Numerical Analysis of Thin Plates using Finite Element Software

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***Abstract*—Plates are vital structural members. They have applications in the field of structural engineering, ship technology, and aerospace engineering. For aesthetics and for providing some services holes are provided in thin plates. Holes are either formed manually or formed due to pitting corrosion. These holes induce stress concentration and re-distribution of stress around the hole and it causes a reduction in strength, sudden dynamic responses, and changes in the buckling characteristics. In this project, the static analysis of thin plates with holes is going to be done using a popular finite element software ANSYS. The influence of shape, size, the orientation of holes is to be analyzed. Also, the influence of boundary conditions on thin plates is analyzed. Foundation for strength assessment of steel plates with holes and residual strength of plates subjected to pitting corrosion can be formed using this study.**

Keywords— Stress concentration, ANSYS, Pitting corrosion, Residual strength, Finite element software, Boundary conditions.

I. INTRODUCTION

Thin metallic plates have several applications. A number of them are within the field of aerospace, marine, and automobile engineering. Thus it is important to understand their structural behavior and possible condition of failures. Usually, holes are introduced in steel plates for providing some services or for aesthetics. Holes can even be induced because of pitting corrosion and therefore the presence of holes within the plates may end up in stress concentration, stress redistribution, abrupt dynamic responses, and reduction in strength. It also ends up in changes within the buckling characteristics and necessitating rigorous contemplation.

So many researches had been completed and going on to analyze the plates subjected to axial force. In 1898, Kirsch [1] developed analytical equations for stresses within the proximity of a circular hole in an exceeding plate of infinite length subjected to in-plane uniaxial loading. In 2007, Gunwant *et al*. [2] investigated the stress distribution in an exceedingly very continuous elastic plate with a central elliptical hole. And in 2013, Mirji [3] utilized the finite element technique to find the stress distribution within an oblong plate with two holes, subjected to in-plane load. Diany [7] in 2013, developed stress concentration factors for a plate with holes of varied shapes and orientations. In 2013, Nagpal *et al*. [8] investigated stress concentration around the holes and openings in both isotropic and orthotropic plates, subjected to in-plane or transverse loading conditions. Various shaped cut-outs and their effects on stress concentration in the steel plates were studied by Watsar *et al*. [4] in 2015. Similar studies are also conducted by Mekalke *et al*. [6], Saraçoğlu and Albayrak [10], Jain [5] ,Vanam *et al*. [9], N V Divya [13], Gokul PV et al [14]. Also, some researchers have conducted studies on plates with holes created due to the explanation for pitting corrosion [11],[12].

In this paper, a study on stress patterns in an isotropic plate with holes subjected to uniaxial loading is presented. ANSYS, which might be a preferred finite element software is used within the current study. And therefore the numerical model is validated using the Kirsch problem [1]. An in-depth parametric study is additionally presented to assess the behavior of the plate with the shape of the hole, size of the hole further due to the gap between two holes in proximity.

II. METHOD OF STUDY

A. KIRSCH PROBLEM

Stress values that are greater than the applied average stress are observed within the proximity of a hole in a very stressed plate. These magnified stress values are often remarked as stress concentration. It occurs due to the irregularities present within the component and sudden changes of the cross-section. To assess this issue, it's worthy to define a Stress Concentration Factor (SCF) with the ratio of maximum stress and the average stress. Kirsch proposed stress concentration factors of 3P and -P around a circular hole in an axially loaded thin plate as shown in Fig. 1, where P is the applied average stress.

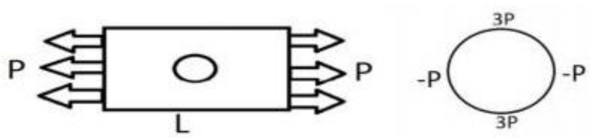

Fig. 1 Stress Concentration Factors

B. SHELL181 ELEMENT

It has 4 nodes with three translational and three rotational degrees of freedom at each node and linear interpolation is employed within the element. Within the present study, a four-noded shell element SHELL181 is used to discretize the plate. It's suitable for modeling thin to moderately thick shells. SHELL181 has six degrees of freedom per node and may sustain large deflections also. Within the present numerical model, a 'washer type' of mesh is provided within the vicinity of holes.

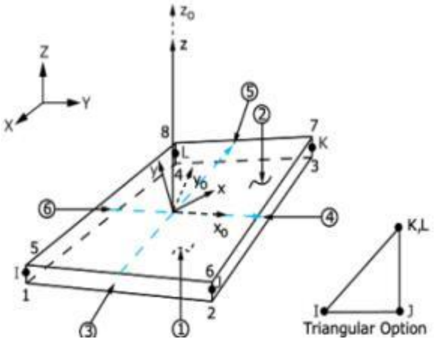

Fig. 2 SHELL181 geometry

III. PROCEDURES

A. 2D Modeling of Thin Plate

The First 2D model of the Thin plate is developed using ANSYS.

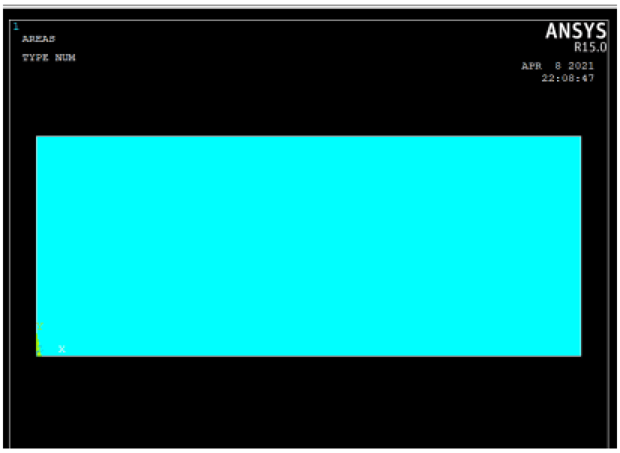

Fig. 3 2D Model of Thin Plate

B. Thin Plate With Hole

A hole of 10mm diameter is induced in the plate.

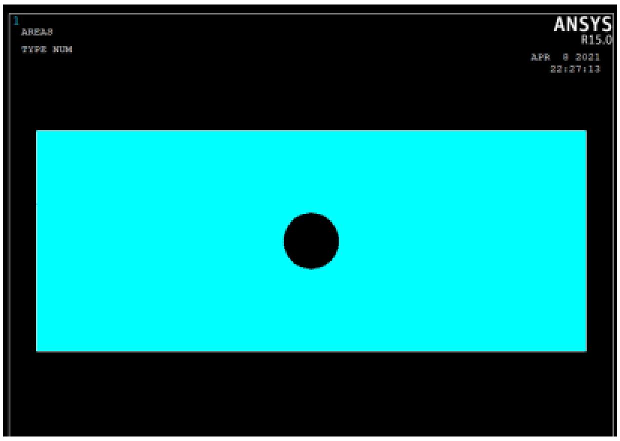

Fig. 4 Thin Plate With Hole

C. Loads and Constraints

Load of 10N/mm^2 is applied and the other end is restrained.

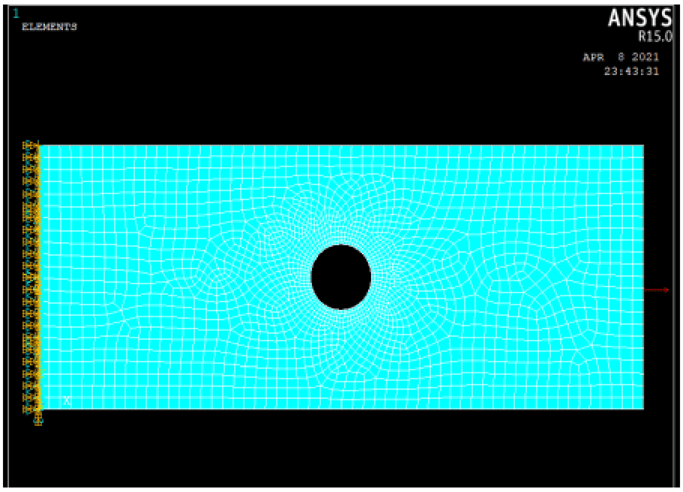

Fig. 5 Loads and constraints

D. 3D Modeling Of Thin Plate With Stress Distribution

After meshing, von Mises stress contours are presented and a 3D model is developed.

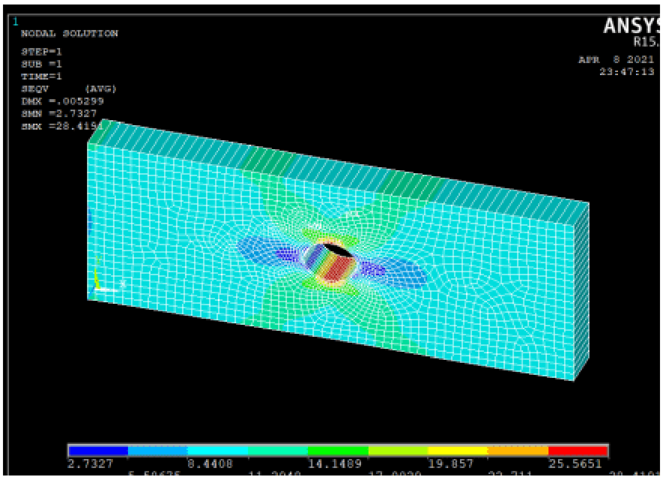

Fig .6 Stress Distribution in 3D Model

IV. NUMERICAL EXAMPLES

A. Plate With One Hole

A mild plate of dimensions 100 mm × 40 mm × 10 mm is developed. It is supplied with a central hole of a radius of 5 mm. Axial stress of 10 N/mm^2 is applied to the plate with boundary conditions. Validation of the developed numerical model is completed by using Kirsch problem. The plate is analyzed and the resulting Von Mises stress contours are presented in Fig. 7.

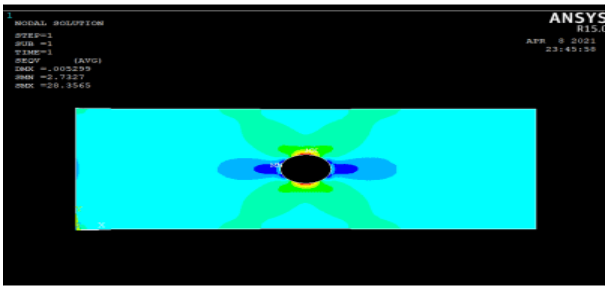

Fig. 7 Stress concentrations around the hole

TABLE 1. RESULTS FROM ANALYTICAL AND NUMERICAL METHOD

Position	Stress Around Hole(N/mm2)	
	Analytical Method	*Numerical Method*
A	30	28.5
B	-10	-8.6

The effect of the shape and size of the hole on the stress pattern in the plates is assessed by performing a parametric study.

V. RESULTS OF PARAMETRIC STUDY

A. Effect Of Shape Of The Hole

Different shapes of the hole are provided to the thin plates based on their purpose. Sometimes it is for aesthetics or for achieving any service. So it is important to know how the shape of a hole affects the strength and stress distribution in a thin plate. Keeping the areas of the hole the same, the plate with circular and square holes is analyzed and the results of which are represented in Table 2. From the table, we can find that the circular hole imparts very few stress concentrations compared to that of the square hole. When we consider the square hole, the stress concentration factor is increased due to the irregularities in the hole compared to circular.

B. Effect Of Size Of The Hole

Depending upon the size of the circular hole, the stress concentrations in the plate vary. The diameter of the hole was varied from 10 mm to 50 mm, to determine the effect of the size of the circular hole on stress concentrations in the plate. And the results are presented in Table 3. From this, it is clear that, as the diameter of the hole increases, the von Mises stress also increases. It is because, as diameter increases, the hole becomes closer to the plate edges, resulting in high-stress concentration.

TABLE 2. SCF OF THE PLATE WITH VARYING SHAPES OF HOLES

Hole area (mm^2)	Circular Hole		Square Hole	
	Maximum von Mises stress (N/mm^2)	*SCF*	*Maximum von Mises stress (N/mm^2)*	*SCF*
78.50	30.12	3.01	40.89	4.09
314.11	30.80	3.08	43.04	4.30
705.45	31.47	3.15	46.32	4.63
1253.58	35.09	3.51	49.53	4.95
1961.63	40.31	4.03	56.78	5.68

TABLE 3. SCF OF THE PLATE WITH VARYING DIAMETERS OF HOLE

Diameter	Maximum von Mises stress (N/mm^2)	SCF
10	30.12	3.01
20	30.80	3.08
30	31.47	3.15
40	35.09	3.51
50	40.31	4.03

VI. CONCLUSION

In this study, the popular finite element software, ANSYS is utilized to develop a numerical model of thin plates with holes for the static analysis. It's validated by using Kirsch problem. In this study, the effect of holes based on their size and shape in the stress distribution within the plate is found out. The results show that as the diameter of the opening increases, stresses also increase because the fringe of the opening gets closer to the edge of the plate. Also, the circular holes induce less concentration compared to the square ones. This can be because the sudden change in geometry is absent within the circular holes. This study can be further extended by including modeling of pitting corrosion and the non-linear material models. So that we can find out the strength and stress distribution in plates subjected to pitting corrosion.

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