frequencies of the structure decrease as the crack in the structure increases.. The natural frequency will reduce as the crack grow bigger in depth and size because of reduction in the stiffness and material degradation. With the increase in the damage level in the structure, a time will come when the structure will lead to the failure. Decrease in Frequencies can be used to detect damage in the structure to monitor health of a structure.

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