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ACKNOWLEDGEMENT

I want to show my sincere gratitude to all those who made this study possible. First of all, I am very thankful to the helpful staff and all the faculty of NTUA School of Naval Architecture. One of the most important tasks in every good study is the critical evaluation and feedback which has been provided by my supervisor Manolis Samuelidis. I am very thankful to my supervisor for investing his precious time to discuss and criticize this study in depth, and explained the meaning of different concepts and how to think when it comes to problem formulations and theoretical discussions. All these interactions made my tasks interesting and challenging, and, moreover, provided the opportunity to enhance my understanding of structural mechanics. My sincere thanks go to my family and friends, who, indirectly, participated in this study by encouraging and supporting me.

Karvounis Elias

PREFACE

The strength of ships is a topic of key interest to naval architects and shipbuilders. Ships which are built too strong are heavy, slow, and cost extra money to build and operate since they weigh more, whilst ships which are built too weakly suffer from minor hull damage and in some extreme cases catastrophic failures and sinking.

The scope of the present thesis is to create a useful tool which is able to compute the scantlings of the Midship section of a Bulk Carrier, B/C, based on the IACS Common Structural Rules, CSR, so as to satisfy all the strength criteria. Moreover, a Finite Element Analysis (FEA) is conducted in order to compare the results given by two differently meshed models with the one proposed by the IACS Rules.The structure of the thesis is the following:

- Chapter 1: Reference to the IACS CSR procedures of designing the Midship section of a Bulk carrier.
- Chapter 2: Ship Loads and stresses. Types of loads applied on ship structures. Types and distribution of bending stresses.
- Chapter 3: Introduction to the basic materials used in shipbuilding. Definition of thicknesses required in CSR.
- Chapter 4: Principles of the Finite element method. Procedure of FEA analysis. Type of elements used in ship structures. Yielding check procedure based on FEA according to the CSR.
- Chapter 5: Software used. Analytic description and guidelines of the spreadsheets created.
- Chapter 6: Procedure followed for the calculation of scantlings using developed spreadsheets. Analytic presentation of calculation. Evaluation of spreadsheets loads results in comparison to MARS 2000.
- Chapter 7: Modeling using FEA method. Loading and Boundary conditions. Evaluation of the model.
- Chapter 8: Post processing. Presentation of the results.
- Chapter 9: General Conclusions

INTRODUCTION

Before analyzing the basic elements of this diploma thesis, there will be a first approach of two methodologies of analysis and design used in considering the strength of ship structures.

Classification societies are governmental agencies that develop, establish and apply technical requirements for the design, construction and survey and operation of marine-related facilities, principally ships and offshore structures. These requirements are published as classification rules. Classification societies maintain research departments that participate in the on-going development of technical safety standards. The vast majority of ships are built and surveyed to the standards laid down by classification societies. Classification rules have been developed over many years by each society through extensive research and development and service experience. In addition, certain Unified Requirements have been agreed by IACS members and transposed into the individual members' rules. As mentioned above, 'statutory' requirements have been developed at International Maritime Organization (IMO) and, where necessary, Unified Interpretations of them are adopted by IACS.

IACS can trace its origins back to the International Load Line Convention of 1930 and its recommendations. The Convention recommended collaboration between classification societies to secure as 'much uniformity as possible in the application of the standards of strength'.

Following the Convention, RINA hosted the first conference of major societies in 1939 - also attended by ABS, BV, DNV, GL, LR and NK - which agreed on further cooperation between the societies. Nowadays , the association consists of the major societies mentioned above as well as the RS, KR, CCS who joined during the following years.

In recent years some attempts have been made to analyze part of or the complete vessel as a three-dimensional model. Traditionally, ship structural design criteria are based on long experiences as set forth in the rules of ship classification societies mentioned above. The last thirty five years have seen many departures from conventional ship design with respect to ship size and types. For example, oil tankers have increased in size from a typical 30,000 tones to well over 300,000 tones. The period saw the birth of container ships and the great increase in size of the bulk carriers. Since little or no experience has been accumulated for these vessels more rational methods of analysis had to be employed. The finite element method has been appearing as a powerful tool for the analysis of various types of structures, with result to be introduced into all the classification societies design methodologies, 1993, ABS SafeHull 1.1.

The finite element method requires that the actual continuous ship structure to be replaced by a mathematical model made up of discrete structural elements of known elastic and geometric properties. The objective is to develop a model which simulates the elastic behavior of the continuous structure as closely as required. The original structure is approximated by an assemblage of a finite number of approximately shaped elements interconnected at a finite number of points, called nodal points or nodes. The basic unknowns of this model are the values of the displacement components at these nodal points. The loading on the structure is approximated by concentrated forces acting at the nodal points and in the direction of nodal displacement parameters. Calculation of displacements compliant with the applied boundary conditions can also produce the corresponding deformation fields, and, for the given elasticity properties, the stresses developed in the vessel.

ΕΚΤΕΝΗΣ ΠΕΡΙΛΗΨΗ

Η παρούσα διπλωματική, η οποία χωριζεται σε τρία βασικά μέρη, βασίζεται στην κατασκευή ενός χρήσιμου εργαλείου για τη σχεδίαση της μέσης τομής ενός Bulk Carrier. Η σχεδίαση στηρίχτηκε στους κανονισμούς του διεθνούς οργανισμού νηογνομόνων, IACS, (International Association of Classification Societies), και το ηλεκτρονικό εργαλείο έγινε μέσω του προγράμματος Excel. Στη συνέχεια ακολουθεί μία ανάλυση με τη μέθοδο των Πεπερασμένων Στοιχείων χρησιμοποιώντας το πρόγραμμα Femap.

- Στο <u>πρώτο μέρος</u>, κεφάλαια 1-4, γίνεται μία αναφορά στη διαδικασία που ακολουθείται από τους κανονισμούς για τη σχεδιαση της μέσης τομής, καθώς και στα φορτια και τις τασεις που αναπτύσονται στο πλοίο. Επίσης, παρατίθενται κάποιες βασικές αρχές της μεθόδου των πεπερασμένων στοιχείων και του ελεγχου που γίνεται μέσω αυτής της αναλυσης από τους κανονισμούς. Το πρώτο μέρος περιγράφεται αναλυτικα παρακάτω.

Οι διεθνής οργανισμος των Νηογνομόνων, (IACS), ορίζει μια διαδικασία σχεδίασης, η οποία πρέπει να ακολουθείται από όλα τα φορτηγά πλοία, πλην των μικρών ή μεγάλων σε διαστάσεις, πχ κάτω από 90m ή πάνω από 350m. Τα πλοία, που δεν εμπίπτουν στους περιορισμούς του μήκους και κάποιων ακόμα χαρακτηριστικών, εξετάζονται από τον οργανισμό αυτόνομα. Περαιτέρω διακριτοποίηση γίνεται, επίσης, χωρίζοντάς τα σε κατηγορίες ανάλογα με την πυκνότητα του φορτίου που μεταφέρουν. Κατά τη διαδικασία σχεδίασης, αρχικά υπολογίζονται οι κινήσεις και επιταχύνσεις του πλοίου, οι διαμήκεις φορτίσεις και οι κάθετες στατικές και αδρανειακές φορτίσεις. Οι κάθετες στατικές φορτίσεις είναι οι υδροστατικές, οι οποίες ασκούνται στο εξωτερικό περίβλημα και αυτές που ασκούνται στις εσωτερικές επιφάνειες. Οφείλονται στο θαλάσσιο περιβάλλον και στο έρμα καθώς και το φορτίο που μεταφέρει το πλοίο και θεωρούνται σταθερές στο χρόνο. Οι αδρανειακές φορτίσεις οφείλονται στη μετακίνηση μεγάλων μαζών κατά τη κινηση του σκαφους εξωτερικά αλλά και εσωτερικά του πλοίου. Τελος, οι διαμήκεις φορτίσεις προέρχονται από τις διαφορές της κατανομής του βάρους και της φόρτισής του κατά το μήκος του πλοίου, καθώς και στους κυματισμούς όταν το πλοίο βρισκεται σε κατάσταση shagging ή hogging.

Βάσει των παραπάνω φορτίσεων υπολογίζονται τα πάχη των ελασμάτων και οι διαστάσεις των ενισχυτικών που τα στηρίζουν. Στη συνέχεια, γίνεται ένας πρώτος έλεγχος της διαμήκους αντοχής της μέσης τομής του πλοίου, που πρέπει να ικανοποιεί τα κριτήρια των κανονισμών με βάση τη ροπή αντίστασης της διατομής. Οι ορθές τασεις που προκύπτουν στα διαμήκη κατασκευαστικά στοιχεια του πλοίου δεν πρεπει να υπερβαίνουν το όριο διαρροής, δηλαδή να κινούνται πάντα μεσα στην ελαστική ζώνη. Έπεται ο έλεγχος για τις διατρητικές τάσεις. Ο επόμενος έλεγχος που ακολουθει είναι ο έλεγχος για το όριο αντοχής όλης της μέσης τομής, (Ultimate strength check). Τα τελευταια χρόνια η Μέθοδος των Πεπερασμένων στοιχείων έχει εισέλθει στις ναυπηγικές κατασκευές και αποτελεί έναν αριθμητικό έλεγχο των τάσεων και της απόκρισης της κατασκευής, ορίζοντας την φόρτισή της. Η μεθοδος αυτή θα αναλυθεί παρακάτω.

Στο τρίτο κεφάλαιο της διπλωματικής εργασίας γίνεται μια αναφορά στα υλικά που χρησιμοποιούνται στη ναυπηγική ζώνη. Το υλικό που χρησιμοποιείται για την κατασκευή των πλοίων είναι ο ήπιος χάλυβας λόγω της υψηλής του αντοχής, της ολκιμότητας και της χαμηλής του οικονομικής αξίας. Στη διπλωματική εργασία παρατίθεται και το αντίστοιχο διάγραμμα τάσης – παραμόρφωσης του υλικού. Οι χαλυβες χωρίζονται σε κατηγορίες ανάλογα με τις χημικές τους περιεκτικότητες σε αλλά στοιχεία και την κατεργασία τους. Εκτός από τους ήπιους χάλυβες, χρησιμοποιούνται τα τελευταια χρόνια ευρέως, και χάλυβες υψηλής αντοχής. Το αποτέλεσμα είναι οι κατασκευές να γίνονται ελαφρότερες, καθώς το οριο αντοχής τους είναι αρκετά υψηλότερο από τους ήπιους.

Στο επόμενο κεφάλαιο αναφέρονται κάποιες βασικές αρχές της Μεθόδου των πεπερασμένων στοιχείων, που όπως προαναφέρθηκε, χρησιμοποιούνται στην σχεδίαση των πλοίων. Η ΜΠΣ αποτελεί μια υπολογιστική μέθοδο που επιλύει με προσεγγιστικές μεθόδους τις θεμελιώδεις εξισώσεις που διέπουν μια ευρεία ομάδα προβλημάτων συνεχούς μέσου τα οποία έχουν αυθαίρετη γεωμετρία, συνοριακές συνθήκες και φόρτιση. Βασική ιδέα της μεθόδου είναι η διακριτοποίηση του συνεχούς μέσου σε επιμέρους τμήματα, όπου τα τμήματα αυτά ονομάζονται πεπερασμένα στοιχεία. Στην απόλυτα ορισμένη αυτή περιοχή κάθε πεπερασμένου στοιχείου επιλύονται οι εξισώσεις ισορροπίας, και εν συνεχεία γίνεται συναρμολόγηση όλων των εξισώσεων αυτών για την επίλυσή τους στα πλαίσια του συνεχούς μέσου. Έτσι η μέθοδος επιλύει κάθε πρόβλημα που περιγράφεται από μια μερική διαφορική εξίσωση (προβλήματα παραμορφώσιμων στερεών, μετάδοσης θερμότητας, μηχανικής των ρευστών, κλπ), η οποία προσεγγίζεται από ένα σύστημα γραμμικών εξισώσεων, που επιλύεται με τεχνικές γραμμικής άλγεβρας.

- Στο <u>δευτερο μέρος</u>, κεφάλαιο 5,6, γίνεται μια αναφορά στα υπολογιστικά εργαλεία που χρησιμοποιήθηκαν για την διεκπεραίωση της διπλωματικής εργασίας καθώς και αναλυτική επεξήγηση του προγραμματος που κατασκευάστηκε στο Excel για την σχεδίαση της μέσης τομής.

Τα προγράμματα που χρησιμοποιήθηκαν είναι το Excel, το Mars2000, το Femap και το Nastran. Το Mars2000 είναι το πρόγραμμα που χρησιμοποιείται κατά κύριο λόγο από τον Γαλλικό Νηογνώμονα, (Bureau Veritas), για τον έλεγχο των κατασκευαστικών στοιχείων της μέσης τομής του πλοίου με βάση τα CSR (Common Structural Rules). Το Femap είναι το πρόγραμμα πεπερασμένων στοιχείων της PLM Siemens, που χρησιμοποίει ο Αμερικάνικος Νηογνώμονας (ABS), με το οποίο έγινε η μοντελοποίηση στην παρούσα διπλωματική εργασία. Τέλος, το Nastran είναι ο λύτης που έπεται της μοντελοποίησης για την επίλυση του προβλήματος.

Δύο ηλεκτρονικά εργαλεία κατασκευάστηκαν στο Excel, τα οποία από εδώ και στο εξής θα αναφέρονται με τις ονομασίες ‘CSR. CALC’ και ‘SM CALC’. Το ‘CSR. CALC’ έχει σκοπό τον υπολογισμό των παχών των ελασμάτων και των διαστάσεων των ενισχυτικών της μέσης τομής ενός Bulk Carrier. Στηρίζεται στους κανονισμούς του IACS και απαιτεί οσο το δυνατόν λιγότερα δεδομένα, καθιστώντας το εύχρηστο και φιλικό προς τον χρήστη. Επίσης, δεν απαιτείται ο σχεδιασμός της μέσης τομής σε εικονικό περιβάλλον. Με αυτόν τον τρόπο, μπορει να χρησιμοποιηθεί και τοπικά για τον έλεγχο του πάχους ενός ελάσματος, κατά τη διάρκεια μιας επισκευής, χωρίς να είναι χρονοβόρο.

Αρχικά, όπως φαίνεται και από τις εικόνες που παρατίθενται στη διπλωματική εργασία, εισάγονται οι βασικές διαστάσεις του πλοίου, μήκος, πλατος, κοίλο, κτλ.

Μέσω αυτών υπολογίζονται οι κινήσεις του πλοίου και οι επιταχύνσεις του ως προς τη διαμήκη, εγκάρσια και κατακόρυφη διεύθυνση. Οι επιταχύνσεις διαφέρουν από σημείο σε σημείο της κατασκευής. Ο χρήστης εισάγει τις συντεταγμένες του σημείου προς έλεγχο στο αντίστοιχο πεδίο. Οι υπολογισμοί γίνονται για την άθικτη, την έμφορτη, καθώς και για την κατάσταση ερματισμού. Στα επόμενα πεδία φαίνονται οι διαμήκεις φορτίσεις του πλοίου, όπως ακριβώς προδιαγράφουν οι κανονισμοί. Στη συνέχεια υπολογίζονται οι κάθετες φορτίσεις, όπως οι υδροστατικές και υδροδυναμικές πιέσεις, καθώς και οι στατικές και αδρανειακές πιέσεις που οφείλονται στη μεταφορά φορτίου και έρματος. Οι πιέσεις αυτές διαφέρουν ανάλογα με την κίνηση του πλοίου, και την θέση του, σε sagging ή hogging κατάσταση. Ο κανονισμός προδιαγράφει οχτώ ‘load cases’ που αναλύονται μεσα στην εργασία. Για τον υπολογισμό των πιέσεων που προέρχονται από το φορτίο και το έρμα απαιτούνται περισσότερα δεδομένα από τον χρήστη, όπως για παράδειγμα, το μήκος του κύτους, το ύψος του διπυθμένου, την πυκνότητα του φορτίου, κ.α., τα οποία είναι εμφανή στα βασικά κατασκευαστικά σχέδια ενός πλοίου. Εισάγοντας τα παραπάνω δεδομένα, και τις συντεταγμένες του σημείου προς εξέταση, και χωρίς να διευκρινίζει ο χρήστης τη θέση του, πχ. αν το σημειο αυτό βρίσκεται πάνω ή κατω από την ίσαλο επιφανεια ή αν βρίσκεται στον πυθμένα ή στο διπύθμενο, παίρνει ως αποτέλεσμα το πάχος που θα έπρεπε να έχει το έλασμα στο σημείο αυτό. Προτού ληφθεί η τιμή αυτή, εισάγονται και κάποιες ιδιότητες του υλικού, καθώς και η απόσταση μεταξύ των ενισχυτικών που το στηρίζουν. Αντίστοιχοι πίνακες έχουν κατασκευαστεί για την επιλογή των κατάλληλων διαστασεων των ενισχυτικών της μέσης τομής.

Το ‘SM calc’, είναι το εργαλείο, το οποίο χρησιμοποιείται για τον έλεγχο του ορίου διαρροής της μέσης τομής. Εισάγοντας τα υπολογισθέντα πάχη στα αντίστοιχα πεδία, τα αποτελέσματα που προκύπτουν είναι τα εξής: το εμβαδόν της μέσης τομής, η θέση του ουδέτερου άξονα και η ροπή αντίστασης στον πυθμένα και στο κατάστρωμα, που δεν πρέπει να υπερβαίνει την τιμή που προκύπτει από τους κανονισμούς, η οποία φαίνεται σε παρακάτω πεδιο. Το ‘CSR. CALC’ μπορεί να χρησιμοποιηθεί για οποιοδήποτε Bulk Carrier ,ενώ το ‘SM calc’ περιορίζεται μονο για το εξεταζόμενο πλοίο της εργασίας.

Η διαδικασία για τη σχεδίαση της μέσης τομής θα περιγραφεί συνοπτικά. Υπενθυμίζεται ότι οι τάσεις που προκύπτουν από την διαμήκη κάμψη στα ελάσματα του πλοίου δεν είναι παντού η ίδια. Όσο πιο πολύ απέχει ένα έλασμα από τον ουδέτερο άξονα της διατομής, τόσο πιο μεγάλη καταπόνηση δέχεται. Στον υπολογισμό του πάχους των ελασμάτων χρησιμοποιείται έμμεσα η τιμή αυτής της τάσης. Αρχικά, για να γίνει μια πρώτη εκτίμηση της απόστασης του ουδέτερου άξονα από τον πυθμένα, θεωρείται ότι αυτή η ταση είναι ίδια για όλα τα ελάσματα και ίση με το μέγιστο όριο διαρροής του χάλυβα που χρησιμοποιείται. Στη συνέχεια, έχοντας μια πρώτη εικόνα για τη θέση του ουδέτερου άξονα γίνεται ένας δεύτερος υπολογισμός με το ‘CSR. CALC’ για την καλύτερη προσέγγιση του πάχους των ελασμάτων. Αφου εισαχθούν τα αποτελέσματα στο ‘Sm Calc’ για την δεύτερη και ακόμα καλύτερη προσέγγιση της θέσης του ουδέτερου άξονα, κρίνεται αν χρειάζεται μία ακόμα κυκλική διαδικασία. Αν δεν απαιτείται μία τέτοια επανάληψη, ελέγχεται αν η ροπή αντίστασης της διατομής είναι μεγαλύτερη από το ελάχιστο όριο. Αν η ροπή αντίστασης της διατομής είναι μικρότερη από το ελάχιστο όριο, αυξάνονται τα πάχη των ελασμάτων του καταστρώματος (το οποίο δέχεται τη μεγαλύτερη καταπόνηση), μέχρις ότου να ικανοποιεί η διατομή τα κριτήρια. Στη συνέχεια, χρησιμοποιείται το Mars2000 για τον έλεγχο της μέγιστης αντοχής της διατομής (Ultimate strength). Αν χρειάζεται, γίνεται μια ακόμη αύξηση του πάχους του καταστρώματος από το σχεδιαστή. Τελικά, αν τα πάχη του ελάσματος του καταστρώματος έχουν αυξηθεί σημαντικά μέχρι αυτό το βήμα, με αποτέλεσμα ο ουδέτερος άξονας να έχει μετατοπιστει προς τα επάνω, γίνεται ένας τελευταίος υπολογισμός των παχών των ελασμάτων με το ‘CSR. CALC’, ορίζοντας τη νέα θέση του ουδέτερου άξονα.

Στην παρούσα εργασία χρησιμοποιήθηκαν τα στοιχεία ενός ήδη υπάρχοντος Bulk Carrier, και σχεδιάστηκαν τέσσερις μέσες τομές με αλλαγές στις αποστάσεις των διαμήκων και εγκάρσιων ενισχυτικών. Ο σκοπός ήταν ο προσδιορισμός της επιρροής που εχουν οι αλλαγές στην ενίσχυση του πλοίου στη συνολική επιφάνεια της μέσης τομής. Παρατηρήθηκε ότι οι αλλαγές στην απόσταση των εγκάρσιων ενισχυτικών έχουν μικρότερη επιρροή στην επιφάνεια της μέσης τομής από τις αλλαγές στις αποστάσεις της διαμήκους ενίσχυσης. Περισσότερα διαμήκη ενισχυτικά στο ίδιο πλοίο κατέληξαν σε μια πιο μικρής επιφανειας μέση τομη, που σημαινει πιο ελαφριά κατασκευή και πιο οικονομικά συμφέρουσα.

- Στο τρίτο μέρος, κεφάλαιο 7,8, γίνεται μια αναλυτική παρουσίαση των μοντέλων που κατασκευάστηκαν με πεπερασμένα στοιχεια και των αποτελεσμάτων που προέκυψαν.

Ο IACS έχει ορίσει τον τρόπο διακριτοποίησης ενός μέρους του πλοίου σε πεπέρασμένα στοιχεία για την περαιτέρω ανάλυσή του. Η έκταση του μοντέλου αυτού είναι τρία κύτη στο μέσο του πλοίου. Στο πρώτο βήμα, δημιουργείται το μοντέλο με τα εξής χαρακτηριστικά μοντελοποίησης: α) τα στοιχεία που χρησιμοποιούνται είναι τετρακομβικά, τρικομβικά στοιχεία κελύφους και στοιχεία δοκοί, που χρησιμοποιούνται στη μοντελοποίηση των ελασμάτων και των ενισχυτικών αντίστοιχα, β) το υλικό είναι ισοτροπικό, πλήρως ελαστικό με μέτρο ελαστικότητας κατά Young 206 GPa, πυκνότητα 7.85 t/m^3 και λόγο Poisson 0.3, γ) το πλέγμα δεν είναι πυκνό, δ) κατά την εγκάρσια διεύθυνση ανάμεσα σε δυο διαμήκη ενισχυτικά υπάρχει ένα μόνο στοιχείο και στη διαμήκης διεύθυνση υπάρχουν ένα ή δύο στοιχεία μεταξύ δυο εγκάρσιων ενισχυτικών (transverse frame stiffeners), ε) στα σημεία όπου οι τάσεις ξεπερνούν το 95% της μέγιστης, το πλέγμα, είτε γίνεται πιο πυκνό μέσα στο ήδη υπάρχον μοντέλο, ή χρησιμοποιούνται υπομοντέλα (sub-modeling techniques). Στην παρούσα εργασία κατασκευάστηκαν τρία μοντέλα με διαφορετικό τρόπο διακριτοποίησης. Τα μοντέλα αυτά αποτελούνται απο το διπύθμενο (double bottom) και τις πλάγιες κάτω δεξαμενές (hopper tanks) και κατά μήκος έχουν έκταση όσο ένα κύτος. Η διακριτοποίηση στο 1^o μοντέλο έγινε με βάση τους κανονισμούς, όπως αναφέρθηκε παραπάνω. Στο 2^o μοντέλο χρησιμοποιήθηκαν στοιχεία κελύφους για τα διαμήκη ενισχυτικά, όπως και για τα ελάσματα. Εδώ υπάρχουν 6 στοιχεία ανάμεσα σε δύο διαμήκη ενισχυτικά και 8 μεταξύ δύο εγκάρσιων. Τα ενισχυτικά αποτελούνται από δύο στοιχεία στο ‘web’ και δύο στο ‘flange’. Το 3^o μοντέλο έγινε με ακόμα πιο πυκνό πλέγμα και πάλι μόνο με στοιχεία κελύφους. Μεταξύ των διαμήκων ενισχυτικών υπάρχουν τώρα 10 στοιχεία και μεταξύ των εγκάρσιων ενισχυτικών 16. Επίσης, το web των ενισχυτικών έχει χωριστεί σε 4 στοιχεία από 2 στην προηγούμενη διακριτοποίηση. Το 1^o , 2^o ,3^o μοντέλο αποτελείται τελικά από 14.778 στοιχεία, 220.780 στοιχεία και 814.442 στοιχεία, αντίστοιχα. Σε όλα τα μοντέλα οι εξωτερικοί κόμβοι της πρωραίας και της πρυμναίας μέσης τομής συνδέθηκαν μέσω άκαμπτων ενώσεων με 'master' κόμβο, ένας για κάθε πλευρά, στους οποίους εφαρμόστηκαν τα φορτία και οι οριακές συνθήκες. Στην εργασία έγιναν δυο σενάρια.

Στο σενάριο Α στον έναν κόμβο περιορίστηκαν όλες οι μετατοπίσεις και στροφές (πάκτωση), και στον άλλο κόμβο αφέθηκε ελεύθερη μόνο η μετατόπιση κατά το x άξονα, δηλαδή κατά το μήκος του πλοίου. Στον κόμβο αυτό και κατά τη x διεύθυνση εφαρμόστηκε θλιπτική δύναμη. Επίσης, υπολογισμένες από το CSR. CALC εισήχθησαν οι υδροστατικές και υδροδυναμικές εξωτερικές πιέσεις, καθώς και οι στατικές και αδρανειακές πιέσεις του φορτίου για την Full Load Condition και για το load case H2 (κατασταση hogging), υπό την μορφή εξισώσεων.

Στο σενάριο Β και οι δύο κόμβοι είναι πακτωμένοι και ασκούνται μόνο οι υδροστατικές πιέσεις. Για την επίλυση τους, χρησιμοποιήθηκε ο γραμμικός κώδικας του ANSYS, (linear static analysis). Οι χρόνοι επίλυσης ήταν: 13sec, 45min, 7h:32min, αντίστοιχα.

Επιλέχθηκαν πέντε περιοχές προς ανάλυση. Μία στο έλασμα του πυθμένα στο μέσο του μοντέλου, μία στο έλασμα του διπύθμενου πάλι στο μέσο του μοντέλου, και μία στο διπύθμενο δίπλα στο κεκλιμένο έλασμα της κάτω τριγωνικής δεξαμενής. Οι άλλες δύο ήταν στις φλάντζες των ενισχυτικών, ενός στο μέσο του μοντέλου και ενός στο σημειο επαφής με εγκάρσια έδρα. Τα αποτελέσματα προς σύγκριση ήταν οι τάσεις στην x και y διεύθυνση, καθώς και η τάση Von Misses. Πιο συγκεκριμένα, η περιοχή της ανάλυσης ήταν σε έκταση όσο ήταν ένα στοιχείο του πρώτου μοντέλου. Οι τιμές των τάσεων που προκύπτουν για το πρώτο στοιχείο, συγκρίνονται με τις τιμές των τάσεων από τα επόμενα δύο μοντέλα, στα οποία το αρχικό στοιχείο έχει διαιρεθεί σε μικρότερα τμήματα. Εκτός από τη μέση τάση των στοιχείων, στο 2^{o} και 3^{o} μοντέλο παρουσιάζεται επίσης και το εύρος των τιμών, δηλαδή η μέγιστη και η ελάχιστη τιμή που εμφανίστηκε στην περιοχή αυτή. Εκεί βασίστηκε η σύγκριση των τιμών που προέκυψαν.

Στο σεναριο Α, με την θλιπτική δύναμη, δεν παρατηρήθηκαν μεγάλες διαφορές των σx τάσεων στα γειτονικά στοιχεία κατά την x διεύθυνση, σε αντίθεση με τη σy τάση στην εγκάρσια διεύθυνση μεταξύ των διαμήκων ενισχυτικών. Η τιμή που εξάγεται από το 1^{o} μοντέλο είναι μία, λόγω της ύπαρξης ενός μόνο στοιχείου, μεταξύ των διαμήκων ενισχυτικών. Με τη διακριτοποίηση της απόστασης αυτής σε έξι και δέκα στοιχεία, στα υπόλοιπα μοντέλα δημιουργήθηκαν διαγράμματα κατανομής της σy τάσης σε μία ίνα ανάμεσα στα ενισχυτικά. Αυτές οι τάσεις είναι οι τριτεύουσες τάσεις, οι οποίες δεν παραλαμβάνονται με το αραιό πλέγμα που προτείνουν οι κανονισμοί. Επίσης παρουσιάζονται διαγράμματα κατανομής της σx τάσης, κατά το μήκος της φλάντζας των ενισχυτικών.

Στο σενάριο B, χωρίς την θλιπτική δύναμη, παρατηρούνται μεγάλες διαφορές των τάσεων σε γειτονικά στοιχεία στην y όσο και στην x διεύθυνση στο 2^o και 3^o μοντέλο. Εδώ η εικόνα που παίρνουμε από το 1^o μοντέλο, αραιό πλέγμα, δεν μπορεί να μας δώσει ικανοποιητικά την ακριβή κατανομή των τάσεων ούτε στην x ούτε στην y διεύθυνση, κυρίως στα ελάσματα όπου ασκείται η υδροστατική πίεση άμεσα.

Ο σκοπός της ανωτέρω εργασίας είναι η σύγκριση του μοντέλου με τη διακριτοποίηση που προδιαγράφουν οι κανονισμοί, 1^o μοντελο, με μοντέλα πυκνότερου πλέγματος. Επίσης, παρουσιάζονται οι διαφορές που προκύπτουν στα αποτελέσματα, όταν για τη μοντελοποίηση των ενισχυτικών χρησιμοποιούνται στοιχεία κελύφους αντί των στοιχείων δοκού, καθώς και η αμεση εξάρτηση του αποδοτικού πλέγματος για ένα μοντέλο με τις συνθήκες φόρτισης αυτού.

Από το σενάριο A, το οποίο προσεγγίζει τις συνθήκες φόρτισης του πλοίου, φάνηκε ότι το πλέγμα που χρησιμοποιούν οι κανονισμοί για τον έλεγχο της διαμήκους αντοχής ενός πλοίου, όπου η σx τάση έχει τον κύριο ρόλο, παρέχει ικανοποιητικά αποτελέσματα, καθώς δεν παρουσιαστήκαν μεγάλες διαφορές με την περαιτέρω διακριτοποίηση. Το μειονέκτημα είναι ότι δεν προσδίδει καμία εικόνα για την κατανομή των τριτεύουσων τάσεων. Επίσης τα αποτελέσματα με τα στοιχεία δοκών ήταν ελαφρώς υψηλότερα από αυτά που προέκυψαν με τα στοιχεία κελύφους στα ενισχυτικά.

Τέλος, ακολουθούν μερικές προτάσεις για μετέπειτα εργασία και βελτίωση:

- Να αυτοματοποιηθούν οι κυκλικές επαναλήψεις που χρειάζονται κατά τη διάρκεια της σχεδίασης με το CSR Calc, με τη χρηση προγραμματισμού. Με αυτόν τον τρόπο θα μπορούσαν να γίνουν δοκιμές για πολλές εναλλάγες στον τρόπο ενίσχυσης μίας μέσης τομής και να οδηγήσουν σε συμπεράσματα για τη σχεδίαση πιο ελάφριών – οικονομικών κατασκευων.

- Να μοντελοποιηθεί και η υπολοιπη μέση τόμη με πεπερασμένα στοιχεία και να εφαρμοστούν οι καμπτικές ροπές για να γίνει μια καλύτερη προσέγγιση στη φόρτιση του πλοίου.
- Να ακολουθηθεί η ίδια διαδικασία σύγκρισης για το πλέγμα που χρησιμοποιούν οι κανονισμοί σε υπομοντέλα, αλλα με πιο αυστηρές απαιτήσεις.

Chapter 1 - IACS CSR Procedure

The IACS Common structural rules apply to ships of single and double skin bulk carriers, which have length of 90m or above. Generally, these bulk carriers are constructed with a specific way; single deck, double bottom, hopper side tanks, topside tanks and single or double skin construction in the cargo length area. For single skin bulk carriers all the members except the side shell plating, are longitudinally framed. However, for the side shell plating transverse stiffening is used. For double skin bulk carriers, longitudinal framing or transverse framing is used to support all the structural members.

The present rules contain requirements which apply on ships with the following characteristics:

- $L < 350m$
- $L/B > 5$
- $B/D < 2.5$
- $C_B > 0.6$

For the ships with an unusual hull design the scantlings of the structural members are to be considered individually by the Society, on the basis of the principles and criteria adopted in the Rules.

As per CSR, the Bulk Carriers are divided into three categories according to the specific service features. These types are:

a) **BC-A**: Bulk carriers which are designed to carry dry bulk cargoes of cargo density 1.0 t/m^3 and above with specified holds empty at maximum draught in addition to BC-B conditions.

b) **BC-B**: Bulk carriers designed to carry dry bulk cargoes of cargo density of 1.0 t/m^3 and above with all cargo holds loaded in addition to BC-C conditions.

c) **BC-C**: Bulk carriers which are designed to carry dry bulk cargoes of cargo density less than 1.0 t/m^3

In the present thesis the Bulk carrier considered is classified as a BC-C type.

The procedure for the design according to the rules, (Fig.1.1), is as follows:

- Calculation of the ships motions and accelerations
- Calculation of the longitudinal strength loads
- Calculation of the transverse strength loads
- Calculation of the scantlings of plates and stiffeners
- Yielding check busing beam theory
- Ultimate strength check based on simplified beam theory
- Yielding strength assessment using FEA (3-Hold Model, fine mesh and very fine/hot spot mesh stress analysis)
- Buckling and ultimate strength assessment using FEA
- Liner fatigue analysis of structural connections for 25 years lifetime.

In the present thesis, a buckling and ultimate strength assessment using the FEA is not conducted or further analyzed. Similarly, for the traditional shear flow/stresses evaluation close to the transverse bulkheads. For the calculation of the scantlings, the stresses due to the bending moments applied on the ship are used implicitly, as described in CSR, Chapter 6, Section 1. Subsequently, the actual stresses are calculated using the FEA method.

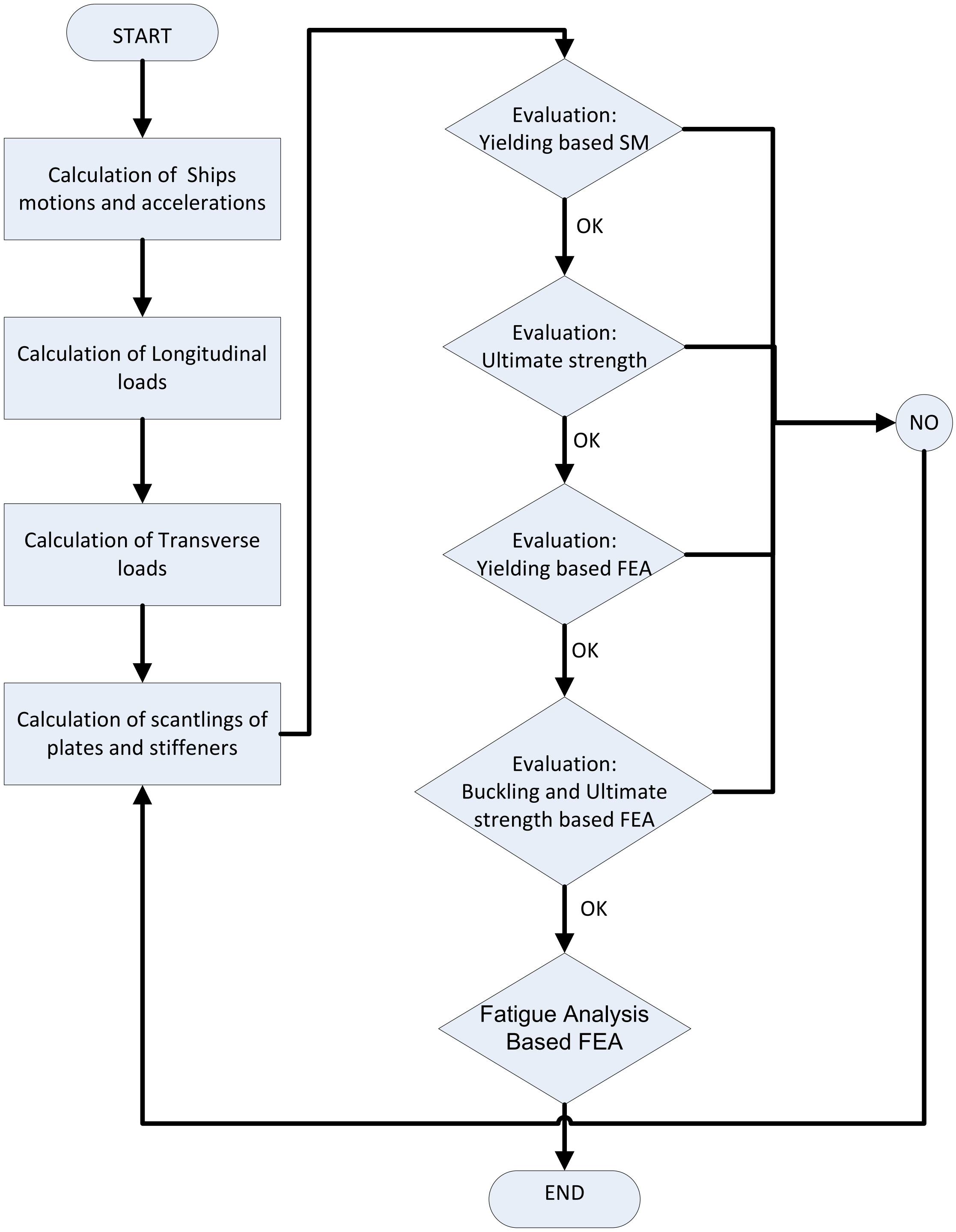


Fig. 1.1 IACS CSR Procedure

Chapter 2 – Ship Loads and Stresses

2.1 Types of Loads

When a ship is sailing at sea, it is subjected to various load patterns with many magnitudes which cause deformation of its structure, as well as stresses. The structural designer needs to know the hull structure load features, as accurately as possible: direction of the working load, frequency of occurrence, distribution pattern on the hull structure and behavior in the time domain, etc. The first design step is to assume exact loads acting on the structure concerned, in order to estimate the structural strength in a reasonable way and consequently to develop the design. Loads are assumed to be linear, independent from the structural response and their effects could be superimposed.

When considering the load features where the load is transmitted gradually and continuously from a local structural member to an adjacent bigger supporting member, the best way to categorize loads on the hull structure is as follows:

- Longitudinal loads
- Transverse loads

(1) Longitudinal Loads-Global Response:

Longitudinal load means the load concerning the overall strength of the ship's hull, such as the bending moment, shear force and torsional moment acting on a hull girder and result in global displacements (large wavelength deformations). Since a ship has a slender shape, it will behave like a beam from the point view of global deformation. Now let's assume a ship is moving diagonally across a regular wave. The wave generates not only a bending moment deforming the vessel in a longitudinal vertical plane but also a bending moment working in the horizontal plane, because of the horizontal forces acting on side shell. In addition, the wave causes a torsional moment due to the variation of the wave surface at different sections along the ship's length. If the above longitudinal strength loads exceed the upper limit of longitudinal strength for the hull, the hull will be bent or twisted. Therefore the longitudinal strength load is one of the most important loads when calculating the overall strength of a hull structure.

(2) Transverse Loads-Local Response:

Transverse loads denote the loads which cause distortion of local members due to unbalance of external and internal loads, including structural and cargo weights and their dynamic effects. These loads can be regarded as being independent of longitudinal strength loads, for the longitudinal loads only cause a ship to behave as a beam and they do not cause distortion of the transverse section. These loads are categorized as follows:

(a) Structural weight, ballast water weight and cargo weight: These loads are dead loads, which mean constant loads that are time independent, induced by gravity at the centers of gravity of the members.

(b) Hydrostatic and hydrodynamic loads: The hydrostatic load is the static pressure from the water surrounding a transverse section, which acts on the hull structure as an external load. Another external load is the hydrodynamic load induced by the interaction between waves and the ship motion and subjects the outer shell of the ship to fluctuating water pressure. It is superimposed on the hydrostatic load and creates the total water pressure.

(c) Inertia force of cargo or ballast due to ship motion: The inertia force is induced by the reaction force of self weight, cargo weight or ballast weight due to the acceleration of the ship motion. Assume that a vessel is rolling among waves in a fully loaded condition, then the cargo in each hold has a cyclic movement in the vertical and/or transverse direction. This must result in a fluctuating pressure of the hull structure of the hold due to the inertia force of the cargo movement. In addition, internal pressure is introduced not only by rolling but also by the ship's other motions, such as heaving, pitching, etc.

(d) Impact loads on bow, green sea affects on main deck and slamming of the forward part of the double bottom sub-structure: Slamming may be categorized as a local load, as well as a longitudinal strength load and it is associated with the impact force as the shell plating hits the water surface severely; it is quite important while vessel is sailing in light ballast condition and influences decisively the local design of the forward bottom of the vessel. Many ships are damaged by slamming, resulting in denting of bottom shell plating. Wave impact pressure is an item for which the pure theoretical approach is very difficult, so experiments are necessary to estimate the impact pressure with reliable accuracy.

Sloshing is a phenomenon where the fluid movement in the tank gets into resonance with the ship motion and creates an impact force between the moving free surface of the fluid and the tank structure. Sloshing is caused by the movement of the fluid's free surface, therefore, if the tank is fully filled with fluid, sloshing will never happen since the free movement of the liquid's surface is restricted. When the level of the liquid reaches to a certain portion of the tank, the liquid resonates with the movement of the tank and then sloshing occurs. The natural frequency of sloshing is determined by the tank dimensions and the level of the liquid. Application of sloshing loads is not applicable to bulk carriers design but only to tanker ships, chemical ships and liquefied natural gas carriers.

These loads are not always equal to each other at every point, consequently loads working on transverse members will produce transverse distortion as shown by the broken line in Fig. 2.1.1.

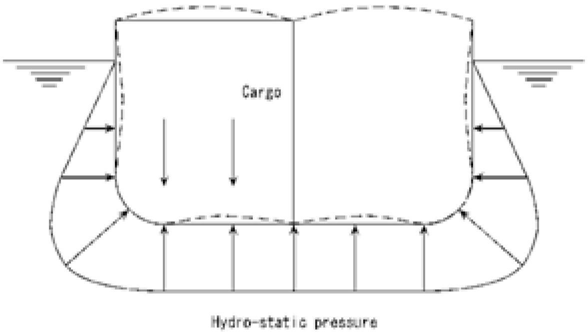


Fig. 2.1.1 Example of deformation due to transverse strength loads

2.2 Subdivision of longitudinal strength loads

The longitudinal strength loads may be divided into two categories: static longitudinal loads and dynamic longitudinal loads.

Static longitudinal loads are induced by the local inequalities of weight and buoyancy in the still water condition. For instance, differences between weight and buoyancy in longitudinal direction cause a static bending moment and a static shear force, and asymmetrical cargo loading causes in a static torsional moment.

Dynamic longitudinal loads are induced by waves. When the ship is on top of a wave crest in head sea condition, it causes a "hogging" bending moment and a shear force. When in a wave trough a "sagging" bending moment and shear force are experienced, as indicated in Fig. 2.2.1. These loads act alternately on the hull girder as the wave progresses along the ship.

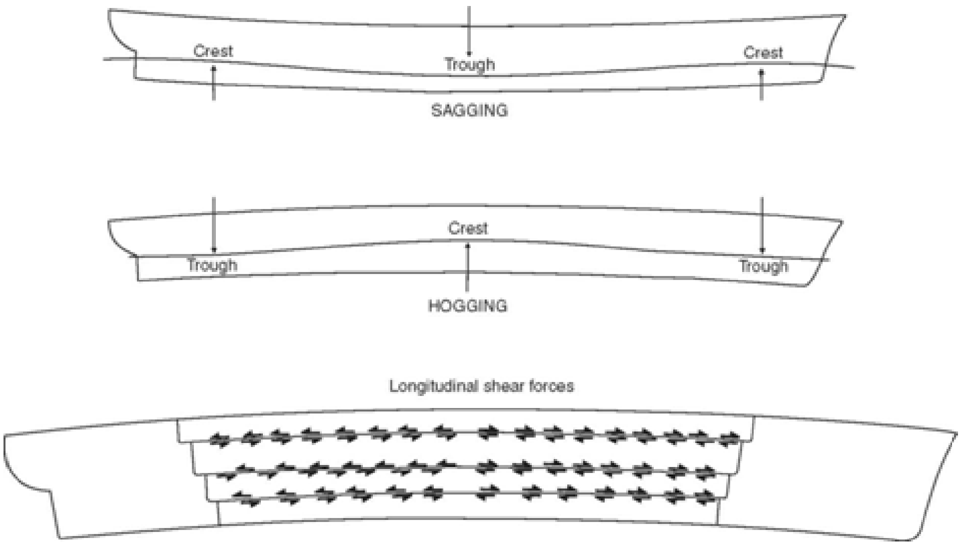


Fig. 2.2.1 Wave Bending

The magnitude of the dynamic longitudinal load used in strength calculations of wave bending moment and wave shear force used to vary with each Classification Society. However, the rules were standardized by the IACS (International association of Classification Societies) in the Unified Rule Requirement in 1989 and were accepted by all Classification Societies. For instance, IACS specifies the wave bending moments with the following equations, which are common equations used by the major Classification Societies that belong to IACS:

$Mw(+) = +0.19C_1C_2L^2BC_b$ (kN-m)

$Mw(-) = -O.11C_1C_2\,L^2\,B(C_b + 0.7)$ (kN-m)

Where :

$Mw(+)$: the wave bending moment of hogging

$Mw(-)$: the wave bending moment of sagging

C_1: the parameter determined by ship length

$C = 10.75 - (300 * L/100)^{1.5}$ $90m < L < 300m$

$C1 = 10.75$ $300m < L < 350m$

C_2: distribution factor along ship length as specified in Fig. 2.2.2

C_b: block coefficient

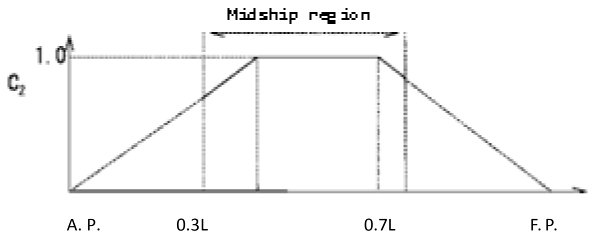


Fig. 2.2.1 Still water bending moment

The wave induced bending moment of IACS is determined in such a way that the magnitude of the bending moment is expected to be approximately equal to the maximum value once in 20 years, i.e. the expected probability of occurrence is: $Q = 1 \times 10^{-8}$. The IACS formulae were found to be reasonable with the aid of the above mentioned long-term prediction method carried out by several classification societies.

2.3 Bending Stresses

From classic bending theory the bending stress (σ) at any point in a beam is given by:

$\sigma = M*y/I$

where M = applied bending moment.

y = distance of point considered from neutral axis.

I = second moment of area of cross-section of beam about the neutral axis.

When the beam bends it is seen that the extreme fibres are, say in the case of hogging, in tension at the top and in compression at the bottom. Somewhere between the two there is a position where the fibres are neither in tension nor compression. This position is called the *neutral axis,* and at the farthest fibres from the neutral axis the greatest stress occurs for plane bending. It should be noted that the neutral axis always contains the centre of gravity of the cross-section. In the equation the second moment of area (I) of the section is a divisor; therefore the greater the value of the second moment of area the less the bending stress will be. This second moment of area of section varies as the depth and therefore a small increase in depth of the section can be very beneficial in reducing the bending stress. Occasionally reference is made to the

sectional modulus (Z) of a beam; this is simply the ratio between the second moment of area and the distance of the point considered from the neutral axis, i.e. $I/y=Z$.
The bending stress (σ) is then given by $\sigma=M/Z$.

THE SHIP AS A BEAM - It was seen earlier that the ship bends like a beam; and in fact the hull can be considered as a box-shaped girder for which the position of the neutral axis and second moment of area may be calculated. The deck and bottom shell form the flanges of the hull girder, and are far more important to longitudinal strength than the sides which form the web of the girder and carry the shear forces. In a ship the neutral axis is generally nearer the bottom, since the bottom shell will be heavier than the deck, having to resist water pressure as well as the bending stresses; moreover, inner bottom and hopper plates also contribute to the moment of inertia and to the placement of neutral axis lower than the mid-depth of the ship. In calculating the second moment of an area of the cross-section all longitudinal material is of greatest importance and the further the material from the neutral axis the greater will be its second moment of area about the neutral axis. However, at greater distances from the neutral axis the sectional modulus will be reduced and correspondingly higher stress may occur in extreme hull girder plates such as the deck stringer, sheerstrake, and bilge. These strakes of plating are generally thicker than other plating.

2.4 Subdivisions of stresses

The geometrical arrangement and resulting stress or deflection response patterns of typical ship structures are such that it is usually convenient to divide the structure and the associated response into three components, which are labelled *primary, secondary* and *tertiary.* These are illustrated in Fig. 2.4.1, please see {6}, and described as follows:

Primary response is the response of the entire hull, when bending and twisting as a beam, under the external longitudinal distribution of vertical, lateral and twisting loads.

Secondary response comprises the stress and deflection of a single panel of stiffened plating, e.g., the panel of bottom structure contained between two adjacent transverse bulkheads. The loading of the panel is normal to its plane and the boundaries of the secondary panel are usually formed by other secondary panels (side shell and bulkheads).

Tertiary response describes the out-of-plane deflection and associated stress of an individual panel of plating. The loading is normal to the panel, and its boundaries are formed by the stiffeners of the secondary panel of which it is a part.

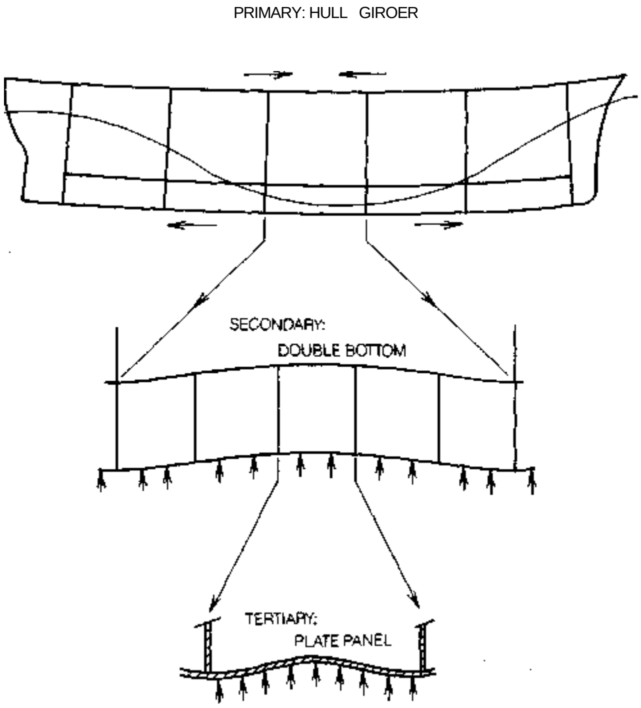


Fig. 2.4.1 Primary, secondary and tertiary structure

Chapter 3 - Scantlings

3.1 Materials

3.1.1 Hull steel

Selection of materials is very important in structural design, because it directly affects ship cost and strength. Hence, the structure designer should know well the characteristics of materials, especially newly developed ones.

Mild steel and higher-strength steel are used for hull structure because of their comparative advantages such as high strength, sufficient ductility, welding ability and low price.

Fundamental strength evaluations of the steel are done by a tension test, which is illustrated in Fig. 3.1.1.1 as a stress-strain curve. The line from O to A is called the elastic zone, in which the stress is proportional to the strain, while B to E is called plastic zone. B and C are called the upper yield point and lower yield point respectively, and the latter is the nominal yield stress, which is 235-280 MPa for mild steel in shipbuilding structures. Some materials have no dominant peak on yield point, in this case the stress corresponding to 0.2% strain is assumed as the yield stress. As shown in the figure, the elongation becomes much larger after yield, and the stress reaches a maximum value at D, which is termed the tensile strength, of 400-500 MPa for mild steel. After that, the strain becomes large and finally the steel fractures at E or E'; D-E is for nominal stress using the original cross-sectional area and D-E' is for actual stress using actual cross-sectional area considering its reduction.

If it is unloaded in the plastic zone, it goes from F to G in the figure, parallel to O-A, and residual strain O-G remains, while in the elastic condition this value is zero. If it is loaded again after the plastic deformation, the stress increases again along G-F, hence, the yield stress is greater than B. This is termed work hardening.

In the case of mild steel, strain at the beginning of yielding is 0.01-0.001, and at failure is 0.3-0.4, therefore it retains some strength after yielding and before failure. Hence it is assumed that mild steel is a superior material.

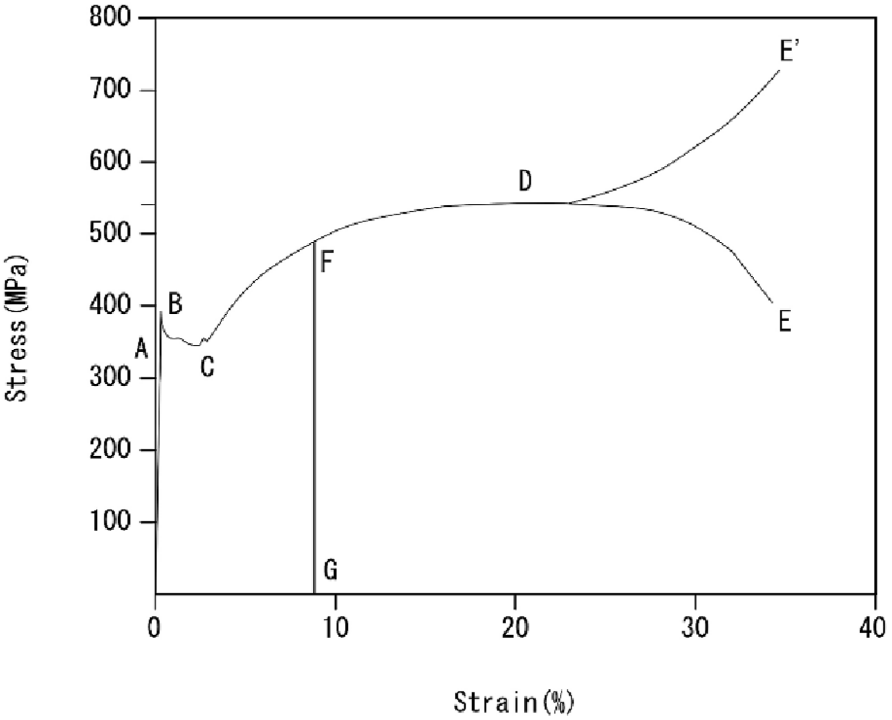


Fig. 3.1.1.1 Strain - Stress curve

3.1.2 Grades of Steel

Since rivets were used to join plates and stiffeners in old steel ships before world war II, cracks often stopped at a rivet hole. However, if crack occurs in a more recently built welded ship, it can propagate a long distance and it may cause disaster. Hence, quality design to prevent and arrest crack propagation as well as weldability are required for hull steel. Welded structure ships newly built in USA during World War II sometimes broke in two under sail in winter with a loud bang. Almost all of the failed sections of the steel were crystalloid on the surface, therefore it was concluded after the investigations that the failure was brittle fracture. Hence IACS regulated the application of ship hull steel, categorized as A, B, C, D, and E in accordance with the notch toughness.

- Grade A steel is widely used. Rimmed steel is allowed to be used up to and including 12.5 mm in thickness, otherwise killed or semi-killed steels should be used. There is no requirement for the impact test of a specimen.
- Grade B steel is killed or semi-killed steel. It has higher notch toughness than A steel.
- Grade C is no longer used.

- Grade D steel has much toughness as defined by impact tests. The value of absorbed energy is specified by whether cracks were arrested or not in previously built ships. D steel is also killed or semi-killed steel up to and including 25 mm in thickness.
- Grade E steel is used as a crack arrester, hence it is highest grade. It is killed steel.

Grade B, D, E steels are used for thick enough steels fitted at highly stressed areas of the vessel exposed to low temperatures such as shear strake, main deck, bilge plate and junctions of longitudinal bulkheads with deck and bottom plates.

Chemical compositions are defined by the percentage of C, Si, Mn, P, S, etc contained in the steel alloy. The hardness of the steel alloy is summarized by the carbo equivalent content defined by the formula:

$$E_c = \%C + \left(\frac{\%Mn + \%Si}{6}\right) + \left(\frac{\%Cr + \%Mo + \%V}{5}\right) + \left(\frac{\%Cu + \%Ni}{15}\right)$$

The larger the percentage of carbon, the stronger it becomes, but the ductility, toughness, and weldability become worse. Hence, the percentage of carbon is restricted to within about 0.2%, and Si and Mn are added. P and S are also limited within 0.04% each. The mechanical properties of mild as well as high strength steels are shown at Table 3.1.2.1

Steel grades for plates with t < 100mm		**Minimum yield stress R_{eH}, in N/mm^2**	**Ultimate tensile strength R_m, in N/mm^2**
A-B-D-E	*Mild*	235	450 - 520
AH32-DH32-EH32-FH32	*HTS*	315	440 - 570
AH36-DH36-EH36-FH36	*HTS*	355	490 - 630
AH40-DH40-EH40-FH40	*HTS*	390	510 - 660

Table 3.1.2.1 Mechanical Properties of hull steels

3.1.3 Higher-Strength Steel (HTS)

Higher-strength steel is recently widely used in main hull structures, because of decreasing material costs and hull steel weight, resulting in increased dead weight and ship speed. At first, it was expensive and the welding procedure for it was difficult and complicated, however it is now not so expensive and is easy to weld thanks to improvements in the steel making process. Hence, in recent merchant ships, the application of HTS has expanded up to 60-70% of the total hull steel.

The newly developed higher-strength steel is termed CR (Controlled Rolling) or TMCP (Thermo Mechanical Controlled Process) steel, which improves notch toughness and weldability by the treatment of rapid water cooling using control cooling technology during steel making. The plate has a finer grain size than that of conventional higher-strength steel, and hence increases strength.

Classification societies regulate scantling reduction formulas for higher-strength steel by using a coefficient k based on yield stress criterion. Coefficient k is a ratio of yield stresses. The values of the coefficient can be found in the Table 3.1.3.1

On the other hand, the fatigue strength of higher-strength steel does not increase proportionally with yield strength, therefore it is necessary to take care of design details and working procedures, especially stress concentrations around the welding. In addition, consideration of deflection and buckling strength are necessary, because plate scantlings decrease relative to the yield stress.

Minimum yield stress R_{eH}, in N/mm^2	**k**
235	1
315	0.78
355	0.72
390	0.68

Table 3.1.3.1 Material factor

3.2 Scantling Approach

This approach is to clearly specify the differences between the thicknesses of the plates referred in the CSR Rules.

The plating thicknesses are divided in the following categories and will be explained further on:

- $t_{\text{as built}}$
- $t_{\text{net required}}$
- $t_{\text{gross required}}$
- $t_{\text{corrosion}}$
- $t_{\text{voluntary addition}}$

- $t_{\text{as built}}$: This value refers to the actual thickness that will be provided at the new building of the ship. It may, or it may not include any voluntarily added values, such as the owner's extra margin.
- $t_{\text{net required}}$: This value refers to the thickness calculated from the formulas that IACS provides in the CSR rules.
-$t_{\text{gross required}}$: This value refers to the net thickness value plus the corrosion addition regarding the position of the plating.
-$t_{\text{corrosion}}$: This value refers to the corrosion addition needed according to the CSR rules
- $t_{\text{voluntary addition}}$: This value refers to the voluntarily added thickness as the owner's extra margin for corrosion wastage.

For additional information on corrosion matters refer to *Chapter 5.2.9.*

Chapter 4 - Verification

4.1 FEA Method

4.1.1 Fundamentals of FEA Method

Nowadays the finite element analysis (FEA) is an essential and powerful tool for solving structural problems not only in the field of shipbuilding but also in the design of most industrial products and even in non-structural fields. FEA can be used for a wide variety of problems in linear and nonlinear solid mechanics, dynamics, and ships' structural stability problems, in accordance with the development of computer technology and its popularization.

The conventional method in solving stress and deformation problems is an analytical one using theories of beams, columns and plates, etc. Hence its application is restricted to most simple structures and loads. On the other hand FEA:

(1) divides a structure into small elements
(2) assumes each element to be a mathematical model
(3) assembles the elements and solves the overall

The element shown in Fig. 4.1.1.1 as a typical example is termed a finite element. Characteristics of FEA are as follows:

It does not give an exact solution but solves approximately, because structures are modeled as a combination of simple elements and loads.

- It is a kind of numerical experiment without experimental devices, models, or instruments. Hence it is economical and time-saving.
- It can solve actual structural problems by using some models, although their shapes and loads are complex. It is even used for non-structural problems.
- It is used for a wide variety of steel, nonferrous materials and complex materials.
- It relies on computer technology for both hardware and software.

- FEA programs, which are easy to operate because of the quite simplified processors, should not be applied as "a black box tool", but engineers do have to know the theory and the numerical features of the code they use.

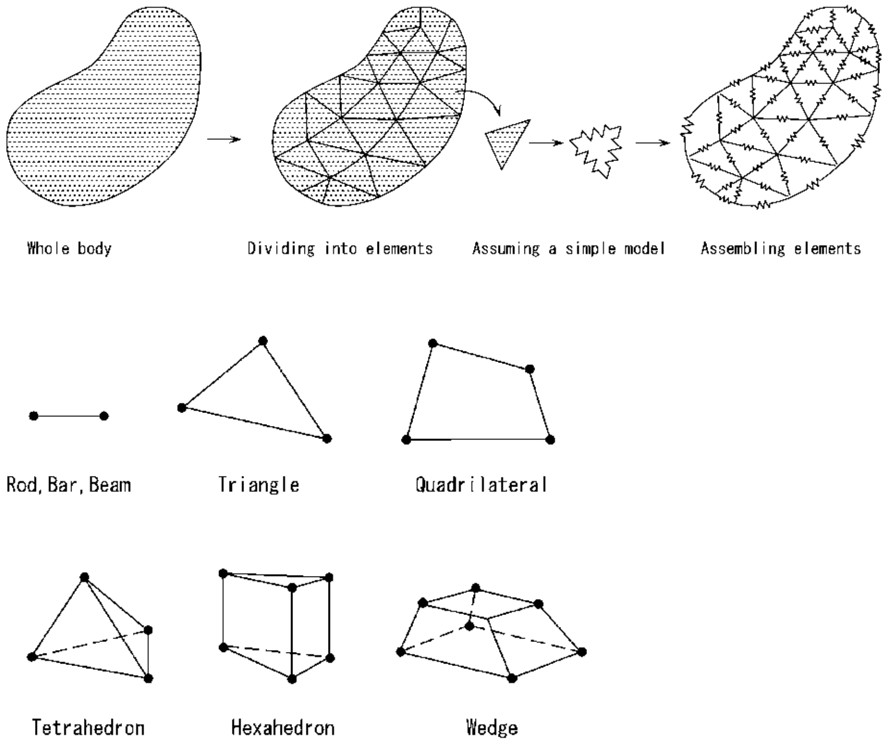


Fig. 4.1.1.1 Concepts of FEA and type of Elements

4.1.2 Plate Elements

A ship's structure consists mainly of thin plate structures and it is assumed to be flat locally, although there are curved shell plates. Therefore, we now examine the in-plane deformation of a plate element in the case of linear stress analysis in plane stress condition. A triangular element of constant thickness **t** is used for its simplicity, as shown in Fig. 3.2.1. The displacements and forces are represented by three nodes, as shown in the figure:

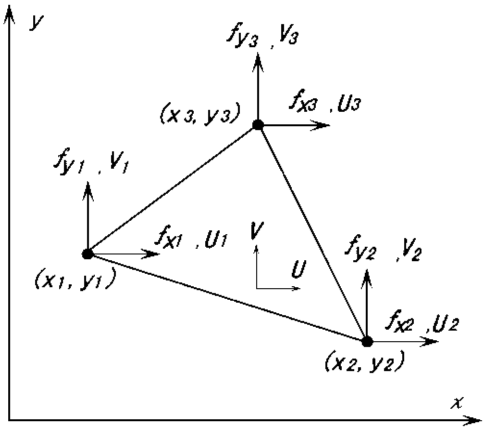


Fig. 4.1.2.1 Triangle element

$$\{f\} = \begin{Bmatrix} fx1 \\ fy1 \\ fx2 \\ fy2 \\ fx3 \\ fy3 \end{Bmatrix} \qquad \{u\} = \begin{Bmatrix} u1 \\ v1 \\ u2 \\ v2 \\ u3 \\ v3 \end{Bmatrix}$$

We choose a polynomial to describe the internal displacements in the triangle, and represent each of these displacement components by a linear polynomial in the x- and y-direction. This means that the strain in the element is constant in x and y.

$$u = c_1 + c_2 x + c_3 y$$

$$v = c_4 + c_5 x + c_6 y$$

Since there are 6 degrees of freedom as shown in Fig. 3.1.2, the coefficients $c_j \sim c_6$ can be represented by u_j, v_j, u_2, v_2, u_3, v_3.

$\{u\} = |$ [illegible] $| * \{$ [illegible] $\} = [F] * \{c\}$

On the other hand

$\{\varepsilon_y\} = |0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1| \{$ [illegible] $\} = [S] * \{c\}$

Therefore $\{\varepsilon\} = [S]\{c\} = [S][F^{-1}]\{u\} = [B]\{u\}$

$[B]$: *strain coefficient matrix*

The stress – strain relationship is shown in the following equation:

$$\{\sigma\} = [D]\{\varepsilon\}$$

$[D] =$ [illegible] $|\nu \quad 1 \quad 0 \quad |$

$[D] =$ *elasticity matrix*

E : Young Modulus

V: Poisson ratio

$\{\sigma\} =$ *stress vector*

The stiffness equation for the triangular elelment is :

$$\{f\} = [K] * \{u\}$$

Where :

$[K]$: *Stiffness Matrix*

$[K] = At[B]^T[D][B]$

t: element thickness

When combining many elements, we assemble the overall stiffness matrix from each element and solve the stiffness equation with the given loads and displacements at the nodes. We then can get the displacement of each node, the strain and the stress one by one.

4.1.3 Procedure of FEA

The procedure of displacement and stress calculations by computer, in the case of requiring linear solutions, is generally as follows:

(1) Calculate [B] matrix using the geometry of an element, and to calculate *[D]* matrix using material properties.

(2) Calculate matrix *[K]* of an element

(1) and (2) are repeated for all elements.

(3) Assemble the overall stiffness matrix

(4) Calculate displacements of each node from load and support conditions by solving the stiffness

(5) Calculate the strains of each element

(6) Calculate the stresses of each element

(7) Calculate principal stresses, equivalent stresses, etc.

Figure 4.1.3.1 shows the process from (1) to (4) and Fig. 4.1.3.2 shows the program flow of FEA. Figure 4.1.3.3 also shows the procedure of the FEA analysis

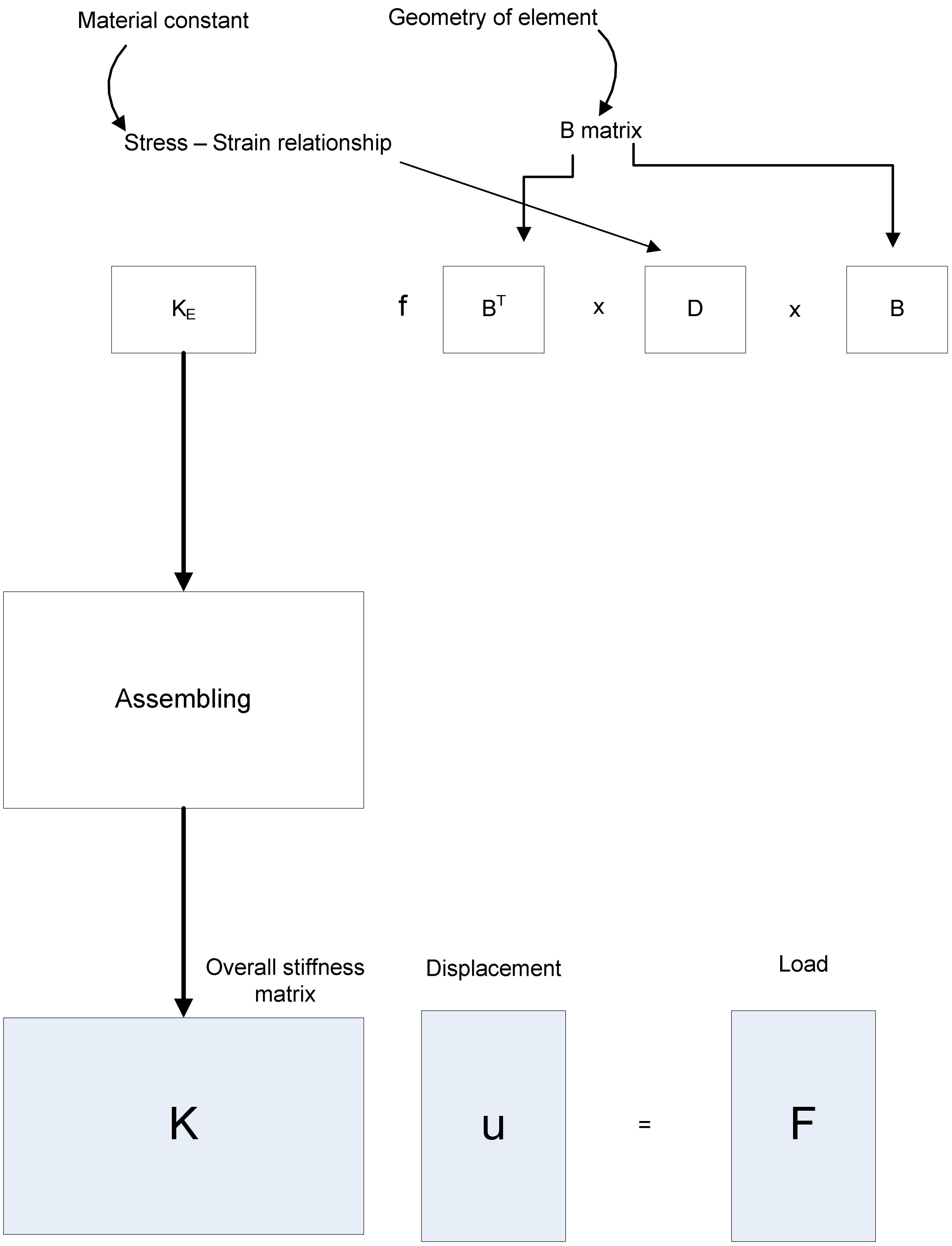


Fig. 4.1.3.1 – Procedure to get Stiffness equation

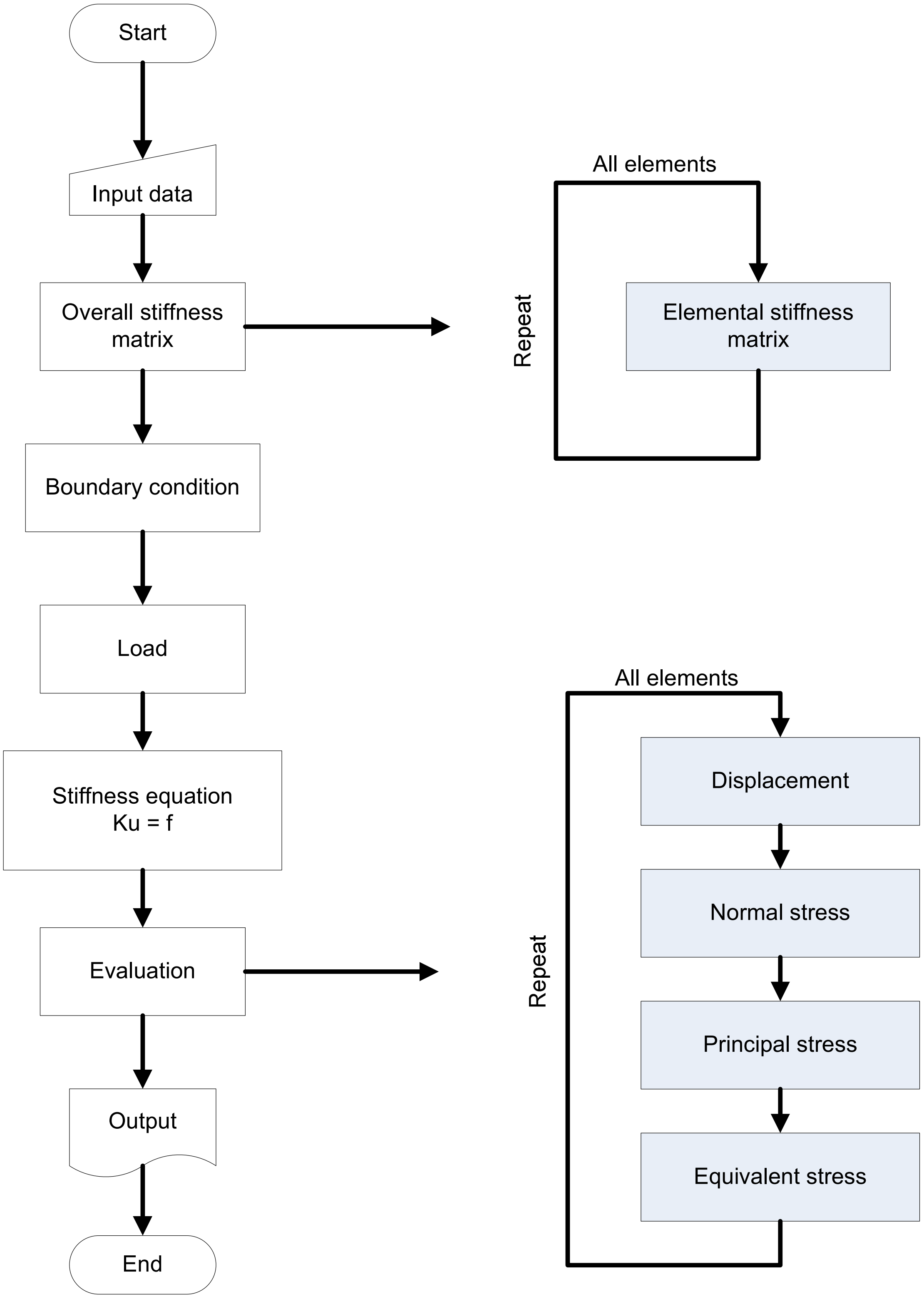


Fig. 4.1.3.2 – Sequence of FEA calculation

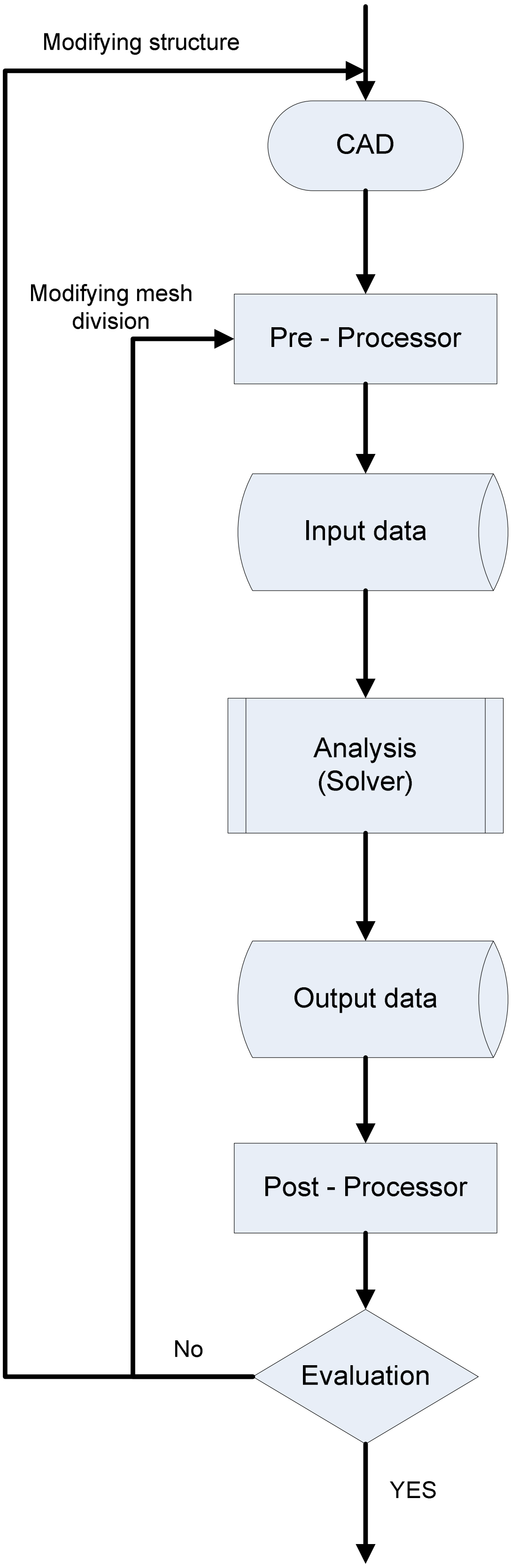


Fig. 4.1.3.3 – Procedure of FEA Analysis

4.2 Yielding check according to IACS rules

A three hold length finite element model is recommended for the analysis by the IACS rules, with the mid-hold as the target of assessment. The elements used are shell elements for the plates and beam elements for the stiffeners. IACS uses as the reference value for the verification of the model the Von Misses stress at the center of the shell element or the axial stress for the beam elements. These values should not be greater than the maximum allowable stress which is 235/k N/mm^2, where k is the material factor defined in Chapter 3.1.3.

A detailed strength assessment is additionally conducted for the areas where the calculated stresses exceed 95% of the allowable stress. These areas are modeled with finer meshes in order to evaluate the stresses more precisely. There are two methods which can be used for refining the high stressed areas. The refined areas can be directly included in the global model or they can be analyzed using sub-models. Within the refined areas the allowable stress is not to be greater than the maximum allowable stress which in this case is 280/k N/mm^2

Chapter 5 - Software Guidelines

5.1 *Software tools*

- Excel : Based on the IACS Common structural rules for Bulk Carriers (Jan 2006) , an Excel sheet was created with the purpose to calculate the ship motions and accelerations, still water loads, external and internal pressures and finally the scantlings of the midship section defining the coordinates of the plate for analysis. Despite the scantlings of the plates an additional calculation is conducted in order to select the appropriate longitudinal stiffeners that will support the section based on their minimum section modulus and area requirements. Further on, the excel sheet will be referred as 'CSR calc'. A complementary excel sheet will also be used to examine if the section as a unit satisfies the minimum Section Modulus and Area requirements of the IACS Rules. This sheet will be referred as 'SM calc'.

- Mars2000 : Mars2000 is a software used by the Bureau Veritas for the Classification of Ships according to the IACS Common Structural Rules for Bulk Carriers and Tankers. It is a tool which is able to check the scantlings of plating and ordinary stiffeners of any transverse section located all along the ship length by using the rules formulas. It also allows to check the scantling of any transverse sections or any transverse bulkheads all along the ship length. For any transverse section, it calculates:

- The geometric properties (area, inertia and modulus,etc)
- The hull girder strength criteria
- The hull girder ultimate strength
- The rule scantling of strakes, longitudinal and transverse stiffeners taking into account:
    - Yielding criteria

  - Minimum thickness criteria
  - Buckling criteria

During the progress of the thesis, Mars2000, will be used as a complementary tool needed to check the minimum ultimate strength criteria of the cross section.

- Femap V.10 : Femap is an engineering analysis program sold by Siemens PLM Software that is used to build finite element models of complex engineering problems ("pre-processing") and view solution results ("post-processing"). It runs on Microsoft Windows and provides CAD import, modeling and meshing tools to create a finite element model, as well as post processing functionality that allows mechanical engineers to interpret analysis results. It is the main software used by ABS (American Bureau of Shipping), since the FEA method was introduced by IACS in the ship constructions. It has a wide variety of tools that can make the design of the geometry and the meshing easier for the modeler engineer as well as a big library of materials and element types. Three differently meshed models will be analyzed and compared further on.

- Nx Nastran 6 : Nx Nastran is primarily a solver for finite element analysis. It does not have functionality that allows for graphically building a model or meshing. All input and output to the program is in the form of text files. However, multiple software vendors market pre- and post-processors designed to simplify building a finite element model and analyzing the results. These software tools as Femap, include functionality to import and simplify CAD geometry, mesh with finite elements, and apply loads and restraints. The tools allow the user to submit an analysis to Nx Nastran, and import the results and show them graphically. Nx Nastran uses many common solution sequence codes for different kind of problems like , Linear Static, Modal, Non-Linear Static, Explicit Non-Linear , etc. However, all models in the thesis will be examined in Linear Static response.

5.2 Csr. Calc. Guidelines

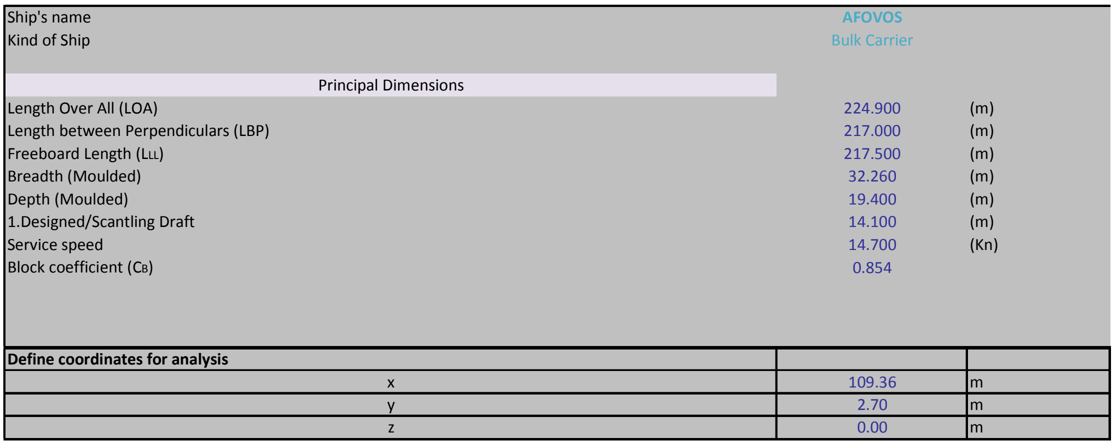
The ‘Csr. Calc.’ requires the least possible input data making it easy for the engineer to use without having to design the geometry of the midship section in a visual environment.

Input:

5.2.1 Principle Dimensions

The cells that indicate the user’s input are in blue colour. In the beginning of the sheet, as illustrated in Fig.5.2.1, the principle dimensions of the ship are to be inserted:

- Length overall
- Length between Perpendiculars
- Freeboard Length
- Breadth
- Depth
- Scantling Draft
- Ballast Draft
- Service speed
- Block coefficient

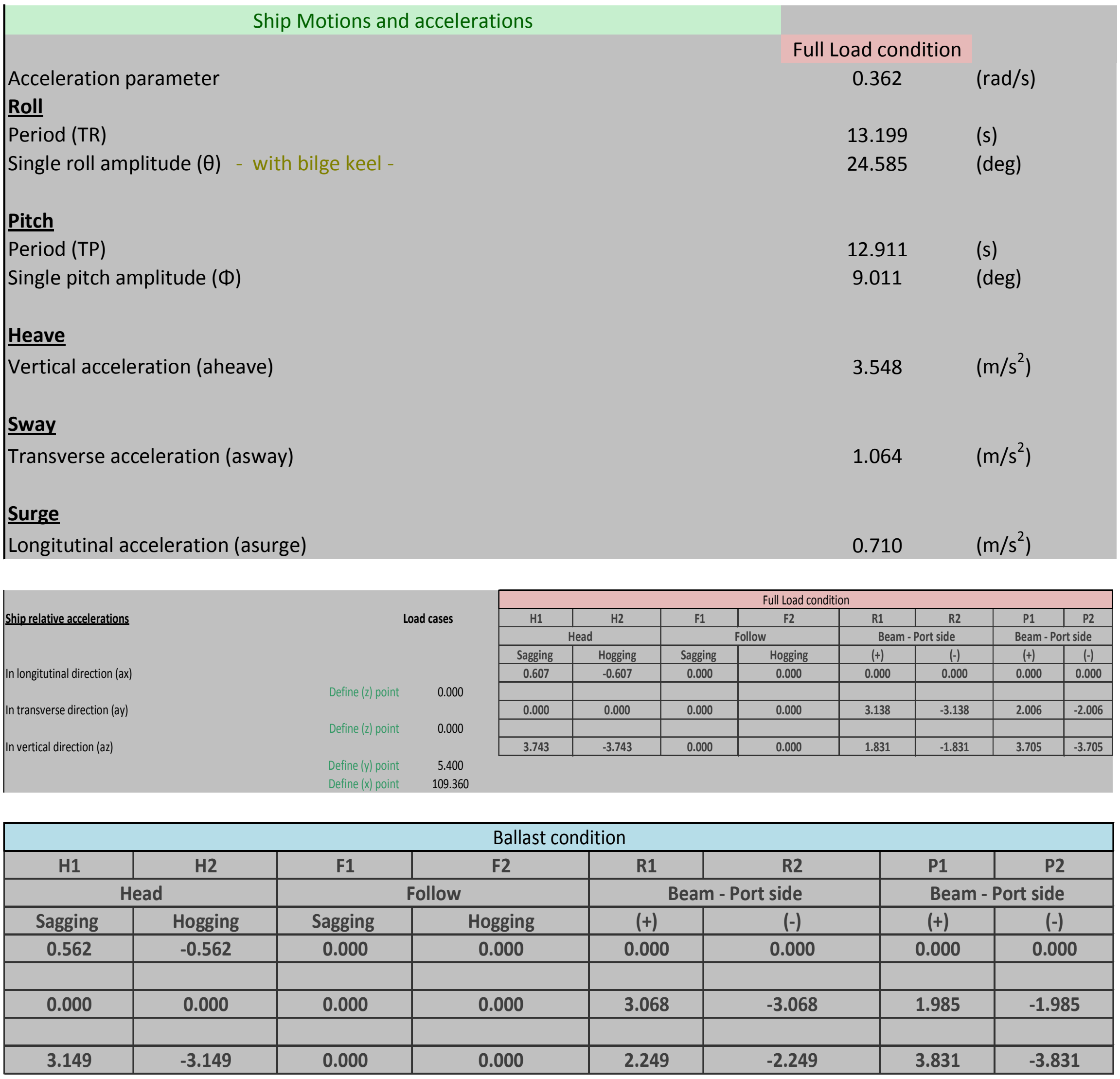


Ship's name	AFOVOS	
Kind of Ship	Bulk Carrier	
Principal Dimensions		
Length Over All (LOA)	224.900	(m)
Length between Perpendiculars (LBP)	217.000	(m)
Freeboard Length (L_{LL})	217.500	(m)
Breadth (Moulded)	32.260	(m)
Depth (Moulded)	19.400	(m)
1.Designed/Scantling Draft	14.100	(m)
Service speed	14.700	(Kn)
Block coefficient (C_B)	0.854	
Define coordinates for analysis		
x	109.36	m
y	2.70	m
z	0.00	m

Fig. 5.2.1 – Principle Dimensions

5.2.2 *Ship Motions and Accelerations*

Further down, in Fig. 5.2.2.1 all the ship absolute motions and accelerations in the Full Load and Ballast condition are calculated, using the equations given by IACS, i.e (Roll, Pitch, Heave, Sway, Surge, Yaw). In general, the values of ship motions and accelerations to be computed are those which can be reached with a probability level of 10^{-8} .The ship's relative accelerations will result according to the X, Y, Z coordinates inserted in the appropriate table in the sheet. They will be computed forthe longitudinal, transverse, and vertical directions for both loading conditions (Full load-Ballast) and for all the load cases, (H1, H2, F1, F2, R1, R2, P1, P2), Tab. 5.2.2.2



Ship Motions and accelerations		
	Full Load condition	
Acceleration parameter	0.362	(rad/s)
Roll		
Period (TR)	13.199	(s)
Single roll amplitude (θ) - with bilge keel -	24.585	(deg)
Pitch		
Period (TP)	12.911	(s)
Single pitch amplitude (Φ)	9.011	(deg)
Heave		
Vertical acceleration (aheave)	3.548	(m/s^2)
Sway		
Transverse acceleration (asway)	1.064	(m/s^2)
Surge		
Longitutinal acceleration (asurge)	0.710	(m/s^2)

Ship relative accelerations			Full Load condition							
	Load cases		H1	H2	F1	F2	R1	R2	P1	P2
			Head		Follow		Beam - Port side		Beam - Port side	
			Sagging	Hogging	Sagging	Hogging	(+)	(-)	(+)	(-)
In longitutinal direction (ax)			0.607	-0.607	0.000	0.000	0.000	0.000	0.000	0.000
	Define (z) point	0.000								
In transverse direction (ay)			0.000	0.000	0.000	0.000	3.138	-3.138	2.006	-2.006
	Define (z) point	0.000								
In vertical direction (az)			3.743	-3.743	0.000	0.000	1.831	-1.831	3.705	-3.705
	Define (y) point	5.400								
	Define (x) point	109.360								

Ballast condition							
H1	H2	F1	F2	R1	R2	P1	P2
Head		Follow		Beam - Port side		Beam - Port side	
Sagging	Hogging	Sagging	Hogging	(+)	(-)	(+)	(-)
0.562	-0.562	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	3.068	-3.068	1.985	-1.985
3.149	-3.149	0.000	0.000	2.249	-2.249	3.831	-3.831

Fig 5.2.2.1 – Ship motions and accelerations

The load cases present equivalent Design waves which consist of:

- Regular waves when the vertical wave bending moment becomes maximum in head sea (‘H’)
- Regular waves when the vertical wave bending moment becomes maximum in following sea (‘F’)
- Regular waves when the roll motion becomes maximum (‘R’)
- Regular waves when the hydrodynamic pressure at the waterline becomes maximum (‘P’)

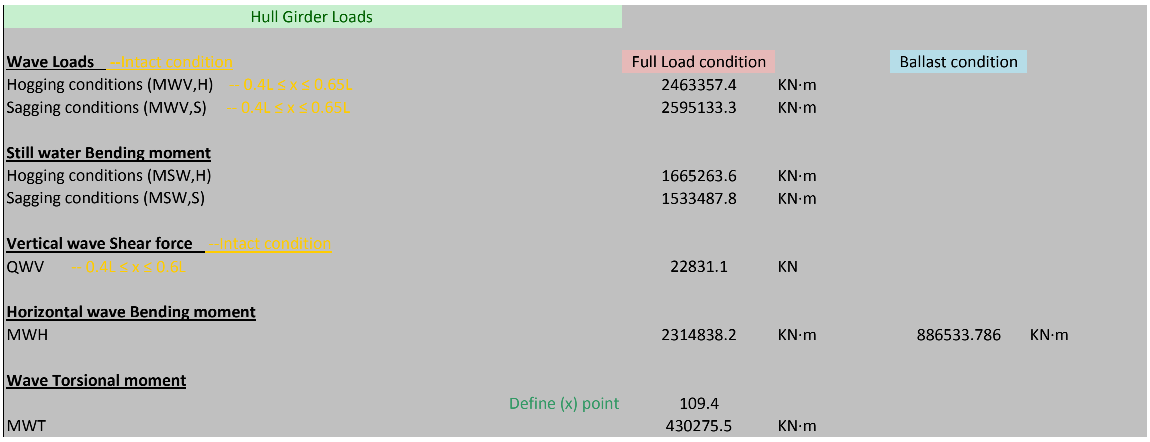
Load case	HI	H2	Fl	F2	Rl	R2	PI	P2
EDW	"H"		«F"		"R"		"P"	
Heading	Head		Follow		Beam (Port: weather side)		Beam (Port: weather side)	
Effect	Max.Bending Moment		Max.Bending Moment		Max. Roll		Max. Ext. Pressure	
	Sagging	Hogging	Sagging	Hogging	(+)	(-)	(+)	(-)

Tab. 5.2.2.2 – Load cases

5.2.3 Hull girder Loads

The second part of the sheet computes the Hull Girder loads, Fig. 5.2.3.1, in the mid-part of the ship, (0.3 – 0.7 L), for both loading conditions. The hull girder loads consist of the Still water bending moment, Vertical and Horizontal bending moment, Vertical Shear Force and Wave Torsional Moment.

In general, the value of still water Bending Moment and shear force are to be treated as the upper limits with respect to hull girder strength. In case the loading of the ship is known from the design the exact still water bending moment to be considered.



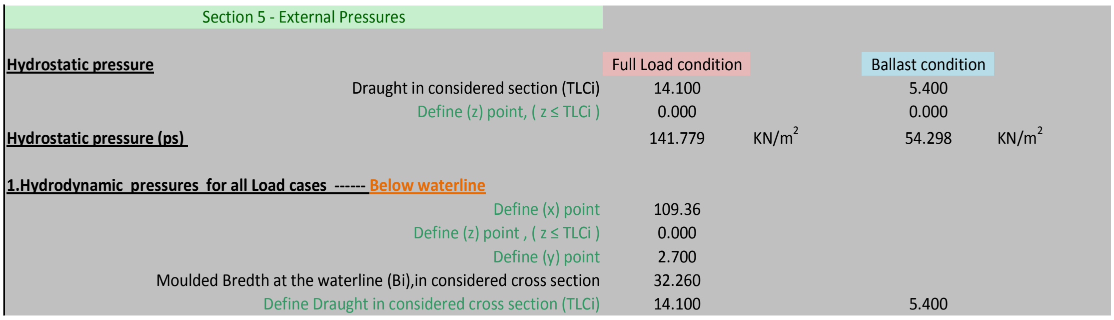
Hull Girder Loads					
Wave Loads	--Intact condition	Full Load condition		Ballast condition	
Hogging conditions (MWV,H)	-- 0.4L ≤ x ≤ 0.65L	2463357.4	KN·m		
Sagging conditions (MWV,S)	-- 0.4L ≤ x ≤ 0.65L	2595133.3	KN·m		
Still water Bending moment					
Hogging conditions (MSW,H)		1665263.6	KN·m		
Sagging conditions (MSW,S)		1533487.8	KN·m		
Vertical wave Shear force	--Intact condition				
QWV	-- 0.4L ≤ x ≤ 0.6L	22831.1	KN		
Horizontal wave Bending moment					
MWH		2314838.2	KN·m	886533.786	KN·m
Wave Torsional moment					
	Define (x) point	109.4			
MWT		430275.5	KN·m		

Fig. 5.2.3.1 – Hull Girder Loads

5.2.4 External Pressures

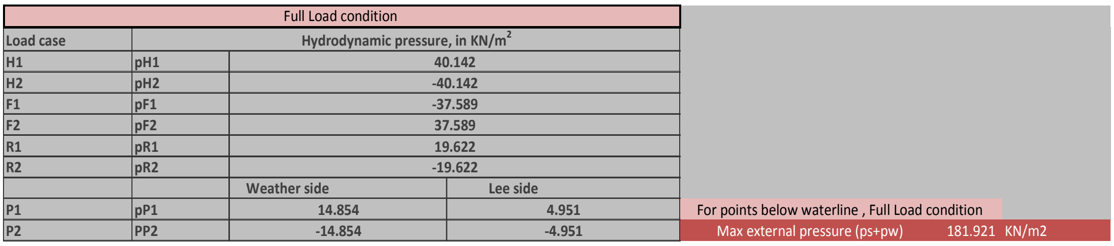
The external pressures calculated according to the coordinates given by the user are divided in the following categories:

- Hydrostatic pressure, Fig.5.2.4.1
- Hydrodynamic pressures below waterline, Fig.5.2.4.2
- Hydrodynamic pressures above waterline, Fig.5.2.4.3
- External pressures on exposed Freeboard and Forecastle deck, Fig.5.2.4.4



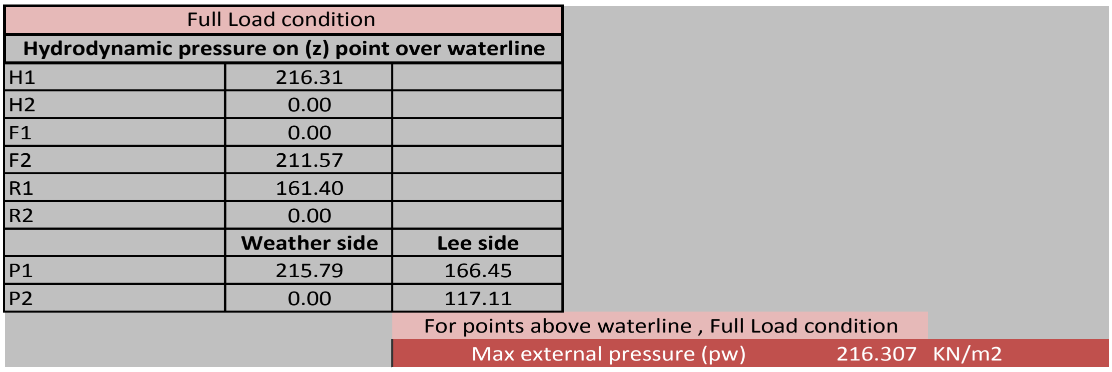
Section 5 - External Pressures				
Hydrostatic pressure	Full Load condition		Ballast condition	
Draught in considered section (TLCi)	14.100		5.400	
Define (z) point, (z ≤ TLCi)	0.000		0.000	
Hydrostatic pressure (ps)	141.779	KN/m^2	54.298	KN/m^2
1.Hydrodynamic pressures for all Load cases ------ Below waterline				
Define (x) point	109.36			
Define (z) point , (z ≤ TLCi)	0.000			
Define (y) point	2.700			
Moulded Bredth at the waterline (Bi),in considered cross section	32.260			
Define Draught in considered cross section (TLCi)	14.100		5.400	

Fig. 5.2.4.1 – Hydrostatic pressure



Full Load condition				
Load case		Hydrodynamic pressure, in KN/m^2		
H1	pH1	40.142		
H2	pH2	-40.142		
F1	pF1	-37.589		
F2	pF2	37.589		
R1	pR1	19.622		
R2	pR2	-19.622		
		Weather side	Lee side	
P1	pP1	14.854	4.951	For points below waterline , Full Load condition
P2	PP2	-14.854	-4.951	Max external pressure (ps+pw) 181.921 KN/m2

Fig. 5.2.4.2 – Hydrodynamic pressures below waterline

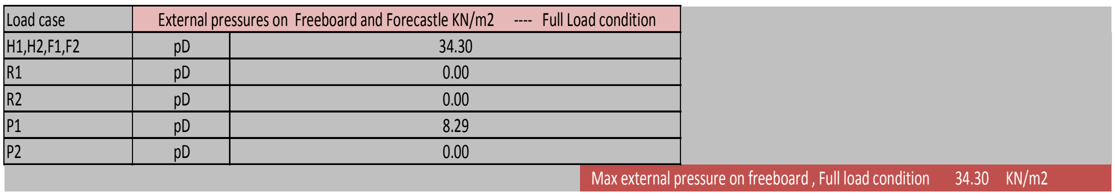


Full Load condition		
Hydrodynamic pressure on (z) point over waterline		
H1	216.31	
H2	0.00	
F1	0.00	
F2	211.57	
R1	161.40	
R2	0.00	
	Weather side	**Lee side**
P1	215.79	166.45
P2	0.00	117.11

For points above waterline , Full Load condition

Max external pressure (pw) 216.307 KN/m2

Fig. 5.2.4.3 – Hydrodynamic pressures above waterline



Load case	External pressures on Freeboard and Forecastle KN/m2 ---- Full Load condition	
H1,H2,F1,F2	pD	34.30
R1	pD	0.00
R2	pD	0.00
P1	pD	8.29
P2	pD	0.00

Max external pressure on freeboard , Full load condition 34.30 KN/m2

Fig. 5.2.4.4 – External pressures on exposed Freeboard and Forecastle deck

The same results are given for the Ballast condition as well. The total pressure p_{ex} at any point of the hull is obtained from the following formula and is not to be negative:

$$p_{ex} = ps_{ex} + pw_{ex}$$

where:

ps_{ex} : Hydrostatic pressure

pw_{ex}: Wave pressure equal to the hydrodynamic pressure

5.2.5 *Internal pressure and forces*

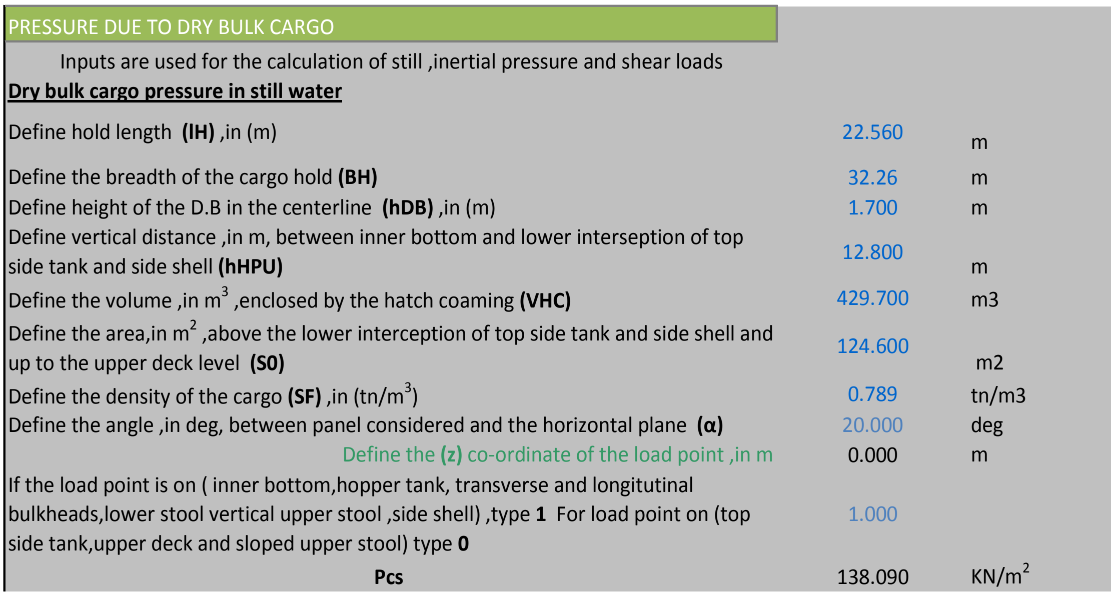
The internal pressures of a Bulk Carrier can be divided in still and lateral pressure induced by :

- Dry Bulk Cargo
- Water Ballast

In order to compute the pressure and forces mentioned above some additional input data are needed to define the geometry of the area for both cases. The input necessary for the Cargo Hold are:

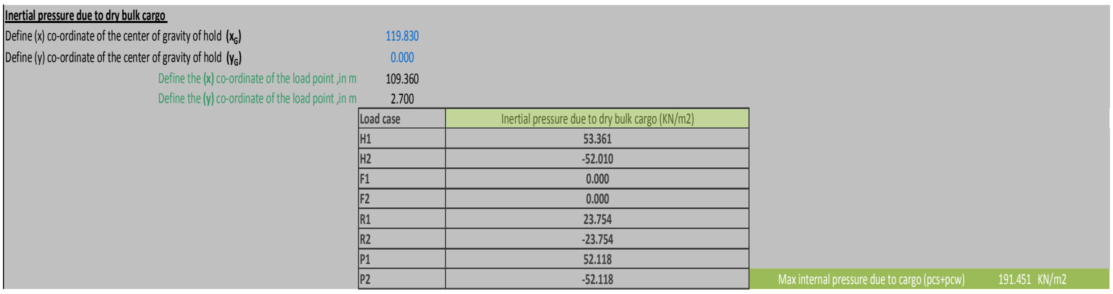
- Hold Length, (l_H)
- Hold Breadth, (B_H)
- Height of D.B, (h_{DB})
- Vertical distance between inner bottom and lower interception of top side tank and side shell, (h_{HPU})
- Volume of hatch coaming, (V_{HC})
- Area above the lower interception of topside tank and side shell till the upper deck level, (S_o)
- Density of the cargo, (S_F)
- X coordinate of the center of gravity of hold, (x_G)
- Y coordinate of center of gravity of hold, (y_G)

According to the X, Y, Z, coordinates the results appear in the following figures:



PRESSURE DUE TO DRY BULK CARGO		
Inputs are used for the calculation of still ,inertial pressure and shear loads		
Dry bulk cargo pressure in still water		
Define hold length **(lH)** ,in (m)	22.560	m
Define the breadth of the cargo hold **(BH)**	32.26	m
Define height of the D.B in the centerline **(hDB)** ,in (m)	1.700	m
Define vertical distance ,in m, between inner bottom and lower interseption of top side tank and side shell **(hHPU)**	12.800	m
Define the volume ,in m^3 ,enclosed by the hatch coaming **(VHC)**	429.700	m3
Define the area,in m^2 ,above the lower interception of top side tank and side shell and up to the upper deck level **(S0)**	124.600	m2
Define the density of the cargo **(SF)** ,in (tn/m^3)	0.789	tn/m3
Define the angle ,in deg, between panel considered and the horizontal plane **(α)**	20.000	deg
Define the **(z)** co-ordinate of the load point ,in m	0.000	m
If the load point is on (inner bottom,hopper tank, transverse and longitutinal bulkheads,lower stool vertical upper stool ,side shell) ,type **1** For load point on (top side tank,upper deck and sloped upper stool) type **0**	1.000	
Pcs	138.090	KN/m^2

Fig. 5.2.5.2 – Dry bulk cargo pressure in still water



Inertial pressure due to dry bulk cargo

Define (x) co-ordinate of the center of gravity of hold (x_G) 119.830

Define (y) co-ordinate of the center of gravity of hold (y_G) 0.000

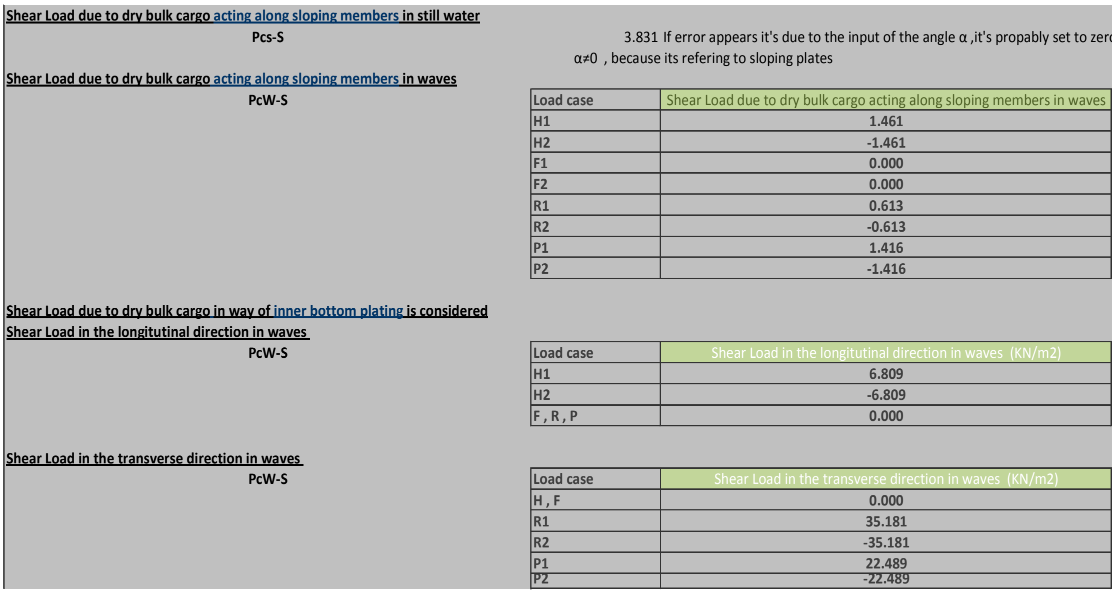
Define the (x) co-ordinate of the load point ,in m 109.360

Define the (y) co-ordinate of the load point ,in m 2.700

Load case	Inertial pressure due to dry bulk cargo (KN/m2)
H1	53.361
H2	-52.010
F1	0.000
F2	0.000
R1	23.754
R2	-23.754
P1	52.118
P2	-52.118

Max internal pressure due to cargo (pcs+pcw) 191.451 KN/m2

Fig. 5.2.5.3 – Inertial pressure due to to dry bulk cargo



Shear Load due to dry bulk cargo acting along sloping members in still water

Pcs-S 3.831 If error appears it's due to the input of the angle α ,it's propably set to zer

α≠0 , because its refering to sloping plates

Shear Load due to dry bulk cargo acting along sloping members in waves

PcW-S

Load case	Shear Load due to dry bulk cargo acting along sloping members in waves
H1	1.461
H2	-1.461
F1	0.000
F2	0.000
R1	0.613
R2	-0.613
P1	1.416
P2	-1.416

Shear Load due to dry bulk cargo in way of inner bottom plating is considered

Shear Load in the longitutinal direction in waves

PcW-S

Load case	Shear Load in the longitutinal direction in waves (KN/m2)
H1	6.809
H2	-6.809
F , R , P	0.000

Shear Load in the transverse direction in waves

PcW-S

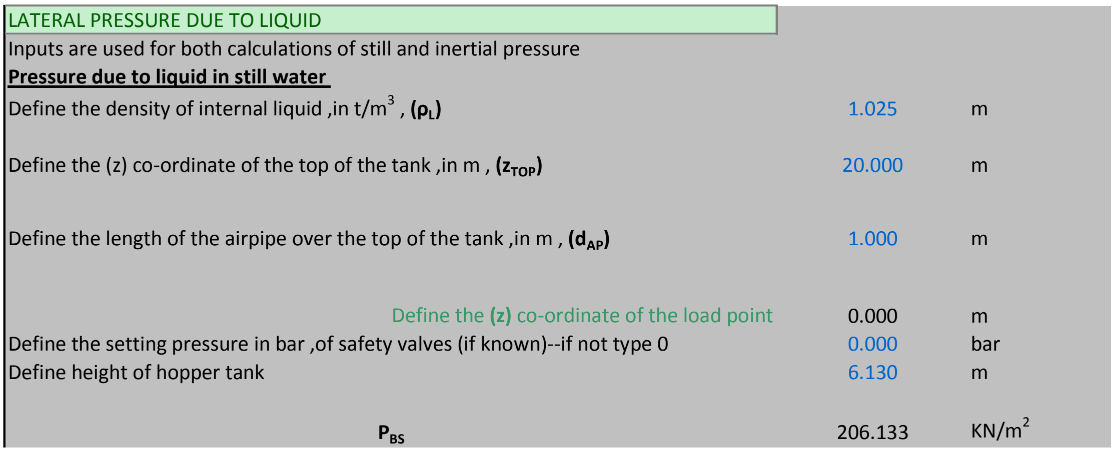
Load case	Shear Load in the transverse direction in waves (KN/m2)
H , F	0.000
R1	35.181
R2	-35.181
P1	22.489
P2	-22.489

Fig. 5.2.5.3 – Inertial Shear Loads

As far as the still, Fig.5.2.5.4 and inertial pressures, Fig. 5.2.5.5, due to liquid are concerned, the input required to define the geometry of the ballast holds are :

- Density of liquid, (ρ_L)
- Length of airpipe over the top of the tank, (z_{TOP})
- Setting pressure of safety valves (not necessary)
- Height of hopper tank
- Length of Ballast Tank
- Y co-ordinate of the tank top located at the most lee side and at the most weather side

The results given in this case are the following:



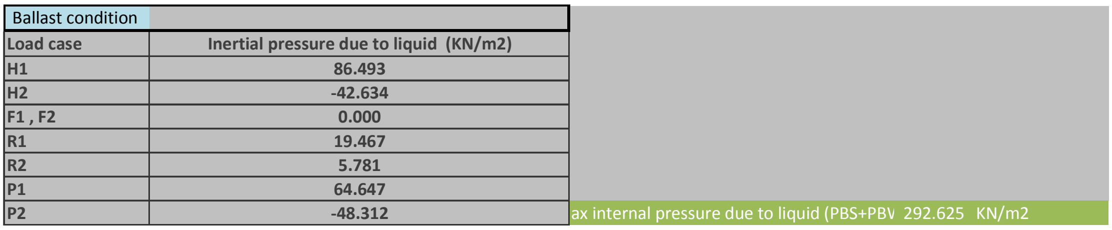
LATERAL PRESSURE DUE TO LIQUID

Inputs are used for both calculations of still and inertial pressure

Pressure due to liquid in still water

Define the density of internal liquid ,in t/m^3 , **(ρ_L)**	1.025	m
Define the (z) co-ordinate of the top of the tank ,in m , **(z_{TOP})**	20.000	m
Define the length of the airpipe over the top of the tank ,in m , **(d_{AP})**	1.000	m
Define the **(z)** co-ordinate of the load point	0.000	m
Define the setting pressure in bar ,of safety valves (if known)--if not type 0	0.000	bar
Define height of hopper tank	6.130	m
P_{BS}	206.133	KN/m^2

Fig.5.2.5.4 – Still Pressure due to liquid in still water



Ballast condition

Load case	Inertial pressure due to liquid (KN/m2)
H1	86.493
H2	-42.634
F1 , F2	0.000
R1	19.467
R2	5.781
P1	64.647
P2	-48.312

ax internal pressure due to liquid (PBS+PBV 292.625 KN/m2

Fig.5.2.5.5 – Inertial pressure due to liquid in still water

5.2.6 Scantlings

The scantling requirements of this section apply for the strength check of plating contributing to the longitudinal strength subjected to lateral pressure and to in-plane hull girder normal stress. The thicknesses do not include any corrosion addition. The corrosion addition is added separately according to specific tables that will be discussed further on.

The net thickness of laterally loaded panels is to be not less than the value obtained, in mm, from the following formula :

$$t = 15.8\, c_a\, c_r\, s \sqrt{\frac{p_s + p_w}{\lambda_p R_Y}}$$

λ_P : Coefficient defined in Tab 5.2.6.1

Plating		Coefficient λ_p
Contributing to the hull girder longitudinal strength	Longitudinally framed plating	$0.95 - 0.45\left\|\frac{\sigma_x}{R_Y}\right\|$, without being taken greater than 0.9
	Transversely framed plating	$0.95 - 0.90\left\|\frac{\sigma_x}{R_Y}\right\|$,without being taken greater than 0.9
Not contributing to the hull girder longitudinal strength		0.9

Table 5.2.6.1: Coefficient λ_P

c_a : Coefficient of aspect ratio of the plate panel, equal to:

$$c_a = 1.21\sqrt{1+0.33\left(\frac{s}{l}\right)^2} - 0.69\frac{s}{l}$$, not greater than 1

c_r : Coefficient of curvature of the panel, equal to:

$$c_r = 1 - 0.5\,\frac{s}{r}$$, to be taken not less than 0.4

The complementary input in order to compute the net scantling of a plate is:

- length of the sorter side of the elementary plate panel (s)
- length of the longer side of the elementary plate panel (l)
- radius of curvature
- define if the plate is longitudinally or transversely framed
- maximum normal stress of the material (σ_x)
- yield point of the material (R_Y)

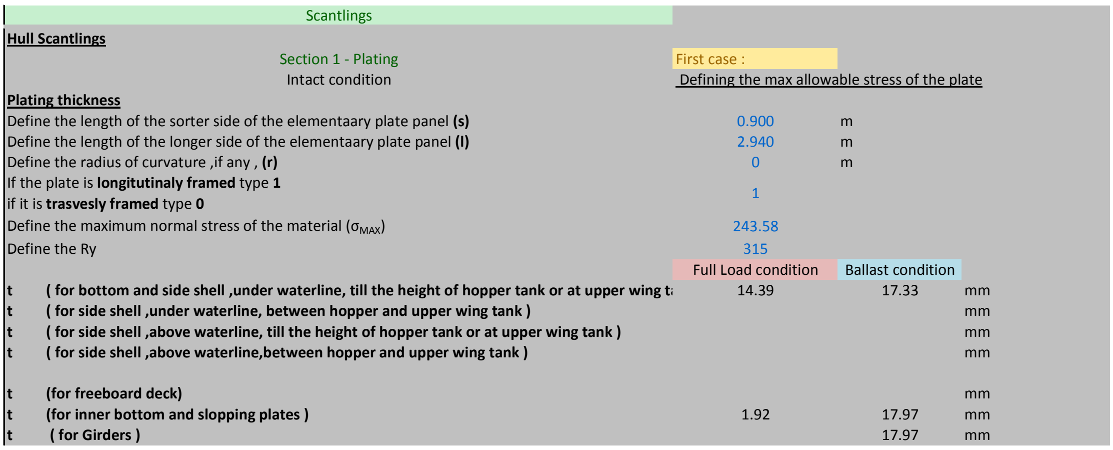
'Elementary plate panel': The elementary plate panel is the smallest unstiffened part of plating between stiffeners.

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure. Still water pressure p_S includes:

- the hydrostatic pressure

- the still water internal pressure for the various types of cargoes and for ballast. Wave pressure p_W includes for each load case H1, H2, F1, F2, R1, R2, P1 and P2:
- the hydrodynamic pressure
- the inertial pressure for the various types of cargoes and for ballast.

Further on, some figures of the input and output fields are presented :



Scantlings

Hull Scantlings

Section 1 - Plating

Intact condition

First case :

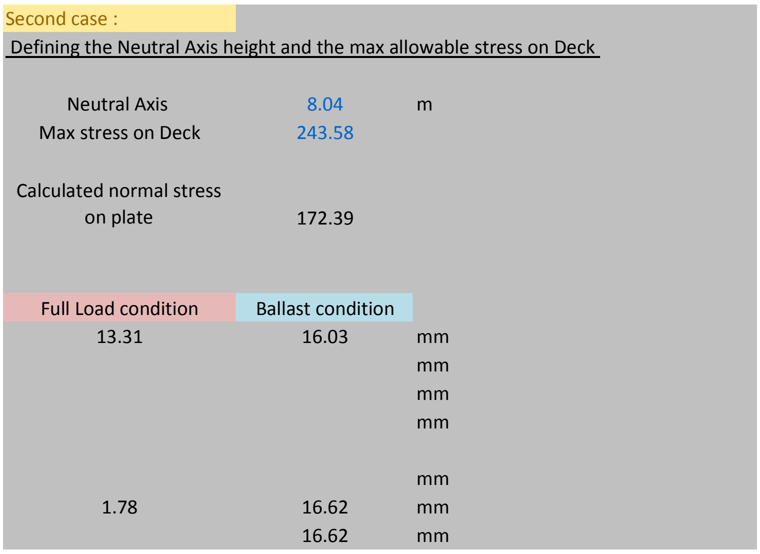
Defining the max allowable stress of the plate

Plating thickness

Define the length of the sorter side of the elementaary plate panel **(s)**	0.900	m
Define the length of the longer side of the elementaary plate panel **(l)**	2.940	m
Define the radius of curvature ,if any , **(r)**	0	m
If the plate is **longitutinaly framed** type **1** if it is **trasvesly framed** type **0**	1	
Define the maximum normal stress of the material (σ_{MAX})	243.58	
Define the Ry	315	

		Full Load condition	Ballast condition	
t	**(for bottom and side shell ,under waterline, till the height of hopper tank or at upper wing t**	14.39	17.33	mm
t	**(for side shell ,under waterline, between hopper and upper wing tank)**			mm
t	**(for side shell ,above waterline, till the height of hopper tank or at upper wing tank)**			mm
t	**(for side shell ,above waterline,between hopper and upper wing tank)**			mm
t	**(for freeboard deck)**			mm
t	**(for inner bottom and slopping plates)**	1.92	17.97	mm
t	**(for Girders)**		17.97	mm

Fig.5.2.6.1 – Input for hull scantlings



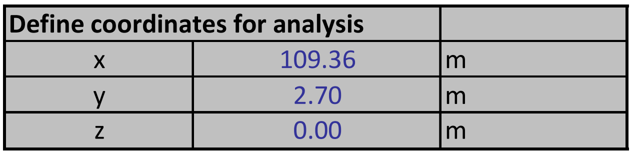
Second case :

Defining the Neutral Axis height and the max allowable stress on Deck

Neutral Axis	8.04	m
Max stress on Deck	243.58	
Calculated normal stress on plate	172.39	

Full Load condition	Ballast condition	
13.31	16.03	mm
		mm
		mm
		mm
		mm
1.78	16.62	mm
	16.62	mm

Fig.5.2.6.2 – Output of hull scantlings



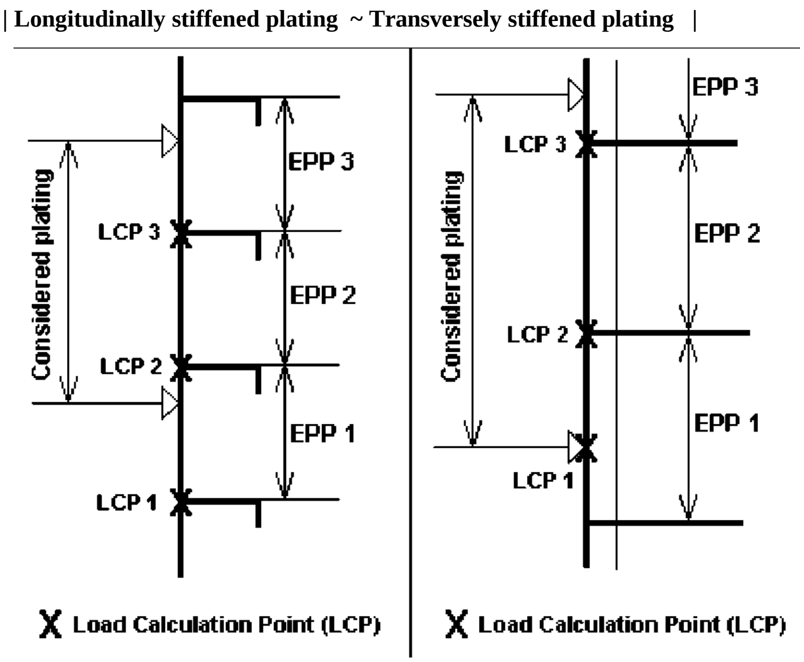
Define coordinates for analysis		
x	109.36	m
y	2.70	m
z	0.00	m

Fig.5.2.6.3 – Definitions of co-ordinates for analysis

Load calculation point:

Lateral pressure and hull girder stresses are to be calculated:

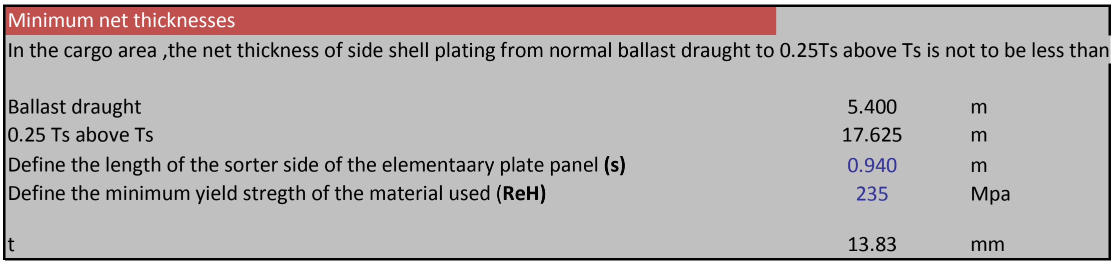
- for longitudinal framing, at the lower edge of the elementary plate panel or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered, as the case may be
- for transverse framing, at the lower edge of the elementary plate panel or at the lower edge of the strake or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered, as the case may be.



The net thickness, in mm, of each plating is given by the greatest of the net thicknesses, (in Full load or Ballast condition), calculated for each load calculation point (rounded up to 0.5), representative of the considered plating. The geometry to be considered is that of the elementary plate panel related to the load calculation point. Regarding the location of the plate the equivalent result thickness is used by the designer.

5.2.7 Minimum Thicknesses and General requirements

The minimum net thicknesses of the plates regarding the principle dimensions of the ship as well as the transverse framing space and the material yield strength are also calculated and presented in the following figures:



Minimum net thicknesses		
In the cargo area ,the net thickness of side shell plating from normal ballast draught to 0.25Ts above Ts is not to be less than		
Ballast draught	5.400	m
0.25 Ts above Ts	17.625	m
Define the length of the sorter side of the elementaary plate panel **(s)**	0.940	m
Define the minimum yield stregth of the material used (**ReH)**	235	Mpa
t	13.83	mm

Fig.5.2.7.1 – Minimum net thicknesses of side shell plating

Plating	Minimum net thicknesses ,in mm	
Keel	14.01	
Bottom, Inner bottom	12.01	
Weather strength deck and trunk deck ,if any	8.84	
Side shell , bilge	12.52	
Inner side , hopper sloping plate and topside sloping plate	10.31	
Transverse and longitutinal watertight bulkhead	8.84	
Wash bulkheads	6.50	
Accomodation deck	6.00	

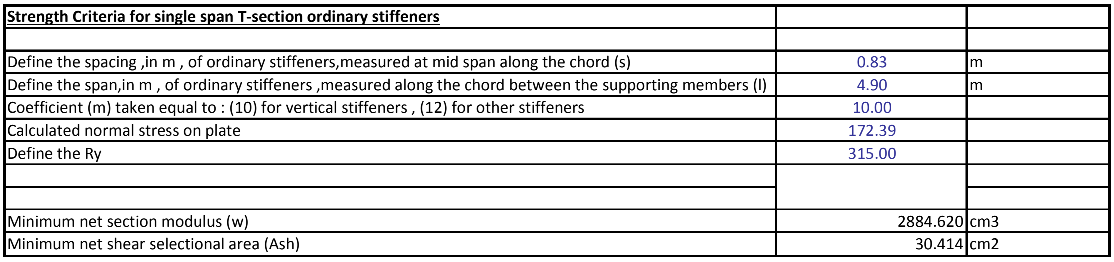
Fig.5.2.7.2 – Minimum net thicknesses of platings

- Bilge Plating: The net thickness of the bilge plating is to be not less than the actual net thicknesses of the adjacent 2 m width bottom or side plating, whichever is the greater.
- Keel Plating: The net thickness of the keel plating is to be not less than the actual net thicknesses of the adjacent 2 m width bottom plating.

- <u>Sheerstrake</u>: The net thickness of a welded sheerstrake is to be not less than the actual net thicknesses of the adjacent 2 m width side plating, taking into account higher strength steel corrections if needed.

5.2.8 Strength criteria for single span ordinary stiffeners

The net section modulus w, and the net shear selectional area A_{sh} of single span ordinary stiffeners subjected to lateral pressure should not be less than the values obtained by the Tab. 5.2.8.1



<u>Strength Criteria for single span T-section ordinary stiffeners</u>		
Define the spacing ,in m , of ordinary stiffeners,measured at mid span along the chord (s)	0.83	m
Define the span,in m , of ordinary stiffeners ,measured along the chord between the supporting members (l)	4.90	m
Coefficient (m) taken equal to : (10) for vertical stiffeners , (12) for other stiffeners	10.00	
Calculated normal stress on plate	172.39	
Define the Ry	315.00	
Minimum net section modulus (w)	2884.620	cm3
Minimum net shear selectional area (Ash)	30.414	cm2

Table 5.2.8.1 – Strength criteria for single span ordinary stiffeners

The input necessary to obtain the results are in blue colour.

For the selection of the appropriate stiffeners an additional table is available which can compute the section modulus and sectional Area by defining the dimensions of the T-bar, Fig.4.2.8.1, or Flat bar stiffener, Fig.4.2.8.2 and the attached plate dimensions and thickness as well.

The effective width b_p of the attached plating to be considered in the actual net section modulus for the yielding check of ordinary stiffeners is to be obtained, in m, from the following formulae:

- where the plating extends on both sides of

the ordinary stiffener:

$b_p = 0.2\,l$ or $bp = s$

whichever is lesser.

- where the plating extends on one side of the ordinary stiffener (i.e. ordinary stiffeners bounding openings):

b_p = 0.5s

b_p = 0.1l

whichever is lesser.

Calculation of section modulus of T-section stiffener			
Define web dimensions (mm)	340	12	mm
Define flange dimenions (mm)	120	15	mm
Define plate dimensions (mm)	980	11.5	
			cm3
Z	945.8		cm2
Net shear selectional area (Ash)	57		

Fig.5.2.8.1 – Calculation of section modulus of T- section stiffener

Calculation of section modulus of Flat Bar stiffener			
Define web dimensions (mm)	500	30	mm
Define plate dimensions (mm)	980	11.5	mm
Z	1901.2		cm3
Net shear selectional area (Ash)	150		cm2

Fig.5.2.8.2 – Calculation of section modulus of Flat stiffener stiffener

5.2.9 Corrosion addition for steel

The corrosion addition for each of the two sides of a structural member, t_{C1} or t_{C2}, is specified in Tab.5.2.9.1

The total corrosion addition t_C, in mm, for both sides of the structural member is obtained by the following formula:

$t_C = Roundup_{0.5} (t_{c1} + t_{c2}) + t_{reserve}$

For an internal member within a given compartment, the total corrosion addition t_C is obtained from the following formula:

$t_C = \text{Roundup}_{0.5} (2t_{c1}) + t_{reserve}$

where t_{C1} is the value specified in Tab.5.2.9.1 for one side exposure to that compartment.

When a structural member is affected by more than one value of corrosion addition (e.g. a plate in a dry bulk cargo hold extending above the lower zone), the scantling criteria are generally to be applied considering the severest value of corrosion addition applicable to the member.

In addition, the total corrosion addition t_C is not to be taken less than 2 mm, except for web and face plate of ordinary stiffeners.

$t_{reserve}$: Thickness, in mm, to account for anticipated thickness diminution that may occur during a survey interval of 2.5 years ($t_{reserve}$ =0.5mm)

Table 5.2.9.1: Corrosion addition on one side of structural members

<table>
<tr><th rowspan="2">Compartment Type</th><th rowspan="2" colspan="2">Structural member</th><th colspan="2">Corrosion addition, t_{C1} or t_{C2} in mm</th></tr>
<tr><th>BC-A or BC-B ships with $L > 150$ m</th><th>Other</th></tr>
<tr><td rowspan="4">Ballast water tank [2]</td><td rowspan="2">Face plate of primary members</td><td>Within 3 m below the top of tank [3]</td><td colspan="2">2.0</td></tr>
<tr><td>Elsewhere</td><td colspan="2">1.5</td></tr>
<tr><td rowspan="2">Other members</td><td>Within 3 m below the top of tank [3]</td><td colspan="2">1.7</td></tr>
<tr><td>Elsewhere</td><td colspan="2">1.2</td></tr>
<tr><td rowspan="8">Dry bulk cargo hold [1]</td><td rowspan="3">Transverse bulkhead</td><td>Upper part [4]</td><td>2.4</td><td>1.0</td></tr>
<tr><td>Lower stool: sloping plate, vertical plate and top plate</td><td>5.2</td><td>2.6</td></tr>
<tr><td>Other parts</td><td>3.0</td><td>1.5</td></tr>
<tr><td rowspan="3">Other members</td><td>Upper part [4]
Webs and flanges of the upper end brackets of side frames of single side bulk carriers</td><td>1.8</td><td>1.0</td></tr>
<tr><td>Webs and flanges of lower brackets of side frames of single side bulk carriers</td><td>2.2</td><td>1.2</td></tr>
<tr><td>Other parts</td><td>2.0</td><td>1.2</td></tr>
<tr><td rowspan="2">Sloped plating of hopper tank, inner bottom plating</td><td>Continuous wooden ceiling</td><td>2.0</td><td>1.2</td></tr>
<tr><td>No continuous wooden ceiling</td><td>3.7</td><td>2.4</td></tr>
<tr><td rowspan="2">Exposed to atmosphere</td><td colspan="2">Horizontal member and weather deck [5]</td><td colspan="2">1.7</td></tr>
<tr><td colspan="2">Non horizontal member</td><td colspan="2">1.0</td></tr>
<tr><td colspan="3">Exposed to sea water [7]</td><td colspan="2">1.0</td></tr>
<tr><td colspan="3">Fuel oil tanks and lubricating oil tanks [2]</td><td colspan="2">0.7</td></tr>
<tr><td colspan="3">Fresh water tanks</td><td colspan="2">0.7</td></tr>
<tr><td>Void spaces [6]</td><td colspan="2">Spaces not normally accessed, e.g. access only through bolted manholes openings, pipe tunnels, etc.</td><td colspan="2">0.7</td></tr>
<tr><td>Dry spaces</td><td colspan="2">Internal of deck houses, machinery spaces, stores spaces, pump rooms, steering spaces, etc.</td><td colspan="2">0.5</td></tr>
<tr><td colspan="3">Other compartments than above</td><td colspan="2">0.5</td></tr>
</table>

Notes

(1) Dry bulk cargo hold includes holds, intended for the carriage of dry bulk cargoes, which may carry water ballast.

(2) The corrosion addition of a plating between water ballast and heated fuel oil tanks is to be increased by 0.7 mm.

(3) This is only applicable to ballast tanks with weather deck as the tank top.

(4) Upper part of the cargo holds corresponds to an area above the connection between the top side and the inner hull or side shell. If there is no top side, the upper part corresponds to the upper one third of the cargo hold height.

(5) Horizontal member means a member making an angle up to 20° as regard as a horizontal line.

(6) The corrosion addition on the outer shell plating in way of pipe tunnel is to be considered as water ballast tank.

(7) Outer side shell between normal ballast draught and scantling draught is to be increased by 0.5 mm.

5.3 SM. Calc. Guidelines

In addition to the previous excel sheet, 'CSR calc', an extra sheet was created which is used for the Yielding check of the Mid-ship section according to the IACS rules. The section is to be considered as being constituted by the members contributing to the hull girder longitudinal strength, i.e, all continuous longitudinal members including the strength deck. These members are to be considered as having net offered scantlings increased by 0.5 t_c.

The section modulus at any point of the transverse section is obtained from the following formula:

- $Z_A = \frac{I_Y}{|z-N|}$
- $Z_{AB} = \frac{I_Y}{N}$, at bottom
- $Z_{AD} = \frac{I_Y}{V_D}$, at deck

where:

N : Z co-ordinate, in m, of the center of gravity of the hull transverse secion

I_Y : Moment of Inertia of the hull transverse secion, about the horizontal neutral axis

V_D : Vertical distance, in m taken equal to:

$$V_D = z_D - N$$

where:

z_D : Z co-ordinate, in m, of strength deck at side

Defining some of the principle dimensions of the ship as well as the still water moment and vertical wave moment which derive from the 'CSR calc', the minimum requirements of the Section Modulus and Moment of Inertia appear in the following Tab. 4.3.1. The values vary according to the strength of the steel used in the strength deck.

Requirments	k=1 - Mild Steel		k=0.78 - High Tensile	
ZRmin	21.23	m3	16.56	m3
ZR	21.73	m3	16.95	m3
Imin	138.23	m4	138.23	m4

Table 5.3.1 – Section Modulus and Moment of Inertia requirements

In order to calculate the Section modulus of the section after the approach of the scantlings from the 'CSR calc', two tables have been created, one for the calculations of the plate scantlings and one for the calculation of all the stiffener scantlings that support the section. The two Tables are presented below :

Calculation Of Section Modulus									
	b(m)	t(m)	AREA(m^2)	Y(m)	AY($m*m^2$)	AY^2(m3*m)	i=Lb3/12(m3*m)		
Deck plating (strake 1)	2.496	0.024	0.059	19.400	1.138	22.076	2.70E-06		
Deck plating (strake 2)	2.770	0.024	0.065	19.400	1.263	24.499	3.00E-06		
Deck plating (strake 3)	2.770	0.024	0.066	19.400	1.290	25.020	3.19E-06		
Side plate (strake 1)	2.400	0.021	0.049	18.200	0.895	16.297	2.36E-02		
Side plate (strake 2)	2.200	0.020	0.043	15.900	0.682	10.846	1.73E-02		
Side plate (strake 3)	3.120	0.023	0.070	13.240	0.929	12.306	5.69E-02		
Side plate (strake 4)	3.120	0.023	0.070	11.680	0.820	9.577	5.69E-02		
Side plate (strake 5)	3.120	0.023	0.070	10.120	0.710	7.189	5.69E-02		
Side plate (strake 6)	3.880	0.018	0.068	8.180	0.555	4.543	8.52E-02		
Slopping plate (upper wing) .-(strake1)	2.754	0.021	0.056	18.500	1.044	19.322	2.23E-03		
Slopping plate (upper wing) .-(strake2)	2.650	0.020	0.052	17.400	0.899	15.645	1.89E-03		
Slopping plate (upper wing) .-(strake3)	2.500	0.020	0.049	16.100	0.785	12.636	1.59E-03		
Slopping plate (upper wing) .-(strake4)	1.950	0.020	0.039	15.000	0.585	8.775	7.73E-04		
Slopping plate (hopper tank) .-(strake 1)	3.125	0.020	0.063	5.000	0.313	1.563	3.18E-03		
Slopping plate (hopper tank) .-(strake 2)	3.140	0.022	0.069	2.900	0.200	0.581	3.55E-03		
Double bottom plate (strake 1)	1.875	0.024	0.044	1.700	0.075	0.127	2.03E-06		
Double bottom plate (strake 2)	3.300	0.024	0.078	1.700	0.132	0.224	3.57E-06		
Double bottom plate (strake 3)	3.300	0.024	0.078	1.700	0.132	0.224	3.57E-06		
Double bottom plate (strake 4)	3.225	0.024	0.076	1.700	0.129	0.219	3.49E-06		
Keel plate (strake 1)	1.875	0.019	0.035	0.000	0.000	0.000	9.89E-07		
Bottom plate (strake 2)	3.030	0.019	0.058	0.000	0.000	0.000	1.73E-06		
Bottom plate (strake 3)	3.030	0.020	0.059	0.000	0.000	0.000	1.87E-06		
Bottom plate (strake 4)	3.030	0.020	0.059	0.000	0.000	0.000	1.87E-06		
Bottom plate (strake 5)	3.200	0.020	0.062	0.000	0.000	0.000	1.98E-06	**Autocad**	
Bilge Plate		0.020	0.052	0.595	0.031			I (OA) :	1.86
								Girder Hole Breadt	**Girder Height**
Girder (1/4)	1.700	0.013	0.022		0.019	0.020	1.33E-03	0	1.7
Girder (2/4)	1.130	0.013	0.015		0.012	0.015	3.91E-04	0.57	1.7
Girder (3/4)	1.130	0.013	0.015		0.012	0.015	3.91E-04	0.57	1.7
Girder (4/4)	1.130	0.013	0.015		0.012	0.015	3.91E-04	0.57	1.7
TOTAL			**1.554**		**12.664**	**191.737**	**0.313**		

Table 5.3.2 – Plate Properties

Stiffeners	b(m)	t(m)	AREA(m2)-Total	AREA (web)	AREA (flange)	Y (web)	Y (flange)	AY (web)	AY (flange)	AY2(m3*m)- (Total)	i=Lb3/12(m3*m)- Total
Deck longi ' l (x7)	315×12+100×15		0.058	0.039	0.019	19.214	19.005	0.750	0.367	21.398	4.61E-04
Bottom longi ' l (x11)	340×12+120×15		0.082	0.058	0.024	0.352	0.370	0.020	0.009	0.010	6.07E-04
Bottom longi ' l -flat bar- (x2)	300×20		0.013	-	-	0.150	-	0.002		0.000	0.000099
Inner Bottom longi ' l (x8)	340×12+120×15		0.056	0.039	0.017	1.378	1.360	0.053	0.024	0.105	3.39E-04
Inner bottom longi ' l -flat bar- (x2)	300×20		0.013	-	-	1.550	-	0.020		0.032	0.000099
Web space longi ' l (1/9)	370×12+120×20		0.008	0.005	0.003	18.900	19.000	0.023	0.012	0.673	1.66E-05
Web space longi ' l (2/9)	370×12+120×20		0.008	0.005	0.003	18.500	18.680	0.020	0.011	0.572	1.66E-05
Web space longi ' l (3/9)	370×12+120×20		0.008	0.005	0.003	18.100	18.220	0.017	0.009	0.474	1.66E-05
Web space longi ' l (4/9)	370×12+120×20		0.008	0.005	0.003	17.680	17.800	0.014	0.007	0.376	1.66E-05
Web space longi ' l (5/9)	370×12+120×20		0.008	0.005	0.003	17.310	17.450	0.011	0.006	0.287	1.66E-05
Web space longi ' l (6/9)	370×12+120×20		0.008	0.005	0.003	16.880	17.000	0.088	0.047	2.281	1.66E-05
Web space longi ' l (7/9)	370×12+120×20		0.008	0.005	0.003	16.500	16.600	0.086	0.046	2.178	1.66E-05
Web space longi ' l (8/9)	370×12+120×20		0.008	0.005	0.003	16.080	16.200	0.084	0.045	2.070	1.66E-05
Web space longi ' l (9/9)	370×12+120×20		0.008	0.005	0.003	15.610	15.800	0.081	0.044	1.957	1.66E-05
Hopper space longi ' l (1/5)	315×12+100×15		0.006	0.004	0.002	4.500	4.400	0.020	0.008	0.125	1.02E-05
Hopper space longi ' l (2/5)	315×12+100×15		0.006	0.004	0.002	3.900	3.820	0.017	0.007	0.094	1.02E-05
Hopper space longi ' l (3/5)	315×12+100×15		0.006	0.004	0.002	3.320	3.210	0.015	0.006	0.068	1.02E-05
Hopper space longi ' l (4/5)	315×12+100×15		0.006	0.004	0.002	2.700	2.600	0.012	0.005	0.045	1.02E-05
Hopper space longi ' l (5/5)	315×12+100×15		0.006	0.004	0.002	2.120	2.000	0.009	0.004	0.027	1.02E-05
Upper side longi ' l (1/4)	370×12+120×20		0.008	0.005	0.003	18.570	18.570	0.097	0.051	2.747	5.37E-05
Upper side longi ' l (2/4)	370×12+120×20		0.008	0.005	0.003	17.740	17.740	0.092	0.001	1.651	5.37E-05
Upper side longi ' l (3/4)	370×12+120×20		0.008	0.005	0.003	16.910	16.910	0.088	0.001	1.500	5.37E-05
Upper side longi ' l (4/4)	370×12+120×20		0.008	0.005	0.003	16.080	16.080	0.084	0.001	1.357	5.37E-05
Lower side longi ' l (1/4)	315×12+100×15		0.006	0.004	0.002	4.250	4.250	0.019	0.008	0.113	3.33E-05
Lower side longi ' l] (2/4)	315×12+100×15		0.006	0.004	0.002	3.450	3.450	0.015	0.006	0.074	3.33E-05
Lower side longi ' l (3/4)	315×12+100×15		0.006	0.004	0.002	2.650	2.650	0.012	0.005	0.044	3.33E-05
Lower side longi ' l (4/4)	315×12+100×15		0.006	0.004	0.002	1.850	1.850	0.008	0.003	0.021	3.33E-05
Upper longi ' l of Center girder	220 x 15		0.003			1.135		0.004		0.004	6.19E-08
Lower longi ' l of Center girder	220 x 15		0.003			0.283		0.001		0.000	6.19E-08
Upper longi ' l of girders	150 x 12		0.005			1.135		0.006		0.007	6.48E-08
Lower longi ' l of girders	150 x 12		0.005			0.283		0.002		0.000	6.48E-08
TOTAL			0.400					2.501		40.293	2.15E-03

Table 5.3.3 – Stiffener properties

Net scantlings	Corrosion
23.5	0
23.5	0
24	0
20.5	0
19.5	0
23.5	0
23.5	0
23.5	0
17	0
20.5	0
19.5	0
19.5	0
20	0
19.5	0
21	0
22.5	0
22.5	0
22.5	0
22.5	0
18	0
18.5	0
18.5	0
18.5	0
19	0
19	0
	0
13	0
13	0
13	0
13	0

Table 5.3.4 – Input of plate scantlings

Net scantlings					Corrosion addition	Number of stiffeners
h	t	bf	tf			
395	15	120	23		0	7
370	15	120	18		0	11
300	22	-	-		0	2
340	15	120	18		0	8
300	22	-	-		0	2
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
315	15	100	18		0	
315	15	100	18		0	
315	15	100	18		0	
315	15	100	18		0	
315	15	100	18		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
370	15	120	23		0	
315	15	100	18		0	
315	15	100	18		0	
315	15	100	18		0	
315	15	100	18		0	
220	15				0	1
220	15				0	1
150	12				0	3
150	12				0	3

Table 5.3.5 – Input of stiffener scantlings

The input required appear in blue color and are summarized below :

- Width of plates
- Computed thickness of plates
- Vertical distance of each plate from bottom
- Girder hole breadth
- Corrosion addition (not necessary)
- Dimensions of stiffeners
- Number of stiffeners, where applicable
- Vertical distance of web and flange from bottom

The moment of inertia of the bilge plate is inserted individually due to it's curved geometry. In the present thesis Autocad was used as a complementary tool for the calculation of the value.

The output table 5.3.6 consists of :

- Area of Midship section
- Z co-ordinate of neutral axis from B.L
- Moment of Inertia
- Vertical distance of strength deck from neutral axis
- Section Modulus at strength deck
- Section modulus at bottom

Area of section	**3.09**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.95**	**m**
Moment of Inetia, I	**162.98**	**m4**
Vertical distance from Deck to neutral axis	**12.45**	**m**
Section Modulus at Deck	**13.09**	**m3**
Section Modulus at Bottom	**23.46**	**m3**

Table 5.3.6 – Output of 'SM calc'

In case that corrosion addition has been inserted in the corresponding tables the output properties of the section calculated are based on the net approach of the scantlings increased by 0.5 t_c as specified by the IACS rules.

Chapter 6 - Designing a Midship section

Selected Vessel

The vessel selected as a base for the present thesis has been built by DAEWOO for a Greek shipping company. Built in February 2001, and classified by ABS (American Bureau of Shipping). The main particulars of the vessel are summarized below. The size of the selected vessel is justified by the fact that it is a very usual bulk carrier design placed between the existing bulk carrier size extremes (cape and handy size), thus better allowing the generalization of any obtained results from this work. In general terms, the ship is single skin and longitudinally stiffened except for the side shell between hopper tank and the top-side tank which are transversely stiffened.

Length OA (m)	224.9
Breadth (m)	32.26
Depth (m)	19.4
LS weight (t)	12.048
Deadweight (t)	74427
Number of holds	7
Type of vessel	PANAMAX single-skin construction
Class	ABS Bureau of Shipping

A midship section drawing is cited in the end of the thesis.

6.1 Procedure

The two excel sheets, mentioned above, are useful tools in order to design the midship section of a bulk carrier without relying on a pilot ship and with no need to import geometry.

The procedure by steps is stated below:

- 1st run : Computation of scantlings using 'CSR calc' without knowledge of the position of the neutral axis
  (receive scantling values from the section 'First case' in the 'CSR calc', in this section the thickness values arise using as input for the maximum normal stress in the calculations, the maximum allowable strength of the steel used. The longitudinal stiffeners are selected according to the requirements of their net section modulus and sectional area. Generally in a transverse section the plates are liable to lower stress values as they get closer to the neutral axis. The purpose of this run is to make a first estimation of the neutral axis of the section)

- The scantlings that arise from the previous run are imported in the 'SM calc', for the first estimation of the neutral axis. No input of corrosion addition is necessary, the values can be set to zero.

- 2nd run : Computation of scantlings using the first estimation of the neutral axis that derived from the previous run. The values are received from the 'second case' of the 'CSR calc'.

- The new scantlings are imported in the 'SM calc' for a second and better estimation of the neutral axis. Corrosion addition is also imported in the corresponding input cells in order to check if the section satisfies the yield criteria by the IACS rules.

- In case the section modulus of the section is lower than the minimum value required, the top strakes (deck, stringer, upper slopping plate), are increased by the designer till the requirement is satisfied.

- Import of Gross scantlings in Mars2000 for the calculation of the ultimate strength of the midship section. In case the value of the ultimate strength of the section is lower than the required the thickness of the upper strakes are increased.

- Due to the significant increase of the scantlings of the upper strakes during the previous steps, the neutral axis has raised, submiting the bottom strakes to higher normal stresses. For this reason the gross scantlings are imported from mars to the 'SM calc', and the new neutral axis is computed.

- 3rd run : Last run of the 'CSR calc' using the neutral axis from the previous step, in order to define the final net scantlings of the midship section.

- The final gross scantlings are now imported to the 'SM calc' and the properties of the section are defined

6.2 Analytical run of a model

In this chapter, both the excel sheets with cooperation with Mars, will be used in order to compute the scantlings of a midship section with different combinations of transverse and longitudinal stiffener spacings. In the first case, the stiffening arrangement of the selected vessel will be used. In the second case, the frame space will be increased from 940 to 980 mm. Afterwards, two more runs will be conducted, the first having a frame space of 940mm and the second 980mm, and reduced longitudinal stiffener spacing. To be more precise, an extra stifferner was added to each plate except the bottom and Inner bottom, where two stiffeners were added. A final comparison of the four midship sections will be presented.

The materials used for the design of the section can be seen in the midship section drawing which is cited in the end of the thesis.

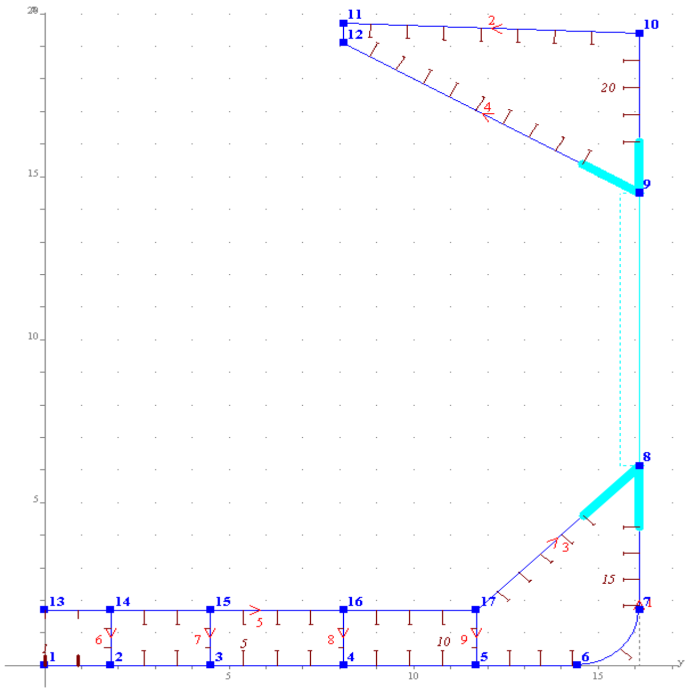


Fig.6.2.1 Midship section with no changes to the longitudinal stiffener spacing

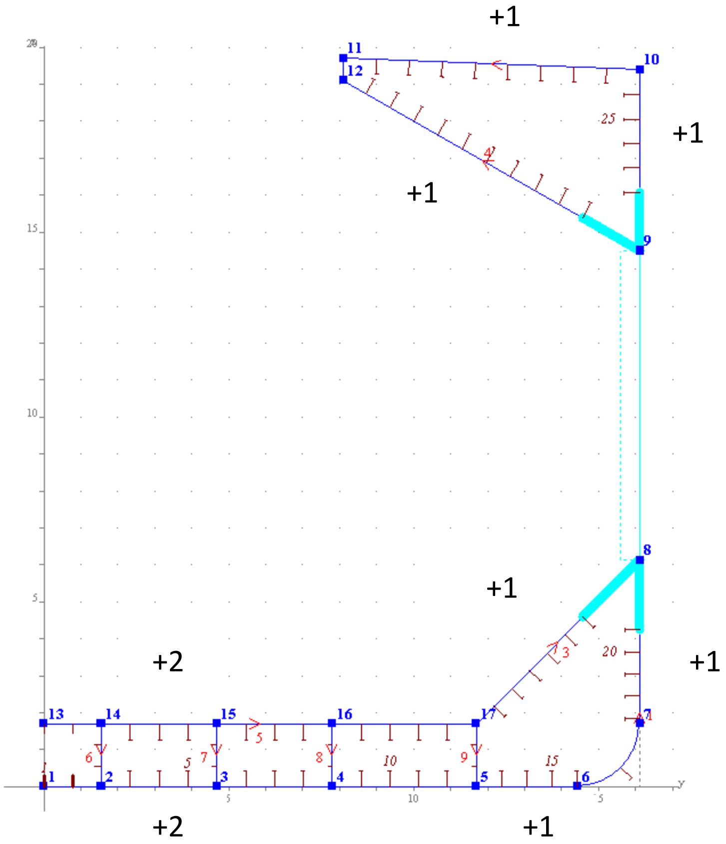


Fig.6.2.2 Midship section with reduced longitudinal stiffener spacing (addition of stiffeners)

Area of cross section		
Spacing of longitudinal Stiffeners	Frame spacing	
	940mm	980mm
As in Pilot ship	Case 1	Case 2
Pilot ship with reduced spacing of longitudinal stiffeners	Case 3	Case 4

Tab.6.2.1 – Four occasions examined

Detailed presentation of the results:

Case 1 :

- Frame space (Cargo hold) : 940 mm
- Floor space (Double Bottom) : 2.82 mm
- Web space (TST): 4.6 m
- Longitudinal stiffeners : As in Pilot ship

✓ The floor space was reduced from the already existing Bulk Carrier due to the IACS rules recommendations. The original floor space was 3.76 m. According to the rules the floor spacing is reccomened not to be greater than 3.5 m or 4 frame spaces, whichever is smaller.

1. Without knowledge of the position of the neutral axis a first estimation of the cross section is made using the ‘CSR calc’.

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	7.5	0
Deck plating (strake 2)	7.5	0
Deck plating (strake 3)	8	0
Side plate (strake 1)	12.5	0
Side plate (strake 2)	12.5	0
Side plate (strake 3)	29	0
Side plate (strake 4)	29	0
Side plate (strake 5)	29	0
Side plate (strake 6)	17	0
Slopping plate (upper wing) .-(strake1)	10	0
Slopping plate (upper wing) .-(strake2)	10.5	0
Slopping plate (upper wing) .-(strake3)	13	0
Slopping plate (upper wing) .-(strake4)	13	0
Slopping plate (hopper tank) .-(strake 1)	18	0
Slopping plate (hopper tank) .-(strake 2)	19	0
Double bottom plate (strake 1)	20.5	0
Double bottom plate (strake 2)	20.5	0
Double bottom plate (strake 3)	20.5	0
Double bottom plate (strake 4)	20.5	0
Keel plate (strake 1)	17.5	0
Bottom plate (strake 2)	17.5	0
Bottom plate (strake 3)	17.5	0
Bottom plate (strake 4)	18	0
Bottom plate (strake 5)	18	0
Bilge Plate	18	0
Girder (1/4)	11	0
Girder (2/4)	11	0
Girder (3/4)	11	0
Girder (4/4)	11	0

Table 6.2.1 – 1st estimation of Plate net scantlings

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	**h**	**t**	**bf**	**tf**		
Deck longi ' l (x7)	395	12	120	20	0	7
Bottom longi ' l (x11)	450	12	120	25	0	11
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x8)	425	12	120	25	0	8
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/9)	425	12	120	25	0	
Web space longi ' l (2/9)	425	12	120	25	0	
Web space longi ' l (3/9)	425	12	120	25	0	
Web space longi ' l (4/9)	425	12	120	25	0	
Web space longi ' l (5/9)	425	12	120	25	0	
Web space longi ' l (6/9)	425	12	120	25	0	
Web space longi ' l (7/9)	425	12	120	25	0	
Web space longi ' l (8/9)	425	12	120	25	0	
Web space longi ' l (9/9)	425	12	120	25	0	
Hopper space longi ' l (1/5)	395	12	120	20	0	
Hopper space longi ' l (2/5)	395	12	120	20	0	
Hopper space longi ' l (3/5)	395	12	120	20	0	
Hopper space longi ' l (4/5)	395	12	120	20	0	
Hopper space longi ' l (5/5)	395	12	120	20	0	
Upper side longi ' l (1/4)	425	12	120	25	0	
Upper side longi ' l (2/4)	425	12	120	25	0	
Upper side longi ' l (3/4)	425	12	120	25	0	
Upper side longi ' l (4/4)	425	12	120	25	0	
Lower side longi ' l (1/4)	425	12	120	25	0	
Lower side longi ' l] (2/4)	425	12	120	25	0	
Lower side longi ' l (3/4)	425	12	120	25	0	
Lower side longi ' l (4/4)	425	12	120	25	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Table 6.2.2 – 1st estimation of Stiffeners net scantlings

Area of section	**3.30**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.69**	**m**
Moment of Inetia, I	**161.83**	**m4**
Vertical distance from Deck to neutral axis	**12.71**	**m**
Section Modulus at Deck	**12.73**	**m3**
Section Modulus at Bottom	**24.18**	**m3**

Table 6.2.3 – 1st estimation of Area properties

2. The first estimation of the neutral axis was 6.69m,(Tab. 6.2.3). Using this value a second run is being held that leads to the following results.

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	7.5	0
Deck plating (strake 2)	7.5	0
Deck plating (strake 3)	8	0
Side plate (strake 1)	10.5	0
Side plate (strake 2)	10.5	0
Side plate (strake 3)	21	0
Side plate (strake 4)	21	0
Side plate (strake 5)	21	0
Side plate (strake 6)	14	0
Slopping plate (upper wing) .-(strake1)	9.5	0
Slopping plate (upper wing) .-(strake2)	10	0
Slopping plate (upper wing) .-(strake3)	13	0
Slopping plate (upper wing) .-(strake4)	13.5	0
Slopping plate (hopper tank) .-(strake 1)	15	0
Slopping plate (hopper tank) .-(strake 2)	16.5	0
Double bottom plate (strake 1)	18	0
Double bottom plate (strake 2)	18	0
Double bottom plate (strake 3)	18	0
Double bottom plate (strake 4)	18	0
Keel plate (strake 1)	15.5	0
Bottom plate (strake 2)	15.5	0
Bottom plate (strake 3)	15.5	0
Bottom plate (strake 4)	15.5	0
Bottom plate (strake 5)	16	0
Bilge Plate	16	0
Girder (1/4)	10	0
Girder (2/4)	10	0
Girder (3/4)	10	0
Girder (4/4)	10	0

Table 6.2.4 – 2nd estimation of Plate net scantlings

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x7)	395	12	120	20	0	7
Bottom longi ' l (x11)	340	12	120	15	0	11
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x8)	315	12	100	15	0	8
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/9)	370	12	120	20	0	
Web space longi ' l (2/9)	370	12	120	20	0	
Web space longi ' l (3/9)	370	12	120	20	0	
Web space longi ' l (4/9)	370	12	120	20	0	
Web space longi ' l (5/9)	370	12	120	20	0	
Web space longi ' l (6/9)	370	12	120	20	0	
Web space longi ' l (7/9)	370	12	120	20	0	
Web space longi ' l (8/9)	370	12	120	20	0	
Web space longi ' l (9/9)	370	12	120	20	0	
Hopper space longi ' l (1/5)	315	12	100	15	0	
Hopper space longi ' l (2/5)	315	12	100	15	0	
Hopper space longi ' l (3/5)	315	12	100	15	0	
Hopper space longi ' l (4/5)	315	12	100	15	0	
Hopper space longi ' l (5/5)	315	12	100	15	0	
Upper side longi ' l (1/4)	370	12	120	20	0	
Upper side longi ' l (2/4)	370	12	120	20	0	
Upper side longi ' l (3/4)	370	12	120	20	0	
Upper side longi ' l (4/4)	370	12	120	20	0	
Lower side longi ' l (1/4)	315	12	100	15	0	
Lower side longi ' l] (2/4)	315	12	100	15	0	
Lower side longi ' l (3/4)	315	12	100	15	0	
Lower side longi ' l (4/4)	315	12	100	15	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Table 6.2.5 – 2nd estimation of Stiffeners net scantlings

Area of section	**2.77**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.85**	**m**
Moment of Inetia, I	**143.77**	**m4**
Vertical distance from Deck to neutral axis	**12.55**	**m**
Section Modulus at Deck	**11.46**	**m3**
Section Modulus at Bottom	**20.97**	**m3**

Table 6.2.6 – 2nd estimation of Area properties

3. The Area of the section was reduced significantly from 3.30 m^2 to 2.77 m^2 . The new estimation of the neutral axis is 6.85 m. The next step is to check if the section satisfies the yielding criteria of the rules. Adding the appropriate corrosion margin, (no voluntary corrosion margin is added), to all the plates including stiffeners the results that derived from the 'SM calc' appear below :

	Net scantlings (mm)	**Corrosion (mm)**
Deck plating (strake 1)	7.5	4
Deck plating (strake 2)	7.5	4
Deck plating (strake 3)	8	4
Side plate (strake 1)	10.5	3.5
Side plate (strake 2)	10.5	3
Side plate (strake 3)	21	2.5
Side plate (strake 4)	21	2.5
Side plate (strake 5)	21	2.5
Side plate (strake 6)	14	3
Slopping plate (upper wing) .-(strake1)	9.5	3.5
Slopping plate (upper wing) .-(strake2)	10	3.5
Slopping plate (upper wing) .-(strake3)	13	3
Slopping plate (upper wing) .-(strake4)	13.5	3
Slopping plate (hopper tank) .-(strake 1)	15	4.5
Slopping plate (hopper tank) .-(strake 2)	16.5	4.5
Double bottom plate (strake 1)	18	4.5
Double bottom plate (strake 2)	18	4.5
Double bottom plate (strake 3)	18	4.5
Double bottom plate (strake 4)	18	4.5
Keel plate (strake 1)	15.5	2.5
Bottom plate (strake 2)	15.5	3
Bottom plate (strake 3)	15.5	3
Bottom plate (strake 4)	15.5	3
Bottom plate (strake 5)	16	3
Bilge Plate	16	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Table 6.2.7 – 2nd estimation of Plate net scantlings with corrosion margin

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x7)	395	12	120	20	3	7
Bottom longi ' l (x11)	340	12	120	15	3	11
Bottom longi ' l -flat bar- (x2)	300	20	-	-	2	2
Inner Bottom longi ' l (x8)	315	12	100	15	3	8
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	2	2
Web space longi ' l (1/9)	370	12	120	20	3	
Web space longi ' l (2/9)	370	12	120	20	3	
Web space longi ' l (3/9)	370	12	120	20	3	
Web space longi ' l (4/9)	370	12	120	20	3	
Web space longi ' l (5/9)	370	12	120	20	3	
Web space longi ' l (6/9)	370	12	120	20	3	
Web space longi ' l (7/9)	370	12	120	20	3	
Web space longi ' l (8/9)	370	12	120	20	3	
Web space longi ' l (9/9)	370	12	120	20	3	
Hopper space longi ' l (1/5)	315	12	100	15	3	
Hopper space longi ' l (2/5)	315	12	100	15	3	
Hopper space longi ' l (3/5)	315	12	100	15	3	
Hopper space longi ' l (4/5)	315	12	100	15	3	
Hopper space longi ' l (5/5)	315	12	100	15	3	
Upper side longi ' l (1/4)	370	12	120	20	3	
Upper side longi ' l (2/4)	370	12	120	20	3	
Upper side longi ' l (3/4)	370	12	120	20	3	
Upper side longi ' l (4/4)	370	12	120	20	3	
Lower side longi ' l (1/4)	315	12	100	15	3	
Lower side longi ' l] (2/4)	315	12	100	15	3	
Lower side longi ' l (3/4)	315	12	100	15	3	
Lower side longi ' l (4/4)	315	12	100	15	3	
Upper longi ' l of Center girder	220	13			2	1
Lower longi ' l of Center girder	220	13			2	1
Upper longi ' l of girders	150	10			2	3
Lower longi ' l of girders	150	10			2	3

Table 6.2.8 – 2nd estimation of Stiffeners net scantlings with corrosion

Area of section	**3.09**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.95**	**m**
Moment of Inetia, I	**162.98**	**m4**
Vertical distance from Deck to neutral axis	**12.45**	**m**
Section Modulus at Deck	**13.09**	**m3**
Section Modulus at Bottom	**23.46**	**m3**

Table 6.2.9 – Check of 2nd estimation scantlings Yielding criteria

Requirments	**k=0.78 - High Tensile**	
ZRmin	16.56	m3
ZR	16.95	m3
Imin	138.23	m4

Table 6.2.10 –Yielding requirements

4. It can be seen that that the section modulus at deck, (13.09m3), is below the lower limit from IACS rules, (16.95m3). As a result, the thickness of the upper plates is increased till the requirement is satisfied. The scantlings appear below:

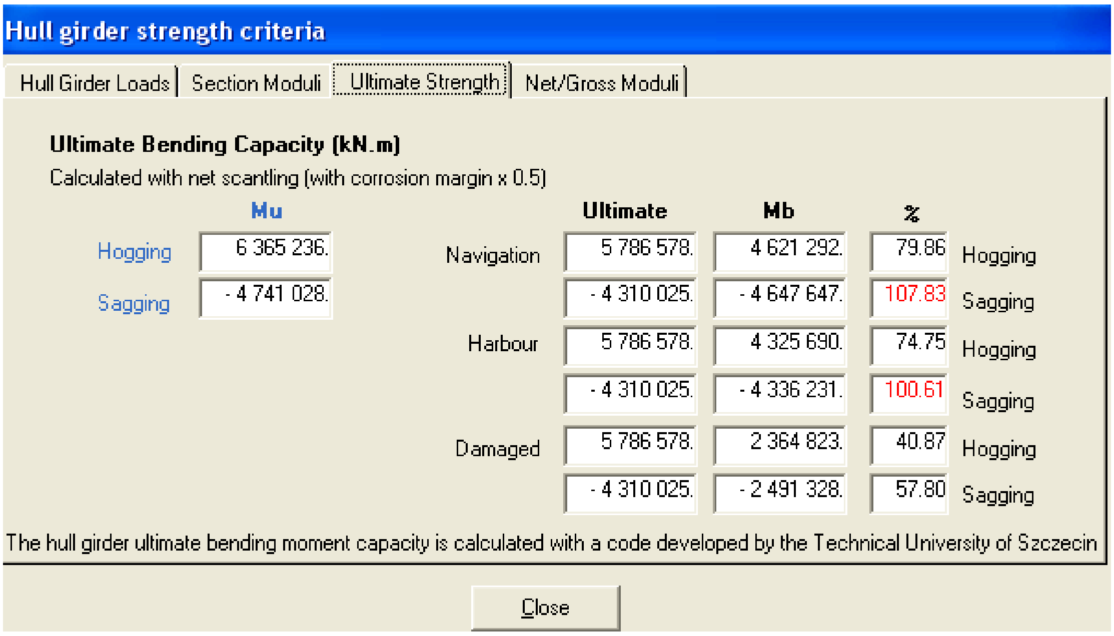
	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	18	4
Deck plating (strake 2)	18	4
Deck plating (strake 3)	18	4
Side plate (strake 1)	15	3.5
Side plate (strake 2)	15	3
Side plate (strake 3)	21	2.5
Side plate (strake 4)	21	2.5
Side plate (strake 5)	21	2.5
Side plate (strake 6)	14	3
Slopping plate (upper wing) .-(strake1)	15	3.5
Slopping plate (upper wing) .-(strake2)	15	3.5
Slopping plate (upper wing) .-(strake3)	16	3
Slopping plate (upper wing) .-(strake4)	16	3
Slopping plate (hopper tank) .-(strake 1)	15	4.5
Slopping plate (hopper tank) .-(strake 2)	16.5	4.5
Double bottom plate (strake 1)	18	4.5
Double bottom plate (strake 2)	18	4.5
Double bottom plate (strake 3)	18	4.5
Double bottom plate (strake 4)	18	4.5
Keel plate (strake 1)	15.5	2.5
Bottom plate (strake 2)	15.5	3
Bottom plate (strake 3)	15.5	3
Bottom plate (strake 4)	15.5	3
Bottom plate (strake 5)	16	3
Bilge Plate	16	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Table 6.2.11 –Plate scantlings increased due to Yielding criteria

Area of section	**3.37**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.93**	**m**
Moment of Inetia, I	**198.61**	**m4**
Vertical distance from Deck to neutral axis	**11.47**	**m**
Section Modulus at Deck	**17.32**	**m3**
Section Modulus at Bottom	**25.03**	**m3**

Table 6.2.12 – Area properties after increase due to Yielding cretiria

5. The section modulus has now increased to 17.32 m^3. Care must be taken so that the section is not overdesigned, meaning that the section modulus is not significantly higher than the lower limit of the Rules. The last requirement needed to be satisfied is that of the Ultimate strength. In order to check the ultimate strength of the section Mars2000 will be used. Following the geometry, the scantlings are imported to Mars2000 and the results are the appear below :



Ultimate Bending Capacity (kN.m)

Calculated with net scantling (with corrosion margin x 0.5)

	Mu
Hogging	6 365 236.
Sagging	- 4 741 028.

	Ultimate	Mb	%	
Navigation	5 786 578.	4 621 292.	79.86	Hogging
	- 4 310 025.	- 4 647 647.	107.83	Sagging
Harbour	5 786 578.	4 325 690.	74.75	Hogging
	- 4 310 025.	- 4 336 231.	100.61	Sagging
Damaged	5 786 578.	2 364 823.	40.87	Hogging
	- 4 310 025.	- 2 491 328.	57.80	Sagging

The hull girder ultimate bending moment capacity is calculated with a code developed by the Technical University of Szczecin

Fig. 6.2.1 – Check for Ultimate Bending Capacity

6. The Ultimate bending capacity of the section is 6365236 (Kn.m), in hogging condition and -4741028 (KN.m), in sagging condition. A safety factor taken equal to 1.1 is used and the values drop to 5786578 (KN.m) and -4310025

(KN.m), respectively for the three conditions, Navigation, Harbour and Damaged. The lower limits according to the IACS rules appear on the second column. The formula to calculate these values is:

$$M = M_{SW} + \gamma_W * M_{WV}$$

where :

M_{SW}, $M_{SW,F}$, $M_{SW,P}$: Design still water bending moment in sagging and hogging condtions at the hull transverse section , to be calculated respectively in intact, flooded and harbor conditions

M_{WV}, $M_{WV,F}$, $M_{WV,P}$: Vertical wave bending moment in sagging and hogging condtions at the hull transverse section , to be calculated respectively in intact, flooded and harbor conditions

γ_W : Safety factor on wave hull girder bending moments taken equal to 1.20

In order to increase the section modulus of the transverse section at the Navigation and Harbour condition, (sagging), some of the upper plate thickness will be increased. The modified gross scantlings appear on the table below:

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	19.5	4
Deck plating (strake 2)	19.5	4
Deck plating (strake 3)	20	4
Side plate (strake 1)	17	3.5
Side plate (strake 2)	16.5	3
Side plate (strake 3)	21	2.5
Side plate (strake 4)	21	2.5
Side plate (strake 5)	21	2.5
Side plate (strake 6)	14	3
Slopping plate (upper wing) .-(strake1)	17	3.5
Slopping plate (upper wing) .-(strake2)	16	3.5
Slopping plate (upper wing) .-(strake3)	16.5	3
Slopping plate (upper wing) .-(strake4)	17	3
Slopping plate (hopper tank) .-(strake 1)	15	4.5
Slopping plate (hopper tank) .-(strake 2)	16.5	4.5
Double bottom plate (strake 1)	18	4.5
Double bottom plate (strake 2)	18	4.5
Double bottom plate (strake 3)	18	4.5
Double bottom plate (strake 4)	18	4.5
Keel plate (strake 1)	15.5	2.5
Bottom plate (strake 2)	15.5	3
Bottom plate (strake 3)	15.5	3
Bottom plate (strake 4)	15.5	3
Bottom plate (strake 5)	16	3
Bilge Plate	16	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Table 6.2.13 –Plate scantlings increased due to Ultimate Bending Capacity

Area of section	**3.75**	**m^2**
Z co-ordinate of neutral axis from B.L	**8.08**	**m**
Moment of Inetia, I	**223.70**	**m4**
Vertical distance from Deck to neutral axis	**11.32**	**m**
Section Modulus at Deck	**19.77**	**m3**
Section Modulus at Bottom	**27.67**	**m3**

Table 6.2.14 – Area properties after increase due to Ultimate Bending Capacity

7. Therefore, it can be noticed that the neutral axis has risen significantly from 6.85m, before the increase due to the yield and ultimate strength check, to 8.08m. As a result, a final run of the 'SM calc' will be conducted using this value of the position of neutral axis. An increase in the thickness of the bottom plates is expected. The Final Scantlings and section properties of the section appear below:

	Gross scantlings (mm)
Deck plating (strake 1)	23.5
Deck plating (strake 2)	23.5
Deck plating (strake 3)	24
Side plate (strake 1)	20.5
Side plate (strake 2)	19.5
Side plate (strake 3)	22.5
Side plate (strake 4)	22.5
Side plate (strake 5)	22.5
Side plate (strake 6)	17.5
Slopping plate (upper wing) .-(strake1)	20.5
Slopping plate (upper wing) .-(strake2)	19.5
Slopping plate (upper wing) .-(strake3)	19.5
Slopping plate (upper wing) .-(strake4)	20
Slopping plate (hopper tank) .-(strake 1)	20
Slopping plate (hopper tank) .-(strake 2)	22
Double bottom plate (strake 1)	23.5
Double bottom plate (strake 2)	23.5
Double bottom plate (strake 3)	23.5
Double bottom plate (strake 4)	23.5
Keel plate (strake 1)	18.5
Bottom plate (strake 2)	19
Bottom plate (strake 3)	19.5
Bottom plate (strake 4)	19.5
Bottom plate (strake 5)	19.5
Bilge Plate	19.5
Girder (1/4)	13
Girder (2/4)	13
Girder (3/4)	13
Girder (4/4)	13

Table 6.2.15 –Final gross Plate scantlings

	Gross scantlings				Number of stiffeners
Stiffeners	h	t	bf	tf	
Deck longi ' l (x7)	395	15	120	23	7
Bottom longi ' l (x11)	370	15	120	18	11
Bottom longi ' l -flat bar- (x2)	300	22	-	-	2
Inner Bottom longi ' l (x8)	340	15	120	18	8
Inner bottom longi ' l -flat bar- (x2)	300	22	-	-	2
Web space longi ' l (1/9)	370	15	120	23	
Web space longi ' l (2/9)	370	15	120	23	
Web space longi ' l (3/9)	370	15	120	23	
Web space longi ' l (4/9)	370	15	120	23	
Web space longi ' l (5/9)	370	15	120	23	
Web space longi ' l (6/9)	370	15	120	23	
Web space longi ' l (7/9)	370	15	120	23	
Web space longi ' l (8/9)	370	15	120	23	
Web space longi ' l (9/9)	370	15	120	23	
Hopper space longi ' l (1/5)	315	15	100	18	
Hopper space longi ' l (2/5)	315	15	100	18	
Hopper space longi ' l (3/5)	315	15	100	18	
Hopper space longi ' l (4/5)	315	15	100	18	
Hopper space longi ' l (5/5)	315	15	100	18	
Upper side longi ' l (1/4)	370	15	120	23	
Upper side longi ' l (2/4)	370	15	120	23	
Upper side longi ' l (3/4)	370	15	120	23	
Upper side longi ' l (4/4)	370	15	120	23	
Lower side longi ' l (1/4)	315	15	100	18	
Lower side longi ' l] (2/4)	315	15	100	18	
Lower side longi ' l (3/4)	315	15	100	18	
Lower side longi ' l (4/4)	315	15	100	18	
Upper longi ' l of Center girder	220	15			1
Lower longi ' l of Center girder	220	15			1
Upper longi ' l of girders	150	12			3
Lower longi ' l of girders	150	12			3

Table 6.2.16 –Final gross Stiffeners scantlings

Area of section	**3.91**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.76**	**m**
Moment of Inetia, I	**233.01**	**m4**
Vertical distance from Deck to neutral axis	**11.64**	**m**
Section Modulus at Deck	**20.02**	**m3**
Section Modulus at Bottom	**30.02**	**m3**

Table 6.2.17 –Final Area Properties

1. The Final properties of the Midship section appear on the table above. It is reminded that the materials used are appear in the midship section drawing cited in the end of the thesis. The same procedure is being followed for the three additional modificated midship sections.
   The Tables are attached in the Appendix 1.

6.3 Evaluation of the Excel sheets

An evaluation of the 'Csr calc' and 'SM calc' was conducted by the comparison of their output values with the ones deriving from Mars2000. It will be noticed that the differences are negligible, resulting to the increase of their reliability.

6.3.1 'Csr calc'

The external still and wave pressure for all load cases and the internal respectively, at a point with random coordinates will be compared and summarized in the table below:

- Co-ordinates of point for analysis : (x, y, z) = (109.36, 2.7, 0)
- Output Values: External pressures on the above point for both Full load and Ballast conditions, Ship Motions and accelerations, Moments and Shear forces.

Full Load condition					
EXTERNAL PRESSURES	Load cases	**CSR CALC**		**MARS2000**	
Hydrostatic pressure (KN/m^2)		141.78		141.78	
Hydrodynamic pressure (KN/m^2)	H1	40.14		38.67	
	H2	-40.14		-38.67	
	F1	-37.59		-36.21	
	F2	37.59		36.21	
	R1	19.62		16.93	
	R2	-19.62		-16.93	
		Weather side	*Lee side*	*Weather side*	*Lee side*
	P1	14.85	4.95	11.06	-3.69
	P2	-14.85	-4.95	-11.06	3.69

Table 6.3.1.1 –External pressures, Full Load condition

Ballast condition					
EXTERNAL PRESSURES	Load cases	**CSR CALC**		**MARS2000**	
Hydrostatic pressure		54.3		54.2	
Hydrodynamic pressure	H1	-29.45		-24.98	
	H2	29.45		24.98	
	F1	-37.59		-32.92	
	F2	37.59		32.92	
	R1	18.56		15.77	
	R2	-18.56		-15.77	
		Weather side	*Lee side*	*Weather side*	*Lee side*
	P1	12.94	4.31	9.63	-3.21
	P2	-12.94	-4.31	-9.63	3.21

Table 6.3.1.2 – External pressures, Ballast condition

Ship Motions and accelerations	**CSR CALC**		**MARS2000**	
Surge acceleration	0.71		0.71	
Sway acceleration	1.064		1.064	
Heave acceleration	3.548		3.548	
Roll	*Full Load condition*	*Ballast condition*	*Full Load condition*	*Ballast condition*
- Amplitude	24.58	26.56	24.57	26.55
- Period	13.19	10.23	13.19	10.23
Pitch			-	-
- Amplitude	9.01	9.01	9.01	9.01
- Period	12.91	10.73	12.91	11.49

Table 6.3.1.3 – Ship Motions and accelerations

Moments and Shear Forces	**CSR CALC**	**MARS2000**
Vertical Wave Bending Moments		
- Hogging	2463357	2463357
-Sagging	2595133	2595133
Vertical still water Bending Moments		
- Hogging	1665263	1665263
-Sagging	1533488	1533488
Vertical Wave shear Force	22831	22831
Horizontal wave Bending Moment	2314838	2314838

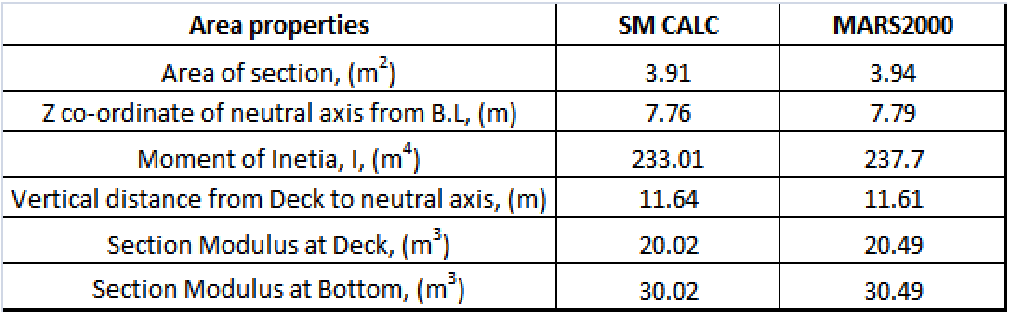
Table 5.3.1.2 – Moments and shear Forces

Regarding the 'Ship motions and accelerations' and 'Moments and shear forces', the values of both programs are identically equal. A few differences exist in the external hydrodynamic pressures. As it can be noticed Mars2000 outputs lower pressure values for most of the loading cases. However, given the fact that the differences are small, the impact upon the final scantlings is inconsiderable.

6.3.2 'SM calc'

The 'SM calc' is a helpful tool in order to calculate the properties of the trasverse section of the vessel for analysis. It cannot be used, without modifications, for all bulk carriers due to the different number of stiffeners they might have. For this reason, some additional cells where added in order to analyze the midship section when the span of the stiffeners was decreased. Mars2000 can also compute the properties of a section when geometry is imported, and it can be used as a verification tool for the validation of the output from 'SM calc'.

The properties of the section for case 1, designed in the previous chapter, will be compared with the values from Mars2000. The results are presented in the following table 6.3.2.1:



Area properties	SM CALC	MARS2000
Area of section, (m^2)	3.91	3.94
Z co-ordinate of neutral axis from B.L, (m)	7.76	7.79
Moment of Inetia, I, (m^4)	233.01	237.7
Vertical distance from Deck to neutral axis, (m)	11.64	11.61
Section Modulus at Deck, (m^3)	20.02	20.49
Section Modulus at Bottom, (m^3)	30.02	30.49

Table 6.3.2.1 – Area properties

The output obtained from both programs are approximately the same. The values differ after the second decimal number and no further optimization is necessary. The purpose of this sheet is to check if the transverse section satisfies the longitudinal strength requirements according to the IACS rules. The section modulus of the section should be greater than a minimum value which depends on the principle dimensions of the ship and the vertical moments applied.

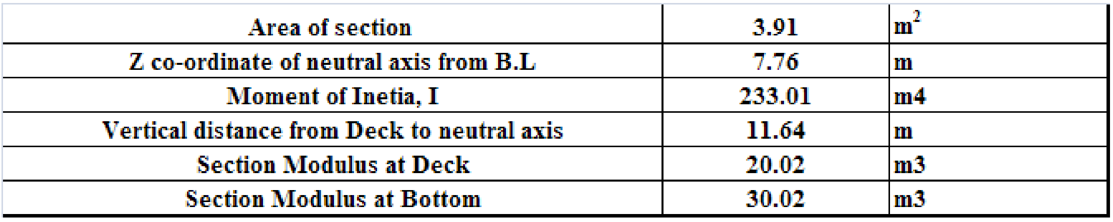
6.4 Results

In order to examine the impact that some structural changes might have on the final scantlings of the transverse section four different runs where conducted with modifications in the frame spacing and in the spacing of the longitudinal stiffeners. The results of the final area properties are depicted in the following tables.

Case 1 :

Frame space 940 mm

Spacing of stiffeners : As in Pilot ship



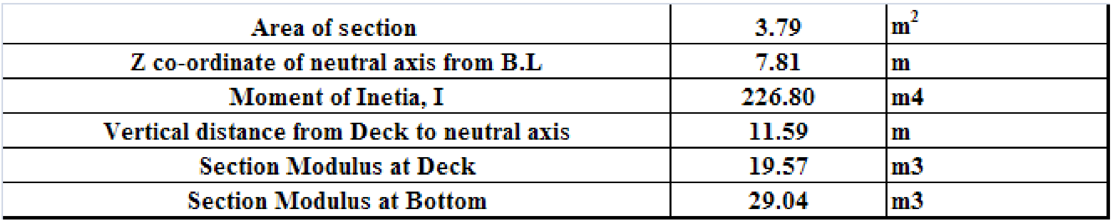
Area of section	**3.91**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.76**	**m**
Moment of Inetia, I	**233.01**	**m4**
Vertical distance from Deck to neutral axis	**11.64**	**m**
Section Modulus at Deck	**20.02**	**m3**
Section Modulus at Bottom	**30.02**	**m3**

Table 6.4.1 – Area properties for case 1

Case 2:

Frame space 940mm

Spacing of stiffeners : Decrease of spacing



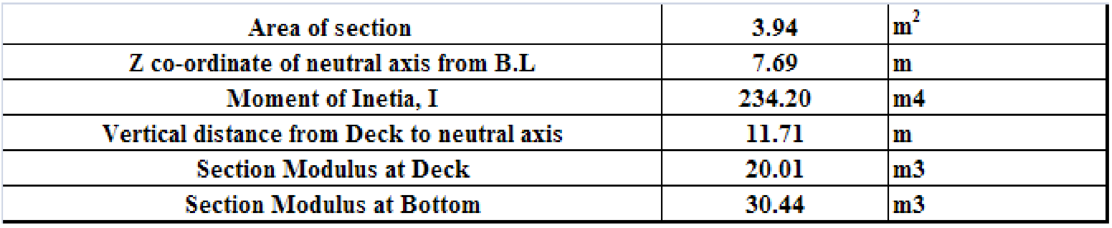
Area of section	3.79	m^2
Z co-ordinate of neutral axis from B.L	7.81	m
Moment of Inetia, I	226.80	m4
Vertical distance from Deck to neutral axis	11.59	m
Section Modulus at Deck	19.57	m3
Section Modulus at Bottom	29.04	m3

Table 6.4.2 – Area properties for case

Case 3:

Frame space 980mm

Span of stiffeners : As in Pilot ship



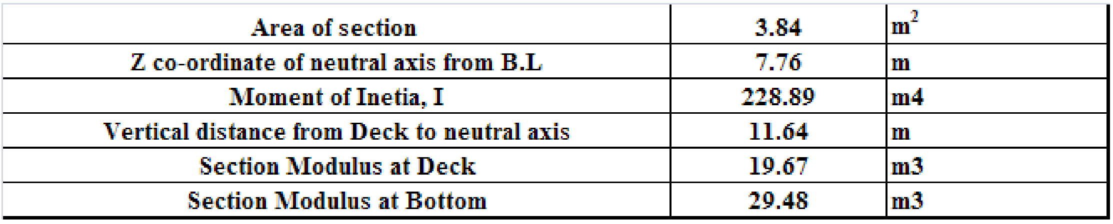
Area of section	3.94	m^2
Z co-ordinate of neutral axis from B.L	7.69	m
Moment of Inetia, I	234.20	m4
Vertical distance from Deck to neutral axis	11.71	m
Section Modulus at Deck	20.01	m3
Section Modulus at Bottom	30.44	m3

Table 6.4.3 – Area properties for case 3

Case 4:

Frame space 980mm

Spacin of stiffeners : Decrease of spacing



Area of section	3.84	m^2
Z co-ordinate of neutral axis from B.L	7.76	m
Moment of Inetia, I	228.89	m4
Vertical distance from Deck to neutral axis	11.64	m
Section Modulus at Deck	19.67	m3
Section Modulus at Bottom	29.48	m3

Table 5.4.4 – Area properties for case 4

A *summary table* with the cross section Areas of each case is shown below :

Area of cross section		
Spacing of longitudinal Stiffeners	Frame spacing	
	940mm	980mm
As in Pilot ship	3.91 m^2	3.94 m^2
Pilot ship with reduced spacing of longitudinal stiffeners	3.79 m^2	3.84 m^2

Table 6.4.5 – Area for all cases

6.5 Conclusions

The increase of the transverse frames spacing by 40mm , leads to an increase of the Area of the section of about 0.03 – 0.05 m^2 . However, the change of the spacing of the longitudinal stiffeners has a bigger influence which leads to values around 0.1 m^2 , almost doubled. The affect is significant, it reaches 2.5% of the area/weight of the ship. The cost of the steel during the ship built would decrease if more stiffeners were added due to the smaller scantlings of the shell plates. The requirements of the IACS rules would also be satisfied as there is no limit about the spacing of the stiffeners that the designer will decide on. Welding work would increase, as well as working man hours , thus, it would be a more cost efficient choice.

Chapter 7 - Modeling using Finite Elements

IACS CSR for Bulk carriers contain guidelines on the procedure that and the type of elements which are used in order to design a model for further analysis. The model should have a length of three holds, for ships over 150m, while for the rest of the ships the use of the FEA method is not necessary. The model consists of two types of elements. Plate elements for the outer shell and the primary supporting members, i.e girders, floors, and beam elements for the stiffeners. The properties and differences of these two types will be depicted further on.

On this thesis, three models have been created. They consist of the double bottom and hopper tank including all the longitudinal and transverse stiffening, with length of one cargo hold. The scantlings and loads as well as the boundary conditions will be the same and a comparison of the output values obtained will be presented in the end.

7.1 Properties of Elements and material used

Type of elements :

- Beam element :

  Description: Uniaxial element with tension, compression, torsion, and bending capabilities. This element can be tapered. Different properties can be specified at each end of the beam.

  Properties: Area, Moments of Inertia (I1, I2, I12), Torsional Constant, Shear Areas (Y, Z), Nonstructural Mass/Length, Warping Constant, Stress Recovery Locations, Neutral Axis Offsets (Nay, Naz, Nby and Nbz).

- Plate element :

  Description: A combined planar shell element. This element typically resists membrane (in-plane), shear forces, and bending moments.

Properties: Thickness (average, or varying at each corner), Nonstructural mass/area, Bending Stiffness parameter, Transverse shear/Membrane thickness, Bending, Shear and Membrane-Bending Coupling Materials, Fiber distances for stress recovery.

- Rigid element:
  Description: Represents a rigid connection between a master node and one or more other nodes. It is used for modeling connections which are very stiff relative to the remainder of the structure.
  Properties: None

Material used in the models : The material used is elastic isotropic with Young modulus equal to 206 GPa, mass density 7.85 t/m^3 and Poisson ratio 0.3

7.2 Loading and Boundary conditions

Loading cases : Each model response was examined under two different loading cases and boundary conditions.

In the first scenario, (Scenario A), the loads applied on the models were the hydrostatic and hydrodynamic external pressures that act on the ship in the Full load condition and the H2 load cace, (hogging condition), with draught equal to 14.1m. The internal still and inertia pressures due to the cargo were also calculated by the 'CSR calc' and were applied on the models. In hogging condition all the elements below the neutral axis of a midship section underlie to compression. In order to simulate this condition, without having the rest of the midship section modeled, a compression force on the x-axis was applied on the model. All the nodes of the longitudinal members at each edge of the model were connected to a master node with rigid links ,(Fig.7.2.1) and the force was applied on it.

In the second scenario, (Scenario B), only the external still water loads were applied in the outer shell and no other pressure or compression force.

Pressure equations: 'SM calc' was used in order to reach the final equations of still and inertia pressures that a ship is submitted to. These equations were used in Femap for the calculation of the load of each element.

External still pressure:

$$(H.Pr_0) + (1025 * 9.81 * (ZEL))$$

External hydrodynamic pressure,(hogging):

$$-1000 * (- (1 + \left(\frac{6}{C_B}\right) * \left(3 - \frac{4 * |YEL|}{B}\right) * \left|\frac{XEL}{L} - 0.5\right|^3 \\ * \left(14.75 - \left(\frac{300 - L}{100}\right)^{\frac{3}{2}}\right) * \sqrt{2.2 - \frac{125}{L}} * \left(\frac{ZEL}{T} + \left|\frac{2YEL}{T}\right| + 1\right)$$

Still dry bulk cargo pressure:

$$SF * 9.81 * \left(\cos\left(\frac{a * 3.14}{180}\right)\right)^2 * 0.5 * \left(\sin\left(\frac{a * 3.14}{180}\right)\right)^2 \\ * \left(h_{HPU} + \frac{S_0 + \frac{V_{HC}}{L_H}}{B_H} + h_{DB} - ZEL\right)$$

Inertial pressure due to dry bulk cargo:

$$
\begin{aligned}
SF * \Bigg[0.25 * \Bigg(& -9.81 \\
& * \sin\left(\frac{\Phi * 3.14}{180}\right) - 0.8 * a_{surge} \\
& + \left(\Phi * \frac{3.14}{180} * \left(\frac{6.18}{T_p}\right)^2 * \left(ZEL - MIN\left(\left(\frac{D}{4} + \frac{T}{2}\right), \frac{D}{2} \right) \right) \right) \Bigg) \\
& * (-0.25 * L_H) + \left(\left(\cos \frac{a * 3.14}{180} \right)^2 + 0.5 * \left(\sin \frac{a * 3.14}{180} \right)^2 \right) \\
& * \Bigg(-0.6 * a_{heave} \\
& + \left(\frac{3.14 * \Phi}{180} * \left(\frac{6{,}18}{T_p}\right)^2 * MAX(0{,}2L\,, |XEL - 0.45L|) \right) \Bigg) \\
& * \left(h_{HPU} + \frac{S_0 + \frac{V_{HC}}{L_H}}{B_H} + h_{DB} - ZEL \right) \Bigg]
\end{aligned}
$$

All the values obtained from the previous formulae are in Pa.

Where:

- Hold Length, (l_H)
- Hold Breadth, (B_H)
- Height of D.B, (h_{DB})
- Vertical distance between inner bottom and lower interception of top side tank and side shell, (h_{HPU})
- Volume of hatch coaming, (V_{HC})
- Area above the lower interception of topside tank and side shell till the upper deck level, (S_o)
- Density of the cargo, (S_F)
- Legth between peperdiculars, (L)

- Moulded Breadth, (B)
- Depth, (D)
- T, (Draught)
- Breadth of cargo hold, (B_H)
- Block coefficient, (C_B)
- Angle between panel and considered horizontal plane in degrees, (α)
- X co-ordinate of element, (XEL)
- Y co-ordinate of element, (YEL)
- Z co-ordinate of element, (ZEL)
- Initial hydrostatic pressure, ($H.Pr_0$)
- Single pitch amplitude in degrees, (Φ)
- Vertical acceleration, (a_{heave})
- Longitudinal acceleration, (a_{surge})

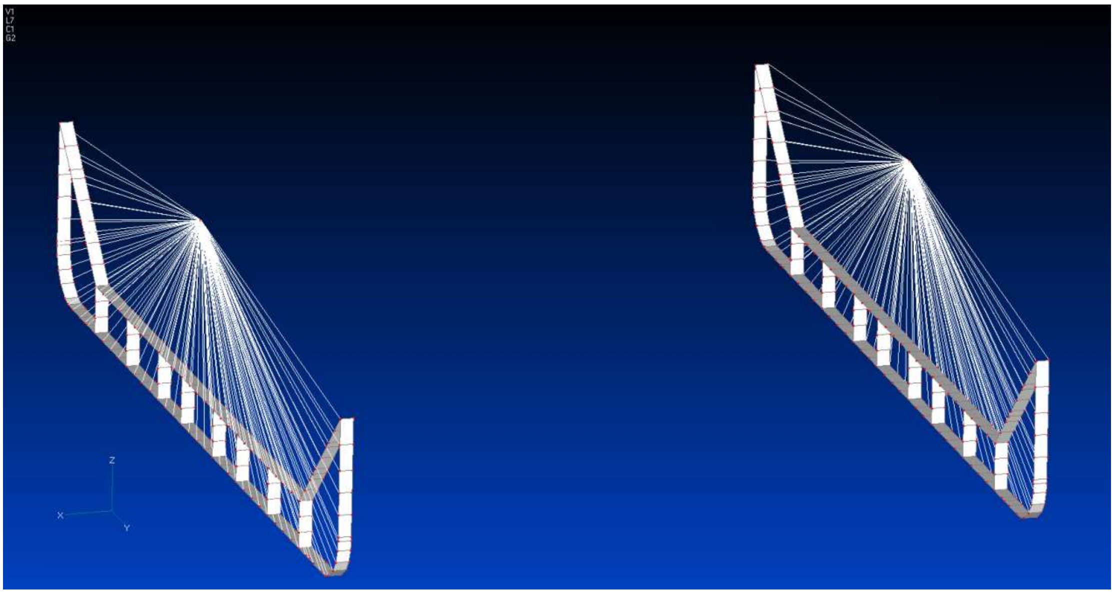


Fig.7.2.1 – Rigid Links

Boundary conditions: The boundary conditions differ for each loading case, but remain the same for all models and they were applied only on the two master nodes in the fore and aft of the model.

In the first scenario, (Scenario A), one master node was fixed, meaning that all rotations and translations were restricted, while the other was able to translate only in the X axis in which the compression force was applied. Connecting the outer nodes with rigid elements makes the edge transverse sections of the model to remain in plane.

In the second scenario, (Scenario B), all translations and rotations are restricted for both master nodes.

7.3 F.E Model evaluation

Most classification societies indicate the maximum distortion values for the elements, which can be used for evaluation of the model that has been designed. However, IACS does not refer to a way of evaluation of the F.E model rather than the aspect ratio of the elements that is not to exceed 1:4.

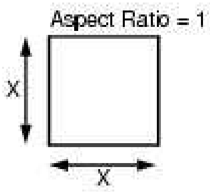
ABS, (American Bureau of Shipping), guidelines for the verification of the model were followed during this thesis. These are:

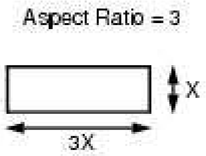
- Aspect ratio should be less than 3
- Taper should be less than 10
- Warping should be less than 10
- Internal angles should not be less than 30 degrees
- No free edge caused by wrong element connectivity
- Coincident nodes should be merged
- No coincident elements should exist

Femap is equipped with tools to check the distortion of the elements, so that in all models no element exceeded the above limits. A further explanation of the four first restrictions follows:

Aspect Ratio Checking

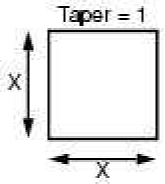
Is based on the ratio of the length of the longest element side, to the length of the shortest side. This check looks at all element edges to find the maximum and minimum lengths. Only element corners are used. Midside nodes of parabolic elements are simply ignored.

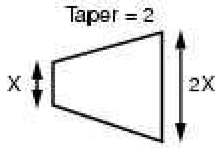




Taper Checking

Is similar to aspect ratio checking. It formulates a ratio of the length of a longest edge to a shortest edge. Whereas aspect ratio checking looks at all edge combinations, Taper checking only considers ratios of edges which are opposite to each other on a face. Midside nodes are ignored.

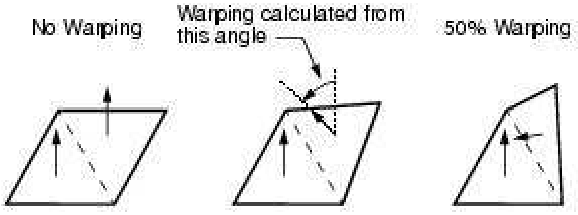




Taper checking is only done on quadrilateral faces. It will identify elements which have trapezoidal faces.

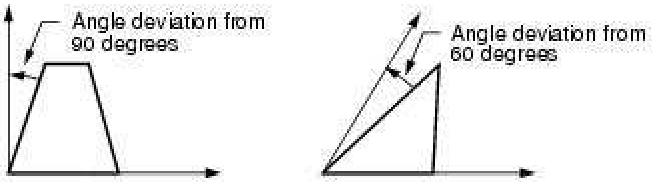
Warping Checking

Evaluates the planarity of element faces. This check evaluates "out of plane" parameters. This check only looks at quadrilateral faces. Internally, this check divides the quadrilateral face into triangles. If the face is planar, then all triangles should be coplanar. That is, their normals will all point in the same direction. If the face is warped however, the normals will not be in the same direction. This check evaluates the maximum angle between the normals, and identifies any elements where the angle exceeds the limit you specify.



Internal Angles Checking

Evaluates whether the included angles at the corners of an element face deviate from an optimal condition. For quadrilateral faces, the deviation is based on a 90 degree angle. For triangular faces, the deviation is based on a 60 degree angle.



This check will identify elements which are skewed from a square or equilateral triangle.

7.4 *Mesh Description*

7.4.1 *1 st Model description*

The first model was created according to the specifications of the IACS rules and is consisted of 14.778 elements. The outer shell and primary supporting members were modeled using plate elements. However, beam elements were used for all the stiffeners. The size of the plate elements is 470 x 900. The spacing of the longitudinal stiffeners is 900mm, and only one element lies between two longitudinal stiffeners. The frame spacing is 940mm. It was decided that two elements should cover this length. IACS indicates that the mesh size is to be equal to or less than the representative longitudinal stiffener or transverse side frame spacing. A global view of the model is shown at Fig.7.4.1.1

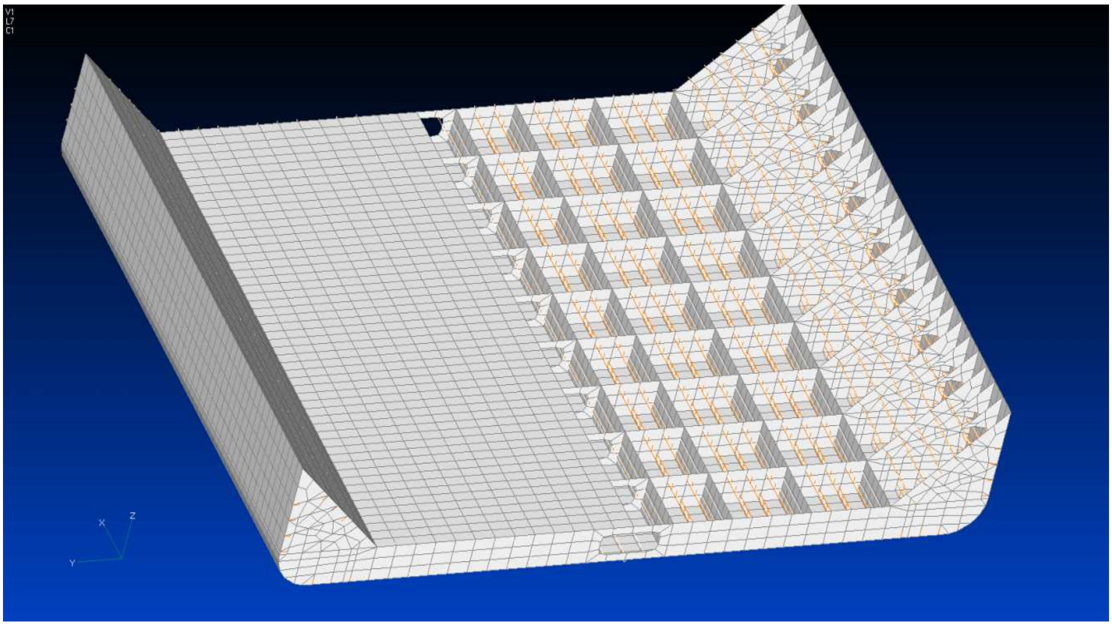


Fig.7.4.1.1 – 1st Model Global view

There were some difficulties in the meshing of the hopper web plates due to the stiffeners that had to be added. That’s the reason why a mapped meshing could not be followed. However, in all cases none of the elements exceeded the maximum distortion values given from the classification societies. The mesh of the hopper web plates with the attached stiffeners is shown at Fig.7.4.1.2

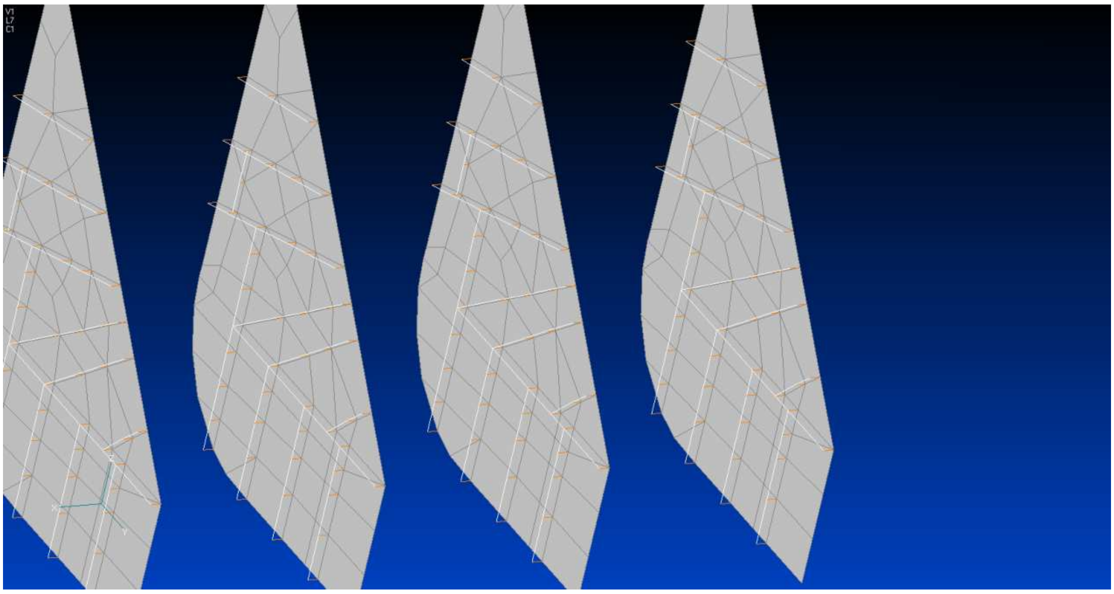
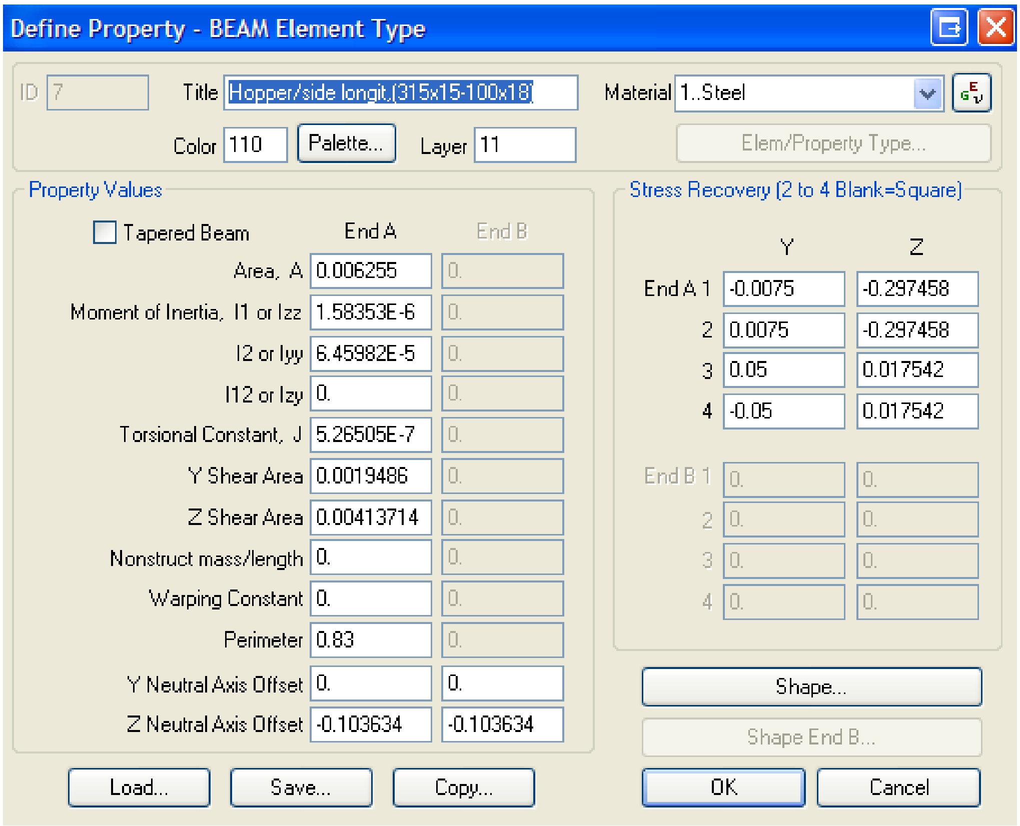


Fig.7.4.1.2 – 1st Model – Hopper web plate

Referring to the beam elements, all properties of the transverse section area where calculated by defining the geometry, Fig.7.4.1.3. An offset was also given at both ends.



ID 7 Title Hopper/side longit.(315x15-100x18) Material 1..Steel

Color 110 Layer 11

☐ Tapered Beam

	End A	End B
Area, A	0.006255	0.
Moment of Inertia, I1 or Izz	1.58353E-6	0.
I2 or Iyy	6.45982E-5	0.
I12 or Izy	0.	0.
Torsional Constant, J	5.26505E-7	0.
Y Shear Area	0.0019486	0.
Z Shear Area	0.00413714	0.
Nonstruct mass/length	0.	0.
Warping Constant	0.	0.
Perimeter	0.83	0.
Y Neutral Axis Offset	0.	0.
Z Neutral Axis Offset	-0.103634	-0.103634

	Y	Z
End A 1	-0.0075	-0.297458
2	0.0075	-0.297458
3	0.05	0.017542
4	-0.05	0.017542
End B 1	0.	0.
2	0.	0.
3	0.	0.
4	0.	0.

Fig.6.4.1.3 – Beam Element Properties

7.4.2 2^{nd} Model description

The second model was created with a finer mesh, (220.780 elements) and with plate elements only, without the use of beams. A global view of the model is shown at Fig.7.4.2.1. The size of the plate elements is about 0.15 x 0.1175 m. In this case six elements lie between two longitudinal stiffeners and eight between two transverse frames. The web and the flange of the longitudinal stiffeners are divided by two elements respectively. The mesh of the longitudinal stiffeners is shown at Fig.7.4.2.2 and Fig. 7.4.2.3

Specific nodes lied on the surface of the hopper web plate due to the stiffeners attached on it. In order to avoid free nodes on this surface the primary mapped mesh of the hopper web plate had to be modified giving the result shown at Fig. 7.4.2.4

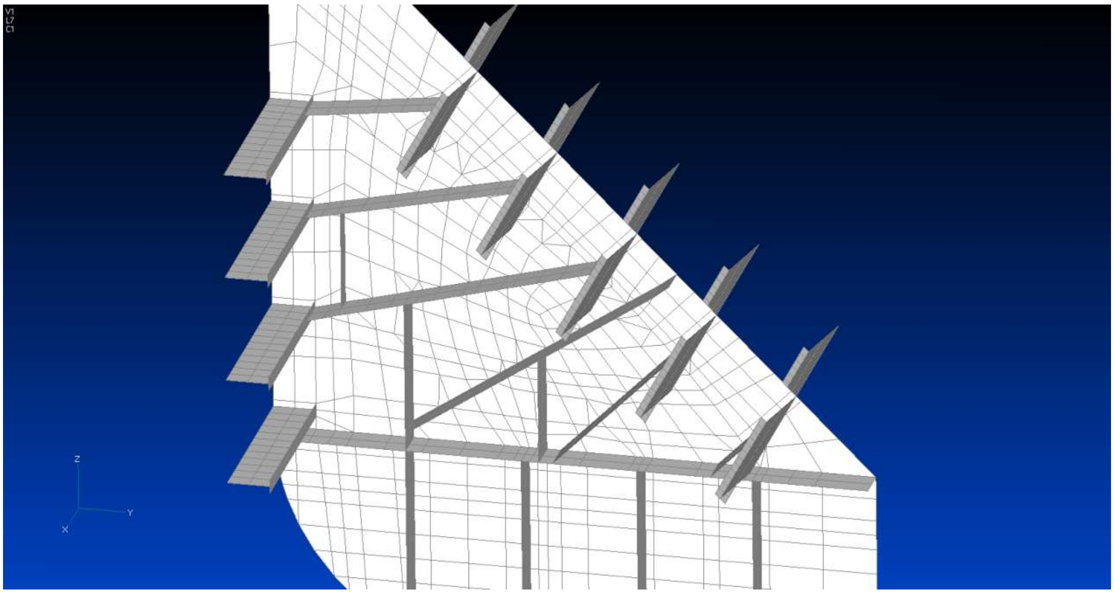


Fig.7.4.2.4 – 2nd Model – Hopper web plate

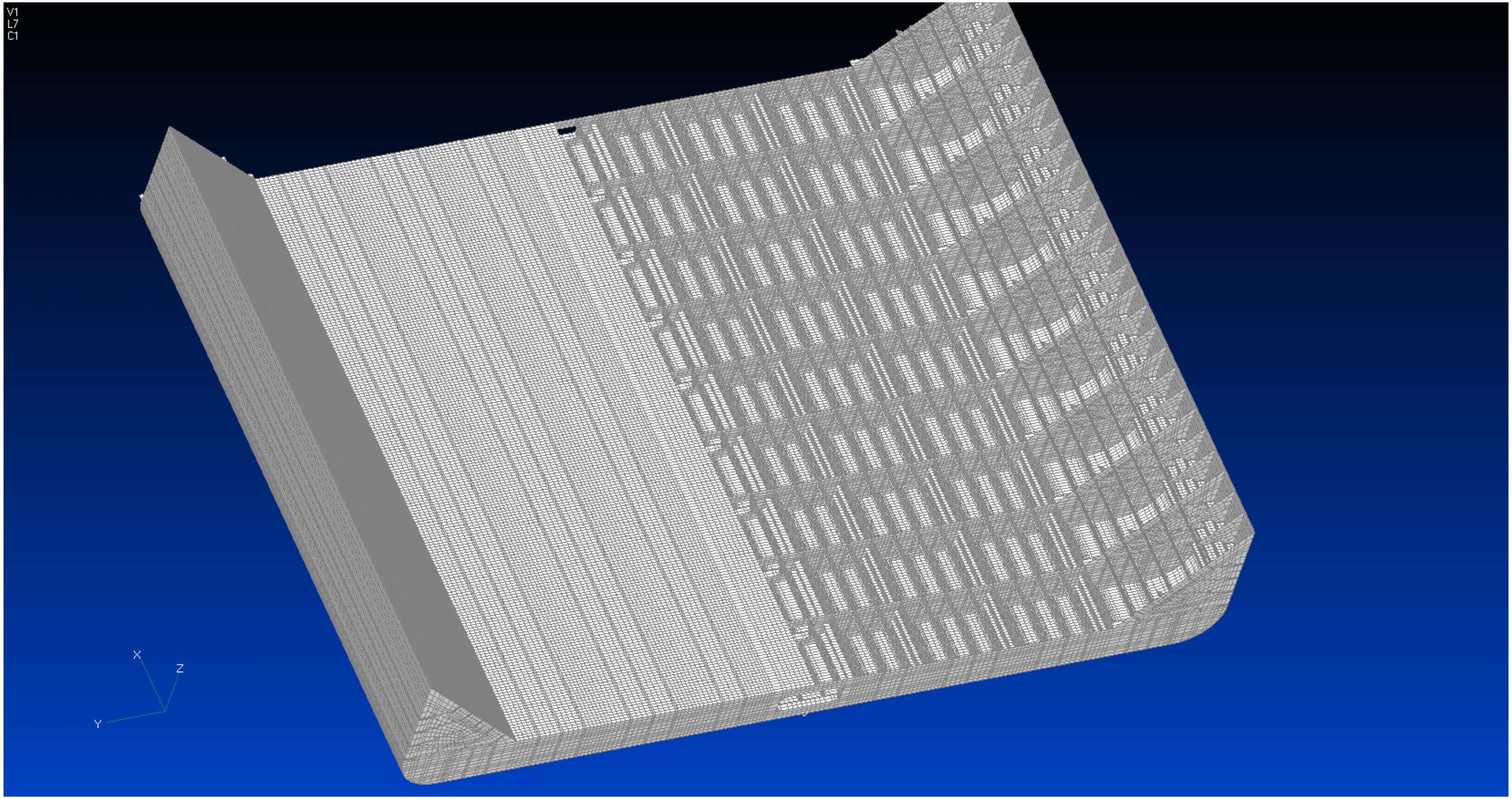


Fig.7.4.2.1 – 2nd Model Global view

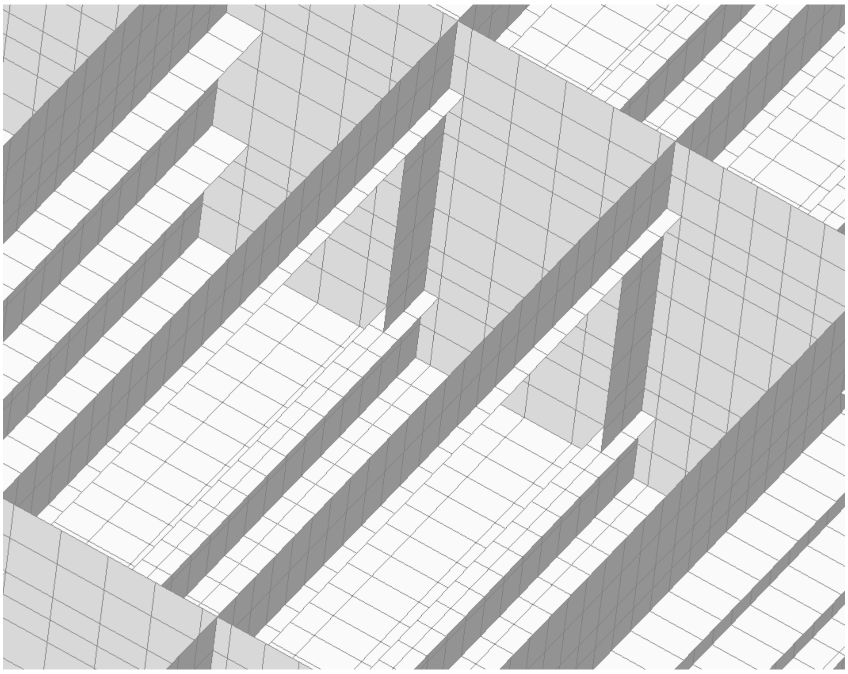


Fig.7.4.2.2 – 2nd Model - Stiffening of Double Bottom

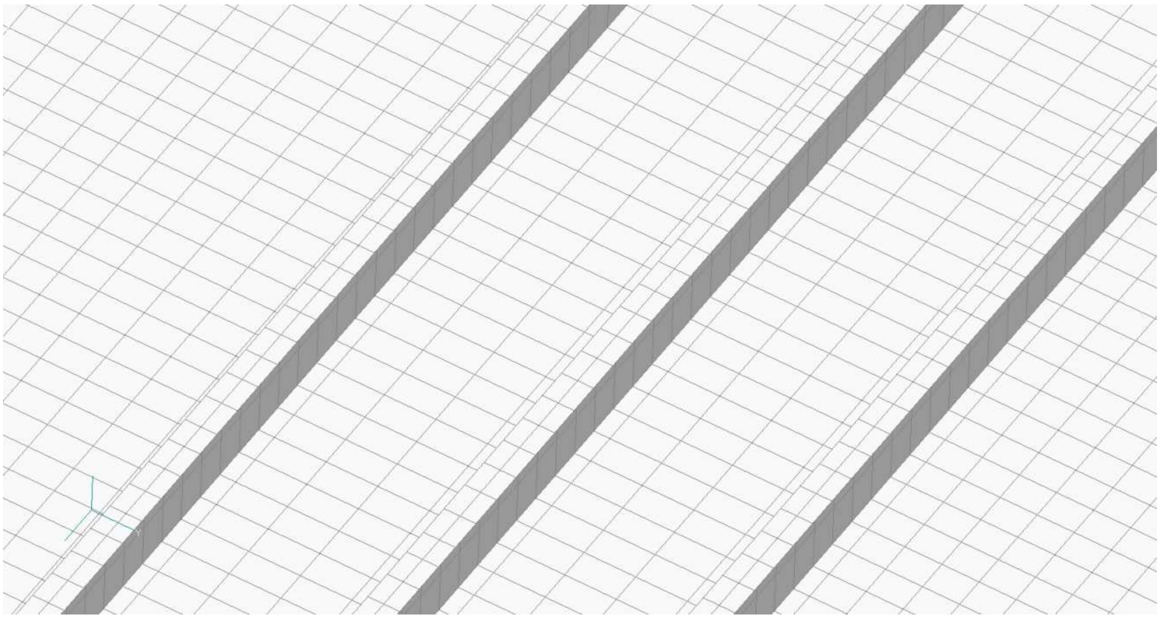


Fig.7.4.2.3 – 2nd Model – Bottom Plate and Longitudinal Stiffeners

7.4.3 3rd Model description

The third model was created with a very fine mesh, (814.442 elements), and with plate elements as in the previous case. A global view of the model is shown at Fig.7.4.3.1. The size of the plate elements is now about 0.097 x 0.058 m. In this case ten elements lie between two longitudinal stiffeners and sixteen between two transverse frames. The web of the longitudinal stiffeners is divided by four elements and the flange by two. The mesh of the longitudinal stiffeners is shown at Fig.7.4.3.2

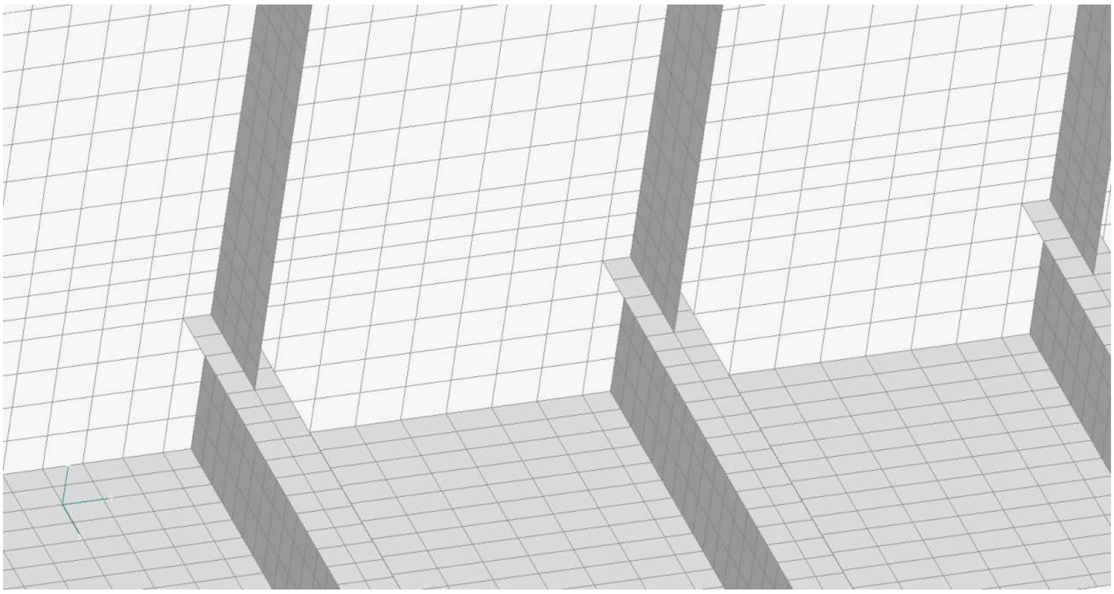


Fig.7.4.3.2 – 3rd Model - Stiffening of Double Bottom

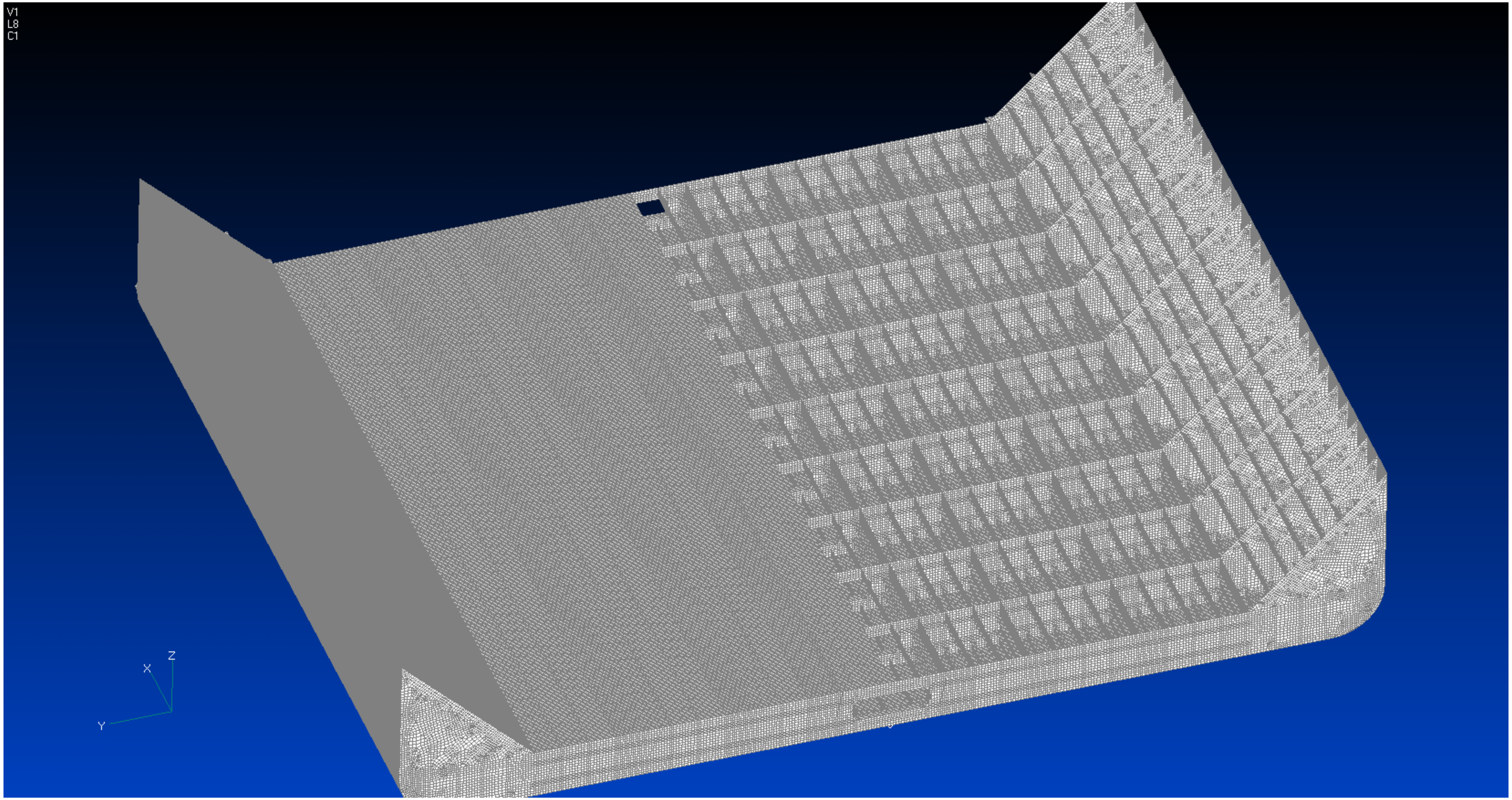


Fig.7.4.3.1 – 3rd Model Global view

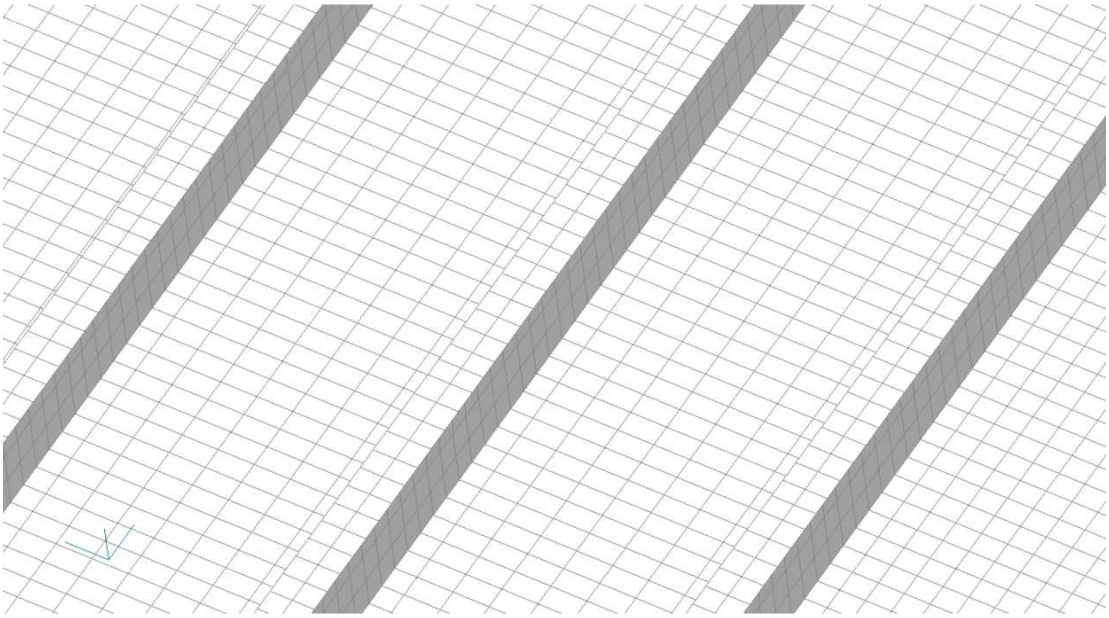


Fig.7.4.2.4 – 3rd Model – Bottom Plate and Longitudinal Stiffeners

Chapter 8 - Post-Processing

8.1 Post-processing the results

8.1.1 Areas of Analysis

For both scenarios and for all three models the output values examined after the analysis where the Von Misses stress and the primary stresses in X, (σ_X), and Y, (σ_Y), axis. The stress on the Z axis (normal to the face of the element) was not computed, because the elements supported only in-plane stress.

Five areas of the models, shown in Fig. 8.1.1.1, Fig 8.1.1.2 were chosen in order to compare the output results.. These were:

I. A plate of the bottom panel between two longitudinal stiffeners, in the middle of the model

II. A plate of the Inner bottom panel between two longitudinal stiffeners, in the middle of the model

III. A plate of the Inner bottom panel attached to the slopping plate of the hopper, in the middle of the model

IV. A plate of the flange of a longitudinal stiffener on the bottom panel

V. A plate of the flange of a longitudinal stiffener attached to a transverse floor.

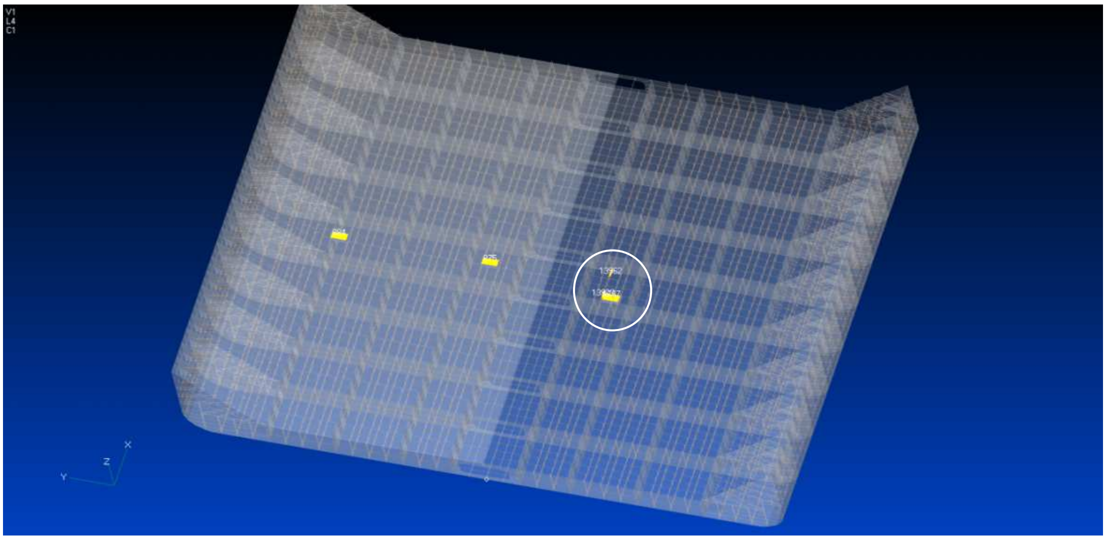


Fig. 8.1.1.1 – Areas of Analysis

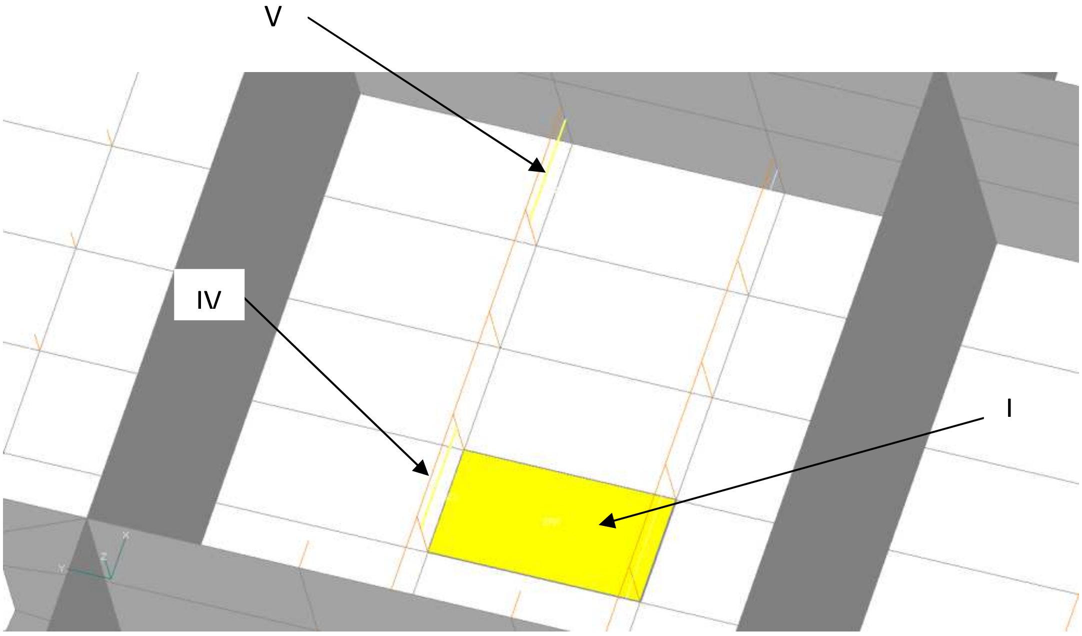


Fig. 8.1.1.2 – Elements subjected to analysis – Closer view

In the first three areas the type of elements (Plate elements) is the same for the three models. The longitudinal stiffeners though, were designed in the first model using beam elements and in the second and third using shell elements as mentioned before. Beam elements can compute only axial stress, thus it will be compared with the σ_x stress of the shell elements in the rest of the models.

In the second and third model elements with significantly smaller size were used. For this reason, the average stress of the elements included in the area corresponding to the size of the element in the first model, will be calculated.

In the figures below the mesh density of the three models is depicted.

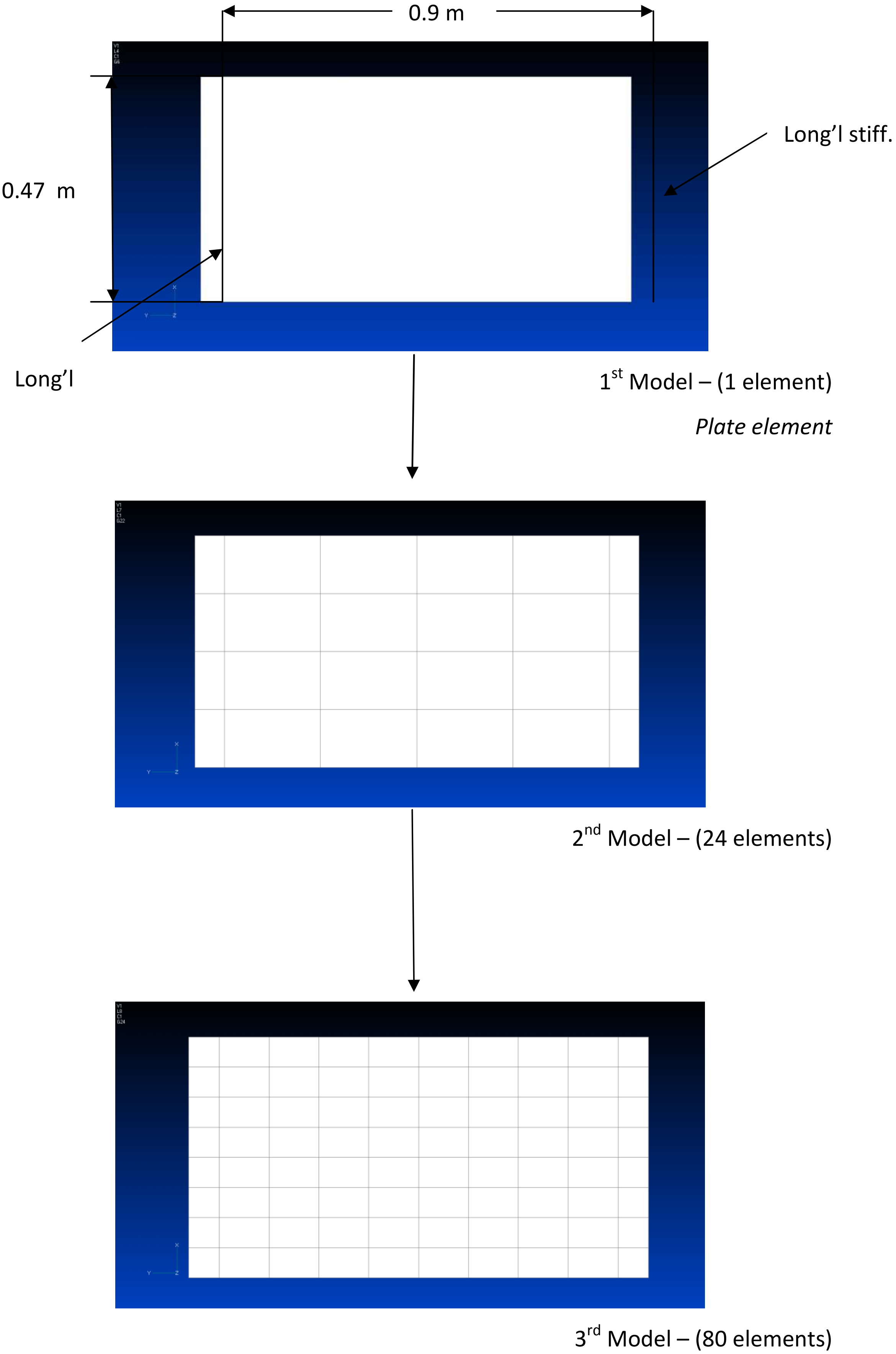
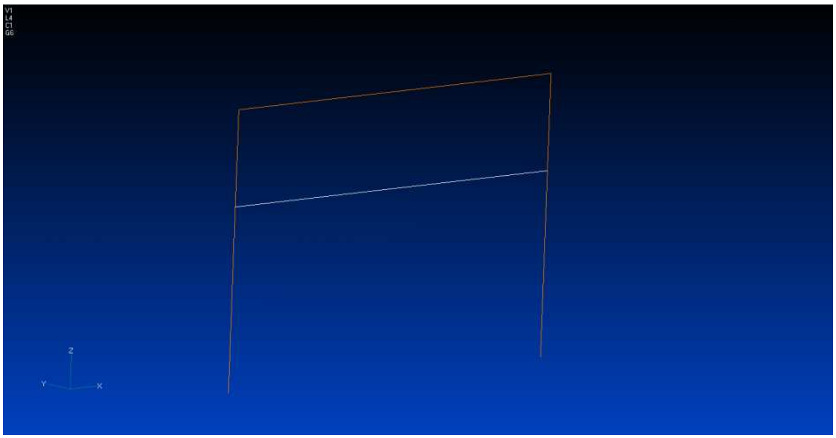


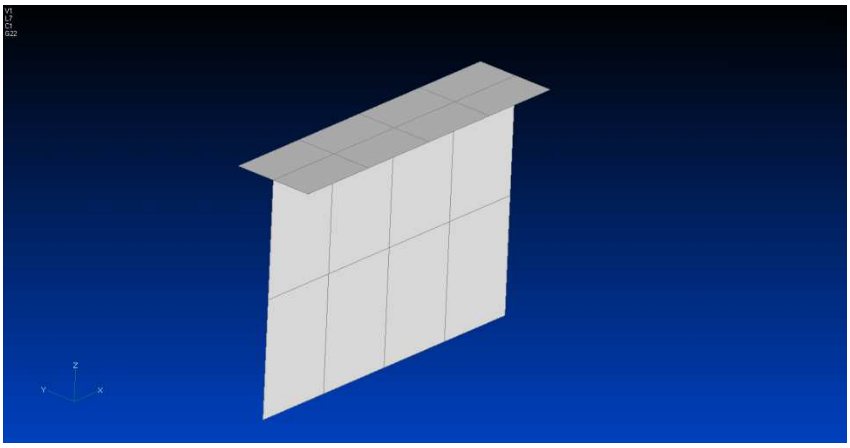
Fig.8.1.1.3 – Mesh of Plates



1st Model – (1 element)

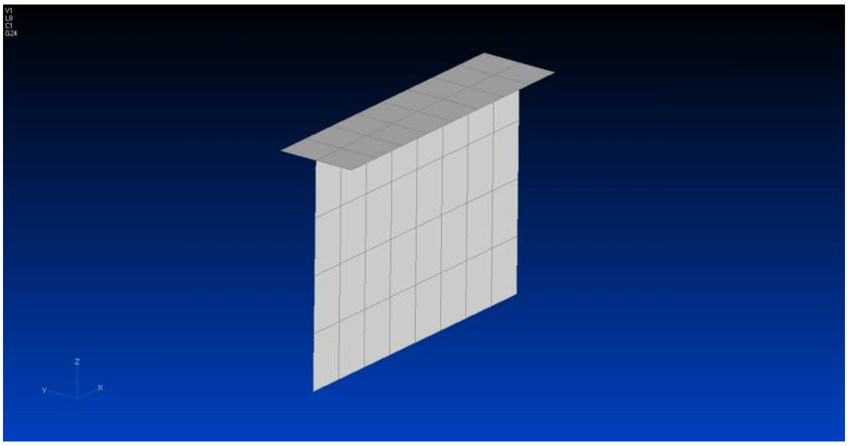
Beam element

Length: 0.47 m



2nd Model – (16 elements)

Plate element



3rd Model – (48 elements)

Fig. 8.1.1.4 – Mesh of stiffeners

8.1.2 Presentation of the Results

- Indicative Criteria plots for σ_x and σ_y stress fluctuation on elements of the Bottom plate for Scenario A

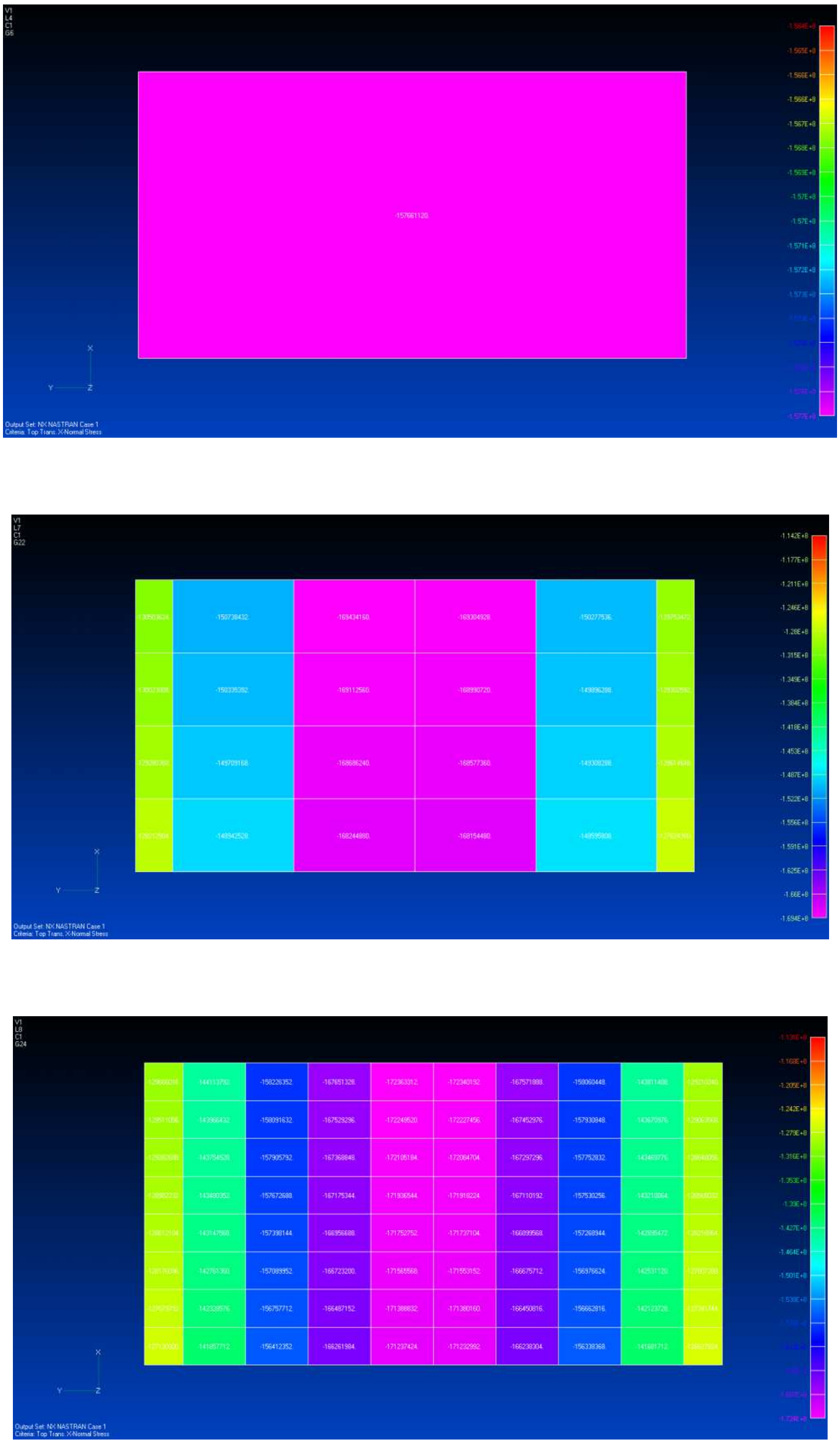


Fig.8.1.2.1 - σx stress in Bottom plate for Scenario A

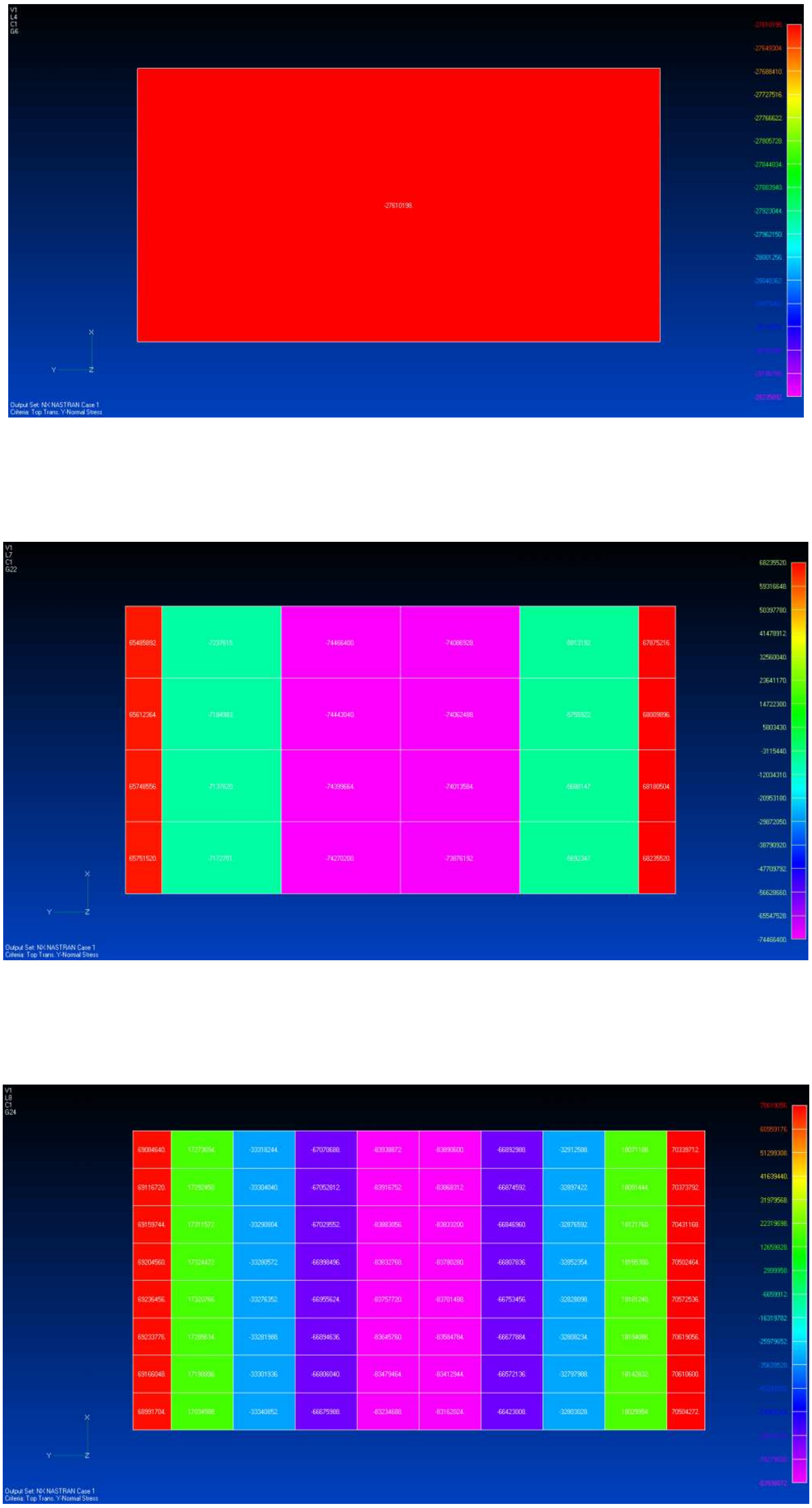


Fig.8.1.2.2 - σy stress in Bottom plate for Scenario A

Scenario A

Loads: Still and Inertia pressures (hogging condition) and Axial compression, (300MN) – (137MPA average stress)

I. Bottom Plate

Stresses - Bottom Plate	Von Misses - average
1st Model	146 Mpa
2nd Model	138 Mpa
3rd Model	142 Mpa

Stresses - Bottom Plate	σx - average (Min-Max)
1st Model	-158 Mpa
2nd Model	-149Mpa (-128 , -169)
3rd Model	-154 Mpa (-127 , -172)

Stresses - Bottom Plate	σy - average (Min-Max)
1st Model	-27.6 Mpa
2nd Model	-26 Mpa (-74.5 , 68.2)
3rd Model	-26.6 Mpa (-83.9 , 70.6)

II. Inner Bottom Plate

Stresses - Inner Bottom Plate	Von Misses - average
1st Model	135 Mpa
2nd Model	136 Mpa
3rd Model	133 Mpa

Stresses - Inner Bottom Plate	σx - average (Min-Max)
1st Model	-140 Mpa
2nd Model	-138 Mpa (-151 , -124)
3rd Model	-135 Mpa (-122 , -152)

Stresses - Inner Bottom Plate	σy - average (Min-Max)
1st Model	-9.92 Mpa
2nd Model	-3.91 Mpa (-55 , 22.5)
3rd Model	-3.6 Mpa (-56.7 , 27.9)

III. Inner Bottom attached to hopper slopping plate

Stresses - Inner Bottom Plate attached to hopper slopping plate	Von Misses
1st Model	135 Mpa
2nd Model	135 Mpa
3rd Model	132 Mpa

Stresses - Inner Bottom Plate attached to hopper slopping plate	σx - average (Min-Max)
1st Model	-138 Mpa
2nd Model	-136 Mpa (-154 , -123)
3rd Model	-135 Mpa (-154 , -123)

Stresses - Inner Bottom Plate attached to hopper slopping plate	σy - average (Min-Max)
1st Model	-6.27 Mpa
2nd Model	-3.35 Mpa (-57.3 , 28.2)
3rd Model	-5.6 Mpa (-57.8 , 28)

IV. Flange of a longitudinal stiffener on the bottom plate

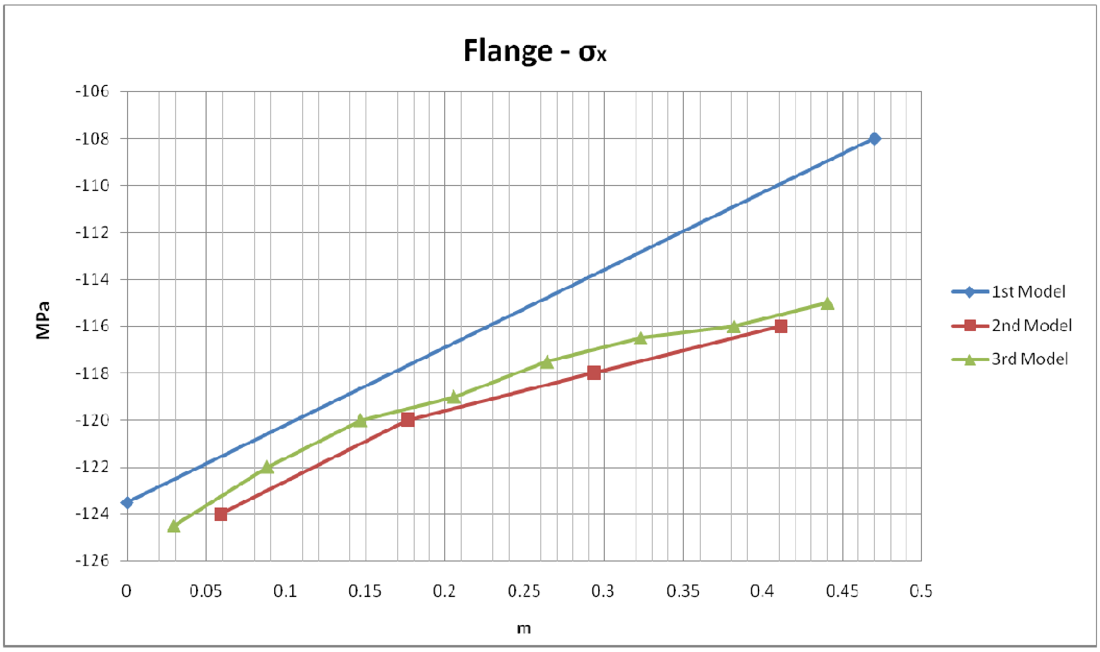


Diagram 8.1.2.1

V. Flange of a longitudinal stiffener attached to a transverse floor

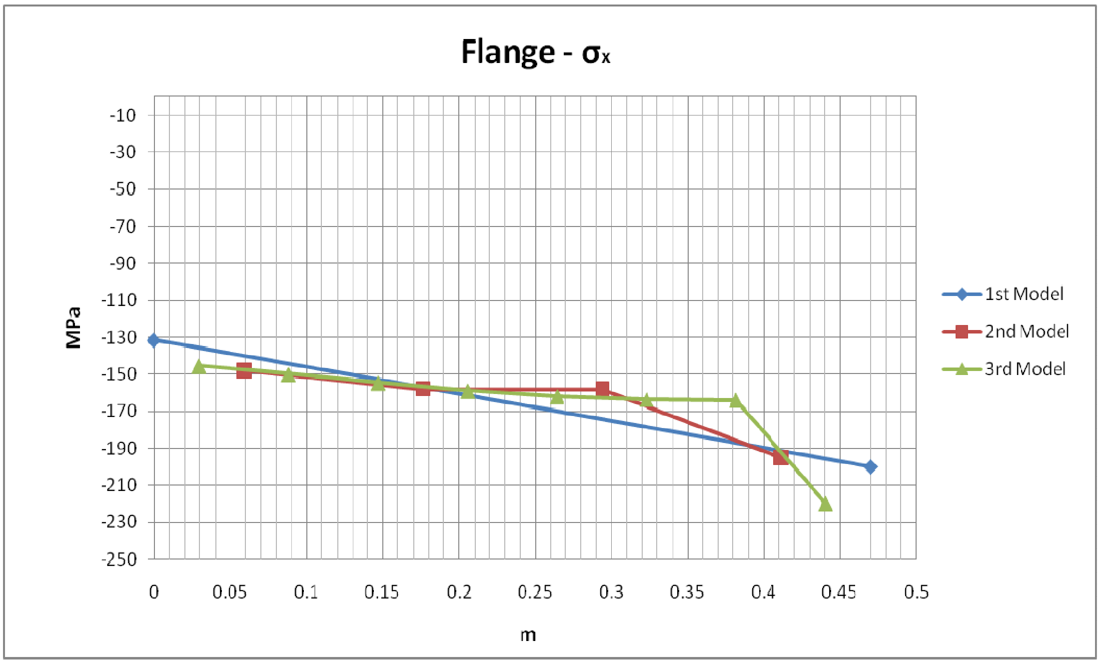


Diagram 8.1.2.2

Scenario B

Loads: Hydrostatic pressure

I. Bottom Plate

Stresses - Bottom Plate	Von Misses - average
1st Model	89.8 Mpa
2nd Model	83.5 Mpa
3rd Model	86.36 Mpa

Stresses - Bottom Plate	σx - average (Min-Max)
1st Model	-89.7 Mpa
2nd Model	- 80 Mpa (-108 , -43.9)
3rd Model	-85.9 Mpa (-112 , -47.6)

Stresses - Bottom Plate	σy - average (Min-Max)
1st Model	-90 Mpa
2nd Model	-86.6 Mpa (-155 , 45.5)
3rd Model	-87.3 Mpa (-168 , 50.5)

II. Inner Bottom Plate

Stresses - Inner Bottom Plate	Von Misses - average
1st Model	54.6 Mpa
2nd Model	51.8 Mpa
3rd Model	51.7 Mpa

Stresses - Inner Bottom Plate	σx - average (Min-Max)
1st Model	62.4 Mpa
2nd Model	58.6 Mpa (57.5 , 59.9)
3rd Model	58.6 Mpa (57.4 , 59.8)

Stresses - Inner Bottom Plate	σy - average (Min-Max)
1st Model	23.4 Mpa
2nd Model	19.4 Mpa (18.3 , 20.1)
3rd Model	19.2 Mpa (18.2 , 20)

III. Inner Bottom attached to hopper slopping plate

Stresses - Inner Bottom Plate attached to hopper slopping plate	Von Misses - average
1st Model	24.2 Mpa
2nd Model	21.1 Mpa
3rd Model	19.3 Mpa

Stresses - Inner Bottom Plate attached to hopper slopping plate	σx - average (Min-Max)
1st Model	-10.6 Mpa
2nd Model	- 8.54 Mpa (-11.1 , -5.7)
3rd Model	-9.32 Mpa (-11 , -6.1)

Stresses - Inner Bottom Plate attached to hopper slopping plate	σy - average (Min-Max)
1st Model	-27.6 Mpa
2nd Model	-23.2 Mpa (-33.6 , -10.5)
3rd Model	-21.4 Mpa (-33.6 , -9.2)

IV. Flange of a longitudinal stiffener on the bottom plate

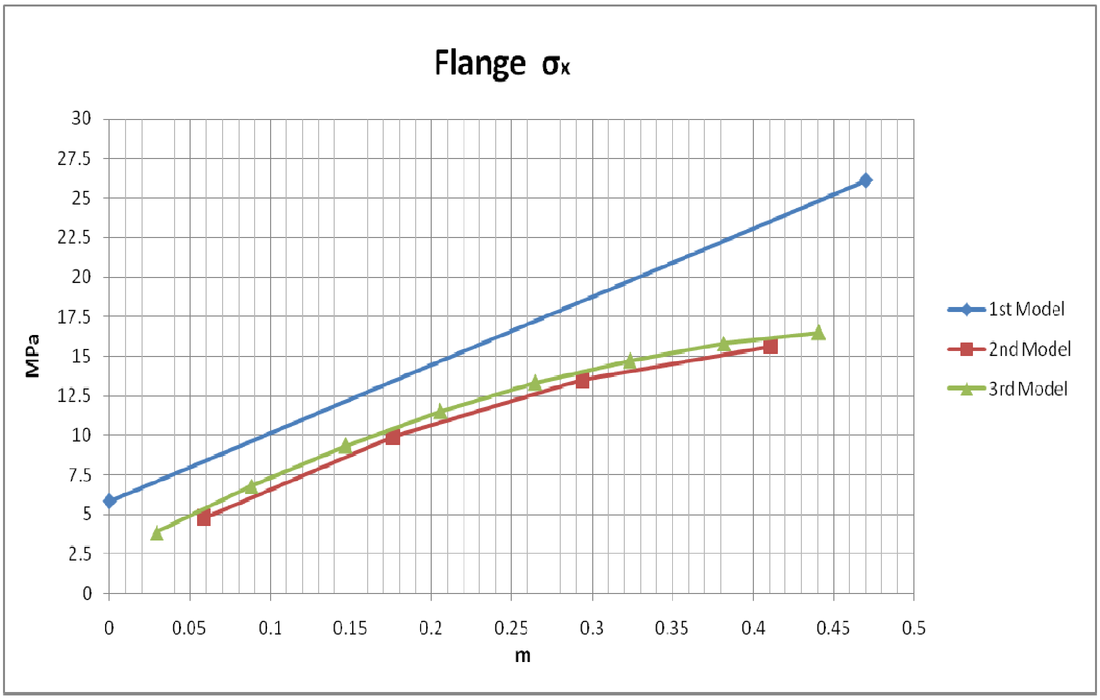


Diagram 7.1.2.4

V. Flange of a longitudinal stiffener attached to a transverse floor

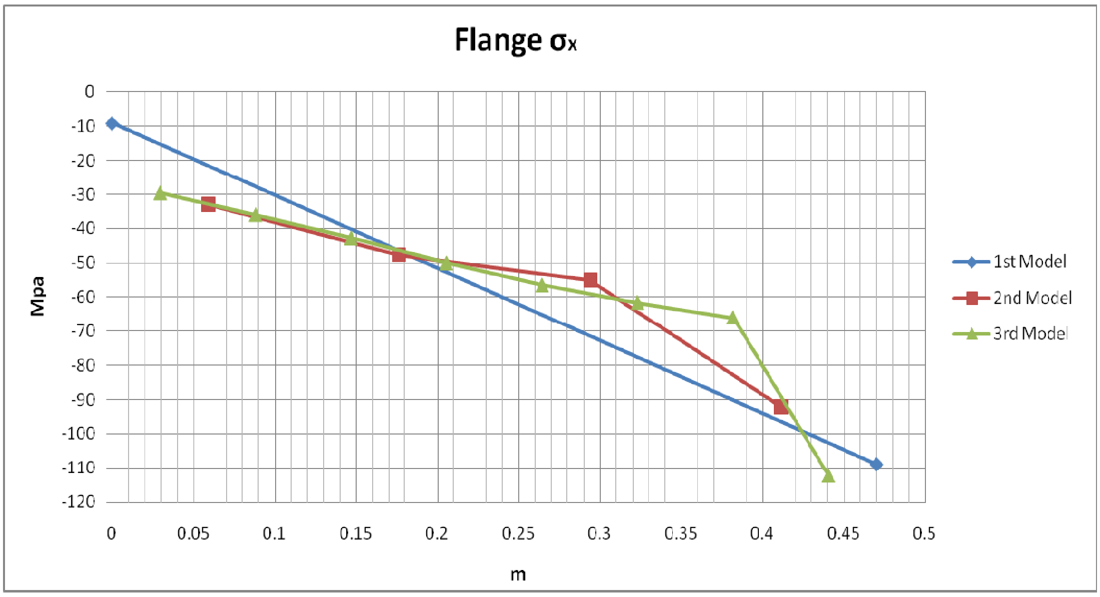


Diagram 7.1.2.3

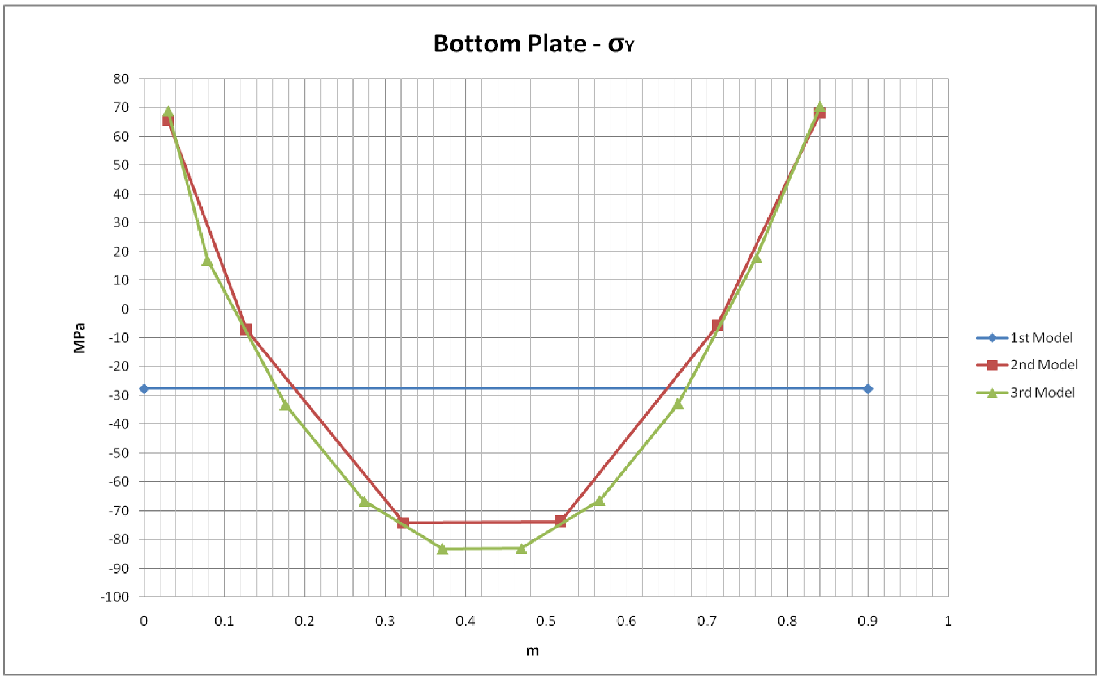


Diagram 7.1.2.5 – Scenario A

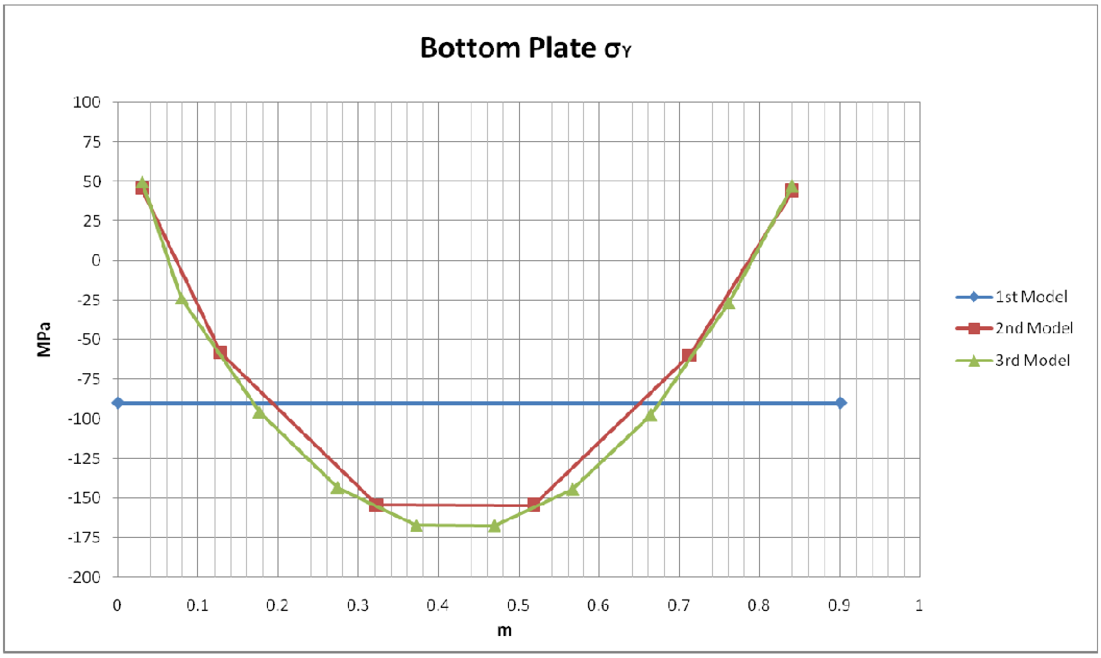


Diagram 7.1.2.6.- Scenario B

8.2 Conclusions

It is noted that, all the average values presented are calculated with weight factors where the area of analysis was not equally divided by the elements, in the x or y direction. In this way, the average values are more representative. In addition, the minimum and maximum values are also shown for the 2nd and 3rd model.

In the first scenario, where the axial compression is present, the values of the σ_x stresses are significantly higher than the σ_y stresses, as it can be seen in the tables above. The differences which appear in the average value of the x stress between the three models are small, about 4 %, and between the 2nd and 3rd model they are even less. Additionally, it is noticed that there is not a big fluctuation of the stress in the x direction in the area of analysis. It is reminded, that the area of analysis for the 2nd and 3rd model is determined by the size of the element in the 1st model, meshed according to the Rules. In contrast with the x stress, a very big fluctuation of the y stress appears between two longitudinal stiffeners. These stresses come from the bending of the plate and are the tertiary stresses which cannot be captured by a coarse mesh. In diag.7.1.2.5, the y stress values along the longitudinal stiffener spacing are plotted. The stresses are high close to the stiffeners and have the lowest values in the middle of the spacing. The one and only element which lies between the stiffener spacing in the first model gives only one value which approximates well the average stress, thus, cannot present the actual behavior. In the 2nd model six elements lie between the stiffener spacing and in the 3rd , ten. Finer meshes in this area could give even more precise results.

In the second scenario, the loading case is different. Only hydrostatic pressure is applied, without axial force. In this case, the differences between the stress values in the x and y direction are smaller. Looking at the average values it can be seen that they are well approximated by all models, despite the finer mesh of the 2nd and 3rd model. However, more consideration should be given in the range of these values and not in the average. The range of the values in the area of analysis indicate if there is a need for a finer mesh. It is significant to notice that a change in the loading case changes completely the behavior of the structure and its need for a finer mesh. In this scenario, the maximum and minimum values differ significantly leading to the fact that a fine mesh is appropriate. The meshing of the 1st model is very coarse and cannot represent adequately the stressed areas. An indicative diagram, diag.7.1.2.6, for the stresses in the y direction is also presented for this scenario.

The σ_x stress on the flange of the stiffeners is also very well approximated from all the models, (diag.7.1.2.4, diag.7.1.2.3). Slightly higher stress values are noticed in the first model where beam elements are used.

Chapter 9 – General Conclusions

Taking into consideration the importance of the strength of a ship construction several studies have been conducted. The aim is to optimize in the way of design and scantlings, the transverse section, so as, to be capable to cope with the loads which is submitted to and be cost efficient as well. The weight added on the lightship of a vessel, with no significant reason, is against to the cargo that will be capable to carry and will also raise it's cost of built.

Under the scope of this thesis the spreadsheet created, referred as 'CSR.CALC', was used to compute the scantlings of the midship section of a Bulk Carrier for four cases. The differences between the cases were in the spacing of the transverse and longitudinal stiffeners of the cross section. It is noticed from the results depicted in the thesis that the decrease of the transverse stiffener spacing has a lower impact in the scantlings of the plates, in comparison with the decrease of the longitudinal stiffener spacing. However, the frame spacing affects the scantlings of the longitudinal stiffeners. A vessel with increased transverse frames, has decreased the span of the longitudinal stiffeners and smaller scantlings.

From the cases studied, the conclusion is that longitudinal stiffening has a bigger impact on the total section area of the midship section. It is reminded that by adding one extra stiffener in each plating and by calculating the scantlings by the Rules, the area was reduced by 0.1 m^2. The study was made in a Bulk carrier (78000 DWT), where the above reduction of the area lightens the construction by 180 tones. The above mentioned spreadsheet can be also used as a tool for computing locally the thickness of the plating or the scantlings of the stiffeners in case of a ship repair.

Referring to the FEA analysis conducted in the thesis, the final conclusion is that the results given from the FE model used by IACS (the 1st model in the thesis) can provide adequately a general view of the stressed areas. These stressed areas can be further on examined using sub – modeling techniques, with a finer mesh, for a more precise analysis. A disadvantage of the coarse mesh used in the first model is that tertiary stresses cannot be captured. However, the advantage of this mesh and the fact that IACS uses beam elements in order to model the stiffeners makes the FE model computationally efficient. Finally given the fact that only the Von Misses stress is used as the reference stress to check the longitudinal strength efficiency of a ship, the differences between the three models are negligible.

FUTURE WORK

Some future capabilities of the tools created in this thesis and some suggestions for future studies are presented below:

It would be interesting to use the spreadsheet, ‘CSR.CALC’, to examine many combinations of longitudinal and transverse stiffening arrangements in a Bulk Carrier and derive conclusions which could be helpful in the design of a more cost efficient cross section. Moreover, a further development of this tool could be accomplished using Visual Basic. The procedure of the cyclic consecutive runs till the final estimation of the neutral axis and the scantlings of the section could be done automatically. An output file with all the information of the plate thicknesses could be also created, using programming techniques. This could consist the input for other ship design programs, i.e Tribon, Napa, etc.

Regarding the FEM Analysis, the rest of the cross section could be modeled for all three models. The pressures calculated from the spreadsheet, as well as the bending moments, could be applied FE Model and give a better approximation of the real loading cases in which a ship is submitted to. Finally, the sub-modeling techniques could be further examined and lead to the most efficient pattern of mesh that should be used.

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APPENDIX 1

PRESENTATION OF CSR.CALC RESULTS

Case 2:

Frame space 980mm

Spacing of stiffeners: As in Pilot ship

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	7.5	0
Deck plating (strake 2)	7.5	0
Deck plating (strake 3)	8	0
Side plate (strake 1)	12.5	0
Side plate (strake 2)	12.5	0
Side plate (strake 3)	30	0
Side plate (strake 4)	30	0
Side plate (strake 5)	30	0
Side plate (strake 6)	17	0
Slopping plate (upper wing) .-(strake1)	10	0
Slopping plate (upper wing) .-(strake2)	10.5	0
Slopping plate (upper wing) .-(strake3)	13	0
Slopping plate (upper wing) .-(strake4)	13	0
Slopping plate (hopper tank) .-(strake 1)	18.5	0
Slopping plate (hopper tank) .-(strake 2)	19	0
Double bottom plate (strake 1)	20.5	0
Double bottom plate (strake 2)	20.5	0
Double bottom plate (strake 3)	20.5	0
Double bottom plate (strake 4)	21	0
Keel plate (strake 1)	17.5	0
Bottom plate (strake 2)	17.5	0
Bottom plate (strake 3)	17.5	0
Bottom plate (strake 4)	18	0
Bottom plate (strake 5)	18	0
Bilge Plate	18	0
Girder (1/4)	11	0
Girder (2/4)	11	0
Girder (3/4)	11	0
Girder (4/4)	11	0

Case 2 : 1st estimation of Plate net scantlings using the 'CSR calc'.

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x7)	395	12	120	20	0	7
Bottom longi ' l (x11)	450	12	120	25	0	11
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x8)	425	12	120	25	0	8
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/9)	455	12	120	20	0	
Web space longi ' l (2/9)	455	12	120	20	0	
Web space longi ' l (3/9)	455	12	120	20	0	
Web space longi ' l (4/9)	455	12	120	20	0	
Web space longi ' l (5/9)	455	12	120	20	0	
Web space longi ' l (6/9)	455	12	120	20	0	
Web space longi ' l (7/9)	455	12	120	20	0	
Web space longi ' l (8/9)	455	12	120	20	0	
Web space longi ' l (9/9)	455	12	120	20	0	
Hopper space longi ' l (1/5)	395	12	120	20	0	
Hopper space longi ' l (2/5)	395	12	120	20	0	
Hopper space longi ' l (3/5)	395	12	120	20	0	
Hopper space longi ' l (4/5)	395	12	120	20	0	
Hopper space longi ' l (5/5)	395	12	120	20	0	
Upper side longi ' l (1/4)	425	12	120	25	0	
Upper side longi ' l (2/4)	425	12	120	25	0	
Upper side longi ' l (3/4)	425	12	120	25	0	
Upper side longi ' l (4/4)	425	12	120	25	0	
Lower side longi ' l (1/4)	425	12	120	25	0	
Lower side longi ' l] (2/4)	425	12	120	25	0	
Lower side longi ' l (3/4)	425	12	120	25	0	
Lower side longi ' l (4/4)	425	12	120	25	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Case 2 : 1st estimation of Stiffeners net scantlings

Area of section	**3.32**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.71**	**m**
Moment of Inetia, I	**162.18**	**m4**
Vertical distance from Deck to neutral axis	**12.69**	**m**
Section Modulus at Deck	**12.78**	**m3**
Section Modulus at Bottom	**24.17**	**m3**

Case 2 : 1st estimation of Area properties

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	7.5	0
Deck plating (strake 2)	7.5	0
Deck plating (strake 3)	8	0
Side plate (strake 1)	11.5	0
Side plate (strake 2)	11.5	0
Side plate (strake 3)	21	0
Side plate (strake 4)	21	0
Side plate (strake 5)	21	0
Side plate (strake 6)	14.5	0
Slopping plate (upper wing) .-(strake1)	9.5	0
Slopping plate (upper wing) .-(strake2)	10	0
Slopping plate (upper wing) .-(strake3)	13	0
Slopping plate (upper wing) .-(strake4)	13.5	0
Slopping plate (hopper tank) .-(strake 1)	15	0
Slopping plate (hopper tank) .-(strake 2)	17	0
Double bottom plate (strake 1)	19.5	0
Double bottom plate (strake 2)	19.5	0
Double bottom plate (strake 3)	19.5	0
Double bottom plate (strake 4)	19.5	0
Keel plate (strake 1)	15.5	0
Bottom plate (strake 2)	15.5	0
Bottom plate (strake 3)	15.5	0
Bottom plate (strake 4)	16	0
Bottom plate (strake 5)	16	0
Bilge Plate	16	0
Girder (1/4)	10	0
Girder (2/4)	10	0
Girder (3/4)	10	0
Girder (4/4)	10	0

Case 2 : 2nd estimation of Plate net scantlings using the 'CSR calc'

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x7)	395	12	120	20	0	7
Bottom longi ' l (x11)	340	12	120	15	0	11
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x8)	315	12	100	15	0	8
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/9)	370	12	120	20	0	
Web space longi ' l (2/9)	370	12	120	20	0	
Web space longi ' l (3/9)	370	12	120	20	0	
Web space longi ' l (4/9)	370	12	120	20	0	
Web space longi ' l (5/9)	370	12	120	20	0	
Web space longi ' l (6/9)	370	12	120	20	0	
Web space longi ' l (7/9)	370	12	120	20	0	
Web space longi ' l (8/9)	370	12	120	20	0	
Web space longi ' l (9/9)	370	12	120	20	0	
Hopper space longi ' l (1/5)	315	12	100	15	0	
Hopper space longi ' l (2/5)	315	12	100	15	0	
Hopper space longi ' l (3/5)	315	12	100	15	0	
Hopper space longi ' l (4/5)	315	12	100	15	0	
Hopper space longi ' l (5/5)	315	12	100	15	0	
Upper side longi ' l (1/4)	370	12	120	20	0	
Upper side longi ' l (2/4)	370	12	120	20	0	
Upper side longi ' l (3/4)	370	12	120	20	0	
Upper side longi ' l (4/4)	370	12	120	20	0	
Lower side longi ' l (1/4)	315	12	100	15	0	
Lower side longi ' l] (2/4)	315	12	100	15	0	
Lower side longi ' l (3/4)	315	12	100	15	0	
Lower side longi ' l (4/4)	315	12	100	15	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Case 2 : 2nd estimation of Stiffeners net scantlings

Area of section	**3.16**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.94**	**m**
Moment of Inetia, I	**167.33**	**m4**
Vertical distance from Deck to neutral axis	**12.46**	**m**
Section Modulus at Deck	**13.43**	**m3**
Section Modulus at Bottom	**24.11**	**m3**

Case 2 : 2nd estimation of Area properties

Requirments	**k=1 - Mild Steel**		**k=0.78 - High Tensile**	
ZRmin	21,23	m3	16,56	m3
ZR	21,73	m3	16,95	m3
Imin	138,23	m4	138,23	m4

Yielding requirements

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	18	4
Deck plating (strake 2)	18	4
Deck plating (strake 3)	18	4
Side plate (strake 1)	15	3.5
Side plate (strake 2)	15	3
Side plate (strake 3)	21	2.5
Side plate (strake 4)	21	2.5
Side plate (strake 5)	21	2.5
Side plate (strake 6)	14.5	3
Slopping plate (upper wing) .-(strake1)	15	3.5
Slopping plate (upper wing) .-(strake2)	15	3.5
Slopping plate (upper wing) .-(strake3)	16	3
Slopping plate (upper wing) .-(strake4)	16	3
Slopping plate (hopper tank) .-(strake 1)	15	4.5
Slopping plate (hopper tank) .-(strake 2)	17	4.5
Double bottom plate (strake 1)	19.5	4.5
Double bottom plate (strake 2)	19.5	4.5
Double bottom plate (strake 3)	19.5	4.5
Double bottom plate (strake 4)	19.5	4.5
Keel plate (strake 1)	15.5	2.5
Bottom plate (strake 2)	15.5	3
Bottom plate (strake 3)	15.5	3
Bottom plate (strake 4)	16	3
Bottom plate (strake 5)	16	3
Bilge Plate	16	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Case 2: Plate scantlings increased due to Yielding criteria

Area of section	**3.44**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.88**	**m**
Moment of Inetia, I	**202.26**	**m4**
Vertical distance from Deck to neutral axis	**11.52**	**m**
Section Modulus at Deck	**17.56**	**m3**
Section Modulus at Bottom	**25.66**	**m3**

Case 2: Area properties after increase due to Yielding cretiria

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	19.5	4
Deck plating (strake 2)	19.5	4
Deck plating (strake 3)	19.5	4
Side plate (strake 1)	17	3.5
Side plate (strake 2)	16.5	3
Side plate (strake 3)	21	2.5
Side plate (strake 4)	21	2.5
Side plate (strake 5)	21	2.5
Side plate (strake 6)	14.5	3
Slopping plate (upper wing) .-(strake1)	17	3.5
Slopping plate (upper wing) .-(strake2)	16	3.5
Slopping plate (upper wing) .-(strake3)	16.5	3
Slopping plate (upper wing) .-(strake4)	17	3
Slopping plate (hopper tank) .-(strake 1)	15	4.5
Slopping plate (hopper tank) .-(strake 2)	17	4.5
Double bottom plate (strake 1)	19.5	4.5
Double bottom plate (strake 2)	19.5	4.5
Double bottom plate (strake 3)	19.5	4.5
Double bottom plate (strake 4)	19.5	4.5
Keel plate (strake 1)	15.5	2.5
Bottom plate (strake 2)	15.5	3
Bottom plate (strake 3)	15.5	3
Bottom plate (strake 4)	16	3
Bottom plate (strake 5)	16	3
Bilge Plate	16	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Case 2 : Plate scantlings increased due to Ultimate Bending Capacity

	Gross scantlings (mm)
Deck plating (strake 1)	23.5
Deck plating (strake 2)	23.5
Deck plating (strake 3)	23.5
Side plate (strake 1)	20.5
Side plate (strake 2)	19.5
Side plate (strake 3)	22.5
Side plate (strake 4)	22.5
Side plate (strake 5)	22.5
Side plate (strake 6)	18
Slopping plate (upper wing) .-(strake1)	20.5
Slopping plate (upper wing) .-(strake2)	19.5
Slopping plate (upper wing) .-(strake3)	19.5
Slopping plate (upper wing) .-(strake4)	20
Slopping plate (hopper tank) .-(strake 1)	20.5
Slopping plate (hopper tank) .-(strake 2)	22
Double bottom plate (strake 1)	23.5
Double bottom plate (strake 2)	23.5
Double bottom plate (strake 3)	23.5
Double bottom plate (strake 4)	23.5
Keel plate (strake 1)	19
Bottom plate (strake 2)	19.5
Bottom plate (strake 3)	19.5
Bottom plate (strake 4)	19.5
Bottom plate (strake 5)	19.5
Bilge Plate	19.5
Girder (1/4)	14
Girder (2/4)	14
Girder (3/4)	14
Girder (4/4)	14

Case 2: Final gross Plate scantlings

	Gross scantlings			
Stiffeners	**h**	**t**	**bf**	**tf**
Deck longi ' l (x7)	395	15	120	23
Bottom longi ' l (x11)	370	15	120	23
Bottom longi ' l -flat bar- (x2)	300	22	-	-
Inner Bottom longi ' l (x8)	340	15	120	18
Inner bottom longi ' l -flat bar- (x2)	300	22	-	-
Web space longi ' l (1/9)	370	15	120	23
Web space longi ' l (2/9)	370	15	120	23
Web space longi ' l (3/9)	370	15	120	23
Web space longi ' l (4/9)	370	15	120	23
Web space longi ' l (5/9)	370	15	120	23
Web space longi ' l (6/9)	370	15	120	23
Web space longi ' l (7/9)	370	15	120	23
Web space longi ' l (8/9)	370	15	120	23
Web space longi ' l (9/9)	370	15	120	23
Hopper space longi ' l (1/5)	315	15	100	18
Hopper space longi ' l (2/5)	315	15	100	18
Hopper space longi ' l (3/5)	315	15	100	18
Hopper space longi ' l (4/5)	315	15	100	18
Hopper space longi ' l (5/5)	315	15	100	18
Upper side longi ' l (1/4)	370	15	120	23
Upper side longi ' l (2/4)	370	15	120	23
Upper side longi ' l (3/4)	370	15	120	23
Upper side longi ' l (4/4)	370	15	120	23
Lower side longi ' l (1/4)	340	15	120	18
Lower side longi ' l] (2/4)	340	15	120	18
Lower side longi ' l (3/4)	340	15	120	18
Lower side longi ' l (4/4)	340	15	120	18
Upper longi ' l of Center girder	220	15		
Lower longi ' l of Center girder	220	15		
Upper longi ' l of girders	150	12		
Lower longi ' l of girders	150	12		

Case 2 : Final gross Stiffeners scantlings

Area of section	**3.94**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.69**	**m**
Moment of Inetia, I	**234.20**	**m4**
Vertical distance from Deck to neutral axis	**11.71**	**m**
Section Modulus at Deck	**20.01**	**m3**
Section Modulus at Bottom	**30.44**	**m3**

Case 2 : Final Area Properties

Case 3:

Frame space 940mm

Spacing of stiffeners : Decreased spacing

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	6,5	0
Deck plating (strake 2)	6,5	0
Deck plating (strake 3)	7	0
Side plate (strake 1)	9	0
Side plate (strake 2)	9	0
Side plate (strake 3)	29	0
Side plate (strake 4)	29	0
Side plate (strake 5)	29	0
Side plate (strake 6)	13	0
Slopping plate (upper wing) .-(strake1)	9	0
Slopping plate (upper wing) .-(strake2)	10	0
Slopping plate (upper wing) .-(strake3)	12,5	0
Slopping plate (upper wing) .-(strake4)	13	0
Slopping plate (hopper tank) .-(strake 1)	15,5	0
Slopping plate (hopper tank) .-(strake 2)	16	0
Double bottom plate (strake 1)	18	0
Double bottom plate (strake 2)	18	0
Double bottom plate (strake 3)	18	0
Double bottom plate (strake 4)	18	0
Keel plate (strake 1)	15,5	0
Bottom plate (strake 2)	15,5	0
Bottom plate (strake 3)	15,5	0
Bottom plate (strake 4)	16	0
Bottom plate (strake 5)	16	0
Bilge Plate	16	0
Girder (1/4)	11	0
Girder (2/4)	11	0
Girder (3/4)	11	0
Girder (4/4)	11	0

Case 3 : 1st estimation of Plate net scantlings using the 'CSR calc'.

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x8)	370	12	120	20	0	8
Bottom longi ' l (x14)	395	12	120	20	0	14
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x10)	395	12	120	20	0	10
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/10)	425	12	120	25	0	
Web space longi ' l (2/10)	425	12	120	25	0	
Web space longi ' l (3/10)	425	12	120	25	0	
Web space longi ' l (4/10)	425	12	120	25	0	
Web space longi ' l (5/10)	425	12	120	25	0	
Web space longi ' l (6/10)	425	12	120	25	0	
Web space longi ' l (7/10)	425	12	120	25	0	
Web space longi ' l (8/10)	425	12	120	25	0	
Web space longi ' l (9/10)	425	12	120	25	0	
Web space longi ' l (10/10)	425	12	120	25	0	
Hopper space longi ' l (1/6)	370	12	120	20	0	
Hopper space longi ' l (2/6)	370	12	120	20	0	
Hopper space longi ' l (3/6)	370	12	120	20	0	
Hopper space longi ' l (4/6)	370	12	120	20	0	
Hopper space longi ' l (5/6)	370	12	120	20	0	
Hopper space longi ' l (6/6)	370	12	120	20	0	
Upper side longi ' l (1/5)	395	12	120	20	0	
Upper side longi ' l (2/5)	395	12	120	20	0	
Upper side longi ' l (3/5)	395	12	120	20	0	
Upper side longi ' l (4/5)	395	12	120	20	0	
Upper side longi ' l (5/5)	395	12	120	20	0	
Lower side longi ' l (1/5)	370	12	120	20	0	
Lower side longi ' l] (2/5)	370	12	120	20	0	
Lower side longi ' l (3/5)	370	12	120	20	0	
Lower side longi ' l (4/5)	370	12	120	20	0	
Lower side longi ' l (5/5)	370	12	120	20	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Case 3 : 1st estimation of Stiffeners net scantlings

Area of section	3,20	m^2
Z co-ordinate of neutral axis from B.L	6,61	m
Moment of Inetia, I	157,45	m4
Vertical distance from Deck to neutral axis	12,79	m
Section Modulus at Deck	12,31	m3
Section Modulus at Bottom	23,81	m3

Case 3 : 1st estimation of Area properties

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	6,5	0
Deck plating (strake 2)	6,5	0
Deck plating (strake 3)	7	0
Side plate (strake 1)	9	0
Side plate (strake 2)	9	0
Side plate (strake 3)	21	0
Side plate (strake 4)	21	0
Side plate (strake 5)	21	0
Side plate (strake 6)	11	0
pping plate (upper wing) .-(strak	9	0
pping plate (upper wing) .-(strak	9,5	0
pping plate (upper wing) .-(strak	12	0
pping plate (upper wing) .-(strak	12,5	0
pping plate (hopper tank) .-(strak	13	0
pping plate (hopper tank) .-(strak	14	0
Double bottom plate (strake 1)	17	0
Double bottom plate (strake 2)	17	0
Double bottom plate (strake 3)	17	0
Double bottom plate (strake 4)	17,5	0
Keel plate (strake 1)	13,5	0
Bottom plate (strake 2)	13,5	0
Bottom plate (strake 3)	14	0
Bottom plate (strake 4)	14	0
Bottom plate (strake 5)	14	0
Bilge Plate	14	0
Girder (1/4)	10	0
Girder (2/4)	10	0
Girder (3/4)	10	0
Girder (4/4)	10	0

Case 3 : 2nd estimation of Plate net scantlings using the 'CSR calc'

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x8)	370	12	120	20	0	8
Bottom longi ' l (x14)	315	12	100	15	0	14
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x10)	315	12	100	15	0	10
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/10)	370	12	120	20	0	
Web space longi ' l (2/10)	370	12	120	20	0	
Web space longi ' l (3/10)	370	12	120	20	0	
Web space longi ' l (4/10)	370	12	120	20	0	
Web space longi ' l (5/10)	370	12	120	20	0	
Web space longi ' l (6/10)	370	12	120	20	0	
Web space longi ' l (7/10)	370	12	120	20	0	
Web space longi ' l (8/10)	370	12	120	20	0	
Web space longi ' l (9/10)	370	12	120	20	0	
Web space longi ' l (10/10)	370	12	120	20	0	
Hopper space longi ' l (1/6)	315	12	100	15	0	
Hopper space longi ' l (2/6)	315	12	100	15	0	
Hopper space longi ' l (3/6)	315	12	100	15	0	
Hopper space longi ' l (4/6)	315	12	100	15	0	
Hopper space longi ' l (5/6)	315	12	100	15	0	
Hopper space longi ' l (6/6)	315	12	100	15	0	
Upper side longi ' l (1/5)	340	12	120	15	0	
Upper side longi ' l (2/5)	340	12	120	15	0	
Upper side longi ' l (3/5)	340	12	120	15	0	
Upper side longi ' l (4/5)	340	12	120	15	0	
Upper side longi ' l (5/5)	340	12	120	15	0	
Lower side longi ' l (1/5)	315	12	100	15	0	
Lower side longi ' l] (2/5)	315	12	100	15	0	
Lower side longi ' l (3/5)	315	12	100	15	0	
Lower side longi ' l (4/5)	315	12	100	15	0	
Lower side longi ' l (5/5)	315	12	100	15	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Case 3: 2nd estimation of Stiffeners net scantlings

Area of section	**3,04**	**m^2**
Z co-ordinate of neutral axis from B.L	**6,79**	**m**
Moment of Inetia, I	**160,18**	**m4**
Vertical distance from Deck to neutral axis	**12,61**	**m**
Section Modulus at Deck	**12,70**	**m3**
Section Modulus at Bottom	**23,60**	**m3**

Case 3 : 2nd estimation of Area properties

Requirments	k=1 - Mild Steel		k=0.78 - High Tensile	
ZRmin	21,23	m3	16,56	m3
ZR	21,73	m3	16,95	m3
Imin	138,23	m4	138,23	m4

Yielding requirements

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	18	4
Deck plating (strake 2)	18	4
Deck plating (strake 3)	18	4
Side plate (strake 1)	14	3,5
Side plate (strake 2)	13	3
Side plate (strake 3)	21	2,5
Side plate (strake 4)	21	2,5
Side plate (strake 5)	21	2,5
Side plate (strake 6)	11	3
Slopping plate (upper wing) .-(strake1)	14	3,5
Slopping plate (upper wing) .-(strake2)	13	3,5
Slopping plate (upper wing) .-(strake3)	14	3
Slopping plate (upper wing) .-(strake4)	14	3
Slopping plate (hopper tank) .-(strake 1)	13	4,5
Slopping plate (hopper tank) .-(strake 2)	14	4,5
Double bottom plate (strake 1)	17	4,5
Double bottom plate (strake 2)	17	4,5
Double bottom plate (strake 3)	17	4,5
Double bottom plate (strake 4)	17,5	4,5
Keel plate (strake 1)	13,5	2,5
Bottom plate (strake 2)	13,5	3
Bottom plate (strake 3)	14	3
Bottom plate (strake 4)	14	3
Bottom plate (strake 5)	14	3
Bilge Plate	14	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Case 3: Plate scantlings increased due to Yielding criteria

Area of section	**3,37**	**m^2**
Z co-ordinate of neutral axis from B.L	**7,81**	**m**
Moment of Inetia, I	**199,56**	**m4**
Vertical distance from Deck to neutral axis	**11,59**	**m**
Section Modulus at Deck	**17,21**	**m3**
Section Modulus at Bottom	**25,56**	**m3**

Case 3 : Area properties after increase due to Yielding cretiria

	scantlings	Corrosion (mm)
Deck plating (strake 1)	18,5	4
Deck plating (strake 2)	18,5	4
Deck plating (strake 3)	18,5	4
Side plate (strake 1)	16	3,5
Side plate (strake 2)	15,5	3
Side plate (strake 3)	21	2,5
Side plate (strake 4)	21	2,5
Side plate (strake 5)	21	2,5
Side plate (strake 6)	11	3
Slopping plate (upper wing) .-(strake1)	15	3,5
Slopping plate (upper wing) .-(strake2)	15	3,5
Slopping plate (upper wing) .-(strake3)	14,5	3
Slopping plate (upper wing) .-(strake4)	15,5	3
Slopping plate (hopper tank) .-(strake 1)	13	4,5
Slopping plate (hopper tank) .-(strake 2)	14	4,5
Double bottom plate (strake 1)	17	4,5
Double bottom plate (strake 2)	17	4,5
Double bottom plate (strake 3)	17	4,5
Double bottom plate (strake 4)	17,5	4,5
Keel plate (strake 1)	13,5	2,5
Bottom plate (strake 2)	13,5	3
Bottom plate (strake 3)	14	3
Bottom plate (strake 4)	14	3
Bottom plate (strake 5)	14	3
Bilge Plate	14	3
Girder (1/4)	10	3
Girder (2/4)	10	3
Girder (3/4)	10	3
Girder (4/4)	10	3

Case 3 : Plate scantlings increased due to Ultimate Bending Capacity

	Net scantlings (mm)
Deck plating (strake 1)	22,5
Deck plating (strake 2)	22,5
Deck plating (strake 3)	22,5
Side plate (strake 1)	19,5
Side plate (strake 2)	18,5
Side plate (strake 3)	22,5
Side plate (strake 4)	22,5
Side plate (strake 5)	22,5
Side plate (strake 6)	14,5
Slopping plate (upper wing) .-(strake1)	19
Slopping plate (upper wing) .-(strake2)	18,5
Slopping plate (upper wing) .-(strake3)	17,5
Slopping plate (upper wing) .-(strake4)	18,5
Slopping plate (hopper tank) .-(strake 1)	18
Slopping plate (hopper tank) .-(strake 2)	19,5
Double bottom plate (strake 1)	21,5
Double bottom plate (strake 2)	21,5
Double bottom plate (strake 3)	21,5
Double bottom plate (strake 4)	22
Keel plate (strake 1)	17,5
Bottom plate (strake 2)	17,5
Bottom plate (strake 3)	17,5
Bottom plate (strake 4)	17,5
Bottom plate (strake 5)	17,5
Bilge Plate	17,5
Girder (1/4)	13
Girder (2/4)	13
Girder (3/4)	13
Girder (4/4)	13

Case 3 : Final gross Plate scantlings

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x8)	370	15	120	23	0	8
Bottom longi ' l (x14)	340	15	120	18	0	14
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x10)	315	15	100	18	0	10
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/10)	370	15	120	23	0	
Web space longi ' l (2/10)	370	15	120	23	0	
Web space longi ' l (3/10)	370	15	120	23	0	
Web space longi ' l (4/10)	370	15	120	23	0	
Web space longi ' l (5/10)	370	15	120	23	0	
Web space longi ' l (6/10)	370	15	120	23	0	
Web space longi ' l (7/10)	370	15	120	23	0	
Web space longi ' l (8/10)	370	15	120	23	0	
Web space longi ' l (9/10)	370	15	120	23	0	
Web space longi ' l (10/10)	370	15	120	23	0	
Hopper space longi ' l (1/6)	315	15	100	18	0	
Hopper space longi ' l (2/6)	315	15	100	18	0	
Hopper space longi ' l (3/6)	315	15	100	18	0	
Hopper space longi ' l (4/6)	315	15	100	18	0	
Hopper space longi ' l (5/6)	315	15	100	18	0	
Hopper space longi ' l (6/6)	315	15	100	18	0	
Upper side longi ' l (1/5)	340	15	120	18	0	
Upper side longi ' l (2/5)	340	15	120	18	0	
Upper side longi ' l (3/5)	340	15	120	18	0	
Upper side longi ' l (4/5)	340	15	120	18	0	
Upper side longi ' l (5/5)	340	15	120	18	0	
Lower side longi ' l (1/5)	315	15	100	18	0	
Lower side longi ' l] (2/5)	315	15	100	18	0	
Lower side longi ' l (3/5)	315	15	100	18	0	
Lower side longi ' l (4/5)	315	15	100	18	0	
Lower side longi ' l (5/5)	315	15	100	18	0	
Upper longi ' l of Center girder	220	15			0	1
Lower longi ' l of Center girder	220	15			0	1
Upper longi ' l of girders	150	12			0	3
Lower longi ' l of girders	150	12			0	3

Case 3 : Final gross Stiffeners scantlings

Area of section	**3,79**	**m^2**
Z co-ordinate of neutral axis from B.L	**7,81**	**m**
Moment of Inetia, I	**226,80**	**m4**
Vertical distance from Deck to neutral axis	**11,59**	**m**
Section Modulus at Deck	**19,57**	**m3**
Section Modulus at Bottom	**29,04**	**m3**

Case 3 : Final Area Properties

Case 4:

Frame space 980mm

Spacing of stiffeners : Decreased spacing

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	6.5	0
Deck plating (strake 2)	6.5	0
Deck plating (strake 3)	7	0
Side plate (strake 1)	9	0
Side plate (strake 2)	9	0
Side plate (strake 3)	29	0
Side plate (strake 4)	29	0
Side plate (strake 5)	29	0
Side plate (strake 6)	13	0
Slopping plate (upper wing) .-(strake1)	9	0
Slopping plate (upper wing) .-(strake2)	10	0
Slopping plate (upper wing) .-(strake3)	12.5	0
Slopping plate (upper wing) .-(strake4)	13	0
Slopping plate (hopper tank) .-(strake 1)	15.5	0
Slopping plate (hopper tank) .-(strake 2)	16	0
Double bottom plate (strake 1)	18	0
Double bottom plate (strake 2)	18	0
Double bottom plate (strake 3)	18	0
Double bottom plate (strake 4)	18	0
Keel plate (strake 1)	15.5	0
Bottom plate (strake 2)	15.5	0
Bottom plate (strake 3)	15.5	0
Bottom plate (strake 4)	16	0
Bottom plate (strake 5)	16	0
Bilge Plate	16	0
Girder (1/4)	11	0
Girder (2/4)	11	0
Girder (3/4)	11	0
Girder (4/4)	11	0

Case 4: 1st estimation of Plate net scantlings using the 'CSR calc'.

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x8)	395	12	120	20	0	8
Bottom longi ' l (x14)	425	12	120	25	0	14
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x10)	425	12	120	25	0	10
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/10)	450	12	120	25	0	
Web space longi ' l (2/10)	450	12	120	25	0	
Web space longi ' l (3/10)	450	12	120	25	0	
Web space longi ' l (4/10)	450	12	120	25	0	
Web space longi ' l (5/10)	450	12	120	25	0	
Web space longi ' l (6/10)	450	12	120	25	0	
Web space longi ' l (7/10)	450	12	120	25	0	
Web space longi ' l (8/10)	450	12	120	25	0	
Web space longi ' l (9/10)	450	12	120	25	0	
Web space longi ' l (10/10)	450	12	120	25	0	
Hopper space longi ' l (1/6)	395	12	120	20	0	
Hopper space longi ' l (2/6)	395	12	120	20	0	
Hopper space longi ' l (3/6)	395	12	120	20	0	
Hopper space longi ' l (4/6)	395	12	120	20	0	
Hopper space longi ' l (5/6)	395	12	120	20	0	
Hopper space longi ' l (6/6)	395	12	120	20	0	
Upper side longi ' l (1/5)	425	12	120	25	0	
Upper side longi ' l (2/5)	425	12	120	25	0	
Upper side longi ' l (3/5)	425	12	120	25	0	
Upper side longi ' l (4/5)	425	12	120	25	0	
Upper side longi ' l (5/5)	425	12	120	25	0	
Lower side longi ' l (1/5)	395	12	120	20	0	
Lower side longi ' l] (2/5)	395	12	120	20	0	
Lower side longi ' l (3/5)	395	12	120	20	0	
Lower side longi ' l (4/5)	395	12	120	20	0	
Lower side longi ' l (5/5)	395	12	120	20	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Case 4 : 1st estimation of Stiffeners net scantlings

Area of section	**3.31**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.62**	**m**
Moment of Inetia, I	**163.57**	**m4**
Vertical distance from Deck to neutral axis	**12.78**	**m**
Section Modulus at Deck	**12.80**	**m3**
Section Modulus at Bottom	**24.70**	**m3**

Case 4 : 1st estimation of Area properties

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	7	0
Deck plating (strake 2)	7	0
Deck plating (strake 3)	7	0
Side plate (strake 1)	9	0
Side plate (strake 2)	9	0
Side plate (strake 3)	21	0
Side plate (strake 4)	21	0
Side plate (strake 5)	21	0
Side plate (strake 6)	11	0
Slopping plate (upper wing) .-(strake1)	9	0
Slopping plate (upper wing) .-(strake2)	9.5	0
Slopping plate (upper wing) .-(strake3)	12	0
Slopping plate (upper wing) .-(strake4)	12.5	0
Slopping plate (hopper tank) .-(strake 1)	13	0
Slopping plate (hopper tank) .-(strake 2)	14.5	0
Double bottom plate (strake 1)	16	0
Double bottom plate (strake 2)	16	0
Double bottom plate (strake 3)	16	0
Double bottom plate (strake 4)	16	0
Keel plate (strake 1)	14	0
Bottom plate (strake 2)	14	0
Bottom plate (strake 3)	14	0
Bottom plate (strake 4)	14	0
Bottom plate (strake 5)	14	0
Bilge Plate	14	0
Girder (1/4)	10.5	0
Girder (2/4)	10.5	0
Girder (3/4)	10.5	0
Girder (4/4)	10.5	0

Case 4: 2nd estimation of Plate net scantlings using the 'CSR calc'

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x8)	395	12	120	20	0	8
Bottom longi ' l (x14)	340	12	120	15	0	14
Bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Inner Bottom longi ' l (x10)	315	12	100	15	0	10
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/10)	370	12	120	20	0	
Web space longi ' l (2/10)	370	12	120	20	0	
Web space longi ' l (3/10)	370	12	120	20	0	
Web space longi ' l (4/10)	370	12	120	20	0	
Web space longi ' l (5/10)	370	12	120	20	0	
Web space longi ' l (6/10)	370	12	120	20	0	
Web space longi ' l (7/10)	370	12	120	20	0	
Web space longi ' l (8/10)	370	12	120	20	0	
Web space longi ' l (9/10)	370	12	120	20	0	
Web space longi ' l (10/10)	370	12	120	20	0	
Hopper space longi ' l (1/6)	315	12	100	15	0	
Hopper space longi ' l (2/6)	315	12	100	15	0	
Hopper space longi ' l (3/6)	315	12	100	15	0	
Hopper space longi ' l (4/6)	315	12	100	15	0	
Hopper space longi ' l (5/6)	315	12	100	15	0	
Hopper space longi ' l (6/6)	315	12	100	15	0	
Upper side longi ' l (1/5)	340	12	120	15	0	
Upper side longi ' l (2/5)	340	12	120	15	0	
Upper side longi ' l (3/5)	340	12	120	15	0	
Upper side longi ' l (4/5)	340	12	120	15	0	
Upper side longi ' l (5/5)	340	12	120	15	0	
Lower side longi ' l (1/5)	315	12	100	15	0	
Lower side longi ' l] (2/5)	315	12	100	15	0	
Lower side longi ' l (3/5)	315	12	100	15	0	
Lower side longi ' l (4/5)	315	12	100	15	0	
Lower side longi ' l (5/5)	315	12	100	15	0	
Upper longi ' l of Center girder	220	13			0	1
Lower longi ' l of Center girder	220	13			0	1
Upper longi ' l of girders	150	10			0	3
Lower longi ' l of girders	150	10			0	3

Case 4: 2nd estimation of Stiffeners net scantlings

Area of section	**3.06**	**m^2**
Z co-ordinate of neutral axis from B.L	**6.81**	**m**
Moment of Inetia, I	**162.29**	**m4**
Vertical distance from Deck to neutral axis	**12.59**	**m**
Section Modulus at Deck	**12.89**	**m3**
Section Modulus at Bottom	**23.83**	**m3**

Case 4: 2nd estimation of Area properties

Requirments	**k=1 - Mild Steel**		**k=0.78 - High Tensile**	
ZRmin	21,23	m3	16,56	m3
ZR	21,73	m3	16,95	m3
Imin	138,23	m4	138,23	m4

Yielding requirements

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	17	4
Deck plating (strake 2)	17	4
Deck plating (strake 3)	17	4
Side plate (strake 1)	15	3.5
Side plate (strake 2)	15	3
Side plate (strake 3)	21	2.5
Side plate (strake 4)	21	2.5
Side plate (strake 5)	21	2.5
Side plate (strake 6)	11	3
Slopping plate (upper wing) .-(strake1)	14	3.5
Slopping plate (upper wing) .-(strake2)	14	3.5
Slopping plate (upper wing) .-(strake3)	13	3
Slopping plate (upper wing) .-(strake4)	13	3
Slopping plate (hopper tank) .-(strake 1)	13	4.5
Slopping plate (hopper tank) .-(strake 2)	14.5	4.5
Double bottom plate (strake 1)	16	4.5
Double bottom plate (strake 2)	16	4.5
Double bottom plate (strake 3)	16	4.5
Double bottom plate (strake 4)	16	4.5
Keel plate (strake 1)	14	2.5
Bottom plate (strake 2)	14	3
Bottom plate (strake 3)	14	3
Bottom plate (strake 4)	14	3
Bottom plate (strake 5)	14	3
Bilge Plate	14	3
Girder (1/4)	10.5	3
Girder (2/4)	10.5	3
Girder (3/4)	10.5	3
Girder (4/4)	10.5	3

Case 4: Plate scantlings increased due to Yielding criteria

Area of section	**3.37**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.78**	**m**
Moment of Inetia, I	**199.71**	**m4**
Vertical distance from Deck to neutral axis	**11.62**	**m**
Section Modulus at Deck	**17.19**	**m3**
Section Modulus at Bottom	**25.67**	**m3**

Case 3 : Area properties after increase due to Yielding cretiria

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	22.5	4
Deck plating (strake 2)	22.5	4
Deck plating (strake 3)	22.5	4
Side plate (strake 1)	19.5	3.5
Side plate (strake 2)	18	3
Side plate (strake 3)	23.5	2.5
Side plate (strake 4)	23.5	2.5
Side plate (strake 5)	23.5	2.5
Side plate (strake 6)	14	3
Slopping plate (upper wing) .-(strake1)	18.5	3.5
Slopping plate (upper wing) .-(strake2)	18.5	3.5
Slopping plate (upper wing) .-(strake3)	17.5	3
Slopping plate (upper wing) .-(strake4)	17.5	3
Slopping plate (hopper tank) .-(strake 1)	17.5	4.5
Slopping plate (hopper tank) .-(strake 2)	19	4.5
Double bottom plate (strake 1)	20.5	4.5
Double bottom plate (strake 2)	20.5	4.5
Double bottom plate (strake 3)	20.5	4.5
Double bottom plate (strake 4)	20.5	4.5
Keel plate (strake 1)	16.5	2.5
Bottom plate (strake 2)	17	3
Bottom plate (strake 3)	17	3
Bottom plate (strake 4)	17	3
Bottom plate (strake 5)	17	3
Bilge Plate	17	3
	0.5	
Girder (1/4)	13.5	3
Girder (2/4)	13.5	3
Girder (3/4)	13.5	3
Girder (4/4)	13.5	3

Case 4 : Plate scantlings increased due to Ultimate Bending Capacity

	Net scantlings (mm)	Corrosion (mm)
Deck plating (strake 1)	22.5	
Deck plating (strake 2)	22.5	
Deck plating (strake 3)	22.5	
Side plate (strake 1)	19.5	
Side plate (strake 2)	18	
Side plate (strake 3)	23.5	
Side plate (strake 4)	23.5	
Side plate (strake 5)	23.5	
Side plate (strake 6)	14.5	
Slopping plate (upper wing) .-(strake1)	18.5	
Slopping plate (upper wing) .-(strake2)	18.5	
Slopping plate (upper wing) .-(strake3)	17.5	
Slopping plate (upper wing) .-(strake4)	17.5	
Slopping plate (hopper tank) .-(strake 1)	18	
Slopping plate (hopper tank) .-(strake 2)	19.5	
Double bottom plate (strake 1)	21.5	
Double bottom plate (strake 2)	21.5	
Double bottom plate (strake 3)	21.5	
Double bottom plate (strake 4)	21.5	
Keel plate (strake 1)	17.5	
Bottom plate (strake 2)	17.5	
Bottom plate (strake 3)	17.5	
Bottom plate (strake 4)	17.5	
Bottom plate (strake 5)	17.5	
Bilge Plate	17.5	
Girder (1/4)	13.5	
Girder (2/4)	13.5	
Girder (3/4)	13.5	
Girder (4/4)	13.5	

Case 4 : Final gross Plate scantlings

	Net scantlings				Corrosion addition	Number of stiffeners
Stiffeners	h	t	bf	tf		
Deck longi ' l (x8)	395	15	120	23	0	8
Bottom longi ' l (x14)	370	15	120	23	0	14
Bottom longi ' l -flat bar- (x2)	300	22	-	-	0	2
Inner Bottom longi ' l (x10)	315	15	100	18	0	10
Inner bottom longi ' l -flat bar- (x2)	300	20	-	-	0	2
Web space longi ' l (1/10)	370	15	120	23	0	
Web space longi ' l (2/10)	370	15	120	23	0	
Web space longi ' l (3/10)	370	15	120	23	0	
Web space longi ' l (4/10)	370	15	120	23	0	
Web space longi ' l (5/10)	370	15	120	23	0	
Web space longi ' l (6/10)	370	15	120	23	0	
Web space longi ' l (7/10)	370	15	120	23	0	
Web space longi ' l (8/10)	370	15	120	23	0	
Web space longi ' l (9/10)	370	15	120	23	0	
Web space longi ' l (10/10)	370	15	120	23	0	
Hopper space longi ' l (1/6)	315	15	100	18	0	
Hopper space longi ' l (2/6)	315	15	100	18	0	
Hopper space longi ' l (3/6)	315	15	100	18	0	
Hopper space longi ' l (4/6)	315	15	100	18	0	
Hopper space longi ' l (5/6)	315	15	100	18	0	
Hopper space longi ' l (6/6)	315	15	100	18	0	
Upper side longi ' l (1/5)	340	15	120	18	0	
Upper side longi ' l (2/5)	340	15	120	18	0	
Upper side longi ' l (3/5)	340	15	120	18	0	
Upper side longi ' l (4/5)	340	15	120	18	0	
Upper side longi ' l (5/5)	340	15	120	18	0	
Lower side longi ' l (1/5)	315	15	100	18	0	
Lower side longi ' l] (2/5)	315	15	100	18	0	
Lower side longi ' l (3/5)	315	15	100	18	0	
Lower side longi ' l (4/5)	315	15	100	18	0	
Lower side longi ' l (5/5)	315	15	100	18	0	
Upper longi ' l of Center girder	220	15			0	1
Lower longi ' l of Center girder	220	15			0	1
Upper longi ' l of girders	150	12			0	3
Lower longi ' l of girders	150	12			0	3

Case 4 : Final gross Stiffeners scantlings

Area of section	**3.84**	**m^2**
Z co-ordinate of neutral axis from B.L	**7.76**	**m**
Moment of Inetia, I	**228.89**	**m4**
Vertical distance from Deck to neutral axis	**11.64**	**m**
Section Modulus at Deck	**19.67**	**m3**
Section Modulus at Bottom	**29.48**	**m3**

Case 4 : Final Area Properties