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A New Quantitative Fatigue Life Assessment using Alternative Stiffened Panels in Midship Section

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Abstract

The objective of this work is to estimate the hull girder fatigue life for an unconventionally stiffened midship section stiffened with Y-stiffeners. Specific dimensions of the Y-stiffener are obtained starting from the actual T-stiffener aiming at a higher section modulus whilst at the same time achieving lighter or same weight. Using AutoCAD software, validation tests are carried out for some cases. Common Structural Rules are used to calculate the fatigue damage for 11 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 assessment.

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

1. Introduction

Fatigue is one of the most significant failure modes for marine structures such as ships and offshore platforms. Accurate prediction of the fatigue life of marine structures under service loading is very important for both safe and economic design and operation. Ships operate in environments that apply variable amplitude loading cycles, meaning that the structural components of a ship will experience repeated loading or strain events throughout the life of the ship.

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses. Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. Furthermore, fatigue is catastrophic and insidious, occurring very suddenly and without warning. Therefore, fatigue is an important criterion during design.

Marine and offshore structures are subjected to fatigue primarily due to the action of seawater waves and the sea environment. The load cycles in such an environment can be in the order of million cycles per year. The fatigue life of structural members is an important aspect in the hull design of ships. Fatigue life calculation is assumed to give a good indication as to whether fatigue is a significant criterion for design or not. The objective of the present work is to estimate the hull girder fatigue life for midship sections unconventionally stiffened with Y- stiffeners. Fatigue life calculation is assumed to give a good indication as to whether fatigue is a significant criterion for design or not. The aim of the present study is to carry out the hull girder fatigue analysis of an existing oil tanker caused by global dynamic loads according to new common structural rules and to suggest modifications regarding the use of unconventional Y-stiffeners to replace conventional ones such as T- and bulb plate stiffeners.

The Common Structural Rules (CSR) (2010) for double-hull oil tankers has 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 to increase 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. Literature Survey

3. Hansen and Wintersteint (1995) proposed a model to analyze a segregated ballast tanker, and the results were compared to previously registered fatigue cracks. The analysis was performed for I-shaped and L-shaped stiffeners. Naar et al. (2002) compared resistance forces, energy absorption and penetration with fracture for four different structures, one of which was a Y-shape support web. Ludolphy (2001) studied the Y-shape support web during two full scale tests and showed it to contribute substantially to the safety of ships during collisions. Jurišić et al. (2007) 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. Nielsen et al. (2011) presented an outline of a calculation procedure for fatigue damage rate prediction in hull girders taking into account whipping stresses. Fricke and Paetzold (2010) 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. A brief overview of some important issues in multi-axial fatigue and life estimation was presented by Fatemi and Shamsaei (2011). Gomez et al. (2011) 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. 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. (2011). Lotsberg (2006) 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. Fricke et al. (2002) studied a pad detail on the longitudinal coaming of a Panamax container vessel. The detail was chosen because of the well-defined loading due to hull girder bending. Large differences in predicted fatigue lives were found, ranging from 1.8 to 20.7 years. The spreading of results is attributable to assumptions regarding loads, local stress determination and S–N curve. For comparison, a direct calculation of loads using the spectral method was performed. Also this calculation showed a relatively short fatigue life of 5.3 years, although the structural detail was believed not to be prone to fatigue failures. Taheri et al. (2003) conducted an experimental fatigue program consisting of constant and semi-random (variable) amplitude cyclic loadings on 350WT steel 40J at -40°C. The fatigue models examined in the literature review were then compared to results obtained from the experiments. Castiglioni and Pucinotti (2009) 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. Chakarov et al. (2008) presented an analysis of the stress concentration factors of a deck structure, accounting for several structural imperfections. The studied imperfections were generally present in the stress response characteristics and the fatigue damage model applied. Assakkaf et al. (2000) developed design methods for fatigue of structural details for conventional displacement type surface mono-hull ships. The methods were based on structural reliability theory and were either direct reliability-based or based on the load and resistance factor design (LRFD) format.

4. 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.

4.1. Hull Girder Fatigue Requirement

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

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

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_{al} = 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).

4.2. 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):

$$DM_i = \frac{\alpha_i N_L}{K_2} \cdot \frac{S_{Ri}^m}{(\ln N_g)^{\frac{m}{\xi}}} \cdot \mu_i \cdot \Gamma(1 + \frac{m}{\xi}) \tag{3}$$

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.

$$N_L = \frac{f_0 \cdot U}{4 \cdot \log L} \tag{4}$$

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

$$\mu_i = 1 - \frac{\gamma(1+\frac{m}{\xi}, v_i) - v_i^{\frac{\Delta m}{\xi}} \cdot \gamma(1+\frac{m+\Delta m}{\xi}, v_i)}{\Gamma(1+\frac{m}{\xi})} \tag{5}$$

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

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:

$$\xi = f_{weibull} \cdot (1.1 - 0.35 \cdot \frac{L-100}{300}) \tag{7}$$

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

$$Fatigue\ Life = \frac{Design\ Life}{DM} Years \tag{8}$$

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:

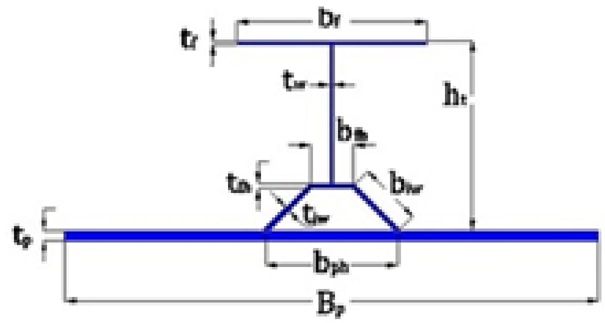
$$M_{Ri} = M_{wv\text{-}hog} - M_{wv\text{-}sag} \tag{10}$$

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.

5. Y-stiffened Panels

Basic dimensions of the Y-stiffener are shown in Figure 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. The inclination angle of the two webs of the hat is taken to be 45 degrees. The selection of the 45 degrees angle keeps the contribution of the hat webs in bending resistance about the *x*- and *y*- axes the same.

Table 1: Basic dimensions of T-stiffeners in the midship section

T	Plate Breadth	Plate Thickness	Web Length	Web Thickness	Flange Breadth	Flange Thickness
T1	850	15.5	300	12	150	15
T2	850	15.5	330	12	150	15
T3	850	15.5	350	12	150	18
T4	850	16.5	380	12	150	18
T5	850	16.5	440	12	150	18
T6	850	17	420	12	200	18
T7	850	17.5	420	12	200	18
T8	850	17.5	450	12	200	18
T9	850	17	600	12	175	15
T10	850	15	300	12	150	15
T11	850	15	300	12	150	18
T12	850	15	360	12	150	18
T13	850	15	370	12	150	18
T14	850	15.5	370	12	150	18
T15	850	15.5	420	12	150	18
T16	850	17	400	12	150	18
T17	850	17.5	420	12	150	18
T18	840	15.5	430	12	150	18
T19	840	15.5	470	12	150	18
T20	840	18.5	450	12	150	18
T21	840	17.5	450	12	150	18
T22	840	18.5	430	15	150	18
T23	850	15.5	460	12	200	18
T24	850	15.5	450	12	175	18
T25	850	16	450	12	175	18
T26	850	15	430	12	150	18
T27	850	15	330	12	150	18
T28	850	17.5	600	12	175	15
T29	850	17.5	600	14	200	15

Table 2: Y-stiffeners with 45° inclination angle between hat webs (with same weight as T-stiffener)

Y	b_f	t_f	h_w	t_w	b_{fh}	t_{fh}	b_{iw}	t_{iw}	hh	b_{ph}	h_{totat}	Z_{ratio}
Y1	180	6	570	3.9	64.34	9.3	104.8	9.3	74.08	212.5	654.73	1.22
Y2	195	6	643.5	3.9	68.66	9.3	101.7	9.3	71.92	212.5	726.07	1.304
Y3	285	6	682.5	3.9	69.2	9.3	101.3	9.3	71.65	212.5	764.8	1.452
Y4	262.5	6	760	3.9	61.98	9.9	106.4	9.9	75.26	212.5	846.21	1.421
Y5	277.5	6.9	748	4.485	64.55	9.9	104.6	9.9	73.98	212.5	833.83	1.358
Y6	360	6.9	756	4.485	71	10	100.1	10.2	70.75	212.5	838.75	1.421
Y7	360	6.9	735	4.485	68.04	11	102.1	10.5	72.23	212.5	819.38	1.378
Y8	370	6.9	742.5	4.83	67.77	11	102.3	10.5	72.37	212.5	827.02	1.331
Y9	323.75	8.25	810	5.3625	60.32	10	107.6	10.2	76.09	212.5	899.44	1.301
Y10	172.5	6	600	3.9	61.61	9	106.7	9	75.44	212.5	685.94	1.273
Y11	247.5	6	600	3.9	61.61	9	106.7	9	75.44	212.5	685.94	1.395
Y12	255	6	720	4.2	64.03	9	105	9	74.24	212.5	804.74	1.441
Y13	300	6	740	3.9	67.24	9	102.7	9	72.63	212.5	823.13	1.543
Y14	285	6	740	3.9	65.12	9.3	104.2	9.3	73.69	212.5	824.34	1.495
Y15	262.5	6.9	756	4.485	66.65	9.3	103.1	9.3	72.92	212.5	840.47	1.414
Y16	277.5	6	760	3.9	65.41	11	104	10.5	73.55	212.5	844.8	1.369
Y17	285	6	756	4.2	69.13	11	101.4	10.5	71.68	212.5	838.93	1.328

Table 2: Y-stiffeners with 45° inclination angle between hat webs (with same weight as T-stiffener) - continued

Y18	285	6.9	752.5	4.485	63.19	9.3	103.8	9.3	73.4	210	837.45	1.435
Y19	300	6.9	728.5	5.175	68	9.3	100.4	9.3	71	210	811.05	1.324
Y20	277.5	6	765	4.5	66.13	11	101.7	11.1	71.94	210	848.49	1.243
Y21	277.5	6.9	742.5	4.485	60.52	11	105.7	10.5	74.74	210	829.39	1.307
Y22	300	7.8	752.5	5.07	65.62	11	102.1	11.1	72.19	210	838.04	1.533
Y23	350	7.8	759	5.07	65.67	9.3	103.8	9.3	73.42	212.5	844.87	1.414
Y24	350	6.9	742.5	4.83	63.89	9.3	105.1	9.3	74.31	212.5	828.36	1.41
Y25	323.75	6.9	765	4.83	66.35	9.6	103.3	9.6	73.08	212.5	849.78	1.386
Y26	292.5	6.9	752.5	4.485	63.81	9	105.1	9	74.34	212.5	838.24	1.461
Y27	270	6	660	3.9	64.03	9	105	9	74.24	212.5	744.74	1.46
Y28	350	8.25	750	5.3625	55.15	11	111.3	10.5	78.68	212.5	842.18	1.254
Y29	390	9.75	750	6.3375	71.53	11	99.68	10.5	70.49	212.5	835.49	1.37

Table 3: Y-stiffeners with 45° inclination angle between hat webs (lighter weight than T-stiffener)

Y	b_f	t_f	h_w	t_w	b_{fh}	t_{fh}	b_{iw}	t_{iw}	hh	b_{ph}	h_{totat}	A_{ratio}	Z_{ratio}
Y1	150	6	585	3.9	131.572	9.3	57.225	9.3	40.464	212.5	636.114	0.98	1.05952
Y2	127.5	6	643.5	3.9	114.491	9.3	69.303	9.3	49.005	212.5	703.155	0.97	1.00265
Y3	202.5	6	682.5	3.9	97.0461	9.3	81.638	9.3	57.727	212.5	750.877	0.97	1.15438
Y4	195	6	760	3.9	118.931	9.9	66.163	9.9	46.785	212.5	817.735	0.97	1.1471
Y5	285	6	748	3.9	68.8909	9.9	101.55	9.9	71.805	212.5	830.755	0.97	1.20365
Y6	400	6	735	3.9	91.0083	10	85.908	10.2	60.746	212.5	806.846	0.97	1.2732
Y7	350	6	756	3.9	61.9221	11	106.47	10.5	75.289	212.5	842.539	0.97	1.22756
Y8	370	6	765	4.2	70.0614	11	100.72	10.5	71.219	212.5	847.469	0.97	1.20385
Y9	350	7.5	750	4.88	59.1264	10	108.45	10.2	76.687	212.5	839.287	0.97	1.14292
Y10	157.5	6	585	3.9	121.565	9	64.301	9	45.468	212.5	640.968	0.98	1.10041
Y11	180	6	600	3.9	106.275	9	75.113	9	53.113	212.5	663.613	0.97	1.10344
Y12	232.5	6	666	3.9	72.4756	9	99.012	9	70.012	212.5	746.512	0.97	1.19763
Y13	225	6	721.5	3.9	111.142	9.3	71.671	9.3	50.679	212.5	782.829	0.97	1.21036
Y14	232.5	6	703	3.9	104.094	9.3	76.655	9.3	54.203	212.5	767.853	0.97	1.20096
Y15	270	6	756	3.9	65.0772	9.3	104.24	9.3	73.711	212.5	840.361	0.97	1.26035
Y16	225	6	740	3.9	129.382	11	58.773	10.5	41.559	212.5	792.809	0.97	1.1095
Y17	225	6	798	3.9	127.865	11	59.846	10.5	42.318	212.5	851.568	0.97	1.15105
Y18	300	6	752.5	3.9	68.3012	9.3	100.2	9.3	70.849	210	833.999	0.97	1.29121
Y19	262.5	6.9	752	4.49	64.0491	9.3	103.2	9.3	72.975	210	836.525	0.97	1.21195
Y20	255	6	787.5	3.9	110.267	11	70.522	11.1	49.867	210	848.917	0.97	1.12152
Y21	285	6	787.5	3.9	111.19	11	69.869	10.5	49.405	210	848.155	0.97	1.19996
Y22	285	6.9	752.5	4.49	49.7403	11	113.32	11.1	80.13	210	845.08	0.97	1.33733
Y23	360	6.9	759	4.49	60.1748	9.3	107.71	9.3	76.163	212.5	846.713	0.97	1.28785
Y24	341.3	6	765	4.2	65.3839	9.6	104.03	9.6	73.558	212.5	849.358	0.97	1.25541
Y25	341.3	6	765	4.2	65.3839	9.6	104.03	9.6	73.558	212.5	849.358	0.97	1.25541
Y26	300	6	752.5	3.9	53.0412	9	112.75	9	79.729	212.5	842.729	0.97	1.31037
Y27	255	6	577.5	3.9	109.775	9	72.637	9	51.362	212.5	639.362	0.97	1.15029
Y28	341.3	7.5	780	4.88	99.6355	11	79.807	10.5	56.432	212.5	849.182	0.97	1.14063
Y29	400	8.3	750	5.78	40.2286	11	121.81	10.5	86.136	212.5	849.636	0.97	1.24263

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 4.

Table 4: Main characteristics of the double hull tanker

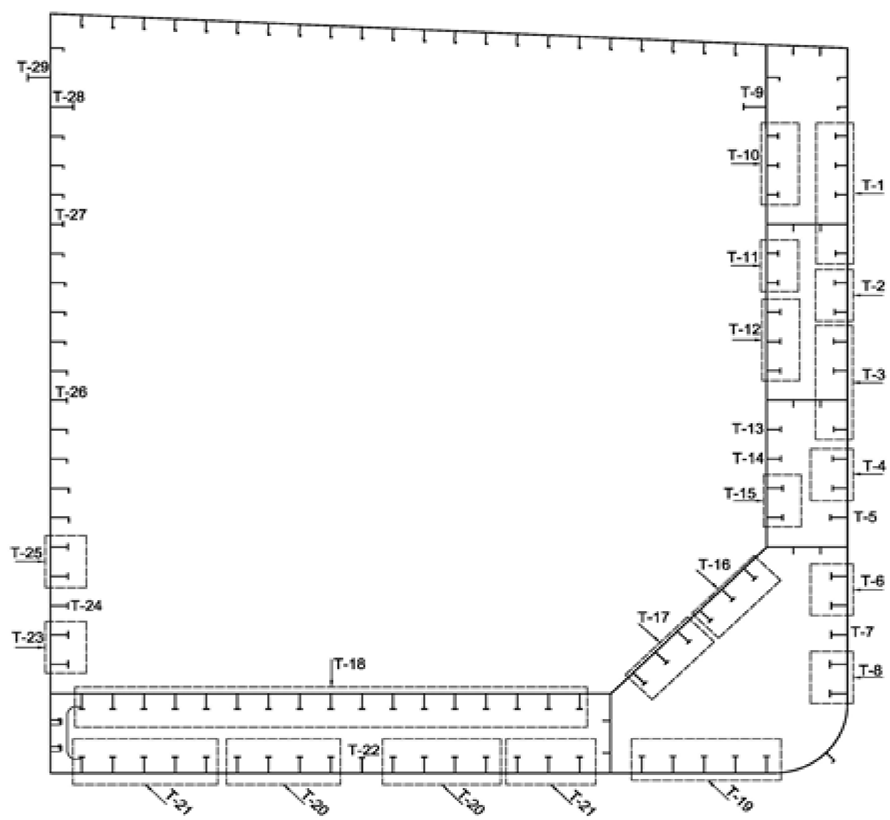
Length between perpendiculars (L_{PP})	238.0 m
Moulded breadth, (B)	43.0 m

Table 4: Main characteristics of the double hull tanker - continued

Moulded depth, (D)	21.0 m
Scantling draught, (T)	14.3 m
Deadweight, (DWT)	97000 tonne

The midship section of the vessel is shown in Figure 2.

Figure 2: Midship Section of Double Hull Tanker



1. 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 section modulus ratios the Y-stiffener to the T-stiffener greater than 1 while obtaining lighter or same weight as listed in tables 1,2 and 3, 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.

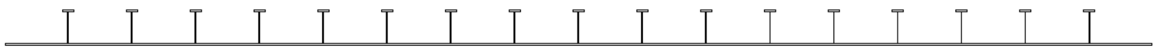
1.1. Validation for Inner Bottom with Y-stiffener Replacing T-stiffener

In this case, the T-stiffeners in the inner bottom plate are replaced by Y-stiffeners having the same weight or lighter weight as shown in Figure 3 (the Y-stiffener used in this case is **Y18** from tables 2 and 3), see table 5.

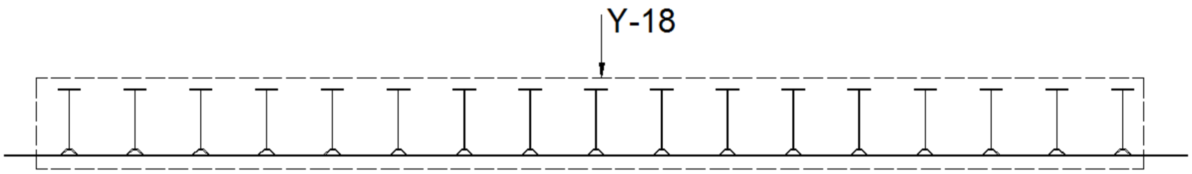
Table 5: Comparison between section modulus of inner bottom with Y-stiffener replacing T--stiffener

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)	0.0434	1.43	1.43
Inner bottom plate with attached Y-stiffeners (lighter weight)	0.0391	1.29	1.29

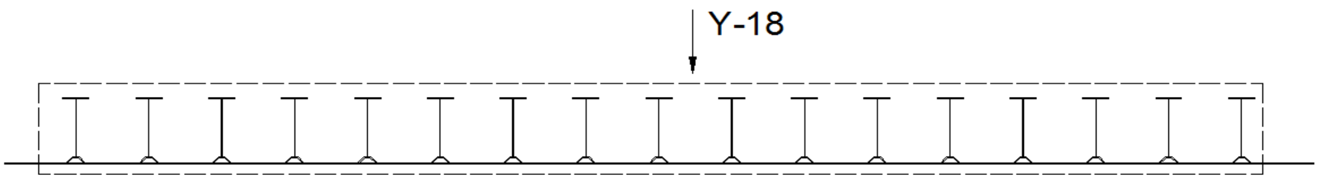
Figure 3: Comparison between section moduli



Inner Bottom with T-Sections, Z = 0.0303 m^3



Inner Bottom with Y-Sections - same weight, Z = 0.0434 m^3 and Z_{Ratio} = 1.43



Inner Bottom with Y-Sections – lighter weight, Z = 0.0391 m^3 and Z_{Ratio} = 1.29

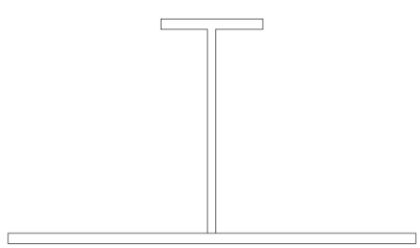
1.2. Validation of Single and Double Y-stiffeners Replacing T-stiffeners

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 6 shows the comparison between the section moduli also shown in Figure 4.

Table 6: Comparison between section moduli in cases of single and double stiffened panel, replacing T-stiffeners with Y-stiffeners

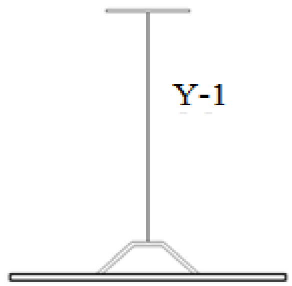
Item	Z (m^3)	Z_{Ratio} (Matlab)	Z_{Ratio} (Autocad)
Attached plate with T-stiffener	9.7611×10^{-4}	--	
Attached plate with Y-stiffener (same weight)	0.0012	1.22	1.22
Attached plate with two T-stiffeners	0.0036	--	
Attached plate with two Y-stiffeners (same weight)	0.0051	1.43	1.43

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



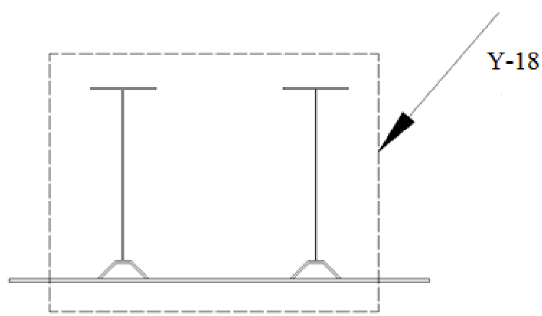
Attached plate with single T-section having Z = 9.7611×10^{-4} m^3

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



Attached plate with single Y-section for the same weight having Z = 0.0012 m^3

Attached plate with double T-sections having Z = 0.0036 m^3



Attached plate with double Y-sections for the same weight having Z = 0.0051 m^3

2. Case Studies

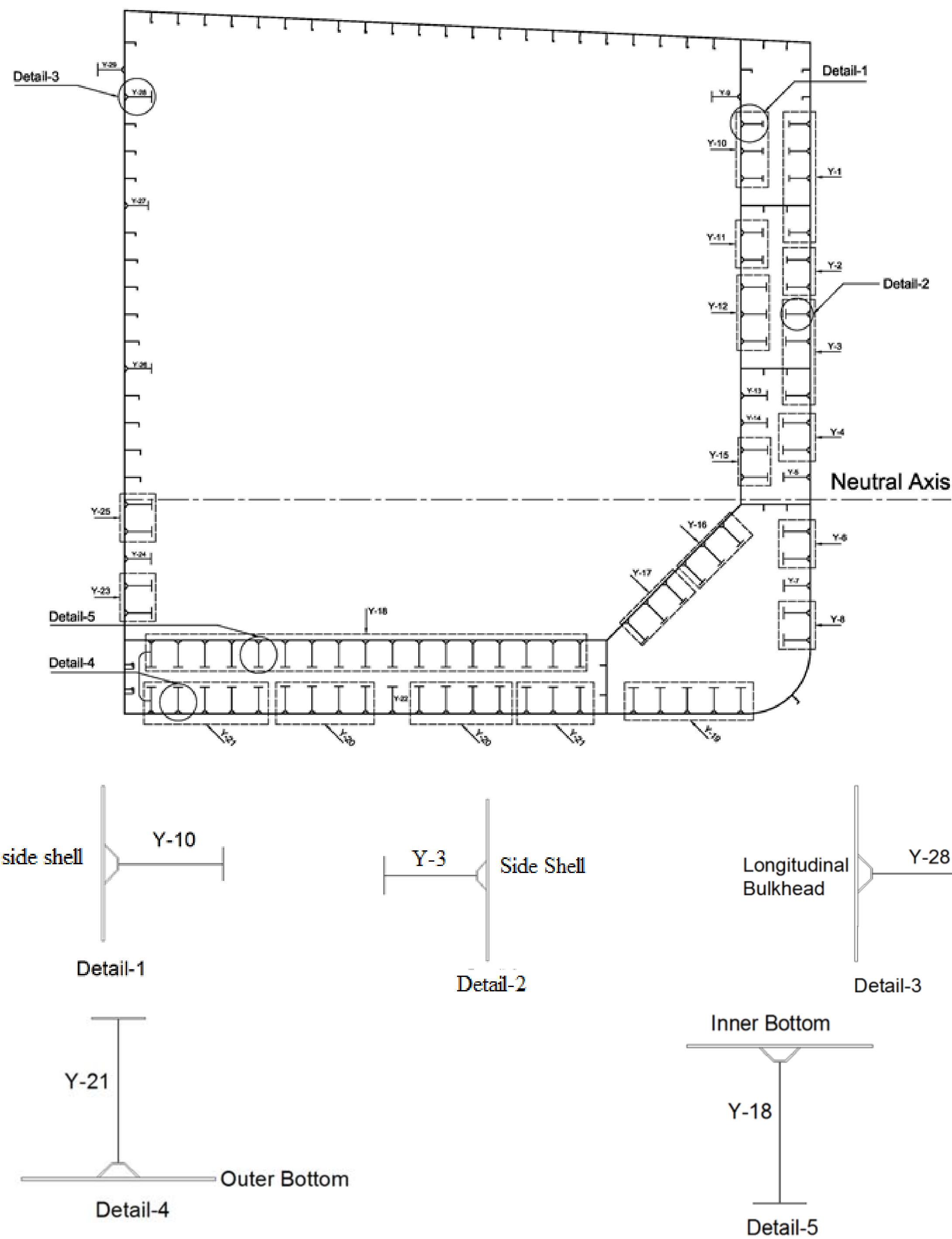
The existing "net" section modulus of the midship section calculated with the appropriate corrosion deduction (CSR table 6.3.1- Corrosion addition), should be greater than the CSR minimal required fatigue section modulus. The original midship section with T-stiffeners is shown in Figure 6. Input parameters and results of detailed fatigue calculations are presented in table 7.

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 areas of the midship section.

2.1. Case Study (1)

In this case, all T-stiffeners in the midship section are replaced by Y-stiffeners with weight equivalent to that of the original T-stiffeners, as given in table 2, but having higher section modulus. The midship section with Y-stiffeners is shown in Figure 5**.** Input data and results of detailed fatigue calculations are presented in table 6.

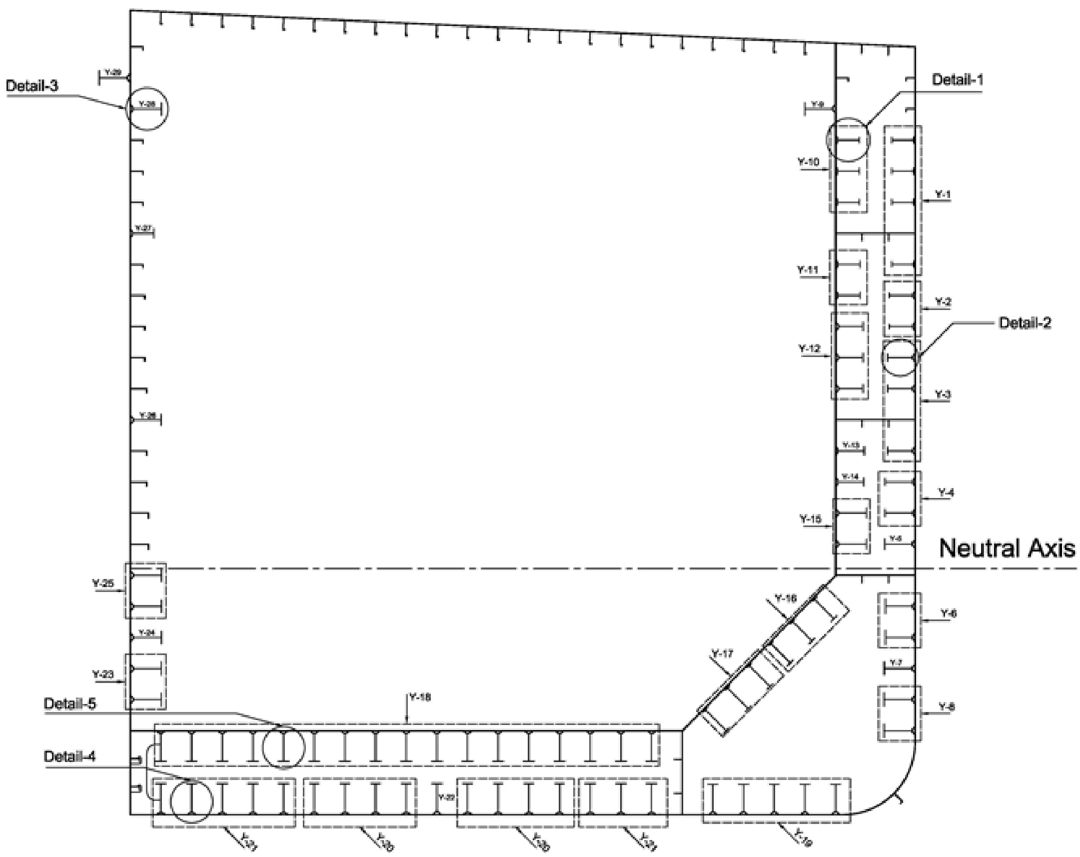
Figure 5: Midship section with Y-stiffeners



7.2. Case Study 2

In this case, all T-stiffeners in the midship section are replaced by Y-stiffeners of lighter weight as shown in Figure 6.

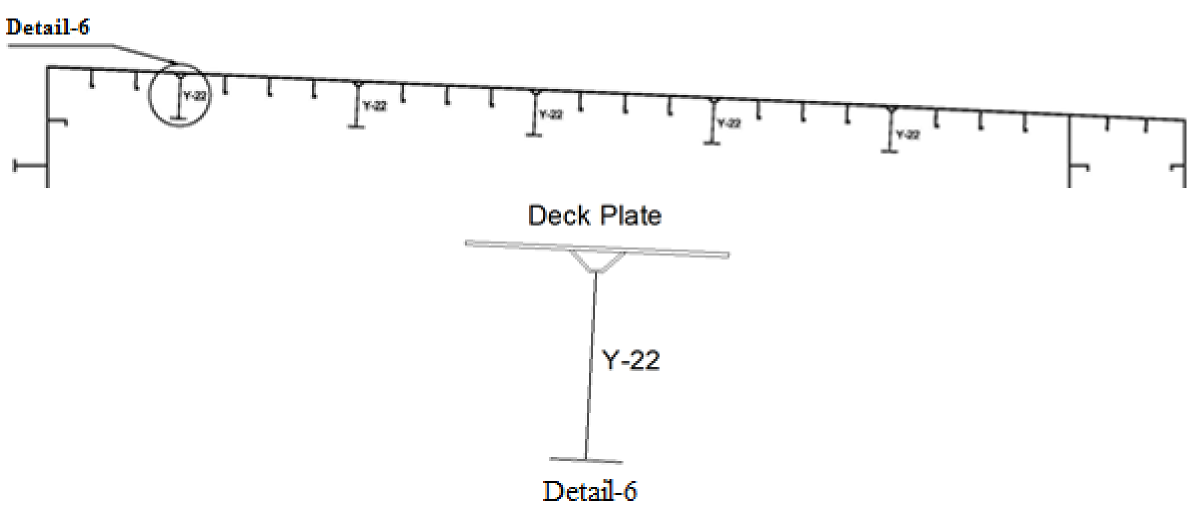
Figure 6: Lighter weight midship section with Y-stiffeners



7.3. Case Study 3

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 **Y22** from table 3 and the weight of the deck structure is slightly increased. The modified midship section with Y-stiffeners in the deck is shown in Figure 7.

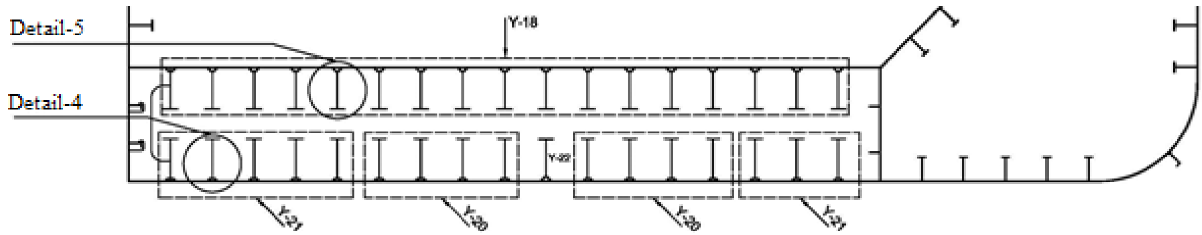
Figure 7: Midship section with some Y-stiffeners in the deck structure



7.4. Case Study 4

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 Figure 8.

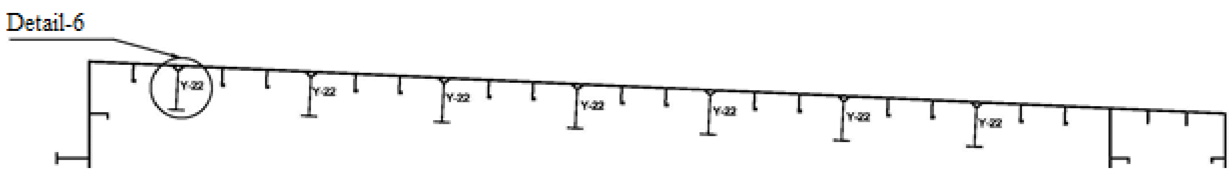
Figure 8: Midship section with Y-stiffeners in the double bottom instead of T-stiffeners



7.5. Case Study (5)

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 **Y22** 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 Figure 9.

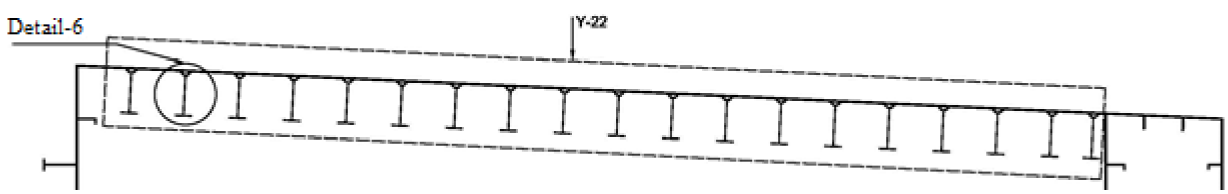
Figure 9: Deck structure with Y-stiffener after every two bulb plate stiffeners



7.6. Case Study (6)

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 **Y22** from table 2. The modified mi-ship section with Y-stiffeners is shown in Figure 10.

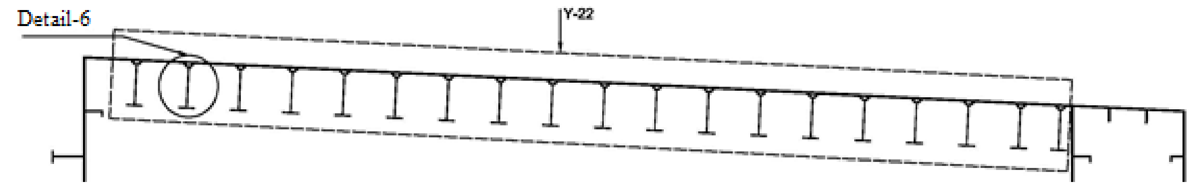
Figure 10: Midship section with bulb plate stiffeners replaced with Y-stiffeners in the deck structure



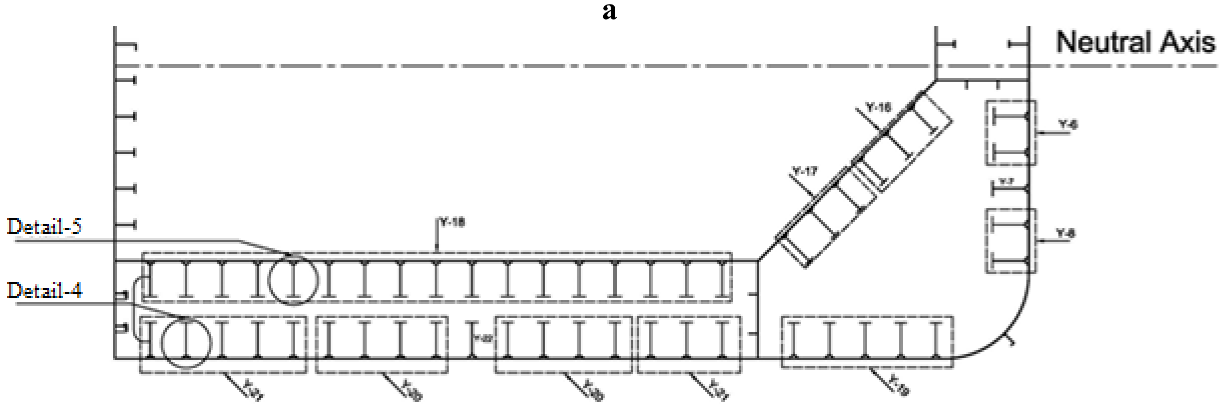
7.7. Case Study (7)

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 with lighter weight. The used Y-stiffener in the deck is **Y22** from table 2 and the used Y-stiffeners in the double bottom and hopper tanks are **Y6**, **Y7**, and **Y8** and **Y16** to **Y22** from table 3. The modified midship section with Y-stiffeners in the deck structure, double bottom and hopper tanks is shown in Figure 11.

Figure 11: 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

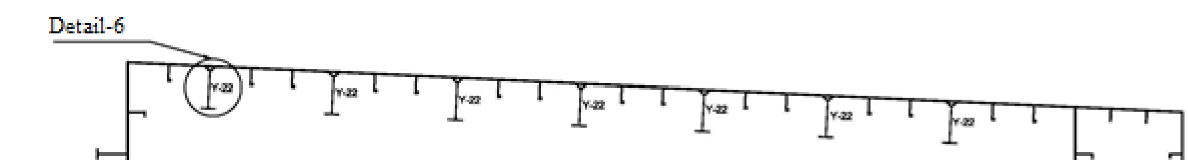


b

7.8. Case Study (8)

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 **Y22** in the deck structure and **Y6**, **Y7**, **Y8** and **Y16** to from table 3. The modified midship section with Y-stiffeners in the deck structure as well as below the neutral axis is shown in Figure 12.

Figure 12: Structure with Y stiffener replacing bulb plate stiffener after every two bulb stiffeners in the deck and all T-stiffeners below the neutral axis replaced by Y-stiffeners of lighter weight



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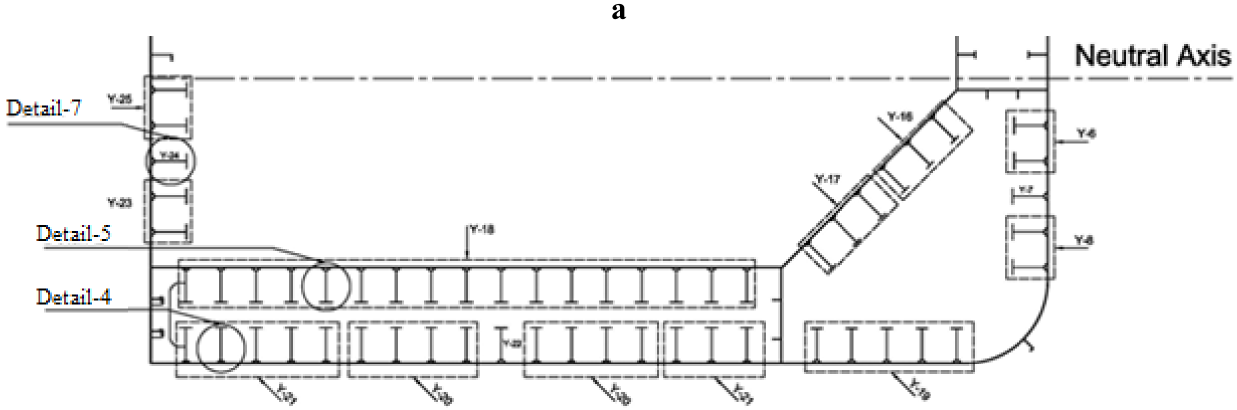
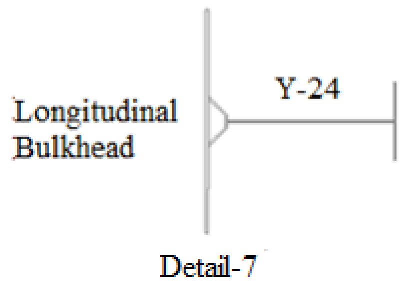


b

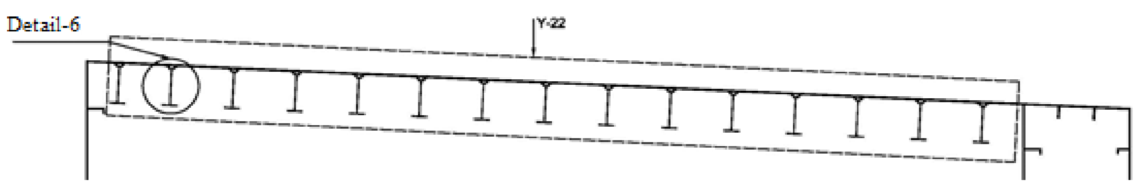
Figure 12: Structure with Y stiffener replacing bulb plate stiffener after every two bulb stiffeners in the deck and all T-stiffeners below the neutral axis replaced by Y-stiffeners of lighter weight - continued



7.9. Case Study (9)

In this case, all bulb plate stiffeners are replaced by Y-stiffeners without changing the thickness of the attached plate and keeping the total area of the deck structure constant. In other words, the half deck has twenty two bulb plates which are replaced by fifteen Y-stiffeners of the same area of the total weight deck structure. All T-stiffeners in double bottom and hopper tanks are replaced by Y-stiffeners. The used Y-stiffener in the deck structure is **Y22** from table 2 and **Y6**, **Y7**, and **Y8** and **Y16** to **Y22** from table 2 in the double bottom and hopper tanks, respectively. The modified midship section with Y-stiffeners in the deck structure, double bottom and hopper tanks is shown in Figure 13.

Figure 13: a- All bulb plate stiffeners replaced by Y-stiffeners (while keeping the total area of the deck structure constant) b- All T-stiffeners in double bottom and hopper tanks replaced by Y-stiffeners of same weight



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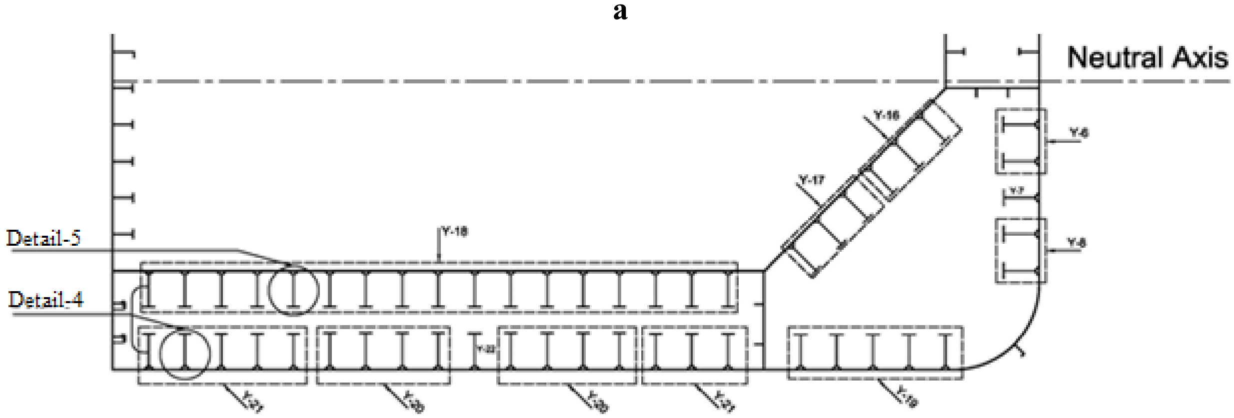
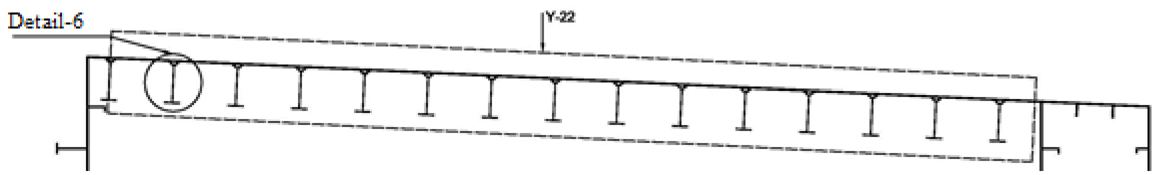


b

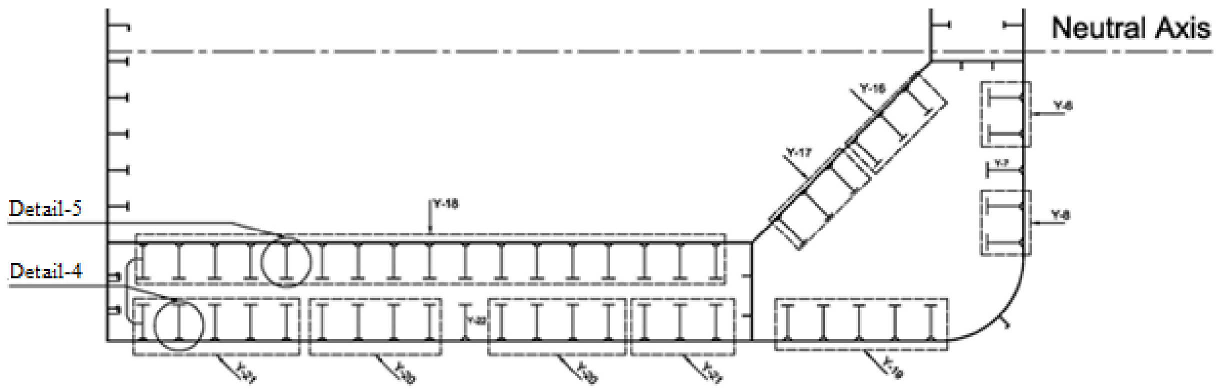
7.10. Case Study (10)

In this case, all bulb plate stiffeners are replaced by Y-stiffeners without changing the plate thickness and keeping the same area of deck structure. In other words, the half deck has twenty two bulb plates that are replaced by fifteen Y-stiffeners for the same deck area. All T-stiffeners in double bottom and hopper tanks are replaced by lighter weight Y-stiffeners. The used Y-section in the deck structure is **Y22** from table 2 and in the double bottom and hopper tanks **Y6**, **Y7**, and **Y8** and from **Y16** to **Y22** from table 3, respectively. The midship section with Y-stiffeners in the deck structure, double bottom and hopper tanks is shown in Figure 14.

Figure 14: a- Midship section with all bulb plate stiffeners replaced by Y-stiffeners for the same total area of the deck structure b- All T-stiffeners in double bottom and hopper tanks replaced by lighter weight Y-stiffeners



a



b

7.11. Case Study (11)

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 **Y22** from table 3. The obtained total weight of the deck structure with Y-stiffeners is larger than for bulb plate stiffeners. The modified midship section with Y-stiffeners in the deck structure is shown in Figure 15.

Figure 15: All bulb plate stiffeners replaced by Y-stiffeners in deck structure

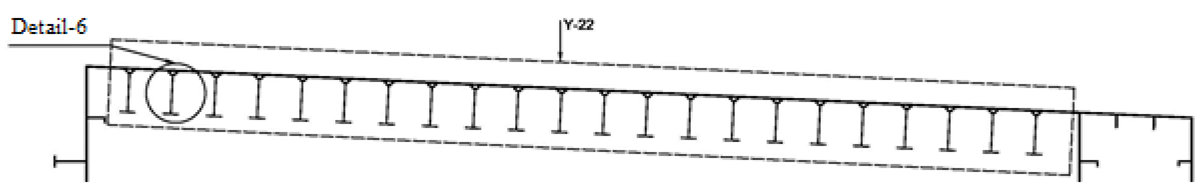


Table 7: Results for the different case studies of Y-Stiffeners with inclined web at 45°

Terms	**Original case**	**Case (1)**	**Case (2)**	**Case (3)**	**Case (4)**	**Case (5)**	**Case (6)**	**Case (7)**	**Case (8)**	**Case (9)**	**Case (10)**	**Case (11)**
Actual section modulus Z_v (m^3)	33.164	32.981	32.834	33.509	33.121	33.647	34.330	34.277	33.598	32.923	33.069	34.680
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
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
Inputs												
M_w (MNm)	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
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
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
K_2	0.63E+12	0.63 E+12	0.63E+12	0.63E+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	119.712	120.248	117.825	119.206	117.342	115.008	115.185	117.513	119.923	119.393	113.847
Outputs												
DM_i	0.52	0.529	0.536	0.505	0.523	0.498	0.469	0.471	0.501	0.532	0.525	0.455
DM	1.041	1.058	1.073	1.009	1.045	0.997	0.938	0.943	1.001	1.064	1.05	0.91
Fatigue Life (years)	24.017	23.621	23.307	24.774	23.923	25.081	26.640	26.517	24.972	23.497	23.811	27.463
Steel Weight (ton)	9100	9100	8888 (-212)	9119.5 (+ 19.5)	9005 (- 95)	9128 (+ 28)	9175 (+75)	9039 (-61)	8987 (-113)	9032 (-68)	8964 (-136)	9191 (+ 91)

8. Interpretation of the Results

From the results obtained and shown in table 7, the following may be deduced:

Case (1): the actual section modulus and fatigue life are very close to the original case, and the weight is unchanged.

Case (2): shows that the actual section modulus and fatigue life are quite close to the original case, and the obtained weight is less by 212 tons.

Case (3): the actual section modulus and fatigue life are starting to increase but the weight is more than the original case by 19.5 tons.

From case (4), it is clear that the actual section modulus and fatigue life do not change considerably and the weight decreases by 95 tons.

In case (5), the actual section modulus is slightly increased and fatigue life increases by one year while the weight increases by 28 tons.

Case (6): shows that the actual section modulus apparently increases, fatigue life increases by two and a half years and the weight increases by 75 tons.

Case (7): gives an increase in the actual section modulus and fatigue life close to that obtained in case (6) but the obtained weight is less than the original case by 61 tons.

Case (8): 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.

Case (9): gives an actual section modulus and a fatigue life time quite close to cases (1) and (2) but the weight is reduced by 68 tons.

In case (10), the section modulus and fatigue life are quite close to the original case though the weight is reduced by 136 tons.

From the results of case (11), it is clear that the actual section modulus is largest among all studied cases though close to cases (6) and (1). The fatigue life is increased by three years and five months and the weight is increased by 91 tons.

9. Conclusions

Ship structures are subjected to variable cyclic loading during navigation. The cyclic motion of waves induces variable and complex loadings in the structure, which could generate fatigue damage. So, the role of the designer is to reduce the fatigue damage by making various design improvements especially in the locations subjected to high fatigue loads in the ship especially in the midship section.

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 3 and 4.

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 to calculate the allowable fatigue stress, required fatigue section modulus and the cumulative fatigue damage ratio. Finally, assessment of fatigue lives for the midship sections resulting is carried out.

A summary of the results for the eleven cases was summarized in Table 7. The cases that showed an improvement were cases (3), (5), (6), (7), (8), (10) and (11). Case (7) where bulb plate stiffeners in the deck were replaced with Y-stiffeners without changing the thickness of the deck plating and the T-stiffeners in the double bottom and hopper tanks were replaced by Y-stiffeners with lighter weight has yielded the best results since the section modulus and fatigue life were increased while a reduction in weight was obtained.

10. Recommendations for Future Work

This study illustrates the fatigue life estimation for a tanker vessel after using unconventional stiffeners instead of T-stiffeners and flat bulbs in the midship section. However, there are several technical and practical issues that deserve further investigation in regards to the fatigue life estimation and use of the unconventional stiffeners.

- The spectral analysis method is based only on the vertical wave bending moment. The horizontal wave bending moment, inner liquid pressure in tanks and outside sea pressure effect should be included in the fatigue life estimation.
- The cost of fabrication of the Y - stiffener should be taken into account and compared with the fabrication cost of the T-stiffener & flat bulbs.
- The ability of maintaining the Y-stiffeners at various locations in the ship and the maintenance cost is to be considered also in the design phase.
- The method or welding technique should be investigated and also the welding cost should be considered in the design phase.
- This work should be extended further in the future to appropriately check all suggested cases against failure by buckling or local bending. Appropriate modifications could then be implemented.

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