International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 02 Feb. 2025, pp: 484-490 www.ijaem.net ISSN: 2395-5252

Stability Analysis of a Structural Element (Plate), Subjected to External Load.

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Date of Submission: 05-02-2025 Date of Acceptance: 15-02-2025

ABSTRACT: A plate of Clamped Clamped Fixed Fixed orientationt, whose vertical axis rest on clamped and fixed supported edges while the horizontal axis rests on also clamped and fixed boundaries, forming a plate of CCFF shape orientation, remains the plate of focus in the work. Third order energy Functional was adopted in the research work. The clamped clamped fixed fixed plate was considered as the direct independent plate, meaning that the material properties are uniform round about the shape of the element. These includes the flexural rigidity, poison ratio and young elastic modulus of elasticity. Considering the plate arrangement, the shape functions were first formulated, after which the various integral values of the differentiated shape functions, of the various boundary conditions were all generated. Next to this was the formulation of the stiffness coefficients for the various boundary cases. Further minimization yielded the controlling functional known as the overall potential energy functional. The differential value of the Third Order Overall Potential Energy Functional, with respect to the amplitude was further integrated. The integration gave rise to the result known as the Lead equation. From the lead equation comes the derivation of the non-dimensional buckling load parameters. The rest of the analysis which is detailed below was conducted using the buckling equation

Key words: Buckling load Equation, L-Equation, V-Buckling load, Third order Functional.

I. INTRODUCTION:

Plate elements are mostly used as engineering materials. Due to their importance and wide application, several researches have been conducted with the target of maximizing their high values for wider structural applications. They can be either straight or curved. They known for having three dimensions called the primary, secondary and tertiary dimensions. The plate thickness is usually referred to as the tertiary dimension. They are smaller than the rest of the plate dimensions. The isotropic rectangular CCFF plate have all their material properties in all directions as the same and so they are classified as direction independent element. The subject has been a subject of study in solid structural mechanics for a long time now. Although the buckling analysis of rectangular plates has received the attention of many researchers for several centuries prior to this time, other researchers have gotten solution using even order energy functional for Buckling of plate and so the analysis of the buckling activities of CLAMPED CLAMPED FIXED FIXED isotropic plate using odd order energy functional is the gap the work tends to fill.

The Overall Energy: The overall potential energy, O_v was first formulated by the summation of External Work E_w and Strain energy, Є. The strain energy, is gotten from the product of normal stress and normal strain,
both in the x components as

$$§_i ð_i = \frac{Ez^2}{1-\mu^2}\left(\left[\frac{\partial^2 fu}{\partial x^2}\right]^2 + \mu\left[\frac{\partial^2 fu}{\partial x\,\partial y}\right]^2\right) \qquad 1$$

while also in vertical axis as shown in the Equation iii

$$§_j ð_j = \frac{Ez^2}{1-\mu^2}\left(\left[\frac{\partial^2 fu}{\partial y^2}\right]^2 + \mu\left[\frac{\partial^2 fu}{\partial x\,\partial y}\right]^2\right) \qquad 2$$

Considering the parallel effect of the stress and strain on the plate surface, gives the product of the in-plane shear stress and in-plane shear strain as

$$\tau_{ij}\gamma_{ij} = 2\,\frac{Ez^2(1-\mu)}{(1-\mu^2)}\left[\frac{\partial^2 fu}{\partial x\,\partial y}\right]^2 \qquad 3$$

Bringing Equations ii, iii and iv together gives

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Volume 7, Issue 02 Feb. 2025, pp: 484-490 www.ijaem.net ISSN: 2395-5252

$$§_i ð_i + §_j ð_j + \tau_{ij}\gamma_{ij} = \frac{Ez^2}{1-\mu^2}\left(\left[\frac{\partial^2 fu}{\partial x^2}\right]^2 + 2\left[\frac{\partial^2 fu}{\partial x\,\partial y}\right]^2 + \right.$$
∂2fu∂y22 4

where $$\bar{\epsilon} = \frac{Ez^2}{1-\mu^2}\int\left(\left[\frac{\partial^2 fu}{\partial x^2}\right]^2 + 2\left[\frac{\partial^2 fu}{\partial x\,\partial y}\right]^2 + \right.$$
∂2fu∂y22 5

Further rearrangement of Equation vii, gives the third order strain energy equation

as $$\epsilon = \frac{G}{2}\int_0^n\int_0^m\left(\frac{\partial^3 fu}{\partial x^3}.\frac{\partial fu}{\partial x} + 2\frac{\partial^3 fu}{\partial x\,\partial y^2}.\frac{\partial fu}{\partial x} + \right.$$
∂3fu∂y3.∂fu∂ydxdy
6

with the external load as $$v = -\frac{bkl_x}{2}\int_0^n\int_0^m\left(\frac{\partial fu}{\partial x}\right)^2 dxdy$$
7

The third order total potential energy functional is expressed mathematically as

O_v=
$$\frac{G}{2}\int\int\left(\frac{\partial^3 fu}{\partial x^3}.\frac{\partial fu}{\partial x} + 2\frac{\partial^3 fu}{\partial x^2\,\partial y}.\frac{\partial fu}{\partial y} + \frac{\partial^3 fu}{\partial y^3}.\frac{\partial fu}{\partial y}\right)dxdy - \frac{bkl_x}{2}\int\int\frac{\partial^2 fu}{\partial x^2}dxdy \qquad x$$

Rearranging the total potential energy equation in terms of non-dimensional
parameters I, J the buckling load equation is gotten as

$$bkl_t = \frac{G}{a^2}\int_0^1\int_0^1.\left(\left[\frac{\partial^3 fu}{\partial J^3}\right].\frac{\partial fu}{\partial J} + 2\frac{1}{p^2}\left[\frac{\partial^3 fu}{\partial J\,\partial I^2}\right].\frac{\partial fu}{\partial J} + \frac{1}{p^4}\left[\frac{\partial^3 fu}{\partial I^3}\right].\frac{\partial fu}{\partial I}\right)dJdI \qquad xi$$

$$bkl_b = \int_0^1\int_0^1\left(\frac{\partial fu}{\partial J}\right)^2 dJdI$$

$$bkl_x = \frac{bkl_t}{bkl_b}$$

Boundary conditions: Two boundary cases were treated, in the derivation of the shape functions and they namely Clamped edge which was denoted as C and Fixed edge which is denoted as F. For the Clamped edge situation, the equation of deflection fw and the 2nd order derivative of the same equation fw ^{2}, were equated to zero and simultaneous equations were formed by considering I=0 at the left hand edge in the case of the horizontal axis and I = 1 at the right side of the same component. Also considering the top as J = 0 and J = 1 at the bottom support for the vertical direction. These equations were solved simultaneously to obtain the various values of the primary and secondary dimensions (n_1, m_1, n_2, m_2 n_3, m_3, n_4 and m_4) for the CCFF plate element. Where I and J are non-dimensional parameters parallel to horizontal and vertical axis respectively as earlier explained.

Deflection Formula: The first side support is denoted clamped, the second plate support is also denoted as Clamped. The remaining two sides are fixed making it difficult for the plate to rotate. Fig. i shows the support orientation.

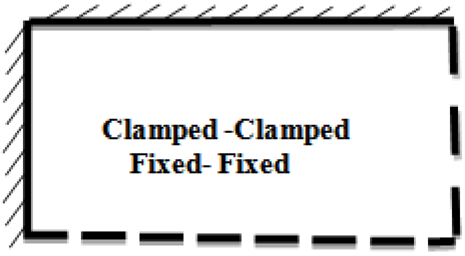

Fig. i Isotropic Rectangular CCFF Plate

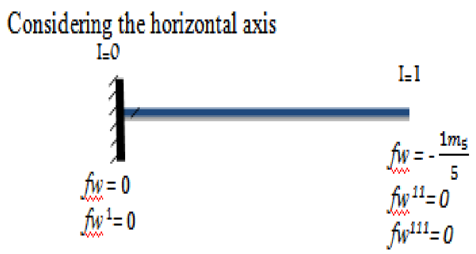

Fig. ii Horizontal Supports
xii

Since the left side is clamped and the right side fixed, that means that xiii

$fw_x = m_o + m_1 I + m_2 I^2 + m_3 I^3 + m_4 I^4 + m_5 I^5$ 1

The first derivation of Equation 1 gives

$fw_x^{1} = m_1 + 2m_2 I + 3m_3 I^2 + 4m_4 I^3 + 5m_5 I^4$ 2

also the second derivative of the Equation 1 gives

$fw_x^{11} = 2m_2 + 6m_3 I + 12m_4 I^2 + 20m_5 I^3$ 3

and finally the third derivative the same Equation gives

$fw_x^{111} = 6m_3 + 24m_4 I + 60m_5 I^2$ 4

On introducing the boundary conditions to the horizontal axis

At the left support, I = 0

When $fw_x = 0$

$fw_x = 0 = m_o + 0 + 0 + 0 + 0$

5

$m_o = 0$

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Also when $fw_x^{11} = 0$

6

$fw_x^{1} = 0 = m_1 + 0 + 0 + 0 + 0$

7

$m_1 = 0$

8

$m_1 = 0$

9

at the right support, I =1

$fw_x^{1} = 2m_2 + 3m_3 + 4m_4 + 5m_5 = -\frac{1m_5}{5}$ 10

Further simplifying Equation 10 gives

$m_2 = \frac{-3m_3 - 4m_4 - 5m_5 - \frac{1m_5}{5}}{2}$

11

Also for the second derivative of the deflection on the X axis,

$fw_x^{11} = 0 = 0 + 2m_2 + 6m_3 + 12m_4 + 20m_5$ 12

rearranging the equation and making n_3 the subject gives

$2m_2 = -6m_3 - 12m_4 - 20m_5$ 13

in simpler form as

$m_2 = -3m_3 - 6m_4 - 10m_5$ 14

Solving for the third derivative of the deflection on the horizontal component gives

$fw_x^{111} = 0 = 6m_3 + 24m_4 + 60m_5$ 15

That is

$fw_x^{111} = 0 = m_3 + 4m_4 + 10m_5$ 16

$m_3 = -10m_5 - 4m_4$ 17

Resolving Equation 11 and 14 together gives

$\frac{-3m_3 - 4m_4 - 5m_5 - \frac{1m_5}{5}}{2} = \frac{-10m_5}{3} - 2m_4$ 18

and further simplifying gives

$-1.5m_3 - 2m_4 - 2.6m_5 = -3m_3 - 6m_4 - 10m_5$ 19

Bringing the like terms together

$1.5m_3 + 4m_4 + 7.4m_5 = 0$

$m_3 = \frac{-4m_4 - 7.4m_5}{1.5}$

20

Further simplification gives

$m_3 = -2.66667m_4 - 4.9333m_5$

21

Solving Equations 17 and Equation 21 together gives

$-10m_5 - 4m_4 = -2.66667m_4 - 4.9333m_5$

22

Collecting the like terms together gives

$-4m_4 + 2.66667m_4 = 10m_5 - 4.9333m_5$ 23i

$-1.3333m_4 = 5.06667m_5$

That means $m_4 = \frac{5.06667}{-1.3333}m_5 = -3.73337m_5$

23ii

In order to obtain the values of the m_2 *and* m_3 *interms of* m_5, *substitute* Equation 23ii into Equation 11 and 21 and gives

$m_3 = -2.66667(-3.73337m_5) - 4.9333m_5$

$m_3 = 9.955666m_5 - 4.9333m_5$

$m_3 = 9.955666m_5 - 4.9333m_5 = 5.022366m_5$

23iii

$m_2 = \frac{-3(5.022366m_5) - 4(-3.73337m_5) - 5m_5 - \frac{1m_5}{5}}{2}$

$m_2 = \frac{-15.0671m_5 + 14.933m_5 - 85m_5 - 0.2m_5}{2}$

$m_2 = -2.667m_5 \text{ or } -2.7m_5$

23iv

When Equations 23ii , 23iii and 23iv substituted back into Equation 1 gives

$fw_x = (-2.7m_5I^2 + 5.02m_5I^3 - 3.7m_5I^4 + m_5I^5)$

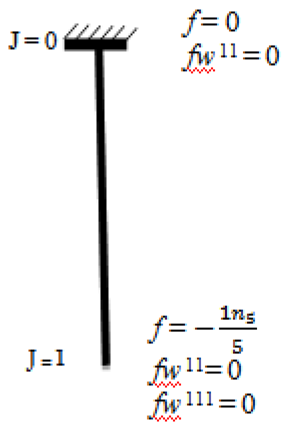
or $= m_5\,(2.7I^2 - 5.02I^3 + 3.7I^4 - I^5)$

24i

when multiplied by negative one.

The Vertical Analysis

The case of horizontal Direction (Y- Y axis)



Similarly the Top edge is clamped and the bottom edge fixed, that means that

$fw_y = n_o + n_1J + n_2J^2 + n_3J^3 + n_4J^4 + n_5J^5$ 25

The first derivation of Equation 25 gives

$fw_y^{1} = n_1 + 2n_2J + 3n_3J^2 + 4n_4J^3 + 5n_5J^4$ 26

also the second derivative of the Equation 25 gives

$fw_y^{11} = 2n_2 + 6n_3J + 12n_4J^2 + 20n_5J^3$ 27

and finally the third derivative the same Equation gives

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$fw_x^{111} = 6n_3 + 24n_4J + 60n_5J^2$ 28

On introducing the boundary conditions to the horizontal axis

At the left support, J = 0

When $fw_y = 0$

$fw_y = 0 = m_o + 0 + 0 + 0 + 0$ 29

$m_o = 0$

Also when $fw_y^{11} = 0$ 30

$Fw_y^1 = 0 = m_1 + 0 + 0 + 0 + 0$ 31

$m_1 = 0$ 32

$m_1 = 0$ 33

at the right support, J =1

$fw_y^1 = 2n_2 + 3n_3 + 4n_4 + 5n_5 = -\frac{1n_5}{5}$ 34

Further simplifying Equation 34 gives

$n_2 = \frac{-3n_3 - 4n_4 - 5n_5 - \frac{1n_5}{5}}{2}$ 35

Also for the second derivative of the deflection on the X axis,

$fw_x^{11} = 0 = 0 + 2n_2 + 6n_3 + 12n_4 + 20n_5$ 36

rearranging the equation and making n_3 the subject gives

$2n_2 = -6n_3 - 12n_4 - 20n_5$ 37

in simpler form as

$n_2 = -3n_3 - 6n_4 - 10n_5$ 38

Solving for the third derivative of the deflection on the horizontal component gives

$fw_x^{111} = 0 = 6n_3 + 24n_4 + 60n_5$ 39

That is

$fw_x^{111} = 0 = n_3 + 4n_4 + 10n_5$ 40

$n_3 = -10n_5 - 4n_4$ 41

Resolving Equation 35 and 38 together gives

$\frac{-3n_3 - 4n_4 - 5n_5 - \frac{1n_5}{5}}{2} = -3n_3 - 6n_4 - 10n_5$ 42

and further simplifying gives

$-1.5n_3 - 2n_4 - 2.6n_5 = -3n_3 - 6n_4 - 10n_5$ 43

Bringing the like terms together

$1.5n_3 + 4n_4 + 7.4n_5 = 0$

$n_3 = \frac{-4n_4 - 7.4n_5}{1.5}$ 44

Further simplification gives

$n_3 = -2.66667n_4 - 4.9333n_5$ 45

Solving Equations 41 and Equation 45 together gives

$-10n_5 - 4n_4 = -2.66667n_4 - 4.9333n_5$ 46

Collecting the like terms together gives

$-4n_4 + 2.66667n_4 = 10n_5 - 4.9333n_5$ 47

$-1.3333n_4 = 5.06667n_5$

That means $n_4 = \frac{5.06667}{-1.3333}n_5 = -3.73337n_5$ 48

In order to obtain the values of the n_2 *and* n_3 *interms of* n_5, *substitute* Equation 48 into Equation 45 and 35 and gives

$n_3 = -2.66667(-3.73337n_5) - 4.9333n_5$

$n_3 = 9.955666n_5 - 4.9333n_5$

$n_3 = 9.955666n_5 - 4.9333n_5 = 5.022366n_5$ 49

$n_2 = \frac{-3(5.022366n_5) - 4(-3.73337n_5) - 5n_5 - \frac{1n_5}{5}}{2}$

$n_2 = \frac{-15.0671n_5 + 14.933n_5 - 85n_5 - 0.2n_5}{2}$

$n_2 = -2.667n_5$ *or* $-2.7n_5$ 50

Similarly when Equations 50, 49 and 48 substituted back into Equation 25, that gives

$fw_y = (-2.7n_5J^2 + 5.02n_5J^3 - 3.7n_5J^4 + n_5J^5)$

$= n_5 (2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)$ 51

when multiplied by negative one.

Then the Shape function is expressed as

$fw = m_5 n_5 (2.7I^2 - 5.02I^3 + 3.7I^4 - I^5) * (2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)$ 52i

The Bucking Analysis

The shape functions were further differentiated at different stages, and the integration of the differential values gave the stiffness coefficients. These includes

$f = (2.7I^2 - 5.02I^3 + 3.7I^4 - I^5) * (2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)$

$\frac{\partial f}{\partial I} = (5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)$ 52ii

$\frac{\partial^2 f}{\partial I \partial J} = (5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4J + 15.06J^2 - 15.2J^3 + 5J^4)$ 52iii

$\frac{\partial^3 f}{\partial I \partial J^2} = (5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4 + 15.06J^2 - 15.2J^3 + 5J^4)$ 53

$\frac{\partial^2 f}{\partial I^2} = (5.4 + 30.12I - 45.6I^2 + 20I^3)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)$ 54

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$\frac{\partial^3 f}{\partial I^3} = (30.12 - 91.2I + 60I^2)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)$ 55

also

$\frac{\partial f}{\partial J} = (2.7I^2 - 5.02I^3 + 3.7I^4 - I^5) * (5.4J + 15.06J^2 - 15.2J^3 + 5J^4$ 56

$\frac{\partial^2 f}{\partial J^2} = (2.7I^2 - 5.02I^3 + 3.7I^4 - I^5)(5.4 + 30.12J - 45.6J^2 + 20J^3)$ 57

$\frac{\partial^3 f}{\partial J^3} = (2.7I^2 - 5.02I^3 + 3.7I^4 - I^5)(30.12 - 91.2J + 60J^2)$ 58

Integrating the product of the Equation 55 and 50 gives the first stiffness coefficient.

That is

$k_1 = \int_0^1 \int_0^1 \frac{\partial^3 f}{\partial I^3} * \frac{\partial f}{\partial I} dIdJ$

59

$k_1 = \int_0^1 \int_0^1 [(30.12 - 91.2I + 60I^2)(2.7J^2 - 5.02J3 + 3.7J4 - J5 * (5.4J + 15.06J2 - 15.2J3 + 5J4)(2.7J2 - 5.02J3 + 3.7J4 - J5) dIdJ$

60

bringing the like terms together gives

$= \int_0^1 \int_0^1 [(30.12 - 91.2I + 60I^2)5.4I + 15.06J2 - 15.2J3 + 5J4) * 2.7J2 - 5.02J3 + 3.7J4 - J5(2.7J2 - 5.02J3 + 3.7J4 - J5) dIdJ$

61

further minimization and substitution of the upper and lower limits yields

$k_1 = 0.15792$

also integrating the product Equation 53 and 51 give the second stiffness coefficient.

That is

$k_2 = \int_0^1 \int_0^1 \frac{\partial^3 f}{\partial I \partial J^2} * \frac{\partial f}{\partial I} dIdJ$

62

Fixing the real values gives

$k_2 = \int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4 + 15.06J2 - 15.2J3 + 5J4 * (5.4J + 15.06J2 - 15.2J3 + 5J4)(2.7J2 - 5.02J3 + 3.7J4 - J5) dIdJ$

63

Bring the like terms together gives

$\int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4I + 15.06J2 - 15.2J3 + 5J4 * 5.4 + 15.06J2 - 15.2J3 + 5J4(2.7J2 - 5.02J3 + 3.7J4 - J5) dIdJ$

64

Multiplying and further integrating the differential values gives

$k_2 = 0.035689$

65

Furthermore integrating the product Equation 58 and 56 give the third stiffness coefficient.

That is

$k_3 = \int_0^1 \int_0^1 \frac{\partial^3 f}{\partial J^3} * \frac{\partial f}{\partial J} dIdJ$

66

$k_3 = \int_0^1 \int_0^1 [(2.7I^2 - 5.02I^3 + 3.7I^4 - I^5)(30.12 - 91.2J + 60J2 * (2.7J2 - 5.02J3 + 3.7J4 - J5) * (5.4J + 15.06J2 - 15.2J3 + 5J4) dIdJ$

67

$k_3 = \int_0^1 \int_0^1 [(2.7I^2 - 5.02I^3 + 3.7I^4 - J5 2.7J2 - 5.02J3 + 3.7J4 - J5 * 30.12 - 91.2J + 60J2(5.4J + 15.06J2 - 15.2J3 + 5J4) dIdJ$

68

integrating Equation 65 and introducing the upper and lower limits gives

$k_3 = 0.15792$

and finally integrating the product Equation 51 and 51 gives the sixth stiffness coefficient.

That is

$k_6 = \int_0^1 \int_0^1 (\frac{\partial f}{\partial I} * \frac{\partial f}{\partial I}) dIdJ$

69

That is

$k_6 = \int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5J4 2.7J2 - 5.02J3 + 3.7J4 - J5 * (5.4J + 15.06J2 - 15.2J3 + 5J4)(2.7J2 - 5.02J3 + 3.7J4 - J5) dIdJ$

70

Collecting the like terms together gives

$= \int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4I + 15.06J2 - 15.2J3 + 5J4 * 2.7J2 - 5.02J3 + 3.7J4 - J5(2.7J2 - 5.02J3 + 3.7J4 - J5) dIdJ$

71

Putting the upper and lower limit values gives

$k_6 = 0.011423$

Reducing Equation (xiii) in terms of the stiffness coefficients gives

$Bkl_v = \frac{D(kccff_1 + 2\frac{1}{p^2}kccff_2 + \frac{1}{p^4}kccff_3)}{kccff_6 m^2}$

65

Substituting the real values in to Equation 65 gives

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$$bklv = \frac{D\left(0.15792 + 2\frac{1}{p^2}0.035689 + \frac{1}{p^4}0.15792\right)}{0.011423\, m^2}$$

66

II. RESULTS:

The values of the coefficients and the buckling load coefficients were derived. Taking into account the critical buckling load coefficients at different aspect ratios, the values of the buckling loads were all derived. The first table represents the values of the stiffness coefficients while the other contains the critical buckling coefficients for the aspect ratio of m/n, both for the previous and present study..

Table 1.1 Stiffness Coefficients from present work/previous researchers

Stiffness coeffi., k	Present Work	Previous Work
k_1	0.1579	0.1580
k_2	0.0356	0.0357
k_3	0.15782	0.1585
k_6	0.011323	0.01134

Table 1.2 Critical buckling load values for C-C-F-F plate from previous/present.

m/n		2	1.9	1.8	1.7	1.6
B		42.9346	43.0759	43.2415	43.4373	43.6711
B_x	Previous	43.3728	43.5151	43.6826	43.8814	44.1201
	Present	43.9346	44.0759	44.2415	44.4373	44.6711

m/n		1.5	1.4	1.3	1.2	1.1	1
B		43.953	44.298	44.726	45.267	45.9632	46.88
	Previo us	44.410	44.767	45.214	45.785	46.5315	47.531

$B_{x\frac{G}{n^2}}$	Present	44.953	45.298	45.726	46.267	46.9632	47.88

Table 1.2 cont'd.

III. DISCUSSION:

The values of the aspect ratios ranges from 2.0 to 1.0 with arithmetic increase of 0.1. From the values generated in the tables, it was observed that as the aspect ratio increases from 1.0 to 2.0, the critical buckling load decreases. This occurred both in the present and previous results and so in both cases showing an inverse relationship to each other.

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