BUCKLING ANALYSIS OF PLATES WITH HOLES OF VARIOUS SHAPES

By

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ABSTRACT

In many structural components such as beams, columns or plates, failure develops not only from excessive stresses but also from buckling. The buckling behavior of plates subjected to in-plane loads is an important aspect in the preliminary design of any structural component. The knowledge of critical buckling loads, mode shapes is vital for reliable structural design. There is a necessity for providing the holes of various shapes in the plates for various purposes. In this paper, the buckling behavior of rectangular plates with holes of various shapes is investigated. The finite element modeling and buckling analysis of the plates has been carried out using ANSYS 14.5. Plates with three varieties of shapes of holes i.e., Triangular, Square and Rhombus have been studied. The plates are investigated for different positions of the holes (i.e. Center, Top) and for various a/b ratios ranging from 2 to 12 at an increment of 2 and for various b/t ratios ranging from 20 to 100 at an increment of 20. Finally, buckling loads of the plates with holes is compared wrt. shape of the hole, location of the hole and some useful conclusions are drawn.

Keywords: Buckling Analysis, Buckling Behavior, In-plane Load, a/b Ratio, b/t Ratio.

INTRODUCTION

The buckling characteristics of structures are often considered with less significance than the static and dynamic response. When structural engineers carry out finite element analysis of plates in most cases, they are primarily interested in stress at various points and displacements rather than buckling. However the buckling analysis of plate structures is of a sufficient practical important class of problems in literature. The knowledge of the buckling behavior of plate structures is vital for a sound design.

Buckling loads are the critical loads, where the structures become unstable. Each load has an associated Buckled mode shape. Methods of performing buckling analysis are primarily are of two types. (i.e. Eigen buckling analysis and Nonlinear buckling analysis). Eigen buckling analysis computes eigenvalues for a given system of loading and constraints. A nonlinear buckling analysis is carried out using the standard geometric nonlinear solver. In this method load is applied incrementally, from zero up towards the maximum.

1. Aim of the Study

- To determine the buckling loads for Plates with holes at different locations.
- To determine the buckling loads for Plates with holes of various shapes.

2. Objective of the Study

- To perform the buckling analysis of plates by changing the following parameters.
  - Position of holes (central, Top).
  - Shape of the hole (Triangular, Square, & Rhombus).

3. Literature Review

Hsuan-The Hu, and Jiing-Sen Yang (1999) studied the buckling resistance of fiber-reinforced laminated cylindrical panels with a given material system and subjected to uniaxial compressive force is maximized with respect to fiber orientations by using a sequential linear programming method.

Abdulkareem Al Humdany and Emad Q. Hussein (2012) studied the buckling behavior of antisymmetrically angle ply laminated composite plate under uniaxial compression using eigen value buckling analysis. It is found that, in design of an antisymmetric laminate; the thickness is not only the element which must be determined, to satisfy the constraints of the problem, but in addition, the number of layers in the laminate and their relative fiber orientation must also be considered.

Adnan Naji Jameel, and Kawther Khalid Younus, (2012) investigated the buckling behavior of composite laminated plates subjected to mechanical loads. Levy method of classical laminated plate theory and Finite element coded by ANSYS 13.0 is used to formulate the theoretical model. It was noted that inserting cutout doesn't always decrease the buckling loads.

T. Subramani, and Athulya Sugathan, (2012) found out the buckling strength of cylindrical and elliptical members. Both the members are created using ANSYS top down approach. The result shows reduction of nonlinear buckling loads compared to the elastic buckling loads.

Nagendra Singh Gaira, Nagendra Kumar Maurya, and Rakesh Kumar Yadav (2012) determined the buckling load factors for different aspect ratios, d/b ratio & d/D ratio. It is noted that the presence of cutout lowers the buckling load.

T. Susmitha, V. Rama Krishna Rao and S Mahesh Babu (2012) carried out the buckling analysis in FRP (fibre Reinforced Plastic) thin cylinder, which is subjected to uniaxial compression using 2-D finite element analysis.

M.M. Jadhav, and P.V. Gunjavate (2012) investigated about the optimum laminate which can sustain maximum critical buckling load. The homogenization method can be used to find optimum laminate.

Joshi .A, P. Ravinder Reddy, V.N. Krishnar Reddy, and V. Sushma (2013) determined the buckling load per unit length in rectangular plate with circular cut-outs under bi-axial compression using 2D finite element analysis. It was noted that, the buckling load/unit length decreases with increases of aspect ratio. As the b/t ratio increases, the buckling load decreases.

Sa'el Saleh Al-Jameel, and Rafi, K. Albazzaz (2014) carried out buckling analysis of multilayer composite plates consisting of Aluminum, Brass, and Steel with Unsaturated Polyester Resin (UPE) as a core material. Result shows that, the buckling load highly dependent on the type of composite material, and the buckling load increased by increasing elliptical hole orientation angle.

Rajappan, Magesh, and Gurunathan (2015) conducted the buckling experiments on uni-directional laminated composite plate specimens and the, length to thickness ratio, orientation and aspect ratio are examined and determined experimentally.

4. Methodology in ANSYS

1) Go to Preferences=>select structural.
2) Preprocessor=>ElementType=>Add/Edit=> select (Shell =>3D 4 node 181 from the list of the elements.
3) Material properties=>Material Models=> select Structural =>linear =>elastic=> orthotropic=> values of EX, EY, EZ, PRXY, PRYZ, PRXZ,GXY,GYZ and GXZ were given.
4) Sections=> Shell=> Lay-up=>Add/Edit=> Value of thickness is given.
5) Modeling=>Create=>Areas=>rectangle=>By dimensions=> Enter Coordinates=> o.k
6) Meshing =>Mesh Tool (smart size and the shape of the mesh were chosen and then the structure was meshed).
7) Go to File=> Change Job name => Buckling1.
8) Go to File=> Change Title => Buckling1.
9) Go to Solution =>Analysis Type => Static Analysis.
10) Solution => Analysis Type=> Analysis options => Pressure effects ON
11) Solution=> Define Loads => Apply=> Structural=> Displacement=> on Lines
12) Solution=> Define Loads =>Apply=> Structural=> Pressure=> on Lines.
13) Solve =>Current LS
14) Solution => Analysis Type=> New Analysis => Eigen buckling=> o.k
15) Solution=> Analysis Type=>Analysis options => select Mode Extraction Method as Block Lanczos=> Give no. of Modes to extract as 5=> o.k
16) Solution=> Load step opts.=>Expansion Pass=> Single expand => expand Modes=> Give no. of

Modes to Expand as 5=> o.k

17) Solve =>Current LS General Post processor=> Results Summary General Post processor=> Read Results=> Last set

18) General Post processor=> Plot Results=> Deformed Shape=> select Deformed +Undeformed => o.k

5. Modeling and Analysis

In this paper, Buckling analysis has been carried out for a rectangular plate, varying a/b ratio, b/t ratio and boundary conditions. Finite element modelling of the plates is carried out using the layered shell element. The buckling load factors are evaluated for a rectangular plate subjected to uniaxial compression are found using ANSYS 14.5. In this study, shell 3D 4 noded 181 elements are used for modeling. The plate has a length 'a', width 'b' & thickness 't'. The width of plate is taken as constant i.e. b = 1 m. The properties of the plate shown in Table 1.

5.1 Description of the Problem

Length of the Plate, a (in m) : 2,4,6,8,10,12

Width of the Plate, b (in m) : 1(constant)

a/b ratio : 2,4,6,8,10,12

b/t ratio : 20,40,60,80,100

Position of Holes : Centre, Top

Shapes of Holes : Triangle, Square & Rhombus

Side of the Square hole : 0.5m

Side of the Rhombus hole : 0.5m

Side of the Triangular hole : 0.5m

Load : 1 N/m^2

Type of analysis : Eigen buckling

Element chosen : 3D 4 Noded Shell element in ANSYS

Rectangular plates with three varieties of shapes of holes i.e. Triangular, Square and Rhombus have been investigated. i.e., plate with triangular hole, plate with square hole, and plate with rhombus hole. Each sub case has been investigated for two position of holes. (i.e. center, top) and for various a/b ratios from 2 to 12 at an increment of 2 and for various b/t ratios from 20 to 100 at an increment of 20.

Young's modulus (Mpa)	E_{11} = 139x10^3	E_{22} = 11x10^3	E_{33} = 11x10^3
Poisson's ratio	υ_{12} = 0.32	υ_{23} = 0.46	υ_{13} = 0.32
Rigidity modulus (Mpa)	G_{12} = 4.7x10^3	G_{23}= 3.7x10^3	G_{13} = 4.7x10^3

Table 1. Material Properties of the Plate

6. Results and Discussion

6.1 Plate with Triangular Hole at Centre

From Figure 13, it is observed that for a plate with a triangular hole at the centre (T-C) with a constant a/b ratio (i.e., 2), the buckling load decreased by 99.1%, as the b/t ratio increases from 20 to 100. Finite Element Model of

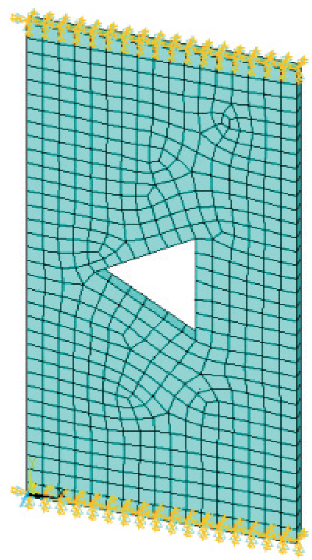

Figure 1. Finite Element Model of Plate with Triangular Hole at Centre

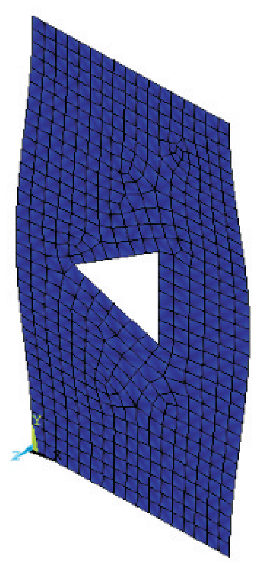

Figure 2. Fundamental Mode Shape of Plate with Triangular hole at Centre

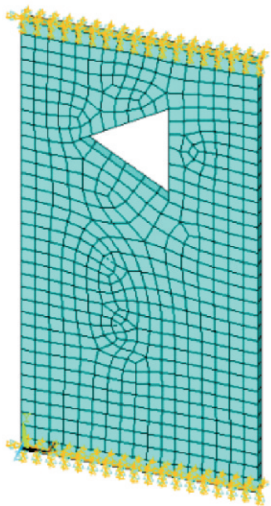

Figure 3. Finite Element Model of Plate with Triangular Hole at Top

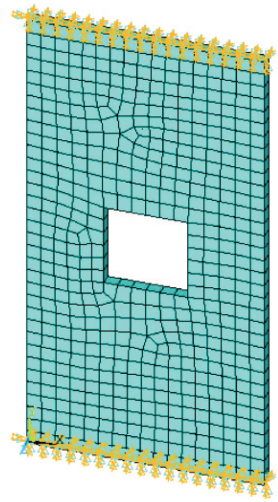

Figure 5. Finite Element Model of Plate with Square Hole at Centre

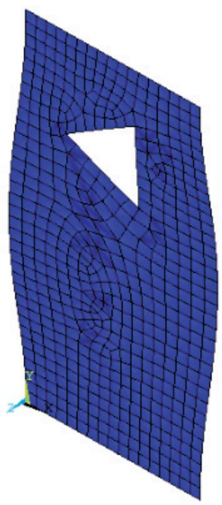

Figure 4. Fundamental Mode Shape of Plate with Triangular Hole at Top

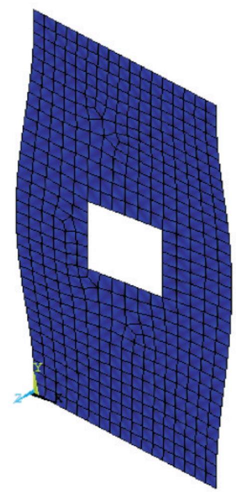

Figure 6. Fundamental mode shape of Plate with Square Hole at Centre

Plate with Triangular Hole at the Centre, Fundamental Mode Shape of Plate with Triangular Hole at Centre, Buckling loads of Plates with Triangular Hole at the Centre, are shown in Figures 1, 2 & 13 respectively.

It is observed that for a plate with a triangular hole at centre (T-C) with constant b/t ratio (i.e., 20), the buckling load decreased by 98.96%, as a/b ratio increases from 2 to 12.

6.2 Plate with Triangular Hole at Top

From Figure 14, it is observed that for a plate with a triangular hole at the top (T-T) with constant a/b ratio (i.e., 2), the buckling load decreased by 99.1%, as b/t ratio increases from 20 to 100. Finite Element Model of Plate with Triangular Hole at Top, Fundamental Mode Shape of Plate with Triangular hole at Top, Buckling loads of Plates with Triangular Hole at Top are shown in Figures 3, 4 & 14 respectively.

It is observed that for a plate with a triangular hole at the top (T-T) with a constant b/t ratio (i.e., 20), the buckling load decreased by 98.79%, as a/b ratio increases from 2 to 12.

6.3 Plate with Square Hole at Centre

From Figure 15, It is observed that for a plate with Square hole at centre (S-C) with constant a/b ratio (i.e., 2), the buckling load decreased by 99.1%, as the b/t ratio increases from 20 to 100. Finite Element Model of Plate with Square Hole at Centre, Fundamental Mode Shape of Plate with Square hole at Centre, Buckling loads of Plates with

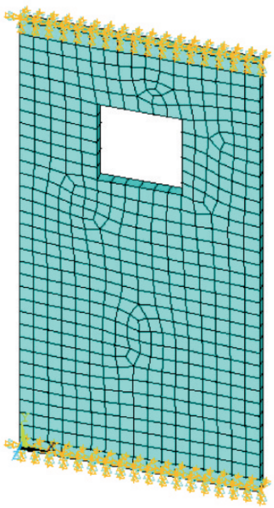

Figure 7. Finite Element Model of Plate with Square Hole at Top

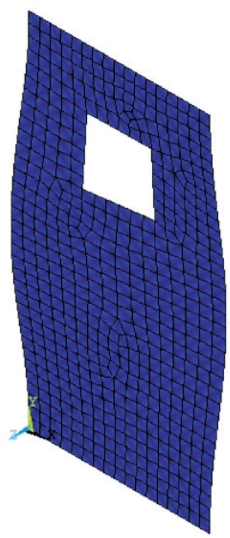

Figure 8. Fundamental Mode Shape of Plate with Square Hole at Top

Square Hole at Centre are shown in Figures 5, 6 & 15 respectively.

It is observed that for a plate with Square hole at the centre (S-C) with a constant b/t ratio (i.e., 20), the buckling load decreased by 98.89%, as a/b ratio increases from 2 to 12.

6.4 Plate with Square Hole at Top

From Figure 16, It is observed that for a plate with Square hole at the top (S-T) with a constant a/b ratio (i.e., 2), the buckling load decreased by 99.1%, as b/t ratio increases from 20 to 100. Finite Element Model of Plate with Square Hole at Top, Fundamental Mode Shape of Plate with Square Hole at Top, Buckling loads of Plates with Square

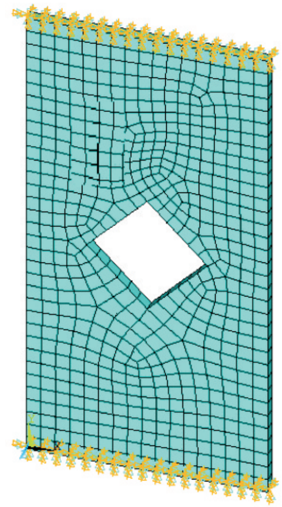

Figure 9. Finite Element Model of Plate with Rhombus Hole at Centre

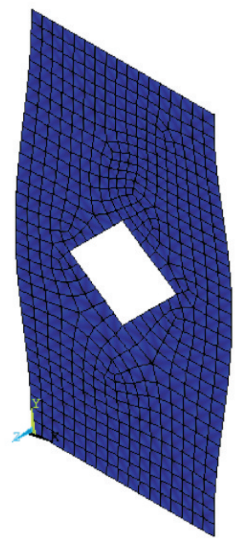

Figure 10. Fundamental Mode Shape of Plate with Rhombus Hole at Centre

Hole at Top are shown in Figures 7,8 & 16 respectively.

It is observed that for a plate with Square hole at the top (S-T) with a constant b/t ratio (i.e., 20), the buckling load decreased by 98.7%, as a/b ratio increases from 2 to 12.

6.5 Plate with Rhombus Hole at Centre

From Figure 17, It is observed that for a plate with Rhombus holes at the centre (R-C) with a constant a/b ratio (i.e., 2), the buckling load decreased by 99.14%, as the b/t ratio increases from 20 to 100. Finite Element Model of Plate with Rhombus Hole at the Centre, Fundamental Mode Shape of Plate with Rhombus hole at Centre, Buckling loads of Plates with Rhombus Hole at Centre are shown in Figures 9,10 & 17

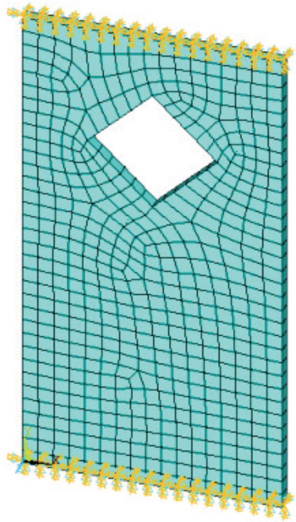

Figure 11. Finite Element Model of Plate with Rhombus Hole at Top

Figure 12. Fundamental Mode Shape of Plate with Rhombus Hole at Top

respectively.

It is observed that for a plate with Rhombus holes at centre (R-C) with a constant b/t ratio (i.e., 20), the buckling load decreased by 98.93%, as a/b ratio increases from 2 to 12.

6.6 Plate with Rhombus Hole at Top

From Figure 18, It is observed that for a plate with Rhombus hole at the top (R-T) with a constant a/b ratio (i.e., 2), the buckling load decreased by 99.12%, as b/t ratio increases from 20 to 100. Finite Element Model of Plate with Rhombus Hole at Top, Fundamental Mode Shape of Plate with Rhombus hole at Top, Buckling loads of Plates with Rhombus Hole at Top, are shown in Figures 11,12 &18 respectively.

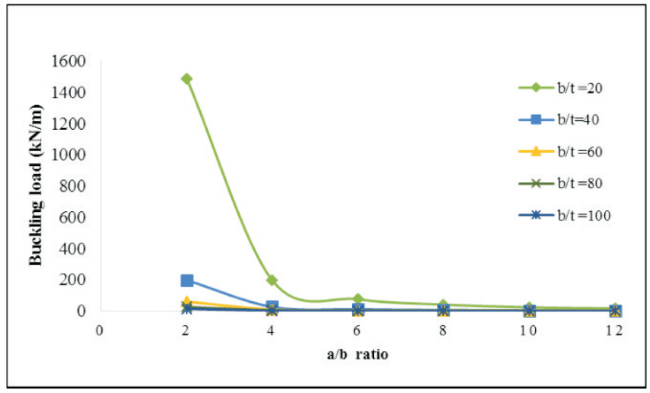

Figure 13. Buckling loads of Plates with Triangular Hole at Centre

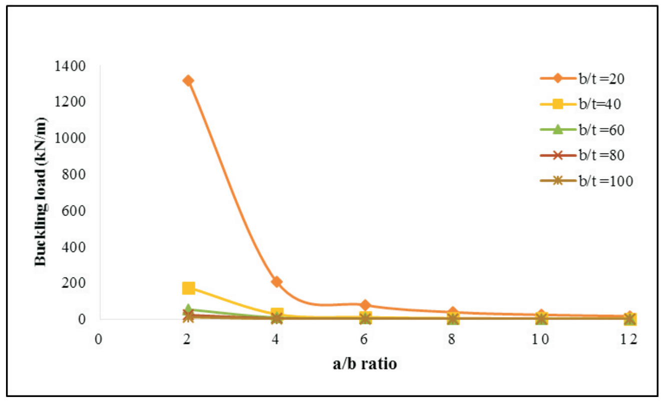

Figure 14. Buckling loads of Plates with Triangular Hole at Top

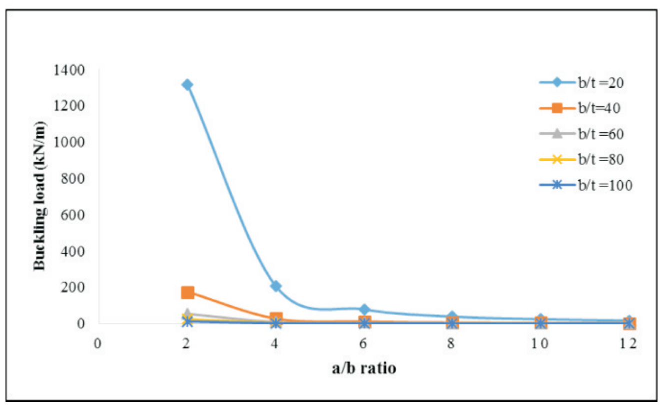

Figure 15. Buckling loads of Plates with Square Hole at Centre

respectively.

It is observed that for a plate with Rhombus hole at the top (R-T) with a constant b/t ratio (i.e., 20), the buckling load decreased by 98.83%, as a/b ratio increases from 2 to 12.

Buckling loads of Plates of various Shapes with Central hole are shown in Figure 19, Buckling loads of Plates of various Shapes with Top hole are shown in Figure 20, buckling loads of Plates with Triangular Hole at different positions is shown in

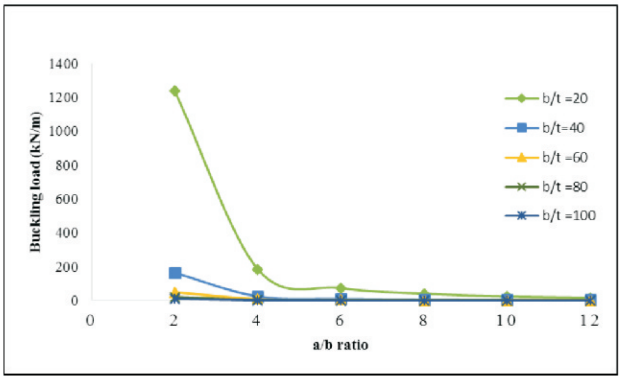

Figure 16. Buckling loads of Plates with Square Hole at Top

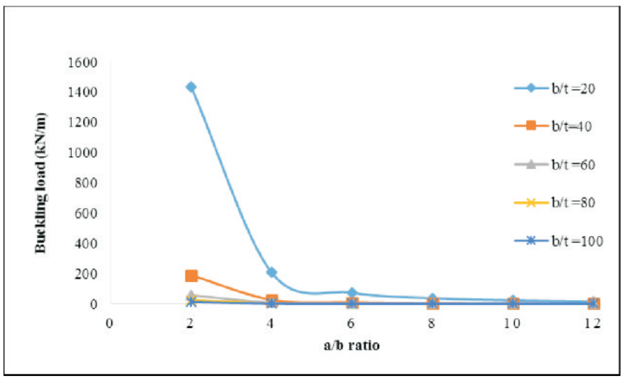

Figure 17. Buckling loads of Plates with Rhombus Hole at Centre

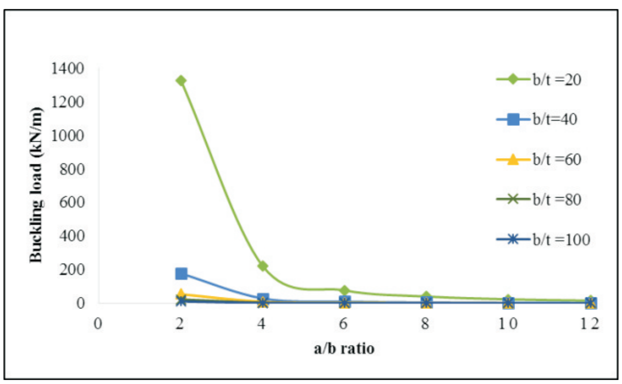

Figure 18. Buckling loads of Plates with Rhombus Hole at Top

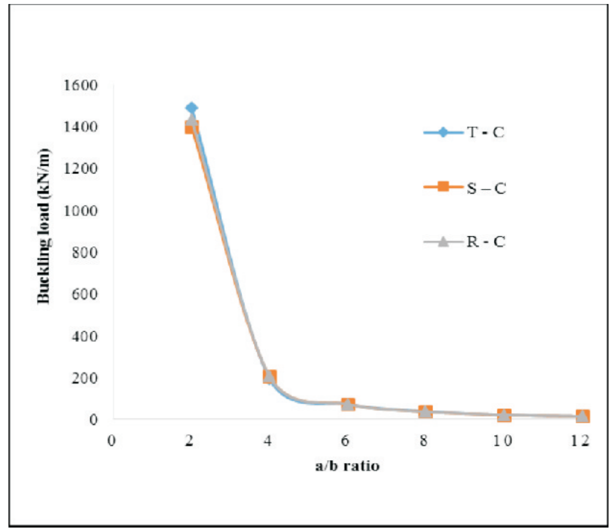

Figure 19. Buckling loads of Plates of various Shapes with Central Hole

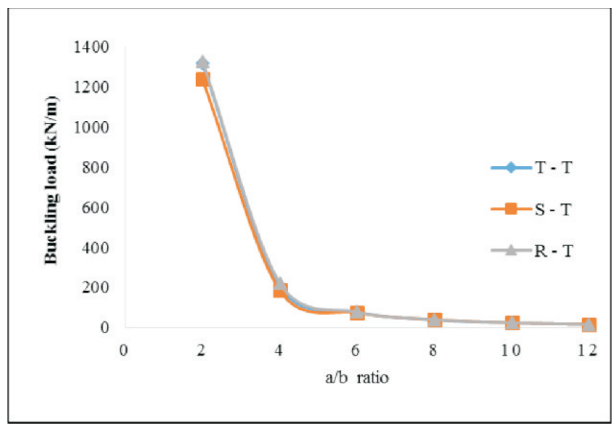

Figure 20. Buckling loads of Plates of various Shapes with Top Hole

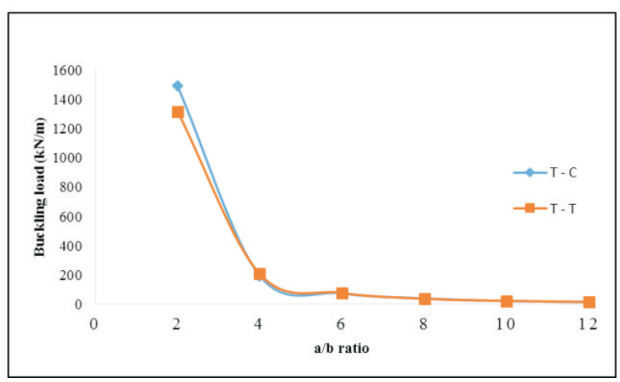

Figure 21. Buckling loads of Plates with Triangular Hole at different positions

Figure 21, buckling loads of Plates with Square Hole at different positions is shown in Figure 22, buckling loads of Plates with Rhombus Hole at different positions is shown in Figure 23.

Conclusions

- It is observed that the buckling load decreases due to the presence of hole in the plate. As the surface area decreases due to the presence of hole, the load required to buckle the plate and to deform becomes less
- The plate with Triangular hole at centre had more buckling load compared to the plate with Triangular hole at top.
- The plate with square hole at centre had more buckling

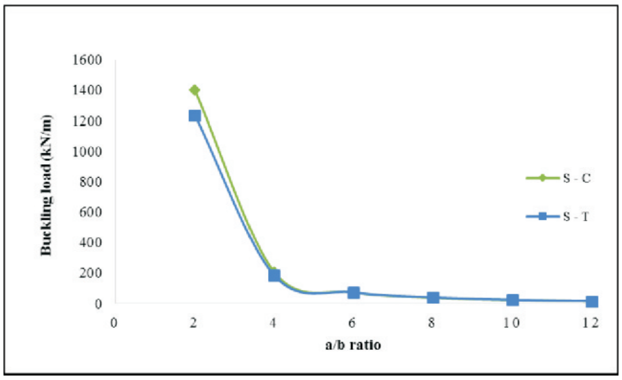

Figure 22. Buckling loads of Plates with Square Hole at different positions

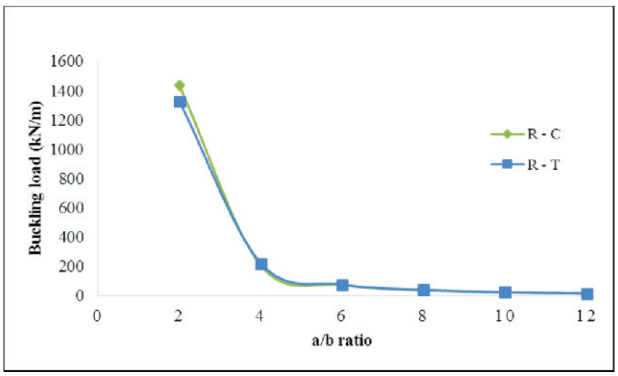

Figure 23. Buckling loads of Plates with Rhombus Hole at different positions

load compared to the plate with square hole at top.

- The plate with Rhombus hole at centre had more buckling load compared to the plate with Rhombus hole at top.
- Plate with triangualr hole at centre carries higher buckling load than plate with square and rhombus holes at centre.
- Plate with rhombus hole at top carries higher buckling load than plate with triangular and square holes at top.

Recommendations for the Study

The present research work can be further extended as given below.

- Buckling loads for plates having multiple cutouts may be studied.
- Buckling behavior of plates subjected to bi-axial compression may be studied for various shapes of cutouts and located at various places.
- The plates can be subjected to temperature variation and the variation of thermal stresses can be studied.
- Post buckling behavior of plates may also be investigated.
- Nonlinear analysis may be carried out to know the realistic behavior.

Nomenclature

E_{11} - Longitudinal Elasticity Modulus

E_{22} - Transverse Elasticity Modulus

E_{33} - Longitudinal Elasticity Modulus

υ_{12} - In-plane Poisson's ratio

υ_{23} - Transverse Poisson's ratio

υ_{31} - In-plane Poisson's ratio

G_{12} - In-plane Shear Modulus

G_{23} - Transverse Shear Modulus

G_{31} - In-plane Shear Modulus

T-C - Triangular hole at Centre

T-T - Triangular hole at Top

S-C - Square hole at Centre

S-T - Square hole at Top

R-C - Rhombus hole at Centre

R-T - Rhombus hole at Top

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