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"Safe Struck Ship"(3S):Software Package for Structural analysis of collision between ships

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ABSTRACT

Each year, thousands of tons of crude oil and petroleum products are spilled in the seas as a result of collision between ships. So, as a part of the overall effort to promote maritime safety and environmental protection an integrated software package of collision analysis is developed and used to calculate mid-ship plastic neutral axis position, moment of inertia about the plastic neutral axis in addition to maximum and minimum ship sectional modulus for actual and smeared mid-ship section for the intact ship. The minimum required moment of inertia and section modulus as required by the common structural rules in damaged condition are also calculated. Moreover, the program calculates the working bending moment in both cases; hogging and sagging conditions either for actual mid-ship section or smeared mid-ship section. The critical penetration, damaged mid-ship plastic neutral axis position, damaged moment of inertia about the plastic neutral axis and critical maximum and minimum ship sectional modulii are calculated. Finally the program calculates a new proposed strength safety factor based on the residual strength of the ship after collision and which ensures adequate structural redundancy to survive in the event that the ship's hull is accidently damaged. All the results will be appeared in a printable reports.

Keywords : Software ; Collision ;Maritime Safety ;Critical Penetration ; CSR; Damage

1. Introduction

There is a trend in the marine sector towards rational risk analysis where modern methods are being used to predict the probability, damage and consequence of various accidents.
Collision accidents are among the most common causes of ship disasters. Although continuous efforts are being made to prevent such accidents, it is certain that they will continue to occur.

Hegazy investigated the possibility of a single hull struck ship being broken into two after collision due to the loss of her longitudinal strength. The concept of the ultimate bending strength developed by Caldwell [5] has been used to calculate the transverse extent of damage (i.e. penetration) to the struck ship after collision, as well as to develop a procedure to find the critical penetration (and hence, the corresponding residual strength) beyond which the struck ship might be broken into two if the longitudinal bending moment subsequently exceeds the "design value" [1]. In addition, Hegazy proposed a simple method, which enables the amounts of energy absorbed by different parts of ship structures during a collision to be estimated. His formulae were derived by using theoretical plastic analysis of various structure failure mechanics of different ship's structural members to evaluate the total absorbed energy by the struck ship and striking vessel's structures during collision [4]. Hegazy investigated the residual longitudinal strength of double hull oil tankers after collision accidents [1]. Zhang established a method that canbe used as a simple design tool for analyzing ship collision and grounding. The expression gives a relation between the absorbed energy and the volume of the destroyed materials, which takes into account the structure, the material properties and the damage mode [10]. Hegazy et al. studied the residual strength of three double hull oil tankers. The modulus of sections of them before and after damage were calculated and were compared with the minimum modulus of section required by the common structural rules. A new concept of structural safety for ship's hull is introduced based on the residual strength of ships after collision [2,3]. Vaughan established a similar formula, based on the experiments, which also related the absorbed energy (E) and the destroyed volume (R_T) and the destroyed area (A). (Vaughan, 1978) $E = 93R_T + 33\ \mathrm{A}\ (MJ)$ [11].Paik introduced two different modifications for Minorsky formula, which can be used only for a quick estimation of the amount of damage expected in a collided VLCC double hull tanker side structure. The first formula is based on the energy capable of being absorbed until the bow of the striking vessel penetrates to the original position of the inner hull of struck ship without rupture of the inner hull. His second formula is based on the energy capable of being absorbed up to the inner hull rupture [12].The American Bureau of Shipping (ABS) published a paper in July 1995 which provides guidelines and assumptions for facilitating an assessment of structural redundancy and hull girder residual strength at an early design stage [6].Ozgur Ozguc investigated the collision resistance and residual strength of single side skin (SSS) and double side skin (DSS) bulk carriers subject to collision damage. The impact dynamics analyses were conducted using special computer programs for the evaluation of resistance forces, energy absorption and penetration depth for various collision scenarios [13]. The computer program developed in this paper calculates mid-ship plastic neutral axis position, moment of inertia about the plastic neutral axis, maximum and minimum ship sectional modulus for actual and smeared mid-ship section for the intact ship. The minimum moment of inertia and section modulus as required by the common structural rules (CSR) in damaged condition are also calculated. The program calculates the working bending moment in both hogging and sagging conditions for actual mid-ship section and smeared mid-ship section for the ship in damaged condition after severe collision as explained in [1]. Finally the program calculates a new strength safety factor based on the residual strength of the damaged ship after severe collision. All data as inputs and outputs appeared in a printable report and can be saved as PDF, MS. Excel sheet, MS. Word files. The overall functionality of 3S software are shown in figure (1).

2.Software capability

The software **3S,** for analysis of collision between ships contains the following three modules:-

First module:-

Entering actual intact mid-ship section scantlings to calculate mid-ship plastic neutral axis position , moment of inertia about the plastic neutral axis , maximum and minimum ship sectional modulus , working bending moment (in sagging condition), critical penetration (the critical transverse extent of damage resulting from a critical major collision beyond which the struck ship will be broken into two parts),damaged mid-ship plastic neutral axis position ,damaged moment of inertia about the plastic neutral axis and critical maximum and minimum ship sectional modulus .

Second module:-

The same as first module but the calculations are carried out for idealized smeared mid-ship section (i.e. where longitudinal stiffeners are smeared into plates thickness). In addition, damaged mid-ship plastic neutral axis position, damaged moment of inertia about the plastic neutral axis and critical maximum and minimum ship sectional modulus are calculated.

Third module:-

Calculates the minimum working bending moment (sagging or hogging condition), moment of inertia and section modulus as required by the CSR , the recommended residual section modulus by ABS rules and minimum vertical section modulus .

At the end, the structural safety factor is calculated.

3. Program’s Graphical-User-Interfaces

All the graphical-user-interfaces of this program have been created using the tools and functions of Microsoft Visual Studio 2005 [14].The software is fully described in the next sections.

3.1 Main Window

The main window contains the main ship principal dimensions, loading conditions (sagging or hogging) and the steel yield stress with different strength. It contains also the main ship items like deck, side, side stringers, inner hull longitudinal bulkhead, inner bottom, outer bottom and longitudinal bulkheads in forms of tabs as shown in figure (2). To avoid any misunderstanding between the user and the program, a data sketch will be shown as the first tab in the main window containing a simple sketch indicating all main longitudinal items for a half double hull tanker’s mid-ship section according to the common structural rules’ double hull tanker configuration.

It must be noted that the program gives the ability to the user to enter any number of bottom side girders, side stringers and longitudinal bulkheads

3.2 Decks’ Details

The deck tab’s interface gives the user the ability to add the deck’s platting dimensions through the"plates" button and the same is for deck longitudinal’s groups through the longitudinal’s groups button. In addition, if the double hull tanker has a deck center girder, the user can enter its dimensions with its longitudinal as shown in figure

(3). The user will enter the decks’ plates first (only for the half breadth) with its dimensions including breadth and thickness of each one in a window called deck plates as shown in figure (4). Then the user can enter all deck longitudinals; flat bar, bulb, tee or angle section. To get the data entering for the longitudinal easier than the normal entering, the longitudinals which have the same section dimensions and the same section type can be entered in form of groups, in this case the user must enter the number of these longitudinals in each group.

Also each longitudinal’s section type is shown in the deck longitudinals group’s window as shown in figure (5). These figures are used to help the user recognize the required dimensions for each type of longitudinals.

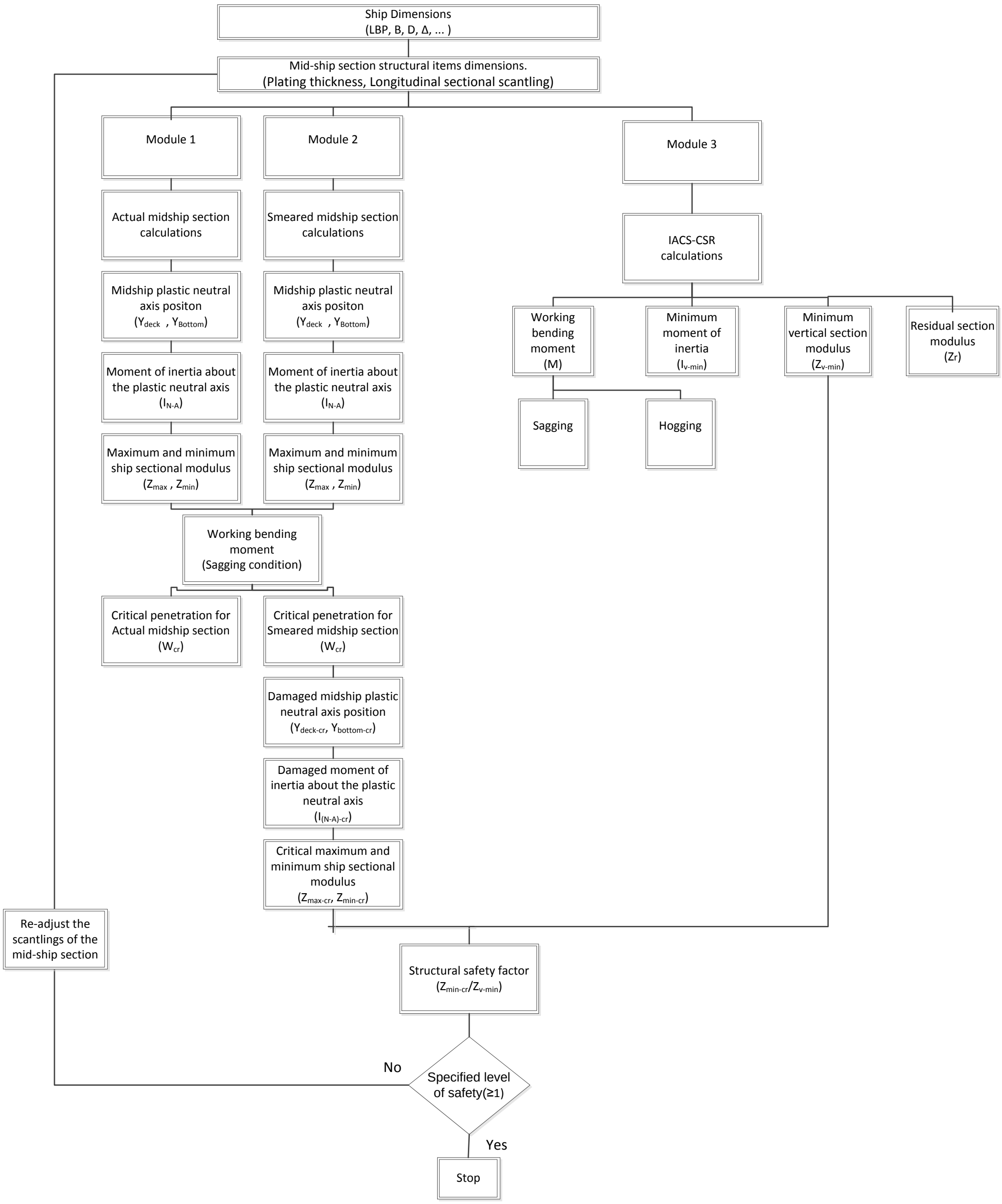

Figure 1: The overall functionality of 3S software.

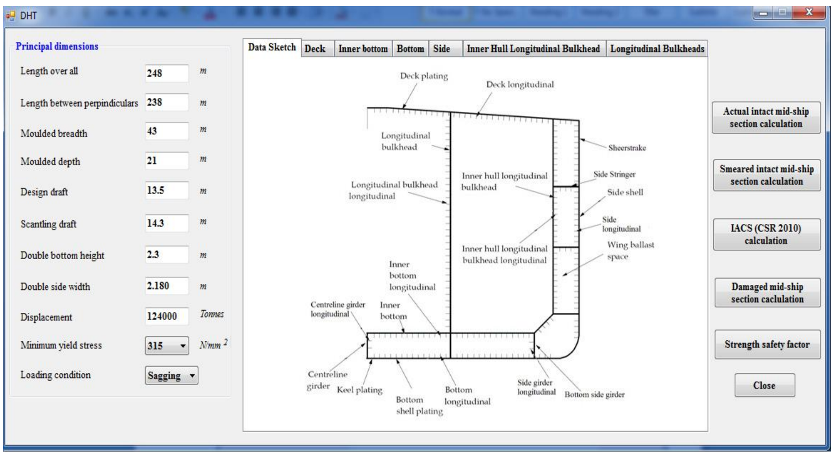

Figure (2) Program's main window

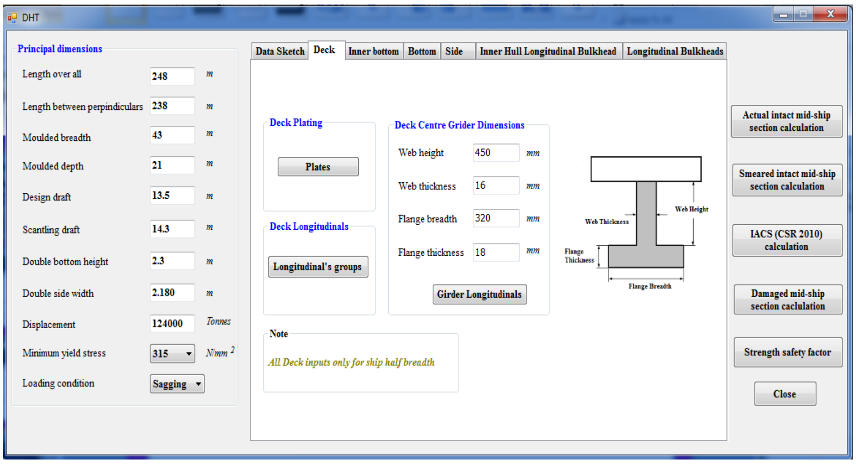

Figure (3) Deck's window

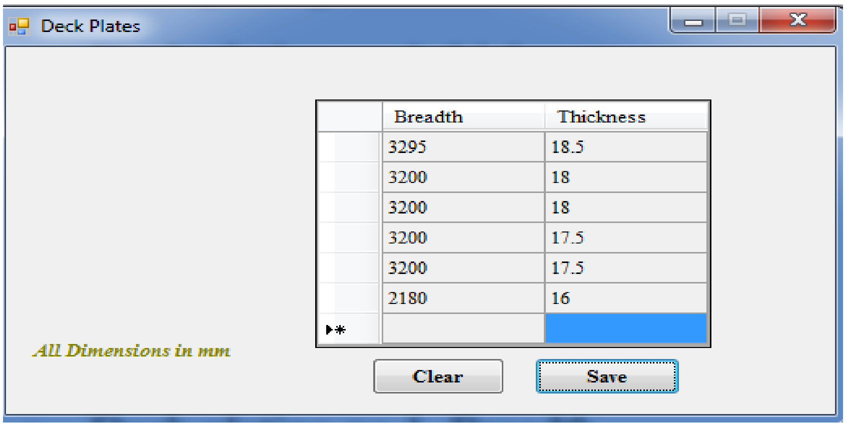

Figure (4) Deck plate's window

3.3 Inner Bottom's Window

The inner bottom tab's interface gives the user the ability to add the inner bottom's platting dimensions through the "plates" button and the same is for the inner bottom longitudinal's groups as shown in figure (6).

3.4 Bottom's Window

The bottom tab's interface gives the user the ability to add the bottom's platting dimensions through the "plates" button and the same is for bottom longitudinal's groups as shown in figure (7).

The bottom center girder can be added (plates and longitudinals), also the program gives the user the ability to add any number of bottom side girders with its longitudinals but only for the ship's half breadth as shown in figure (7).

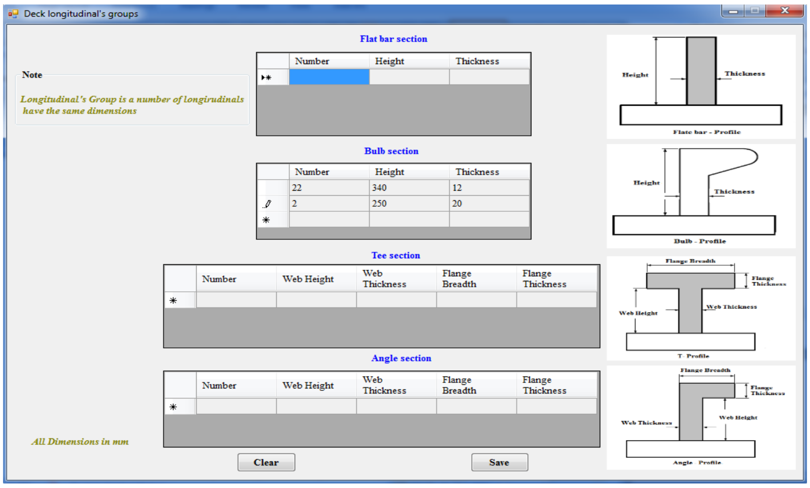

Figure (5) Deck longitudinal's window

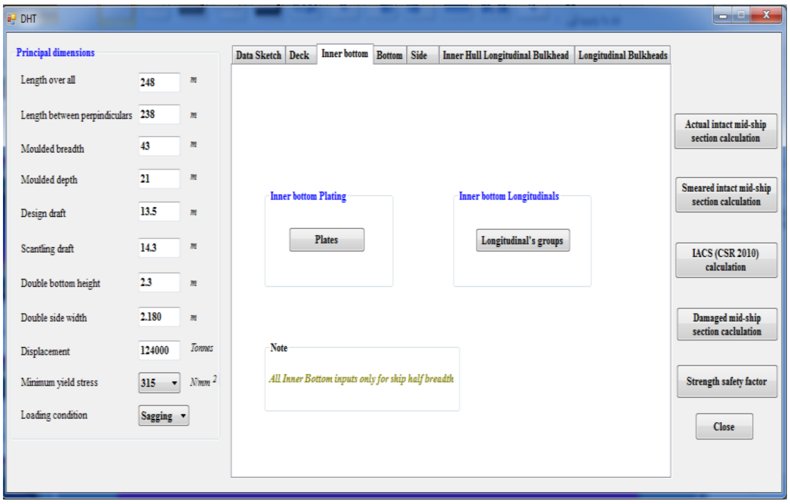

Figure (6) Inner bottom's window

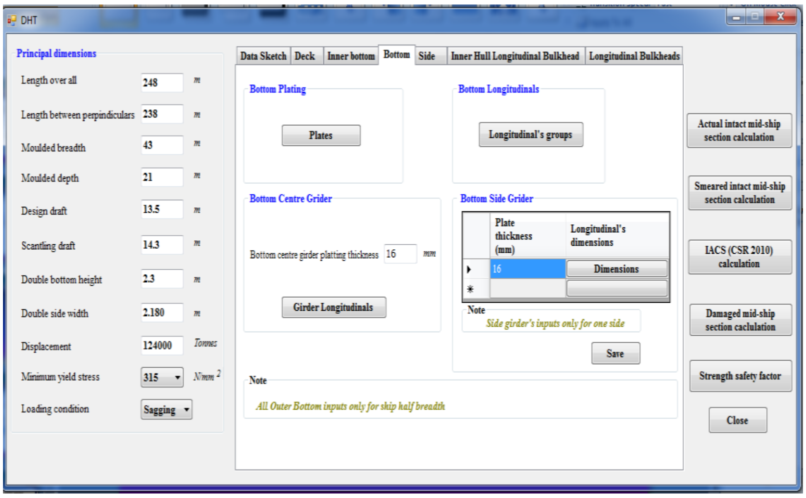

Figure (7) Bottom's window

3.5 Side's Window

The side tab's interface gives the user the ability to add the side's platting dimensions through the "plates" button and the same is for its longitudinals as shown in figure (8).

The program gives the user the ability to add any number of side stringers with its longitudinals but only for the ship's half breadth. It is very important for the user to determine the order of side longitudinals located before each side stringer as shown in figure (8).

3.6 Inner Hull Longitudinal Bulkhead's Window

The inner hull longitudinal bulkhead tab's interface gives the user the ability to add the platting dimensions through the "plates" button and the same is for its longitudinals as shown in figure (9).

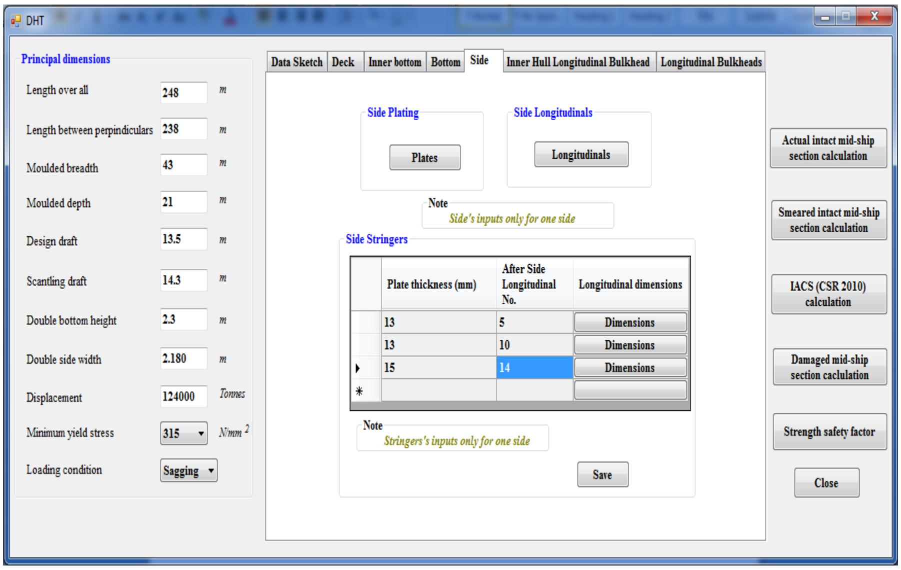

Figure (8) side's window

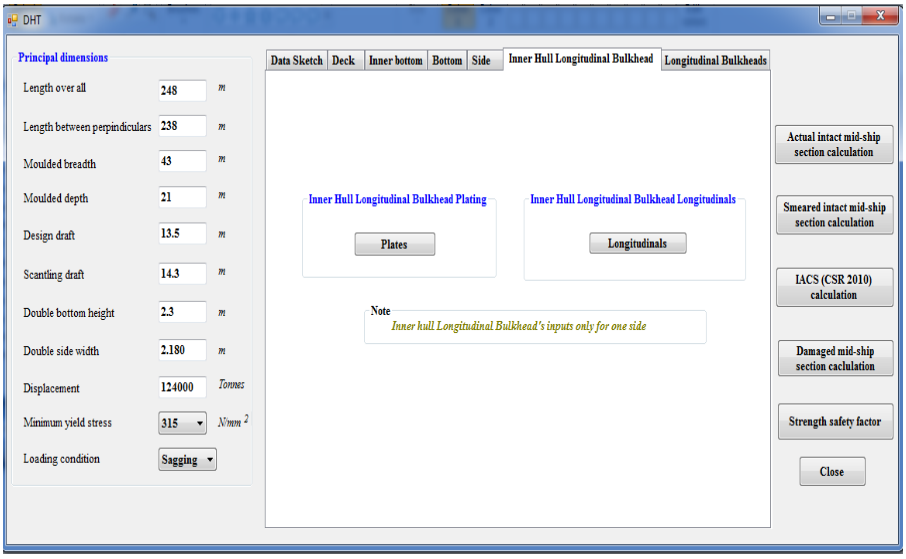

Figure (9) Inner hull longitudinal bulkhead's window

3.7 Longitudinal Bulkheads' Window

The program gives the user the ability to add any number of longitudinal bulkheads with its platting and longitudinal's dimensions as shown in figure (10), but the user has to add all the longitudinal bulkheads separately not only for the ship half breadth but for all the breadth.

4- Program Verification

The results of the program for three double hull tankers (see Table 1), for which the critical penetration values for actual and smeared mid-ship were calculated and compared with the results obtained by using Microsoft Excel and good agreement between both results was found in all cases (see Table 2).

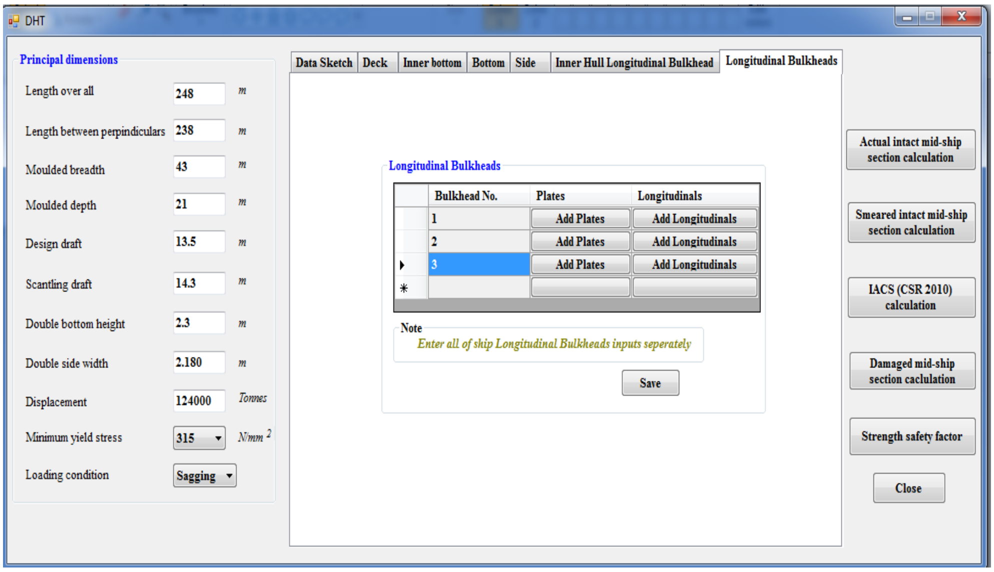

Figure (10) Longitudinal bulkhead's window

Table 1

Struck ships structural characteristics.[8, 9]

	DHT 45000	DHT 97000	DHT 15000
Displacement (Δ) (ton)	47448	124000	151861
Length between perpendiculars (LBP) (m)	190.5	238	261
Moulded breadth (B) (m)	29.26	43	50
Moulded depth to upper deck (D) (m)	15.24	21	25.1
Designed draft (T) (m)	10.58	13.5	16.76
Double bottom height (Y) (m)	2.1	2.3	3.34
Wing width (b) (m)	2.438	2.18	3.34

Table 2
Comparison between program results and Microsoft results

Vessel	DHT 45000		DHT 97000		DHT 150000	
Results	Analytical Results	Software Results	Analytical Results	Software Results	Analytical Results	Software Results
Z (m^3)	11.965	11.965510604401	30.406	30.40644622011	40.095	40.09596721691
w_{cr} (m)	13.53156	13.53155302151	22.2658	22.26580085213	25.8531	25.853186746842
Z_{cr} (m^3)	6.70351	6.7035076410302	13.915886	13.915886122201	18.055053	18.055053711202
	11.4276	11.427639680001	25.6263	25.62627754103	37.1422	37.14221606018
	0.587	0.5866047432064	0.5430	0.543031897503	0.4861	0.4861059898666
	1.3840	1.384038262225	1.49509	1.495093404006	1.67017	1.670177749141

5-Comparison between Section Modulus Calculated for Actual and Smeared Mid-ship section

The results of calculations are given in Table (3).It is clear from Table (3) that the percentage of error in all of the above values between the two methods of calculations (actual and smeared section) is too small (0.035%). Because of the processing for the actual mid-ship section takes more effort and time than the smeared one, it is recommended to use the smearing way for idealizing the mid-ship section.

Table (3).Comparison between Section Modulus Calculated for Actual, Smeared Mid-ship section

Item	**Symbol**	**Actual calculation**	**Smearing calculation**	**Error %**
Ship Total Cross Sectional Area *(m^2)*	*A*	*5.63879*	*5.6399*	*0.019*
Midship sectional neutral axis position above the bottom level *(m)*	Y_{bottom}	*8.808*	*8.758*	*0.563*
Midship sectional neutral axis position below the upper deck level *(m)*	Y_{Deck}	*12.209*	*12.267*	*0.475*
Minimum Section Modulus (before damage) *(m^3)*	Z_{min}	*29.869*	*30.406*	*1.801*
Maximum Section Modulus (before damage) *(m^3)*	Z_{max}	*41.403*	*42.588*	*2.864*
Critical Transverse Penetration (after damage) *(m)*	W_{cr}	*26.194*	*26.203*	*0.035*
Critical Transverse Penetration's Percentage from the Ship Breadth *(%)*		*60.92*	*60.94*	*0.035*

6. Comparison between the smeared modulus of section of intact ship (before damage) and the minimum sectional modulus required by the common structural rules (CSR2010)

From Table (4), one can see that the real section modulus of the intact ship is higher than its value as required by CSR (2010) by 19 %. This difference is coming from owner's specification of requirements above the general classification or statutory requirements which may affect the structural design [7].

7. Comparison between modulus of section of ships in critical damaged condition (z critical) and the minimum sectional modulus as required by CSR 2010 (Zmin)

From Table 5 one can see that the mean value of Z_{cr}/Z_{min} (the modulus of section of the struck ship being involved in critical major collision divided by minimum modulus of section required by CSR or (strength safety factor) is about 0.539, which means that the ship's hull girder is not designed to have adequate structural redundancy to survive in the event that the hull is accidentally damaged (i.e. subjected to critical major collision)[1] and in this case there is a probability for a ship's hull girder to be broken into two after such collision.

To avoid such a case for ships carrying dangerous or powered by nuclear power, we do recommend to take the minimum value of modulus of section as required by the CSR (Z_{min}) to be the value of the modulus of the hull girder in the critical damage condition (Z_{cr}). The developed software in this paper will provide a useful tool to carry out the calculations of (Z_{cr}) in the preliminary stage of design in order to adjust the scantling of mid-ship section to satisfy this requirement (i.e. $Z_{cr}= Z_{min}$). In this way collision between ships becomes as a design criteria which can be taken into consideration during ship's design procedures. We know that such procedure will lead to an increase in the steel hull weight of the ship, but it will be very useful in some cases where collision may cause very catastrophic results for property, lives and environment.

Table (4). Comparison between Smeared and the Minimum by IACS (CSR 2010)

Item	Smearing calculation(z)	IACS (CSR, 2010) (z_{min}.)	Safety Factor (Z/Zmin.)
Section Modulus of intact ship before damage *(m^3)*	*30.406*	25.6263	*1.19*

Table (5). Comparison between $Z_{Critical}$ and Z_{min}.

Vessel	Modulus of section before damage in m^3 (Z)	Critical Modulus of section after damage in m^3 ($Z_{Critical}$)	Minimum modulus of section as required by CSR in m^3 (Z_{min})	Z_{cr}/Z_{min}
DHT 45000	11.965	6.7035	11.4276	0.587
DHT 97000	30.406	13.9159	25.6263	0.543
DHT 150000	40.095	18.0551	37.1422	0.487

8. Result's Report

If the user chooses to start his calculations with an actual or smeared double hull mid-ship section by pressing on the button named (Actual intact mid-ship section calculation) which appears in the main window and the same is for the second button named (Smeared intact mid-ship section calculation), then, all the results will be appearing in a printable report as shown in figure (11).

Calculation Report
(Intact Ship)

Ship Data		
Length over all	248.000	*m*
Length between perpendiculars	238.000	*m*
Moulded breadth	43.000	*m*
Moulded depth	21.000	*m*
Design draft	13.500	*m*
Scantling draft	14.300	*m*
Double bottom height	2.300	*m*
Wing width	2.180	*m*
Displacement	114,117.600	*Tonnes*
Minimum yield stress	315.000	N/mm^2
Results		
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in deck.	958709.7788125730	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in one side.	524475.0000000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in one inner hull longitudinal bulkhead.	519755.0000000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in inner bottom.	1030470.0000000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in outer bottom.	1104110.0000000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in the ship longitudinal bulkhead no. 1	458155.0000000000	mm^2
Mid-ship sectional area	5639904.7788125	mm^2
Maximum distance between the natural axis and the deck	12267.351935196	*mm*
Maximum distance between the natural axis and the bottom level	8758.3250415480	*mm*
Mid-ship moment of intertia	373.0065742095	m^4
Minimum section modulus	30.4064460024	m^3
Maximum section modulus	42.5888023612	m^3
Working bending moment due sagging condition IACS (CSR 2010)	-5908280.6551111	*kN.m*
Critical penetration (The transverse damage length above which the struck ship will be broken into two after collision) due to sagging condition.	22.26580085	*m*

Figure (11) Computer program's final calculation report

If the user chooses to calculate the damaged mid-ship section area, critical moment of inertia, critical section modulus and neutral axis position of a damaged double hull mid-ship section (struck ship) by pressing on the button named (Damaged mid-ship section calculation) which appears in the main window, all the results will appear in a printable report as shown in figure (12).

If the user chooses to calculate the minimum moment of inertia or the minimum section modulus of a double hull mid-ship section by pressing on the button named (Minimum IACS-2010 calculation) which appears in the main window, all the results will appear in a printable report as shown in figure (13)

Calculation Report
(Damaged Ship)

Ship Data		
Length over all	248.000	*m*
Length between perpendiculars	238.000	*m*
Moulded breadth	43.000	*m*
Moulded depth	21.000	*m*
Design draft	13.500	*m*
Scantling draft	14.300	*m*
Double bottom height	2.300	*m*
Wing width	2.180	*m*
Displacement	114,117.600	*Tonnes*
Minimum yield stress	315.000	N/mm^2
Results		
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in deck.	462280.9182000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in one side.	524475.0000000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in one inner hull longitudinal bulkhead.	519755.0000000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in inner bottom.	496882.9503000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in outer bottom.	532391.5494000000	mm^2
Total cross sectional area of the longitudinally continues material (plating and longitudinal stiffeners) in the ship longitudinal bulkhead no. 1	00.0000000000	mm^2
Critical penetration (The transverse damage length above which the struck ship will be broken into two after collision) due to hogging condition.	22.26580085	*m*
Damage mid-ship sectional area	2535785.418	mm^2
Maximum distance between the natural axis and the deck after damage	12395.40082	*mm*
Maximum distance between the natural axis and the bottom level after damage	8630.276158	*mm*
Critical mid-ship moment of inertia	172.4929862	m^4
Critical minimum section modulus (after damage)	13.91588612	m^3
Critical maximum section modulus (after damage)	19.98696021	m^3
Structural safety factor	0.543031897	
Recommended residual section modulus by ABS (1995) to the critical section modulus due to sagging condition	1.495093404	

Figure (12) Computer program's final calculation report for damaged ship.

Calculation Report
IACS (CSR 2010)

Ship Data		
Length over all	248.000	*m*
Length between perpendiculars	238.000	*m*
Moulded breadth	43.000	*m*
Moulded depth	21.000	*m*
Design draft	13.500	*m*
Scantling draft	14.300	*m*
Double bottom height	2.300	*m*
Wing width	2.180	*m*
Displacement	114,117.600	*Tonnes*
Minimum yield stress	315.000	N/mm^2
Results		
Working bending moment due hogging condition IACS (CSR 2010)	0.000	*kN.m*
Working bending moment due sagging condition IACS (CSR 2010)	-5,908,280.6551	*kN.m*
Rule minimum vertical hull girder moment of inertia IACS (CSR 2010)	234.5790021	m^4
Rule minimum vertical hull girder section modulus IACS (CSR 2010)	25.62627754	m^3
Recommended residual section modulus by (ABS 1995) due to hogging condition.	0.000	m^3
Recommended residual section modulus by (ABS 1995) due to sagging condition.	20.80554955	m^3

Figure (13) Computer program's final calculation report for IACS Calculations.

9. Conclusion and Analysis of Results

From the analysis the following conclusions can be picked up:

1. There is minor difference between the results obtained by using actual mid-ship section and smeared mid-ship section. So it is recommended to use smeared section to save effort and time of calculations.

2. The average ratio between the critical modulus of section of such ships (Z_{cr}) when involved in critical major collision (i.e. with extent of transverse damage equal to critical penetration) to the minimum modulus of section required by CSR (Z_{min}) is 0.539.
3. The ratio of Z_{cr} / Z_{min} (about 0.539) explains that ship's structure is not designed to have adequate structural redundancy to survive in the event the structure is accidently damaged (e.g. subjected to critical major collision). The factor Z_{cr} / Z_{min} is considered the true structural safety factor of ship's hull during its life time.
4. The above procedure can be used to calculate the factor (Z_{cr} / Z_{min}) in the early stage of design. Its required value (low or high) will depend on the degree of safety required which in turn will depend on many factors such as: ship's type (e.g. it will be needed to be very high for nuclear powered ships and navy vessels), the service area, the speeds, displacements of ships sailing in the same area, type of cargo carried.....etc.
5. The design of an easy-to-use computational software package for analysis of critical major ship collision analysis was presented. The computer program consists of an analysis module and a Graphical User Interface. The given simulation of three examples of ships shows the functionality and capability of the new software. The analysis module is capable of performing the simulation of collapse propagation processes for these structural systems and has powerful tool capabilities. The program produced in this study is an available analytical tools for designers to build a new mid-ship section against critical major collision.

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