ISSN 2395-1621

Buckling failure analysis in rectangular plates using FEA software when both edges of plate are fixed

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ABSTRACT

This Research article Presents the study of buckling failure Analysis in rectangular plates. It gives information about the theoretical and simulation analysis of buckling in rectangular plates when both edges of plate are fixed. In this, the theoretical calculation of critical buckling load on the plates are given with the help of buckling formula which is given by the Euler's buckling theory & the analytical or simulation calculation is given with the help of Ansys R21.

Keywords— Buckling, Rectangular Plate, Critical Buckling load.

ARTICLE INFO

Article History

Received: 24nd May 2021

Received in revised form : 24nd May 2021

Accepted: 26th May 2021

Published online :

26th May 2021

I. INTRODUCTION

In structural engineering, buckling is the sudden change in shape (deformation) of a structural component under load, such as the bowing of a column under compression or the wrinkling of a plate under shear. If a structure is subjected to a gradually increasing load, when the load reaches a critical level, a member may suddenly change shape and the structure and component is said to have buckled.

Steel plates are widely used in buildings, bridges, automobiles and ships. Unlike beams and columns, which have lengths longer than the other two dimensions and so are modelled as linear members, steel plates have widths comparable to their lengths and so are modelled as two-dimensional plane members. Just as long slender columns undergo instability in the form of buckling, steel plates under membrane compression also tend to buckle out of their plane. The buckled shape depends on the loading and support conditions in both length and width directions. However, unlike columns, plates continue to carry loads even after buckling in a stable manner. [1]

This Project aims to design the rectangular plate and calculating the critical buckling load with the help of Eulers buckling theory.

This project also deals with the buckling failure analysis using the different load boundary conditions using Ansys R21.

Problem Statement

The Design & Analysis of rectangular buckling plate & calculation of the critical buckling load and stresses acting on the plate under different load boundary conditions

Objectives of Study

1) Design and selection of plate for the buckling process.
2) Theoretical Calculation of critical buckling loads and stresses acting on plate under different boundary conditions.
3) Simulation Analysis of the plate under different boundary condition using ANSYS R21 and validation of result with theoretical results.

II. LITERATURE SURVEY

1) Ahmed Hassan Ahmed Hassan, Naci Kurgan

In the research paper, they discussed about the modelling and buckling analysis of rectangular plate with the help of Ansys.

In the paper, this article investigates modelling and buckling analysis of rectangular plates in ANSYS® Mechanical APDL, Release 17.1, through a series of comparative studies conducted on various models and options. Shell and solid models of homogeneous and functionally graded plate (FGP) using various elements are investigated. Expressing boundary conditions on both shell and solid models of plate for buckling analysis is discussed. Procedures of buckling analysis in ANSYS are presented and effects of meshing, boundary conditions and element options are examined though comparative studies. Results obtained from ANSYS are compared to various analytical solutions.

The conclusion of the paper is that for various solid elements they give comparison between their critical values of loads and stresses with the help of Ansys. Meshing plays an important role in obtaining accurate results. Just enough number of elements is needed; much more elements lead to slower analysis with no significant gain in accuracy, while very low number of elements leads to wrong solutions. Because of the wide range of element types and options in ANSYS, having this comparative study facilitates using the software more efficiently in performing buckling analyses on rectangular plates. [1]

2) Saumit Kumar Mandal, Pradeep Kumar Mishra

This paper tells us about the buckling analysis of substance which is made up of homogenous as well as heterogeneous materials.

This paper summarizes the numerical study carried out using finite element software ANSYS and Timoshenko’s methodology to examine the buckling behaviour of homogeneous and heterogeneous rectangular plate element with and without hole. Also the effect of aspect ratio on the buckling behaviour with varying plate thickness for different material and different boundary conditions was also examined. The results shows that buckling load per unit length is in simply-supported boundary conditions and the laminated composite plates have varying aspect ratio, varying thickness (t), cut out edge, centre of hole and without cut plate.

The conclusion of this paper is that this study considers the critical buckling load response of homogeneous and laminated heterogeneous rectangular with simply supported boundary conditions. The laminated composite plates have varying aspect ratio, varying thickness t ratio, cut out edge, centre of hole and without cut plate are considered.

From the present analysis, the following conclusions are made:

- It was noted that the buckling load/unit length decreases with increases of aspect ratio (a/b).
- As the b/t ratio increases the buckling load decreases.
- The critical buckling load is increases with the different materials in plate thickness 3mm.
- The critical buckling load for homogeneous plate is more compare to laminated heterogeneous plate. [1]

III. BUCKLING OF PLATES

The classical buckling analysis of plates is best explained on an example of a rectangular plate subjected to compressive loading in one direction.

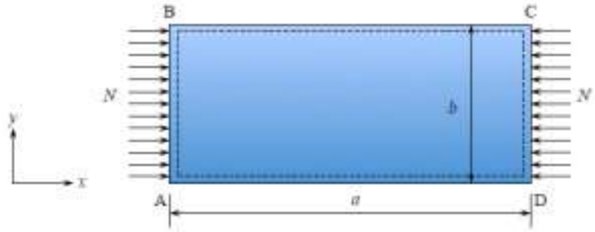

Figure 1 Rectangular Plate with compressive loading

The plate is simply supported along all four edges. The edges AB and CD are called the loaded edges because in-plane loading N is applied to these edges. The other two edges AD and BC are called the unloaded edges.

The simply supported boundary conditions apply to vanishing of transverse defections and the normal bending moments.

w = 0 on ABCD   Mn = 0 on ABCD

Separate boundary condition must be formulated in the in-plane direction in the normal and tangential direction

For a rectangular plate, supported along every edge, loaded with a uniform compressive force per unit length, the derived governing equation can be stated by

D {δ^4ω/δx^4 + 2 δ^4ω/δx^2*δy^2 + δ^4/δy^4}+N δ^2ω/δx^2 = 0

The solution of the above linear partial deferential equation with constant coincident is sought as a product of two harmonic functions

ω (x, y) = sin mπx/a * sin nπy/b

Where m and n are number of half waves in the longitudinal and transverse directions, respectively. The function w(x; y) satisfies the boundary condition for displacement.

The deferential equation is satisfied for all values of (x; y) if the coefficients satisfy

N = D*(π*a/m) ^2 * {(m/a) ^2 + (n/a) ^2} ^2

It is seen that the smallest value of N for all values of a, b and m is obtained if n = 1. This means that only one half waves will be formed in the direction perpendicular to the load application finally the simple form of equation of critical buckling load is as follows

Nc = Kc *π^2*D/b^2

Where the buckling coefficients kc is a function of both the plate aspect ratio a / b and the wavelength parameter.

Kc = (m*b/a + a/m*b) ^2

The parameter m is an integer and determines how many half waves will fit into the length of the plate. Its Value must be found by inspection, i.e., by plotting the buckling coefficient as a function of a=b for subsequent values of the parameter m. [1]

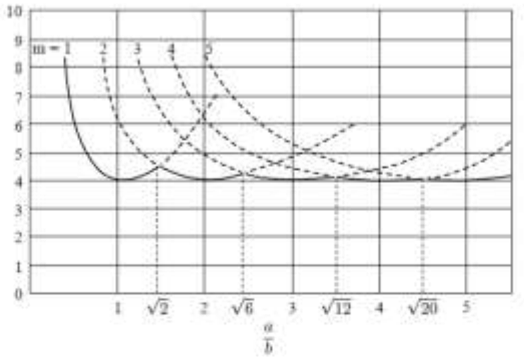

Figure 2 Buckling coefficient chart

Values of Buckling Coefficient Kc for different load – boundary conditions –

Load Condition	Support Condition	Kc Value
Compressive load	Hinged-Hinged	4.00
Compressive load	Fixed – Fixed	6.97
Compressive load	Hinged – Free	1.27
Compressive load	Fixed – Free	0.43

The D value is known as Elastic bending stiffness of plate the formula to find D is as follows

D = E* t^3 /12 (1 -μ^2)

Where D = elastic bending stiffness
t = thickness of plate
E = Young's Modulus
μ = Poisson's ratio. [1]

IV. THEORATICAL CALCULATIONS

Design of plate –

For this project, we selected the rectangular plates of 2 different dimensions with their different thickness sizes.

1) Rectangular plate-1 –

Length of plate (L) = 150 mm = 0.15 m
Breath of plate (B) = 75mm = 0.075 m
Thickness of plate (t) = 5mm, 8mm, 10mm, 12mm.
= 0.005m, 0.008m, 0.010m, 0.012m

2) Rectangular plate -2 –

Length of plate (L) = 200 mm = 0.2 m
Breath of plate (B) = 100mm = 0.1 m
Thickness of plate (t) = 5mm, 8mm, 10mm, 12mm.
= 0.005m, 0.008m, 0.010m, 0.012m

Selection of material –

For this project, we taken the plate of structural steel .the properties of structural steel are as follows

Properties of structural steel –

1) Density = 7850 kg/m^3
2) Young's Modulus = 210000 MPa = 2.1*10^11 N/m^2
3) Poisson's ratio = 0.30

Boundary Conditions used –

Both Edges of Rectangular Plate are fixed.

Critical Buckling Load Calculation –

Both Edges of Rectangular Plate are fixed – (Kc = 6.97)

Therefore,
For Rectangular plate-1 –
Length of plate (L) = 150 mm = 0.15 m
Breath of plate (B) = 75mm = 0.075 m
Thickness (t) = 5mm =0.005m

Elastic bending stiffness (D) =

D = E* t^3 /12 (1 -μ^2)

= 2.1*10^11*(0.005) ^3 / 12*(1- 0.30^2)

= 26250 /10.92

= 2403.846

Critical buckling load – (Nc)

Nc = Kc *π^2*D/b^2

Nc = 6.97*π^2* 2403.846 /(0.075)^2

Nc = 293979.2234 N/m.

Similarly for Thickness 8mm, 10mm, 12 mm –

The critical buckling load value –

Sr. No.	Thickness (mm)	Critical buckling load (N/m)
1	5 (0.005m)	293979.2234
2	8(0.008m)	1204138.8730
3	10(0.010m)	2351833.9094
4	12(0.012m)	4063969.0163

For Rectangular plate -2 –

Length of plate (L) = 200 mm = 0.2 m
Breath of plate (B) = 100mm = 0.1 m
Thickness (t) = 5mm =0.005m

Elastic bending stiffness (D) =

D = E* t^3 /12 (1 -μ^2)

= 2.1*10^11*(0.005) ^3 / 12*(1- 0.30^2)

= 26250 /10.92

= 2403.846

Critical buckling load – (Nc)

$N_c = K_c * \pi^2 * D/b^2$

$N_c = 6.97*\pi^2* 2403.846 /(0.1)^2$

Nc = 165363.3267 N/m

Similarly for Thickness 8mm, 10mm, 12 mm –

The critical buckling load value –

Sr. No	Thickness (mm)	Critical buckling load (N/m)
1	5 (0.005m)	165363.3267
2	8(0.008m)	677328.174
3	10 (0.010m)	1322906.574
4	12 (0.012m)	2285982.587

V. FEA ANALYSIS

CAD Model –

Plate 1-

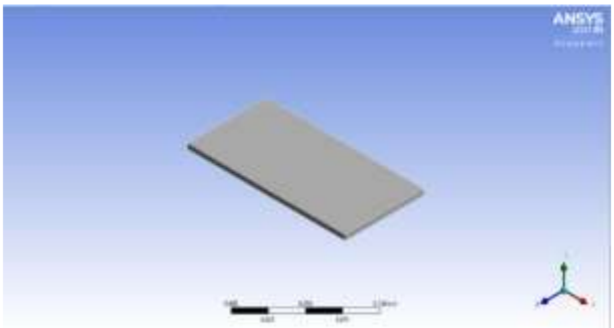

Figure 3 Rectangular plate 1 (150mm*75mm*5mm)

Plate 2 –

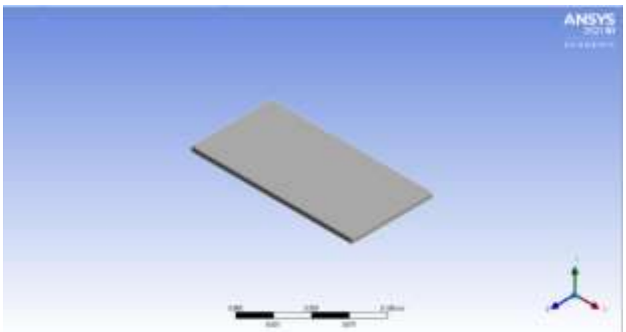

Figure 4 Rectangular plate 2 (200mm*100mm*5mm)

Meshed CAD Model –

Plate 1-

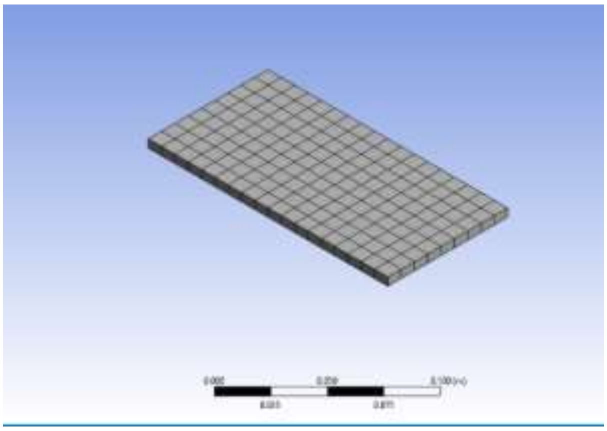

Figure 5 Meshed Rectangular plate 1

Plate 2 –

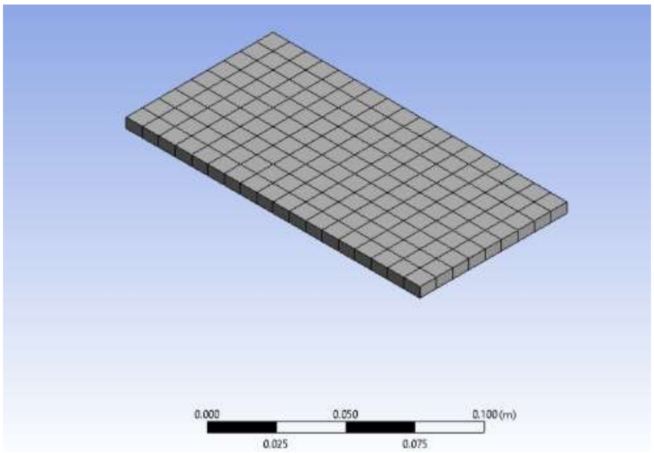

Figure 6 Meshed Rectangular Plate 2

Load – Boundary Conditions –

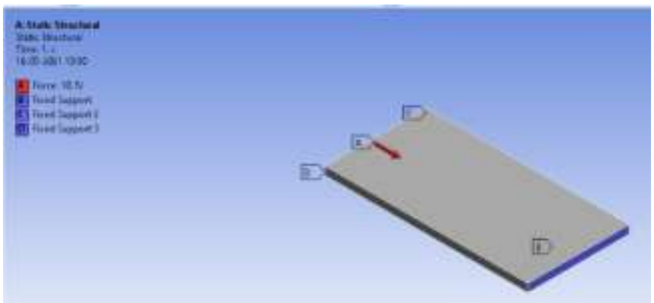

Figure 7 Rectangular plate with both edges of plate are fixed

Results –

Plate 1-

1) for mode 1 -

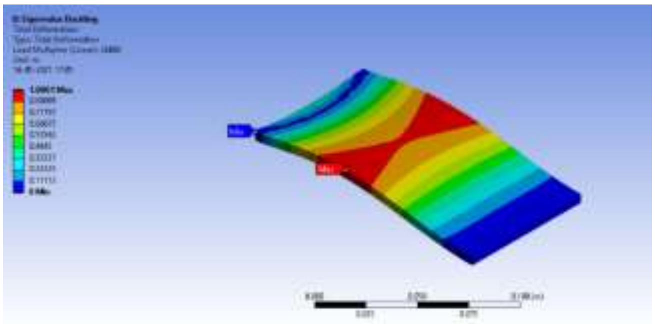

Figure 8 first buckling mode of plate 1

2) for mode 2 –

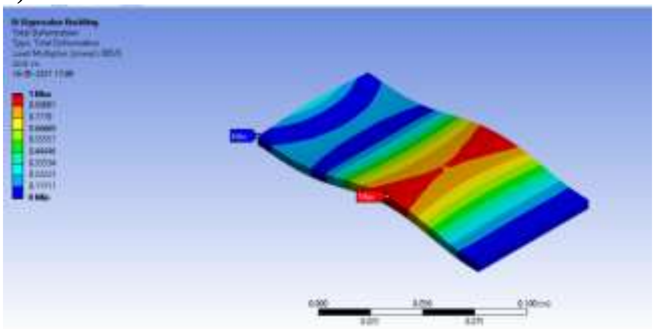

Figure 9 Second buckling mode of plate 1

Plate 2-

1) For mode 1-

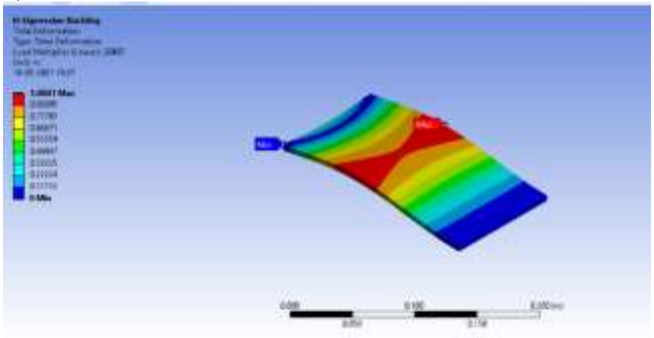

Figure 10 First buckling mode of plate 2

2) For mode 2 –

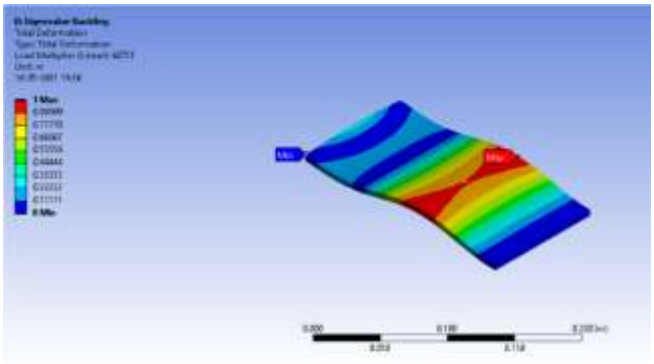

Figure 11 Second buckling mode of plate 2

VI. VALIDATION OF RESULTS

Sr. No	a mm	b (mm)	t (mm)	a/b	b/t	Tho. load (*10^6 N/m)	Ansys load (*10^6 N/m)	Diff.
1	150	75	5	2	15	0.293	0.266	0.027
2	150	75	8	2	9.3	1.204	1.045	0.159
3	150	75	10	2	7.5	2.351	1.983	0.36
4	150	75	12	2	6.2	4.063	3.362	0.701
5	200	100	5	2	20	0.165	0.204	0.039
6	200	100	8	2	12.5	0.677	0.804	0.127
7	200	100	10	2	10	1.322	1.540	0.218
8	200	100	12	2	8.3	2.285	2.596	0.311

VII. CONCLUSION

Based on the theoretical Calculation & FEA analysis given through the Ansys R21, It is concluded that

1) As the thickness of rectangular plate increases, the critical buckling load also increases.
2) As the b/t ratio of the rectangular plate decreases, the critical buckling load increases.
3) There is slight difference in the theoretical and Ansys values of critical buckling loads from this the buckling of plate's takes place.

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