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Increasing Fatigue Life in Ship Structures using Y-Stiffeners with Right Angle of Hat

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Abstract

Few researches have been performed in the past on the solution of fatigue life assessment using stiffened panels. The objective of the present work is to increase the fatigue life. The available analytical models for predicting the fatigue life of midship sections having Y-stiffeners with two variations of the inclination angle of the hat part are compared. The dimensions of the Y-stiffener are deduced from the actual T-stiffener such that the Y-stiffener will have a higher section modulus and lighter or same weight. The weight of structure per meter of length amidships is computed. In the early design stage, this weight is taken as uniform for a portion of the midship length. Using AutoCAD software, validation tests are carried out for some cases. Common Structural Rules are used to calculate the fatigue damage for 7 modified midship section cases taking into consideration the effect of corrosion thickness reduction. A comparison is held between all cases from the point of view of fatigue life prediction. Another comparison is carried out between Y-stiffened panels having inclined web of the hat and those having right angle web.

Keywords: IACS, Y-Stiffener, Fatigue life, CSR

1. Introduction

Fatigue results from repeated loads that can lead to failure at less than design loads. This type of failure happens due to the damage growth when a structure is subjected to cyclic loadings. It is due a very complex phenomenon affected by many parameters. Any environment or condition that results in cyclic loading and reversal of component stresses may cause fatigue damage. Cyclic stresses are typically caused by machinery vibrations, temperature changes and wind and wave actions. But although vibrations and temperature changes may induce fatigue in a local component, these loadings are not a major concern in the global behavior of typical marine structures.

It has been possible to design ships with lighter scantlings than normal, owing to the availability and use of improved analytical techniques for calculating fatigue life and driven by the continuing desire to reduce construction costs. However, reduced scantlings due to the incorporation of corrosion control measures are no longer allowed by the classification society rules. Only full scantlings or increased scantlings are permissible. The deliberate selection of scantlings greater than classification rule minimum requirements for ship structural members which have historically been found to be prone to corrosion, or of areas that are difficult to protect, provides an additional corrosion allowance and lowers the working stress. Requirements for the section modulus a midship, plate thickness, and stiffener scantlings along the hull are to be determined. In this study, structural requirements will be extended and structural members will be selected to obtain a midship section with same or lighter weight and higher section modulus. The damaged case represents a considerably different challenge to the general design condition. To avoid the loss of structural integrity under different hull girder loadings, each individual case of midship using Y-stiffened panels with 90º angle between hat web and plate at different locations in the midship section is examined and compared with those having 45º angle. A methodology has been applied and case studies for an oil tanker, are presented for a series of developed fatigue life damage cases according to IACS rules.

Our contribution is not including characterizing the buckling strength of Y stiffeners in stiffened panels under the action of uniaxial compressive loads. In future work a lot of effort will be made to investigate the ability of Y – stiffened panels in the mid ship section to withstand all stresses during service at sea. But, as far as our study is mainly concentrating on fatigue. The Y – stiffened panels are achieving good results whereas it increased the fatigue life time.

The Common Structural Rules (CSR) [1] for double-hull oil tankers have been developed by a group of IACS classification societies to increase the standard of structural safety of oil tankers. The most important new CSR rule requirement is the one for ultimate vertical bending moment capacity of hull-girder; a “net” thickness approach is also an important new feature of CSR, where the structural capacity for different failure modes is to be calculated by assuming that the thickness of structural elements is reduced because of corrosion effects. CSR proposes a corrosion deduction thickness for different structural elements and different levels of calculation. Design scantlings of structural elements are then obtained by adding this corrosion deduction thickness to the minimum calculated “net” thickness. The objective of the present work is to estimate the fatigue life of the midship section of a double hull oil tanker with Y-stiffeners replacing more conventional ones.

A MATLAB program has been developed to produce specific dimensions of Y-stiffeners with attached plate starting from standard T-stiffener with attached plate in the midship section under some relationship ratios between both stiffeners to satisfy a section modulus of Y-stiffener higher than the T-stiffener and having same or lighter weight, see tables 1 and 2 respectively. Using AutoCAD software, validation tests are carried out for several cases having the same ratio of section modulus of Y-section to T-section (Z_{ratio}) resulting from the MATLAB program. Different section moduli of midship section at different positions of Y-stiffener are examined. The Common Structural Rules (CSR) for Double-Hull Oil Tankers which have been developed by a group of IACS classification societies are used to calculate the fatigue damage for 11 midship section cases applying current rules and taking into consideration the effect of corrosion thickness reduction. Furthermore, a comparison is held between midship sections built using Y- stiffeners and those using T-stiffeners from the point of view of fatigue life assessment of ship structural details. The different cases are studied with the aim of increasing fatigue life with minimum weight of midship section in some cases or to maintain the fatigue life with change in weight of midship section.

2. Review of Previous Ship Structure Fatigue Research

Maitournam et al. presented a high-cycle fatigue life model for structures subjected to variable amplitude multiaxial loadings. Their work was based on a multiscale approach in which the fatigue life behavior is governed by the accumulated plastic mesoscopic strain per stabilized cycle. The model has six parameters. A simplified version and a robust identification procedure are proposed. A validation by comparing simulated lifetimes to experimental ones is carried out [2]. Naar et al compared resistance forces, energy absorption and penetration with fracture for four different structures, one of which was a Y-shape support web [3]. Ludolphy studied the Y-shape support web during two full scale tests and showed it to contribute substantially to the safety of ships during collisions [4]. Jurišić et al studied the fatigue analysis of the connection of the main deck longitudinals and transverse web girders and found that an overall steel weight increase of 6.2% (620 tons increase for about 10000 tons weight of cargo hold area) would be necessary to reinforce an existing Aframax tanker in order to comply with the new CSR hull girder fatigue requirements [5]. Navarro et al analysed the influence of different multiaxial fatigue criteria on life assessment in fretting fatigue conditions. Five groups of fretting fatigue tests were used for analysis, with different materials, geometries, sizes, and contact forces. The materials were aluminium and titanium, and the geometries were spherical and cylindrical contact. The life prediction model applied combines initiation with propagation, without a prior definition of when one begins and the other ends [6]. Fricke and Paetzold carried out two types of full-scale tests. The first involved web frame corners typical in roll-on/roll-off ships (ro/ro) ships, from which three models were tested under constant amplitude loading. The second type was the intersection between longitudinals and transverse web frames, which had shown fatigue failures in containerships. Five models were tested, three under constant and two under variable amplitude loading [7]. A brief overview of some important issues in multi-axial fatigue and life estimation was presented by Fatemi and Shamsaei [8]. Gomez et al estimated the high and low cycle fatigue life of a type of welding steel used for construction, subject to in-phase and out-of phase multi-axial loading, by means of different classical multi-axial fatigue damage models [9]. A proposed frequency-domain formulation of a stress invariant based multi-axial fatigue criterion suitable for estimating fatigue life in the presence of complex multi-axial loadings was presented by Cristofori et al [10]. Lotsberg reviewed two procedures with respect to fatigue capacity. The proposed JBP and JTP analysis procedures were compared with 200 fatigue test data where the test specimens were subjected to 5 different loading conditions. The procedures were also compared with a typical welded connection subjected to different mean stress levels [11]. Crupi developed a theoretical model that focused on damping, a material property able to correlate vibration parameters with high cycle fatigue parameters and related to the damage of materials and structures. The measure of damping is based on experimental techniques currently used for damage detection, so the Unifying Approach could be applied also for structural health monitoring. Good predictions were achieved applying the new approach to ship structural details [12]. Roiko and Murakami presented an overview of critical variables that affect fatigue failure with respect to steel components in ultralong life regimes. The key role of hydrogen trapped by non-metallic inclusions in the ultralong life fatigue failure process was documented. The role of non-metallic inclusions on ultralong fatigue life was shown in the master curve of ODA (Optically Dark Area) surrounding a non-metallic inclusion at fracture origin growth. A design approach was introduced for calculating the effects of different loading levels for ultralong fatigue life [13]. Castiglioni and Pucinotti presented an investigation in terms of failure criteria. A damage index and a failure criterion for steel components under cyclic loading based on the capacity of the structural details to dissipate energy were presented [14]. Kim et al carried out a series of fatigue tests to investigate the fatigue strength of longi-web connection weld details, which are considered to be typical fatigue prone spots in ship-like structures. Estimation of the fatigue life on the test specimens was also performed using the structural stress approach. Based on the experimental and analytical results, it was deduced that it is possible to develop a more precise fatigue strength evaluation technique and to reduce time and cost associated with the fatigue design of ship and offshore structures [15]. Kim and Frangopol, presented an approach and applied it to ship hull structures subjected to fatigue. The resulting inspection plan was the solution of an optimization problem based on the minimization of expected fatigue damage detection delay. Damage detection delay produces the maintenance delay which, in turn, is likely to endanger the serviceability and even the survival of the structure. The formulation of the expected damage detection delay includes uncertainties associated with damage occurrence, propagation, and detection [16]. Experimental determination of strain–fatigue life curve is expensive considering the time and effort involved as noted by Hariharan et al. Several empirical relations based on monotonic tensile properties and/or hardness were available for estimating strain–fatigue life properties. Existing criteria to evaluate the accuracy of these empirical relations are limited by the data points in the strain–fatigue life curve.

A new criterion based on the prediction errors of fatigue constants was proposed to overcome the limitation [17]. Nguyen et al performed a fatigue damage assessment of double hull oil tanker structural details, based on global and local structural finite element models. The wave-induced vertical and horizontal bending moments, as well as local pressure loads were accounted for in the fatigue damage calculations [18]. Schijve has presented a comprehensive treatise on fatigue covering fatigue of structures and materials, load spectra and fatigue under variable-amplitude loading, special fatigue conditions, fatigue tests and scatter and fatigue of joints and structures [19]. Pook [20], Paik and Thayamballi [21] and Okumoto et al [22]

3. Fatigue in CSR

Hull girder fatigue calculations in CSR are performed in two steps:

- Simplified check of hull girder fatigue section modulus
- Detailed fatigue life assessment for structure detail in the midship section

These two calculation methods are described as follows.

3.1. Hull Girder Fatigue Requirement

Hull girder fatigue strength is checked by a simplified fatigue control measure against dynamic hull girder stresses in the midship section. The required hull girder fatigue section modulus $Z_{v\text{-}fat}$ in m^3 is given in CSR (Section 8.1.5) [1]:

$$Z_{v-fat} = \frac{M_{wv-hog} - M_{wv-sag}}{1000 R_{al}} \tag{1}$$

where:

$M_{wv\text{-}hog}$=*hogging vertical wave bending moment for fatigue (kN.m)*
$M_{wv\text{-}sag}$=*sagging vertical wave bending moment for fatigue (kN.m)*
R_{a1}=*allowable stress range (N/mm^2)*
R_{al} =0.17L + 86 *for class F - details*
=015L + 76 *for class F2 - details*

Hogging and sagging vertical wave bending moments for fatigue are obtained by multiplying rule wave bending moments for strength assessment by a factor of 0.5. In this way, the representative probability level of wave bending moments is reduced from 10^{-8} to 10^{-4}. This aspect is described in CSR (Section 7.3.4.1.3) [1].

3.2. Detailed Fatigue Prediction of Midship Section

The calculation of hull girder stress for the detailed fatigue strength assessment of a midship section is based on the fatigue hull girder sectional properties calculated by deducting a quarter of the corrosion addition (-0.25 t_{corr}) from the gross thickness of all structural elements comprising the hull girder cross section.

The capacity of welded steel joints with respect to fatigue strength is characterized by the Wöhler curves (S-N curves) which give the relationship between the stress ranges applied to a given detail and the number of constant amplitude load cycles to failure, with the zero mean stress. The hull detail which is taken into consideration for the fatigue assessment of a midship structure, is classed as an F-detail, CSR (Table C.1.7-Classification of Structural Details).

The fatigue assessment of the structural details is based on the application of the Palmgren-Miner cumulative damage rule. When the cumulative fatigue damage ratio DM is greater than 1, the fatigue capability of the structure is not acceptable. DM is determined according to CSR (Appendix C 1.4.1):

$$DM = \sum_{i=1}^{2} DM_i \tag{2}$$

where:

DM_i = cumulative fatigue damage ratio for the applicable loading condition
i = 1 for full load condition
= 2 for normal ballast condition

Assuming that the long term distribution of stress ranges fits a two-parameter Weibull probability distribution, the cumulative fatigue damage DM_i for each relevant condition is taken as follows (CSR Appendix C, Sec.1.4.1.4):

$$DM_i = \frac{a_i \cdot N_L}{K_2} \cdot \frac{S_{Ri}^m}{(\ln N_R)^{\frac{m}{\xi}}} \cdot \mu_i \cdot \Gamma\left(1 + \frac{m}{\xi}\right) \quad (3)$$

where:

N_L = number of cycles for the expected design life. The value is generally between 0.6×10^8 and 0.8×10^9 cycles for a design life of 25 years.

$$N_L = \frac{f_0 \cdot U}{4 \cdot \log L} \quad (4)$$

where:

f_0 = 0.85, factor taking into account non-sailing time for operations such as loading and unloading, repairs, etc.

U= design life (s) = 0.788×10^9 for a design life of 25 years, L = rule length
m= S-N curves exponent as given in CSR (Table C.1.6).
K_2= 0. 63×10^{12} S-N curves coefficient as given in CSR (Table C.1.6).
α_i= proportion of the ship's life:
α_1 = 0.5 for full load condition
α_2 = 0.5 for ballast condition
S_{Ri} = stress range at the representative probability level of 10^{-4} (N/mm^2).
N_R = 10000, number of cycles corresponding to the probability level of 10^{-4}.
ξ = Weibull shape parameter
Γ = Gamma function
μ_i = coefficient taking into account the change in the slope of the S-N curve

$$\mu_i = 1 - \frac{\gamma\left(1 + \frac{m}{\xi}, \nu_i\right) - \nu_i^{\frac{\Delta m}{\xi}} \gamma\left(1 + \frac{m + \Delta m}{\xi}, \nu_i\right)}{\Gamma\left(1 + \frac{m}{\xi}\right)} \quad (5)$$

$$\nu_i = \left(\frac{S_q}{S_{Ri}}\right)^{\xi} \cdot \ln N_R \quad (6)$$

where

S_q = stress range at the intersection of two segments ("knee") of the S-N curves, CSR (Table C.1.6).

Δ_m = 2 - slope change of the upper-lower segment of the S-N curve
$\gamma(a, x)$ = incomplete Gamma function, Legendre form
The Weibull shape parameter ξ is calculated as:

$$\xi = f_{Weibull} \cdot \left(1.1 - 0.35 \cdot \frac{L - 100}{300}\right) \quad (7)$$

The cumulative fatigue damage ratio, DM, is finally converted into a calculated fatigue life:

$$Fatigue\ Life = \frac{Design\ Life}{DM} \quad Years \quad (8)$$

According to CSR requirements, the calculated fatigue life should be more than 25 years.

Stress range S_{Ri} required for the calculation of accumulated damage in Eq. (3), is calculated by the simple beam theory assumptions i.e.:

$$S_{Ri} = \frac{M_{Ri}}{Z_{v-net75}} \tag{9}$$

where $Z_{v\text{-}net75}$ is the "net" section modulus (-0.25 t_{corr}) of the midship cross section, while M_{Ri} is the range of wave bending moment at a representative probability level of 10^{-4}. M_{Ri} is calculated as:

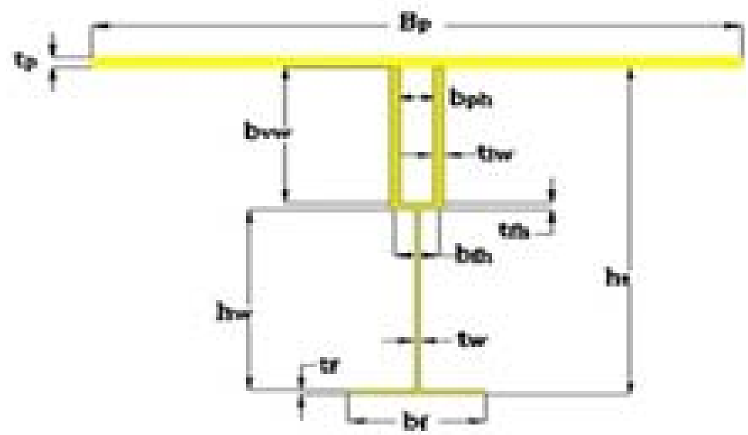
$$M_{Ri}=M_{wv\text{-}hog} - M_{wv\text{-}sag} \tag{10}$$

It should be noted that the stress range and all calculation parameters are the same for ballast and full load conditions. Consequently, the same parameters have been obtained for both conditions.

4. Y-stiffened Panels

Basic dimensions of the Y-stiffener are shown in Fig. 1.

Figure 1: Geometry of Y-stiffener



Since the dimensions of the Y-stiffeners are not standard, as is the case of I, T, L, C, and other sections; suggested proportions for construction of Y-stiffeners are introduced. The suggested dimensional proportions depend on the production method of the Y-stiffener. The Y-stiffener is a built-up section and the simplest production method is to weld the lower end of the web of a T-stiffener to the top of the hat part. The hat part of the Y-stiffener is made either by bending a standard steel plate or by a hot-rolling process.

Table 1: Y-stiffeners with 90° inclination angle of hat webs (with same weight as T-stiffener)

Y	bf	tf	hw	tw	bfh	tfh	bvw	tvw	hh	bph	htotat	A ratio	Z ratio
Y1	150	6	600	3.9	40.6452	9.3	120	9.3	120	40.645	730.65	1	1.300412
Y2	127.5	6	660	3.9	44.7097	9.3	132	9.3	132	44.71	802.65	1	1.229418
Y3	195	6	700	3.9	42.5806	9.3	140	9.3	140	42.581	850.65	1	1.352268
Y4	157.5	6	741	3.9	41.9697	9.9	152	9.9	152	41.97	903.95	1	1.199422
Y5	165	6	792	3.9	42.0606	9.9	176	9.9	176	42.061	978.95	1	1.141296
Y6	280	6	798	3.9	41.2353	10.2	168	10.2	168	41.235	977.1	1	1.306221
Y7	260	6	798	3.9	41.8857	10.5	168	10.5	168	41.886	977.25	1	1.252432
Y8	280	6	787.5	3.9	44.6429	10.5	180	10.5	180	44.643	978.75	1	1.200826
Y9	315	6	720	3.9	22.6471	10.2	240	10.2	240	22.647	971.1	1	1.05528
Y10	157.5	6	600	3.9	45	9	120	9	120	45	730.5	1	1.332826
Y11	232.5	6	600	3.9	45	9	120	9	120	45	730.5	1	1.464011
Y12	202.5	6	720	3.9	45	9	144	9	144	45	874.5	1	1.38524
Y13	202.5	6	740	3.9	41.6667	9	148	9	148	41.667	898.5	1	1.390468
Y14	187.5	6	740	3.9	40.4516	9.3	148	9.3	148	40.452	898.65	1	1.336965
Y15	172.5	6	819	3.9	41.5161	9.3	168	9.3	168	41.516	997.65	1	1.273432
Y16	187.5	6	720	3.9	19.7143	10.5	160	10.5	160	19.714	891.25	1	1.191889

Table 1: Y-stiffeners with 90° inclination angle of hat webs (with same weight as T-stiffener) - continued

Y17	180	6	693	3.9	40.8857	10.5	168	10.5	168	40.886	872.25	1	1.064897
Y18	210	6	774	3.9	41.0968	9.3	172	9.3	172	41.097	956.65	1	1.275854
Y19	240	6	775.5	3.9	40.7258	9.3	188	9.3	188	40.726	974.15	1	1.248704
Y20	195	6	675	3.9	27.1622	11.1	180	11.1	180	27.162	866.55	1	1.002702
Y21	135	6	787.5	3.9	41.7857	10.5	180	10.5	180	41.786	978.75	1	1.01898
Y22	292.5	6	795.5	3.9	42.7162	11.1	172	11.1	172	42.716	979.05	1	1.454962
Y23	360	6	805	3.9	42.8065	9.3	184	9.3	184	42.806	999.65	1	1.400841
Y24	288.8	6	787.5	3.9	42.8226	9.3	180	9.3	180	42.823	978.15	1	1.337527
Y25	271.3	6	787.5	3.9	41.1719	9.6	180	9.6	180	41.172	978.3	1	1.289884
Y26	202.5	6	817	3.9	40.3	9	172	9	172	40.3	999.5	1	1.335573
Y27	232.5	6	643.5	3.9	42.15	9	132	9	132	42.15	786	1	1.436794
Y28	288.8	6	720	3.9	23.2857	10.5	240	10.5	240	23.286	971.25	1	1.002822
Y29	400	7	720	4.39	47.7143	10.5	240	10.5	240	47.714	972	1	1.199806

Table 2: Y-stiffeners with 90° inclination angle of hat webs (lighter weight than T-stiffener)

Y	bf	tf	hw	tw	bfh	tfh	bvw	tvw	hh	bph	theta	htotat	A ratio	Z ratio
Y1	105	6	585	3.9	35.05376	9.3	120	9.3	120	35.05376	90	715.65	0.98	1.075311
Y2	90	6	627	3.9	41.05376	9.3	132	9.3	132	41.05376	90	769.65	0.98	1.006803
Y3	142.5	6	682.5	3.9	40.61828	9.3	140	9.3	140	40.61828	90	833.15	0.98	1.128738
Y4	120	6	703	3.9	36.66667	9.9	152	9.9	152	36.66667	90	865.95	0.98	1.002969
Y5	142.5	6	748	3.9	28.57576	9.9	176	9.9	176	28.57576	90	934.95	0.98	1.000299
Y6	190	6	819	3.9	40.87255	10.2	168	10.2	168	40.87255	90	998.1	0.98	1.100346
Y7	190	6	798	3.9	37.09524	10.5	168	10.5	168	37.09524	90	977.25	0.98	1.066236
Y8	200	6	787.5	3.9	44.88095	10.5	180	10.5	180	44.88095	90	978.75	0.98	1.00579
Y9	315	6	720	3.9	22.6471	10.2	240	10.2	240	22.647	90	971.1	1	1.05528
Y10	120	6	585	3.9	35.16667	9	120	9	120	35.16667	90	715.5	0.98	1.137768
Y11	142.5	6	600	4.2	42.66667	9	120	9	120	42.66667	90	730.5	0.98	1.167206
Y12	142.5	6	720	3.9	41.06667	9	144	9	144	41.06667	90	874.5	0.98	1.172098
Y13	150	6	721.5	3.9	40.48333	9	148	9	148	40.48333	90	880	0.98	1.168695
Y14	142.5	6	703	3.9	41.31183	9.3	148	9.3	148	41.31183	90	861.65	0.98	1.106584
Y15	120	6	819	3.9	30.4086	9.3	168	9.3	168	30.4086	90	997.65	0.98	1.099993
Y16	187.5	6	720	3.9	19.7143	10.5	160	10.5	160	19.714	90	891.25	1	1.191889
Y17	180	6	693	3.9	40.8857	10.5	168	10.5	168	40.886	90	872.25	1	1.064897
Y18	127.5	6	795.5	3.9	40.40323	9.3	172	9.3	172	40.40323	90	978.15	0.98	1.058363
Y19	150	6	752	4.2	38.45161	9.3	188	9.3	188	38.45161	90	950.65	0.98	1.001078
Y20	195	6	675	3.9	27.1622	11.1	180	11.1	180	27.162	90	866.55	1	1.002702
Y21	135	6	787.5	3.9	41.7857	10.5	180	10.5	180	41.786	90	978.75	1	1.01898
Y22	127.5	6.9	795.5	4.485	35.15608	11.1	172	11.1	172	35.15608	90	979.95	0.98	1.115856
Y23	190	6.9	782	4.485	46.60538	9.3	184	9.3	184	46.60538	90	977.55	0.98	1.087058
Y24	175	6	787.5	4.2	44.08602	9.3	180	9.3	180	44.08602	90	978.15	0.98	1.071409
Y25	520	6	720	3.9	41.14286	10.5	240	10.5	240	41.14286	90	971.25	1	1.282781
Y26	225	6	623.5	3.9	40.45	9	172	9	172	40.45	90	806	0.97	-
Y27	150	6	660	3.9	46.86667	9	132	9	132	46.86667	90	802.5	0.98	1.177335
Y28	288.8	6	720	3.9	23.2857	10.5	240	10.5	240	23.286	90	971.25	1	1.002822
Y29	200	6	1080	3.9	40.2381	10.5	240	10.5	240	40.2381	90	1331.25	0.98	1.150953

5. Ship Description

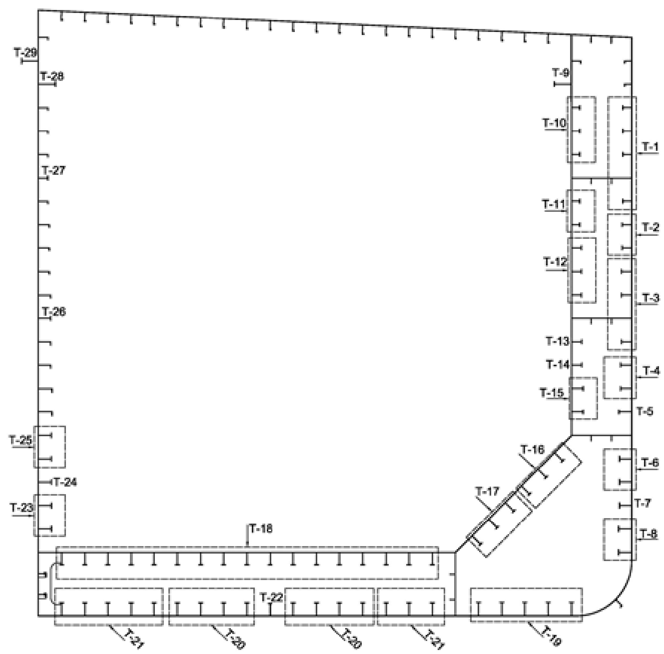
The ship analyzed in the present study is an existing oil tanker operating in Red Sea (Gulf of Suez) with main particulars as presented in table 3. The midship section of the vessel is shown in Fig. 2.

Table 3: Main characteristics of the double hull tanker

Length between perpendiculars (L_{PP})	238.0 m
Moulded breadth, (B)	43.0 m
Moulded depth, (D)	21.0 m
Scantling draught, (T)	14.3 m
Deadweight, (DWT)	97000 tonne

The original midship section with T-stiffeners is shown in Fig. 2. Input parameters and results of detailed fatigue calculations are presented in table 6.

Figure 2: Midship Section of Double Hull Tanker



6. Validation of Two Sample Cases

A MATLAB program has been developed to produce specific dimensions of Y-stiffeners with attached plate deduced from standard T-stiffeners in the midship section of a double hull tanker with ratios of section modulus of Y-stiffener to the T-stiffener greater than 1 while obtaining lighter or same weight as listed in tables 1 and 2, respectively.

Using AutoCAD, software validation tests for the shown two cases have been carried out to check that the results of section modulus of Y-section to T-section (Z_{ratio}) give the same ratio resulting from the MATLAB program.

6.1. Validation for Inner bottom with Y-Stiffener Replacing T-Stiffener

In this case, the T-stiffeners in the inner bottom plate are replaced by Y-stiffeners having a 90° angle between web and plate and the same weight and lighter weight as shown in Fig. 3 (the Y-stiffener used in this case is **Y18** from tables 1 and 2), see table 4.

Figure 3: Comparison between section moduli

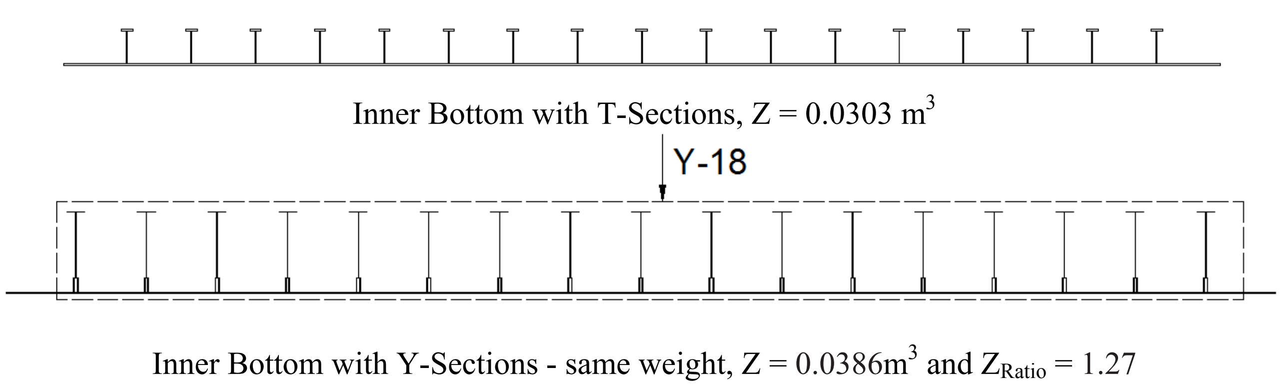
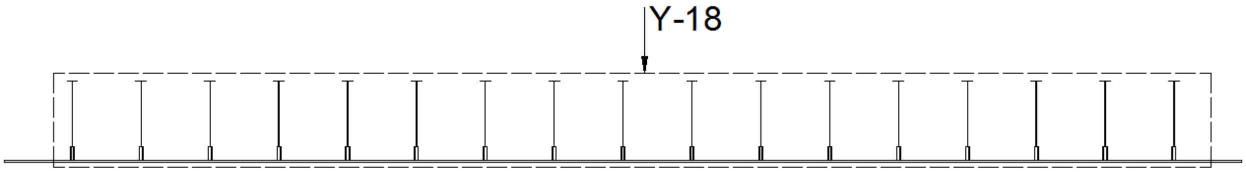


Figure 3: Comparison between section moduli - continued



Inner Bottom with Y-Sections – lighter weight, Z = 0.032 m^3 and Z_{Ratio} = 1.05

Table 4: Comparison between section modulus of inner bottom with Y-stiffener replacing T--stiffener

Item	Z (m^3)	Z_{Ratio} (Matlab)	Z_{Ratio} (Autocad)
Original inner bottom plate with attached T-stiffeners	0.0303	--	
Inner bottom plate with attached Y-stiffeners (same weight)	0.0386	1.27	1.268
Inner bottom plate with attached Y-stiffeners (lighter weight)	0.032	1.05	1.048

6.2. Validation of Single and Double Y-Stiffeners Replacing T-Stiffeners

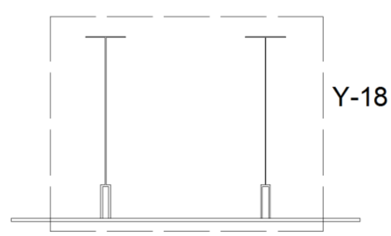
In this case, a comparison was made between T-stiffener with attached plate and Y-stiffener with attached plate for the same weight (the Y-stiffeners used in this case are **Y1 and Y18** as given in table 2). Table 5 shows the comparison between the section moduli also shown in Fig. 4.

Table 5: Comparison between section moduli in cases of single and double stiffened panel, replacing T-stiffeners with Y-stiffeners

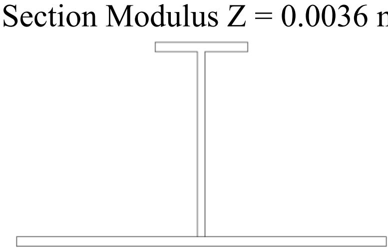
Item	Z (m^3)	Z_{Ratio} (Matlab)	Z_{Ratio} (Autocad)
Attached plate with T-stiffener	9.7611×10^{-4}	--	
Attached plate with Y-stiffener (same weight)	0.001268	1.30	1.29
Attached plate with two T-stiffeners	0.0036	--	
Attached plate with two Y-stiffeners (same weight)	0.004572	1.27	1.267

Figure 4: Section modulus in cases of single and double stiffened panels, replacing T-stiffeners with Y-stiffeners

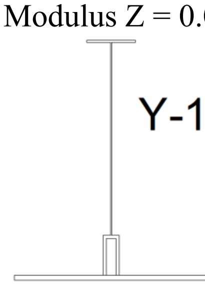
Section Modulus Z = 0.0036 m^3



Section Modulus Z = 0.00457 m^3



Section Modulus Z = 9.7611×10^{-4} m^3



Section Modulus Z = 9.7611×10^{-4} m^3

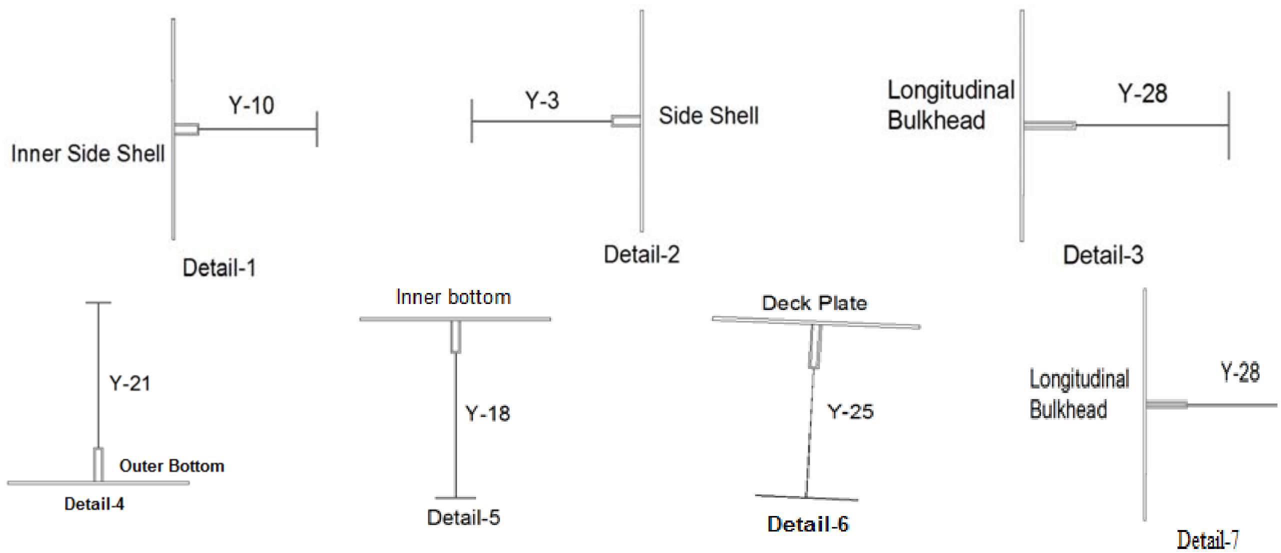
7. Case Studies

The existing "net" section modulus of the midship section calculated with the appropriate corrosion deduction (CSR table 6.3.1- Corrosion addition), should be greater than the CSR minimal required fatigue section modulus.

The following cases are studied to obtain a longer fatigue life for the tanker vessel through replacement of the T-sections with Y-sections with same or lighter weights, in different locations of the midship section.

These modifications of the midship section are shown in Figs. 5 to 12 using some ship details as shown in Fig. 5.

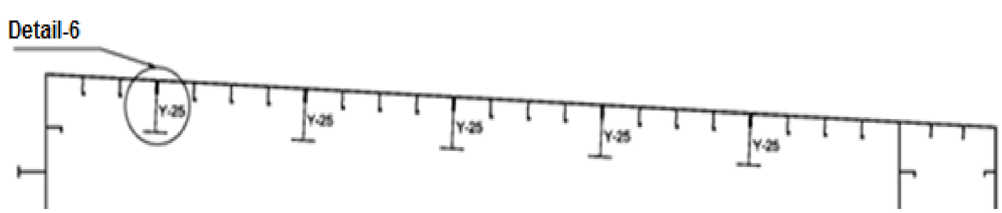
Figure 5: Midship section details



7.1. Case Study 1

In this case, after every three bulb plate stiffeners in the deck structure, a bulb plate stiffener is replaced by a Y-stiffener. The used Y-stiffener in this case is **Y25** from table 2 (light weight) and the weight of the deck structure is slightly increased. The modified midship section with Y-stiffeners in the deck is shown in Fig. 6.

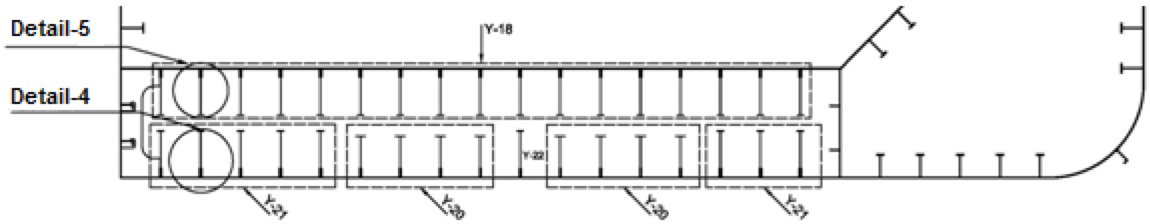
Figure 6: Midship section with some Y-stiffeners in the deck structure



7.2. Case Study 2

In this case, T-stiffeners are replaced by Y-stiffeners in the double bottom only. The used Y-stiffeners in this case are **Y20**, **Y21**, **Y22** and **Y18** from table 2. The modified midship section with Y-stiffeners in the double bottom is shown in Fig. 7.

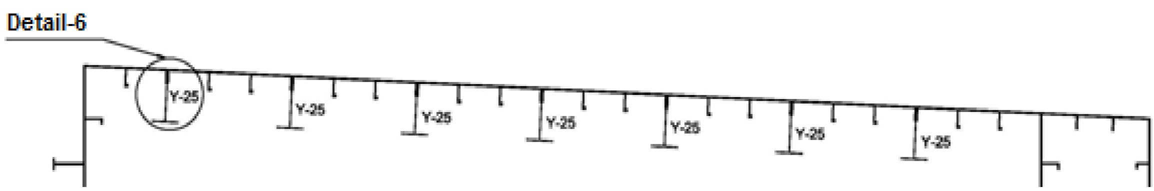
Figure 7: Midship section with Y-stiffeners in the double bottom instead of T-stiffeners



7.3. Case Study (3)

In this case, after every two bulb plate stiffeners in the deck, a Y-stiffener is used. The used Y-stiffener in this case is **Y25** from table 2 such that the weight of deck structure is slightly increased. The modified midship section with Y-stiffeners in the deck structure is shown in Fig. 8.

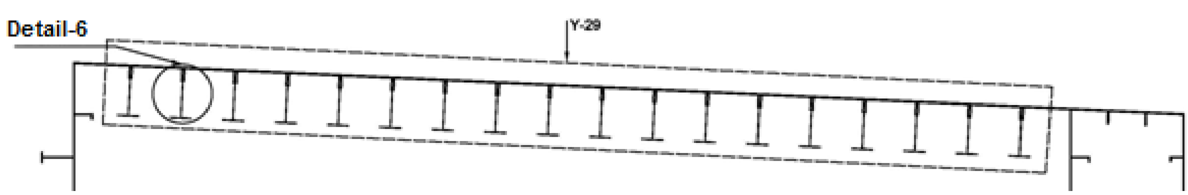
Figure 8: Deck structure with Y-stiffener after every two bulb plate stiffeners



7.4. Case Study (4)

In this case, a new midship section with all bulb plate stiffeners in the deck replaced by Y-stiffeners without changing the thickness of the deck plating, regardless of the weight change of the deck structure, see table 6. The used Y-stiffener in this case is **Y29** from table 1 (same weight). The modified midship section with Y-stiffeners is shown in Fig. 9.

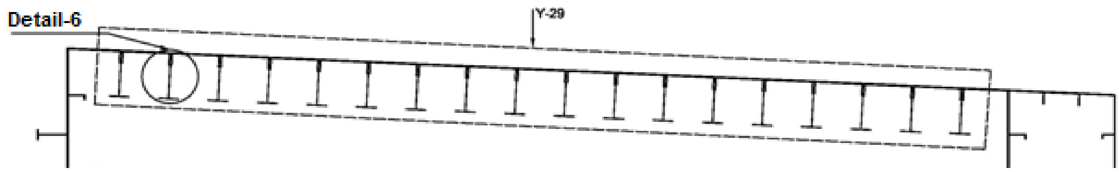
Figure 9: Midship section with bulb plate stiffeners replaced with Y-stiffeners in the deck structure



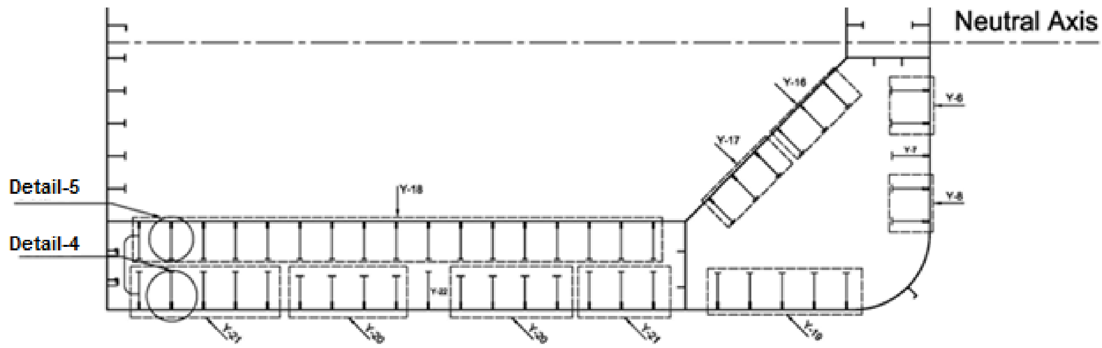
7.5. Case Study (5)

In this case, bulb plate stiffeners in the deck are replaced with Y-stiffeners without changing the thickness of the deck plating and the T-stiffeners in the double bottom and hopper tanks are replaced by Y-stiffeners having lighter weight. The used Y-stiffener in the deck is **Y29** from table 1 and the used Y-stiffeners in the double bottom and hopper tanks are **Y6**, **Y7**, and **Y8** and **Y16** to **Y22** from table 2. The modified midship section with Y-stiffeners in the deck structure, double bottom and hopper tanks is shown in Fig. 10.

Figure 10: a-Y-stiffeners replacing bulb plate stiffeners in the deck structure b- lighter weight Y-stiffeners replacing T-stiffeners in the double bottom and hopper tanks



a

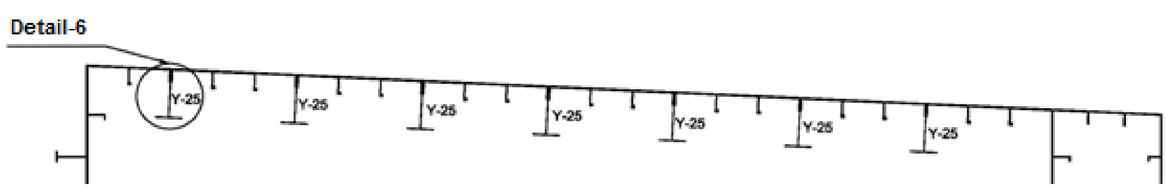


b

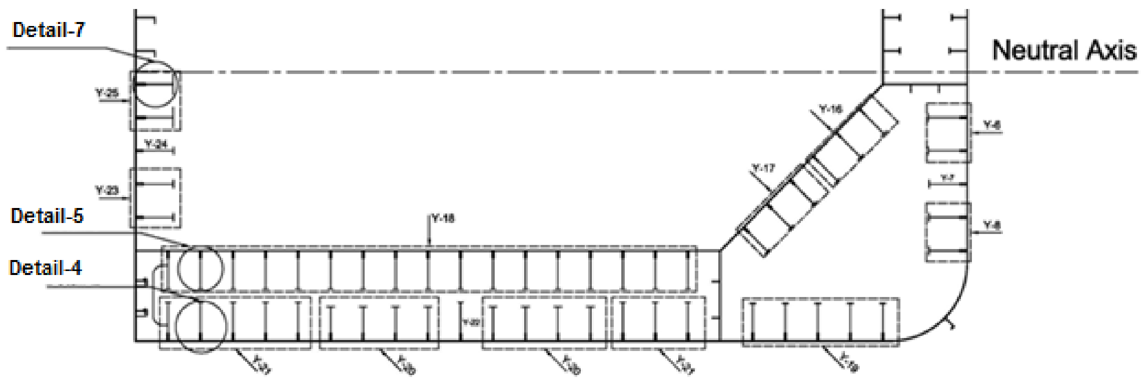
7.6. Case Study (6)

In this case, after every two bulb plate stiffeners a Y-stiffener is placed instead of one bulb plate stiffener in the deck structure regardless of the increase in the total weight of the deck structure. Below the neutral axis all T-stiffeners are replaced by Y-stiffeners of lighter weight. The used Y-stiffeners are **Y25 (light weight)** in the deck structure and **Y6**, **Y7**, **Y8** and **Y16** to **Y25 (light weight)** from table 3. The modified midship section with Y-stiffeners in the deck structure as well as below the neutral axis is shown in Fig. 11.

Figure 11: a- Structure with Y stiffener replacing bulb plate stiffener after every two bulb stiffeners in the deck and b- all T-stiffeners below the neutral axis replaced by Y-stiffeners of lighter weight



a

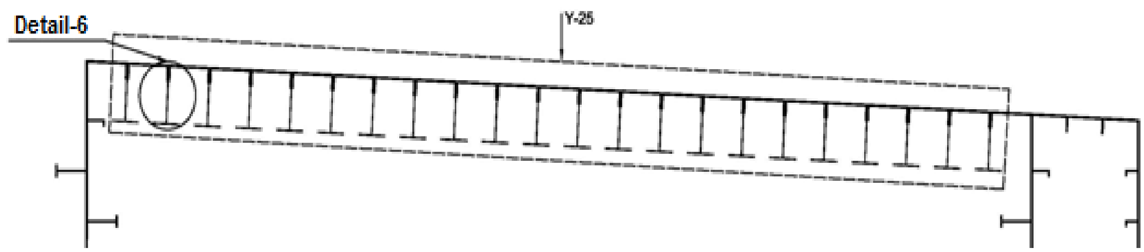


b

7.7. Case Study (7)

In this case, all bulb plate stiffeners are replaced by Y-stiffeners in the deck structure, regardless of the difference in the weight of the deck with bulb plate and the deck with Y-stiffeners. The used Y-stiffener in the deck structure is **Y25** from table 2 (light weight). The obtained total weight of the deck structure with Y-stiffeners is larger than that of bulb plate stiffeners. The modified midship section with Y-stiffeners in the deck structure is shown in Fig. 12.

Figure 12: All bulb plate stiffeners replaced by Y-stiffeners in deck structure



8. Approach for Comparison of Analytical Results

The following comparative analysis will be an extension of the comparative design study of midship section. The original case study was for a midship section with conventional stiffener.

The results of the preliminary fatigue analysis showed an increase in the section modulus amidship with an increase in fatigue life in some of the cases.

The approach for evaluation of analytical results is based on the comparison of the original case study with the other cases having Y-stiffeners with hat web having an inclination angle of 45 or 90 degrees.

Table 6: Comparison of results for the different case studies of Y-Stiffeners with right and inclined web

Terms	**Original case**	***Case (1) Y at 45°***	**Case (1) Y at 90°**	***Case (2) Y at 45°***	**Case (2) Y at 90°**	***Case (3) Y at 45°***	**Case (3) Y at 90°**	***Case (4) Y at 45°***	**Case (4) Y at 90°**	***Case (5) Y at 45°***	**Case (5) Y at 90°**	***Case (6) Y at 45°***	**Case (6) Y at 90°**	***Case (7) Y at 45°***	**Case (7) Y at 90°**
Actual section modulus Z_v (m^3)	33.164	33.509	34.04	33.121	33.146	33.647	34.39	34.330	35.163	34.277	35.136	33.598	34.362	34.680	37.006
Allowable fatigue stress R_{al} (N/mm^2)	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906	125.906
Required fatigue section modulus $Z_{v\text{-}fat}$ (m^3)	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358	31.358
Inputs															
M_w (MNm)	3948	3948	3948	3948	3948	3948	3948	3948	3948	3948	3948	3948	3948	3948	3948
N_L	7.064E+7	7.064E +7	7.064E+7	7.064E+7	7.064E+7	7.064E+7	7.064E+7	7.064E+7	7.064E+7	7.064E+7	7.064E+7	7.064E+ 7	7.064E+7	7.064E+ 7	7.064E+7
α	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ζ	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943
K_2	0.63E+12	0.63E+ 12	0.63×10^{12}	0.63 E+12	0.63×10^{12}	0.63 E+12	0.63×10^{12}	0.63 E+12	0.63 E+12	0.63 E+12	0.63 E+12	0.63 E+12	0.63 E+12	0.63 E+12	0.63 E+12
S_{Ri} (N/mm^2)	119.051	117.825	115.987	119.206	119.116	117.342	114.807	115.008	112.283	115.185	112.369	117.513	114.901	113.847	106.691
Outputs															
DM_i	0.52	0.505	0.481	0.523	0.521	0.498	0.467	0.469	0.437	0.471	0.438	0.501	0.468	0.455	0.375
DM	1.041	1.009	0.963	1.045	1.043	0.997	0.934	0.938	0.873	0.943	0.875	1.001	0.936	0.91	0.749
Fatigue Life (years)	24.017	24.774	25.971	23.923	23.978	25.081	26.78	26.640	28.627	26.517	28.561	24.972	26.715	27.463	33.368
Steel Weight (ton)	9100	9119.5 (+ 19.5)	9152 (+ 52)	9005 (- 95)	939 (-61)	9128 (+ 28)	9174 (+ 74)	9175 (+75)	9226 (+ 126)	9039 (-61)	9139 (+ 39)	8987 (-113)	9090 (-10)	9191 (+ 91)	9338 (+ 238)

9. Interpretation of the Results

From the results obtained and shown in table 6, the following may be deduced:

Case (1): the actual section modulus and fatigue life are starting to increase but the weight is more than the original case by 19.5 tons for Y-stiffened panels which have 45 degree inclined web of the hat but in the stiffeners which have the right angle, fatigue life increases by one year and nine months and the weight is more than the original case by 52 tons.

From case (2), it is clear that the actual section modulus and fatigue life do not change considerably and the weight decreases by 95 tons for Y-stiffened panels which have 45 degree inclined web of the hat and the weight decreases by 61 tons for Y-stiffened panels which have right angle inclination of the web of the hat.

In case (3), the actual section modulus is slightly increased and fatigue life increases by one year while the weight increases by 28 tons for Y-stiffened panels which have inclined web of the hat. But, in the Y stiffened panels that have right angle, the section modulus increases and fatigue life increases by two years and a half and the weight is more than the original case by 74 tons for Y-stiffened panels which have 45 degrees inclined web of the hat.

Case (4): shows that the actual section modulus apparently increases, fatigue life increases by two years and half and the weight increases by 75 tons for Y-stiffened panels which have 45 degrees inclined web of the hat. But in those which have right angle, the section modulus increases and fatigue life increases by four years and a half and the weight is more than the original case by 126 tons.

Case (5): gives an increase in the actual section modulus and fatigue life is close to that obtained in case (6) but the obtained weight is less than the original case by 61 tons for Y-stiffened panels which have 45 degrees inclined web of the hat. In the case of right angle the section modulus increases and fatigue life increases by four years and a half and the weight is more than the original case by 39 tons.

Case (6): shows that the actual section modulus and fatigue life are quite close to those for case (5) but the obtained weight is reduced by 113 tons for Y-stiffened panels which have 45 degrees inclined web of the hat. But in those which have right angle fatigue life increases by two years and a half and the weight is less than the original case by 10 tons and section modulus is quite close to case (5).

From the results of case (7), it is clear that the actual section modulus is largest among all studied cases though close to case (4). The fatigue life is increased by three years and five months and the weight is increased by 91 tons for Y-stiffened panels which have 45 degrees inclined and right angle web of the hat. But in those which have right angle fatigue life increases by nine years and half, the weight is more than the original case by 238 tons and section modulus is highest among all the studied cases.

10. Conclusions

This paper addresses the question of how to increase fatigue life for midship section with light weight having high section modulus using a useful process for the quantitative assessment of performance of alternative fatigue designs of new stiffened panels.

Comparison of the effect of fatigue life on alternative designs is becoming more commonplace in the design process, in particular when considering the effects on the structural integrity of the competing designs.

Models of new stiffened panels with successful results have been developed and the authors suggest new dimensions of Y-stiffened panels resulting from actual T-stiffened panels in the midship section of double hull tankers. A MATLAB program is used to obtain dimensions for Y-stiffeners as listed in tables 2 and 3.

To validate the ratio of section modulus of Y-stiffened panels to T-stiffened panels resulting from the MATLAB program, some tests were performed using AutoCAD. The same section modulus ratios were obtained. The aim of the current work is to minimize the weight of the midship section for a double hull tanker or to keep it constant while maintaining or increasing the section modulus while at the same time achieving a longer fatigue life. To reach this aim, eleven cases were considered replacing existing T-stiffeners or bulb plate stiffeners with Y-stiffeners in the midship section.

For those eleven cases, the total section modulus is calculated. The fatigue analysis according to CSR is carried out to calculate the allowable fatigue stress, required fatigue section modulus and the cumulative fatigue damage ratio. Finally, assessment of fatigue lives for the resulting midship sections is carried out.

A summary of the results for the eleven cases was presented in table 6. The cases that showed an improvement were cases (1), (2), (3), (4), (5), (6) and (7) both for Y-stiffened panels which have 45 degrees inclined web of the hat and for those which have right angle.

Case (6) where one bulb plate stiffener in the deck is replaced with Y-stiffeners after every two bulb plate without changing the thickness of the deck plating and below the neutral axis all T-stiffeners are replaced by Y-stiffeners of lighter weight has yielded the best results since the section modulus and fatigue life were increased while a reduction in weight was obtained.

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