A NEW BUCKLING PREVENTION TECHNIQUE FOR PLATE PANELS CONSTRUCTED WITH HIGHER STRENGTH STEEL

(Report I) -Plate panels subjected to uniaxial compression-

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ABSTRACT

Recently, higher strength steel is widely utilized in plate panels of ship structures. Lighter scantlings with a local plate buckling are expected [1]. Preventing the occurrence of plate buckling by adding a stiffener between the stiffener space, is impractical. In this paper, a new technique is suggested to prevent the occurrence of plate buckling until the ultimate strength of the plate panel is attained. Instead of an additional stiffener, two short end-struts are welded to the ends of the plate panel. These end-struts are called here the buckling prevention end-struts (BPES). The behavior of the plate panel with the BPES under uniaxial compression is analyzed using a FEM program. Several examples of analysis are carried out to examine the effect of the location ,lengths and cross sectional areas of the BPES upon the strength of the plate panel. The results have shown that a proper length of BPES which is much smaller than a stiffener length, welded in the middle ends of the plate panel could prevent the buckling and increase its ultimate strength.

Keywords: Stiffened panel, Overall, Local, Buckling, Yielding, Ultimate strength, Ends-struts.

Nomenclature

a	Plate panel length
a_s	End-strut length
BPES	Buckling prevention end-struts
E	Young's modulus of elasticity
F	Ultimate load
F_y	Yielding load
h_s	End-strut height
t	Plate panel thickness
t_s	End-strut thickness
W_o	Initial deflection
W	lateral deflection
Δ	Acting displacement
Δ_y	Yielding displacement

1. INTRODUCTION

Among the trends of revolution in the shipbuilding industry, stiffened panels are considered for use in large parts of ship structures. Lighter scantlings with a local plate buckling are expected when effectively utilizing the high yield strength of the material. From practical view point on improvement of buckling strength, reducing the stiffener space in proportion to the high yield strength of material is not intelligent solution. A philosophy of buckling accepted design was suggested by accepting the buckling of local plate panels, whereupon a reduction of plate thickness was achieved [1]. However, the buckled plate panels led to non-linear aspects in ship structural behavior.

In this paper a new technique is suggested to prevent the occurrence of a plate buckling under uniaxial compression without increase the numbers of stiffeners in the plate panel. Instead of adding a new stiffener between the stiffener space, two short end-struts are welded to the ends of the plate panel in the same direction of the acting load. The function of the end-struts is to prevent the occurrence of buckling until the ultimate strength of the plate panel is attained. Here, the end-struts are called the buckling prevention end-struts (BPES). The behavior of the plate panel with BPES under uniaxial compression is examined using a FEM program. The FEM program results are checked with results of other numerical methods [2].

Intuitively, the buckling and the ultimate strengths of the plate panel are affected by the location of the BPES in the plate panel. Therefore, three different locations of the BPES laying on the plate panel are suggested. Then, the strength of the plate panel corresponding to each location of BPES is evaluated.

To evaluate the suitable BPES lengths and their cross sectional areas, several analyses are carried out on uniaxially compressed square plate panels with different plate thicknesses. The results have shown that a proper length of BPES which is much smaller than a stiffener length, welded in the middle of the ends of the plate panel could prevent the buckling and increase its ultimate strength.

2. METHOD OF ANALYSIS

A finite element program based on the large deflection elasto-plastic plate theory is used in this research work[3]. The plate element is a four-node quadrilateral element with two membrane and three bending degrees of freedom per node. The material behavior is described using Von Mises yield criterion with the associated flow rule. In addition, elastic-perfect-plastic material behavior is considered. Variable magnitude of prescribed load and/or displacement steps can be used during the calculation. A full Newton-Raphson iterations technique is employed in the program.

To prove the applicability of FEM program in this research work, a comparison is made with an example of thin stiffened plate solved using FINAS program[2]. The dimensions of the plate and the stiffener are 2250x1500x5 and 100x75x7 mm, respectively, as shown in Figure (1). The magnitudes of the yield strength and the Young's modulus are equal to 24 kg/mm^2 and 21000 kg/mm^2 respectively. The stiffened plate is assumed to be simply supported at its edges and subjected to uniaxial compression in x-direction. Based on the symmetric behavior of the stiffened plate under uniaxial compression, the model of analysis is selected as shown in Figure (1). In the model using the FEM program, the stiffener is assumed to be connected to the plate panel at the middle surface nodes.

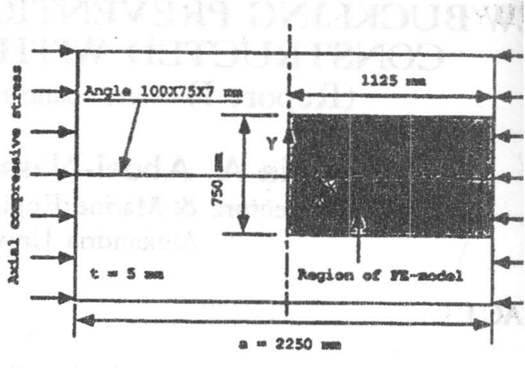

Figure 1. Mesh division of the stiffebed pa

Figure (2) shows the relationship betw normalized load and displacement for the s plate computing using both the employed F FINAS programs. In the elastic stage and buckling, the results of analyses are nearly th however, after buckling there is a slight diffe the results. This is mainly due to the diffe modeling the connection between the plate stiffener at the weld line. Generally, there i agreement between the results computed FEM and that obtained using FINAS progr

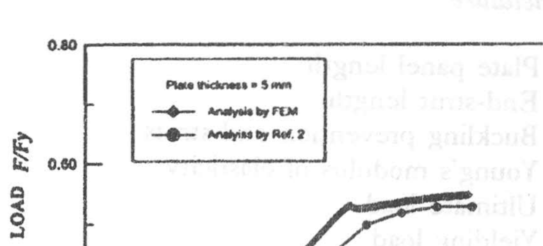

Figure 2. Normalized load-displacement relat of uniaxially compressed stiffened plates.

3. PROPOSED BUCKLING PREVENTION ENDS-STRUTS TECHNIQUE

Traditionally in shipbuilding, Increasing the buckling strength of a plate panel by reducing the stiffener space in proportion to the yield strength of the material is widely applied. Although, this technique is simple but from the economical and the strength view points is impractical. From the economical view point, the reduction of the stiffener space will increase the numbers of stiffeners in the plate panel. This leads to increase in both the material and the fabrication costs. In addition, imperfection aspect costs due to the welding of additional stiffeners to the plate panel will also increase [4]. From the strength view point, reducing the stiffener space leads to an excessive local buckling strength of the plate panel. In this case, the occurrence of the initial yielding of the plate panel may take place first. Otherwise, the failure of the plate panel is inevitably occurred due to yielding, in spite of the high buckling strength.

In this research work, a new technique is suggested to increase the buckling strength of a plate panel with a reasonable safety factor and without adding a new stiffener to reduce the stiffener space. Based on the known behavior of the buckled plate panel under uniaxial compression, it is found that the out of plane deflection may be reduced when a short strut is welded to the plate panel in the same direction of the acting load . To achieve a further reduction in the developed deflection, a strut at each end of the plate panel is welded. Strictly speaking, when the struts have sufficient dimensions and proper locations, the developed deflection is drastically decreased and the plate strength is increased [5].

Therefore, two short end-struts instead of a complete stiffener are suggested to be welded to the ends of the plate panel in the same direction of the acting load. Each strut has a length, a_s which is much smaller than the stiffener length, a and a rectangular cross sectional area of a thickness,t_s and a height ,h_s. When selecting the proper location of the struts and determine their dimensions, the end-struts enable to prevent the occurrence of buckling and to increase the ultimate strength of the plate panel.

To examine the effect of the strut locations on the strength of the plate panel, several analyses have been carried out using the FEM program. For simplicity, a square plate panel of 1000x1000x12 mm and with a yield strength equals to 25 kg/mm^2 is considered. The plate panel is assumed to be simply supported around its edges and subjected to uniaxial compression. In these analyses, the struts dimensions are kept constant and three different locations of the struts in the plate panel are selected as shown in Figure (3). The three locations are as follows;

i- Two ends-struts are located in the middle of the ends of the plate panel Figure (3a).

ii- Two struts are located in the central of the plate panel Figure (3b).

iii- Two ends-struts are located near the side on the ends of the plate panel Figure (3c).

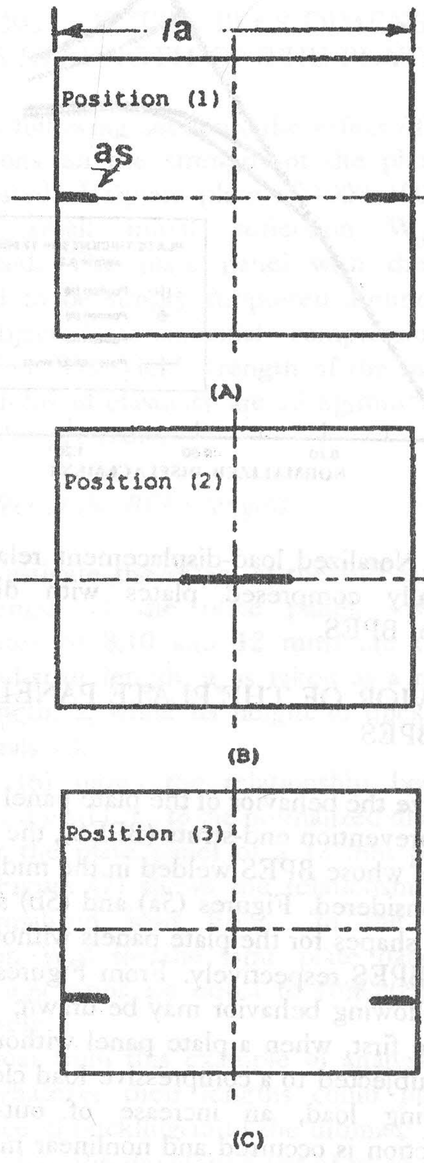

Figure 3. Possible locations of BPES in the plate panel.

Figure (4) shows the normalized load-displacement relationships for the plate panel with the three locations of the struts. It may be concluded that the best location of the struts which prevent the occurrence of the buckling and increase the ultimate strength is in the middle of the ends of the plate panel. Hence, these two end-struts are called the buckling prevention end-struts (BPES).

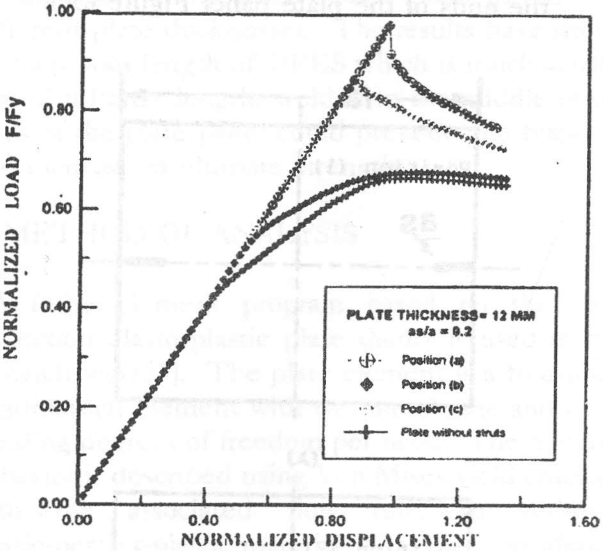

Figure 4. Noralized load-displacement relatiosnhip of uniaxially compressed plates with diefferent locations of BPES.

4. BEHAVIOR OF THE PLATE PANEL WITH THE BPES

To analyze the behavior of the plate panel with the buckling prevention end-struts (BPES), the previous plate panel whose BPES welded in the middle of its ends is considered. Figures (5a) and (5b) show the deflection shapes for the plate panels without BPES and with BPES respectively. From Figures (4) and (5), the following behavior may be drawn;

a- At the first, when a plate panel without BPES and subjected to a compressive load close to its buckling load, an increase of out-of-plane deflection is occurred and nonlinear membrane and bending stresses are developed in the plate panel. Here, the buckling load is referred to the critical buckling stress of the plate panel without BPES under uniaxial compression only. With the increase of the acting load, the ultimate strength is reached with a value much smaller than the yielding load [6].

b- In case of a stiffened plate panel under uniaxial compression, the stiffened plate will buckle either in local mode or in overall mode depending on the minimum stiffness ratio of the stiffener to the plate [7 and 8]. Consequently, the collapse will occur in either local or overall modes depending on a minimum stiffness ratio similar to that of the buckling strength [8].

c- In case of the plate panel with BPES, its behavior is different from both the behavior of the plate panel without BPES and the behavior of the stiffened plate panel. At the beginning, when the acting load is smaller than the buckling load, this plate panel shows no deflection in its field and only linear membrane compressive stresses are developed along its edges.

d- With a higher load than the buckling load, the plate panel with BPES has shown a negligible deflection in the plate field, particularly in the regions beside the end-struts. It should be mentioned here, that the plate panel with BPES is still carrying additional load without any occurrence of buckling. This indicates that the end-struts (BPES) enable to prevent the occurrence of buckling and to increase the plate buckling strength.

e- With a further acting load ,the plate panel with BPES will buckle into either local or overall modes depending on the stiffness ratio of the BPES to the plate panel. Here, the overall buckling mode is similar to that of a stiffened plate panel. The plate panel and the BPES buckle together in the same buckling mode accompanied with a large deflection in the whole plate field. While the local buckling mode of the plate panel with BPES is accomplished by the occurrence of buckling only in the central region of the plate field as shown in Figure (5b). Clearly, the deflection has developed in the off-struts regions, while the regions beside struts have shown no deflection in this mode.

f- The occurrence of buckling in the plate panel with BPES is accompanied with a substantially increase in the membrane and bending stresses in the plate panel. When the resultant stresses at a point satisfies the specified yielding condition [9], the initial yielding at this point is occurred. Then, yielding gradually spreads to locations of higher stresses. Finally the ultimate strength of the plate panel is attained. It should be clarified that the location of the initial yielding is changed according to the buckling mode of the plate panel with BPES. After the overall buckling had occurred, the initial yielding is occurred in the central region of the plate field, then the yielding spreads to the regions around the end-struts. Contrary, in case of local buckling, the initial yielding is occurred in the regions beside the end-struts, then yielding spreads to the central region.

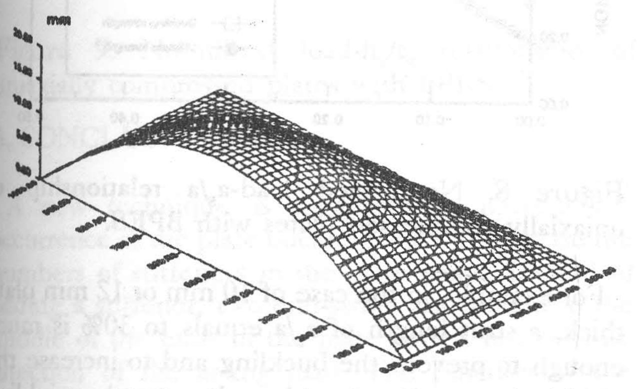

Figure 5a. Deflection mode of a plate panel without BPES.

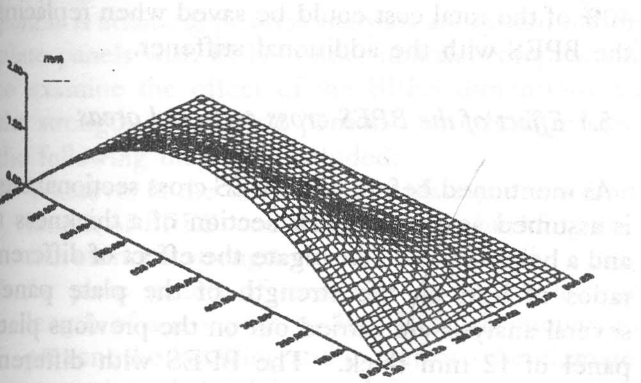

Figure 5b. Deflection mode of a plate panel with BPES.

g- In this technique, the developed deflection in the plate panel with BPES is smaller than that of the plate panel without BPES. Also values of the buckling and the ultimate strengths become higher. However, highly local stresses will be developed in the plate panel field. These stresses have a significant effect on the fatigue strength of the plate panel, particularly when it subjected to combined lateral and im-plane loading. This problem will be investigated in a further research work.

5. EFFECT OF THE BPES DIMENSIONS ON THE STRENGTH OF THE PLATE PANEL

In the following sections, the effect of the BPES dimensions on the strength of the plate panel is investigated. A square plate of 1000x1000 mm and with a small initial deflection $W_o/t=0.01$ is considered. The plate panel with the BPES is assumed to be simply supported around its edges and subjected to uniaxial compression in the x-direction. The yield strength of the material and the modulus of elasticity are 25 kg/mm^2 and 21000 kg/mm^2 respectively.

5.1 *Effect of the BPES lengths*

To investigate the effect of the BPES lengths on the strength of the plate panel, several plate thicknesses of 8,10 and 12 mms are considered. Each end-strut length, a_s is taken as a ratio of the plate length, a, while its height to thickness ratio, h_s/t_s equals 10.

Figure (6) shows the relationship between the normalized load F/F_y to the normalized displacement Δ/Δ_y for the plate panel of a 12 mm plate thick. While, Figure (7) shows the relationship between the normalized load F/F_y to the maximum deflection W_o/t for the same plate panel. In this analysis a_s/a ratios are equal to 10%,20% and 30% respectively.

It is clear from this example of analysis that the BPES whatever their lengths could prevent the occurrence of buckling until the ultimate strength is attained. Also the developed out-of-plane deflection is sharply reduced in the plate panel. However, values of the buckling and the ultimate strengths are changed according to how long are the BPES lengths.

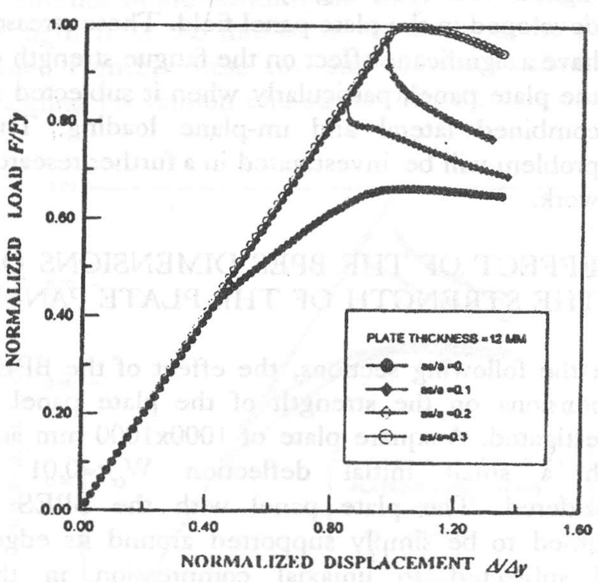

Figure 6. Normalized load-displacement relationshp of uniaxially compressd plates with BPES.

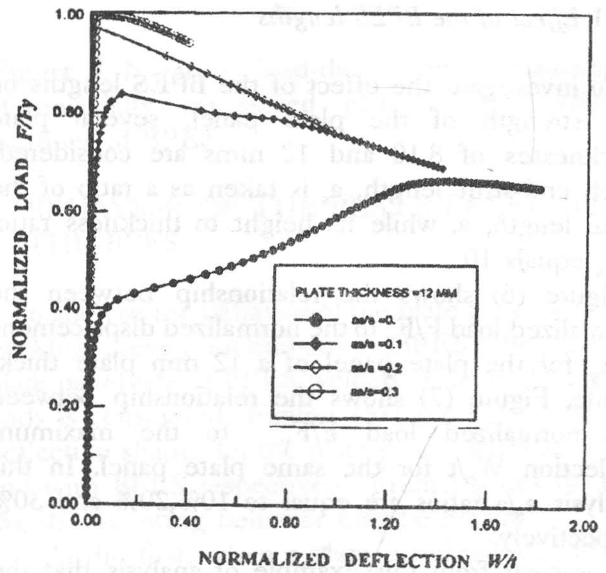

Figure 7. Normalized load-deflection relationship uniaxially compressed plates with BPES.

Figure (8) shows the relationship between the normalized load F/F_y to a_s/a ratios for the above mentioned plate panels. It is noted here that the thicker plate has the same value of the buckling and the ultimate strengths in spite of the change in a_s/a ratios of BPES. While the thinner plate panels with BPES of small a_s/a ratio are buckled first, then their ultimate strengths are reached. Strictly speaking, for thinner plate panels longer BPES are required to increase the buckling and the ultimate strengths to a value close to the yielding load. While for thicker plate panels shorter BPES are enough to reach the ultimate strength near to the yielding load.

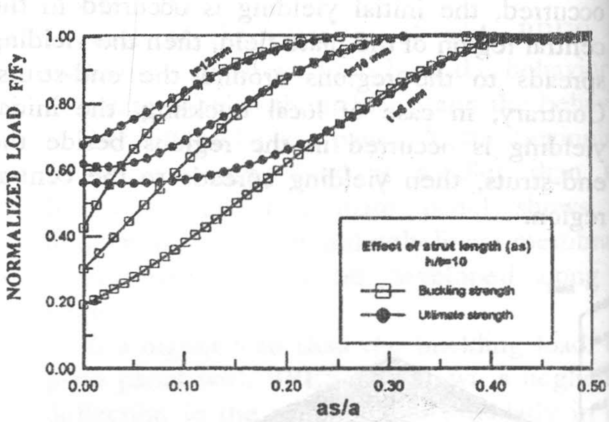

Figure 8. Normalized load-a_s/a relationship of uniaxially compressed plates with BPES.

For example, in the case of 10 mm or 12 mm plate thick, a strut length of a_s/a equals to 30% is much enough to prevent the buckling and to increase the ultimate strength to a value close to the yielding load as shown in Figures (7) and (8). It means about 40% of the total cost could be saved when replacing the BPES with the additional stiffener.

5.1 *Effect of the BPES cross sectional areas*

As mentioned before, the BPES cross sectional area is assumed as a rectangular section of a thickness t_s and a height h_s. To investigate the effect of different ratios of h_s/t_s on the strength of the plate panel, several analysis are carried out on the previous plate panel of 12 mm thick. The BPES with different ratios of a_s/a are also considered.

Figure (9) shows the relationship between the normalized load F/F_y to h_s/t_s ratios. When the ratio of h_s/t_s increases up to 10, the buckling and the ultimate strengths are slightly increased. Wherein, the plate panel with BPES is buckled in the overall mode and its ultimate strength is also attained in the same mode. For h_s/t_s values higher than 10,the plate panel with BPES is locally buckled and hence its buckling and ultimate strengths are independent on h_s/t_s ratios.

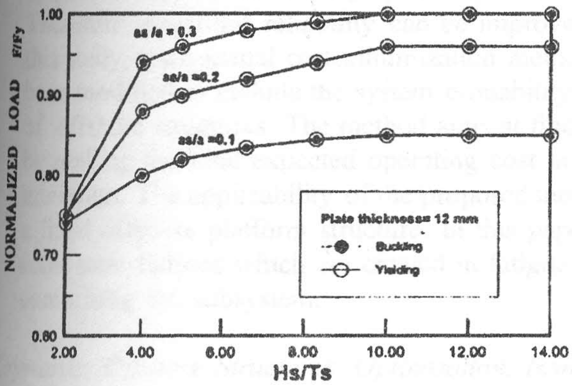

Figure 9. Normlized load-h_s/t_s relationship of uniaxially compressed plates with BPES.

6. CONCLUSIONS

A new technique is suggested to prevent the occurrence of the plate buckling without increase the numbers of stiffeners in the plate panel. Instead of adding a stiffener, two end-struts are welded in the middle of the ends of the plate panels in the same direction of the acting load. The function of the end-struts (BPES) are to prevent the occurrence of buckling until the ultimate strength of the plate panels is attained. Several analyses are carried out on plate panels with BPES under uniaxial compression to examine the effect of the BPES dimensions on the strength of the plate panels. From these results, the following may be concluded;

1- Whatever is the thickness of a plate panel, a short length of BPES could increase the buckling and the ultimate strengths of the plate panel.
2- for plate panels of moderate thickness, a strut length of a_s/a equals to 30% is much enough to prevent the buckling and to increase the ultimate strength to the yielding load. It means about 40% of the total cost could be saved when replacing the BPES with the additional stiffener.
3- For thinner plate panels longer BPES are required to increase the buckling and the ultimate strengths to a value close to the yielding load. However, BPES lengths are still smaller than a replacing stiffener.
4- Practical values of h_s/t_s ratios of the BPES have a slight effect on the ultimate strength of the plate panel.

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