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An Approach to Finite Element Analysis of Boiler Tube-Sheet

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Abstract: - This paper work deals with the stress analysis of plates perforated by holes in square pitch pattern. For this consider the in plane loading condition. In this paper, for in plane loading a 4 x 4 pattern of hole i.e. 16 holes arranged in square pattern and subjected to uniaxial tension is considered. For this case first photo elastic models are fabricated by using photo elastic materials. Then the same models are analyzing by using the photo elastic method. The same configuration is used and tested for uniaxial tension by using the finite element method.

I. INTRODUCTION

For the structural design of various types of pressure vessels, various equations are used. These equations are based on the strength of material approach. This approach assumes that there is a continuous elastic action throughout the member and the stress distributed on any cross section of the member by a mathematical law. But these assumptions are not valid for geometric discontinuity, which is present in the section of the member. The geometric discontinuity is in the form of crack or hole or any cutout of some different shape. Due to these irregularities stresses of large magnitudes are developed in the small portion of the member. These stresses are called as the localized stresses or stress concentrations.

Flat plates with a hole, which may be subjected to different types of loads, are the best example of such localized stresses. For this analytical formulae have been developed to find out the stress concentration effects. But when there are large numbers of holes in the plate, the problem becomes complicated. Stress distribution around each hole is altered due to interaction effect of other holes. These holes may be arranged in the uniform pattern or they may be arbitrarily oriented. The holes arranged in the uniform pattern are of practical importance. Such a plate popularly known as tube plate or tube sheet.

Tube plates or tube sheets have rows of holes with diameter of ‘D’ and pitch ‘P’. The material remaining between these holes are called ligament and the cross sectional area of the ligament compared to the area in a normal unpierced cross section of width ‘P’ is called ligament efficiency. In other words SCF is defined as the ratio of maximum principal stress σ_1 in the stressed model to the nominal stress applied at the boundary of the plate (σ_{nom}).

II. STATEMENT OF THE PROBLEM

The main objective is to obtain the stress distribution in a flat plate that is perforated by equal circular holes and subjected to uniaxial loads. Square pattern of holes is considered for study. The stress distribution changes with the change in ligament efficiency for any given type of loading. Therefore effect of ligament efficiency on stress concentration factor will be studied for uniaxial loading condition.

III. FINITE ELEMENT METHOD

Many times the governing differential equation for stress analysis in the field of plane stress problem for plate is invariably complex. It is extremely difficult and tedious. Sometimes it is impossible to obtain analytical solutions. Hence numerical methods are used to solve these partial differential equations. One of the most powerful techniques that have been developed in the engineering analysis is the Finite Element Method. In work, use popular software of finite element i. e. ANSYS.

Due to symmetry of geometry and load only one quarter part of the plate was modeled. Figure (1) shows plate geometry and loading for quarter part of the model.

Normal stress = 100 N/mm^2

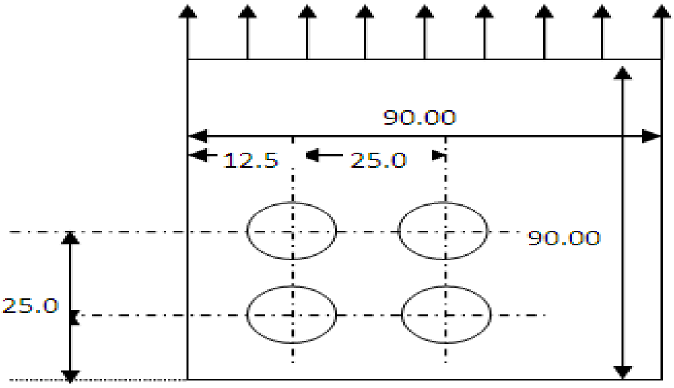


Fig.1 Plate geometry and boundary conditions.

Boundary conditions For X-Axis Ux $\neq$ 0 and Uy= 0 For Y-Axis Ux= 0 and Uy $\neq$ 0 All dimensions are in mm.

The typical area pattern used for making entire model is as shown in figure (2) Entire model was constructed by taking symmetry and translation of this typical area pattern about appropriate axis and in appropriate direction respectively. For each small area defined the element size of 3 was specified. This resulted in three divisions for each side of the area and hence 9 elements per area. Then meshing was done with the help of in built meshing facility available with ANSYS program. More fine mesh (i.e. small element size) was used around the boundaries of the holes and at the bottom left corner of the model. Figure (3) shows the mesh generated for the plate model with details regarding number of element and nodes used for analysis. Boundary conditions used for the model are as shown in figure (1).

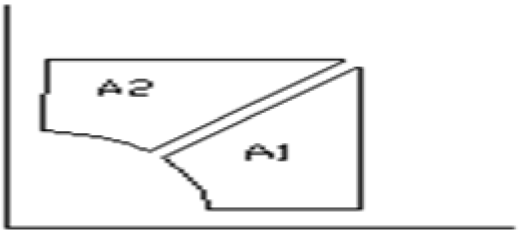


Fig.2 Typical area pattern used for model generation.

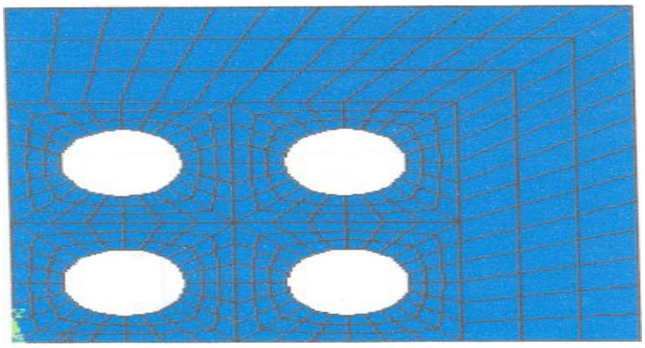


Fig. 3 Mesh generation for plate geometry.

IV. MACHINING OF MODEL

Machining of photoelastic model should not give rise to lock in stresses or residual stresses in the model. Otherwise these stresses will affect the actual stress distribution and hence fringe pattern in the model. Therefore models were machined on CNC machine or any other automatic machine, which gives constant speed and constant feed. Drilling operation was done at very low value of feed. Final hole size was obtained by using drills of gradually increasing sizes upto the desired hole size. The material fringe value is f_σ taken as 11 N/mm.

V. EXPERIMENTAL METHOD

The main motive of the experimentation is to support analytical and numerical solution. The most commonly used methods for determining stress values experimentally are strain gauges and photoelasticity principles. Overall picture of the stress distribution and regions of both high stress and low stress, are available for much detailed stress analysis in photoelasticity.

VI. EXPERIMENTAL SETUP

To give the uniformly distributed loading i. s. tensile force at the edge of the plate in the principle direction, a fixture was designed and manufactured with following guidelines. The assembly drawing of the fixture is shown in fig. 4. Figure 4 shows the modified load frame, mounted in the polariscope and the table1 shows the part list with material. The load frame consists of a power screw connected to a horizontal square bar of 25 mm size at the topside of the plate. A hole of 11mm diameter is drilled, at the center, to hold the frame under experimentation. The load cell is mounted with the help of connector 1 and connector 2 as shown in fig. 4 The load cell was employed to measure the applied tensile force. Application of the load at connector 1 configures in point load. To have the uniformly distributed load, the linkage 4 was incorporated as shown in fig. 4.This enabled the connector 1 to share the load into two parts of the boss plate.The applied load was transferred to the specimen in uniformly distributed way, through, specimen clamping plates. The clamping plates held the specimen with the help of 10 mm diameter holes, along the edge as shown in fig.4. To ensure, proper vertical alignment, welded boss, on each side of plate2 were provided. The same configuration of linkage as used in the upper edge of specimen was employed at lower edge of specimen to ensure proper fixing and loading.

The M. S. plates of thickness 5 mm were used in the fixture. The 10 mm diameter holes were drilled in the specimen plates for alignment, as shown in fig.4. The thickness of the plates was governed by the equation d = 6□t = 3mm for holes 10mm, was required but 5mm thickness is provided for safe configuration. Figure 5 and 6 shows the photograph for the experimental setup.

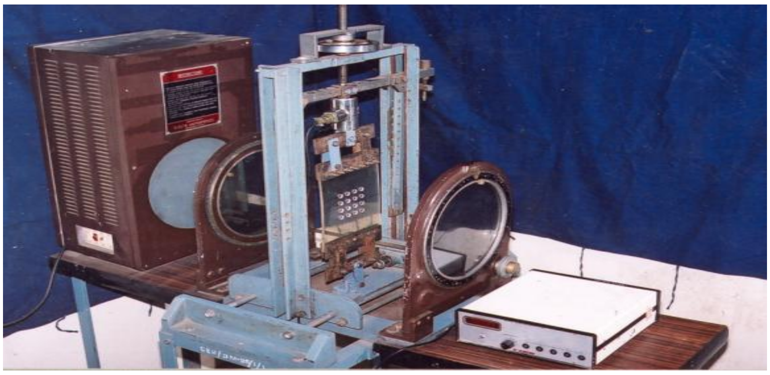


Fig.5 Experimental setup for uniform tension in photo-elasticity method.

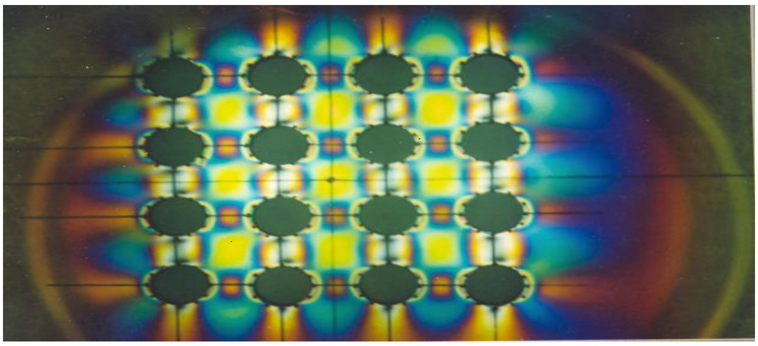


Fig.6 Fringes developed in photo-elasticity method for uniform tension.

VII. THE TEST AND RESULT

Analyzer and polariser were kept in crossed position i. s. dark field setup. Model was gradually loaded to observe the fringe growth. Fractional fringe order was measured by Tardy's compensation method. Fig 6 shows the photograph of the fringes produced on the model with holes in square pattern due to uniaxial tension. The load suspended at the pulley was 30 kg. Maximum stress is produced at the boundary of the hole shown in fig. 6.The procedure to find out the maximum stress is given below.

A circular disk specimen was employed as calibration model and obtained material fringe value, which is near about 11 N/mm for each plate. Then point of interest is marked on the specimen and plate is connected to the fixture for loading. The fixture designed for tensile tension was mounted on the polariscope along with the specimen and tensile force was given with the help of power screw. Direction of the principle stress and exact fringe order were determined by using Tardy's compensation method at point of interest. In this case the point of interest is at the hole boundary at which the value of $\sigma_2 = 0$ and σ_1 was determined by the formula.

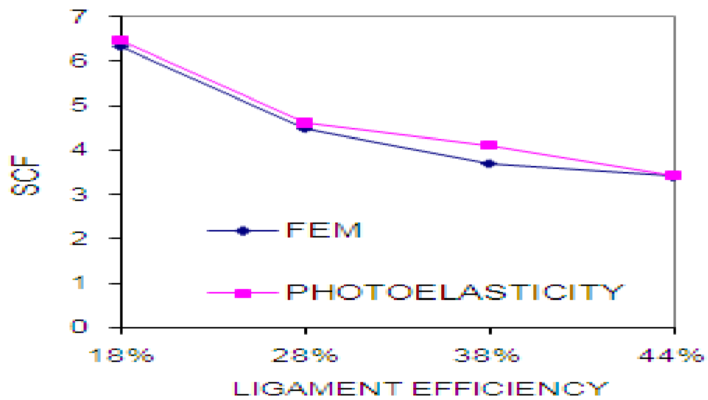
$\sigma_1 =$ N x f_σ / t, Then value of SCF is given by the following equation

SCF $= \sigma_1/\sigma_{nom}$

The tests were carried out on the models with different ligament efficiencies for square pattern of holes the result for square hole pattern is tabulated in table 2. Values of SCF obtained by ANSYS program are also given in the table 6.2.The graph of SCF Vs Ligament efficiency for FEM and Photo-elasticity method are given in graph.1

LIGAMENT EFFICIENCY	SCF BY	
	FEM	PHOTOELASTICITY
18	6.33	6.47
28	4.49	4.46
38	3.70	4.12
44	3.41	3.43

Table-1 SCF for square plate having square pattern, Uniaxial Loading.



Graph.1 Graph of SCF for FEM and Photo-elasticity method.

VIII. CONCLUSION

While comparing the results with finite element analysis it is found that the percentage variation of experimental values with FEM were about 10- 15%.

This can be attributed to following points.

1) The load applied to the model may not be uniformly distributed over entire cross section of model. Some bending may result due to misalignment of upper and lower clamping plates of the loading frame.

2) In spite of extreme care being taken in manufacturing of models, some small amount of machining stress are developed in the model, which changes the fringe pattern in the model.

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