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Change Examination of Structural Clamped Clamped Fixed Fixed Edged Plate Under Stability Analysis.

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ABSTRACT

The effect of buckling load on at structural plate element which is support on four edges. The vertical axis rest on clamped and fixed supported edge while the horizontal axis rests on also clamped and fixed boundaries, forming a plate of CCFF shape orientation. 3rd 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:

- Third order Functional
- Buckling load Equation
- C-C-F-F Plate
- Overall Potential Energy Functional,
- Lead Equation,
- Vital Buckling load

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.

Section A

The overall potential energy, O_v was first formulated by the summation of External Work E_w and Strain energy, ϵ . This is shown in Equation i

$$E_x + \epsilon = O_v \quad \text{i}$$

The strain energy, is gotten from the product of normal stress and normal strain,

both in the x components as

$$§_i ð_i = \frac{Ez^2}{1-μ^2}\left(\left[\frac{\partial^2 fu}{\partial x^2}\right]^2 + μ\left[\frac{\partial^2 fu}{\partial x \partial y}\right]^2\right) \quad \text{ii}$$

while also in vertical axis as shown in the Equation iii

$$§_j ð_j = \frac{Ez^2}{1-μ^2}\left(\left[\frac{\partial^2 fu}{\partial y^2}\right]^2 + μ\left[\frac{\partial^2 fu}{\partial x \partial y}\right]^2\right) \quad \text{iii}$$

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

$$\tau_{ij}\gamma_{ij} = 2\,\frac{Ez^2(1-μ)}{(1-μ^2)}\left[\frac{\partial^2 fu}{\partial x \partial y}\right]^2 \quad \text{iv}$$

Bringing Equations ii, iii and iv together gives

$$§_i ð_i + §_j ð_j + \tau_{ij}\gamma_{ij} = \frac{Ez^2}{1-μ^2}\left(\left[\frac{\partial^2 fu}{\partial x^2}\right]^2 + 2\left[\frac{\partial^2 fu}{\partial x \partial y}\right]^2 + \left[\frac{\partial^2 fu}{\partial y^2}\right]^2\right) \quad \text{v}$$

The strain Energy is given mathematically as $\epsilon = \frac{1}{2}\iint_{xy}\overline{\epsilon}\,\mathrm{dxdy}$ vi

$$\text{where} \quad \overline{\epsilon} = \frac{Ez^2}{1-μ^2}\int\left(\left[\frac{\partial^2 fu}{\partial x^2}\right]^2 + 2\left[\frac{\partial^2 fu}{\partial x \partial y}\right]^2 + \left[\frac{\partial^2 fu}{\partial y^2}\right]^2\right) \quad \text{vii}$$

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

$$\text{as } \epsilon = \frac{G}{2}\int_0^n\int_0^m\left(\frac{\partial^3 fu}{\partial x^3}\cdot\frac{\partial fu}{\partial x} + 2\,\frac{\partial^3 fu}{\partial x\,\partial y^2}\cdot\frac{\partial fu}{\partial x} + \frac{\partial^3 fu}{\partial y^3}\cdot\frac{\partial fu}{\partial y}\right)\mathrm{dxdy} \quad \text{viii}$$

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

The third order total potential energy functional is expressed mathematically as

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

Rearranging the total potential energy equation in terms of non-dimensional

parameters I, J the buckling load equation is gotten as

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

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

$$bkl_x = \frac{bkl_t}{bkl_b} \quad \text{xiii}$$

Section B

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.

Section C

The Deflection Equation

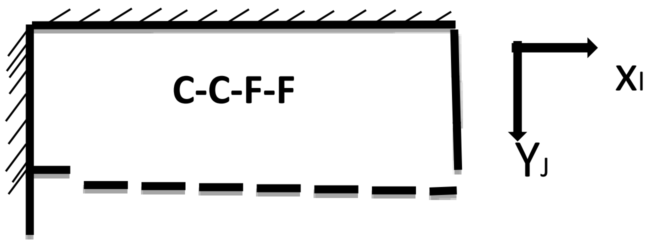


Fig. i Isotropic Rectangular CCFF Plate

Considering the horizontal axis

Fig. ii Horizontal Supports

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

$fw_x = m_o + m_1I + m_2I^2 + m_3I^3 + m_4I^4 + m_5I^5$ 1

The first derivation of Equation 1 gives

$fw_x^{1} = m_1 + 2m_2I + 3m_3I^2 + 4m_4I^3 + 5m_5I^4$ 2

also the second derivative of the Equation 1 gives

$fw_x^{11} = 2m_2 + 6m_3I + 12m_4I^2 + 20m_5I^3$ 3

and finally the third derivative the same Equation gives

$fw_x^{111} = 6m_3 + 24m_4I + 60m_5I^2$ 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

$m_o = 0$

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

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

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

$m_2=-2.667m_5$ or $-2.7m_5$ 23iv

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

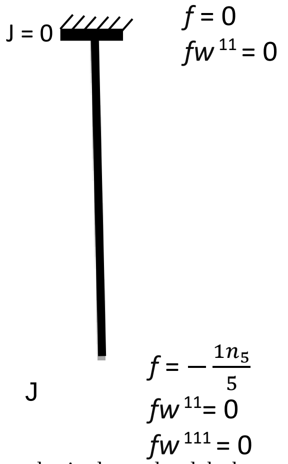
$fw_x=(-2.7m_5I^2+5.02m_5I^3-3.7m_5I^4+m_5I^5)$

or $= m_5(2.7I^2-5.02I^3+3.7I^4-I^5)$ 24i

when multiplied by negative one.

1.3.2 Analysis of the Vertical Component

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

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

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

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

$n_2 = -2.667n_5 \text{ or } -2.7n_5$ 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

Section D

The Stiffness Coefficients

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

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

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

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

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

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

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

also

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

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

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

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

That is

$$k_{ccff1} = \int_0^1 \int_0^1 \frac{\partial^3 f}{\partial I^3} * \frac{\partial f}{\partial I}\, dIdJ \quad 59$$

$$k_{ccff1} = \int_0^1 \int_0^1 [(30.12 - 91.2I + 60I^2)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5) * (5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)]\, dIdJ \quad 60$$

bringing the like terms together gives

$$= \int_0^1 \int_0^1 [(30.12 - 91.2I + 60I^2)5.4I + 15.06I^2 - 15.2I^3 + 5I^4) * (2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)]\, dIdJ \quad 61$$

further minimization and substitution of the upper and lower limits yields

$k_{ccff1} = 0.15792$

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

That is

$$k_{ccff2} = \int_0^1 \int_0^1 \frac{\partial^3 f}{\partial I\,\partial J^2} * \frac{\partial f}{\partial I}\, dIdJ \quad 62$$

Fixing the real values gives

$$k_{ccff2} = \int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4 + 15.06J^2 - 15.2J^3 + 5J^4) * (5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)]\, dIdJ \quad 63$$

Bring the like terms together gives

$$\int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4I + 15.06I^2 - 15.2I^3 + 5I^4) * (5.4 + 15.06J^2 - 15.2J^3 + 5J^4)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)]\, dIdJ \quad 64$$

Multiplying and further integrating the differential values gives

$k_{ccff2} = 0.035689$ 65

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

That is

$$k_{ccff3} = \int_0^1 \int_0^1 \frac{\partial^3 f}{\partial J^3} * \frac{\partial f}{\partial J}\, dIdJ \quad 66$$

$$k_{ccff3} = \int_0^1 \int_0^1 [(2.7I^2 - 5.02I^3 + 3.7I^4 - I^5)(30.12 - 91.2J + 60J^2) * (2.7I^2 - 5.02I^3 + 3.7I^4 - I^5) * (5.4J + 15.06J^2 - 15.2J^3 + 5J^4)]\, dIdJ \quad 67$$

$k_{ccff3} = \int_0^1 \int_0^1 [(2.7I^2 - 5.02I^3 + 3.7I^4 - I^5)(2.7I^2 - 5.02I^3 + 3.7I^4 - I^5) * (30.12 - 91.2J + 60J^2)(5.4J + 15.06J^2 - 15.2J^3 + 5J^4)]\, dIdJ$

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integrating Equation 65 and introducing the upper and lower limits gives

$k_{ccff3} = 0.15792$

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

That is

$k_{ccff6} = \int_0^1 \int_0^1 (\frac{\partial f}{\partial I} * \frac{\partial f}{\partial I}) dIdJ$ 69

That is

$k_{ccff6} = \int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5) * (5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)]\, dIdJ$

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Collecting the like terms together gives

$= \int_0^1 \int_0^1 [(5.4I + 15.06I^2 - 15.2I^3 + 5I^4)(5.4I + 15.06I^2 - 15.2I^3 + 5I^4) * (2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)(2.7J^2 - 5.02J^3 + 3.7J^4 - J^5)]\, dIdJ$

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Putting the upper and lower limit values gives

$k_{ccff\,6} = 0.011423$

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

$bkl_x = \frac{D(kccff_1 + 2\frac{1}{p^2}kccff_2 + \frac{1}{p^4}kccff_3)}{kccff_6 m^2}$ 65

Substituting the real values in to Equation 65 gives

$bkl_x = \frac{D(0.15792 + 2\frac{1}{p^2}0.035689 + \frac{1}{p^4}0.15792)}{0.011423m^2}$ 66

RESULTS AND DISCUSSION.

The actual values of the stiffness coefficients and the critical buckling load coefficients were derived. Considering the critical buckling load coefficients at different aspect ratios, the values of the critical buckling loads were calculated. 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. 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.

Table 1.1 Stiffness Coefficients from Present Work/ Previous researchers

Stiffness coefficients, sc	Present Work	Previous Work
k_{ssff1}	0.15792	0.158015
k_{ssff2}	0.035689	0.0357990
k_{ssff3}	0.15792	0.158015
k_{ssff6}	0.011423	0.011434

Table 1.2 Critical buckling load values for CCFF Plate from Previous/Present.

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

Table 1.2 cont'd.

m/n		1.5	1.4	1.3	1.2	1.1	1
B		44.9533	45.2985	45.7268	46.2674	46.9632	47.88
$B_x\frac{G}{n^2}$	Previous	44.4101	44.7674	45.2148	45.7859	46.5315	47.5319
	Present	44.9533	45.2985	45.7268	46.2674	46.9632	47.88

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