Investigation and Analysis of Multiple Cracks in Cantilever Beam by Using FEM

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Abstract: The present study outlines free vibration analysis of uniform and stepped beam subjected with single to multiple cracks victimization Finite part methodology (FEM). The crack thought-about is transversal crack that open in nature. Because of the presence of crack, the overall flexibility matrix is established by adding native extra flexibility matrix to the flexibleness matrix of the corresponding intact beam part .The native extra flexibility matrix is obtained from Linear Elastic Fracture Mechanics theory. An experimental study is administrated to examine the accuracy of the numerical results. Soft-cast steel specimens of sq. space of cross section square measure thought-about for the experiment and also the experimental results square measure compared with numerical analysis victimization Finite part methodology (FEM) in MATLAB atmosphere. The results obtained from experimental square measure checked for accuracy with the current analysis by plotting non- dimensional frequencies for initial 3 modes as perform of crack depth ratios for various locations of cracks.

Keywords- Vibration based mostly detection, multiple crack, crack location and crack depth.

I. INTRODUCTION

For several engineering applications, beams square measure essential models for the structural components and are studied extensively. Optimization necessities crystal rectifier to reduction within the weight of structure ensuing to increased in operation stress levels. A number of the applications of beam-like components square measure chopper rotor blades, robot arms, craft wings, artificial satellite antennae, and long span bridges. Structural components and systems are terribly of subject to hundreds dynamic with time. Ignoring the presence of fabric defects whereas planning crystal rectifier to spectacular failures. Because of this fatigue changes within the part conceive cracks that hinders the potential of the part to resist its capability. The sharp failure of structures is results of the crack injury propagation if it's not detected well before. So, it becomes essential relating to safety question of the structure performance to watch such defects. winning style of engineering structures for future life needs the understanding of various modes of failures and degradation mechanisms (crack growth because of service hundreds, corrosion, atomic number 1 embrittlement etc); in order that sufficient margins against these mechanisms will be inbuilt throughout the look part itself.

The natural frequencies suggest the dynamic stiffness of any structure. The frequency being higher indicates that the structure is stiffer dynamically. It depends on the values of mass, stiffness distributions and also the finish conditions. The vibration response is affected because of the native flexibility that is initiated because of presence of crack in support. It results in decrease in frequencies in comparison to the frequencies that occurred naturally and changes in mode patterns of vibrations. Any discover in of those variations makes doubtless to detect cracks.

II. LITERATURE REVIEW

A. Vibration of Uniform beam with cracks

Vibration of Uniform beam with cracks Kisaetal (2000) sculptural cracked structures by desegregation the finite part methodology, the linear elastic fracture mechanics theory and also the part mode synthesis methodology. The experimental investigations of the consequences of cracks on the primary 3 modes of vibratory beams for each hinged-hinged and stuck -fixed boundary condition are elaborate by Owolabi (2003). The Frequency Response perform (FRF) amplitudes and changes in natural frequencies obtained from the measurements of dynamic responses of cracked beams as a perform of crack depth and site of crack square measure used for the detection of crack. Zheng et al. (2004) obtained the natural frequencies and mode shapes of cracked beam victimization Finite part methodology (FEM). The overall flexibility matrix is established by adding overall extra flexibility matrix to the flexibleness matrix of the corresponding intact beam element. Patil et.al (2005) verified a way to imagine the placement and depth of crack by experimentation for cantilever beams with 2 and 3 edge cracks. The energy approach methodology is employed for analysis and also the crack is delineate as a motility spring. For a specific mode, variable crack location, a plot of stiffness versus crack location is obtained. The intersection of those curves subsequent to the 3 modes offers the crack location and also the associated motility spring stiffness. Yoon et.al (2007) investigated analytically and by experimentation have an effect on of presence of 2 open cracks on the dynamic response of a double cracked hinged-hinged terminated beam.

III. MATHEMATICAL FORMULATION

Introduction the idea associated with vibration and also the Linear Elastic Fracture Mechanics (LEFM) square measure conferred. Then the eye is given to the mathematical formulation of a cracked uniform cantilever beam. The presence of crack reduces the native stiffness matrix that alters the dynamic response of the system. / Figure 3.1 Input-Output relationship of a moving system.

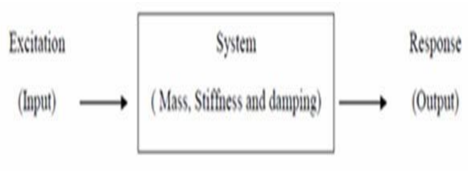


Figure 3.1 Input-Output relationship of a vibratory system.

IV. METHODOLOGY

A cracked uniform cantilever beam part of rectangular space of cross section with depth h” and breadth„ b” with crack depth„ a” is as shown in Figure 1.Theleftsideendwhichis mounted is denoted with node „I” and right facet node is denoted with „j". The cracked beam part is subjected to cutting force, $P1'$ and bending moment,

$P2'$. The governing equations of the vibration analysis of the uniform beam with open transversal crack square measure patterned on the idea of the FEM model projected by Zheng (2004).

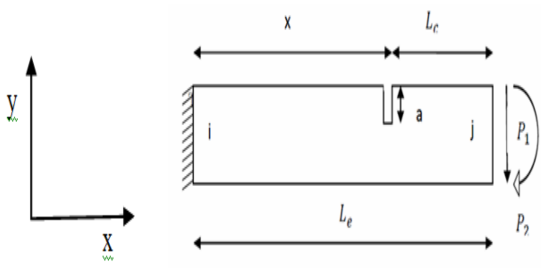


Figure 3.3 A typical cracked beam element subjected to shearing force and bending moment

According to Zheng (2004), the additional strain energy due to the presence of crack is π = $\int G dA_c$

G = the strain energy release rate and

dA_c= the effective cracked area

Where, G = strain energy release rate

$$G = \frac{1}{E}[(\sum_{n=1}^{2} K_{1n})^2 + (\sum_{n=1}^{2} K_{11n})^2 + (\sum_{n=1}^{2} K_{111n})^2]$$

K_1, K_{11}, K_{111} are stress intensity factors for opening, sliding and tearing type cracks. According to the principle of Saint-Venant, the strain field is affected solely within the region adjacent to the crack.

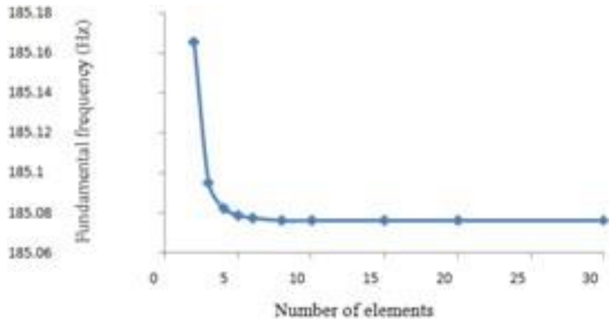


Figure 1: Convergence of fundamental frequency of uniform cantilever beam with single crack

The part stiffness matrix, aside from the cracked part, could also be considered unchanged underneath an exact limitation of part size. Considering the result of cutting force and bending moment the (neglecting action of axial force) higher than equation becomes,

$$G = \frac{1}{E}[(KI1 + KI2)^2 + (KII1)^2]$$

$$KI1 = \frac{6P_1 L_c^2}{bh^2}\sqrt{\pi\xi F_I}\left(\frac{\xi}{h}\right)$$

$$KI2 = \frac{6P_2}{bh^2}\sqrt{\pi\xi F_{I1}}\left(\frac{\xi}{h}\right)$$

$$KII2 = \frac{P_2}{bh^2}\sqrt{\pi\xi F_{I1}}\left(\frac{\xi}{h}\right)$$

Where, and F_{11} are correction factors for stress intensity factors

$$FI(S) = \sqrt{\frac{\tan\frac{\pi s}{2}}{\frac{\pi s}{2}}}\left[\frac{0.923 + 0.199\left(\left(1-\sin\frac{\pi s}{2}\right)\right)}{\cos\frac{\pi s}{2}}\right]$$

$$FII(S) = \frac{1.122 - 0.561s + 0.085s^2 + 0.180s^3}{\sqrt{1-s}}$$

V. RESULTS AND DISCUSSIONS

A. Convergence study

In this section, the convergence study is done to verify the accuracy of the present FEM analysis.

B. Uniform Cantilever Beam with crack

The convergence study is done for the cantilever uniform beam of square cross-section with single crack with the case considered in Lee et.al (2000). A 300mm cracked cantilever beam of cross section (20x20) mm with Young's modulus, E=206GPa and mass density ϱ=7750 $kg/m3$. It is observed that convergence starts when the number of elements is 14 and convergence up to 30 numbers of elements, is shown in Fig. As per the convergence study, 20 elements are considered for the discretization of whole structure.

C). Two-stepped cantilever beam without crack

The convergence study for the two-stepped cantilever of rectangular cross-section is done with the case considered in Zhang et.al (2009). The thickness of beam is 12mm. The material properties of the beam are modulus of elasticity, E= 210Gpa, length of beam, L =500mm, density, ϱ = 7860 kg/$m3$, $h1$= 20mm, $h2$= 16mm. It is observed that convergence starts when the number of mesh divisions is 10 and convergence up to 30 numbers of elements is shown in Fig. Hence for the present study for all stepped beams, mesh division of 30 elements is considered.

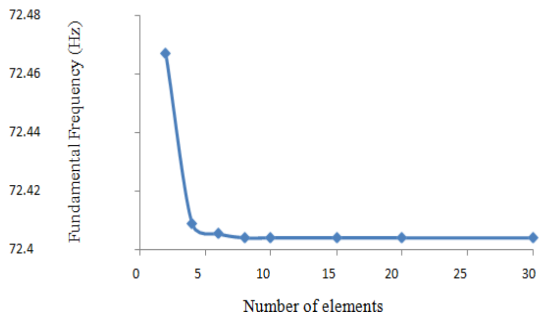


Figure 2: Convergence of fundamental

VI. COMPARISON WITH PREVIOUS STUDY

A. Free Vibration Analysis of Cracked Uniform Cantilever Beam

The present FEM formulation is validated with literature. The variation of natural frequency with respect to the uniform cantilever beam with single crack is studied and compared with Shiffrin (1999) as shown in the Table.

The material properties of the beam are, Elastic modulus of the beam, E = 210MPa, Poisson's Ratio, υ = 0.3, Density, Q = 7800 kg/m3, Beam Width, b = 0.02m, Beam depth, h=0.02 m, Beam length, L = 0.8m, Position of the crack from clamped end x1= 0.12m, Crack depth a1=0.002 m.

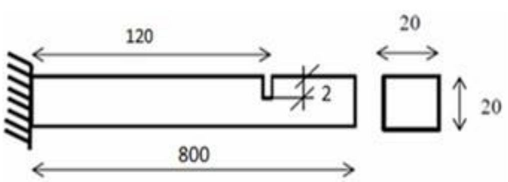


Figure 3: Cracked cantilever beam (mm)

Table 2: Comparison of natural frequency drawn between Shiffrin (1999) and present FEM analysis

MODE	Natural Frequency (Hz) Shiffrin (1999)	Present analysis FEM (Hz)
MODE 1	26.123	26.168
MODE 2	164.092	164.109
MODE 3	459.607	459.558

B. Free Vibration Analysis of Cracked Stepped Beams of Rectangular Cross-Section

The problem contains computation of natural frequencies for cracked Bernoulli-Euler Cantilever beam using Finite Element Analysis are validated with the results obtained by Zhang et.al (2009).The thickness of beam is 12mm. The material properties of the beam are modulus of elasticity, E= 210Gpa, length of beam, L =500mm, density, ϱ = 7860 kg/$m3$, $h1$= 20mm, $h2$= 16mm.

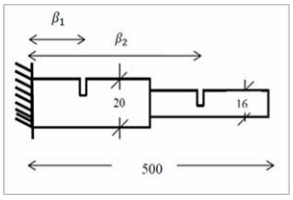


Figure: Cracked cantilever stepped beam (mm)

Free vibration of uniform beam subjected to single crack

Uniform fixed-free beam

The geometrical properties of the beam shown in Fig 5.5 are administrated for free of charge vibration analysis.

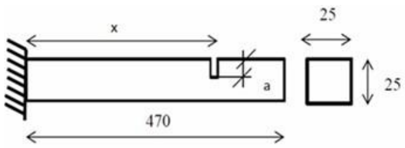
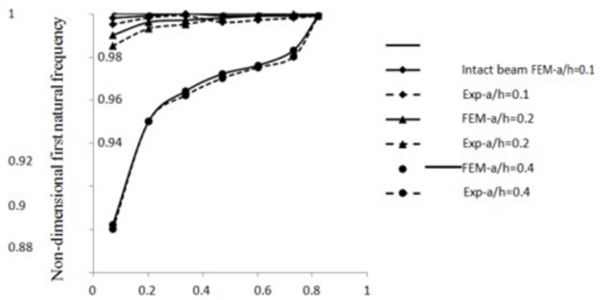


Figure: Cracked uniform beam



Location of crack (x/L)

Figure: Comparison of FEM and experimental results for non -dimensional first natural

For all the various locations of crack thought-about, the elemental frequency is a lot of affected once crack is found at x=0.0325L , the primary mode of non-dimensional frequency decreases by 0.15%, 0.92%, 9.70% compared to intact beam for the crack depth ratios 0.1, 0.2, 0.4 respectively.

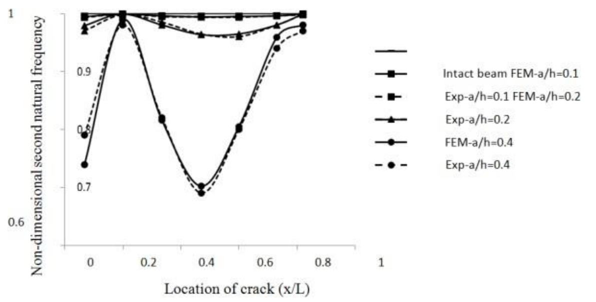


Figure: Comparison of FEM and experimental results for non - dimensional second natural

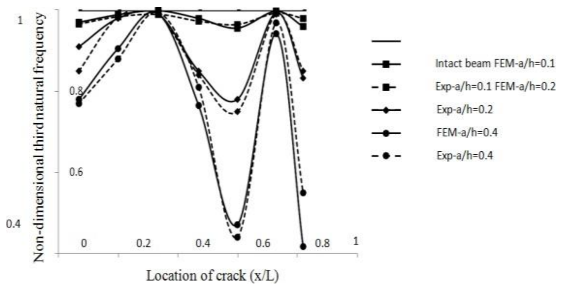


Figure: single cracked cantilever beam with location of crack(x/L) for varying crack depth ratios.

From the plot, it will be inferred that for crack locations, x/L= 0.60, a forceful amendment within the third mode of non-dimensional natural frequency happens. once the crack is found at x/L = 0.0325, the non-dimensional frequency decreases by 0.34%, 2.13%, 18.41% compared to intact beam for the crack depth ratios 0.1,0.2,0.4 respectively. And it's additionally ascertained that for x/L = 0.375, 0.734 because of existence of nodal points, the reduction is slightly detected. The result of crack close to mounted and free ends of the beam on the third mode non-dimensional natural frequency has terribly less result.

VII. CONCLUSIONS

Free vibration analysis of uniform and stepped beam subjected with single to multiple cracks is finished victimization Finite part methodology (FEM). An experimental study is administrated to examine the accuracy of the numerical results. Mathematical formulation for free of charge vibration of uniform and stepped beam with transversal open cracks is conferred well. All told the modes of vibration, because the crack depth magnitude relation will increase, the frequency reduction will increase no matter uniform or stepped beam and condition. The natural frequencies of the beam are a lot of influenced by the placement of cracks than the depth of crack. Within the case of uniform cantilever beam, crack positioned close to the mounted finish affects the natural frequency in initial mode quite the crack gift within the free finish of the beam. This can be explained from the explanation that position of crack is critical within the region of upper bending moment. Due to the presence of node points, the result of crack close to mounted and free ends of the beam on the third mode non-dimensional natural frequency has terribly less result. For free-free condition, the crack positioned within the center of beam is a lot of crucial for the primary and third mode natural frequency. The second mode natural frequency is barely affected once cracks square measure placed at free ends and middle span of beam.

REFERENCES

[1] D.N.Thatoi,Sasanka Choudhury, H.C.Das, P.K. Jena, Giridhari lal Agrawal ― CFBP Network A Technique for Crack Detection ‖International Conference on Materials Processing and Characterization (ICMPC2014).

[2] Labib, D. Kennedy, C. Featherstone Free vibration analysis of beams and frames with multiple cracks for damage detection ‖Journal of Soundand Vibration 333 (2014) 4991-5003.

[3] A. Ghadmi, A. Maghsoodi, H. R. M iradamadi A new adaptable multiple-crack detection algorithm Arch. Mech., 65, 6, pp. 469-483,Warszawa 2013.

[4] Ameneh M., Amin G. and Hamid R. M., “Multiple-crack damage detection in multi- step beams by a novel local flexibility-based damage index”, Journal of sound and vibration, 2012, 332, 294-305.

[5] Celalettin Karaagac, Hasan Ofztuf rk , Mustafa Sabuncu, “Free vibration and lateral buckling of a cantilever slender beam with an edge crack: Experimental and numerical studies”, Journal of Sound and Vibration, 2009, 326,235-250.

[6] Chen et.al. “Detection of crack location and size in structures using wavelet finite element methods”, Journal of Sound and Vibration, 2005, 285, 767-782.

[7] Guohui D., and Xinwei W., “Free vibration analysis of multiple-stepped beams by the discrete singular convolution”, Applied Mathematics and Computation, 2013, 219, 11096-11109.

[8] H M., and Shen H., “Free vibrations of beams with a single-edge crack”, Journal of sound and vibration, 170(2), 1994, 237-259.

[9] Han-Ik Yoon, In-Soo Son, Sung-Jin Ahn,” Free Vibration Analysis of Euler-Bernoulli Beam with Double Cracks”, Journal of Mechanical Science and Technology, 2007, 21, 476~485.

[10] Jaworski J. W., and Dowell D. H., “Free vibration of a cantilevered beam with multiple steps”, Journal of Sound and Vibration, 2008, 312, 713-725.

[11] Khiem N.T., Lien T.V., "Multi-crack detection for beam by the natural frequencies", Journal of Sound and Vibration, 2004, 273, 175-184.

[12] Kisaet.al, "Free vibration analysis of multiple open- edge cracked beams by component mode synthesis". Structural Engineering Mechanics, 2000, 10 (1), 81- 92.

[13] Yatika Gori*, Pushpendra Kumar[1], Pravin P. Patil "FEA Simulation of Vibrating Cantilever Plate with Transverse Surface Crack" Materials Today: Proceedings 4 (2017) 9466–9470 ICEMS 2017

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