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Effect of Web Dimensions on the Critical Buckling Stress of T Sections under Axial and Combined Loads

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Abstract

The aim of this paper is to clarify the influence of different levels of initial imperfections and the effect of web dimensions for T stiffener on the estimation of the critical buckling stress of stiffened panels under axial and combined loads using Ansys software. The post buckling behavior of the plate-stiffener combination consisting of a T-girder with the attached effective plating between two adjacent transverse frames is investigated in case of longitudinal axial load and of combined longitudinal axial load and lateral pressure as normally encountered in bottom and deck panels. To accomplish the intended parametric study, the sections modeled have been classified into two sets according to different values of web depth and different values of web thickness. Two different levels of initial imperfections attributed to the plate and to the web were taken into account. The finite element model is attempted using the element SOLID45 for its advantages in the non-linear analysis. The square deflection method is used to estimate the critical stress for the FEM models; the results are seen to be in good agreement with Perry-Robertson formulation. It has been concluded that the web depth of T-section greatly affects the value of critical buckling stress in case of combined load. The proposed model can be useful to determine the minimum web depth to be adopted if a minimum value of the critical stress is intended. The influence of the level of initial imperfections on the post buckling behavior of the plate-stiffener combination is assessed.

Keywords: T-stiffener; combined loads; axial loads; critical stress; ship structures; square deflection

Nomenclature

A	Cross-sectional area (mm^2)	w	Deflections functions of plate
b_e	Effective width	w_o	Initial imperfection functions
d	Overall depth of girder	ϕ	Panel aspect ratio
E	Modulus of elasticity of steel	ν	Poisson's ratio
I_e	Moment of inertia of the plate-stiffener combination section (mm^4)	δ_o	Maximum initial deflection at mid-span(mm)
k	Buckling Coefficient	λ_e	Column slenderness ratio
P_{cr}	Critical Load	σ_y	Material yield strength (MPa)

1. Introduction

For stiffened panels encountered in ship structures, local buckling and collapse of plating between stiffeners is a primary failure mode, and thus it would also be important to evaluate the buckling and collapse strength interactions of plating between stiffeners under combined loading.The behavior ofship plating normally depends on a variety of influential factors, namely geometric/material properties, loading characteristics, initial imperfections (i.e., initial deflections and residual stresses), boundary conditions and existing local damage related to corrosion, fatigue crack and denting. The boundary condition for the rectangular plate elements making up steel plated structures is mostly assumed to be simply supported. In real ship plating, however, such ideal edge conditions may never occur due to rotational restraint by support members along the plate edges.Unlike plate panels, columns cannot be expected to have residual strength after the inception of buckling and thus buckling strength typically is considered to be synonymous with the ultimate strength for column members. The column or beam-column will collapse if the load reaches the ultimate load. The real ultimate strength of a plate-stiffener combination will be determined as the lowest value among the various ultimate loads calculated for potential failure patterns, namely column or beam-column types of collapse, lateral-torsional buckling and stiffener web buckling. Paik and Seo(2009) developed ultimate strength expressions for stiffened panels subjected to combined axial load, in-plane bending and lateral pressure. Ohgaa et al.(2006) examined the effects of the lateral pressure on the FEM and reduced stiffness lower bound buckling strength of axially loaded sandwich cylindrical shell. Zheng and Hu (2005) studied the tripping stiffeners under combined loads of axial force, lateral pressure and end moment. Fujikubo et al. (2005) have conducted and presented a set of design formulae to estimate the ultimate strength of a continuous stiffened panel subjected to combined transverse thrust and lateral pressure.The stability of T-stiffeners was studied by Byklum et al. (2004) who derived a computational model for global buckling and postbuckling analysis of stiffened panels. The loads considered were biaxial in-plane compression or tension, shear, and lateral pressure. Graciano and Lagerqvist (2003) have described a methodology for the determination of buckling coefficients for longitudinally stiffened plate girders subjected to partial edge loading or concentrated loads. Saddek (2006)developed a finite element model using ANSYS to investigate the effect of large displacements on the behavior due to buckling and four girders were tested subjected to two concentrated loads. Paik (2007) has developed design-oriented ultimate strength expressions for stiffened panels subject to combined axial load, in-plane bending and lateral pressure. Sheikh et al. (2003) have presented a part of a series of investigations of the behavior of steel plates stiffened with tee-shape stiffeners loaded with axial compressive forces with or without bending moments. Xie and Chapman (2003) have examined the effects caused by axial forces in the stiffeners. Some methods may be used to estimate critical loads for plated structure under various cases of loading such as buckling of members with initial curvature under axial compression. Among these methods are Southwell method for determination of buckling load, the vertical tangent method and the method of load square deflection adopted in this study.The elastic critical buckling stress is estimated by using the load vs. squared lateral deflection method, as described by Venkataramaiah and Roorda(1982),whereby a tangent to the curve is drawn in the post buckling range, and the intersection point of this line with the vertical load axis gives the elastic buckling load, for the case of pure compression (Bambach, Rasmussen ,Venkataramaiah and Roorda)as shown in Fig. 1.

Figure 1: Typical load-lateral displacement squared curve (Venkataramaiah and Roorda, 1982)

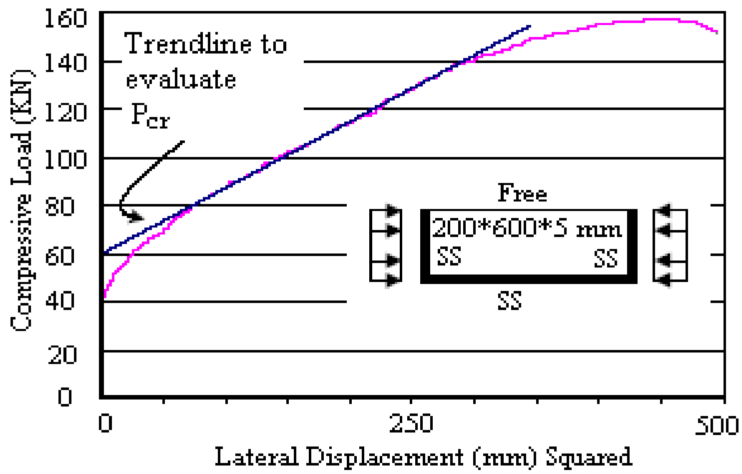


Fig.1 shows a test result for a three-sided simply supported plate under uniform compression, with the pins inserted. The elastic buckling load is very close to that for a plate with simply supported ends (60 kN).Bambach and Rasmussen (2002) tested unstiffened elements under combined compression and bending. RezaZareeiandRigo (2010)made empirical formulations for estimation of ultimate strength of continuous stiffened aluminum plates under combined in-plane compression and lateral pressure.Abdel-Lateef and Tohamy(2005)studied bending of isotropic plates under transverse line loading.

2. The Analytical Model

The analytical model used in the current study consists of a simply supported stiffener subjected to axial and axial versus lateral pressure (combined loads) as shown in figures 2.The dimensions of the T-section and associated plating are shown in figure3.

Figure 2: Plate-stiffener combination

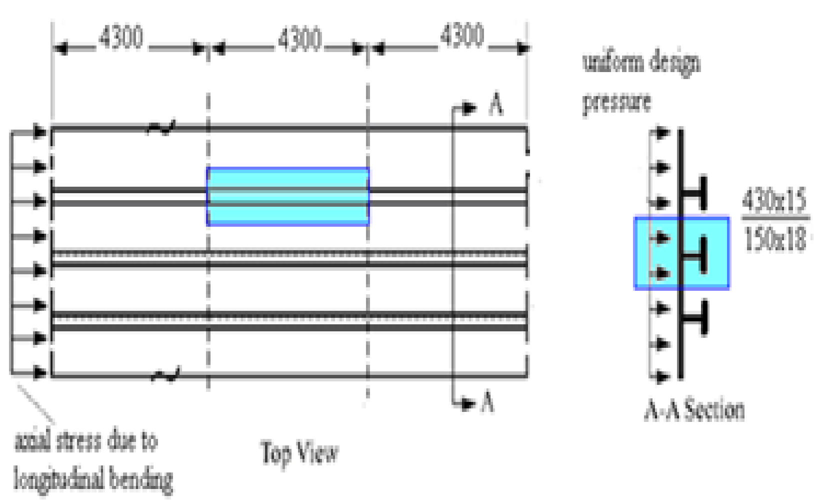
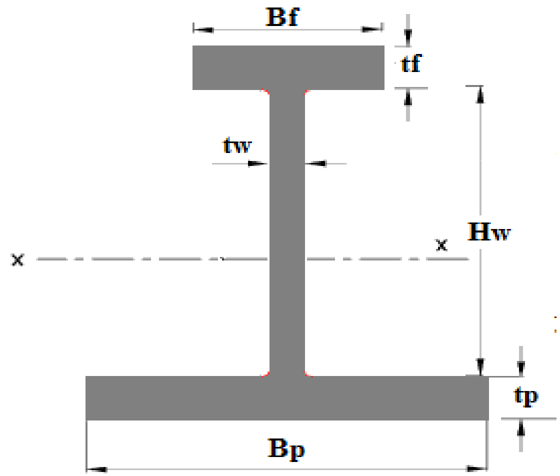


Figure 3: Dimensions of the T-section and associated plating



Two sets of T-sections have been modeled to carry out the study. The sections of the first set have different web thickness while all other scantlings are fixed. The sections of the second set have different web depth while all other scantlings are fixed. Table 1 illustrates the dimensions of the sections with smallest and largest web thickness and web depth respectively.

Table 1: Dimensions of sections modeled

	B_p (mm)	t_p (mm)	B_f (mm)	t_f (mm)	H_w (mm)	t_w (mm)
Model TT1	840	18.5	150	18	430	10
Model TT9	840	18.5	18	18	430	18
Model TH1	840	18.5	150	18	290	15
Model TH9	840	18.5	18	18	570	15

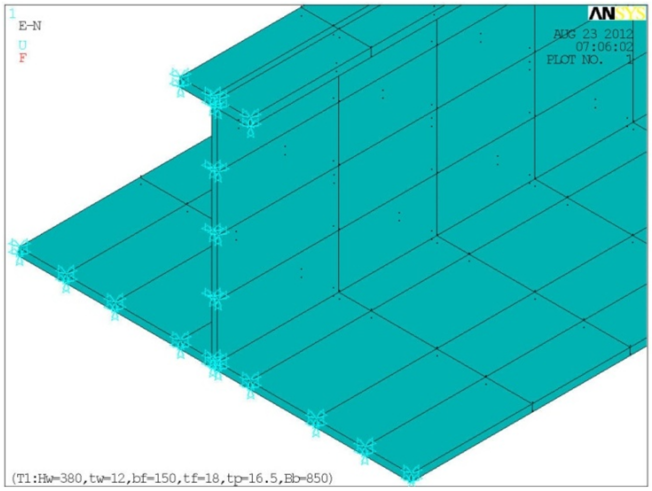
3. Non-linear Finite Element Analysis

The primary objective of a nonlinear analysis is to find the state of equilibrium of a structure corresponding to a set of applied loads. In such a nonlinear analysis, the solution cannot be calculated by solving a single system of linear equations but rather the solution is found by specifying the loading as a function of time and incrementing time in small steps, so as to trace nonlinear equilibrium response.In the incremental method, each step of the finite element analysis is assumed to be linear with the loading or displacement applied in a series of increments. A new configuration of the structure, a beam in the case of the present study, is defined each time a new displacement increment is computed and added to previous calculated displacements. Changes in the beam are observed through each new configuration. In nonlinear analysis the tangent stiffness matrix is used as a means for relating changes in load with changes in displacement.The Solid45 element was chosen mainly because it has plasticity, large deflection and strain capabilities. This will give an accurate representation of the actual spread of plasticity and yielding behavior of the girder model.

3.1. Panel and Boundary Conditions

The model used in the current study consists of a simply supported stiffener subjected to axial and lateral pressure; the cross section of the single plate-stiffener combination is shown in Fig. 4.

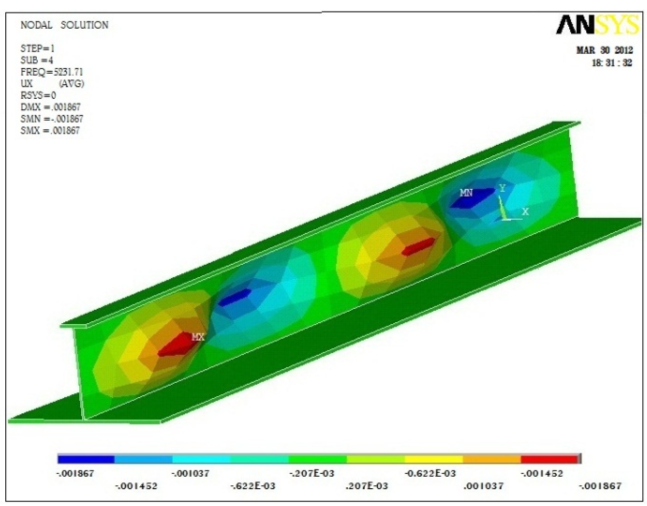
Figure 4: Finite element model with end conditions



3.2. Initial Imperfections

Due to manufacture and delivery process, geometric imperfections always exist in the stiffened plates. Thin walled structures like stiffened plates are usually imperfection sensitive. The presence of geometric imperfections may influence buckling and behavior of structure. It is therefore important to investigate the influence of geometric imperfections on the ultimate load and failure shape of stiffened plates.The imperfections were added in the finite element analysis by using eigenvectors that result from an eigenvalue buckling analysis. The eigenvector determined is the closest estimate of the actual mode of buckling. The imperfections added should be small when compared to a typical thickness of the beam being analyzed. The imperfections remove the sharp discontinuity in the load-deflection response. The representation of initial imperfection through eigenvalue buckling analysis for web and plate are shown in Figures 5 and 6, respectively.

Figure 5: Initial deflection patterns for the stiffener web

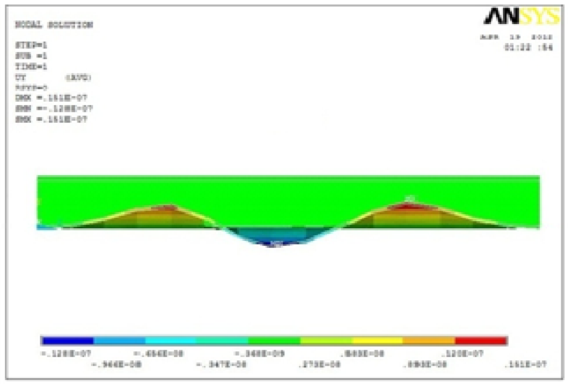


Two different levels of initial imperfections have been considered for all models in both sets:

- Level A: the initial deflection amplitude of the web is 5%of the web thickness, and the initial deflection amplitude of the plate is 5% of the plate thickness.
- Level B: the initial deflection amplitude of the web is 20%of the web thickness, and the initial deflection amplitude of the plate is 20% of the plate thickness.

The analysis was performed for a specific value of the pressurefor the imperfect stiffener. This load was automatically incremented (Force Control or Displacement Control) until the program stops due to the control of load or displacement or the convergence of solution.

Figure 6: Initial deflection patterns for the stiffener plate



4. Effect of Web Thickness

The relationship between the compressive stress versus and squared deflection at mid height of web under the action of axial pressure for TT1 and TT9 for different degree of initial imperfections are shown in Fig.7and 8.

Figure. 7-a: Relationship between stress and square displacement for TT1- level of imperfection A

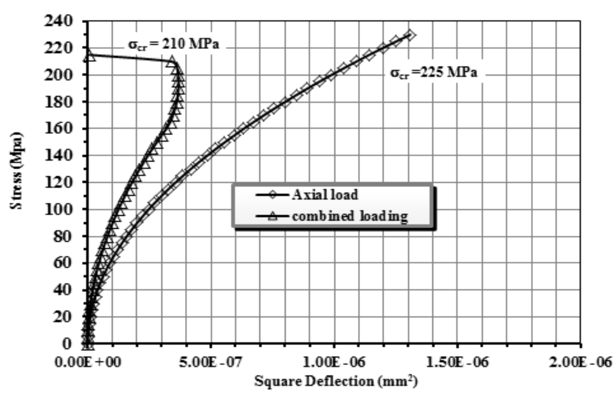


Figure 7-b: Relationship between stress and square displacement for TT1- Level of imperfection B

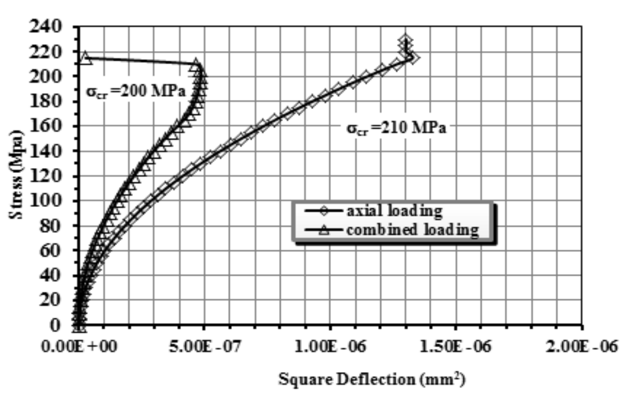


Figure 8-a: Relationship between stress and square displacement for TT9- Level of imperfection A

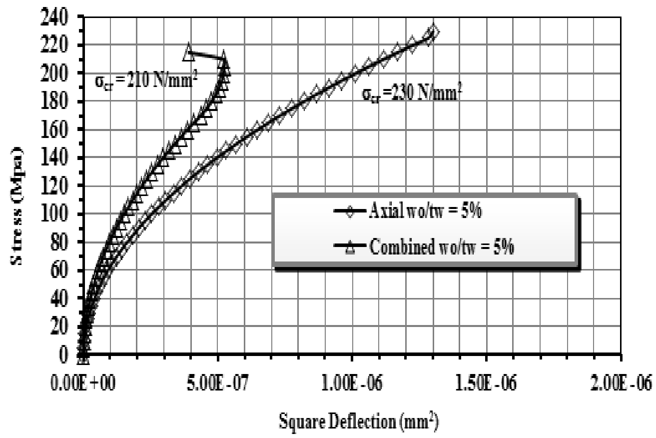
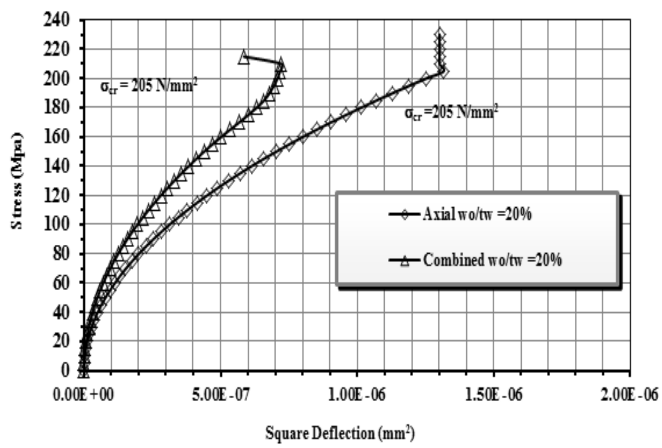


Figure 8-b: Relationship between stress and square displacement for TT9- Level of imperfection B



5. Effect of Web Depth

The relationship between the stress and square displacement at mid height of web under the action of axial pressure for TW1 and TW9 for different degree of initial imperfections are shown in Fig.9and Fig.10,respectively.

Figure 9-a: Relationship between stress and square displacement for TW1- Level of initial imperfection A

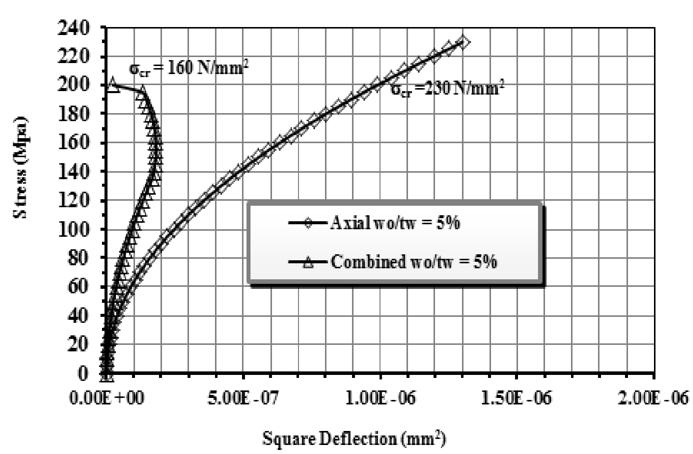


Figure 9-b: Relationship between stress and square displacement for TW1- Level of initial imperfection B

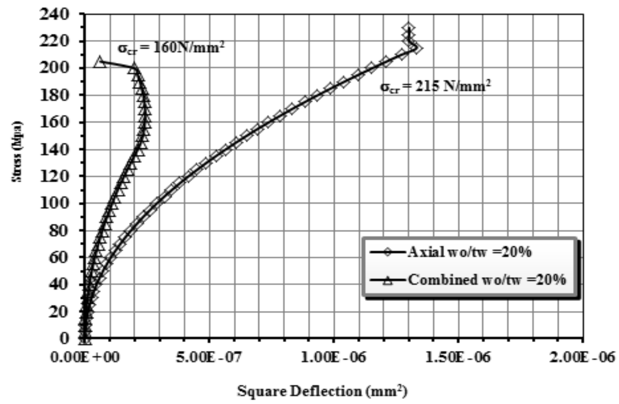


Figure 10-a: Relationship between stress and square displacement for TW9- Level of initial imperfection A

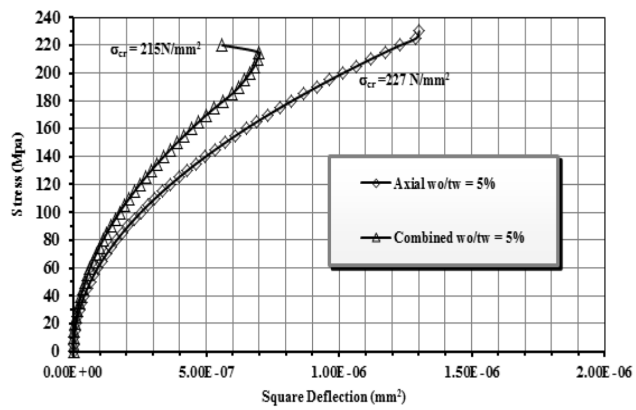
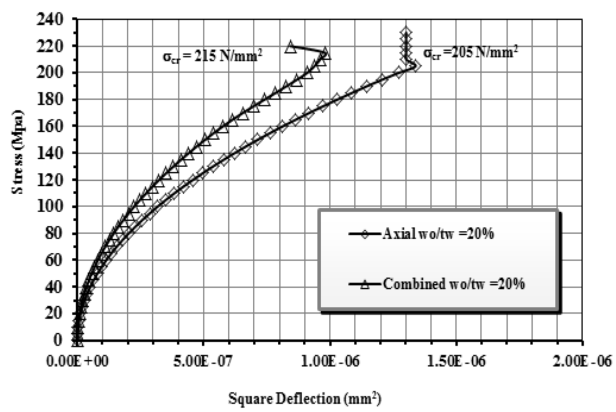


Figure 10-b: Relationship between stress and square displacement for TW9- Level of initial imperfection B



The main results obtained according to Figs.7, 8, 9and 10 are summarized in Table 2.

Table 2: Critical stress for the sections under different loading conditions

Section	TT1		TT9		TW1		TW9	
Level of imperfection	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Critical stress (axial)	225	210	230	205	230	215	227	205
Critical stress (combined)	210	200	210	205	160	160	215	215

6. Validation of the Finite Element Model

Among the various available ultimate strength formulations for the plate–beam combinations under predominantly axial compression,the Perry-Robertson formulation is used to check the validation of the numerical model. The real ultimate strength σ_u is given by:

$$\frac{\sigma_u}{\sigma_y} = \frac{1}{2}\left(1 + \frac{1+\eta}{\lambda^2}\right) - \left[\frac{1}{4}\left(1 + \frac{1+\eta}{\lambda_e^2}\right)^2 - \frac{1}{\lambda_e^2}\right]^{0.5}$$

Where

$$\lambda_e = \left(\frac{l}{\pi r_e}\right)\sqrt{\frac{\sigma_y}{E}}, \eta = A\delta_o\left(\frac{z_c}{I_e}\right)$$

A= cross-sectional area,

z_c= distance from outer fiber to neutral axis,

I_e=Moment of inertia of the plate-stiffener combination section for a straight column, i.e, without initial deflection the constant $\eta = 0$

The modified Perry-Robertson formula is used for plate-beam combination under axial compression and lateral load, as given by the formula:

$$\frac{\sigma_u}{\sigma_y} = \frac{1}{2}\left(1 - \mu + \frac{1+\eta}{\lambda_e^2}\right) - \left[\frac{1}{4}\left(1 - \mu + \frac{1+\eta}{\lambda_e^2}\right)^2 - \frac{1-\mu}{\lambda_e^2}\right]^{0.5}$$

Where

$$\mu = \frac{M_{q\,max}}{\sigma_y}\frac{Z_c}{I_e}$$

Figures (11 and 12) show the validation in such cases of loading for group TT and group TW.

Figure 11: Effect of web depth on ultimate stress

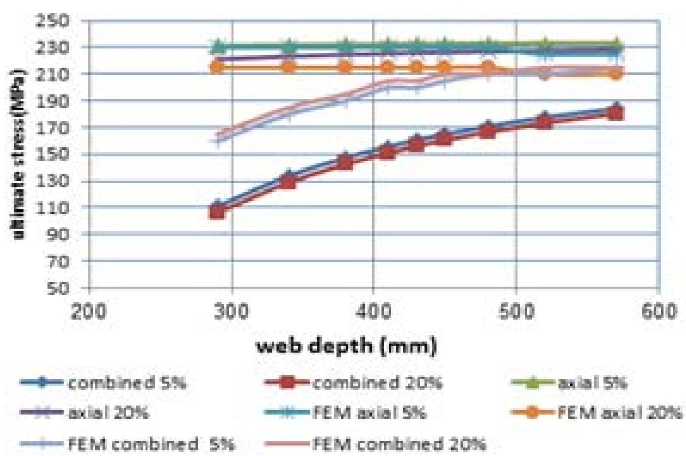
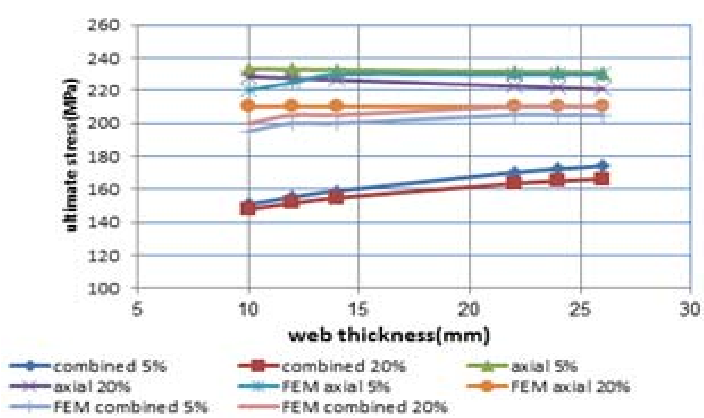


Figure 12. Effect of web thickness on ultimate stress



7. Discussion of Results and Conclusion

The current research deals with the determination of the critical stress for a plate-stiffener combination under combined longitudinal axial and lateral pressure. The following conclusions have been obtained:

- In case of panels under longitudinal axial load, the FEM is in good agreement with Perry-Robertson formulation; the effect of change in web depth or change in web thickness is not significant. The increase in initial imperfections does not greatly affect the value of critical stress.
- In case of panels under combined longitudinal axial load and lateral pressure, the FEM gives higher values of the ultimate stress than the modified Perry-Robertson formulation. An increase in web depth or web thickness would result in an increase in the ultimate stress; however, the increase in web depth has a greater effect on the ultimate stress value. The effect of initial imperfections is greater for larger web thickness; for a web thickness of 24mm, the ultimate stress in case of 20% imperfections is 4.5% greater than in case of 5% initial imperfections.
- The value of the critical stress is not affected by the proportions of the web; it is only affected by the overall characteristic of the section, namely the section modulus and the moment of inertia.
- The curves show that the presence of lateral pressure combined with the longitudinal axial load does not cause an important reduction in the value of the critical load; however , the behavior of the plate-stiffener combination as presented by the displacement squared is quite different compared to the case of longitudinal axial load alone .
- The level of imperfections doesn't affect the value of critical stress in case of combined longitudinal axial load and lateral pressure. However, in case of pure axial load, as the degree of imperfections is increased, the value of the critical stress is decreased by about 7%.

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