Fault identification of mild steel rod and hollow (steel/aluminium) pipe using finite element program, ANSYS

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***Abstract*— This study focuses to identify the faults of the ductile materials like steel aluminium etc, using finite element approach by comparing local stresses, strains and global displacement results between uncracked and cracked members. For simplicity of calculation and reduction of computational time and resources, a piece different size of steel rods and aluminium pipes were used in numerical analysis. In order to develop finite element meshes of the member twenty nodded solid rectangular brick elements & fifteen nodded wedge elements were used to model the and considered for this analysis. Impact dynamic load was applied at specified location (at the midpoint) of the member. ANSYS finite element software was used to solve the problem and process all information related to the above mentioned global and local responses. From the analysis response variables (displacements, strain & stress) were obtained at different locations for the different types of members is under applied load and two conditions (uncaracked & cracked). From the result obtained in this analysis it is seen that stresses and strains increase as crack depth increases and become maximum near the crack location. After making this comparison of the results it is determined whether there is fault within the member or not.**

***Keywords*— Variables Uncracked, Cracked, Dimension, Finite element, Analysis.**

I. INTRODUCTION

Building and other structure have a certain useful life (CPWD, 2002). At the design stage, the loading of the structure is defined and appropriate material choices are made based on their properties (Vijay et al., 2004). So when fault is created the structure can no longer operate satisfactorily. If one defines the quality of a structure or system as its fitness for purpose or its ability to meet customer or user requirements, it suffices to define a fault as a change in the system that produces an unacceptable reduction in quality. The fault in any member may be due to cracks or any other irregularities present in that member. These faults of members greatly affect the strength of the engineering structure.

In order to obtain a damage tolerant structure it is necessary to introduce monitoring systems, so that one can decide when the structure is no longer operating in a satisfactory manner. This means that a fault has to have a strict definition, e.g. the stiffness of the structure has deteriorated beyond a certain level. There are four key multidisciplinary areas for which monitoring and assessing damage (Worden K et al., 2004) are principal concerns:

- Structural Health Monitoring (SHM)
- Condition Monitoring (CM)
- Non-Destructive Evaluation (NDE)
- Statistical Process Control (SPC)

SHM is one of the most promising monitoring system can provide engineers with some valuable information such as real-time monitoring (Fahit 2014) that is relevant behaviour to structures such as aircraft and buildings and implies a sensor network. CM is relevant to rotating and reciprocating machinery, such as used in manufacturing. CM also uses on-line techniques that are often vibration based and use accelerometers as sensors (Edoardo 2013). NDE is usually carried out off-line after the damage has been located using on-line sensors (Charles et al. 2006). (There are exceptions to this rule, NDE is used as a monitoring tool for e.g. pressure vessels and rails.) NDE is therefore primarily used for characterization and as a severity check when there is a priori knowledge of the location of the damage (Jan 2012). Typical techniques include ultrasound, thermography and shearography. SPC is process based rather than structure based and uses a variety of sensors to monitor changes in the process (Arnaud 2012).

Objectives

1. To determine the response variables (displacement, strain, stress & acceleration) of the uncracked members (mild steel rod & hollow pipe) after applying impact load at specified location (mid point) of the member.
2. To determine the response variables of the cracked members under the applied impact load at the same locations of the member.
3. To compare the results of the uncracked & cracked conditions of the members and to find out whether the member is faulted or not.
4. To determine the condition of the members in the field or in the factory at instance.

II MATERIALS AND METHODS

Stress analysis of uncracked and cracked member

Impact Load

When the live load is applied gradually, the deformation of the member to which the live load is applied is greater than it would be. Since the deformation is greater, the stresses in the member are higher. The increase in stress due to live load over and above the value that this stress would have if the load were applied gradually is known as impact stress, and the live load causing this stress is known as impact load.

For purposes of structural design, impact load are usually obtained by multiplying the live load stresses by a fraction called the impact fraction (Stephen 1986). It depends on the time function with which the live load applied, the portion of the member over which the live load is applied, and the elastic and inertia properties of the member itself.

Effect of Crack

With the increase of crack size of a structure, the stress concentration will also increase and hence the rate of crack propagation will increase. The crack propagation as a function of crack size can be represented by a rising curve as the figure given below.

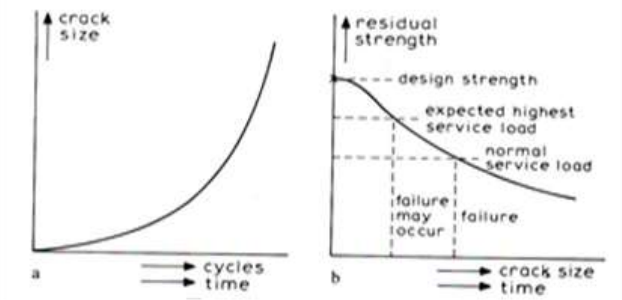


Fig 1. (a) Crack growth curve; (b) Residual strength curve

Source: Broek D.（Elementary engineering fracture mechanics）

With the increase of crack size, the residual strength will decrease. After a certain time, the residual strength has become so low that the structure may fail by a certain service loading.

Short Beam Element

In this model the presence of a crack is taken into account by introducing a short beam element with a reduced bending stiffness at the position of the crack. The modelling of the beam in the neighbourhood of the crack is solely based on traditional beam theory.

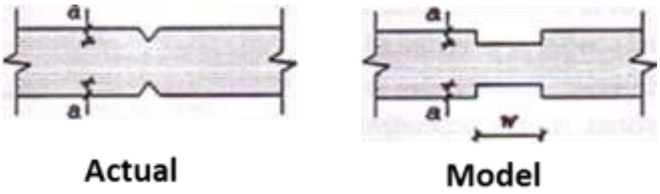


Fig 2. Short beam element models

This way of modelling a cracked beam was probably the most commonly used model until the mid-seventies, where the fracture mechanical model became the most preferred model.

The main reason for the widespread use of the model is that it is easy and quick to use in connection with both analytical solutions and traditional FE-program. A further feature of the model is that no details of the geometry of the cracked zone are required.

Notches and cracks in a beam will cause irregularities in the stress distribution and local deformations in the vicinity of the notch/crack. Part of the beam will in fact be inefficient due to the changes in the stress distribution. The main disadvantage of the short beam element model is that it does not take account of this ineffective material and. the local deformations.

This lack of the model has been known for many years, but a general solution to the problem has never been given. The most commonly suggested solution is the introduction of an equivalent width w of the slot/crack or instance this solution has been suggested by Kirsmer, Thomson and Petroski.

Kirsmer obtained a relationship between the changes in the first natural frequency of a simply supported beam and an equivalent slot width through energy considerations. Kirsmer used experimental data to calibrate his expression with respect to the equivalent width of the slot. He found that an equivalent width equal to five times the actual width of the slot gave reasonable agreement between analytical and experimental data.

In 1949 Thomson developed a procedure for the determination of the vibrational characteristics of slender bars with discontinuities in stiffness due to a narrow slot or crack. Thomson developed his model from a method given by Hetdnyi for a statically loaded beam. The basic idea is to determine the deflection of the slotted/cracked beam by considering the beam to be uniform with a pair of moments M' applied at the slot/crack position. However it was pointed out by Thomson, that the procedure would only be applicable, if an equivalent slot accounting for the inefficient material adjacent to the slot was determined through experiments.

Petroski used results from tests with a three point bending specimen and fracture mechanics theory to calculate an equivalent width of the slot/crack to be used in the model developed by Thomson. Petroski found that the equivalent width W,, of the slot in this special case should be taken as

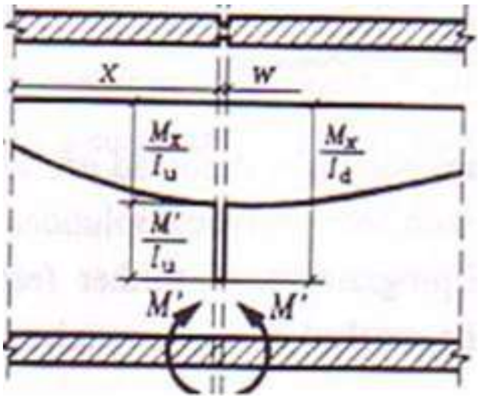


Fig 3. Thompson’s model

Where

$$W_{eq} = \frac{PL^2V(l)}{16M} \qquad \text{.......2.1}$$

$$l = \frac{a}{h}$$

$$V(l) = \left(5.58 - 19.57l + 36.82l^2 - 34.94l^3 + 12.77l^4\right)\left(\frac{l}{1-l}\right)^2$$

Where P is the point load, L is the beam length, M is the bending moment, a is the crack length and h is the beam height.

Three-Dimensional Stress and Strain

Consider the tree-dimensional infinitesimal element in Cartesian coordinates with dimensions dx, dy, and dz, and normal and shear stresses as shown in Figure4. This element conveniently represents the state of stress on three mutually perpendicular planes of a body in a state of three-dimensional stress. As usual, normal stresses are perpendicular to the faces of the element, and are represented by σ_x, σ_y and σ_z shear stresses act in the faces (planes) of the element, and are represented by τ_{xy}, τ_{yz}, τ_{zx} and so on.

From moment equilibrium of the element,

$$\tau_{xy} = \tau_{yx} \quad \tau_{yz} = \tau_{zy} \qquad \tau_{zx} = \tau_{xz}$$

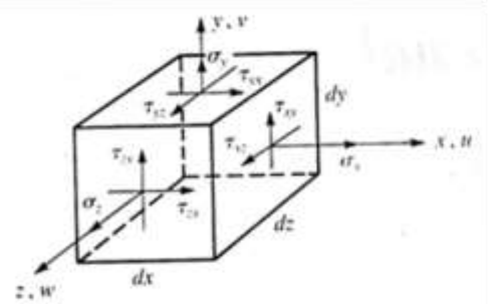


Fig 4. Three-dimensional stresses on an element

Hence, there are only three independent shear stresses, along with the three normal stresses

$$\varepsilon_{xy} = \frac{\partial u}{\partial x} \qquad \varepsilon_y = \frac{\partial v}{\partial y} \qquad \varepsilon_z = \frac{\partial w}{\partial z} \qquad \text{............ (3.1)}$$

Where and are the displacements associated with the x, y, and z directions. The shear strains are now given by

$$\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} = \gamma_{yx}$$

$$\gamma_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} = \gamma_{zy} \qquad \text{............ (3.2)}$$

$$\gamma_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} = \gamma_{xz}$$

Where, similar to shear stresses, only three independent shear strains exist. Representing the stresses and strains by column matrices as

$$\{\sigma\} = \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{Bmatrix} \qquad \{\varepsilon\} = \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix} \qquad \text{............ (3.3)}$$

The stress/strain relationships for an isotropic material are again given by

$$\{\sigma\} = [D]\{\varepsilon\}$$

Where $\{\sigma\}$ and $\{\varepsilon\}$ are define by Eqs. (3.3), and the constitutive matrix [D] is now given by

$$\{d\} = \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ \vdots \\ u_4 \\ v_4 \\ w_4 \end{Bmatrix} \qquad \text{............ (3.4)}$$

Hence, there are 3 degrees of freedom per node, or 12 total degrees of freedom per element.

Where,

$$[D] = \frac{E}{(1+v)(1-v)} \begin{bmatrix} 1-v & v & v & 0 & 0 & 0 \\ & 1-v & v & 0 & 0 & 0 \\ & & 1-v & 0 & 0 & 0 \\ & & & \frac{1-2v}{2} & 0 & 0 \\ & & & & \frac{1-2v}{2} & 0 \\ \text{Symmetry} & & & & & \frac{1-2v}{2} \end{bmatrix}$$

Finite Element Modelling

Finite element modelling is partly an art guided by visualizing physical interactions taking place within the body (Dary 2011). In modelling the following things must be taken into consideration

- The physical behaviour of the member to be model.
- Physical behaviour of various elements available for use.
- Choosing of the proper type of elements to match as closely as possible the physical behaviour of the problem.

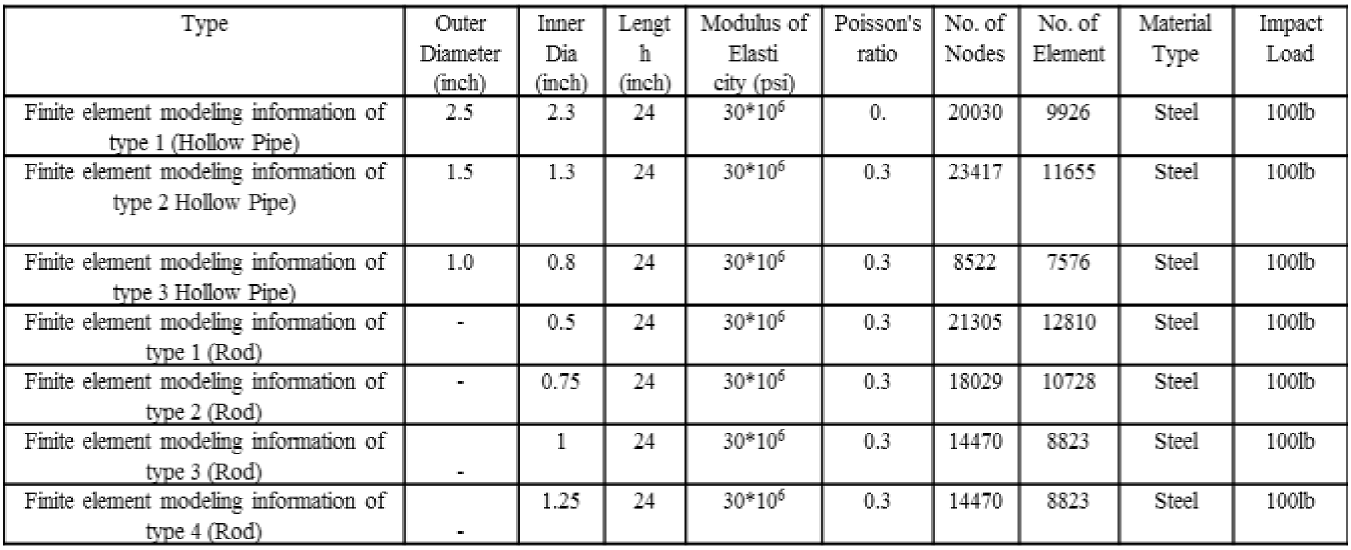
In the present study 3D solid element is considered to be used for capturing the above mentioned things in FEM analysis.

Modelling of the Members Using 3D Solid Element

20-nodded rectangular brick elements are used to model a part of the member. For the limitation of ANSYS software it was not possible to model the entire member using this element.

Therefore a part of the member is considered for determining the variation of stress- strain at specific point between cracked and uncracked structures. Fixed boundary condition was applied around the steel bar/pipe at both ends. Impact load was applied as force. Some element were deleted in order to provide crack at which crack is introduced. Fine mesh was provided at the surrounding of the crack. Dynamic analysis was done. The necessary information of the modelling of these members using 3D solid element is given below.

Table1. Finite element modeling information of type 1 (Hollow Pipe)



Type	Outer Diameter (inch)	Inner Dia (inch)	Length (inch)	Modulus of Elasticity (psi)	Poisson's ratio	No. of Nodes	No. of Element	Material Type	Impact Load
Finite element modeling information of type 1 (Hollow Pipe)	2.5	2.3	24	$30*10^6$	0.	20030	9926	Steel	100lb
Finite element modeling information of type 2 Hollow Pipe)	1.5	1.3	24	$30*10^6$	0.3	23417	11655	Steel	100lb
Finite element modeling information of type 3 Hollow Pipe)	1.0	0.8	24	$30*10^6$	0.3	8522	7576	Steel	100lb
Finite element modeling information of type 1 (Rod)	-	0.5	24	$30*10^6$	0.3	21305	12810	Steel	100lb
Finite element modeling information of type 2 (Rod)	-	0.75	24	$30*10^6$	0.3	18029	10728	Steel	100lb
Finite element modeling information of type 3 (Rod)	-	1	24	$30*10^6$	0.3	14470	8823	Steel	100lb
Finite element modeling information of type 4 (Rod)	-	1.25	24	$30*10^6$	0.3	14470	8823	Steel	100lb

III RESULTS AND DISCUSSIONS

We have observed the variation of principal stress in local x,y and z-direction with the various crack depths of 2.5 inch 1.5 inch and 1 inch dia hollow pipes (Fig 5, 6 and 7). It is seen that the principal stress increases if the crack depth increases gradually. This figure also shows the principal stresses of 1 inch dia hollow pipe is more than that of principal stresses of 1.5 inch and 2.5 inch dia hollow pipes. The points that are used into consideration for the comparison are node no. 1, 1033, 5129, 7236, 8039.

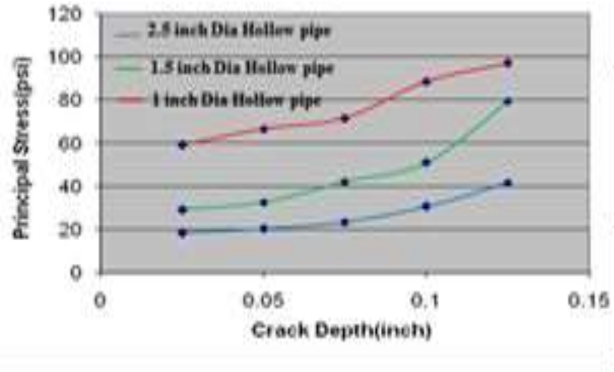


Fig 5. Variation of principal stress of local x-direction with crack depth

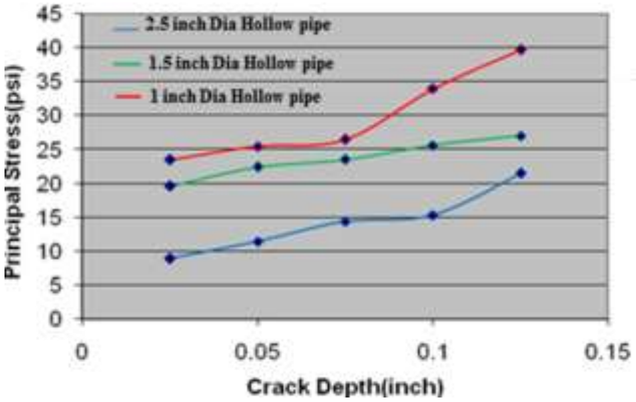


Fig 6. Variation of principal stress of local y-direction with crack depth

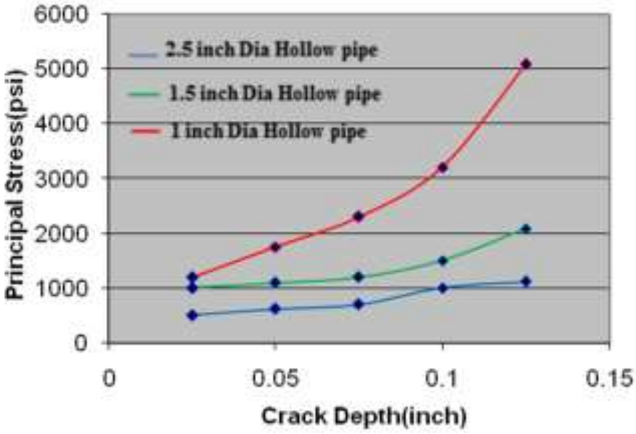


Fig 7. Variation of principal stress of local z-direction with crack depth

In this study the Fig 7, 8 and 10 showed variation of principal strain in local x,y and z-direction with the various crack depths of 2.5 inch 1.5 inch and 1 inch dia hollow pipes. It is seen that the principal strain increases if the crack depth increases gradually. This figure also shows the principal strain of 1 inch dia hollow pipe is more than that of principal stresses of 1.5 inch and 2.5 inch dia hollow pipes for the same magnitude of impact load. The points that are used into consideration for the comparison are node no. 1, 1033, 5129, 7236, 8039.

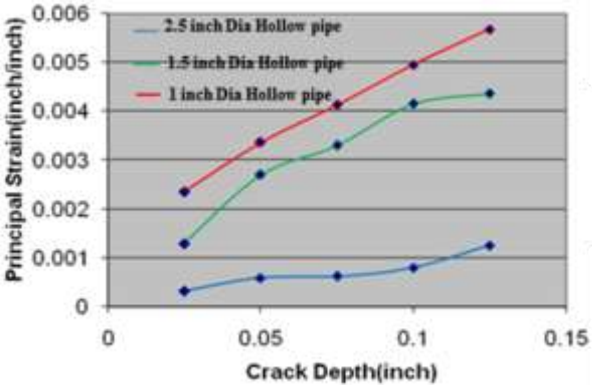


Fig 8. Variation of principal strain of local x-direction with crack depth

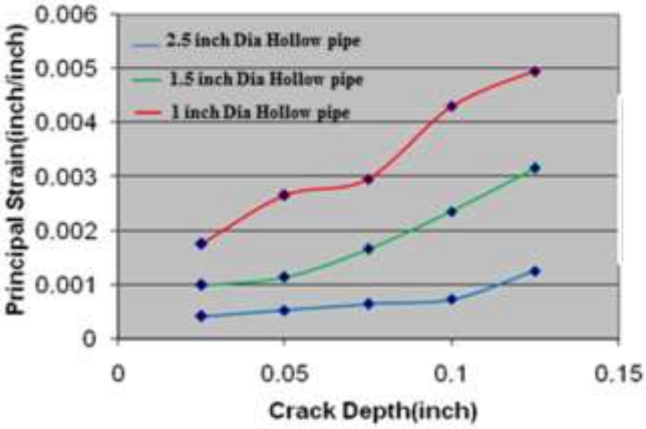


Fig 9. Variation of principal strain of local y-direction with crack depth

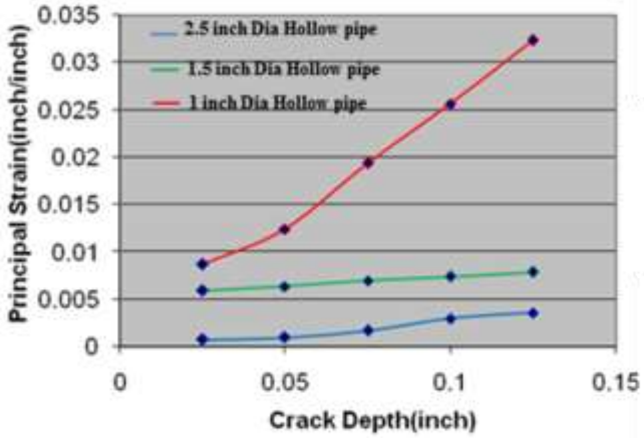


Fig 10. Variation of principal strain of local z-direction with crack depth

The variation of displacement in x- direction along the different crack depth of the mild steel rod was showed in Fig 11. From this graphs it is seem that the variation of displacement between different mild steel rods of same points along the different depth are about 8%.

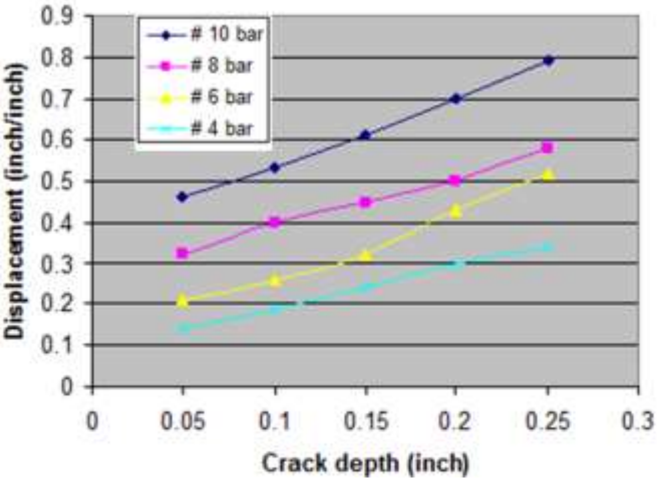


Fig 11. Variation of displacement in X direction at different crack depth of various mild steel rods.

The observed variation of principal stress in local x, y and z- direction were in Fig 12, 13 and 14 respectively. It is seen that principal stresses in local x, y, and z- direction gradually at the same point when the crack depth increases gradually. The points that are used into consideration for the comparison are node no. 1, 3176, 5184, 12122,14011.

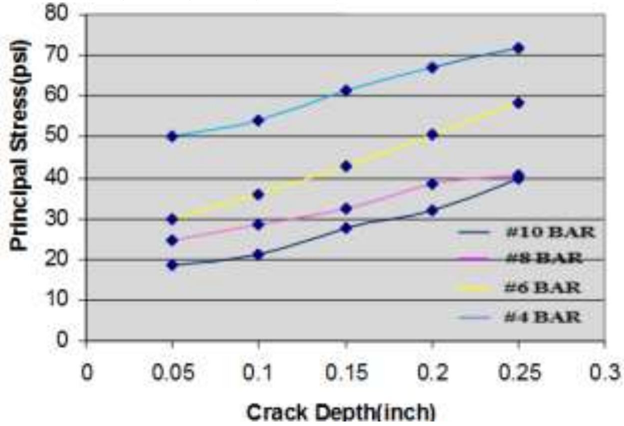


Fig 12. Variation of principal stress in local x-direction with crack depth of different mild steel rod

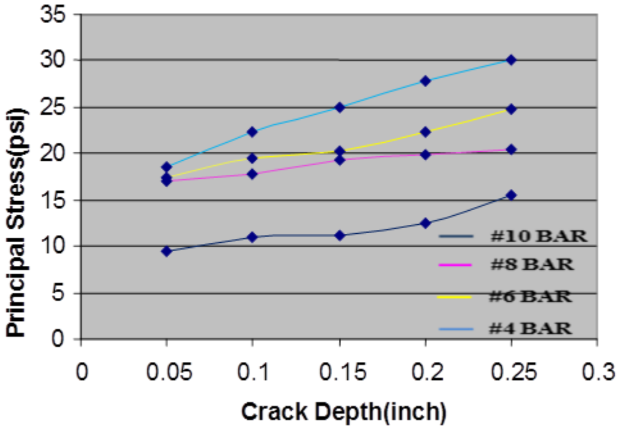


Fig 13. Variation of principal stress in local y-direction with crack depth of different mild steel rod.

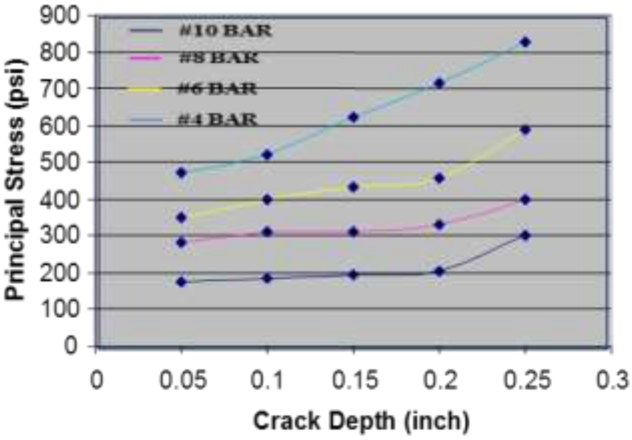


Fig 14. Variation of principal stress in local z-direction with crack depth of different mild steel rod.

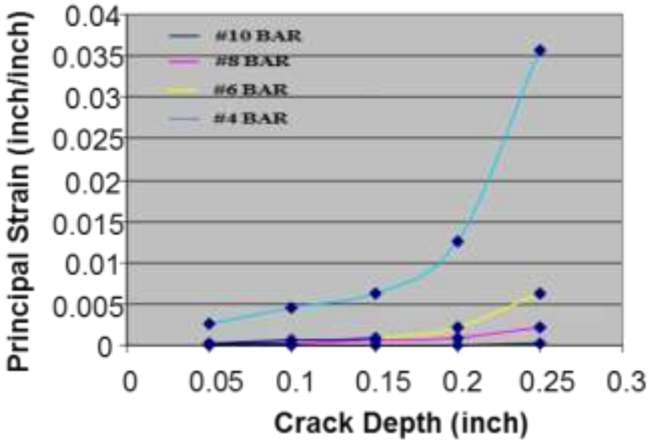


Fig 15. Variation of principal strain in local x-direction with crack depth of different mild steel rod.

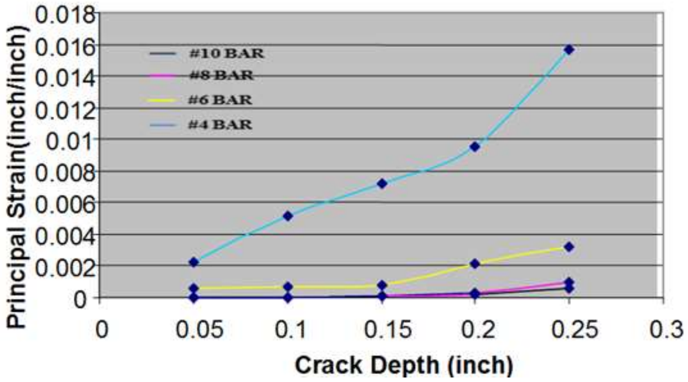


Fig 16. Variation of principal strain in local y-direction with crack depth of different mild steel rod.

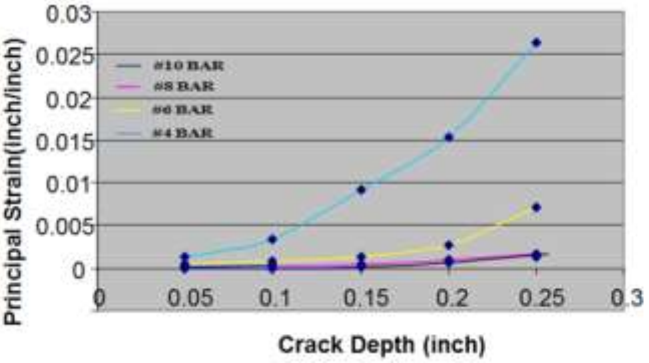


Fig 17. Variation of principal strain in local z-direction with crack depth of different mild steel rod

IV. CONCLUSIONS

From the analysis carried out in this study it is seen that the displacements, stresses and strains, etc. of a member (i.e. hollow pipe, mild steel rod) increase if any accidental faults such as cracks occur at any point of member. It has been obtained from the analysis that if the crack depth increases in the member the displacements, stresses and strains also increase. From the displacement plot it is seen that when a crack having depth equal to 0.025 in is introduced at any critical part of member (i.e. hollow pipe, mild steel rod) displacement increases about 2.6 to 2.9 percent for hollow pipe and about 1.3 to 1.8 percent for mild steel rod respectively. When crack starts to increase, displacements also start to increase. There was one crack introduced at the midpoint of each member. These variations can be detected by using different type of sensor such as strain gauge fixed at the different location of the member (i.e. hollow pipe, mild steel rod).

Recommendation

In this study the analysis was done using 3-D solid element. If the number of element is increased to model the member the result will be more close to the actual result and modeling of the crack within the member will be obtained exact.

ACKNOWLEDGMENT

This study was a part bachelor degree program work of the first author. The authors would like to express gratitude to the Department of Civil Engineering, Chittagong University of Engineering & Technology for research facilities.

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