Ultimate Limit State Assessment of Tankers considering Common Structural Rules

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Abstract

As Common Structure Rules (CSR) comes into effect, the ultimate state assessment has been recognized as an important field in ship structural analysis.

This paper describes the results of comparative studies on ultimate limit state assessment of ship plates, stiffened plates, and hull girders, using some candidate methods. Nonlinear FEA, DNV PULS and ALPS/ULSAP are employed for the assessment of plating and stiffened plates. For the ultimate strength of hull girder, ALPS/HULL, ANSYS nonlinear FEA and IACS CSR methods are used.

The assessments are applied to a double hull oil tankers structure. The ultimate limit states of bottom plates, deck stiffened panels, and bottom stiffened panels are analyzed. The most critical load case for each location is selected among about 40 CSR defining load cases.

The ultimate vertical bending moment capacity of the hull structure is also assessed by ALPS/HULL, ANSYS nonlinear FEA and IACS CSR methods, and their results are compared.

From this research, overall knowledge for the ultimate state assessment can be established and the difference of currently available systems can be identified.

1 INTRODUCTION

It is now well recognized that the limit state approach is a better basis for design and strength assessment of various types of structures than the traditional allowable working stress approach, because it is not possible to determine the true margin of structural safety as long as the limit states remain unknown. While the offshore industry has extensively applied the limit state approach for design, the shipbuilding industry has traditionally utilized classification society guidance based on the allowable working stress approach for design of trading ships.

In recent years, substantial efforts by stakeholders such as International Organization for Standardization(ISO), International Maritime Organization (IMO), and classification societies have been directed to the developments of limit state based standards (ISO 2006a, 2006b, IMO 2006), and rules (IACS 2006a, 2006b).

Although four types of limit states are relevant, namely serviceability limit states (SLS), ultimate limit states (ULS), fatigue limit states (FLS) and accidental limit states (ALS), the present paper is focused on ultimate limit states of ships and offshore structures.

In the present paper, a benchmark study is carried out on ultimate limit state assessment of ship structures, using some candidate methods such as ANSYS nonlinear finite element analysis (FEA) (ANSYS 2006), DNV PULS (DNV 2006), ALPS/ULSAP (2006), ALPS/HULL (2006), and IACS Common Structural Rules (CSR) (IACS 2006a). Ultimate limit states of ship bottom plates, deck stiffened panels, and bottom stiffened panels of a hypothetical double hull oil tanker are analyzed under uniaxial compression or biaxial compression or combined biaxial compression and lateral pressure loads using ANSYS FEA, DNV PULS and ALPS/ULSAP methods. The ultimate vertical bending moment of the hull structure is analyzed by ALPS/HULL and IACS CSR methods. The modeling uncertainties of each method are studied. The results and insights obtained from the present study are presented.

2 CANDIDATE METHODS

For ultimate limit state assessment of plates and stiffened plate structures, the following three methods are employed for the present benchmark study, namely

ANSYS nonlinear FEA (ANSYS 2006);

DNV PULS (DNV 2006);

ALPS/ULSAP (2006).

For ultimate vertical bending moment calculations of hull girders, the following two methods are used, namely

ALPS/HULL (2006);

IACS CSR method (IACS 2006a).

The ANSYS nonlinear FEA is the most refined method among the three candidate methods, and believed to give the most accurate solutions as long as the modeling technique applied is appropriate enough in terms of representing actual structural behavior associated with geometrical nonlinearity, material nonlinearity, type and magnitude of initial imperfections, boundary condition, loading condition, mesh size, and so on.

Both DNV PULS and ALPS/ULSAP are using semi-analytical approaches. While the details of DNV PULS may be found in the documents by DNV (2006), the theory of ALPS/ULSAP developed by the first author (Paik and Thayamballi 2003, 2007) is described briefly herein.

For ultimate limit state assessment of unstiffened plates, membrane stress distribution inside plates is calculated analytically by directly solving the nonlinear governing differential compatibility and equilibrium equations of plates which involve only geometric nonlinearity without plasticity. It is considered that the plates collapse if one of multiple ultimate limit state criteria specified is satisfied, where each of ultimate limit state criteria is a function of membrane stresses inside the plates, as well as initial imperfections and other parameters of influence. This approach is quite beneficial because the solutions of the plate governing differential equations are very accurate. Further, the types and magnitude of fabrication related initial imperfections in the form of initial deflection and residual stress can be dealt with as parameters of influence, i.e., in an explicit form rather than an implicit form.

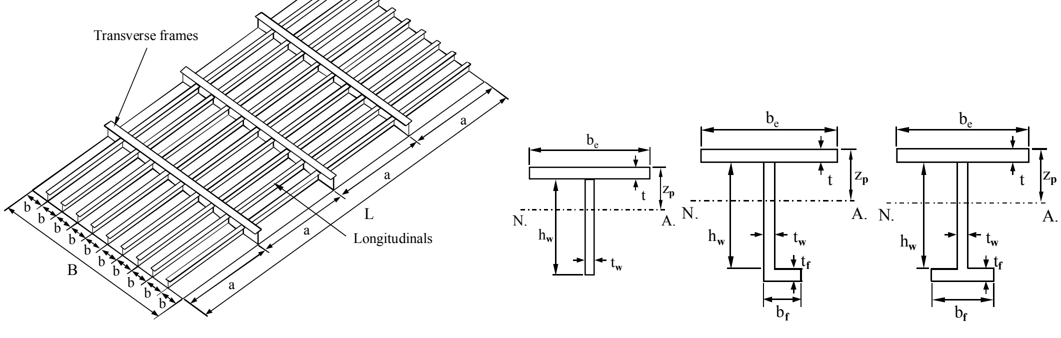


Fig. 1 Nomenclature: A stiffened plate structure considered for ULS assessment by ALPS/ULSAP method

For the purpose of ultimate limit state assessment of stiffened plate structures as shown in Fig.1, ALPS/ULSAP method follows the suggestion of Paik and Thayamballi (2003, 2007) by classifying the panel collapse modes into six types, namely

Mode I: Overall collapse after overall buckling;

Mode II: Biaxial compressive type collapse in plating between support members, i.e., without failure of support members;

Mode III: Beam-column type collapse of plate-stiffener combination, i.e., stiffener with associated plating;

Mode IV: Buckling of stiffener web;

Mode V: Flexural-torsional buckling or tripping of stiffener;

Mode VI: Gross yielding.

For ALPS/ULSAP calculations, it is considered that the stiffened panel collapses if one of the six collapse modes noted above takes place as applied actions increase. Mathematically, the minimum value of the ultimate strengths calculated for each of the six collapse modes above will then be the real ultimate limit state value. The ultimate strengths for each of the six collapse modes are obtained using semi-analytical methods. It is noted that the nomenclature of stiffened plate structure applied for DNV PULS may differ from that of ALPS/ULSAP. For example, the stiffener height h_w used for DNV PULS calculations is defined by inclusion of stiffener flange thickness t_f, in contrast to the nomenclature used for ALPS/ULSAP as indicated in Fig.1.

For the ultimate bending moment calculations, IACS CSR method provides two approaches, namely single step method and incremental-iterative method, although the present study uses the incremental-iterative method. It is noted that the IACS CSR method is more likely to be closed-form expressions that cannot take into account the progressive failures of individual components and their interacting effects.

For nonlinear analysis of a system structure that is composed of a number of individual structural components, however, the progressive collapse analysis is desirable. This is because the progressive failures of individual components and their interacting effects cannot be accounted for unless otherwise. Another common issue arose in the nonlinear computations of large complex system structures is computational efforts. It is now well recognized that idealized structural unit method (ISUM) can resolve the two issues above (Paik and Thayamballi 2003, 2007).

ALPS/HULL method is a special program for the progressive hull collapse analysis of ships and ship-shaped offshore structures (e.g., FPSOs) using ISUM. The latest version of ALPS/HULL (version 2006.3) uses advanced ISUM elements which the number of degree of freedom at each nodal point of individual ISUM elements is six, i.e., three translational degrees of freedom and three rotational degrees of freedom, although the old version used the elements with only three translational degrees of freedom at each nodal point. The benefit of the use of the advanced ISUM elements with six degrees of freedom at each nodal point is that the method can now be applied for three dimensional structures under more general condition of hull girder actions. For ultimate limit state assessment of individual structural components within ALPS/HULL, ALPS/ULSAP is employed as a major module.

The material of the hull structure considered for the present benchmark study is high tensile steel with the yield stress (σ_Y) of 315MPa. The elastic modulus is E=205.8GPa and Poisson's ratio is $\nu = 0.3$. For the ultimate limit state assessment by the candidate methods, the plate initial deflection is assumed to be the following,

$$w_{opl} = \frac{b}{200} \tag{1}$$

where w_{opl} = maximum plate initial deflection, b = breadth of plating between longitudinal stiffeners. It is assumed that the pattern of the plate initial deflection is equivalent to the plate buckling mode. Also, no residual stress is supposed to exist in plates, although all the candidate methods can deal with the effect of residual stress as a parameter of influence.

Also, the fabrication related initial distortions of stiffeners are assumed as follows

$$w_{oc} = w_{os} = \frac{a}{1000} \quad (2)$$

where w_{oc} = column type initial deflection of stiffeners in the vertical direction, w_{os} = sideways initial deflection of stiffeners in the horizontal direction, a = stiffener length as defined in Fig.1. The pattern of both column type initial deflection and sideways initial deflection of stiffeners is supposed to be buckling mode that results in the minimum buckling strength of stiffeners.

It is noted that stiffened plate structures at deck and bottom have non-identical plate thickness over the structures. Although ANSYS FEA can directly handle the different plate thickness at each plate in the finite element modeling, both DNV PULS and ALPS/ULSAP may need to define an equivalent panel thickness which is identical over the structure. In the present study, the weighted average approach was applied to determine the equivalent plate thickness as follows

$$t_{eq} = \frac{1}{\text{entire plate surface area}} \left(\frac{\text{actual panel weight}}{\gamma} - \text{stiffeners volume} \right) \quad (3)$$

where t_{eq} = equivalent plate thickness, γ = density of material (=7,850 kg/m^3 for steel). It was confirmed that the equivalent panel thickness approach applying Eq.(3) gives a few percent discrepancy in terms of the resulting ultimate strength computations, and it is thought to be sufficient enough to adopt for practical design purpose.

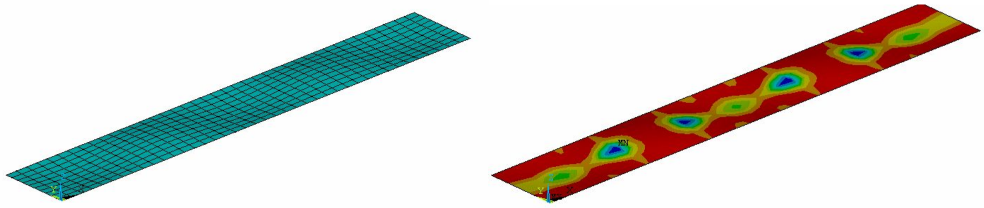
For nonlinear FEA, the elastic-perfectly plastic material model is applied by neglecting strain-hardening effect of material.

3 ULTIMATE LIMIT STATES OF BOTTOM PLATES

Ultimate strength of outer bottom plates is now analyzed using the candidate methods such as ANSYS, DNV PULS, and ALPS/ULSAP. The length and breadth of plating supported by longitudinal stiffeners and transverse floors is 4,300mm and 815mm, respectively. The plate thickness over the bottom structure is not identical. Four kinds of plate thickness, namely 16mm, 14.5mm, 14mm and 13.5mm, are selected for the present study. Regardless of lateral pressure loading, both ANSYS FEA and ALPS/ULSAP methods assume that each plate is simply supported along all (four) edges. The plate initial deflection is assumed as indicated in Eq.(1), and residual stress is not considered.

Under design hull girder actions, i.e., in the most unfavorable condition, each plate is subjected to biaxial compression and lateral pressure loads (p = 0.16MPa), which could be estimated from the action effect analysis of the hull structure using a three cargo hold model.

Fig. 2(a) shows a typical mesh modeling applied for the present ANSYS nonlinear FEA of bottom plates, together with deformed shape at the ultimate limit state, which is believed to be sufficiently fine mesh in terms of the resulting accuracy. Fig. 2(b) represents the associated membrane stress distribution immediately after ultimate limit state is reached.



(a) (b)

Fig. 2 ANSYS nonlinear FE analysis for bottom plates under biaxial compression and lateral pressure loads: (a) Mesh modeling and deformed shape, (b) Associated membrane stress distribution of the bottom plate at ultimate limit state, for t = 14mm

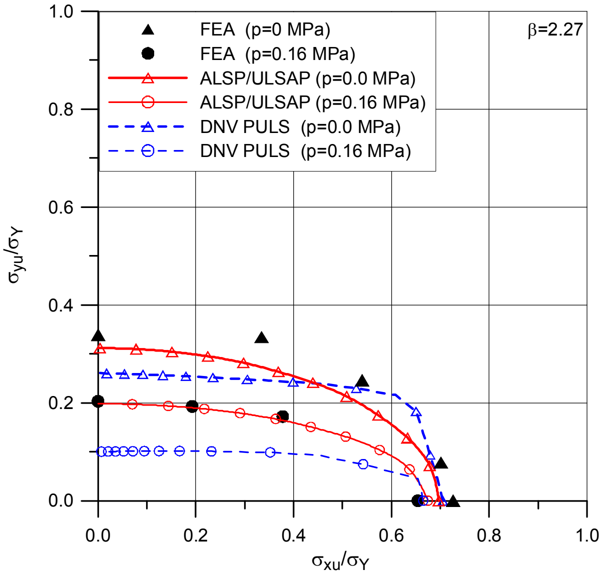
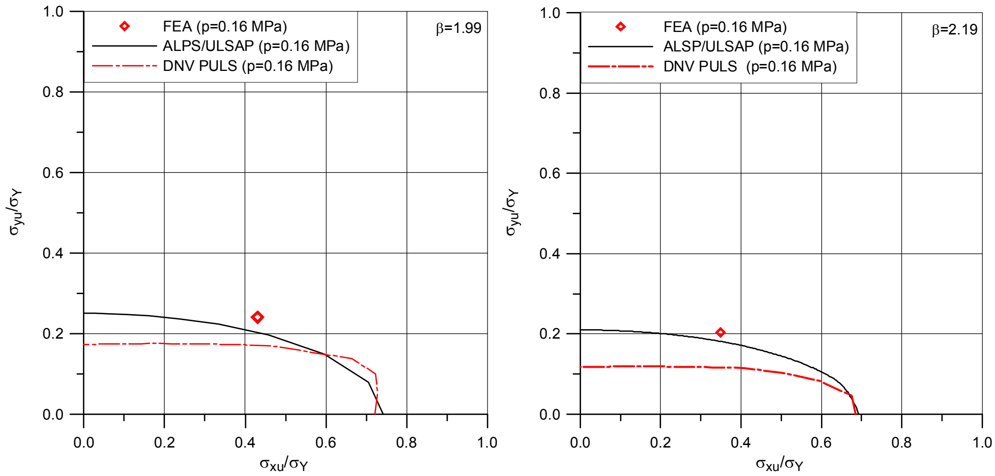


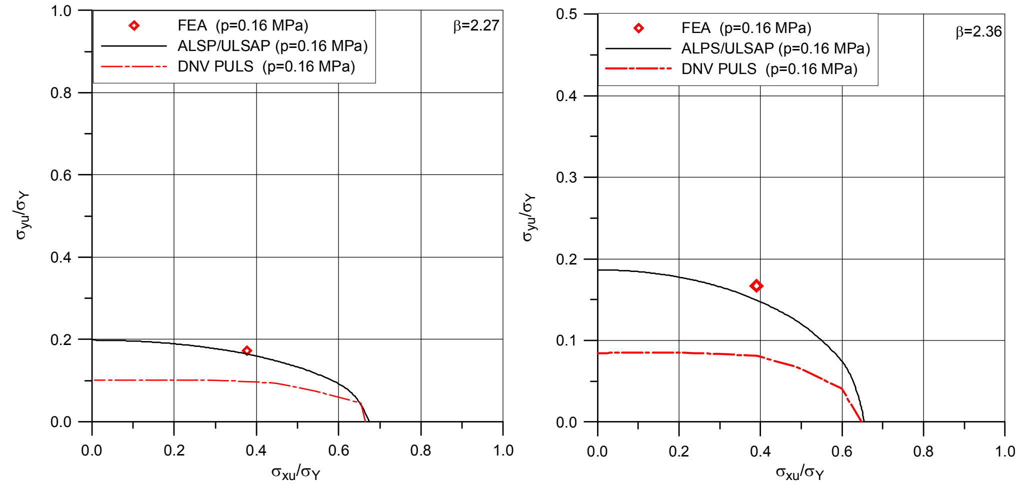
Fig. 3 Ultimate strength interaction relationships of bottom plates under biaxial compression with or without lateral pressure loads, for t=14mm

Fig. 3 compares the plate ultimate strength interaction relationships under biaxial compression with or without lateral pressure loads calculated by the candidate methods, for t=14mm. It is seen from Fig.3 that ANSYS FEA and ALPS/ULSAP solutions correlate very well regardless of either lateral pressure loading or biaxial compressive loading ratio. On the other hand, DNV PULS largely underestimates the plate ultimate strengths when transverse axial compressive loads are predominant for both with and without lateral pressure loads.

Fig. 4 shows the effect of plate slenderness ratio (or plate thickness) $\beta = b/t \cdot \sqrt{\sigma_Y / E}$ on the plate ultimate strength interaction relationships. It is seen from Fig.4 that DNV PULS tends to more likely to underestimate the plate ultimate strength as the plate thickness becomes smaller. The modeling uncertainties of DNV PULS and ALPS/ULSAP against more refined ANSYS solutions will be studied in Section 6.



(a) t = 16mm (b) t = 14.5mm



(c) t = 14mm (d) t = 13.5mm

Fig. 4 Effect of plate slenderness ratio on ultimate strength interaction relationships for bottom plates under combined biaxial compression and lateral pressure loads (p=0.16MPa)

4 ULTIMATE LIMIT STATES OF DECK STIFFENED PANELS

The ultimate limit states of deck stiffened panels of the hypothetical double hull oil tanker are now analyzed by the candidate methods. The plate thickness of the deck panel (excluding 100% corrosion margins) is not identical and has three different kinds as indicated in Fig.5. The spacing of longitudinal stiffeners and transverse frames of the standard deck panel is 815mm and 4,300mm, respectively. The number of deck longitudinal stiffeners is 22 with angle type for the standard deck panel, as shown in Fig.5. With the nomenclature of Fig.1, the stiffener dimension (excluding 100% corrosion margins) is $h_w \times t_w = 284 \times 7$mm, and $b_f \times t_f = 90 \times 12$mm. The initial distortions of plating and stiffeners are supposed as defined in Eqs.(1) and (2). No residual stress is considered in both plating and stiffeners. Considering the hull girder sagging bending actions, the panel ultimate strength is analyzed under uniaxial compressive loads.

For ANSYS FEA, the two bay panel model, i.e., in the panel extent of a/2+a+a/2 was adopted, as shown in Fig.5, in order to precisely account for the effect of rotational restraints along transverse frames. Unloaded edges, i.e., supported by deck girders, are modeled to be simply supported, keeping straight. Symmetric conditions are applied at the two loaded edges, i.e., along the two lines with the distance of a/2 from transverse frames. It is also assumed that transverse frames are strong enough to support the panels so that a supported condition is applied along the transverse frames instead of a direct modeling by finite elements. On the other hand, only a single panel between transverse frames in the extent of $a \times B$ as illustrated in Fig.5 is adopted for DNV PULS and ALPS/ULSAP calculations, considering that all edges are simply supported.

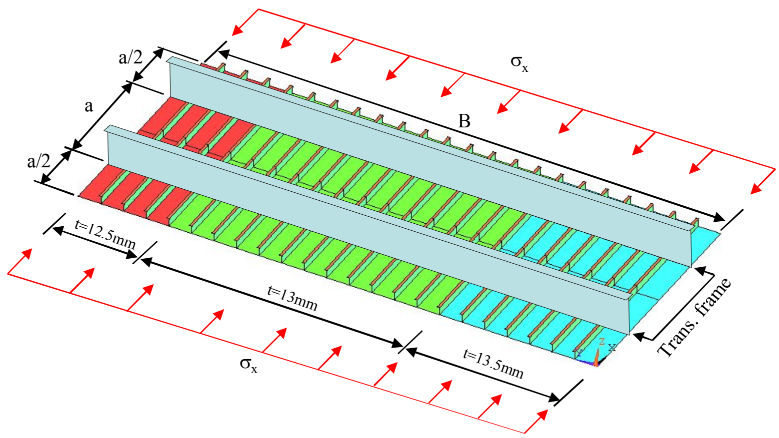


Fig. 5(a) The two bay model taken for ANSYS FEA of the standard deck stiffened plate structure (case D2) under uniaxial compressive loads (B=18,745mm, a=4,300mm, b=815mm)

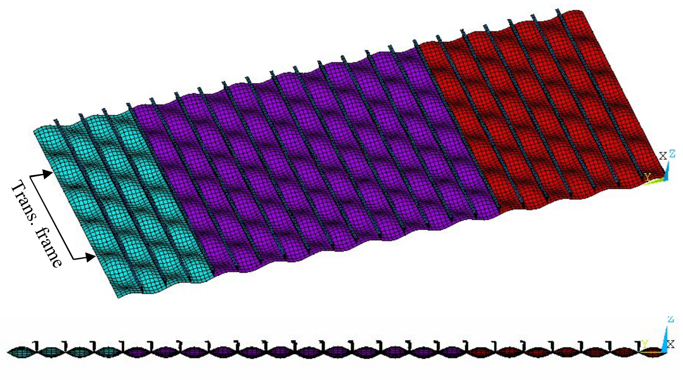


Fig. 5(b) Deformed shape of the deck stiffened plate structure at the ultimate limit state under uniaxial compression, for the panel case D2

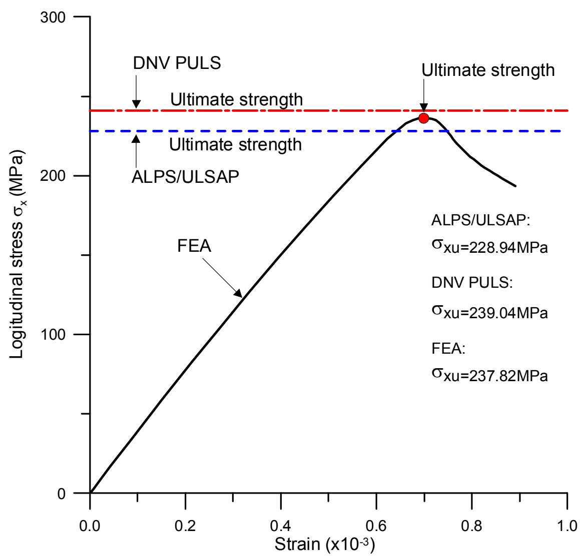


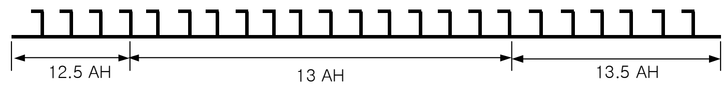
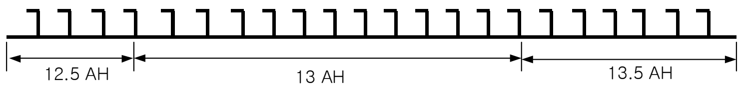
Fig. 6 The axial compressive stress versus strain relationship obtained by ANSYS, together with the DNV PULS and ALPS/ULSAP computations, for the deck panel case D2

Table 1(a) Geometric properties of deck stiffened panels

Case	a (mm)	b (mm)	n_s	t_{eq} (mm)	h_w (mm)	t_w (mm)	b_f (mm)	t_f (mm)
D1	4300	782	23	13.062	284	7	90	12
D2	4300	815	22	13.060	284	7	90	12
D3	4300	850	21	13.068	284	7	90	12
D4	3762.5	782	23	13.062	284	7	90	12
D5	3762.5	815	22	13.060	284	7	90	12
D6	3762.5	850	21	13.068	284	7	90	12

Note: n_s = number of longitudinal stiffeners.

Table 1(b) Type of plate thickness and number of stiffeners for deck panels

Case	Type of plate thickness and number of stiffeners
D1 D4	
D2 D5	
D3 D6	

Note: AH = high tensile steel with σ_Y =315MPa.

Table 2 Ultimate strength computations for the deck stiffened panel with varying the spacing of longitudinal stiffeners and deck frames

Case	ANSYS	ALPS/ULSAP	DNV PULS
	σ_{xu}/σ_Y	σ_{xu}/σ_Y	σ_{xu}/σ_Y
D1	0.7366	0.7221	0.7778
D2	0.7550	0.7268	0.7588
D3	0.7219	0.7044	0.7360
D4	0.7633	0.7277	0.7710
D5	0.7423	0.7074	0.7746
D6	0.7527	0.7209	0.7555

To investigate the ultimate strength characteristics of the deck panel with different spacing of longitudinal stiffeners and deck frames, the number of longitudinal stiffeners and/or deck frames on deck structures was varied in the candidate method computations of ultimate limit states. It is noted that the panel breadth (B) may not be exactly the same for all of the panel cases, while B is nearly 18,745mm. Tables 1(a) and 1(b) indicate a total of 6 study cases with different dimensions. The plate thickness over the deck panel is not identical as indicated in Table 1(b), and an equivalent plate thickness of each panel case was determined from Eq.(3) as indicated in Table 1(a).

Fig. 6 shows the axial compressive stress versus strain curve for the case D2 obtained by ANSYS. Table 2 presents the ultimate strength computations obtained by ANSYS, DNV PULS and ALPS/ULSAP. It is evident that the solutions of the three methods correlate quite well in the present loading case, i.e., under uniaxial compression alone. A comparison between ANSYS and DNV PULS on ultimate strength of stiffened panels under uniaxial compression with or without lateral pressure loads is found in the literature (Ozguc et al. 2006), showing similar trends to the present benchmark study.

5 ULTIMATE LIMIT STATES OF BOTTOM STIFFENED PANELS

The ultimate strength of the bottom stiffened panel with T type longitudinal stiffeners as illustrated by Fig.7 is now analyzed. The spacing of bottom longitudinal stiffeners and transverse floors of the standard bottom panel is 815mm and 4,300mm, respectively. With the nomenclature indicated in Fig.1, the dimension of stiffeners (excluding 100% corrosion margins) is $h_w \times t_w$=385×8.5mm, and $b_f \times t_f$=150×12mm. The initial distortions of plating and stiffeners are supposed as defined in Eqs.(1) and (2). No residual stress is considered. The bottom panel is subjected to biaxial compression and lateral pressure loads (p=0.16MPa).

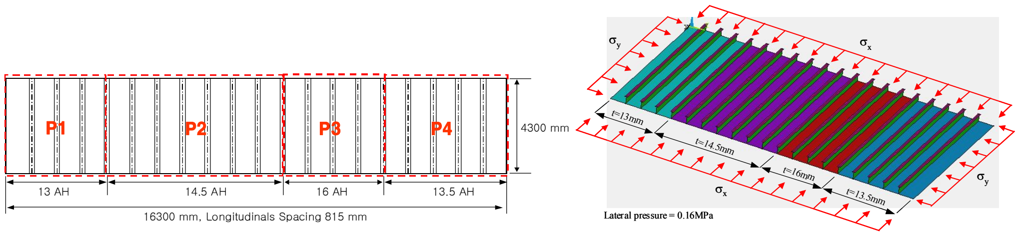


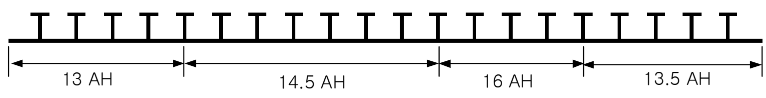
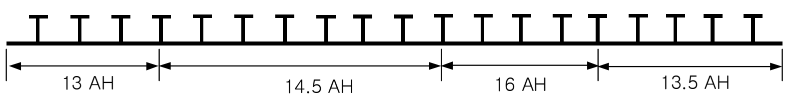
Fig. 7 The standard bottom stiffened plate structure (case B2) of the hypothetical double hull oil tanker, under combined biaxial compression and lateral pressure loads (B=16,300mm, a=4,300mm, b=815mm, n_s=19 =number of longitudinal stiffeners)

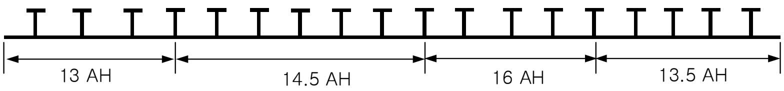
Table 3(a) Geometric properties of bottom stiffened panels

Case	a (mm)	b (mm)	n_s	t_{eq} (mm)	h_w (mm)	t_w (mm)	b_f (mm)	t_f (mm)
B1	4300	782	20	14.19	385	8.5	150	12
B2	4300	815	19	14.25	385	8.5	150	12
B3	4300	850	18	14.23	385	8.5	150	12
B4	3762.5	782	20	14.19	385	8.5	150	12
B5	3762.5	815	19	14.25	385	8.5	150	12
B6	3762.5	850	18	14.23	385	8.5	150	12

Note: n_s = number of longitudinal stiffeners.

Table 3(b) Type of plate thickness and number of stiffeners for bottom stiffened panels

Case	Type of plate thickness and number of stiffeners
B1 B4	
B2 B5	

B3	
B6	

Note: AH = high tensile steel with σ_Y =315MPa.

The plate thickness is not identical over the bottom panel, and has four different kinds as shown in Fig.7. The equivalent panel thickness determined from Eq.(3) was used for both DNV PULS and ALPS/ULSAP computations, although ANSYS FEA directly modeled the different plate thickness.

To investigate the ultimate strength characteristics of the bottom panel with different spacing of longitudinal stiffeners and bottom floors, the number of longitudinal stiffeners and/or bottom floors was varied in the candidate method computations of ultimate limit states. It is noted that the panel breadth (B) may not be exactly the same for all of the panel cases, while B is nearly 16,300mm. Table 3 indicates the panel dimensions (excluding 100% corrosion margins) for a total of six panel cases considered in the present study.

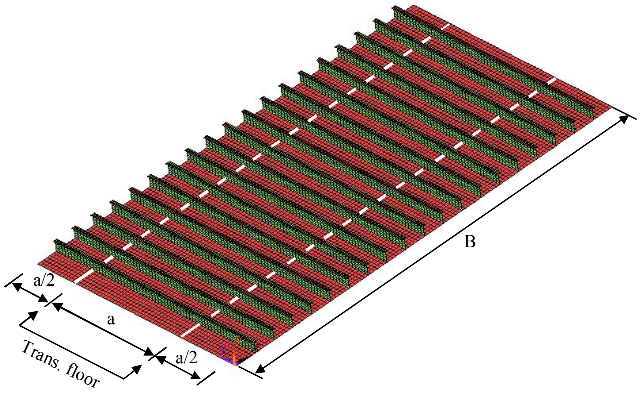


Fig. 8(a) The two bay model used for ANSYS FEA of the bottom stiffened panel under biaxial compression and lateral pressure loads, for the bottom panel case B2

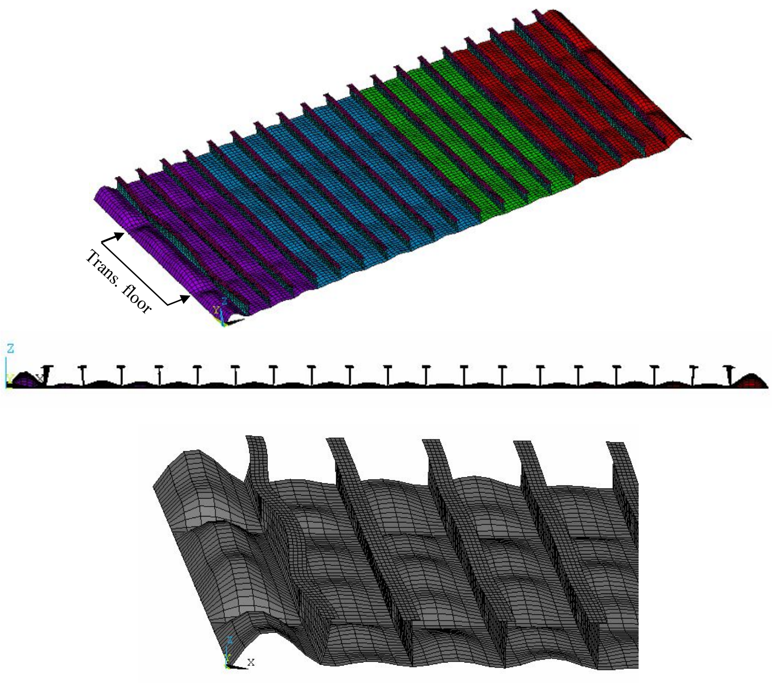


Fig. 8(b) Deformed shape at the ultimate limit state under biaxial compression and lateral pressure loads, for the bottom panel case B2

Fig. 8 shows the ANSYS nonlinear FE modeling used for the ultimate limit state assessment of the standard bottom stiffened panel, together with the deformed shape at the ultimate limit state under combined biaxial compression and lateral pressure loads. The two bay panel model, i.e., in the panel extent of a/2+a+a/2 was adopted for the FEA, although only a single stiffened panel between transverse floors was used for both DNV PULS and ALPS/ULSAP computations. Similar boundary conditions used for the analyses of the deck stiffened panel described in Section 4 were applied. It is surmised from Fig.8(b) that some large degrees of rotational restraints were happening along transverse floors, due to lateral pressure loading as well as structural continuity with regard to the transverse floors.

Table 4 summarizes the ultimate strength computations obtained with varying the spacing of bottom longitudinal stiffeners and transverse floors. In particular, the ultimate strength characteristics under biaxial compression, i.e., without lateral pressure loads are also studied. Fig. 9 represents a selected ultimate strength interaction relationship of the panel under biaxial compression with keeping lateral pressure loads constant at the design value of 0.16MPa.

Table 4(a) Ultimate strength computations for the bottom stiffened panel under biaxial compressive loads with keeping lateral pressure loads constant at the design value of 0.16MPa, with varying the spacing of bottom longitudinal stiffeners and transverse floors

Case	ANSYS		ALPS/ULSAP		DNV PULS	
	σ_{xu}/σ_Y	σ_{yu}/σ_Y	σ_{xu}/σ_Y	σ_{yu}/σ_Y	σ_{xu}/σ_Y	σ_{yu}/σ_Y
B1	0.5172	0.1416	0.4899	0.1342	0.6980	0.1911
B2	0.5117	0.1400	0.4813	0.1318	0.6790	0.1859
B3	0.4923	0.1348	0.4612	0.1263	0.6570	0.1798
B4	0.5556	0.1521	0.5302	0.1452	0.7360	0.2015
B5	0.5460	0.1494	0.5100	0.1397	0.7170	0.1963
B6	0.5227	0.1431	0.4878	0.1336	0.6920	0.1894

Table 4(b) Ultimate strength computations for the bottom stiffened panel under biaxial compressive loads, with varying the biaxial compressive loading ratio with or without lateral pressure loads, for the bottom panel case B2

Loading ratio	p (MPa)	ANSYS		ALPS/ULSAP		DNV PULS	
σ_x:σ_y		σ_{xu}/σ_Y	σ_{yu}/σ_Y	σ_{xu}/σ_Y	σ_{yu}/σ_Y	σ_{xu}/σ_Y	σ_{yu}/σ_Y
1.0:0.0	0	0.7512	0	0.7281	0	0.8093	0
	0.16	0.6630	0	0.6309	0	0.6981	0
0.9:0.1	0	0.7312	0.0824	0.7047	0.0794	0.8018	0.1102
	0.16	0.6303	0.0710	0.5957	0.0663	0.6902	0.0948
0.7:0.3	0	0.6502	0.1781	0.6156	0.1686	0.7494	0.2099
	0.16	0.5022	0.1375	0.4814	0.1318	0.6795	0.1904
0.67:0.33	0	0.5300	0.2650	0.4771	0.2386	0.5035	0.2609
	0.16	0.3925	0.1962	0.3425	0.1712	0.4616	0.2391
1.0:1.0	0	0.3012	0.3012	0.2897	0.2897	0.2989	0.2989
	0.16	0.2143	0.2143	0.1940	0.1940	0.2699	0.2699
0.0:1.0	0	0	0.3117	0	0.3158	0	0.2973
	0.16	0	0.2201	0	0.2039	0	0.2618

It is interesting to note from Fig.9 and Table 4 that DNV PULS shows an opposite trend to the plates discussed in Section 3, now by significantly overestimating the ultimate strength of the stiffened panel under biaxial compression together with lateral pressure loads compared to more refined ANSYS solutions. This seems to be due to the modeling of boundary conditions; The DNV PULS method models that the edges of a stiffened panel are always clamped, i.e., with infinitely large degrees of rotational restraints, when lateral pressure loads are applied (DNV PULS 2006, Ozguc et al. 2006), although both ANSYS FEA and ALPS/ULSAP methods automatically deal with the degrees of rotational restraints or ultimate compressive strengths depending on the levels of lateral pressure loads, i.e., as a function of the magnitude of lateral pressure loads together with structural dimensions. In fact, the degree of rotational restraints must be small with relatively small pressure loads, but it will become larger with increase in pressure loads (Paik and Thayamballi 2003, 2007).

As shown in Fig.9, when lateral pressure loads are not applied, DNV/PULS largely overestimates the stiffened panel ultimate strength under predominantly longitudinal compressive loads, although the method gives accurate solutions under predominantly transverse compressive loads. On the other hand, ALPS/ULSAP solutions correlate very well with more refined ANSYS results regardless of lateral pressure loading and biaxial compressive loading ratio.

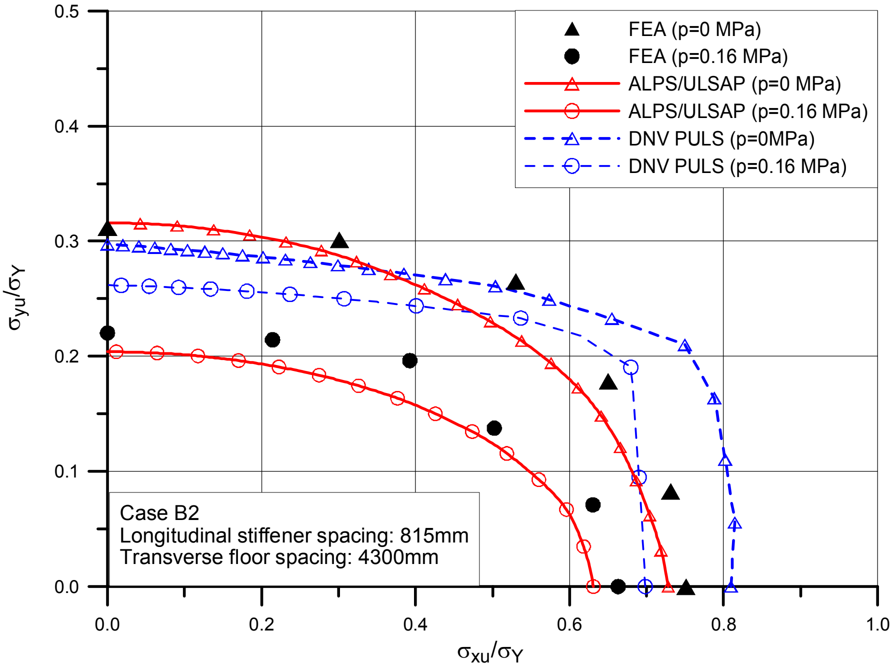


Fig. 9 Ultimate strength interaction relationships of the bottom stiffened panel between biaxial compressive loads, with keeping lateral pressure loads at the design value of 0.16MPa, and without lateral pressure loads, for the bottom panel case B2

6 MODELING UNCERTAINTIES OF DNV PULS AND ALPS/ULSAP METHODS

It is important to identify the modeling uncertainties when one attempts to apply the candidate methods for design and strength assessment of ship structures. Based on some limited database obtained from the present benchmark study on ultimate limit state assessment of bottom plates, deck stiffened panels, and bottom stiffened panels under uniaxial compression or combined biaxial compression or combined biaxial compression and lateral pressure loads, the modeling uncertainties of both DNV PULS and ALPS/ALPS could be analyzed against more refined ANSYS nonlinear FEA solutions.

Fig. 10 indicates the analysis results of the modeling uncertainties for the two methods. It is seen that the three candidate methods correlate reasonably well under uniaxial compression in the longitudinal stiffener direction with or without lateral pressure loads. However, DNV PULS method has some large discrepancy against either ANSYS FEA or ALPS/ULSAP when biaxial compressive loads with or without lateral pressure loads are applied. As indicated in Table 5, the DNV PULS method tends to overestimate the ultimate limit states by some 10 percent with the coefficient of variation (COV) of 16.8 percent, while the ALPS/ULSAP method tends to underestimate the ultimate limit states by some 5 percent discrepancy with the COV of 3.98 percent against nonlinear FEA.

Table 5 Mean and standard deviation of DNV PULS and ALPS/ULSAP method results

Method	$(\sigma_{xu})_{ALPS/ULSAP}/(\sigma_{xu})_{FEA}$	$(\sigma_{xu})_{DNV/PULS}/(\sigma_{xu})_{FEA}$
Bias	0.9419	1.1024
COV	0.0398	0.1677

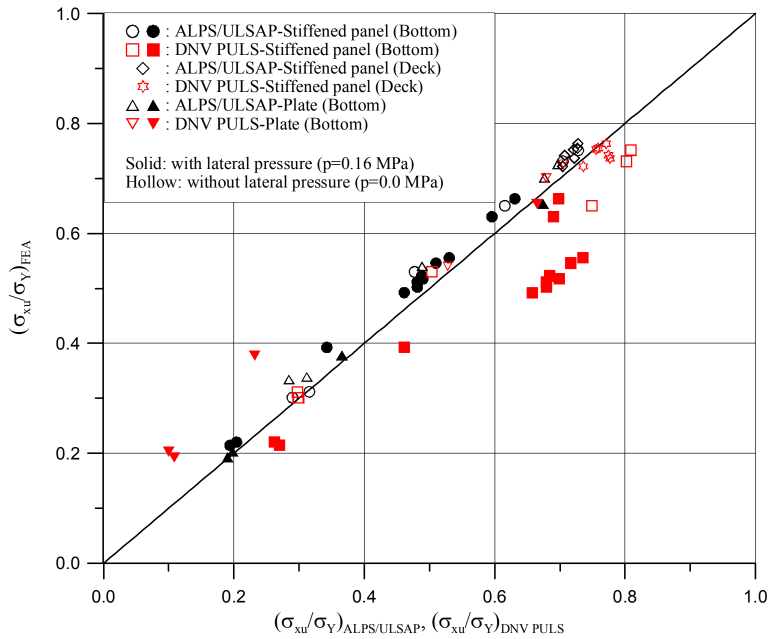
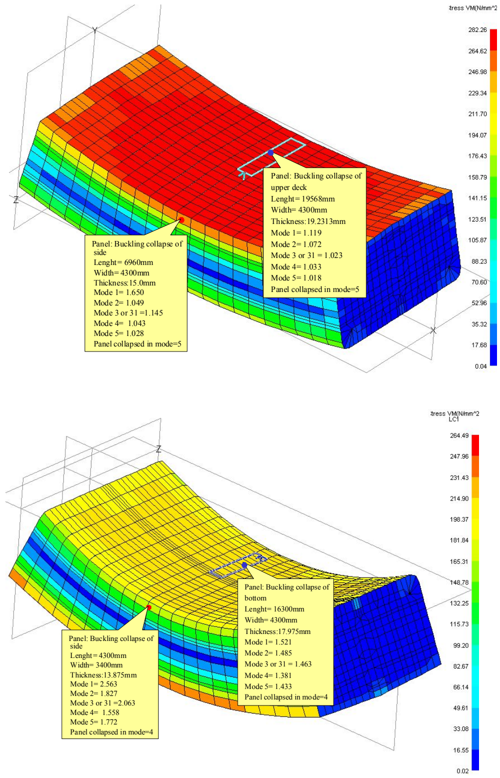


Fig. 10 Analysis of modeling uncertainties of DNV PULS and ALPS/ULSAP methods associated with ultimate limit state assessment of bottom plates, deck stiffened panels, and bottom stiffened panels

7 APPLICATION OF ALPS/ULSAP TO THREE CARGO HOLD HULL STRUCTURE

ALPS/ULSAP has been linked with MAESTRO program (MAESTRO 2006) for efficient pre- and post-processing. An application example of ALPS/ULSAP for the ultimate limit state assessment of plate panels in the three cargo hold hull structure under design vertical bending moment is now demonstrated. For the simplicity of the present calculations, the effect of lateral pressure loads is not considered, but only vertical sagging or hogging bending actions are applied. The design bending moments were predicted by IACS CSR (IACS 2006a).



(a) (b)

Fig. 11 Deformed shape and associated von Mises stress distribution of the three cargo hold structure of a hypothetical double hull oil tanker: (a) Under design sagging bending action, (b) Under design hogging bending action (upside down)

The design working stresses of plate panels and support members in the three cargo hold hull structure are calculated by linear elastic FEA using MAESTRO. The ultimate limit state assessment of plate panels and support members is carried out by ALPS/ULSAP. The safety factor of individual structural components is then determined as a ratio of the ultimate strength to the corresponding working stress.

Fig.s 11(a) and 11(b) show the deformed shape and associated von Mises stress distribution of individual components in the three cargo hold hull structure under design sagging or hogging moment, respectively. It was confirmed that the structural components of the hull structure has safety factors greater than 1.0, but in some components the safety factors are marginal and design improvements may subsequently be required. It is worthwhile to note that the deck longitudinal stiffeners are most likely to fail by tripping mode (mode V), and bottom longitudinal stiffeners are most likely to fail by buckling of stiffener web (mode IV), as shown in Fig.11. The computing time used for each loading case of the ultimate limit state assessment is less than 3 minutes using a personal computer with Pentium 2.4GHz processor.

8 ULTIMATE HULL GIRDER STRENGTH

The ultimate vertical bending moment of a hypothetical double hull oil tanker is now studied using IACS CSR and ALPS/HULL methods. It is noted that the hull structural dimensions applied for the present analysis were defined by excluding 50% corrosion margin values of individual structural components as specified by IACS (2006a), because the hull structure was designed by IACS CSR. The incremental-iterative approach suggested by IACS (2006a) is used for the ultimate hull girder strength calculations, while ALPS/HULL performs the progressive hull collapse analysis.

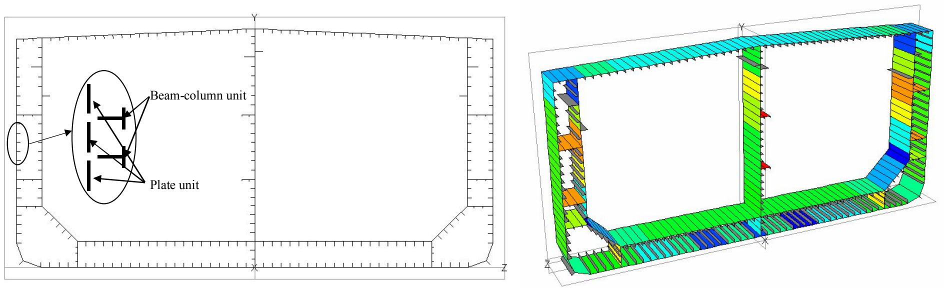


Fig. 12 ALPS/HULL model used for the progressive hull collapse analysis of a hypothetical double hull oil tanker structure under vertical bending

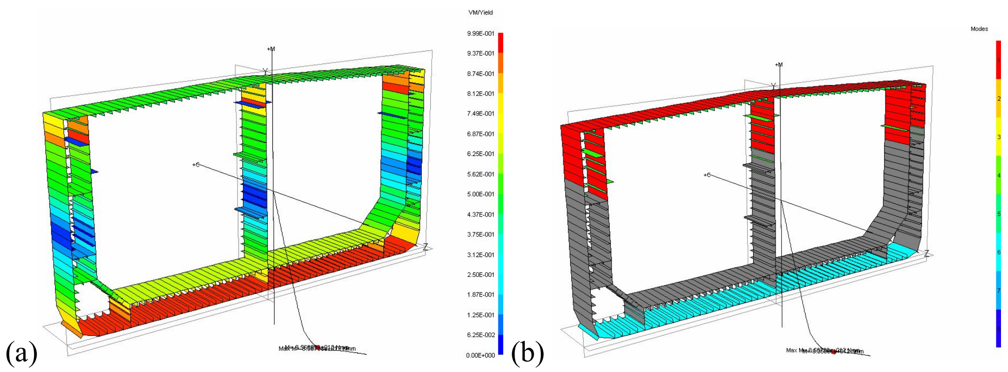


Fig. 13 ALPS/HULL progressive collapse analysis results of a hypothetical double hull oil tanker structure at ultimate limit state under sagging: (a) von Mises stress distribution, (b) Collapse mode distribution of individual components

Fig. 12 shows the ALPS/HULL model used for the progressive collapse analysis of the tanker hull under vertical bending. A sliced single hull cross section model between two adjacent transverse frames at mid-ship is adopted as the extent of the ALPS/HULL analysis. Plate elements between support members are idealized by ISUM plate elements, and support members (excluding attached plating) are idealized by ISUM beam-column elements. The initial distortions of plating and stiffeners are supposed as defined in Eqs.(1) and (2). No residual stresses exist. For ALPS/HULL progressive collapse analysis, two types of plate initial deflection shape, namely buckling mode and 'hungry horse mode' are considered.

The cross sectional data of the hypothetical hull structure computed by ALPS/HULL is as follows

- Cross sectional area = 5.4982 m^2
- Moment of inertia at vertical direction = 378.4787 m^4
- Section modulus = 40.7442 m^3 at bottom, 29.9172 m^3 at deck
- Full plastic bending moment = 12742.76 MNm

Fig. 13 represents the von Mises stress distribution and collapse modes of individual structural components over the hull cross section at the ultimate limit state under sagging. Fig. 14 shows the vertical bending moment versus curvature curves under both sagging and hogging. The required bending moment capacities specified by IACS CSR as well as the IACS CSR method predictions of the ultimate bending moments are also plotted in the Fig..

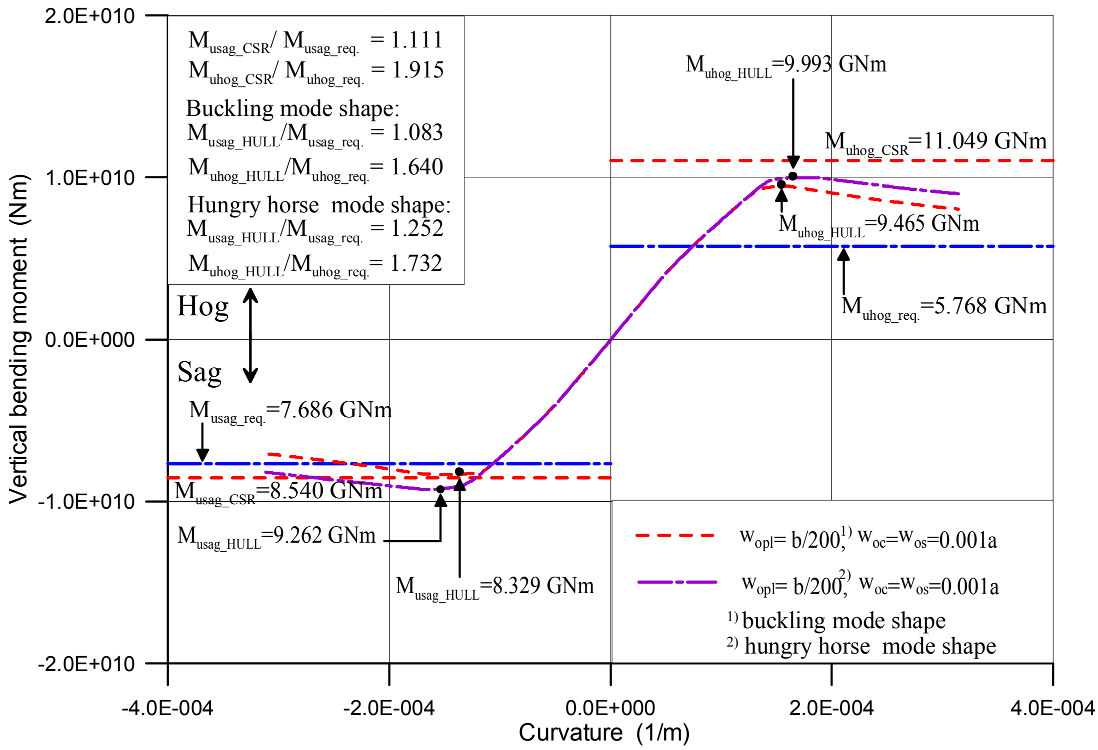


Fig. 14 Vertical bending moment versus curvature curves of a hypothetical double hull oil tanker structure obtained by ALPS/HULL, together with IACS CSR capacity predictions and requirements

According to ALPS/HULL progressive collapse analysis results under sagging condition, most deck longitudinal stiffeners failed by tripping. It was found that horizontal stringers with a large web height failed in earlier loading stage by stiffener web buckling, and thus some structural improvements were recommended to prevent such failures. As would be expected, the ultimate hull girder bending moments are more pessimistically evaluated when the shape of the plate initial deflection is the buckling mode than the hungry horse shape.

It is observed that IACS CSR predictions of ultimate sagging bending capacity correspond well with more refined ALPS/HULL progressive analysis results, but the IACS CSR method overestimates the ultimate hogging bending capacity by some 27.5 percent for the present specific ship hull structure.

In terms of ultimate sagging moment, it is found that the double hull oil tanker structure considered in the present study has a safety margin greater than the required capacity specified by IACS CSR, at least by some 8 percent.

9. CONCLUDING REMARKS

While the offshore industry has extensively applied the limit state approach for design, the shipbuilding industry has traditionally utilized classification society guidance based on the allowable working stress approach for design of trading ships. It would seem that there may be a need for requiring minimum compression strength standards for primary structure, and this should be considered. In shipbuilding industry, this will provide more robust ships at a time when ship sizes and speeds are increasing and the associated risks are greater.

In recent years, International Organization for Standardization, International Maritime Organization, and Classification Societies have provided substantial efforts to develop standards or regulations based on limit state approaches.

The aim of the present paper has been to identify the modeling uncertainties of some candidate methods which are considered to be useful for ultimate limit state assessment of ships and offshore structures.

In closing, it is important to adopt the ultimate limit state approach for all aspects of ship structural design. During the last decade, fast advances have been achieved in the areas of the ultimate limit state design technologies, and it is convinced that the developments are mature enough to enter the day-by-day design and strength assessment practice.

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