

Sesam Tutorial

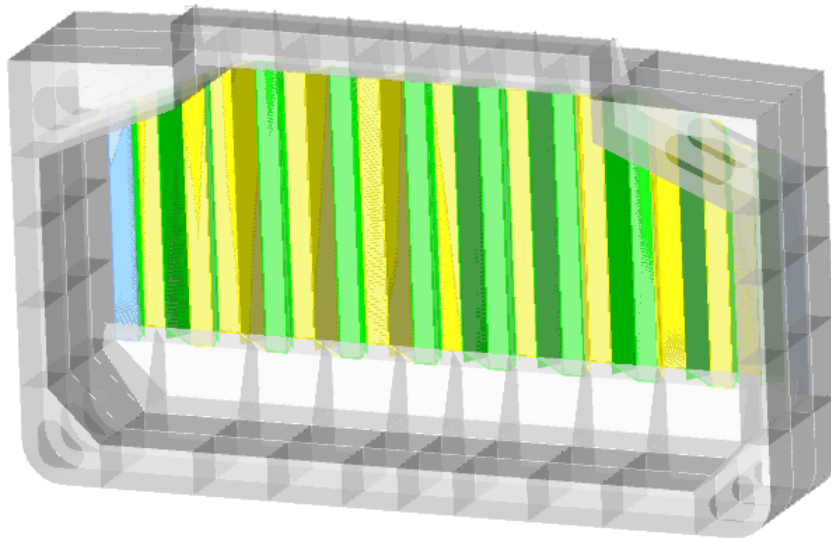
Evaluation of Corrugated Bulkhead based on DNV rules

DNV – Digital Solutions



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This workshop will explain how to evaluate corrugated bulkhead structure based on DNV ruleset.

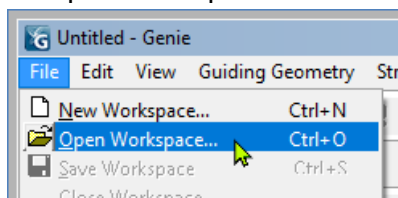
Below programs are used for this tutorial

- GeniE 8.6
- Sestra 10.17
- Xtract 6.0

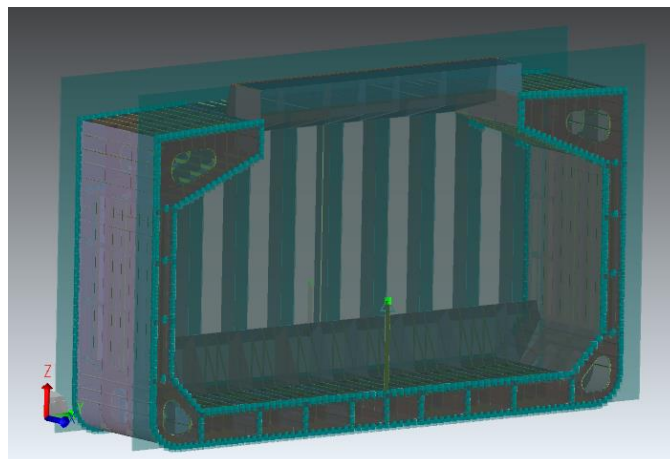
1 CHECK MODEL AND RUN ANALYSIS

1.1 Open corrugated Bulkhead model

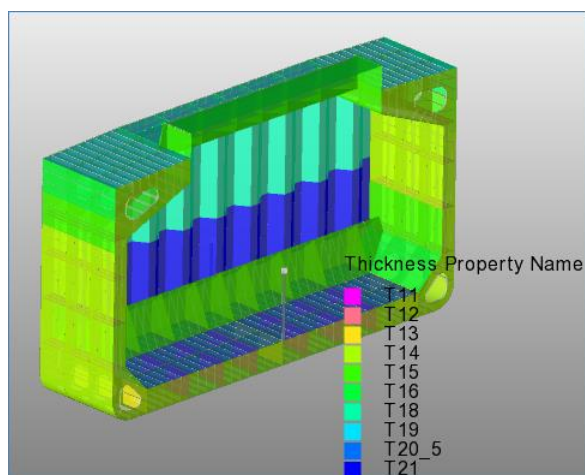
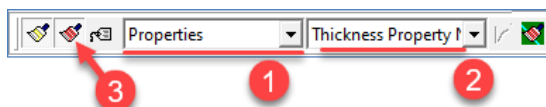
- Open GeniE
- open “Corr_BHD_model.gnx” in “File → Open Workspace”



Then model will be displayed as shown right.



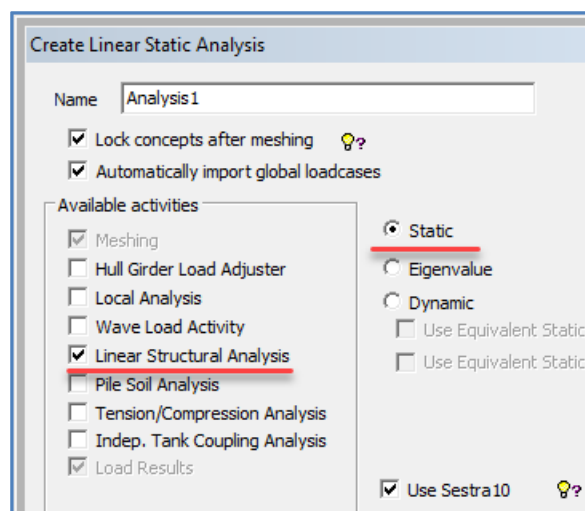
- Check model, i.e. thickness property name.



1.2 Check Model – 2D plate mesh

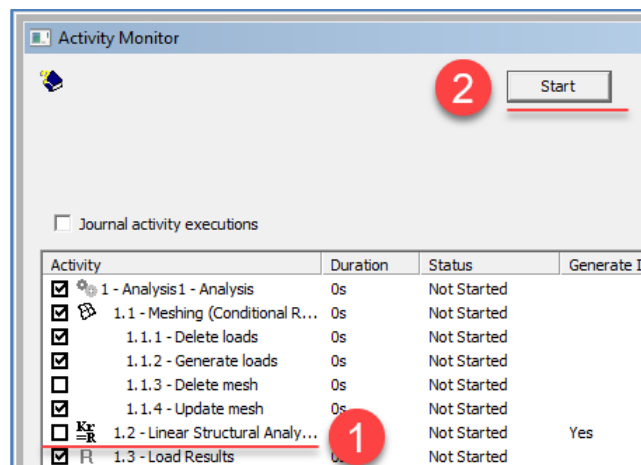
1.2.1 Create Analysis Activity

- “Alt+D” to create Analysis Activity
- Include “Linear Structure Analysis” and select “Static” analysis → OK



1.2.2 Generate mesh

- **Deactivate “Linear Structure Analysis”**
(This time, we will check mesh only)
- **“Start”** the analysis to generate mesh



1.2.3 Check Meshing result

- The rule (DNVGL-CG-0127) also requires mesh shapes as below

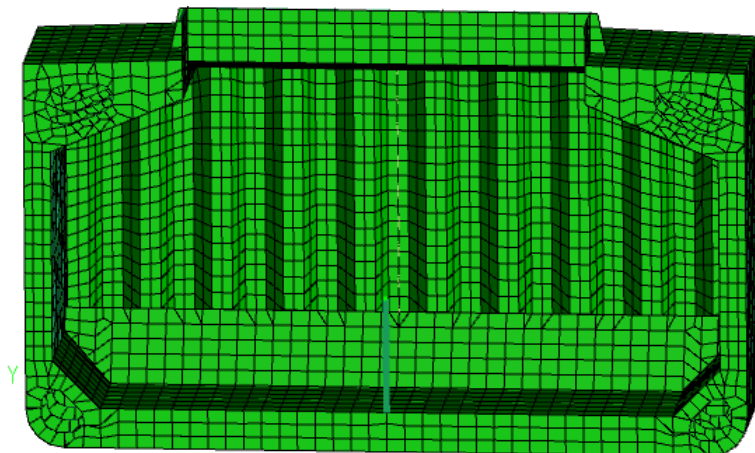
2.2.5 Corrugated bulkhead

Diaphragms in the stools, supporting structure of corrugated bulkheads and internal longitudinal and vertical stiffeners on the stool plating shall be included in the model. Modelling shall be carried out as follows:

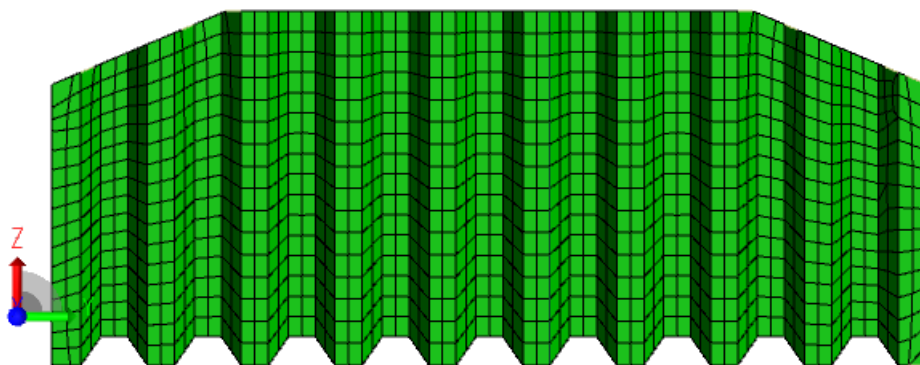
- The corrugation shall be modelled with its geometric shape.
- The mesh on the flange and web of the corrugation is in general to follow the stiffener spacing inside the bulkhead stool.
- The mesh on the longitudinal corrugated bulkhead shall follow longitudinal positions of transverse web frames, where the corrections to hull girder vertical shear forces are applied in accordance with [6.3.5].
- The aspect ratio of the mesh in the corrugation is not to exceed 2 with a minimum of 2 elements for the flange breadth and the web height.
- Where difficulty occurs in matching the mesh on the corrugations directly with the mesh on the stool, it is acceptable to adjust the mesh on the stool in way of the corrugations.
- For a corrugated bulkhead without an upper stool and/or lower stool, it may be necessary to adjust the geometry in the model. The adjustment shall be made such that the shape and position of the corrugations and primary supporting members are retained. Hence, the adjustment shall be made on stiffeners and plate seams if necessary.

- Shall be modelled with its geometric shape
- Aspect ratio < 2
- Not to exceed 2 elements for flange breadth and web height

- Check mesh quality in View.



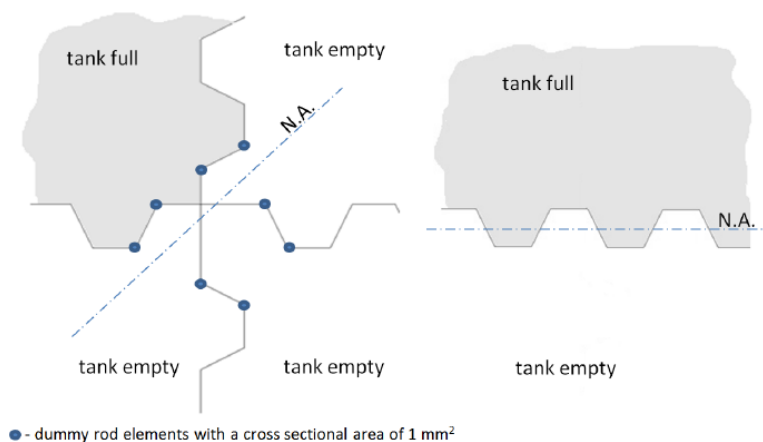
- Below is detail view for corrugate bulkhead



1.3 Check Model – Dummy Beam

- [DNVGL-CG-0127](#) requires that 1mm^2 rod need to be added.
 - g) Dummy rod elements with a cross sectional area of 1 mm^2 shall be modelled at the intersection between the flange and the web of corrugation, see [Figure 10](#). It is recommended that dummy rod elements are used as minimum at the two corrugation knuckles closest to the intersection between:
 - transverse and longitudinal bulkheads
 - transverse bulkhead and inner hull
 - transverse bulkhead and side shell.
 - h) As illustrated in [Figure 10](#), in areas of the corrugation intersections the normal stresses are not constant across the corrugation flanges. The maximum stresses due to bending of the corrugation under lateral pressure in different loading configurations occur at edges on the corrugation. The dummy rod elements capture these stresses. In other areas there is no need to include dummy elements in the model as

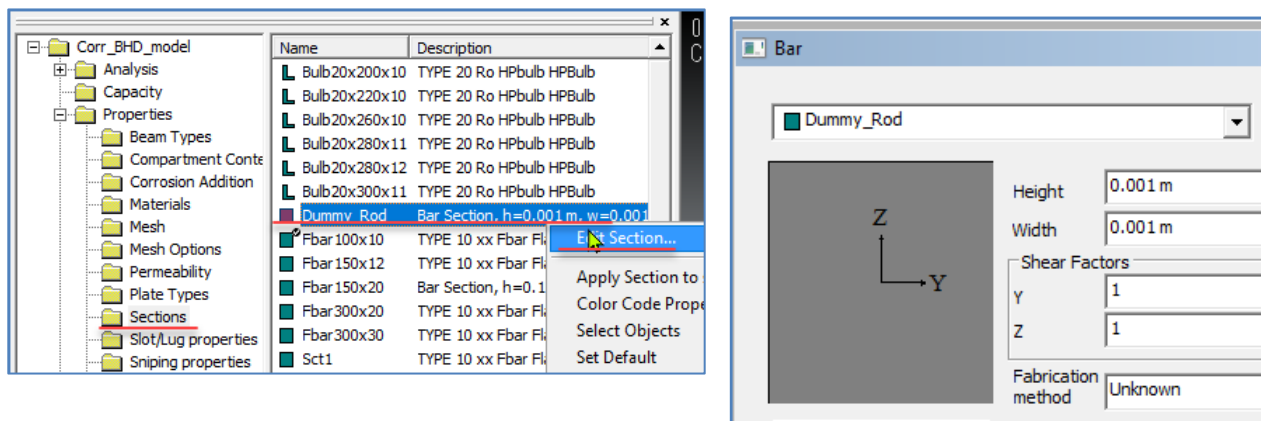
normally the stresses are constant across the corrugation flanges and the stress results in the shell elements are sufficient.



1.3.1 Check Section of the Dummy Beam

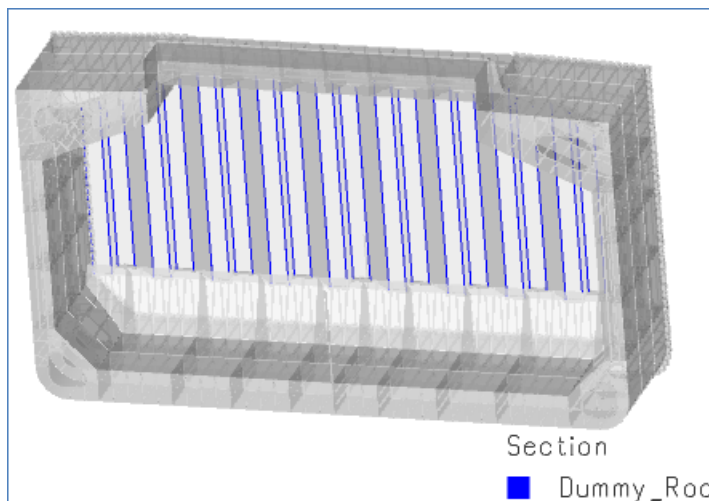
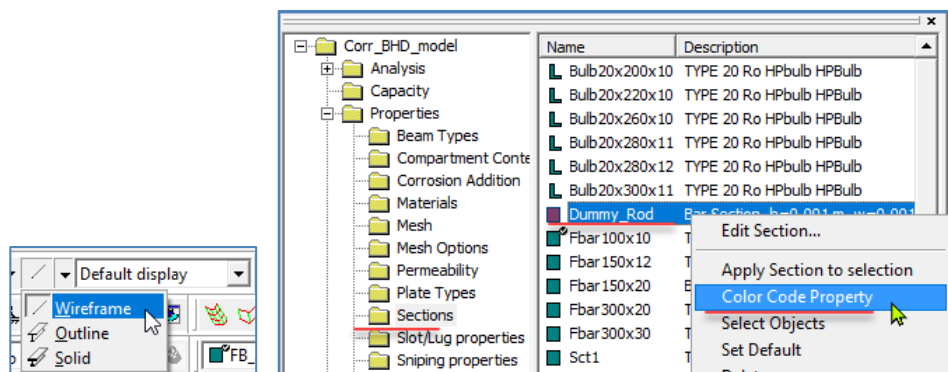
- Check section property of “**Dummy_Rod**”.

Here the sectional area is **1 mm²**.

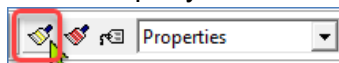


- Then do “**Color Code Property**” to check whether the rod element has been added:

Hint: You may have to select Wireframe view since the cross section is so thin:

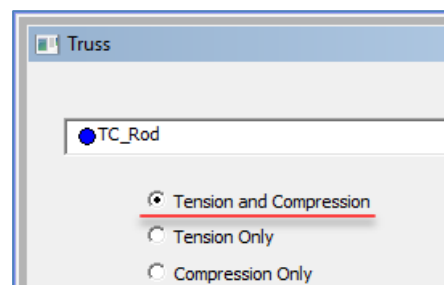
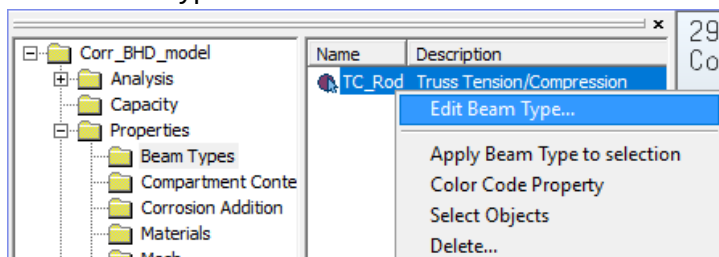


Click “Property Color coding” to revert to original view.



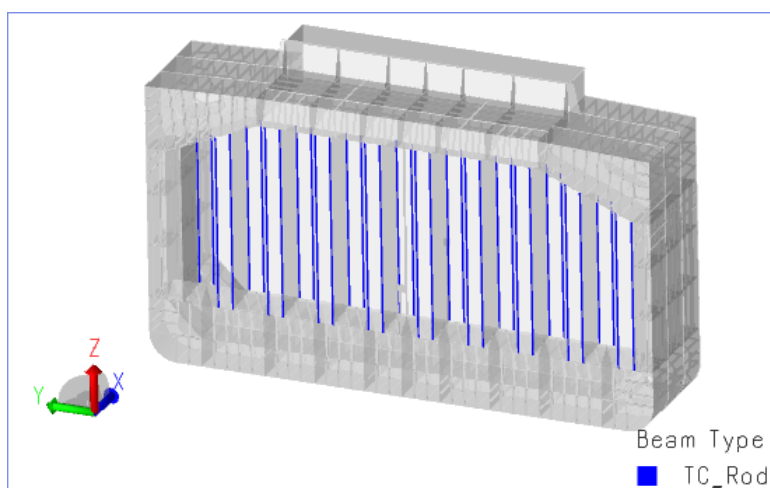
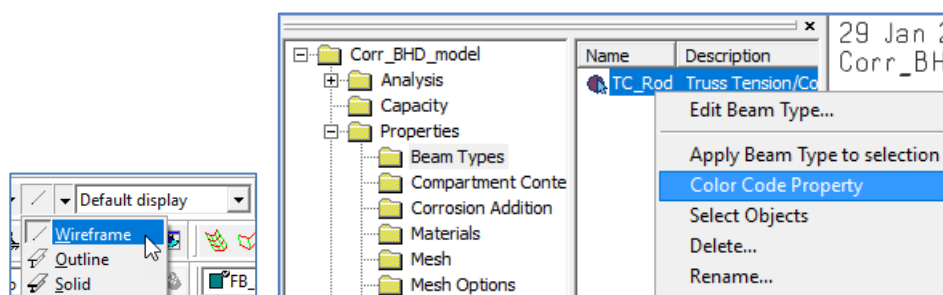
1.3.2 Check Beam Type of the Dummy Beam

- Check Beam Types property of “TC_Rod”.
“**Tension and Compression**” property can be used for rod element type.



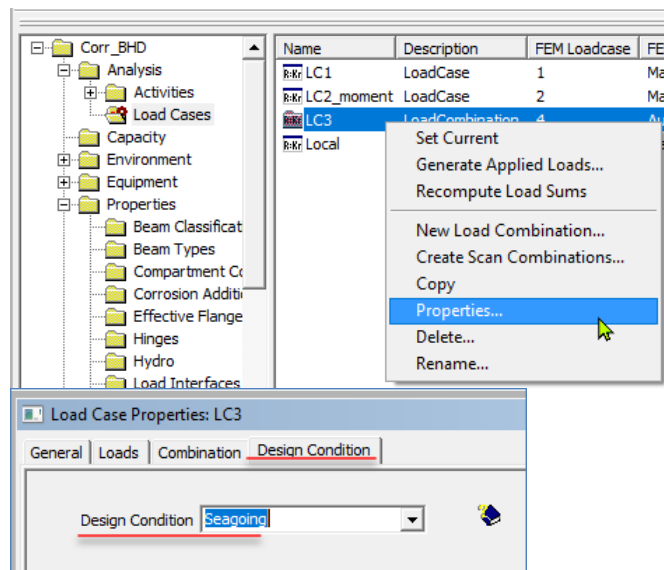
- Then do “**Color Code Property**” to check whether the rod element has been added:

Hint: You may have to select Wireframe view since the cross section is so thin:

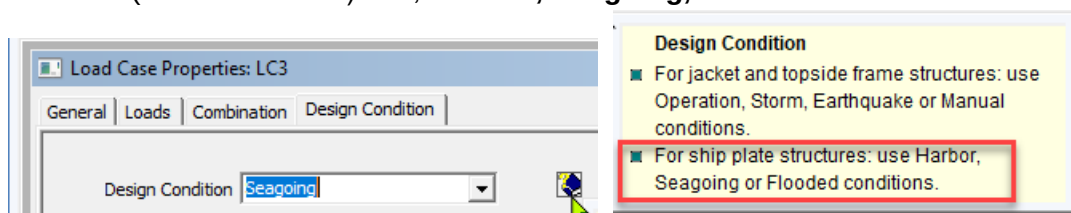


1.4 Check Design Condition

- Open **property** of load combination LC3.



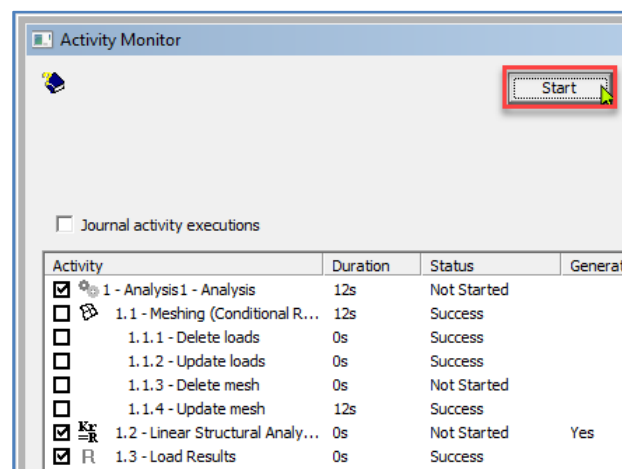
- Then check “Design Condition” in “Design Condition” tab. Currently it’s “**Seagoing**” condition
- This will be related to evaluation criteria, mentioned in “2.1.3 Add Run” & “2.2.3 Add Run”
- For DNV (or CSR BC&OT) rule, “**Harbor, Seagoing, or Flooded**” condition can be used.



1.5 Run structural analysis

Now it's ready to run the analysis.

- Open “**Activity Monitor**” by “**Alt+D**”
- Check **Linear Structural Analysis**
- “**Start**” Analysis

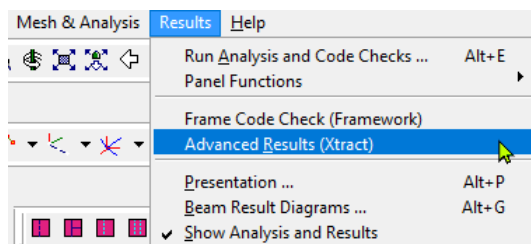


1.6 Check Analysis result in Xtract

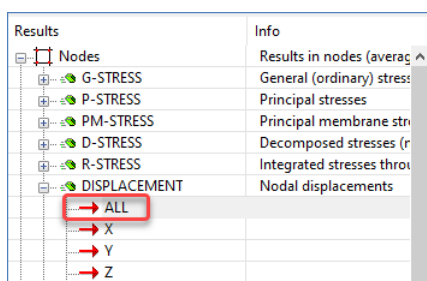
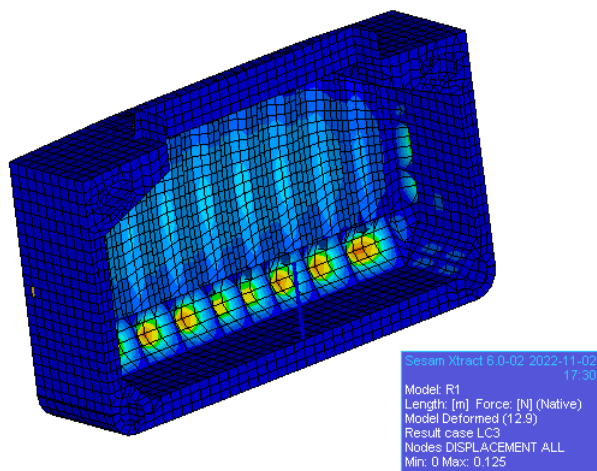
Check the analysis result in Xtract. Displacements, deformation shape, applied loads, stress

components etc.

- Open Xtract in “Result → Advanced Result (Xtract)”

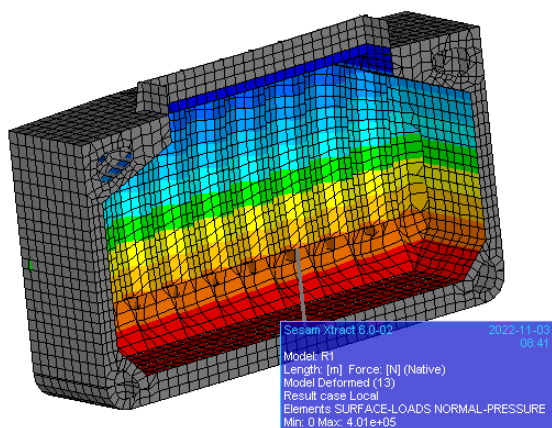


- Check analysis result in Xtract. Below is shown deformation of load combination LC3 case.

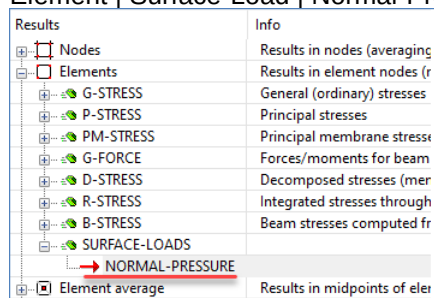


(select “Node | Dipslayment | All”)

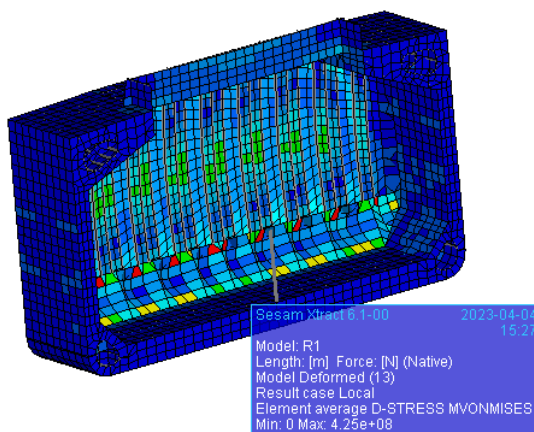
- Normal pressure for load case



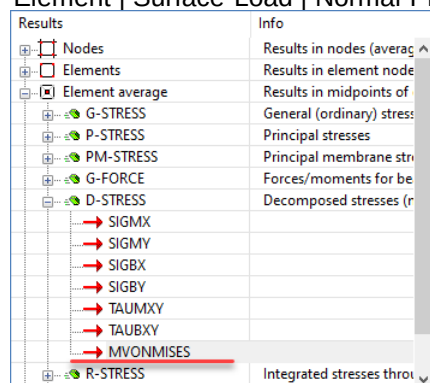
(select “Element | Surface-Load | Normal-Pressure”)



- Von-Mises stress for load combination case



(select “Element | Surface-Load | Normal-Pressure”)

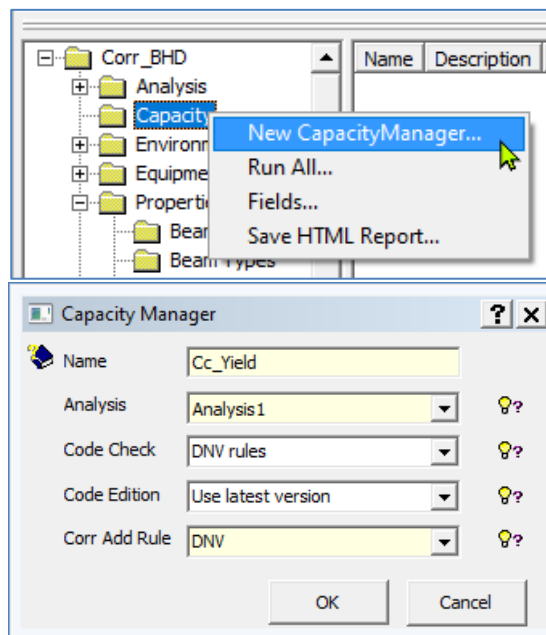


2 STRENGTH EVALUATION

2.1 Yield Strength Evaluation

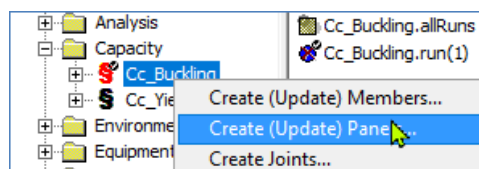
2.1.1 Create Capacity Manager

- Create new capacity manager in “**New Capacity Manager**”
- Setting as below
 - Name : **Cc_Yield**
 - Analysis : **Analysis1**
 - Code Check : **DNV Rules**
 - Corr Add : **DNV**

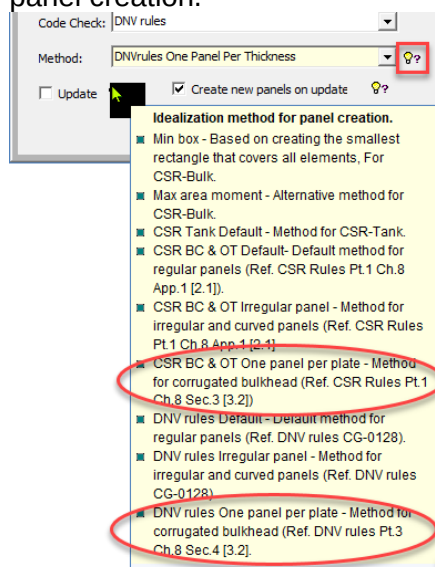
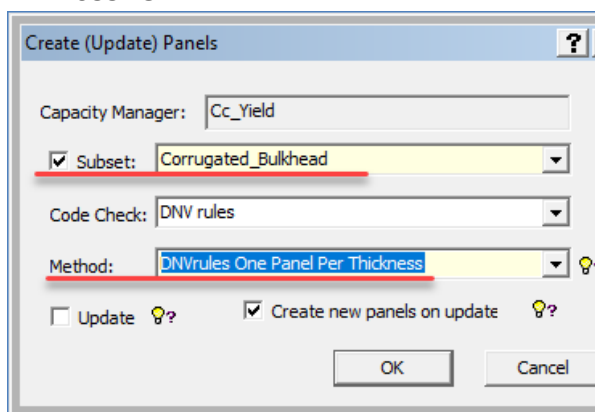


2.1.2 Create Panel

- “**Create (Update) Panel**”
- Subset : “**Corrugated_Bulkhead**”
- Method : “**One Panel per Thickness**”
- Press “**OK**”



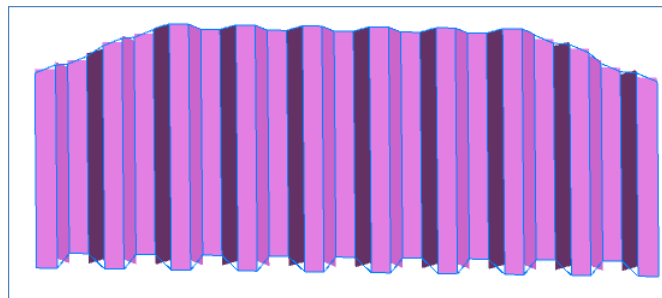
Refer below information for idealization method for panel creation.



- Change view into “**Capacity Models**”

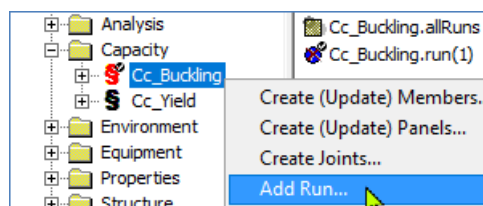
Capacity Models

to see whether the capacity panel has been created well.

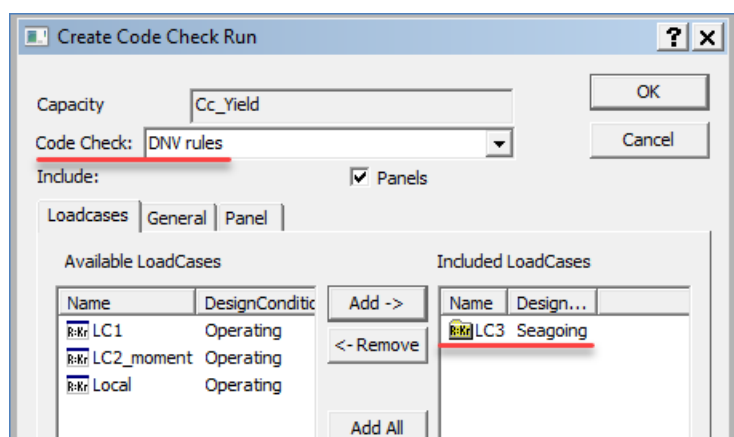


2.1.3 Add Run

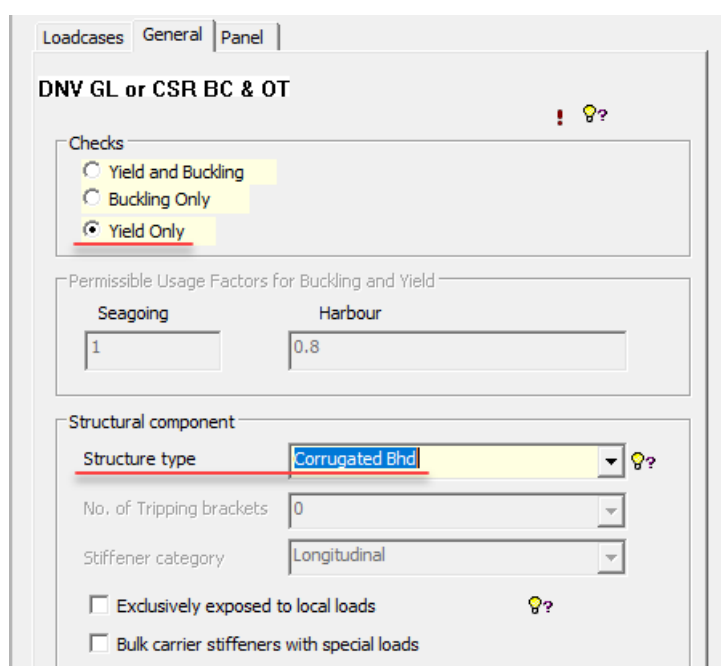
- “**Add Run**”



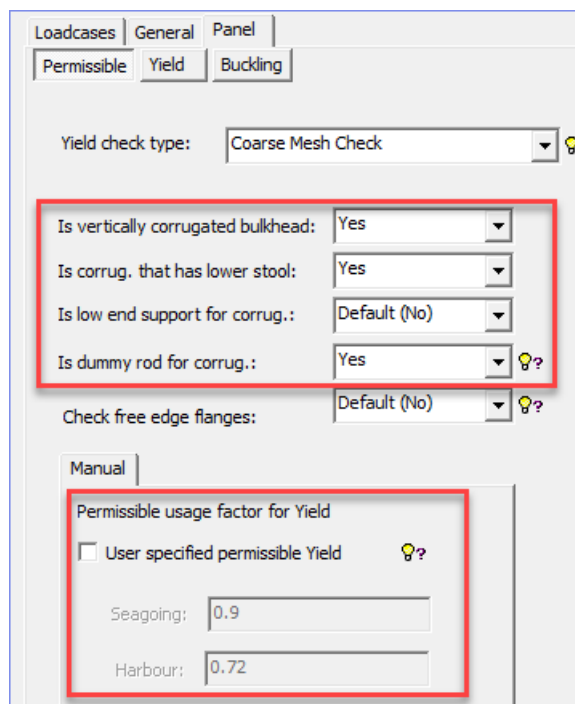
- Code Check : **DNV Rule**
- Add “**LC3**” for included loadcase



- Select “**General**” tab → Select “**Yield Only**”
- Structure Type : “**Corrugated Bhd**”



- Select “Panel” tab then check whether proper options are selected, like **“Is vertically corrugated bulkhead : Yes”** and also check other options.
- It’s also important to check whether proper usage factors are used, especially for **“Permissible Yield”** for this moment.



- Criteria for **Yield** according to [DNV-RU-SHIP](#) are:

Table 1 Permissible coarse mesh yield utilisation factor λ_{yperm}

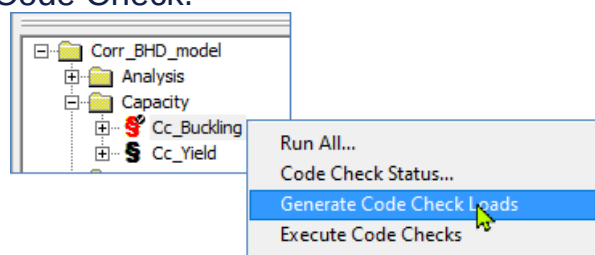
Structural member	Acceptance criteria	Load components ²⁾	λ_{yperm}
Plating of all longitudinal hull girder structural members, primary supporting structural members and bulkheads. Dummy rod of corrugated bulkhead. Face plate of primary supporting members modelled using shell or rod elements.	AC-I	S	0.8 ⁽³⁾
	AC-II	S + D	1.0
	AC-III ⁽¹⁾	A, T	1.00
Corrugation of corrugated bulkheads under lateral pressure from liquid loads, for shell elements only. For corrugation angle between 45° and 55° the reduction in λ_{yperm} as given in Ch.3 Sec.6 [6.1.1] applies.	AC-I	S	0.72 ⁽⁴⁾
	AC-II	S + D	0.90
	AC-III ⁽¹⁾	A, T	0.90

1) For members of the collision bulkhead, AC-I shall be used.
2) See [Ch.1 Sec.2 \[4.2\]](#).
3) $\lambda_{yperm} = 0.85$ when hull girder permissible loads for harbour operations or special operations are applied.
4) $\lambda_{yperm} = 0.77$ when hull girder permissible loads for harbour operations or special operations are applied.

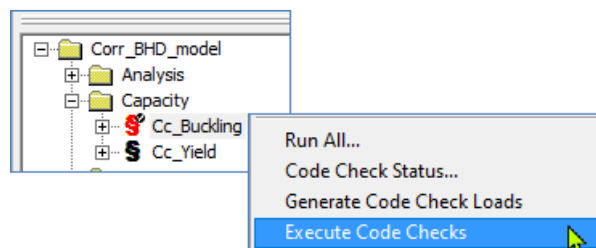
- Press **“OK”** to create run.

2.1.4 Generate Code check & Execute Code Check.

- **“Generate Code Check loads”**

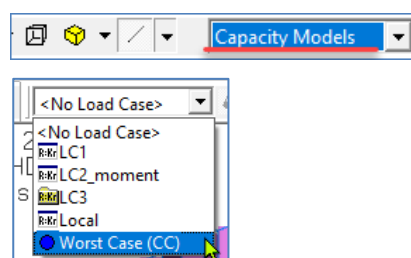


- “Execute Code Checks”



2.1.5 Check Yield result of Plate

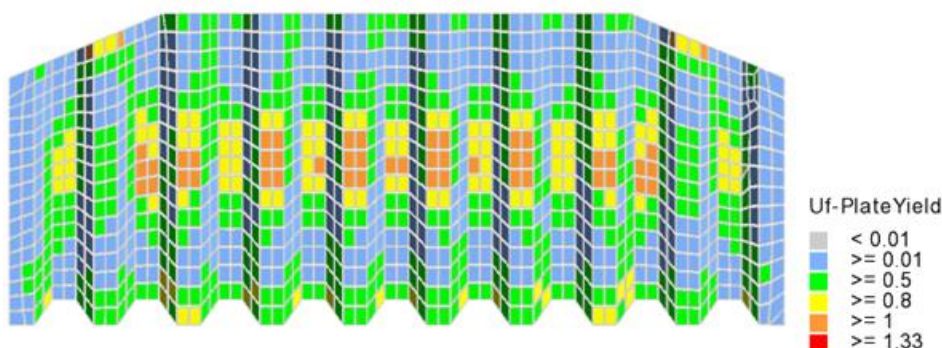
- Change view as “Capacity Models”
- Change load case into “Worst Case(CC)”



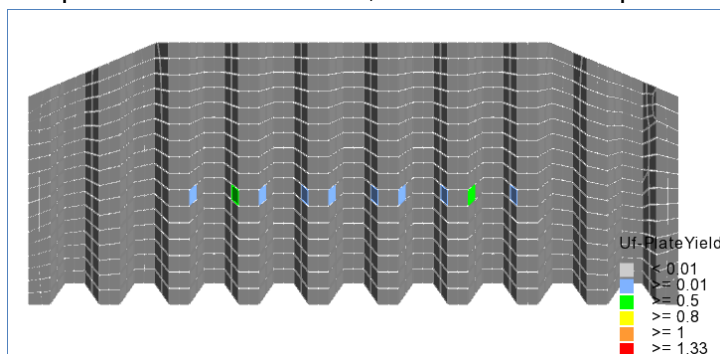
- Select “Result → Uf-PlateYield” → then activate color code for that



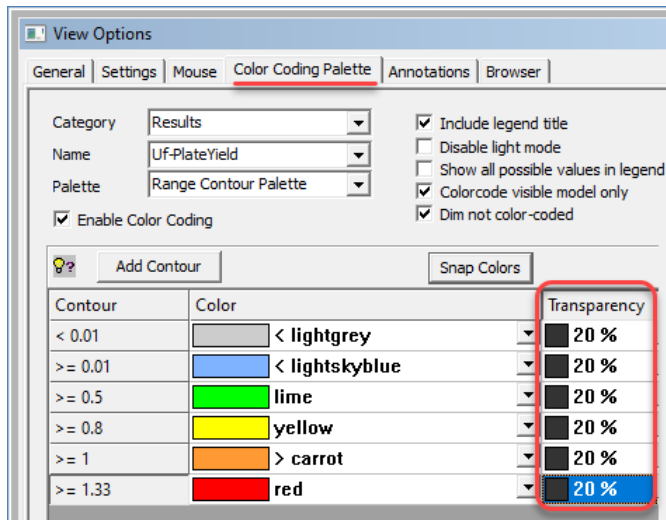
- Then Plate Yield can be displayed as below.



If you encounter graphic issues like below, this is due to overlapping, because there are two panels in same location, when “One Panel per thickness” option is used.

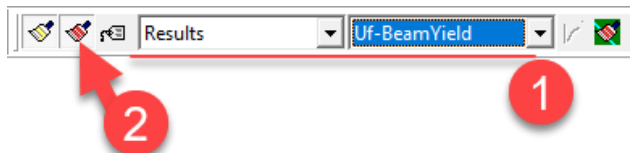


For such cases, please try to increase “Transparency” in “View | Option | Color Coding Palette”.

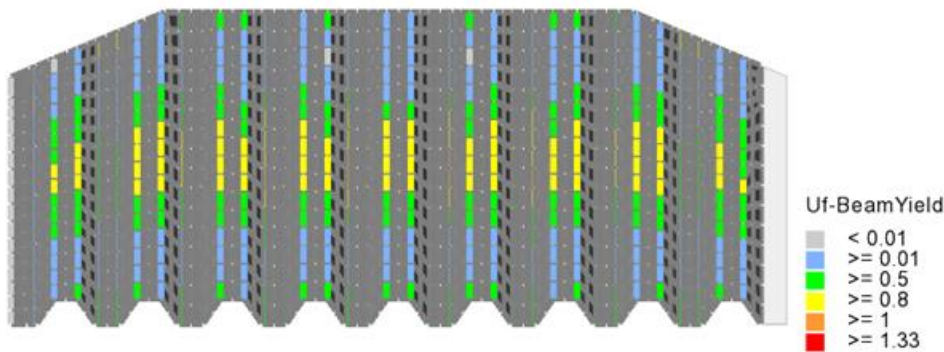


2.1.6 Check Yield result of Dummy Beam

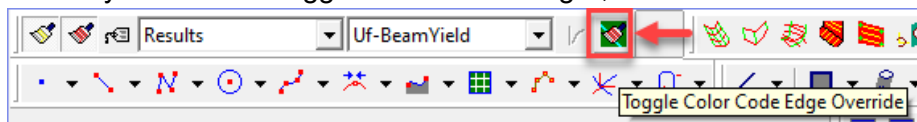
- Select **Result → Uf Beam Yield**



- Then yield for dummy rod can be checked.

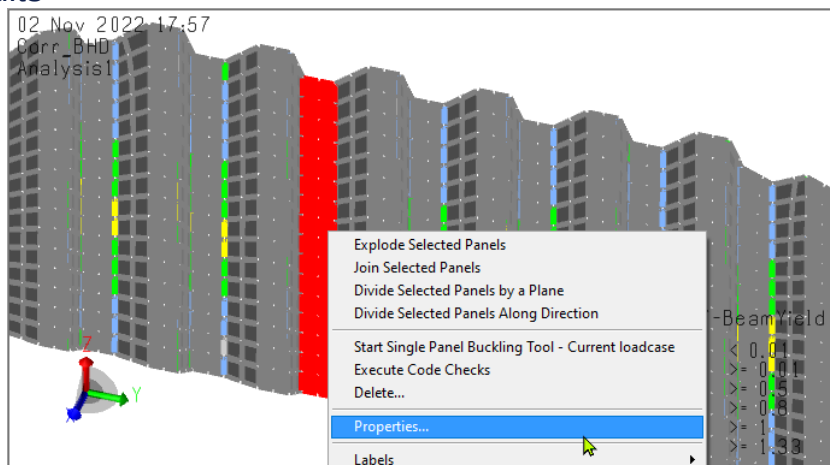


Hint: Try to turn off "Toggle Color Code Edge", if the color code is not displayed clearly.

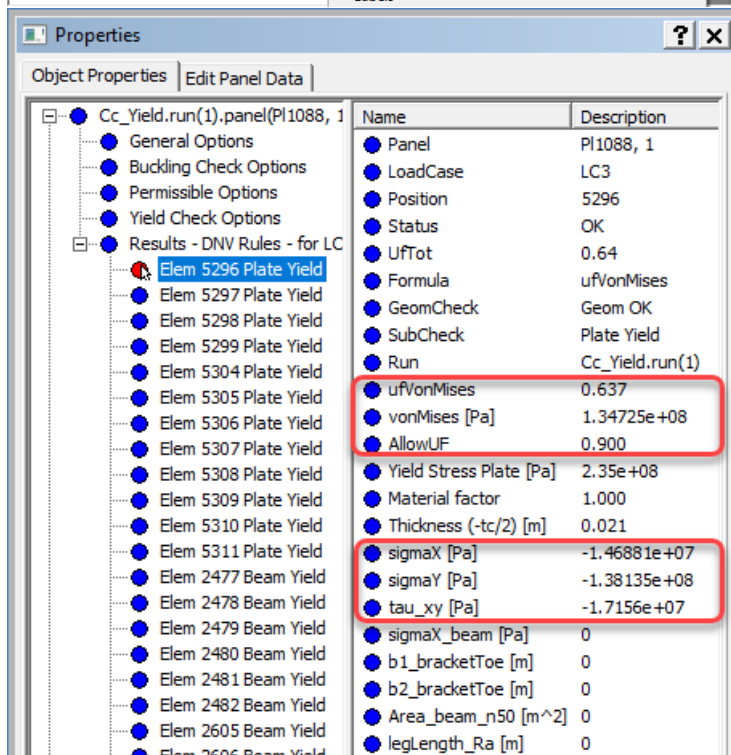


2.1.7 Check details of yield results

- Select 1 panel (i.e. panel(PI1088,1)) → select **Properties**



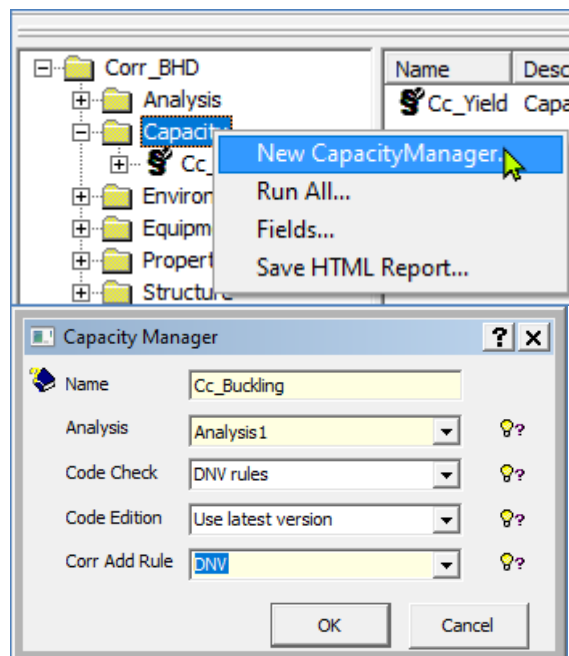
- Select “Object Properties”, expand the available fields and then select one element (“5296” is element number.)
- Check whether criteria are correct, as well as each stress component, if want.
- Press **OK** to close



2.2 Buckling Strength Evaluation

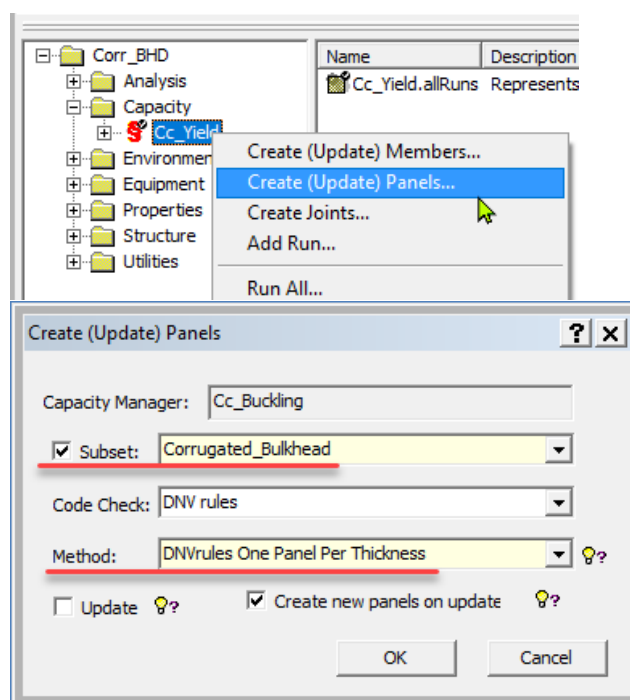
2.2.1 Create Capacity Manager

- Create new capacity manager in “**New Capacity Manager**”
 - Users can create capacity run in existing capacity manager.
- Define settings as below
 - Name : **Cc_Buckling**
 - Analysis : **Analysis1**
 - Code Check : **DNV Rule**
 - Corr Add : **DNV**



2.2.2 Create Panel

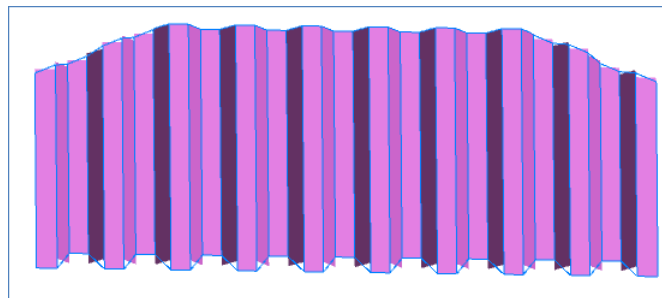
- “**Create (Update) Panel**”
- Subset : “**Corrugated_Bulkhead**”
Method : “**One Panel per Thickness**”



- Change view into “**Capacity Models**”

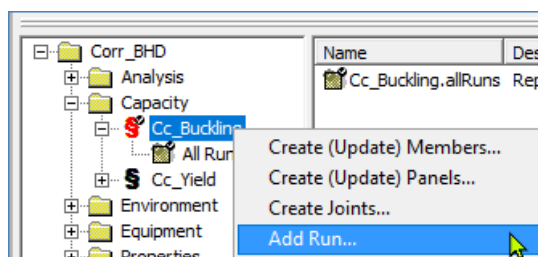
Capacity Models

to see whether the capacity panel has been created well.



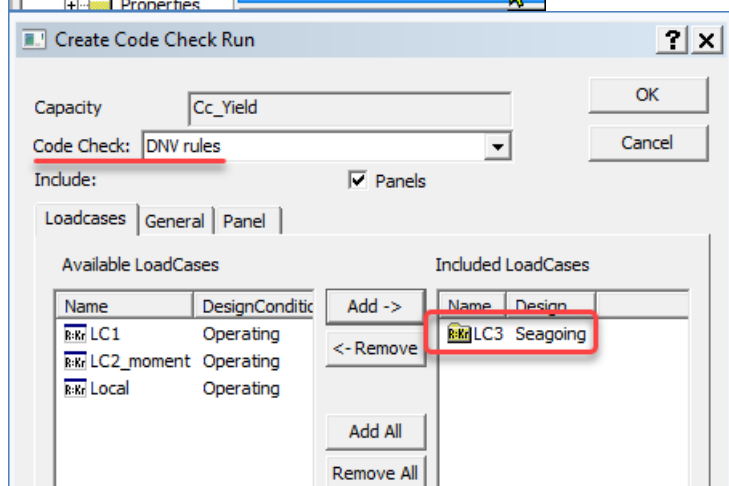
2.2.3 Add Run

- “**Add Run**” for “Cc_buckling” capacity manager



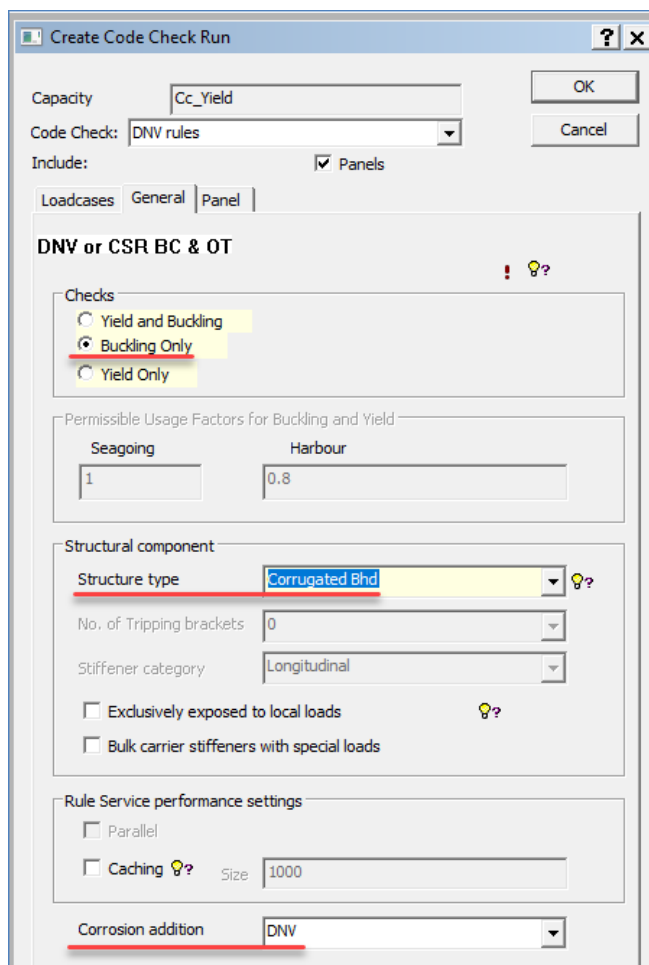
In Loadcases tab

- Code Check : **DNV Rule**
- Add “**LC3**” for included loadcase

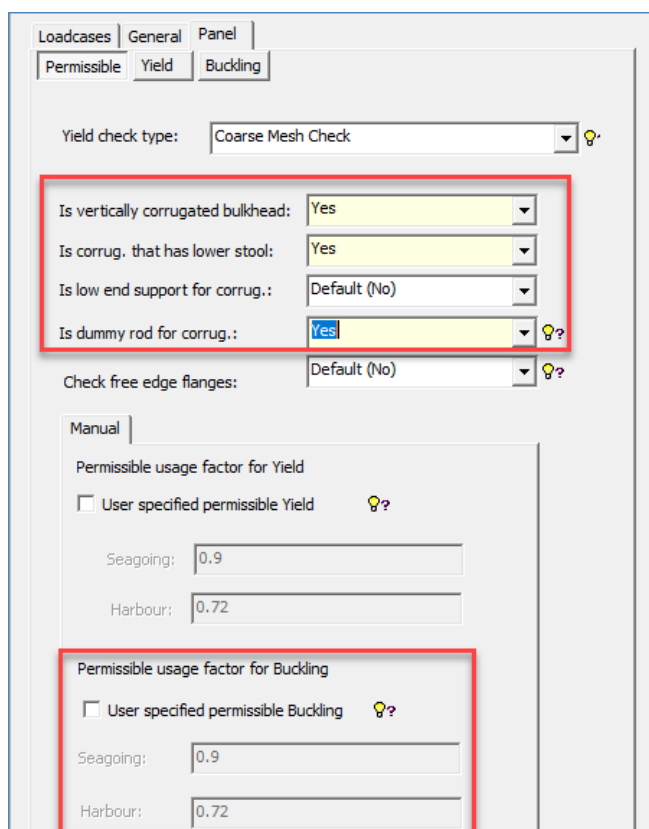


Select “General” Tab

- and select “**Buckling Only**”
- Structure Type : “**Corrugated Bhd**”
- Corrosion Addition : **DNV**
(This example model does not have corrosion property, but corrosion should be included in actual buckling calculation).



- Check whether proper options are selected in “Permissible” tab, like “**Is vertically corrugated bulkhead : Yes**” and also check other options.
- Also, it’s important to check the permissible criteria, especially for “**Permissible Buckling**” for this moment.



- Criteria for **Buckling** according to [DNV-RU-SHIP](#) are:

3.4 Allowable buckling utilisation factor

The allowable buckling utilisation factor is defined in [Table 3](#).

Table 3 Allowable buckling utilisation factor η_{all}

Structural member	Acceptance criteria	Design load scenario ²⁾	η_{all}
Plates and stiffeners/stiffened panels	AC-I	S	0.8 ⁽³⁾
	AC-II	S + D	1.00
	AC-III ¹⁾	A, T	1.00
Struts, pillars and cross-ties	AC-I	S	0.65
	AC-II	S + D	0.75
	AC-III ¹⁾	A, T	0.75
Corrugation of corrugated bulkheads under lateral pressure from, liquid loads For corrugation angle between 45° and 55° the reduction in η_{all} as given in Ch.3 Sec.6 [6.1.1] applies	AC-I	S	0.72 ⁽⁴⁾
	AC-II	S + D	0.90
	AC-III ¹⁾	A, T	0.90

1) For members of the collision bulkhead, AC-I shall be used.

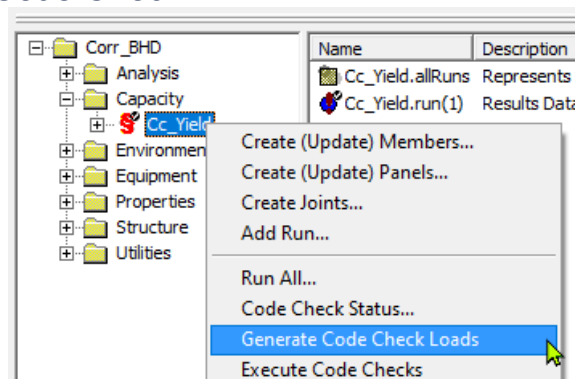
2) See [Ch.1 Sec.2 \[4.2\]](#).

3) $\eta_{all} = 0.85$ when hull girder permissible loads for harbour operations or special operations are applied.

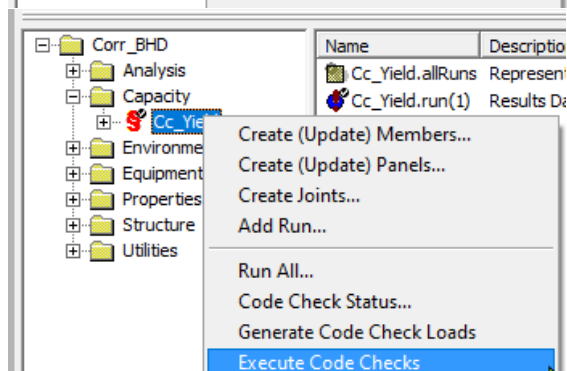
4) $\eta_{all} = 0.77$ when hull girder permissible loads for harbour operations or special operations are applied.

2.2.4 Generate Code check & Execute Code Check.

- “Generate Check check loads”



- “Execute Code Checks”



- Then Buckling calculation for corrugated bulkhead will be performed for the below 4 cases, based on [DNV-RU-SHIP](#).

4 Vertically stiffened longitudinal plating in way of horizontal neutral axis

4.1 Buckling criteria

4.1.1 Plating

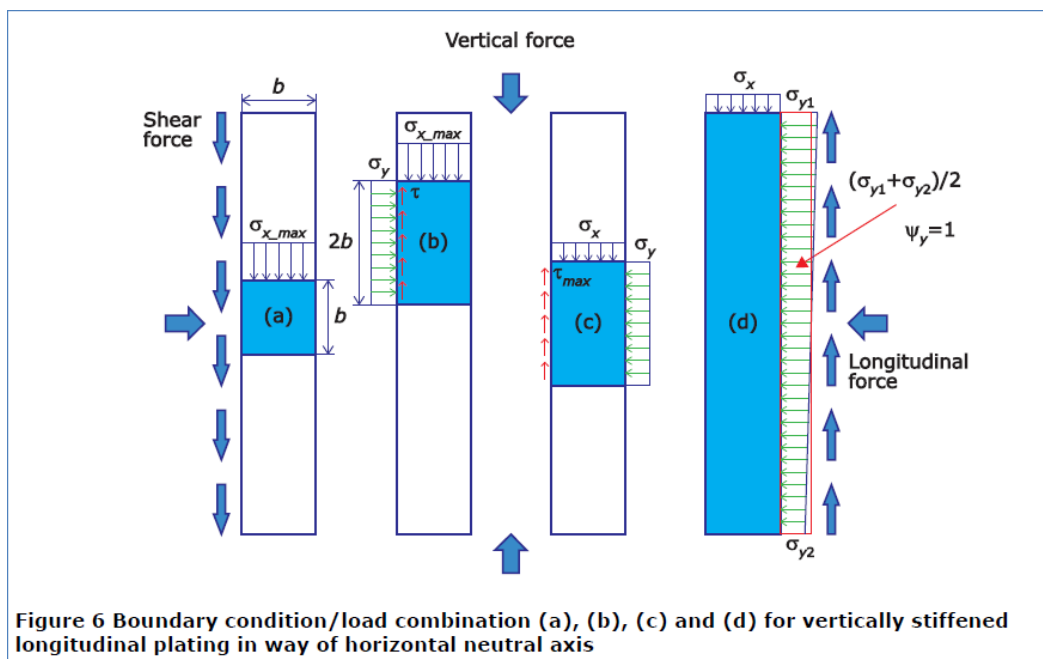
The compressive buckling strength for vertically stiffened longitudinal plating with the shorter edges supported by longitudinal plating/decks and located within $0.7z_1$ from horizontal neutral axis, where z_1 is the distance from horizontal neutral axis to equivalent deck line or baseline respectively as defined in [Ch.5 Sec.2 \[1.6\]](#), may be verified based on the following criterion:

$$\eta_{vsp} \leq \eta_{all}$$

where:

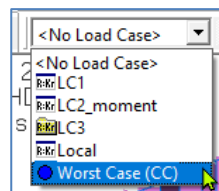
η_{vsp} = maximum utilization factor calculated according to method A as defined in [DNV-CG-0128 Sec.3 \[2.2.1\]](#) and considering the following boundary conditions and stress combinations:

- 4 edges simply supported, see cases 1, 2 and 15 in [DNV-CG-0128 Sec.3 Table 3](#):
 - a) Pure vertical stress:
 - the maximum vertical stress of stress elements is used with $\alpha = 1$ and $\psi_x = 1$
 - b) Maximum vertical stress combined with longitudinal and shear stress:
 - the maximum vertical stress in the buckling panel plus the shear and longitudinal stresses at the location where the maximum vertical stress occurs is used with $\alpha = 2$ and $\psi_x = \psi_y = 1$
 - the plate thickness to be considered in the buckling strength check is the one where the maximum vertical stress occurs.
 - c) Maximum shear stress combined with longitudinal and vertical stress:
 - the maximum shear stress in the buckling panel plus the longitudinal and vertical stresses at the location where maximum shear stress occurs is used with $\alpha = 2$ and $\psi_x = \psi_y = 1$
 - the plate thickness to be considered in the buckling strength check is the one where the maximum shear stress occurs.
- The 2 shorter edges of the plate panel clamped, see cases 11, 12 and 16 in [DNV-CG-0128 Sec.3 Table 3](#):
 - a) Distributed longitudinal stress associated with vertical and shear stress:
 - the actual size of the buckling panel is used to define α
 - the average values for longitudinal, vertical and shear stresses shall be used
 - $\psi_x = \psi_y = 1$
 - the plate thickness to be considered in the buckling strength check is based on [Sec.3 \[1.2.2\]](#).



2.2.5 Check Buckling result of Plate

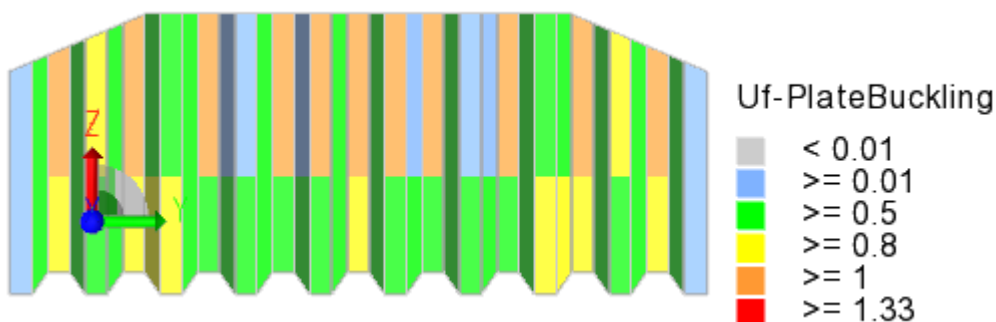
- Change load case into “**Worst Case(CC)**”



- Select “**Result → Uf-Buckling**” → then activate color code for that

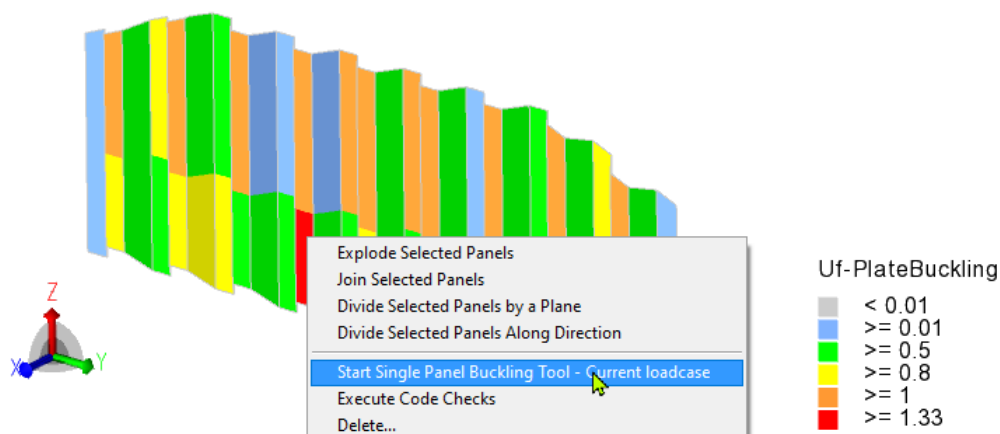


- Then Plate Yield can be checked.



2.2.6 Start Single Panel Buckling Tool (SPBT) for design iteration

- Select one Panel (i.e. panel(PI1088,1)) → “Start Single Panel Buckling Tool”



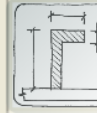
- Press buttons (1), (2), (3) to see the input parameters in detail.

DNV, single Panel Buckling window: D:\OD\yocho\300_GeniE\30_Best Practice\Corrugated_Buckling\Test_v02_s02\Cc_Buckling.run1\SinglePanelInput.xml

Buckling of plate and stiffeners

DNV Rules for Ships - Part 3, Chapter 8.










Description: Panel from GeniE analysis Panel Name: Cc_Buckling.run(1)-panel(PI1088, 1) Load case name: LC3 Load type: Other Rule version: DNV rules, Jul

Stiffener Types: Stiffener 1: Unstiffened Stiff. type 0

Plate Data: Pl. length: 1850 mm Plate width: 925 mm Plate thckn.: 21 mm Safety fact. pl.: 1.00 Safety fact. st.: 1.00

Hole length: 0 mm Hole width: 0 mm PSM opt.: Other, not F

Material Data: Yield stress: 235 MPa Poisson ratio: 0.3 E-Module: 206000 MPa

Stress Data: σ_x stress: σ_{y_1} σ_{y_2} ψ_y τ t_p at point Note:

Panel Least sq.: 164.383 MPa 0 MPa 0 MPa 1.00 -5.59503 MPa - compression stress is positive...

Max compr.: 164.383 MPa 0 MPa - 1.00 -4.94693 MPa 22 mm

Max shear: -48.7873 MPa 0 MPa - 1.00 -5.0096 MPa 22 mm

Allowable UF: 0.90 surface pressure: -183.96 kPa [kN/m2] (pos. pressure on plate side, neg. on stiffener side)

Stress from: FEA calculation. Special cases: Corrugated Bulkhead. Assessm. met.: Method B. No. of tripping brackets: No Brackets

Boundary Data: Long side 1: Simply supported Long side 2: Simply supported

Short side 1: Simply supported Short side 2: Simply supported

Length between brackets: 1850 mm

☒ Subtract corr. add. from profile Plate corr.: 2 mm Stiff.1 Corr.: 0 mm Stiff.2 corr.: 0 mm

☒ Add angle of plate and profile Stiff. angle: 0 W.to Fl. ang.: 90 Stiff.2 angle: 0 W.to Fl. ang.2: 90

☐ Check curved plate buckling R long edge: 0 mm R short edge: 0 mm Use radius R = 0 for flat or non-curved edge: ☐ Bilge plate

Run Buckling analysis (Default units above are [mm] or [MPa] if no other units are given.)

Plate Results: Usage factor: Req. pl. thckn.: (Estimated required plate thickness shown here is estimated net value and only considering plate buckling)

Least square: 0.80 14.0 mm

Max compr.: 0.78 13.9 mm

Max shear: 0.23 4.0 mm

Slenderness: tp >= - OK

(Please Note: After changing to estimated values or after iteration on scantlings based on local considerations, it is necessary to re-check the whole Cross Section.)

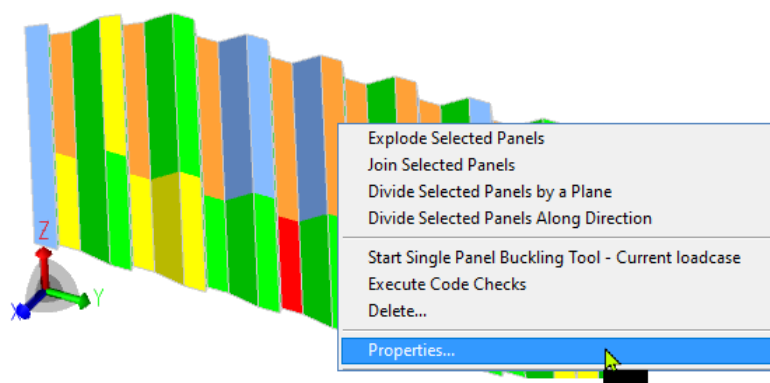
View intermediate plate buckling and stiffener buckling results in a spreadsheet. Save Save As... Open... Print... Exit / Close

Calculated Date: 05 April 2023, Program version Build: 20.23.2212.1412

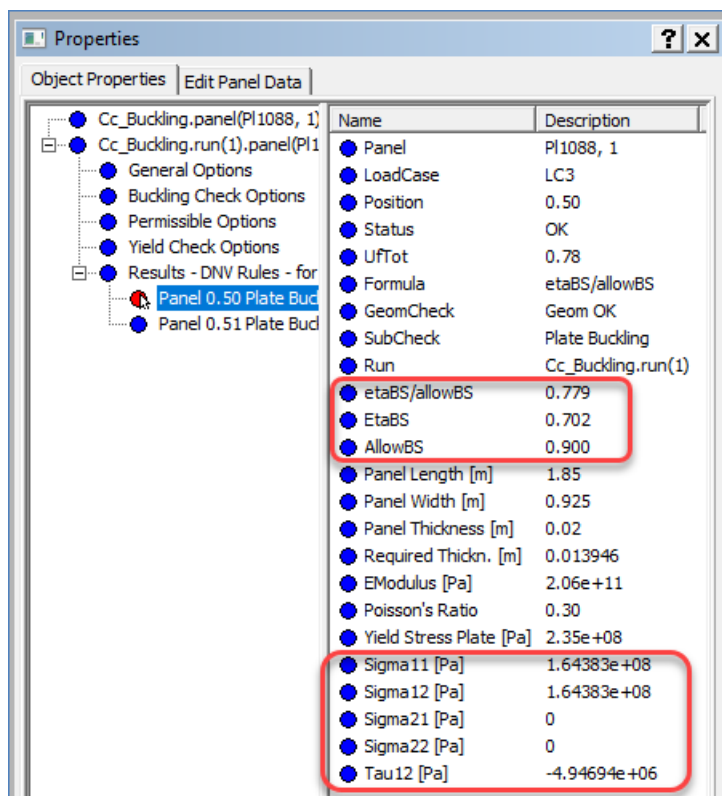
- (4) Modify them for design iteration → (5) run Buckling Analysis → (6) new usage factor will be obtained.
- Select “Exit/Close” to close the Single Panel Buckling Tool

2.2.7 Check detail result of yield result

- Select 1 panel (i.e. panel(PI1088,1)) → **Properties**



- Then select one calculation (Panel 0.51 or Panel 0.51)
- Check whether criteria are correct, also check each stress component.



The screenshot shows the 'Properties' window in DNV software. The left pane shows a tree view with 'Panel 0.50 Plate Bud' selected. The right pane shows a table of properties and their values. Two red boxes highlight specific results: one for 'etaBS/allowBS' and another for stress components.

Name	Description
Panel	PI1088, 1
LoadCase	LC3
Position	0.50
Status	OK
UF _{Tot}	0.78
Formula	etaBS/allowBS
GeomCheck	Geom OK
SubCheck	Plate Buckling
Run	Cc_Buckling.run(1)
etaBS/allowBS	0.779
EtaBS	0.702
AllowBS	0.900
Panel Length [m]	1.85
Panel Width [m]	0.925
Panel Thickness [m]	0.02
Required Thickn. [m]	0.013946
EModulus [Pa]	2.06e+11
Poisson's Ratio	0.30
Yield Stress Plate [Pa]	2.35e+08
Sigma11 [Pa]	1.64383e+08
Sigma12 [Pa]	1.64383e+08
Sigma21 [Pa]	0
Sigma22 [Pa]	0
Tau12 [Pa]	-4.94694e+06

3 REFERENCES

- DNVGL-CG-0127 Finite element analysis, Nov 2020
- DNV-RU-SHIP Pt.3 Hull, July 2021
- DNV-CG-0128 Buckling, Sep 2021



About DNV

We are the independent expert in risk management and quality assurance. Driven by our purpose, to safeguard life, property and the environment, we empower our customers and their stakeholders with facts and reliable insights so that critical decisions can be made with confidence. As a trusted voice for many of the world's most successful organizations, we use our knowledge to advance safety and performance, set industry benchmarks, and inspire and invent solutions to tackle global transformations.

Digital Solutions

DNV is a world-leading provider of digital solutions and software applications with focus on the energy, maritime and healthcare markets. Our solutions are used worldwide to manage risk and performance for wind turbines, electric grids, pipelines, processing plants, offshore structures, ships, and more. Supported by our domain knowledge and Veracity assurance platform, we enable companies to digitize and manage business critical activities in a sustainable, cost-efficient, safe and secure way.