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DETECTION OF STRUCTURAL DAMAGE IN BUILDING USING CHANGES IN MODAL DAMPING MECHANISM

Egba Ernest I.
Technology and Vocational Education Department, Ebonyi State University, Abakaliki, Nigeria.

ABSTRACT
The basis for the approach to damage detection is that changes in the physical properties of the structure affect the modal parameter of the structure. The paper explored the dynamic performance of a steel beam at damaged and undamaged states by laboratory tests. The effects of damage on modal damping of the structure were determined. It was discovered that damage on structures causes changes of the ratio of critical damping value. The rate of change increases at the increase in the severity of the damage.

KEYWORDS: Damage Detection, Damping, Local Stiffness, Energy Dissipation, Frequency Response Function, Excitation Signal

INTRODUCTION

An abrupt failure in a building can be very expensive and may be disastrous in terms of human life and property damage. Failure occurs when there is incessant damage to structures. Damage can be defined as changes introduced into a system that adversely affects the current or future performance of that system (Farrar, doubling and David, 2001). Structural damage detection is the capability to conduct damage and safety assessments of civil, commercial, and residential infrastructures and to perform structural inspections, and mitigation activities.

Many techniques of non-destructive evaluation are certainly available to detect structural damage in building. Such techniques include visual inspections, ultrasonic testing, acoustic emission, and so on (Kirkegaard and Rytter, 1994). However, most of these techniques are awkward in many circumstances due to the need for the investigator to have access to the structure. A usual evidence of structural damage in building is the presence of crack.

One of the consequences of the development of crack in building is a decrease in local stiffness which in turn results in a decrease in some of the natural frequencies. The most commonly applied vibration based inspection damage assessment technique is based on changes of natural frequencies only. This is dazzling since natural frequencies can be obtained from measurements at a single point on the structure. If measurements at several points are carried out the mode shapes in discrete points of the structure corresponding to the different natural frequencies may be established. Then, mode shape information can also be used for damage assessment. However, in order to be able to evaluate the deterioration state of a structure by vibration based inspection, it is necessary to estimate size and location of the damage. A review of vibration based damage assessment techniques can be found in Rytter (1993). Again, modal damping can also be used to detect structural damage in building.

Damping is any effect that tends to reduce the amplitude of oscillations in an oscillatory system. It is the energy dissipated properties of a mterial or system under cyclic stress (John, 2010). Damping may be mathematically modelled as a force synchronous with the velocity of the object but opposite in direction to it. The presence of damage alters the energy dissipation mechanism in a structure: the direct consequence is that the damaged structure presents higher modal damping rates. This change is particularly significant in the case of reinforced concrete structures, where damage is usually associated with the formation of a crack. Zonta (2000) disclosed that many experience shows how these variations are in the order of 100% of the values measured in uncracked structures. Hence modal damping represents a very sensitive parameter to discriminate damaged from undamaged structures. Since changes in dissipation properties is generally due to a localized modification in the characteristics of the damaged structures, one can expect that this modification affects in different ways each vibration mode.

Savov and Wenzel (2004) discussed damage detection in a prestressed concrete test beam by means of finite element model updating. Model-based damage detection approach with sensitivity based finite element model updating procedure was used. They considered damage effects subject to prestressing forces in a concrete test beam. Damage was simulated by reducing the prestressing force in the tendons. After each reduction phase, the accelerometers placed on the top surface were used to measure the vibration behaviour of the system due to impact device. The obtained results showed that relaxing of the tendons in prestressed concrete structures lead to an increase of crack propagation.

Titurus, Friswell, and Starek (2003) looked at the use of generic elements as a viable tool for parametric model based damage detection. The form of generic element parameterization they assumed in their work was a modification of a standard formulation where only changes in the stiffness are allowed. An H-shaped four thin-walled tubes frame structure connected by four-fillet weld was used to evaluate the idea. The joints were manipulated to produce one healthy and six damaged cases. The finite element model of the structure was created using Euler-Bernoulli planer elements with three degrees of freedom per node. The subject was divided into two major parts. Part one considered only the undamaged structure where the model requires updating while part two considered damage detection by comparing the selected damage cases to the updated mathematical model of the undamaged structure. The results proved satisfactory especially in the idea that presence of damage in a structure affects the modal damping of the structure.

Ren and Roeck (2002) verified damage identification on a simply supported beam using element damage index method. The beam was equally divided into 15 two-dimensional beam elements. Damage was simulated by reducing the stiffness of the selected element. They used three different solution techniques namely: the Moore-Penrose pseudonoiverse method, the Non-Negative Least-Square (NNLS) method and the Singular Value Decomposition (SVD) method to compare the results of the damage scenario. They concluded that the method should not only be tested with simulated data, but also with real measurement data as a reliable technique to verify structural damage in practice.

Salawu and Williams (1993) presented a paper on structural damage detection using experimental modal analysis. The paper reviewed four basic methods. One of the methods exploits the changes in the eigen parameters and the other three utilize system identification and modal updating procedures. They made comparison of their effectiveness. Their studies on a 4.9m simply supported beam showed that experimental results from modal testing of a structure are all that is needed for effective and efficient structural damage identification.

In this paper, the researcher carried out experiments on an I-section universal steel beam to detect damages on the structure using changes in the modal damping. Damping which is a force that resists motion and is proportional to the velocity of motion is often expressed in terms of ratio of critical damping ζ (zeta). It is calculated thus:

$$\left[\frac{X_n}{X_0}\right] = e^{-2\pi n\zeta} \qquad (1.0)$$

Where (X_o) is the initial amplitude, (X_n) is the amplitude (n) cycles later and ζ (zeta) is the ratio of critical damping.

Materials Used

The materials used were vibrator, dynamic signal analyzer, accelerometer, sweep signal function generator, computer, frequency function generator, cutting machine, markers, measuring tape, transducer and amplifier. A 5.5m universal steel beam of 203 x 102 x 23mm section with properties as recorded in Davison and Owen (2003) was also used.

Methods

The experimental set-up for the beam tests is shown in figure 1. The test beam was I-section (UB 203 x 102 x 23 Kg/m) steel beam. The beam was excited by electro-magnetic vibrator while the dynamic response in the vertical direction was measured at different locations using accelerometers. A periodic random signal was used as the excitation signal. The tests were conducted within the frequency range of 0 - 200 Hz which was sufficient to cover the first three bending modes. A computer was used to control the test and acquire frequency response function data via a dynamic signal analyzer which also served as the excitation signal generator. A single degree of freedom was used to extract the modal parameters. The procedures were repeated for a number of times. Results were taken to serve as control. The first damage was introduced through the bottom flange and at 2.4925m from the first support. The second damage was introduced at the top flange near the supports. The third damage was introduced by cutting the same position in as in the first damage but now through and to the middle of the web. Tests were done simultaneously after each damage stage and results were as well taken.

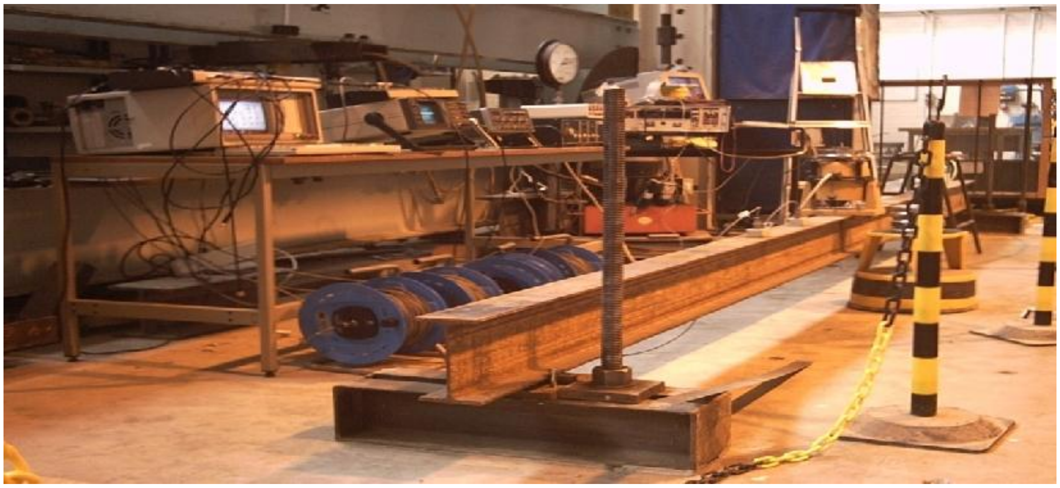

Figure 1: Modal testing set-up

RESULTS

Table 1 shows values of ratio of critical damping of the damaged and undamaged structure. The table of values was derived from the decay traces of the first three lowest modes for the damaged and undamaged structure. Values were calculated using equation (1.0). Figure 2 is the decay trace of the first mode for the undamaged structure. Figure 3 presents the information in a column chart.

Table 1: Values of ratio of critical damping of the damaged and undamaged structure.

Frequency modes	Undamaged (ζ)	First damage (ζ)	Second damage (ζ)	Third damage (ζ)
First mode	0.017	0.022	0.023	0.082
Second mode	0.004	0.003	0.002	0.004
Third mode	0.004	0.005	0.005	0.015

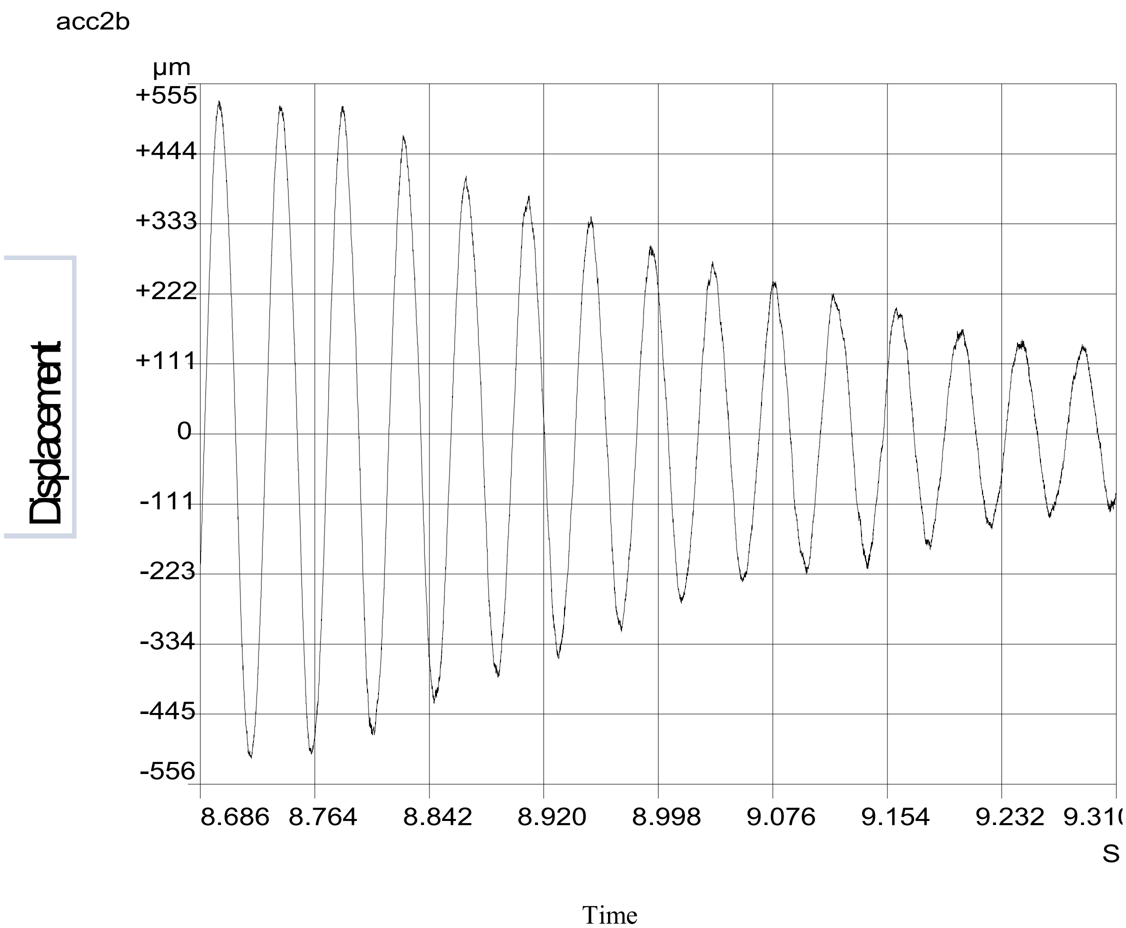

Figure 2: Decay trace of the first mode for undamaged structure

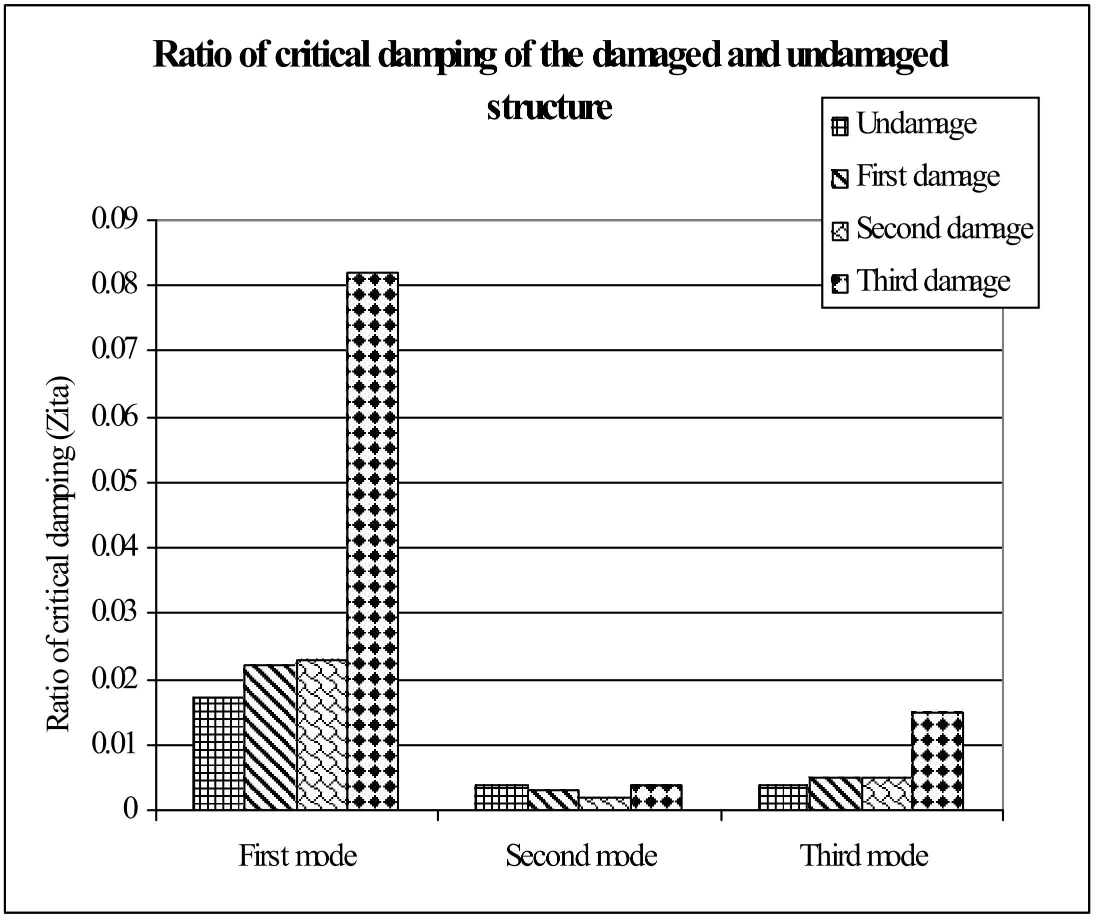

Figure 3: Column chart of ratios of critical damping of the damaged and undamaged structure for the first three lowest modes.

The chart revealed continuous increase in damping value from undamaged case to the damaged cases in the first and third mode. Increase of severity of damage led to increase of damping values. There were both decrease and increase of damping values due to damage for the second mode.

Discussion

Damage to the structure could be construed as change in the value of the ratio of critical damping as the structure passed through test from undamaged to damaged states. Table 1 disclosed that there were 29.41%, 4.55% and 256.22% increments in the ratio of critical damping value for the first mode after the first, second and third damage respectively.

The table also showed that there is a massive increase in the value of ratio of critical damping after the third damage was introduced. This was because the third damage was at the center of the beam and affected the web of the beam and as such encouraged beam deflection.

The second damage did not impart serious change in the ratio of critical damping value as seen in table 1. This was so since the second damage was close to the first support and the structure in question was a simply supported structure.

Figure 3 revealed continuous increase in damping value from undamaged case to the damaged cases in the first and third mode. The higher the increase of damping values the higher the effect of damage. For the second mode, there was first a decrease in the damping value, followed by another decrease and then an increase of damping.

The work of Salawu and Williams (1994) supports the reports above. Their work revealed that damping values generally increase with increasing degree of damage. However, some cases exist where the values decrease after an initial increase.

Conclusion / Recommendation

The physical properties of structure such as mass, stiffness and damping play major role in determining modal parameters of structures. Cracks as a change in physical property of structure due to reduction in stiffness cause detectable changes in modal parameter. The work was carried out to detect damage using modal damping changes. Results showed that damage on a structure would cause increase in the ratio of critical damping value; increase of severity of damage increases the rate of change of damping value. However, some cases exist where the values decrease after an initial increase. The researcher recommends that regular inspection and maintenance should be carried out on building structural members to avoid damage on the structural members that would cause changes in modal damping.

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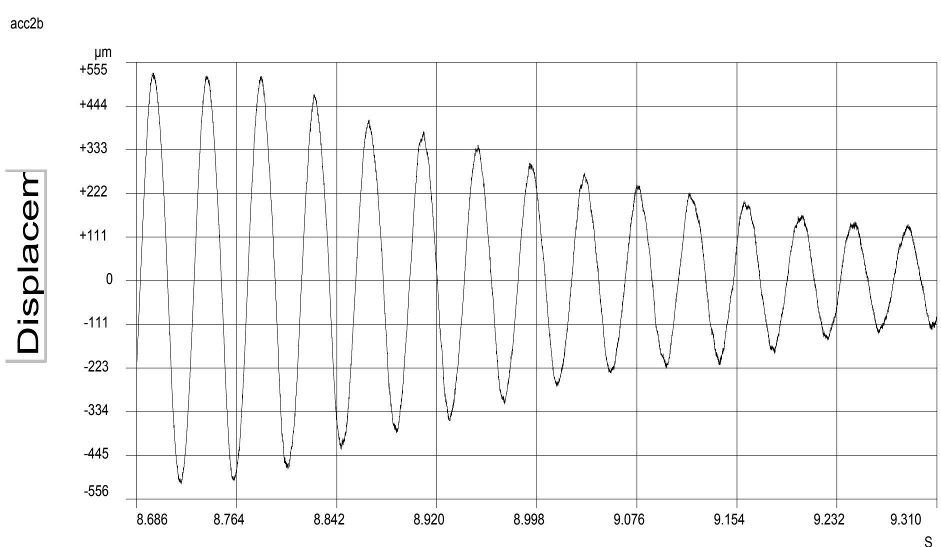

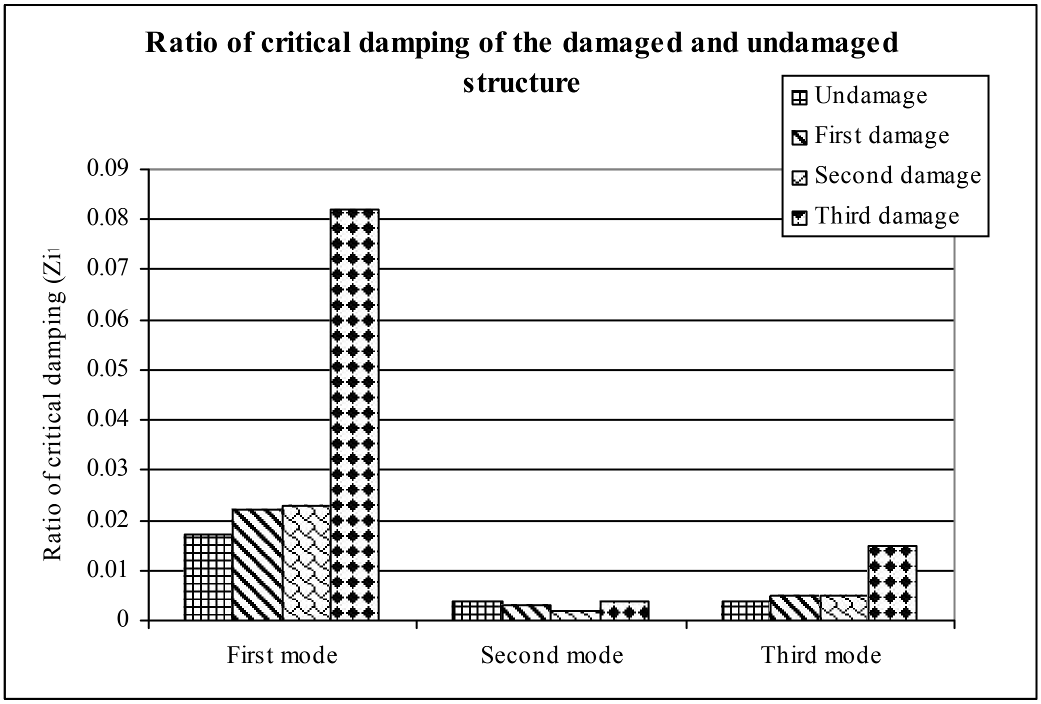
Ratio of critical damping of the damaged and undamaged structure
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