



# Stress Analysis of a Perforated Plate through Experimental and Computational Methods

#<sup>1</sup>Prashant Jayavant Thorawat, #<sup>2</sup>Prof. Rahul A. Marne

<sup>1</sup>prashant7789@gmail.com

<sup>2</sup>rahulandram1@gmail.com

#<sup>1,2</sup>Mechanical Engineering Department, Savitribai Phule Pune University, All India Shree Shivaji Memorial Society College Of Engineering

## ABSTRACT

The analysis of perforated plate has immediate application to tube sheet design. However successful stress analysis required knowledge about elastic properties. Considerable effort has been directed towards their determination. Moe ever ASME has accepted the codes for the tube seats with triangular pitch pattern, but the codes standard for square pitch patterns have not been accepted so far. This is the motivation behind solving the present problem. Various design methods has been proposed by number of researchers for analysing stress and deflection in multi-perforated plates, properly known as tube sheets. The purpose for this dissertation work is to show the different techniques developed by various researchers in the analysis of perforated plates. The dissertation works deals with the stress analysis of perforated plates by holes in square pitch patterns for consider in plane loading condition. In this thesis, for in plane loading a square patterns are subjected to uniaxial tension is considered. For this case, first photo elastic model are fabricated by using photo elastic materials. Then this material is calibrated by calibration techniques for finding the material fringe of the same material.

*Keywords*— Perforated plate, ASME code, Square pattern, stress analysis

## ARTICLE INFO

### Article History

Received :18<sup>th</sup> November 2015

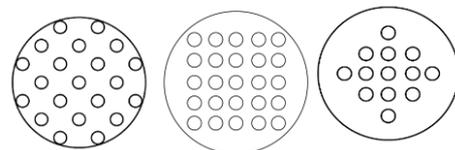
Received in revised form :  
19<sup>th</sup> November 2015

Accepted : 21<sup>st</sup> November ,  
2015

Published online :  
22<sup>nd</sup> November 2015

## I. INTRODUCTION

Perforated components are widely used in the construction of Heat exchanger, steam generator, nuclear reactor and pressure vessel of similar kind for supporting number of tubes. The simplest of these is perforated plates. They are popularly known as tube sheets or tube plates. The holes in the tube sheet are arranged in three different patterns shown in figures.



Equilateral triangle Square Staggered Square

Fig. 1 Holes in tube sheet arranged in different pattern. The important parameter which described the geometry of holes pattern is the ligament efficiency which is defined as  $\mu = h \times 100$  percent



Fig.2 Ligament Efficiency relationship

Because of large number of holes in the tube sheet, it is difficult to obtain the exact theoretical solution for the stress and deflection in the tube sheet. The perforated material is replaced by the solid material but whose material properties will be adjusted to account for penetration. Our work is concern with examination these limit in detail through the use of elastic finite element analysis of perforated region. For the structural design of various heat exchanger, pressure vessel,

various equation are used. These equations are based on the strength of material approach. But these assumption are not valid for geometric discontinuity, which is present in the section of the member. The geometric discontinuity may be in the form of crack or hole or any cutout of some different size and shape. Due to presence of these irregularities stresses of large magnitude are developed in the small portion of the member these stresses are called as the localized stresses or stress concentrations. The perforated plate may be subjected to different types of loads, are 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 the holes. These holes may be arranged in the uniform pattern or they may be arbitrarily oriented. The holes are arranged in the uniform pattern are of practical importance. Such a plate popularly known as a tube plate or tube sheet. Tube plate or tube sheets have rows 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 maximum principal stress  $\sigma_1$  in the stressed model to the nominal stress applied at the boundary of the plate ( $\sigma_{nom}$ ). Our work will present two and three dimensional elastic analysis for iso-tropic and in plane and bending Mechanical loading for the a plate containing 4x4 pattern of holes i.e. sixteen arranged in square pattern. These forces will resist the action of external forces acting on body in equilibrium. These forces distributed over the surface on which it acts and are usually defined by their intensity. i.e. Force per unit area. The intensity of these internal; forces is called Stress. Stress can be defined as internal forces per unit area exerted on specified surface. When the forces is tangential to the surface, the stress are called as shear stress, when the forces is normal to the surface, the stress are called normal stress, when normal stress are directed towards the surface, it is called as tensile stresses.

Application of perforated plate

1. Heat exchanger
2. steam generator
3. Nuclear reactors
4. pressure vessel

## II. PROBLEM STATEMENT

In the construction of perforated plate such as heat exchangers, reactor do-grids, Boiler drum, spinnerets and some civil engineering structure as even larger scale, elastic plate pierced by numerous holes of constant diameters drilled on equilateral triangular or square or rectangular, lay out are encountered as stress bearing elements of construction. The pitch of such hole is often a small fraction of the span of the perforated beam or plate in which they are drilled and array of holes are frequently found grouped in to zones within they are drilled and array of holes are frequently found grouped in to zones within the outer or supported boundary of the complete plate. Initially perforated plate were classified as 'continuously' and 'non-continuously' drilled. The rigidity of the later under the conditions of flexure was shown to depend upon the fundamental rigidity of continuously drilled zones and geometrical shape and arrangement of those zones. An establishment procedure for analyzing the stress in perforated plates is based on treating the perforated material as an equivalent solid material with modified elastic constants. The constants referred to as the effective elastic constants are determined from the requirements that gross deformation in the perforated material and the equivalent solid material be the same under same loading conditions. The stress concentration factor found around at the edges of the hole in a stress plate is of greater practical importance. The exact theoretical solution for the stress and deformation every-where in the tube sheet is not possible but approximate solution can be obtained by various design methods have been proposed by number of researcher for analyzing stress and deflection in multi perforated plates, properly known as tube sheets. During the last decade many authors have proposed analytical, experimental or numerical technique to solve this problems. The deflection and the stress in a drilled plate subjected to any type of loading is more compared to the solid plate of the same dimensions under similar type of loading. The weakening effect of the perforation may be described either in terms of deflection and ligament efficiencies or in terms of ratio of elastic properties such as young's modulus, poissons ratio for the drilled plate and solid plate. The objective of the project are mention below

1. To obtain the stress distribution of perforated plate subjected to uni-axial loads and procure material and test for validation
2. To study the effect of ligament efficiency on stress concentration factor.
3. To obtain the experimental result of stress distribution by Polariscope
4. To identify the advantages or limitations of Computational results obtained from ANSYS.
5. To compare results obtained from ANSYS and Polariscope.

## III. METHODOLOGY

The purpose of dissertation work is to analyses stress of perforated plates by holes in square pitch patterns for consider in plane loading condition. 1<sup>st</sup> step of this project is to design the actual model in CREO software and to analyses the stress using ANSYS. First analysis is for 4x4 pattern of holes in rectangular plate subjected to axial tension. 2<sup>nd</sup> analysis will be for diagonal patterns in which rectangular plate with 16 holes are arranged in diagonal

patterns and subjected to uniaxial loading. Similar analysis will be extended for bi-axial loading also. After that actual model will be prepared by using Photoelastic material, stress analysis experiment will be done Polariscopes. The results obtained from the polariscopes are validated with ANSYS i.e. computational result

#### IV. CASTING PROCEDURE FOR PHOTOELASTIC SHEET

100 parts of araldite cy-230 mixed with 9 parts of hardener Hy-951 by weight will be used for casting the sheets. Before making sheets the resin will be heated in oven about 80° c to 100° c. for about 2 hours so that all air bubble and moisture will be removed and it will be then cool slowly at room temperature. The hardener then added slowly in araldite. Then the mixture should be stirred in one direction continuously for 15 minutes till it is transparent and clear. After that mixture is poured in mould for preparation of sheet.

#### V. MACHINE MODEL

Machining of Photoelastic model should not give rise to lock in stress or residual stress in the model otherwise the stress will be affected by the actual stress distribution and hence fringe pattern in the model. Therefore the models were to be machined on CNC or any other automatic machine which give constant feed or constant speed. Drilling operation is to be done at very low speed

#### VI. EXPERIMENTAL TEST PROCEDURE

Experimental stress analysis is an experimental method to determine stress distribution in the material. The method is mostly used in cases where mathematical methods become quite cumbersome. Unlike the analytical methods of stress determination, photo elasticity gives a fairly accurate picture of stress distribution even abrupt discontinuities in a material.

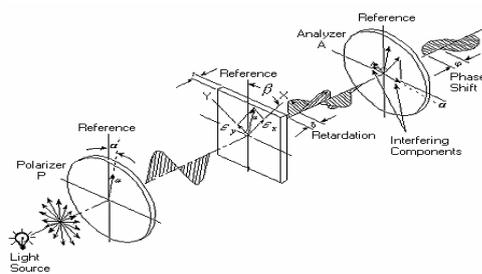


Fig. 3 Polariscopes set up

The method serves as an important tool for determining the critical stress points in the material and is often used for determining stress concentration factor in irregular geometries. The development of digital polariscopes using LEDs and laser diode enables continuous online monitoring of structure and dynamic photo elasticity. Development of rapid prototyping



Fig 4. Experimental set up for photo elasticity method

Using stereo lithography allows the generation of accurate three dimensional models from a liquid polymer, without the use of the traditional molding method. Principle-Many transparent non-crystalline material that are optically isotropic when forces of stress become optically and display characteristic similar to crystal when they are stressed. These characteristics persist while loads on the material are maintained but disappear when the load are removed. The optical anisotropy (temporary double refraction) which develops in material as result of stress can be represented by an ellipsoid, known in this case as index ellipsoid. The semi axes of the index ellipsoid represented the principal indices of refraction of the material at the point. Any radius of the ellipsoid represented direction of light propagation through the point. A plane through the origin, which is perpendicular to the radius, intersects the ellipsoid as an ellipse. The semi axes of ellipse represented the indices of refraction associated with light waves having plane of vibration which contain the radius vector and an axis of ellipse. For a material which is optically isotropic, the three principal indices of refraction are equal and index ellipsoid become sphere. The index of refraction is then same for all direction of light propagation through the material. The similarities which exists between the stress ellipsoid for the state of stress at a point and index ellipsoid for the optical properties of a material exhibiting temporary double refraction suggest the presence of a relationship between the two quantities. The relationship, which forms the basis for an experimental determination of stress is known as stress-optic law. The Stress Optic Law-The theory which relates changes in the indices of refraction of the material exhibiting temporary double refraction to the state of stress in the material is due to Maxwell, who reported the phenomenon in 1853. Maxwell noted that the changes in the indices of refraction were linearly proportional to the loads and thus to stresses or strains for linearly elastic material. The relationship can be expressed in equation form as

$$n_1 - n_0 = c_1 \sigma_1 + c_2 (\sigma_2 + \sigma_3)$$

$$n_2 - n_0 = c_1 \sigma_2 + c_2 (\sigma_3 + \sigma_1)$$

$$n_3 - n_0 = c_1 \sigma_3 + c_2 (\sigma_1 + \sigma_2)$$

The equations above are the fundamental relationship between stress and optical effects and are known as the stress optic law. These equations indicate that the complete

state of stress at a point can be determined by measuring the three principal indices of refraction and established the directions of the three principal optical axes. Since the measurements are extremely difficult to make the three dimensional case, practical application has been limited to cases of plane stress  $\sigma_3=0$ . For the plane stress situation the

equation reduces to

$$n_1 - n_0 = (c_1\sigma_1 - c_2\sigma_2)$$

$$n_2 - n_0 = (c_1\sigma_2 - c_2\sigma_1)$$

The Stress Optic Law In Terms Of Relative Retardation Equation describe the changes in index of refraction due to applied stress experienced by material exhibiting temporary double refraction. The method photo elasticity makes use of relative changes in index of refraction which can be written by eliminating  $n_0$  equation

$$n_2 - n_1 = (c_2 - c_1)(\sigma_1 - \sigma_2) = c(\sigma_1 - \sigma_2)$$

$$n_3 - n_2 = (c_2 - c_1)(\sigma_2 - \sigma_3) = c(\sigma_2 - \sigma_3)$$

$$n_2 - n_1 = (c_2 - c_1)(\sigma_1 - \sigma_2) = (\sigma_1 - \sigma_2)$$

Where,  $c = (c_2 - c_1)$  is the relative stress optic coefficient.

Photoelastic materials are considered to exhibit positive birefringence when the velocity of propagation of light wave associated with the principal stress  $\sigma_1$  is greater than

the velocity of waves associated with principal  $\sigma_2$ . since the

principal stresses are order such that  $\sigma_1 \geq \sigma_2 \geq \sigma_3$  the

principal indices of refraction of positive doubly refraction material can be order such that  $n_3 \geq n_2 \geq n_1$ .

**VII.FINITE ELEMENT ANALYSIS**

A ANSYS is comprehensive general purpose finite element analysis software which capable of performing structural, heat transfer, fluid flow, electromagnetism and biomedical analysis. The ANSYS version has multiple windows incorporating Graphics users interface, pull down menus, dialog box and tool bar. Different equations are used for stress analysis for plate which is complex. Sometimes it is impossible to obtain analytical solutions so that the numerical methods are used to this type of partial equations. Finite element analysis is one of most powerful technique use for

engineering analysis, use popular software of finite element i.e. ANSYS.

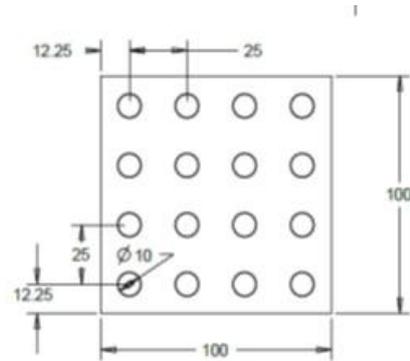


Fig 5. Plate geometry

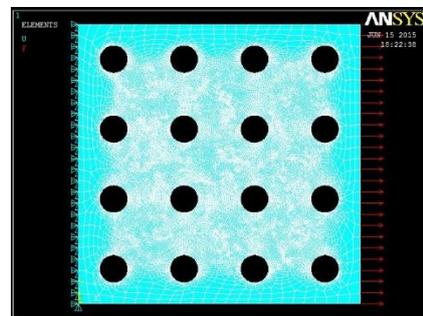


Fig 6. Plate meshing

Boundary conditions for on X-axis  $u \neq 0, v \neq 0$ . On Y-axis  $u \neq 0, v \neq 0$ . All dimension are in mm

The meshing is done with the help of mesh tool which is built meshing facility available with ANSYS programme. More fine mesh is use around the boundaries of the holes at the bottom and left corner of the model. Boundary conditions used for the model are as shown in Fig.6

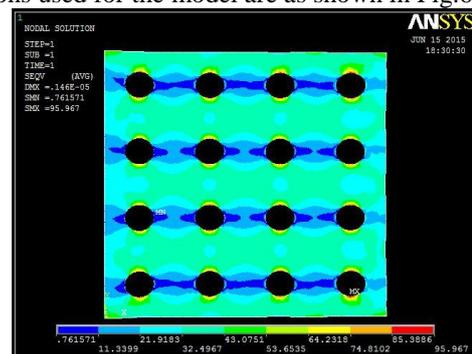


FIG 7. EQUIVALENT STRESS

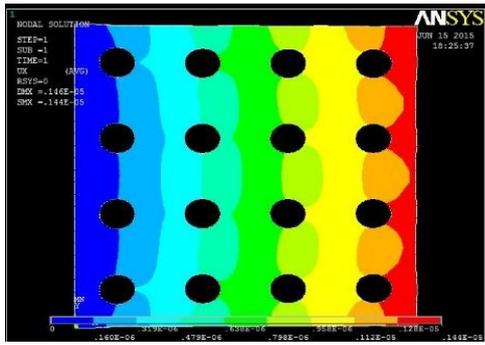


Fig 8. Displacement in X-direction

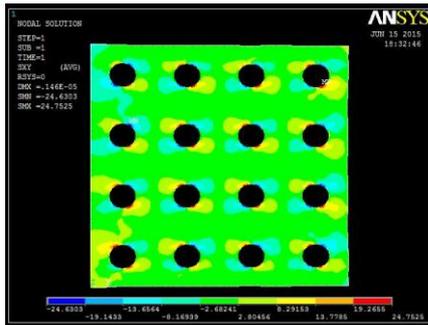


Fig 9. Fig 6. Shear stress in XY direction

**ACKNOWLEDGEMENT**

The authors are thankful to Dr. S.P. Danao, Professor and Principal AISSMS'COE, Prof. A. V. Waghmare, Head, Dept. of Mechanical Engg., AISSMS'COE, and our guide Prof. R.A. Marne for their constant encouragement and cooperation throughout the work.

*Nomenclature:*

$\sigma_1, \sigma_2, \sigma_3$  = principal stresses at point

$n_0$  = index of refraction of material in unstressed state

$n_1, n_2, n_3$  = principal indices of refraction which coincide

with the principal stress directions.

$c_1, c_2$  = constants known as stress optic coefficients.

$c = (c_2 - c_1)$  is the relative stress optic coefficient.

**REFERENCES**

[1] Jae-Hoon Kang “Exact solutions of stresses, strains, and displacements of a perforated rectangular plate by a central circular hole subjected to linearly varying in-plane normal stresses on two opposite edges.”. International Journal of Mechanical Sciences 84 (2014) 18–24.

[2] A. Bhattacharya, V. Venkat Raj “Peak stress multipliers for thin perforated plates with square arrays of circular holes”. International Journal of Pressure Vessels and Piping 80 (2003) 379–388, Received 5 December 2000; revised 24 April 2003; accepted 15 May 2003.

[3] Antonino Cirello, Franco Furguele, Carmine Maletta, Antonino Pasta “Numerical simulations and experimental measurements of the stress intensity factor in perforated plates”. Engineering Fracture Mechanics 75 (2008) 4383–4393.

[4] I.V. Andrianova, V.V. Danishevs'ky, A.L. Kalamkarov “Asymptotic analysis of perforated plates and membranes. Part 1: Static problems for small holes”, International Journal of Solids and Structures 49 (2012) 298–310.

[5] A. Bhattacharya, V. Venkat Raj “Yield surfaces for perforated plates with square arrays of holes”, Nuclear Engineering and Design 231 (2004) 219–233.