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Permanent Means of Access 강도 평가 방법에 대한 연구

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A Procedure for a Strength Assessment of Permanent Means of Access Structure

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Abstract

Common structural rule (CSR) doesn’t provide any other specific regulations for permanent means of access (PMA) platform structure in a cargo oil tank. The PMA platform is recommended to comply with scantling requirement of local support member. However, it leads to too conservative scantlings compared with actual loads imposed on the platform. This paper proposes a strength assessment procedure for the PMA structure based on a nonlinear ultimate strength. The ultimate strength is evaluated in a sufficiently conservative way. The first linear buckling mode is used as an initial imperfection shape and its magnitude is determined using the definitions of DNV PULS. Since the same imperfection mode as the failure mode of the ultimate limit state is assumed, it can accelerate the failure. Au ultimate strength capacity curve obtained from a series of nonlinear FE analysis is compared with actual stresses calculated by CSR cargo hold analysis.

※Keywords: Permanent means of access, Common structural rule, Nonlinear FE analysis(비선형 유한요소 해석), Ultimate strength analysis(최종 강도해석)

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1. Introduction

IACS common structural rules (CSR) has just started to be applied to double hull oil tankers of 150m length and above which has been contracted for construction on or after 1 April 2006. CSR provides detailed regulations and requirements for most structural members. However, it doesn' t offer any specified requirements for permanent means of access (PMA) platform. It is welded on side or centerline longitudinal bulkhead just as other longitudinal stiffeners, but its web height is 550~600mm larger than those of normal longitudinal stiffeners in order to provide the space for a hull inspector to walk on. Since, the PMA platform has been recommended to comply with the scantling requirement of local support member described in CSR Sec.10 Pt.2 (IACS 2006), it has been designed with excessive scantlings compared with real loads to be imposed on the structure.

This paper proposes a method to prove the structural safety through an evaluation of ultimate strength using a nonlinear FE analysis and a comparison of the strength with the actual loads to be imposed on the PMA structure. The actual loads to be applied on the PMA structure are evaluated by a cargo hold analysis in accordance with CSR. The method is illustrated by an evaluation of structural adequacy of the PMA structure including its adjacent stiffened plate even if it doesn' t satisfy the scantling requirements of the local support member. The scantling regulation of the local support members defined in CSR Sec.10 Pt.2 requires minimum 1150X20.5+287.5X16.5 as depicted in Fig. 1. However, this paper proposes a smaller scantling of 1150X12+150X15 and verifies its structural adequacy.

The analysis procedure begins with defining load conditions by varying the ratio of longitudinal and transverse loads on the PMA structure while imposing the maximum lateral pressure value on the plate among loading conditions defined in CSR cargo hold analysis. Linear elastic buckling analysis (eigenvalue analysis) is performed to obtain linear buckling modes for each loading condition. The first buckling mode is used as an initial imperfection shape for the nonlinear buckling analysis.

Regarding the fabrication-related initial imperfections, Paik and Thayamballi(2003) proposed some typical initial deflection patterns between stiffeners using a combination of sine functions and investigated the effect of initial deflection shape on the ultimate strength of a simply supported steel plate under biaxial compression using nonlinear finite element method (FEM). The linear buckling mode offers sufficiently conservative capacity curve.

Next, non linear FE analysis is performed for the FE model of PMA structure after applying the initial imperfection. An ultimate strength capacity curve for the PMA structure can be generated by performing a series of ultimate strength analyses for all the loading conditions. If the failure mode of the nonlinear FE analysis is found to be different from the initial imperfection shape, the initial imperfection shape is changed into the same buckling mode as the failure mode. This approach can be sufficiently conservative because the same initial imperfection mode as the failure mode can accelerate the failure.

The structural adequacy can be verified by comparing the capacity curve with the actual stresses calculated by CSR cargo hold analysis. The procedure is summarized in Fig. 2. The finite element model is constructed in MSC.PATRAN 2005r2 (MSC.PATRAN 2005) and the linear elastic buckling analysis and nonlinear finite element analysis are performed using MSC. NASTRAN 2005r3b(MSC.NASTRAN 2005), respectively.

As similar researches, Paik et al.(2004) conducted some benchmark studies on ultimate limit state assessment of a stiffened panels using some candidate methods such as ANSYS (2006) nonlinear FEA, DNV PULS(2006) and ALPS/ULSAP (2006) developed by Paik and Thayamballi(2003, 2007). Paik et al.(2007) made similar comparison for a stiffened panel of cargo oil tanker designed complying with CSR Researches on ultimate strength for a stiffened plate have been made widely(Paik et al. 1988, Paik and Lee 1996)

Section 2 describes a definition of initial imperfection by linear buckling analysis and Section 3 nonlinear ultimate strength assessment for a capacity curve. The capacity curve is compared with actual stresses from CSR cargo hold analysis. Conclusion is laid in Section 4. Appendix provides an illustrating example to verify the proposed ultimate strength assessment based on FE analysis by a comparison with DNV PULS.

2. Initial imperfection by linear buckling analysis

IACS common structural rules (CSR) has just started to be applied to double hull oil tankers of The degree of out-of-plane initial imperfection of stiffened plate is small, but it can affect the ultimate capacity of the stiffened plate considerably. In a real ship structure, the initial imperfection can have various shapes caused by welding deformation, residual stress, hull deflection and so on. It can even vary during the operation of the vessel, so, it' s practically impossible to exactly identify the actual imperfection.

SECTION 10 - BUCKLING AND ULTIMATE STRENGTH

2.2 Plates and Local Support Members

2.2.1 Proportions of plate panels and local support members

2.2.1.1 The net thickness of plate panels and stiffeners is to satisfy the following criteria:

(a) plate panels

$$t_{net} \geq \frac{s}{C}\sqrt{\frac{\sigma_{yd}}{235}}$$

d_w=1150mm

(b) stiffener web plate

$$t_{w-net} \geq \frac{d_w}{C_w}\sqrt{\frac{\sigma_{yd}}{235}}$$

CSR : t_{f_net} = 17.75mm
Paper : t_{f_net} =12.5mm

(c) flange/face plate

$$t_{f-net} \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{\sigma_{yd}}{235}}$$

CSR : t_{f_net} = 13.87mm
Paper : t_{f_net} =12.5mm

Note

1. The total flange breadth, b_f, for angle and T profiles is not to be less than: $b_f = 0.25 d_w$
2. Measurements of breadth and depth are based on gross scantlings as described in *Section 4/2.4.1.2.*

CSR : b_f=287.5mm
Paper : b_f=150mm

Fig. 1 PMA platforms sizes requested in CSR and proposed in this paper.

This paper assumes an initial imperfection mode which can deteriorate the ultimate strength the most. The same initial imperfection shape as the final shape when the stiffened plate reaches its ultimate limit state is assumed since it can accelerate the collapse of entire structure. The first buckling mode from a linear elastic buckling analysis is selected as the initial imperfection.

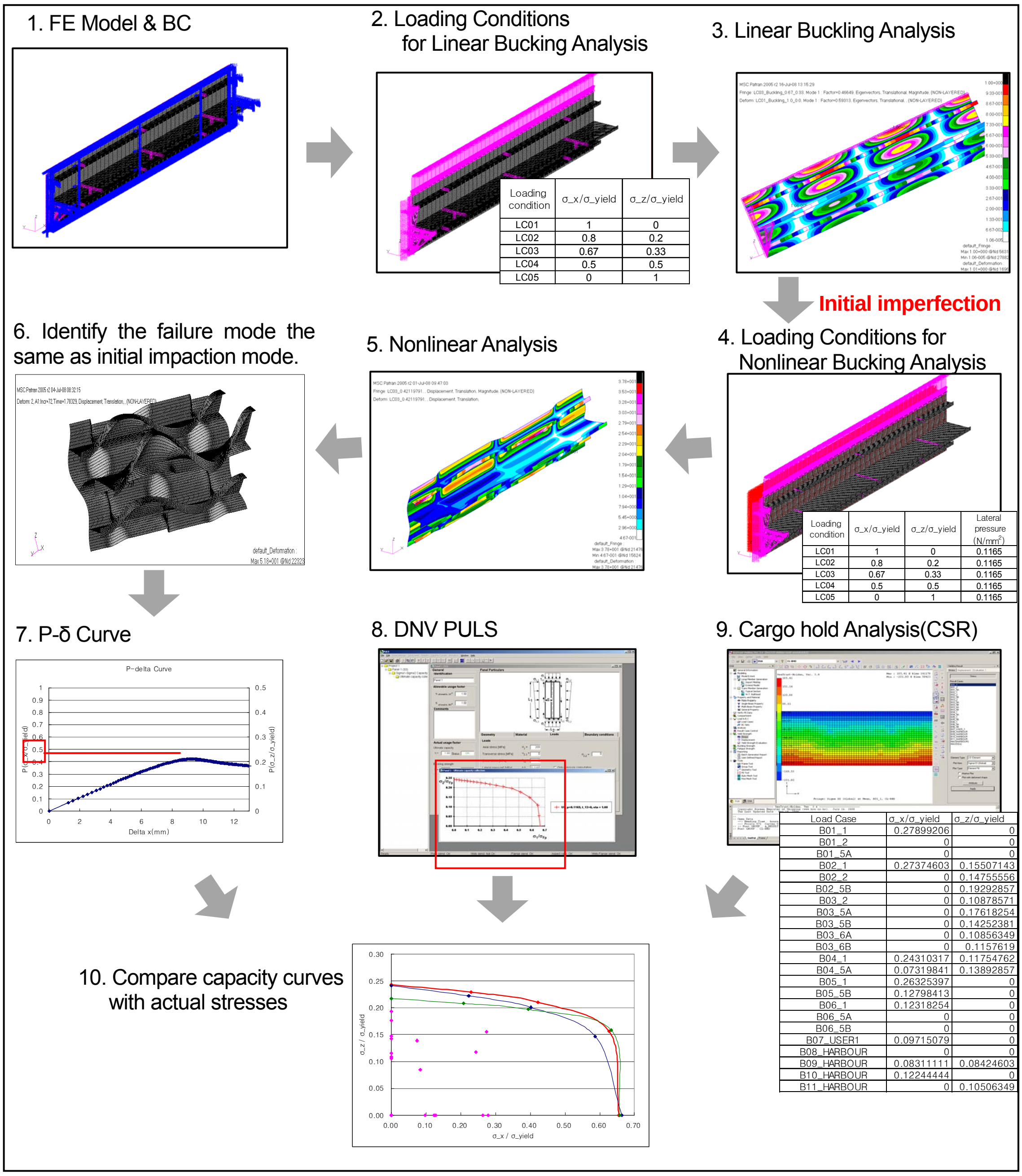

Fig. 2 A procedure of the ultimate strength assessment of the PMA structure

The lineal buckling strength may be different from that of nonlinear buckling strength, but their failure modes must be the same since the mode is the optimal shape which the stiffened plate can take to absorb a specific load.

If the collapse mode resulted from nonlinear ultimate strength analysis doesn't coincide with the initially assumed imperfection shape, the same linear buckling mode is to be selected among all linear bucking modes and the nonlinear ultimate strength analysis is to be conducted again.

2. Initial imperfection by linear buckling analysis

The degree of out-of-plane initial imperfection of stiffened plate is small, but it can affect the ultimate capacity of the stiffened plate considerably. In a real ship structure, the initial imperfection can have various shapes caused by welding deformation, residual stress, hull deflection and so on. It can even vary during the operation of the vessel, so, it's practically impossible to exactly identify the actual imperfection.

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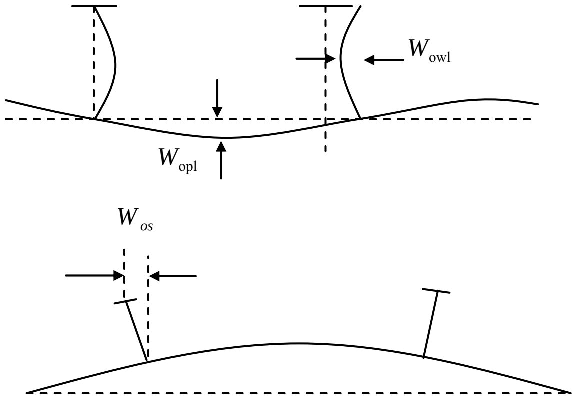
If the collapse mode resulted from nonlinear ultimate strength analysis doesn't coincide with the initially assumed imperfection shape, the same linear buckling mode is to be selected among all linear bucking modes and the nonlinear ultimate strength analysis is to be conducted again.

2.1 The magnitude of initial imperfection

The magnitude of the initial imperfection is also affective to the ultimate strength. This paper complies with the definitions of DNV PULS(2006) as depicted in Fig. 3.



Initial imperfection for plate between stiffeners (W_{opl}) :

$W_{opl} = L_s/200$,

L_s=longi.l stiffener spacing (short length of panel)

Initial imperfection for web of stiffener (W_{owl}) :

$W_{owl} = H_w/200$, H_w= web height of stiffener

Initial imperfection for side way of stiffener

Fig. 3 The definition of the magnitude of initial imperfection in DNV.PULS

2.2 FE model and boundary conditions.

Finite element model is constructed for the stiffened plate including PMA structure as depicted in Fig. 4. Shell elements are used for the entire model and the size of elements is kept small enough. Especially, mesh of about 50mm for stiffener web and mesh of about 40mm for stiffener flange are used in order to observe their tripping behaviors resulting from the partial yielding. The FE model range is three web frames (1/2+2+1/2) in longitudinal direction and three longitudinal stiffener spacings (1/2+2+1/2) in vertical direction, in order to avoid boundary condition effect. Net scantling considering corrosion deduction regulated in CSR is applied.

Boundary condition applied in this analysis is described in Fig. 5. Plane A and Plane B represent x-symmetric boundary condition while x-directional translation of Plane B is not restricted to apply x-directional load on Plane B. Z-symmetric boundary conditions are applied to Line A and Line B in the same manner. The effect of in-plane stiffness of web frame is reflected by restrictions on Frame line, Point C and RBE C (rigid body element).

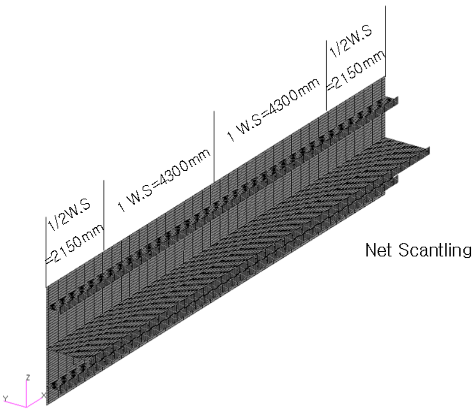


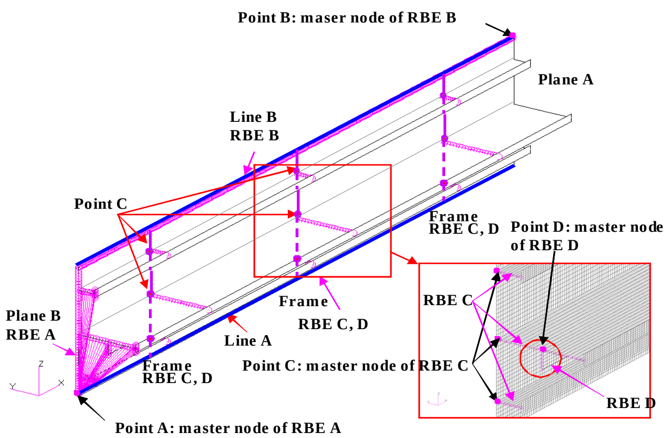
Fig. 4 FE model

2.3 Loading conditions

Table 1 summarizes loading conditions for generating a capacity curve of the stiffened plate. Linear elastic buckling analysis is performed to decide initial imperfection shape for each loading condition.

Table 1 Summary of loading condition

Loading condition	Load combination ratio		Remark
	σ x (longitudinal direction)	σ z (transverse direction)	
LC1	1.0	0.0	Uni-axial
LC2	0.8	0.2	Bi-axial
LC3	0.67	0.33	Bi-axial
LC4	0.5	0.5	Bi-axial
LC5	0.0	1.0	Uni-axial



Location	Constrained DOF	REB Link
Plane A	Ux, Ry, Rz	-
Plane B	Ry, Rz	-
Line A	Uz, Rx, Ry	-
Line B	Rx, Ry	-
Frame line	Uy	-
Point C	Rx	-
RBE A	-	Ux
RBE B	-	Uz
RBE C	-	Uz
RBE D	-	Uy

Fig. 5 Boundary condition

Distributed load is applied to the edges of the stiffened plate in longitudinal and vertical directions. Here, the longitudinal load is calculated separately for different members of different thicknesses such that the same nominal stress occurs on the members. The load of each member is determined by just multiplying its yield stress with its thickness as follows;

$$w_i = \sigma_{i,yield} \times t_{i,applied}$$

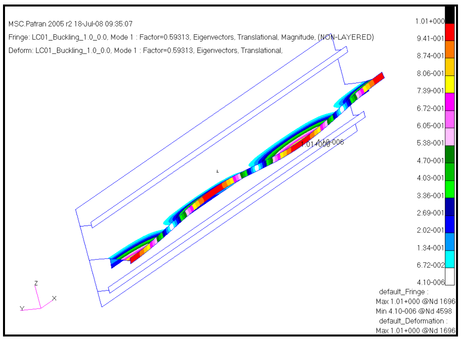
Where,

w_i = Distributed load for i-th member (N/mm),

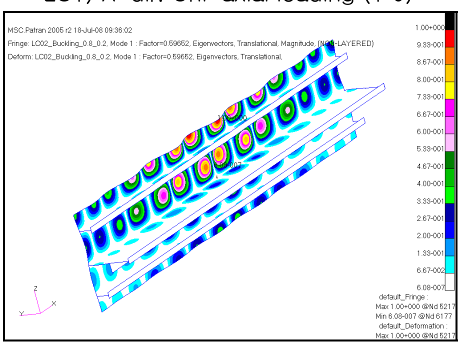
$\sigma_{i,yield}$ = Yield stress of i-th member(N/mm^2),

$t_{i,applied}$ = Thickness of of i-th member (mm).

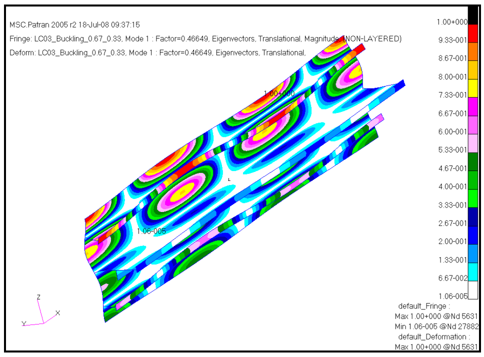
In case of bi-axial load, each load combination ratio in Table 1 is used to scale down the magnitude of the loads calculated above. The x-directional and z-directional loads are applied Plane B and Line B, respectively in Fig. 5.



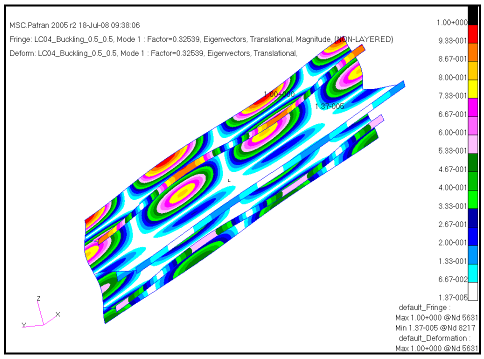
LC1) X-dir. Uni-axial loading (1:0)



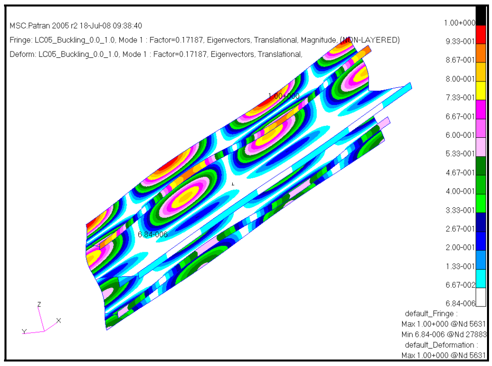
LC2) Bi-axial loading (0.8:0.2)



LC3) Bi-axial loading (0.67:0.33)



LC4) Bi-axial loading (0.5:0.5)



LC5) Z-dir. Uni-axial loading (0:1)

Fig. 6 Eigen mode shapes

2.4 Results of linear buckling analysis

Linear elastic buckling analysis is performed for each loading condition. The first buckling mode shape for each loading condition is shown in Fig. 6. In case of LC 1, the buckling occurs at the flange of PMA structure while the others at plate between stiffeners.

Since the maximum value of the buckling mode shape is 1.0 for each case, the shape needs to be scaled up using the magnitude defined in Section 2.1. The scale factor is the magnitude of a member of the maximum displacement. For example, if plate between stiffeners has the maximum displacement, the initial imperfection for plate between stiffeners (W_{opl}) is used to scale up the overall shape. The imperfection is reflected into FE model by moving nodes directly.

3. Ultimate strength assessment

Next, ultimate strength assessment for the PMA structure is performed using nonlinear FE analysis. An ultimate strength capacity curve is generated by conducting the assessments for all loading conditions listed in Table 1. The capacity curve is compared with actual stresses under all loading conditions of CSR cargo hold analysis to verify the safety of PMA structure. The stresses can cover all actual stress distributions on the PMA structure. For the nonlinear FE analysis, MSC NASTRAN SOL600 IMPLICIT code is used.

3.1 FE model and lateral pressure

The initial imperfection is reflected into FE model using the result of linear buckling analysis. Fig. 7 shows an example of FE model which the initial imperfection of LC1 is reflected into.

For the nonlinear analysis, the same loading and boundary conditions as the linear buckling analysis are used except for lateral pressure. For each loading condition, lateral tank pressure of 0.0165 N/mm^2 is applied on the plate. The maximum pressure value is selected from those imposed on the PMA structure under all load conditions defined in CSR cargo hold analysis to be conservative.

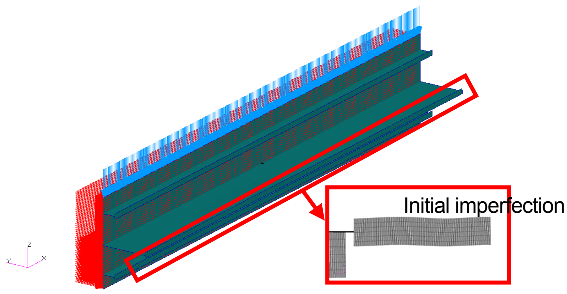


Fig. 7 Loads for nonlinear analysis – bi-axial load , LC1

3.2 Result of nonlinear ultimate strength analysis

A series of nonlinear ultimate strength analyses are performed for all loading conditions in Table 2 and a capacity curve is obtained. The ultimate strength capacity results are summarized in Table 2 and the capacity curve is plotted in Fig. 8. In case of LC 2, the final ultimate strength mode was identified to be different from the initially assumed imperfection shape. Therefore, the second linear buckling mode which is the same as the failure mode is selected instead and the nonlinear FE analysis was performed again. As a result, a smaller capacity value was calculated.

Table 2 Summary of buckling/ultimate strength analysis for stiffened panel

Loading Condition	Ultimate strength		Remark
	$\sigma_x / \sigma_{yield}$	$\sigma_z / \sigma_{yield}$	
LC1	0.655	0.0	Uni-axial
LC2	0.627	0.157	Bi-axial
LC3	0.421	0.211	Bi-axial
LC4	0.229	0.229	Bi-axial
LC5	0.0	0.243	Uni-axial

The capacity curve is compared with the stress results from CSR cargo hold analysis. The maximum values of σ_x/σ_{yield} or σ_z/σ_{yield} on the PMA structure for all loading conditions of CSR cargo analysis are plotted in Fig. 8 and listed in Table 3. Fig. 8 shows all points are inside the capacity curve. It means the structure has the sufficient strength from buckling/ultimate strength point of view. Especially, the PMA structure has large margin for LC1 where the PMA platform reaches yielding first.

According to the results, the stiffened plate reaches yielding earlier than PMA platform except for a longitudinal uni-axial loading condition(LC1). Even under the longitudinal uni-axial load, the yielding occurs at the PMA platform and the stiffened plate almost at the same time. They are displayed in Fig. 9 and Fig. 10.

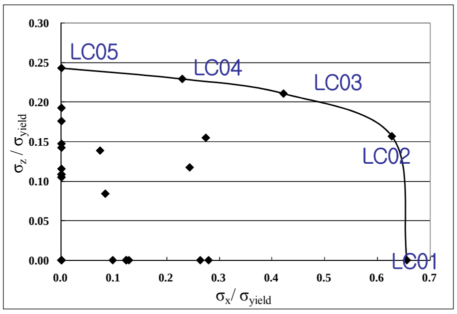


Fig. 8 Ultimate strength capacity curve of PMA structure

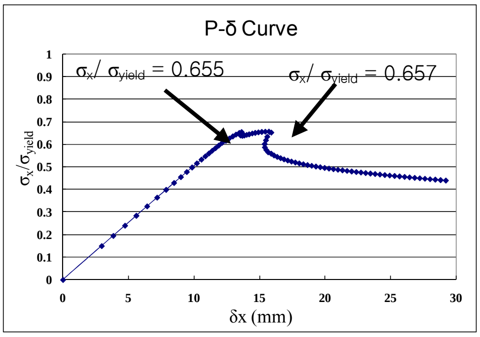


Fig. 9 P-δ curve under LC1

Table 3 CSR cargo hold analysis results on stiffened panel including PMA structure

Loading Condition	Maximum compressive stress σ_x	Maximum compressive stress σ_z	σ_x/σ_{yield}	σ_z/σ_{yield}
B01-1	87.9	0.0	0.279	0.0
B01-2	0.0	0.0	0.0	0.0
B01-5A	0.0	0.0	0.0	0.0
B02-1	86.2	48.8	0.274	0.155
B02-2	0.0	46.5	0.0	0.148
B02-5B	0.0	60.8	0.0	0.193
B03-2	0.0	34.3	0.0	0.109
B03-5A	0.0	55.5	0.0	0.176
B03-5B	0.0	44.9	0.0	0.143
B03-6A	0.0	34.2	0.0	0.109
B03-6B	0.0	36.5	0.0	0.116
B04-1	76.6	37.0	0.243	0.117
B04-5A	23.1	43.8	0.073	0.139
B05-1	82.9	0.0	0.263	0.0
B05-5B	40.3	0.0	0.128	0.0
B06-1	38.8	0.0	0.123	0.0
B06-5A	0.0	0.0	0.0	0.0
B06-5B	0.0	0.0	0.0	0.0
B07	30.6	0.0	0.097	0.0
B08-harbor	0.0	0.0	0.0	0.0
B09-harbor	26.2	26.5	0.083	0.084
B10-harbor	38.6	0.0	0.122	0.0
B11-harbor	0.0	33.1	0.0	0.105

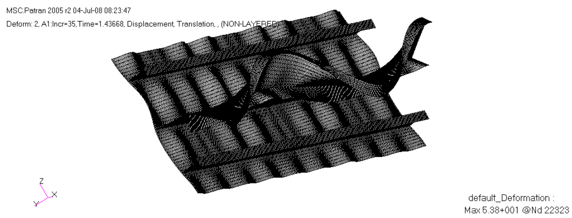


Fig. 10 Deformation under LC1

4. Conclusion

This paper proposes a procedure for ultimate strength assessment of permanent means of access (PMA) structure including walking platform and its adjacent stiffened plate. The method is illustrated by a PMA structure which doesn't satisfy the scantling requirements of local support member of CSR. The procedure starts from defining a set of loading conditions by varying the ratio of longitudinal and transversal loads on the stiffened panel. Linear elastic buckling analysis(eigenvalue analysis) under each loading condition is performed to obtain the initial imperfection shape to be used in the ultimate strength analysis. The same imperfection mode as the failure mode at the ultimate limit state is assumed to be sufficiently conservative. A capacity curve of the stiffened plate is obtained from a series of the ultimate strength analyses for the PMA structure. According to the results, the stiffened plate reaches yielding earlier than PMA platform except for a longitudinal uni-axial loading condition. Under even the longitudinal uni-axial load, the yielding occurs at the PMA platform and the stiffened plate nearly simultaneously. The structural adequacy is evaluated by comparing the capacity curve with actual stresses obtained from common structure rule (CSR) cargo hold analysis. Conclusively, even if a PMA structure doesn't comply with the requirement of local support member in CSR, its strength can be verified using the proposed method.

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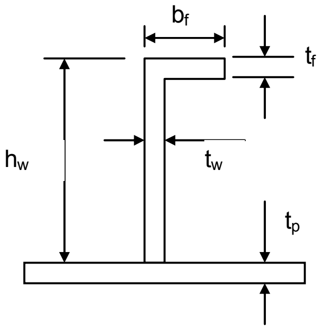
APENDIX : Comparison of the proposed approach with DNV PULS

The proposed approach need to be verified by a comparison with DNV PULS. However, DNV PULS doesn't work for the PMA scantling of 1150X12+150X15 for the reason of inappropriate slenderness ratio. Instead, for a common stiffened plate, the same procedure described in Section 2 and Section 3 is applied for the purpose of verifying the proposed procedure. Two cases are considered; one case with lateral pressure and the other case without lateral pressure.

Scantlings of a stiffened plate and the corresponding FE model are depicted in Table A.1 and Fig. A.1. The loading conditions and the results are described in Table A.2. The ultimate capacity from nonlinear FE analysis and DNV PULS capacity curve are plotted in Fig. A.2 and A.3. They match sufficiently well. From this illustrating example, the validity of the proposed approach is identified.

Table A.1 Scantling of stiffened plate (mm)

F.S	L.S	t_p	t_w	t_f	b_f	h_w	N_s	σ_0
4300	815	14.25	8.5	12	150	397	10	315



Where, F.S = Frame spacing

L.S = Longi. spacing

t_p = Plate thickness

t_w = Thickness of stiffener web

t_f = Thickness of stiffener flange

b_f = Breadth of stiffener flange

N_s = Number of stiffener

σ_0 = Material yield stress

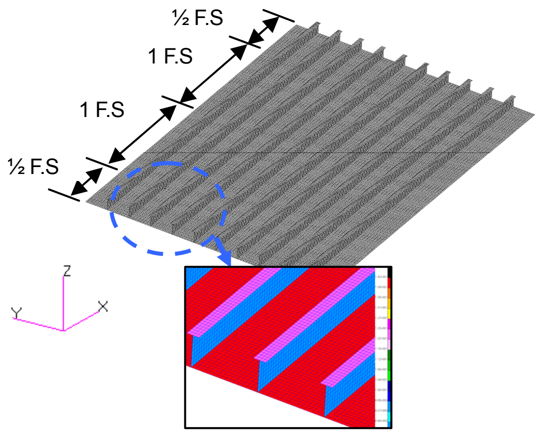


Fig. A.1 FE model

Table A.2 Summary of loading conditions and ultimate strength assessment results.

Loading condition	Load combination ratio		Lateral press. (N/mm²)	Ultimate strength	
	σ_x	σ_y		σ_x/σ_{yield}	σ_y/σ_{yield}
LC1-1	1.0	0.0	0	0.790	0.0
LC1-2	0.8	0.2	0	0.687	0.172
LC1-3	0.67	0.33	0	0.483	0.242
LC1-4	0.5	0.5	0	0.249	0.249
LC1-5	0.0	1.0	0	0.0	0.274
LC2-1	1.0	0.0	0.165	0.633	0.0
LC2-2	0.8	0.2	0.165	0.647	0.162
LC2-3	0.67	0.33	0.165	0.480	0.240
LC2-4	0.5	0.5	0.165	0.243	0.243
LC2-5	0.0	1.0	0.165	0.0	0.264

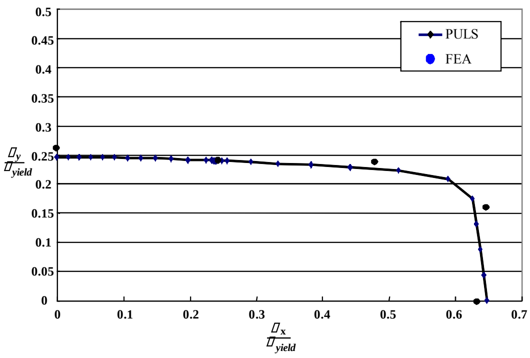


Fig. A.2 Ultimate strength of stiffened panel without lateral pressure

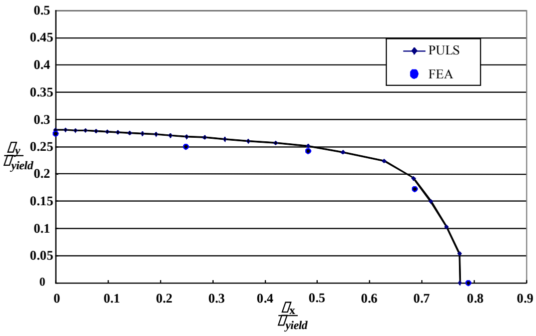


Fig. A.3 Ultimate strength of stiffened panel with lateral pressure

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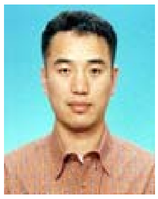

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