2004년도 해양환경안전학회 춘계학술발표회

論 文

A Study on the Ultimate Strength Behaviour of Stiffened Plate according to the Stiffener Section

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ABSTRACT: *A steel plated is typically composed of plate panels. The overall failure of the structure is certainly affected and can be governed by the bulking and plastic collapse of these individual members. In the ultimate limit state design, therefore, a primary task is to accurately calculate the buckling and plastic collapse strength of such structural members. Structural elements making up steel palated structures do not work separately, resulting in high degree of redundancy and complexity in contrast to those of steel framed structures. To enable the behavior of such structures to be analyzed, simplifications or idealizations must essentially be made considering the accuracy need and degree of complexity of the analysis to be used. Generally the more complex the analysis the greater is the accuracy that may be obtained. The aim of this study is the investigation of the effect of the tripping behaviour including section characteristic for a plate under uniaxial compression.*

For this purpose of study, in used elasto-plasticity deformation FEA method are used for this study.

KEY WORDS : Ultimate limit state design, Buckling, Plastic collapse, Tripping, Ultimate strength

1. Introduction

A steel plating structure is typically composed of plate members. The overall failure of the structure is certainly affected and can be governed by the buckling and plastic collapse of these individual members. In the ultimate limit state design, therefore a primary task is to accurately calculate the buckling and plastic collapse strength of such structural members. Structural elements making up steel plated structures do not fuction separately, resulting in high degree of redundancy and complexity in contrast to those of steel framed structure. Conventionally, the possible failure modes of a stiffened plate subject to predominantly compressive loads are categorized into the following five types, namely

[1] Overall collapse after overall buckling
[2] Plate-induced (Overall) collapse after local buckling between stiffeners.
[3] Stiffener-induced (Overall) collapse after local buckling between stiffeners (except rotation ofstiffner)
[4] Torsional / Flexural buckling (Tripping) of stiffener
[5] Gross yielding

The collapse of stiffened panels can be postulated to occur at the lowest value among the variety ultimate loads calculated for each of the above failure modes. In case ship's stiffened panels, the collapse mode [2]-[4] are usually happened. A number of studies on the collapse mode [2] and [3] have been reported in the literature, while relatively less work on collapse mode [4]. Tripping behavior appears to exist so far. However, tripping remains an important failure mode, since once tripping occurs for a stiffener, the stiffened panel plating is left with no effective stiffening and global failure of the whole stiffened panel can be followed.

Tripping is thus a phenomenon potentially leading to rapid unloading of the stiffened panel, and such failure is an undesirable occurrence for a structure. In case ship's, stiffened plate with flat-bar section contain relatively little torsional rigidity which are susceptible to tripping or local buckling are widely used due to their simplicity in fabrication. In the case, one should be careful to design the stiffened panel such that tripping behavior and web local buckling are widely used because of there simplicity in fabrication. In such cases, one would be careful to design the stiffened panel so that tripping behavior or local buckling of stiffner would not occur earlier than buckling of the plating between stiffeners. To analysis this perpectly, a good basic understanding of the characteristics

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of tripping behavior or web local buckling with flat-bar section stiffeners must be satisfy requirement.

A brief review of earlier work related to tripping is first made in order. Bleich [1] and Timoshenko and Gere [2] both give the governing differential equation for instability of stiffeners by torsion and bending, and also provide various solutions of the equations for certain loading cases and edge conditions. Following these early necessary work, other noteworthy past studies of tripping are as follows.

Faulkner [3] gives a detailed description of lateral-torsional instability (tripping) of stiffeners welded to continuous plating. Caridis [4] performed a series of elasto-plastic large deflection analyses for stiffened panels under uniaxial compression. The interaction effects between flexural and torsional buckling of stiffened panel on the collapse behavior are accounted for. The influence of the aspect ratio, the slenderness ratio, and the initial deflections of plating on the collapse behavior of the stiffened panel was investigated.

Tanaka and Endo [5] carried out analytical, numerical and experimental investigations on the local buckling of stiffeners in compression, taking into account the interaction effects of stiffener and plating. Based on the results, they suggested the critical value of slenderness ratio for flat-bar stiffeners which would separate their anticipated behavior into two distinct zones, namely tripping of stiffener and local buckling of plating between stiffeners.

Panagiotopoulos [6] carried out parametric nonlinear finite element calculations to assess the interactive flexural-torsional failure behavior of flat-bar stiffeners in stiffened panels under uniaxial compression. The influence of the rotational restraint at the plate-stiffener intersection on the tripping strength of outstands in stiffened panels was studied.

Yao et al. [7] performed a series of elasto-plastic large deflection finite element analyses for stiffened panels with flat-bar type of stiffeners under uniaxial compression. the influence of dimensions of the stiffener web on the buckling and collapse behavior of stiffened panels was investigated.

Hughes and Ma [8] proposed an elastic tripping model using the Rayleith-Ritz approach. They extended the elastic model into the inelastic range, using deformation theory and an iterative formulation [9].

More recently, Paik et al. [10] analytically investigated the tripping strength of a stiffener web under uniaxial compression as a characteristic value problem. The governing differential equation for a stiffener web which is simply supported at its loaded edges and elastically restrained at the plate-stiffener intersection or at the edge of the stiffener web attached to the stiffener flange was analytically solved. A series of analyses were carried out varying the aspect ratio of the stiffener web and the torsional rigidities of plating and stiffener flange. Based on the computed results, closed-form approximate expressions suitable for predicting the tripping strength of a flat-bar stiffener web were derived. Design guidelines for predicting tripping in stiffened panels were also suggested.

Other tripping related design guidelines also exist. In particular, the International Association of Classification Societies (IACS) [11] and also leading classification societies (e.g. ABS) [12] provide widely used design formulations validated by service experience.

Not all existing studies and guidelines related to tripping are necessarily complete in terms of the phenomena they consider. Tripping often occurs in stiffened panels with stiffeners which have relatively little torsional rigidity. Tripping of stiffener web and buckling of plating between stiffeners normally interact, and they can take place in either order, depending on the relative dimensions of plating and stiffener. In particular, many of the existing studies do not account for the interacting effects of tripping and local buckling of plating between stiffeners and the influence of elasto-plastic rotational restraint at the plate-stiffener intersection.

The objectives of the present study are to investigate numerically the characteristics of tripping behavior of flat-bar stiffeners and also to study the accuracy of two selected design formulations for predicting the local buckling strength of the stiffener web. To account precisely for the interacting effects of stiffener tripping and local buckling of plating between stiffeners and also the influence of elasto-plastic rotational restraint at the plate-stiffeners intersection, the nonlinear finite element method is applied. The conventional finite element method normally requires a large amount of computer time when applied in the nonlinear analysis of structures. Further, the use of such procedures requires expert knowledge. In this context, a simplified special purpose nonlinear finite element method is developed and demonstrated in the present study for more easily and efficiently predicting the nonlinear behavior of stiffened panels. While demonstrated for the important case of flat-bar stiffeners, the finite element method developed is considerably more general applicability.

A series of elasto-plastic large deflection finite element analyses for stiffened panels with flat-bar type of stiffeners under uniaxial compression are carried out varying the proportions of plating and stiffeners web. Based on the results of the parametric study, a basic investigation for tripping with flat-bar stiffeners is undertaken. The accuracy of three existing design formulations for predicting the critical buckling strength of the flat-bar stiffener web, one from IACS [11] and the Paik thesis and the other from FEM theoretical results are investigated by comparing the relevant theoretical solutions with corresponding finite element results.

2. Geometric and material propertise

The first geometric properties of the structure are;

a = 1200mm, b = 600mm, $t_p = 7mm$,

$t_w = 3.5 - 20mm,\ h_w = 77 - 270mm$

are considered in the analysis. The material yield stress for both plating and stiffeners is 352.8MPa, Young's modulus is 205,800MPa and Possion's ratio is 0.3. It is assumed that plating between stiffeners has the buckling mode initial deflection of 1.8mm which corresponds to $0.1 \times \beta^2 \times t$ where $\beta = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}}$. The column type or sideways initial deflection of the stiffeners between transverse frames are considered to be 0.0015a respectively. Residual stress is not contain this analysis for welding or cutting.

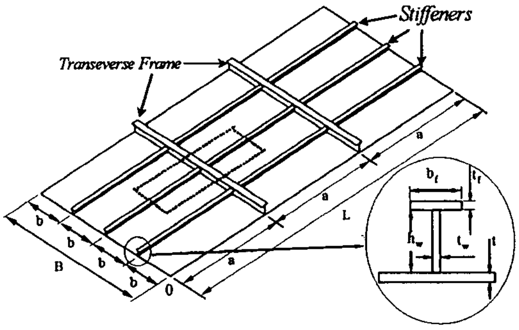

Fig.1 Range in used analysis of finite element method

The second geometric properties of the structure are;

a = 2640mm, b = 900mm, $t_p = 21mm$,

$t_w = 6 - 16mm,\ h_w = 150 - 350mm$ are considered in the analysis. The material yield stress for both plating and stiffeners is 313.6Pa, Young's modulus is 205,800MPa and Possion's ratio is 0.3. It is assumed that plating between stiffeners has the buckling mode initial deflection of 10.3mm which corresponds to $0.1 \times \beta^2 \times t$ where $\beta = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}}$. The column type or sideways initial deflection of the stiffeners between transverse frames are considered to be 0.0025a respectively. Residual stress is not contain this analysis for welding or cutting.

3. Finite Element Analysis - [1]

To investigated the characteristics of tripping behavior of the stiffened plate with flat-bar section stiffeners, a parametric series of nonlinear finite element analysis were carried out by varying the stiffener web dimensions and the magnitude of initial imperfections, see Table 1.

Table 1. Dimension of flat-bar stiffened plates

	a	b	t_p	h_w	t_w	h_w/t_w
F1	1200	600	7	154	7	22
F2	1200	600	7	154	3.5	44
F3	1200	600	7	154	10	15.4
F4	1200	600	7	77	7	11
F5	1200	600	7	231	7	33
F6	1200	600	7	154	18	8.56
F7	1200	600	7	154	20	7.7
F8	1200	600	7	154	14	11
F9	1200	600	7	154	5	30.8
F10	1200	600	7	112	7	16
F11	1200	600	7	192	7	27.43
F12	1200	600	7	270	7	38.57

in the present analysis, parametric studies are performed under the following two variables.

[1] Varying the thickness of the stiffener web, with the web height kept constant and [2] varying the height of the stiffener web , with the web thickness kept constant. The model F1 of Table 1. is considered the reference case, against which all other results of the parametric study cases are compared.

The ultimate strength solution by four methods, namely the present special purpose FEM, IACS formula and Paik formula and ANSYS results are compared Table 2. It should be noted here that two design formulations are based solely on the local buckling modes for the plating and stiffener web, during all potential failure modes and their interacting effects are included in the FEM results.

Table.2 Dimension and analysis results of flat-ba stiffened plates

	FEM	IACS	*Paik*	*ANSYS*
F1	0.424	0.355	0.425	0.412
F2	0.336	0.272	0.298	0.287
F3	0.458	0.479	0.519	0.510
F4	0.365	0.372	0.382	0.380
F5	0.401	0.307	0.397	0.391
F6	0.512	0.651	0.657	0.652
F7	0.527	0.673	0.677	0.677
F8	0.498	0.588	0.604	0.602
F9	0.367	0.292	0.355	0.341
F10	0.404	0.380	0.409	0.410
F11	0.417	0.327	0.421	0.415
F12	0.386	0.291	0.362	0.354

Comparison of formula and finite element results. the ultimate strength solutions by four method, namely the present special purpose finite element method, the IACS formula and the ANSYS results are compared in Table 2. It should be noted here that the two design formulations are based solely on the local buckling modes for the plating and the stiffener web, while all potential failure modes and their interacting effects are included in the finite element results.

As shown in Figs. 2 and 3, a threshold value of the slenderness ratio of the stiffener web which serves to individual plate and stiffener web buckling failure modes can be discerned. The zone where the critical tripping strength is less than the magnitude of the ultimate strength by the finite element method is where tripping of the stiffener occurs earlier than collapse of plating between stiffener. This particular ordering of the two failure modes is normally undesirable design. It is seen from the results that the relevant threshold value for the slenderness ratio of the stiffener web is approximately $h_w/t_w = 12$ from results based on the pessimistic IACS method and about 22 from the more optimistic Paik method and about 22.2 from the more optimum results in present analysis.

This is based on a limited series of results with only one plate slenderness ratio having been considered, and to defined a more accurate threshold value further study is needed. To prevent tripping prior to plate collapse between stiffeners, the slenderness ratio of the flat-bar stiffener web in any particular case needs to be less than the threshold value noted. In this respect, it is seen that in comparison to the finite element results, the Paik formulation together with Johnson-Ostenfeld plasticity correction appears to provide reasonably accurate solutions for tripping failure of a flat-bar stiffened panel. The exact threshold value, however, is expected to be somewhat less than 22.2, because neither the finite element results nor the Paik formula includes potential residual stress effects. It is noted in this regard that a limited value of 16 is sometimes used in the tripping design of mild steel structures stiffened by flat bars [12]. This value, while strictly experience based, thus does not appear to be an unreasonable one to use.

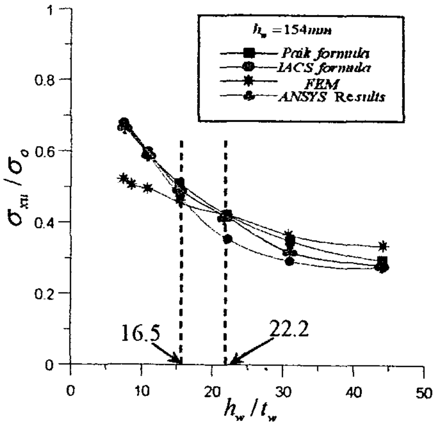

Fig.2 Ultimate strength of flat-bar stiffened panels varying h_w/t_w ratio

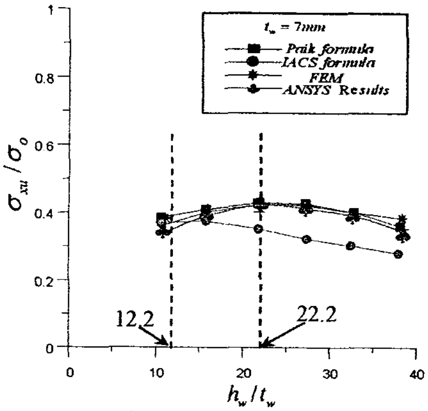

Fig.3 Ultimate strength of flat-bar stiffened panels varying h_w/t_w ratio

As a comparison to our results, we refer to the following existing proposals and design guidance for potentially avoiding tripping in flat-bar stiffeners of steel (converted to a yield strength basis assuming high tensile steel parameters where the original work provides a height to thickness limit alone)

3. Finite Element Analysis - [2]

The second analysis is extend to actual model in 4000TEU container ship. Fig. 4 and 5 show the variation of the ultimate strength for flat-bar stiffened panels. The height of the stiffener web regularly increases, express the highest ultimate strength on the web height 200mm. while express the lowest ultimate strength on the web height 150mm. Furthermore, case 5 is evaluated for in plane-rigidity equal zero after ultimate strength. Flat-bar stiffener is depend on ultimate strength in basis of web height 200mm but web thickness do not cause large effect on ultimate strength. In this case, web thickness 8mm express the most efficient strength and web height 6mm is happened complicated tripping behavior early point.

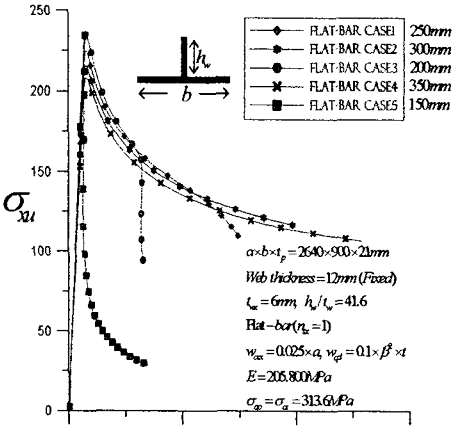

Fig.4 A comparison stress with strain at the flat-bar stiffened plate of container ship(4,000TEU)

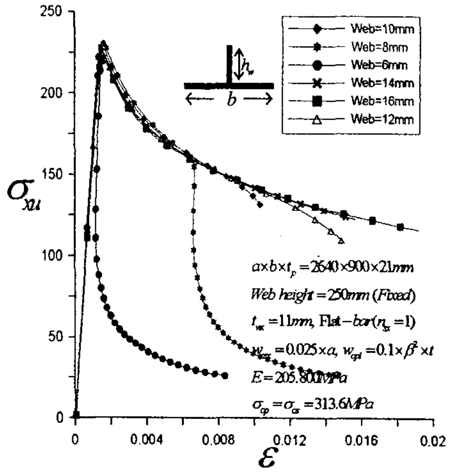

Fig.5 A comparison stress with strain at the T-section bar stiffened plate of container ship(4,000TEU)

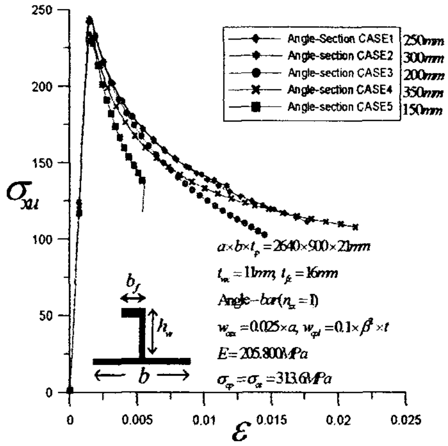

Fig.6 A comparison stress with strain at the Angle-bar stiffened plate of container ship(4,000TEU)

Fig. 6 and 7 show the variation of the ultimate strength for angle-bar stiffened panels. web height 200, 250, 300mm are equal to evaluate ultimate strength value and do not effect strength with angle-bar stiffener. If stiffened panels have a flange, it should be evaluated more high stiffness.

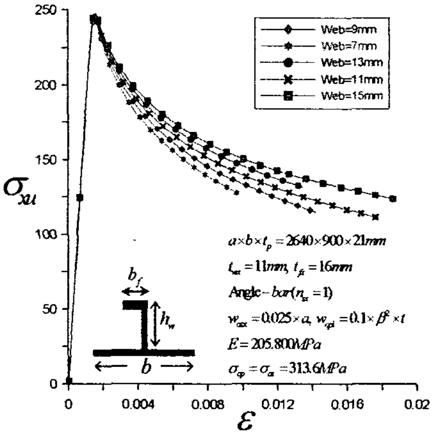

Fig.7 A comparison stress with strain at the Angle-bar stiffened plate of container ship(4,000TEU)

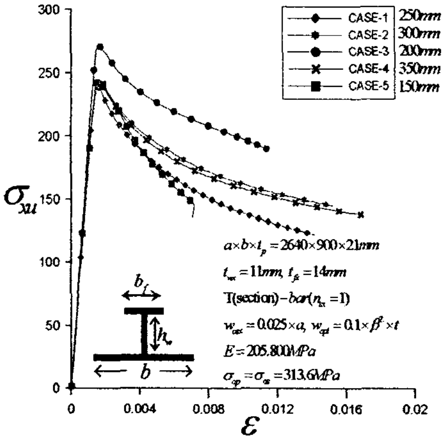

Fig.8 A comparison stress with strain at the Angle-bar stiffened plate of container ship(4,000TEU)

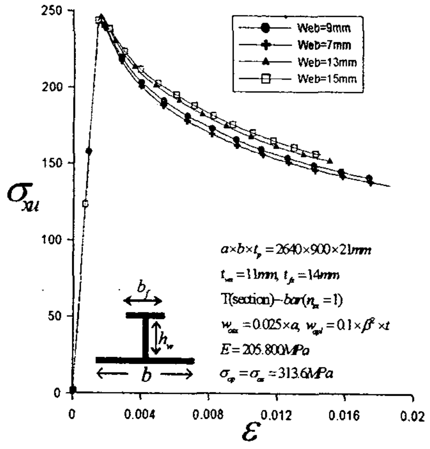

Fig.9 A comparison stress with strain at the Angle-bar stiffened plate of container ship(4,000TEU)

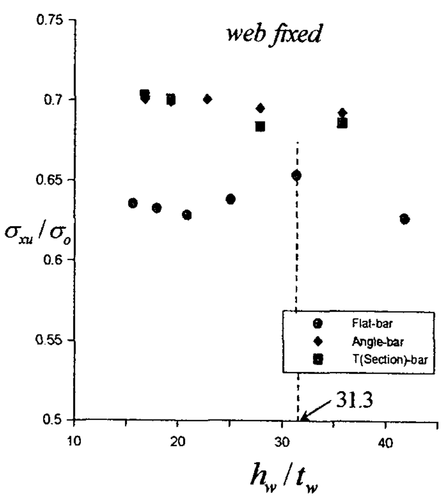

Fig.10 A comparison average-stress with h_w/t_w at each stiffener section on the web height fixed condition

Fig. 8 and 9 show the variation of the ultimate strength for T(section)-bar stiffened panels.

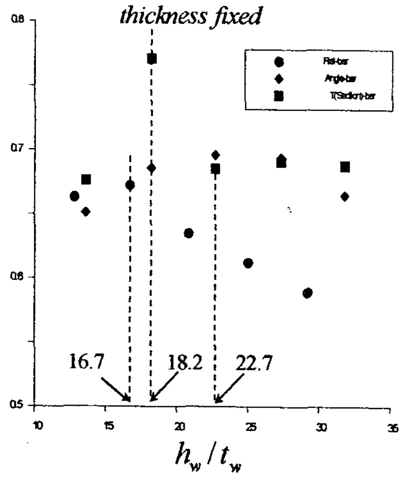

Fig.11 A comparison average-stress with h_w/t_w at each stiffener section on the web thickness fixed condition

Fig 8 is evaluated most highest ultimate strength in contrary to the each cases on the web height 200mm.

Fig. 10 is show ultimate strength behavior according to the each stiffener section in the web height fixed condition. Flat-bar stiffened panel is distinguish from strength but not divide with flange type.

Fig. 11 in used dot line indicate tripping critical point each stiffener section designed to be less more 22.2. The objectives of the present study are to analysis numerically the characteristics of tripping of flat-bar, angle-bar and t-bar stiffened panels subject to uniaxial compressive loads, and also to investigate the accuracy of two existing design formulations for predicting the buckling strength of a stiffener web in such panels.

A simplified nonlinear finite element method which is capable of more efficiently analyzing the elasto-plastic large deflection behavior of a stiffened panel is developed and used in the study. A benefit of the application of the nonlinear finite element method of that it makes possible a more precise accounting and inclusion of the interacting effects of stiffener tripping and plating collapse as well as the influence of the varying elasto-plastic rotational at the plate-stiffener intersection.

A parametric series of elasto-plastic large deflection analyses for flat-bar stiffened panels under uniaxial compression are carried out by varying the proportions of plate and stiffener. Based on the computed results, some insights into the phenomenon of tripping are provided. The accuracy of two available design formulations for predicting the local buckling strength of the stiffener web, one from IACS and the orther from Paik et al., is studied through a comparison of formula predictions against applicable ANSYS result. A guideline for preventing the tripping of stiffener web prior to the collapse fo the plating between stiffener is also suggested.

While demonstrated for flat-bar stiffened panels under uniaxial compression, the finite element method described and used in the present study can in principle be applied to stiffened panels with any type of stiffening, and for other types of loading as well.

4. Concluding remarks

A parametric series of elasto-plastic large deformation analyses for flat-bar stiffened panels under uniaxial compression are carried out by varying the proportions of plating and stiffener. The accuracy of three available design formulations for predicting the tripping behavior of the stiffener web, one from IACS, Paik and the other from ANSYS results and extend to analysis according to the stiffener section type.

1) When height of stiffened plate with flat-bar section is fixed, stiffened plate does thraw buckling if reduce place thickness of backstop rises, As a result, fall compression last strength.

2) When place thickness of stiffened plate is fixed, compressive ultimate strength increases basically if increase web height of stiffener, but web height of stiffener is overgrown, stiffener web happen local buckling, as a result, down torsional rigidity of web and ultimate strength decreases preferably.

3) Tripping occurrence critical point must be designed stiffener as less than case of flat-bar type stiffener about h_w/t_w 22.2.

4) The compressive ultimate strength is estimated highest in web height 200mm Flat-bar and T (Section) - bar.

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