IACS Common Structural Rules for Double Hull Oil Tankers, January 2006

Background Document

SECTION 9/2 – DESIGN VERIFICATION STRENGTH ASSESSMENT (FEM)

NOTE:

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- The content of the TB is not to be considered as requirements.

- This TB cannot be used to avoid any requirements in CSRs, and in cases where this TB deviates from the Rules, the Rules have precedence.

- This TB provides the background for the first version (January 2006) of the CSRs, and is not subject to maintenance.

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2 STRENGTH ASSESSMENT (FEM)

2.1 General

2.1.1 Application

2.1.1.a The finite element strength assessment is applicable to double hull oil tankers greater or equal to 150m in length. The assessment procedure is applicable to double hull oil tankers with the following configurations:

(a) two longitudinal oil-tight bulkheads between cargo tanks with no centreline longitudinal bulkhead and with a cross tie arrangement in the centre cargo tank
(b) two longitudinal oil-tight bulkheads between cargo tanks with no centreline longitudinal bulkhead and with a cross tie arrangement in the wing cargo tanks
(c) two longitudinal oil-tight bulkheads between cargo tanks with no centreline longitudinal bulkhead and without a cross tie arrangement
(d) one centreline longitudinal oil-tight bulkhead between cargo tanks.

2.1.1.b The detailed description of the assessment procedure is given in *Appendix B of the Rules*. The acceptance criteria are given in *Section 9/2.2.5 and 9/2.3.5 of the Rules*. The application of the verified scantlings of the structural members in the midship region to the whole cargo tank region is described in *Section 9/2.4 of the Rules*.

2.1.2 Submission of results

2.1.2.a It is considered that for this topic, no information in addition to that shown in the Rules, is necessary to explain the background.

2.1.3 Computer programs

2.1.3.a It is considered that for this topic, no information in addition to that shown in the Rules, is necessary to explain the background.

2.2 Cargo Tank Structural Strength Analysis

2.2.1 Objective and scope

2.2.1.a Further explanation on mandatory and optional shear strength assessment in way of transverse bulkheads is given in *Appendix B/1.1.1 of the Rules*.

2.2.1.b Yield and buckling are two main failure modes of structure under static and dynamic loads related to Serviceability Limited State. The structural strength capability against these two modes of failure is verified by the strength assessment.

2.2.2 Structural modelling

2.2.2.a See *Appendix B/2.2 of the Rules* for a detailed description of structural modelling procedure.

2.2.3 Loads and loading conditions

2.2.3.a See *Appendix B/2.3 of the Rules* for a detailed description of standard and optional FE load cases.

2.2.4 Load applications and boundary conditions

2.2.4.a One important aspect of FE analysis is to determine the response of the structure as accurately as possible for a given set of applied loads. For this reason, the Rules require that all simultaneously acting hull girder and local loads are to be applied directly to the FE model. This ensures that the effect of the interaction of all structural parts is included in the solution. The method of superimposition of stresses derived from FE analysis for local loads and simplified beam theory model for hull girder loads is not adapted as important structural interaction cannot be preserved.

2.2.4.b See *Appendix B/2.4 of the Rules* for a detailed description of application of loads to FE models.

2.2.4.c See *Appendix B/2.6 of the Rules* for a detailed description of application of boundary conditions to FE models.

2.2.5 Acceptance criteria

2.2.5.a Verification of results against the acceptance criteria is carried out for structural members within the longitudinal extent of the middle tanks of the three-tank FE model, and the regions forward and aft of the middle tanks up to the extent of the transverse bulkhead stringer and buttress structure. The FE result in this region is considered to be valid for assessment against the acceptance criteria, as:

- The analysis procedure ascertains that the required hull girder bending moments and shear force are correctly applied within middle-tank region of the model. Also see *Appendix B/2.5 of the Rules* for a detailed explanation of the procedure for adjusting hull girder bending moments and shear forces.
- The boundary of the model is sufficiently remote from the area under assessment so that the constraint applied at the model ends will not affect the stress responses. Also see *Appendix B/2.2.1* for further information.

2.2.5.b The stress criteria are based on Von-Mises stress and an explicit criterion on pure shear stress is not used. A Von-Mises stress criteria will normally be more stringent than a pure shear criteria (i.e. based on shear yield stress with the same factor of utilization) as the calculation of Von-Mises stress includes shear stress and other additional axial stress components. Note that shear and biaxial direct stresses are used in the calculation of the buckling utilization factor of panels.

2.2.5.c The stress criteria are based on membrane stress of elements, which represents the stress due to hull girder effect and deflection of primary support members but does not include local bending stress in plates and stiffeners caused by lateral pressure load. If shell (or bending plate) elements are used, the stress is evaluated at the mid-thickness plane of the element. The stress is evaluated at the element centroid for assessing against the acceptance criteria.

2.2.5.d As the stress assessment is based on membrane stress, plate bending stresses due to local pressure loads are not included in the FE stress result for plates forming the water or oil tight boundaries of tanks. This plate bending stress that is not included in the FE result is accounted for by assigning lower allowable membrane stresses for structural members at the tight boundaries. The structural members at tight boundaries are divided into two groups:

- Group 1 represents structural members where the combined total stress is dominated by the stresses in the FE model (i.e. hull girder shear/bending and primary support member deflection) and includes deck, sides and longitudinal bulkheads. For this group, the allowable pure membrane stress is set at 0.9 times of that for non-tight structural members.

- Group 2 represents structural members such as bottom, inner bottom and transverse bulkhead where the tertiary plate bending stresses have a relatively higher contribution to the total stress. The allowable pure membrane stress is set at a lower value for this group, which is equal to 0.8 times of that for non-tight structural members.

For non-tight structural members, tertiary plate bending stress can be neglected as the applied net pressure is zero. The allowable membrane stress for non-tight structural members is equal to yield stress for seagoing load cases (S + D design combination) and 80% of yield stress for harbour/tank testing load cases (S design combination).

2.2.5.e For elements in way of areas of stress concentration, i.e. corners of openings, knuckle joints, toes and heels of brackets of primary supporting structural members, the yield stress of material is not to be taken as greater than 315 N/mm^2 in the calculation of yield utilization factor for seagoing load cases (S + D design combination). This is used as an implicit means to control high cycle fatigue damage where the use of higher tensile steel does not improve the fatigue strength of structural details under high cycle loads. In many cases, the fatigue damage of structural details constructed using higher tensile steel is actually worse compared to those constructed using mild steel because of the higher stress allowed in the structure. This limitation in the utilization of the yield strength of higher tensile steel is not applied to harbour/tank testing load cases (S design combinations). The relevant failure mode represented by these load cases is low cycle fatigue (repeated yield), that may occur as a result of the loading/unloading sequence. For low cycle fatigue, the fatigue strength increases with increasing yield strength and is proportional to the yield strength of the material. Also see *2.3.5.h*.

2.2.5.f For the assessment of local buckling of panels, it is required to consider the combined interaction of biaxial compressive stresses and shear stress due to the effect of hull girder deflection, primary supporting member deflection and local lateral pressure load. It is acceptable to use a local model of the panel, together with the membrane stresses obtained from the FE analysis and combined with contribution by the local lateral pressure load based on the panel model. As all loads are considered in the panel buckling assessment, therefore only one acceptance criterion on the buckling utilization factor is applied to all structural members for seagoing load cases (S + D design combination), and one for harbour/tank testing load cases (S design combination). The allowable buckling utilization factor is 1.0 for seagoing load cases and 0.8 for harbour/tank testing load cases.

2.2.5.g The harbour/tank testing load cases (S design combination) are assessed based on static loads only. The acceptance criteria on yield and buckling utilization factors for harbour/tank testing load cases (S design combination) is set at 80% of the corresponding criteria for seagoing load cases (S + D design combination) which effectively allow a margin equal to 20% of the criteria for dynamic loads. This margin allows for some dynamic wave loads in harbour and tank testing operations which may be carried out at sea in sheltered waters, and also gives a safety margin to ensure that temporary accidental overloading will not cause permanent deformations.

2.2.5.h Where a lower bulkhead stool is not fitted to a corrugated bulkhead, the arrangement of the structure is to comply with special requirements given in *Section 8/2.5.7.9 of the Rules*. An additional factor of safety (equivalent to 10% reduction in the stress and buckling acceptance utilisation factors) is applied in the assessment of corrugated bulkhead and its supporting structure when a lower bulkhead stool is not fitted to achieve the same level of confidence as in designs fitted with a lower bulkhead stool. Service experience indicates that corrugated bulkhead designs without a lower stool are more critical (e.g. prone to local fracture) than those fitted with a lower bulkhead stool due to higher stress level and alignment problems with the supporting structure in the double bottom. The reduction in acceptance utilisation factors is introduced also as a measure to account for lack of prescriptive requirements for corrugated bulkheads without lower stool.

2.2.5.i Please see *Appendix B/2.7.2 and 2.7.3 of the Rules* for further information on evaluation of stresses and buckling utilization factor.

2.3 Local Fine Mesh Structural Strength Analysis

2.3.1 Objective and scope

2.3.1.a The selection of locations for investigation is based on service experience and previous finite element studies carried out on tanker designs. Detailed description of the locations is given in *Appendix B/3.1.2 to 3.1.5 of the Rules*. The locations identified cover the most critically stressed areas in the midship region for conventional designs. As the number of locations that are required to be investigated is extensive, a screening procedure has been developed, which is based on a correlation study of the stresses obtained from the ‘coarse mesh’ cargo tank FE analysis and fine mesh FE analysis, to identify the critical locations that need to be assessed using fine mesh analysis, and avoid unnecessary and repetitive analysis being carried out. The screening criteria for fine mesh analysis are given in *Appendix B/3.1.6 of the Rules*.

2.3.1.b Originally, the Rules imposed a relative deflection criterion, which was derived based on a simple beam under deflection and calibration with existing designs, to control the stress level at the end connection of the stiffeners caused by the relative deflection between primary support members. If the deflection criteria was not satisfied, a mandatory fine mesh analysis was required to assess the total stress in way of the end brackets and attached web stiffeners of longitudinal stiffeners of double bottom and deck, and adjoining vertical stiffener of transverse bulkhead, where maximum relative deflection between primary supports exists. It was later decided to delete the deflection criteria and require a local fine mesh analysis in all cases. The advantage of using a fine mesh analysis over a simple relative deflection criterion is that the fine mesh analysis can provide a more accurate control of the stress level as the analysis takes into account the actual geometry of the connection detail, bracket arrangement and all load components. The intention of the fine mesh analysis is to verify that the structure has adequate strength when subjected to the increased stress caused by the relative deflection of the stiffener and all other applied loads.

2.3.1.c In the case where the geometry of a structural detail cannot be adequately represented by the ‘coarse mesh’ in the cargo tank finite element model, then a fine mesh analysis can be used to obtain the stress for comparison with the criteria. It is to be noted that this analysis option is only applicable to area of stress concentration and structural discontinuity (i.e. high stress gradient), and is not intended as a substitute to the 'coarse mesh' cargo tank analysis in areas under uniform stresses where no stress concentration exists, such as the upper deck of the ship. Also see *2.3.5.f*.

2.3.2 Structural modelling

2.3.2.a A mesh size not greater than 50mm x 50mm is required for the fine mesh area. This mesh size is chosen because this is the maximum mesh size that is sufficient to represent the geometry of structural details, such as bracket toes and corners of openings. Larger mesh sizes, such as 100mm x 100mm, are considered insufficient to model the geometry of details properly, resulting in stress values not reflecting the geometry of the details.

2.3.2.b See *Appendix B/3.2 of the Rules* for a detailed description of the structural modelling procedure.

2.3.2.c See *Section 6/3.3.6.3* for an explanation of the choice of modelling thickness.

2.3.3 Loads and loading conditions

2.3.3.a See *Appendix B/3.3 of the Rules* for a description of the loading conditions to be analysed.

2.3.4 Load applications and boundary conditions

2.3.4.a See *Appendix B/3.4 of the Rules* for a description of the loads and boundary conditions to be applied.

2.3.5 Acceptance criteria

2.3.5.a Steel is ductile. Through ductility, structural steel is able to absorb extensive local yielding without the danger of structural failure. Yielding commonly occurs in steel structures even before the intended service loads are applied. For hull structures which are complex in geometry as well as in connection details, local yielding is actually inevitable. Yielding can occur during fabrication and erection. For instance, welding often produces over-yield residual stresses in the heated zone, especially in the joint connections. Yielding is also possible when structural members are fitted into positions and formed into desired shapes. In most cases, the yielding is highly localised, and that will be surrounded by lower stress regions causing load re-distributions, and as a result, constitutes no consequence to the integrity of the structure.

2.3.5.b It is noted that in order to account for the redistribution of localized stresses as mentioned in *2.3.5.a* above, ASME pressure vessel codes allow membrane stresses in the shell to go up to yield strength, and for membrane plus bending, the allowable is 1.5 times yield. If local bending is present due to a structural discontinuity, the allowable is two times yield.

2.3.5.c For ship structures, there is no reason why very localised yielding, which occurs commonly during construction, should then be prohibited during their service life.

2.3.5.d It is well known that calculated stresses in linear finite element analysis can continue to increase beyond yield as the mesh size decreases, particularly in way of structural connections or discontinuities. It is important to note that all stresses that exceed the yield point are direct results of linear finite element analysis based on a linear stress-strain relationship. In reality, a stress in steel can only go slightly beyond the yield stress, and a stress of "1.5 or 2 times yield" does not exist physically. In other words, without resorting to non-linear analysis for more accurate structural behaviour beyond yield, an over-yield stress should really be evaluated in conjunction with the corresponding stress in the area in question, with a view of load actions and not solely based on the magnitude of the over-yield stress itself. Calibration of the load model, the structural model and the acceptance criteria against service experience is therefore essential in the setting of the acceptance criteria.

2.3.5.e The Rules adopted an approach commonly used by shipbuilding industries in which the localized area acceptance stress criteria (For static and dynamic load cases; 1.7 times yield in general and 1.5 times yield for element adjacent to a weld. For static load cases; 1.36 times yield in general and 1.2 times yield for element adjacent to a weld.) are set against a standard mesh size (50mm x 50mm) to obtain a standard of the scantling requirement. The acceptance stress criteria are calibrated against the applied load model using existing service experience of design details to ensure the set standard is not lower (and in many cases higher) than that currently required.

2.3.5.f In addition to the criterion set for individual element stress level, average stress calculated over an area equivalent to the mesh size of the cargo tank finite element model is not to exceed the allowable stress required by the cargo tank finite element analysis (i.e. below yield) to retain the consistency between fine mesh analysis and cargo tank analysis. The average stress is calculated based on weighted average of Von Mises stress and area of elements within the equivalent area.

2.3.5.g As the acceptance criteria are set against a given mesh size, these criteria should not be used in conjunction with stresses obtained from a model with mesh size larger than that is intended as this will lead to non-conservative scantling requirement. For models with a mesh size smaller than that intended, an average scheme can be used to calculate the equivalent stress over a patch size of 50mm x 50mm.

2.3.5.h For elements within the fine mesh zone (i.e. elements in way of areas of stress concentration), a higher tensile factor is introduced in the calculation of yield utilization factor. This higher tensile steel factor is not to be taken as greater than 0.78, which limits the utilization of the yield stress of higher tensile steel to 301 N/mm^2 in areas of stress concentration. This is used as a means to implicitly control high cycle fatigue damage. This limitation in material yield stress is applied to seagoing load cases (S + D design combination) and is not applied to harbour/tank testing load cases (S design combination). In addition, a lower value of allowable stress is applied to the fine mesh elements in way of a weld to account for lower fatigue strength of welded material compared to that of the parent material. Note that for the stress criteria of the cargo tank FE analysis, a higher tensile steel factor is not applied resulting in a slightly higher allowable utilization of the yield stress at 315 N/mm^2 because the larger area considered for element size used (typically 750mm x 750mm to 900mm x 900mm). Also see *2.2.5.e*.

2.3.5.i The stress acceptance criteria for harbour/tank testing load cases (S design combination), which is based on static loads only, are set at 80% of the corresponding criteria for seagoing load cases (S + D design combination) which effectively allow a margin equal to 20% of the criteria for dynamic loads. This approach is consistent with the criteria setting of the cargo tank FE analysis. Also see *2.2.5.g*.

2.4 Application of Scantlings in Cargo Tank Region

2.4.1 General

2.4.1.a As a minimum rule requirement, finite element analysis is mandatory for the assessment of hull girder and primary supporting structural members in the midship cargo region and required strengthening of side shell, longitudinal bulkheads and inner hull in way of transverse bulkheads for hull girder shear loads. The requirements given in *Section 9/2.4 of the Rules* are aimed at defining the application of the verified scantlings to the whole cargo region of the ship to retain certain continuity in the scantling requirements. It is to be noted that the required scantlings of a structural member are to be taken as the most onerous scantlings required by all parts of the rules.

2.4.1.b See *Appendix B/1.1.1 of the Rules* for a description of the scope of mandatory finite element analysis.

2.4.2 Application of scantlings to deck

2.4.2.a The deck scantlings are to be maintained within 0.4L amidships. Depending on the actual loading condition of the ship, the maximum permissible bending moment may occur at any location within 0.4L amidships, therefore the deck scantlings are based on the maximum along the length of the middle tanks of the cargo tank finite element model required by the finite element analysis.

2.4.3 Application of scantlings to inner bottom

2.4.3.a The stress in the inner bottom is predominately due to the deflection of the bottom girders and floors which varies along the length and breadth of a cargo tank, therefore a variation of plate thickness is allowed.

2.4.3.b For typical tanker designs, with the exception of the fore-most and aft-most cargo tanks, all cargo tanks are normally of similar size, configuration and arrangement, and subjected to internal pressure load of similar (i.e. with small variation) magnitude. Based on these reasons, the scantling requirement for the inner bottom of the midship tanks is applied to the inner bottom of all cargo tanks within the cargo region, with the exception of the fore-most and aft-most cargo tanks.

2.4.3.c For the fore-most and aft-most cargo tanks, the scaling formula (as shown below) considers the effect of bending span and stiffener spacing. The transverse stress is dominated by the axial stress component caused by sea pressure acting on the ship sides and the bending stress component caused by lateral pressure acting on the double bottom. An exponent index of 0.25 is introduced to the bending span ratio to account for the increase in hull pressure towards the ends of the ship. This is to ensure that the scaling formula will not give non-conservative scantlings in the forward and aft cargo tanks. Full credit to the reduction of the span is not given as the increase in dynamic pressure towards the ends of the ship is not explicitly account for in the simplified scaling procedure. The stiffener spacing is included in the scaling formula to account for buckling capacity due to transverse stresses.

$$t_{ib-net} = t_{ib-net-mid}\left(\frac{l_{bdg}}{l_{bdg-mid}}\right)^{0.25}\frac{s_{ib}}{s_{ib-mid}} \qquad \text{mm}$$

Where:

$t_{ib\text{-}net\text{-}mid}$	required net thickness of the inner bottom for corresponding location in midship tank, in mm
l_{bdg}	effective bending span of floor at location under consideration, in accordance with *Figure 4.2.7 of the Rules*, in m
$l_{bdg\text{-}mid}$	effective bending span of floor at corresponding location in midship tank, defined in accordance with */Figure 4.2.7of the Rules*, in m
s_{ib}	spacing between longitudinal stiffeners at location under consideration, in mm
$s_{ib\text{-}mid}$	spacing between longitudinal stiffeners at corresponding location in midship tank, in mm

2.4.4 Application of scantlings to bottom

2.4.4.a The reason for maintaining the scantlings of the bottom longitudinal stiffeners longitudinally within 0.4*L* amidship is as explained in *2.4.2.a* for the deck structure.

2.4.4.b The scaling formula for plate thickness is similar to that for the inner bottom, see *2.4.3.b*.

2.4.5 Application of scantlings to side shell, longitudinal bulkheads and inner hull longitudinal bulkheads

2.4.5.a The reason for maintaining the scantlings of the plating and longitudinal stiffeners (located within 0.15*D* from deck) longitudinally within 0.4*L* amidship is as explained in *2.4.2.a* for the deck structure.

2.4.5.b The bending span of the primary support members on side shell, longitudinal bulkheads and inner hull longitudinal bulkheads in the fore and aft cargo tanks are similar to those in the midship cargo tanks. Therefore, the bending span is omitted in the scaling formula for these structural members

$$t_{net} = t_{net-mid}\,\frac{s}{s_{mid}} \qquad \text{mm}$$

where:

t_{net}	required net thickness of side shell, longitudinal bulkheads or inner hull longitudinal bulkheads (including hopper plating) outside 0.15 from deck, for fore-most or aft-most cargo tank
$t_{net\text{-}mid}$	required net thickness for corresponding location in midship tank, in mm
s	spacing between longitudinal stiffeners at location under consideration, in mm

s_{mid} spacing between longitudinal stiffeners at corresponding location in midship tank, in mm

2.4.6 Application of scantlings to transverse bulkheads

2.4.6.a For typical tanker designs, all transverse bulkheads between cargo tanks are normally of similar configuration and arrangement, and subjected to internal pressure load of similar (i.e. with small variation) magnitude. Based on these reasons, the scantling requirement for the transverse bulkhead in the midship cargo region is applied to all transverse bulkheads between cargo tanks within the cargo region.

2.4.7 Application of scantlings to primary structural support members

2.4.7.a It is considered that for this topic, no information in addition to that shown in the Rules, is necessary to explain the background.

2.4.8 Structural details and openings

2.4.8.a It is considered that for this topic, no information in addition to that shown in the Rules, is necessary to explain the background.