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PROBABILISTIC EVALUATION OF PLATE EFFECTIVENESS IN TERMS OF EFFCTIVE WIDTH OF ATTACHED PLATING

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ABSTRACT

A ship hull is a complex structure consisting of unstiffened/stiffened plates, longitudinals, frames, transverses, etc. and is subject to longitudinal bending, transverse bending and torsion. A primary load effect in ship hull components is axial compression induced due to longitudinal bending. The stiffened plate which is the backbone of the primary support members in a ship hull is widely modeled to consist of the stiffener with an attached plating of a certain effective width. This is called the beam-column model and its behaviour largely depends on its cross-section properties and hence on the effective width of the attached plating. Many researchers in the past assumed a convenient constant value of effective width. However, fabrication related initial imperfections in the form of initial deflection and welding induced residual stresses always develop in the plate elements between two longitudinals and they do affect plate behaviour. Field measurements indicate that plate design parameters such as material yield strength, initial deflection, welding residual stresses as well as corrosion loss are random in nature. Growing concern towards ship safety and reliability through Goal Based Standards (GBS) highlights the need to employ probabilistic methods in studying the mechanical behaviour of stiffened plates. In this paper, the effective width of the attached plating is assessed using probabilistic methods considering the effect of random material yield strength, initial deflection, welding residual stresses and corrosion loss in the plating between two longitudinals of a bulk carrier and a oil tanker. The results obtained are presented by platting histograms of effective width ratio for various cases. The results obtained in this study can be very useful for reliability analysis of ship plated structures.

Key words: Effective width, random, average stress-strain relationship, reliability analysis.

1. INTRODUCTION

A ship hull is a complex structure mainly consisting of continuous unstiffened/stiffened plates, longitudinals, frames, transverses, etc. and is subject to longitudinal bending, transverse bending and torsion. A primary load effect is axial compression induced due to longitudinal bending. Behaviour of structural element under axial compressive load is very important. The plate effectiveness can be reduced by lateral deflection that may arise due to (i) initial deflection and welding residual stresses due to welding process, (ii) lateral pressure due to cargo or sea load, and (iii) buckling due to axial compression. Hence, the plate effectiveness is the function of initial imperfections (initial deflection and welding residual stresses) and the applied load actions.

Depending upon the applied load actions, Paik [1] measured the effectiveness of the plate by using three different concepts: (i) effective breadth, (ii) effective width and (iii) effective shear modulus. Effectiveness of the deflected plate is evaluated by considering an equivalent flat plat but with reduced effectiveness and this reduced effectiveness is measured by the three different concepts as stated above depending upon the applied load action. The term effective breadth is typically used when the lateral deflection is caused by out-of-plane or lateral pressure action in association with shear lag effect. The term effective width is typically used when the lateral deflection is caused by in-plane compressive loads and the term effective shear modulus is used when a plate is predominantly bucked by edge shear action. In this paper, we have concentrated on the evaluation of effectiveness using the term effective width.

A equation originally presented by von Karman *et al.* (1932) for effective width (b_{eff}) of plates as $b_{eff} / b = \sqrt{\sigma_{cr} / \sigma_Y}$; where b is the full width of the plate, σ_{cr} is the critical buckling stress and σ_Y is the material yield stress. This expression was reasonably accurate for thin plates but is found to be relatively conservative in case of thick plates.

The classification societies use the following formula for effective width proposed by Faulkner [2] for merchant ship plating that implicitly considers a moderate level of initial deflection but does not consider welding residual stresses:

$$\frac{b_{eff}}{b} = \begin{cases} 1.0 & \text{for } \beta < 1, \\ \dfrac{C_1}{\beta} - \dfrac{C_2}{\beta^2} & \text{for } \beta \geq 1. \end{cases} \quad (0.1)$$

where C_1 and C_2 are constants and depends on the applied boundary conditions of the plate (C_1 = 2.0 , C_2 = 1.0 for all edges simply supported; C_1 = 2.25 , C_2 = 1.25 for all edges clamped), $\beta = (b/t_P)\sqrt{\sigma_Y / E}$ is the plate slenderness ratio (b = plate breadth or stiffener spacing, t_P = plate thickness and E = Young's modulus). It can be seen that Faulkner's expression does not consider the effect of the applied load: under axial compressive load, the effective width should naturally decrease as the load increases. Also, Faulkner neglected the presence of the welding residual stresses induced during the manufacturing process.

The presence of initial imperfection reduces the effective width of attached plating (analytically demonstrated by Paik *et al.*, [3]). Higher the magnitude of initial imperfection (both, initial deflection and welding residual stresses), lower the value of effective width/ultimate strength of plating. Hence, it is obvious that the cross-sectional area of combined attached plating and stiffener structure (stiffened plate element) will be reduced, which subsequently reduces the ultimate load carrying capacity of individual stiffened plate element. In turn, this reduces the ultimate strength of the hull girder.

The aim of the present paper is to study the effect of influential parameters in the evaluation of plate effectiveness using the term 'effective width'. Further, randomness in the influential parameters (material yield stress, initial imperfections due to welding process and aging effect due to corrosion) is considered to propose the effective width as a random variable. Four different candidate plates (two of a bulk carrier and two of a oil tanker) are analysed in this study. The results are presented through histoghrams and are compared with Faulkner's formula [2] and IACS CSR formula [4].

2. CONCEPT OF EFFECTIVE WIDTH

Generally, the stiffened plate is represented by beam-column approach [5-9] which is an assembly of stiffener and attached plating. If the stiffened plate is subjected to axial compressive load actions, the extent of attached plating is defined by the term 'effective width' of attached plating.

As the plate buckles under uniform compressive loads, the membrane stress distribution inside the plate becomes non-uniform provided the unloaded edges (intersection at which stiffener and plating are welded) of the plate remain straight. The membrane stresses, compressive in nature, become maximum at the plate edges and minimum in the middle region associated with membrane tensile stresses due to the plate deflection. The plate width that supports the maximum membrane stresses is called the effective width of the plate. Immediately after buckling, the maximum membrane stress becomes larger than the average value of non-uniform membrane stresses in longitudinal direction as shown in Fig. 1.

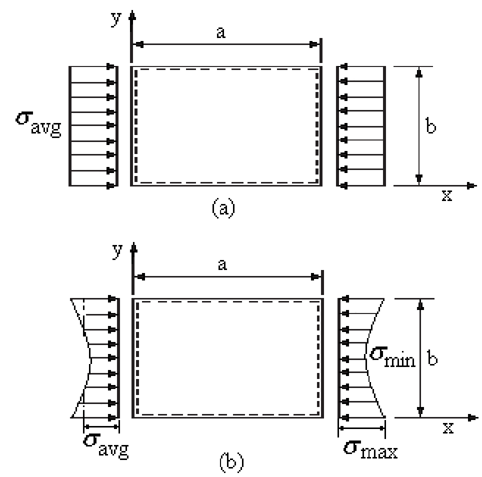

Figure 1. Membrane stress distribution, (a) before buckling, and (b) after buckling

After buckling, the maximum membrane stress becomes larger than the average stress (Fig. 1-b). In this case, the ratio of effective width to the full width is same as the ratio of the average stress (σ_{avg}) to the maximum stress (σ_{max}) [1] and can be presented as:

$$\frac{b_e}{b} = \frac{\int_{-b/2}^{b/2} \sigma_x \mathrm{dy}}{\sigma_{\max}} = \frac{\sigma_{avg}}{\sigma_{\max}} \quad (0.2)$$

It is traditional to compare the reduced strength of the plate with full width (b) by equating it to the strength of another plate that has an effective width (b_{eff}) and collapses at the material yield stress. Therefore, the effective width becomes equal to the ultimate strength [9]. Hence, ratio of effective width (b_{eff}) to the full width (b) is same as the ratio of ultimate strength (σ_u) to the yield stress (σ_Y) as:

$$\frac{b_{eff}}{b} = \frac{\sigma_u}{\sigma_Y} \quad (0.3)$$

Analytical methods, experimental tests, empirical approaches and non-linear finite element method have been used widely to determine the buckling and ultimate strengths of ship platings and significant progress has been achieved. However, some important aspects of this subject remain areas of active research:

- development of analytical formulas,
- development of simplified methods,
- assessment of effects of initial imperfections,
- assessment of effects of fatigue cracks.

An analytical formulation to determine the effective width or ultimate strength of plating between two stiffeners, considering presence of initial imperfections (initial deflection and welding residual stresses), is presented in our earlier publication [10] by deriving average stress-strain relationship under axial compressive load action as prescribed. The average stress-strain relationship is established by taking advantage of two different methods in combination: the membrane stress method by involving large elastic deformation theory and the rigid plastic collapse mechanism theory. Using the methodology, it shown that the effective width and/or ultimate strength of plate under compressive load is a function of applied load, material yield strength (σ_Y) and magnitude of initial imperfections (A_0 and σ_r) in Fig 2-4. The circles on the curves shown in Fig. 4 are effective width ratio when the plate is on the verge of yielding and is important in the determination of ultimate strength of plating.

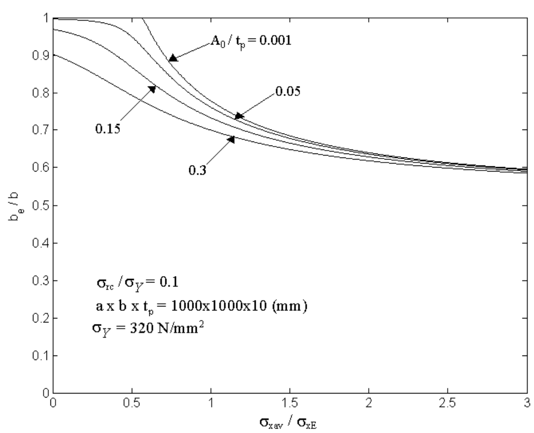

Figure 2. Variation in the effective width ratio with different magnitudes of initial deflection

If the magnitudes of material yield strength and initial imperfection are random, the effective width of attached plating, and hence the properties of the stiffened plate are random in nature. Thus, the hull girder ultimate strength should be described as a random variable as well.

In the following sections, the probabilistic modeling of initial imperfections (initial deflection amplitude and welding residual stresses), material yield strength and corrosion is described. Following that the statistics of effective width of candidate plates are investigated.

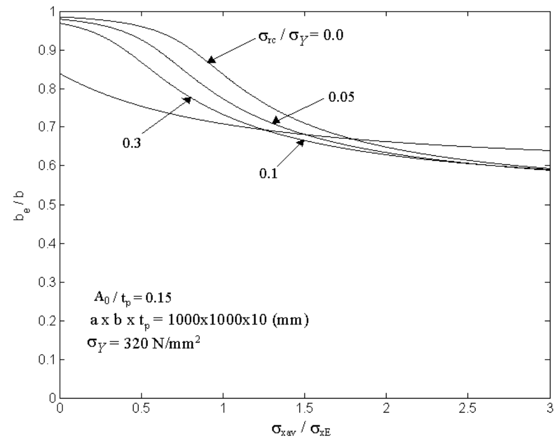

Figure 3. Variation in the effective width ratio with different magnitudes of welding residual stresses

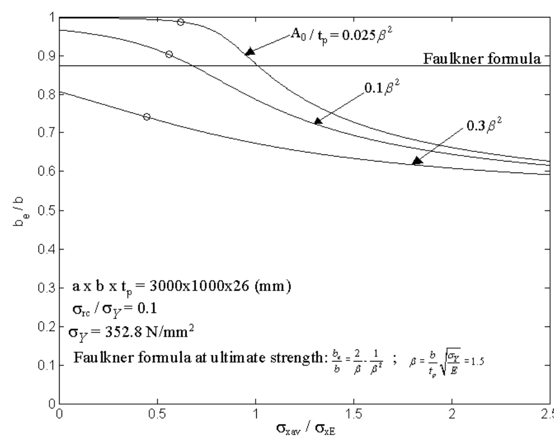

Figure 4. Effective width compared with Faulkner's formula

3. INITIAL IMPERFECTIONS

The initial imperfections (initial deflection, A_0 and welding residual stresses, σ_{rc}) are introduced into the plating because of welding process used in ship building during fabrication process. When the welded zone cools down, it shrinks but can not regain its original shape and thus tensile stresses develop. Consequently, compressive stresses develop in the adjacent colder parts. The plate effective width at the ultimate strength is different depending on the level of initial deflection. Smith et al. [11] and Paik and Thayamballi [12] have defined three different levels of initial imperfections as slight, average and severe as:

Table 1. Initial Imperfection Levels [11-12]

Level	Initial deflection (A_0)	Welding residual stress (σ_{rc})
Slight	$0.025\beta^2 t_P$	$0.05\sigma_y$
Average	$0.1\beta^2 t_P$	$0.15\sigma_y$
Severe	$0.3\beta^2 t_P$	$0.3\sigma_y$

However, Faulkner formula [2] explicitly does not take into account the effect of initial deflection as a parameter of influence. Most of the shipyards apply manual welding processes and so there is possibility of variation in the welding process parameters. Due to such variations which are inherent and uncertain, the initial imperfections are random in nature. This is supported by actual statistical data collected by [13] and [14].

We now assume that the initial deflection amplitude (A_0) is a random variable while the pattern of the initial deflection (w_0) over the plate, as shown in Fig. 5, remains the same:

$$w_0 = A_0 \sin\frac{m\pi x}{a}\sin\frac{\pi y}{b} \qquad (0.4)$$

where, A_0 = defined is the initial deflection amplitude.

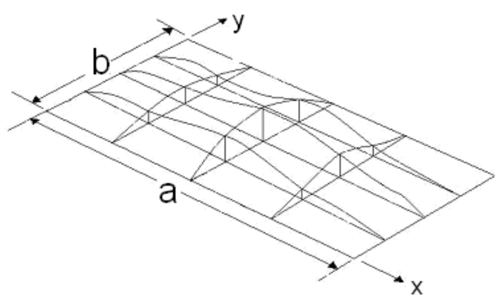

Figure 5. Initial deflected shape of plating between the stiffeners

With reference to [14], a Normal probability model for A_0 normalized by b (A_0/b) is used in the present study to demonstrate the random initial deflection amplitude and thus the random initial deflection of plating between two stiffeners. Hence,

$$A_0 / b \sim \text{Normal}(\mu,\sigma) \qquad (0.5)$$

where, mean (μ) is given by

$$\mu = 0.12 b\sigma_Y / t_P E \qquad (0.6)$$

and the coefficient of variation (c.o.v.) given by:

$$\text{c.o.v.} = 0.675 - 0.004 b / t_P \qquad (0.7)$$

The above model is based on data measured on plates for $b/t_P \le 120$, the majority being in the range of $20 \le b/t_P < 120$. It can be seen that the mean increases while the c.o.v. decreases with increasing b/t_P.

In the idealized welding induced residual stress distribution used in the present method (previously shown in Fig. 6), the tensile residual stresses, σ_{rt}, are developed at the edges of the plating i.e. along the welding line; the residual compressive stresses, σ_{rc}, are developed in the middle of part of the plating. The breadth of the tensile residual stress may reach the yield stress but a somewhat reduced 80% of the yield stress tensile residual stress may be used.

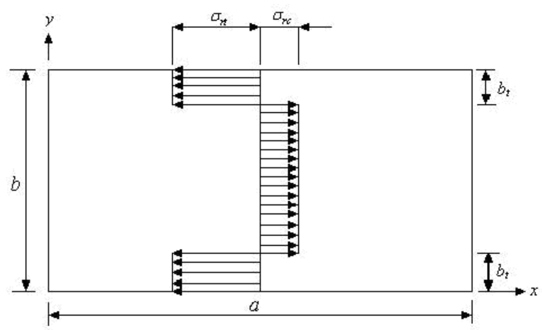

Figure 6. Idealized welding residual stress distribution of plating between stiffeners

The model of uncertainty in welding residual stress proposed by [14] is:

$$\frac{\sigma_r}{\sigma_Y} = \frac{2\eta}{\left[\dfrac{b}{t_P} - 2\eta\right]} \qquad (0.8)$$

where, σ_r = welding residual stress, σ_Y = material yield strength, $\eta = b_t / t_P$ = non-dimensional width of tensile stress block (as shown in Fig. 6) having a Normal distribution with mean

$$E[\eta] = 1.20 + 0.06 b / t_P \qquad (0.9)$$

and a standard deviation given by

$$\sigma_\eta = 0.04 b / t_P \qquad (0.10)$$

4. RANDOM YIELD STRENGTH

The hull girder ultimate strength is rather sensitive to the variation in the yield strength. The material yield strength of each structural member (stiffener, plate panels or hard corner) in the mid-ship section of hull girder is considered to be random. According to the existing literature on the statistics of yield strength of structural steel used in the marine industry, the bias (i.e., mean/ nominal) is between 1.00 and 1.10 (Table 2) while the coefficient of variation (c.o.v., i.e., standard deviation / mean) varies between 6% and 10%. In this study, it is assumed that the material yield strength is lognormal with c.o.v. 6% and mean value of 1.1 times the nominal value.

Table 2. Randomness in yield strength

Source	Distribution Type	Bias	c.o.v. (%)
DnV [15]	Lognormal	1.1	6.0
Guedes Soares and Kmiecik [16]	Lognormal	1.0	10.0
Paik and Frieze [17]	Normal	1.0	10.0
Harada and Shigemi [18]	Lognormal	1.1	6.0

5. RANDOM CORROSION WASTAGE

The corrosion growth of the marine structures depends on the loss of coating effectiveness and corrosion rate. Generally, it is assumed that corrosion starts immediately after coating loss. Paik et al. [19] proposed a time dependent corrosion wastage model wherein the transition between the coating breakdown and corrosion initiation (τ_t) was considered and is shown as (Fig. 7):

$$d(t) = A(t - \tau_c - \tau_t)^B \qquad (0.11)$$

where: A = corrosion rate (mm/year); B = constant; t = present age of the ship (years); τ_c = coating life (years); τ_t = transition between the coating breakdown and corrosion initiation (years).

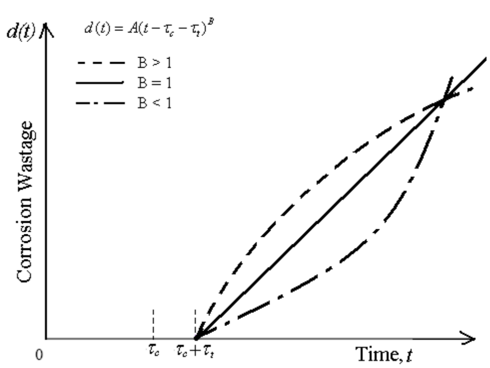

Figure 7. Paik' corrosion wastage model

In the present study, it is assumed that the corrosion starts immediately after loss of coating and hence transition between the coating breakdown and corrosion initiation is ignored (τ_t = 0). It is assumed that the coating life, τ_c follows normal distribution with mean of 7.5 and c.o.v. of 0.4 [19]. For corrosion of marine structure, B may be typically vary in the range of 0.3 – 1.5. For the sake of simplicity and to demonstrate the effect of random corrosion wastage on effective width of attached plating, we assume value of B to be equal to 1. The corrosion rate, A is taken from [19].

6. NUMERICAL EXAMPLES AND DISCUSSION

In this section, the effective width of the attached plating to the stiffener is determined under the effect of random initial imperfections (as described in Sections 3), random yield strength (as described in Section 4) and random corrosion wastages in Section 5. The candidate deck and bottom plates used in these examples are taken from two ship structures (a bulk carrier and double hull tanker) from a benchmark study of ISSC Technical Committee VI.2 [20] and the details are given in Table 3 and Table 4 shows the effective width for each plating calculated deterministically using Faulkar [2] and IACS CSR [4] formula

Table 3. Plating details

Plating	a (mm)	b (mm)	t_P (mm)	β	σ_Y
Tanker bottom plate	4950	830	22.5	1.44	313.6
Tanker deck plate	4950	830	20.0	1.62	313.6
Bulk carrier bottom plate	2610	880	18.5	1.85	313.6
Bulk carrier deck plate	5220	880	24.5	1.57	392

Table 4. Effective width of plating

Plating	Fualkner (1975)	IACS (2008b)
Tanker bottom plate	0.90	0.98
Tanker deck plate	0.85	0.98
Bulk carrier bottom plate	0.79	0.80
Bulk carrier deck plate	0.87	0.98

As stated, effective width is the function of applied load and decreases with increase in the load action. The same is demonstrated in Fig.8. Three different cases are shown: (i) random yield strength combined with slight level of initial imperfection, (ii) random yield strength combined with average level of initial imperfection and (iii) random yield strength combined with severe level of initial imperfection.

Monte-Carlo simulation is performed to obtain statistics of effective width ratio. Firstly, we have considered random material yield strength associated with deterministic levels of initial imperfections as mentioned in Table 1. Figure 9 shows the histogram of effective width ratio of tanker bottom plate when random yield strength is combined with slight level of imperfection. Mean and c.o.v. of effective width ratio is given. Figure 10 and Fig. 11 shows the histogram of same plate when random yield is combined with severe level of imperfections and random yield strength and random initial imperfections in combination respectively.

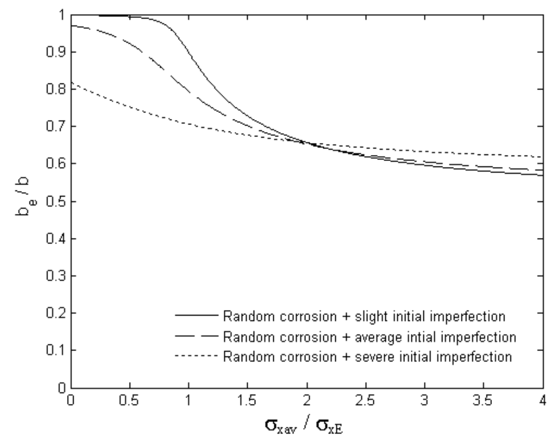

Figure 8. Variation in the effective width ratio with applied uniaxial compressive load

It is observed that the mean is of effective width decreases with increase in the level of initial imperfection from slight to severe and c.o.v. increases. However, in case of combined random yield and random initial imperfections the mean is higher than combined random yield strength severe initial imperfection but is lower than combined random yield strength and slight initial imperfection. The c.o.v. is higher than both the cases. Remaining plots for tanker deck plate (Fig. 12-14), for bulk carrier bottom plate (Fig. 15-17) and for bulk carrier deck plate (Fig. 18-20) also reinforce the same findings. The c.o.v. which is the measure of uncertainty is upto 7 to 8 % when both yield strength and initial imperfections are random. Comparing the mean effective width ratio with Faulkner's formula [2] and IACS CSR formula [4] in Table 4, it is observed that the effective width obtained by Faulkner's formula resembles with the one obtained when combined random yield strength and random initial imperfections are accounted in the analysis.

Later, random corrosion wastage (as described in Section 5) is considered in the evaluation of effective width of the candidate plates. The corrosion rate, A assumed to have Weibull distribution as given in [19] and Table 5 shows the mean and c.o.v. of A for each of the candidate plates.

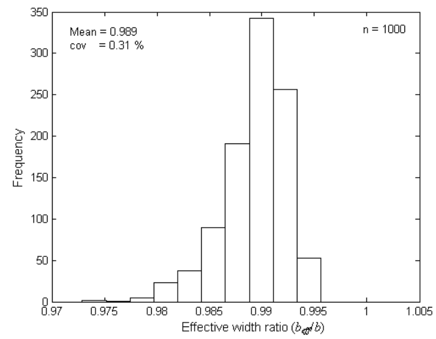

Figure 9. Tanker bottom plate – random yield strength + slight initial imperfection

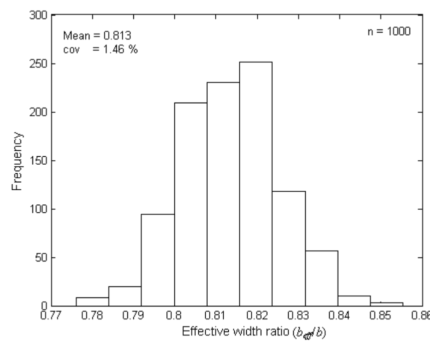

Figure 10. Tanker bottom plate – random yield strength + severe initial imperfection

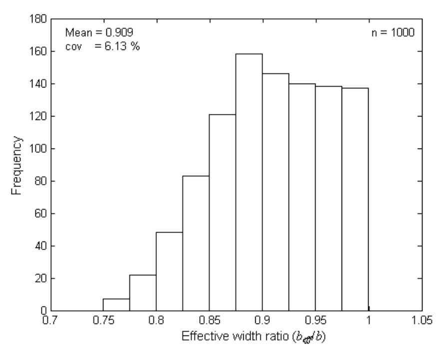

Figure 11. Tanker bottom plate – random yield strength + random initial imperfection

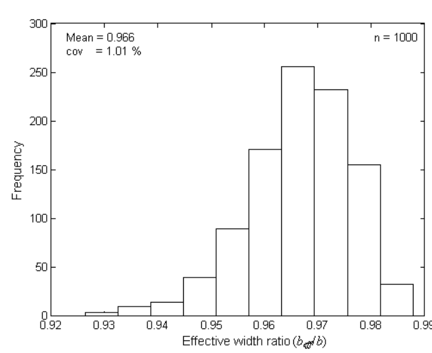

Figure 12. Tanker deck plate – random yield strength + slight initial imperfection

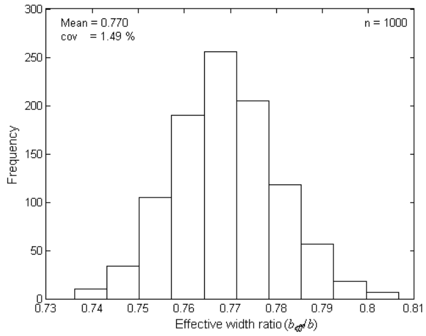

Figure 13. Tanker deck plate – random yield strength + severe initial imperfection

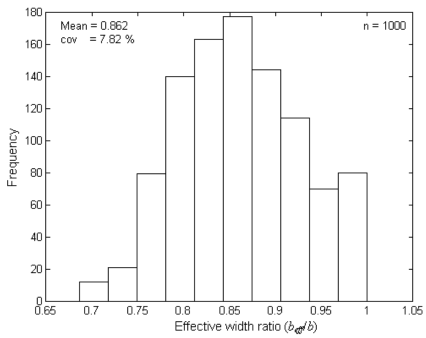

Figure 14. Tanker deck plate – random yield strength + random initial imperfection

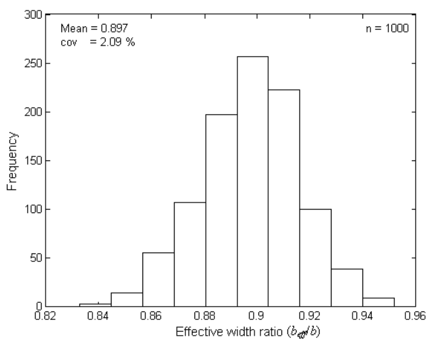

Figure 15. Bulk carrier bottom plate – random yield strength + slight initial imperfection

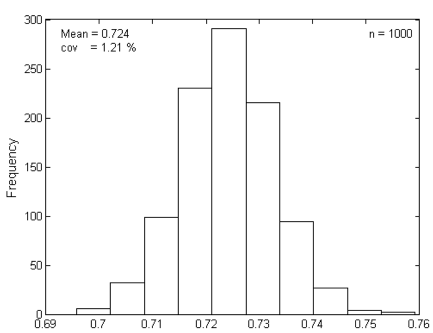

Figure 16. Bulk carrier bottom plate – random yield strength + severe initial imperfection

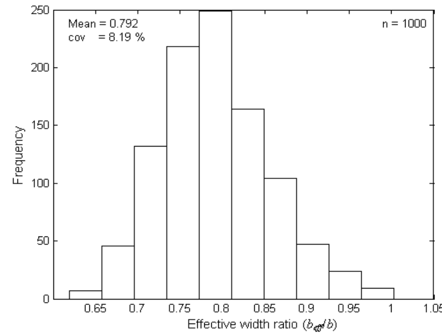

Figure 17. Bulk carrier bottom plate – random yield strength + random initial imperfection

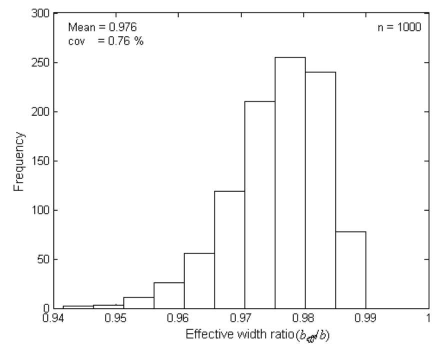

Figure 18. Bulk carrier deck plate – random yield strength + slight initial imperfection

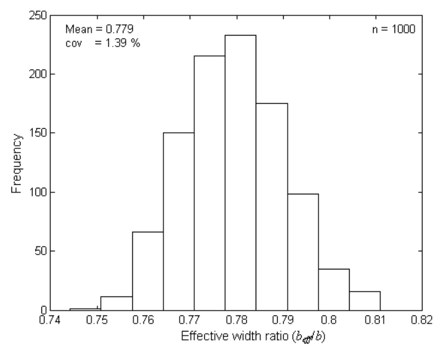

Figure 19. Bulk carrier deck plate – random yield strength + severe initial imperfection

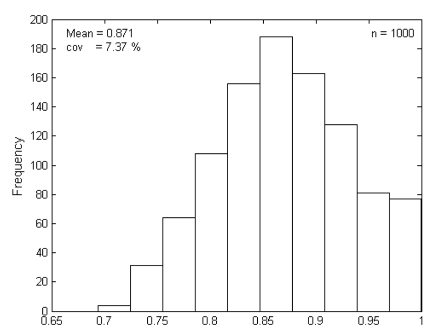

Figure 20. Bulk carrier deck plate – random yield strength + random initial imperfection

Table 5. Probabilistic details of the corrosion rate

Plating	Mean (mm/yr)	c.o.v. (%)
Tanker bottom plate	0.0597	0.9901
Tanker deck plate	0.0581	0.8262
Bulk carrier bottom plate	0.0497	0.9557
Bulk carrier deck plate	0.1188	0.9217

Figure 21 shows the variation in the effective width ratio with applied load at various values of present age (*t*). This is evident that the effective width decreases with increasing time from new built structure.

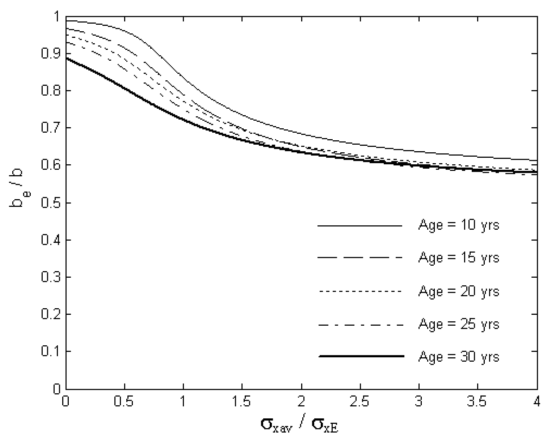

Figure 21. Variation in the effective width ratio at different age (*t*) values

In different cases, random corrosion wastage is combined with the three levels of initial imperfections as mentioned in Table 1. For each case, 1000 samples of effective width ratio are obtained by Monte-Carlo simulation. Table 6 presented the statistical parameters of effective width ratio of the tanker bottom plate for different assumed ages of 15, 20, 25 and 30 yrs.

Table 6. Effective width ratio- Tanker bottom plate

	t = 15 yrs		*t* = 20 yrs		*t* = 25 yrs		*t* = 30 yrs	
	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.
1*	0.99	0.28	0.99	0.59	0.98	1.40	0.98	2.11
2*	0.92	1.11	0.92	1.72	0.91	2.46	0.91	3.66
3*	0.80	1.33	0.79	1.94	0.79	2.65	0.78	3.87

*Initial imperfection level: 1= Slight; 2=Average; 3=Severe

There not a significant change in the mean of effective width ratio. But, the c.o.v. increases with the time for a particular level of initial imperfection. At any particular age, reduction in the mean (around 20%) and increase in the c.o.v. upto 3.87 % is observed. Similar trends in the mean and c.o.v. is obtained in case of deck plate of tanker as given in Table 7. Surprisingly, c.o.v. in case of severe initial imperfection is lower than average level initial imperfection.

Table 7. Effective width ratio- Tanker deck plate

	t = 15 yrs		*t* = 20 yrs		*t* = 25 yrs		*t* = 30 yrs	
	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.
1*	0.97	0.62	0.97	1.17	0.96	2.03	0.95	2.91
2*	0.87	1.13	0.86	2.02	0.86	2.64	0.85	3.30
3*	0.75	1.05	0.75	1.64	0.74	2.10	0.74	2.58

*Initial imperfection level: 1= Slight; 2=Average; 3=Severe

In Table 8, the results of bulk carrier bottom plate are given. The mean is reduced by 22% from slight level to severe level imperfection in all cases and c.o.v. is increased by 38 to 46 % at *t* =15 yrs to *t* = 30 yrs respectively. There is reduction of around 21~22 % in mean of bulk carrier deck plate as given in Table 9 with increasing level of initial imperfection and c.o.v. follows the same trend as obtained in case of tanker deck plate i.e. c.o.v. at any particular age increases from slight to average level but it is lower in case of severe level than average level.

Table 8. Effective width ratio- Bulk carrier bottom plate

	t = 15 yrs		*t* = 20 yrs		*t* = 25 yrs		*t* = 30 yrs	
	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.
1*	0.91	1.55	0.90	2.35	0.89	3.43	0.88	4.65
2*	0.80	1.40	0.79	2.17	0.79	3.05	0.78	4.12
3*	0.70	0.95	0.70	1.45	0.69	1.93	0.69	2.47

*Initial imperfection level: 1= Slight; 2=Average; 3=Severe

Table 9. Effective width ratio- Bulk carrier deck plate

	t = 15 yrs		*t* = 20 yrs		*t* = 25 yrs		*t* = 30 yrs	
	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.
1*	0.97	1.38	0.94	3.27	0.95	5.06	0.94	7.10
2*	0.88	2.18	0.86	3.58	0.85	5.46	0.84	6.88
3*	0.76	1.93	0.75	3.09	0.74	4.00	0.73	5.09

*Initial imperfection level: 1= Slight; 2=Average; 3=Severe

Now, both corrosion wastage and initial imperfections are combined and are random. The mean and c.o.v. for each of the candidate plate are given in Table 10 with four different values of assumed ages. The mean effective width reduces by 2~3 % from *t* =15 yrs to *t* = 30 of age. The c.o.v. is dependent on plate details and can not be commented in generalized manner.

Table 10. Effective width ratio- combined random corrosion and random initial imperfection

	t = 15 yrs		*t* = 20 yrs		*t* = 25 yrs		*t* = 30 yrs	
	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.	μ	c.o.v.
1*	0.92	5.60	0.91	6.09	0.90	6.60	0.90	6.89
2*	0.87	7.25	0.86	7.44	0.85	7.78	0.84	8.17
3*	0.80	8.09	0.80	8.32	0.79	8.53	0.78	8.86
4*	0.87	7.22	0.86	8.45	0.85	8.79	0.84	9.88

*Candidate plate: 1= Tanker bottom plate; 2=Tanker deck plate; 3=Bulk carrier bottom plate; 4=Bulk carrier deck plate

7. CONCLUSION

In this paper, effectiveness of the deflected plate is assessed using the term 'effective width'. It demonstrated that the effective width is a function of initial imperfections, yield strength, corrosion loss and applied compressive load. Next, the randomness in initial imperfections, in material yield strength and in corrosion wastage is discussed in the determination of effective width of the four candidate plates from a bulk carrier and a oil tanker. Monte-Carlo simulation is performed to obtain statistics of effective width and the results are presented by histograms different cases.

It is observed that the mean is of effective width decreases with increase in the level of initial imperfection from slight to severe and c.o.v. increases at random yield strength. However, in case of combined random yield and random initial imperfections the mean is higher than combined random yield strength severe initial imperfection but is lower than combined random yield strength and slight initial imperfection. The c.o.v. is higher than both the cases.

Aging effect is considered by reduction in the plate thickness due to random corrosion. The obtained results show that there not a significant change in the mean of effective width ratio. But, the c.o.v. increases with the time for a particular level of initial imperfection. At any particular age, reduction in the mean (around 20 – 22 %) and increase in the c.o.v. upto 6-7 % is observed. When both random corrosion wastage and random initial imperfections are combined, the mean effective width reduces by 2~3 % from t =15 yrs to t = 30 of age. This information seems to be important for reliability analysis of un-stiffened plates. However, to make a general conclusive remark a series of cases need to be analysed and that remains our future work.

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