Finite Element Analysis of Perforated Steel Plate during Compression

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Abstract- Compression of the perforated plate is complicated due to the bending of the plate. Other complexity is of the slip of the plate on the UTM machine. It is very difficult to conduct experimental investigations to get the results. Hence FEM is the best tool to analyze such problems as long as it has been validated. In the present research work, results have been obtained for perforated plate with different perforation area, different length of plate, different shape of perforation area and with various loading ratio. In the present research work the data has been used through out, has been validated by prior researcher, who have worked on same type of plate of different loading ratio, different length and different shape of perforation area.

Keywords: - FEM, Ultimate Strength, Loading Ratio, Biaxial Loading, Perforation Area.

I. INTRODUCTION

Like other types of structures such as aerospace structures and land based structures, ships and offshore structures now tend to be designed based on ultimate strength instead of allowable working stress. Therefore, it is increasingly required to identify the ultimate strength characteristics of various types of structural components. Perforated plates are used in ships and ship-shaped offshore structures to make a way of access or to lighten the structure. Since these perforations may reduce the ultimate strength of the plate, it is necessary to investigate the effect of perforations on the ultimate strength of the plate. The introduction of openings in plated structures (e.g. ship grillages, stressed skins of airplane wings. etc.) for access and service results in changes in the stress distribution within the member and causes a reduction of strength. The performance of such a plate is influenced by the type of applied stress, as well as by the shape, location, size and number of holes.

II. GEOMETRY GENERATION & PROBLEM FORMULATION

Ultimate strength of a plate without openings is found to be maximum for an aspect ratio of a/b=3.0, 2.0 and 1.0. So a plate size of 2400x 800 mm, 1600 x 800 mm and 800 x 800 mm is considered for the study. The circular type and square type of cutouts are considered in this study. While an elliptical type of cutouts is also used for ships and ship-shaped offshore structures. Also, it is assumed that the cutout is located at the centre of the plate while it may be lean toward the plate edge in some cases. As shown in fig.3.1 the plate dimensions are a×b×t. The young modulus is E, the material yield stress is σY and the Poisson's ratio is υ. The diameter of the cutout is dc. It is assumed in the numerical computations that the plate material follows the elastic-perfectly plastic scheme, i.e. by neglecting the strain-hardening effect, check this in ANSYS.

A. Material of the Plate used –

The material which is used in this thesis is HT-9/2239. Alloy HT-9 is a Cr containing martensitic stainless steel, also known as 12Cr-1MoVW. It contains 12 weight percent of Cr. Cr provides significant resistance to atmospheric corrosion, while Mo enhances the resistance of this alloy to seawater corrosion. A small Ni content in this alloy offset the ferritizing effect of low carbon content. Alloy HT-9 has a body centered cubic (BCC) lattice structure. The circular type and square type of cutouts are considered in this study.

Material/ Heat no.	Element (wt %)											
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	W	Fe
HT-9/2239	0.20	0.40	0.011	0.003	0.19	12.50	0.53	0.99	0.01	0.29	0.46	0.029

Table1: Chemical Composition of Materials Tested (wt %)

B. Geometry of the Plate –

Ultimate strength of a plate without openings is found to be maximum for an aspect ratio of a/b=3.0, 2.0 and 1.0. So a plate size of 2400x 800 mm, 1600 x 800 mm and 800 x 800 mm is considered for the study. The thickness of the plate is fixed 15mm to obtain the slenderness ratio {$\beta = (b/t)\sqrt{\sigma y/E}$} in the practical range of 1.0 to 4.5 used in the ships construction. Circular and square type of openings is provided in the centre of the plate as shown in the figure 1 & 2. The diameter of the circular hole is varied as dc/b = 0.4, 0.3, 0.2, and 0.1. The value of b is same in the whole study. The area of square hole is same as the area of the circular hole. The details of the parametric study are given in Table 2. The yield strength of the plate (σY) is 798.33 MPa with Young's modulus of elasticity (E) 160 GPa as and Poisson's ratio (υ) of 0.33. All the edges of the plate are assumed to be simply supported. The unloaded edges are allowed to deform in plane but remains straight. This is achieved by coupling the deformation of nodes in that direction. The reaction edge is constrained to obtain an equal force caused due to loading edge.

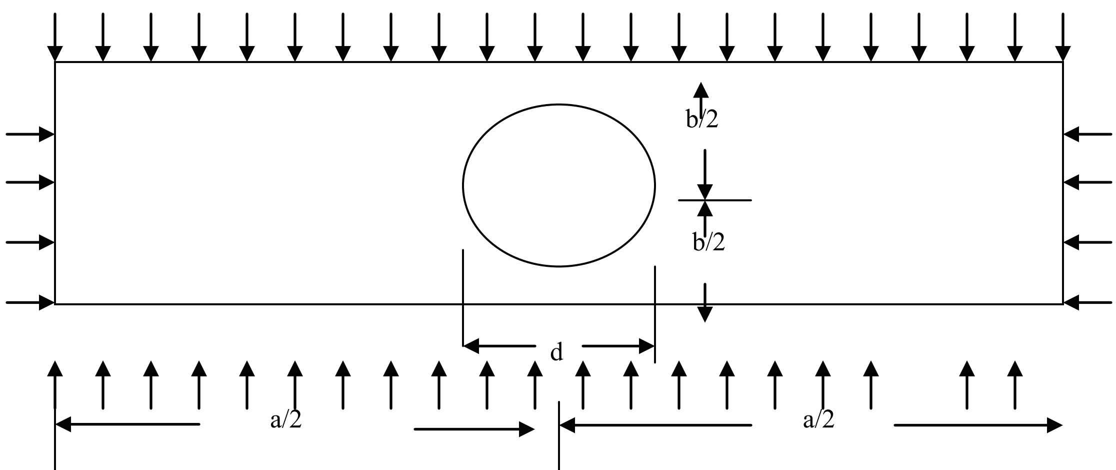

Figure 1: Perforated plates (circular hole) under biaxial compression

S.No.	Specimen	Length (mm)	Width (mm)	Thickness (mm)	d/b	Area of cutout (mm^2)	Shape of cutout (mm^2)
		2400	800	15	0.4	80384	circular
		2400	800	15	0.5	80384	square
		2400	800	15	0.3	45216	circular
		2400	800	15	0.38	45216	square
1	P1	2400	800	15	0.2	20096	circular

		2400	800	15	0.25	20096	square
		2400	800	15	0.1	5024	circular
		2400	800	15	0.125	5024	square
2	P2	1600	800	15	0.4	80384	circular
		1600	800	15	0.5	80384	square
3	P3	800	800	15	0.4	80384	circular
		800	800	15	0.5	80384	square

Table 2: Details of Parametric Study

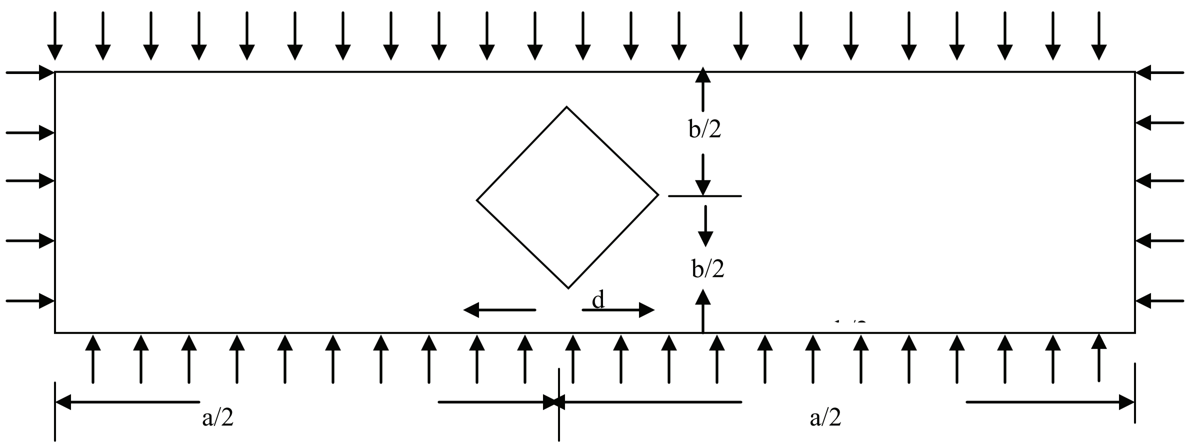

Figure 2.2 Perforated plates (square hole) under biaxial compression

III. FINITE ELEMENT ANALYSIS OF PERFORATED STEEL PLATE

A. Meshing of the Plate –

Meshing of the perforated plate is done as shown in the fig.3 for the circular hole opening and in the fig.4 for the square hole opening. The plate is divided in to the three areas. In the middle area of the perforated plate the meshing is very fine, because the main effect of the loading is on the perforation area. In the side area of the perforated plate the meshing is coarse as comparison to the middle area. So the meshing is finer in the effected area.

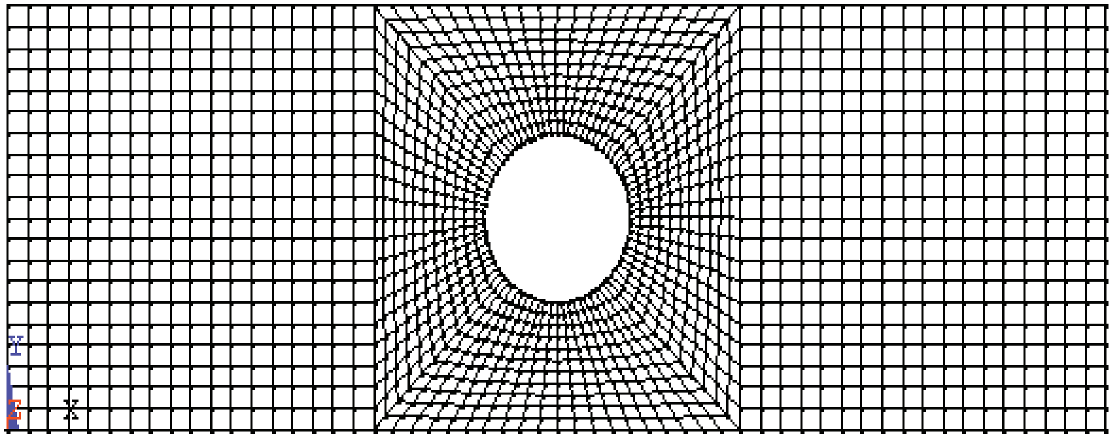

Fig.3: A sample of the FE mesh for a plate with a centrally located circular hole

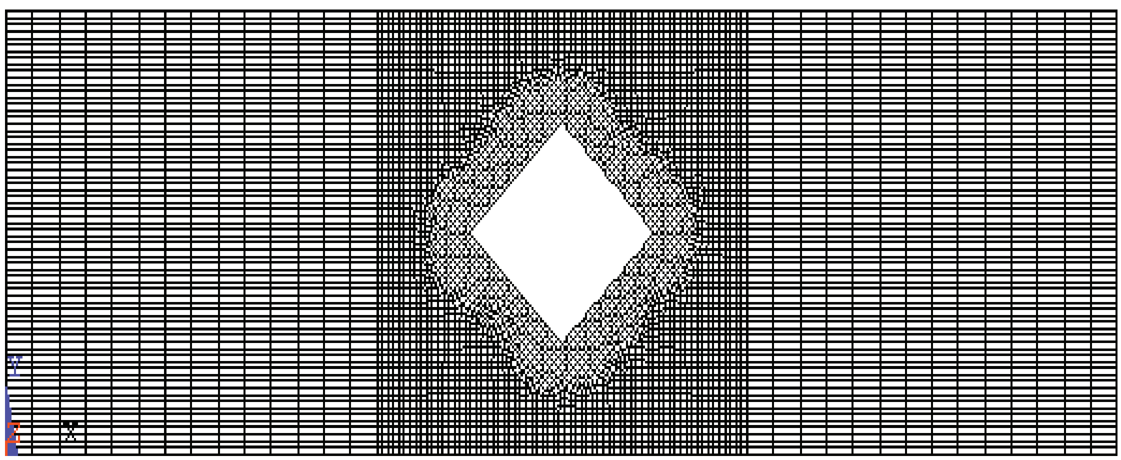

Fig.4: A sample of the FE mesh for a plate with a centrally located square hole

B. Validation of the Model – Validation of the developed FE model is done with the published results of Jeom Kee paik 2007.

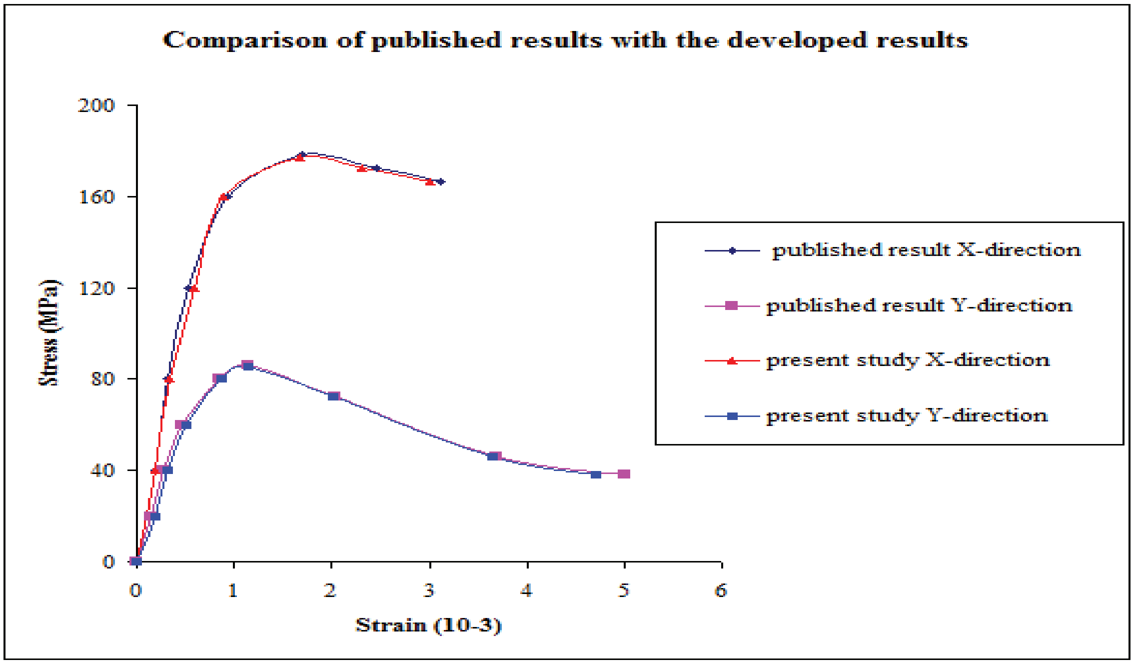

Figure5: Stress Strain diagram under biaxial compression of comparison between published

Result & ANSYS (present study)

Sr.No	Stress/Strain	Published result	Ansys (present Study)	% Error
1	σu_x	178.46	177	0.81
2	σu_y	86.15	85.5	0.75
3	εu_x	1.692306	1.678997	0.78
4	εu_y	1.153845	1.145687	0.70

Table 3: Comparison between published result & ANSYS (present study)

IV. RESULTS & DISCUSSION

Perforated plate has been analyzed by many researchers. During these researches, load has been applied like axial, biaxial, and shear. But no work so far has been done on perforated plate under biaxial compression with change in perforation area, change in length of plate and change the loading ratio in X & Y direction. The present research work is wholly concentrated on effect of variation in perforation area, length of plate, loading ratio to the ultimate strength of the perforated plate.

A. Effect of Change in Perforation Area on the Ultimate Strength of Plate –

As it is expected, the increase in perforation area results in reduced ultimate strength of the plate. It is due to increase in stress concentration at the edge of the perforation. In present work, the above effect has been analyzed in case of circular perforated geometry on 2400×800×15 mm plate for uniaxial compression (in both X and Y direction) and biaxial compression with various loading ratios (1:2 & 2:1).

B. Effect of Change in length on the Ultimate Strength of Plate –

As it is expected, the increase in length results in increased ultimate strength of the plate. It is due to decrease in stress concentration at the edge of the perforation. In present work, the above effect has been analyzed in case of circular and square perforation area on 2400×800×15 mm, 1600×800×15 mm and 800×800×15 plate for uniaxial compression (in both X and Y direction) and biaxial compression with various loading ratios.

C. Effect of Change in length on the Ultimate Strength of Plate –

The results show that, the plate with circular geometry has more ultimate strength than the plate with square geometry. It is due to increase in stress concentration at the sharp corner of the square hole. In present work, the above effect has been analyzed in case of circular and square perforated geometry on 2400×800×15 mm,1600×800×15 mm, 800×800×15 mm plate for uniaxial compression (in both X and Y direction) and biaxial compression with various loading ratios.

D. Effect of Change in length on the Ultimate Strength of Plate –

As it is expected, for the plate 2400 880 15 mm, the ultimate stress is decrease in X-direction for circular and square hole geometry, when load is applied biaxial for the loading ratio 1: 1 to 4:1 and 1:1 to 1:4. The ultimate stress is also decrease in Y-direction for circular and square hole geometry, when load is applied biaxial for the loading ratio 1:1 to 4:1. But when load is applied from 1:1 to 1:4 the stress is first increase and then decrease like X-direction. The same type of trend of result is found for the plate 1600 800 15mm.

E. Effect of Change in length on the Ultimate Strength of Plate –

Curve fitting of results have been performed to get an idea of variation- trend of the effects. It also helps us in getting an approximate idea of variation results of different geometric parameters at intermediate points. The curve fitting equation is made for d/b ratio (circular geometry in X & Y direction), length wise a/b ratio (circular and square geometry in X & Y direction) and for various loading ratio (circular and square geometry with different length of plates) which are listed below.

Abbreviation	Shape of hole	Load applied in	Geometry of plate	Range
α= d/b	Circular	X-direction	2400×800×15 mm	0.1 to 0.4
λ= d/b	Circular	Y-direction	2400×800×15 mm	0.1 to 0.4
γ= a/b	Circular	X-direction	2400×800×15 mm	3 to 1
φ= a/b,	Circular	Y-direction	2400×800×15 mm	3 to 1
ω=a/b	Square	X-direction	2400×800×15 mm	3 to 1
δ=a/b	Square	Y-direction	2400×800×15 mm	3 to 1
ζ=Lx/Ly	Circular	X-Y direction	2400×800×15 mm	1:4to 4:1
Ψ=Lx/Ly	Square	X-Y direction	2400×800×15 mm	1:4to 4:1
ξ=Lx/Ly	Circular	X-Y direction	1600×800×15 mm	1:4to 4:1
Є=Lx/Ly	Square	X-Y direction	1600×800×15 mm	1:4to 4:1

Φ=Lx/Ly	Circular	X-Y direction	800×800×15 mm	1:4to 4:1
ς =Lx/Ly	Square	X-Y direction	800×800×15 mm	1:4to 4:1

Table 4: Abbreviation –range table

Here, a= length of plate, b=width of plate, d= diameter of the perforated circle
Lx, Ly = loading in X and Y direction in biaxial compression.

A. Curve fitting equation of d/b ratio for the plate 2400×800×15 mm having circular geometry (loading in X-direction)

The curve fitting equation is

$$\sigma_{ux} = -500\alpha^2 -290\alpha +755$$

With the equation we can find the value of ultimate stress of the perforated (circular geometry) plate by putting the value of d/b =α, load is applied in the X-direction. By changing the value of 'α' one can gets the value of $\sigma_{ux.}$

B. Curve fitting equation of d/b ratio for the plate 2400×800×15 mm having circular geometry (loading in Y-direction)

The curve fitting equation is

$$\sigma_{uy} = 250\lambda^2-395\lambda+767.5$$

With the equation we can find the value of ultimate stress of the perforated (circular geometry) plate by putting the value of d/b =λ, load is applied in the Y-direction. By changing the value of 'λ' one can gets the value of $\sigma_{uy.}$

C. Curve fitting equation of a/b ratio for the plate having circular geometry (loading in X-direction)

The curve fitting equation is

$$\sigma_{ux} = -30\gamma^2+160\gamma+350$$

This equation is made to find the value of ultimate stress by putting the value of a/b =γ in the above equation. By changing the value of 'γ' one can gets the value of $\sigma_{ux.}$

D. Curve fitting equation of a/b ratio for the plate having circular geometry (loading in Y-direction)

The curve fitting equation is

$$\sigma_{uy}= -15\varphi2 +135\varphi+380$$

This equation is made to find the value of ultimate stress by putting the value of a/b = in the above equation. By changing the value of 'φ' one can gets the value of $\sigma_{uy.}$

E. Curve fitting equation of a/b ratio for the plate having square geometry (loading in X-direction)

The curve fitting equation is

$$\sigma_{ux} = -40\omega^2+205\omega+175$$

With the equation we can find the value of ultimate stress of the perforated (square geometry) plate by putting the value of a/b =ω, load is applied in the X-direction. By changing the value of 'ω' one can gets the value of $\sigma_{ux.}$

F. Curve fitting equation of a/b ratio for the plate having square geometry (loading in Y-direction)

The curve fitting equation is

$$\sigma_{uy} = -33\delta^2+177\delta+216$$

With the equation we can find the value of ultimate stress of the perforated (square geometry) plate by putting the value of a/b =δ, load is applied in the Y-direction. By changing the value of 'δ' one can gets the value of $\sigma_{uy.}$

G. Curve fitting equation of Lx/Ly ratio for the plate 2400×800×15 mm having circular geometry (loading in biaxial compression)

The curve fitting equation is

$$\sigma_{ux}= -85.192\zeta^2 +438.624\zeta +121.958$$
$$\sigma_{uy} = 21.892\zeta^2 -248.852\zeta +764.186$$

Equation helps to find value of ultimate stress of the perforated (circular geometry) plate when we apply biaxial loading. The two equations are made to find the value of ultimate stress in X and Y direction. By putting the value of loading ratio Lx/Ly=ζ in the above equation we can the find the results.

H. Curve fitting equation of Lx/Ly ratio for the plate 2400×800×15 mm having square geometry (loading in biaxial compression)

The curve fitting equation is

$$\sigma_{ux} = -73.871\psi^2 + 370.857\psi + 91.882$$

$$\boldsymbol{\sigma_{uy} = 0.86120\psi^2 - 118.876\psi + 542.283}$$

Equation helps to find value of ultimate stress of the perforated (square geometry) plate when we apply biaxial loading. The two equations are made to find the value of ultimate stress in X and Y direction. By putting the value of loading ratio Lx/Ly=ψ in the above equation we can the find the results.

I. Curve fitting equation of Lx/Ly ratio for the plate 1600×800×15 mm having circular geometry (loading in biaxial compression)

The curve fitting equation is

$$\sigma_{ux} = -80.566\xi^2 + 419.256\xi + 122.938$$

$$\sigma_{uy} = 20.638\xi^2 - 238.302\xi + 743.222$$

The equations are fit to find the value of ultimate stress when we apply the biaxial loading on the plate. By putting the value of various loading Lx/Ly=ξ ratio in the above equation on can gets the results.

J. Curve fitting equation of Lx/Ly ratio for the plate 1600×800×15 mm having square geometry (loading in biaxial compression)

The curve fitting equation is

$$\sigma_{ux} = -65.968\epsilon^2 + 341.432\epsilon + 87.254$$

$$\sigma_{uy} = 8.803\epsilon^2 - 150.172\epsilon + 548.015$$

The equations are fit to find the value of ultimate stress when we apply the biaxial loading on the plate. By putting the value of various loading Lx/Ly= Є ratio in the above equation on can gets the results.

K. Curve fitting equation of Lx/Ly ratio for the plate 800×800×15 mm having circular geometry (loading in biaxial compression)

The curve fitting equation is

$$\sigma_{ux} = -83.111\Phi^2 + 430.082\Phi + 96.008$$

$$\sigma_{uy} = 6.6008\Phi^2 - 161.106\Phi + 645.035$$

With the equation we can find the value of ultimate stress of the perforated (circular geometry) plate by putting the value of Lx/Ly =Φ, biaxial load is applied on the plate. By changing the value of 'Φ' one can gets the value σf $_{ux}$ and $\sigma_{uy.}$

L. Curve fitting equation of Lx/Ly ratio for the plate 800×800×15 mm having square geometry (loading in biaxial compression)

The curve fitting equation is

$$\sigma_{ux} = -65.867\varsigma^2 + 329.397\varsigma + 76.007$$

$$\sigma_{uy} = 2.436\varsigma^2 - 114.382\varsigma + 488.460$$

With the equation we can find the value of ultimate stress of the perforated (square geometry) plate by putting the value of Lx/Ly =ς, biaxial load is applied on the plate. By changing the value of 'ς' one can gets the value of σ_{ux} and $\sigma_{uy.}$

V. CONCLUSIONS

Compression of the perforated plate is complicated due to the bending of the plate. Other complexity is of the slip of the plate on the UTM machine. It is very difficult to conduct experimental investigations to get the results. Hence FEM is the best tool to analyze such problems as long as it has been validated.

In the present research work, results have been obtained for perforated plate with different perforation area, different length of plate, different shape of perforation area and with various loading ratio. In the present research work the data has been used through out, has been validated by prior researcher, who have worked on same type of plate of different loading ratio, different length and different shape of perforation area. From the present research work, following conclusion are drawn:

A. It is observed that due to change in the perforation area, the value of the ultimate stress of the plate effects. As the size of the perforation area decreases, value of the ultimate strength of the plate increases.
B. Size of the length of the plate affects the value of the ultimate stress of the plate. As the length of the perforated (circular and square) plate decreases, the value of ultimate stress decreases.
C. Similar trend of results are found in square geometry and other loading ratio.
D. It is observed that due to change in the shape of the perforation area, ultimate stress of the plate effects. As it is concluded that plate with square geometry have less ultimate strength than the plate having circular geometry.
E. Similar trend of results are found in other length of plates and loading ratio.
F. As it is expected, for the plate 2400 880 15 mm, the ultimate stress is decrease in X-direction for circular and square hole geometry, when load is applied biaxial for the loading ratio 1: 1 to 4:1 and 1:1 to 1:4. The ultimate stress is also decrease in Y-direction for circular and square hole geometry, when load is applied biaxial for the loading ratio 1:1 to 4:1. But when load is applied from 1:1 to 1:4 the stress is first increase and then decrease like X-direction. The same type of trend of result is found for the plate 1600 800 15mm.
G. Above results shows that ultimate strength of the plate 2400×800×15 mm in X-direction with circular geometry decreases 9.67 % when loading ratio is increases from 1:1 to 4:1 and decreases 73.87 % when loading ratio is decreases from 1:1 to 1:4 in and ultimate strength of the plate 2400×800×15 mm in Y-direction decreases 77.41 % when loading ratio is increases from 1:1 to 4:1 and first increases by 11.29 % when loading ratio is decreases from 1:1 to 1:2and then decreases 6.08 % when loading ratio is decreases from 1:2 to 1:4, when load is applied biaxial.
H. Similar trend of results are found for 1600×800×15 mm length of plates and square geometry. So to avoid repeatability results are not write here.

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