A Review on Design and analysis of Rectangular plate for stress relief

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ABSTRACT

Almost all structures consist of assembly of simple elements, which are connected to each other by joints. Joints are usually made in steel structures are mechanical fastening using bolts or rivets. In the mechanical fastening, holes are made to place the bolts or rivets; these make the structure weak and susceptible to failure. Plates and shells with different discontinuities of various sizes and shapes are also frequently used as load-bearing members of thin-walled structures in various areas of engineering. In analyzing the strength of those structural members, engineers should take into account the presence of stress concentrators and other factors. Therefore, it is necessary to investigate the state of stress in the fastening plate around the hole for the safety and proper design of such structures. It is very important to understand the behavior of the steel structure with holes or notches. For the solution of such problems several methodologies can be followed, however, all of these methods can be classified as experimental, analytical and numerical method. To understand the behavior of fastening plate, finite element methods are used. The finite element method is a numerical technique for obtaining approximate solution to a wide variety of engineering problems. Stress concentration in plate can be reduced by introducing auxiliary hole. Because of auxiliary hole the flow of the tensile stresses will get smooth and it results in a reduction in stress concentration factor. With such reduction in maximum stress levels, the improvement in fatigue life of a component can be significant.

Keyword: - *Fastening plate, Stress, Stress concentration factor, Auxiliary hole*

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1. Introduction

Plates and shells with different discontinuities of various sizes and shapes are frequently used as load-bearing members of thin-walled structures in various areas of engineering. In analyzing the strength of those structural members, engineers should take into account the presence of stress concentrators and other factors. Almost all structures consist of assembly of simple elements, which are connected to each other by joints. Joints or connections that are usually made in steel structures are mechanical fastening using bolts or rivets. In the mechanical fastening, holes are made to place the bolts or rivets; these make the structure weak and susceptible to failure. Therefore, it is necessary to investigate the state of stress around the holes for the safety and proper design of such structures. From the point of view of the above facts, it is of great importance to understand the behavior of the steel structures with holes/ notches. For the solution of the problem several methodologies can be followed, however, all of these methods can be classified in the following three general categories: experimental, analytical and numerical method. The experimental methods are very costly, as it requires special equipment's, testing facilities etc. Analytical solution of every problem is almost impossible because of complex boundary conditions and shapes. For this reason the numerical methods had become the ultimate choice by the researchers in the last few decades. Sophisticated high performance computers, also played an important role for the increasing popularity of the numerical methods. There are various numerical methods available which use partial differential equations. Among them most popular methods are: Finite Element Method (FEM) and Finite Difference Method (FDM). The finite element method is a numerical technique for obtaining approximate solution to a wide variety of engineering problems. Stress concentration can be reduced in plate by introducing auxiliary hole. The introduction of these holes helps to smooth flow of the tensile stresses passes through the main hole and it results in a reduction in stress concentration factor. With such reduction in maximum stress levels, the improvement in fatigue life of a component can be significant.

The strength of the structure is affected by any discontinuity in structure. The flow of stress is altered due to discontinuity. The concentration of stress forms near the discontinuity. These stress concentrations are of concern during both the preliminary and detail design of any structure. The particular interest of designers is the maximum value of the stress concentration factors K. The location and magnitude of this maximum will vary depending on a number of factors. These factors include the size of the discontinuity, the shape of the discontinuity, the number of discontinuity, the location of the discontinuity and the relative size of the discontinuity when compared with the structural member that it is in. It is desirable to apply techniques to reduce these factors as much as is practicable.

2. Literature Review

Nashwan T. Younis in his study determined a different issue of mechanical engineering interests for threaded fastened joints. A series of photo elastic experiments were performed to determine the maximum strains and the stress concentration factors (SCFs) for the holes in a tensile flat plate subjected to bolt-nut stresses. Pertinent strain distributions were examined to determine the roll of the torques on the bolts in minimizing the stress concentration. The experimental results indicate that SCF can decrease significantly with the increase of the bolt's pre-load.

Jain N.K. made a comprehensive plane stress finite element study for reduction of stress concentration factor (SCF) in a uni-axially loaded infinite width rectangular isotropic/orthotropic plate with central circular hole. The finite element formulation is carried out by the ANSYS package. With the help of his work, stress concentration can be reduced up to 24.4 % in an isotropic and 31 % in an orthotropic plate by introducing four coaxial auxiliary holes on either side of main hole. The study reveals that the introduction of these holes helps to smooth flow of the tensile stresses passes through the main hole and results, a reduction in stress concentration factor. With such reduction in maximum stress levels, the improvement in fatigue life of a component can be significant.

Khudhayer J. Jadee,A.R. Othman investigated the effect of the defence hole system (DHS) on the stress distribution around the bolt-hole in glass fibre reinforced polymer (GFRP) composite bolted joint using a finite element method. The analyses have been carried out on a double-lap composite bolted joint with various geometric parameters for two cases of without and with DHS. In analyses they have taken into account a 3D stress plane condition, in which the circumferential and radial stresses at the bearing region, shear-out and net tension regions of the bolt-hole have been determined. Their results have shown that the auxiliary hole contributed in reducing the stress concentration in the vicinity of the bolt-hole; this reduction related to the geometric parameters of the laminate (W/D and E/D) and the size and position of the auxiliary hole (DHD and DS). Optimum stress mitigation was obtained for the wide laminates (W/D >2) with the DHS of auxiliary hole diameter of DHD=0.625D at a distance of DS=2.5D from the bolt-hole, which obtained a maximum stress reduction of 18.6% than those of the counterparts without the DHS.

Shubhrata Nagpal, S.Sanyal, Nitin Jain studied many structural elements having holes and notches of different shapes made to fulfill the requirements. The presence of holes and notches in structural elements creates stress concentration, which eventually reduces the mechanical strength of the structure. In their work they made efforts to reduce this stress concentration effect. They obtained mitigation of maximum stress by area reduction method, which can be achieved by introducing relief holes around main hole or notch. However the size and place of these relief holes and relief notches depends on the geometry of the structural element and are required to be analyzed or experimented individually. An analytical form for determination of the location and size of relief holes will be very useful to mitigate the maximum stress. In their work they proposed a generalized analytical form for mitigation curve which can be used for similar type of discontinuity. FEA has been used to analyze and determine the optimum size and position of relief holes. The analysis is used to formulate the expression for mitigation curve. The use of these mitigation curves are carried out to generate the optimum results which are then validated through analysis and experiments carried out earlier.

C.G.Mekalke, M.V.Kavade, S.S.Deshpande analyzed a plate with a circular hole subjected to a uniform stress, the effect of an initial stretching of a rectangular plate with a cylindrical hole on the stress and displacement distributions around the hole, which are caused by the additional loading, was studied using the finite element method. It is assumed that the initial stresses are caused by the uniformly stretching forces acting on the 2 opposite ends. It is also assumed that the cylindrical hole contained by the thick plate is between these ends and goes in parallel with them. The aim of this paper is to analyze a plate with a circular hole subjected to a uniform stress and observe the Variation in the results obtained through various meshes. Thus we observe that a lot of variation in the results is obtained through various meshes. The FEA results are significantly affected by the meshing algorithm. The ruled mesh (Middle Ruled Mesh without Washer) which is symmetric offers a symmetric response in the plots whereas the other meshes don't offer that symmetry of solution to a desirable extent. Further scope of the work lies in investigating the mesh quality parameters impact on the results.

V. G. Ukadgaonker et al. introduced a general form of mapping function and an arbitrary biaxial loading condition into the boundary conditions. By introducing into the computer program the constants of mapping function, the arbitrary biaxial loading factor, the orientation angle and the complex parameters for the laminates, the stresses around the hole can be easily obtained. Failure strength is determined by using different failure criteria. The general solution provided in this paper is extremely useful to study the effects of various parameters i.e. the hole geometry, type of loading and laminate geometry on stress distribution. However the stress reduction technique is not given in the paper. The general solution given for finding stresses is useful for single holes of different geometry and shapes.

Zheng Yang, Chang Boo Kim, Chongdu Cho, Hyeon Gyu Beom investigated the elastic stress and strain fields of finite thickness plate containing a hole subjected to uniaxial tension by finite element method. The maximum stress and strain do not always occur in the mid plane of the plate. The location of maximum stress and strain concentration factor is different in thick plates. The influence of Poisson's ratio and plate thickness upon stress concentration factor, strain concentration factor and their relation is investigated using finite element method. The stress concentration factor is equal to the strain concentration factor only at the notch root of the plate surface. The stress and strain concentration factors at notch root of mid plane, maximum point and plate surface are the functions of thickness which depend on the Poisson's ratio of plate.

Table 1: Literature survey

S.No.	Author	Year	Discontinuity	Material	Loading	Analysis Techniques	Mitigation Techniques	Review
1	Nashwan T. Younis	2005	threaded fastened joints	Many aluminum specimens	Uniform Tension	Photo-elastic experiments	increase of the bolt's pre-load.	The results indicate that SCF can decrease significantly with the increase of the bolt's pre-load.
2	Jain N.K.	2011	Rectangular plate with central circular hole	Isotropic/ orthotropic	Uni-axially loaded	Finite Element Method	Co-axial auxiliary hole	the introduction of auxiliary holes helps to smooth flow of the tensile stresses passes through the main hole and results, a reduction in SCF
3	Khudhayer J. Jadee,A.R. Othman	2015	Bolted joint	glass fiber reinforced polymer	tensile loading	finite element method	Defence hole	Results showed that adding defence hole near

				(GFRP) composite				the bolt-hole has contributed in reducing the stresses in the vicinity of the bolt-hole.
4	Shubhrata Nagpal, S.Sanyal, Nitin Jain	2013	Rectangular plate with central circular hole	Isotropic/ orthotropic	in plane static loading	Finite Element Method	auxiliary holes	SCF for all stresses shows marked mitigation upon introduction of auxiliary holes.
5	C.G.Mekalke, M.V.Kavade, S.S.Deshpand e		Plate with central circular hole			Finite Element Method		
6	V.G. Ukadgaonker et al.	2002	Hole in symmetric laminates		arbitrary biaxial loading	computer program	Not given	The general solution provided in this paper is extremely useful to study the effects of various parameters.
7	Zheng Yang, Chang Boo Kim, Chongdu Cho, Hyeon Gyu Beom	2008	Plate with circular hole	Functionall y Graded Material	uniaxial tension	Finite Element Method		The stress and strain concentration factors at notch root of mid plane, maximum point and plate surface are the functions of thickness which depend on the Poisson's ratio of plate

Stress

An applied external force F causes inner forces in the carrying structure. Inner forces F' are shown by the blue lines spread throughout the structure. Inner forces are distributed differently in each part of the structure. To describe the inner forces in a section of the structure we use stress defined as the force divided by the cross-sectional area. Stress corresponds to the force acting on a unit of area (square millimeter, square inch, square meter, etc.). A smaller cross-sectional area creates a larger amount of stress under the same external force.

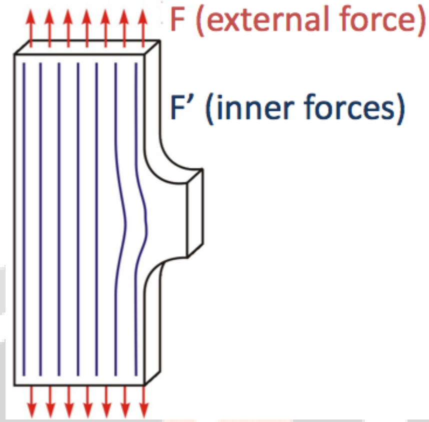

Fig.1. Stress

Strain

The shape of a structure will change under loading. For example, a structure will elongate under tension. To estimate this process the value of the strain was introduced. Strain is the ratio of elongation to initial length and is therefore dimensionless. It is also linearly proportional to stress.

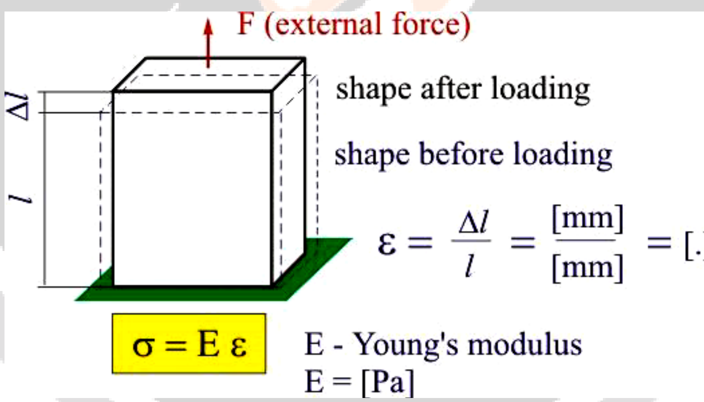

Fig.2. Strain

Concentrators

When inner forces go around holes or notches, they will concentrate near such "obstacles." Stress concentrators are areas that tend to magnify the stress level within a part. Stress that is higher in one area than it is in surrounding regions can cause the part to fail. If the radius of curvature in the notch tip is very small or if there is no radius (crack), the stress level is very high. Sharp corners are especially critical. Holes and slots, Notches or grooves, Ribs, gussets, and posts, Sharp wall thickness transitions, Surface roughness, Bosses, Corners etc can serve as stress concentrators.

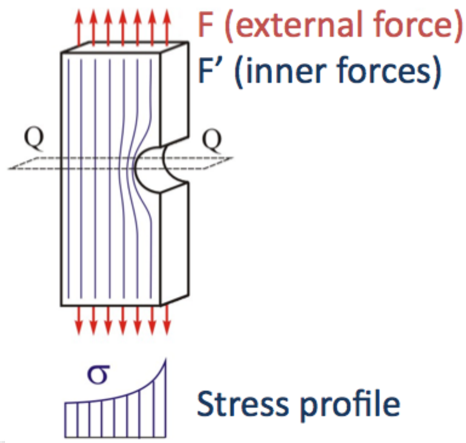

Fig.3. Concentrators

Stress Concentration Factor

Stress concentrators cause high stresses in the structure. The stress concentration factor is the ratio of maximum stress to nominal stress. It is greater than 1 and a dimensionless parameter. The authors of the theory of elasticity proved that tensile stress near a hole in a wide plate is three times higher than nominal stress. This means that the stress concentration factor is equal to 3 in this case. The stress concentration factor increases depending on: a) The larger size of the obstacle on force line path a b) The smaller size of the obstacle along force line path b c) The smaller radius of curvature in the notch tip.

Fracture Criteria

There are several types of fracture in a plate with a stress concentrator. If the plate material is brittle, the main mechanism of failure is cleavage, and new cracks will start perpendicular to the maximum tangential stress in the notch tip. For plastic material, a possible mechanism of failure is shear along the maximal tangential shear stress. Directions are not the same, as they depend on the loading scheme and geometry of the structure.

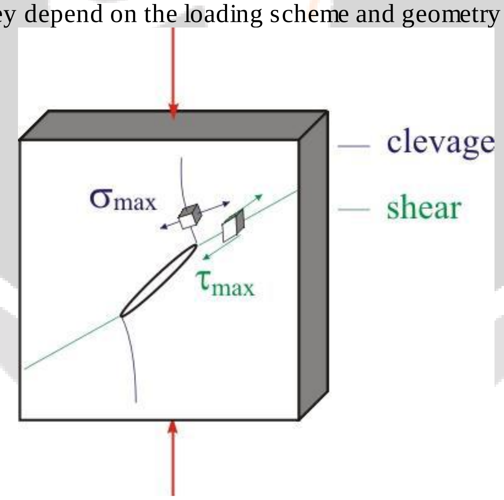

Fig.4. Stress Concentration

CONCLUSION

The sudden change in stress flow lines increases the stress to a significant level. With the gradual change in gradient of flow lines stress relief can be observed. The rise in the stress concentration factor reaches to its maximum value 3 at the periphery of central circular hole. The maximum SCF value can be reduced either by material removal at the vicinity or by shape optimization or by strengthening the hole by inclusion of additional stronger material. Material removal by inclusion of auxiliary holes will be beneficial if the distance between the holes and its diameter is optimum. The material removal method will be more feasible in infinite plates due to the availability of sufficient space around the central circular hole.

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