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Development of HighCRest Software for Ship Structure Verifications under CSR-H Requirements

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Abstract
Harmonized Common Structural Rules (CSR-H) have recently been released by the International Association of Classification Societies (IACS). These rules will be applicable to every oil tanker over 150 m and bulk carrier over 90 m in length contracted for construction on or after the 1st of July 2015. CSR-H are comprehensive and complex structural rules that involve numerous evaluations, such as wave loads, yielding, buckling, ultimate strength, fatigue life assessment, finite element analyses, and so on. CR Classification Society (CR) has developed HighCRest software to verify the compliance of ship transverse sections and bulkheads structure scantlings with the prescriptive requirements of the rules. HighCRest can thus automatically compute the rule loads, hull girder section properties, shear flow, ultimate and residual capacities, as well as the local scantling relevant to the yielding and buckling capacity and fatigue life. HighCRest also provides a user-friendly interface to model the structures and visualizes the results of the considered ship section. Therefore, HighCRest is of particular interest to ship structure engineers who require flexible, fast, and reliable decision-making tools for safe ship structure design.

Keyword: Ship structure, verification software, CSR-H

1. INTRODUCTION

Goal-based ship construction standards (GBS) for bulk carriers and oil tankers [1] have been implemented and have been set up in SOLAS II-1 Reg.3-10. GBS apply to oil tankers and bulk carriers that are 150 m in length and above and the classification rules must be verified by an IMO Audit Team according to the guidelines in IMO Resolution MSC.296(87) to achieve the goal of safety. The two sets of current Common Structural Rules for oil tankers and bulk carriers (CSR) do not fully comply with the GBS. Therefore, IACS developed the Harmonized Common Structural Rules for bulk carriers and oil tankers (CSR-H) to meet the GBS requirements.

The rules have been established based on numerous classification societies' experience and on the latest research results. The requirements are thus significantly more complex than those of the previous CSR. Therefore, to be applied by industry, these comprehensive rules require an efficient tool to execute all the verifications to enable the design of safe ship structures. CR Classification Society (CR) has thus developed HighCRest software to verify the compliance of ship transverse sections and bulkhead structure scantlings with the prescriptive requirements of the rules. HighCRest can automatically compute the rule loads, hull girder section properties, shear flow, ultimate and residual capacities, as well as the local scantling relevant to the yielding and buckling capacity and fatigue life. HighCRest also provides a user-friendly interface to input and visualizes the results of the considered rules' prescriptive requirements.

This article is divided into three sections. The first section presents the HighCRest capabilities regarding ship structure design. The second section describes the global strength check of the hull girder under yield, ultimate, and residual strength requirements. The third section presents the local member strength verification, particularly for the buckling and the fatigue life assessment.

2. SHIP STRUCTURE DESIGN USING HIGHCREST

HighCRest is two-dimensional structure calculation software, which was developed using the language, JAVA. HighCRest can verify the compliance of ship transverse sections and bulkheads with the CSR-H.

2.1 Transverse section and bulkhead modeling

First the user can define the main particulars of the considered ship, including the ship name, type, length, breadth, and draft. The transverse section or the transverse bulkhead geometry can then be modeled using panels shaped through nodes. The user can also define the compartments (i.e., tanks or cargo holds) by specifying the nodes. The plate width can be input on each panel, as well the thickness and material of each panel. Longitudinal and transverse stiffeners can also be modeled by keying in their spacing, section, and material. HighCRest enables the type of longitudinal stiffener end connection to be defined for the fatigue calculation. Figure 1 shows the main modules for the ship section modeling.

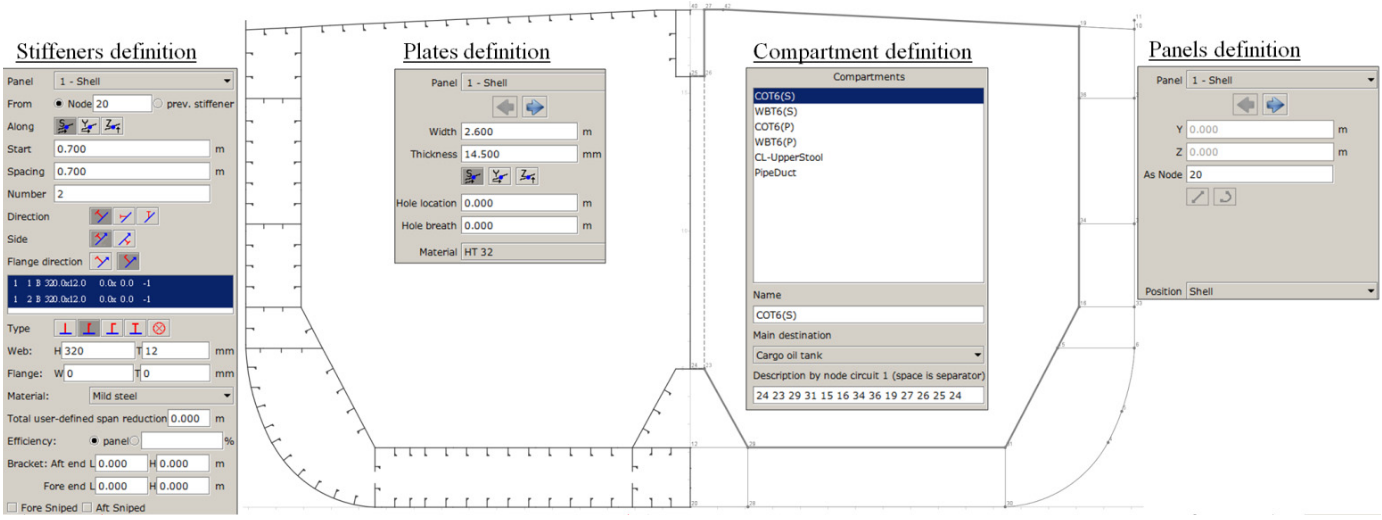


Fig. 1 *Ship section modeling in HighCRest*

The program can then be used to automatically evaluate the corrosion addition of the plates and stiffeners using the panel definition (side shell and main deck) and the type of compartment (cargo hold and ballast), according to the rules [2] Pt1 Ch3 Sec3 [1.2].

HighCRest then divides the structural arrangement into structural elements (i.e., a longitudinal stiffener with its attached plating) or elementary plate panels (i.e., the smallest plate element surrounded by structural members), allowing the hull girder ultimate capacity or the local scantling strength verification to be executed according to the rule methodologies [2]. Therefore, the designer only needs to input the gross scantling based on the construction drawings in an intuitive manner. HighCRest then automatically pre-processes the structure to prepare the required structure verification presented in Section 2.2. In addition, HighCRest exhibits a function called "Check" that helps the designer to conveniently validate the ship section structural arrangement by items (i.e., material, thickness, and stiffeners section) that is input in HighCRest before performing the rule verification.

2.2 Structure verification

Once the ship particulars and the transverse section or bulkhead structure scantling have been defined, HighCRest proceeds to the verification of global and local strength according to the rules [2]. Figure 2 shows the flowchart of the verifications executed by HighCRest.

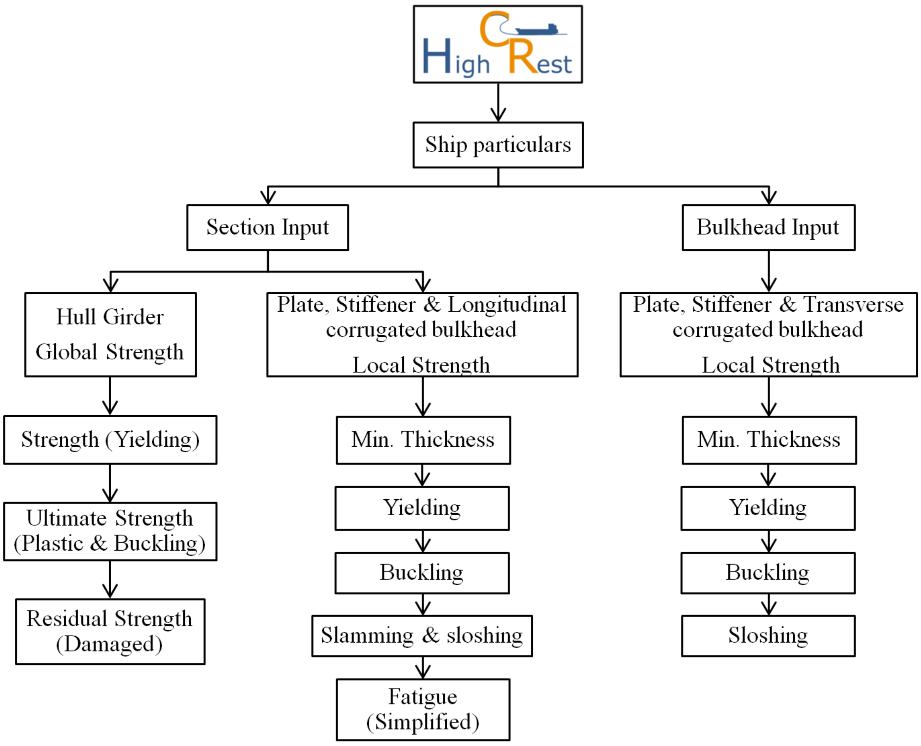


Fig. 2 *Flowchart of the verifications in HighCRest*

The verifications are formulated in the program according to the rules [2], as well as by using the detailed explanations provided in the technical background reference document [3] and reports [4] of the rules. Particular attention was paid to implement these verifications in an efficient manner, allowing HighCRest to rapidly execute the calculations. At the end of the verification processes, a report can be automatically printed that presents all of the global and local strength checks performed by HighCRest, highlighting all of the members that have scantlings that do not comply with the rules.

3. GLOBAL STRENGTH

The global strength verification in the rules [2] consists of two parts:

(1) The yield strength (see [2] Pt1 Ch5 Sec1) that encompasses the hull girder bending and shear strength requirements; and

(2) The ultimate strength requirements of the intact section and the residual strength of the damaged section (see [2] Pt1 Ch5 Sec2 and Sec3) that evaluate the ultimate bending capacity of the hull girder at the considered section, including the yielding and buckling effect of each longitudinal member.

This section focuses on the shear flow, ultimate, and residual strength computation methods.

3.1. Direct calculation of shear flow

CSR-H requires the verification of the hull girder shear strength along the ship length. The hull girder shear capacity is thus derived from the shear flow that is obtained by numerical computations based on the thin-walled beam theory described in [2] Pt1 Ch5 App1. The unit shear flow is set to equal the sum of the determinate shear flow plus the indeterminate shear flow. The shear flow formulations provided by the rules enable the direct evaluation of the shear flow at both ends of a straight plate. When the shear flow is computed through an open cross section, the indeterminate shear flow is null. When the shear flow is computed through a cross section containing closed cells (i.e., tanks in oil tankers and bulk carriers), the cells must be cut by virtual slits that enable the determinate shear flow to be computed for an open section. The indeterminate shear flow is then computed for each cell and added to the determinate shear flow to correct the longitudinal slip (i.e., twist of the cell) that occurs between the two cut edges at the virtual slits. The contribution of the longitudinal stiffeners to the determinate unit shear flow must also be considered.

HighCRest can automatically detect enclosed cells in the ship section; thus making the determinate shear flow linear equation system consistent by opening the cells using virtual slits. The program then computes the indeterminate shear flow in each cell. HighCRest can thus be used to evaluate the shear flow of any section shape without restrictions on the number of closed cells. Figure 3 shows how virtual slits can be used to calculate the determinate shear flow (q_d) in two adjacent closed cells.

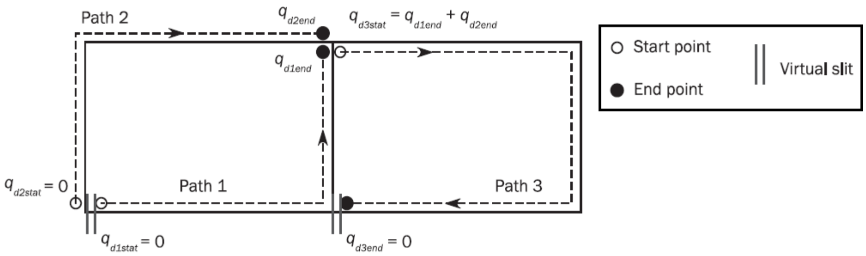


Fig. 3 *Determinate shear flow calculation in closed cells [2]*

Figure 4 shows the shear flow distribution in the ship section. For the sake of accuracy, HighCRest focuses on two types of plate. First, the rounded plates (i.e., bilge) are divided into small straight segments to accurately consider the shear flow distribution along those plates (see Fig.4). Then, the shear strength criterion of the rules states that the shear capacity corresponds to the maximum shear stress in the hull section. The shear stress is directly derived from the unit shear flow that reaches its maximum at the intersection of the plating with the ship section's neutral axis (N.A.). Therefore, HighCRest divides every plate at the N.A. during the pre-processing phase to ensure that the maximum value of shear capacity can be correctly extracted (see Fig. 4).

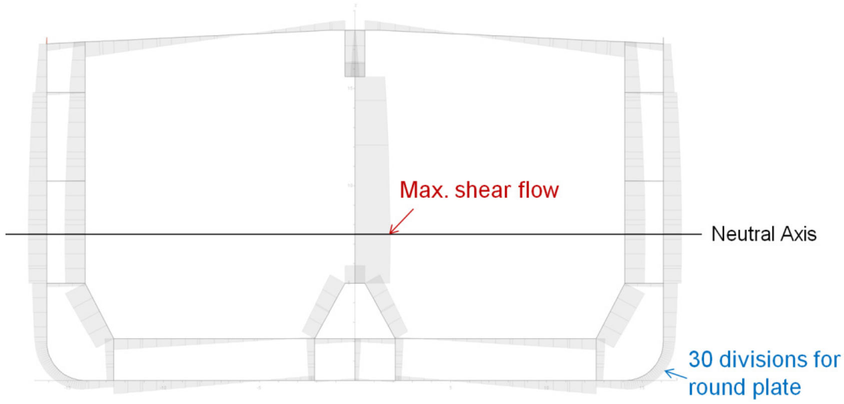


Fig. 4 *Shear flow in the ship section*

3.2. Hull girder ultimate strength

HighCRest evaluates the ultimate bending capacity of the hull girder by using the incremental-iterative method [4] based on the Idealized Structural Unit Method (ISUM) [5] to verify that the checking criteria in the rules [2] are satisfied.

HighCRest can model the transverse section with a set of stiffener elements, stiffened plate elements, and hard corner elements. The hull girder section is supposed to remain plane during hull girder bending to calculate the strain in every element. To calculate the ultimate hull girder capacity, six modes of failure and the load-end shortening curves of each structural element are defined in CSR-H, as shown in Table 1. Figures 5 and 6 show the load-end curve for elasto-plastic collapse and stiffener buckling, respectively. These load-end shortening curves are based on the elasto-plastic collapse for the lengthened elements and on the buckling collapse for the shortened elements. The contribution of each element to global bending can be determined based on the smallest produced critical stress among the six failure modes.

Table 1. *Modes of failure of stiffened plate element and stiffener element [2]*

Element	Mode of failure
Lengthened stiffened plate element or stiffener element	Elasto-plastic collapse
Shortened stiffener element	Beam column buckling Torsional buckling Web local buckling of flanged profiles Web local buckling of flat bars
Shortened stiffened plate element	Plate buckling

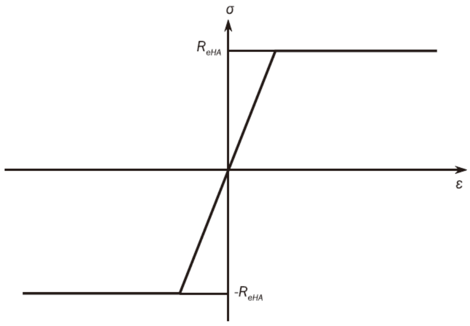


Fig. 5 *Load-end curve for elasto-plastic collapes[2]*

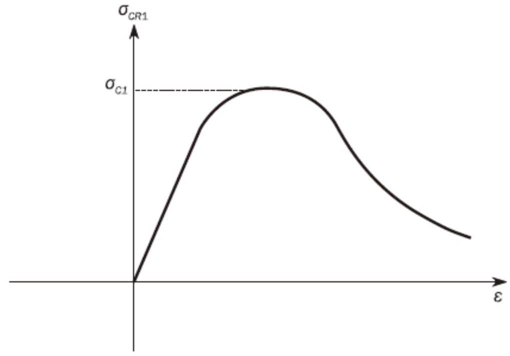


Fig. 6 *Load-end curve for stiffener buckling[2]*

After summing all of the elements' forces, HighCRest can generate the bending moment for the corresponding level of curvature. Figure 7 shows the bending moment obtained by applying an increasing curvature to the ship section in hogging and sagging conditions. The ultimate bending capacity can thus be extracted because it corresponds to the maximum value. Figure 7 shows a comparison of the ultimate bending capacity (full line) to the required bending moment (dash lines) provided by the rules at a probability level of 10^{-8}. Figure 8 shows a snapshot of the animation that demonstrates the yielding ratio of the stiffeners and plates and the section N.A. position when the ultimate bending capacity is reached.

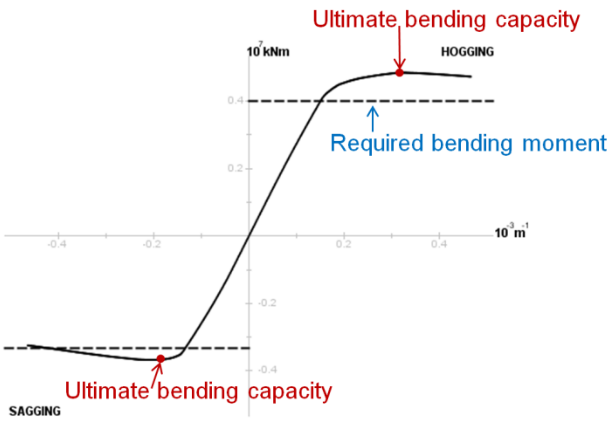


Fig. *7 Bending moment of the intact ship section versus curvature.*

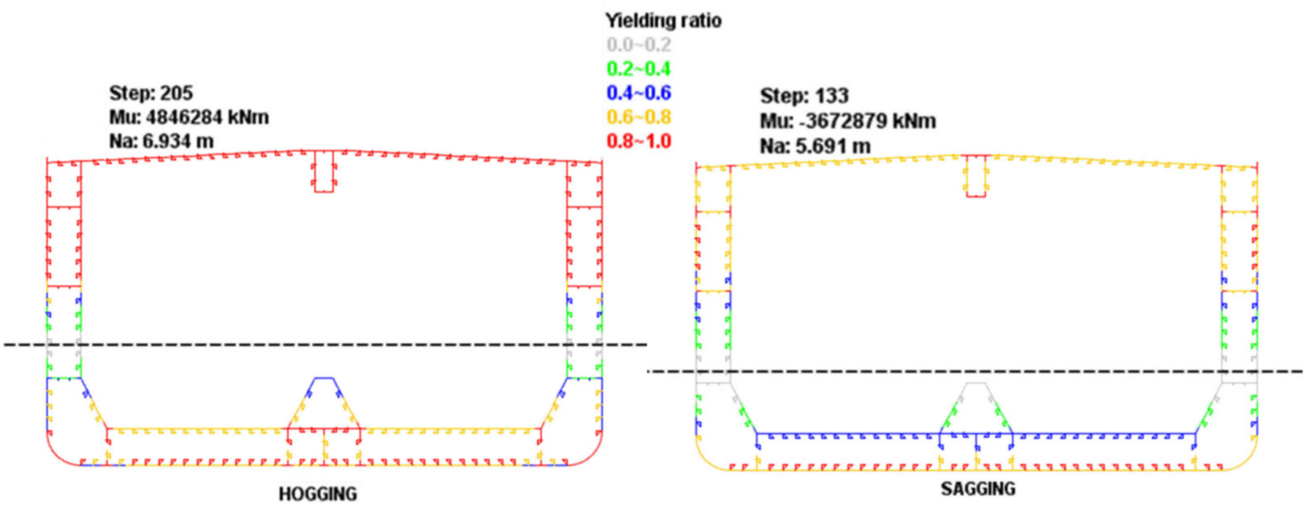
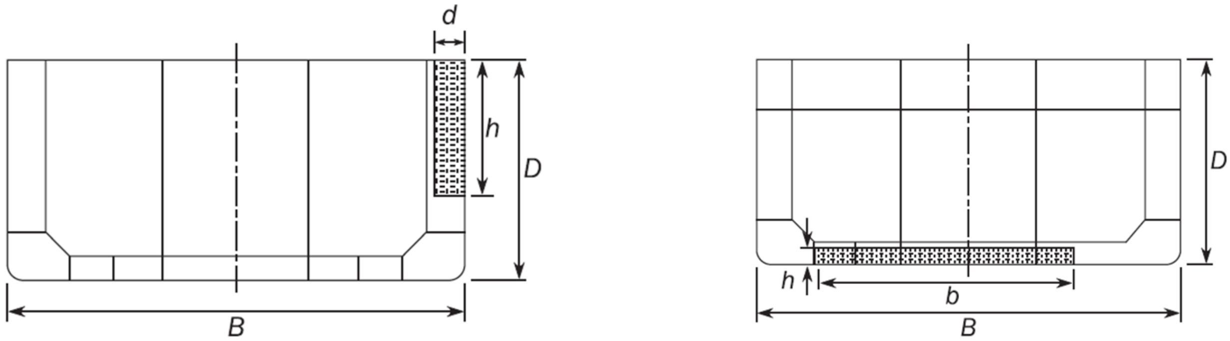


Fig. 8 *Yielding Ratio and neutral axis position at the ultimate capacity*

3.3. Hull girder residual strength

HighCRest can also evaluate the ultimate bending capacity of the hull girder, including collision and grounding damage, to verify that the checking criteria in the rules [2] are satisfied. HighCRest assumes that the structural members located inside the damage extent are excluded from the hull girder bending strength, according to the rules. The rules provide two types of damage extent, as shown in Figure 9.



Damage penetration, in m	Side shell arrangement	
	Single side	Double side
Height, *h*	0.75 *D*	0.60 *D*
Depth, *d*	*B* /16	*B* /16

Damage penetration, in m	Bulk carriers	Oil tankers
Height, *h*	Min (*B* /20, 2)	Min (*B* /15, 2)
Breadth, *b*	0.60 *B*	0.60 *B*

Fig. 9 *Damage extent for collision (left) and grounding (right) [2]*

Figure 10 shows the bending moment of the damaged hull girder transverse section in both hogging and sagging conditions, as generated by HighCRest. Figures 11 and 12 show snapshots of the animations that demonstrate the yielding ratio of the stiffeners and plates and the section N.A. position when the ultimate bending capacity is reached during a collision and grounding, respectively.

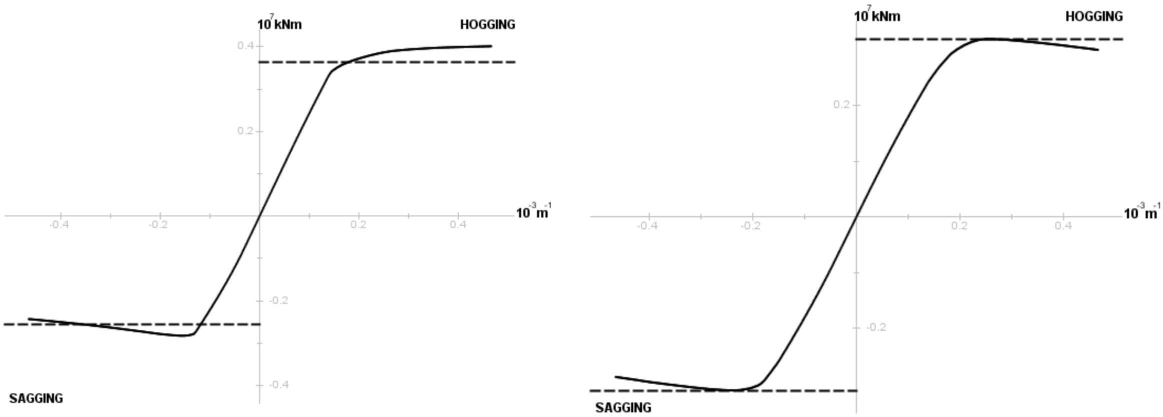


Fig. 10 *Bending moment of the damaged ship section versus curvature for collision (left) and grounding (right).*

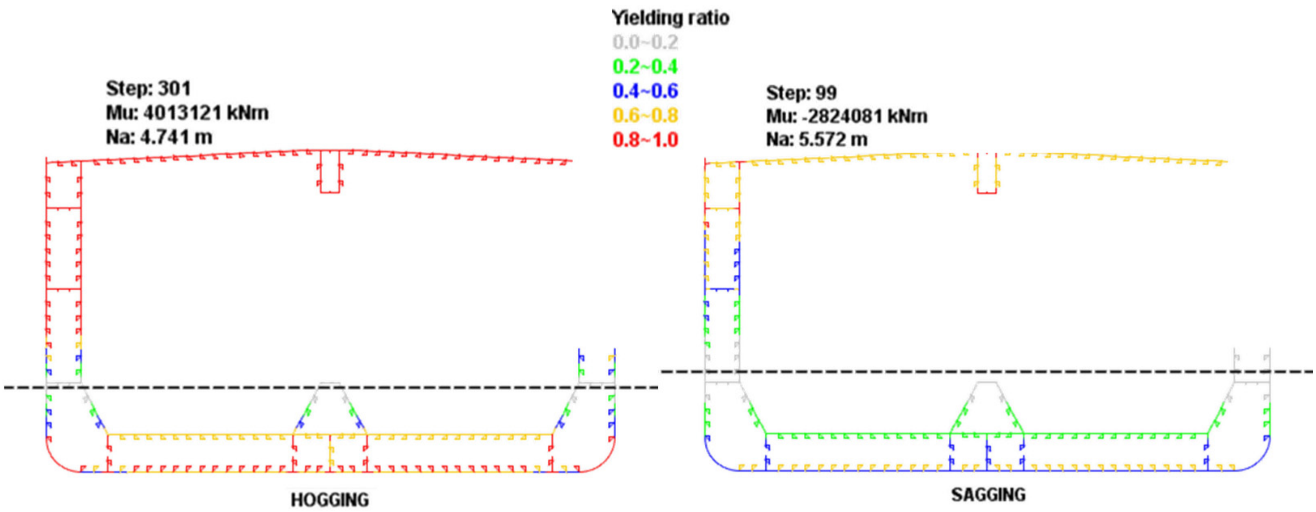


Fig. 11 *Yielding Ratio and neutral axis position at the ultimate capacity for collision*

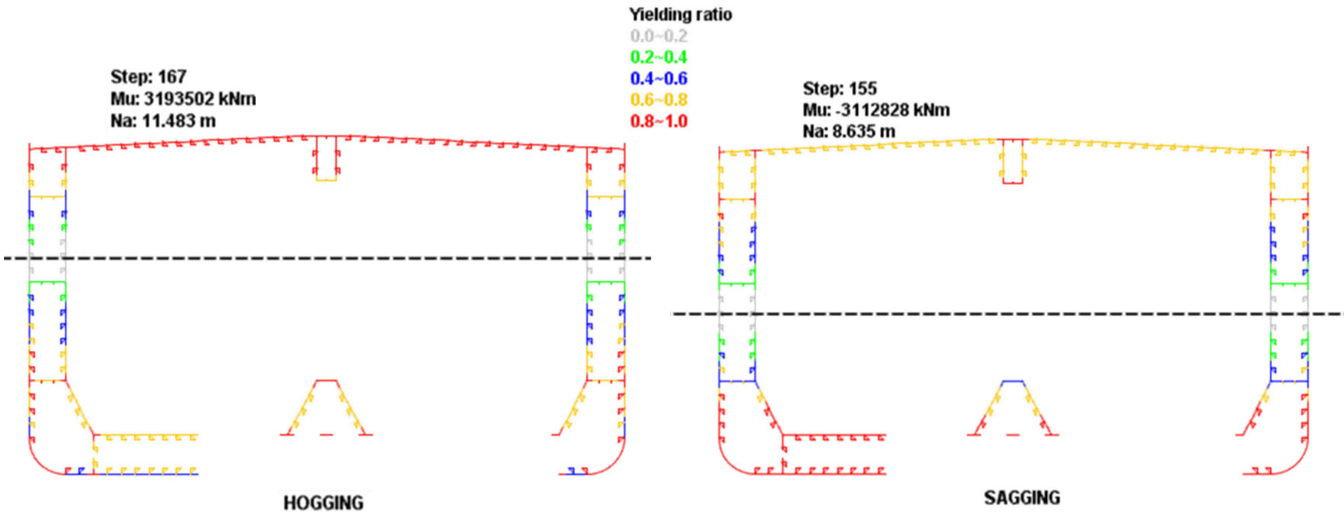


Fig. 12 *Yielding Ratio and neutral axis position at the ultimate capacity for grounding*

4. LOCAL STRENGTH

The local scantling verifications in the rules [2] consist of three major parts:

(1) The yield strength (see [2] Pt1 Ch6 Sec3 to Sec5), which includes the minimum thickness requirements, plating, and stiffener under lateral pressure strength requirements;

(2) The buckling strength (see [2] Pt1 Ch8 Sec2, Sec3, and Sec5), which includes the slenderness requirements and the prescriptive buckling requirements with the buckling capacity formulation; and

(3) The fatigue life assessment of the longitudinal stiffener end connections (see [2] Pt1 Ch9 Sec3 and Sec4) derived from the simplified stress analysis.

This section focuses on the buckling strength and the fatigue life assessment.

4.1. Buckling strength

HighCRest can evaluate the buckling strength of the plates, stiffeners, and overall stiffened panels according to the interaction formulae provided by the rules [2] (Pt1 Ch. 8 Sec2) for all loading conditions. The buckling strength is the ultimate strength of the structure under in-plane compressions or shear and lateral loads. The initial imperfection, stress combinations, boundary conditions, types of stiffeners are considered in the interaction formulae. After computation, the buckling utilization factor can be obtained for the most severe load condition and buckling mode, represents the ratio of the applied loads to the corresponding ultimate capacity. Figure 13 shows the buckling utilization factor of the plates, stiffeners, and stiffened panels for the most severe load cases.

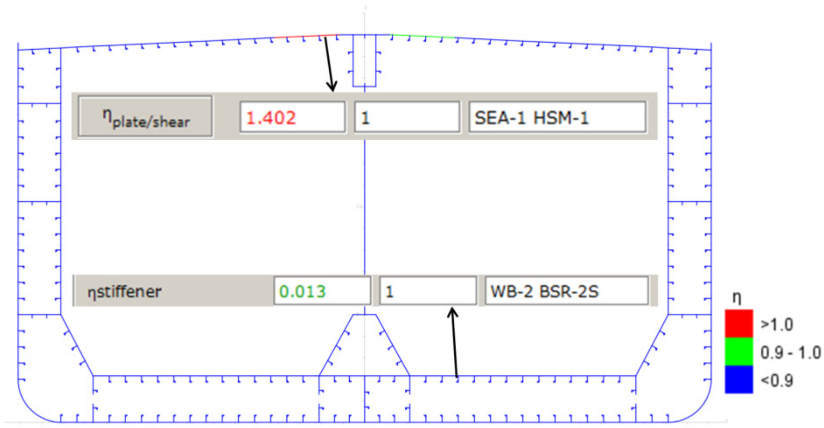


Fig. 13 *Buckling utilization factor in the ship section*

4.2. Simplified fatigue life assessment

HighCRest can perform simplified hot spot stress analyses to determine the fatigue life at the weld toes of longitudinal stiffener end connections. The hot spot stress range is obtained by multiplying the nominal stress range by a stress concentration factor (SCF) for the considered stiffener end connection according to the rules [2]. The nominal stress is calculated using analytical methods based on beam theory, including global hull girder bending stress and local stiffener bending stress. The fatigue stress range is then produced by applying additional correction factors to the hotspot stress range, including the factor for the mean stress effect. The reference fatigue stress range corresponds to the maximum fatigue stress of all the design load cases that are established for a probability level of 10^{-2}.

The reference fatigue stress range is then used to scale a two-parameter Weibull distribution of the fatigue stress range. The fatigue damage is then computed based on this distribution by using an appropriate S-N curve and a number of cycles corresponding to the 25-year design life. The fatigue damage is produced for each design loading condition. The total fatigue damage is obtained by summing the fatigue damage contribution in each loading condition weighted by the corresponding fraction of life in the considered loading condition. Finally, the fatigue life of every longitudinal stiffener end connection can be compared to the required 25-year design life. Figure 14 shows the ratio of the calculated fatigue life to the 25-year target fatigue life for each stiffener end connection in the section.

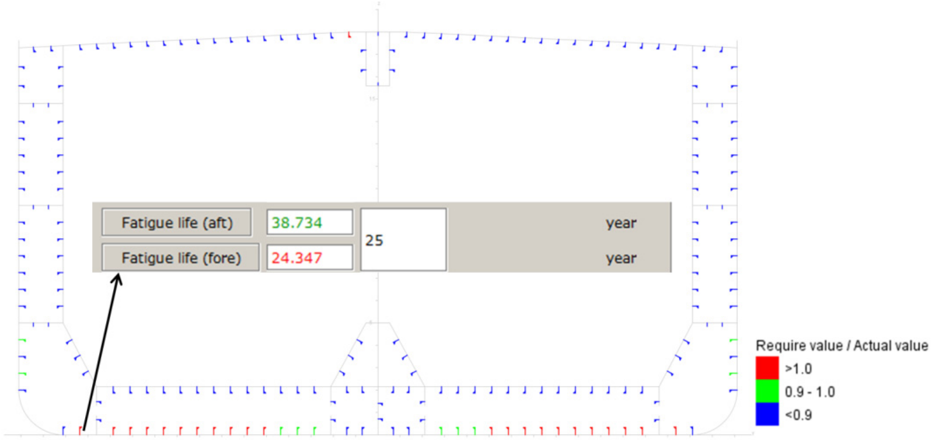


Fig. 14 *Fatigue life in the ship section*

CONCLUSION

This study demonstrates that CSR-H requires numerous calculations to verify the safety of ship structures. CR Classification Society has thus developed ship structural scantling verification software, called HighCRest, to manage the complexity of CSR-H in an efficient manner. This paper indicates that HighCRest enables a ship designer to model the structure in an intuitive manner and it includes a convenient tool to check the actual input scantling. This study shows that HighCRest is capable of efficiently executing the verifications according to the rules. Finally, HighCRest can provide figures, animations, and automatic reporting of the verification results. Therefore, HighCRest is of particular interest to ship structure engineers who require flexible, fast, and reliable decision-making tools to ensure the design of safe ship structures.

REFERENCES

[1] IMO, Adoption of the international goal-based ship construction standard for Bulk Carriers and Oil Tankers, *MSC.290(87), Maritime Safety Committee*, (2010)

[2] IACS, Harmonised Common Structure Rules for Bulk Carriers and Oil Tankers, (2014)

[3] IACS, Technical Background Rule Reference for CSR-H, (2014)

[4] IACS, TB Report for CSR-H, (2014)

[5] Smith CS, Influence of local compressive failure on ultimate longitudinal strength of ship's hull, *Proceedings of the International Symposium on Practical Design in Shipbuilding, Tokyo,* (1977)