THE DEVELOPMENT, IMPLEMENTATION AND MAINTENANCE OF IACS COMMON STRUCTURAL RULES FOR BULK CARRIERS AND OIL TANKERS

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SUMMARY

This paper outlines challenges in the development of the International Association of Classification Societies (IACS) Common Structural Rules (CSR) for bulk carriers and oil tankers regarding the modeling techniques used and incorporated into the load prediction, structural response and acceptance criteria. The paper also outlines how IACS is responding to the need for consistent implementation and future maintenance of the Rules.

As a document that contains rule requirements, a balance had to be made between the incorporation of highly technically advanced methods and practical deterministic application needs, noting that industry has been increasingly calling for the use of advanced predictive models while at the same time asking for a format that will lend itself to quick determinations of initial designs and quick design and building cycles. All the while keeping in mind the main objective; developing Rules that produce safety, robustness and longevity levels expected by society at large.

During the criteria development of the CSR a similar balance had to be made in incorporating existing Rule requirements or incorporating risk-based approaches to identify hazards and consequences to concentrate the new rule development attention to the most critical areas. While the CSRs tend to incorporate elements of the existing Class rules and IACS Unified Requirements, it is noted that many areas have been developed or validated using more advanced techniques and employing analysis of hazards and consequences.

At the same time the CSRs were being developed, the International Maritime Organization (IMO) were starting to develop broad reaching goal-based standards (GBS) aimed at determining the basic standards used during vessel design. The CSR developers continuously monitored the GBS developments at IMO in order to incorporate pertinent criteria into the CSRs.

This paper describes the new relationships which resulted between the classification societies and industry as a consequence of the consultation processes during the development phase. Implementation of CSR by all ten members of IACS represents a step change in the way that IACS functions and the governance requirements of the individual members are satisfied. Also as a result of the CSR implementation, IACS is in a new phase where the CSR rule set has to be maintained. Processes have been established to ensure that the CSR will be maintained effectively, with proper industry consultation. Interpretations and feedback have to be gathered from all IACS members and industry and the response has to be accepted and adopted by all members. Thereafter, there is a program which intends to harmonize the current versions of CSR for oil tankers and bulk carriers to establish a platform for possible future extension into other ship types.

NOMENCLATURE

CSR IACS Common Structural Rules. Applicable to bulk carriers and double hull oil tankers.
GBS IMO goal-based new ship construction standards.
IACS International Association of Classification Societies.

1. INTRODUCTION

This paper outlines the joint rule development work of IACS classification societies who have worked on formulating new Common Structural Rules for bulk carriers and tankers. The aim is to give an idea of the challenges in the development process and extensive work performed by the IACS project team members. The paper details some of the modelling aspects of the common rules and how they were developed and calibrated to represent loads and structural responses.

Rule requirements must contain a balance between incorporating highly technical advanced methods and practical deterministic application needs. General industry has been increasingly calling for the use of advanced predictive models in rule evaluations while at the same time calling for rule formats that lend themselves to quick determinations of initial designs as well as being able to fit rule evaluations within accelerated design and building cycles. All the while IACS had to keep in mind the main objective of developing Rules that produce safety, robustness and longevity levels expected by society at large.

During the criteria development of the CSR a similar balance had to be made in incorporating existing Rule requirements or incorporating risk-based approaches to identify hazards and consequences to concentrate the new rule development attention to the most critical areas. While the CSRs tended to incorporate elements of the existing Class rules and IACS Unified Requirements, it is noted that areas have been developed or validated using more advanced techniques and employing analysis of hazards and consequences.

At the same time the CSRs were being developed, the International Maritime Organization (IMO) were starting to develop broad reaching goal-based standards (GBS) aimed at determining the basic standards which will be used to assess class rules. The CSR developers continuously monitored the GBS developments at IMO in order to incorporate pertinent criteria into the CSRs.

After the publication of the first draft of the CSRs and supporting information, extensive review periods were established so that the project could receive public comments resulting from independent industry review and application. It was also a good opportunity for the project to conduct further rule refinement and adjustments based on additional iterations of the rule development and rule application testing cycle. This included refinements of the rules and consequence documents.

In addition to the technical enhancements that were made, editing of the rules continued for corrections and clarifications highlighted by the public feedback.

2. INITIAL DEVELOPMENT GOALS

The first steps in the CSR rule development process involved establishing the project goals, which highlighted increasing vessel safety, durability and robustness. Developing these underlying goals and framework was very important to insure common understanding and project direction. These goals are summarized as follows:

- To eliminate potential for competition between class societies with regard to structural requirements and standards, a situation which, if continued, could eventually lead to an inconsistent approach to the assessment and verification of hull structural integrity and hence compromise ship safety. The intent is that future competition will be based on service provided to clients.
- To embrace the intentions of the anticipated IMO requirements for Goal-based standards for new buildings.
- To employ the combined experience of IACS societies to develop a single agreed Standard, or set of Rules and Procedures, that will result in the same structural requirements irrespective of which society classes the vessel.
- To ensure that a ship meeting the new Rules will be recognized by industry as being at least as safe, robust and durable as would have been required by any of the existing rules.
- To reduce the cost of dealing with a number of similar but different Rules sets.
- To insure that the resulting rules and procedures are written in such a way as to result in common scantling requirements.

For each set of rules, these goals were developed by the project team and steering committee in response to requests from owners and shipyards for standardization which is common in other industries and in response to national proposals to coordinate scantling requirements that have been made within the International Maritime Organization (IMO). Within IMO, the requirements will be higher-level goal based requirements, which are similar to the underlying goal based underpinning of the CSR Rules.

The outcome of the CSR rules is a single recognized Standard for the verification of double hull oil tanker structures greater or equal to 150 meters in length that has been developed by the IACS Joint Tanker Project (JTP) Group and of single or double side skin bulk carriers greater or equal to 90 meters in length that has been developed by the IACS Joint Bulk Carrier Project (JBP) Group with active input from the shipping community at the earliest stage.

3. MODELING TECHNIQUES

3.1 NET THICKNESS CONCEPT

The CSR rules are formulated using a net thickness approach. This approach assumes that various degrees of corrosion will occur to the structural members during the life of the vessel. The net scantling approach sets out to determine and verify the minimum hull scantlings that are to be maintained from the new building stage throughout the ship's design life to satisfy the structural strength requirements. It clearly separates the net thickness from the thickness added for corrosion that is likely to occur during the ship in operation phase.

The basic concepts that are currently being applied to pre-CSR existing vessels in service have been codified in the CSR rules. This consists of applying a general average global hull girder and primary support member wastage such that the overall strength of these large structural members is maintained. The strength of these large members is assessed using a lower average corrosion margin. However, these large members are made up from a composite of local members comprising local elementary plate panels and stiffeners. The strength of these local strength members are assessed using the full local corrosion margins. The strength of the members is assessed using the structural capacity in the wasted condition, or net thickness, while applying the expected extreme loads. This will ensure that the vessel will meet the minimum strength requirements even while in the defined extreme wasted condition. Since fatigue is a cumulative mode of failure that starts from the first day of service when the vessel is in the as-built condition up until the last days of service when the vessel could be in a fully corroded state, the net thickness associated with hull girder and local thickness for fatigue is averaged or taken as half of the full margins.

The vessel structure is monitored in service using similar gauging review thickness measurement criteria as was used during the newbuilding assessment. The newbuilding *corrosion additions* are defined in each set of rules (for CSR/Tanker the corrosion additions are given in Section 6/3 and the wastage allowances for ship in operation in Section 12/1; for CSR/Bulk, respectively in Chap 3, Sec 3 and Chap 13, Sec 2). For consistency, the two items are linked by a margin to cover the anticipated corrosion which may occur during the interval between surveys. The net thickness is illustrated in Figure 1.

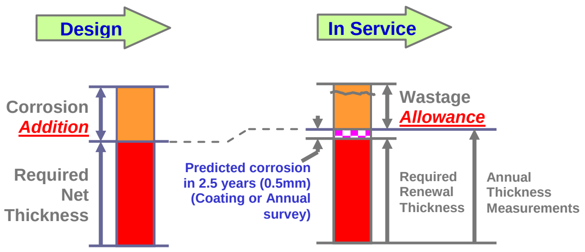


Figure 1 : Net thickness principle

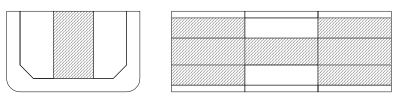
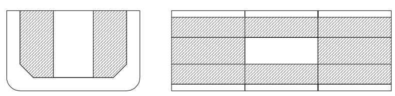
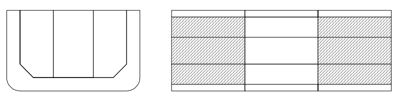
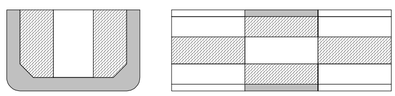
The actual corrosion values included in the rules have been established based on the extensive work of the IACS working party on strength that assembled a database of over 600,000 thickness measurements [1]. This database covers measurements taken over a wide variation of corrosion associated with exposure to the marine environment such as dry cargo, cargo oil, ballast water, temperature variations, etc. and covers the structural members to which the margins are applied. Corrosion processes from initial occurrence through propagation were investigated on extensive thickness measurement data, and a corrosion process model was developed based on probabilistic theory, thus estimating the thickness diminution of structural members. A statistical analysis of the database was performed in order to extract the margins associated with a probability of the margin 95% for 25 years. It is noted that portions of the vessel are coated in order to combat the effects of corrosion. While it is agreed that coatings perform this function, the effects of coatings are not directly included in the application of corrosion additions used for design. In other words the corrosion additions may not be reduced due to the presence of coatings. The main reason for this is that it is well known that coatings will eventually breakdown at some point and it is not always possible to re-coat the structure while the vessel is in service and exposed to adverse environmental conditions. On the other hand the efficiency of the coating during the ship's life depends on the conditions of application and the owner maintenance policy. Even considering the new IMO Performance Standard for Protective Coatings, these conditions could not be considered for hull structural member appraisal at the new building stage.

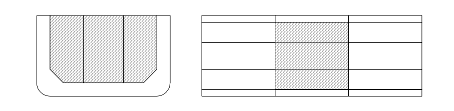
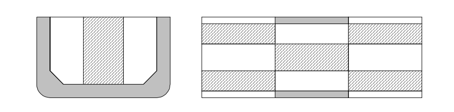
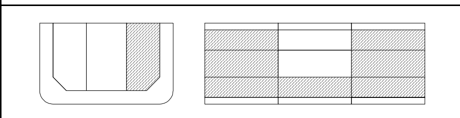
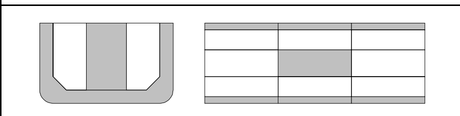
The philosophy of net scantling approach and the corrosion addition values are adopted in the IACS CSR for bulk carriers and oil tankers.

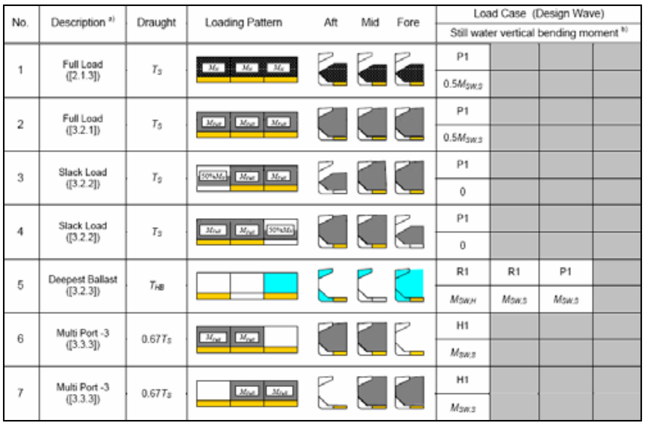
3.2 LOADS

The fundamental building block upon which the rules are based are the loads to be applied. The loads to be applied set up the two other fundamental building blocks, which are the engineering strength application formulations and the acceptance criteria. The loads are broken down into two major categories comprising of static and dynamic components. The static, or still water, components typically represent the loads associated with vessel operation loading conditions such as lightship weight, cargo, ballast, external buoyancy conditions. Figure 2 illustrates sample static load patterns, which are used for VLCC-type of tank arrangements and typical bulk carrier arrangements. The dynamic, or wave-induced, components represent the loads associated with the vessel motions and accelerations imposed from the vessel reacting to the seaway.

The dynamic loads are based on the fundamental vessel parameters in order to first calculate characteristic vessel motions and accelerations and then obtain the dynamic components of external pressure loads, hull girder bending and shear, and internal pressure. Dynamic loads associated with sloshing, local impact at the bottom forward, forward bow and green water on deck are also specified. Many of these load components were based on existing IACS Unified Requirements as developed by the working party on wave data and sea loads, which are available on the IACS web site www.iacs.org.uk

Load Pattern	Figure	Draft
A1(3)		0.9 T_{sc}
A2(3)		T_{sc}
A3(4)		0.6 T_{sc} see note (4)
A4		0.6 Tsc

A5		0.6 T_{SC}
A6		0.6 T_{SC}
A7 (5)		T_{LC}
A8(6)		T_{balH}



No.	Description a)	Draught	Loading Pattern	Aft	Mid	Fore	Load Case (Design Wave) / Still water vertical bending moment b)			
1	Full Load ([2.1.3])	T_S	M_S M_S M_S				P1 / 0.5$M_{SW,S}$			
2	Full Load ([3.2.1])	T_S	M_{Full} M_{Full} M_{Full}				P1 / 0.5$M_{SW,S}$			
3	Slack Load ([3.2.2])	T_S	50%M_S M_{Full} M_{Full}				P1 / 0			
4	Slack Load ([3.2.2])	T_S	M_{Full} M_{Full} 50%M_S				P1 / 0			
5	Deepest Ballast ([3.2.3])	T_{HB}					R1 / $M_{SW,H}$	R1 / $M_{SW,S}$	P1 / $M_{SW,S}$	
6	Multi Port -3 ([3.3.3])	0.67T_S	M_{Full} M_{Full}				H1 / $M_{SW,S}$			
7	Multi Port -3 ([3.3.3])	0.67T_S	M_{Full} M_{Full}				H1 / $M_{SW,S}$			

Figure 2 : Example of load arrangement for oil tankers and bulk carriers

The dynamic loads are further broken down into load scenarios which cover the range of operations associated with the rule requirements. For overall strength evaluations the characteristic loads are imposed using extreme weather and waves a vessel may encounter, which are based on a probability of exceedance of 10^{-8}. These loads represent the extreme loads based on exposure to the North Atlantic environment defined in IACS Recommendation 34, over a 25 year design life. It was noted during development that many vessels sail their whole life without ever transiting the North Atlantic, however the North Atlantic was selected as the characteristic environment for design in order to not limit future flexibility. In addition, calls from industry and public demanded that enhanced safety, robustness and durability be incorporated into the rules and the application of an onerous wave environment is one way to demonstrate these principles. The dynamic loads are represented by a series of Load Combination Factors (LCF) which represent the superposition of the various dynamic load components at a given point in time when the major dynamic load component is being maximized. The LCFs are applied in combination with the static load cases as shown in Figure 2.

The rules specify the loading conditions and loading patterns to consider during the strength evaluation of the hull structure. The loading patterns correspond to the most usual operational conditions that the size and type of vessel have to comply with. They constitute the minimum level in terms of loading that tankers or bulkers have to satisfy, but they come in addition to the loading patterns specified in the loading manual.

For bulk carriers, the loading patterns are based on IACS Unified Requirement for Strength, UR S25. This IACS UR was introduced in June 2002 following an IACS/industry discussion ignited by a paper put forward by the Hong Kong Ship Owners Association in which they expressed their concerns about design flaws in existing bulk carriers. UR S25 was developed for avoiding the design of a vessel only to specific loading conditions presented in the loading manual and to avoid the situation where the ship was approved but in many cases did not give the owner the ability to use the full potential of his ship.

For fatigue evaluations, representative characteristic loads are used to represent the large number of modest fatigue-inducing fluctuating load ranges, which are based on a probability of exceedance of 10^{-4}. Since fatigue calculation results are very sensitive to load and corresponding stress range applications, the most representative characteristic loads are applied which strive to eliminate any large conservative assumptions. It should be noted that the follow-on fatigue calculation methods impose safety margins later in the applied method and acceptance criteria itself, therefore imposing additional conservatisms at the load determination stage is not necessary. Of course as noted above, the North Atlantic environment is used.

The rule dynamic loads, whether determined at the extreme 10^{-8} level or at the representative fatigue 10^{-4} level, have been extensively developed and checked using direct hydrodynamic studies.

The major portion of work represented in the rules is the inclusion of the load combination factors which are used to combine the various load components. The loads are combined into sets which apply the specified maximum parameters along with the corresponding remaining components in order to set up equivalent wave approach to represent realistic dynamic-based loads. The dynamic load parameters, such as hull girder bending, external pressure, internal pressure, etc., are each maximized in turn to impose corresponding static and dynamic loads on the various structural members. The Rules include specified load sets to be applied during the structural review process.

3.3 STRUCTURAL REQUIREMENTS

The general scope of the structural requirements is similar to the current rules of all class societies. The structural requirements cover global hull girder strength, primary support members and local structural members. The requirements employ easily understood transparent engineering principles along with the net thickness and load applications as previously summarized, with associated acceptance criteria. The acceptance criteria are defined in association with the load set applied and the failure mode being checked.

In addition to the goal of transparently describing and defining the rule criteria, consistency is also a main goal so that similar loads, failure modes and acceptance criteria are used for similar rule applications.

3.3 (a) Hull Girder Strength

Hull girder strength requirements for onboard documentation and rule strength formulations are in accordance with IACS Unified Requirements (S1, S7, S11 in general, and S17, S25 for bulkers). The rule requirements cover the detail procedures for the structural evaluation for static and dynamic components for bending and shear. Also included is the evaluation of the local plate and stiffener members to resist buckling associated with the global hull girder loads, primarily the hull bending mode.

3.3 (b) Primary Support Member

Primary support member prescriptive requirements are included for oil tanker rules for the double bottom and double side structure, longitudinal bulkhead vertical web frames, deck transverse web frames, cross ties, and bulkhead stringers. Loading tank patterns and load combinations for these members are specified so that the resulting loads are maximized to check relevant failure modes using load-based engineering formulations. General examples of the load-based requirements are shown in Equations (1) and (2) for bending and shear respectively. These requirements are easily understood to contain load, bending or shear equations and allowable stress components. A representative web frame configuration for a VLCC arrangement is shown in Figure 3 which also illustrates some of the formula parameters.

The structural arrangement of bulk carriers are not prone to be pre-checked by prescriptive requirements. For instance, the double bottom structure is made of members mutually supporting themselves.

For CSR Rules, additional minimum prescriptive depth, thickness and stiffened panel ratio criteria are applied to control overall deflections, minimum robustness factors and provide a first review of panel buckling and flange stability.

The primary support members are later checked using the required direct strength FE analysis. The FE analysis is better able to calculate the interaction of the structural members such as the hull girder, grillage effects, shear lag, etc., which can not always be fully accounted for in the load-based prescriptive requirements. The load-based prescriptive requirements are typically more conservative than the FE results so that in areas where FE is not performed, the prescriptive requirements satisfactorily provide necessary strength.

However, for CSR/Tanker only, in areas where FE analysis is performed, a 15 percent reduction below the load-based prescriptive requirements is permitted subject to acceptable associated results and analysis of the prescribed FEA.

$$Z = \frac{1000\,M}{C_{s-pr}\,\sigma_{yd}} \quad \text{cm}^3 \qquad (1)$$

Where:

M	design bending moment, in kNm $= c\,P\,S\,l_{bdg-vw}{}^2$
P	design pressure for the Design Load Set being considered, in kN/m^2.
l_{bdg-vw}	bending span, in m.
S	spacing of vertical web frames, in m
C_{s-pr}	permissible bending stress factor
σ_{yd}	specified minimum yield stress of the material, in N/mm^2
C	coefficient to cover structural configuration

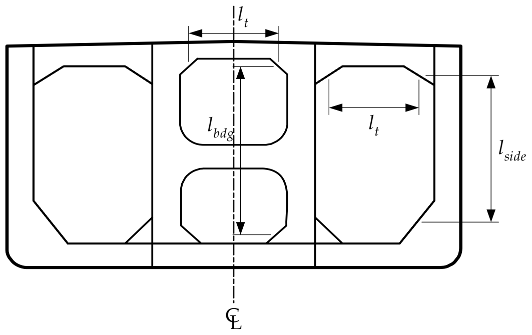
$$A_{shr} = \frac{10\,Q}{C_{t-pr}\,\tau_{yd}} \quad \text{cm}^2 \qquad (2)$$

Where:

Q	design shear force, in kN: $= S\ [c_u\,l_{vw}\,(P_u + P_l) - h_u\,P_u]$
P_u	design pressure for the Design Load Set being considered, calculated at the mid height of upper bracket of the vertical web frame, h_u, located at the mid tank, in kN/m^2
P_l	design pressure for the Design Load Set being considered, calculated at the mid height of lower bracket of the vertical web frame, h_l, located at the mid tank, in kN/m^2
l_{vw}	Length of the vertical web frame, in m
S	spacing of the vertical web frames, in m
h_u	effective shear length of the upper bracket of the vertical web frame, in m
h_l	effective shear length of the lower bracket of the vertical web frame, in m
c_u	coefficient to cover structural configuration
C_{t-pr}	permissible shear stress factor as given in *2.6.2.2*

τ_{yd} $= \dfrac{\sigma_{yd}}{\sqrt{3}}$ N/mm^2

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



c.

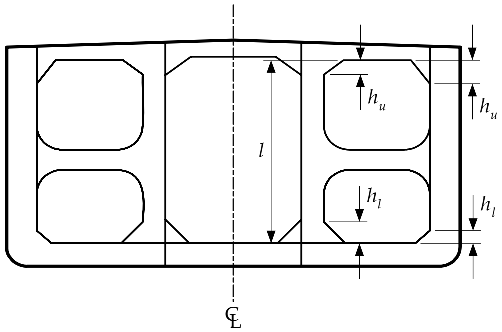


Figure 3 : Sample Primary Support Member requirement

3.3 (c) Local Support Members

Local support member prescriptive requirements are included for the hull envelope and inner structure such as, inner bottom, inner hull, deck, transverse and longitudinal bulkheads, etc. The loads used for the evaluation of tank/cargo boundaries are based on the maximum possible loading assessed with a full condition on one side and an empty condition on the other side. The full and empty capacities are then reversed to reflect the opposite situation so that both load scenarios are considered. Similarly the shell envelope is assessed for maximum external pressure at the deepest draft without internal counteracting loads and then the opposite situation is evaluated so that the full tank/hold is applied in association with the lightest draft, i.e. ballast draft. Relevant failure modes using load-based engineering formulations are applied to the plating and stiffening. The stiffener requirements also include detail checks of the end connection which take into account whether collar plates and web stiffeners are provided.

The local members are later checked for in-plane stress criteria using the required direct strength FE analysis. The FE analysis is better able to calculate the interaction of the structural members and their local influence on the local structural members such as the shell, inner hull, and transverse and bulkhead plating, etc., which can not always be fully accounted for in the load-based prescriptive requirements. This evaluation covers local yielding and buckling/ultimate strength considerations.

The local support members also include the rules for evaluation corrugated bulkhead stiffness and local plate, as well as the corrugated bulkhead stool structure.

Additional minimum prescriptive thickness, panel ratios, stiffener web and flange ratios and other local minimum criteria are applied to control overall minimum robustness factors and provide a first review of panel buckling and stiffener stability.

3.3 (d) Forward-most and Aft-most Tank Structural Members

Forward-most and aft-most tank structural members are evaluated in CSR/Tanker using the prescribed procedures for tapering the longitudinal strength members as well as using the prescribed methods for local evaluation. A general procedure to apply the midship FE analysis results to the tanks outside of the 0.4 length amidships is also included.

3.3 (e) Forward, Machinery and Aft Structural Members

Forward, Machinery and Aft Structural Members are evaluated using the included detailed requirements. The forward structure is evaluated for bottom slamming and bow impact considerations which take into account the various operating drafts and tank filling operations.

In addition to the scantling requirements mentioned above, general requirements such as welding, materials, closing appliances, superstructure, mooring and anchoring equipment, etc. are also included in the CSR Rules.

3.3 (f) Compliance with SOLAS XII/6.5.1 & 3 for Bulk carriers

The new SOLAS chapter XII which came into force on 1st July 2006 (construction date) has an additional requirement with respect to damages of stiffeners surrounding the cargo hold. The exact wording is: "*The structure of cargo areas shall be of such that single failure of one stiffening structural member will not lead to immediate consequential failure of other structural items potentially leading to the collapse of the entire stiffened panels*".

Within IACS, UR S12 rev. 4 has been under discussion from mid-2002 to the beginning of 2004. As a result of that discussion, IACS working group ISR ISWG 1/4 and SOLAS XII/6.5.3 have been incorporated in CSR for Bulk Carriers. The objective was initially to increase the strength of the side shell structure (side frames, but also brackets and longitudinals supporting these brackets). Moving on, the discussion focussed on how to prevent the domino effect of side frames collapsing.

The following principles were considered:

- Local deformation of about 20 mm imposed to one stiffener of the structure adjacent to cargo hold before checking ultimate strength of the stiffened panel under 80% of wave-induced loads (global moments + pressure)
- If the damage is a crack or welding damage, ensure that brittle fracture possibility is avoided

The structural redundancy requirements of SOLAS XII/6.5.1 and 6.5.3 were covered by the CSR for Bulk carriers through the following requirements which were presented and accepted by IMO:

- 80% of dynamic loads are applied
- Require safety factor of 1.15 for the ultimate strength calculation of stiffened panels surrounding the cargo holds (except the deck)
- Request grade D/DH for lower brackets of side shell frames and the corresponding side shell strake in way.

3.4 FINITE ELEMENT ANALYSIS

The CSR for oil tankers and for bulk carriers require an assessment of the hull structure using Finite Element Analysis (FEA) on a model extending on 3 cargo holds/tanks.

As mentioned previously, the objective of the structural assessment is to verify that the stress levels and buckling capability of the primary support members and hull structure are within acceptable limits associated with the applied static and dynamic loads. In addition the fatigue strength of selected structural details also must be verified.

The structural assessment is based on a three-dimensional FEA in accordance with the detailed procedure included in the rules. The analysis procedure covers all aspects of the modelling details, loads and boundary conditions to be applied, and acceptance criteria utilized to determine whether the structure arrangements and scantlings are within compliance. Also included in the rules is the procedure for local fine mesh and very fine mesh analysis to evaluate local high stress areas and details to ensure that the acceptance criteria is satisfied in these areas.

The rules specify the extent of the global FE model, three-cargo tank/hold lengths, mesh density and net thickness to use in the analysis.

Figure 4 shows examples of two global FE models. The extent of fine mesh modelling and associated mesh density and net thicknesses are also included in the rules.

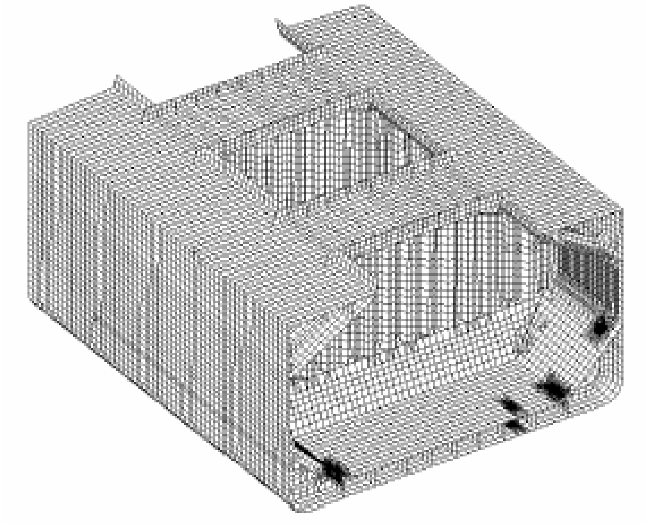


Figure 5 shows an example of the fine mesh model with very fine mesh areas imbedded within the model.

The rules include full details of the acceptance criteria to apply to each structural member type, rule load condition, and analysis model employed.

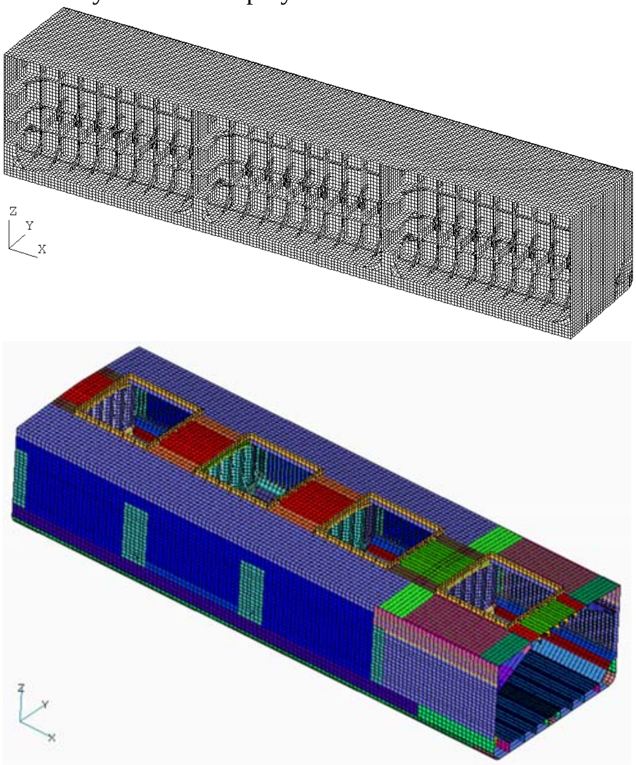


Figure 4 : FE Global Models

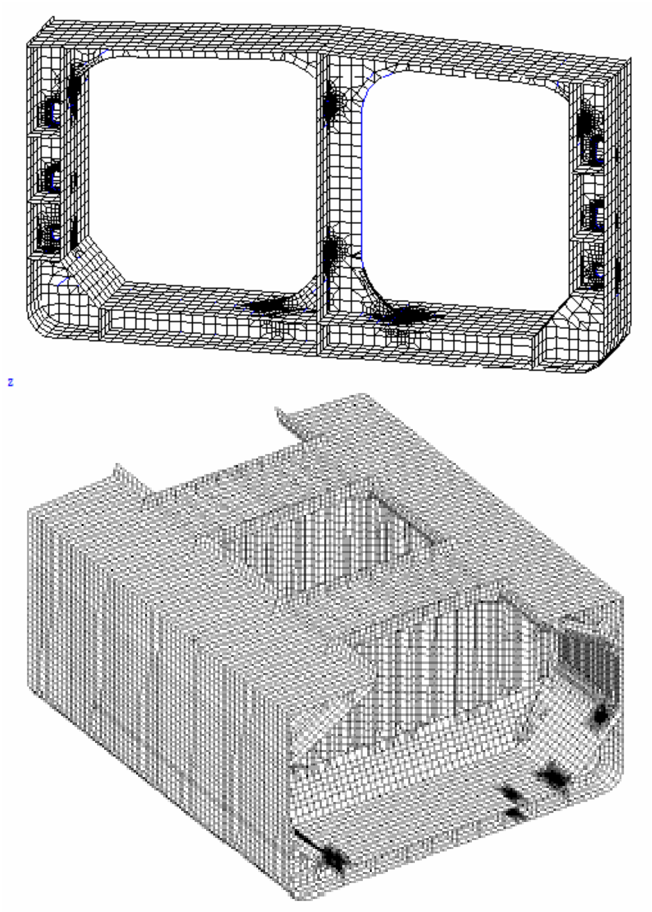


Figure 5 : Local Fine Mesh FE Model

3.5 HULL GIRDER ULTIMATE STRENGTH

The CSR rules include a simplified hull girder ultimate strength assessment in order to provide a second level of hull girder assessment in addition to the current elastic-based assessment contained in IACS Unified Requirement S11 which is also included in the rules. This simplified ultimate strength assessment is not intended to replicate a complete extensive hull girder ultimate strength assessment where the full load and capacity curves for the hull girder are developed (typically using non-linear approaches.) Instead, a screening requirement has been developed, which assess the relative hull girder ultimate strength capacity of the cross section in order to rule out those vessel designs where this failure mode is an issue.

For both tankers and bulkers, an additional level of safety is introduced for seagoing conditions with respect to the total hull girder bending moment corresponding to the wave bending moment at the probability of 10^{-8} and the permissible still water bending moment in way of the checked cross section. In addition, for the bulk carriers the accidental conditions is considered when a holds are flooded one by one with a reduced wave bending moment.

Since the sagging condition is the limiting critical ultimate strength condition for double hull tankers, the CSR/Tanker rules only cover the sagging case only while CSR/Bulk provide criteria in hogging and sagging conditions.

3.6 FATIGUE

The general aim of the fatigue control included in the rules is to ensure that the hull structure, subjected to fatigue (dynamic cyclic) loading, have an adequate fatigue life for the duration of the vessel design life.

The procedure provides a designer oriented approach to fatigue strength assessment which may be used for certain structural details in lieu of more elaborate methods, such as spectral fatigue analysis. The term simplified approach is used here to distinguish this approach from the more elaborate analysis.

The criteria in the rules were developed from various sources, including the Palmgren-Miner linear damage model, S-N curve methodologies, a long-term environment data of the North Atlantic Ocean (IACS Wave Data) etc., and assume workmanship of commercial marine quality acceptable to the Surveyor. The capacity of structures to resist fatigue is given in terms of fatigue damage control to allow designers the maximum flexibility possible.

The procedure is specifically written to evaluate fatigue strength of structural details at welded connections based on a simplified fatigue assessment procedure. The assessment is applicable to the evaluation of longitudinal end connections using beam theory based nominal stress approach and other critical details, such as the hopper corner, using FEM based hot spot stress approach.

The main assumptions employed are listed below:

- A linear cumulative damage model (i.e. Palmgren-Miner’s Rule) has been used in connection with the S-N data.
- Cyclic stresses due to the loads have been used and include the effects of mean stress.
- The minimum design life of the vessel is taken to be 25 years.
- The environmental data for the North Atlantic is used.
- The long-term stress ranges of a structural detail can be characterized using a modified Weibull probability distribution parameter (ξ).
- Structural details are idealized and applied fatigue class (tanker) or stress concentration factors (bulk carrier) are provided in the procedure.
- For longitudinal stiffener end connections, simple nominal stresses obtained by empirical formula and Rule based loads form the basis of nominal stress based fatigue assessment.

The structural detail classification in the rules is based on joint geometry under simplified loadings. Samples of the fatigue joint types and associated fatigue class is included in Figure 6 (for tanker) and of fatigue stress concentration factors in
Figure 7 (for bulker).

Where the loading or geometry is too complex for a simple classification, a finite element analysis of the detail is to be carried out to determine the fatigue stress of that detail. Guidance on the finite element analysis required to determine hot-spot stress for weld toe locations are included in the procedure. The details to be analysed by fatigue under FE analysis are at least the knuckle between inner bottom and hoper for both types of ship and others requested by the rules as shown in Figure 8.

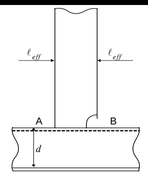
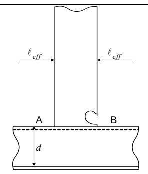
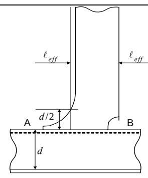
ID	Connection type	Critical Locations A	Critical Locations B
1		F2	F2
2		F2	F2 (see note iv)
3		F	F2

Figure 6 : Fatigue Joint Classification

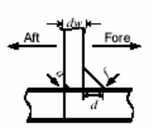
2 	a	watertight	$dw \le d < 1.5dw$	1.45	1.1	1.15	1.4
			$1.5dw \le d$	1.4	1.05	1.15	1.35
		non-watertight	$dw \le d < 1.5dw$	1.55	1.1	-----	-----
			$1.5dw \le d$	1.5	1.05	-----	-----
	f	watertight	$dw \le d < 1.5dw$	1.1	1.05	1.15	1.1
			$1.5dw \le d$	1.05	1.05	1.1	1.05

Figure 7 : Fatigue Stress Concentration Factors

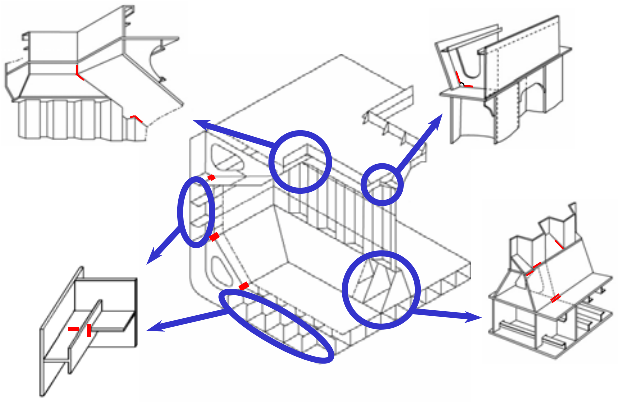


Figure 8 : Example of bulk carrier details to be checked in fatigue

The rules also permit the optional use of more detailed spectral fatigue evaluation to assess fatigue. However, this more refined analysis may not be used to reduce the requirements of the prescriptive requirements.

4. GOAL-BASED NEW SHIP CONSTRUCTION STANDARDS

At the time the CSRs were being developed, the International Maritime Organization (IMO) were starting to develop broad reaching goal-based new ship construction standards (GBS) aimed at determining the basic standards which will be used to assess class rules. The development of the IMO GBS continues at this time. The IMO are discussing two formats for the GBS; a "prescriptive format" and a "safety level approach". Regardless of the format, in essence, IMO is developing "rules for the rules" so that rules developed by Classification Societies will meet an overarching basic level of safety. The CSR developers continuously monitored the GBS developments in order to incorporate pertinent criteria into the CSRs.

At this point in time, IACS have agreed to use the CSR to test the GBS process by carrying out a pilot project. This pilot project will be used to improve the GBS as well as to identify any areas where the CSR can be improved.

5. IACS IMPLEMENTATION OF THE COMMON STRUCTURAL RULES

In June 2003 the IACS Council responded to initiatives at IMO and Industry and decided to develop a set of common Rules and procedures for the determination of the structural scantlings for oil tankers and bulk carriers. On the 1st of April 2006 these rules entered into force. They encompass all the changes and updates above, and also provide a harmonized structural approach across all IACS classification societies.

5.1 CSR MAINTENANCE

In parallel to the Rules entry into force, IACS implemented two project teams under the supervision of the IACS Hull Panel. Each team is in charge of the maintenance for one set of the CSR. The Figure 9 shows the IACS organisation.

Each team is made of four IACS members, three belonging to the class societies in charge of the Rule development for the corresponding ship type and another member.

Today the maintenance is ensured by:

- CSR for Oil Tankers
  - DNV,
  - ABS,
  - LRS,
  - BV
- CSR for Bulk Carriers
  - ClassNK,
  - BV,
  - GL,
  - ABS

A rotation will be organized among the members every two years.

Further to questions and requests of interpretations raised by IACS members, the teams could propose corrigenda and Rules change proposals. The corrigenda concern mainly editorial amendments of the Rules while the Rules change proposals have to be proposed to the technical committees of individual IACS members before its definitive adoption by the Council.

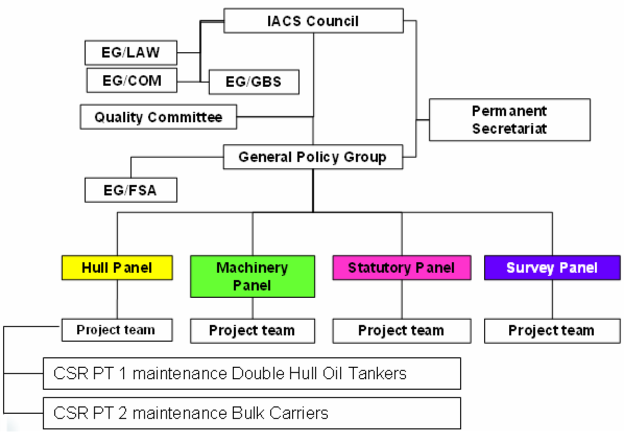


Figure 9 : IACS Organisation

5.2 CSR INTERPRETATIONS

The teams involved in the CSR maintenance are also tasked with providing Rule interpretations. This is a means to provide a solution to be applied by all IACS members in the same way. The interpretations are also a step towards the possible Rule change process providing a temporary solution to members and ship designers.

Those interpretations are recorded in a database accessible by IACS members. When considered valuable for the Industry, IACS secretariat posts some of them on the IACS web site.

Once a year the teams review the interpretations for proposing to the Hull Panel a list of Rule modifications.

5.3 CSR HARMONIZATION

The common structural rules for tankers and bulk carriers began at different points in time and initially followed individual paths of development. IACS member societies agreed to harmonise the two approaches and a high degree of harmonisation between the two sets of rules has already been achieved. The wording adopted by individual societies in relation to the IACS common structural rules is identical and work on further harmonisation will continue.

The process was divided into three terms: a short, a medium and a long term harmonisation process.

The short term focused on:

- Vertical wave shear force
- Corrosion additions and allowances
- Ultimate hull girder strength

The medium term on:

- Prescriptive buckling
  - Buckling under hull girder loads, not in FE
  - Direct analysis comparison
- Direct strength Analysis
  - To eliminate the major concern against two procedures with regard to common scantlings
  - Comparative analysis of Tanker and Bulker structures by JTP and JBP teams

The long term on:

- Loads harmonisation
- Fatigue

The short and medium term tasks have been completed and the result is included in the CSR text. The Long term projects are tasked to expert groups under the supervision of the IACS hull panel. This task will start after three years of Rule implementation allowing IACS to take advantage of experience gained during Rule application.

5.4 CSR RECOGNITION FOR COMPLIANCE

For tankers and bulk carriers of the specified dimensions contracted after 1st April 2006, there will be a new class notation **CSR** added to the service notation which will signify that vessels are in compliance with the IACS **C**ommon **S**tructural **R**ules. This will be standard procedure for all classification societies which are members of IACS.

6. CONCLUSIONS

The development of the CSR by IACS has been outlined. Examples of how the balance between incorporating highly technically advanced methods and practical deterministic application needs were incorporated. At the time the CSRs were being developed, the IMO broad reaching goal-based standards (GBS) were continuously monitored in order to incorporate pertinent criteria into the CSRs.

The new relationships between the classification societies and industry developed as a consequence of the consultation processes during the development phase were described along with the implementation and maintenance of the CSR by all ten members of IACS.

7. ACKNOWLEDGEMENTS

The authors would like to acknowledge the considerable research and rule development work performed by all IACS members, it is hoped that this paper illustrates the team members hard work and professionalism. The support and leadership of the senior management of IACS are also acknowledged.

This paper, which summarizes the basic aspects of the CSR, is the work of the authors. For additional details please refer to the actual rule and background documents assembled by the IACS project teams. The opinions expressed in this paper are the authors' and does not necessarily represent the policy of ABS, BV or IACS.

8. REFERENCES

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9. AUTHORS' BIOGRAPHIES

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