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Comparison of the IACS CSR for Bulk Carriers and Double Hull Oil Tankers and consequent investigation



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ΜΕΤΑΦΡΑΣΗ ΣΤΑ ΕΛΛΗΝΙΚΑ

A.ΕΙΣΑΓΩΓΗ

I) Η ΔΗΜΙΟΥΡΓΙΑ ΤΩΝ CSR

Οι Κοινοί Κατασκευαστικοί Κανονισμοί (CSR) εκδόθηκαν για πρώτη φορά σε μορφή προσχεδίου τον Ιούνιο του 2004, υιοθετήθηκαν την 1^η Ιανουαρίου του 2006 και ξεκίνησαν να εφαρμόζονται για πλοία των οποίων το συμβόλαιο υπογράφηκε μετά την 1^η Απριλίου του 2006. Οι λόγοι για τη δημιουργία τους ήταν αρκετοί. Οι κύριοι, ήταν η ανάσχεση του ανταγωνισμού μεταξύ των Νηογνωμόνων σε σχέση με τις κατασκευαστικές απαιτήσεις για τα πλοία, καθώς επίσης και η μείωση της δυνατότητας των ναυπηγείων να εκμεταλλεύονται την ποικιλία μεταξύ των προτεινόμενων κατασκευαστικών απαιτήσεων των Νηογνωμόνων και συνεπώς τον ανταγωνισμό μεταξύ τους για οικονομικούς λόγους, καθώς αυτό είχε ως αποτέλεσμα τα ναυπηγικά σχέδια να ακολουθούν τις ελάχιστες απαιτήσεις του κάθε Νηογνώμονα, δημιουργώντας ως εκ τούτου ερωτήματα για την ασφάλεια και την αντοχή των υπό κατασκευή πλοίων [14]. Οι CSR αναπτύχθηκαν χρησιμοποιώντας τα καλύτερα κομμάτια των προ-CSR κανονισμών και τη συνδυασμένη εμπειρία όπως και τους πόρους όλων των Νηογνωμόνων, οι οποίοι συμμετείχαν σε αυτή την πρωτοβουλία.

II) ΚΥΡΙΟ ΑΝΤΙΚΕΙΜΕΝΟ ΤΩΝ CSR

Το αντικείμενο των CSR είναι ο καθορισμός των απαιτήσεων εκείνων οι οποίες θα οδηγήσουν σε αποδεκτά επίπεδα την αντοχή-στιβαρότητα της μεταλλικής κατασκευής του πλοίου και θα μειώσουν το κίνδυνο κατασκευαστικής αστοχίας αυξάνοντας την ασφάλεια της ανθρώπινης ζωής, του περιβάλλοντος και της περιούσιας . Ο στόχος αυτός εξασφαλίζεται με τον καθορισμό των αποδεκτών κατασκευαστικών προδιαγραφών των κατασκευαστικών στοιχείων του πλοίου. Η ακολουθούμενη διαδρομή για την εξασφάλιση του προηγούμενου στόχου είναι κοινοί για τους δύο CSR. Πιο συγκεκριμένα η γενική ιδέα των CSR και των δύο τύπων πλοίων είναι ο υπολογισμός των φορτίσεων που εφαρμόζονται στην μεταλλική κατασκευή των πλοίων, έπειτα ο καθορισμός των απαιτούμενων ελάχιστων παχών των ελασμάτων και των ενισχυτικών και τέλος η επαλήθευση του σχεδιασμού εξετάζοντας διάφορες οριακές καταστάσεις όπως: κατά την υπηρεσιακή του λειτουργία (Serviceability Limit State), σε ακραίες καταστάσεις (Ultimate Limit State), λόγω των εναλλασσόμενων φορτίσεων στη διάρκεια ζωής του πλοίου (Fatigue Limit State) και κατά την εμπλοκή του σε ατυχήματα (Accidental Limit State).

III) ΣΚΟΠΟΣ ΤΗΣ ΠΑΡΟΥΣΑΣ ΔΙΠΛΩΜΑΤΙΚΗΣ ΕΡΓΑΣΙΑΣ

Ο σκοπός της παρούσας διπλωματικής εργασίας είναι να συγκρίνει τους αντίστοιχους Κοινούς Κατασκευαστικούς Κανονισμούς (CSR) του Ιουλίου 2010 κατά IACS για πετρελαιοφόρα διπλού τοιχώματος και για πλοία μεταφοράς ξηρού φορτίου χύδην. Η σύγκριση διεξάγεται τόσο σε θεωρητικό όσο και σε πρακτικό επίπεδο. Πιο συγκεκριμένα, η σύγκριση αφορά και τη μεθοδολογία των IACS CSR για τους δύο τύπους πλοίων αλλά και τα αριθμητικά αποτελέσματα στα οποία οδηγεί η εφαρμογή τους. Τα επόμενα κεφάλαια

σκοπεύουν να παρουσιάσουν τα αποτελέσματα της έρευνας στα τρία κύρια σημεία και των δύο CSR: φορτίσεις (loads), κατασκευαστικές προδιαγραφές (structural scantlings) και επαλήθευση του σχεδιασμού (design verification).

Οι κανονισμοί είναι η σύνδεση θεωρίας και πρακτικής, δηλαδή μεταξύ θεωρητικής έρευνας και εμπειρίας στην πράξη. Η μελέτη-έρευνα γύρω από τους CSR των δύο αυτών τύπων πλοίων έχει πολύ μεγάλη σημασία διότι τα πετρελαιοφόρα διπλού τοιχώματος και τα πλοία μεταφοράς ξηρού φορτίου χύδην αποτελούν ένα πολύ μεγάλο κομμάτι του παγκόσμιου στόλου. Επιπλέον η σύγκριση των IACS CSR του Ιουλίου 2010 έχει πολύ μεγάλο ενδιαφέρον σήμερα όπου ο IACS εξέδωσε σε μορφή προσχεδίου τους εναρμονισμένους CSR (harmonized CSR) που αφορούν και τα πετρελαιοφόρα διπλού τοιχώματος και τα πλοία μεταφοράς ξηρού φορτίου χύδην και η συζήτηση για την πρωτοβουλία αυτή του IACS έχει μόλις κάποιους μήνες που έχει ξεκινήσει.

IV) ΠΕΡΙΛΗΨΗ ΤΗΣ ΠΑΡΟΥΣΑΣ ΔΙΠΛΩΜΑΤΙΚΗΣ ΕΡΓΑΣΙΑΣ

Κεφάλαιο 1^ο: Παρουσίαση, ερμηνεία και σύγκριση των φορτίσεων (loads) που εφαρμόζονται στη μέση τομή των πετρελαιοφόρων διπλού τοιχώματος και των πλοίων μεταφοράς ξηρού φορτίου χύδην σύμφωνα με τους αντίστοιχούς CSR.

Κεφάλαιο 2^ο: Σύγκριση και θεωρητική ανάλυση των κατασκευαστικών προδιαγραφών (structural scantlings) των ελασμάτων και των ενισχυτικών της μέσης τομής των εξεταζόμενων τύπων πλοίων.

Κεφάλαιο 3^ο: Σύγκριση της διαδικασίας επαλήθευσης του σχεδίου (design verification) μεταξύ των δύο τύπων πλοίων. Δηλαδή αυτό το κεφάλαιο εστιάζει στον έλεγχο αντοχής λόγω κάμψης, έλεγχο απέναντι σε λυγισμό των ελασμάτων και των ενισχυτικών, έλεγχο της μέγιστης αντοχής καθώς και στον έλεγχο απέναντι σε κόπωση των διαμήκων ενισχυτικών. Η ανάλυση της αντοχής του πλοίου με την χρήση πεπερασμένων στοιχείων είναι πέρα από τους σκοπούς της παρούσας διπλωματικής εργασίας.

Κεφάλαιο 4^ο: Παρουσίαση και ερμηνεία των αποτελεσμάτων της εφαρμογής των IACS CSR σε τρία πλοία. Πιο συγκεκριμένα η σύγκριση διεξάγεται μεταξύ ενός πετρελαιοφόρου διπλού τοιχώματος με μια κεντρική διαμήκη φρακτή, το οποίο χρησιμοποιείται σαν βάση για τη σύγκριση, ενός πλοίου μεταφοράς φορτίου χύδην διπλού τοιχώματος και ενός πλοίου μεταφοράς ξηρού φορτίου χύδην μονού τοιχώματος.

Κεφάλαιο 5^ο: Συμπεράσματα

Β.ΣΥΜΠΕΡΑΣΜΑΤΑ

Στην παρούσα διπλωματική εργασία μελετήθηκαν οι κοινοί κατασκευαστικοί κανονισμοί (CSR) για πετρελαιοφόρα διπλού τοιχώματος και για πλοία μεταφοράς ξηρού φορτίου χύδην έτσι ώστε να συγκριθεί η θεωρητική τους δομή, οι αρχές πίσω από τις διατυπώσεις τους και τα αριθμητικά αποτελέσματα της εφαρμογής τους. Πιο συγκεκριμένα, ο σκοπός της διπλωματικής εργασίας ήταν να ερμηνευθεί και να συγκριθεί παράλληλα ο τρόπος με τον οποίο υπολογίζονται οι φορτίσεις (loads) που δέχεται η μέση τομή των δύο ειδών πλοίων σύμφωνα με τους αντίστοιχους CSR, ο τρόπος με τον οποίο προκύπτουν οι προδιαγραφές (structural scantlings) των κατασκευαστικών στοιχείων της μέσης τομής και τέλος ο τρόπος με τον οποίο διεξάγεται η επαλήθευση του σχεδίασης (design verification) σύμφωνα με τον κάθε CSR. Πέρα από αυτά, αναγκαίο κρίθηκε να επεξηγηθεί ο τρόπος με τον οποίο τα τρία παραπάνω τμήματα των CSR συνδέονται μεταξύ τους. Με λίγα λόγια, ο κύριος στόχος της παρούσας διπλωματικής ήταν να απαντήσει στην ερώτηση “Πως δουλεύουν οι CSR;” και με την απάντηση στην ερώτηση αυτή να συγκριθούν παράλληλα οι CSR των δύο αυτών τύπων πλοίων.

Για να εξασφαλιστεί ο σκοπός αυτός, χρειάστηκε να λάβει χώρα ένα αριθμητικό παράδειγμα. Δηλαδή να αποκτηθούν αριθμητικά αποτελέσματα της εφαρμογής του κάθε CSR. Η αλήθεια είναι πως το πιο σημαντικό σε τελική ανάλυση συμπέρασμα της παρούσας διπλωματικής εργασίας είναι η αναγκαιότητα διεξαγωγής με αριθμητικά δεδομένα του ελέγχου και της σύγκρισης των CSR. Δηλαδή για να γίνει κατανοητό κάτι σε βάθος, ένα αριθμητικό παράδειγμα – ή ένα πείραμα σε άλλους τομείς – είναι απολύτως αναγκαίο. Ως εκ τούτου, τρία πλοία με τα ίδια κύρια χαρακτηριστικά συγκρίθηκαν: ένα πετρελαιοφόρο διπλού τοιχώματος με μια κεντρική διαμήκη φρακτή, ένα πλοίο μεταφοράς φορτίου χύδην διπλού τοιχώματος και ένα μεταφοράς φορτίου χύδην μονού τοιχώματος.

Από την έρευνα η οποία διεξήχθη, παρατηρήθηκε πως και οι δύο CSR ακολουθούν την ίδια διαδρομή για τον καθορισμό των κατασκευαστικών χαρακτηριστικών και την εκτίμηση της αντοχής και της στιβαρότητας του πλοίου. Επιπλέον διαπιστώθηκε πως δεν υπάρχει «σημαντική» φόρτιση την οποία να μην λαμβάνουν υπόψη τους οι CSR. Δηλαδή μελετώντας τα σημεία υψηλής φόρτισης σε πετρελαιοφόρα διπλού τοιχώματος και σε πλοία μεταφοράς ξηρού φορτίου χύδην [9] διαπιστώθηκε πως δεν υπάρχει κάποιο κατασκευαστικό στοιχείο της μέσης τομής στο οποίο να μην μπορούν να εφαρμοστούν οι CSR.

Παρόλα αυτά υπάρχουν αρκετές διαφορές μεταξύ των τύπων-διατυπώσεων που προτείνει ο κάθε CSR και στα τρία κομμάτια που ερευνώνται στην παρούσα διπλωματική. Πιο συγκεκριμένα, στην περίπτωση των φορτίσεων που εφαρμόζονται στη μέση τομή, κάθε CSR λαμβάνει υπόψη του διαφορετικές περιπτώσεις φορτίσεων (load cases) και έτσι παρέχει και διαφορετικούς τύπους και διατυπώσεις στα δυναμικά φορτία. Όσον αφορά τα φορτία που ασκούνται συνολικά στη γάστρα θεωρούμενη ως δοκό, η διαφορά στον τρόπο εφαρμογής της “net thickness approach” στους δυο τύπους πλοίων οδηγεί και σε διαφορετικές διατυπώσεις των ελάχιστων επιτρεπόμενων καμπτικών ροπών σε ήρεμο νερό (still water bending moments). Η στρεπτική ροπή κυματισμού λαμβάνεται υπόψη μόνο από

τους CSR των πλοίων μεταφοράς ξηρού φορτίου χύδην εξαιτίας των μεγάλων ανοιγμάτων στο κατάστρωμα τους (στόμια κυτών), αλλά μόνο στον έλεγχο της αντοχής απέναντι σε κόπωση. Η διαφορά στο τύπο του φορτίου μεταξύ των δύο ειδών πλοίων οδηγεί και σε διαφορές μεταξύ των εξεταζόμενων φορτίσεων μεταξύ των δύο CSR. Για παράδειγμα η φόρτιση λόγω διατοιχισμού (sloshing) εξετάζεται μόνο από τους CSR για πετρελαιοφόρα διπλού τοιχώματος.

Στην περίπτωση των προδιαγραφών των κατασκευαστικών στοιχείων (structural scantlings), και οι δύο CSR παρέχουν ένα αριθμό τύπων για τον υπολογισμό του ελάχιστου καθαρού πάχους των ελασμάτων. Πιο συγκεκριμένα και οι δύο προτείνουν 4 ειδών τύπους. Έναν εμπειρικό τύπο, ο οποίος είναι συνάρτηση του μήκους του πλοίου, ένα τύπο που βασίζεται στην ασκούμενη τάση για ελάσματα που υπόκεινται σε πλευρικές πιέσεις, ένα τύπο που αφορά συγκεκριμένα ελάσματα, όπως είναι τα ελάσματα του πλευρικού εξωτερικού τοιχώματος σε μια συγκεκριμένη περιοχή (quay region) ή το έλασμα της παραπυθμενίδας (bilge plate), και ένα τύπο ο οποίος δεν βασίζεται στην ασκούμενη τάση και ορίζεται ως μέγιστος βαθμός λυγηρότητας. Το ελάχιστο καθαρό πάχος των κατασκευαστικών στοιχείων της μέσης τομής δεν μπορεί να είναι μικρότερο από τις τιμές που δίνουν οι προαναφερθέντες τύποι. Το αριθμητικό παράδειγμα το οποίο διεξήχθη στα τρία πλοία έδειξε ότι και οι τέσσερις τύποι πρέπει να ληφθούν υπόψη για τον καθορισμό των ελάχιστων απαιτούμενων καθάρων παχών των ελασμάτων και των ενισχυτικών. Δεν υπάρχει κάποιος από αυτούς που να είναι μικρότερης σημασίας.

Η επαλήθευση του κατασκευαστικού σχεδιασμού (design verification) και στους δύο CSR αφορά τον έλεγχο της καμπτικής τάσης στο πλοίο θεωρούμενου ως δοκάρι αλλά και σε τοπικό επίπεδο, τον έλεγχο λυγισμού των ελασμάτων και των ενισχυτικών, τον έλεγχο της μέγιστης αντοχής καθώς και τον έλεγχο απέναντι σε κόπωση. Ο έλεγχος της καμπτικής τάσης για το πλοίο θεωρούμενου ως δοκάρι καθώς και ο έλεγχος λυγισμού των ενισχυτικών γίνεται με τον ίδιο τρόπο και στους δύο CSR. Ο έλεγχος απέναντι σε λυγισμό των ελασμάτων και στους δύο CSR βασίζεται στην ανάλυση αντοχής απέναντι σε μονοαξονική θλιπτική καταπόνηση των CSR για πλοία μεταφοράς ξηρού φορτίου χύδην, η οποία παρουσιάζεται στο κεφάλαιο 6/υποκεφάλαιο 3, παρόλα αυτά οι δύο CSR διαφέρουν στο συνδυασμό των τάσεων οι οποίες χρησιμοποιούνται στη διαδικασία ελέγχου της αντοχής. Ο έλεγχος της μέγιστης αντοχής και στους δύο CSR βασίζεται στο ίδιο κριτήριο, αλλά διαφέρει ως προς τους σχεδιαστικούς συνδυασμούς φορτίσεων (design load combinations) καθώς και στο γεγονός ότι στην ανάλυση των πετρελαιοφόρων διπλού τοιχώματος μόνο η κατάσταση sagging λαμβάνεται υπόψη ενώ στα πλοία μεταφοράς ξηρού φορτίου χύδην και η hogging και η sagging. Η διαδικασία ελέγχου της αντοχής σε κόπωση διαφέρει μεταξύ των δύο CSR καθώς πρόκειται για δύο διαδικασίες οι οποίες αναπτύχθηκαν ανεξάρτητα η μία από την άλλη. Παρότι εντοπίζονται ομοιότητες όπως: τα κριτήρια αποδοχής, ο τύπος που παρέχει τη συσσωρευμένη φθορά λόγω κόπωσης, η ζωή σχεδίασης των 25 ετών στο περιβάλλον του Βόρειου Ατλαντικού, υπάρχουν αρκετές διαφορές στον υπολογισμό της hot spot stress. Κάθε CSR αναφέρει τα σημεία στη γάστρα του πλοίου τα οποία πρέπει να ελεγχθούν έναντι της κόπωσης καθώς παρουσιάζουν τις περισσότερες πιθανότητες να υποστούν φθορά εξαιτίας της. Όμως η συντριπτική πλειοψηφία αυτών των σημείων δεν μπορεί παρά να ελεγχθεί μέσω της χρήσης ανάλυσης πεπερασμένων στοιχείων για να αποκτηθούν αξιόπιστα αποτελέσματα. Ως εκ τούτου στην

παρούσα εργασία, η εκτίμηση της αντοχής έναντι κόπωσης διεξάγεται μόνο για τα σημεία σύνδεσης των διαμήκων ενισχυτικών με εγκάρσια κατασκευαστικά στοιχεία, η οποία μπορεί να γίνει με υπολογιστικά εργαλεία τα οποία χρησιμοποιούνται στην παρούσα διπλωματική εργασία.

INTRODUCTION

0.1 CSR background

The Common Structural Rules (CSR) were introduced in draft form in June 2004, adopted in 1st of January 2006 and implemented for ships contracted after the first of April 2006. There were a lot of reasons for that project. The major objectives were to stop the competition between Class Societies, as far as structural requirements are concerned, and also to reduce the possibility of ship builders to exploit the variety of structural standards provided by each Class Society and the competition between them for economic reasons which resulted in designs that were following the minimum rules of each and every individual Society, raising questions about the safety and robustness of the constructed ships [14]. CSR were developed using the best parts in the pre-CSR rules and the combined experience and resources of the Classification Societies that were involved in that project.

0.2 General concept of CSR

The main objective of both CSR is to establish requirements that reduce the risks of structural failure in order to help improve the safety of life, environment and property and to provide adequate durability of the hull structure for the design life. This aim is achieved by the determination of the adequate scantling values of the structural elements of the ship. Both CSR follow the same “route” in order to achieve the previously mentioned goal. More specifically the general concept of Common Structural Rules for both kinds of ships is the calculations of the loads applied on the vessel’s hull, then the determination of the required minimum thicknesses for plates and stiffeners and finally the design verification that concerns all the kinds of strength assessments that are included in the serviceability limit state, the ultimate limit state, the fatigue limit state and the accidental limit state.

0.3 Scope of the present thesis

The scope of the present diploma thesis is to compare the respective IACS Common Structural Rules of July 2010 for double hull oil tankers (DHOT) and for bulk carriers (BC). The comparison is carried out in both theoretical as well as practical point of view. To be more precise, the comparison concerns both the methodology that IACS CSR incorporate as well as the numerical results that conduct the implementation of the IACS CSR for these two kinds of ships. The following chapters are aiming to present the results of research in the three main topics of both CSR: hull girder and local loads, structural scantlings and design verification.

The rules are the link between theory and practice, namely between research and in service experience. CSR of these two kinds of ships are of great importance because double hull oil tankers and bulk carriers constitute a large part of the world fleet. In addition, the comparison of IACS CSR July 2010 for these two kinds of vessels is of great interest nowadays that IACS released the Harmonised CSR for bulk carriers and oil tankers in draft form and the discussion for this project has started a few months ago.

0.4 *Layout of the thesis*

Chapter 1: Presentation, explanation and comparison of the hull girder and local loads that are applied in the midship section of double hull oil tankers and bulk carriers according to their respective CSR.

Chapter 2: Comparison and theoretical analysis of the structural scantlings of the midship section of double hull oil tankers and bulk carriers as far as plates and longitudinal stiffeners are concerned.

Chapter 3: Comparison of the design verification procedures for double hull oil tankers and bulk carriers. Namely, this chapter focuses on hull girder bending strength assessment, buckling check of plates and stiffeners, hull girder ultimate strength check and fatigue check of longitudinal stiffeners. Direct strength analysis through finite elements methods and assessment of accidental limit state is beyond the scope of the present diploma thesis.

Chapter 4: Presentation and explanation of the results of the implementation of IACS CSR in three ships. More specifically the comparison is carried out among a double hull oil tanker with a centreline bulkhead, which is used as the basis of the comparison, and a double skin bulk carrier as well as a single skin bulk carrier, which have the same main particulars with the double hull oil tanker.

Chapter 5: Conclusions

Chapter 1 - LOADS

In this chapter the main objective is to explain the background of loads formulations and compare the provided formulae from CSR for double hull oil tankers and CSR for bulk carriers. The categorization of loads applied on hull structure can be done in many ways. The first level of loads discrimination chosen in the present thesis is the one between hull girder and local loads. The second concerns their static and dynamic components. Hence this chapter begins with hull girder loads' analysis divided in static and dynamic load components. Then follows the analysis of load cases provided in each CSR and finally local loads come next also divided in their static and dynamic components. The subchapter of load cases comes before the one of local loads because it's presentation is necessary in order to proceed to the dynamic local loads analysis.

1.1 HULL GIRDER LOADS

The category of hull girder loads contains still water bending moment and still water vertical shear force, vertical wave bending moment and vertical wave shear force, horizontal wave bending moment and wave torsional moment.

1.1.1 STATIC LOADS

Minimum hull girder still water bending moment

Rules give a minimum permissible still water bending moment and its distribution, in order to ensure that all ships have certain flexibility regardless of conditions included in the loading manual. The designer however is free to decide a larger hull girder bending moment, which will then be the basis for the strength analysis and strength assessment. The requirement about the still water bending moment was developed as a combination of IACS Unified Requirement 7 and 11. IACS UR S7 defines a minimum hull girder section modulus and IACS UR S11 an allowable hull girder stress and a rule hull girder wave bending moment. More specifically UR S11 states the allowable hull girder stress for gross scantlings to be $\sigma = 175/\kappa$ (N/mm²) for seagoing operations and provides the rule hull girder wave bending moment, whose value is presented in the following pages. UR S7 states the minimum midship section modulus at deck and keel for ships $90\text{m} \leq L \leq 500\text{m}$ to be $Z_{V-MIN} = cL^2B(C_B+0.7)k$, where $c = C_{WV}$ for "new" ships and $0.9C_{WV}$ for ships in service. According to UR S7 "new" ships are ships in the stage directly after completion.

To be more precise, the analysis starts from the following formula and results to the formulation of still water bending moments.

$$\sigma_{PERM} = \frac{M_{SW-MIN} + M_{WV}}{Z_{V-MIN} 10^3}$$

The previous formula is turned to:

$$\text{Hogging: } M_{SW-MIN-SEA-MID} = f_{sea} (Z_{V-MIN} \sigma_{PERM-SEA} 10^3 - M_{WV-HOG}) \text{ kNm}$$

$$\text{Sagging: } M_{SW-MIN-SEA-MID} = f_{sea} (Z_{V-MIN} \sigma_{PERM-SEA} 10^3 + M_{WV-SAG}) \text{ kNm}$$

The factor f_{sea} is used only in double hull oil tankers' analysis.

Where

$f_{sea} = -0.85$ for sagging

1 for hogging

$M_{SW-MIN-SEA-MID}$ = minimum hull girder hogging/sagging still water bending moment for seagoing operations at amidships

$\sigma_{PERM-SEA}$ = allowable seagoing hull girder bending stress at amidships

$M_{WV-HOG/SAG}$ = envelope values of hogging/sagging vertical wave bending moment amidships

Z_{V-MIN} = rule minimum hull girder section modulus

The difference of factor f_{sea} between hogging and sagging condition has to do with the fact that when the resulting moments (the rule minimum hull girder still water bending moments) were compared with permissible still water bending moments found in loading manuals for typical double hull tankers with a reasonable number of loading conditions and operational flexibility, there was a good agreement with permissible hogging moment of the ships (that is why $f_{sea}=1$) while IACS minimum permissible hull girder still water sagging moment was significantly higher than that found from the conditions in the mentioned loading manuals. That conducted to the calibration by multiplication of 0.85 with the implicit permissible IACS sagging moment.

By including the factor 0.9 from UR S7, in order to convert the section modulus requirement from "new ships" to be applicable to "ships in service", the allowable stress level in the gross scantling approach is divided by 0.9 at the value : $175 / (0.9k) = 194/k \text{ N/mm}^2$. The previous factor after rounding is turned to $190/k \text{ N/mm}^2$ in order to ensure that the CSR Rules for both types of ships in the "net" format are on the conservative side and also to ensure compliance with the corresponding IACS URS 11 gross requirement.

Consequently after replacing σ_{PERM} with its value (190/k), Z_{V-MIN} with its net format $[0.9C_{WV}L^2B(C_B+0.7)]$ and rule minimum hull girder wave bending moments that are presented in the following pages, the formulae for hogging and sagging still water bending moments for double hull oil tankers result to the formulae given in CSR DHOT, section 7.2, page 1:

$$\text{Hogging: } M_{SW-MIN-SEA-MID} = 0.01C_{WV}L^2B(11.97 - 1.9C_B) \text{ kNm}$$

$$\text{Sagging: } M_{SW-MIN-SEA-MID} = -0.05185C_{WV}L^2B(C_B + 0.7) \text{ kNm}$$

Where: L= rule length, in m

B= moulded breadth, in m

C_B = block coefficient

C_{WV} = wave coefficient to be taken as:

$$= 10.75 - (300 - L/100)^{3/2} \quad \text{for } 150 \leq L \leq 300$$

$$= 10.75 \quad \text{for } 300 < L \leq 350$$

$$= 10.75 - (L - 350/150)^{3/2} \quad \text{for } 350 < L \leq 500$$

For harbour operations, the rule minimum hull girder still water bending moment is taken as 25% higher than that for the seagoing operations in order to allow for reasonable flexibility during loading and unloading operations. The value of increase is based on review of actual at-sea and in-port conditions.

$$M_{SW-MIN-HARB} = 1.25M_{SW-MIN-SEA} \quad \text{kNm}$$

In bulk carriers' analysis the formulation of rule minimum hull girder still water bending moments is based as in case of double hull oil tankers on the criteria of UR S7 and 11. Hence rule hogging and sagging still water bending moments are given according to CSR by the following types:

$$\text{Hogging: } M_{SW-MIN-SEA-MID} = 175C_{WV}L^2B(C_B + 0.7)10^{-3} - M_{WV,H}$$

$$\text{Sagging: } M_{SW-MIN-SEA-MID} = 175C_{WV}L^2B(C_B + 0.7)10^{-3} - M_{WV,S}$$

In other words CSR for bulk carriers formulate rule still water bending moment using σ_{PERM} for gross scantlings which is equal to 175/k and $Z_{V-MIN} = C_{WV}L^2B(C_B + 0.7)$ (the formula of "new ships" according to UR S7 or the gross section modulus as far as the thickness approach used is concerned). Hence the formulae of rule minimum still water bending moments are turned to:

$$\text{Hogging: } M_{SW-MIN-SEA-MID} = 0.01C_{WV}L^2B(12.25 - 1.5C_B)$$

$$\text{Sagging: } M_{SW-MIN-SEA-MID} = 0.065C_{WV}L^2B(C_B + 0.7) \quad (\text{given as absolute value})$$

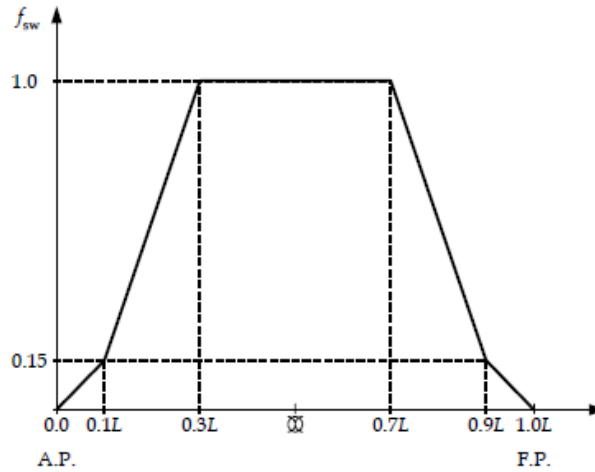
The slight difference between tankers and bulk carriers as far as the formula of still water bending moment amidships in hogging condition is concerned, is due to the fact that in tankers' CSR are used the net hull girder section modulus (Z_{V-MIN}) and the σ_{PERM} for net scantlings while in bulk carriers' CSR this is not case as they use σ_{PERM} for gross scantling and the gross hull girder section modulus. In sagging condition apart from the difference mentioned above, the factor f_{sea} is used only in tankers' analysis and not in CSR for bulk carriers.

The distribution of still water bending moment is given by the following equation:

$$M_{SW-MIN-SEA} = f_{sw}M_{SW-MIN-SEA-MID} \quad \text{kNm}$$

Where:

For tankers $f_{sw} = 1$ within 0.4L amidships
 $= 0.15$ at 0.1L from A.P. or F.P.
 $= 0$ at A.P. and F.P.

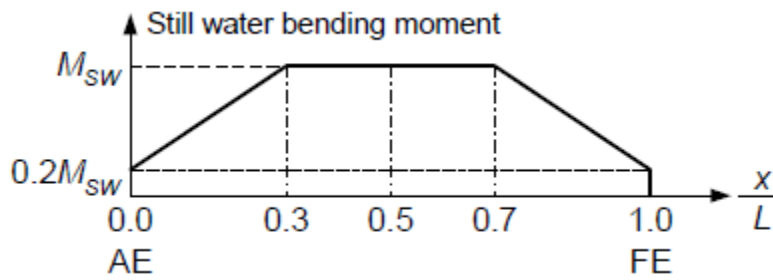


Distribution of still water bending moment for double hull oil tankers

For bulk carriers $f_{sw} = 0.2$ at A.P. and F.P.

1 within 0.4 amidships

Intermediate values are to be obtained by linear interpolation.



Distribution of still water bending moment for bulk carriers

Still water shear force

The following formulations represent the local shear force that is created by the difference of cargo weight, steel weight and buoyancy between adjacent holds. The permissible positive and negative still water shear force in intact condition at any hull transverse section is obtained for both types of ships from the following formula:

$$Q_{sw} = \varepsilon |Q_T| - Q_{wv}$$

that is turned to:

$$Q_{sw} = \varepsilon \left(\frac{\tau_{ij-perm} t_{ij-net50}}{1000 q_v} + \Delta Q_C \right) - Q_{wv}$$

Where:

$\varepsilon = \text{sgn}()$, [sgn(): signum function]

$\tau_{ij-perm}$: permissible hull girder shear stress for plate ij equal to $120/k$ in N/mm^2 for seagoing condition

κ =material factor whose value is a function of the minimum yield stress of the steel used

Minimum yield stress, in N/mm ²	κ
235	1
315	0.78
355	0.72
390	0.68

$t_{ij-net50}$: net thickness for plate ij in mm equal to: $t_{grs}-0.5t_{corr}$ (t_{grs} : gross thickness)

q_v : unit shear flow per mm for the plate being considered and based on net scantlings. Where direct calculation of the unit shear flow is not available, the unit shear flow may be taken equal to:

$$q_v = \delta \left(\frac{q_{1-net50}}{I_{v-net50}} \right) 10^{-9} \quad \text{mm}^{-1}$$

δ = shear force distribution coefficient for the main longitudinal hull girder shear carrying members being considered defined for bulk carriers in Table 1 in CSR BC, chapter 5, section 1, page 10 and for double hull oil tankers in Figure 8.1.2 in CSR DHOT, section 8.1, page 11

$q_{1-net50}$: net first moment, in cm³, about the horizontal neutral axis of the effective longitudinal members between the vertical level at which the shear stress is being determined and the vertical extremity, taken at the section being considered. Net first moment of area is to be based on the net thickness, t_{net50}

$I_{v-net50}$ =net vertical hull girder moment of inertia, in m⁴, of the hull transverse section about its horizontal neutral axis. The net moment of inertia is to be calculated based on gross thickness minus the corrosion addition $0.5t_{corr}$ of all effective structural members comprising the hull girder section.

Q_{wv} =vertical wave shear force in intact condition, in kN, at the hull transverse section considered, presented in the following pages

ΔQ_C = shear force corrections, to be considered independently forward and aft of the transverse bulkhead. The shear force correction takes into account, when applicable, the portion of loads transmitted by the double bottom girders to the transverse bulkheads.

For bulk carriers there are two cases:

For ships with any non-homogeneous loading conditions, such as alternate hold loading conditions and heavy ballast conditions carrying ballast in holds:

$$\Delta Q_C = \alpha \left| \frac{M}{B_H l_H} - \rho T_{LC, mh} \right| \quad \text{for each non-homogeneous loading condition}$$

For other ships (e.g. double hull oil tankers) and homogeneous loading conditions

$$\Delta Q_C = 0$$

Where:

$$a = g \frac{l_o b_o}{2 + \varphi \frac{l_o}{b_o}}$$

$$\varphi = 1.38 + 1.55 \frac{l_o}{b_o} \text{ to be taken not greater than } 3.7$$

l_o, b_o = length and breadth, respectively, in m, of the flat portion of the double bottom in way of the hold considered. b_o is to be measured on the hull transverse section at the middle of the hold

l_H = length, in m, of the hold considered, measured between the middle of the transverse corrugated bulkheads

B_H = ship's breadth, measured at the level of inner bottom on the hull transverse section at the middle of the hold

M = mass, in t, in the considered section

-if the adjacent cargo hold is loaded in a non homogeneous loading condition then M is to include the total mass in the hold and the mass of water ballast in double bottom tank, bounded by side girders in way of hopper tank plating or longitudinal bulkhead.

-on the other cases M is the total mass in the hold

$T_{LC,mh}$ = draught, in m, measured vertically on the hull transverse section at the middle of the hold considered, from the moulded baseline to the waterline in the loading condition considered

Hence, the previous formula that gives the permissible still water shear force is turned to:

$$Q_{SW} = \varepsilon \left(\frac{120 I_{v-net50} t}{\kappa \delta q_{l-net50}} 10^6 + \Delta Q_C \right) - Q_{WV} \quad \text{kN}$$

In CSR for double hull oil tankers the minimum hull girder positive and negative still water shear force for seagoing operation $Q_{sw-min-sea}$ is given for the two different cases expressed below from the following formulae (CSR DHOT, Section 7.2, page 4):

-Ships with 2 longitudinal bulkheads

In way of transverse bulkheads between centre cargo tanks

For seagoing operation:

$$Q_{sw-min-sea} = \pm \max \left\{ \begin{array}{l} 0.225 \rho g B_{local} l_{tk} T_{SC} \\ 0.5 \rho g [0.98(V_{CT} + 2V_{ST}) - 0.7 B_{local} l_{tk} T_{SC}] \end{array} \right.$$

For harbour/sheltered water operation:

$$Q_{sw-min-harb} = \pm \max \left\{ \begin{array}{l} 0.275 \rho g B_{local} l_{tk} T_{SC} \\ 0.5 \rho g [0.98(V_{CT} + 2V_{ST}) - 0.6 B_{local} l_{tk} T_{SC}] \end{array} \right.$$

-Ships with centerline longitudinal bulkhead

In way of transverse bulkheads between cargo tanks

For seagoing operation:

$$Q_{sw-min-sea} = \pm 0.4 \rho g B_{local} l_{tk} T_{sc} \quad \text{kN}$$

For harbour/sheltered water operation:

$$Q_{sw-min-sea} = \pm 0.45 \rho g B_{local} l_{tk} T_{sc} \quad \text{kN}$$

Where:

ρ : density of cargo/sea water, not to be taken less than 1.025 tonnes/m³

g : acceleration due to gravity

B_{local} : local breadth at scantling draught at the middle length of the tank under consideration, in m

l_{tk} : length of cargo tank under consideration, taken at the forward or aft side of the transverse bulkhead under consideration, in m

T_{sc} : scantling draught, in m

V_{CT} : volume of centre cargo tank, taken for the cargo tank on the forward or aft side of the transverse bulkhead under consideration, in m

V_{ST} : volume of side cargo tank, taken for the cargo tank on the forward or aft side of the transverse bulkhead under consideration, in m

1.1.2 DYNAMIC LOADS

Vertical wave bending moment

The wave induced hull girder vertical bending moment in the intact condition is based, as mentioned above, on IACS UR S11. It is specified as an envelope value at a 10^{-8} probability level, which corresponds to the maximum value of 25 years (design life). Both double hull oil tankers and bulk carriers have the same formula for the vertical wave bending moment.

$$\text{Hogging: } M_{WV-HOG} = f_{\text{prob}} 0.19 f_{wv-v} C_{WV} L^2 B C_B \quad \text{kNm}$$

$$\text{Sagging: } M_{WV-SAG} = -f_{\text{prob}} 0.11 f_{wv-v} C_{WV} L^2 B (C_B + 0.7) \quad \text{kNm}$$

Where:

For scantling requirements/strength assessment

$f_{wv-v} = 0.0$ at A.P.

1.0 for $0.4L$ to $0.65L$ from A.P.

0.0 at F.P.

Intermediate values are to be obtained by linear interpolation.

For fatigue strength:

$f_{wv-v} = 0.0$ at A.P.

0.1 at $0.1L$ from A.P.

1.0 for $0.4L$ to $0.65L$ from A.P.

0.1 at $0.9L$ from A.P.

0.0 at F.P.

Intermediate values are to be obtained by linear interpolation.

$$C_{WV} = 10.75 - \left(\frac{300-L}{100} \right)^{3/2} \quad \text{for } 150 \leq L \leq 300$$

$$10.75 \quad \text{for } 300 < L \leq 350$$

$$10.75 - \left(\frac{L-350}{150} \right)^{3/2} \quad \text{for } 350 < L \leq 500$$

The C_{WV} values are valid for worldwide service and are representative for the North-Atlantic wave statistics.

$f_{\text{prob}} = 1$ scantling requirements/strength assessment

0.5 fatigue strength

The application of an adjustment factor, f_{prob} , of 0.5 for fatigue assessment accounts for the probability level and speed effects. As far as speed effects are concerned, for full load condition the speed effects are considered small, while for ballast condition the speed effect is greater, which justifies that the same wave vertical bending moment can be used for the two loading conditions.

Vertical wave shear force

Both tankers and bulk carriers' rules have the same formula for the wave induced hull girder shear force which is also based on IACS UR S11, i.e.:

$$Q_{wv-pos} = 0.3f_{qvw-pos} C_{wv} LB(C_b + 0.7) \quad \text{kN}$$

$$Q_{wv-neg} = -0.3f_{qvw-neg} C_{wv} LB(C_b + 0.7) \quad \text{kN}$$

Where:

$f_{qvw-pos}$: distribution factor for positive vertical wave shear force along the vessel length and is to be taken:

0.0	at A.P.
$1.59 \frac{C_b}{(C_b+0.7)}$	for 0.2L to 0.3L from A.P.
0.7	for 0.4L to 0.6L from A.P.
1.0	for 0.7L to 0.85L from A.P.
0.0	at F.P.

$f_{qvw-neg}$: distribution factor for negative vertical wave shear force along the vessel length and is to be taken:

0.0	at A.P.
0.92	for 0.2L to 0.3L from A.P.
0.7	for 0.4L to 0.6L from A.P.
$1.73 \frac{C_b}{(C_b+0.7)}$	for 0.7L to 0.85L from A.P.
0.0	at F.P.

Horizontal wave bending moment

The wave induced hull girder horizontal bending moment, is determined as the envelope value with a probability level of exceedance of 10^{-8} . It is an oblique or beam Sea dominated response. The following formula is applied in every loading condition by using the draught. Both CSR use the following type for the horizontal wave bending moment.

$$M_{wv-h} = f_{prob} \left(0.3 + \frac{L}{2000} \right) f_{wv-h} C_{wv} L^2 T_{LC} C_b$$

Where:

f_{wv-h} : distribution factor for wave horizontal bending moment along the vessel length, is to be taken as:

For scantling requirements/strength assessment

$f_{wv-h} = 0.0$	at A.P.
1.0	for 0.4L to 0.65L from A.P.
0.0	at F.P.

Intermediate values are to be obtained by linear interpolation.

For fatigue strength:

$f_{wv-h} = 0.0$	at A.P.
0.1	at 0.1L from A.P.
1.0	for 0.4L to 0.65L from A.P.
0.1	at 0.9L from A.P.
0.0	at F.P.

Intermediate values are to be obtained by linear interpolation.

$$C_{wv} = \begin{cases} 10.75 - \left(\frac{300-L}{100} \right)^{3/2} & \text{for } 150 \leq L \leq 300 \\ 10.75 & \text{for } 300 < L \leq 350 \\ 10.75 - \left(\frac{L-350}{150} \right)^{3/2} & \text{for } 350 < L \leq 500 \end{cases}$$

$$f_{\text{prob}} = \begin{cases} 1 & \text{scantling requirements/strength assessment} \\ 0.5 & \text{fatigue strength} \end{cases}$$

Wave torsional moment

This type of load concerns ships whose deck has discontinuities (i.e. hatches) and as a result suffer from torsion. Hence there is only in CSR for bulk carriers reference to the wave torsional moment. The wave induced torsional moment and its formula is used only in the fatigue strength analysis of structural members at the hatch corners. That is why the value corresponding to the exceedance probability level of 10^{-4} is used, in other words $f_p=0.5$. The following formula is based on the wave torsional moment of GL Rules.

$$M_{WT} = f_p (|M_{WT1}| + |M_{WT2}|)$$

Where:

$$M_{WT1} = 0.4C \sqrt{\frac{L}{T}} B^2 D C_B F_{T1}$$

$$M_{WT2} = 0.22CLB^2 C_B F_{T2}$$

and

$$F_{T1} = \sin\left(\frac{2\pi x}{L}\right)$$

$$F_{T2} = \sin^2\left(\frac{\pi x}{L}\right)$$

DISCUSSION

The value of the minimum permissible still water bending moment differs between bulk carriers and double hull oil tankers. Namely the difference between the minimum permissible still water bending moment of a bulk carrier and a double hull oil tanker is equal to:

$$\text{Hogging: } 0.01C_{wv}L^2B(0.28 - 0.4C_B)$$

$$\text{Sagging: } 0.01315C_{wv}L^2B(C_B + 0.7)$$

The reason of this difference is shown in the respective subsection of the present thesis and has to do with the implementation of net thickness approach in each CSR. To be honest, that difference should not exist as it is only a matter of application. Apart from that, it can be easily seen that the difference between bulk carriers and double hull oil tankers in the values of minimum permissible still water bending moment is higher in sagging. That happens because of the factor f_{sea} that is incorporated in the formula of double hull oil tankers only in sagging.

As far as permissible still water shear force is concerned, both CSR provide the same formulae. That happens also in case of vertical wave bending moments and vertical wave shear force, which are based on UR S11, as well as in case of horizontal wave bending moment. The formula of wave torsional moment is provided only in CSR for bulk carriers because of the cross deck bending induced by wave torsion moments, hence its determination is necessary in the calculation of the nominal stress range in fatigue strength assessment.

1.2 LOAD CASES

Before mentioning the local loads for both types of ships, it is necessary to quote the method of equivalent design wave (EDW), the formulae of ships motions and accelerations and finally the dynamic load cases that are used in both types of ships.

1.2.1 EQUIVALENT DESIGN WAVE METHOD (EDW)

In order to present the way design loads are formulated according to CSR, it is necessary to quote the equivalent design wave method (EDW). The dynamic loads (hull girder or local loads) are given for every dynamic load case, by multiplying the dynamic load combinations factors (LCF) with their respective load envelope value at 10^{-8} probability level. This procedure conducts to the formulation of the simultaneously acting load components for a particular design dynamic load combination case. Each dynamic load case is based on maximizing one critical load component. The load is maximized by placing the vessel in a wave which produces the envelope value at 10^{-8} probability level.

In order to extract the dynamic load combination factors, is necessary to take a “snap-shot” of the other dynamic loads acting simultaneously as the maximized response is taken. The ratios between the values of these dynamic loads at the “snap shot” and their corresponding longterm envelope values give the dynamic load combinations factors (LCF) for each dynamic load case. This concept of finding LCF is the Equivalent Design Wave method.

The design conditions mentioned below are the basic conditions of Common Structural Rules for both types of vessels.

- (a) Operating sea area: North Atlantic Ocean. The applied wave-scatter diagram and short-term and long-term statistical prediction approach is given in IACS Rec. 34.
- (b) Design life: 25 years (exceedance probability: $Q=10^{-8}$ level)
- (c) The Pierson-Moskowitz wave spectrum
- (d) An equal probability on all wave headings
- (e) A wave energy-spreading of $\cos^2$

Ship motions and accelerations

Ship motions and accelerations are assumed to vary periodically. The amplitude calculated from the following formulae is as half the amplitude from the peak to the trough. In addition, the value corresponding to an exceedance probability level of 10^{-8} corresponds to the maximum ship motion and acceleration that the ship is expected to experience in its lifetime.

Roll motion

The roll period is the natural period of roll and is based on simple physical relations. The added mass effect is taken into account by the replacement of 2 with 2.3. Hence roll period (T_R) is given for both types of ships by the following formula:

$$T_R = \frac{2.3k_r}{\sqrt{GM}} \text{ secs}$$

Where k_r is the roll radius of gyration, in m, in the considered loading condition and GM the metacentric height in the considered loading condition.

Values of k_r and GM

Loading condition	T_{LC}		GM		k_r	
	Tankers	Bulk carriers	Tankers	Bulk carriers	Tankers	Bulk carriers
Full load condition	Between $0.9T_{SC}$ and T_{SC}	Alternate or homogeneous loading	0.12B	0.12B	0.35B	0.35B
		Steel coil loading		0.24B		0.42B
Loaded on reduced draught	$0.6T_{SC}$	Heavy ballast draught	0.24B	0.25B	0.40B	0.40B
In ballast	Normal ballast draught	Normal ballast draught	0.33B	0.33B	0.45B	0.45B

As it is shown above, there is only a slight difference between the two types of ships, in the value of GM when the ship is loaded on reduced draught.

The roll amplitude θ is the roll-angle, which considers the influence of roll period, the effect of bilge keels, the mass distribution and the GM on the roll period. Hence, for both types of ships:

$$\theta = \frac{9000(1.25 - 0.025T_R)f_p k_b}{(B + 75)\pi} \text{ deg} \quad \text{or} \quad \theta = \frac{50(1.25 - 0.025T_R)f_p k_b}{(B + 75)} \text{ rads}$$

Where k_b is a coefficient equal to: 1.2 for ships without bilge keel
1 for ships with bilge keel

Pitch motion

The pitch period is the wave period at which the pitch motion response function RAO (Response Amplitude Operator which indicates the motion at a given wave period) becomes maximum. Pitching motion generally becomes maximum in the head sea conditions. The wavelength λ at which the pitch motion response function becomes maximum is practically the same as the regular wavelength λ at which the vertical wave bending moment at the midship part of the hull becomes maximum. The wave length is given, in both CSR, by the following formula:

$$\lambda = 0.6 \left(1 + \frac{T_{LC}}{T_S} \right) L = \frac{g}{2\pi} T_P^2$$

Where T_{LC} is the midship draught in the considered loading condition and T_S the scantling draught. The following formula gives the value of pitch period (T_P):

$$T_P = \sqrt{\frac{2\pi\lambda}{g}}$$

The pitch angle is given by the following equation:

$$\varphi = f_p \frac{960}{L} \sqrt[4]{\frac{V}{C_B}} \frac{\pi}{180} \text{ radians}$$

The pitch period is mainly proportional to $\sqrt{L}$ (it is extracted from the equation of λ) but it is also affected by the loading condition. This is accounted for by $\frac{T_{LC}}{T_{SC}}$, which is in the formula of λ . In addition, it is dependent on the main wave periods in head sea and is strongly linked to the encounter period and thus the ship speed will influence the characteristic pitch period. The pitch period will decrease for increasing ship speed.

Ship relative accelerations

The accelerations are combinations of the basic rigid body global motion accelerations in all six degrees of freedom, where its component is assumed to be independent, and factors to account for phase-differences between the accelerations.

Common acceleration parameter

It is the basic vertical acceleration parameter representing heave, sway, yaw and surge motion. It is given in both CSR by the following formula:

$$a_0 = (1.58 - 0.47C_B) \left(\frac{2.4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2} \right)$$

- Vertical acceleration

The vertical acceleration, a_v , is acceleration along the body-fixed z-axis. The general expression predicts vertical acceleration with a 10^{-8} probability of exceedance anywhere on the ship. a_v includes heave, pitch and roll components. The motion reference point is assumed to be at the centerline and 0.45L from aft end of L. However the formulae given for both types of ships have differences and more specifically:

In CSR for double hull oil tankers, the envelope vertical acceleration is equal to:

$$a_v = f_{prob} \sqrt{a_{heave}^2 + a_{pitch-z}^2 + a_{roll-z}^2} \text{ m/s}^2$$

Where:

a_{heave} : vertical acceleration due to heave, in m/s^2

$$a_{heave} = f_v a_o g$$

The factor f_v accounts for speed effects, defined in next page

$a_{pitch-z}$: vertical acceleration due to pitch, in m/s^2

$$a_{pitch-z} = \left(0.3 + \frac{L}{325} \right) \varphi \left(\frac{2\pi}{T_p} \right)^2 |x - 0.45L|$$

The factor of $(0.3 + L/325)$ that $a_{pitch-z}$ is multiplied by, is there in order to account for different phase relation between the acceleration components (i.e. roll and heave acceleration). As it can be easily extracted by the given formula, this phasing is dependent on the ship length.

a_{roll-z} vertical acceleration due to roll, in m/s^2

$$a_{roll-z} = 1.2\theta \left(\frac{2\pi}{T_R} \right)^2 |y| \quad \text{where } \theta \text{ in rads}$$

The factor of 1.2 that the a_{roll-z} is multiplied by is used in order to account for the phase difference between roll acceleration and the combined heave and pitch acceleration. Speed is assumed to have no influence on the roll vertical acceleration because roll is a beam sea dominant response, and the encounter frequency in beam sea is not affected by a speed change.

For scantling requirements and strength assessment:

$$f_{prob} = 1$$

$$f_v = 1$$

For fatigue strength

$$f_{prob} = 0.45$$

The probability factor for fatigue takes the value above, because it gives the best fit with direct calculations and accounts for the difference in probability level for fatigue strength assessment (10^{-4} instead of 10^{-8} for strength assessment and scantling requirements) and speed effects.

$$f_v = \left(\frac{C_{B-LC}}{C_B} \right)^2 \left(1.2 - \frac{L}{1000} \right)$$

Where

C_{B-LC} : block coefficient for considered loading condition

C_B : block coefficient at scantling draught

The formula of the f_v factor is calibrated (as it is shown above) in order to match the trends between the direct calculations for the loads in loaded and ballast condition, as far as fatigue strength assessment is concerned.

In CSR for bulk carriers, the reference value of vertical acceleration is equal to::

$$a_v = C_{ZH} a_{heave} + C_{ZR} a_{roll-z} + C_{ZP} a_{pitch-z}$$

Where

C_{ZH} , C_{ZR} , C_{ZP} are load combination factors given in Table 3 of the following subsection

$$a_{heave} = a_o g$$

$$a_{pitch-z} = \varphi \frac{\pi}{180} \left(\frac{2\pi}{T_p} \right)^2 |(x - 0.45L)|, \text{ where } |(x - 0.45L)| \text{ is to be taken not less than } 0.2L$$

$$a_{roll-z} = \theta \frac{\pi}{180} \left(\frac{2\pi}{T_R} \right)^2 y \quad \text{where } \theta \text{ in deg}$$

- Transverse acceleration

Roll, sway and yaw acceleration along the body-fixed y-axis contribute in the formation of the transverse acceleration a_t . Its value does not change along the breadth of the vessel, assuming that the yaw acceleration component is negligible (which is not explicitly given). In a_t form is also included the g-component of roll. However, as it happened in the formula of vertical acceleration, transverse acceleration for tankers differs from that for bulk carriers. More specifically:

In CSR for double hull oil tankers, the envelope transverse acceleration is equal to:

$$a_t = f_{prob} \sqrt{a_{sway}^2 + (g \sin \theta + a_{roll-y})^2} \quad \text{m/s}^2$$

Where

$f_{prob} = 1$ for scantling requirements and strength assessment
 0.5 for fatigue strength

In CSR for bulk carriers, the reference value of transverse acceleration is equal to:

$$a_t = C_{YG} g \sin \theta + C_{YS} a_{sway} + C_{YR} a_{roll-y} \quad \text{m/s}^2$$

Where

C_{YG} , C_{YS} , C_{YR} are load combination factors given in a following table

Both tankers and bulk carriers have same forms for a_{sway} and a_{roll-y} .

$$a_{sway} = 0.3 g a_0 \quad \text{m/s}^2$$

$$a_{roll-y} = \theta \left(\frac{2\pi}{T_R} \right)^2 R \quad \text{m/s}^2, \text{ where } \theta \text{ in rads}$$

$R = z - \left(\frac{D}{4} + \frac{T_{LC}}{2} \right)$ or $z - \left(\frac{D}{2} \right)$ whichever is the greater, in m. It is an approximation of the vertical centre of gravity of the ship.

It is assumed that the transverse acceleration has no speed effects because it is beam seas dominant.

- Longitudinal acceleration

Surge, yaw, and pitch acceleration contribute in the formation of the longitudinal acceleration. By its general expression, can be predicted the longitudinal acceleration with a 10^{-8} probability of occurrence anywhere on the ship. Its value does not change along the length of the vessel, assuming that the yaw acceleration component is negligible. Hence, the yaw term, as in the case of transverse acceleration, is not explicitly given. The g-component of the pitch angle is included in the expression. However, as it happened in the previous two cases of accelerations, there are differences in the expression of longitudinal acceleration between tankers and bulk carriers.

In CSR for double hull oil tankers, the envelope longitudinal acceleration is equal to:

$$a_{ln g} = 0.7 f_{prob} \sqrt{a_{surge}^2 + \left(\frac{L}{325} (g \sin \varphi + a_{pitch-x}) \right)^2} \quad \text{m/s}^2$$

Where:

$$a_{pitch-z} = f_v \varphi \left(\frac{2\pi}{T_p} \right)^2 R$$

$f_{prob} =$ 1 for scantling requirements and strength assessment
 0.5 for fatigue strength (this value is given in order to fit with direct calculations at the 10^{-4} probability level)

f_v : speed factor

= 1 for scantling requirements and strength assessment
 1.7 for fatigue strength

$R = z - \left(\frac{D}{4} + \frac{T_{LC}}{2} \right)$ or $z - \left(\frac{D}{2} \right)$ whichever is the greater, in m. It is an approximation of the vertical centre of gravity of the ship.

Pitch and surge accelerations are considered to be statistically independent for larger ships. But for shorter ships, the accelerations start cancelling each other. That is why the factor of $L/325$ is included, which account for this.

In CSR for bulk carriers, the reference value of longitudinal acceleration is equal to:

$$a_{lng} = C_{XG} g \sin \varphi + C_{XS} a_{surge} + C_{XP} a_{pitch-x} \quad m/s^2$$

Where:

C_{XG} , C_{XS} , C_{XP} are load combination factors given in a following table

$$a_{pitch-z} = \varphi \frac{\pi}{180} \left(\frac{2\pi}{T_p} \right)^2 |(x - 0.45L)|, \text{ where } |(x - 0.45L)| \text{ is to be taken not less than}$$

0.2L

For both kinds of ships

$$a_{surge} = 0.2g a_o$$

1.2.2 DYNAMIC LOAD CASES

The load cases mentioned below are used in strength analysis and strength assessment. They are used in local strength analysis for structural scantlings (plate, stiffeners, and primary supporting members), direct strength analysis of structural members and fatigue assessment of structural details.

In bulk carriers' CSR 8 load cases (H1, H2, F1, F2, R1, R2, P1, P2) corresponding to 4 equivalent design waves are considered. The load components which are selected as dominant load components for structural strength in the Rules are vertical wave bending moment (head sea and following sea), roll and external pressure at waterline. These load cases are defined in the following table:

Load case	H1	H2	F1	F2	R1	R2	P1	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	(+)	(-)	(+)	(-)

Table1

More specifically, the design sea state H is the short- term sea state at which the vertical acceleration due to combination of pitching and heaving, and the vertical bending moment become maximum. The design sea state F is similar to the design sea state H, but at this set the vertical acceleration becomes minimum (i.e. inertia forces become minimum). At the design sea state R the transverse acceleration due to roll and the hydrodynamic pressure having asymmetric distribution become maximum. Finally at the P design sea state the hydrodynamic pressure at the waterline of the weather side and the vertical acceleration due to heave become maximum.

Reference hull girder loads and motions of ship

Load case	H1	H2	F1	F2	R1	R2	P1	P2
Vert.BM & SF	Yes		Yes		-		Yes	
Hor.BM	-		-		Yes		-	
Heave	Down	Up	-	-	Down	Up	Down	Up
Pitch	Bow down	Bow up	-	-			-	-
Roll	-	-	-	-	Starboard up	Starboard down	Starboard up	Starboard down
Surge	Stern	Bow	-	-	-	-	-	-
Sway	-	-	-	-	-	-	Port	Starboard

Table2

In order to obtain the hull girder loads and the acceleration components in each load case H1, H2, F1, F2, R1, R2, P1, and P2 the reference value of each component is multiplied by the relevant load combination factor LCF defined in the following Table:

	LCF	H1	H2	F1	F2	R1	R2	P1	P2
M _{wv}	C _{wv}	-1	1	-1	1	0	0	$0.4 - \frac{T_{LC}}{T_s}$	$\frac{T_{LC}}{T_s} - 0.4$
Q _{wv}	C _{QW (1)}	-1	1	-1	1	0	0	$0.4 - \frac{T_{LC}}{T_s}$	$\frac{T_{LC}}{T_s} - 0.4$
M _{WH}	C _{WH}	0	0	0	0	$\frac{T_{LC}}{T_s} - 1.2$	$\frac{T_{LC}}{T_s} - 1.2$	0	0
a _{surge}	C _{XS}	-0,8	0,8	0	0	0	0	0	0
a _{pitch x}	C _{XP}	1	-1	0	0	0	0	0	0
g _{sinΦ}	C _{XG}	1	-1	0	0	0	0	0	0
a _{sway}	C _{YS}	0	0	0	0	0	0	1	-1
a _{roll y}	C _{YR}	0	0	0	0	1	-1	0,3	-0,3
g _{sinθ}	C _{YG}	0	0	0	0	1	-1	0,3	-0,3
a _{heave}	C _{ZH}	$0.6 \frac{T_{LC}}{T_s}$	$-0.6 \frac{T_{LC}}{T_s}$	0	0	$\frac{\sqrt{L}}{40}$	$-\frac{\sqrt{L}}{40}$	1	-1
a _{roll z}	C _{ZR}	0	0	0	0	1	-1	0,3	-0,3
a _{pitch z}	C _{ZP}	1	-1	0	0	0	0	0	0
(1) The LCF for C _{QW} is only used for the aft part of midship section. The inverse value of it should be used for the forward part of the midship section.									

Table3

In CSR for double hull oil tankers, as far as scantling requirements are concerned, 9 load cases are used corresponding to 3 equivalent design waves (design regular waves). Three load cases exist for the design sea state «Head sea», two for the design sea state «Oblique sea» and six for the design sea state «Beam sea». The load components which are maximized in the load cases are vertical wave bending moment, vertical acceleration, longitudinal acceleration, horizontal wave bending moment, transverse acceleration, dynamic wave pressure at bottom centerline, and dynamic wave pressure at waterline. The dynamic load combination factors are found from analysis at four longitudinal positions along the ships. That is necessary in order ensure that the phasing differences along the hull are taken into account, in addition to the variation of the magnitude and the variation of the importance of local dominance against global dominance. Two different loading conditions are considered: the heavy ballast condition and the full load condition at scantling draught.

In order to obtain the dynamic loads (global or local) in every load case, the dynamic load combination factors are multiplied with the associated load component or acceleration. As far as the hull girders loads are concerned, their value in each load case is obtained by the following formulae:

Vertical wave bending moment for a considered dynamic load case:

$$\begin{aligned} M_{wv} &= f_b f_{mv} M_{wv-hog} & \text{for } f_{mv} \geq 0 \\ M_{wv} &= -f_b f_{mv} M_{wv-sag} & \text{for } f_{mv} \leq 0 \end{aligned}$$

Where:

f_b : heading correction factor

0.8 for beam sea dynamic load cases

1.0 for all other dynamic load cases

f_{mv} : dynamic load combination factor (DLCF) for vertical wave bending moment for considered dynamic load case, given in Table 4

Vertical wave shear force for a considered dynamic load case:

$$\begin{aligned} Q_{wv} &= f_b f_{qv} Q_{wv-pos} & \text{for } f_{qv} \geq 0 \\ Q_{wv} &= -f_b f_{qv} Q_{wv-neg} & \text{for } f_{qv} < 0 \end{aligned}$$

f_{qv} : dynamic load combination factor (DLCF) for vertical wave shear force for considered dynamic load case, given in Table 4

Horizontal wave bending moment for a considered dynamic load case:

$$M_h = f_b f_{mh} M_{wv-h}$$

Where:

f_{mh} = dynamic load combination factor (DLCF) for horizontal wave bending moment for considered dynamic load case, given in Table 4

The load cases mentioned above for mid and aft cargo tank region are defined in the following tables (the first for full load and the second for ballast condition):

Dynamic Load Cases for Mid and Aft Cargo Tank Region for Loaded Condition													
Wave direction			Head Sea			Oblique Sea		Beam Sea					
Max response			M_{wv}	a_v	a_{lng}	M_{wv-h}		a_t		P_{ctr}		P_{WL}	
Dynamic Load Case			1	2	3	4a	4b	5a	5b	6a	6b	7a	7b
Global loads	M_{wv}	f_{mv}	1.0	-1.0	0.5	-0.2	-0.2	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3
	M_{wv-h}	f_{mh}	0.0	0.0	0.0	1.0	-1.0	-0.1	0.1	0.0	0.0	0.0	0.0
Accelerations	a_{v-mid}	f_{v-mid}	-0.2	0.5	-0.4	-0.1	-0.1	0.5	0.5	1.0	1.0	1.0	1.0
	a_{v-pt}	f_{v-pt}	-0.2	0.5	-0.4	-0.1	-0.1	0.2	0.6	0.8	1.0	0.8	1.0
	a_{v-stb}	f_{v-stb}	-0.2	0.5	-0.4	-0.1	-0.1	0.6	0.2	1.0	0.8	1.0	0.8
	a_t	f_t	0	0	0	0	0	1	-1	0,5	-0,5	0,6	-0,6
	$a_{lng-mid}$	$f_{lng-mid}$	0.3	-0.6	1.0	-0.3	-0.3	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
	a_{lng-pt}	f_{lng-pt}	0.3	-0.6	1.0	-0.4	-0.2	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
	$a_{lng-stb}$	$f_{lng-stb}$	0.3	-0.6	1.0	-0.2	-0.4	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
	$a_{lng-ctr}$	$f_{lng-ctr}$	0.3	-0.6	1.0	-0.3	-0.3	-0.1	-0.1	-0.5	-0.5	-0.6	-0.6
Dynamic wave pressure for starboard side	P_{ctr}	f_{ctr}	0.7	-0.6	0.2	-0.3	-0.3	0.5	0.5	1.0	1.0	0.9	0.9
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	-0.4	-0.1	0.8	-0.3	0.9	0.4	1.0	0.4
	P_{WL}	f_{WL}	0.3	-0.3	0.1	-0.6	-0.1	0.5	-0.2	0.8	0.4	1.0	0.4
Dynamic wave pressure for port side	P_{ctr}	f_{ctr}	0.7	-0.6	0.2	-0.3	-0.3	0.5	0.5	1.0	1.0	0.9	0.9
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	-0.1	-0.4	-0.3	0.8	0.4	0.9	0.4	1.0
	P_{WL}	f_{WL}	0.3	-0.3	0.1	-0.1	-0.6	-0.2	0.5	0.4	0.8	0.4	1.0
a_{v-pt} vertical acceleration for port tank, in m/s ² a_{v-stb} vertical acceleration for starboard tank, in m/s ² $a_{lng-mid}$ longitudinal acceleration for centre tank, in m/s ² a_{lng-pt} longitudinal acceleration for port tank, in m/s ² $a_{lng-stb}$ longitudinal acceleration for starboard tank, in m/s ² $a_{lng-ctr}$ longitudinal acceleration for centre double bottom ballast tank, in m/s ² f_{lng-pt} dynamic load combination factor associated with the longitudinal acceleration of a port side cargo or ballast tank $f_{lng-stb}$ dynamic load combination factor associated with the longitudinal acceleration of a starboard side cargo or ballast tank $f_{lng-ctr}$ dynamic load combination factor associated with the longitudinal acceleration of a centre double bottom ballast tank $f_{lng-mid}$ dynamic load combination factor associated with the longitudinal acceleration of a centre tank													

Table4

Dynamic Load Cases for Mid and Aft Cargo Tank Region for Ballast Condition													
Wave direction			Head Sea			Oblique Sea		Beam Sea					
Max response			M_{WV}	a_v	a_{Ing}	M_{WV-h}		a_t		P_{ctr}		P_{WL}	
Dynamic Load Case			1	2	3	4a	4b	5a	5b	6a	6b	7a	7b
Global loads	M_{WV}	f_{mv}	1.0	-1.0	0.4	-0.4	-0.4	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
	M_{WV-h}	f_{mh}	0.0	0.0	0.0	1.0	-1.0	0.1	-0.1	-0.1	0.1	-0.2	0.2
Accelerations	a_{v-mid}	f_{v-mid}	-0.1	0.4	-0.2	0.1	0.1	0.5	0.5	1.0	1.0	1.0	1.0
	a_{v-pt}	f_{v-pt}	-0.1	0.4	-0.2	0.1	0.1	0.1	0.8	0.7	1.0	0.6	1.0
	a_{v-stb}	f_{v-stb}	-0.1	0.4	-0.2	0.1	0.1	0.8	0.1	1.0	0.7	1.0	0.6
	a_t	f_t	0	0	0	0	0	1	-1	0,8	-0,8	0,6	-0,6
	$a_{Ing-mid}$	$f_{Ing-mid}$	0.2	-0.1	1.0	-0.6	-0.6	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	a_{Ing-pt}	f_{Ing-pt}	0.2	-0.1	1.0	-0.6	-0.4	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	$a_{Ing-stb}$	$f_{Ing-stb}$	0.2	-0.1	1.0	-0.4	-0.6	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	$a_{Ing-ctr}$	$f_{Ing-ctr}$	0.2	-0.1	1.0	-0.4	-0.4	0.0	0.0	-0.2	-0.2	-0.1	-0.1
	P_{ctr}	f_{ctr}	1.0	-0.8	0.3	-0.5	-0.5	0.3	0.3	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	-0.4	0.0	0.9	-0.4	0.9	0.3	0.9	0.2
	P_{WL}	f_{WL}	0.3	-0.2	0.1	-0.6	0.0	0.7	-0.4	0.9	0.2	1.0	0.2
Dynamic wave pressure for starboard side	P_{ctr}	f_{ctr}	1.0	-0.8	0.3	-0.5	-0.5	0.3	0.3	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	0.0	-0.4	-0.4	0.9	0.3	0.9	0.2	0.9
	P_{WL}	f_{WL}	0.3	-0.2	0.1	0.0	-0.6	-0.4	0.7	0.2	0.9	0.2	1.0
Dynamic wave pressure for port side	P_{ctr}	f_{ctr}	1.0	-0.8	0.3	-0.5	-0.5	0.3	0.3	0.8	0.8	0.4	0.4
	P_{bilge}	f_{bilge}	0.3	-0.2	0.1	0.0	-0.4	-0.4	0.9	0.3	0.9	0.2	0.9
	P_{WL}	f_{WL}	0.3	-0.2	0.1	0.0	-0.6	-0.4	0.7	0.2	0.9	0.2	1.0

Table 5

1.3 LOCAL LOADS

The analysis of local loads will be divided in two sections. The first will cover local loads for double hull oil tankers and the second one will cover local loads for bulk carriers. This type of analysis is followed in order to facilitate the presentation of loads covered by the IACS CSR of each type of ship while there are differences which do not permit the direct correlation. Hence a parallel-simultaneous presentation is chosen.

- DOUBLE HULL OIL TANKERS

External pressure on side shell and bottom

External pressure used for strength assessment and structural analysis is the sum of the hydrostatic pressure at the position of the member being examined as well as the hydrodynamic.

The static sea pressure is obtained for each loading condition, at any point of the hull, from the following formula (CSR DHOT, section 7.2, page6):

$$P_{\text{hys}} = \rho_{\text{sw}} g (T_{\text{LC}} - z)$$

Where:

ρ_{sw} : density of sea water, 1.025 tonnes/m³

z : vertical coordinate of load point, in m, and is not to be greater than T_{LC}

T_{LC} : draught in the loading condition being considered

g : acceleration due to gravity, 9.81 m/s²

The dynamic wave pressure $P_{\text{EX-DYN}}$ is to be taken as the greater of the following:

$$P_1 = 2f_{\text{prob}} f_{\text{nl-P1}} \left[\left((3f_s + 0.8)C + \frac{135B_{\text{LOCAL}}}{4(B+75)} - 1.2(T_{\text{LC}} - z) \right) f_1 + \frac{135B_{\text{LOCAL}}}{4(B+75)} f_2 \right]$$

$$P_2 = 26f_{\text{prob}} f_{\text{nl-P2}} \left[\left(\frac{B_{\text{LOCAL}}}{8} \theta + f_T C_B \frac{0.25B_{\text{LOCAL}} + 0.8C}{14} \left(0.7 + \frac{2z}{T_{\text{LC}}} \right) \right) f_1 + \left(\frac{B_{\text{LOCAL}}}{8} \theta + f_T C_B \frac{0.25B_{\text{LOCAL}}}{14} \left(0.7 + \frac{2z}{T_{\text{LC}}} \right) \right) f_2 \right]$$

Where

B_{LOCAL} : local breadth at the draught, not to be taken less than 0.5B, in m

θ : roll angle, in rads

C : wave coefficient explained above

$$f_1 = f_{\text{ln g}} - \frac{f_{\text{ln g}}}{f_v} f_2 + f_2$$

$$f_2 = 0.25f_v \left(\frac{4|y|}{B_{\text{LOCAL}}} - 1 \right) \quad \text{for } |y| < 0.25 B_{\text{LOCAL}}$$

$$f_2 = f_v \left(\frac{4|y|}{B_{LOCAL}} - 1 \right) \quad \text{for } |y| \geq 0.25 B_{LOCAL}$$

$$f_T = \frac{T_{LC}}{T_{SC}}$$

$$f_s = C_B + \frac{1.33}{\sqrt{C_B}} \quad \text{at, and aft of A.P.}$$

$$C_B \quad \text{between 0.2L and 0.7L from A.P.}$$

$$C_B + \frac{1.33}{\sqrt{C_B}} \quad \text{at, and forward of F.P.}$$

Intermediate values are to be obtained by linear interpolation

$$f_{ing} = 1.0 \quad \text{at, and aft of A.P.}$$

$$0.7 \quad \text{for 0.2L to 0.7L from A.P.}$$

$$1.0 \quad \text{at, and forward of F.P.}$$

Intermediate values are to be obtained by linear interpolation

y,z : transverse and vertical respectively coordinates, in m

f_{nl-p1} , f_{nl-p2} , f_{prob} and f_v are given for scantling requirements and fatigue strength in the following page

The P_1 pressure is dominated by pitch motion in head/quartering seas, while P_2 pressure by roll motion in beam seas. P_2 will dominate in the amidships region and P_1 will dominate in forward and aft ends of the ship.

The P_1 expression is a combination of approximately 80% of the greatest wave induced pressures resulting from pitch and heave motion and approximately 40% of the wave induced pressure from roll motion. More precisely: the factor $3f_s C$ represents the induced pressure from pitch and heave motion. $0.8C$ represents a stow-up effect of incoming wave and $\frac{135B_{local}}{(B+75)}$ expresses the contribution from the roll motion at the ship-side. In addition

$1.2(T_{LC} - z)$ accounts for the dynamic wave reduction of pressure down along the ship hull and f_i reduces the pressure on the bottom towards the centre-line, generally a reduction of the roll-effect.

The P_2 expression is dominated by the pressures due to roll and heave motion, which are greater in beam sea wave conditions than in head seas wave conditions. P_2 pressure is constant along the ship length for a given transverse distance from the centerline and vertical distance from base line. In more detail: $\frac{B_{local}}{2} \theta$ takes into account the effect of roll

motion and $f_T C_B \frac{B_{local} + 0.8C}{14} \left(0.7 + \frac{2z}{T_{LC}} \right)$ represents dynamic pressures due to the

incoming wave, like excitation and built-up of wave. The term accounts for the reduction down along the side. In addition, this term is corrected with f_T which represents the difference depending on the draught of the loading condition.

For scantling requirements and strength assessment, the envelope maximum dynamic wave pressure and the minimum are to be obtained by the following formulae:

$$P_{EX-MAX} = P_{EX-DYN} \quad \text{below still waterline}$$

$$P_{WL} - 10(z - T_{LC}) \quad \text{for } T_{LC} < z \leq T_{LC} + \frac{P_{WL}}{10}$$

$$0 \quad \text{for } z > T_{LC} + \frac{P_{WL}}{10}$$

$$P_{EX-MIN} = -P_{EX-DYN} \quad \text{below still waterline}$$

$$0 \quad \text{above still waterline}$$

Never less than: $-\rho_{sw}g(T_{LC}-z)$. In other words, the total pressure (static + dynamic load component) cannot be less than zero.

P_{EX-DYN} envelope dynamic wave pressure, in kN/m^2 , defined above with

f_{prob} : probability factor
 $=1$

f_{n1-P1} : non linear correction factor
 $=0.69$

f_{n1-P2} : this factor consists of a non linear correction together with operational considerations
 $=0.65$

$f_v = 1$

P_{WL} pressure at waterline, to be taken as P_{EX-DYN} at still waterline, in kN/m^2

For fatigue strength assessment, the dynamic wave pressure pseudo-amplitude (half range) is given by:

$$P_{EX-AMP} = 0 \quad \text{for } z \geq T_{LC} + \frac{P_{WL}}{10} \text{ or } D, \text{ whichever is the lesser}$$

$$0.5P_{WL} \quad \text{at still waterline}$$

$$P_{EX-DYN} \quad \text{for } z \leq T_{LC} - \frac{P_{WL}}{10} \text{ or } D, \text{ whichever is the greater}$$

Intermediate values between the still waterline and $z = T_{LC} - h_{WL}$ are to be obtained by linear interpolation

The factors f_{prob} , f_{n1-P1} , f_{n1-P2} , f_v take different values from those in strength assessment and scantling requirements. More precisely:

For P_1 (which is defined above)

$f_{prob} = 0.5$ (in order to fit with direct calculations)

$f_{n1-P1} = 1$

$f_v = 1$ at, and aft of $0.7L$

1.5 at, and forward of F.P

For P_2

$f_{prob} = 0.5$ (in order to fit with direct calculations)

$f_{n1-P2} = 1$

$f_v = 1$

Dynamic wave pressure distribution for a considered dynamic load case

The simultaneously acting dynamic wave pressure , P_{wv-dyn} , for the port and starboard side within the cargo tank region for a considered dynamic load case is given by the following formula, but not to be less than $-\rho_{sw}g(T_{LC} - z)$ below still waterline or less than 0 above still waterline:

$$P_{wv-dyn} = P_{CTR} + \frac{|y|}{0.5B_{LOCAL}} (P_{BILGE} - P_{CTR}) \quad \text{between centerline and start of bilge}$$

$$P_{wv-dyn} = P_{BILGE} + \frac{z}{T_{LC}} (P_{WL} - P_{BILGE}) \quad \text{between end of bilge and still waterline}$$

$$P_{wv-dyn} = P_{WL} - 10(z - T_{LC}) \quad \text{for side-shell above still waterline}$$

Intermediate values of P_{wv-dyn} around the bilge are to be obtained by linear interpolation along the vertical distance.

Where:

P_{CTR} : dynamic wave pressure at bottom centreline, to be taken as: $f_{CTR} P_{EX-MAX}$

P_{BILGE} : dynamic wave pressure at $z = 0$ and $y = B_{LOCAL} / 2$, to be taken as: $f_{BILGE} P_{EX-MAX}$

P_{WL} :dynamic wave pressure at waterline, to be taken as: $f_{WL} P_{EX-MAX}$

f_{WL} : dynamic load combination factor for dynamic wave pressure at still waterline for considered dynamic load case, see Table

f_{BILGE} : dynamic load combination factor for dynamic wave pressure at bilge for considered dynamic load case, see Table

f_{CTR} :dynamic load combination factor for dynamic wave pressure at centreline for considered dynamic load case, see Table

B_{LOCAL} : local breadth at waterline for considered draught , in m

T_{LC} : draught in the loading condition being considered, in m

y :transverse coordinate, in m

z :vertical coordinate, in m

ρ_{sw} = density of sea water, 1.025tonnes/m³

g : acceleration due to gravity, 9.81m/s²

Green sea load

The green sea pressure is defined as a function of the side-shell wave pressure at the deck corner. The envelope green sea load on the weather deck, P_{wdk} , is to be taken as the greater of the following:

$$P_{WDK} = \text{the greater of} \begin{cases} P_{1-dk} = f_{1-dk} (f_{op} P_{1-WL} - 10z_{dk-T}) \\ P_{2-dk} = 0.8f_{2-dk} (P_{2-WL} - 10z_{dk-T}) \end{cases} \quad \text{kN/m}^2$$

34.3

P_{1-dk} and P_{2-dk} result from pressures P_1 and P_2 (which give the value of dynamic pressure on side shell and bottom shell) respectively.

$$f_{1-dk} = 0.8 + \frac{L}{750}$$

The factor f_{1-dk} represents the dynamic effects due to bow acceleration and plummeting of the green water on board in head sea condition, and applies to the P_{1-dk} green sea pressure on the fore deck. For the aft region, the operational factor, f_{op} , is used which assumes that the ship will not operate in following seas in a severe storm. In other words the likelihood of encountering waves spilling onto the aft deck is reduced. Hence:

$$f_{op} = \begin{cases} 1.0 & \text{at and forward of } 0.2L \text{ from A.P.} \\ 0.8 & \text{at and aft of A.P.} \end{cases}$$

Intermediate values to be obtained by linear interpolation

$$f_{2-dk} = 0.5 + \frac{|y|}{B_{WDK}}$$

The variation of the f_{2-dk} across the deck represents the green sea load distribution in beam seas. As it can be seen, f_{2-dk} is set to 1 at the deck corner on weather side and zero at deck corner on lee side, assuming that the side shell pressure on the lee side will always become zero.

P_{1-WL} : P_1 pressure at still waterline for considered draught, in kN/m^2 , defined above

P_{2-WL} : P_2 pressure at still waterline for considered draught, in kN/m^2 , defined above

z_{dk-T} : distance from the deck to the still waterline at the applicable draught for the loading condition being considered, in m

B_{WDK} : local breadth at the weather deck, in m

For fatigue strength, the green sea load is taken as zero as the effect of green sea loading on fatigue damage is negligible.

Green sea load for a considered dynamic load case

The simultaneously acting green sea load on the weather deck, $P_{WDK-DYN}$, for scantling requirements is to be taken as the greater of:

$$P_{WDK-DYN} = f_{1-dk} (f_{WL} f_{op} P_{1-WL} - 10z_{dk-T}) \quad \text{but is not to be taken less than } 34.3 \text{ kN/m}^2 \text{ when } f_{WL}=1.0 \text{ and the ship's draught used in the design load case is greater or equal to } 0.9T_{SC}$$

$$P_{WDK-DYN} = 0.8f_{2-dk} (f_{WL} P_{2-WL} - 10z_{dk-T}) \quad \text{but is not to be taken less than } 34.3 \text{ kN/m}^2 \text{ when } f_{WL}=1.0 \text{ and } f_{2-dk} \text{ and the ship's draught used in the design load case is greater or equal to } 0.9T_{SC}$$

$$P_{WDK-DYN} = 0$$

All the factors comprised in the functions above are explained in the previous equations. f_{WL} is a dynamic load combination factor for dynamic wave pressure at still waterline for considered dynamic load case (Table 4, 5).

Tank pressure

The static tank pressure is given by the following formula:

$$P_{in-tk} = \rho g z_{tk}$$

Where

z_{tk} vertical distance from highest point of tank excluding small hatchways, to the load point
 P_{in-tk} defines the static pressure in a tank due to liquid filling. This pressure assumes that the tank is 100% full and is measured from the highest point in the tank.

In case of overfilling or filling during flow through ballast water exchange:

$$P_{in-air} = \rho_{sw} g z_{air}$$

P_{in-air} is applicable for ballast tanks and other tanks where the tank will be overfilled. The pressure is measured from the top of the air-pipe or from the top of any possible over-flow.

Where:

z_{air} : vertical distance from top of air pipe or overflow pipe to the load point, whichever is the lesser, in m

$$= z_{tk} + h_{air}$$

h_{air} = height of air pipe or overflow pipe, in m, is not to be taken less than 0.76m above highest point of tank, excluding small hatchways. For tanks with tank top below the weather deck the height of air-pipe or overflow pipe is not to be taken less than 0.76m above deck at side unless a lesser height is approved by the flag Administration.

The increase in pressure due to resistance in the air-pipe during pumping operation, p_{drop} , is taken as 25 kN/m² for ballast tanks and zero for other tanks. If the actual pressure drop is available this should be used instead of the minimum value of 25 kN/m² if it is greater.

Dynamic tank pressure

The envelope dynamic tank pressure, P_{IN-V} , due to vertical tank acceleration is to be taken as:

$$P_{IN-V} = \rho a_v (z_o - z) \quad \text{for strength assessment and scantling requirements}$$

$$P_{IN-V} = \rho a_v |z_o - z| \quad \text{for fatigue strength}$$

Where:

ρ : density of liquid in the tank, in tonnes /m³, and is not to be taken as less than:

0.9 for cargo tanks for fatigue strength

1.025 otherwise

z : vertical coordinate of load point, in m

z_o : vertical coordinate of reference point, for scantling requirements, strength assessment, and for fatigue strength, in m, see CSR-DHOT, section 7.6, page 12, figure 7.6.4

a_v : envelope vertical acceleration, in m/s² and is to be taken at tank centre of gravity

The envelope dynamic tank pressure, P_{IN-T} , due to transverse acceleration is to be taken as:

$$P_{IN-T} = f_{ull-t} \rho a_t (y_o - y) \quad \text{for strength assessment and scantling requirements}$$

$$P_{IN-T} = \rho a_t |y_o - y| \quad \text{for fatigue strength}$$

Where:

ρ : density of tank liquid, in tonnes /m³, and is not to be taken as less than:

0.9 for cargo tanks for fatigue strength

1.025 otherwise

f_{ull-t} : factor to account for ullage in cargo tanks, and is to be taken as:

0.67 for cargo tanks, including cargo tanks designed for filling with water ballast

1.0 for ballast and other tanks

f_{ull-t} is necessary because tankers' CSR are based on the assumption that a tank is completely filled with liquid and the tank wall is rigid. But the cargo tanks are normally not more than 98% full, hence an ullage factor is essential to represent the difference between the tank pressure at 98% tank filling and 100% tank filling at the tank sides.

y : longitudinal coordinate of load point, in m

y_o : longitudinal coordinate of reference point, see CSR-DHOT, section 7.6, page 13, figure 7.6.5

a_t : envelope longitudinal acceleration, in m/s², and is to be taken at tank centre of gravity

The envelope dynamic tank pressure, P_{IN-LNG} , due to longitudinal acceleration is to be taken as:

$$P_{IN-LNG} = f_{ull-lng} \rho a_{lng} (x_o - x) \quad \text{for strength assessment and scantling requirements}$$

$$P_{IN-LNG} = f_{ull-lng} \rho a_{lng} |x_o - x| \quad \text{for fatigue strength}$$

Where:

ρ : density of tank liquid, in tonnes /m³, and is not to be taken as less than:

0.9 for cargo tanks for fatigue strength

1.025 otherwise

$f_{ull-lng}$: factor to account for ullage in cargo tanks, and is to be taken as:

0.62 for cargo tanks, including cargo tanks designed for filling with water ballast

1.0 for ballast and other tanks

x : longitudinal coordinate of load point, in m

x_o : longitudinal coordinate of reference point see CSR-DHOT, section 7.6, page 14, figure 7.6.6

a_{lng} : envelope longitudinal acceleration, in m/s², and is to be taken at tank centre of gravity

The simultaneous acting dynamic tank pressure for a considered dynamic load case

For scantling requirements and strength assessment

a) in the cargo region

$$P_{in-dyn} = f_b (f_v P_{in-v} + f_t P_{in-t} + f_{lng} P_{in-lng})$$

P_{in-v} : envelope dynamic tank pressure due to vertical acceleration as with reference point z_o taken as:

- (i) top of tank
- (ii) top of air pipe/overflow for ballast tanks designed for BWE (ballast water exchange) by flow-through method in kN/m^2

P_{in-t} : envelope dynamic tank pressure due to transverse acceleration with reference point y_o taken as:

- (i) tank top towards port side for $f_t > 0$
- (ii) tank top towards starboard side for $f_t < 0$

P_{in-lng} : envelope dynamic tank pressure due to longitudinal acceleration with reference point x_o taken as:

- (i) forward bulkhead for $f_{lng} > 0$
- (ii) aft bulkhead of the tank for $f_{lng} < 0$

f_v : dynamic load combination factor for vertical acceleration for considered dynamic load case. f_v is to be taken as appropriate to the tank location

f_t : dynamic load combination factor for transverse acceleration for considered dynamic load case

f_{lng} : dynamic load combination factor for longitudinal acceleration for considered dynamic load case. f_{lng} is to be taken as most appropriate dependent on tank location

b) outside the cargo region

$$P_{in-dyn} = f_b \left(f_{v-mid} P_{in-v} + |f_t P_{in-t}| + |f_{lng} P_{in-lng}| \right)$$

P_{in-v} : envelope dynamic tank pressure due to vertical acceleration as with reference point z_o taken as:

- (i) top of tank
- (ii) top of air pipe/overflow for ballast tanks designed for BWE (ballast water exchange) by flow-through method in kN/m^2

P_{in-t} : envelope dynamic tank pressure due to transverse acceleration using (y_o-y) as extreme breadth of tank

P_{in-lng} : envelope dynamic tank pressure due to longitudinal acceleration using (x_o-x) as extreme length of tank

f_v : heading correction factor taken as:

- 0.8 for beam sea dynamic load case
- 1.0 for all other dynamic load cases

f_{v-mid} : dynamic load combination factor for vertical acceleration for considered dynamic load case. f_v is to be taken as appropriate to the tank location

f_t : dynamic load combination factor for transverse acceleration for considered dynamic load case

f_{lng} : dynamic load combination factor for longitudinal acceleration for considered dynamic load case. f_{lng} is to be taken as most appropriate dependent on tank location

For fatigue strength

a) On a tank boundary with adjacent tank empty

$$P_{in-amp} = f_v P_{in-v} + f_{ull-t} f_t P_{in-t} + f_{ull-lng} f_{lng} P_{in-lng}$$

f_{ull-t} : factor to account for ullage in cargo tanks, not to be taken less than 0.0 nor greater than 1.0

$$= \frac{|z_o - z| + h_{roll}}{2h_{roll}} \quad \text{for cargo tanks}$$

$$= 1.0 \quad \text{for ballast tanks}$$

$f_{ull-lng}$: factor to account for ullage in cargo tanks, not to be taken less than 0.0 nor greater than 1.0

$$= \frac{|z_o - z| + h_{pitch}}{2h_{pitch}} \quad \text{for cargo tanks}$$

$$= 1.0 \quad \text{for ballast tanks}$$

$$h_{roll}: \text{roll height} = \frac{b_{fs} f_{prob} \theta}{2}$$

At a distance h_{roll} below the free surface the full pressure range is achieved, and h_{roll} above the free surface the pressure range is taken as zero. Between the two points the pressure range varies linearly, so at the free surface the tank pressure range is found to be half of full contribution from transverse acceleration.

$$h_{pitch}: \text{pitch height} = \frac{l_{fs} f_{prob} \phi}{2}$$

$$f_{prob} = 0.5$$

θ : roll angle, in rads

ϕ : pitch angle, in secs

b_{fs} : tank breadth at the top of the tank, in m

l_{fs} : tank length at the top of the tank, in m

x_o : longitudinal coordinate of reference point, and is to be taken as the middle of tank length at the top of the tank, in m

y_o : transverse coordinate of reference point, and is to be taken as the middle of tank breadth at the top of the tank, in m

z_o : vertical coordinate of reference point, and is to be taken as the highest point of the tank, excluding small hatchways, in m

f_v : pressure combination factor

f_t : pressure combination factor

f_{lng} : pressure combination factor

b) On a longitudinal tank boundary with adjacent tank full

$$P_{in-amp} = f_v \left| P_{in-v-tk1} - P_{in-v-tk2} \right| + f_t \left| f_{ull-t-tk1} P_{in-t-tk1} - f_{ull-t-tk2} P_{in-t-tk2} \right| \\ + f_{lng} \left| f_{ull-lng-tk1} P_{in-lng-tk1} - f_{ull-lng-tk2} P_{in-lng-tk2} \right|$$

Where:

$P_{in-v-tk1}$: dynamic tank pressure due to vertical acceleration in tank 1, in kN/m^2

$P_{in-v-tk2}$: dynamic tank pressure due to vertical acceleration in tank 2, in kN/m^2

$P_{in-t-tk1}$: dynamic tank pressure due to vertical acceleration in tank 1, in kN/m^2

$P_{in-t-tk2}$: dynamic tank pressure due to vertical acceleration in tank 2, in kN/m^2

$P_{in-lng-tk1}$: dynamic tank pressure due to vertical acceleration in tank 1, in kN/m^2

$P_{in-lng-tk2}$: dynamic tank pressure due to vertical acceleration in tank 2, in kN/m^2

$f_{ull-t-tk1}$: factor to account for ullage for tank 1

$f_{ull-t-tk2}$: factor to account for ullage for tank 2
 $f_{ull-lng-tk1}$: factor to account for ullage for tank 1
 $f_{ull-lng-tk2}$: factor to account for ullage for tank 2
 f_v, f_t, f_{lng} : pressure combination factors, given in Table 6
 Tank 1 and 2 are adjacent tanks with common longitudinal boundary

Pressure combination factors for fatigue assessment		
	Cargo tanks	Ballast tanks
f_v	0.9	0.9
f_t	0.9	0.6
f_{lng}	0.4	0.4

Table 6

Deck pressure from distributed loading

The static pressure on decks and inner bottom is given by the following formula:

$$P_{stat} = P_{deck} \quad \text{kN/m}^2$$

Where:

P_{deck} is the uniformly distributed pressure on lower decks and decks within superstructures, including platform decks in the main engine room and for other spaces with heavy machinery components, in kN/m^2 . P_{deck} is not to be taken less than 16kN/m^2 .

The envelope dynamic deck pressure, $P_{deck-dyn}$, on decks, inner bottom and hatch covers is to be taken as:

$$P_{deck-dyn} = P_{deck} \frac{a_v}{g} \quad \text{kN/m}^2$$

Where a_v the envelope vertical acceleration, in m/s^2

The simultaneously acting dynamic deck load for uniformly distributed load, P_{dk-dyn} , on the enclosed upper deck, where a forecastle or poop is fitted, and also on all lower decks, is to be taken as:

$$P_{dk-dyn} = f_b f_{v-mid} P_{deck-dyn}$$

where:

$P_{deck-dyn}$: envelope dynamic deck pressure on decks, inner bottom and hatch covers, in kN/m^2
 f_{v-mid} : dynamic load combination factor for vertical acceleration for considered dynamic load case

Deck loads from the heavy units

The static deck load, F_{stat} , which consists of heavy units of cargo and equipment whose mass is more than 20 tonnes and which is acting on supporting structures and securing systems, is to be taken as:

$$F_{stat} = m_{un} g \quad \text{kN}$$

Where m_{un} is the mass of unit in tonnes

The envelope dynamic deck loads, F_v , F_t , F_{LNG} acting vertically, transversely and longitudinally on supporting structures and securing systems for heavy units of cargo, equipment or structural components are to be taken as:

$$\begin{aligned} F_v &= m_{un} a_v & \text{kN} \\ F_t &= m_{un} a_t & \text{kN} \\ F_{LNG} &= m_{un} a_{lng} & \text{kN} \end{aligned}$$

Where

m_{un} : mass of unit, in tonnes

a_v : envelope vertical acceleration, in m/s^2 , at centre of gravity of considered unit

a_t : envelope transverse acceleration, in m/s^2 , at centre of gravity of considered unit

a_{lng} : envelope longitudinal acceleration, in m/s^2 , at centre of gravity of considered unit

The simultaneously acting dynamic vertical force for heavy units, F_{dk-dyn} , acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components, is to be taken as:

$$F_{dk-dyn} = f_b f_{v-mid} F_v \quad \text{kN}$$

Where

f_{v-mid} : dynamic load combination factor for vertical acceleration for the considered dynamic load case (see Tables 4-5 of the previous subsection "Load cases")

Sloshing and Impact Loads

In CSR for double hull oil tankers there is a sub-section which covers sloshing pressure in tanks, bow impact and bottom slamming pressures.

Sloshing pressure in tanks

This kind of pressure is pressure induced by free movement of the tank liquids as a result of ship motions. All structural members in tanks containing liquid are subject to sloshing pressure.

1) Sloshing pressure due to longitudinal liquid motion

The sloshing pressure in way of transverse tight and wash bulkheads due to longitudinal liquid motion, $P_{slh-lng}$, for a particular filling height, is to be taken as:

$$P_{slh-lng} = \rho g l_{slh} f_{slh} \left[0.4 - \left(0.39 - \frac{1.7 l_{slh}}{L} \right) \frac{L}{350} \right]$$

Where:

ρ : density of liquid in the tank, not to be taken as less than 1.025 tonnes/m³

g : acceleration due to gravity, 9.81 m/s²

$$f_{slh} = 1 - 2 \left(0.7 - \frac{h_{fill}}{h_{max}} \right)^2$$

h_{fill} : filling height, measured from inner bottom, in m

h_{max} : maximum tank height excluding small hatchways, measured from inner bottom, in m

l_{slh} : effective sloshing length at considered filling height

The effective sloshing length, l_{slh} , in m, for calculation of sloshing pressures in way of transverse tight bulkheads is to be taken as:

$$l_{slh} = \frac{(1 + n_{wash-t} a_{wash-t})(1 + f_{wf} a_{wf}) l_{tk-h}}{(1 + n_{wash-t})(1 + f_{wf})}$$

In way of transverse wash bulkheads

$$l_{slh} = \frac{[1 + (n_{wash-t} - 1) a_{wash-t}](1 + f_{wf} a_{wf}) l_{tk-h}}{(1 + n_{wash-t})(1 + f_{wf})}$$

Where:

n_{wash-t} : number of transverse wash bulkheads in the tank

a_{wash-t} : transverse wash bulkhead coefficient

$$= \frac{A_{opn-wash-t}}{A_{tk-t-h}}$$

a_{wf} : transverse web frame coefficient

$$= \frac{A_{\text{opn-wf-h}}}{A_{\text{tk-t-h}}}$$

for tanks with changing shape along the length and/or with web frames of different shape the transverse web frame coefficient, a_{wf} , may be taken as the weighted average of all web frame locations in the tank given as

$$= \frac{\sum_{i=1}^n \frac{A_{\text{opn-wf-h-i}}}{A_{\text{tk-t-h-i}}}}{n_{\text{wf}}}$$

$A_{\text{opn-wash-t}}$: the total area of openings in the transverse section in way of the wash bulkhead below the considered filling height, in m^2

$A_{\text{tk-t-h}}$: total transverse cross sectional area of the tank below the considered filling height, in m^2

$A_{\text{opn-wf-h}}$: the total area of openings in the transverse section in way of the web frame below the considered filling height, in m^2

f_{wf} : factor to account for number of transverse web frames and transverse wash bulkheads in the tank:

$$= n_{\text{wf}} / (1 + n_{\text{wash-t}})$$

n_{wf} : number of transverse web frames, excluding wash bulkheads, in the tank

$l_{\text{tk-h}}$: length of cargo tank, at considered filling height, in m

The sloshing pressure, $P_{\text{slh-lng}}$, is to be taken as a constant value over the full tank depth and is to be taken as the greater of the sloshing pressure s calculated for filling heights from $0.05h_{\text{max}}$ to $0.95h_{\text{max}}$, in $0.05h_{\text{max}}$ increments.

For tanks with internal web frames the sloshing pressure acting on a web frame adjacent to a transverse tight or wash bulkhead, $P_{\text{slh-wf}}$, provided it is located within $0.25l_{\text{slh}}$ from the bulkhead, is to be taken:

$$P_{\text{slh-wf}} = P_{\text{slh-lng}} \left(1 - \frac{s_{\text{wf}}}{l_{\text{slh}}} \right)^2$$

Where:

$P_{\text{slh-lng}}$: sloshing pressure acting on bulkhead due to longitudinal liquid motion

s_{wf} : distance from bulkhead to web frame under consideration

l_{slh} : effective sloshing length, at considered filling height for transverse tight and wash bulkheads

The design sloshing pressure due to longitudinal liquid motion is to be applied to the following members:

- transverse tight bulkheads
- transverse wash bulkheads
- stringers on transverse tight and wash bulkheads
- plating and stiffeners on the longitudinal bulkheads, deck and inner hull which are between the transverse bulkhead and the first web frame from the bulkhead or the bulkhead and $0.25l_{\text{slh}}$, whichever is lesser.

2) Sloshing pressure due to transverse liquid motion

The sloshing pressure in way of longitudinal tight and wash bulkheads due to transverse liquid motion, P_{slh-t} , for a particular filling height, is to be taken as:

$$P_{slh-t} = 7\rho g f_{slh} \left(\frac{b_{slh}}{B} - 0.3 \right) GM^{0.75}$$

Where:

$$f_{slh} = 1 - 2 \left(0.7 - \frac{h_{fill}}{h_{max}} \right)^2$$

b_{slh} : effective sloshing breadth for longitudinal tight bulkheads and longitudinal wash bulkheads, not to be taken less than $0.3B$, in m

GM : metacentric height, which is taken as $0.33B$ for calculations of sloshing pressures in ballast tanks and $0.24B$ for calculations of sloshing pressure in cargo tanks. The value of $0.33B$ for Gm is representative for a ballast condition and this of $0.24B$ is representative for a part load condition with some cargo tanks full and some empty or with reduced filling.

The effective sloshing breadth, b_{slh} , in m, for calculation of sloshing pressures in way of longitudinal tight bulkheads is to be taken as:

$$b_{slh} = \frac{(1 + n_{wash-lng} a_{wash-lng})(1 + f_{grd} a_{grd}) b_{tk-h}}{(1 + n_{wash-lng})(1 + f_{grd})}$$

In way of longitudinal wash bulkheads

$$b_{slh} = \frac{[1 + (n_{wash-lng} - 1) a_{wash-lng}](1 + f_{grd} a_{grd}) b_{tk-h}}{(1 + n_{wash-lng})(1 + f_{grd})}$$

Where:

$n_{wash-lng}$: number of longitudinal wash bulkheads in the tank

$a_{wash-lng}$: longitudinal wash bulkhead coefficient

$$= \frac{A_{opn-wash-lng}}{A_{tk-lng-h}}$$

a_{grd} : girder coefficient

$$= \frac{A_{opn-grd-h}}{A_{tk-lng-h}}$$

$A_{opn-wash-lng}$: the total area of openings in the longitudinal section in way of the wash bulkhead below the considered filling height, in m^2

A_{tk-t-h} : total longitudinal cross sectional area of the tank below the considered filling height, in m^2

$A_{opn-wf-h}$: the total area of openings in the longitudinal section in way of the web frame below the considered filling height, in m^2

f_{wf} : factor to account for number of longitudinal girders and transverse wash bulkheads in the tank:

$$= n_{grd} / (1 + n_{wash-lng})$$

n_{grd} : number of longitudinal girders, excluding longitudinal wash bulkheads, in the tank

b_{tk-h} : tank breadth at considered filling height, in m

For tanks with internal longitudinal girders or web frames, the sloshing pressure on the girder/web frame adjacent to a longitudinal wash bulkhead, $P_{slh-grd}$, provided it is located within $0.25b_{slh}$ from the bulkhead, is to be taken as:

$$P_{slh-grd} = P_{slh-t} \left(1 - \frac{s_{grd}}{b_{slh}} \right)^2$$

Where:

P_{slh-t} : sloshing pressure acting on bulkhead due to transverse liquid motion

s_{grd} : distance from longitudinal bulkhead to longitudinal girder under consideration

b_{slh} : effective sloshing breadth for longitudinal tight bulkheads and longitudinal wash bulkheads

The design sloshing pressure due to transverse liquid motion is to be applied to the following members:

- longitudinal tight bulkheads
- longitudinal wash bulkheads
- horizontal stringers on longitudinal tight and wash bulkheads
- plating and stiffeners on the transverse tight bulkheads, including stringers and deck which are between the longitudinal bulkhead and the first girder from the bulkhead or the bulkhead and $0.25b_{slh}$, whichever is lesser.

Minimum sloshing pressure

The reason of the existence of the minimum sloshing pressure is to ensure that all internal structures are able to withstand the pressures due to fluid motion in the tank. $P_{slh-min}$, in cargo and ballast tanks except tanks of cellular construction, is to be taken as 20 kN/m^2 . In cellular construction ballast tanks, $P_{slh-min}$ is to be taken as 12 kN/m^2 .

Bottom slamming pressures

The slamming loads covered in CSR for double hull oil tankers have to do with vessels with $C_B \geq 0.7$ and bottom slamming draught $\geq 0.001L$ and $\leq 0.045L$. The bottom slamming pressure is to be taken as the greater of:

$$P_{slm-mt} = f_{slm} 130gc_{slm-mt} e^{c1} \quad \text{kN/m}^2 \quad \text{for empty ballast tanks}$$

$$P_{slm-full} = f_{slm} 130gc_{slm-full} e^{c1} - c_{av} \rho g z_{ball} \quad \text{kN/m}^2 \quad \text{for full ballast tanks}$$

The reduction of the bottom slamming pressure expressed in the formula for full ballast tanks is applied to account for the counteracting head of ballast water.

Where:

f_{slm} : longitudinal slamming distribution factor

=0 at $0.5L$

1 at $[0.175 - 0.5(C_{bl} - 0.7)]L$ from F.P.

1 at $[0.1-0.5(C_{bl}-0.7)]L$ from F.P.

0.5 at, and forward of F.P.

Intermediate values to be obtained by linear interpolation

$C_{bl} = C_b$ (not to be taken less than 0.7 or greater than 0.8)

c_{slm-mt} : slamming coefficient for empty ballast tanks

$$= 5.95 - 10.5 \left(\frac{T_{FP-mt}}{L} \right)^{0.2}$$

$c_{slm-full}$: slamming coefficient for full ballast tanks

$$= 5.95 - 10.5 \left(\frac{T_{FP-full}}{L} \right)^{0.2}$$

$$c_1 = 0 \quad \text{for } L \leq 180\text{m}$$

$$= -0.0125(L-180)^{0.705} \quad \text{for } L > 180\text{m}$$

T_{FP-mt} : design slamming ballast draught at F.P. with ballast tanks within the bottom slamming region empty. T_{FP-mt} is not to be greater than the minimum draught at the F.P. indicated in the loading manual for all seagoing conditions wherein the ballast tanks within the bottom slamming region are empty. This includes any loading conditions with tanks inside the bottom slamming region that use the “sequential” ballast water exchange method.

$T_{FP-full}$: design slamming ballast draught at F.P. with ballast tanks within the bottom slamming region full. $T_{FP-full}$ is not to be greater than the minimum draught at the F.P. indicated in the loading manual for any seagoing conditions wherein the ballast tanks within the bottom slamming region are full. This includes any loading condition with tanks inside the bottom slamming region that use the “flow-through” ballast water exchange method.

c_{av} : dynamic load coefficient, to be taken as 1.25

z_{ball} : vertical distance from tank top to load point, in m

- BULK CARRIERS

External sea pressure on side shell and bottom

The hydrostatic pressure is given by the same formula as double hull oil tankers. The difference between CSR for bulk carriers and CSR for double hull oil tankers is detected in the formula of hydrodynamic pressure, which in CSR BC is formed according to each load case. To be more specific, there are three categories of hydrodynamic pressure's formulae, corresponding to the load cases H1, H2, F1 and F2 (the first), R1 and R2 (the second) and P1, P2 (the last).

1) Hydrodynamic pressures for load cases H1, H2, F1, and F2
(CSR BC, chapter 4, section 5, page 20)

At any point of the hull below the waterline

Load case	Hydrodynamic pressure, in kN/m ²
H1	$P_{H1} = -k_i k_p p_{HF}$
H2	$P_{H2} = k_i k_p p_{HF}$
F1	$P_{F1} = -p_{HF}$
F2	$P_{F2} = p_{HF}$

where:

$$p_{HF} = 3f_p f_{nl} C \sqrt{\frac{L + \lambda - 125}{L}} \left(2 \frac{z}{T_{LCi}} + \frac{|2y|}{B_i} + 1 \right) \quad \text{with } \frac{|2y|}{B_i} \leq 1.0 \quad \text{and } z \leq T_{LCi}$$

$f_{nl} = 0.9$ for the probability level of 10^{-8} (scantling requirements and strength assessment)

1.0 for the probability level of 10^{-4} (fatigue strength assessment)

$$k_i = 1 + \frac{12}{C_B} \left(1 - \sqrt{\frac{|2y|}{B}} \right) \left| \frac{x}{L} - 0.5 \right|^3 \quad \text{for } 0.0 \leq x/L \leq 0.5$$

$$= 1 + \frac{6}{C_B} \left(3 - \frac{|4y|}{B} \right) \left| \frac{x}{L} - 0.5 \right|^3 \quad \text{for } 0.5 \leq x/L \leq 1.0$$

$k_p = -1.0$ for local strength analysis in full load condition

$$= \left(1.25 - \frac{T_{LC}}{T_s} \right) \cos \left(\frac{2\pi |x - 0.5L|}{L} \right) - \frac{T_{LC}}{T_s} + 0.25 \quad \text{for local strength analysis in conditions}$$

other than full load condition, for direct strength analysis and for fatigue strength assessments

λ : wave length

$$\lambda = 0.6 \left(1 + \frac{T_{LC}}{T_s} \right) L \quad \text{for load cases H1 and H2}$$

$$\lambda = 0.6 \left(1 + \frac{2}{3} \frac{T_{LC}}{T_s} \right) L \quad \text{for load cases F1 and F2}$$

y : co-ordinate of the load point, in m, taken positive on the portside

L : rule length, to be taken not greater than 300m

B_i : moulded breadth at the waterline, in m, in the considered cross section

2) Hydrodynamic pressures for load cases R1 and R2
(CSR BC, chapter 4, section 5, page 21)

$$p_{R1} = f_{nl} \left(10y \sin \theta + 0.88f_p C \sqrt{\frac{L + \lambda - 125}{L}} \left(\frac{|2y|}{B} + 1 \right) \right)$$

$$p_{R1} = -p_{R2}$$

where:

$f_{nl} = 0.8$ for the probability level of 10^{-8} (scantling requirements and strength assessment)
 1.0 for the probability level of 10^{-4} (fatigue strength assessment)

$$\lambda = \frac{g}{2\pi} T_R^2$$

3) Hydrodynamic pressures for load cases P1 and P2
(CSR BC, chapter 4, section 5, page 22)

Load case	Hydrodynamic pressure, in kN/m ²	
	Weather side	Lee side
P1	$p_{P1} = p_p$	$p_{P1} = p_p/3$
P2	$p_{P2} = -p_p$	$p_{P2} = -p_p/3$

$$p_p = 4.5f_p f_{nl} C \sqrt{\frac{L + \lambda - 125}{L}} \left(2 \frac{|z|}{T_{LCi}} + 3 \frac{|2y|}{B} \right)$$

$f_{nl} = 0.65$ for the probability level of 10^{-8} (scantling requirements and strength assessment)
 1.0 for the probability level of 10^{-4} (fatigue strength assessment)

$$\lambda = \left(0.2 + 0.4 \frac{T_{LC}}{T_s} \right) L$$

CORRECTION TO THE HYDRODYNAMIC PRESSURES

For the positive hydrodynamic pressure at the waterline, in load cases H1, H2, F2, R1, R2 and P1, the wave pressure at the waterline is converted to head of sea water and the wave pressure above the waterline is assumed to occur linearly (inclination of 45 degrees) up to the converted water head position. The hydrodynamic pressure at the side above the waterline is given:

$$p_{W,C} = p_{W,WL} + \rho g (T_{LCi} - z) \quad \text{for } T_{LCi} \leq z \leq h_W + T_{LCi}$$

$$p_{W,C} = 0 \quad \text{for } z \geq h_W + T_{LCi}$$

Where:

$p_{W,WL}$: positive hydrodynamic pressure at the waterline for the considered load case

$$h_W = \frac{p_{W,WL}}{\rho g}$$

For the negative hydrodynamic pressure at the waterline, in load cases H1, H2, F2, R1, R2 and P1, the wave pressure below the waterline is taken as the sum of the wave pressure and

the hydrostatic pressure that does not become negative. The hydrodynamic pressure at the side above the waterline is given:

$$p_{w,c} = p_w, \text{ without being taken less than } p_g(z - T_{LCi})$$

Where:

p_w : negative hydrodynamic pressure under the waterline for the considered load case

External pressures on exposed decks

Load cases H1, H2, F1 and F2

The external pressure p_D , at any point on the exposed deck in head seas and following seas is estimated by the pressure p_w (which is obtained from the formulae in Table 7) acting on the exposed deck specified in LL Convention and the pressure coefficient ϕ for the exposed deck, which depends on height of deck and becomes smaller as the height of deck increases. More specifically:

$$p_D = \phi p_w$$

Location	Pressure p_w , in kN/m^2	
	$L_{LL} \geq 100\text{m}$	$L_{LL} \leq 100\text{m}$
$0 \leq x_{LL}/L_{LL} \leq 0.75$	34.3	$14.9 + 0.195L_{LL}$
$0.75 \leq x_{LL}/L_{LL} \leq 1$	$34.3 + (14.8 + \alpha(L_{LL} - 100)) \left(4 \frac{x_{LL}}{L_{LL}} - 3 \right)$	$12.2 + \frac{L_{LL}}{9} \left(5 \frac{x_{LL}}{L_{LL}} - 2 \right) + 3.6 \frac{x_{LL}}{L_{LL}}$
where: $\alpha = 0.0726$ for type B freeboard ships 0.356 for type B-60 or type B-100 freeboard ships x_{LL} : x coordinate of the load point measured from the aft end of the freeboard length L_{LL}		

Table 7

Exposed deck location	ϕ
Freeboard deck	1.00
Superstructure deck, including forecastle deck	0.75
1 st tier of deckhouse	0.56
2 st tier of deckhouse	0.42
3 st tier of deckhouse	0.32
4 st tier of deckhouse	0.25
5 st tier of deckhouse	0.20
6 st tier of deckhouse	0.15
7 st tier of deckhouse and above	0.10

Table 8

Load cases R1, R2, P1 and P2

The external pressure p_D , at any point on the exposed deck in beam seas is obtained using the wave pressure at the side shell position on the exposed deck, the pressure coefficient ϕ at the exposed deck and the considered position z . More specifically:

$$p_D = 0.4\phi p_W$$

Where:

ϕ : as above

p_W : hydrodynamic pressure at side of the exposed deck for the load cases P1, P2, R1 and R2, in kN/m^2 , which is determined by the type of $p_{W,C}$ at the topic "Correction to the hydrodynamic pressures". p_W is to be taken as the greater one of the hydrodynamic pressures $p_{W,C}$ at both sides of the exposed deck (portside and starboard), and is not to be taken less than zero.

Load carried on exposed deck

a) Pressure due to distributed load

If the exposed deck is loaded with distributed cargo load (i.e. lumber, etc.) the static and dynamic loads due to such cargo are considered in the following way. The static pressure p_s is to be defined by the designer but, in general, is taken more than 10kN/m^2 . The total pressure is to be taken equal to the greater value obtained from the following formulae:

$$p = p_s + p_W$$

$$p = p_D$$

Where:

p_s : static pressure due to distributed load carried, if any. Is not to be taken less than 10kN/m^2

p_W : dynamic pressure due to distributed load carried, equal to:

$$= \frac{a_z}{g} p_s$$

a_z : vertical acceleration at the centre of gravity of the distributed load carried for the load case considered, in m/s^2

p_D =pressure for the exposed deck as defined for load case H1 ,H2, F1, F2 and R1, R2, P1, P2

b) Concentrated forces due to unit load

When unit load is carried on the exposed deck (i.e. outfitting items) the total forces (static + dynamic) due to this load must be considered. They must not be simultaneously considered to the pressures defined in the topic "external pressures on exposed decks". The total force F is to be taken as:

$$F = F_s + F_W$$

Where:

F_s : static force due to unit load carried

$$=m_u g$$

F_w : dynamic force due to unit load carried

$$=m_u a_z$$

m_u : mass of the unit

a_z : vertical acceleration at the centre of gravity of the distributed load carried for the load case considered, in m/s^2

External pressures on hatch covers

If a specific load is carried on a hatch cover, the pressure is to be obtained according to the way described in the topic "Load carried on exposed deck". The wave pressure at any point of the hatch cover is to be obtained according to the topic "external pressure on exposed decks for load cases H1, H2, F1 and F2", considering ϕ equal to 1.0. However, when the hatchway is located at least one superstructure standard height higher than the freeboard deck, the pressure p_w may be taken equal to 34.3 kN/m^2 . This wave pressure is applicable only to scantling requirements of members of hatch covers.

Internal pressures and forces

- Lateral pressure due to dry bulk cargo

The dry bulk cargo pressure in still water p_{CS} , in kN/m^2 is given by the following formula:

$$p_{CS} = \rho_C g K_C (h_C + h_{DB} - z)$$

Where:

ρ_C : density of the dry bulk cargo, in t/m^3 , taken equal to:

-the value given in the following Table for ships having a length L of 150m and above

-the maximum density from the loading manual for ships having a length L less than 150 m

Type of loading	Density	
	BC-A,BC-B	BC-C
Cargo hold loaded up to the upper deck	Max (M_H/V_H , 1.0)	1.0
Cargo hold not loaded up to the upper deck	3.0 ⁽¹⁾	-
(1) Except otherwise specified by the designer		

K_C : coefficient equal to:

$K_C = \cos^2 \alpha + (1 + \sin \psi) \sin^2 \alpha$ for inner bottom, hopper tank, transverse and longitudinal bulkheads, lower stool, vertical upper stool, inner side and side shell

$K_C = 0$ for top side tank, upper deck and sloped upper stool

α : angle, in deg, between panel considered and the horizontal plane

ψ : assumed angle of repose, in deg, of bulk cargo (considered drained and removed) in the absence of more precise evaluation, the following values may be taken:

$\psi = 30^\circ$ in general

$\psi = 35^\circ$ for iron ore

$\psi = 25^\circ$ for cement

h_{DB} : height, in m, of the double bottom in the centerline

h_C : vertical distance, in m, from the inner bottom to the upper surface of bulk cargo given as follows:

1) When the dry bulk cargo density is such that the cargo hold is loaded to the top of hatch coaming, the upper surface of the dry bulk cargo is an equivalent horizontal surface to be determined in considering the same loaded cargo volume in the considered hold bounded by the side shell or inner hull, as the case may be.

For holds of cylindrical shape, the equivalent horizontal surface of the dry bulk cargo may be taken at a distance h_C , in m, above the inner bottom obtained from the following formula:

$$h_C = h_{HPU} + h_O$$

Where:

$$h_O = \frac{S_A}{B_H}$$

$$S_A = S_O + \frac{V_{HC}}{l_H}$$

h_{HPU} : vertical distance, in m, between inner bottom and lower intersection of top side tank and side shell or inner side, as the case may be

S_O : area, in m^2 , above the lower intersection of top side tank and side shell or inner side, as the case may be, and up to the upper deck level

V_{HC} : volume, in m^3 , enclosed by the hatch coaming

2) When the dry bulk cargo density is such that the cargo hold is not loaded up to the upper deck, the upper surface of the dry bulk cargo is considered as having a plane surface of width $B_H/2$ in the centreline and inclined parts with an angle equal to half the angle of repose ($\psi/2$) at sides, and is to be determined in considering the same loaded cargo volume in the considered hold, taken equal to M/ρ_C .

For holds of cylindrical shape, the upper surface of the dry bulk cargo may be taken at a distance h_C , in m, above the inner bottom obtained from the following formula:

$$h_C = h_{HPL} + h_1 + h_2$$

Where:

h_{HPL} : vertical distance, in m, between inner bottom and upper intersection of hopper tank and inner side. h_{HPL} is to be taken equal to 0 if there is no hopper tank.

$$h_1 = \frac{M}{\rho_C B_H l_H} - \frac{B_H + b_{IB}}{2 B_H} h_{HPL} - \frac{3}{16} B_H \tan \frac{\psi}{2} + \frac{V_{TS}}{B_H l_H}$$

M : mass, in t, of the bulk cargo to be considered

B_H : mean breadth of the cargo hold

b_{IB} : breadth of inner bottom, in m

l_H : length of the cargo hold

V_{TS} : total volume, in m^3 , of transverse stools at bottom of transverse bulkheads within the concerned cargo hold length l_H . This volume excludes the part of hopper tank passing through the transverse bulkhead.

h_2 : bulk cargo upper surface, in m, depending on γ , given by:

$$h_2 = \frac{B_H}{4} \tan \frac{\psi}{2}, \text{ if } \frac{B_H}{4} \leq |y| \leq \frac{B_H}{4}$$

$$h_2 = \left(\frac{B_H}{2} - |y| \right) \tan \frac{\psi}{2}, \text{ if } \frac{B_H}{4} \leq |y| \leq \frac{B_H}{2}$$

For holds of non-cylindrical shape, and in case of prescriptive rule requirements, the upper surface of the bulk cargo may be taken at the upper deck level with a density of dry bulk cargo equal to M/V_H .

The inertial pressure induced by dry bulk cargo p_{CW} , in kN/m^2 , for each load case is given by the following formulae:

for load case H: $p_{CW} = \rho_C [0.25a_x(x - x_G) + K_C a_z(h_C + h_{DB} - z)]$

for load case F: $p_{CW} = 0$

for load case R and P: $p_{CW} = \rho_C [0.25a_y(y - y_G) + K_C a_z(h_C + h_{DB} - z)]$

$(x - x_G)$ is to be taken as $0.25l_H$ in the load case H1 or $-0.25l_H$ in the load case H2 for local strength and fatigue check for longitudinal stiffeners.

The total pressure $(p_{CS} + p_{CW})$ is not to be negative.

Where:

x_G, y_G, z_G : X,Y,Z coordinate, in m, of the centre of gravity of the hold or tank considered with respect to the reference coordinate system

x, y, z : X,Y,Z coordinates, in m, of any point considered with respect to the reference coordinate system

a_x : longitudinal acceleration at the centre of gravity of the hold or tank considered, in m/s^2

a_y : transverse acceleration at the centre of gravity of the hold or tank considered, in m/s^2

a_z : vertical acceleration at the centre of gravity of the hold or tank considered, in m/s^2

Shear load due to dry bulk cargo

In order to consider a balance between the overall internal pressure or force (gravity and inertial force due to vertical acceleration), shear load due to dry bulk cargo acting along the sloping plates in way of bilge hopper tank and lower stool is to be evaluated, in addition the static and dynamic internal pressure. The shear load is considered only for direct structural analysis (FE analysis). The shear load due to dry bulk cargo acting along the sloping members in still water p_{CS-S} (positive down to inner bottom plating), in kN/m^2 , is given by:

$$p_{CW-S} = \rho_C a_z \frac{(1 - K_C)(h_C + h_{DB} - z)}{\tan \alpha}$$

The shear load due to dry bulk cargo acting along the sloping members in waves p_{CW-S} (positive down to inner bottom plating), in kN/m^2 , is given by:

For load cases H, R and P:

$$p_{CW-S} = \rho_C a_z \frac{(1 - K_C)(h_C + h_{DB} - z)}{\tan \alpha}$$

For load case F:

$$p_{CW-S}=0$$

In order to evaluate the total force in the longitudinal and transverse directions, shear load due to dry bulk cargo in way of inner bottom plating is to be considered. The shear load due to dry bulk cargo in the longitudinal direction in waves p_{CW-S} (positive forward), in kN/m^2 , is given by:

For load case H:

$$p_{CW-S} = 0.75 \rho_C \alpha_X h_C$$

For load cases F, R and P

$$p_{CW-S}=0$$

The shear load due to dry bulk cargo in the transverse direction in waves p_{CW-S} (positive weather side), in kN/m^2 is given by:

For load cases R and P: $p_{CW-S} = 0.75 \rho_C \alpha_Y h_C$

For load cases H and F: $p_{CW-S}=0$

- Lateral pressure due to liquid

The liquid pressure in still water p_{BS} , in kN/m^2 is given by the greater of the following formulae:

$$p_{BS} = \rho_L g (z_{TOP} - z + 0.5 d_{AP})$$

$$p_{BS} = \rho_L g (z_{TOP} - z) + 100 P_{PV}$$

Where:

p_{PV} : setting pressure, in bar, of safety valves to be considered if any. For local strength assessment, the static pressure p_{BS} is to be taken not less than 25 kN/m^2

d_{AP} : distance from the top of air pipe to the top of compartment, in m, taken equal to:

$$d_{AP} = z_{BO} - z_{TOP}$$

z_{BO} : Z coordinate, in m, of the top of the overflow pipe

z_{TOP} : Z coordinate, in m, of the top of the tank, in upright condition

When checking ballast water exchange operations by means of the flow through method, the static pressure p_{BS} for local strength assessments and direct strength analysis is to be not less than:

$$p_{BS} = \rho_L g (z_{TOP} - z + d_{AP}) + 25$$

Additional calculations may be required where piping or pumping arrangements may lead to a higher pressure.

For fatigue strength assessment, the liquid pressure in still water p_{BS} is given by the following formula:

$$p_{BS} = \rho_L g (z_{TOP} - z)$$

If the p_{BS} is negative, p_{BS} is to be taken equal to 0.

Where the considered load point is located in the fuel oil, other oils or fresh water tanks, liquids are assumed to be fulfilled up to the half height of the tanks and z_{TOP} is taken to the Z coordinate of the liquid surface at the upright position.

The inertial pressure due to liquid p_{BW} , in kN/m^2 , for each load case is given as follows. When checking ballast water exchange operations by means of the flow through method, the inertial pressure due to ballast water is not to be considered for local strength assessments and direct strength analysis.

For load case H: $p_{BW} = \rho_L [a_z (z_{TOP} - z) + a_x (x - x_B)]$, $(x - x_B)$ is to be taken as $0.75l_H$ in the load case H1 or $-0.75l_H$ in the load case H2 for local strength and fatigue check for longitudinal stiffeners.

For load case F: $p_{BW} = 0$

For load case R and P: $p_{BW} = \rho_L [a_z (z_B - z) + a_y (y - y_B)]$

Where:

x_B : X coordinate, in m, of the aft end of the tank when the bow side is downward, or of the fore end of the tank when the bow side is upward, as defined in the following figure

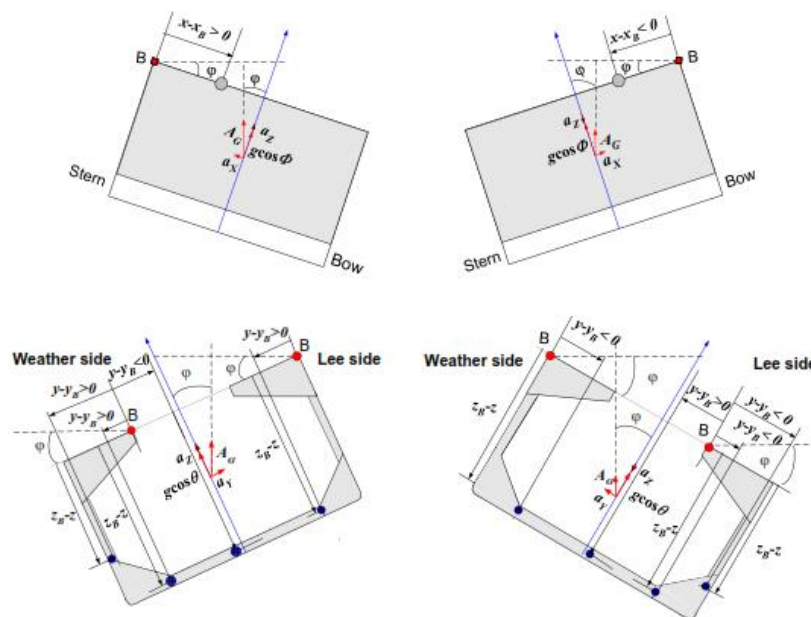
y_B : Y coordinate, in m, of the tank top located at the most lee side when the weather side is downward, or of the most weather side when the weather side is upward, as defined in the following figure

z_B : Z coordinate of the following point:

for completely filled spaces: the tank top

for ballast hold: the top of the hatch coaming

The reference point B is defined as the upper most point after rotation by the angle ϕ between the vertical axis and the global acceleration vector $\vec{A}_G$ shown in the following figure.



Definition of x_B and y_B

ϕ is obtained from the following formula:

Load cases H1 and H2:

$$\varphi = \tan^{-1} \left(\frac{|a_x|}{g \cos \Phi + a_z} \right)$$

Load cases R1(P1) and R2(P2)

$$\varphi = \tan^{-1} \left(\frac{|a_y|}{g \cos \theta + a_z} \right)$$

Where:

θ :single roll amplitude

Φ :single pitch amplitude

The total pressure ($p_{BS} + p_{BW}$) is not to be negative

Design bottom slamming pressure

The bottom slamming pressure for the reinforcement of the flat bottom forward is to be obtained from the following formula:

$$p_{SL} = 162c_1c_{SL}\sqrt{L} \quad \text{for } L \leq 150\text{m}$$

$$p_{SL} = 1984c_1c_{SL}(1.3 - 0.002L) \quad \text{for } L > 150\text{m}$$

where:

$$c_1 = 3.6 - 6.5 \left(\frac{T_{BFP}}{L} \right)^{0.2}$$

And never greater than 1

T_{BFP} : smallest design ballast draught, in m, defined at forward perpendicular for normal ballast conditions. Where the sequential method for ballast water exchange is intended to be applied, T_{BFP} is to be considered for the sequence of exchange.

c_{SL} : distribution factor

$$c_{SL} = 0 \quad \text{for } \frac{x}{L} \leq 0.5$$

$$c_{SL} = \frac{\frac{x}{L} - 0.5}{c_2} \quad \text{for } 0.5 < \frac{x}{L} \leq 0.5 + c_2$$

$$c_{SL} = 1.0 \quad \text{for } 0.5 + c_2 < \frac{x}{L} \leq 0.65 + c_2$$

$$c_{SL} = 0.5 \left(1 + \frac{1 - \frac{x}{L}}{0.35 - c_2} \right) \quad \text{for } \frac{x}{L} \geq 0.65 + c_2$$

$$c_2 = 0.33C_B + \frac{L}{2500} \quad \text{never greater than 0.3}$$

DISCUSSION

Local loads, as far as their dynamic components are concerned, depend on the load cases that each CSR take into account. Both CSR use the equivalent design wave method (EDW). In CSR DHOT, 9 load cases are used corresponding to 3 equivalent design waves. On the other hand, in CSR BC 8 load cases are used corresponding to 4 equivalent design waves. In each load case of both CSR, a load component is maximized (e.g. vertical wave bending moment, vertical acceleration, dynamic wave pressure at waterline, etc). In CSR DHOT two load cases exist for the design state “Oblique sea”, which is not taken into account by CSR BC, while in CSR BC two load cases exist for the design state “Following sea”, which is not incorporated in DHOT’s load cases. Apart from the difference in load cases used by each CSR, there are also differences in the values of design load combination factors given in the respective Tables.

As far the formulae of local loads are concerned, the formula that provides dynamic wave pressure in CSR DHOT differs from that in CSR BC. Hence the values obtained by the implementation of these formulae are different. The same happens in case of external pressures on exposed decks (green sea load for double hull oil tankers). The formulae that provide internal pressures and forces of BC differ from these of DHOT, as far as static tank pressure due to liquid (ballast tanks in bulk carriers) is concerned and in case of dynamic components (inertial pressures), the difference that is noticed is because of the different values of dynamic load combination factors.

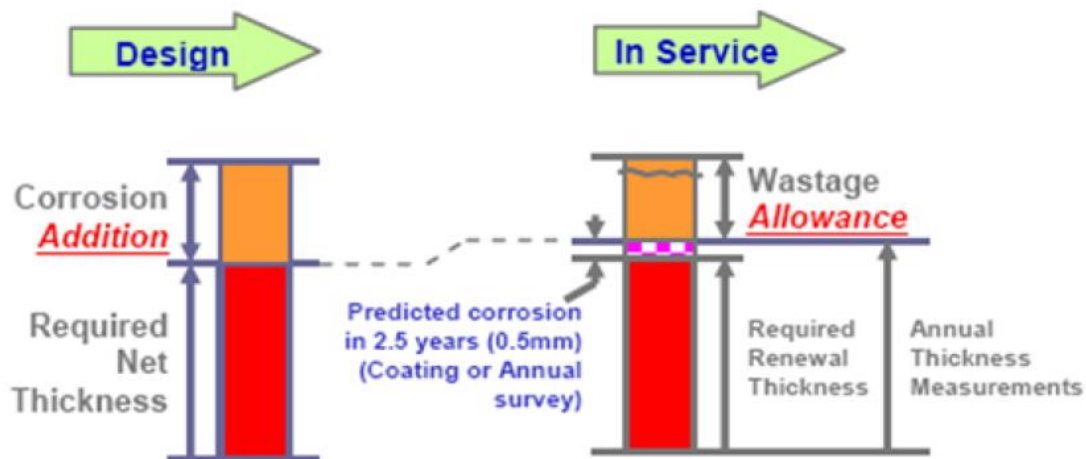
Because of the kind of cargo they carry in their cargo tanks CSR DHOT take into consideration sloshing pressure, in contrast to BC that there is no such a need as they carry dry bulk cargo.

Chapter 2 - SCANTLINGS OF THE MIDSHIP SECTION

The thickness of plating and stiffeners in the cargo tank region for both types of ships (double hull oil tankers and bulk carriers) is to comply with the minimum thickness requirements given in Chapter 8 and Chapter 6 respectively of IACS CSR. The aim of this chapter is to present, explain and finally compare the requirements that concern the scantlings of the plates and stiffeners at midship section of both types of ships.

2.1 BASIS OF THE APPROACH

IACS CSR are formulated using net thickness approach. That happens in order to provide and verify the minimum hull scantlings that are to be maintained from the new building stage throughout the ship's design life. In other words net thickness approach is used to provide a link between the assumed reduction in strength during new building stage evaluations and the in service gauging assessment criteria.



Gross thickness is derived from net thickness as far as plating and local support members are concerned by adding the full corrosion additions specified in the following tables. CSR for double hull oil tankers provide in Chapter 6 the total corrosion addition for typical structural elements in the cargo tank region, while CSR for bulk carriers provide in Chapter 3 the corrosion addition on one side of structural members and the total corrosion addition is given by the formula:

$$t_c = \text{Roundup}_{0.5}(t_{c1} + t_{c2}) + t_{\text{reserve}}$$

Where:

t_{c1} , t_{c2} : corrosion addition, in mm, on one side of the considered structural member.

t_{reserve} : reserve thickness, in mm, taken equal to: 0.5

Corrosion addition for double hull oil tankers:

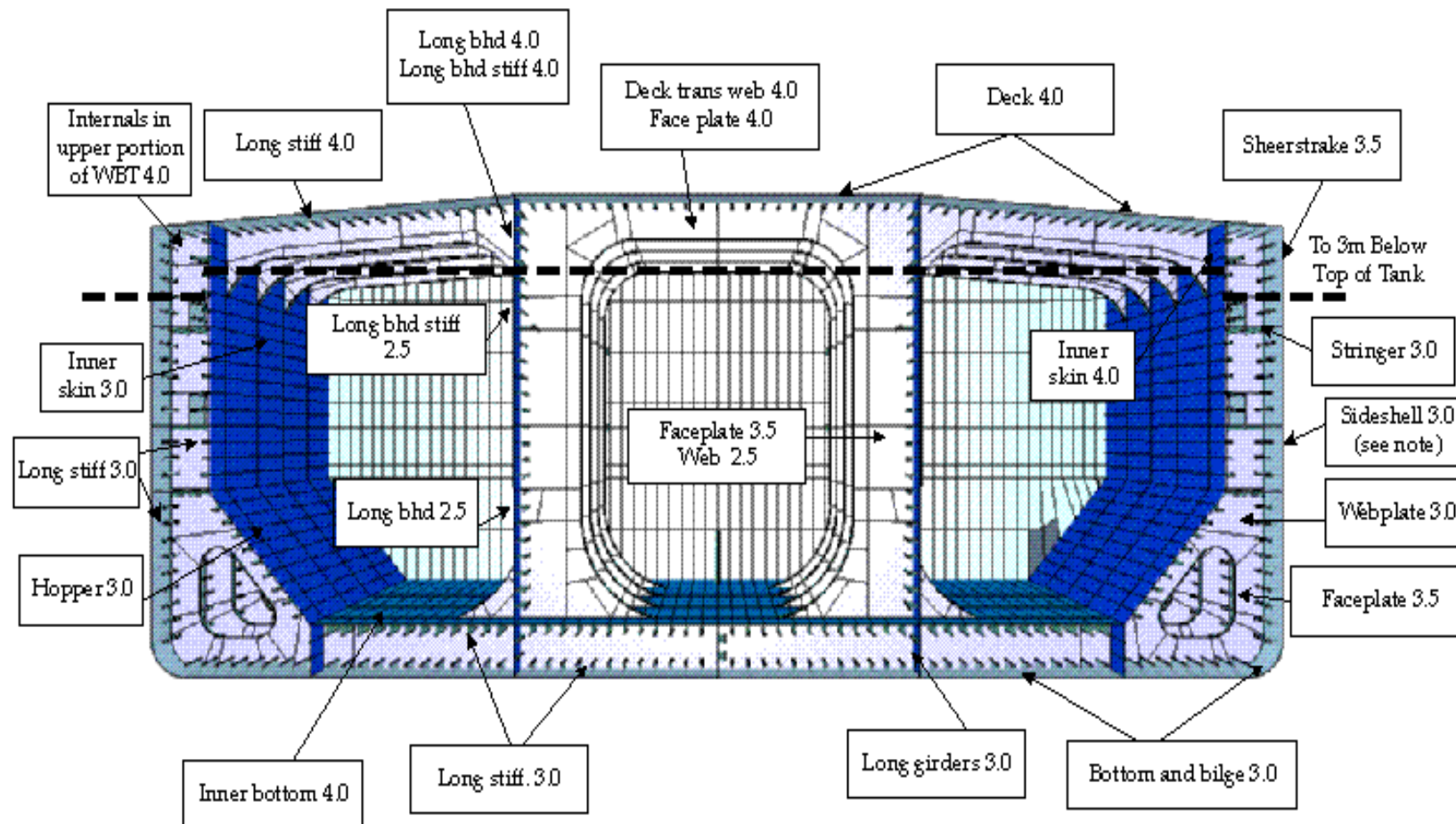
Corrosion addition for typical structural elements within the cargo tank region			
Category of contents			Corrosion addition t _{corr} , in mm
Internal members and plate boundary between spaces with the same category of contents			
In and between ballast water tanks	Face plate of PSM	Within 3m below top of tank	4.5
		Elsewhere	3.5
	Other members	Within 3m below top of tank	4
		Elsewhere	3
	Stiffeners on boundaries to heated cargo tanks	Within 3m below top of tank	4.5
		Elsewhere	3.5
In and between cargo oil tanks	Face plate of PSM	Within 3m below top of tank	4
		Elsewhere	3.5
	Other members	Within 3m below top of tank	4
		Elsewhere	2.5
Exposed to atmosphere on both sides	Support members on deck		2.5
In and between void spaces	Spaces not normally accessed ,e.g. access only via bolted manhole openings,pipe tunnels,etc		2
In and between dry spaces	Internals of deckhouses, machinery spaces,pump room, store rooms,steering gear space,etc.		1.5
Plate boundary between spaces having a different category			
Boundary between ballast tank and cargo oil tank	Unheated cargo tank	Within 3m below top of tank	4
		Inner bottom plating	4
		Elsewhere	3
	Heated cargo tank	Within 3m below top of tank	4.5
		Inner bottom plating	4.5
		Elsewhere	3.5
Boundary between ballast tank and atmosphere or sea	Weather deck plating		4
	Other members	Within 3m below top of tank	3.5
		Elsewhere	3
Boundary between ballast tank and void or dry space	Within 3m below top of tank		3
	Elsewhere		2.5
Boundary between cargo tank and atmosphere	Weather deck plating		3
Boundary between cargo tank and void spaces	Within 3m below top of tank		3
	Elsewhere		2.5
Boundary between cargo tank and dry spaces	Within 3m below top of tank		3
	Elsewhere		2

Corrosion additions for bulk carriers:

Corrosion addition on one side of structural members				
Compartment type	Structural member		Corrosion addition t _{c1r} or t _{c2} , in mm	
			BC-A or BC-B ships with L ≥ 150m	Other
Ballast water tank	Face plate of PSM	Within 3m below top of tank	2	
		Elsewhere	1.5	
	Other members	Within 3m below top of tank	1.7	
		Elsewhere	1.2	
Dry bulk cargo hold (intended for the carriage of dry bulk cargoes and water ballast)	Transverse bulkhead	Upper part	2.4	1
		Lower stool:sloping plate,vertical plate and top plate	5.2	2.6
		Other parts	3	1.5
	Other members	Upper part	1.8	1
		Web and flanges of the upper end brackets of side frames of single side bulk carriers		
		Web and flanges of lower brackets of side frames of single side bulk carriers	2.2	1.2
		Other parts	2	1.2
	Sloped plating of hopper tank, inner bottom plating	Continuous wooden ceiling	2	1.2
		No continuous wooden ceiling	3.7	2.4
	Exposed to atmosphere	Horizontal member and weather deck (≤20°)		1.7
Non horizontal member (>20° as regard as a horizontal line)		1		
Exposed to sea water			1	
Fuel oil tanks and lubricating oil tanks			0.7	
Fresh water tanks			0.7	
Void spaces	Spaces not normally accessed,e.g. access only through bolted manholesopenings,pipe tunnels, etc.		0.7	
Dry spaces	Internal of deck houses, machinery spaces, stores spaces, pump rooms, steering spaces, etc.		0.5	
Other compartments than above			0.5	
Note The corrosion addition of a plating between water ballast and heated fuel oil tanks is to be increased by 0.7mm				

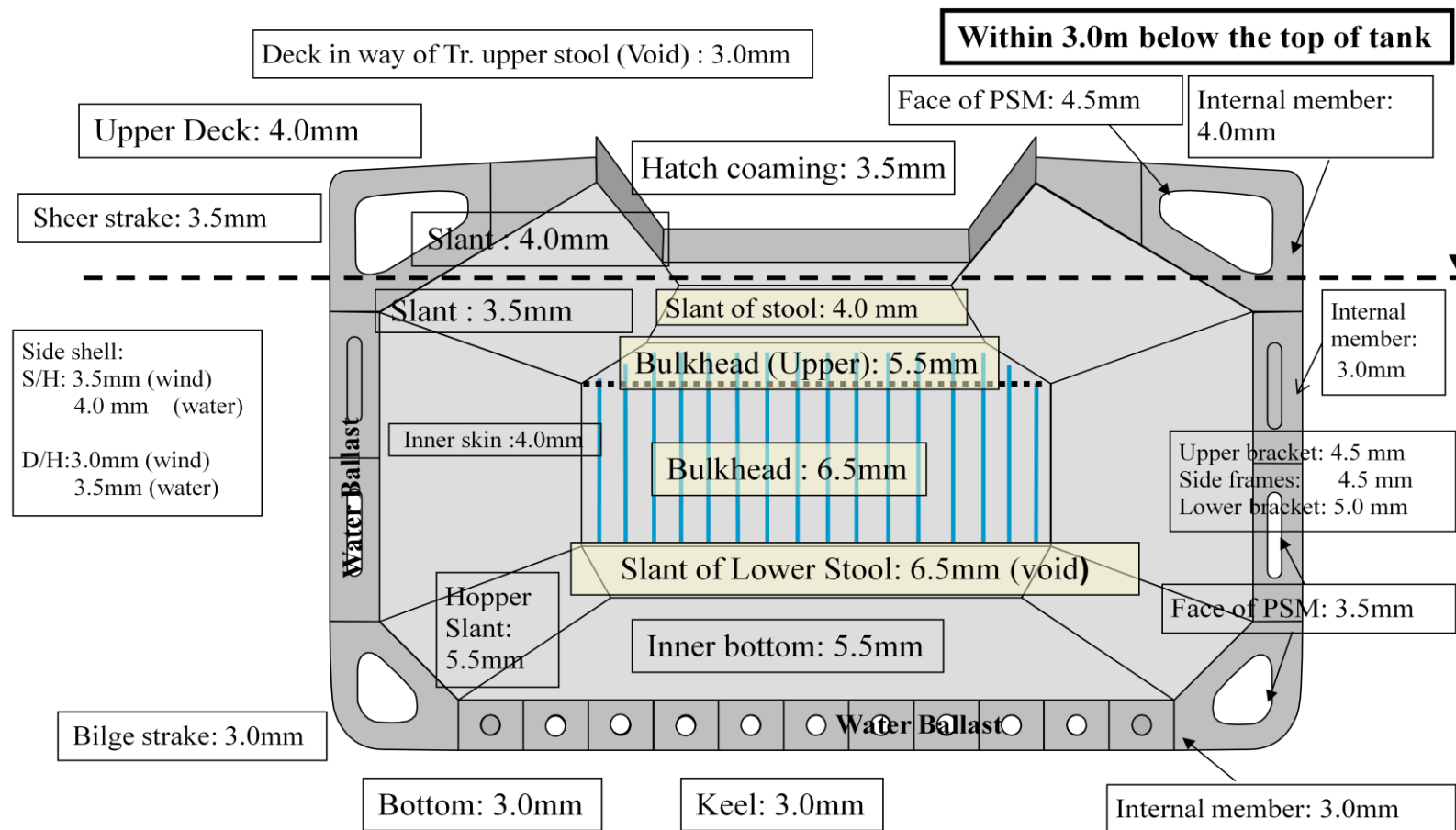
Both CSR demand 0.5mm to be added for side shell plating in the quay contact region.

Corrosions additions for typical structural elements within the cargo tank region of a double hull oil tanker

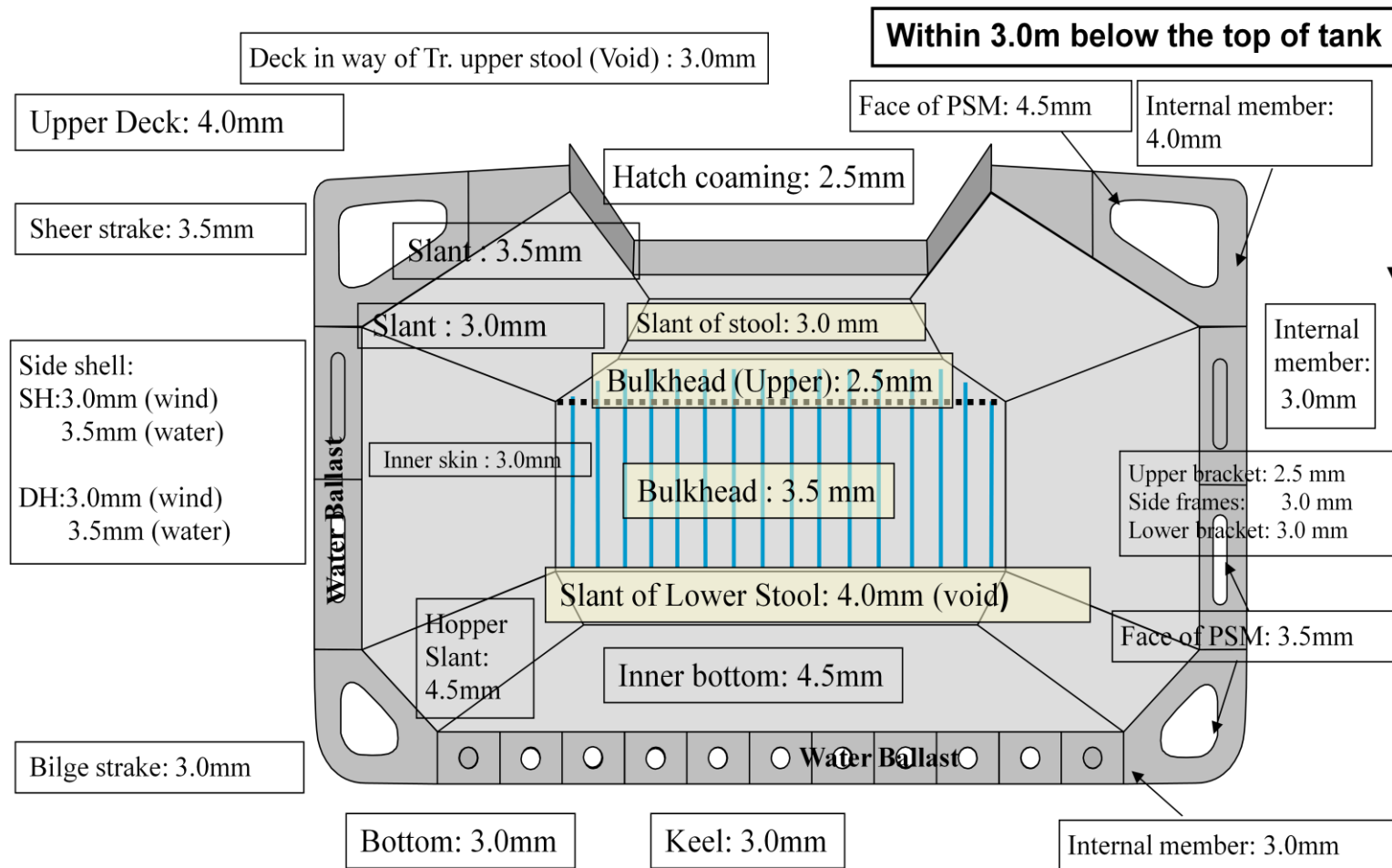


Note: 0.5mm to be added for side plating in the quay contact region, defined in subsection "Special requirements" of the present chapter

Corrosion additions for typical structural elements within the cargo tank region of a BC-A or BC-B bulk carrier with $L \geq 150m$



Corrosion additions for typical structural elements within the cargo tank region of a BC-C or bulk carrier with $L \leq 150m$



2.2 MINIMUM THICKNESS FOR PLATING, LOCAL & PRIMARY SUPPORT MEMBERS

At the beginning of the evaluation of minimum thickness of plating and stiffeners, CSR of both types of ships provide tables with empirical types that present the lower limit of minimum net thickness as a function of L (length between perpendiculars of the ship). Namely, the net thicknesses presented by the following tables are not stress based requirements, but absolute minimum thickness requirements.

More specifically the thickness of plating and stiffeners in the cargo tank region of a double hull oil tanker is to comply with the following minimum thickness requirements:

Minimum net thickness for plating and local support members in the cargo tank region			
Scantling location			Net thickness (mm)
Plating	Shell	keel plating	6.5+0.03L
		bottom shell/bilge/side shell	4.5+0.03L
	Upper deck		4.5+0.02L
	Other structure	hull internal tank boundaries	4.5+0.02L
		non-tight bulkheads ,bulkheads between dry spaces and other plates in general	4.5+0.015L
Local support members	Local support members on tight boundaries		3.5+0.01L
	Local support members on other structure		2.5+0.015L
Tripping brackets			5.0+0.015L

Minimum net thickness for primary support members in cargo tank region	
Scantling location	Net thickness (mm)
Double bottom centreline girder	$5.5+0.025L$
Other double bottom girders	$5.5+0.02L$
Double bottom floors, web plates of side transverses and stringers in double hull	$5.0+0.015L$
Web and flanges of vertical web frames on longitudinal bulkheads, horizontal stringers on transverse bulkhead, deck transverses (above and below upper deck) and cross ties	$5.5+0.015L$

On the other hand the minimum net thickness of plating for a bulk carrier has to comply with the following net thickness requirements given from the following table:

Plating	Minimum net thickness, in mm
Keel	$7.5+0.03L$
Bottom, Inner bottom	$5.5+0.03L$
Weather strength deck and trunk deck, if any	$4.5+0.02L$
Side shell, bilge	$0.85L^{1/2}$
Inner side, hopper slopping plate and topside sloping plate	$0.7L^{1/3}$
Transverse and longitudinal watertight bulkhead	$0.6L^{1/4}$
Wash bulkheads	6.5
Accommodation deck	5

As far as stiffeners are concerned, CSR for bulk carriers define the minimum net thickness of webs of ordinary stiffeners other than side frames of single side bulk carriers. It has to be not less than the greater of (in mm):

$$t = 3 + 0.015L$$

40% of the net required thickness of the attached plating

In case of side frames of single side bulk carriers, their net thickness, in mm, is to be not less than the value obtained from the following formula:

$$t = 0.75a(7 + 0.03L)$$

Where $a = 1.15$ for the frame webs in way of the foremost hold
 $= 1$ for the frame webs in way of other holds

In addition CSR define the upper limit of the net thickness of the web of ordinary stiffeners, in mm, which is to be less than 2 times the net offered thickness of the attached plating.

2.3 PLATING SUBJECTED TO LATERAL PRESSURE

The minimum net thickness of plating and local support members is to be taken as the greatest value for all applicable design load sets and given by the following formula which is similar for double hull oil tankers and bulk carriers. The difference is found, as far as the general format is concerned, in factor c_r which is a coefficient of curvature of the panel and which is incorporated only in the formula of bulk carriers.

More specifically the net thickness of plating and local support members for double hull oil tankers is derived from the following formula:

$$t_{net} = 0.0158a_p s \sqrt{\frac{|P|}{C_a \sigma_{yd}}}$$

For bulk carriers the formula above becomes:

$$t_{net} = 0.0158a_p c_r s \sqrt{\frac{|P|}{C_a \sigma_{yd}}}$$

Where

P: design pressure for the design load set being considered and calculated at the load calculation point, in kN/m^2

α_p : correction factor for the panel aspect ratio

The formula of this factor differs between oil tankers and bulk carriers.

Namely, for oil tankers

$$\alpha_p = 1.2 - \frac{s}{2100l_p}$$

While for bulk carriers

$$\alpha_p = 1.21 \sqrt{1 + 0.33 \left(\frac{s}{l_p} \right)^2} - 0.69 \frac{s}{l_p}$$

Both formulae never take values greater than 1.0

s: stiffener spacing, in mm

l_p : length of plate panel, to be taken as the spacing of primary support members, S, unless carlings are fitted, in m

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

r : radius of curvature, in m

σ_{yd} : specified minimum yield stress of the material, N/mm²

C_a : permissible bending stress coefficient for the design load set being considered

$$= \beta_\alpha - \alpha_\alpha \frac{|\sigma_{hg}|}{\sigma_{yd}} \text{ but not to be taken greater than } C_{a-\max}$$

The values of β_α and α_α for oil tankers and bulk carriers are given in the following tables respectively.

Acceptance criteria set	Structural Member		β_α	α_α	$C_{a-\max}$
AC1	Longitudinal strength members	Longitudinally stiffened plating	0.9	0.5	0.8
		Transversely or vertically stiffened plating	0.9	1	0.8
	Other members		0.8	0	0.8
AC2	Longitudinal strength members	Longitudinally stiffened plating	1.05	0.5	0.95
		Transversely or vertically stiffened plating	1.05	1	0.95
	Other members		1	0	1

Plating		β_α	α_α	$C_{a-\max}$
Contributing to the hull girder longitudinal strength	Longitudinally stiffened plating	0.95	0.45	0.9
	Transversely stiffened plating	0.95	0.9	0.9
Not contributing to the hull girder longitudinal strength		0.9		

σ_{hg} =normal stress, induced by acting vertical and horizontal bending moments at the position considered. It is given, for the design load set being considered, from the following formula:

$$\sigma_{hg} = \left(\frac{(z - z_{NA-net50}) M_{v-total}}{I_{v-net50}} - \frac{y M_{h-total}}{I_{h-net50}} \right) 10^{-3} \quad N / mm^2$$

$M_{v-total}$: design vertical bending moment at the longitudinal position under consideration for the design load set being considered, in kNm. It is the sum of still water and wave bending

moment. The still water bending moment is to be taken with the same sign as the simultaneously acting wave bending moment.

$M_{h-total}$: design horizontal bending moment at the longitudinal position under consideration for the design load set being considered, in kNm.

$I_{v-net50}$: net vertical hull girder moment of inertia, at the longitudinal position being considered, in m^4 . Net vertical hull girder moment of inertia is to be calculated based on gross thickness minus the corrosion addition $0.5t_{corr}$ of all effective structural members comprising the hull girder section, where t_{corr} is given in the figure of the midship section above.

$I_{h-net50}$: net horizontal hull girder moment of inertia, at the longitudinal position being considered, in m^4 . Net horizontal hull girder moment of inertia is to be calculated based on gross thickness minus the corrosion addition $0.5t_{corr}$ of all effective structural members comprising the hull girder section, where t_{corr} is given in the figure of the midship section above.

y: transverse coordinate of load calculation point, in m

z: vertical coordinate of the load calculation point under consideration, in m

$Z_{NA-net50}$: distance from the baseline to the horizontal neutral axis

The net thickness formula, as it is mentioned in technical background document of CSR for double hull oil tankers, is derived as below:

Considering a beam having a section with a unit width and depth of plate thickness, bending moment when the both ends are supported by local/primary support members (in other words are fixed) is equal to:

$$\text{Bending moment at both ends} = ps^2/12$$

If that beam is further loaded until plastic hinges are created at the midspan and at the ends then:

$$\text{Bending moment at both ends and midspan} = ps^2/16$$

$$\text{Plastic section modulus is equal to: } t^2/4$$

Then the assuming allowable stress

$$= C_a \sigma_{yd} = M / SM = ps^2 / (4t^2) \Rightarrow$$

$$t = \frac{s}{2} \sqrt{\frac{p}{C_a \sigma_{yd}}}$$

Where s is in mm, p is in N/mm^2 and σ_{yd} is in N/mm

If we convert the unit of p from N/mm^2 to kN/m^2

$$t = \frac{s}{2\sqrt{1000}} \sqrt{\frac{p}{C_a \sigma_{yd}}} = 0.0158s \sqrt{\frac{p}{C_a \sigma_{yd}}}$$

The factor a_p is incorporated in the formula above as a correction that has to do with the aspect ratio of the elementary plate panel. The determination of the format of a_p is based on a non-linear analysis carried out using a square plate panel, whose results are in good agreement with the existing DNV formulation. Since the curve in the existing DNV formulation is nearly straight for s/l ratio between 0.4 and 1.0, the format of the equation is changed similar to that in the existing LR rules. Hence the formula of a_p was converted from:

$$a_p = 1.1 - 0.4 \frac{s}{l_p} \text{ which is the formula of } a_p \text{ according to LR to } a_p = 1.2 - \frac{s}{2100l_p}, s \text{ (mm)}$$

and l_p (m), which is the formula of CSR.

Section modulus requirements for stiffeners

The minimum net section modulus Z_{NET} of single span ordinary stiffeners is to be taken as the greatest value calculated for all applicable design load sets, which are mentioned for each type of ship in the next section, and given by the following formula which is the same for both types of ships:

$$Z_{NET} = \frac{|P|sl_{bdg}^2}{f_{bdg}C_s\sigma_{yd}} \text{ cm}^3$$

Where:

P: design pressure for the design load set being considered and calculated at the load calculation point

f_{bdg} : bending moment factor. For continuous stiffeners and where end connections are fitted consistent with idealization of the stiffener as having as fixed ends:

=12 for horizontal stiffeners

=10 for vertical stiffeners

l_{bdg} : effective bending span, in m

s: stiffener spacing

σ_{yd} : specified minimum yield stress of the material, in N/mm^2

C_s : permissible bending stress coefficient for the design load set being considered, to be taken as:

For double hull oil tankers

Sign of hull girder bending stress σ_{hg}	Side pressure acting on	Acceptance criteria
Tension (+ve)	Stiffener side	$C_s = \beta_s - a_s \frac{ \sigma_{hg} }{\sigma_{yd}}$
Compression (-ve)	Plate side	
Tension (+ve)	Stiffener side	$C_s = C_{s-MAX}$
Compression (-ve)	Plate side	

Acceptance criteria set	Structural member	β_s	α_s	C_{S-MAX}
AC1	Longitudinal strength member	0.85	1	0.75
	Transverse or vertical member	0.75	0	0.75
AC2	Longitudinal strength member	1	1	0.9
	Transverse or vertical member	0.9	0	0.9
	Watertight boundary stiffeners	0.9	0	0.9

For bulk carriers

Structural member	C_s
Longitudinal stiffener contributing to the hull girder longitudinal strength	$C_s = 1.2 \left(1.0 - 0.85 \left \frac{\sigma_{hg}}{\sigma_{yd}} \right \right)$
Other stiffeners	0.9

In addition CSR for double hull oil tankers provide the minimum net web thickness, t_{w-net} , which is to be taken as the greatest value calculated for all applicable design load sets. Its value is derived from the following formula:

$$t_{w-net} = \frac{f_{shr} |P| s l_{shr}}{d_{shr} C_t \tau_{yd}} \text{ mm}$$

Where:

P: design pressure for the design load set being considered and calculated at the load calculation point, in kN/m²

F_{shr} : shear force distribution factor. For continuous stiffeners and where end connections are fitted consistent with idealization of the stiffener as having as fixed ends:

=0.5 for horizontal stiffeners

=0.7 for vertical stiffeners

d_{shr} : effective shear depth of stiffeners

$$= (h_{stf} + t_{p-net}) \sin \phi_w$$

h_{stf} : stiffener height, including face plate, in mm

t_{p-net} : net thickness of attached plate, in mm

ϕ_w : angle between the stiffener web and attached plating, in degrees. It is to be taken as 90 degrees if the angle is greater than or equal to 75 degrees

C_t : permissible shear stress coefficient for the design load set being considered, to be taken as: 0.75 for acceptance criteria set AC1

0.90 for acceptance criteria set AC2

l_{shr} : effective shear span, in m

$$\tau_{yd} = \frac{\sigma_{yd}}{\sqrt{3}} \text{ N/mm}^2$$

On the other hand CSR for bulk carriers provide the net shear sectional area A_{sh} , in cm², of single span ordinary stiffeners subjected to lateral pressure, which is derived from the following formula:

$$A_{sh} = \frac{5(p_s + p_w)sl}{\tau_{yd} \sin \phi_w}$$

2.4 DESIGN LOAD SETS

In order to calculate the minimum net load thickness by the type given in the previous subsection ("Plating subjected to lateral pressure"), we must know the dimensions of elementary plate panel (s, l_p) in order to determine a_p , the specified minimum yield stress of the material σ_{yd} and we must also have a first estimation of the horizontal position of the neutral axis at the midship section in order to determine C_a . As far as design pressure (P) is concerned, CSR provide a number of design load sets which must be examined in order to extract the value of minimum net thickness. To be more precise, the static and dynamic lateral pressures in intact or damaged condition induced by the sea and the various types of cargoes, ballast and other liquids are to be considered. Applied loads and their values will depend on the location of the elements under consideration, the adjacent type of compartments, and the loading condition (draft examined).

To be more precise in case of double hull oil tankers, CSR provide a very analytical table for the design load sets that must be checked as far as plating and local support members are concerned. Although CSR for bulk carriers do not provide a table with the design load sets that are necessary to be taken into account, after processing a lot of data we created a table with all the necessary design load sets assembled. The design load sets with the pressures (static + dynamic) that have to be gauged in order to calculate load thicknesses for plates and stiffeners at the midship section of each type of ship are gathered in the following two tables.

Design load sets for plating and local support members for double hull oil tankers

Structural member		Load component	Draught	Comment	Design load combination
Keel, bottom shell, bilge, side shell, sheer stake		P _{EX}	T _{SC}	Sea pressure only	S+D
		P _{EX}	T _{SC}		S
		P _{IN} -P _{EX}	T _{BAL}	Net pressure difference between water ballast pressure and sea pressure	S+D
		P _{IN} -P _{EX}	0.25T _{SC}		S
Deck	In way of cargo tanks	P _{EX}	T _{SC}	Green sea pressure only or other load on deck	S+D
		P _{IN}	0.6T _{SC}	Cargo pressure only	S+D
		P _{IN}	-		S
	In way of other tanks	P _{EX}	T _{SC}	Green sea pressure only or other load on deck	S+D
		P _{IN}	T _{BAL}	Water ballast or other liquid pressure only	S+D
		P _{IN}	0.25T _{SC}		S
	Any location	P _{DK}	T _{BAL}	Distributed or concentrated loads only. Simultaneously occurring green sea pressure may be ignored	S+D
		P _{DK}	-		S
	Inner bottom, inner hull, hopper side		P _{IN}	0.6T _{SC}	Cargo pressure only
P _{IN}			-	S	
P _{IN}			T _{BAL}	Water ballast or other liquid pressure only	S+D
P _{IN}			-		S
P _{IN-FLOOD}			-		A
Longitudinal bulkhead, centreline bulkhead		P _{IN}	0.6T _{SC}	Pressure from one side only. Full cargo tank with adjacent cargo tank empty. Two cases are to be evaluated: Inner empty, outer full/inner full, outer empty	S+D
		P _{IN}	-		S
		P _{IN-FLOOD}	-	A	
Other tank boundaries,e.g girders,floors, stringers		P _{IN}	T _{BAL}	Pressure from one side only. Need to evaluate 2 cases. As above.	S+D
		P _{IN}	0.25T _{SC}		S
		P _{IN-FLOOD}	-		A

Where:

P_{EX} : design sea pressure, in kN/m^2

P_{IN} : design tank pressure, in kN/m^2

P_{DK} : design deck pressure, in kN/m^2

$P_{IN-FLOOD}$: pressure in compartments and tanks in flooded or damaged condition, in kN/m^2
 T_{SC} , T_{BAL} : scantling draught and draught in normal ballast condition respectively, in m
 S denotes the static design load combination, S+D denotes the static plus dynamic design load combination and A denotes the accidental design load combination.

CSR for double hull oil tankers take into account the effect of sloshing and provide specific scantling requirements for boundary and internal structure of tanks subject to sloshing loads, due to the free movement of liquid in tanks. The structure of cargo tanks and main fresh water tanks, are to be assessed for sloshing. Small tanks do not need to be assessed for sloshing pressures. In the previous chapter (“Loads”) are provided the formulae of sloshing pressures applied in tank structural members due to longitudinal liquid motion $P_{SLH-LNG}$ and due to transverse liquid motion P_{SLH-T} . CSR specify the tanks that must be assessed for the design sloshing pressure and these are: cargo and slop tanks, fore peak and aft peak ballast tanks and any other tank which allow the free movement of liquid except that where the effective sloshing length is less than $0.03L$ and that where the effective sloshing breadth s is less than $0.32B$.

The members that the design sloshing pressure due to longitudinal liquid motion is to be applied are: transverse tight bulkheads, transverse wash bulkheads, stringers on transverse tight and wash bulkheads and plating and stiffeners on the longitudinal bulkheads, deck and inner hull which are between the transverse bulkhead and the first web frame from the bulkhead or the bulkhead and $0.25l_{SLH}$ whichever is lesser.

On the other hand, the design sloshing pressure due to transverse liquid motion is to be applied to the following members: longitudinal tight bulkhead, longitudinal wash bulkhead, horizontal stringers on longitudinal tight and wash bulkheads and plating and stiffeners on the transverse tight bulkheads including stringers and deck which are between the longitudinal bulkhead and the first girder from the bulkhead or the bulkhead and the $0.25b_{SLH}$ whichever is lesser. The first girder next to longitudinal tight or wash bulkhead if the girder is located within $0.25b_{SLH}$ from the longitudinal bulkhead is to be assessed for the reflected sloshing pressure $P_{SLH-GRD}$ as defined in the previous chapter (“Loads”).

The load thickness of plates subject to sloshing pressure is derived from the formula given above which is used in every type of plate of the midship section. Only the acceptance criteria set AC1 is checked.

Design load sets for plating and local support members for bulk carriers

Structural member	Load component	Draught	Comment	Design load combination
Keel, bottom shell, bilge, sheer stake, side shell(only for double skin bulk carriers)	P_{EX}	T_{SC}	Sea pressure only	S+D
	$P_{IN}-P_{EX}$	$T_{N.BAL}$	Net pressure difference between water ballast pressure and sea pressure	S+D
	$P_{IN}-P_{EX}$	$T_{H.BAL}$		S+D
Side shell (for single skin bulk carriers)	$P_{IN}-P_{EX}$	T_{SC}	Net pressure difference between bulk homogeneous with D_{max} and sea pressure	S+D
	$P_{IN}-P_{EX}$	T_{SC}	Net pressure difference between bulk homogeneous with D_{full} and sea pressure	S+D
Deck	P_{EX}	T_{SC}	Green sea pressure only or other load on deck	S+D
	P_{IN}	$T_{N.BAL}$	Water ballast pressure only	S+D
	P_{IN}	$T_{H.BAL}$		S+D
Inner bottom, inner hull (in case of double skin bulk carriers), hopper side, topside tank plate	P_{IN}	$T_{N.BAL}$	Water ballast pressure only	S+D
	P_{IN}	$T_{H.BAL}$		S+D
	P_{IN}	T_{SC}	Bulk homogeneous with D_{max}	S+D
	P_{IN}	T_{SC}	Bulk homogeneous with D_{full}	S+D
Other tank boundaries, e.g girders, floors, stringers (double skin bulk carriers)	P_{IN}	$T_{N.BAL}$	Pressure from one side only. Two cases are to be evaluated: Inner empty, outer full/inner full, outer empty	S+D
	P_{IN}	$T_{H.BAL}$		S+D

2.5 SPECIAL REQUIREMENTS

Apart from the empirical formulae, functions of L, that give the minimum net thickness of plating and the stress based formula that provides the minimum net load thickness of plating, CSR incorporate formulae that concern the scantlings of specific plates, which are presented below.

Minimum breadth of keel plating

The breadth of the keel for both types of ships, in mm, is not to be taken less than:

$$b_{kl}=800+5L_2$$

However, in CSR for oil tankers, there is the limitation that L_2 never exceeds 300m while in CSR for bulk carriers L_2 never exceeds 350m (which is also the upper limit of the length of ships in which CSR for bulk carriers are applied).

Minimum thickness of bilge plating

The net thickness of the bilge plating is never less than the actual net thicknesses of the adjacent 2m width bottom or side plating, whichever is the greater.

The net thickness of the longitudinally framed bilge plating, in mm, for both types of ships is to be not less than the value obtained from the formula given above (plating subjected to lateral pressure).

The net thickness of the transversely framed bilge plating, in mm, for bulk carriers is to be not less than the value obtained from the following formula:

$$t = 0.76 \left[(p_s + p_w) S_t \right]^{0.4} r^{0.6} k^{0.5}$$

For double hull oil tankers the net thickness of bilge plating without longitudinal stiffening is derived from the following formula:

$$t = \frac{\sqrt[3]{r_0^2 S_t (p_s + p_w)}}{100}$$

Where

P_s : static external sea pressure

P_w : dynamic external sea pressure

S_t : distance between transverse stiffeners, floors, webs or bilge brackets, in m

r : radius of curvature (mm)

r_0 : effective bilge radius (mm)

$$= r + 0.5(a+b)$$

a =distance between the lower turn of bilge and the outermost bottom longitudinal, in mm.

Where the outermost bottom longitudinal is within the curvature, this distance is to be taken as zero.

b= distance between the upper turn of bilge and the lowest side longitudinal, in mm. Where the lowest side longitudinal is within the curvature, this distance is to be taken as zero.

Minimum thickness of side shell plating

Apart from the requirements for plating subjected to lateral pressure given in the previous chapter with which the thickness of side shell plating has to comply, the net thickness of side shell plating within a specific range is not to be less than:

For double hull oil tankers:

$$t = 26(s + 0.7) \frac{(BT_{sc})^{0.25}}{\sqrt{\sigma_{yd}}} \quad (s \text{ in m})$$

For bulk carriers:

$$t = 28(s + 0.7) \frac{(BT_{sc})^{0.25}}{\sqrt{\sigma_{yd}}} \quad (s \text{ in m})$$

It can be easily extracted that the formula is similar for both types of ships. The net thickness of the side shell plating of bulk carriers is greater than that of the oil tankers according to the formula given above. The extent of the side shell plating to which the previous formula is to be applied is almost the same for bulk carriers and oil tankers. More specifically, for bulk carriers the longitudinal extent is the length of the cargo area and the vertical extent is from the normal ballast draught to $0.25T_{sc}$ (minimum 2.2m) above T_{sc} . For oil tankers the area to which the formula is applied starts longitudinally from a section aft of amidships where the breadth at the waterline exceeds $0.9B$ and finishes at a section forward of amidships where the breadth at the waterline exceeds $0.6B$. Vertically, the extent starts 300mm below normal ballast draught and ends at the same level as bulk carriers.

2.6 STIFFNESS AND PROPORTIONS

Apart from the requirements presented above, all structural elements are to comply with the applicable slenderness and proportional requirements given below. It is about non-stress based requirements, which are defined as maximum allowable slenderness ratios or minimum inertia requirements. In other words, minimum net thicknesses of midship section's structural members cannot be less than the values given by the following formulae. Proportions of plate panels and local support members

The criteria that plate panels and stiffeners of double hull oil tankers and bulk carriers must satisfy as far as their net thickness is concerned are:

a) Plate panels

Double hull oil tankers

$$t_{net} \geq \frac{s}{C} \sqrt{\frac{\sigma_{yd}}{235}} \quad (\text{CSR DHOT, section 10.2, page 1})$$

Bulk carriers

$$t_{net} \geq \frac{s}{100} \quad (\text{CSR BC, chapter 6, section 3, page 48})$$

b) Stiffeners

Double hull oil tankers

i) Stiffener web plate (CSR DHOT, section 10.2, page 1)

$$t_{w-net} \geq \frac{d_w}{C_w} \sqrt{\frac{\sigma_{yd}}{235}}$$

ii) Stiffener flange/face plate (CSR DHOT, section 10.2, page 1)

$$t_{f-net} \geq \frac{b_{f-out}}{C_f} \sqrt{\frac{\sigma_{yd}}{235}}$$

Bulk carriers

In case of bulk carriers the requirements depend on the kind of ordinary stiffener. More specifically:

Flat bar (CSR BC, chapter 6, section 2, page 22)

$$\frac{d_w}{t_{w-net}} \leq 20\sqrt{k}$$

T-section (CSR BC, chapter 6, section 2, page 22)

$$\frac{d_w}{t_{w-net}} \leq 65\sqrt{k}$$

$$\frac{b_f}{t_{f-net}} \leq 33\sqrt{k}$$

$$b_f t_f \geq \frac{h_w t_w}{6}$$

Angle (CSR BC, chapter 6, section 2, page 23)

$$\frac{d_w}{t_{w-net}} \leq 55\sqrt{k}$$

$$\frac{b_f}{t_{f-net}} \leq 16.5\sqrt{k}$$

$$b_f t_{f-net} \geq \frac{d_w t_{w-net}}{6}$$

Where:

s : plate breadth, in mm, taken as the spacing between the stiffeners

t_{net}: net thickness of plate, in mm

t_{w-net}: net web thickness, in mm

t_{f-net}: net flange thickness, in mm

σ_{yd} : specified minimum yield stress
 d_w : depth of web plate
 b_{f-out} : breadth of flange outstands
 b_f : total breadth of flange
 k : material factor, defined in chapter "Loads"
 C, C_w, C_f : slenderness coefficients

Slenderness Coefficients		
Item		Coefficient
plate panel, C	hull envelope and tank boundaries	100
	other structure	125
stiffener web plate, C_w	angle and T profiles	75
	bulb profiles	41
	flat bars	22
flange/face plate, C_f	angle and T profiles	12

In addition CSR for double hull oil tankers provide a requirement that concerns the stiffness of stiffeners, by providing the lower limit of the net moment of inertia of each stiffener. The purpose of the inertia stiffness requirement for stiffeners is to prevent lateral instability and is based on the Euler buckling formula for a simply supported stiffener. More specifically, the minimum net moment of inertia about the neutral axis parallel to the attached plate, I_{net} , of each stiffener with effective breadth of plate equal to 80% of the stiffener spacing s , is given as follows (CSR DHOT, section 10.2, page 2):

$$I_{net} = C l_{stf}^2 A_{net} \frac{\sigma_{yd}}{235}$$

Where:

l_{stf} : length of stiffener between effective supports, in m

A_{net} : net sectional area of stiffener including attached plate assuming effective breadth of 80% of stiffener spacing s , in cm^2 . An effective breadth of attached plating not exceeding 80% of the total width for cross sectional area and moment of inertia is to be considered in order to simplify the approach.

s : stiffener spacing, in mm,

σ_{yd} : specified minimum yield stress of the material of the attached plate, in N/mm^2 . The aim of the stiffener is to stabilize the plate and the higher yield stress of the plate which allows higher compressive stresses in the panel should result in the higher moment of inertia to keep the panel in shape.

C : slenderness coefficient:

= 1.43 for longitudinals subject to hull girder stresses

= 0.72 for other stiffeners

It can be easily extracted from the formula above that the required inertia stiffness is higher for longitudinals subject to hull girder stresses than for other stiffeners. The implementation of the inertia stiffness requirement has as a result the limitation of the use of flat bars for the deck longitudinals.

The formula of the minimum net moment of inertia is derived from the following equation:

$$\sigma_E = \frac{10^{-4} \pi^2 E I_{net}}{l_{stf}^2 A_{net}}$$

Where

σ_E :the elastic buckling stress

and

$$\sigma_E \geq K \sigma_{yd}$$

Where

K: the ratio between elastic buckling stress and yield stress

hence

$$I_{net} = C l_{stf}^2 A_{net} \frac{\sigma_{yd}}{235}$$

The slenderness coefficient C as mentioned above takes the following values (based on current practice with adjustments for the net thickness approach):

1.43. This value is based on K=2 for stiffeners subjected to hull girder stresses, which represents a slenderness ratio of $\lambda=0.71$

0.72. This value is based on K=1 for stiffeners not subjected to hull girder stresses, which represents a slenderness ratio of $\lambda=1.0$, in other words the elastic buckling stress is equal to the yield stress of the material.

Chapter 3 - DESIGN VERIFICATION

The procedure of design verification takes place after the determination of structural scantlings through the way that is presented in the previous chapter. This procedure includes every check that must be done in order to assess structural strength. The limit states that are taken into consideration are: serviceability limit state, ultimate limit state, fatigue limit state and accidental limit state. The structural strength assessment is carried out through the procedures of yielding check, buckling check, ultimate strength check and fatigue check and concerns both local structures (plating subjected to lateral pressure and ordinary stiffeners) as well as the hull girder.

The serviceability limit state (SLS) concerns the normal use and includes the local damage which is able to reduce the working life of the structure or affect the efficiency or appearance of structural members. Apart from that SLS includes the unacceptable deformations which affect the efficient use and appearance of structural members or the functioning of equipment. The ultimate limit state (ULS) corresponds to the maximum load carrying capacity, or the maximum applicable strain or deformations. The fatigue limit state (FLS) is related to the possibility of failure due to cyclic loads. Finally the accidental limit state (ALS) concerns the flooding of any one cargo hold without progression of the flooding to the other compartments in case of bulk carriers, or any compartment in case of double hull oil tankers.

The SLS includes the yielding check of the hull girder, plating and ordinary stiffeners. The ULS includes the ultimate strength check of the hull girder, plating and ordinary stiffeners which is included in the buckling check of stiffeners. The FLS includes the fatigue check of ordinary stiffeners and primary support members and finally the ALS includes the strength assessment of the hull girder and some specific structural elements (i.e. for bulk carriers these are: double bottom structure and bulkhead structure). However the strength assessment of ALS is beyond the scope of the present thesis and consequently there will be no reference on the way strength assessment in ALS is carried out according to CSR.

Both CSR provide direct strength analysis, in other words strength assessment through the use of finite elements. However finite elements are not included in the software tools of the present thesis. Hence strength checks carried out through this kind of analysis are beyond the scope of the present thesis.

In the following pages, the provided methods by both CSR will be presented, explained and compared. However, in order not to mention topics that are presented in other chapters, the study presented in this chapter will concern, hull girder yielding check which means hull girder bending assessment as well as local yielding assessment which is caused by hull girder bending, hull girder ultimate strength, buckling check of plating and ordinary stiffeners and fatigue check in the end connections of ordinary stiffeners. In the rest of the structural elements mentioned in both CSR, fatigue check is carried out only through finite elements analysis.

3.1 HULL GIRDER BENDING ASSESSMENT

Both CSR provide requirements that concern the minimum net vertical hull girder section modulus at the midship cross section and the midship net section moment of inertia required to ensure sufficient hull girder rigidity.

To be more precise, according to IACS CSR for both types of ships, the net section moduli at the deck and keel at the midship cross section is not to be less than the rule minimum hull girder section modulus, Z_{V-MIN} , defined as:

$$Z_{V-MIN} = 0.9kC_{wv}L^2B(C_B + 0.7) \cdot 10^{-6} \text{ m}^3$$

Where:

k: higher strength steel factor, defined in chapter “Loads”

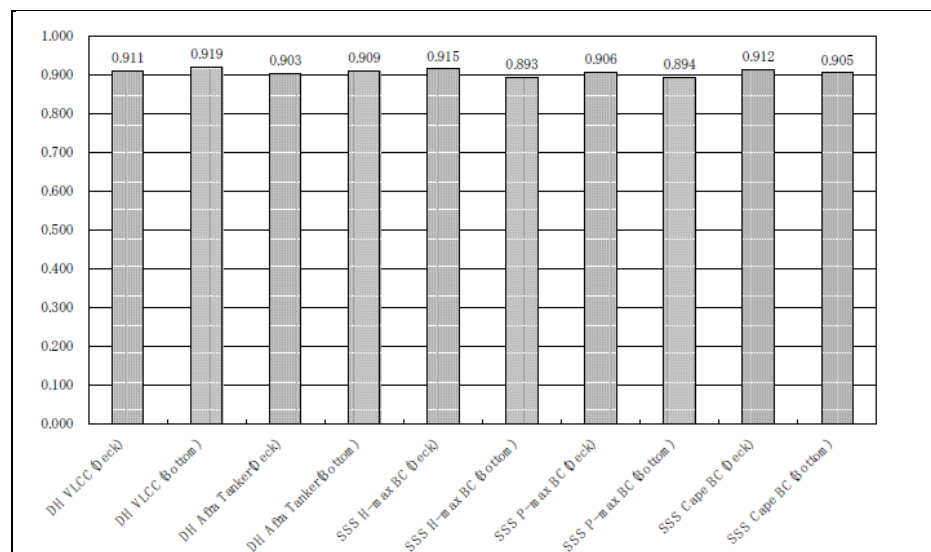
C_{wv} : wave coefficient

L: rule length, in m

B: moulded breadth, in m

C_B : block coefficient, but not to be taken as less than 0.70

The previous formula is based on UR S7 (“Minimum longitudinal strength standards”) calibrated with the requirements of net thickness approach. More specifically, CSR use the net scantling approach, hence the formula provided is 0.9 times the original section modulus (the one provided in UR S7 for new ships). Technical background document of CSR for bulk carriers provide also a figure that shows the ratio between the net section modulus of deck and keel, and the gross section modulus for some types of ships. That figure verifies that the net section modulus amidships is 0.9 times the gross section modulus (in other words the section modulus provided by UR S7 for “new” ships-ships in the stage directly after completion).



Ratio between net and gross section modulus in double hull oil tankers and single side skin bulk carriers

In addition, the net section moduli at the deck and keel with 0.4L amidships are not to be less than the rule required hull girder section modulus, Z_{V-REQ} , based on the permissible still water bending moment and design wave bending moment defined as:

$$Z_{V-REQ} = \frac{|M_{SW-PERM} + M_{WV-V}|}{\sigma_{perm}}$$

The formula above is based on UR S11("Longitudinal strength standard") that defines an allowable hull girder stress and a rule minimum wave bending moment.

Where:

$M_{SW-PERM}$: permissible hull girder hogging or sagging still water bending moment, in kNm

M_{WV-V} : hogging or sagging vertical wave bending moment, in kNm

σ_{perm} : permissible hull girder bending stress. In both CSR σ_{perm} is equal to 190/k within 0.4L amidships, however its inflection differs between the two kind of ships. In double hull oil tankers at seagoing condition, σ_{perm} is equal to 140/k at and forward of 0.9L from A.P. and at and aft of 0.1L from A.P. Between the values given σ_{perm} is to be linearly interpolated. On the other hand in bulk carriers analysis σ_{perm} is equal to 130/k at and forward of 0.9L from A.P. and at and aft of 0.1L from A.P. In addition σ_{perm} is equal to $190/k - (1500/k)(x/L-0.3)^2$ at $0.1 < x/L < 0.3$ and $190/k - (1500/k)(x/L-0.7)^2$ at $0.7 < x/L < 0.9$. Between the values given σ_{perm} is to be linearly interpolated.

The net midship section moment of inertia about its horizontal neutral axis is to be not less than the value obtained, in m^4 from the following formula:

$$I_{V-MIN} = 3Z_{V-MIN}L \cdot 10^{-2} \Rightarrow (\text{assuming } k=1)$$

$$I_{V-MIN} = 2.7C_{WV}L^3(B(C_B + 0.7))10^{-8} \quad m^4$$

The vertical net hull girder section modulus for the strength assessment and the vertical net hull girder moment of inertia and position of horizontal neutral axis is to be calculated, according to both CSR, based on gross thickness minus the corrosion addition $0.5t_{corr}$ of all effective structural members comprising the hull girder section.

3.2 HULL GIRDER ULTIMATE STRENGTH

According to CSR for double hull oil tankers, hull girder bending capacity has to be checked only in sagging. The rule criteria that must be satisfied in case of ultimate strength check are applicable to intact ship structures, in extreme sea conditions and not in harbour or damaged conditions. On the other hand, according to CSR for bulk carriers, hull girder bending capacity must be check in both hogging and sagging in intact, flooded and harbour conditions.

The hull girder ultimate capacity check is categorized as an ultimate limit state. The criterion for the ultimate strength of the hull girder is given in a partial safety factor format and has been calibrated using structural reliability analysis techniques. In case of double hull oil

tankers, failure in sagging is the most critical failure mode. On the other hand, failure in hogging is not identified as critical due to the way double hull oil tankers are loaded and due to the conventional structural arrangement with a double bottom and single skin deck. In general, ballast conditions represent for tankers hogging and loaded conditions sagging. In addition wave induced moment has been found to be greater in loaded than in ballast condition. That is why, in hull girder ultimate strength check only sagging failure in loaded condition is checked and sagging failure in ballast condition is ignored. The focus is on hull girder collapse in heavy weather at sea and in such severe conditions the ship is most likely to operate in head seas, or nearly head seas. In tankers' analysis two different design load combinations of wave and still water moment are evaluated. In the first one the rule value of the wave induced bending moment is linearly superimposed to permissible sagging still water bending moment and in the second one the maximum sagging still water bending moment with the rule value of wave induced bending moment. In bulk carriers analysis one design load combination is evaluated: permissible sagging and hogging still water bending moment with rule value of wave induced bending moment.

Checking criteria

The vertical hull girder ultimate bending capacity in both types of ships is to satisfy the following criteria:

$$\gamma_s M_{sw} + \gamma_w M_{ww} \leq \frac{M_u}{\gamma_R}$$

Where:

M_{sw} : still water bending moment, in kNm

M_{ww} : vertical wave bending moment, in kNm, to be taken as the midship value

M_u : vertical hull girder ultimate bending capacity, in kNm

γ_s , γ_w , γ_R :are the partial safety factors for the design load combinations.

Partial safety factors				
Design load combination	Definition of still water bending moment	γ_s	γ_w	γ_R
DOUBLE HULL OIL TANKERS				
A	Permissible sagging still water bending moment, in kNm	1	1.2	1.1
B	Maximum sagging still water bending moment for operational seagoing homogeneous full load condition, in kNm	1	1.3	1.1
BULK CARRIERS				
A	Permissible sagging and hogging still water bending moment in intact, flooded and harbour conditions, in kNm	1	1.2	1.1

In case of design load combination B for double hull oil tankers, the maximum still water bending moment is to be taken from the departure condition with the ship homogeneously loaded at maximum draught and corresponding arrival and any mid-voyage conditions.

The net thickness of structural members, according to both CSR, in case of ultimate strength check of the hull girder, is to be obtained by deducting $0.5t_{corr}$ from the gross thickness offered.

3.3 BUCKLING AND ULTIMATE STRENGTH OF ORDINARY STIFFENERS AND STIFFENED PANELS

The requirements of this sub section apply for the buckling check of plate panels and longitudinals subjected to compressive stresses, shear stresses and lateral pressure. Buckling assessment for both types of ships is to be derived using local net scantlings, in other words without any corrosion addition.

-Buckling of plates

The analyses followed in chapters 3.2 and 3.3 of uni-axial compressive strength of plane plates and stiffeners are based on the analyses in chapter 6, section 3 of CSR for Bulk carriers and that can be derived by the following equations that present at length the way uni-axial compression of plates and stiffeners is controlled in both types of vessels. More specifically in case of double hull oil tankers, CSR provide the following criteria:

$$n \leq n_{allow}$$

The buckling utilisation factor, n , for uni-axial stress is to be taken as:

$$n = \frac{\sigma_x}{\sigma_{xcr}} \Rightarrow \frac{\sigma_x}{C_x \sigma_{yd}} \text{ for compressive stresses in x-direction}$$

$$n = \frac{\sigma_y}{\sigma_{ycr}} \Rightarrow \frac{\sigma_y}{C_y \sigma_{yd}} \text{ for compressive stresses in y-direction}$$

$$n = \frac{\tau}{\tau_{cr}} \Rightarrow \frac{\tau}{C_\tau \left(\frac{\sigma_{yd}}{\sqrt{3}} \right)} \text{ for shear stress}$$

Where σ_x , σ_y , are the actual compressive stresses, in N/mm^2 , τ is the actual shear stress, in N/mm^2 and C_x , C_y , C_τ are reduction factors given in CSR for double hull oil tankers (table 10.3.1 section 10, sub-section 3, page 3), which in principal depend on the reference degree of slenderness. Critical compressive stresses (σ_{xcr} , σ_{ycr}) and critical shear stress (τ_{cr}) are taken as the ultimate compressive/shear stresses for rectangular plates subjected to uni-axial compressive stresses or shear stress. The allowable buckling utilisation (n_{allow}) for the compressive buckling strength assessment of plate panels is equal to 1 for plate panels at or above 0.5D and 0.9 for plate panels below 0.5D (D: moulded depth). On the other hand, n_{allow} for the shear buckling strength assessment is equal to 0.95.

In case of bulk carriers, CSR takes into consideration that the maximum values of the normal stresses resulting from global bending of hull and the maximum value of shear stress resulting from hull girder shear forces are not acting simultaneously. Hence they provide the following criteria which correspond to 2 different combinations of stresses. These 2 stress combinations are:

Stress combination A: membrane stress in x or y direction is equal to 100% of the normal stress resulting from hull girder bending and shear stress in x-y plane is equal to 70% of the shear stress induced by the shear forces.

Stress combination B: membrane stress in x or y direction is equal to 70% of the normal stress resulting from hull girder bending and shear stress in x-y plane is equal to 100% of the shear stress induced by the shear forces.

The ratio between normal and shear stress is based on Germanischer Lloyd Rules. More specifically each elementary plate panel is to comply with the following criteria:

Longitudinally framed plating:

$$\left(\frac{|\sigma_x|S}{C_x \sigma_{yd}} \right)^{e1} + \left(\frac{|\tau|S\sqrt{3}}{C_\tau \sigma_{yd}} \right)^{e3} \leq 1.0 \quad \text{for stress combination A}$$

$$\left(\frac{|\sigma_x|S}{C_x \sigma_{yd}} \right)^{e1} + \left(\frac{|\tau|S\sqrt{3}}{C_\tau \sigma_{yd}} \right)^{e3} \leq 1.0 \quad \text{for stress combination B}$$

Transversely framed plating:

$$\left(\frac{|\sigma_y|S}{C_y \sigma_{yd}} \right)^{e2} + \left(\frac{|\tau|S\sqrt{3}}{C_\tau \sigma_{yd}} \right)^{e3} \leq 1.0 \quad \text{for stress combination A}$$

$$\left(\frac{|\sigma_y|S}{C_y \sigma_{yd}} \right)^{e2} + \left(\frac{|\tau|S\sqrt{3}}{C_\tau \sigma_{yd}} \right)^{e3} \leq 1.0 \quad \text{for stress combination B}$$

Each term of the above conditions must be less than 1.0

S: safety factor equal to:

S=1.1 for structures which are exclusively exposed to local loads (e.g. hatch covers, foundations)

S=1 except for the cases mentioned below

e1,e2,e3 : functions of the reductions factors C_x , C_y , C_τ

e1=1+ C_x^4 for a plane plate panel

=1.25 for a curved plate panel

e2=1+ C_y^4 for a plane plate panel

=1.25 for a curved plate panel

e3=1+ $C_x C_y C_\tau^2$ for a plane plate panel

=2 for a curved plate panel

C_x , C_y , C_τ :reduction factors given in Table 2 and/or Table 3 chapter 6, section 3, pages 45-47 of CSR for bulk carriers

For transverse compression the correction factor for boundary condition of stiffeners on the longer side of elementary plate panels (F_1) which is incorporated in formula of buckling factor K, in case of bulk carriers is given as follows:

	F_1	Edge stiffener
Stiffeners sniped at both ends	1	
Guidance values where both ends are effectively connected to adjacent structures	1.05	Flat bar
	1.1	Bulb section
	1.2	Angle and tee-sections
	1.3	Girders of high rigidity (e.g. bottom transverses)

On the other hand, in tankers analysis, based on comparison studies with advanced buckling method as well as non-linear FE calculations, this factor is set to 1.0.

-Buckling of stiffeners

Longitudinal and transverse stiffeners in both types of ships must be verified against column and torsional buckling mode.

Column buckling mode (or ultimate strength in lateral buckling mode)

In double hull oil tankers as well as in bulk carriers, longitudinal and transverse stiffeners are to comply with the following criteria:

$$n \leq n_{\text{allow}}$$

where:

n_{allow} :allowable buckling utilisation factor

n:buckling utilisation factor for column buckling given by the following formula:

$$n = \frac{\sigma_a + \sigma_b}{\sigma_{yd}} S$$

However there are some differences in the definition of S (safety factor) and n_{allow} between double hull oil tankers and bulk carriers. These differences are presented in the following table.

	Details	Bulk carriers	Tankers
S	Stiffeners of the hatcway coamings, sloping plating of the topside tanks and hopper tanks, inner bottom, inner side if any, side shell of single side skin construction and top and bottom stools of transverse bulkheads	1.15	1
	Stiffeners of every other structural member	1	
n_{allow}	stiffeners at or above 0.5D (D:moulded depth of ship)	1	1
	stiffeners below 0.5D		0.9

σ_α : uniformly distributed compressive stress, in N/mm^2 , in the direction of the stiffener axis. In bulk carriers' analysis, $\sigma_\alpha = \sigma_x$ (compressive axial stress in the stiffener) for longitudinal stiffeners and $\sigma_\alpha = 0$ for transverse stiffeners.

σ_b : bending stress in the stiffener, in N/mm^2 , equal to:

$$\sigma_b = \frac{M_0 + M_1}{1000Z_{net}}$$

Where:

Z_{net} : net section modulus of stiffener, in cm^3 , including effective breadth of plating.

- 1) if lateral pressure is applied to the stiffener: Z_{net} is the section modulus calculated at flange if the lateral pressure is applied on the same side as the stiffener. If the lateral pressure is applied on the side opposite to the stiffener Z_{net} is the section modulus calculated at attached plate.
- 2) If no lateral pressure is applied on the stiffener: Z_{net} is the minimum section modulus among those calculated at flange and attached plate.

M_1 : bending moment, in Nmm , due to the lateral load P equal to:

$$M_1 = \frac{Pl_{stf}^2}{24} 10^3 \text{ for longitudinal stiffeners}$$

In case of transverse stiffeners bulk carriers' CSR define:

$$M_1 = \frac{Pl_{stf}(n \cdot s)^2}{8c_s} 10^3$$

n : number of elementary plate panel breadths within the partial or total plate panel. For ordinary stiffeners n is taken equal to 1.

c_s : factor accounting for the boundary conditions of the transverse stiffeners

$c_s = 1$ for simply supported stiffeners

$c_s = 2$ for partially constraint stiffeners

s : stiffener spacing, in mm

l_{stf} : span of stiffener, in m , equal to spacing between primary support members. In case of transverse stiffening l_{stf} is defined as the length of the longer side of the partial plate field

M_0 : bending moment, in Nmm , due to the lateral deformation w of stiffener

$$M_0 = F_E \left(\frac{P_Z w}{c_f - P_Z} \right) \text{ with } (c_f - P_Z) > 0$$

F_E : ideal elastic buckling force of the stiffener, in N , taken equal to:

$$F_E = \left(\frac{\pi^2}{l_{stf}^2} \right) EI_{net} 10^{-2}$$

E : modulus of elasticity 206000 N/mm^2

I_{net} : net moment of inertia, in cm^4 , of the stiffener including effective width of attached plating. I_{net} is to comply with the following criteria.

In case of longitudinal stiffeners:

$$I_{net} = I_x \geq \frac{st_{net}^3}{12 \cdot 10^4}$$

In case of transverse stiffeners:

$$I_{net} = I_y \geq \frac{l_{stf} t_{net}^3}{12 \cdot 10^4}$$

t_{net} : net thickness of plate flange, to be taken as the mean thickness of the attached plate panels

P_z : nominal lateral load, in N/mm^2 , acting on the stiffener due to membrane stresses, σ_x , σ_y and τ_1 , in the attached plate in way of the stiffener midspan:

$$P_z = \frac{t_{net}}{s} \left(\sigma_{xl} \left(\frac{\pi s}{1000 l_{stf}} \right)^2 + 2c_y \sigma_y + \tau_1 \sqrt{2} \right) \text{ for longitudinal stiffeners}$$

$$P_z = \frac{t_{net}}{l_{stf}} \left(2c_x \sigma_{xl} + \sigma_y \left(\frac{\pi l_{stf}}{1000 s} \right)^2 \left(1 + \frac{A_y}{l_{stf} t_{net}} \right) + \tau_1 \sqrt{2} \right) \text{ for transverse stiffeners}$$

$$\sigma_{xl} = \sigma_x \left(1 + \frac{A_x}{s t_{net}} \right) N/mm^2$$

$$\tau_1 = \left[\tau - t_{net} \sqrt{\sigma_{yd} E \left(\frac{m_1}{(1000 l_{stf})^2} + \frac{m_2}{s^2} \right)} \right] \geq 0$$

With m_1 and m_2 taken equal to:

For longitudinal stiffeners: $m_1 = 1.47$ $m_2 = 0.49$ for $1000 l_{stf}/s \geq 2.0$

$m_1 = 1.96$ $m_2 = 0.37$ for $1000 l_{stf}/s < 2.0$

For transverse stiffeners: $m_1 = 0.37$ $m_2 = 1.96/n^2$ for $1000 l_{stf}/n s \geq 0.5$

$m_1 = 0.49$ $m_2 = 1.47/n^2$ for $1000 l_{stf}/s < 0.5$

A_x , A_y : net sectional area, in mm^2 , of the longitudinal or transverse stiffener respectively without attached plating

c_x , c_y : factor taking into account the membrane stresses in the attached plating acting perpendicular to the stiffener's axis

$= 0.5(1+\psi)$ for $0 \leq \psi \leq 1$

$= 0.5/(1-\psi)$ for $\psi < 0$

ψ : edge stress ratio taken equal to :

$\psi = \sigma_2/\sigma_1$

where σ_1 is the maximum compressive stress and σ_2 the minimum compressive stress or tensile stress

σ_y : membrane compressive stress in the attached plating acting perpendicular to the stiffener's axis, in N/m^2

τ : shear membrane stress in the attached plating, in N/m^2

σ_{yd} : specified minimum yield stress of the material, in N/mm^2

w : deformation of stiffener, in mm

$w = w_o + w_1$

w_o : assumed imperfection, in mm

$$w_o = \min \left[\frac{1000 l_{stf}}{250}, \frac{s}{250}, 10 \right] \text{ for longitudinal stiffeners}$$

$$w_o = \min \left[\frac{1000 l_{stf}}{250}, \frac{n \cdot s}{250}, 10 \right] \text{ for transverse stiffeners}$$

For stiffeners sniped at both ends w_o is not to be taken less than the distance from the midpoint of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating

w_1 : deformation of stiffener at midpoint of stiffener span due to lateral load P, in mm. in case of uniformly distributed load the w_1 is to be taken as:

$$w_1 = \frac{P s l_{stf}^4}{384 E I_{net}} 10^5$$

c_f : elastic support provided by the stiffener, in N/mm^2

For longitudinal stiffeners:

$$c_f = F_E \frac{\pi^2}{l_{stf}^2} (1 + c_{px}) 10^{-6}$$

$$c_{px} = \frac{1}{1 + \frac{0.91 \left(\frac{12 \cdot 10^4 I_x}{t_{net}^3 s} - 1 \right)}{c_{xa}}}$$

c_{xa} : coefficient taken equal to:

$$c_{ax} = \left[\frac{1000 l_{stf}}{2s} + \frac{2s}{1000 l_{stf}} \right]^2 \text{ for } l_{stf} \geq 2s/1000$$

$$c_{ax} = \left[1 + \left(\frac{1000 l_{stf}}{2s} \right)^2 \right]^2 \text{ for } l_{stf} < 2s/1000$$

For transverse stiffeners:

$$c_f = F_E \frac{\pi^2}{(n \cdot s)^2} (1 + c_{py}) 10^{-6}$$

$$c_{py} = \frac{1}{1 + \frac{0.91 \left(\frac{12 \cdot 10^4 I_y}{t_{net}^3 l_{stf}} - 1 \right)}{c_{ya}}}$$

c_{ya} : coefficient taken equal to:

$$c_{ay} = \left[\frac{n \cdot s}{2000 l_{stf}} + \frac{2000 l_{stf}}{n \cdot s} \right]^2 \text{ for } ns \geq 2000 l_{stf}$$

$$c_{ay} = \left[1 + \left(\frac{ns}{2 l_{stf}} \right)^2 \right]^2 \text{ for } ns < 2000 l_{stf}$$

Stiffeners not subjected to lateral pressure are considered as having acceptable column buckling strength and need not be verified against the column buckling mode if their net moments of inertia, in cm^4 , satisfy the following requirement:

$$\text{For longitudinal stiffener: } I_x \geq 100 \frac{P_Z l_{stf}^2}{\pi^2} \left(\frac{w_o (e_f - 0.5 t_{f-net})}{n_{allow} \frac{\sigma_{yd}}{S} - \sigma_x} + \frac{l_{stf}^2}{\pi^2 E} \right)$$

$$\text{For transverse stiffeners: } I_y \geq \frac{P_z (n \cdot s)^2}{\pi^2 10^4} \left(\frac{w_o (e_f - 0.5t_{f-net})}{n_{allow} \frac{\sigma_{yd}}{S} - \sigma_y} + \frac{(n \cdot s)^2}{\pi^2 E} \right)$$

Where:

e_f : distance from connection to plate (C as shown in the following figure) to centre of flange, in mm

$= (d_w - 0.5t_{f-net})$ for bulb flats

$= (d_w + 0.5t_{f-net})$ for angles and T bars

d_w : depth of web plate, in mm,

t_{f-net} : net flange thickness

n_{allow} , S : allowable buckling utilisation factor and safety factor respectively as defined above

Torsional buckling mode

The torsional buckling mode is to be verified against the allowable buckling utilisation factor, n_{allow} , which take the same value as in column buckling mode for the two kinds of ships. The buckling utilisation factor for torsional buckling of stiffeners is to be taken as:

$$n = \frac{\sigma_x S}{C_T \sigma_{yd}}$$

Where:

C_T : torsional buckling coefficient equal to:

$$C_T = 1 \text{ for } \lambda_T \leq 0.2$$

$$C_T = \frac{1}{\Phi + \sqrt{\Phi^2 - \lambda_T}} \text{ for } \lambda_T > 0.2$$

$$\Phi = 0.5 \left(1 + 0.21(\lambda_T - 0.2) + \lambda_T^2 \right)$$

λ_T : reference degree of slenderness for torsional buckling

$$= \sqrt{\frac{\sigma_{yd}}{\sigma_{ET}}}$$

σ_{ET} : reference stress for torsional buckling, in N/mm^2

$$\sigma_{ET} = \frac{E}{I_{p-net}} \left(\frac{\varepsilon \pi^2 I_{\omega-net} 10^{-4}}{I_t^2} + 0.385 I_{T-net} \right)$$

I_{p-net} : net polar moment of inertia of the stiffener about point C (as shown in the following figure), in cm^4

I_{T-net} : set St. Venant's moment of inertia of the stiffener, in cm^4

$I_{\omega-net}$: net sectorial moment of inertia of the stiffener about point C, in cm^6

ε : degree of fixation taken equal to:

$$\varepsilon = 1 + 1000 \sqrt{\frac{l_t^4}{\frac{3}{4} \pi^4 I_{w-net} \left(\frac{s}{t_{net}^3} + \frac{4(e_f - 0.5t_{f-net})}{3t_{w-net}^3} \right)}}$$

l_t : torsional buckling length to be taken equal to the distance between tripping supports, in m

s : stiffener spacing, in mm

t_{w-net} : net web thickness, in mm

t_{f-net} : net flange thickness, in mm

b_f : flange breadth

d_w : depth of web plate, in mm

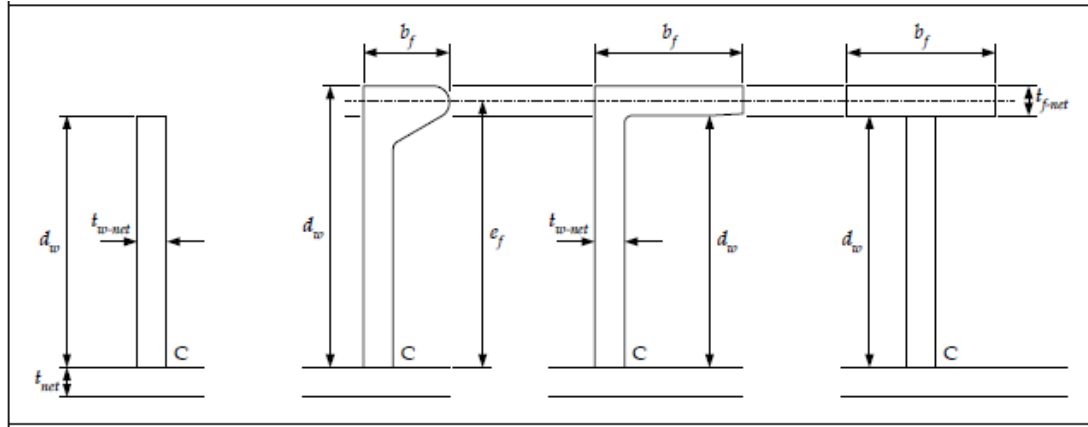
A_{w-net} : net web area, in mm²

$= (e_f - 0.5t_{f-net}) t_{w-net}$

A_{f-net} : net flange area, in mm²

$= b_f t_{f-net}$

Stiffener cross sections



Moments of Inertia

Section property	Flat bars	Bulb flats, angles and T bars
I_{P-net}	$\frac{d_w^3 t_{w-net}}{3 \times 10^4}$	$\left(\frac{A_{w-net} (e_f - 0.5 t_{f-net})^2}{3} + A_{f-net} e_f^2 \right) 10^{-4}$
I_{T-net}	$\frac{d_w^3 t_{w-net}}{3 \times 10^4} \left(1 - 0.63 \frac{t_{w-net}}{d_w} \right)$	$\frac{(e_f - 0.5 t_{f-net}) t_{w-net}^3}{3 \times 10^4} \left(1 - 0.63 \frac{t_{w-net}}{e_f - 0.5 t_{f-net}} \right) + \frac{b_f t_{f-net}^3}{3 \times 10^4} \left(1 - 0.63 \frac{t_{f-net}}{b_f} \right)$
I_{w-net}	$\frac{d_w^3 t_{w-net}}{36 \times 10^6}$	for bulb flats and angles $\frac{A_{f-net} e_f^2 b_f^2}{12 \times 10^6} \left(\frac{A_{f-net} + 2.6 A_{w-net}}{A_{f-net} + A_{w-net}} \right)$ for T bars $\frac{b_f^3 t_{f-net} e_f^2}{12 \times 10^6}$

The effective breadth of attached plating of ordinary stiffeners is to be taken as:

For longitudinal stiffeners: $b_{eff} = \min (C_x s, x_s s)$

For transverse stiffeners: $b_{eff} = \min (C_y l_{stf}, x_s s)$

Where:

$$x_s = 0.0035 \left(\frac{1000 l_{eff}}{s} \right)^3 - 0.0673 \left(\frac{1000 l_{eff}}{s} \right)^2 + 0.4422 \left(\frac{1000 l_{eff}}{s} \right) - 0.0056 \leq 1.0$$

s: stiffener spacing

$C_{x,y}$: average reduction factors for buckling of the two attached plate panels

l_{stf} : span of stiffener, in m, equal to spacing between primary support members

l_{eff} : effective span of stiffeners in m:

For longitudinal stiffeners: $l_{eff} = l_{stf}$ if simply supported at both ends

= $0.6 l_{stf}$ if fixed at both ends

For transverse stiffeners: $l_{eff} = s$ if simply supported at both ends

= $0.6 s$ if fixed at both ends

3.4 FATIGUE STRENGTH ASSESSMENT

This sub-section provides the minimum requirements of CSR for both types of ships for design against fatigue failure. The fatigue analysis is to be carried out using either a “nominal stress approach” or a “hot spot stress approach” depending on structural details. In the following paragraphs, there will be a comparison of the fatigue strength assessment of stiffeners applied in the two kinds of ships examined.

Traditional fatigue calculations are based on the nominal stresses and the use of geometry dependent S-N curves. In the fatigue assessment are made some assumptions that are necessary to be mentioned.

- a) The design life of vessel is taken to be 25 years
- b) A linear cumulative damage model, i.e. Palmgren-Miner’s Rule, has been used in connection with the S-N data
- c) For longitudinal stiffener end connections, nominal stresses obtained by empirical formulae and Rule based loads form the basis of the nominal stress based fatigue assessment
- d) Structural details are idealized and grouped into classes
- e) The long-term stress ranges of a structural detail can be characterized using a modified Weibull probability distribution parameter, ξ

The calculation of hull girder stresses for the fatigue strength assessment in double hull oil tankers is to be based on the net fatigue hull girder sectional properties, calculated by deducting a quarter of the corrosion addition ($-0.25t_{\text{corr}}$) from the offered gross thickness. In cases of stresses in local support members from lateral load for the fatigue strength assessment, the deduction is equal to $0.5t_{\text{corr}}$ from the offered gross thickness. In bulk carriers’ fatigue strength assessment the deduction is always equal to $0.5t_{\text{corr}}$ from the offered gross thickness.

- DOUBLE HULL OIL TANKERS

The fatigue strength analysis considers the following wave induced loads for calculation of the long term distribution of stresses:

- a) Hull girder loads (i.e. vertical and horizontal wave bending moments)
- b) Dynamic wave pressures
- c) Dynamic tank pressure loads resulting from ship motions

The analysis is carried out for the two most representative loading conditions, namely full load condition at design draught at departure and ballast condition at normal ballast draught, while the vessels covered by CSR will normally operate in either fully loaded condition or normal ballast condition.

The fatigue strength assessment of welded structural members includes the following three phases:

- a) Calculation of stress ranges
- b) Selection of the design stress ranges
- c) Calculation of the cumulative damage

As far as the selection of design stress ranges and their values is concerned, there are two categories that are taken into account. The global dynamic stress amplitudes (primary stresses), which are vertical wave hull girder bending stress and horizontal wave hull girder bending stress, and the local dynamic stress amplitudes (total local stress amplitude) due to dynamic wave pressure loads or dynamic tank pressure loads σ_{e-i} . Total local stress amplitude is composed by secondary stress resulting from bending of girder systems, σ_2 , stress amplitude produced by bending of stiffeners between girder supports, σ_{2A} , and tertiary stress amplitude produced by bending of unstiffened plate elements between longitudinals and transverse frames, σ_3 . In other words:

$$\sigma_{e-i} = \sigma_2 + \sigma_{2A} + \sigma_3$$

However the effect of secondary stress σ_2 is in general small for double hull tankers and is therefore not taken into consideration. In addition, longitudinal local tertiary plate bending stress amplitude in the weld at the plate, transverse frame or bulkhead intersection, σ_3 , is not relevant to the critical locations being considered and is to be neglected. Consequently only stress amplitude produced by bending of stiffeners between girder supports, σ_{2A} , is taken into consideration, calculating total local stress amplitude. That is why the total combined stress range, S , is given by the formula:

$$S = f_{SN} |f_1 S_v + f_2 S_h + f_3 S_e + f_4 S_i|$$

Where:

f_1, f_2, f_3, f_4 : stress range combination factors, representing the phase correlation between total stress range and each stress range component which is between 1.0 and -1.0. These factors are given in Tables C.1.3 to C.1.5 of Appendix C in pages 17 to 19.

f_{SN} : 1.06, factor accounting for joints in combined protected and unprotected environment. More specifically, it is assumed that joints are operating under a protected environment for 20 years of the design life time and in unprotected environment 5 years of the design life time. For unprotected joints exposed to sea water the basic S-N curve is reduced by a factor of 2 on life for all joint classes. A factor of 2 is an approximation due to the fact that the S-N curve in unprotected condition has no slope change. To reflect the application of this factor of 2 for 5 years of design life, f_{SN} , is applied to the calculated stress range based on the cubic relationship between stress and fatigue life. Its value is then obtained as $[(20+5 \times 2)/25]^{1/3} = 1.06$

S_v, S_h : corresponding stress range due to vertical and horizontal respectively bending moment, in N/mm^2

$$S_v = 2\sigma_v$$

$$S_h = 2\sigma_h$$

Vertical and horizontal hull girder stress, σ_v and σ_h respectively are given by the following formulae:

$$\sigma_v = \frac{M_{wv-v-amp}}{Z_{v-net75}} 10^{-3} \quad \text{and} \quad \sigma_h = \frac{M_{wv-h-amp}}{Z_{h-net75}} 10^{-3} \quad \text{N/mm}^2$$

$$Z_{v-net75} = \frac{I_{v-net75}}{|z - z_{NA-net75}|} \quad \text{and} \quad Z_{h-net75} = \frac{I_{h-net75}}{|y|} \quad \text{m}^3$$

$I_{v-net75}$: net vertical hull girder moment of inertia, of hull cross section about transverse neutral axis, in m^4

$I_{h-net75}$: net horizontal hull girder moment of inertia, of hull cross section about the vertical neutral axis, in m^4

$I_{v-net75}$ and $I_{h-net75}$ are to be calculated based on gross thickness, minus the corrosion addition $0.25t_{corr}$ for all effective structural elements

$z_{NA-net75}$: distance from baseline to horizontal neutral axis consistent with $I_{v-net75}$

S_e, S_i : stress range due to external and internal respectively tank pressure, in N/mm^2

The stress amplitude produced by bending of stiffeners between girder supports, σ_{2A} , is to be taken as:

$$\sigma_{2A} = K_n K_d \frac{M}{Z_{net50}} 10^3$$

K_d : stress factor for bending stress in longitudinal stiffeners caused by relative deformation between supports, defined by FE analysis of the cargo hold model or taken as:

1 at frames connections

1.15 for all longitudinals at transverse bulkhead connections including wash bulkheads except:

a) in full load condition

1.3 for side and bilge longitudinals at mid position between lowest side stringer and deck at side

1.15 for side and bilge longitudinals at lowest side stringer and deck at side

to be linearly interpolated between these 2 positions

1.5 for bottom longitudinals at mid position between longitudinal bulkhead, bottom girders or buttress structure

1.15 for bottom longitudinals at longitudinal bulkhead, bottom girders or buttress structure to be linearly interpolated between these 2 positions

b) in ballast condition

1.5 for bottom longitudinals in the mid position between longitudinal bulkhead, bottom girders or buttress structure

1.15 for bottom longitudinals at longitudinal bulkhead, bottom girders or buttress structure to be linearly interpolated between these 2 positions

M : moment at stiffener support adjusted to weld toe location at the stiffener (e.g. at bracket toe), in kNm , equal to:

$$\frac{P s l_{bdg}^2}{12} 10^{-3} r_p$$

s : stiffener spacing

l_{bdg} : effective bending span of longitudinal stiffener

Z_{net50} : section modulus of longitudinal stiffener with associated effective plate flange b_{eff} , in cm^3 , calculated based on gross thickness minus the corrosion addition $0.5t_{corr}$.

r_p : moment interpolation factor, for interpolation to weld toe location along the stiffener length equal to:

$$r_p = \left| 6 \left(\frac{x}{l_{bdg}} \right)^2 - 6 \left(\frac{x}{l_{bdg}} \right) + 1.0 \right| \quad \text{where } 0 \leq x \leq l_{bdg} \quad (x: \text{distance to the hot spot})$$

P: lateral dynamic pressure amplitude at the mid-span between the frame considered and the neighboring frame, in kN/m²

K_n: stress factor that takes into account the warping effect due to unsymmetrical profiles of stiffeners and is to be taken as:

$$K_{n1} = \frac{1 + \lambda\beta}{1 + \lambda\beta^2\psi_z} \text{ at the flange edge}$$

$$K_{n2} = \frac{1 + \lambda\beta^2}{1 + \lambda\beta^2\psi_z} \text{ at the web} \quad (K_{n2} \text{ is typically used in the fatigue analysis of longitudinal end connections})$$

$$\beta = \begin{cases} 1 - \frac{2b_g}{b_f} & \text{at the flange edge} \\ 1 - \frac{t_{w-net50}}{b_f} & \text{at the web} \end{cases}$$

b_g: breadth of flange from web centreline, in mm

t_{w-net50}: net web thickness

d_w: depth of stiffener web

ψ_z: ratio between section modulus of the stiffener web with plate flange, as calculated at the flange and the section modulus of the complete panel stiffener equal to:

$$\frac{d_w^2 t_{w-net50}}{4Z_{net50} 10^3} \text{ may be used as an approximate value}$$

λ : factor, to be taken as:

$$\lambda = \frac{3 \left(1 + \frac{n}{280} \right)}{1 + \frac{n}{40}}$$

$$n = \frac{l_{bdg}^4 10^{12}}{b_f^3 t_{f-net50} h_{stf}^2 \left(\frac{4h_{stf}}{t_{w-net50}^3} + \frac{s}{t_{p-net50}^3} \right)}$$

b_f: breadth of flange, in mm

t_{f-net50}: net flange thickness, in mm

h_{stf}: stiffener height, including face plate, in mm

t_{w-net50}: net web thickness, in mm

t_{p-net50}: net plate thickness, in mm

The capacity of welded steel joints in fatigue strength analysis is characterized by S-N curves which give the relationship between the stress ranges applied to a given detail and the constant amplitude load cycles to failure. The total stress range considering the mean stress effect is to be taken as:

$$\begin{aligned} S'_{Ri} &= \sigma_{tensile} - 0.6\sigma_{compressive} & \text{if } \sigma_{compressive} < 0 \text{ and } \sigma_{tensile} > 0 \\ S'_{Ri} &= S & \text{if } \sigma_{compressive} \geq 0 \\ S'_{Ri} &= 0.6S & \text{if } \sigma_{tensile} \leq 0 \end{aligned}$$

Where:

$$\begin{aligned} \sigma_{tensile} &: \text{mean stress plus half stress range, in N/mm}^2 \\ &= \sigma_{mean} + S/2 \end{aligned}$$

$\sigma_{\text{compressive}}$: mean stress minus half stress range, in N/mm^2
 $= \sigma_{\text{mean}} - S/2$

σ_{mean} : mean stress due to static load components in the full load condition or ballast condition

For the nominal stress approach, S and σ_{mean} are to be taken as follows:

S : total combined stress range, in N/mm^2 as defined above

$$= \sigma_{\text{tensile}} - \sigma_{\text{compressive}}$$

$$\sigma_{\text{mean}} = \sigma_{\text{hg}} + \sigma_{\text{ex}} + \sigma_{\text{in}}$$

σ_{mean} : mean stress due to hull girder bending

σ_{ex} : mean local bending stress due to external static sea pressure, if applicable

σ_{in} : mean local bending stress due to internal static tank pressure, if applicable

Taking into account the effect of plate thickness, the total stress range is to be taken as:

$$S_{\text{Ri}} = \frac{S'_{\text{Ri}}}{(22/t_{\text{net50}})^{0.25}} \quad (t_{\text{net50}}: \text{net thickness})$$

To be more precise, the fatigue performance depends on member thickness. This effect is called the “scale effect” and is translated as follows: for the same stress range the joint’s fatigue resistance may decrease as the member thickness increases. The basic design S-N curves are applicable to thicknesses that do not exceed the reference thickness of 22mm. Hence for members with thickness greater than 22mm, total stress range is derived by the formula above.

Calculation of the cumulative damage

As far as the calculation of cumulative damage is concerned, it is based on the application of the Palmgren-Miner cumulative damage rule. The fatigue capability of the structure is not acceptable, when the cumulative fatigue damage ratio, DM, is greater than 1. DM is given by the following formula:

$$DM = \sum_{i=1}^{i=n_{\text{tot}}} \frac{n_i}{N_i}$$

Where:

n_i : number of cycles of stress range S_i

N_i : number of cycles to failure at stress range S_i

n_{tot} : total number of stress range blocks

Taking into consideration that the long term distribution of stress ranges fit a two parameter Weibull probability distribution, DM for each relevant condition can be taken as:

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

and

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

Where:

i = 1 for full load condition

2 for normal ballast condition

N_L : number of cycles for the expected design life. Unless stated otherwise, it is to be taken

$$\text{as: } N_L = \frac{f_o U}{4 \log L}$$

Generally, its value is between 0.6×10^8 and 0.8×10^8 cycles for a design life of 25 years.

f_o : 0.85, factor taking into account non-sailing time for operations (i.e. loading/unloading, repairs). The allowance of 15% of vessel service life for time at sea is consistent with IACS REC.56.

U: design life, in seconds, equal to 0.788×10^9 for a design life of 25 years

L: rule length

a_i : proportion of the ship's life. In both loading conditions (full load condition, ballast condition) a_1, a_2 are equal to 0.5

S_{Ri} : stress range at the representative probability level of 10^{-4} , in M/mm^2

N_R : number of cycles corresponding to the probability level of 10^{-4} equal to 10000

m, K_2 : S-N curve parameters

ξ : Weibull probability distribution parameter, to be taken as:

$$\xi = f_{weibull} \left(1.1 - 0.35 \frac{L - 100}{300} \right)$$

D: moulded depth

$f_{weibull}$: area dependent modification factor, as given in the following table

Distribution of $f_{weibull}$ factors	
Plating Area	$f_{weibull}$
Bottom	0.9 at centreline and 0.95 at side
Side and bulge	1.1 at up to draught T_{LC} and 1 at deck
Deck	1
Inner bottom	1
Inner hull longitudinal bulkhead	1.1 up to D/2 and 1 at deck
Inner longitudinal bulkhead	1.1 up to D/2 and 1 at deck
Centreline longitudinal bulkhead	1.1 up to D/2 and 1 at deck
Intermediate values to be linearly interpolated	

Γ : gamma function

μ_i : coefficient taking into account the change in slope of the S-N curve

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

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

S_q : stress range at the intersection of the two segments of the S-N curve

Δm : slope change of the upper-lower segment of the S-N curve

=2

$\gamma(\alpha, \chi)$: incomplete Gamma function, Legendre form

- BULK CARRIERS

In case of bulk carriers fatigue analysis is carried out for homogeneous and alternate (for BC-A bulk carriers) full load condition as well as for normal and heavy ballast condition and is applicable to ships over 150 m. The fatigue damage statistics shows that the almost fatigue damages were experienced in a ballast hold. As in CSR for double hull oil tankers, in fatigue strength assessment of bulk carriers the effect of mean stress is taken into consideration. The reason for that is that it has been observed that the trend of occurrence of fatigue damage differs from the fatigue damage in land-based welded structures (e.g. bridges) and the primary cause is the effect of mean stress. The assessment method in that kind of ships is based on equivalent hot-spot stress range considering the effect of mean stress is used. Hot spot stress takes into account the influence of structural discontinuities due to geometry of the connection but excludes the effect of welds. However the fatigue strength of welded joints is affected by the stress concentration due to the existence of welds. That is why fatigue strength is assessed based on equivalent stress range which is obtained by multiplying an equivalent hot spot stress range by a fatigue notch factor.

Fatigue strength assessment is to be carried out in cargo hold area, for the following members at the considered locations:

Members	Details
Inner bottom plating	Connection with sloping and/or vertical plate of lower stool
	Connection with sloping plate of hopper tank
Inner side plating	Connection with sloping plate of hopper tank
Transverse bulkhead	Connection with sloping plate of lower stool
	Connection with sloping plate of upper stool
Hold frames of single side bulk carriers	Connection to the upper and lower wing tank
Ordinary stiffeners in double side space	Connection of longitudinal stiffeners with web frames and transverse bulkhead
	Connection of transverse stiffeners with stringer or similar
Ordinary stiffeners in upper and lower wing tank	Connection of longitudinal stiffeners with web frames and transverse bulkhead
Ordinary stiffeners in double bottom	Connection of longitudinal stiffeners with floors and floors in way of lower stool or transverse bulkhead
Hatch corners	Free edges of hatch corners

However, the structural members for which fatigue strength assessment can be carried out with the software tools being used in the present thesis are only the ordinary stiffeners in their end connections with web frames, transverse bulkheads and floors. For every other member mentioned in the previous Table, fatigue strength assessment can be carried out only using finite elements analysis in order to obtain reliable results.

Calculation of fatigue damage

The corrected equivalent notch stress range in loading condition “j” is assessed with the following formula:

$$\Delta\sigma_{E,j} = f_{coat} f_{material} f_{thick} \Delta\sigma_{eq,j}$$

Where:

f_{coat} : correction factor for corrosive environment, taken equal to:

1.05 for water ballast tanks and fuel oil tank

1.03 for dry bulk cargo holds and void space

It can be easily seen that f_{coat} differs from the respective factor f_{SN} in double hull oil tankers' fatigue analysis whose value is 1.06.

$f_{material}$: correction for material, equal to:

$$f_{material} = \frac{1200}{965 + \sigma_{yd}}$$

f_{thick} : correction factor for plate thickness, equal to 1.0 for hatch corners, flat bar or bulb stiffeners, otherwise to be taken as:

$$f_{thick} = \left(\frac{t_{net}}{22} \right)^{0.25} \quad \text{for } t_{net} \geq 22\text{mm}$$

$$f_{thick} = 1.0 \quad \text{for } t_{net} < 22\text{mm}$$

$\Delta\sigma_{eq,j}$: equivalent notch stress range, in N/m, for each loading condition “j”
m²

$$\Delta\sigma_{eq,j} = K_f \Delta\sigma_{equiv,j}$$

K_f : fatigue notch factor, defined below

Subject	Without weld grinding	With weld grinding (not applicable for ordinary stiffeners and boxing fillet weldng)
Butt welded joint	1.25	1.1
Fillet welded joint	1.3	1.15
Non welded part	1	-

$\Delta\sigma_{equiv,j}$: equivalent hot spot stress range, in N/mm²

$$\Delta\sigma_{equiv,j} = f_{mean,j} \Delta\sigma_{w,j}$$

f_{mean} : correction factor for mean stress:

-for hatch corners $f_{mean} = 0.77$

-for primary members and longitudinal stiffeners connections

$$f_{mean,j} = \max \left\{ 0.4, \left[\max \left(0, \frac{1}{2} + \frac{-\ln(10^{-4})}{4} \frac{\sigma_m}{\Delta\sigma_w} \right) \right]^{0.25} \right\}$$

$\sigma_{m,j}$: local hot spot mean stress, in N/mm², in the condition “j”

-if $0.24\Delta\sigma_{w,j} \geq \sigma_{yd}$ then $\sigma_{m,j(j \neq 1)} = -0.18\Delta\sigma_{w,j}$

-if $0.24\Delta\sigma_{w,j} < \sigma_{yd}$ then $\sigma_{m,j(j \neq 1)} = -\sigma_{yd} + 0.24\Delta\sigma_{w,j}$ for $0.24\Delta\sigma_{w,j} > \sigma_{yd} + \sigma_{m,1} - \sigma_{mean,1} + \sigma_{mean,j}$
or $\sigma_{m,j(j \neq 1)} = \sigma_{m,1} - \sigma_{mean,1} + \sigma_{mean,j}$ for $0.24\Delta\sigma_{w,j} \leq \sigma_{yd} + \sigma_{m,1} - \sigma_{mean,1} + \sigma_{mean,j}$

$\sigma_{m,1}$: local hot spot mean stress, in N/mm^2 , in the condition “1”

The condition “1” is the condition in which the maximum stress for the considered member is the largest on the tension side among the loading conditions “homogeneous”, “alternate”, “normal ballast” and “heavy ballast”.

-if $0.6\Delta\sigma_{w,1} \geq 2.5\sigma_{yd}$ then $\sigma_{m,1} = -0.18\Delta\sigma_{w,1}$

-if $0.6\Delta\sigma_{w,1} < 2.5\sigma_{yd}$ then $\sigma_{m,1} = \sigma_{yd} + 0.6\Delta\sigma_{w,1}$ for $0.6\Delta\sigma_{w,1} > \sigma_{yd} - \sigma_{res} - \sigma_{mean,1}$
or $\sigma_{m,1} = \sigma_{mean,1} + \sigma_{res}$ for $0.6\Delta\sigma_{w,1} \leq \sigma_{yd} - \sigma_{res} - \sigma_{mean,1}$

$\sigma_{mean,j}$: structural hot spot mean stress, in N/mm^2 , corresponding to the condition “j”

σ_{res} : residual stress, in N/mm^2 , given by the following formula

$\sigma_{res} = 0.25\sigma_{yd}$ for stiffener end connection

$\sigma_{res} = 0$ for non welded part and primary members (cruciform joint or butt weld)

$\Delta\sigma_{w,j}$: combined hot spot stress range, in N/mm^2

The hot spot stress range due to dynamic loads in stress assessment of stiffeners in load case “i” of loading condition “k” is given by the following formula:

$$\Delta\sigma_{W,i(k)} = \left| \left(\sigma_{GW,i1(k)} + \sigma_{W1,i1(k)} - \sigma_{W2,i1(k)} + \sigma_{d,i1(k)} \right) - \left(\sigma_{GW,i2(k)} + \sigma_{W1,i2(k)} - \sigma_{W2,i2(k)} + \sigma_{d,i2(k)} \right) \right|$$

Where:

$\sigma_{GW,i1(k)}$, $\sigma_{GW,i2(k)}$: stress due to hull girder moment

$\sigma_{W1,i1(k)}$, $\sigma_{W1,i2(k)}$: stress due to hydrodynamic or inertial pressure when the pressure is applied on the same side as the ordinary stiffener depending on the considered case

$\sigma_{W2,i1(k)}$, $\sigma_{W2,i2(k)}$: stress due to hydrodynamic or inertial pressure when the pressure is applied on the side opposite to the ordinary stiffener depending on the considered case

$\sigma_{d,i1(k)}$, $\sigma_{d,i2(k)}$: stress due to relative displacement of transverse bulkhead, or floor in way of stools

Elementary fatigue damage

The elementary fatigue damage for each loading condition is taken as:

$$D_j = \frac{a_j N_L}{K} \frac{\Delta\sigma_{E,j}^4}{(\ln N_R)^{4/\xi}} \left[\Gamma\left(\frac{4}{\xi} + 1, \nu\right) + \nu^{-3/\xi} \gamma\left(\frac{7}{\xi} + 1, \nu\right) \right]$$

Where:

K: S-N curve parameter, equal to $1.014 \cdot 10^{15}$

a_j : coefficient, taken equal to 1 for the assessment of hatch corners and specified in the following table for primary members and longitudinal stiffeners connections

	Loading Conditions	BC-A	BC-B, BC-C
L < 200m	Homogeneous	0.6	0.7
	Alternate	0.1	-
	Normal ballast	0.15	0.15
	Heavy ballast	0.15	0.15
L ≥ 200m	Homogeneous	0.25	0.5
	Alternate	0.25	-
	Normal ballast	0.2	0.2
	Heavy ballast	0.3	0.3

N_L : total number of cycles for the design ship's life, taken equal to:

$$N_L = \frac{0.85T_L}{4 \log L}$$

T_L : design life in seconds, equal to $7.884 \cdot 10^8$

$$\nu = \left(\frac{100,3}{\Delta \sigma_{E,j}} \right)^{\xi} \ln N_R$$

Comparing the formula above with the respective formula of CSR for double hull oil tankers, the two formulae are almost the same. Namely, after a more careful glance in S-N parameters K and m and their values we can come to the conclusion that in fatigue analysis of bulk carriers is used the B class of S-N curve (presented in Table C.1.6 Appendix C.1 page 21 of CSR for double hull oil tankers).

The relevant hot spot stress range taken into consideration in bulk carriers' fatigue assessment of stiffeners is a combination of hull girder bending, local stiffener bending and relative deflections of transverse bulkhead or floor in way of transverse bulkhead or stool. In other words, double hull oil tankers and bulk carriers take into consideration the same kind of stresses in fatigue analysis.

Stress due to hull girder moments

The hull girder hot spot stress, in N/mm^2 , in load cases "i1" and "i2" for loading condition "k" is given by the following formula:

$$\sigma_{GW,ij(K)} = K_{gh} (C_{WV,ij} \sigma_{WV,ij} - C_{WH,ij} \sigma_{WH,(K)}) \quad j=1, 2$$

Where:

K_{gh} : geometrical stress concentration factor for nominal hull girder stress, given in tables 1 and 2 p.24-28 ch.8, section 4 in CSR for BC

$C_{WV,ij}, C_{WH}$: load combination factors for vertical wave bending moment and horizontal wave bending moment respectively for each load case defined in chapter "Loads"

σ_{WV}, σ_{WH} : nominal hull girder stresses due to vertical wave bending moment and horizontal wave bending moment respectively. These stresses are derived from the same formulae as in double hull oil tankers

Stress due to local stiffener bending

The stress amplitude due to wave pressure, due to liquid pressure and due to dry bulk pressure is given by almost the same formula with the one (σ_{2A}) in double hull oil tankers' analysis. To be more precise the differences between the two formulae are in geometrical stress concentration factor due to stiffener geometry, in geometrical stress concentration factor due to lateral pressure that exists only in bulk carriers' formula and in stress factor for bending stress in longitudinal stiffeners caused by relative deformation between supports that exists only in double hull oil tankers' analysis while in bulk carriers this kind of stresses are calculated in a different way. Last but not least, the formulae of the hydrodynamic pressures used in the calculation of hot spot stress differ between the analyses driven by CSR of each kind of ship.

More specifically:

In the formula of hot spot stress due to wave pressure, the hydrodynamic pressure, in kN/m^2 , in load case "i1" and "i2" for loading condition (k) used in bulk carriers' analysis is to be taken as:

$$p_{CW,i1(k)} = \begin{cases} 2C_{NE,i1(k)} p_{w,i1(k)} & C_{NE,i1(k)} < 0.5 \\ p_{w,i1(k)} & C_{NE,i1(k)} \geq 0.5 \end{cases}$$

and

$$p_{CW,i2(k)} = \begin{cases} 0 & C_{NE,i1(k)} < 0.5 \\ (2C_{NE,i2(k)} - 1) p_{w,i2(k)} & C_{NE,i1(k)} \geq 0.5 \end{cases}$$

Where

$C_{NE,ij(k)}$: correction factor for the non linearity of the wave pressure range in load case "i1" and "i2" of loading condition (k) given by the following equation:

$$C_{NE,ij(k)} = \exp \left[- \frac{\left(z - T_{LC(k)} + \frac{|p_{W,ij(k),WL}|}{\rho g} \right)^{2.5}}{\frac{|p_{W,ij(k),WL}|}{\rho g} (-\ln 0.5)^{-1/2.5}} \right] \quad \text{for } z > T_{LC(k)} - \frac{|p_{W,ij(k),WL}|}{\rho g}$$

$$= 1.0 \quad \text{for } z \leq T_{LC(k)} - \frac{|p_{W,ij(k),WL}|}{\rho g}$$

$T_{LC(k)}$: draught, in m, of the considered loading condition (k)

$p_{W,ij(k)}$: hydrodynamic pressure, in kN/m^2 , in load case "i1" and "i2" for loading condition (k), specified in chapter "Loads". In fatigue analysis the coefficient f_p takes the value 0.5. If the location of the considered member is above the waterline, then the hydrodynamic pressure is to be taken as the pressure at the waterline

$p_{W,ij(k),WL}$: hydrodynamic pressure, in kN/m^2 , at waterline in load case "i1" and "i2" of loading condition "(k)"

z : z coordinate, in m, of the point considered

In case of double hull oil tankers, hydrodynamic pressure (half range) used in fatigue analysis is to be taken as:

$$\begin{aligned}
 P_W &= 0 && \text{for } z \geq T_{LC} + h_{WL} \text{ or } D \text{ whichever is the lesser} \\
 &= 0.5P_{WL} && \text{at still waterline} \\
 &= P_{ex-dyn} && \text{for } z \leq T_{LC} - h_{WL} \text{ or } 0 \text{ whichever is the greater}
 \end{aligned}$$

Where:

h_{WL} : dynamic wave pressure head at still waterline, is to be taken as: $P_{WL}/10 \text{ m}$

P_{ex-dyn} : the envelope dynamic wave pressure, given in chapter "Loads". In formula of P_1 $f_{prob}=0.5$, $f_{nl-P1}=1$ and $f_v=1$ at and aft of $0.7L$ and 1.5 at and forward of F.P. in formula of P_2 $f_{prob}=0.5$, $f_{nl-P2}=1.0$ and $f_v=1.0$.

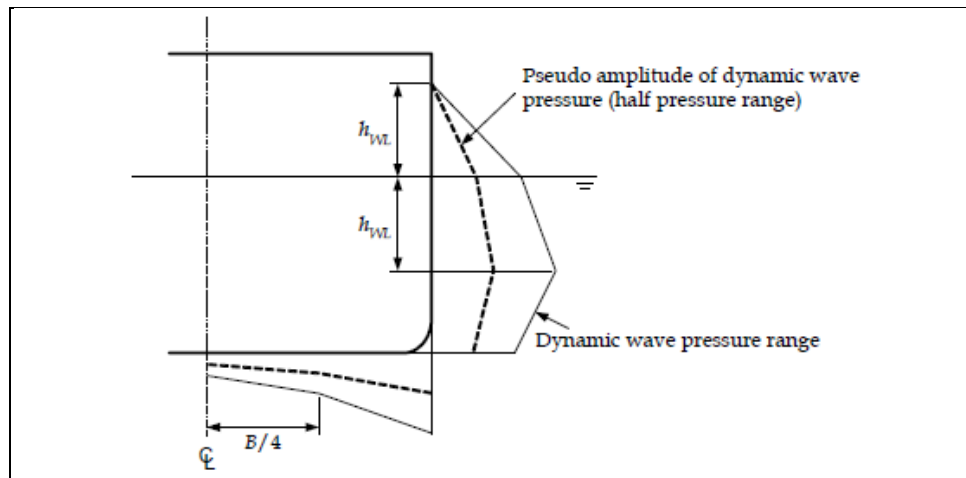
P_{WL} : pressure at waterline, is to be taken as P_{ex-max} at still waterline, in kN/m^2

P_{ex-max} : envelope maximum dynamic wave pressure, to be taken as the greater of P_1 and P_2 defined in the same chapter as P_{ex-dyn}

D : moulded depth, in m

The abbreviations used are kept the same with those ones used in chapter "Loads".

The reduction below the water line and the stretching of the external pressure above the water line is done in order to take into account the intermittent wet and dry area. The head of this area is based on hydrostatic head of the pressure at the water line with a probability of exceedance at 10^4 . The pressure distribution in this area is assumed as linear in order to simplify the procedure.



Transverse distribution of dynamic wave pressure amplitude for fatigue strength

In formula of hot spot stress due to liquid pressure the inertial pressure, in kN/m^2 , is defined in chapter "Loads" with f_p equal to 0.5 in fatigue strength analysis. Where the considered location is located in fuel oil, other oil or fresh water tanks, no inertial pressure is considered for the tank top longitudinals and when the location of the considered member is above the liquid surface in static and upright condition, the inertial pressure is to be taken at the liquid surface line.

In fatigue strength analysis for double hull oil tankers, 2 cases are taken into consideration calculating the dynamic tank pressure.

a) The dynamic tank pressure amplitude, P_{in-amp} on a tank boundary with adjacent tank empty, is to be taken as:

$$P_{in-amp} = f_v P_{in-v} + f_{ull-t} f_t P_{in-t} + f_{ull-lng} f_{lng} P_{in-lng}$$

Where:

f_v, f_t, f_{lng} : pressure combination factors, given in the following table

$P_{in-v}, P_{in-t}, P_{in-lng}$: envelope dynamic tank pressures due to vertical, transverse and longitudinal acceleration respectively, in kN/m^2

f_{ull-t} : factor to account for ullage in cargo tanks, not to be taken less than 0 nor greater than 1.0

$$= \frac{|z_o - z| + h_{roll}}{2h_{roll}} \quad \text{for cargo tanks}$$

= 1.0 for ballast tanks

$f_{ull-lng}$: factor to account for ullage in cargo tanks, not to be taken less than 0 nor greater than 1.0

$$= \frac{|z_o - z| + h_{pitch}}{2h_{pitch}}$$

$$h_{roll}: \text{roll height} = \frac{b_{fs} f_{prob} \theta}{2}$$

$$h_{pitch}: \text{pitch height} = \frac{l_{fs} f_{prob} \phi}{2}$$

$f_{prob}=0.5$ as in bulk carriers

θ : roll angle, in rads

ϕ : pitch angle, in secs

b_{fs} : tank breadth at the top of the tank, in m

l_{fs} : tank length at the top of the tank, in m

x_o, y_o, z_o : coordinates of the reference point

b) The dynamic tank pressure amplitude, P_{in-amp} on a longitudinal tank boundary with adjacent tank full, is to be taken as:

$$P_{in-amp} = f_v |P_{in-v-tk1} - P_{in-v-tk2}| + f_t |f_{ull-t-tk1} P_{in-t-tk1} + f_{ull-t-tk2} P_{in-t-tk2}| \\ + f_{lng} |f_{ull-lng-tk1} P_{in-lng-tk1} - f_{ull-lng-tk2} P_{in-lng-tk2}|$$

The suffix tk1 and tk2 are added in each factor in order to show if it's about tank 1 or tank 2

Pressure combination factors for fatigue assessment		
	Cargo tanks	Ballast tanks
f_v	0.9	0.9
f_t	0.9	0.6
f_{lng}	0.4	0.4

The geometrical stress concentration factor due to stiffener geometry in fatigue strength assessment for bulk carriers in contrast to the formula given in case of double hull oil tankers is taken as:

$$K_s = 1 + \left[\frac{t_f (a^2 - b^2)}{2w_b} \right] \left[1 - \frac{b}{b_f} \left(1 + \frac{w_b}{w_a} \right) \right] 10^{-3}$$

Where:

a,b: eccentricity, in mm, of the face plate as defined in the following figure. For angle profile, "b" is to be taken as half the net actual thickness of the web

t_f, b_f: thickness and breadth of face plate, in mm, respectively

w_a, w_b: net section modulus in A and B respectively, in cm³, of the stiffener about the neutral axis parallel to Z axis without attached plating

The stress due to relative displacement of transverse bulkhead or floor in way of transverse bulkhead or stool in fatigue strength analysis for bulk carriers is calculated individually, in contrast to double hull oil tankers analysis that this kind of stress is incorporated in factor K_d, and is given by the following formula:

$$\sigma_{d,ij(k)} = \begin{cases} K_{dF-a} \sigma_{dF-a,ij(k)} + K_{dA-a} \sigma_{dA-a,ij(k)} & \text{for point "a"} \\ K_{dF-f} \sigma_{dF-f,ij(k)} + K_{dA-f} \sigma_{dA-f,ij(k)} & \text{for point "f"} \end{cases}$$

Where:

a,f: suffix which denotes the location considered, as indicated In Table 2 of CSR for Bulk carriers (p.26-28,ch.8 section 4)

A,F: suffix which denotes the direction, forward (F) and afterwards (A) of the transverse web or floor where the relative displacement is occurred

σ_{dF-a}, σ_{dA-a}, σ_{dF-f}, σ_{dA-f}: additional stress at point "a" and "f", in N/mm², due to the relative displacement between the transverse bulkhead of floors in way of stools and the forward (F) and afterward (A) transverse web or floor respectively

$$\sigma_{dF-a,ij(k)} = \frac{3.9\delta_{F,ij(k)} EI_A I_F}{w_A l_F (l_A I_F + l_F I_A)} \left(1 - 1.15 \frac{|x_{fA}|}{l_A} \right) 10^{-5}$$

$$\sigma_{dA-a,ij(k)} = \left[\frac{3.9\delta_{A,ij(k)} EI_A I_F}{w_A l_A (l_A I_F + l_F I_A)} \left(1 - 1.15 \frac{|x_{fA}|}{l_A} \right) - \frac{0.9\delta_{A,ij(k)} EI_A |x_{fA}|}{w_A l_A^3} \right] 10^{-5}$$

$$\sigma_{dF-f,ij(k)} = \left[\frac{3.9\delta_{F,ij(k)} EI_A I_F}{w_F l_F (l_A I_F + l_F I_A)} \left(1 - 1.15 \frac{|x_{fF}|}{l_F} \right) - \frac{0.9\delta_{F,ij(k)} EI_F |x_{fF}|}{w_F l_F^3} \right] 10^{-5}$$

$$\sigma_{dA-f,ij(k)} = \frac{3.9\delta_{A,ij(k)} EI_A I_F}{w_F l_A (l_A I_F + l_F I_A)} \left(1 - 1.15 \frac{|x_{fF}|}{l_F} \right) 10^{-5}$$

δ_{F,ij(k)}, δ_{A,ij(k)}: relative displacement, in mm, in the direction perpendicular to the attached plate between the transverse bulkhead or floor in way of stools and the forward (F) and the afterward (A) transverse web or floor in load case "i1" and "i2" for loading condition "(k)".

a) For longitudinals penetrating floors in way of stools

Relative displacement is defined as the displacement of the longitudinal in relation to the line passing through the stiffener end connection at the base of the stool measured at the first floor forward (F) or afterward (A) of the stool

b) For longitudinals other than (a)

Relative displacement is defined as the displacement of the longitudinal in relation to its original position measured at the first forward (F) or afterward (A) of the transverse bulkhead.

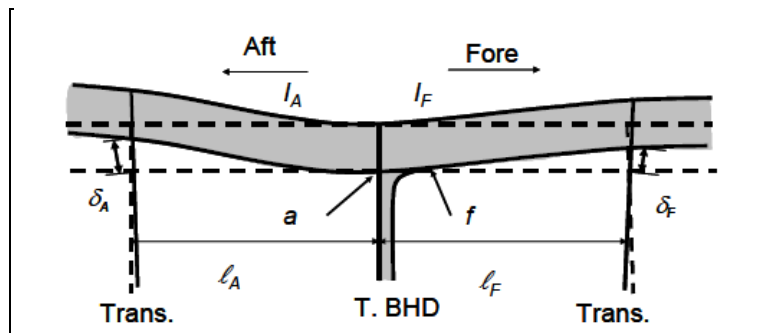
Where the stress of the face of longitudinal at the assessment point due to relative displacement is tension, the sign of the relative displacement is positive.

I_F, I_A : net moment of inertia, in cm^4 , of forward (F) and (A) longitudinal

$K_{dF-a}, K_{dA-a}, K_{dF-f}, K_{dA-f}$: stress concentration factor for stiffener end connection at point “a” and “f” subject to relative displacement between the transverse bulkhead and the forward (F) and afterward (A) transverse web or floors in way of stool respectively defined in Table 2 of CSR for Bulk carriers (p.26-28, ch.8 section 4)

l_A, l_F : span, in m, of forward (F) and afterward (A) longitudinal

x_{fF}, x_{fA} : distance, in m, to the hot spot from the closest end of l_F and l_A respectively



Definition of the relative displacement (example of the side longitudinal)

Chapter 4 - COMPARISON OF CSR DHOT AND CSR BC: A numerical example

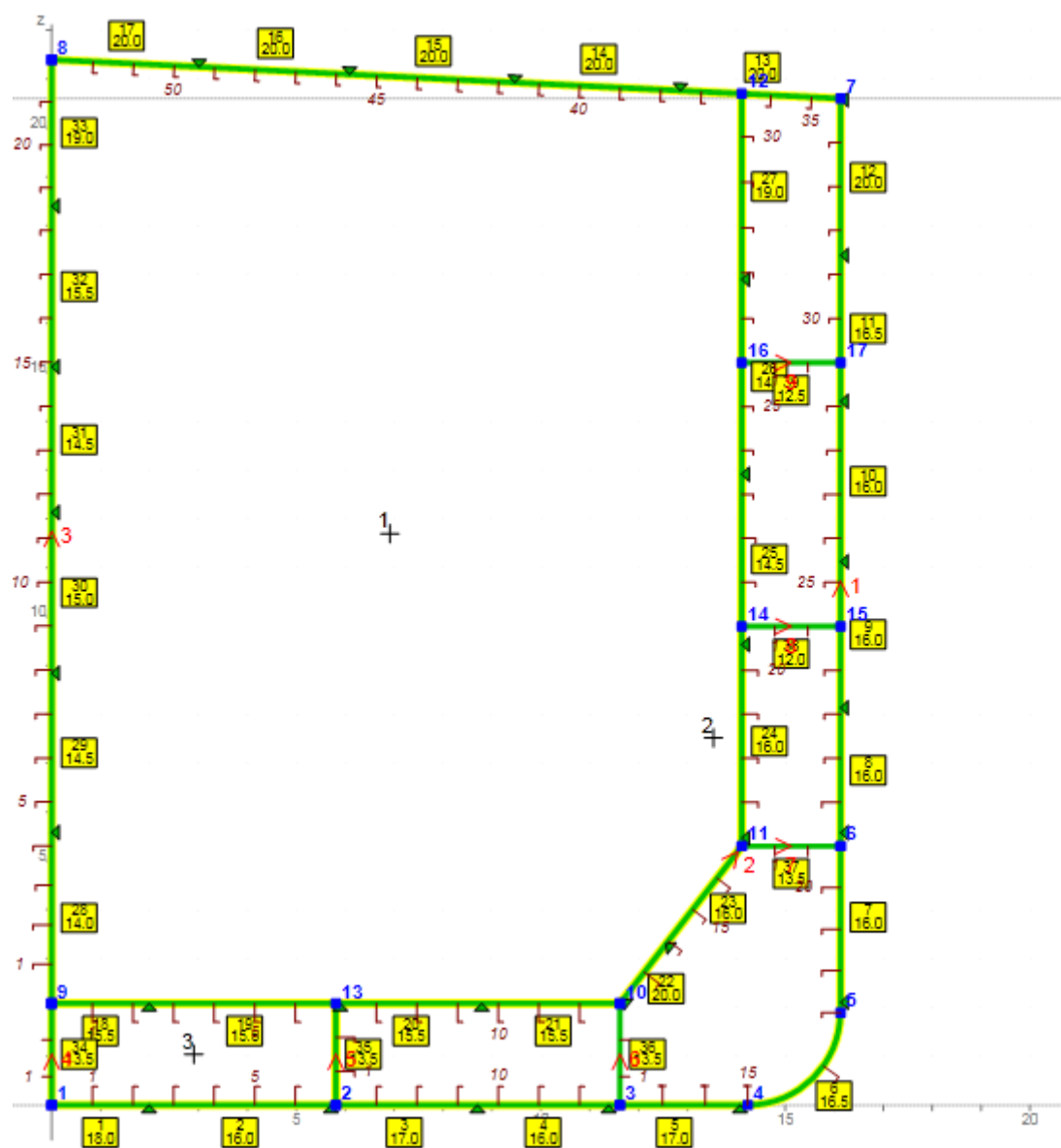
In this chapter, the results of the implementation of CSR formulae, as far as the values of loads and scantlings of midship section are concerned, will be presented. In order to make the comparison, we will examine the midship section of a real double hull oil tanker with one longitudinal bulkhead in the middle and the midship sections of a double skin and a single skin bulk carrier with the same main features as well as the same morphology of midship section (as far as this is possible) with the double hull oil tanker. The double hull oil tanker selected as a base of the comparison has been built by SASEBO HEAVY INDUSTRIES (JAPAN) for a Greek shipping company. It was built in July 2006 and classified by LRS. The main particulars of the vessel are summarized below.

Main features		
Lpp=	220.5	m
Lwl=	224.1	m
B=	32.26	m
D=	20.6	m
Tsc=	14.1	m
LS=	13436	t
Deadweight=	74543	t
Class	LRS	

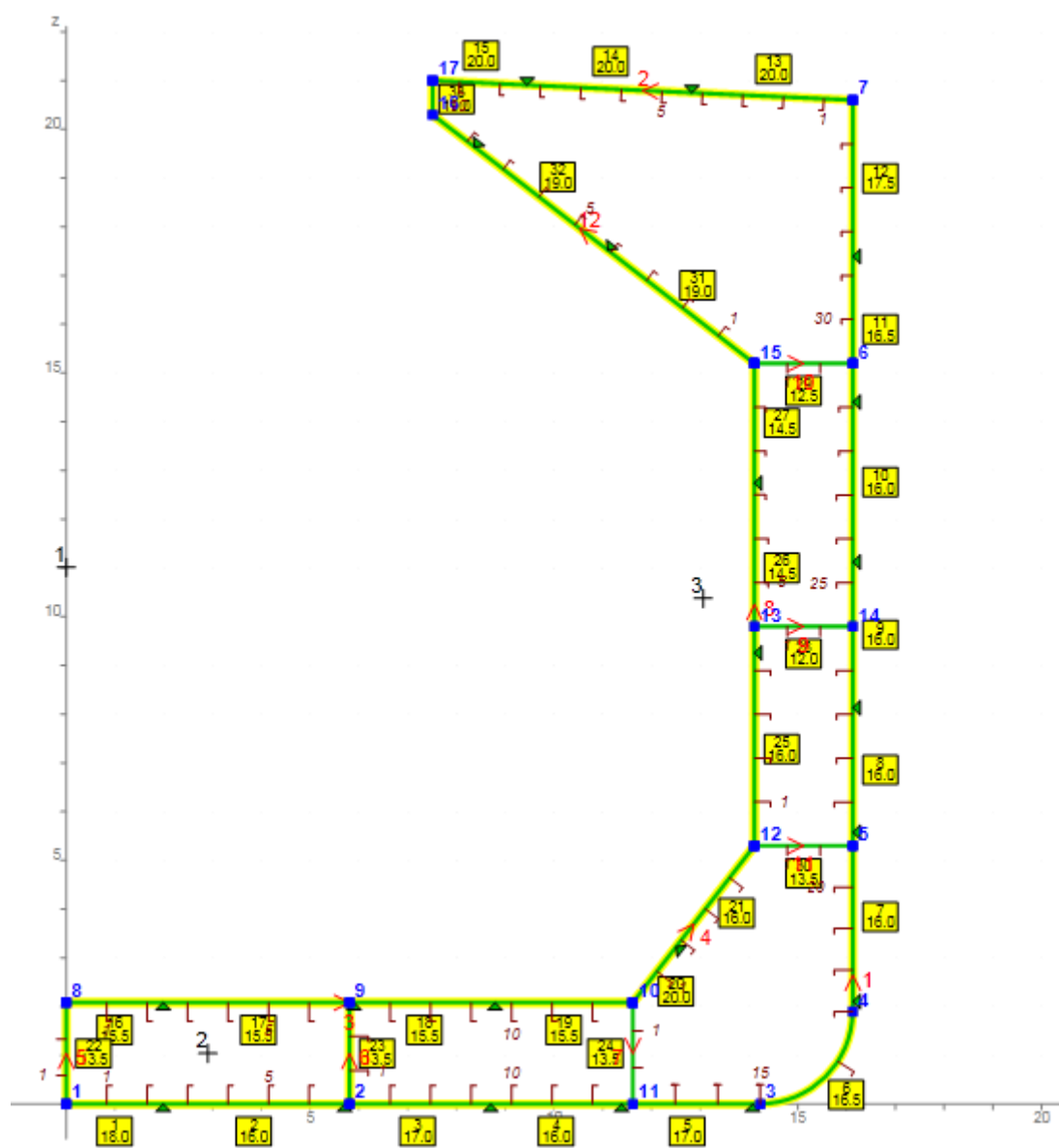
As software tools, we will use Excel and Mars 2000 of Bureau Veritas in order to obtain numerical data, necessary to better understand the way CSR work and to compare the results of the CSR formulae for these types of ships.

Further down are the drawings of the midship sections of the three examined vessels drawn by Mars 2000 of Bureau Veritas. To be more precise, it is about the half sections of the double hull oil tanker, the double skin bulk carrier and the single skin bulk carrier. It can be easily extracted that although the two out of the three ships are of different type and the two bulk carriers have a great difference (double skin), we tried to design the three midship sections with the most possible similarities in order to implement the comparison.

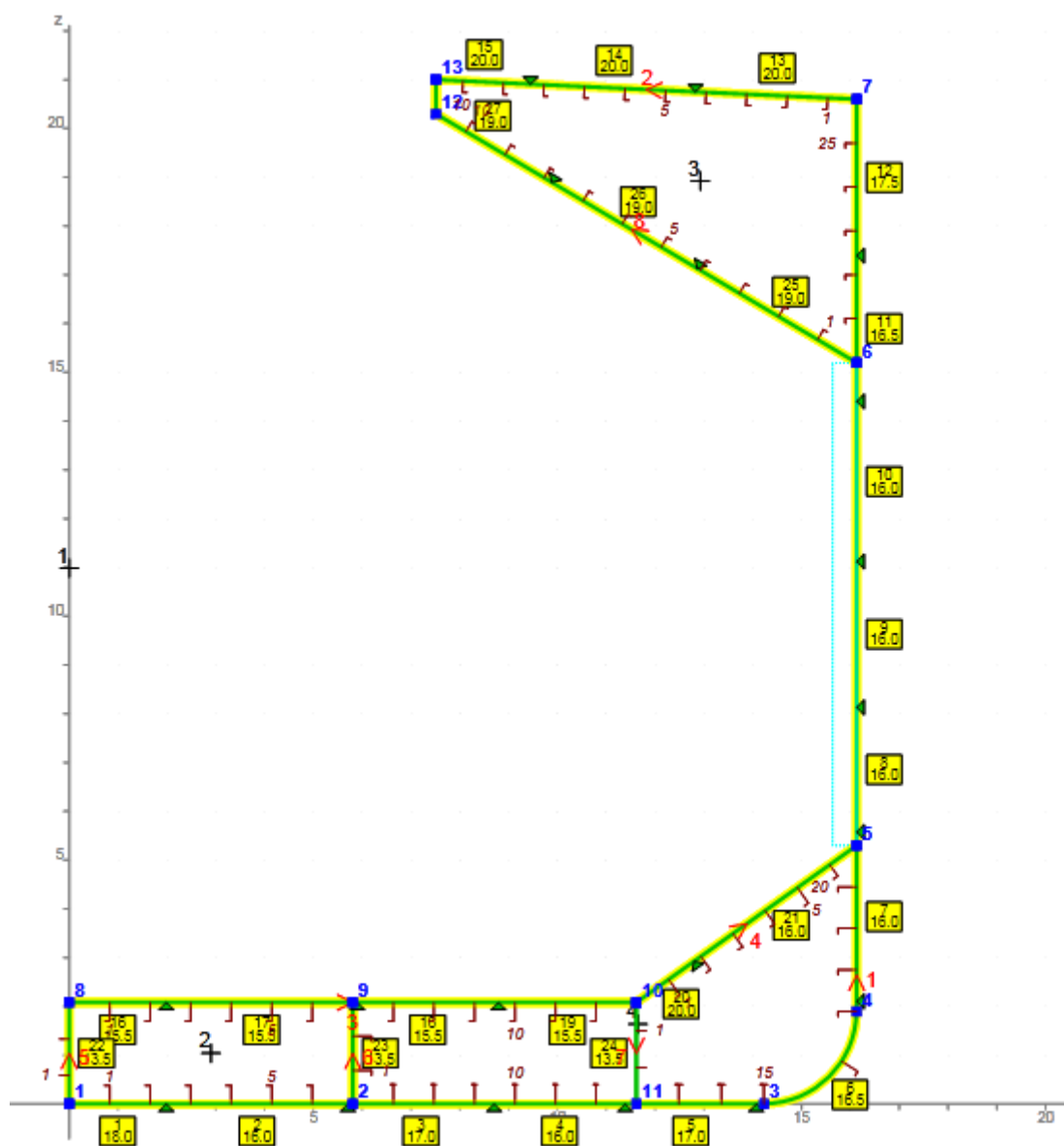
In the following drawings of the examined ships, the boxes that are near the strakes show the number of strake (Istr), in order to be identified, and its “as built” thickness. In addition, every compartment is declared by its number and the longitudinal stiffeners that belong to the same panel of strakes are also numbered.



Midship section of the examined double hull oil tanker



Midship section of the examined double skin bulk carrier



Midship section of the examined single skin bulk carrier

4.1 SHIP MOTIONS AND ACCELERATIONS

At the beginning of the implementation of CSR, ship motions and accelerations must be calculated, because as it is shown in chapter “Loads” their values are necessary at the calculation of dynamic local loads values. More specifically we will gauge roll period and roll angle, pitch period and pitch angle as well as the vertical acceleration due to heave, the transverse acceleration due to sway and the longitudinal acceleration due to surge. All that values must be measured in these draughts that CSR impose for each kind of ship. In oil tankers these draughts are: scantling draught, draught in normal ballast condition and draught at 0.6Tsc. In bulk carriers these draughts are: scantling draught, draught in normal ballast condition and draught in heavy ballast condition.

An excel sheet was created in order to calculate the ships motions and accelerations. Further down are the results from the calculation.

Double hull oil tanker

ships motions and accelerations	Tsc			
acceleration parameter a_0	0.357686	rad/s		
Roll				
period(T_R)	13.19889	s	with bilge keel	
single roll amplitude (θ)	0.428877	rad	24.57286	deg
Pitch				
period(T_P)	13.01818	s	$f_T =$	1
single pitch ampl.(Φ)	8.957174	deg	0.156332	rad
heave				
vertical acceler.	3.508902	m/s^2		
sway				
transverse acceler.	1.052671	m/s^2		
surge				
longitudinal acceler.	0.70178	m/s^2		

ships motions and accelerations	Draught in normal BALLAST CONDITION			
acceleration parameter a_0	0.36208	rad/s		
Roll				
period(T_R)	10.2333	s	with bilge keel	
single roll amplitude (θ)	0.463438	rad	26.55305	deg
Pitch				
period(T_P)	11.36698	s	$f_T =$	0.524823
single pitch ampl.(Φ)	9.03982	deg	0.157775	rad
heave				
vertical acceler.	3.552007	m/s^2		
sway				
transverse acceler.	1.065602	m/s^2		
surge				
longitudinal acceler.	0.710401	m/s^2		

ships motions and accelerations	0.6Tsc			
acceleration parameter ao	0.361181	rad/s		
Roll				
period(T_R)	10.6663	s	with bilge keel	
single roll amplitude (θ)	0.45839	rad	26.26392	deg
Pitch				
period(T_P)	11.64382	s	$f_T =$ 0.6	
single pitch ampl. (Φ)	9.022599	deg	0.157474	rad
heave				
vertical acceler.	3.543187	m/s^2		
sway				
transverse acceler.	1.062956	m/s^2		
surge				
longitudinal acceler.	0.708637	m/s^2		

Double skin bulk carrier

ships motions and accelerations	Tsc			
acceleration parameter ao	0.357686	rad/s		
Roll				
period(T_R)	13.19889	s	with bilge keel	
single roll amplitude (θ)	0.428877	rad	24.57286	deg
Pitch				
period(T_P)	13.01818	s	$\lambda =$ 264.6	
single pitch ampl. (Φ)	8.957174	deg	0.156332	rad
heave				
vertical acceler.	3.508902	m/s^2		
sway				
transverse acceler.	1.052671	m/s^2		
surge				
longitudinal acceler.	0.70178	m/s^2		

ships motions and accelerations	Draught in normal BALLAST CONDITION			
acceleration parameter a_0	0.357686	rad/s		
Roll				
period(T_R)	10.2333	s	with bilge keel	
single roll amplitude (θ)	0.463438	rad	26.55305	deg
Pitch				
period(T_P)	11.36698	s	$\lambda =$	201.734
single pitch ampl.(Φ)	8.95717	deg	0.156332	rad
heave				
vertical acceler.	3.5089	m/s^2		
sway				
transverse acceler.	1.05267	m/s^2		
surge				
longitudinal acceler.	0.70178	m/s^2		

ships motions and accelerations	Draught in heavy BALLAST CONDITION			
acceleration parameter a_0	0.357686	rad/s		
Roll				
period(T_R)	10.45081	s	with bilge keel	
single roll amplitude (θ)	0.460903	rad	26.40781	deg
Pitch				
period(T_P)	11.8839	s	$\lambda =$	220.5
single pitch ampl.(Φ)	8.95717	deg	0.156332	rad
heave				
vertical acceler.	3.5089	m/s^2		
sway				
transverse acceler.	1.05267	m/s^2		
surge				
longitudinal acceler.	0.70178	m/s^2		

The presentation of the values for the single skin bulk carrier is omitted because they are exactly the same with these of the double skin bulk carrier.

DISCUSSION

A first remark that must be done, after calculating ship motions and accelerations is that in case of bulk carriers the acceleration parameter (a_0) and the pitch amplitude (Φ) in normal and heavy ballast conditions is not gauged using the respective C_B (block coefficient) but the one of full load condition. In case of double hull oil tanker this is not case. Consequently the values given by the formulae of each CSR are the same in case of full load condition, due to the fact that both CSR use the same formulae, but not the same in case of normal ballast condition because of the simplification done in the use of C_B by CSR for bulk carriers.

4.2 HULL GIRDER LOADS

Double hull oil tanker

	Hogging	Sagging	
Design still water bending moment (S.W.B.M):	1629658	-1269010	(kNm)
Design vertical wave bending moment	2555505	-2692210	(kNm)
Rule horizontal wave bending moment	2411718		(kNm)
	Positive	Negative	(kN)
Rule vertical wave shear force	23309	-23309	(kN)

Double skin bulk carrier - Single skin bulk carrier

	Hogging	Sagging	
Design still water bending moment (S.W.B.M):	1727557	-1590851	(kNm)
Design vertical wave bending moment	2555505	-2692210	(kNm)
Rule horizontal wave bending moment	2411718		(kNm)
	Positive	Negative	(kN)
Rule vertical wave shear force	23309	-23309	(kN)
Wave torsional moment	432914		(kNm)

DISCUSSION

As it is mentioned in chapter “Loads”, rule wave torsional moment is not specified in case of double hull oil tankers. On the other hand, the existence of hatches on deck of bulk carriers make them “vulnerable” to torsion, hence only CSR for bulk carriers provide a formula for rule wave torsional moment, which is used only in fatigue strength assessment. In addition the difference between the values of still water bending moment in hogging for the two kinds of ships is due to the way still water bending moment is formulated (see chapter “Loads”) and in sagging due to the previous fact as well as due to the existence of factor f_{sea} only in tankers’ CSR which in sagging condition is equal to 0.85.

4.3 LOCAL LOADS

After the evaluation of ship motions and accelerations for these draughts that CSR for each kind of ship demand, we are able to determine the local loads applied in structural elements of the ships’ midship sections. More specifically, next step is the calculation of static and dynamic pressures applied in every element of the midship section of the examined ships according to the design load sets presented in chapter “Scantlings of the midship section”. The filling type of water ballast tanks during water ballast exchange for all the three ships is the sequential. The procedure of determination of static and dynamic pressures applied in the local elements of the midship section is necessary because it provides a great numerical example of the implementation of CSR as well as the numerical data provided is essential for the determination of scantlings of the midship section and more specifically the load thicknesses of plates and stiffeners.

4.4 CALCULATION OF MINIMUM NET THICKNESS OF PLATES

The procedure that must be followed in order to calculate the required gross thicknesses of plates of a midship section is presented in chapter “Scantlings of the midship section”. The results in total are presented for each ship in the following tables. The first table presents the results of the double hull oil tanker, the second of the double skin bulk carrier and the third of the single skin bulk carrier.

Double hull oil tanker

IStr	Thick	Pw+Ps	WLoad Case	Ca	Sig.hg	Tload	TQuay	TMini0	TMiniProp	Act B.Strss	Crit B.Strss	Treq_Net	Treq_Grs	Treq_Grs_Rd	Tcorr
1	18	204.335	SEABAL 3 S Sta	0.78	-75.309	11.956	0	13.115	9.609	-154.722	-251.913	13.115	16.115	16	3
2	16	204.335	SEABAL 3 S Sta	0.78	-75.309	11.956	0	11.115	9.609	-154.722	-225.283	11.956	14.956	15	3
3	17	204.335	SEABAL 2 S Sta	0.78	-75.309	11.956	0	11.115	9.609	-154.722	-238.866	11.956	14.956	15	3
4	16	204.335	SEABAL 2 S Sta	0.78	-75.309	11.956	0	11.115	9.609	-154.722	-225.283	11.956	14.956	15	3
5	17	204.335	SEABAL 2 S Sta	0.78	-75.309	12.532	0	11.115	10.073	-154.722	-230.184	12.532	15.532	15.5	3
6	16.5	204.335	SEABAL 2 S Sta	0.78	-75.309	24.768	0	11.115	10.073	-154.722	-223.608	24.768	27.768	28	3
7	16	186.487	SEABAL 2 S Sta	0.8	-33.129	12.233	0	11.115	10.42	-123.656	-228.645	12.233	15.233	15	3
8	16	186.487	SEABAL 2 S Sta	0.8	-33.129	12.233	10.825	11.115	10.42	-68.063	-218.527	12.233	15.733	15.5	3.5
9	16	159.338	SEABAL 2 S Sta	0.8	-11.641	11.307	10.825	11.115	10.42	-38.462	-250.334	11.307	14.807	15	3.5
10	16	132.189	SEABAL 2 S Sta	0.8	9.847	10.299	10.825	11.115	10.42	-88.789	-214.451	11.115	14.615	14.5	3.5
11	16.5	123.711	SEA BS7b	0.95	-36.193	9.143	10.825	11.115	10.42	-130.574	-217.976	11.115	14.615	14.5	3.5
12	20	41.692	BAL 2 S Sta	0.771	81.473	9.721	10.825	11.115	17.309	-172.814	-168.101	17.309	21.309	21.5	4
13	20	41.692	BAL 2 S Sta	0.771	81.473	9.721	0	8.91	17.309	-172.814	-168.101	17.309	21.309	21.5	4
14	20	44.883	Slosh. 1 Sta	0.785	72.594	5.588	0	8.91	9.609	-177.727	-264.693	9.609	13.609	13.5	4
15	20	39.287	SEA BS7b	0.914	-85.618	4.844	0	8.91	9.609	-180.272	-264.689	9.609	13.609	13.5	4
16	20	44.883	Slosh. 1 Sta	0.781	74.95	5.601	0	8.91	9.609	-182.817	-264.686	9.609	13.609	13.5	4
17	20	44.883	Slosh. 1 Sta	0.78	75.735	5.723	0	8.91	9.81	-184.739	-260.654	9.81	13.81	14	4
18	15.5	263.579	LIQ 1 BS7a	0.95	55.201	12.308	0	8.91	9.609	-120.631	-203.905	12.308	16.308	16.5	4
19	15.5	265.076	LIQ 1 BS7b	0.95	55.201	12.342	0	8.91	9.609	-120.631	-203.905	12.342	16.342	16.5	4
20	15.5	269.037	LIQ 1 BS7b	0.95	55.201	12.434	0	8.91	9.609	-120.631	-203.905	12.434	16.434	16.5	4
21	15.5	272.997	LIQ 1 BS7b	0.95	55.201	12.526	0	8.91	9.609	-120.631	-203.905	12.526	16.526	16.5	4
22	20	272.997	LIQ 1 BS7b	0.95	55.201	12.224	0	8.91	9.378	-120.631	-288.133	12.224	15.224	15	3
23	16	234.594	LIQ 1 BS7b	0.95	31.146	12.59	0	8.91	10.42	-110.16	-236.306	12.59	15.59	15.5	3
24	16	234.594	LIQ 1 BS7b	0.95	31.146	12.59	0	8.91	10.42	-68.063	-225.58	12.59	15.59	15.5	3
25	14.5	187.157	LIQ 1 BS7b	0.95	4.21	11.246	0	8.91	10.42	-60.933	-204.852	11.246	14.246	14	3
26	14.5	143.57	LIQ 1 BS5b	0.95	-20.758	9.85	0	8.91	10.767	-117.11	-192.643	10.767	13.767	14	3
27	19	100.629	LIQ 1 BS5b	0.95	-41.635	8.521	0	8.91	10.767	-173.909	-246.393	10.767	14.767	15	4
28	14	224.48	LIQ 1 BS7a	0.95	31.109	12.316	0	8.91	10.42	-120.631	-216.19	12.316	14.816	15	2.5
29	14.5	224.48	LIQ 1 BS7a	0.95	31.109	12.316	0	8.91	10.42	-67.982	-211.361	12.316	14.816	15	2.5
30	15	190.588	LIQ 1 BS7a	0.95	10.907	11.348	0	8.91	10.42	-47.082	-224.231	11.348	13.848	14	2.5

31	14.5	123.491	LIQ 1 S Sta	0.8	17.049	9.954	0	8.91	10.42	-88.866	-207.363	10.42	12.92	13	2.5
32	15.5	96.342	LIQ 1 S Sta	0.8	38.537	8.792	0	8.91	10.42	-144.192	-200.891	10.42	14.42	14.5	4
33	19	74.734	LIQ 1 BS5a	0.95	-48.959	6.909	0	8.91	10.13	-184.739	-248.215	10.13	14.13	14	4
34	13.5	233.898	BAL 3 S Sta	0.788	-70.653	11.504	0	11.013	8.683	-145.157	-211.037	11.504	14.504	14.5	3
35	13.5	239.78	BAL 2 S Sta	0.78	-75.309	10.845	0	9.91	8.046	-154.722	-223.742	10.845	13.845	14	3
36	13.5	12	Slosh. 2 Sta	0.8	-56.523	2.586	0	9.91	6.947	-145.157	-211.037	9.91	12.91	13	3
37	13.5	12	Slosh. 2 Sta	0.8	-26.503	2.327	0	8.308	6.252	-68.063	-224.05	8.308	11.308	11.5	3
38	12	12	Slosh. 2 Sta	0.8	2.147	2.327	0	8.308	6.252	-38.462	-197.505	8.308	11.308	11.5	3
39	12.5	12	Slosh. 2 Sta	0.8	36.528	2.327	0	8.308	6.252	-88.789	-206.556	8.308	11.308	11.5	3

Note:

IStr: Number of strake (*see Figure of the double hull oil tanker's midship section*)

Thick: as built gross thickness

Pw+Ps: sum of dynamic and static pressure

WLoad Case: the design load set in which load thickness takes its maximum value

SEABAL: differential pressure due to sea and water ballast

LIQ : liquid pressure (i: number of tank)

SEA: sea pressure

BAL: ballast pressure

Slosh: sloshing pressure

The ending "Sta" in the design load sets shows that it is about the static pressure only. When there is no such ending ("Sta"), the name of pressure is followed by the name of the dominant load case. The number incorporated in the design load set shows the number of tank. The design load set named as SEABAL 3 S Sta represents the net pressure difference between water ballast pressure (only its static component) from ballast tank 3 and sea pressure at draught equal to 0.25Tsc (only its static component). The abbreviation Slosh. Sta show that it is about the minimum sloshing pressure, which is equal to 12kN/m².

Ca: factor C_a

Sig.hg: σ_{hg} (hull girder bending stress for the design load set being considered)

Tload: net load thickness

TQuay: net thickness of side shell plating in quay contact region derived from a specific formula (chapter "Scantlings of the midship section")

TminiO: net thickness of plates derived from the empirical formulae which are functions of L (ship's length)

TminiProp: net thickness of plates derived from buckling requirements (stiffness and proportions)

Act B strss: actual buckling stress given in CSR for double hull oil tankers, Section 8.1, page 21

Crit. B strss: critical buckling stress given in CSR for double hull oil tankers, Section 10.3, page 2

Treq_net: required net thickness of plate (the maximum of the calculated net thicknesses)

Treq_Grs: required gross thickness of plate

Treq_Grs_rd: rounded required gross thickness

Tcorr: the corrosion addition

Double skin bulk carrier

IStr	Thick	Pw+Ps	WLoad Case	lambdp	Sig.x	Tload	TQuay	TMini0	TMiniProp	Comb1 Case	Comb1 rat	Comb2 Case	Comb2 rat	Treq_Net	Treq_Grs	Treq_Grs_Rd	Tcorr
1	18	198.709	SEABAL 2 F1	0.683	178.952	12.89	0	14.115	8.3	H	0.619	H	0.376	14.115	17.115	17	3
2	16	204.93	SEABAL 2 F1	0.683	178.952	13.09	0	12.115	8.3	H	0.759	H	0.497	13.09	16.09	16	3
3	17	251.136	SEABAL 3 H1	0.683	178.952	14.491	0	12.115	8.3	H	0.7	H	0.459	14.491	17.491	17.5	3
4	16	253.324	SEABAL 3 H1	0.683	178.952	14.553	0	12.115	8.3	H	0.782	H	0.54	14.553	17.553	17.5	3
5	17	255.583	SEABAL 3 H1	0.683	178.952	15.323	0	12.115	8.7	H	0.745	H	0.497	15.323	18.323	18.5	3
6	16.5	255.583	SEABAL 3 H1	0.683	178.952	15.323	0	12.622	8.7	H	0.78	H	0.528	15.323	18.323	18.5	3
7	16	255.403	SEABAL 3 H1	0.742	138.937	14.35	0	12.622	9	H	0.569	H	0.413	14.35	17.35	17.5	3
8	16	233.336	SEABAL 3 H1	0.849	67.332	13.578	11.657	12.622	9	H	0.334	H	0.336	13.578	17.078	17	3.5
9	16	197.834	SEAHBAL 3 H1	0.9	10.469	12.146	11.657	12.622	9	H	0.335	H	0.349	12.622	16.122	16	3.5
10	16	169.054	SEA P1	0.898	-34.73	11.24	11.657	12.622	9	H	0.712	H	0.574	12.622	16.122	16	3.5
11	16.5	147.252	SEA P1	0.813	-91.484	11.023	11.657	12.622	9	H	0.905	H	0.634	12.622	15.622	15.5	3
12	17.5	120.103	SEA P1	0.75	-134.05	10.369	11.657	12.622	9	H	1.17	H	0.769	12.622	16.122	16	3.5
13	20	48.078	BAL 3 H1	0.567	-256.286	6.963	0	8.91	8.309	H	0.97	H	0.576	8.91	12.91	13	4
14	20	47.697	BAL 3 H1	0.564	-258.721	6.958	0	8.91	8.309	H	0.987	H	0.579	8.91	12.91	13	4
15	20	47.19	BAL 3 H1	0.559	-261.967	6.951	0	8.91	8.309	H	0.992	H	0.584	8.91	12.91	13	4
16	15.5	308.3	BULKHF 1 H1	0.748	135.041	15.335	0	12.115	8.3	H	0.735	H	0.508	15.335	20.835	21	5.5
17	15.5	308.3	BULKHF 1 H1	0.748	135.041	15.335	0	12.115	8.3	H	0.789	H	0.594	15.335	20.835	21	5.5
18	15.5	308.3	BULKHF 1 H1	0.748	135.041	15.335	0	12.115	8.3	H	0.812	H	0.632	15.335	20.835	21	5.5
19	15.5	308.3	BULKHF 1 H1	0.748	135.041	15.335	0	12.115	8.3	H	0.837	H	0.672	15.335	20.835	21	5.5
20	20	278.095	HBAL 1 H1	0.748	135.041	14.214	0	10.394	8.1	H	0.439	H	0.322	14.214	19.714	19.5	5.5
21	16	301.666	HBAL 1 R1	0.846	-69.502	13.921	0	10.394	8.265	H	0.712	H	0.631	13.921	19.421	19.5	5.5
22	13.5	233.898	BAL 2 H1	0.701	166.631	12.47	0	8.91	7.5	H	0.751	H	0.491	12.47	15.47	15.5	3
23	13.5	305.588	HBAL 3 H1	0.683	178.952	13.385	0	8.91	6.95	H	0.754	H	0.482	13.385	16.385	16.5	3
24	13.5					0	0	8.91	7.5	H	0.843	H	0.575	8.91	11.91	12	3
25	16	281.655	HBAL 1 R1	0.874	-51.001	14.708	0	10.394	9	H	0.377	H	0.388	14.708	18.708	18.5	4
26	14.5	240.649	HBAL 1 R1	0.9	-26.995	13.396	0	10.394	9	H	0.721	H	0.678	13.396	17.396	17.5	4
27	14.5	199.644	HBAL 1 R1	0.868	-55.156	12.427	0	10.394	9	H	0.937	H	0.81	12.427	16.427	16.5	4
28	12					0	0	8.91	6.75	H	0.106	H	0.074	8.91	11.91	12	3
29	12.5					0	0	8.91	6.75	H	0.638	H	0.42	8.91	11.91	12	3
30	13.5					0	0	8.91	6.75	H	0.225	H	0.149	8.91	11.91	12	3
31	19	168.89	HBAL 1 R1	0.836	-76.276	12.032	0	10.394	9.3	H	0.806	H	0.526	12.032	15.532	15.5	3.5
32	19	129.223	HBAL 1 R1	0.817	-89.105	10.647	0	10.394	9.3	H	1.028	H	0.659	10.647	14.647	14.5	4
33	19	100.19	HBAL 1 R1	0.798	-101.933	15.182	0	10.394	15.969	H	1.858	H	1.327	15.969	19.969	20	4

Single skin bulk carrier

IStr	Thick	Pw+Ps	WLoad Case	lambdp	Sig.x	Tload	TQuay	TMini0	TMiniProp	Comb1 Case	Comb1 rat	Comb2 Case	Comb2 rat	Treq_Net	Treq_Grs	Treq_Grs_Rd	Tcorr
1	18	179.991	SEA H1	0.689	175.012	12.215	0	14.115	8.3	H	0.6	H	0.365	14.115	17.115	17	3
2	16	187.122	SEA H1	0.689	175.012	12.455	0	12.115	8.3	H	0.738	H	0.483	12.455	15.455	15.5	3
3	17	194.253	SEA H1	0.689	175.012	12.69	0	12.115	8.3	H	0.68	H	0.447	12.69	15.69	15.5	3
4	16	199.601	SEA H1	0.689	175.012	12.863	0	12.115	8.3	H	0.761	H	0.527	12.863	15.863	16	3
5	17	205.122	SEA H1	0.689	175.012	13.668	0	12.115	8.7	H	0.73	H	0.495	13.668	16.668	16.5	3
6	16.5	205.122	SEA H1	0.689	175.012	13.668	0	12.622	8.7	H	0.766	H	0.525	13.668	16.668	16.5	3
7	16	230.599	SEAHBAL 1 H1	0.76	63.465	13.632	0	12.622	8.6	H	1.178	H	1.117	13.632	17.132	17	3.5
8	16	229.811	SEAHBAL 1 H1	0.778	57.625	13.456	11.366	12.622	8.6	H	1.252	H	1.192	13.456	17.456	17.5	4
9	16	219.738	SEAHBAL 1 H1	0.9	3.745	12.232	11.366	12.622	8.6	H	1.252	H	1.192	12.622	16.622	16.5	4
10	16	196.936	SEAHBAL 1 R1	0.785	-55.29	12.401	11.366	12.622	8.6	H	1.252	H	1.192	12.622	16.622	16.5	4
11	16.5	192.833	SEAHBAL 1 R1	0.708	-80.97	12.918	11.657	12.622	9	H	1.087	H	1.03	12.918	16.418	16.5	3.5
12	17.5	134.085	SEABAL 3 R1	0.799	-101.124	10.613	11.657	12.622	9	H	1.196	H	0.793	12.622	16.122	16	3.5
13	20	57.845	BAL 3 H1	0.562	-259.942	7.675	0	8.91	8.309	H	0.992	H	0.594	8.91	12.91	13	4
14	20	56.302	BAL 3 H1	0.558	-262.375	7.597	0	8.91	8.309	H	1.007	H	0.59	8.91	12.91	13	4
15	20	76.03	BAL 3 R2	0.765	124.081	7.542	0	8.91	8.309	H	1.012	H	0.594	8.91	12.91	13	4
16	15.5	301.261	HBAL 1 H1	0.754	131.13	15.101	0	12.115	8.3	H	0.711	H	0.491	15.101	20.601	20.5	5.5
17	15.5	301.261	HBAL 1 H1	0.754	131.13	15.101	0	12.115	8.3	H	0.761	H	0.571	15.101	20.601	20.5	5.5
18	15.5	301.261	HBAL 1 H1	0.754	131.13	15.101	0	12.115	8.3	H	0.783	H	0.607	15.101	20.601	20.5	5.5
19	15.5	301.261	HBAL 1 H1	0.754	131.13	15.101	0	12.115	8.3	H	0.807	H	0.646	15.101	20.601	20.5	5.5
20	20	301.261	HBAL 1 H1	0.754	131.13	14.737	0	10.394	8.1	H	0.421	H	0.303	14.737	20.237	20	5.5
21	16	327.471	HBAL 1 R1	0.839	-74.286	14.566	0	10.394	8.1	H	0.697	H	0.606	14.566	20.066	20	5.5
22	13.5	157.702	BAL 2 H1	0.707	162.7	10.196	0	8.91	7.5	H	0.729	H	0.476	10.196	13.196	13	3
23	13.5	165.51	BAL 2 H1	0.689	175.012	9.808	0	8.91	6.95	H	0.732	H	0.468	9.808	12.808	13	3
24	13.5					0	0	8.91	7.5	H	0.811	H	0.544	8.91	11.91	12	3
25	19	201.41	HBAL 1 R1	0.82	-87.166	13.269	0	10.394	9.3	H	0.781	H	0.516	13.269	16.769	17	3.5
26	19	164.886	HBAL 1 R1	0.808	-95.362	12.096	0	10.394	9.3	H	0.965	H	0.625	12.096	16.096	16	4
27	19	110.1	HBAL 1 R1	0.789	-107.656	14.569	0	10.394	14.114	H	1.691	H	1.181	14.569	18.569	18.5	4

Lambdp: coefficient λ_p (defined in Tab 6 CSR bulk carriers, Chapter 6, section 1, page 15)

Sig.x: σ_x , hull girder bending stress for the design load set being considered

Buckling criteria (CSR for bulk carriers, Chapter 6, Section 3, page 48)

Comb1Case: stress combination 1

Comb1rat: ratio of stress combination 1

Comb2Case: stress combination 2

Comb2rat: ratio of stress combination 2

The abbreviations in Tables of double skin and single skin bulk carriers that are not defined above, are defined in Table of double hull oil tanker. The abbreviation HBAL and BULKHF represent “heavy ballast” and “homogeneous bulk with Dfull density” design load sets respectively. $D_{full} = M_h/V_h$ where M_h : actual cargo mass in a cargo hold corresponding to a homogeneously loaded condition at maximum draught and V_h : volume in m^3 of cargo hold excluding the volume enclosed by hatch coaming. The Figures of bulk carriers’ midship section show the number of each plate.

Next table presents the rounded gross thicknesses of all the three ships that proceed from the implementation of CSR. Although there are differences in the arrangement of the plates of each midship section between the three ships, the presentation focuses in the comparison of the rounded required gross thicknesses of the same type of element. Next to the rounded gross thicknesses are the as built thicknesses of the ships.

Type of ship Structural member	Double hull oil tanker		Double skin bulk carrier		Single skin bulk carrier	
	t (as built)	t (gross) (Rounded)	t (as built)	t (gross) (Rounded)	t (as built)	t (gross) (Rounded)
KEEL	18	16	18	17	18	17
BOTTOM SHELL	16	15	16	16	16	15.5
	17	15	17	17.5	17	15.5
	16	15	16	17.5	16	16
	17	15.5	17	18.5	17	16.5
BILGE STAKE	16.5	28	16.5	18.5	16.5	16.5
SIDE SHELL	16	15	16	17.5	16	17
	16	15.5	16	17	16	17.5
	16	15	16	16	16	16.5
	16	14.5	16	16	16	16.5
	16.5	14.5	16.5	15.5	16.5	16.5
	20	21.5	20	16	20	16
UPPER DECK	20	21.5	20	13	20	13
	20	13.5	20	13	20	13
	20	13.5	20	13	20	13
	20	13.5	-	-	-	-
	20	14	-	-	-	-
INNER BOTTOM	15.5	16.5	15.5	21	15.5	20.5
	15.5	16.5	15.5	21	15.5	20.5
	15.5	16.5	15.5	21	15.5	20.5
	15.5	16.5	15.5	21	15.5	20.5
HOPPER SLOPING PLATE	20	15	20	19.5	20	20
	16	15.5	16	19.5	16	20
INNER HULL	16	15.5	16	18.5	-	-
	14.5	14	14.5	17.5	-	-
	14.5	14	14.5	16.5	-	-
	19	15	-	-	-	-
TOP SIDE SLOPING PLATE	-	-	19	15.5	19	17
	-	-	19	14.5	19	16
	-	-	19	20	19	18.5
LONGITUDINAL BULKHEAD	14	15	-	-	-	-
	14.5	15	-	-	-	-
	15	14	-	-	-	-
	14.5	13	-	-	-	-
	15.5	14.5	-	-	-	-
	19	14	-	-	-	-
CENTER GIRDER	13.5	14.5	13.5	15.5	13.5	13
SIDE GIRDER I	13.5	14	13.5	16.5	13.5	13
SIDE GIRDER II	13.5	13	13.5	12	13.5	12
STRINGER I	13.5	11.5	13.5	12	-	-
STRINGER II	12	11.5	12	12	-	-
STRINGER III	12.5	11.5	12.5	12	-	-

DISCUSSION

The plates of the same panel of strakes in the three examined ships have the same as built thicknesses. The as built thicknesses of plates are derived from the plate gross thicknesses of the real double hull oil tanker, whose main characteristics are presented in the beginning of the chapter. From the presentation of the calculated minimum thicknesses according to CSR, it can be easily extracted as a conclusion that the double hull oil tanker, that is used as basis of the analysis, is not constructed according to the respective CSR. That is why there are some elements whose thicknesses are less than those required by CSR.

The previous Table does not present the final thicknesses of the elements of the midship section, but the implementation of every formula that concerns the net thickness of the midship section's plates. In order to extract the final thicknesses, the procedure of design verification must take place. For example, the required gross thicknesses of the plates of the upper deck in all the three ships are too small. In the following pages, namely in these that present the verification of section modulus requirements, it will be shown that in both bulk carriers the actual net section modulus at deck, using "as built" scantlings, is less than the rule net section modulus. Hence the thickness of plates of the upper deck must be increased. That means that the obtained gross thicknesses, that are lower than the "as built thickness" of deck plates must be increased.

Analyzing the results of the previous Table, we see that the rounded gross thickness of the respective plates of the double skin bulk carriers are bigger than these of the double hull oil tanker, except from the sheerstrake and the plates of the upper deck. The same happens between the single skin bulk carrier and the double hull oil tanker.

In case of the plates of inner bottom, great difference is observed between the two bulk carriers on the one side and the double hull oil tanker on the other, as far as the rounded gross thickness is concerned. Although both CSR provide the same formula for net load thickness, the values of P (total pressure applied) and C_a (factor that is a function of σ_{hg} : normal stress, induced by acting vertical and horizontal bending moments) conduct to the difference among the values of net thickness and consequently the rounded gross thickness. The values of P differ because of the different formulae that provide the static and dynamic tank and hold pressures respectively between the two CSR. In addition, each ship has different dominant load case that provides the maximum net load thickness, consequently different dynamic combination load factors are combined in each case in order to obtain the value of dynamic pressure. The difference in dynamic load combination factors has an impact also on the value of σ_{hg} among the three ships, as well as the difference in the formula of hull girder vertical bending moment. It must be noticed that in contrast to the CSR for bulk carriers, the simultaneously acting vertical wave bending moment in case of double hull oil tankers, is derived in beam sea dynamic load cases by using a heading correction factor equal to 0.8 (CSR DHOT, section 7.6, page 2). Apart from those mentioned above, the z coordinate of neutral axis among the three ships plays a major role in the formulation of σ_{hg} , hence the different morphology of the three midship sections conduct to the difference in values of σ_{hg} .

In case of bilge stake, the value given in the previous Table in case of double hull oil tanker is extremely high related to the plates of the bottom shell and the side shell that are near it. That happens because bilge strake is not stiffened with longitudinal stiffeners at the same spacing as the

adjoining plates. To be more specific, bilge stake is longitudinally stiffened only by bilge keel. Hence the value of net load thickness, which is proportional to stiffeners spacing, is so high in case of bilge stake. This fact does not happen in case of bulk carriers because in the formula of load thickness is incorporated the factor c_r , specifically for that purpose.

Hence in case of bilge stake of double hull oil tanker, the formula that must be used in order to calculate minimum net thickness of the stake is the following one (see Chapter “Scantlings of the midship section”):

$$t = \frac{\sqrt[3]{r_0^2 S_t (p_s + p_w)}}{100}$$

Where:

r_0 : 1900mm

S_t =3.44m

$P=p_s+p_w= 211.466\text{kN/m}^2$

Net minimum thickness of bilge stake: $t_{\text{net}}=13.796\text{mm}$

By adding the corrosion addition , which is 3mm in case of bilge stake, the gross minimum thickness of bilge stake of double hull oil tanker is: 16.796mm and the rounded gross thickness : $t_{\text{gross}}=17\text{mm}$.

4.5 CALCULATION OF SCANTLING REQUIREMENTS FOR STIFFENERS

The following Tables present the required scantlings of longitudinal stiffeners that constitute with the respective stakes the examined midship section. However in these Tables are included only these groups of stiffeners that can be found in more than one ship. More specifically, next Tables present these groups of stiffeners of each ship that can be compared with the respective group of stiffeners of the other one or two ships. Each Table presents the required calculations by CSR and the respective values necessary for the determination of stiffeners' scantlings. As in case of strakes, although it is not totally possible, great effort was made to ensure that the "as built" stiffeners arrangement is almost the same in all the three cases.

Below are the explanations of the abbreviations of the following Tables

Double hull oil tanker

NoStiff.: Number of stiffener

CrssA_Net: net cross sectional area

W_Net: actual net section modulus, in cm^3

Pw+Ps: wave pressure and static pressure, in kN/m^2

WLoadCase: wave load case

Cs: permissible bending stress coefficient for the design load set being considered (CSR DHOT, section 8.2, page 19)

Sig.hg: hull girder bending stress for the design load set being considered (CSR DHOT, section 8.2, page 19)

WLoad_net: net section modulus Z_{net} (CSR DHOT, section 8.2, page 19)

TwShr: minimum net web thickness $t_{w\text{-net}}$ (CSR DHOT, section 8.2, page 20)

tMiniO: minimum web thickness from the formula which is function of L (CSR DHOT, section 8.2, page 3)

tMiniPropW: net web thickness derived from buckling requirements (stiffness and proportions) (CSR DHOT, section 10.2, page 1)

tMiniPropFl: net flange thickness derived from buckling requirements (stiffness and proportions) (CSR DHOT, section 10.2, page 1)

InerA: actual net moment of inertia, in cm^4

InerR: rule minimum net moment of inertia, in cm^4 (CSR DHOT, section 10.2, page 2)

Col.B.Arat: buckling utilisation factor for column buckling (CSR DHOT, section 10.3, page 6)

Tor.B.Arat: buckling utilisation factor for torsional buckling (CSR DHOT, section 10.3, page 9)

AllowBrat: allowable utilisation factor for the two previous buckling modes (CSR DHOT, section 10.3, page 1)

Bulk carriers

ShrA_Net: actual net sectional area, in cm^2 , of the stiffener

lambds: coefficient λ_s (CSR BC, chapter 6, section 2, page 28, Table 3)

Sig.x: σ_x , hull girder bending stress for the design load set being considered

Ash: minimum (rule) net shear sectional area, in cm^2 (CSR BC, chapter 6, section 2, page 27)

Eff.Spac: effective width of attached plating

LatBARat: buckling utilisation factor for lateral (column) buckling (CSR BC, chapter 6, section 3, page 50)

Bcase: dominant load case in lateral (column) of stiffeners

TorBARat: buckling utilisation factor for torsional buckling (CSR BC, chapter 6, section 3, page 54)

KEEL AND BOTTOM LONGITUDINALS

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
1	177.55	1000.942	204.335	SEABAL 3 S Sta	0.621	-72.126	854.937	4.532	6.808	5.943	9.359	31482.48	3462.521	0.522	0.581	0.9
2	177.55	1000.942	204.335	SEABAL 3 S Sta	0.621	-72.126	854.937	4.532	6.808	5.943	9.359	31482.48	3462.521	0.522	0.581	0.9
3	160.95	988.624	204.335	SEABAL 3 S Sta	0.621	-72.126	854.937	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
4	160.95	988.624	204.335	SEABAL 3 S Sta	0.621	-72.126	854.937	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
5	160.95	988.624	204.335	SEABAL 3 S Sta	0.621	-72.126	854.937	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
6	160.95	988.624	204.335	SEABAL 3 S Sta	0.621	-72.126	854.937	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
7	169.25	995.02	195.575	SEABAL 2 HS2	0.555	140.253	916.044	4.543	6.808	5.943	9.359	30848.43	3311.907	0.521	0.584	0.9
8	169.25	995.02	194.977	SEABAL 2 HS2	0.555	140.253	913.247	4.543	6.808	5.943	9.359	30848.44	3311.908	0.521	0.584	0.9
9	169.25	995.02	194.38	SEABAL 2 HS2	0.555	140.253	910.449	4.543	6.808	5.943	9.359	30848.44	3311.908	0.521	0.584	0.9
10	160.95	988.624	193.783	SEABAL 2 HS2	0.555	140.253	907.652	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
11	160.95	988.624	193.186	SEABAL 2 HS2	0.555	140.253	904.854	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
12	160.95	988.624	192.588	SEABAL 2 HS2	0.555	140.253	902.057	4.554	6.808	5.943	9.359	30167.81	3161.294	0.52	0.587	0.9
13	171.52	1092.875	191.365	SEABAL 2 HS2	0.555	140.052	938.443	4.586	6.808	6.19	7.091	35121.48	3337.992	0.52	0.597	0.9
14	171.52	1092.875	190.739	SEABAL 2 HS2	0.555	140.052	935.373	4.586	6.808	6.19	7.091	35121.48	3337.992	0.52	0.597	0.9
15	230.713	1109.774	190.113	SEABAL 2 HS2	0.555	140.052	1436.701	6.521	6.808	6.19	7.091	38299.39	4412.126	0.551	0.604	0.9

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	38.5	989.465	197.153	SEABAL 2 F1	0.594	178.952	901.458	16.181	6.308	7.926	6.656	607.298	0.811	SEABAL 2 H2	0.678
2	38.5	989.465	198.709	SEABAL 2 F1	0.594	178.952	908.57	16.308	6.308	7.926	6.656	607.298	0.81	SEABAL 2 H2	0.678
3	38.5	976.1	200.264	SEABAL 2 F1	0.594	178.952	915.681	16.436	6.308	7.926	6.656	593.603	0.809	SEABAL 2 H2	0.686
4	38.5	976.1	201.819	SEABAL 2 F1	0.594	178.952	922.793	16.564	6.308	7.926	6.656	593.603	0.808	SEABAL 2 H2	0.686
5	38.5	976.1	203.375	SEABAL 2 F1	0.594	178.952	929.905	16.691	6.308	7.926	6.656	593.603	0.807	SEABAL 2 H2	0.686
6	38.5	976.1	204.93	SEABAL 2 F1	0.594	178.952	937.016	16.819	6.308	7.926	6.656	593.603	0.806	SEABAL 2 H2	0.686
7	38.5	983.044	249.677	SEABAL 3 H1	0.594	178.952	1141.616	20.491	6.308	7.926	6.656	607.299	0.804	SEABAL 3 H2	0.682

8	38.5	983.044	250.407	SEABAL 3 H1	0.594	178.952	1144.952	20.551	6.308	7.926	6.656	607.299	0.803	SEABAL 3 H2	0.682
9	38.5	983.044	251.136	SEABAL 3 H1	0.594	178.952	1148.287	20.611	6.308	7.926	6.656	607.299	0.802	SEABAL 3 H2	0.682
10	38.5	976.1	251.865	SEABAL 3 H1	0.594	178.952	1151.622	20.671	6.308	7.926	6.656	593.603	0.801	SEABAL 3 H2	0.686
11	38.5	976.1	252.595	SEABAL 3 H1	0.594	178.952	1154.957	20.731	6.308	7.926	6.656	593.603	0.8	SEABAL 3 H2	0.686
12	38.5	976.1	253.324	SEABAL 3 H1	0.594	178.952	1158.292	20.791	6.308	7.926	6.656	593.603	0.799	SEABAL 3 H2	0.686
13	32.08	1079.481	254.818	SEABAL 3 H1	0.594	178.952	1221.274	21.921	6.308	6.985	5.044	618.943	0.785	SEABAL 3 H2	0.697
14	32.08	1079.481	255.583	SEABAL 3 H1	0.594	178.952	1224.939	21.987	6.308	6.985	5.044	618.943	0.784	SEABAL 3 H2	0.697
15	32.08	1076.298	256.348	SEABAL 3 H1	0.594	178.952	1955.88	35.107	6.308	6.985	5.044	662.595	0.936	SEABAL 3 H2	0.706

Single skin bulk carrier

ISti	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	38.5	989.465	178.208	SEA H1	0.607	175.012	796.945	14.626	6.308	7.926	6.656	607.298	0.677	SEABAL 2 H2	0.663
2	38.5	989.465	179.991	SEA H1	0.607	175.012	804.918	14.772	6.308	7.926	6.656	607.298	0.676	SEABAL 2 H2	0.663
3	38.5	976.1	181.774	SEA H1	0.607	175.012	812.89	14.918	6.308	7.926	6.656	593.603	0.673	SEABAL 2 H2	0.671
4	38.5	976.1	183.556	SEA H1	0.607	175.012	820.863	15.065	6.308	7.926	6.656	593.603	0.672	SEABAL 2 H2	0.671
5	38.5	976.1	185.339	SEA H1	0.607	175.012	828.835	15.211	6.308	7.926	6.656	593.603	0.671	SEABAL 2 H2	0.671
6	38.5	976.1	187.122	SEA H1	0.607	175.012	836.808	15.357	6.308	7.926	6.656	593.603	0.67	SEABAL 2 H2	0.671
7	38.5	983.044	190.687	SEA H1	0.607	175.012	852.753	15.65	6.308	7.926	6.656	607.299	0.655	SEA F2	0.667
8	38.5	983.044	192.47	SEA H1	0.607	175.012	860.726	15.796	6.308	7.926	6.656	607.299	0.656	SEA F2	0.667
9	38.5	983.044	194.253	SEA H1	0.607	175.012	868.699	15.943	6.308	7.926	6.656	607.299	0.656	SEA F2	0.667
10	38.5	976.1	196.036	SEA H1	0.607	175.012	876.671	16.089	6.308	7.926	6.656	593.603	0.665	SEA F2	0.671
11	38.5	976.1	197.819	SEA H1	0.607	175.012	884.644	16.235	6.308	7.926	6.656	593.603	0.666	SEA F2	0.671
12	38.5	976.1	199.601	SEA H1	0.607	175.012	892.616	16.553	6.308	7.926	6.656	593.603	0.667	SEA F2	0.671
13	32.08	1079.481	203.253	SEA H1	0.607	175.012	952.75	18.163	6.308	6.985	5.044	618.943	0.657	SEA F2	0.682
14	32.08	1079.481	205.122	SEA H1	0.607	175.012	961.51	18.578	6.308	6.985	5.044	618.943	0.658	SEA F2	0.682
15	32.08	1076.298	206.99	SEA H1	0.607	175.012	1544.624	30.237	6.308	6.985	5.044	662.861	0.723	SEA F2	0.69

The “as built” scantlings of bottom longitudinals for all the three ships are:

Bottom longitudinals (L1-12): 400x100x13x18 (Inv.angle)

Bottom longitudinals (L13-15):398x15x11x15 (T)

SIDE SHELL

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
17	185.761	962.186	185.19	SEABAL 2 HS2	0.628	117.039	933.184	5.377	6.808	5.943	9.359	31048.04	3594.062	0.425	0.474	0.9
18	156.005	867.398	204.335	SEABAL 2 S Sta	0.718	41.6	757.36	4.648	6.808	5.974	9.359	27364.97	3037.334	0.371	0.424	0.9
19	156.005	867.398	203.581	SEABAL 2 S Sta	0.735	36.333	737.389	4.631	6.808	5.974	9.359	27364.97	3037.334	0.324	0.37	0.9
20	156.005	867.398	195.034	SEABAL 2 S Sta	0.75	31.065	691.98	4.436	6.808	5.974	9.359	27364.96	3037.332	0.277	0.316	0.9
21	158.026	868.212	177.438	SEABAL 2 S Sta	0.75	20.22	666.58	4.241	6.808	5.978	9.359	27484.7	3074.108	0.181	0.207	0.9
22	156.343	760.358	168.388	SEABAL 2 S Sta	0.75	14.642	632.583	4.579	6.808	5.191	9.359	21148.87	3035.919	0.132	0.143	0.9
23	156.343	760.358	159.338	SEABAL 2 S Sta	0.75	9.065	598.586	4.333	6.808	5.191	9.359	21148.87	3035.919	0.131	0.143	0.9
24	156.342	760.358	150.288	SEABAL 2 S Sta	0.75	3.487	564.587	4.087	6.808	5.191	9.359	21148.85	3035.913	0.131	0.143	0.9
25	152.98	729.189	132.189	SEABAL 2 S Sta	0.75	9.847	496.594	3.595	6.808	5.191	9.359	20490.66	2959.646	0.132	0.144	1
26	152.98	729.189	123.139	SEABAL 2 S Sta	0.75	17.01	462.598	3.349	6.808	5.191	9.359	20490.67	2959.648	0.132	0.144	1
27	152.98	729.189	114.09	SEABAL 2 S Sta	0.75	24.172	428.601	3.102	6.808	5.191	9.359	20490.67	2959.648	0.161	0.176	1
28	146.79	529.107	130.277	SEA BS7b	0.9	-29.459	407.842	3.424	6.808	4.434	8.394	13173.25	2819.242	0.214	0.225	1
29	146.79	529.107	123.711	SEA BS7b	0.885	-36.193	393.806	3.252	6.808	4.434	8.394	13173.24	2819.233	0.263	0.276	1
30	147.29	412.054	105.711	SEA BS7b	0.842	-49.661	353.588	3.301	6.808	3.662	8.394	8772.563	2810.167	0.373	0.364	1
31	147.29	412.054	96.711	SEA BS7b	0.821	-56.395	331.908	3.02	6.808	3.662	8.394	8772.564	2810.169	0.424	0.413	1
32	170.98	380.098	87.711	SEA BS7b	0.8	-63.129	309.069	2.711	6.808	3.674	8.297	8488.363	3225.037	0.492	0.463	1
33	170.98	380.098	78.711	SEA BS7b	0.778	-69.863	284.974	2.432	6.808	3.674	8.297	8488.363	3225.037	0.546	0.513	1
34	218.58	382.854	69.711	SEA BS7b	0.757	-76.597	345.303	2.724	6.808	3.674	8.297	8826.998	4088.787	0.68	0.564	1

The “as built” scantlings of side longitudinals are the same for double hull oil tanker and double skin bulk carrier. These are:

Side longitudinals (L17): 400x100x12x18 (Inv.angle)

Side longitudinals (L18-21): 400x100x11.5x16 (Inv.angle)

Side longitudinals (L22-24): 350x100x12x17 (Inv.angle)

Side longitudinals (L25-27): 350x100x11x17 (Inv.angle)

Side longitudinals (L28-29): 300x90x11x16 (Inv.angle)

Side longitudinals (L30-34): 250x90x11x16 (Inv.angle)

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
17	34.65	941.476	255.403	SEABAL 3 H1	0.73	138.937	1108.231	24.428	6.308	7.926	6.656	643.768	0.698	SEABAL 3 H2	0.538
18	32.895	856.603	254.233	SEABAL 3 H1	0.79	121.035	895.076	21.368	6.308	7.967	6.656	613.237	0.623	SEAHBAL 3 H2	0.473
19	32.895	856.603	253.064	SEABAL 3 H1	0.851	103.134	827.495	21.27	6.308	7.967	6.656	613.237	0.56	SEAHBAL 3 H2	0.403
20	32.895	856.603	244.681	SEABAL 3 H1	0.9	85.233	756.377	20.565	6.308	7.967	6.656	613.236	0.498	SEAHBAL 3 H2	0.333
21	32.916	854.403	221.324	SEABAL 3 H1	0.9	48.377	724.419	19.696	6.308	7.972	6.656	611.833	0.429	SEABAL 3 R1	0.19
22	30.263	748.899	209.311	SEABAL 3 H1	0.9	29.423	685.102	18.627	6.308	6.922	6.656	617.187	0.435	SEABAL 3 R1	0.147
23	30.263	748.899	197.834	SEAHBAL 3 H1	0.9	10.469	647.534	17.606	6.308	6.922	6.656	625.1	0.402	SEABAL 3 R1	0.118
24	30.263	748.899	185.711	SEAHBAL 3 H1	0.9	-8.486	607.856	16.527	6.308	6.922	6.656	623.222	0.392	SEABAL 3 R1	0.114
25	26.9	719.232	169.054	SEA P1	0.9	-34.73	553.334	15.045	6.308	6.922	6.656	627.094	0.481	SEAHBAL 3 H1	0.175
26	26.9	719.232	163.815	SEA P1	0.9	-48.918	536.187	14.578	6.308	6.922	6.656	627.094	0.523	SEAHBAL 3 H1	0.247
27	26.9	719.232	158.576	SEA P1	0.9	-63.107	519.04	14.112	6.308	6.922	6.656	621.997	0.566	SEABAL 3 H1	0.319
28	22.98	522.614	153.338	SEA P1	0.9	-77.296	501.893	13.646	6.308	5.914	5.97	615.137	0.718	SEABAL 3 H1	0.384
29	22.98	522.614	147.252	SEA P1	0.89	-91.484	487.238	13.104	6.308	5.914	5.97	610.376	0.755	SEABAL 3 H1	0.454
30	18.96	408.443	129.153	SEA P1	0.794	-119.862	479.044	11.494	6.308	4.879	5.97	627.094	0.934	SEABAL 3 H1	0.569
31	18.96	408.443	120.103	SEA P1	0.746	-134.05	474.157	10.688	6.308	4.879	5.97	627.094	0.964	SEABAL 3 H1	0.637
32	18.98	410.232	111.053	SEA P1	0.698	-148.239	468.596	9.883	6.308	4.884	5.97	627.094	0.996	SEABAL 3 H1	0.703
33	16.643	372.451	102.003	SEA P1	0.65	-162.428	462.213	9.078	6.308	4.895	5.902	627.094	1.066	SEABAL 3 H1	0.779
34	16.643	372.451	92.954	SEA P1	0.602	-176.617	454.81	8.272	6.308	4.895	5.902	627.093	1.133	SEABAL 3 H1	0.848

UPPER DECK

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
35	212.98	382.59	47.674	SEA BS7b	0.741	-81.683	234.242	1.819	6.808	3.674	8.297	8794.59	3987.168	0.735	0.615	1
36	141.179	377.442	46.426	SEA BS7b	0.74	-81.99	140.238	1.173	6.808	3.674	8.297	8168.069	2684.251	0.62	0.614	1
37	159.78	379.219	44.883	Slosh. 1 Sta	0.627	70.219	185.978	1.277	6.808	3.674	8.297	8381.223	3021.801	0.648	0.619	1
38	159.78	379.219	44.883	Slosh. 1 Sta	0.626	70.48	186.225	1.241	6.808	3.674	8.297	8381.223	3021.801	0.65	0.621	1
39	159.78	379.219	44.883	Slosh. 1 Sta	0.625	70.742	186.472	1.205	6.808	3.674	8.297	8381.223	3021.801	0.653	0.624	1
40	159.78	379.219	44.883	Slosh. 1 Sta	0.625	71.004	186.72	1.169	6.808	3.674	8.297	8381.223	3021.801	0.655	0.626	1
41	159.78	379.219	39.287	SEA BS7b	0.734	-83.75	139.055	1.133	6.808	3.674	8.297	8381.223	3021.801	0.658	0.628	1
42	159.78	379.219	29.556	LIQ 1 S Sta	0.566	89.409	135.648	1.097	6.808	3.674	8.297	8381.223	3021.801	0.66	0.63	1
43	159.78	379.219	29.143	LIQ 1 S Sta	0.565	89.737	133.997	1.061	6.808	3.674	8.297	8381.223	3021.801	0.663	0.633	1
44	159.78	379.219	28.729	LIQ 1 S Sta	0.564	90.064	132.339	1.025	6.808	3.674	8.297	8381.223	3021.801	0.665	0.635	1
45	159.78	379.219	28.316	LIQ 1 S Sta	0.563	90.391	130.675	1.019	6.808	3.674	8.297	8381.223	3021.801	0.667	0.637	1
46	159.78	379.219	27.903	LIQ 1 S Sta	0.562	90.718	129.005	1.019	6.808	3.674	8.297	8381.223	3021.801	0.67	0.639	1
47	159.78	379.219	27.489	LIQ 1 S Sta	0.561	91.045	127.329	1.019	6.808	3.674	8.297	8381.223	3021.801	0.672	0.642	1
48	159.78	379.219	35.345	SEA BS7b	0.727	-85.903	126.277	1.019	6.808	3.674	8.297	8381.223	3021.801	0.675	0.644	1
49	159.78	379.219	44.883	Slosh. 1 Sta	0.617	73.36	188.983	1.019	6.808	3.674	8.297	8381.223	3021.801	0.677	0.646	1
50	159.78	379.219	44.883	Slosh. 1 Sta	0.616	73.622	189.238	1.019	6.808	3.674	8.297	8381.223	3021.801	0.68	0.648	1
51	159.78	379.219	44.883	Slosh. 1 Sta	0.615	73.883	189.494	1.019	6.808	3.674	8.297	8381.223	3021.801	0.682	0.651	1
52	161.165	379.334	44.883	Slosh. 1 Sta	0.615	74.145	191.729	1.07	6.808	3.674	8.297	8395.231	3046.931	0.687	0.653	1

The “as built” scantlings of deck longitudinals are the same for all the three ships. These are:

Deck longitudinals: 250x90x11x16 (Inv.angle)

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	16.66	376.98	48.205	BAL 3 H1	0.335	-255.474	335.853	4.557	6.308	4.9	5.902	567.239	1.098	BAL 3 H1	0.912
2	16.66	376.98	48.078	BAL 3 H1	0.332	-256.286	393.436	4.972	6.308	4.9	5.902	607.569	1.177	BAL 3 H1	0.916
3	16.66	376.98	47.951	BAL 3 H1	0.33	-257.097	395.669	4.635	6.308	4.9	5.902	607.569	1.18	BAL 3 H1	0.919
4	16.66	376.98	47.824	BAL 3 H1	0.327	-257.909	397.94	4.298	6.308	4.9	5.902	607.569	1.183	BAL 3 H1	0.922
5	16.66	376.98	47.697	BAL 3 H1	0.324	-258.721	400.25	3.961	6.308	4.9	5.902	607.569	1.186	BAL 3 H1	0.925
6	16.66	376.98	47.57	BAL 3 H1	0.321	-259.532	402.598	3.908	6.308	4.9	5.902	607.569	1.189	BAL 3 H1	0.928
7	16.66	376.98	47.444	BAL 3 H1	0.319	-260.344	404.988	4.227	6.308	4.9	5.902	607.569	1.192	BAL 3 H1	0.93
8	16.66	376.98	47.317	BAL 3 H1	0.316	-261.155	407.419	4.555	6.308	4.9	5.902	607.569	1.195	BAL 3 H1	0.933
9	16.66	376.98	47.19	BAL 3 H1	0.313	-261.967	409.892	4.883	6.308	4.9	5.902	607.569	1.198	BAL 3 H1	0.936
10	16.66	376.98	47.063	BAL 3 H1	0.31	-262.779	342.846	4.333	6.308	4.9	5.902	558.267	1.109	BAL 3 H1	0.938

Single skin bulk carrier

ISti	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	16.66	376.98	58.359	BAL 3 H1	0.323	-259.131	422.2	5.686	6.308	4.9	5.902	567.239	1.149	BAL 3 H1	0.925
2	16.66	376.98	57.845	BAL 3 H1	0.32	-259.942	491.675	6.151	6.308	4.9	5.902	607.569	1.235	BAL 3 H1	0.929
3	16.66	376.98	57.33	BAL 3 H1	0.317	-260.753	491.521	5.678	6.308	4.9	5.902	607.569	1.236	BAL 3 H1	0.932
4	16.66	376.98	56.816	BAL 3 H1	0.314	-261.564	491.365	5.205	6.308	4.9	5.902	607.569	1.238	BAL 3 H1	0.935
5	16.66	376.98	56.302	BAL 3 H1	0.312	-262.375	491.206	4.732	6.308	4.9	5.902	607.569	1.239	BAL 3 H1	0.938
6	16.66	376.98	55.787	BAL 3 H1	0.309	-263.186	491.044	4.643	6.308	4.9	5.902	607.569	1.24	BAL 3 H1	0.941
7	16.66	376.98	55.273	BAL 3 H1	0.306	-263.998	490.879	5.044	6.308	4.9	5.902	607.569	1.241	BAL 3 H1	0.943
8	16.66	376.98	54.758	BAL 3 H1	0.303	-264.809	490.711	5.445	6.308	4.9	5.902	607.569	1.243	BAL 3 H1	0.946
9	16.66	376.98	54.244	BAL 3 H1	0.301	-265.62	490.541	5.846	6.308	4.9	5.902	607.569	1.244	BAL 3 H1	0.949
10	16.66	376.98	53.73	BAL 3 H1	0.298	-266.431	407.654	5.193	6.308	4.9	5.902	558.267	1.146	BAL 3 H1	0.951

INNER BOTTOM

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
1	140.998	859.254	219.217	LIQ 1 S Sta	0.653	-61.899	871.636	4.907	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
2	140.998	859.254	219.217	LIQ 1 S Sta	0.653	-61.899	871.636	4.897	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
3	140.998	859.254	219.217	LIQ 1 S Sta	0.653	-61.899	871.636	4.897	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
4	140.998	859.254	219.217	LIQ 1 S Sta	0.653	-61.899	871.636	4.897	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
5	140.998	859.254	219.217	LIQ 1 S Sta	0.653	-61.899	871.636	4.897	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
6	140.998	859.254	219.217	LIQ 1 S Sta	0.653	-61.899	871.636	4.897	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
7	140.998	859.254	222.022	BAL 2 HS2	0.618	120.367	933.668	4.935	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
8	140.998	859.254	222.022	BAL 2 HS2	0.618	120.367	933.668	4.959	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
9	140.998	859.254	222.022	BAL 2 HS2	0.618	120.367	933.668	4.984	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
10	140.998	859.254	222.022	BAL 2 HS2	0.618	120.367	933.668	5.008	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
11	140.998	859.254	222.022	BAL 2 HS2	0.618	120.367	933.668	5.033	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9
12	140.998	859.254	222.022	BAL 2 HS2	0.618	120.367	933.668	5.058	6.808	5.982	9.359	26331.17	2765.197	0.405	0.47	0.9

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 2 H2	0.542
2	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 2 H2	0.542
3	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 2 H2	0.542
4	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 2 H2	0.542
5	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 2 H2	0.542
6	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 2 H2	0.542
7	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 3 H2	0.542
8	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 3 H2	0.542
9	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 3 H2	0.542

10	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 3 H2	0.542
11	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 3 H2	0.542
12	33.001	840.123	308.3	BULKHF 1 H1	0.743	135.041	1127.544	25.303	6.308	7.993	6.656	477.772	0.933	BAL 3 H2	0.542

Single skin bulk carrier

ISti	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	24.943	6.308	7.993	6.656	477.772	0.765	BAL 2 H2	0.526
2	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.505	25.112	6.308	7.993	6.656	477.772	0.765	BAL 2 H2	0.526
3	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	25.28	6.308	7.993	6.656	477.772	0.765	BAL 2 H2	0.526
4	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.505	25.449	6.308	7.993	6.656	477.772	0.765	BAL 2 H2	0.526
5	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.505	25.618	6.308	7.993	6.656	477.772	0.765	BAL 2 H2	0.526
6	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	25.787	6.308	7.993	6.656	477.772	0.765	BAL 2 H2	0.526
7	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	26.125	6.308	7.993	6.656	477.772	0.721	BAL 4 H2	0.526
8	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.505	26.294	6.308	7.993	6.656	477.772	0.721	BAL 4 H2	0.526
9	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.505	26.462	6.308	7.993	6.656	477.772	0.721	BAL 4 H2	0.526
10	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	26.631	6.308	7.993	6.656	477.772	0.721	BAL 4 H2	0.526
11	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	26.8	6.308	7.993	6.656	477.772	0.721	BAL 4 H2	0.526
12	33.001	840.123	301.261	HBAL 1 H1	0.756	131.13	1082.504	26.969	6.308	7.993	6.656	477.772	0.721	BAL 4 H2	0.526

Scantlings of inner bottom longitudinals: 400x100x11.5x16 (Inv.angle)

HOPPER SHELL

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
13	183.205	883.774	214.384	BAL 2 HS2	0.657	108.056	827.486	4.779	6.808	5.974	9.359	29119.63	3530.911	0.374	0.419	0.9
14	149.12	757.771	206.746	BAL 2 HS2	0.69	97.672	759.875	5.331	6.808	5.187	9.359	20810.28	2904.752	0.338	0.368	0.9
15	149.12	757.771	199.899	LIQ 1 S Sta	0.707	-45.131	717.25	5.173	6.808	5.187	9.359	20810.28	2904.752	0.302	0.33	0.9
16	150.192	758.18	242.4	LIQ 1 BS7b	0.9	-19.329	689.918	5.059	6.808	5.187	9.359	20862.57	2924.2	0.267	0.291	0.9

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	33.001	868.676	269.469	HBAL 1 H1	0.788	121.554	906.084	24.162	6.308	7.993	6.656	601.115	0.841	BAL 3 H2	0.471
2	30.353	740.191	296.689	HBAL 1 R1	0.9	-64.9	873.989	23.763	6.308	6.943	6.656	514.536	0.845	BAL 3 H2	0.411
3	30.353	740.191	291.711	HBAL 1 R1	0.9	-60.298	859.327	23.364	6.308	6.943	6.656	517.116	0.778	BAL 3 H2	0.359
4	30.353	740.191	286.734	HBAL 1 R1	0.9	-55.696	853.26	23.199	6.308	6.943	6.656	509.367	0.743	BAL 3 R1	0.308

Scantlings of hopper longitudinals (DHOT numbering of stiffeners):

Hopper longitudinal (L13):400x100x11.5x16 (Inv.angle)

Hopper longitudinals (L14-L16):350x100x12x17 (Inv.angle)

INNER SHELL

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
17	157.46	730.523	222.735	LIQ 1 BS7b	0.9	-12.537	697.291	5.044	6.808	5.187	9.359	20674.56	3040.849	0.183	0.199	0.9
18	157.46	730.523	210.876	LIQ 1 BS7b	0.9	-9.079	660.164	4.775	6.808	5.187	9.359	20674.55	3040.848	0.132	0.144	0.9
19	157.46	730.523	199.017	LIQ 1 BS7b	0.9	-5.62	623.037	4.507	6.808	5.187	9.359	20674.55	3040.848	0.132	0.144	0.9
20	157.46	730.523	187.157	LIQ 1 BS7b	0.9	-2.162	585.912	4.238	6.808	5.187	9.359	20674.56	3040.85	0.132	0.144	0.9
21	137.77	525.307	165.041	LIQ 1 BS5b	0.9	-10.382	516.675	4.355	6.808	4.43	8.394	12866.44	2655.468	0.134	0.143	1
22	137.77	525.307	154.306	LIQ 1 BS5b	0.9	-15.602	483.067	4.072	6.808	4.43	8.394	12866.44	2655.468	0.134	0.143	1
23	133.77	407.807	143.57	LIQ 1 BS5b	0.9	-20.81	449.458	4.513	6.808	3.659	8.394	8483.33	2564.737	0.168	0.168	1
24	133.77	407.807	132.835	LIQ 1 BS5b	0.9	-26.029	415.85	4.176	6.808	3.659	8.394	8483.33	2564.737	0.218	0.218	1
25	133.77	407.807	122.099	LIQ 1 BS5b	0.9	-31.248	382.242	3.838	6.808	3.659	8.394	8483.33	2564.737	0.268	0.267	1
26	135.495	408.064	100.629	LIQ 1 BS5b	0.868	-41.687	332.214	3.208	6.808	3.659	8.394	8512.04	2596.04	0.371	0.367	1
27	169.81	417.578	89.535	LIQ 1 BS5b	0.851	-47.08	306.484	2.85	6.808	3.666	8.394	9160.633	3218.909	0.436	0.412	1
28	166.48	378.575	78.442	LIQ 1 BS5b	0.833	-52.474	274.027	2.502	6.808	3.674	8.297	8406.139	3143.375	0.497	0.468	1
29	166.48	378.575	67.349	LIQ 1 BS5b	0.816	-57.867	240.209	2.148	6.808	3.674	8.297	8406.139	3143.375	0.553	0.519	1
30	162.744	378.284	56.255	LIQ 1 BS5b	0.799	-63.26	199.453	1.753	6.808	3.674	8.297	8370.396	3075.58	0.604	0.57	1

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
1	26.92	717.518	271.404	HBAL 1 R1	0.9	-43.356	888.337	24.153	6.308	6.927	6.656	593.731	0.715	BAL 3 R1	0.184
2	26.92	717.518	261.152	HBAL 1 R1	0.9	-35.711	854.784	23.241	6.308	6.927	6.656	599.876	0.655	BAL 3 R1	0.135
3	26.92	717.518	250.901	HBAL 1 R1	0.9	-28.065	821.229	22.329	6.308	6.927	6.656	609.321	0.595	BAL 3 R1	0.106
4	26.92	717.518	240.649	HBAL 1 R1	0.9	-26.995	787.675	21.416	6.308	6.927	6.656	607.454	0.563	BAL 3 R1	0.102
5	23	515.768	220.147	HBAL 1 R1	0.9	-41.075	720.567	19.592	6.308	5.919	5.97	530.083	0.731	BAL 3 R1	0.175
6	23	515.768	209.895	HBAL 1 R1	0.9	-48.115	687.013	18.679	6.308	5.919	5.97	547.522	0.75	HBAL 3 H1	0.247
7	19	401.277	199.644	HBAL 1 R1	0.9	-55.156	653.459	17.767	6.308	4.889	5.97	537.935	0.937	BAL 3 H1	0.305

8	19	401.277	189.393	HBAL 1 R1	0.9	-62.196	619.905	16.855	6.308	4.889	5.97	531.837	0.971	BAL 3 H1	0.374
9	19	401.277	179.141	HBAL 1 R1	0.9	-69.236	586.351	15.942	6.308	4.889	5.97	527.609	1.004	BAL 3 H1	0.442

The “as built” scantlings of inner side longitudinals are the same for double hull oil tanker and double skin bulk carrier. These are (DHOT numbering):

Side longitudinals (L17-L20): 350x100x11x17 (Inv.angle)

Side longitudinals (L21-22): 300x90x11x16 (Inv.angle)

Side longitudinals (L23-30): 250x90x11x16 (Inv.angle)

GIRDERS

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
Centre girder																
1	88.088	119.349	233.898	BAL 3 S Sta	0.626	-70.653	781.149	8.445	6.808	10.525	0	2114.553	1680.111	0.599	0.729	0.9
2	96.75	120.119	226.356	BAL 3 S Sta	0.645	-64.684	824.429	9.061	6.808	10.525	0	2156.647	1837.302	0.578	0.673	0.9
Side girder I																
1	118.48	840.857	238.601	BAL 2 HS2	0.569	135.688	911.972	4.52	6.808	5.974	9.359	24279.59	2356.397	0.474	0.56	0.9
2	118.48	840.857	230.311	BAL 2 HS2	0.603	124.932	830.475	4.379	6.808	5.974	9.359	24279.59	2356.397	0.437	0.516	0.9
Side girder II																
1	88.088	119.349	12	Slosh. 2 Sta	0.71	44.014	35.305	0	5.808	10.525	0	2114.553	1680.111	0.599	0.729	0.9
2	96.75	120.119	12	Slosh. 2 Sta	0.722	40.296	39.02	0	5.808	10.525	0	2156.647	1837.302	0.578	0.673	0.9

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
Centre girder															
1	18	119.349	233.898	BAL 2 H1	0.636	166.631	803.665	15.438	6.308	11.323	0	489.428	1.099	BAL 2 H2	0.836
2	18	119.555	226.356	BAL 2 H1	0.689	150.836	806.088	16.787	6.308	11.323	0	504.849	1.081	BAL 2 H2	0.764
Side girder I															

1	32.895	840.228	296.227	HBAL 3 H1	0.644	164.315	1046.846	20.358	6.308	7.967	6.656	495.456	0.863	BAL 3 H2	0.65
2	32.895	840.228	286.866	HBAL 3 H1	0.693	149.678	941.301	19.714	6.308	7.967	6.656	496.666	0.804	BAL 3 H2	0.592
Side girder II															
1	18	119.349					0	0	6.308	11.323	0	490.612	0.609	H2	0.74
2	18	119.555					0	0	6.308	11.323	0	503.722	0.736	H2	0.827

Single skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
Centre girder															
1	18	119.349	157.702	BAL 2 H1	0.65	162.7	530.751	10.409	6.308	11.323	0	489.706	0.883	BAL 2 H2	0.817
2	18	119.555	147.692	BAL 2 H1	0.703	146.915	516.017	10.953	6.308	11.323	0	505.237	0.853	BAL 2 H2	0.744
Side girder I															
1	32.895	840.228	156.234	BAL 2 H1	0.657	160.385	540.941	11.118	6.308	7.967	6.656	495.751	0.705	BAL 4 F2	0.635
2	32.895	840.228	146.958	BAL 2 H1	0.707	145.758	473.16	10.496	6.308	7.967	6.656	497.021	0.646	BAL 4 F2	0.577
Side girder II															
1	18	119.349	-	-	-	-	0	0	6.308	11.323	0	490.95	0.591	H2	0.72
2	18	119.555	-	-	-	-	0	0	6.308	11.323	0	504.054	0.714	H2	0.807

The “as built” scantlings of girders are the same for all the three ships. These are:

Center girder longitudinals (L1-L2): 200x12 (flat bar)

Side girder I longitudinals (L1-L2): 400x100x11.5x16 (inv.angle)

Side girder II longitudinals (L1-L2): 200x12 (flat bar)

STRINGERS

Double hull oil tanker

No Stiff.	CrssA_Net	W_Net	Pw+Ps	WLoad Case	Cs	Sig.hg	WLoad_net	TwShr	tMini0	tMini PropW	tMini PropFl	Iner A	Iner R	Col B Arat	Tor B Arat	Allow B rat
Stringer I																
1	88.875	119.425	12	Slosh. 2 Sta	0.75	21.63	33.81	0	5.808	10.525	0	2118.698	1694.401	0.268	0.342	0.9
2	88.612	119.4	12	Slosh. 2 Sta	0.75	21.63	33.685	0	5.808	10.525	0	2117.324	1689.637	0.267	0.342	0.9
Stringer II																
1	78.75	117.402	12	Slosh. 2 Sta	0.75	0.874	33.81	0	5.808	10.525	0	2037.67	1510.671	0.147	0.201	0.9
2	78.525	117.375	12	Slosh. 2 Sta	0.75	0.874	33.685	0	5.808	10.525	0	2036.218	1506.588	0.147	0.201	0.9
Stringer III																
1	82.125	118.102	12	Slosh. 2 Sta	0.738	35.255	34.356	0	5.808	10.525	0	2065.917	1571.914	0.349	0.458	1
2	81.887	118.076	12	Slosh. 2 Sta	0.738	35.255	34.229	0	5.808	10.525	0	2064.492	1567.604	0.349	0.457	1

Double skin bulk carrier

No Stiff.	ShrA_Net A	W_Net	Pw+Ps	WLoad Case	lambds	Sig.x	WLoad_net	Ash	tMini0	tMini PropW	tMini PropFl	Eff Spac	Lat B Arat	B case	Tor B Arat
Stringer I															
1	18	119.425					0	0	6.308	11.323	0	480.107	0.265	H2	0.338
2	18	119.4					0	0	6.308	11.323	0	479.75	0.264	H2	0.338
Stringer II															
1	18	117.402					0	0	6.308	11.323	0	423.225	0.104	H1	0.184
2	18	117.375					0	0	6.308	11.323	0	422.963	0.104	H1	0.19
Stringer III															
1	18	118.102					0	0	6.308	11.323	0	442.619	0.575	H1	0.727
2	18	118.076					0	0	6.308	11.323	0	442.327	0.574	H1	0.727

The “as built” scantlings of stringers are the same for double hull oil tanker and double skin bulk carrier. These are:

Stringer I longitudinals (L1-L2): 200x12 (flat bar)

Stringer II longitudinals (L1-L2): 200x12 (flat bar)

Stringer III longitudinals (L1-L2): 200x12 (flat bar)

4.6 VERIFICATION

The procedure of verification involves both hull girder strength criteria and local strength criteria. As far as hull girder strength criteria are concerned, section moduli (modulus at deck and bottom) and hull girder moment of inertia as well as ultimate bending capacity are checked. In case of local strength criteria, buckling, ultimate strength and fatigue of stiffeners are checked. Everything else (e.g. elements of Table 1 Chapter 8, Section 1, page 3 in CSR for Bulk carriers) is checked by using finite element analysis, which exceeds the scope of present thesis.

4.6.1 HULL GIRDER STRENGTH CRITERIA

Section modulus- moment of inertia

Double hull oil tanker

	Rule	Actual		Distance from baseline	
Modulus at deck	17.18119	22.98247	m ³	20.6	m
Modulus at bottom	17.18119	27.04953	m ³	0	m
Inertia	145.7097	255.9622	m ⁴		

Double skin bulk carrier

	Rule	Actual		Distance from baseline	
Modulus at deck	17.5831	16.80342	m ³	20.6	m
Modulus at bottom	17.5831	23.93420	m ³	0	m
Inertia	145.7097	203.3706	m ⁴		

Single skin bulk carrier

	Rule	Actual		Distance from baseline	
Modulus at deck	17.5831	16.56573	m ³	20.6	m
Modulus at bottom	17.5831	24.47291	m ³	0	m
Inertia	145.7097	203.5028	m ⁴		

DISCUSSION

Although both CSR provide the same formula as net rule hull girder section modulus at deck and keel at the midship cross section, the previous Tables show that net rule section modulus differs between the examined double hull oil tanker and the two bulk carriers.

Although both CSR require that net rule section modulus can't be less than :

$$Z_v = 0.9kC_{wv}L^2B(C_B + 0.7) \cdot 10^{-6}$$

both CSR also require that (Z_v) can't be less than: (see Chapter "Design verification")

$$Z_v = \frac{|M_{SW-PERM} + M_{WV-V}|}{\sigma_{perm}}$$

In case of double hull oil tanker both formulae give the same result, equal to 17.18119m³. On the other hand, the first formula gives for bulk carriers the same result as in case of oil tanker but the second gives a result equal to 17.5831m³. Consequently, the value of rule minimum net vertical section modulus Z_v is derived from the second formula, and that is why the value of Z_v differs between the examined double hull oil tanker and the examined bulk carriers.

In addition there is great difference between the actual and the rule value of Z_v in case of tanker and that obviously shows bad design of the midship section. In fact that is not true. In order to compare the implementation of CSR in these three ships we used only the rule values of still water hull girder bending moments and not the one provided by the shipyard that constructed the double hull oil tanker that we use as basis of the comparison.

In case of bulk carriers, actual section modulus at bottom is much more higher than the rule section modulus at bottom, but actual section modulus at deck is less than the rule one. That happens because in contrast with oil tankers whose deck extends from one side of the ship to the other, bulk carriers' deck is disrupted by the hatches, which are not involved in calculation of actual section modulus.

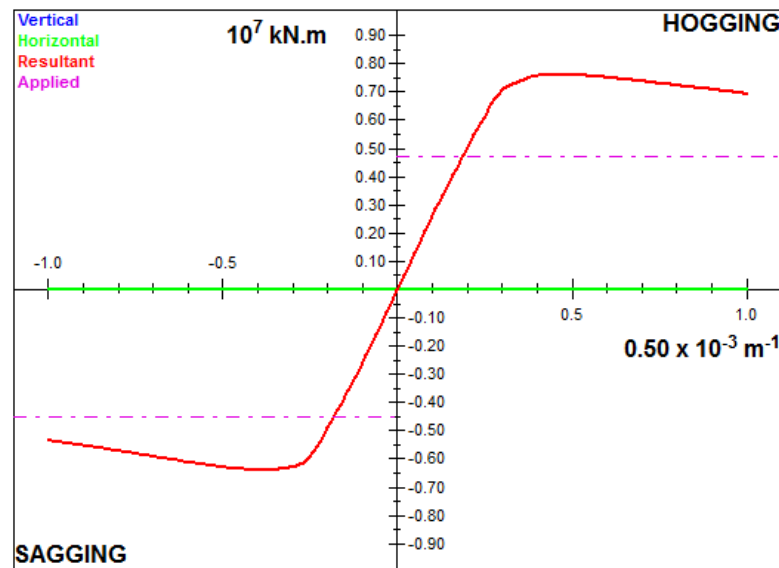
The fact that actual section modulus at deck is less than the rule one conducts us to the conclusion that the thicknesses of the deck plates of the examined bulk carriers must be increased. This remark was also made in paragraph 4.4 "Calculation of minimum net thickness of plates" of the present chapter. The results of the calculation of section modulus verify that conclusion. It is obvious that scantlings are controlled by section modulus requirements.

4.6.2 ULTIMATE BENDING CAPACITY

In the following pages are presented the calculations that concern the ultimate strength check for the three examined ships. In addition, there are provided three figures that present the curves of the hull girder bending moment-curvature relationship (M-k) of the midship section. These curves represent the progressive collapse behavior of hull girder under vertical bending.

Double hull oil tanker

	Mu		Ultimate	Mb	%	
Hogging	7616076	Navigation	6923705	4696264	67.83	Hogging
Sagging	-6402369		-5820335	-4499662	77.31	Sagging
		Full load homogeneous full load condition	-5820335	-3499873	60.13	Sagging



Bending moment-curvature Curve M-k for the double hull oil tanker

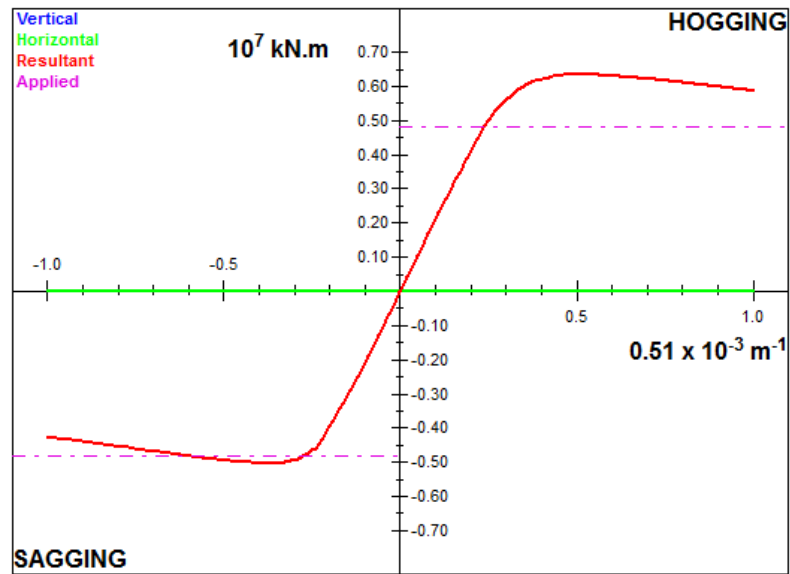
M_U is the vertical hull girder ultimate bending capacity, in kNm, as defined in Appendix A/1.1.1 of CSR for double hull oil tankers. The column with the heading “Ultimate” is defined as $:M_U/\gamma_R$. The capacity is to be based on net scantlings using a corrosion addition, $0.5t_{corr}$. M_b is the vertical hull girder bending moment in the ultimate strength check which is defined as:

$$M_b = \gamma_s M_{sw} + \gamma_w M_{wv-sag} \quad (\text{see chapter “Design verification”})$$

It can be easily seen that the examined double hull oil tanker satisfies the criteria of ultimate strength check according to CSR for double hull oil tankers.

Double skin bulk carrier

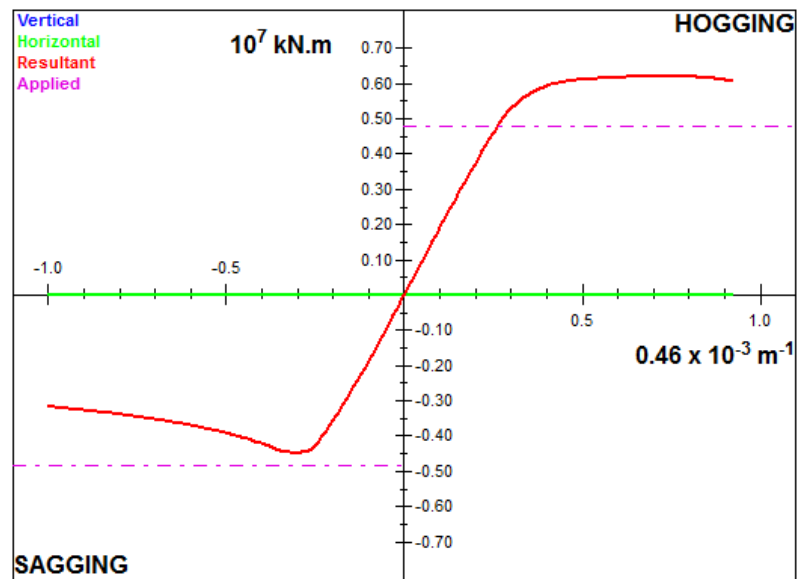
	Mu		Ultimate	Mb	%	
Hogging	6364107	Navigation	5785552	4794163	82.86	Hogging
Sagging	-5032518		-4575017	-4821504	105.39	Sagging
		Harbour	5785552	4487502	77.56	Hogging
			-4575017	-4498439	98.33	Sagging
		Damaged	5785552	2453285	42.40	Hogging
			-4576017	2584522	56.49	Sagging



Bending moment-curvature Curve M-k for the double skin bulk carrier

Single skin bulk carrier

	Mu		Ultimate	Mb	%	
Hogging	6220120	Navigation	5654655	4794163	84.78	Hogging
Sagging	-4479173		-4071975	-4821504	118.41	Sagging
		Harbour	5654655	4487502	79.36	Hogging
			-4071975	-4498439	110.47	Sagging
		Damaged	5654655	2453285	43.39	Hogging
			-4071975	-2584522	63.47	Sagging



Bending moment-curvature Curve M-k for the single skin bulk carrier

The abbreviations used in Tables of the examined bulk carriers have the same definition as in case of double hull oil tanker. The vertical hull girder ultimate bending capacity of tanker is higher than these of bulk carriers and between the two bulk carriers the one of double skin is higher than that of single skin. The hull girder ultimate bending moment capacity is calculated for both types of ships (tanker and bulk carriers) with a code developed by the Technical University of Szczecin that is used in MARS 2000 of Bureau Veritas. Both bulk carriers do not satisfy the criteria of ultimate strength check as it can be easily seen (from the red colored cells) , namely in intact (navigation) condition –for both of them- and in harbour condition –for single skin bulk carrier- and only in sagging.

LOCAL STRENGTH CRITERIA

4.6.3 BUCKLING AND ULTIMATE STRENGTH OF STIFFENERS

The buckling and ultimate strength check of stiffeners is presented in the previous Tables that refer to the scantling requirements of stiffeners. More specifically these Tables present the calculations that have been done in order to verify stiffeners against column buckling mode and torsional buckling mode. As far as torsional buckling in double hull oil tanker is concerned, the wave load cases that are checked are only HS1,HS2,HS3 and OS4a, while in bulk carriers verification of torsional buckling of stiffeners, every wave load case is checked.

4.6.4 FATIGUE STRENGTH OF STIFFENERS

The following Tables present the implementation of CSR requirements as far the fatigue strength assessment of longitudinals stiffeners is concerned. In case of double hull oil tanker the basic design S-N curve that is used was the F class. The breadth of flange from web centreline is 5mm and the distance to the hot spot from the closest end of the span l (x_f) is 0.0mm. On the other hand, in case of bulk carriers, the basic design curve used is the B class, the connection type of the non-watertight longitudinal end connection at transverse webs or floors is the first one (bracket type 1), the breadth of the flange from web centreline is 5mm and the values of relative deflections in the direction perpendicular to the attached plate between the transverse bulkhead or floor in way of stools and the adjacent transverse web or floor $\delta_{F,ij(k)}$, $\delta_{A,ij(k)}$ were not filled because there was not available data.

Double hull oil tanker

BOTTOM SHELL

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
1	13.00x400.00 + 18.00x100.00 (angle)	0.10	0.21	0.31	Life > 40
2	13.00x400.00 + 18.00x100.00 (angle)	0.10	0.20	0.30	Life > 40
3	13.00x400.00 + 18.00x100.00 (angle)	0.10	0.20	0.30	Life > 40
4	13.00x400.00 + 18.00x100.00 (angle)	0.10	0.19	0.30	Life > 40
5	13.00x400.00 + 18.00x100.00 (angle)	0.10	0.20	0.30	Life > 40
6	13.00x400.00 + 18.00x100.00 (angle)	0.11	0.20	0.31	Life > 40
7	13.00x400.00 + 18.00x100.00 (angle)	0.12	3.25	3.37	7.4
8	13.00x400.00 + 18.00x100.00 (angle)	0.12	3.11	3.24	7.7
9	13.00x400.00 + 18.00x100.00 (angle)	0.13	3.02	3.15	7.9
10	13.00x400.00 + 18.00x100.00 (angle)	0.16	3.06	3.22	7.8
11	13.00x400.00 + 18.00x100.00 (angle)	0.18	3.04	3.22	7.8
12	13.00x400.00 + 18.00x100.00 (angle)	0.21	3.05	3.26	7.7
13	11.00x398.00 + 15.00x150.00 (t-bar)	0.16	1.08	1.24	20.2
14	11.00x398.00 + 15.00x150.00 (t-bar)	0.18	1.09	1.26	19.8
15	11.00x398.00 + 15.00x150.00 (t-bar)	0.30	2.70	3.00	8.3

SIDE SHELL

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
17	12.00x400.00 + 18.00x100.00 (angle)	3.19	6.94	10.13	2.5
18	11.50x400.00 + 16.00x100.00 (angle)	2.60	4.35	6.96	3.6
19	11.50x400.00 + 16.00x100.00 (angle)	2.79	3.33	6.12	4.1
20	11.50x400.00 + 16.00x100.00 (angle)	3.21	2.54	5.75	4.4
21	11.50x400.00 + 16.00x100.00 (angle)	3.33	1.65	4.98	5.0
22	12.00x350.00 + 17.00x100.00 (angle)	4.27	1.67	5.95	4.2
23	12.00x350.00 + 17.00x100.00 (angle)	4.12	1.16	5.29	4.7
24	12.00x350.00 + 17.00x100.00 (angle)	3.98	0.77	4.75	5.3
25	11.00x350.00 + 17.00x100.00 (angle)	4.36	0.43	4.79	5.2
26	11.00x350.00 + 17.00x100.00 (angle)	3.74	0.24	3.98	6.3
27	11.00x350.00 + 17.00x100.00 (angle)	3.29	0.15	3.44	7.3
28	11.00x300.00 + 16.00x90.00 (angle)	5.07	0.15	5.21	4.8
29	11.00x300.00 + 16.00x90.00 (angle)	4.26	0.11	4.38	5.7
30	11.00x250.00 + 16.00x90.00 (angle)	2.51	0.18	2.68	9.3
31	11.00x250.00 + 16.00x90.00 (angle)	1.49	0.24	1.73	14.5
32	11.00x250.00 + 16.00x90.00 (angle)	9.36	0.33	1.27	19.7
33	11.00x250.00 + 16.00x90.00 (angle)	6.09	0.48	1.09	22.9
34	11.00x250.00 + 16.00x90.00 (angle)	5.27	0.72	1.25	20.0

UPPER DECK

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
35	11.00x250.00 + 16.00x90.00 (angle)	0.30	0.73	1.03	24.3
36	11.00x250.00 + 16.00x90.00 (angle)	0.27	0.72	0.98	25.4
37	11.00x250.00 + 16.00x90.00 (angle)	0.22	0.70	0.92	27.1
38	11.00x250.00 + 16.00x90.00 (angle)	0.20	0.69	0.90	27.9
39	11.00x250.00 + 16.00x90.00 (angle)	0.19	0.69	0.87	28.6
40	11.00x250.00 + 16.00x90.00 (angle)	0.17	0.69	0.86	29.1
41	11.00x250.00 + 16.00x90.00 (angle)	0.16	0.69	0.85	29.5
42	11.00x250.00 + 16.00x90.00 (angle)	0.15	0.69	0.84	29.7
43	11.00x250.00 + 16.00x90.00 (angle)	0.14	0.70	0.84	29.8
44	11.00x250.00 + 16.00x90.00 (angle)	0.14	0.70	0.84	29.7
45	11.00x250.00 + 16.00x90.00 (angle)	0.13	0.71	0.85	29.5
46	11.00x250.00 + 16.00x90.00 (angle)	0.13	0.73	0.86	29.2
47	11.00x250.00 + 16.00x90.00 (angle)	0.13	0.74	0.87	28.7
48	11.00x250.00 + 16.00x90.00 (angle)	0.13	0.76	0.89	28.1
49	11.00x250.00 + 16.00x90.00 (angle)	0.13	0.77	0.90	27.7
50	11.00x250.00 + 16.00x90.00 (angle)	0.14	0.78	0.92	27.2
51	11.00x250.00 + 16.00x90.00 (angle)	0.14	0.80	0.94	26.7
52	11.00x250.00 + 16.00x90.00 (angle)	0.14	0.82	0.96	26.1

INNER BOTTOM

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
1	11.50x400.00 + 16.00x100.00 (angle)	0.01	0.03	0.04	Life > 40
2	11.50x400.00 + 16.00x100.00 (angle)	0.01	0.03	0.04	Life > 40
3	11.50x400.00 + 16.00x100.00 (angle)	0.01	0.03	0.04	Life > 40
4	11.50x400.00 + 16.00x100.00 (angle)	0.01	0.03	0.04	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	0.01	0.03	0.04	Life > 40
6	11.50x400.00 + 16.00x100.00 (angle)	0.02	0.03	0.05	Life > 40
7	11.50x400.00 + 16.00x100.00 (angle)	0.02	2.65	2.67	9.4
8	11.50x400.00 + 16.00x100.00 (angle)	0.02	2.50	2.52	9.9
9	11.50x400.00 + 16.00x100.00 (angle)	0.03	2.37	2.40	10.4
10	11.50x400.00 + 16.00x100.00 (angle)	0.03	2.24	2.27	11.0
11	11.50x400.00 + 16.00x100.00 (angle)	0.03	2.12	2.15	11.6
12	11.50x400.00 + 16.00x100.00 (angle)	0.05	2.00	2.05	12.2

HOPPER PLATE

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
13	11.50x400.00 + 16.00x100.00 (angle)	0.05	2.24	2.29	10.9
14	12.00x350.00 + 17.00x100.00 (angle)	0.06	2.29	2.35	10.6
15	12.00x350.00 + 17.00x100.00 (angle)	0.07	1.87	1.94	12.9
16	12.00x350.00 + 17.00x100.00 (angle)	0.08	1.54	1.62	15.4

INNER HULL

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
17	11.00x350.00 + 17.00x100.00 (angle)	0.15	1.32	1.47	17.0
18	11.00x350.00 + 17.00x100.00 (angle)	0.18	1.02	1.20	20.9
19	11.00x350.00 + 17.00x100.00 (angle)	0.20	0.79	0.99	25.3
20	11.00x350.00 + 17.00x100.00 (angle)	0.22	0.61	0.83	30.2
21	11.00x300.00 + 16.00x90.00 (angle)	0.46	0.85	1.31	19.1
22	11.00x300.00 + 16.00x90.00 (angle)	0.34	0.58	0.92	27.2
23	11.00x250.00 + 16.00x90.00 (angle)	0.47	0.73	1.20	20.8
24	11.00x250.00 + 16.00x90.00 (angle)	0.37	0.52	0.89	28.0
25	11.00x250.00 + 16.00x90.00 (angle)	0.30	0.41	0.71	35.3
26	11.00x250.00 + 16.00x90.00 (angle)	0.26	0.34	0.60	41.9
27	11.00x250.00 + 16.00x90.00 (angle)	0.26	0.36	0.61	41.3
28	11.00x250.00 + 16.00x90.00 (angle)	0.27	0.46	0.73	34.2
29	11.00x250.00 + 16.00x90.00 (angle)	0.32	0.60	0.92	27.3
30	11.00x250.00 + 16.00x90.00 (angle)	0.35	0.84	1.19	21.0

LONGITUDINAL BULKHEAD

Stiffener N°	Scantlings of stiffeners	Damage		Total Damage	Fatigue life
		Full load	Ballast		
1	11.50x400.00 + 16.00x100.00 (angle)	0.00	0.02	0.02	Life > 40
2	11.50x400.00 + 16.00x100.00 (angle)	0.00	0.01	0.01	Life > 40
3	11.00x350.00 + 17.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
4	13.00x400.00 + 18.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
5	11.00x350.00 + 17.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
6	11.00x350.00 + 17.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
7	11.00x350.00 + 17.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
8	11.00x350.00 + 17.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
9	11.00x350.00 + 17.00x100.00 (angle)	0.00	0.00	0.00	Life > 40
10	11.00x300.00 + 16.00x90.00 (angle)	0.00	0.00	0.00	Life > 40
11	11.00x300.00 + 16.00x90.00 (angle)	0.00	0.00	0.00	Life > 40
12	11.00x300.00 + 16.00x90.00 (angle)	0.00	0.00	0.00	Life > 40
13	11.00x300.00 + 16.00x90.00 (angle)	0.00	0.01	0.01	Life > 40
14	11.00x250.00 + 16.00x90.00 (angle)	0.00	0.03	0.03	Life > 40
15	11.00x250.00 + 16.00x90.00 (angle)	0.00	0.07	0.07	Life > 40
16	11.00x250.00 + 16.00x90.00 (angle)	0.00	0.12	0.12	Life > 40
17	11.00x250.00 + 16.00x90.00 (angle)	0.00	0.20	0.20	Life > 40
18	11.00x250.00 + 16.00x90.00 (angle)	0.00	0.30	0.30	Life > 40
19	11.00x250.00 + 16.00x90.00 (angle)	0.02	0.4	0.42	Life > 40
20	11.00x250.00 + 16.00x90.00 (angle)	0.03	0.54	0.57	Life > 40
21	11.00x250.00 + 16.00x90.00 (angle)	0.07	0.7	0.77	32.6

Double skin bulk carrier

Afterward of the stool

BOTTOM SHELL

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	13.00x400.00 + 18.00x100.00 (angle)	93.67	249.35	294.02	93.67	0.00	0.15	0.47	0.00	0.62	Life > 40
2	13.00x400.00 + 18.00x100.00 (angle)	95.23	252.67	297.80	95.23	0.00	0.16	0.50	0.00	0.66	37.8
3	13.00x400.00 + 18.00x100.00 (angle)	97.49	258.3	303.54	97.49	0.00	0.18	0.54	0.00	0.72	34.7
4	13.00x400.00 + 18.00x100.00 (angle)	99.09	261.68	307.37	99.09	0.00	0.19	0.57	0.00	0.76	32.8
5	13.00x400.00 + 18.00x100.00 (angle)	100.68	265.06	311.20	100.68	0.00	0.20	0.60	0.00	0.80	31.1
6	13.00x400.00 + 18.00x100.00 (angle)	102.28	268.44	315.02	102.28	0.00	0.21	0.63	0.00	0.85	29.5
7	13.00x400.00 + 18.00x100.00 (angle)	105.02	353.19	385.09	105.02	0.00	0.69	1.48	0.00	2.17	11.5
8	13.00x400.00 + 18.00x100.00 (angle)	106.6	354.49	385.59	106.60	0.00	0.70	1.49	0.00	2.19	11.4
9	13.00x400.00 + 18.00x100.00 (angle)	108.18	355.79	386.09	108.18	0.00	0.71	1.50	0.00	2.21	11.3
10	13.00x400.00 + 18.00x100.00 (angle)	110.25	358.53	387.92	110.25	0.00	0.73	1.53	0.00	2.26	11.0
11	13.00x400.00 + 18.00x100.00 (angle)	111.84	359.83	388.41	111.84	0.00	0.74	1.54	0.00	2.28	10.9
12	13.00x400.00 + 18.00x100.00 (angle)	113.44	361.13	388.91	113.44	0.00	0.76	1.54	0.00	2.30	10.8
13	11.00x398.00 + 15.00x150.00 (t-bar)	102.73	325.40	354.82	102.73	0.00	0.49	1.05	0.00	1.54	16.2
14	11.00x398.00 + 15.00x150.00 (t-bar)	103.97	326.47	355.25	103.97	0.00	0.49	1.06	0.00	1.55	16.1
15	11.00x398.00 + 15.00x150.00 (t-bar)	131.12	394.22	415.42	131.12	0.01	1.09	2.03	0.01	3.13	8.0

SIDE SHELL

Stiff. N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
17	12.00x400.00 + 18.00x100.00 (angle)	128.19	402.08	384.71	128.19	0.01	1.18	1.48	0.01	2.67	9.4
18	11.50x400.00 + 16.00x100.00 (angle)	127.74	384.93	363.91	127.74	0.01	0.99	1.17	0.01	2.17	11.5
19	11.50x400.00 + 16.00x100.00 (angle)	136.67	376.51	357.64	136.67	0.01	0.90	1.09	0.01	2.00	12.5
20	11.50x400.00 + 16.00x100.00 (angle)	144.95	367.00	351.27	144.95	0.01	0.81	1.01	0.01	1.84	13.6
21	11.50x400.00 + 16.00x100.00 (angle)	168.76	357.62	345.18	168.76	0.03	0.72	0.94	0.03	1.72	14.5
22	12.00x350.00 + 17.00x100.00 (angle)	205.47	389.07	362.69	205.47	0.08	1.03	1.15	0.08	2.34	10.7
23	12.00x350.00 + 17.00x100.00 (angle)	207.98	257.38	373.10	207.98	0.08	0.17	1.30	0.08	1.64	15.3
24	12.00x350.00 + 17.00x100.00 (angle)	208.01	191.81	368.19	208.01	0.08	0.04	1.23	0.08	1.44	17.4
25	11.00x350.00 + 17.00x100.00 (angle)	210.59	206.38	151.57	210.59	0.09	0.06	0.02	0.09	0.25	Life > 40
26	11.00x350.00 + 17.00x100.00 (angle)	202.92	207.65	140.91	202.92	0.07	0.06	0.01	0.07	0.22	Life > 40
27	11.00x350.00 + 17.00x100.00 (angle)	193.26	202.04	155.99	193.26	0.06	0.06	0.02	0.06	0.19	Life > 40
28	11.00x300.00 + 16.00x90.00 (angle)	238.45	252.4	207.91	238.45	0.15	0.16	0.10	0.15	0.57	Life > 40
29	11.00x300.00 + 16.00x90.00 (angle)	219.36	238.7	201.41	219.36	0.10	0.12	0.08	0.10	0.42	Life > 40
30	11.00x250.00 + 16.00x90.00 (angle)	220.57	265.6	219.47	220.57	0.11	0.20	0.13	0.11	0.54	Life > 40
31	11.00x250.00 + 16.00x90.00 (angle)	193.17	246.38	199.84	193.17	0.06	0.14	0.08	0.06	0.34	Life > 40
32	11.00x250.00 + 16.00x90.00 (angle)	167.74	249.46	204.44	295.15	0.03	0.15	0.09	0.40	0.67	37.4
33	11.00x250.00 + 16.00x90.00 (angle)	150.92	265.92	209.93	331.56	0.02	0.20	0.10	0.66	0.98	25.6
34	11.00x250.00 + 16.00x90.00 (angle)	132.33	281.81	212.37	339.77	0.01	0.26	0.11	0.73	1.11	22.6

INNER BOTTOM

Stiff. N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	50.05	179.49	57.52	115.76	0.00	0.03	0.00	0.00	0.03	Life > 40
2	11.50x400.00 + 16.00x100.00 (angle)	50.52	179.49	58.34	115.76	0.00	0.03	0.00	0.00	0.03	Life > 40
3	11.50x400.00 + 16.00x100.00 (angle)	50.99	179.49	59.16	115.76	0.00	0.03	0.00	0.00	0.03	Life > 40
4	11.50x400.00 + 16.00x100.00 (angle)	51.46	179.49	59.98	115.76	0.00	0.03	0.00	0.00	0.03	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	51.93	179.49	60.80	115.76	0.00	0.03	0.00	0.00	0.03	Life > 40
6	11.50x400.00 + 16.00x100.00 (angle)	52.4	179.49	61.62	115.76	0.00	0.03	0.00	0.00	0.03	Life > 40
7	11.50x400.00 + 16.00x100.00 (angle)	53.34	339.82	46.58	46.58	0.00	0.58	0.00	0.00	0.58	Life > 40
8	11.50x400.00 + 16.00x100.00 (angle)	53.81	339.82	46.58	46.58	0.00	0.58	0.00	0.00	0.58	Life > 40
9	11.50x400.00 + 16.00x100.00 (angle)	54.28	339.82	46.58	46.58	0.00	0.58	0.00	0.00	0.58	Life > 40
10	11.50x400.00 + 16.00x100.00 (angle)	54.75	339.82	46.58	46.58	0.00	0.58	0.00	0.00	0.58	Life > 40
11	11.50x400.00 + 16.00x100.00 (angle)	55.22	339.82	46.58	46.58	0.00	0.58	0.00	0.00	0.58	Life > 40
12	11.50x400.00 + 16.00x100.00 (angle)	55.69	339.82	46.58	46.58	0.00	0.58	0.00	0.00	0.58	Life > 40

HOPPER PLATE

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	41.93	316.97	41.93	41.93	0.00	0.43	0.00	0.00	0.43	Life > 40
2	12.00x350.00 + 17.00x100.00 (angle)	43.29	328.48	37.28	37.28	0.00	0.51	0.00	0.00	0.51	Life > 40
3	12.00x350.00 + 17.00x100.00 (angle)	44.68	313.11	33.52	32.62	0.00	0.41	0.00	0.00	0.41	Life > 40
4	12.00x350.00 + 17.00x100.00 (angle)	46.71	298.6	35.87	27.97	0.00	0.34	0.00	0.00	0.34	Life > 40

INNER SKIN

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.00x350.00 + 17.00x100.00 (angle)	42.68	306.13	44.31	16.69	0.00	0.37	0.00	0.00	0.37	Life > 40
2	11.00x350.00 + 17.00x100.00 (angle)	44.56	292.75	46.91	10.15	0.00	0.31	0.00	0.00	0.31	Life > 40
3	11.00x350.00 + 17.00x100.00 (angle)	46.44	278.97	49.50	7.55	0.00	0.25	0.00	0.00	0.25	Life > 40
4	11.00x350.00 + 17.00x100.00 (angle)	48.32	264.77	52.10	7.55	0.00	0.20	0.00	0.00	0.20	Life > 40
5	11.00x300.00 + 16.00x90.00 (angle)	67.91	294.74	73.62	16.00	0.00	0.32	0.00	0.00	0.32	Life > 40
6	11.00x300.00 + 16.00x90.00 (angle)	69.04	276.54	77.18	22.54	0.00	0.24	0.00	0.00	0.24	Life > 40
7	11.00x250.00 + 16.00x90.00 (angle)	87.51	316.05	102.91	29.08	0.00	0.43	0.00	0.00	0.43	Life > 40
8	11.00x250.00 + 16.00x90.00 (angle)	87.71	293.45	107.65	35.62	0.00	0.31	0.00	0.00	0.31	Life > 40
9	11.00x250.00 + 16.00x90.00 (angle)	87.92	269.7	112.38	42.16	0.00	0.22	0.00	0.00	0.22	Life > 40

TOP SIDE SLOPING PLATE

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.00x250.00 + 16.00x90.00 (angle)	52.83	214.32	118.13	113.81	0.00	0.08	0.00	0.00	0.08	Life > 40
2	11.00x250.00 + 16.00x90.00 (angle)	56.96	219.41	120.21	143.89	0.00	0.08	0.01	0.01	0.10	Life > 40
3	11.00x250.00 + 16.00x90.00 (angle)	61.09	230.59	122.28	166.60	0.00	0.11	0.01	0.03	0.14	Life > 40
4	11.00x250.00 + 16.00x90.00 (angle)	65.23	241.49	124.36	187.32	0.00	0.13	0.01	0.05	0.19	Life > 40
5	11.00x250.00 + 16.00x90.00 (angle)	69.36	252.14	131.36	204.19	0.00	0.16	0.01	0.07	0.24	Life > 40
6	11.00x250.00 + 16.00x90.00 (angle)	73.49	262.55	167.23	223.80	0.00	0.19	0.03	0.12	0.34	Life > 40
7	11.00x250.00 + 16.00x90.00 (angle)	135.34	272.74	222.63	242.81	0.01	0.23	0.13	0.17	0.54	Life > 40
8	11.00x250.00 + 16.00x90.00 (angle)	117.35	282.70	300.23	252.33	0.00	0.26	0.52	0.20	0.98	25.4

Forward of the stool

BOTTOM SHELL

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	13.00x400.00 + 18.00x100.00 (angle)	80.22	208.51	255.68	80.22	0.00	0.07	0.25	0.00	0.32	Life > 40
2	13.00x400.00 + 18.00x100.00 (angle)	81.26	210.7	258.22	81.26	0.00	0.07	0.27	0.00	0.34	Life > 40
3	13.00x400.00 + 18.00x100.00 (angle)	82.77	214.44	262.07	82.77	0.00	0.08	0.28	0.00	0.36	Life > 40
4	13.00x400.00 + 18.00x100.00 (angle)	83.83	216.67	264.66	83.83	0.00	0.08	0.30	0.00	0.38	Life > 40
5	13.00x400.00 + 18.00x100.00 (angle)	84.89	218.89	267.24	84.89	0.00	0.08	0.31	0.00	0.39	Life > 40
6	13.00x400.00 + 18.00x100.00 (angle)	85.96	221.11	269.81	85.96	0.00	0.09	0.32	0.00	0.41	Life > 40
7	13.00x400.00 + 18.00x100.00 (angle)	87.78	304.33	333.74	87.78	0.00	0.36	0.81	0.00	1.18	21.20
8	13.00x400.00 + 18.00x100.00 (angle)	88.84	305.27	334.11	88.84	0.00	0.37	0.82	0.00	1.19	21.10
9	13.00x400.00 + 18.00x100.00 (angle)	89.89	306.21	334.49	89.89	0.00	0.37	0.82	0.00	1.20	20.90
10	13.00x400.00 + 18.00x100.00 (angle)	91.27	308.21	335.86	91.27	0.00	0.39	0.83	0.00	1.22	20.50
11	13.00x400.00 + 18.00x100.00 (angle)	92.33	309.16	336.24	92.33	0.00	0.39	0.84	0.00	1.23	20.30
12	13.00x400.00 + 18.00x100.00 (angle)	93.4	310.10	336.62	93.40	0.00	0.40	0.84	0.00	1.24	20.20
13	11.00x398.00 + 15.00x150.00 (t-bar)	131.65	283.88	311.25	86.25	0.01	0.27	0.60	0.00	0.88	28.40
14	11.00x398.00 + 15.00x150.00 (t-bar)	133.22	284.64	311.56	87.08	0.01	0.27	0.61	0.00	0.89	28.20
15	11.00x398.00 + 15.00x150.00 (t-bar)	105.18	334.59	356.85	105.18	0.01	0.55	1.08	0.01	1.63	15.30

SIDE SHELL

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
17	12.00x400.00 + 18.00x100.00 (angle)	99.26	331.56	324.88	99.26	0.00	0.53	0.72	0.00	1.25	19.9
18	11.50x400.00 + 16.00x100.00 (angle)	91.64	315.36	305.06	91.64	0.00	0.43	0.55	0.00	0.98	25.5
19	11.50x400.00 + 16.00x100.00 (angle)	87.16	305.68	296.19	87.16	0.00	0.37	0.49	0.00	0.86	29.1
20	11.50x400.00 + 16.00x100.00 (angle)	91.55	294.95	287.16	91.55	0.00	0.32	0.43	0.00	0.75	33.5
21	11.50x400.00 + 16.00x100.00 (angle)	109.62	282.51	276.80	109.62	0.00	0.26	0.36	0.00	0.63	39.6
22	12.00x350.00 + 17.00x100.00 (angle)	135.23	304.10	290.24	135.23	0.01	0.36	0.45	0.01	0.83	30.2
23	12.00x350.00 + 17.00x100.00 (angle)	138.03	196.90	286.81	138.03	0.01	0.05	0.42	0.01	0.49	Life > 40
24	12.00x350.00 + 17.00x100.00 (angle)	139.18	144.11	278.34	139.18	0.01	0.01	0.37	0.01	0.40	Life > 40
25	11.00x350.00 + 17.00x100.00 (angle)	251.42	138.45	123.74	297.87	0.20	0.01	0.01	0.42	0.63	Life > 40
26	11.00x350.00 + 17.00x100.00 (angle)	240.44	138.98	98.90	302.37	0.16	0.01	0.00	0.44	0.61	Life > 40
27	11.00x350.00 + 17.00x100.00 (angle)	223.05	133.73	100.75	301.23	0.11	0.01	0.00	0.44	0.56	Life > 40
28	11.00x300.00 + 16.00x90.00 (angle)	165.12	176.06	145.75	277.69	0.03	0.03	0.02	0.31	0.38	Life > 40
29	11.00x300.00 + 16.00x90.00 (angle)	153.52	170.12	148.15	301.49	0.02	0.02	0.02	0.44	0.50	Life > 40
30	11.00x250.00 + 16.00x90.00 (angle)	156.59	207.57	180.98	297.49	0.02	0.06	0.05	0.41	0.55	Life > 40
31	11.00x250.00 + 16.00x90.00 (angle)	139.45	224.84	192.30	313.4	0.01	0.09	0.07	0.52	0.69	36.3
32	11.00x250.00 + 16.00x90.00 (angle)	123.63	241.43	201.05	312.93	0.01	0.13	0.08	0.51	0.73	34.1
33	11.00x250.00 + 16.00x90.00 (angle)	113.54	257.43	207.48	309.49	0.00	0.17	0.10	0.49	0.76	32.7
34	11.00x250.00 + 16.00x90.00 (angle)	179.02	272.88	211.41	301.06	0.04	0.23	0.11	0.44	0.81	31.0

INNER BOTTOM

Stiff. N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	44.46	160.36	86.44	113.09	0.00	0.02	0.00	0.00	0.02	Life > 40
2	11.50x400.00 + 16.00x100.00 (angle)	44.46	160.36	86.44	113.09	0.00	0.02	0.00	0.00	0.02	Life > 40
3	11.50x400.00 + 16.00x100.00 (angle)	44.46	160.36	86.44	113.09	0.00	0.02	0.00	0.00	0.02	Life > 40
4	11.50x400.00 + 16.00x100.00 (angle)	44.46	160.36	86.44	113.09	0.00	0.02	0.00	0.00	0.02	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	44.46	160.36	86.44	113.09	0.00	0.02	0.00	0.00	0.02	Life > 40
6	11.50x400.00 + 16.00x100.00 (angle)	44.46	160.36	86.44	113.09	0.00	0.02	0.00	0.00	0.02	Life > 40
7	11.50x400.00 + 16.00x100.00 (angle)	44.46	290.15	136.08	44.46	0.00	0.30	0.01	0.00	0.31	Life > 40
8	11.50x400.00 + 16.00x100.00 (angle)	44.46	290.15	136.08	44.46	0.00	0.30	0.01	0.00	0.31	Life > 40
9	11.50x400.00 + 16.00x100.00 (angle)	44.46	290.15	136.08	44.46	0.00	0.30	0.01	0.00	0.31	Life > 40
10	11.50x400.00 + 16.00x100.00 (angle)	44.46	290.15	136.08	44.46	0.00	0.30	0.01	0.00	0.31	Life > 40
11	11.50x400.00 + 16.00x100.00 (angle)	44.46	290.15	136.08	44.46	0.00	0.30	0.01	0.00	0.31	Life > 40
12	11.50x400.00 + 16.00x100.00 (angle)	44.46	290.15	136.08	44.46	0.00	0.30	0.01	0.00	0.31	Life > 40

HOPPER PLATE

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	40.02	270.03	133.31	90.12	0.00	0.22	0.01	0.00	0.23	Life > 40
2	12.00x350.00 + 17.00x100.00 (angle)	35.58	275.32	102.52	35.58	0.00	0.24	0.00	0.00	0.24	Life > 40
3	12.00x350.00 + 17.00x100.00 (angle)	31.14	260.53	94.91	31.14	0.00	0.18	0.00	0.00	0.18	Life > 40
4	12.00x350.00 + 17.00x100.00 (angle)	31.29	246.3	87.74	43.50	0.00	0.14	0.00	0.00	0.14	Life > 40

INNER SKIN

Stiff. N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.00x350.00 + 17.00x100.00 (angle)	30.52	232.53	89.18	15.93	0.00	0.11	0.00	0.00	0.11	Life > 40
2	11.00x350.00 + 17.00x100.00 (angle)	30.02	221.46	97.06	27.24	0.00	0.09	0.00	0.00	0.09	Life > 40
3	11.00x350.00 + 17.00x100.00 (angle)	30.34	210.10	104.67	27.29	0.00	0.07	0.00	0.00	0.07	Life > 40
4	11.00x350.00 + 17.00x100.00 (angle)	32.72	198.44	112.08	30.80	0.00	0.05	0.00	0.00	0.05	Life > 40
5	11.00x300.00 + 16.00x90.00 (angle)	48.04	220.45	52.95	36.50	0.00	0.09	0.00	0.00	0.09	Life > 40
6	11.00x300.00 + 16.00x90.00 (angle)	50.40	205.57	92.69	65.71	0.00	0.06	0.00	0.00	0.06	Life > 40
7	11.00x250.00 + 16.00x90.00 (angle)	63.52	235.99	72.47	27.76	0.00	0.12	0.00	0.00	0.12	Life > 40
8	11.00x250.00 + 16.00x90.00 (angle)	67.14	217.51	75.63	80.51	0.00	0.08	0.00	0.00	0.08	Life > 40
9	11.00x250.00 + 16.00x90.00 (angle)	70.75	198.22	78.78	116.64	0.00	0.05	0.00	0.00	0.05	Life > 40

TOP SIDE SLOPING PLATE

Stiff. N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.00x250.00 + 16.00x90.00 (angle)	100.33	201.14	148.35	160.31	0.00	0.06	0.02	0.02	0.10	Life > 40
2	11.00x250.00 + 16.00x90.00 (angle)	115.67	212.26	158.92	174.86	0.00	0.07	0.03	0.03	0.13	Life > 40
3	11.00x250.00 + 16.00x90.00 (angle)	129.94	223.11	168.36	189.34	0.01	0.09	0.03	0.05	0.18	Life > 40
4	11.00x250.00 + 16.00x90.00 (angle)	143.58	233.7	177.00	203.78	0.01	0.11	0.04	0.07	0.23	Life > 40
5	11.00x250.00 + 16.00x90.00 (angle)	153.12	244.04	186.75	216.85	0.02	0.14	0.06	0.10	0.31	Life > 40
6	11.00x250.00 + 16.00x90.00 (angle)	166.98	254.16	195.44	231.50	0.03	0.17	0.07	0.13	0.40	Life > 40
7	11.00x250.00 + 16.00x90.00 (angle)	180.52	264.06	203.52	246.11	0.04	0.20	0.09	0.18	0.51	Life > 40
8	11.00x250.00 + 16.00x90.00 (angle)	180.22	273.75	253.33	255.52	0.04	0.23	0.24	0.21	0.73	34.5

Single skin bulk carrier

Afterward of the stool

BOTTOM SHELL

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	13.00x400.00 + 18.00x100.00 (angle)	92.31	247.22	290.16	92.31	0.00	0.15	0.45	0.00	0.59	Life > 40
2	13.00x400.00 + 18.00x100.00 (angle)	93.87	250.56	293.95	93.87	0.00	0.15	0.47	0.00	0.63	39.8
3	13.00x400.00 + 18.00x100.00 (angle)	96.14	256.18	299.69	96.14	0.00	0.17	0.51	0.00	0.69	36.5
4	13.00x400.00 + 18.00x100.00 (angle)	97.73	259.58	303.53	97.73	0.00	0.18	0.54	0.00	0.72	34.5
5	13.00x400.00 + 18.00x100.00 (angle)	99.32	262.97	307.36	99.32	0.00	0.19	0.57	0.00	0.77	32.6
6	13.00x400.00 + 18.00x100.00 (angle)	100.92	266.36	311.19	100.92	0.00	0.20	0.60	0.00	0.81	30.9
7	13.00x400.00 + 18.00x100.00 (angle)	103.66	286.27	327.27	103.66	0.00	0.28	0.75	0.00	1.03	24.3
8	13.00x400.00 + 18.00x100.00 (angle)	105.24	289.55	331.00	105.24	0.00	0.29	0.78	0.00	1.08	23.1
9	13.00x400.00 + 18.00x100.00 (angle)	106.82	292.09	334.22	106.82	0.00	0.31	0.82	0.00	1.13	22.2
10	13.00x400.00 + 18.00x100.00 (angle)	108.89	295.55	338.40	108.89	0.00	0.32	0.86	0.00	1.19	21.1
11	13.00x400.00 + 18.00x100.00 (angle)	110.49	298.06	341.60	110.49	0.00	0.33	0.90	0.00	1.24	20.2
12	13.00x400.00 + 18.00x100.00 (angle)	112.08	300.53	344.77	112.08	0.00	0.35	0.93	0.00	1.28	19.5
13	11.00x398.00 + 15.00x150.00 (t-bar)	101.37	268.28	316.00	101.37	0.00	0.21	0.64	0.00	0.86	29.2
14	11.00x398.00 + 15.00x150.00 (t-bar)	102.61	270.93	319.01	102.61	0.00	0.22	0.67	0.00	0.89	28.0
15	11.00x398.00 + 15.00x150.00 (t-bar)	129.76	330.23	378.48	129.76	0.01	0.52	1.38	0.01	1.91	13.1

SIDE SHELL

Stiffener N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
17	12.00x400.00 + 18.00x100.00 (angle)	128.62	349.58	376.51	128.62	0.01	0.66	1.35	0.01	2.02	12.4
18	11.50x400.00 + 16.00x100.00 (angle)	128.86	345.68	367.86	128.86	0.01	0.63	1.22	0.01	1.87	13.4
19	11.50x400.00 + 16.00x100.00 (angle)	137.8	335.80	381.23	137.80	0.01	0.56	1.42	0.01	2.00	12.5
20	11.50x400.00 + 16.00x100.00 (angle)	146.08	338.80	389.06	146.08	0.01	0.58	1.55	0.01	2.15	11.6
21	11.00x250.00 + 16.00x90.00 (angle)	221.62	293.58	239.09	221.62	0.11	0.31	0.19	0.11	0.72	34.7
22	11.00x250.00 + 16.00x90.00 (angle)	194.17	275.6	219.92	194.17	0.06	0.24	0.13	0.06	0.48	Life > 40
23	11.00x250.00 + 16.00x90.00 (angle)	168.51	254.87	205.25	168.51	0.03	0.17	0.09	0.03	0.32	Life > 40
24	11.00x250.00 + 16.00x90.00 (angle)	151.68	269.05	210.65	151.68	0.02	0.21	0.10	0.02	0.35	Life > 40
25	11.00x250.00 + 16.00x90.00 (angle)	133.09	284.82	212.43	203.59	0.01	0.27	0.11	0.07	0.46	Life > 40

INNER BOTTOM

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	48.95	175.81	57.88	114.08	0.00	0.03	0.00	0.00	0.03	Life > 40
2	11.50x400.00 + 16.00x100.00 (angle)	49.42	175.81	58.70	114.08	0.00	0.03	0.00	0.00	0.03	Life > 40
3	11.50x400.00 + 16.00x100.00 (angle)	49.89	175.81	59.52	114.08	0.00	0.03	0.00	0.00	0.03	Life > 40
4	11.50x400.00 + 16.00x100.00 (angle)	50.36	175.81	60.33	114.08	0.00	0.03	0.00	0.00	0.03	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	50.83	175.81	61.15	114.08	0.00	0.03	0.00	0.00	0.03	Life > 40
6	11.50x400.00 + 16.00x100.00 (angle)	51.30	175.81	61.97	114.08	0.00	0.03	0.00	0.00	0.03	Life > 40
7	11.50x400.00 + 16.00x100.00 (angle)	52.24	212.69	82.41	114.08	0.00	0.07	0.00	0.00	0.07	Life > 40

8	11.50x400.00 + 16.00x100.00 (angle)	52.71	212.69	84.67	114.08	0.00	0.07	0.00	0.00	0.07	Life > 40
9	11.50x400.00 + 16.00x100.00 (angle)	53.18	212.69	86.93	114.08	0.00	0.07	0.00	0.00	0.07	Life > 40
10	11.50x400.00 + 16.00x100.00 (angle)	53.65	212.69	89.18	114.08	0.00	0.07	0.00	0.00	0.07	Life > 40
11	11.50x400.00 + 16.00x100.00 (angle)	54.12	212.69	91.44	114.08	0.00	0.07	0.00	0.00	0.07	Life > 40
12	11.50x400.00 + 16.00x100.00 (angle)	54.59	212.69	93.70	114.08	0.00	0.07	0.00	0.00	0.07	Life > 40

HOPPER PLATE

Stiffener N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	41.82	192.66	93.09	109.5	0.00	0.04	0.00	0.00	0.05	Life > 40
2	12.00x350.00 + 17.00x100.00 (angle)	54.16	189.58	113.73	104.45	0.00	0.04	0.00	0.00	0.05	Life > 40
3	12.00x350.00 + 17.00x100.00 (angle)	55.11	172.43	116.71	98.94	0.00	0.03	0.00	0.00	0.03	Life > 40
4	12.00x350.00 + 17.00x100.00 (angle)	56.05	155.01	119.69	92.97	0.00	0.01	0.01	0.00	0.02	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	45.84	131.46	106.77	86.52	0.00	0.01	0.00	0.00	0.01	Life > 40
6	12.00x300.00 + 17.00x100.00 (angle)	70.23	123.21	143.80	79.57	0.00	0.00	0.01	0.00	0.02	Life > 40

TOP SIDE SLOPING PLATE

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.00x250.00 + 16.00x90.00 (angle)	53.42	278.89	111.44	53.42	0.00	0.25	0.00	0.00	0.25	Life > 40
2	11.00x250.00 + 16.00x90.00 (angle)	56.86	241.07	115.48	56.86	0.00	0.13	0.00	0.00	0.13	Life > 40
3	11.00x250.00 + 16.00x90.00 (angle)	60.30	228.46	119.52	60.30	0.00	0.10	0.01	0.00	0.11	Life > 40
4	11.00x250.00 + 16.00x90.00 (angle)	63.74	237.60	123.55	63.74	0.00	0.12	0.01	0.00	0.13	Life > 40

5	11.00x250.00 + 16.00x90.00 (angle)	67.18	246.56	127.72	67.18	0.00	0.14	0.01	0.00	0.15	Life > 40
6	11.00x250.00 + 16.00x90.00 (angle)	70.62	255.34	136.60	73.65	0.00	0.17	0.01	0.00	0.18	Life > 40
7	11.00x250.00 + 16.00x90.00 (angle)	74.06	263.96	140.51	142.26	0.01	0.20	0.01	0.01	0.22	Life > 40
8	11.00x250.00 + 16.00x90.00 (angle)	77.50	272.42	143.59	173.19	0.00	0.22	0.02	0.03	0.27	Life > 40
9	11.00x250.00 + 16.00x90.00 (angle)	80.94	280.73	144.72	197.30	0.00	0.26	0.02	0.06	0.34	Life > 40
10	11.00x250.00 + 16.00x90.00 (angle)	84.37	288.90	177.58	180.55	0.00	0.29	0.04	0.04	0.38	Life > 40

Forward of the stool

BOTTOM SHELL

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	13.00x400.00 + 18.00x100.00 (angle)	78.92	206.61	251.98	78.92	0.00	0.06	0.24	0.00	0.30	Life > 40
2	13.00x400.00 + 18.00x100.00 (angle)	79.96	208.80	254.53	79.96	0.00	0.07	0.25	0.00	0.32	Life > 40
3	13.00x400.00 + 18.00x100.00 (angle)	81.47	212.55	258.38	81.47	0.00	0.07	0.27	0.00	0.34	Life > 40
4	13.00x400.00 + 18.00x100.00 (angle)	82.53	214.78	260.97	82.53	0.00	0.08	0.28	0.00	0.36	Life > 40
5	13.00x400.00 + 18.00x100.00 (angle)	83.60	217.01	263.55	83.60	0.00	0.08	0.29	0.00	0.37	Life > 40
6	13.00x400.00 + 18.00x100.00 (angle)	84.66	219.24	266.13	84.66	0.00	0.08	0.30	0.00	0.39	Life > 40
7	13.00x400.00 + 18.00x100.00 (angle)	86.49	233.25	276.67	86.49	0.00	0.11	0.36	0.00	0.47	Life > 40
8	13.00x400.00 + 18.00x100.00 (angle)	87.54	235.50	279.25	87.54	0.00	0.12	0.38	0.00	0.50	Life > 40
9	13.00x400.00 + 18.00x100.00 (angle)	88.59	237.75	281.83	88.59	0.00	0.12	0.39	0.00	0.51	Life > 40
10	13.00x400.00 + 18.00x100.00 (angle)	89.97	241.08	285.36	89.97	0.00	0.13	0.41	0.00	0.55	Life > 40
11	13.00x400.00 + 18.00x100.00 (angle)	91.04	243.35	287.95	91.04	0.00	0.14	0.43	0.00	0.57	Life > 40
12	13.00x400.00 + 18.00x100.00 (angle)	92.10	245.62	290.54	92.10	0.00	0.14	0.45	0.00	0.59	Life > 40
13	11.00x398.00 + 15.00x150.00 (t-bar)	171.44	220.56	269.25	84.96	0.03	0.09	0.32	0.00	0.44	Life > 40
14	11.00x398.00 + 15.00x150.00 (t-bar)	173.20	222.30	271.27	85.79	0.03	0.09	0.33	0.00	0.45	Life > 40
15	11.00x398.00 + 15.00x150.00 (t-bar)	103.89	277.86	322.06	103.89	0.00	0.25	0.70	0.01	0.95	26.4

SIDE SHELL

Stiffener N ^o	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
17	12.00x400.00 + 18.00x100.00 (angle)	97.97	279.09	306.72	97.97	0.00	0.25	0.57	0.01	0.83	30
18	11.50x400.00 + 16.00x100.00 (angle)	90.46	265.4	286.52	90.46	0.00	0.20	0.42	0.00	0.62	39.3
19	11.50x400.00 + 16.00x100.00 (angle)	85.99	260.7	275.00	85.99	0.00	0.18	0.35	0.00	0.53	Life > 40
20	11.50x400.00 + 16.00x100.00 (angle)	134.26	255.7	267.95	92.54	0.01	0.17	0.31	0.00	0.48	Life > 40
21	11.00x250.00 + 16.00x90.00 (angle)	157.51	211.00	183.16	157.51	0.02	0.07	0.05	0.02	0.16	Life > 40
22	11.00x250.00 + 16.00x90.00 (angle)	140.34	228.13	194.11	167.51	0.01	0.10	0.07	0.03	0.21	Life > 40
23	11.00x250.00 + 16.00x90.00 (angle)	124.36	244.59	202.46	244.02	0.01	0.14	0.09	0.17	0.41	Life > 40
24	11.00x250.00 + 16.00x90.00 (angle)	114.27	260.47	208.45	256.56	0.00	0.18	0.10	0.22	0.50	Life > 40
25	11.00x250.00 + 16.00x90.00 (angle)	103.00	275.85	211.85	262.04	0.00	0.24	0.11	0.24	0.59	Life > 40

INNER BOTTOM

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	43.18	157.13	43.18	111.38	0.00	0.02	0.00	0.00	0.02	Life > 40
2	11.50x400.00 + 16.00x100.00 (angle)	43.18	157.13	43.18	111.38	0.00	0.02	0.00	0.00	0.02	Life > 40
3	11.50x400.00 + 16.00x100.00 (angle)	43.18	157.13	43.18	111.38	0.00	0.02	0.00	0.00	0.02	Life > 40
4	11.50x400.00 + 16.00x100.00 (angle)	43.18	157.13	43.18	111.38	0.00	0.02	0.00	0.00	0.02	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	43.18	157.13	43.18	111.38	0.00	0.02	0.00	0.00	0.02	Life > 40
6	11.50x400.00 + 16.00x100.00 (angle)	43.18	157.13	43.18	111.38	0.00	0.02	0.00	0.00	0.02	Life > 40
7	11.50x400.00 + 16.00x100.00 (angle)	43.18	181.49	94.32	111.38	0.00	0.03	0.00	0.00	0.03	Life > 40

8	11.50x400.00 + 16.00x100.00 (angle)	43.18	181.49	98.44	111.38	0.00	0.03	0.00	0.00	0.03	Life > 40
9	11.50x400.00 + 16.00x100.00 (angle)	43.18	181.49	102.53	111.38	0.00	0.03	0.00	0.00	0.03	Life > 40
10	11.50x400.00 + 16.00x100.00 (angle)	43.18	181.49	106.58	111.38	0.00	0.03	0.00	0.00	0.03	Life > 40
11	11.50x400.00 + 16.00x100.00 (angle)	43.18	181.49	110.60	111.38	0.00	0.03	0.00	0.00	0.03	Life > 40
12	11.50x400.00 + 16.00x100.00 (angle)	43.18	181.49	114.60	111.38	0.00	0.03	0.00	0.00	0.03	Life > 40

HOPPER PLATE

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.50x400.00 + 16.00x100.00 (angle)	39.92	165.72	125.98	106.75	0.00	0.02	0.01	0.00	0.03	Life > 40
2	12.00x350.00 + 17.00x100.00 (angle)	36.66	162.21	80.15	101.69	0.00	0.02	0.00	0.00	0.02	Life > 40
3	12.00x350.00 + 17.00x100.00 (angle)	35.86	148.48	82.36	96.22	0.00	0.01	0.00	0.00	0.01	Life > 40
4	12.00x350.00 + 17.00x100.00 (angle)	36.42	134.51	84.57	90.32	0.00	0.01	0.00	0.00	0.01	Life > 40
5	11.50x400.00 + 16.00x100.00 (angle)	32.8	115.96	111.43	83.97	0.00	0.00	0.00	0.00	0.00	Life > 40
6	12.00x300.00 + 17.00x100.00 (angle)	42.54	108.85	101.09	77.16	0.00	0.00	0.02	0.00	0.00	Life > 40

TOPSIDE SLOPING PLATE

Stiffener N°	Scantlings of stiffeners	Loading conditions				Loading conditions				Total Damage Ratio	Fatigue life
		Corrected equivalent stress range				Damage					
		Homogeneous	Normal ballast	Heavy ballast	Alternate	Homogeneous	Normal ballast	Heavy ballast	Alternate		
1	11.00x250.00 + 16.00x90.00 (angle)	50.99	202.76	79.43	123.46	0.00	0.06	0.00	0.01	0.06	Life > 40
2	11.00x250.00 + 16.00x90.00 (angle)	54.28	212.00	81.85	138.57	0.00	0.07	0.00	0.01	0.08	Life > 40
3	11.00x250.00 + 16.00x90.00 (angle)	57.56	221.05	84.28	152.81	0.00	0.09	0.00	0.02	0.10	Life > 40
4	11.00x250.00 + 16.00x90.00 (angle)	60.84	229.92	86.70	166.51	0.00	0.10	0.00	0.03	0.13	Life > 40

5	11.00x250.00 + 16.00x90.00 (angle)	64.12	238.61	89.21	179.73	0.00	0.12	0.00	0.04	0.16	Life > 40
6	11.00x250.00 + 16.00x90.00 (angle)	67.41	247.15	94.86	189.27	0.00	0.15	0.00	0.05	0.20	Life > 40
7	11.00x250.00 + 16.00x90.00 (angle)	70.69	255.53	97.20	202.63	0.00	0.17	0.00	0.07	0.24	Life > 40
8	11.00x250.00 + 16.00x90.00 (angle)	73.97	263.75	98.99	215.77	0.00	0.19	0.00	0.10	0.29	Life > 40
9	11.00x250.00 + 16.00x90.00 (angle)	77.26	271.84	99.47	228.74	0.00	0.22	0.00	0.13	0.35	Life > 40
10	11.00x250.00 + 16.00x90.00 (angle)	80.54	279.79	121.11	228.05	0.00	0.25	0.01	0.13	0.38	Life > 40

DISCUSSION

In case of double hull oil tankers, fatigue strength assessment is carried out according to IACS CSR DHOT (Section 9.3, page 2) for the end connections of longitudinal stiffeners located on the bottom shell, inner bottom, side shell, inner hull longitudinal bulkheads and strength deck. On the other hand, in case of bulk carriers, fatigue strength assessment is carried out according to CSR BC (Chapter 8, section 1, page 3) for the end connections of the longitudinal stiffeners located on the double bottom, upper and lower wing tank and on double side space.

As it can be easily noticed, in case of the examined bulk carriers, fatigue strength assessment is carried out afterward and forward of the transverse web or floor, while in double hull oil tankers' analysis this is not the case. That happens due to the different method of fatigue strength assessment each CSR provide. More specifically, according to CSR BC, in order to calculate the total hot spot stress range due to dynamic loads, we must calculate the additional hot spot stress due to the relative displacement in the direction perpendicular to the attached plate between transverse bulkhead or floor in way of stools and the adjacent forward "f" and afterward "a" transverse web or floor, in both points "a" and "f". On the other hand, the bending stress in longitudinal stiffeners caused by relative deformation between supports, in double hull oil tankers' analysis, is incorporated as a factor (k_d) in the formula of nominal stress range produced by bending of stiffeners due to external wave or internal tank pressure. CSR for double hull oil tankers check the hot spot forward the transverse web or floor.

The difference in fatigue life that is noticed between stiffener No.6 and stiffener No. 7 of the bottom shell in all of the three examined ships is because of the fact that the first 6 stiffeners are in centre ballast tank while the rest of them in side ballast tank. Hence the difference in the applied internal pressure is the reason of the difference in fatigue life. The same fact happens in case of the respective stiffeners of the double bottom shell.

The reduction of fatigue life of stiffener No. 15 in regard to the other stiffeners of the bottom shell in all of the three examined ships is because of the fact that next to stiffener No.15 there is no stiffener but bilge keel only. Consequently the value of stiffener spacing "s" that is used is the distance between stiffener No.15 and bilge keel which is bigger than the usual stiffener spacing of bottom shell. Hence the stress range produced by bending of stiffeners due to dynamic wave or dynamic tank pressure, which is proportional to "s", is higher than that of the other stiffeners of bottom shell.

Fatigue life in case of the stiffeners of the centerline longitudinal bulkhead of double hull oil tanker is over 40 years because of the fact that only the stress range due to the vertical hull girder bending moment is taken into account. Neither the horizontal hull girder bending moment nor the local stress ranges (internal or external). That is why damage ratio is higher in stiffeners near the inner bottom and the deck.

In case of the stiffeners of the upper deck of the double hull oil tanker, the dynamic stress ranges that are taken into account are the stress range due to vertical wave bending moment, which is rising as the distance of stiffener from the neutral axis is becoming bigger, and the stress range due to horizontal wave bending moment, which is decreasing as we approach the centreline. The stiffener which has the smallest damage ratio is the No.43, which is almost in the middle of the half section.

The distribution of fatigue life of the stiffeners of the double hull oil tanker's inner hull has the shape that is presented in the respective Table because it depends predominantly on the stress range due to internal tank pressure (which is a function of the applied internal pressure) and the scantlings of the stiffener which determine its section modulus.

The distribution of fatigue life of the stiffeners on the side shell of the double hull oil tanker depends predominantly on the stress range due to external pressure. That can be easily noticed by the fact that it is the damage ratio in full load condition that contributes the biggest part in the total damage ratio. Consequently the distribution of fatigue life among the stiffeners depends on the fluctuation of the factors k_n , k_d , as well as M (moment at stiffener support) and Z_{net-50} (section modulus of longitudinal stiffener with associate effective plate).

In case of double skin bulk carrier, the difference in fatigue life that we observe between the stiffeners of side shell afterwards of the stool that are in lower position than No.24 and the stiffeners in higher position than that is because of the fact that in case of stiffeners higher than No.24 the contribution of damage ratio in heavy ballast condition is considerably reduced related to that in stiffeners lower than No.24. To be more precise, the z coordinate of stiffener No.25 is 10.7m while the draught in heavy ballast condition is 9.4m, consequently the applied total stress range is much lower. In case of the stiffeners No.32, No.33, No.34, the values of fatigue life they have are these because of the contribution in total damage ratio of the damage ratio in alternate condition, which is rising from stiffener No.32 to No.34 because of the distribution of factor f_{mean} .

In case of single skin bulk carrier afterwards of the stool, the difference that we observe among the stiffeners of side shell is because stiffeners No.17-20 are near the bilge and stiffeners No.21-25 are near the deck (they are in the top side tank). Hence the difference in the applied internal and external pressures conducts to the difference in fatigue life.

Chapter 5 – CONCLUSIONS & FUTURE WORK

5.1 CONCLUSIONS

In the present diploma thesis IACS CSR DHOT and CSR BC are studied in order to compare their theoretical structure, the principals behind the given formulations and the numerical values of their application. To be more precise, the scope of this thesis is to explain and compare the method of calculation of hull girder and local loads applied in these two types of vessels, the way structural scantlings of their midship sections are obtained and finally the way design verification is done according to each CSR. In a few words the carried out research aims to answer to the question “How CSR work” and by the answer of that question to compare the CSR DHOT and CSR BC.

In order to achieve this goal it was necessary to carry out a numerical example, namely to have numerical results of the implementation of each CSR. To tell the truth, the most important conclusion of the present thesis is that in order to understand something deeply, a numerical example, namely the implementation of the provided formulations, is necessary. Hence, three ships with the same main particulars were compared: a double hull oil tanker with a centerline longitudinal bulkhead, a double skin bulk carrier and a single skin bulk carrier.

From the cases studied, it was remarked that both CSR provide the same “roadmap” for the development of structural scantlings and the assessment of ship’s safety and robustness. In addition, the investigation of the highly loaded structural elements of double hull oil tankers and bulk carriers [9], conducted us to the conclusion that both CSR take into consideration every mode of deformation and its respective load type that can face the hull structure of double hull oil tankers and bulk carriers.

However there are a lot of differences in the formulae provided by them which concern all of the examined aspects. In particular, each CSR use different load cases and consequently provide different formulae of the dynamic loads, in cases of loads applied in the midship section. As far as hull girder loads are concerned, the difference in the way net thickness approach is implemented in the two CSR results to different values of minimum permissible still water bending moment. Torsional wave moment is taken into account only by CSR for bulk carriers because of the large openings on their deck (hatches), but only in fatigue strength assessment. The difference in the type of cargo between the two types of ships results to differences in the types of examined loads by each CSR. For example sloshing is taken into consideration only by CSR for double hull oil tankers.

In case of structural scantlings, both CSR provide a number of formulae for the calculation of net thickness of plates. More specifically both of them provide 4 formulae that conduct to the minimum net thickness of plating. An empirical formula, function of the rule length of ship, a stress based formula for plating subjected to lateral pressure, a formula that concerns specific plates, like bilge plate or side shell plate in the quay region and a non-stress based formula, which is defined as maximum allowable slenderness ratio. Minimum net thicknesses of midship section’s structural members cannot be less than the values given by the formulae mentioned above. The numerical

example in the three examined ships showed that all of the four formulae must be taken into consideration in order to obtain the minimum net thickness of plates and stiffeners. There is no formula that prevails to the calculation of net thickness of plates.

Design verification in both CSR concerns hull girder and local bending stress check, buckling check of strakes and stiffeners, hull girder ultimate strength check and fatigue check. Hull girder bending stress assessment and buckling assessment of stiffeners is carried out in the same way in both CSR. Buckling assessment of plates in both CSR is based on uni-axial compressive strength analysis of CSR BC, presented in chapter 6/section 3, however there is a difference in the combination of stresses used in the procedure of assessment. Ultimate strength assessment in both CSR is based on the same criterion, but there is a difference in the design load combinations taken into consideration as well in the fact that in hull girder ultimate strength check of double hull oil tankers only sagging is taken into account, while in bulk carriers this is not the case. In fatigue analysis, we are talking about two different procedures that were independently developed. Although there are similarities in them e.g. acceptance criteria, fatigue damage, design life of 25 years in North Atlantic environment there are a lot of differences in the calculation of hot spot stress range. Each CSR provide a number of locations that must be checked against fatigue. However the vast majority of them is assessed only through finite elements analysis in order to get reliable results. Hence in the present diploma thesis fatigue strength assessment was carried out only in the end connections of longitudinal stiffeners which can be done with the software tools that are used in the present thesis.

5.2 FUTURE WORK

Some suggestions for future studies are presented below:

It would be very interesting to combine the research carried out in CSR DHOT and BC in the present diploma thesis with a research in the harmonized CSR that IACS released a few months ago in draft form. In other words the comparison between CSR July 2010 for the two kinds of ships and Harmonized CSR July 2012 has both theoretical as well as practical interest nowadays that IACS has opened the discussion about its new project. Apart from that the comparison among CSR DHOT, CSR BC and the Rules of Classification Societies for container ships would be a very challenging project.

In addition, the analysis in accidental limit state (ALS) for double hull oil tankers and bulk carriers would be a task of great importance as far as strength and robustness of ships is concerned, which would proceed the research carried out in the present diploma thesis.

Finally the direct strength analysis (finite elements analysis) would conduct in further examination of the aspects that are studied in the previous pages contributing to the research carried out in CSR DHOT and CSR BC.

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