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STUDY OF THE EFFECTS OF A CRACK IN STATICALLY LOADED STRUCTURAL ELEMENTS WITH THE AID OF PIEZOSENSOR

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Abstract: This research proposes a new technique to assess an open crack or any kind of damage in a structural element. In this research work, a piezo sensor is used to assess the effect of crack in a statically loaded cantilever beam with an open crack. The study aims to lead a way through which a crack detection technique be developed to locate the crack in a structural part before severe damage. It is clearly observed that the mechanical properties rigorously get affected due to presence of a crack. Large cracks or severe damage can be detected by following modal parameters but it is difficult for small cracks. One more important parameter can be followed is the discontinuity in slope to detect the crack which takes place due to the crack. This research aims to lead a way to follow the discontinuity by using a piezo sensor. Since the output voltage of a piezo sensor depends on the difference in slope at the two end of it can directly give a high response to the discontinuity in slope curve. To pursue the study a finite element integrated model is prepared in ABAQUS platform. A solid 3D model as well as a shell model is created and slope discontinuity is followed under static load as well as voltage output for different crack locations are obtained.

Keywords: Piezoelectric sensor, Crack, Voltage, Slope

1. INTRODUCTION

Crack or damage severely affects the mechanical behaviour of an element. The detection of cracks by following modal parameters is a very well established way but small cracks are difficult to locate by this method. Smart materials can be used to study the changes in mechanical behaviour of different elements. Smart sensors are commonly made of materials such as shape memory alloys, piezoelectric, etc. Piezoelectric are most common and easily available smart material. Piezoelectric materials also can be used as actuator [1]. Few numerical and experimental studies [2] have shown a scope to use piezoelectric material for crack detection. The Changes due to crack in a simply supported beam under point load is shown by PS Sumant and S K Maiti. Zhang et al. [3] and Yin et al. [4] showed the scope of damage detection in composites by coating them with PVDF films. Fukunaga et al. [5] described a two stage damage identification procedure using piezoelectric sensors. Fukunaga et al. [5] proposed it for a cantilever beam with 10%, 30% and 50% damage. Castillo et al. [6] studied with surface bonded piezoelectric patch. In his study he considered a single patch to generate as well as receive strain waves.

Jiang et al. introduced [7] a novel technique to detect crack in beams by magnifying the change in natural frequency using piezoelectric material. Yan et al. introduced a model of cracked beam following Timoshenko beam theory where the crack is replaced by a rotational spring. PZT sensors are bonded on the beam to assess the crack. A shear lag model is considered to imitate the interaction between PZT and the beam [8]. In this study, the difference in the conductance resonance following EM conductance values are measured to detect the damage at preliminary stage [9]. This paper approaches a method to detect any kind of damage in beams using experimental vibration statistics that possibly results by using sensors/ actuators made of PZT. The considered structure is an intregrated cantilever beam with a piezoelectric patch and accelerometer as actuator and sensor in that order [10]. This research work shows a way to employ cement-based piezoelectric sensors by using which fractures of different modes are experimented. The experiments suggest that a PZT sensor can be effectively used to identify a crack before severe damage [11].

In this present research work a new way is proposed by which the location of a crack in a beam can be easily found. Here a rectangular piezo electric patch (PZT 5H) is tied on the bottom surface of a beam. For a cantilever clamped beam the study is done. At different Patch position output voltage (EPOT) values are taken to follow the changes in characteristics due to crack. All the analysis is done by Finite Element Analysis with the help of ABAQUS 6.12. A Finite Element Model of Al beam with tied PZT 5H is developed then half depth crack is assigned at different locations on at a time. Output Voltage data is taken as output from the Piezo patch. A fixed position of embedded Piezo Electric material with beam is shown in Fig. 1.

Fig 1: Cantilever beam with embedded Piezo patch at the middle

2. FORWARD PROBLEM FORMULATION

At the outset of the study a 3D model of Aluminium beam is modelled in abacus platform, where a deformable 3D solid part is created to simulate as a beam. Simultaneously a shell model of beam is also prepared to follow the discontinuity in slope. In both the cases, properties are taken as given in Table 1. Thence forth a 3D solid model of piezoelectric material is developed considering the properties shown in Table 1. In consideration of that, a polarization direction must be defined for piezoelectric sensor; a local datum is created to make the Z axis along thickness.

2.1 To Travel behind the Change in Discontinuity of Slope

First, a shell model is of beam is developed. A section is created to assign the properties on the model. Encastre boundary condition is used at one of the end of beam to make it a cantilever beam. The beam is meshed following the convergence of tip displacement. The study is done by creating static general step and a point load is created at the open end. To check the slope along length UR- rotational displacement is requested in field output request. Afterwards the required results are obtained from deformed shape of beam which comes as a result of simulation. Next a partition is produced at the mid of shell model and seam crack is assigned on it. Keeping other conditions same the beam is again analyzed and the same parameters are followed.

2.2 To Manoeuvre the Piezo Sensor

In the beginning a 3D deformable model of beam is prepared following the properties as shown in Table: 1. By and by another 3D deformable part is created to model as piezo sensor. Both the parts are made independent instances to make the meshing easier and also to easily give partition on lateral face of beam. Two different sections are created to assign required properties to the prepared models. As earlier stated a datum is created to assign the polarization direction on piezoelectric model. Piezoelectric sensor is assembled at the mid of beam then through the interaction option the sensor is rigidly tied on the beam surface such that no slip can take place. The lateral side face of beam is partitioned at 10 locations, 30mm apart from each other, along the length of beam. Thenceforth the partitions are celled and using special interaction crack is assigned on each cell on at a time. A static step is created considering 105 increments of point loading. Two different boundary conditions are imposed on one beam to make it cantilever element and another on the mating surface between piezoelectric patch and beam to make the contact voltage zero. A new field output request EPOT is created to collect the voltage output from the sensor.

2.3 Characteristic Equations of Piezoelectric Material

The properties of a Piezoelectric material are that it can produce voltage when it is deformed, which is called direct effect, and the reverse property, i.e., it can change its shape when comes under external voltage. Piezoelectric material has dielectric property due to which if there is a difference in voltage between two faces, then it produces electrical charge. In this study, the piezoelectric sensor is obtained considering linear elasticity.

Stress produces in a piezoelectric material due to external loading as well as an external voltage, and it can be expressed as

$$\sigma_{ij} = D^{E}_{ijkl}\varepsilon_{kl} - e^{\emptyset}_{mij}E_m$$

$e^{\emptyset}_{mij}$: Stress constants

By using strain constants, it can be written as

$$\sigma_{ij} = D^{E}_{ijkl}(\varepsilon_{kl} - d^{\emptyset}_{mkl}E_m)$$

$d^{\emptyset}_{mkl}$: are the strain constants

The voltage output from the piezoelectric material can be obtained using the following relationship:

$$q_i = e^{\emptyset}_{ijk}\,\varepsilon_{jk} + D^{\emptyset(\varepsilon)}_{ij}E_j$$

Dielectric properties are assigned as

$$D^{\emptyset(\varepsilon)}_{ij} = D^{\emptyset(\varepsilon)}\delta_{ij}$$

Table 1. Properties of aluminium beam and piezoelectric model

Parameter	Aluminum beam	Piezoelectric material
Substance	Aluminum	PZT 5H
Width	50 mm	50 mm
Thickness	10 mm	0.5 mm
Length	300 mm	50 mm
E_{11}	69 GPa	113 GPa
E_{33}	NA	105 GPa
G		23 GPa
d_{31}		-274×10^{-12} m V^{-1}
d_{33}		593×10^{-12} m V^{-1}
d_{15}		714×10^{-12} m V^{-1}
Relative Dielectric Constant		3100

3. RESULTS AND DISCUSSION

A 3D model of deformable solid part is shown in Fig. 2 with a tied piezoelectric patch. The model is meshed following the convergence study in Fig.3. The beam is statically loaded at the end by a total force 10N, applied such a way that it can keep the crack open.

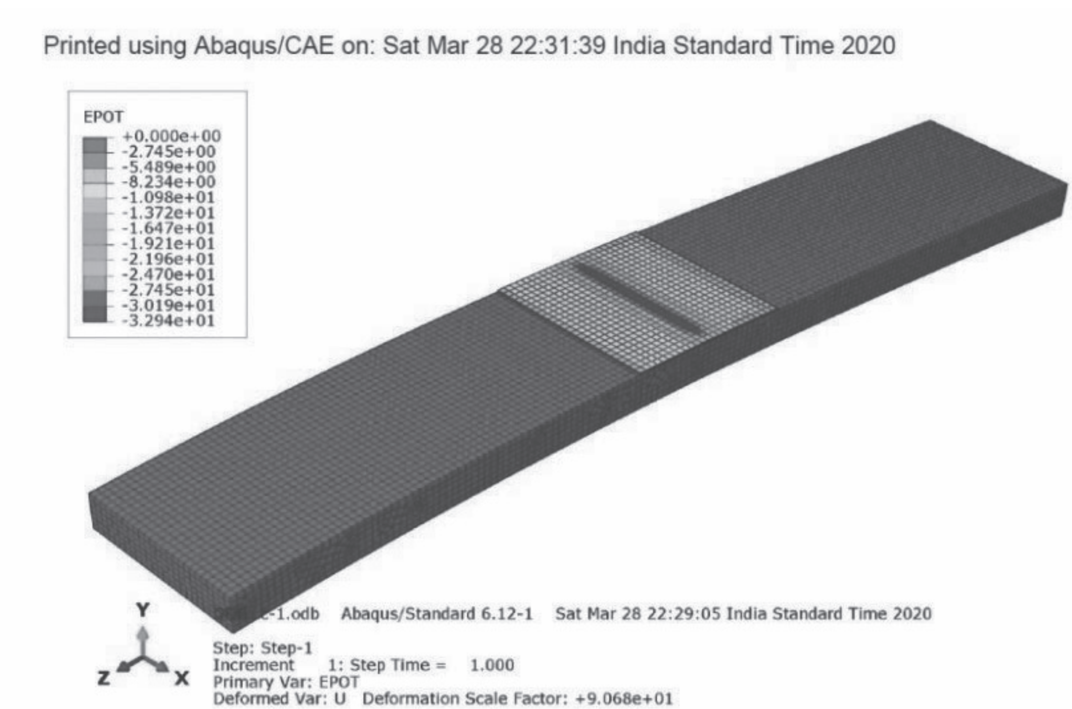

Fig. 2. 3D model of Al beam tied with piezoelectric patch

Fig. 3 clearly shows that a global element size less than 0.002 converges the tip displacement. As a consequence, the meshing is done considering 0.002 as the global element size.

Fig. 4 is the slope curve of a cantilever beam statically loaded under 10N load. In **Fig. 5** which is in the same condition at what is there in Fig. 4, but only a crack is introduced at the middle of beam. As a result, a firm discontinuity in slope is seen at that crack point.

Fig. 6 depicts the response of crack in a cantilever beam through a piezoelectric sensor. It can be clearly observed in the figure that when the location of crack is near the sensor then the sensor gives a very high voltage. The above results can be interpreted in this way; since the characteristic equation of a piezoelectric bending sensor strongly depends on the difference of slope at its two ends and at the same time a discontinuity in slope comes due to crack, so this discontinuity makes the output too large.

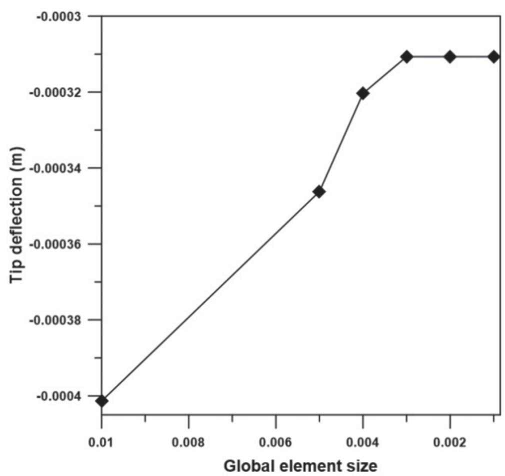

Fig. 3. Mesh convergence study of beam

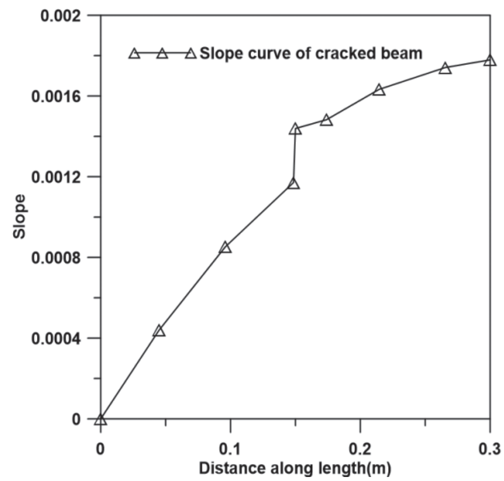

Fig. 5. Slope curve of cracked beam

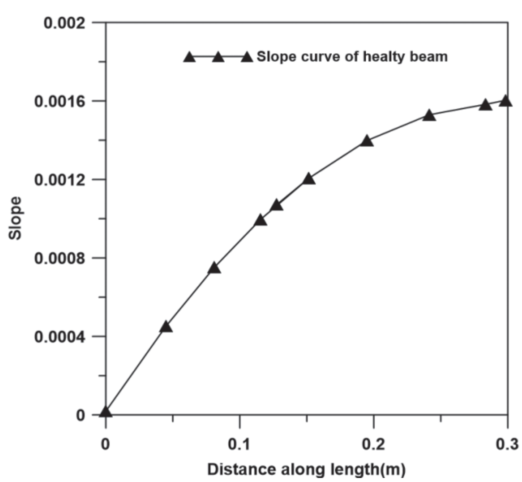

Fig. 4. Slope curve of healthy beam

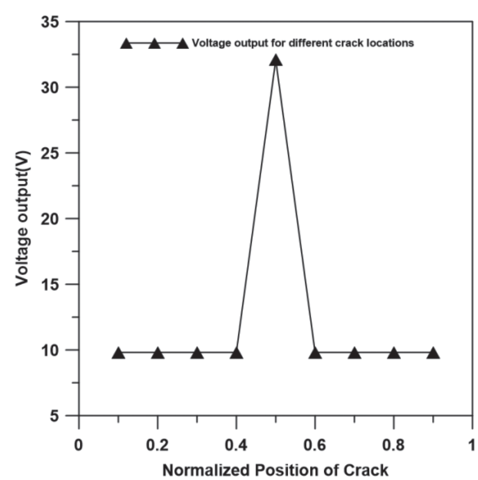

Fig. 6. Voltage output from piezoelectric sensor

4. CONCLUSION

A new way to analyze a cracked beam is approached. An integrated 3D solid finite element model of aluminium beam with piezoelectric patch is prepared and effectively an open crack is introduced. Subsequently a shell model is prepared to obtain the slope curves. The study on slope curves show that there is a firm discontinuity in slope at crack location, but this discontinuity is not easy to measure in practical cases. A voltage with crack location plot is obtained by simulating the integrated solid model. The graphical representation shows that it has a similarity with the slope curve and both are too different at the crack location. So, it can be concluded that a piezoelectric sensor can be used to asses crack in structural element to check the discontinuity in slope, which can lead a way for crack detection.

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REFERENCES

[1] Egashira, M. and Shinya, N., Local Strain Sensing Using Piezoelectric Polymer, Journal of Intelligent Materials, Systems and Structures, Vol. 4, pp.558–60, 1993.

[2] Sumant, P.S. and Maiti, S.K., Crack Detection in a Beam Using PZT Sensors, Smart Materials and Structures, Vol. 15, pp.695–703, 2006.

[3] Zhang, H., Galea, S., Chiu, W. and Lam, Y., An Investigation of Thin PVDF films as Fluctuating-Strain-Measuring and Damage Monitoring Devices, Smart Materials and Structures, Vol. 2, pp.208–216, 1993.

[4] Yin, L., Wang, X. and Shen, Y., Damage Monitoring in Composite Laminates by Piezoelectric Films, Computers & Structures, Vol. 59, pp.623–630, 1996.

[5] Fukunaga, H., Hu, N. and Chang, F., Structural Damage Identification Using Piezoelectric Sensors, International Journal of Solids and Structures, Vol. 34, pp.393–418, 2002.

[6] Castillo, D., Pardo, de V.C. and Guemes, J., Structural Integrity Analysis with Piezoelectric Patches, Key Engineering Materials, Vol. 167, pp.91–101, 1999.

[7] Jiang, L.J., Tang, J. and Wang, K.W., An Enhanced Frequency-Shift-Based Damage Identification Method Using Tunable Piezoelectric Transducer Circuitry, Smart Materials and Structures, Vol. 15, pp.799–808, 2006.

[8] Yan, W., Chen, W., Lim, W. and Cai, J.B., Application of EMI Technique for Crack Detection in Continuous Beams Adhesively Bonded with Multiple Piezoelectric Patches, Mechanics of Advanced Materials and Structures, Vol.15, pp.1–11, 2008.

[9] Narayanan, A. and Subramanian, K.V.L., Damage Assessment in Concrete Structures Using Piezo-electric Based Sensors, Revista ALCONPAT, Vol. 7, No.1, 2017. DOI: http://dx.doi.org/10.21041/ra.v7i1.173

[10] Reddy, M.D. and Swarnamani, S., Influence of Stiffness and Mass Changes on Eigen Frequencies of Beam with Piezo Electric Patch, Proceedings of the 14th International Congress on Sound and Vibration (ICSV14), Cairns, Australia, July 9-12 2007.

[11] Lu, Y. and Li, Z., Crack Detection Using Embedded Cement-Based Piezoelectric Sensor, Proceedings of the 7th International Conference on Fracture Mechanics of Concrete and Concrete Structures (FraMCoS-7), Jeju, Korea, May 23-28, 2010.