INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN: 2278 – 0211 (Online)

Ultimate Strength Analysis Of Stiffened Plates With Initial Imperfections

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Abstract:

The ultimate strength assessment of the hull girder is important in the perspective of full collapse of the ship's hull. Due to the inherent imperfections (initial deflections and welding induced residual stresses) which may arise in steel plating as a result of manufacturing, the strength of the plating is subjected to further degradation. This paper presents a methodology to analyze the ultimate strength of stiffened panels considering the effect of initial deflections. Ship plating representative of Oil tankers and Bulk carriers classed as per the IACS-Common Structural rules has been selected for the ultimate strength evaluation. A series of non linear finite element analyses have been carried out using commercial software. The results have been validated with results available in literature. The effects of consideration of initial imperfections (initial deflections) for the ultimate strength analysis are discussed. The present analyses may prove to be useful for developing a tool for ship designers to evaluate structural safety in a rational manner.

1.Introduction

Steel plating reinforced by stiffeners forms a principal component of the ship hull girder. The scantlings of the hull girder have to be assessed to ensure it withstands the applied loads. For this purpose the hull girder may be assumed to be an assembly of stiffened plates. While fabrication of stiffened plates, initial imperfections (initial deflections and welding residual stresses) may be present owing due to the fabrication process or the manufacturing process of the bare plating. It is evident that these initial imperfections lead to degradation of the load carrying capacity of the plate. Hence their effect needs to be studied on the stiffened panel. In the present study, the ultimate strength of a representative stiffened panel with initial imperfections is investigated considering the longitudinal compression, transverse compression and a combination of these. The analysis results show that initial deflections strongly affect the ultimate strength of stiffened plates.

2.Literature Survey

The study of the effect of the initial imperfections on the ultimate strength has been an active area of study from both the experimental and the numerical aspects.

Experimental studies were performed on stiffened panels by Dowling et al. [1], Smith [2], Horne et al. [3, 4], Faulkner [5], Niho [6], Yao [7], Tanaka and Endo [8], Paik and Lee [9], Chen et al. [10], Gordo et al. [11].

Analytical work has also been performed on this subject by researchers such as Fujikubo and Yao [12], Paik et al. [13], Paik and Kim [14], Byklum and Amdahl [15], Byklum et al. [16], Brubak and Hellesland [17], Paul et al. [18].

Finite element method has been used as a computational tool for evaluation of ultimate strength by Grondin et al. [19], Chen [20], Dongqui [21], Fujikubo et al. [22, 23], Zhang and Khan [24] and Corak and Parunov [25], Paik et al. [26, 27].

Thus finite element analysis has grown in popularity as an effective tool for ultimate strength analysis. Thus the present work utilizes finite element method as a computational tool for the analysis. Candidate plates are taken from Bulk carriers and Oil tankers classed as per IACS common structural rules 2010. These plates shall be analysed for ultimate strength.

3.Assumptions And Methodology

3.1.initial Imperfections

The schematics of the stiffened plates to be analysed are shown in Figure 1 below.

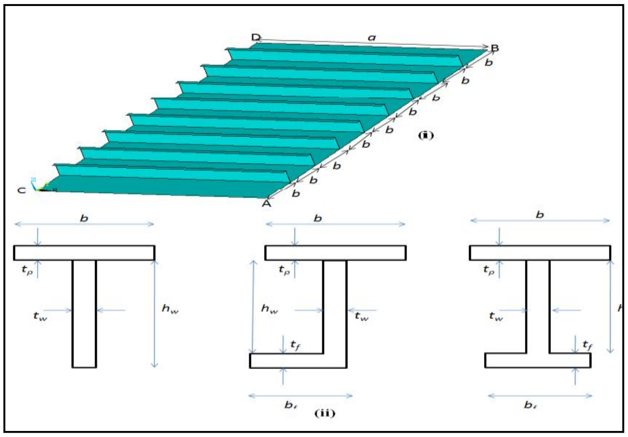

Figure 1: (i) Schematics of the stiffened plate (ii)Stiffener profile definitions

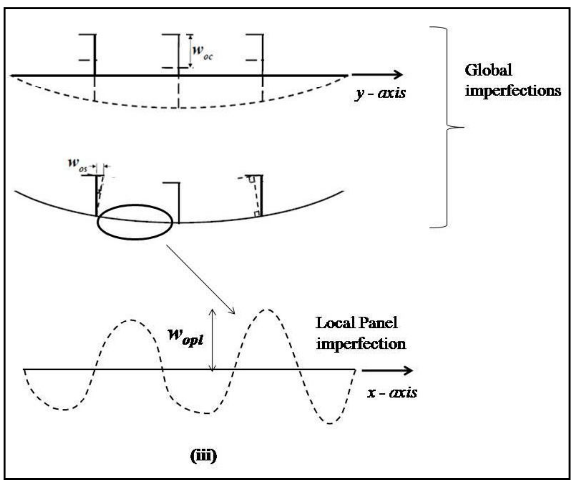

Figure 1: (iii) Initial imperfection levels on the panel

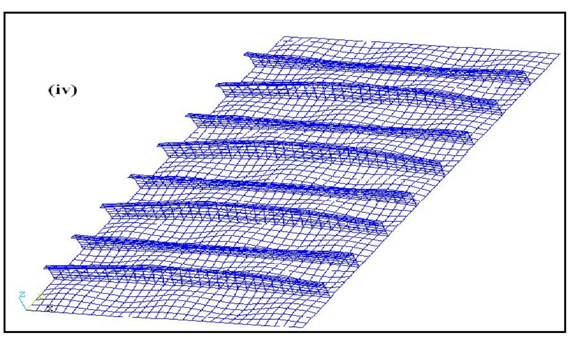

Figure 1: (iv) Stiffened plate after application of initial imperfections

Both global and local initial imperfections are considered in the present work. The local initial imperfections considered represent the local distortion within a panel between two stiffeners. The shape of this imperfection corresponds to the first buckling mode shape of the panel between two stiffeners. The amplitude of the local panel imperfection is defined as shown in Eq. (1).

$$w_{opl} = 0.1\beta^2 t_p$$
$$\beta = \frac{b}{t_p}\sqrt{\frac{\sigma_Y}{E}} \qquad (1)$$

The local initial imperfection on the panel has been defined as per Smith [28].

The global initial imperfections account for the overall distortion of the panel. These are considering the sideways deformation of the stiffener as well as the overall deformation of the plating and the attached stiffeners. These are defined as shown in Eq. (2).

$$w_{oc} = w_{os} = 0.0015a \qquad (2)$$

These imperfections are thus applied on to a 1 bay 1 frame model of the stiffened plate, the final shape of the panel after application of the initial imperfections may be viewed from figure 1 (iv).

3.2.Boundary Conditions

Simply supported boundary conditions have been applied to the stiffened plate model. These are listed below with reference to Fig. 1.

- On Edge AB and CD,
    - U_z = 0, Couple all the plate nodes to have the same displacement in the longitudinal (U_x)direction
- On Edge AC and BD
    - U_z = 0,Couple all the plate nodes to have the same displacement in the transverse (U_y) direction
- Here the stiffener nodes at the edges have not been considered for the coupling. This is mainly to reduce the rigidity of the model which would be induced due to constraint that the stiffener and the plate nodes should not be relatively displaced at the edges.

3.3.Selection Of Representative Panels For Analysis

The panels corresponding to plating observed in Bulk carriers and Oil tankers classed as per Common Structural rules of IACS [29] are selected for analysis. However variation of the dimensions is carried out to study their effects on the ultimate strength. For the present work, it is assumed that the plate and the stiffeners have the same yield strength of 313.6 N/mm^2 considering High Strength steel.

The principal dimensions (listed below) such as the frame and the stiffener spacings are kept unchanged throughout the analyses. The plate thickness, stiffener types and dimensions are however varied to gauge their effect on the ultimate strength. For all the analyses, the number of stiffeners is kept fixed at 8.

a (mm)= 4750

b (mm)= 950

t_p (mm) = 11, 12.5, 15, 18.5, 25, 37

The following are the dimensions of the stiffener

Stiffener type: Tee and Angle

Stiffener size (Applicable to Tee and Angle)

Size 1:

h_w = 235 mm

b_f = 90 mm

t_w = 10 mm

t_f = 15 mm

Size 2:

h_w = 383 mm

b_f = 100 mm

t_w = 12 mm

t_f = 17 mm

For analyses with biaxial loading, the plate thicknesses t_p of 12.5 and 25 mm are considered for the analyses.

3.4.Finite Element Methodology

SHELL281 element of ANSYS is used for the ultimate strength analyses. For the discretization of the model, 6 elements are used along the stiffener spacing direction and 6 elements are used along the stiffener web height. Along the longitudinal direction, the size is chosen in a way so as to permit the elements to maintain an aspect ratio close to unity. Analysis with consideration of both geometric and material non linearities is performed.

4.Validation

The methodology was validated with available reference results [30]. The considered panel had the following particulars.

a (mm)= 2550

b (mm)= 850

t_p (mm) = 9.5, 11, 13, 16, 22, 33

Results were obtained with various stiffener profiles and were compared with other methods such as ALPS/ ULSAP [30], PULS (DNV) [30] and MSC/MARC [30]. These are presented in Figure 2.

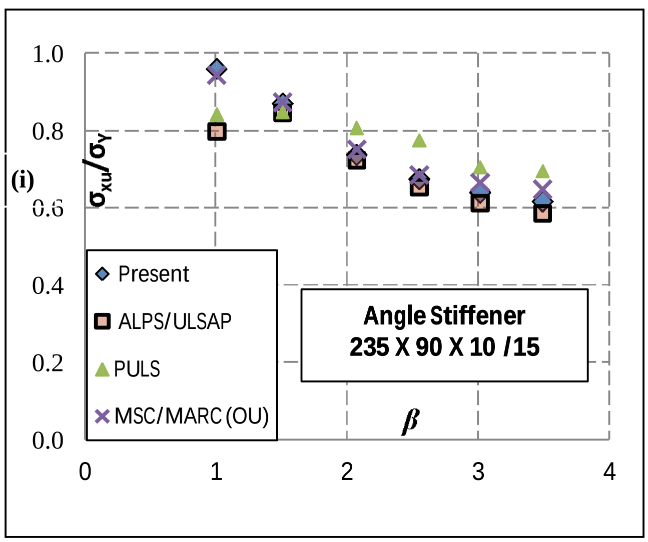

Figure 2: (i)Ultimate Strength for pure longitudinal compression for different plate slenderness ratios

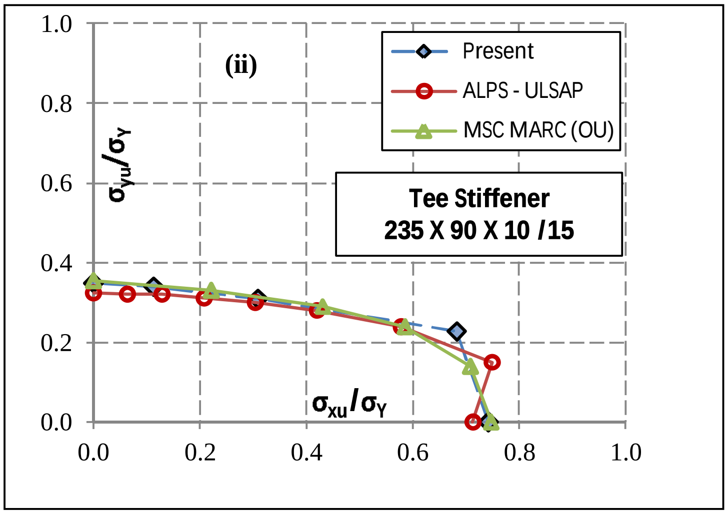

Figure 2:(ii) Biaxial interaction plot for ultimate strength for a typical panel.

The results for longitudinal ultimate strength of the panel with angle stiffener are presented in Fig. 2(i). A good agreement is observed between results predicted by other methods (ALPS/ULSAP and PULS). Agreement with other finite element method based computations (MSC/MARC) is also observed.

The results for the biaxial interaction with different loading scenarios are plotted in Fig. 2(ii). Good agreement is seen between the present results and the reference results.

Thus, the defined methodology works well for the stiffened plate and hence shall be applied for further ultimate strength studies in the present work.

5.Results And Discussion

5.1.Longitudinal Compression

The longitudinal ultimate strengths of the stiffened panels are presented in figure 3.

It can be seen that the size of the stiffener plays a huge role in deciding the ultimate strength characteristics of the plate. For larger sizes of the stiffener, the ultimate strength plot resembles that of a simple panel between two stiffeners, this shows that the stiffener is simply too rigid and failure occurs through the plate between stiffeners. This observation holds true irrespective of the type of stiffener considered whether angle or tee.

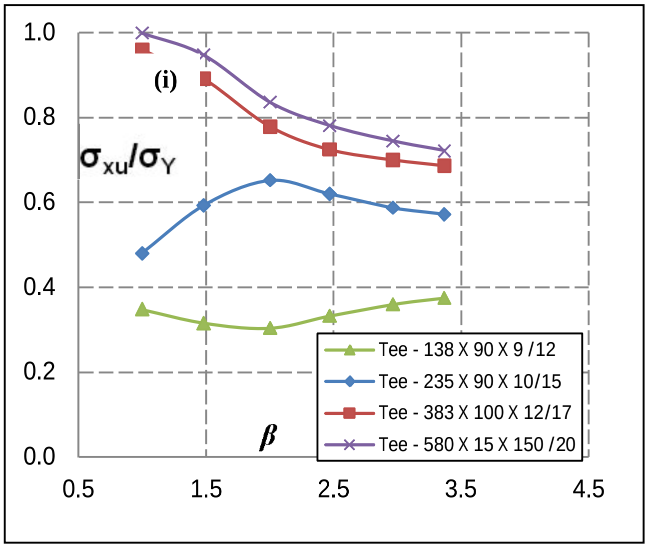

Figure 3:(i)Ultimate longitudinal strength for Tee Stiffeners

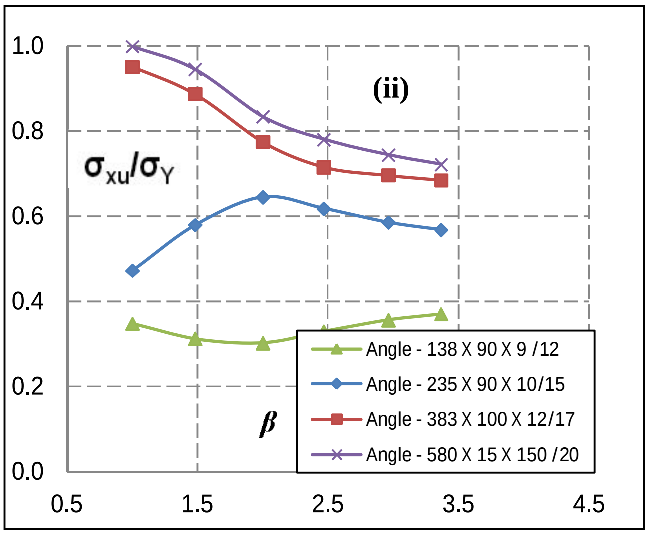

Figure 3: (ii)Ultimate longitudinal strength for Angle Stiffeners.

For lower sized stiffeners, the longitudinal ultimate strength behaviour is difficult to predict. For the lowest size stiffener in figure 3, the ultimate strength initially decreases and then shows an increase with the slenderness ratio. For the next size, the ultimate strength shows an increase with the increasing slenderness and later registers a drop. These phenomena may be explained by the interaction of the plating and the stiffeners. It is clear from figure 3 that for large thickness of plating, the lowest stiffener size proves inadequate to impart rigidity to the panel which thus virtually ends up failing as a whole rather than the plating between stiffeners. For the next size of the stiffener, this becomes less critical as the stiffener and the plate rigidities approach each other.

5.2.Biaxial Interaction

Analyses were also performed for studying the biaxial interaction plots

The interaction plots considering the panel with the Tee stiffeners are shown in figure 4 for various thicknesses. These are also plotted considering the angle profile as well as various stiffener sizes.

It is observed from figure 4 that the ultimate transverse strength of the panels is very much dependent on the plate thickness. The interaction plot shows a change in shape after a given plate thickness or in other words a given slenderness ratio is crossed. The same is reflected in the plots in figure 3.

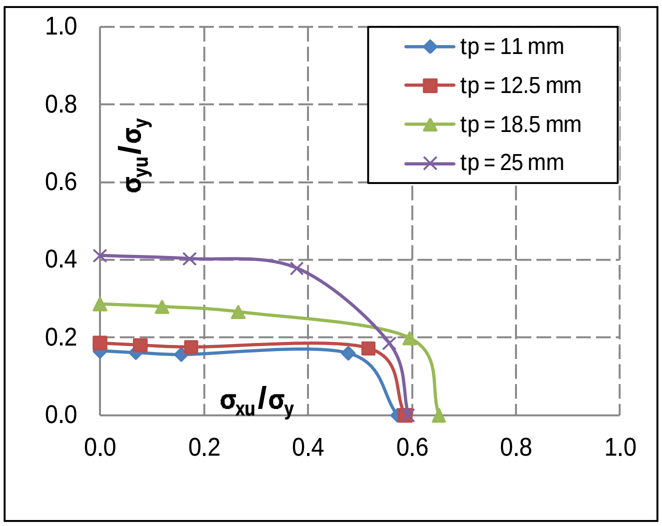

Figure 4: (i) Tee – Size 1

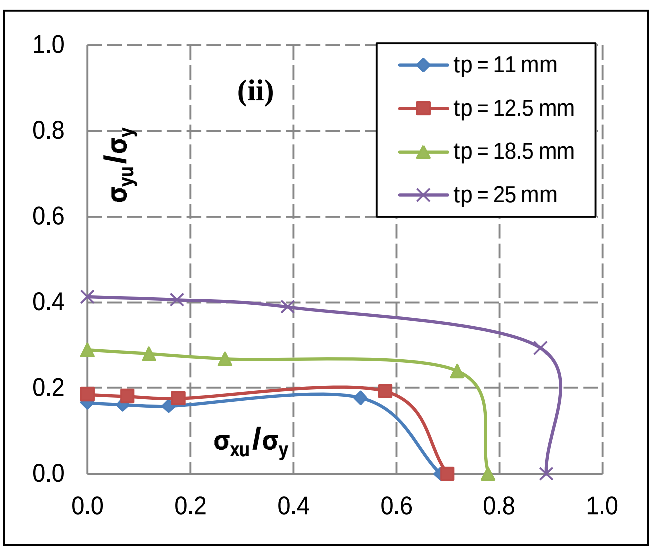

Figure 4:(ii)Tee - Size 2

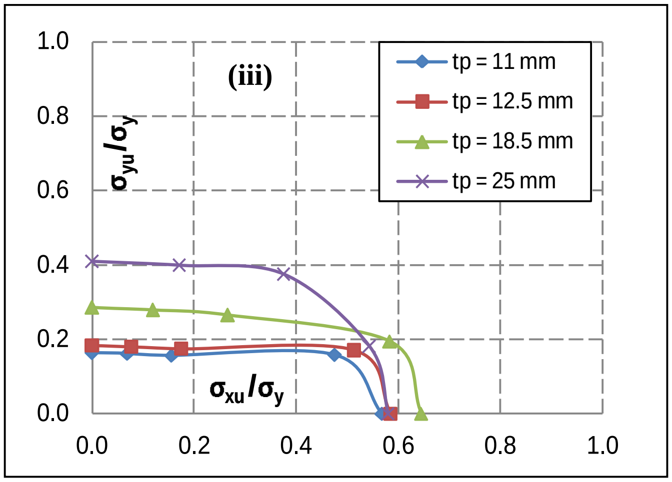

Figure 4: (iii)Angle –Size 1

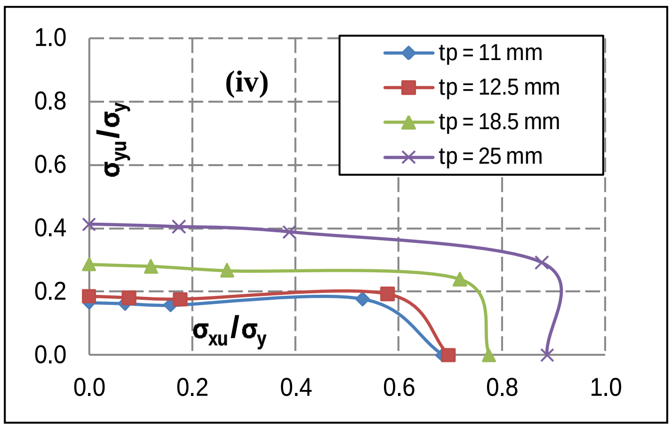

Figure 4: (iv) Angle – Size 2

For the present panel, the stiffener type does not seem to have a major effect on the ultimate strength characteristics at any given thickness. The stiffener size however shows its significance as can be observed lucidly from the differences between figure 4 (i) and (ii) and figure 4 (iii) and (iv).

5.3.Discussion Of The Failure Modes And Load Shortening Curves

The load shortening curves were derived plotting the applied stress load versus the averaged computed strains in the plating along the transverse centreline of the stiffened panel. These are presented through figure 5.

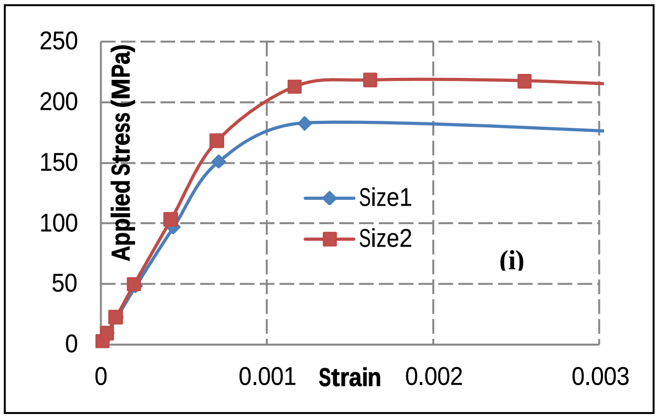

Figure 5: (i) Tee Profile; t_p = 12.5 mm

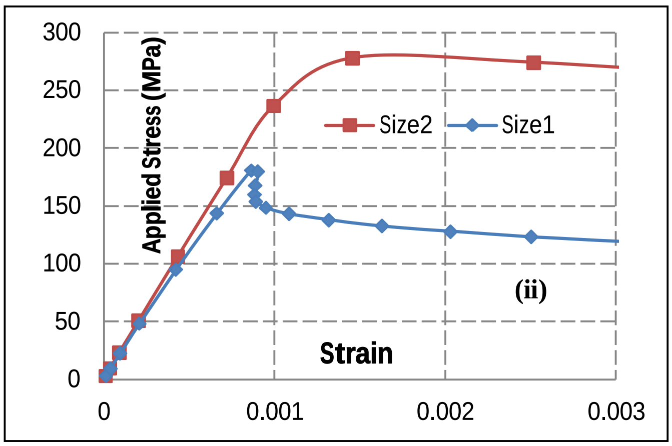

Figure 5: (ii) Tee Profile; t_p = 25 mm

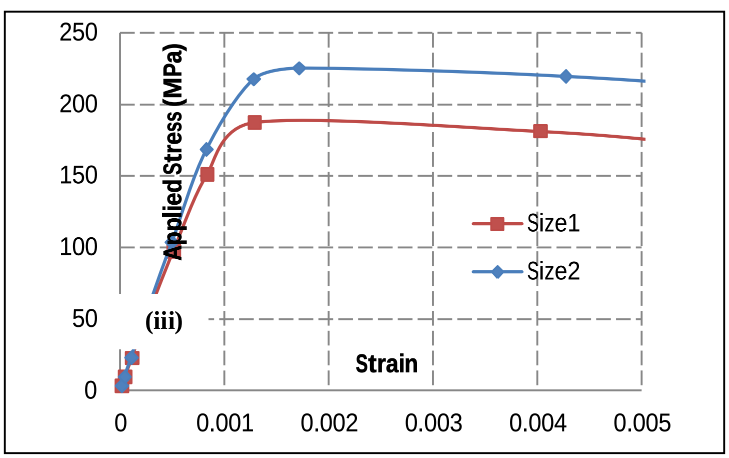

Figure 5: (iii) Angle Profile; t_p = 12.5 mm

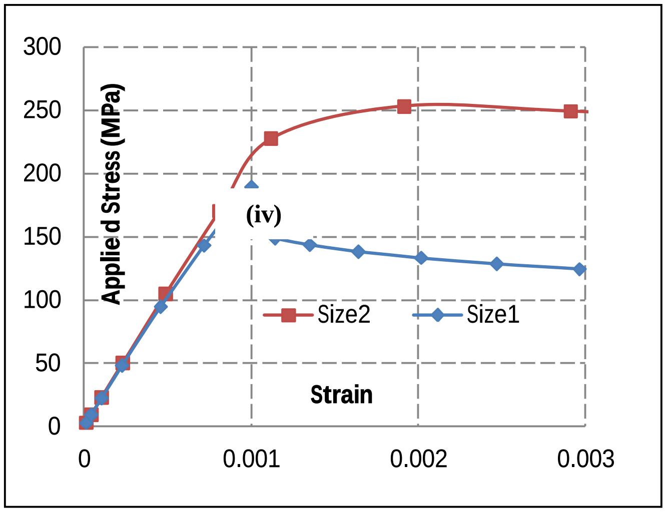

Figure 5: (iv) Angle Profile; t_p = 25mm

From figure 5, for a thickness of 12.5 mm, it can be seen that the load shortening curves are linear and latter flatten out. For higher thickness of 25 mm, the lower stiffener size shows a sudden drop in stress after the linear profile and thus exhibits a softening behaviour. This is attributed to the relative stiffness of the plating compared to that of the stiffener which is low for the stiffener size 1.

For the angle profile, the curves follow an initial linear trend followed by softening behaviour. Similar trend is seen for the angle profile with higher plate thickness of 25mm as was observed with the corresponding Tee profile.

6.Conclusion

A methodology for ultimate strength analysis of stiffened plate with initial imperfections (initial deflections) was performed in the present work. For this purpose a 1 bay 1 frame model was utilized. Through suitable boundary conditions and loading, the model was found to predict the ultimate strength ratio with accuracy as compared to the other reference methods.

It is observed that ultimate strength of a stiffened panel is influenced by the plate dimensions as well as the relative size of the stiffeners. For lower sized stiffeners, the ultimate strength actually decreases with the increased thickness of the attached plating. This effect diminishes as higher stiffener sizes are adopted. For higher stiffener sizes, the plot of the ultimate strength ratio against the plate slenderness ratio resembles that of an unstiffened plate with initial imperfections.

The biaxial compression interaction plots show approximately an elliptical curve, with the major axis lying along the longitudinal direction of the stiffened panel.

The Tee and angle stiffeners seem to perform similarly within the stiffened panel as observed from the load shortening curves. For a higher thickness plate with a relatively flexible stiffener, a sudden drop in the stress is seen after the ultimate strength is achieved. Care must be taken hence to select the appropriate stiffener size with a given plating size.

7.Acknowledgement

The authors are grateful to the Indian Register of Shipping for supporting the reported work.

- **Nomenclature**

a= Frame spacing (mm)

b= Stiffener spacing (mm)

b_f= Width of Stiffener flange (mm)

$h_{w=}$ Depth of Stiffener web (mm)

$t_{p=}$ Plate thickness (mm)

$t_{f=}$ Thickness of stiffener flange (mm)

t_w= Thickness of stiffener web (mm)

$w_{oc=}$ Amplitude of overall imperfection of the stiffened panel (mm)

$w_{os=}$ Amplitude of stiffener sideways imperfection (mm)

$w_{opl=}$ Amplitude of the local initial imperfection of the panel between stiffeners (mm)

$\sigma_{Y=}$ Yield stress of steel (N/mm^2)

E= Elastic modulus of steel (N/mm^2)

B= Plate slenderness ratio

σ_x= Applied longitudinal axial stress (N/mm^2)

σ_{xu} = Ultimate longitudinal axial stress (N/mm^2)

σ_y = Applied transverse axial stress (N/mm^2)

σ_{yu} = Ultimate transverse axial stress (N/mm^2)

τ = Edge shear stress (N/mm^2)

τ_u = Ultimate edge shear stress (N/mm^2)

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