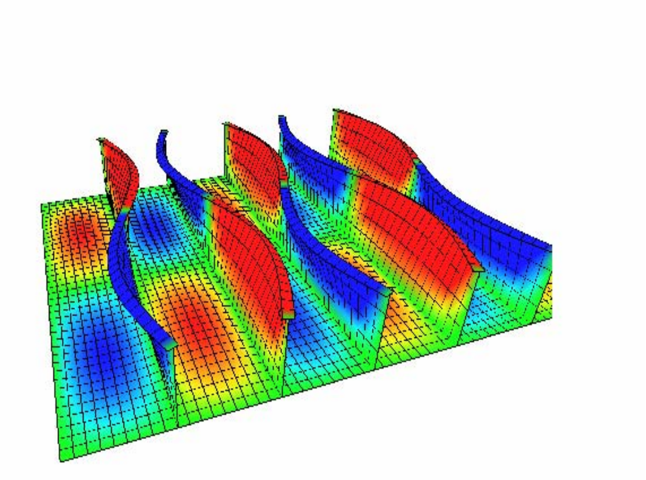
DNV's PULS buckling code

Panel Ultimate Limit State

New Computerized Buckling Code

Non-linear plate theory



Developed by: DNV Maritime/Section for Hydrodynamics and Structures (mtpno361)
Responsible DNV Unit for maintenance/sale: DNV Software

Presentation overview

PULS buckling code

- DNV buckling rules and standards
- Why a new buckling code?
- Theoretical foundation
- PULS element library
- PULS features
- Demonstration of programme
- Practical exercise

PULS implementation in the Rules and Standards

1. Offshore standard RP C-201, Part 2 ”Buckling Strength of Plated Structures”

2003

2. Steel Ship Rules, Part 3 Ch.1, (1A1) ”Hull Structural design - Ships with length 100 meters and above”, Sec.13, D Panel Ultimate strength, ESP additional notation

January 2004

3. LAN (Lloyds/ABS/DNV) common scantlings project for tankers.

2004

PULS in the new Recommended Practice (RP)

Recommended Practice
DNV-RP-C201
Buckling Strength of Plated Structures
October 2002

Part 1:

Conventional buckling code

Updated CN30.1

Semi-empirical

Part 2:

PULS (Panel Ultimate Limit State)

Computerized buckling code

Semi-analytical

Non-linear light

Recommended Practice RP C-201

- The RP C-201 was released early 2003, and replaces the old Classification Note 30.1 (CN30.1)
- The RP is a supporting document for the DNV Offshore Standards describing two equally acceptable approaches for calculating the buckling capacity of flat plated structures
- The RP contains two separate sections
  - Section one covers updating of the “old” Class Note 30.1 with respect to buckling of plates and girders
  - Section two covers the new buckling code PULS
- The curved shell part from CN 30.1 has been placed in a separate RP, RP C-202

Why a new buckling code?

) Ship Rule formulas predicts buckling
imit ..**not** Ultimate Strength

IACS, DNV, Lloyds, ABS has decided to use Ultimate Limit State Principles in new Unified Requirements and Rules currently up for revision

Modern design principles shall be based on Ultimate strength/ULS design principles

⇩

ULS design principles are the only feasible concept for estimating safety margins against failure

) Present Buckling Rules are ”Rule book”
olutions – initial scantling assessment

⇨

Present Buckling Rules are not consistent for use towards linear global FE analysis results, combined loads, bi-axial compression, shear etc. ⇒ final scantling assessment

i) Time for updating rules and implement
nodern ULS design principles using
irectly recognized buckling and non-
near postbuckling theory

⇨

Programming non-linear plate/shell models;

PULS = ”Non-linear light”

⇩

Computerized buckling code based on ”Non-linear light” theory easily implemented into spreadsheets, etc.

Designers will mostly use PC tools in design
PULS ”non-linear light” gives immediate results

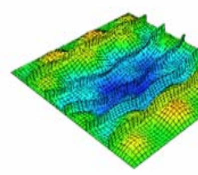
SOFTWARE

Why new buckling code

PULS approach : Direct application of recognized non-linear plate theory

" Non-linear light theories " → Fast and easy

- Buckling and ULS estimates of panels very complex technical issue for combined load situations
- Direct method gives more realistic buckling estimates - Improved safety control
- Buckling Model and Theory Framework "in house"
- Transparent - recognized non-linear text book theory as basis
- More data output – 3D graphics for improved understanding of buckling failure mechanism



Best approach for optimal use of steel per defined target safety

Robust design **Improved Safety control**

SOFTWARE

PULS: Area of application

SHIP HULL STRENGTH SPLIT IN TWO LEVELS:

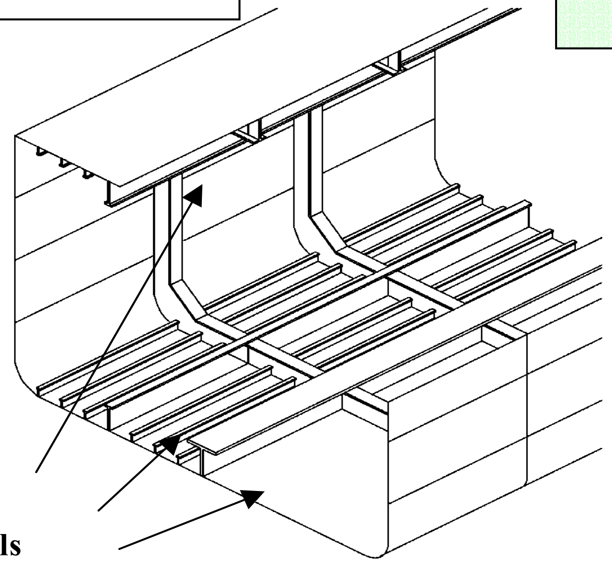
a) GLOBAL

b) LOCAL

Global Strength

a)

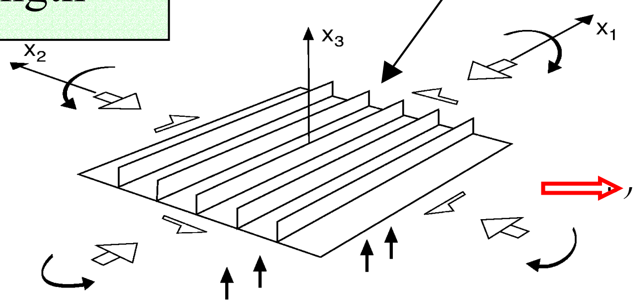
Ship Hull



a)

Stiffened panels

Local Strength



b)

Local strength: PULS is a code for buckling and ULS assessments of stiffened panels, girder plates, stringer decks etc.

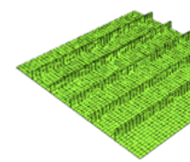
PULS Buckling code

Panel Ultimate Limit State

Based on advanced methods – for non-experts

Purpose:

- Simplified and user-friendly non-expert analyses **tool** for load bearing capacity assessment (ULS) of thin-walled stiffened panels used in ship and offshore constructions



P-ULS design principles for ship structures

Extreme loads

Accepts elastic buckling deflections

Do not accept permanent sets/buckles in plates

Ensure strong stiffeners

PULS Buckling code

- Assessment of <u>ultimate</u> load bearing capacity of stiffened panels as strength measure. Max load capacity - nonlinear analysis

- Assessment of buckling limit of stiffened panels – to be used in cases where construction elements are not allowed/recommended to buckle elastically: Ensures more steel. Buckling limit also relevant for functional requirements (SLS). Linearized analysis (Eigenvalues)

- Consider all types of load combinations (bi-axial, shear, tension/compression and lateral pressure) as consistent with output from linear FE hull/Nauticus models

PULS Buckling code

Programme language:

- Fortran 95: All calculations (solving equilibruim equations, incrementation…)

- Visual Basic: User interface

- VB PulsComClasses.dll file for **easy plug in different User Interfaces**

PULS Stand alone programs: 2 versions – Explorer and Excel

Available from DNV Software Web site download/time limited free lisence

(2 versions: Explorer and Excel versions apply same input file for easy use)

Nauticus Software:

Section Scantling/different FE Rule Packages

Theoretical foundation: Overview

Theoretical Basis

- **von Karman/ Marguerre's geometric non-linear plate theory**
- **Orthotropic plate theory for stiffened panels (S3)**

Moderate large deflections

Establish non-linear elastic equilibrium equations

- **Raleigh-Ritz discretization of deflections (Fourier serie expansion)**
- **Energy methods, virtual work/stationary potential energy**

oad history - load nbinations: bi-axial + ar + lateral pressure

Solves non-linear elastic equilibrium equations

- **Incremental perturbation procedure with arc length control**

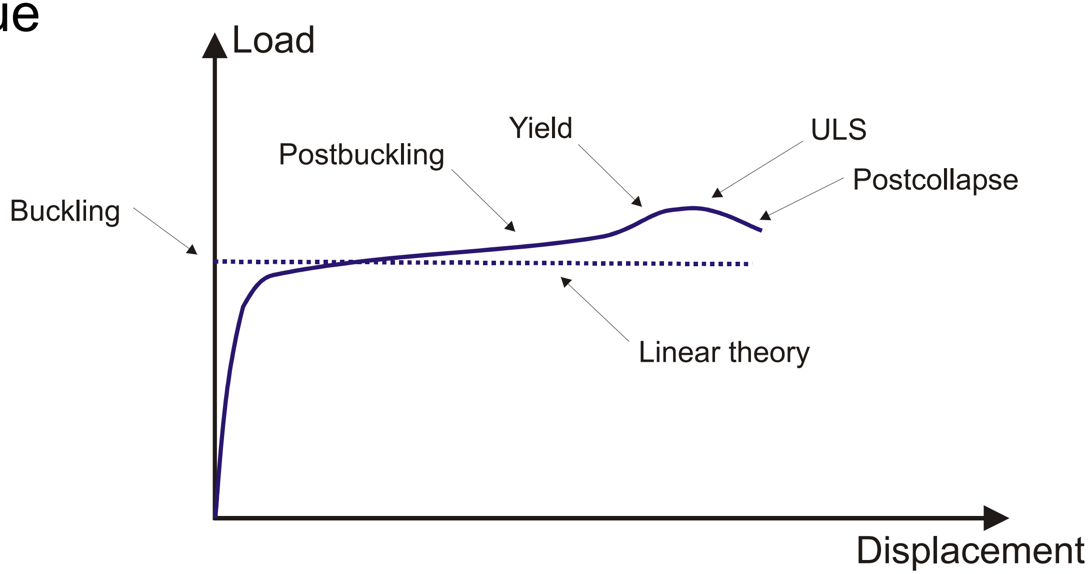
Solve local stress limit state functions

Check of material yield along plate edges and in internal selected "hot spot" positions.

Ultimate strength estimate

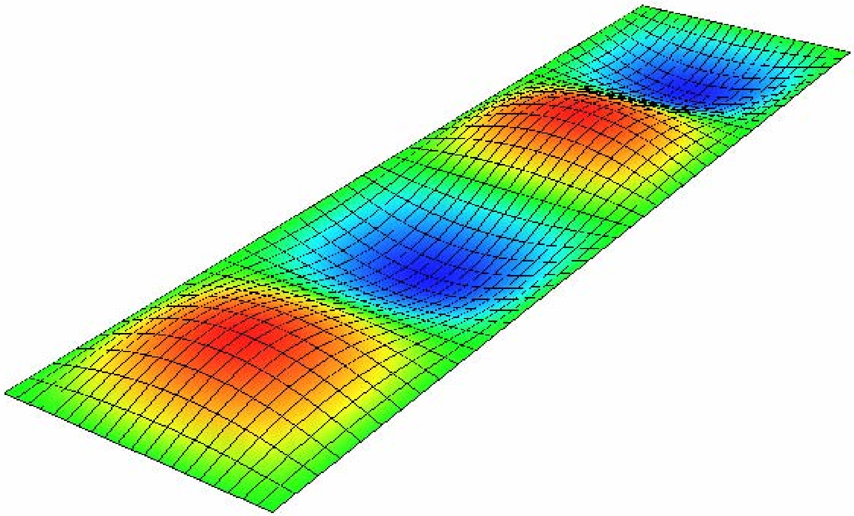
Buckling:

- Linear buckling / Eigenvalue
- Postbuckling, nonlinear
- Ultimate limit state
- Postcollapse



Theory and principles

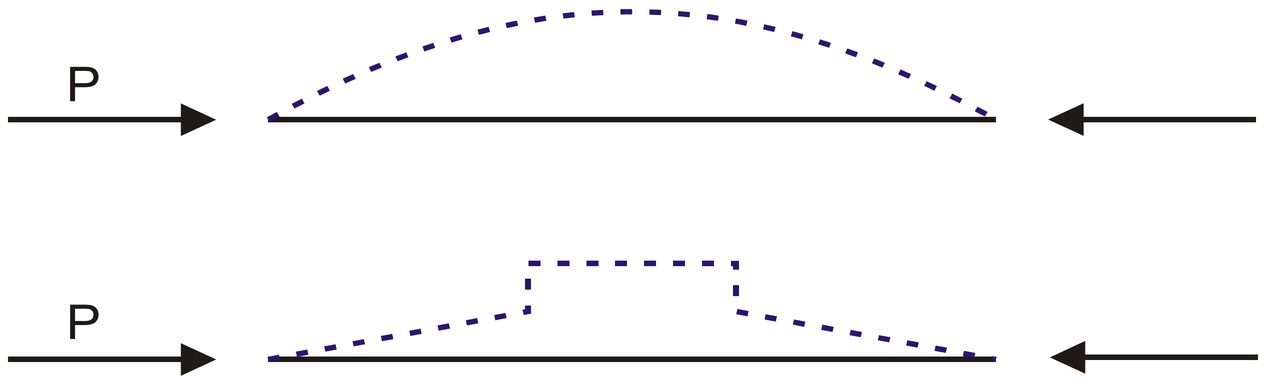
- Deflections represented by trigonometric functions, defined over the entire geometry
  - Buckling deflections tend to be periodic
  - Need very few dof compared to FEM
  - Any shape can be represented by applying sufficiently many terms



- Principle of stationary potential energy:

$$\delta\Pi = \delta U + \delta T = 0$$

- Intuitively: The structure adjusts itself to the shape that requires the least energy



Theory and principles

- Large deflection plate theory, membrane strains (von Karman / Marguerre):

$$\varepsilon_x = u_{,x} + \frac{1}{2} w_{,x}^2 + w_{0,x} w_{,x}$$

$$\varepsilon_y = v_{,y} + \frac{1}{2} w_{,y}^2 + w_{0,y} w_{,y}$$

$$\gamma_{xy} = u_{,y} + v_{,x} + w_{,x} w_{,y} + w_{0,x} w_{,y} + w_{,x} w_{0,y}$$

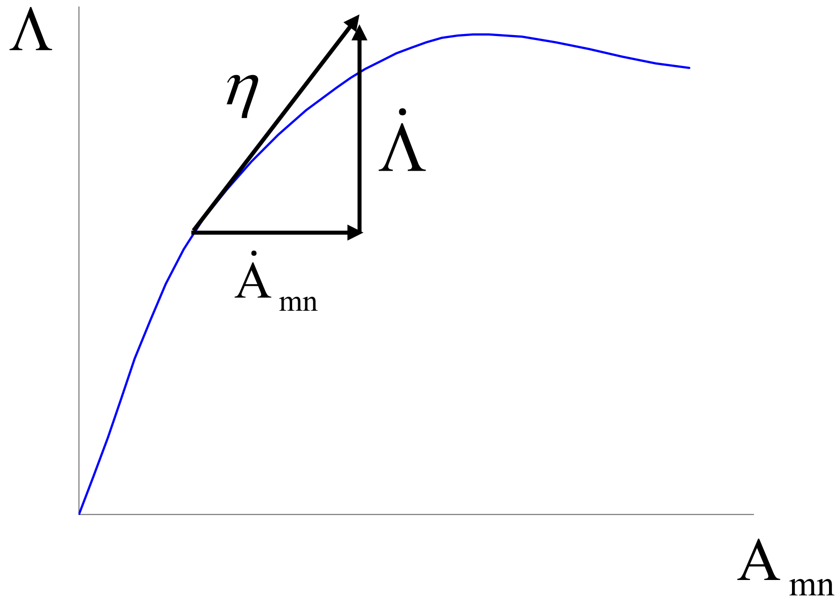
- Total strain found by adding the bending strains according to the Love-Kirchoff assumption:

$$\varepsilon_{ij}^{tot} = \varepsilon_{ij} - z w_{,ij}$$

Incremental solution procedure:

- Linearization – reduce equation system to 1. order
- Arc-length incrementation

$$\dot{A}_{mn} = \frac{\partial A_{mn}}{\partial \eta} \qquad \dot{\Lambda} = \frac{\partial \Lambda}{\partial \eta}$$



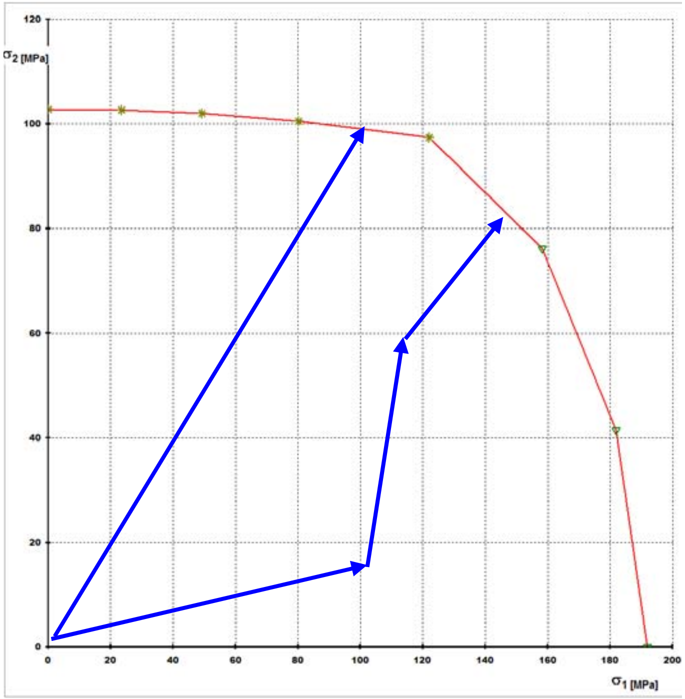
$$A^{i}_{mn} = A^{i\text{-}1}_{mn} + \eta \dot{A}^{i\text{-}1}_{mn}$$

$$\Lambda^{i} = \Lambda^{i-1} + \eta \dot{\Lambda}^{i-1}$$

Staging:

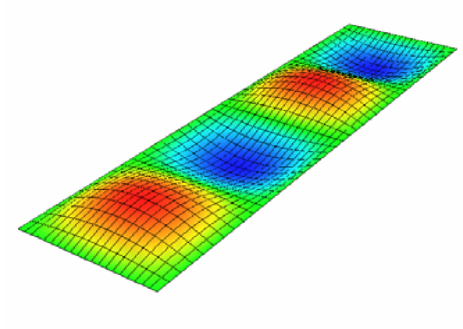
- Assume piecewise linear load path
- Number of load parameters reduced to one

$$P_i(\Lambda) = P_i^{s-1} + \Lambda(P_i^{s} - P_i^{s-1})$$

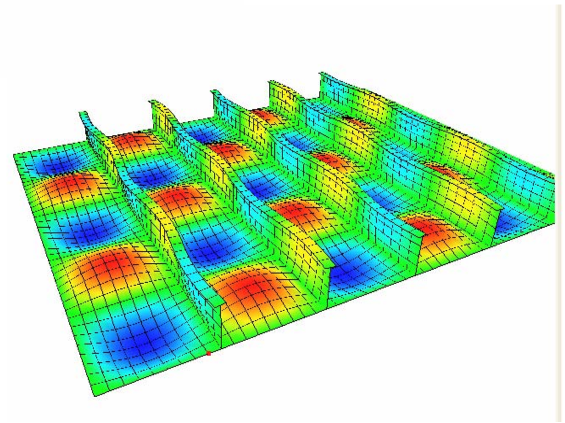


PULS element library: Overview

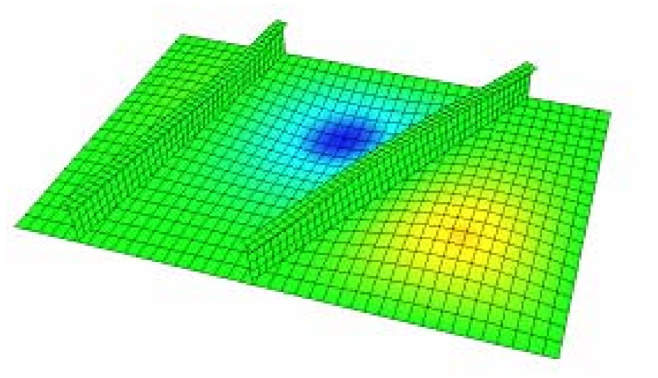
- U3: Unstiffened plate element



- S3: Stiffened plate element

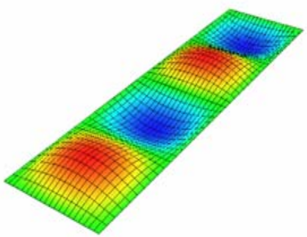


- T1: Stiffened plate element
  (non-regular geometry)

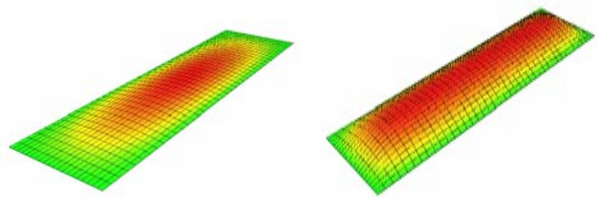


Typical buckling modes in unstiffened plate

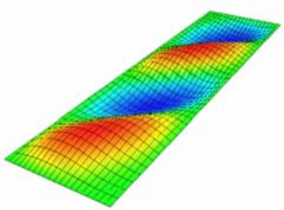
) Axial compression



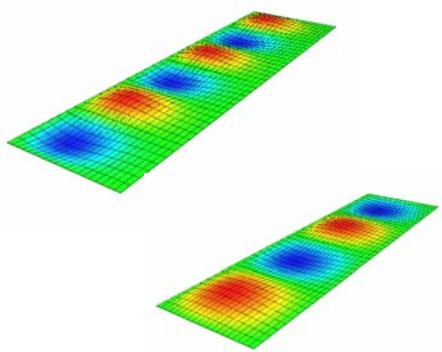
b) Transverse compresson



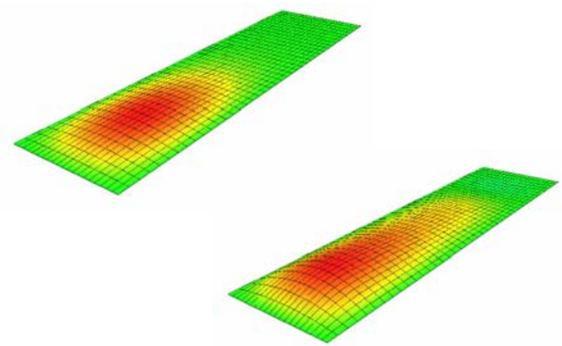
c) shear



c) Axial bending



c) Transverse bending



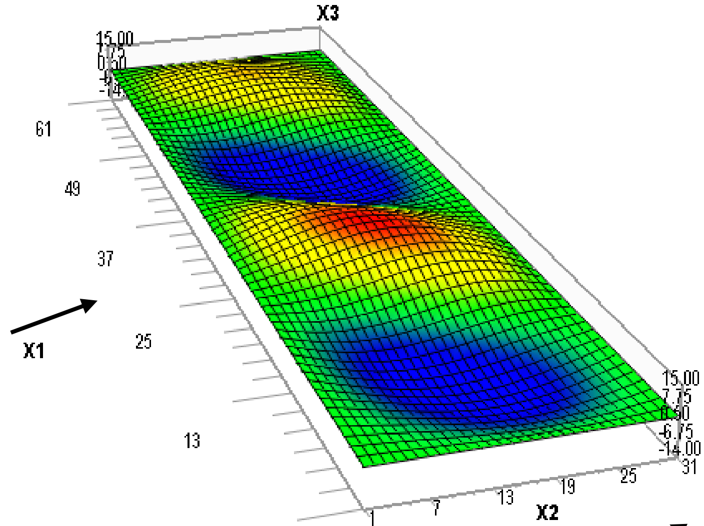
Unstiffened plate: Theoretical model

Buckling mode Deflection :

Raleigh - Ritz discretizations, Fourier expansion

$$w(x,y)=\sum_m\sum_n A_{mn}\,\mathbf{sin}\left(\frac{m\pi x}{a}\right)\mathbf{sin}\left(\frac{n\pi y}{b}\right)$$

$$w_0(x,y)=\sum_m\sum_n B_{mn}\,\mathbf{sin}\left(\frac{m\pi x}{a}\right)\mathbf{sin}\left(\frac{n\pi y}{b}\right)$$



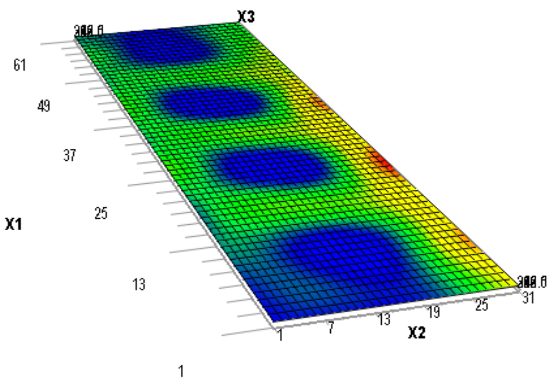
Deflections for combined load case- bending + shear

U3 boundary conditions:

i) simply supported out of plane along all edges

ii) straight but moveable in-plane edges (2D-integrated element)

Von Mises membrane stress distribution



Unstiffened plate (U3): Areas of application

- Ultimate Capacity: Integrated elements (deck, ship side, ship bottom, bulkheads etc)

- Buckling Capacity: Other elements such as girders and stringers. Elastic buckling (eigenvalue cut-off) and yield squash are upper limits

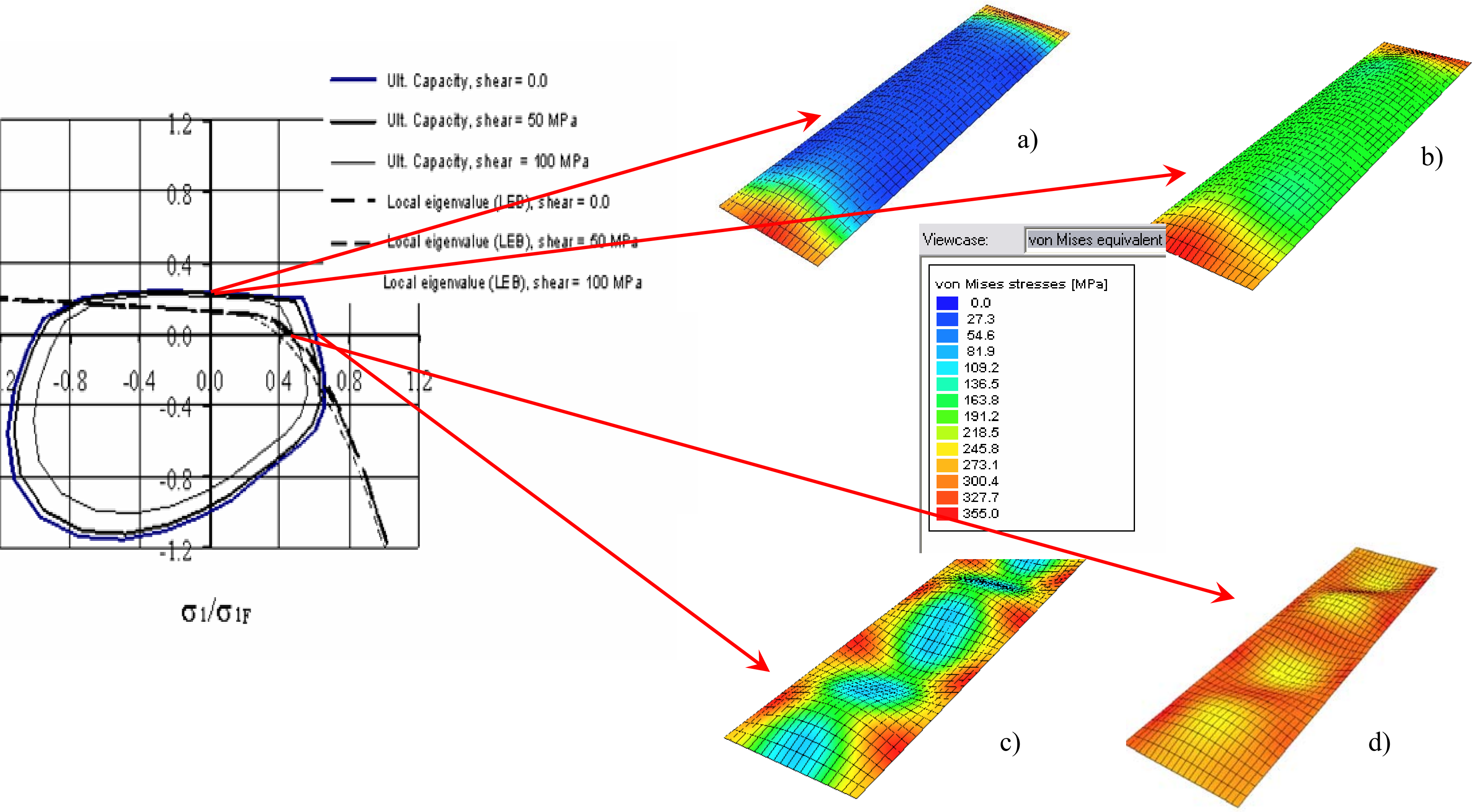
Ultimate strength
=
Redistribution of stresses

Validity range:

Aspect ratio limit: $L_1/L_2 < 20$ for $L_1 > L_2$ (or equivalent $L_2/L_1 < 20$ for $L_1 < L_2$)

Plate slenderness ratio: $L_i/t_p < 200$ (L_i = minimum of L_1 and L_2)

Example: Unstiffened plate, combined loads (U3)

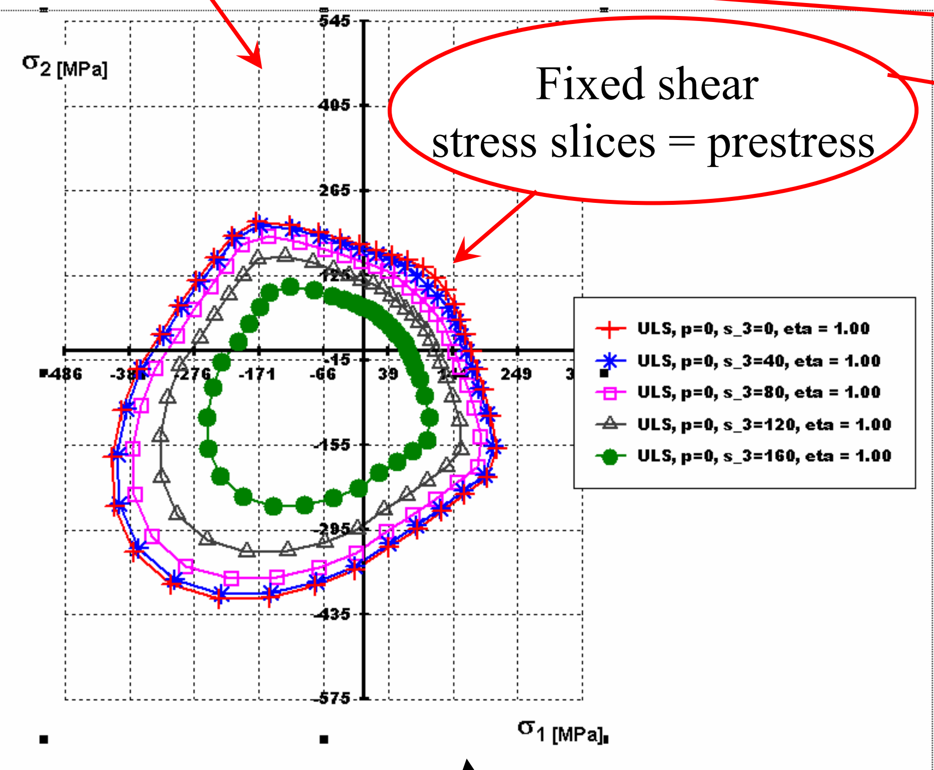


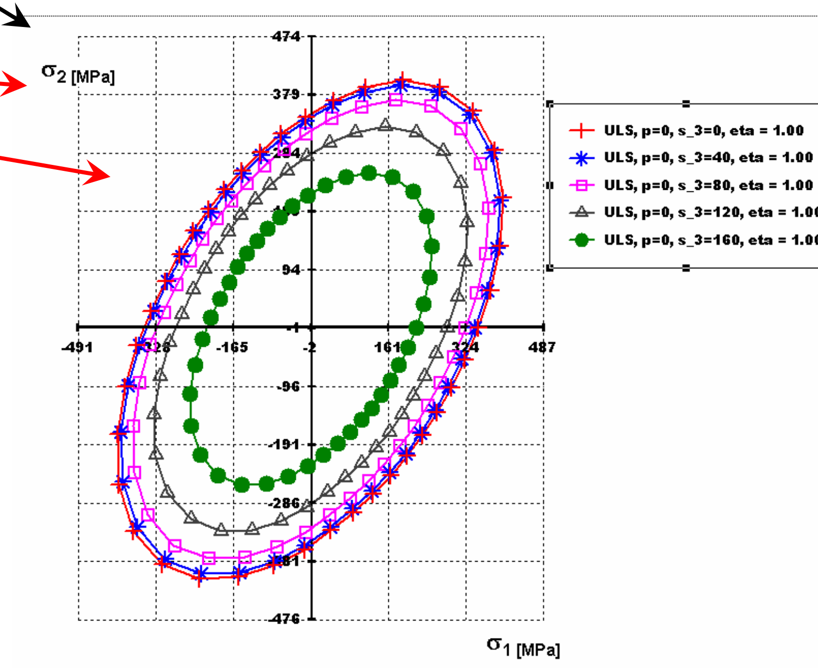
SOFTWARE

Example: Unstiffened plate, Capacity curves for combined loads

axial load space

50 mm plate ≅ Von Mises yield





10 mm plate, Ultimate Capacity curves

Slicing in 3-dim PULS ULS limit state EGG

SOFTWARE

Example: Unstiffened plate, axial compression (U3)

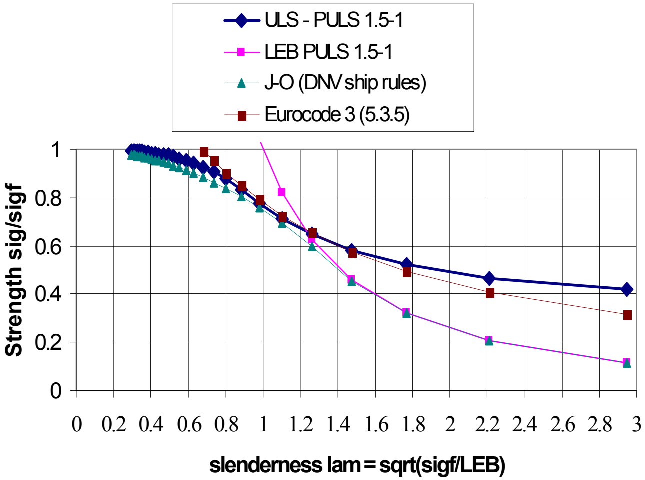
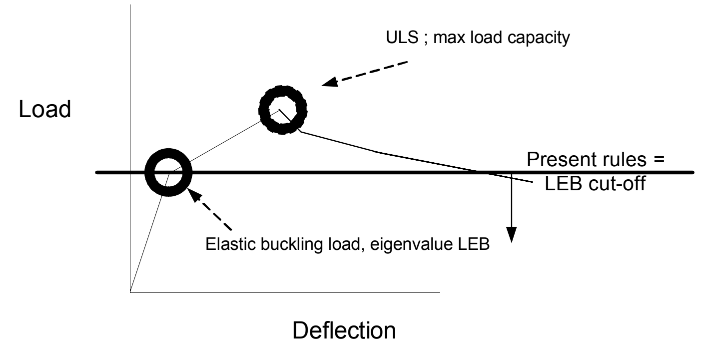
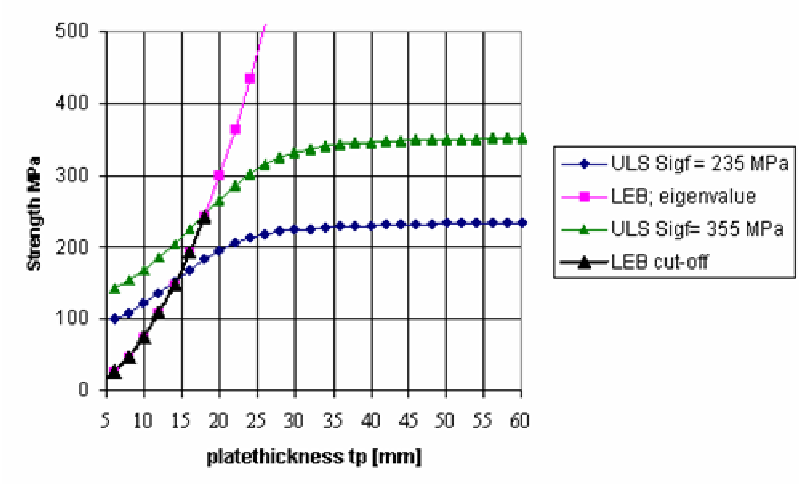
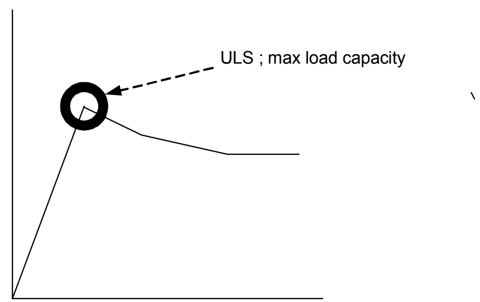


Fig.1 Comparisons between codes: Unstiffened plate in axial compression
DNV ship rules, Eurocode 3, PULS 1.5-1 code; U1-unstiffened plate, ULS and elastic eigenvalue LEB
Case: Sigf = 235 MPa, E = 208000 Mpa, ny = 0.3, L = 4000 mm, s = 1000 mm, variable platethickness



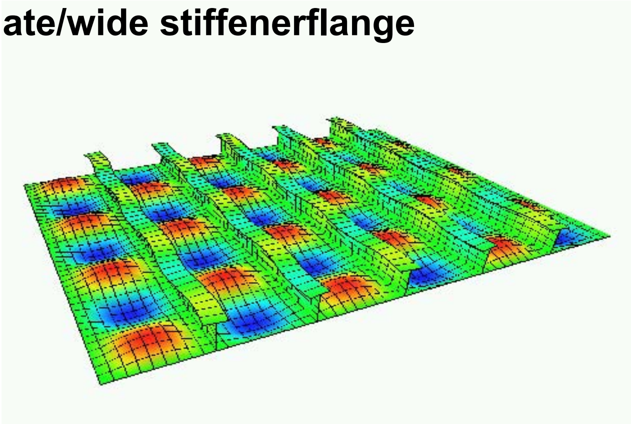




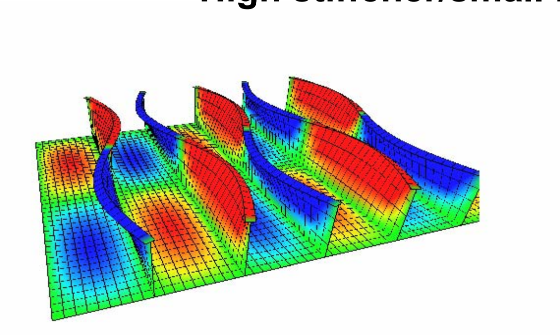
Typical buckling modes in stiffened panels

PULS buckling code

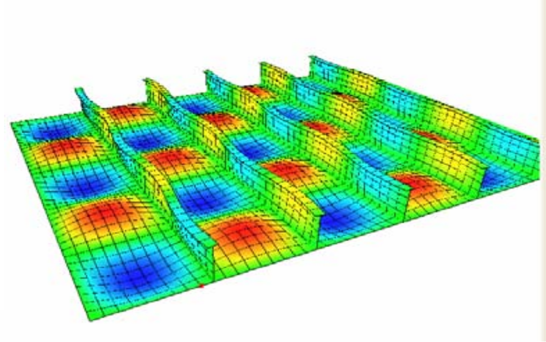
) Weak/thin plate - strong stiffener sideways: thin
late/wide stiffenerflange



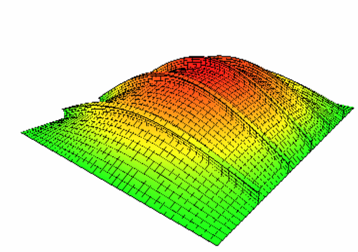
b) Weak stiffener sideways/torsional:
High stiffener/small flange



a) + b) effekt interacting

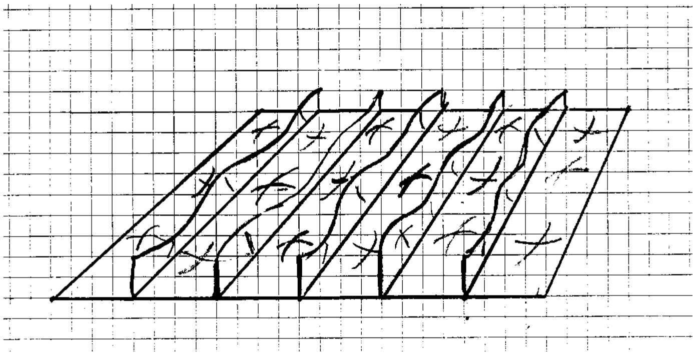


c) Weak stiffener out-of-plane: Low stiffener height/long span/small flange: prevented by PULS design principles



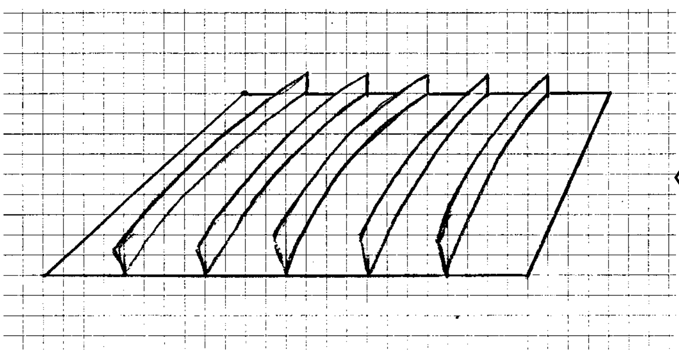
Stiffened panel (S3): Principles

PULS - ULS design principles – S3 element

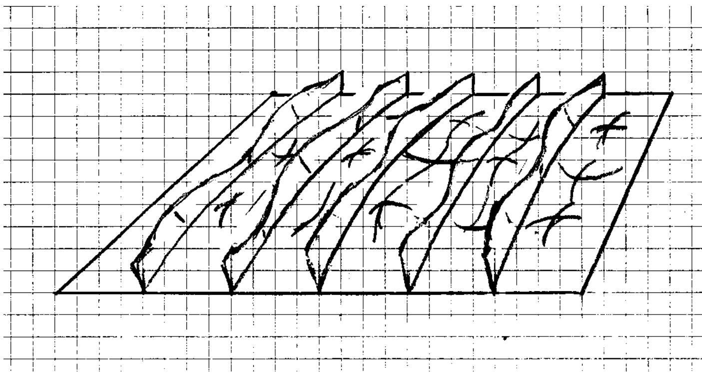


I) Local buckling accepted:
elastic over-critical strength utilised

II) Prevent permanent deformations

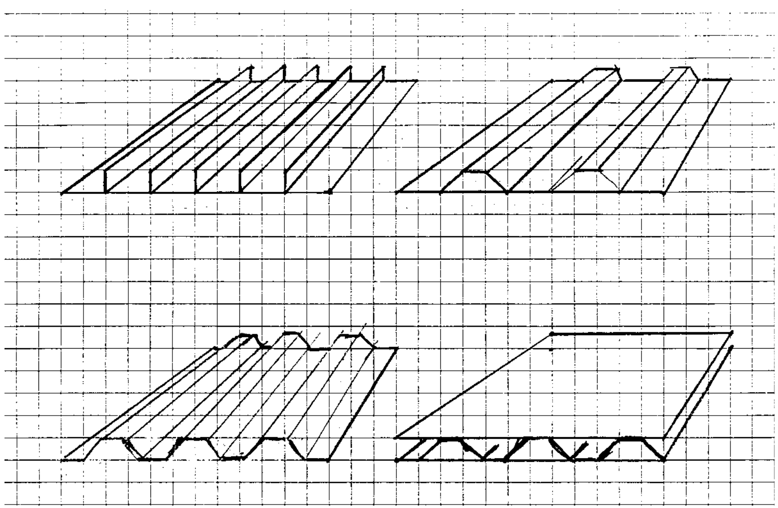


III) Overall buckling not accepted



Stiffened panel (S3): Principles

S3 element
Stiffened Panel model = equivalent orthotropic material



Macro material law

$$
\begin{bmatrix} \Delta\overline{N}_1 \\ \Delta\overline{N}_2 \\ \Delta\overline{N}_3 \\ \Delta\overline{M}_1 \\ \Delta\overline{M}_2 \\ \Delta\overline{M}_3 \end{bmatrix}
=
\begin{bmatrix}
C_{11} & C_{12} & C_{13} & Q_{11} & Q_{12} & Q_{13} \\
C_{21} & C_{22} & C_{23} & Q_{21} & Q_{22} & Q_{23} \\
C_{31} & C_{32} & C_{33} & Q_{31} & Q_{32} & Q_{33} \\
Q_{11} & Q_{21} & Q_{31} & D_{11} & D_{12} & D_{13} \\
Q_{12} & Q_{22} & Q_{32} & D_{21} & D_{22} & D_{23} \\
Q_{13} & Q_{23} & Q_{33} & D_{31} & D_{32} & D_{33}
\end{bmatrix}
\begin{bmatrix} \Delta\varepsilon_1 \\ \Delta\varepsilon_2 \\ \Delta\varepsilon_3 \\ \Delta\kappa_1 \\ \Delta\kappa_2 \\ \Delta\kappa_3 \end{bmatrix}
$$

$$Q_{11}{}^{L} = -E\,\frac{S_s N}{L_2}$$

Coupling bending/membrane

$$D_{11}{}^{L} = \frac{E\,t^3}{12(1-\nu^2)}\left[1 + 12(1-\nu^2)\,\frac{I_s N}{L_2 t^3}\right]$$

bending

$$C_{11}{}^{L} = \frac{E\,t}{1-\nu^2}\left[1 + (1-\nu^2)\,\frac{A_s N}{L_2\,t}\right]$$

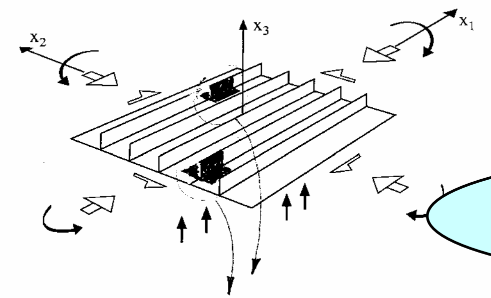
membrane

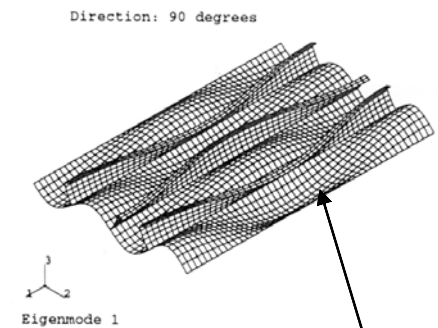
Stiffened panel (S3): Principles

S3 element: Orthotropic Macro Material –

Reduction of stiffness coefficients due to local plate/stiffener buckling

Orthotropic plate theory





Local buckling/stiffness reduction
Non-linear effect

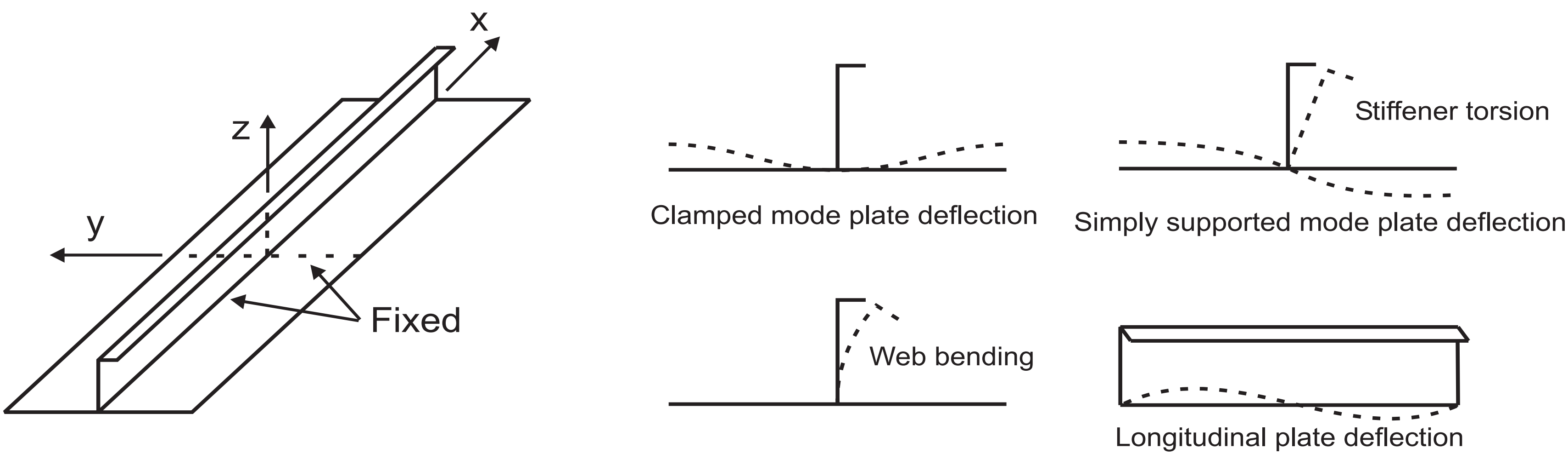
$$
\begin{bmatrix} \Delta N_1 \\ \Delta N_2 \\ \Delta N_3 \\ \Delta M_1 \\ \Delta M_2 \\ \Delta M_3 \end{bmatrix}
=
\begin{bmatrix}
C_{11} & C_{12} & C_{13} & Q_{11} & Q_{12} & Q_{13} \\
C_{21} & C_{22} & C_{23} & Q_{21} & Q_{22} & Q_{23} \\
C_{31} & C_{32} & C_{33} & Q_{31} & Q_{32} & Q_{33} \\
Q_{11} & Q_{21} & Q_{31} & D_{11} & D_{12} & D_{13} \\
Q_{12} & Q_{22} & Q_{32} & D_{21} & D_{22} & D_{23} \\
Q_{13} & Q_{23} & Q_{33} & D_{31} & D_{32} & D_{33}
\end{bmatrix}
\begin{bmatrix} \Delta\varepsilon_1 \\ \Delta\varepsilon_2 \\ \Delta\varepsilon_3 \\ \Delta\kappa_1 \\ \Delta\kappa_2 \\ \Delta\kappa_3 \end{bmatrix}
+ \text{higher order terms}
$$

$$C_{\alpha\beta} \equiv C_{\alpha\beta}{}^{L} + C_{\alpha\beta}{}^{N}$$

$$D_{\alpha\beta} \equiv D_{\alpha\beta}{}^{L} + D_{\alpha\beta}{}^{N}$$

$$Q_{\alpha\beta} \equiv Q_{\alpha\beta}{}^{L} + Q_{\alpha\beta}{}^{N}$$

Stiffened panel (S3): Local buckling modes

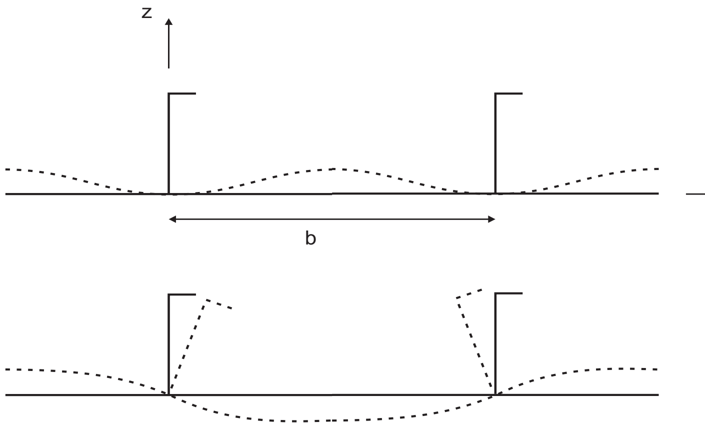


- Local buckling: Assume no vertical deflection of stiffener
- Ship design: Stocky stiffeners, local buckling accepted but global deflectio
is unwanted

Stiffened panel (S3): Local buckling modes

- Plate deflection:

$$w_1(x,y)=\sum_{m=1}^{Ms}\sum_{n=1}^{Ns}A_{mn}^{s}\,\mathbf{sin}\left(\frac{m\pi x}{a}\right)\mathbf{sin}\left(\frac{n\pi y}{b}\right)+\sum_{m=1}^{Mc}\sum_{n=1}^{Nc}\frac{A_{mn}^{c}}{2}\,\mathbf{sin}\left(\frac{m\pi x}{a}\right)\left(1-\mathbf{cos}\left(\frac{2n\pi y}{b}\right)\right)$$



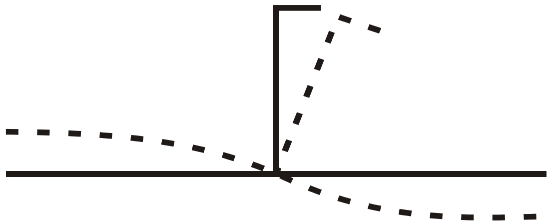
- Stiffener deflection:

$$v(x)=\frac{z}{h}\sum_{m=1}^{Ms}V_{1m}\,\mathbf{sin}\left(\frac{m\pi x}{a}\right)+\left(1-\mathbf{cos}\left(\frac{\pi z}{2h}\right)\right)\sum_{m=1}^{Ms}V_{2m}\,\mathbf{sin}\left(\frac{m\pi x}{a}\right)$$

Stiffened panel (S3): Local model assumptions

- Rotational continuity

$$\left.\frac{\partial v}{\partial z}\right|_{z=0} = -\left.\frac{\partial w}{\partial y}\right|_{y=0}$$

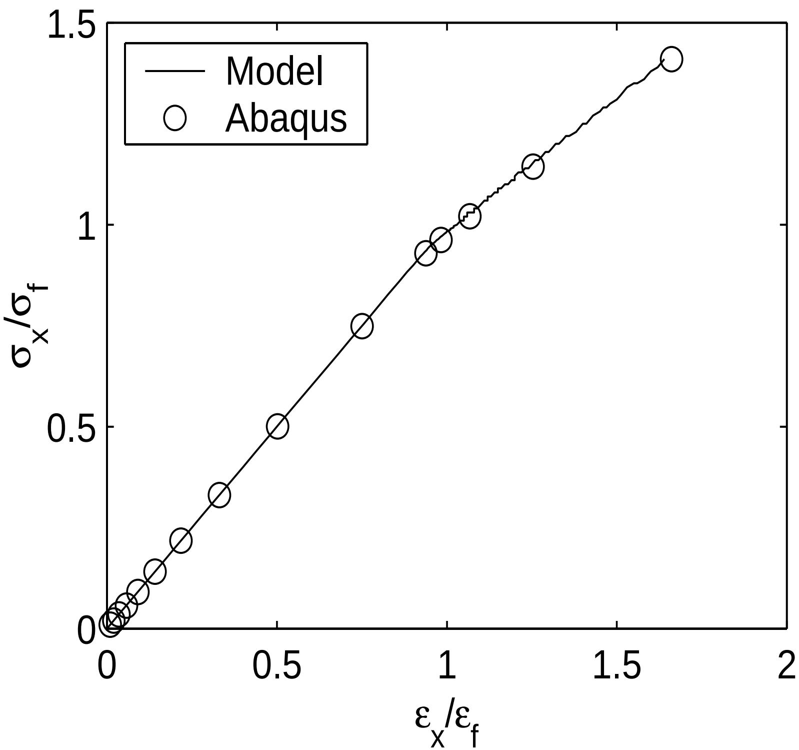


- Longitudinal continuity

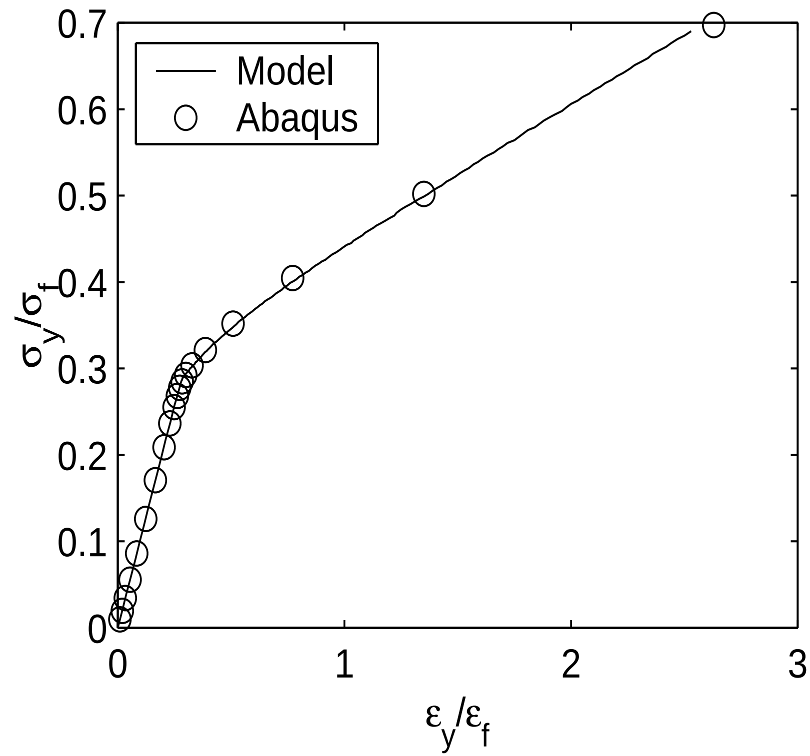
$$\int_a u^p_{,x}\,dx = \int_a u^s_{,x}\,dx$$

Stiffened panel (S3): Local model - validation

Angle bar stiffener, from bulk carrier bottom:



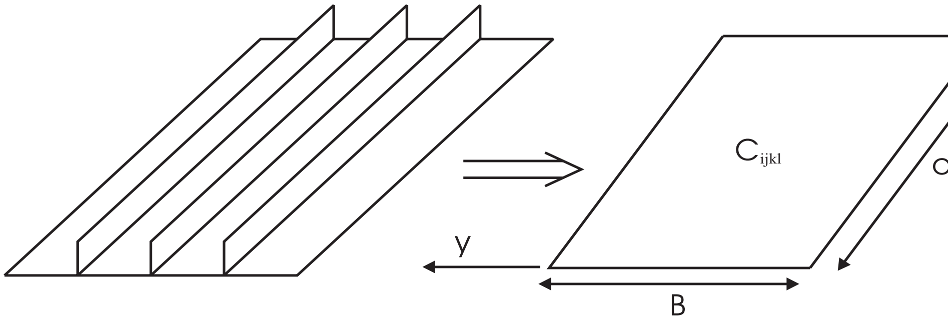
Axial load



Transverse load

Stiffened panel (S3): Global buckling model

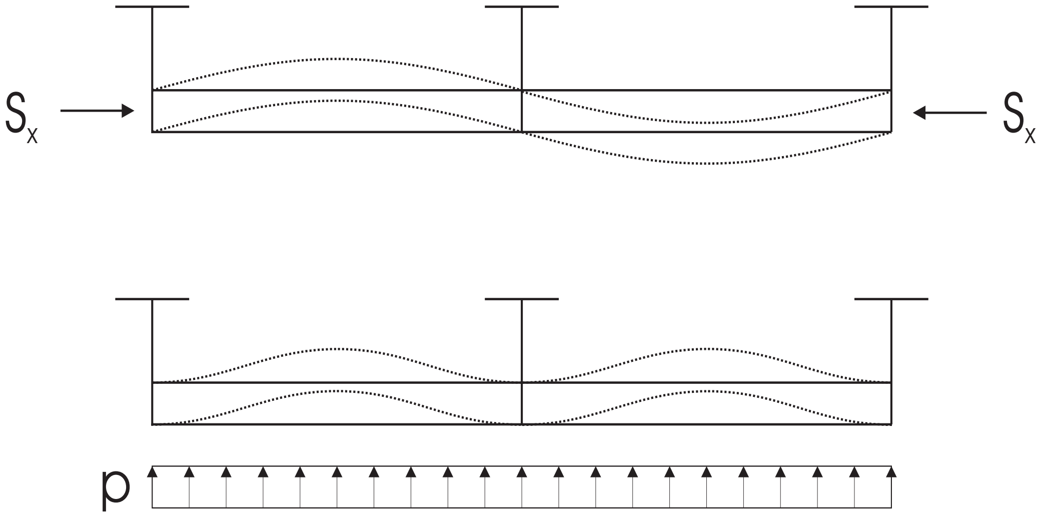
- Anisotropic plate model
- Structural anisotropic stiffness derived from local analysis
- One-way interaction from local to global



Stiffened panel (S3): Global deflection modes

- Deflection shape: $$w_g(x,y)=\sum_{m=1}^{Ms}\sum_{n=1}^{Ns}A_{mn}^{s}\sin(\frac{m\pi x}{a})\sin(\frac{n\pi y}{b})+\sum_{m=1}^{Mc}\sum_{n=1}^{Nc}\frac{A_{mn}^{c}}{2}(1-\cos(\frac{2m\pi x}{a}))\sin(\frac{n\pi y}{B})$$

- Clamped mode accounts for lateral pressure



Stiffness reduction due to local buckling

- Global incremental force-displacement relation:

$$\Delta N_i = C_{ij} \Delta \varepsilon_j$$

- Stiffness coefficients:

$$C_{ij} = \frac{\partial N_i}{\partial \varepsilon_j} = C_{ij}^{L} + C_{ij}^{NL}$$

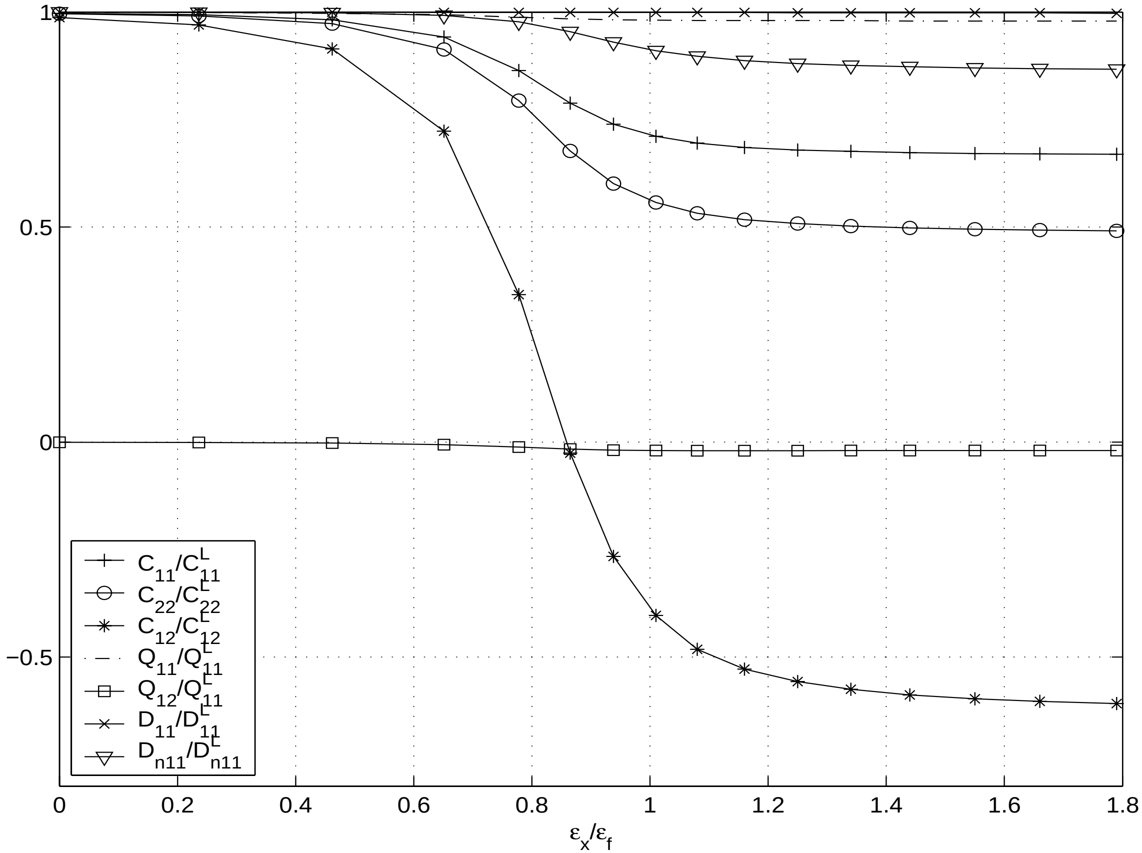
- Nonlinear parts derived from local analysis:

$$C_{ij}^{NL} = \frac{\partial N_i^{NL}}{\partial \varepsilon_j} = \frac{\partial N_i^{NL}}{\partial A_{mn}} \frac{\partial A_{mn}}{\partial \varepsilon_j}$$

SOFTWARE

Stiffness reduction due to local buckling

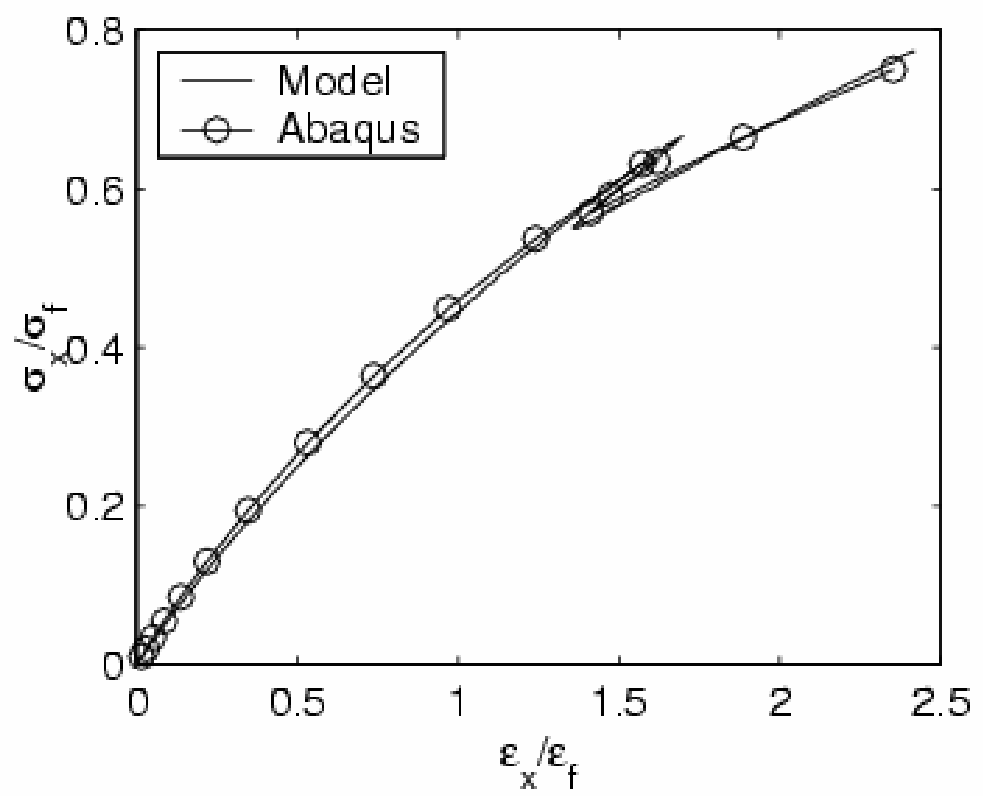
Angle bar stiffener, from bulk carrier bottom:



SOFTWARE

Stiffened panel (S3): Global buckling - validation

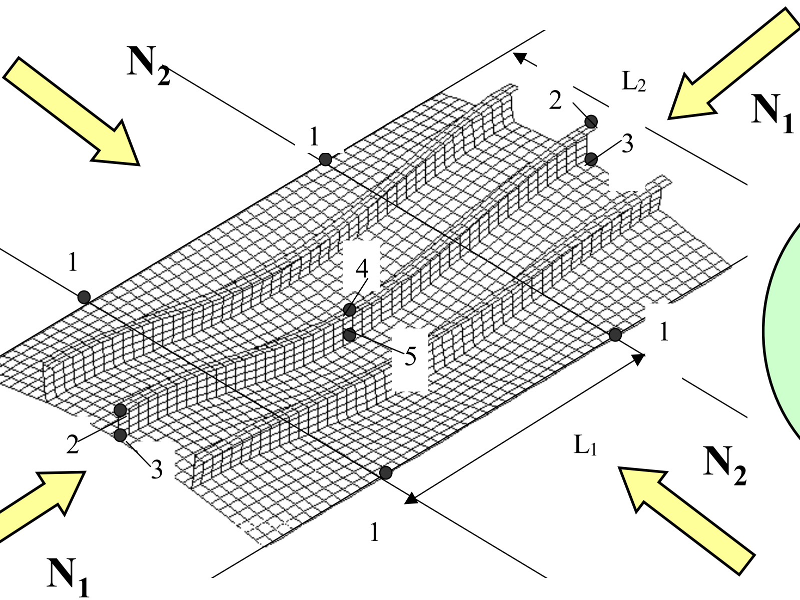
Aluminium panel, from passenger vessel
Combination of lateral pressure and transverse compression:



Stiffened panel (S3): Limit States

PULS - S3 Ultimate limit states

Usage factor assessment - safety margin

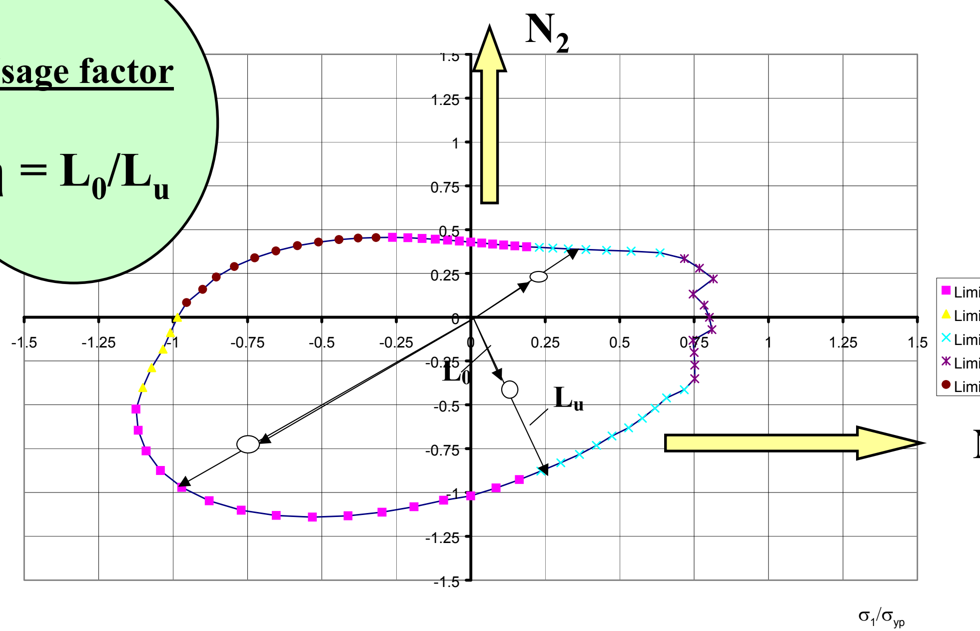


5 limit states in hard corner sections

$$f^{(i)}(N_1, N_2, N_3) > 0 \quad i = 1, 2, 3, 4, 5$$

Usage factor

$$\eta = L_0/L_u$$



Stiffened panel (S3): Limit States

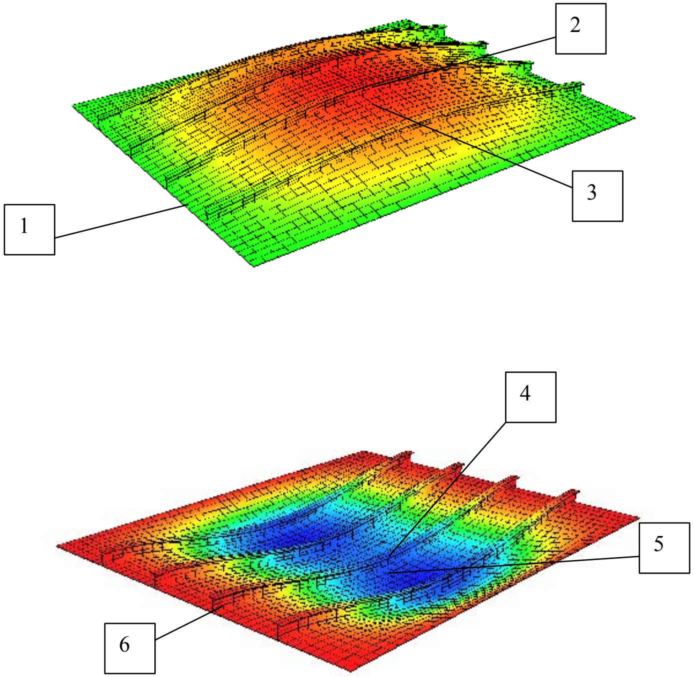


Fig. 9 Stress control points in critical positions in a panel defining the ultimate limit states

The six limit states f_i's are stress controls in the following positions:

i = 1; **Plate criterion**: Stress control along plate edges – based on max edge stresses along supported edges (typical: transverse load when local buckling dominates)

i = 2; **Stiffener tension criterion**: Stress control in stiffener; at midspan $x_1 = L_1/2$; in stiffener flange for global panel deflecting towards stiffener flange, tension criterion - rare for compressive loads, but kicks in for tension loads (will also kick in for transverse compressive loads for panel with small stiffeners, i.e. large global effects)

i = 3; **Plate compression criterion**: Stress control in plate; at midspan $x_1 = L_1/2$; in plating for global panel deflecting towards stiffener flange, compression criterion (PI collapse)

i = 4; **Stiffener compression criterion**: Stiffener criterion Stress control in stiffener; at midspan $x_1 = -L_1/2$: in stiffener flange for global panel deflecting towards plating, compression criterion (SI collapse) (typical for pure axial load)

i = 5; **Plate tension criterion**: Stress control in plate; at midspan $x_1 = -L_1/2$; in platin for global panel deflecting towards plating, tension criterion – rare for compressive lo but kicks inn for tension loads

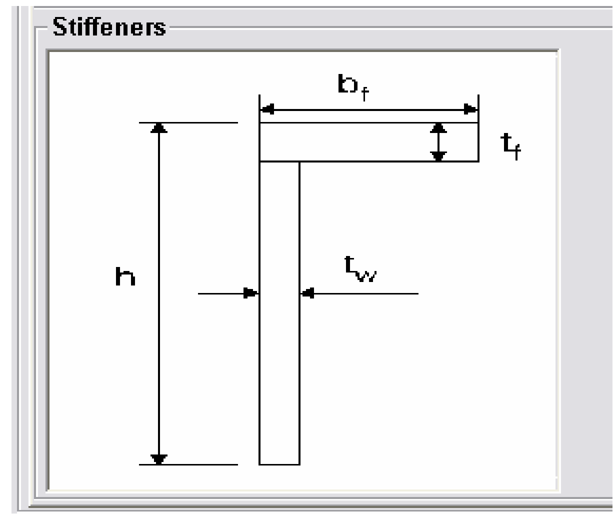
(Note that the limit state criteria i = 2-5 is not always evaluated at midspan. Maximum curvature in x_1 – direction, and thereby the highest bending stress, could be closer to ends for certain geometrical proportions of stiffened panels. Typical are cases with sm stiffeners for which the panel behaves more as a plate than a "column", with a globa buckling mode pattern flattening in the mid-regions.)

i = 6; **Stiffener bending stress criterion at support**: Stress and capacity control at suppor = 0; compressive or tension criterion, kicks in for cases with lateral pressure. This lim state is used to control the bending and shear capacity of the stiffeners under the influence of combined lateral load and in-plane loads. Yielding in the stiffener flange the transverse frames is accepted, since stiffeners have significant strength reserves a first yield when subjected to lateral pressure. The panel is loaded until the plastic cap of the stiffeners is reached. Two criteria are used for this limit state. The first is the capacity of the top and bottom flanges to carry the combined axial force and bending moment resulting from the applied loads, and the second is the capacity of the web to carry the shear force and axial force due to the applied loads.

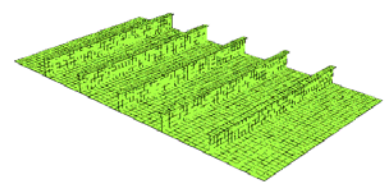
Stiffened plate (S3): Validity range

Validity range for stiffened panel:

- Ultimate Capacity; integrated elements; deck, ship side, ship bottom, bulkheads etc.



Web slenderness for flat bar stiffeners:	35
Web slenderness for L or T profiles:	$h_w / t_w < 80$
ree flange for L or T profiles:	$f_f / t_f < 10$
late between stiffeners:	$s / t < 200$
spect ration of plate between stiffeners	$0.25 < L_l/s < 10$ *



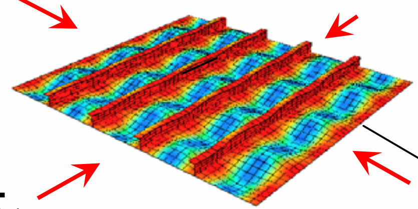
Example: Stiffened plate, axial compression (S3)

PULS 2D Capacity Curves

Slice in 3-dimensional limit state surface egg

Example: Biaxial loads on stiffened panels

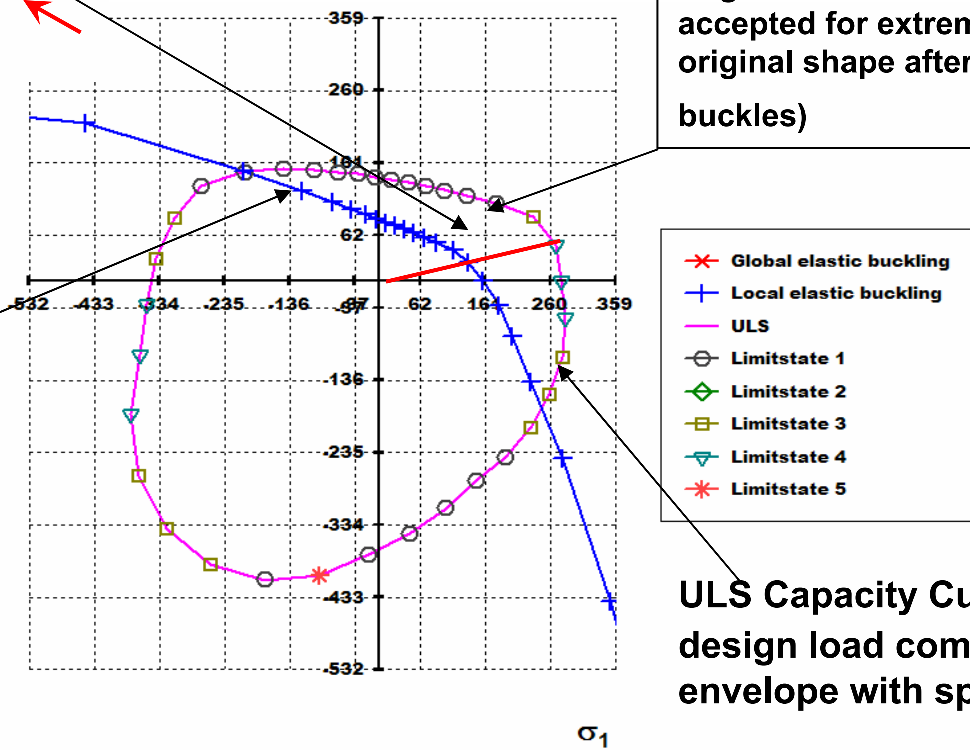
σ_2



σ_1

Stress redistribution from plate to stiffeners: Plate is hanging on strong stiffeners!!!

Elastic buckling cut off or thin plates Eigenvalue curve-LEB)



σ_1

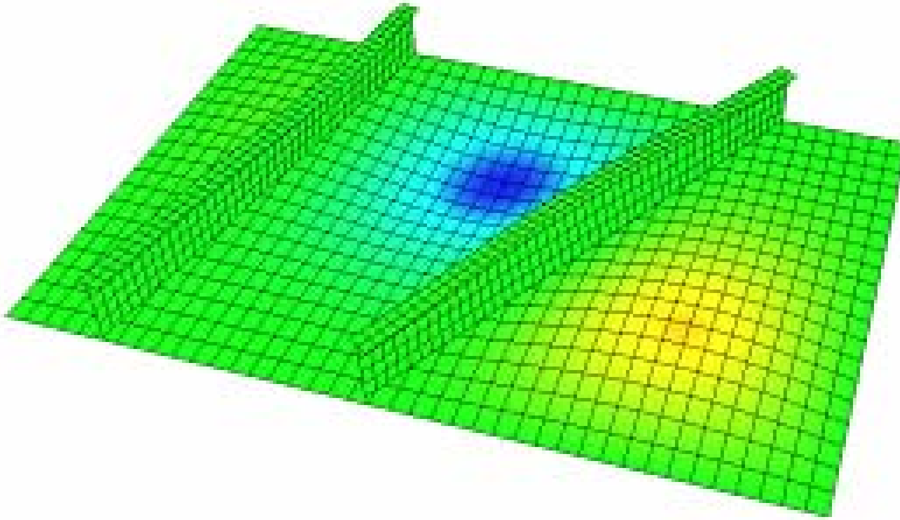
Region of Elastic buckling. Elastic buckli accepted for extreme loads…plate return original shape after unloading (no perma buckles)

ULS Capacity Curve, bi-axial loads, design load combination to be insi envelope with specified rule margin

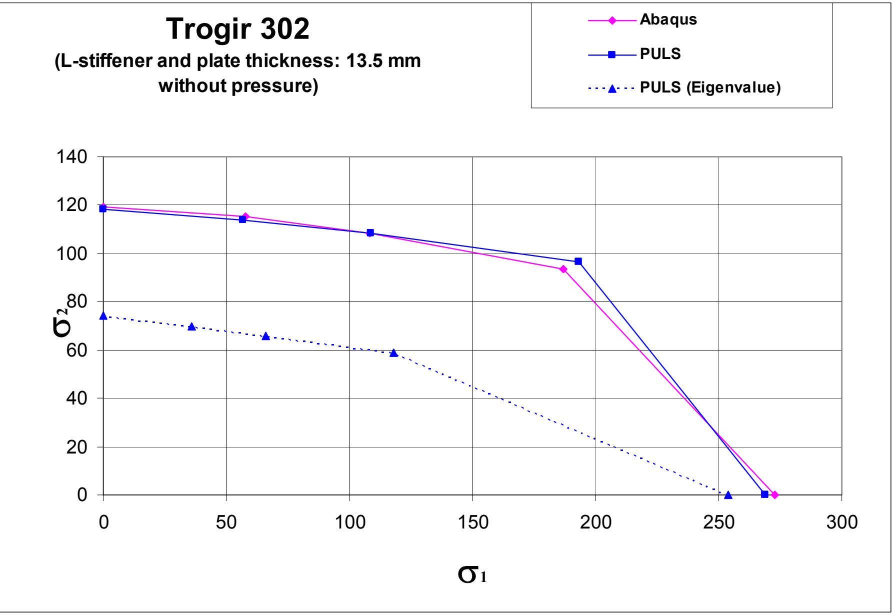
Stiffened plate, non-regular geometry (T1)

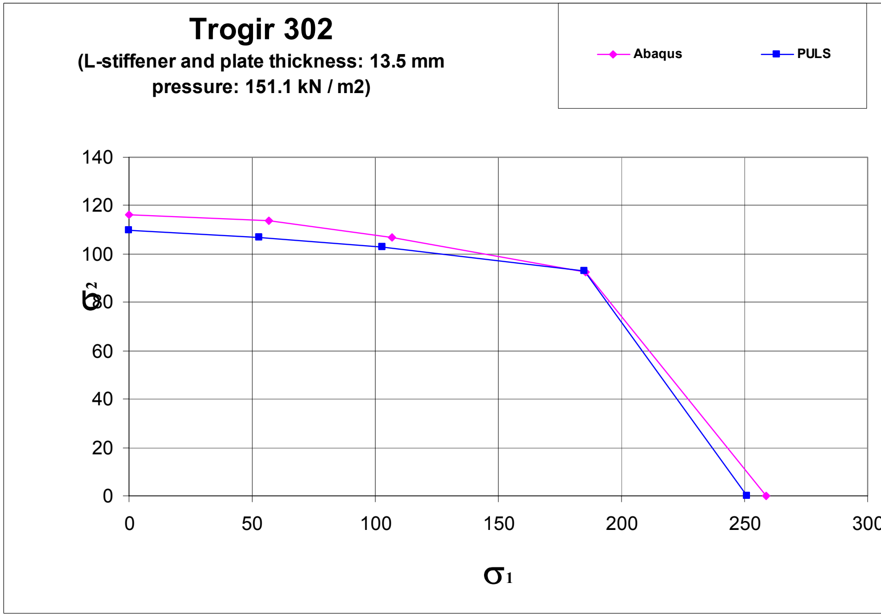
Complex geometry, simplified theory:

- Analysis of stiffened panels with arbitrary oriented stiffeners
- Based on linear theory
- Ultimate limit state estimates based on hot spot stress control, but limited by linear elastic eigenvalue



PULS validation against non-linear FE/ABAQUS

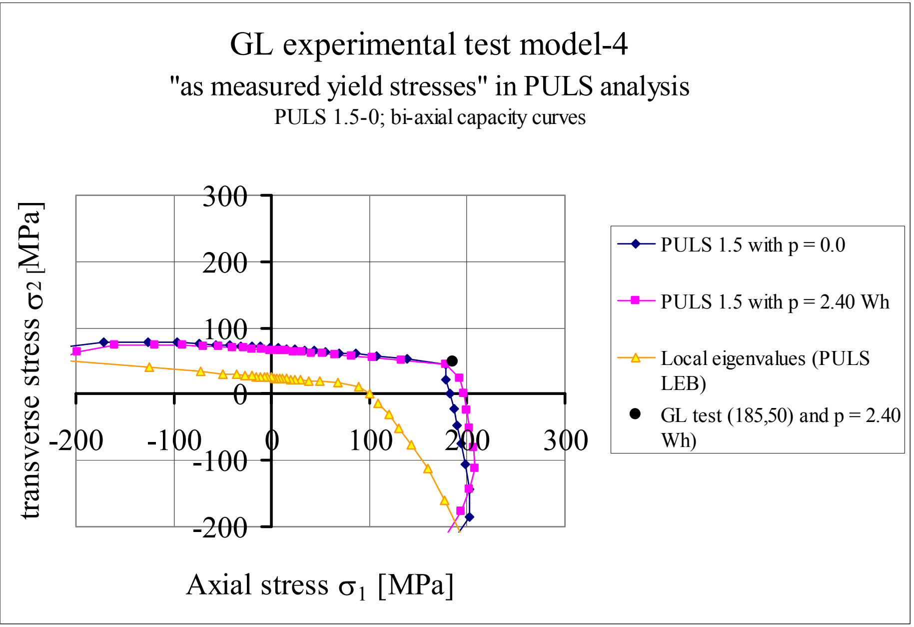


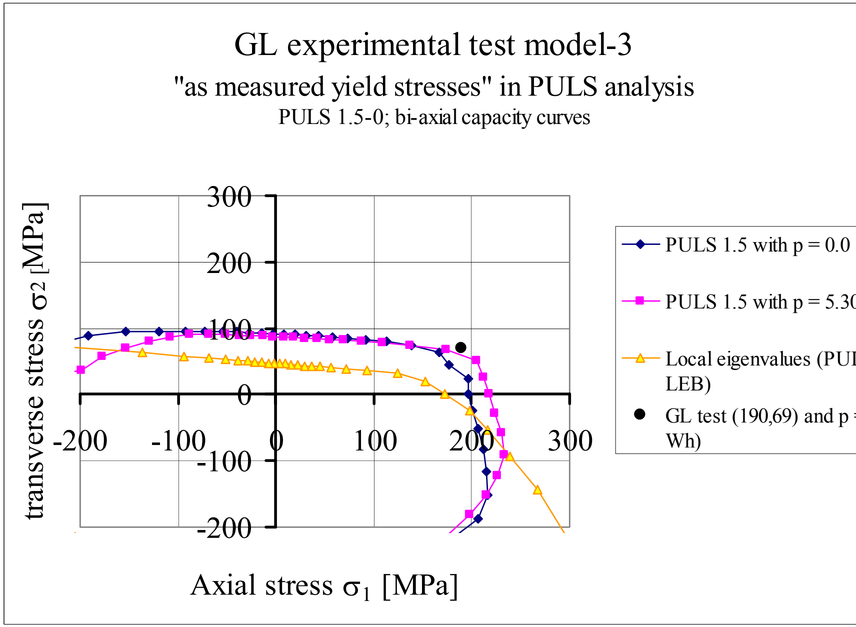


Bottom panel Tanker Lpp =170 m

PULS validation

PULS validation against GL lab test (Egge/95)





SOFTWARE

PULS validation

PULS validation

- Extensive comparisons against non-linear FE/ABAQUS
- Limited comparisons against lab tests (Ex: GL/Egge 95)
- Comparisons against against existing rules

Conclusions

Very satisfactory quantiative comparisons ABAQUS and lab tests; mostly within ± 10%

Same qualitative physical behaviour as seen in ABAQUS and lab tests

PULS: Sound physical models for robust designs

PULS
For easy use

Designers, Non-experts etc.

2 different PULS Stand alone programs

PULS General User Interface (GUI) Version, features:

Visual Basic user interface. Very simple and intuitive to use

ingle parameter output for any load combination: Usage factor measured against accept level rules

ull 3D graphics for illustration of buckling modes, redistributed stress pattern etc.

D **capacity curve** illustration of ULS and elastic buckling limits for combined loads - slices 3-dimensional limit state surface egg

nimation of non-linear buckling process

Same input file

Profile table;
Bulbs, Angles etc

2. PULS Excel spreadsheet version, features:

- Material Optimization studies, parameter variasjons

PULS General User Interface Application

U3 element: Integrated
unstiffened plate

nput:

Geometry

Material

) Loads

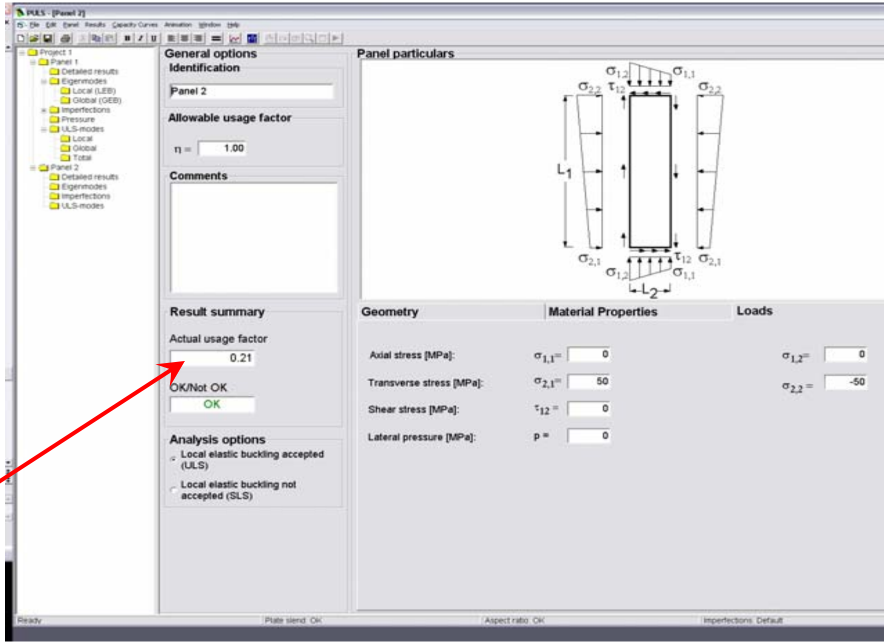
utput:

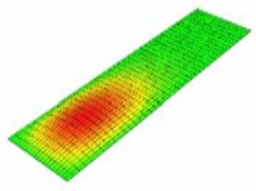
Elastic buckling stresses (LEB; eigenmode)

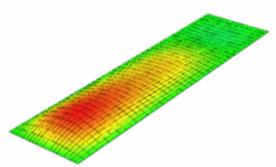
ULS strengh (max capacity)

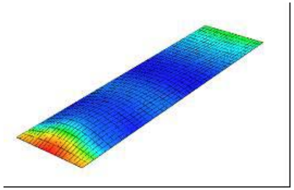
ULS membrane stresses

Single parameter strength evaluation :
ge factor









PULS General User Interface Application

S3 element: Integrated
stiffened plate

nput:

Geometry

Material

) Loads

Profile table button

or from

Menu: define stiffener

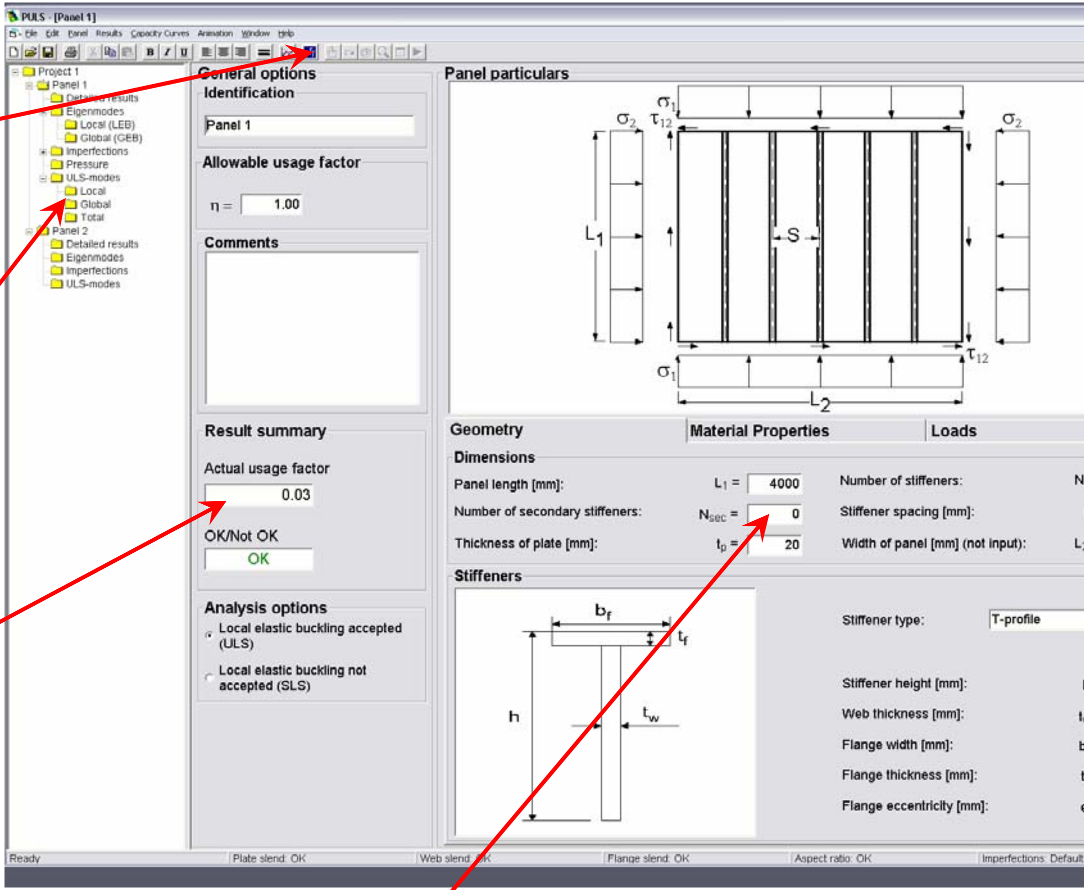
Output:

) Elastic buckling stresses (LEB and GEB;
igenmodes)

) ULS strengh (max capacity)

i) Local ULS membrane stresses

v) Single parameter strength evaluation :
sage factor



Menu: Panel/Secondary stiffeners

SOFTWARE

PULS Excel Application

nput:

Geometry

Material

) Loads

Profile table button

or from

Menu: define stiffener

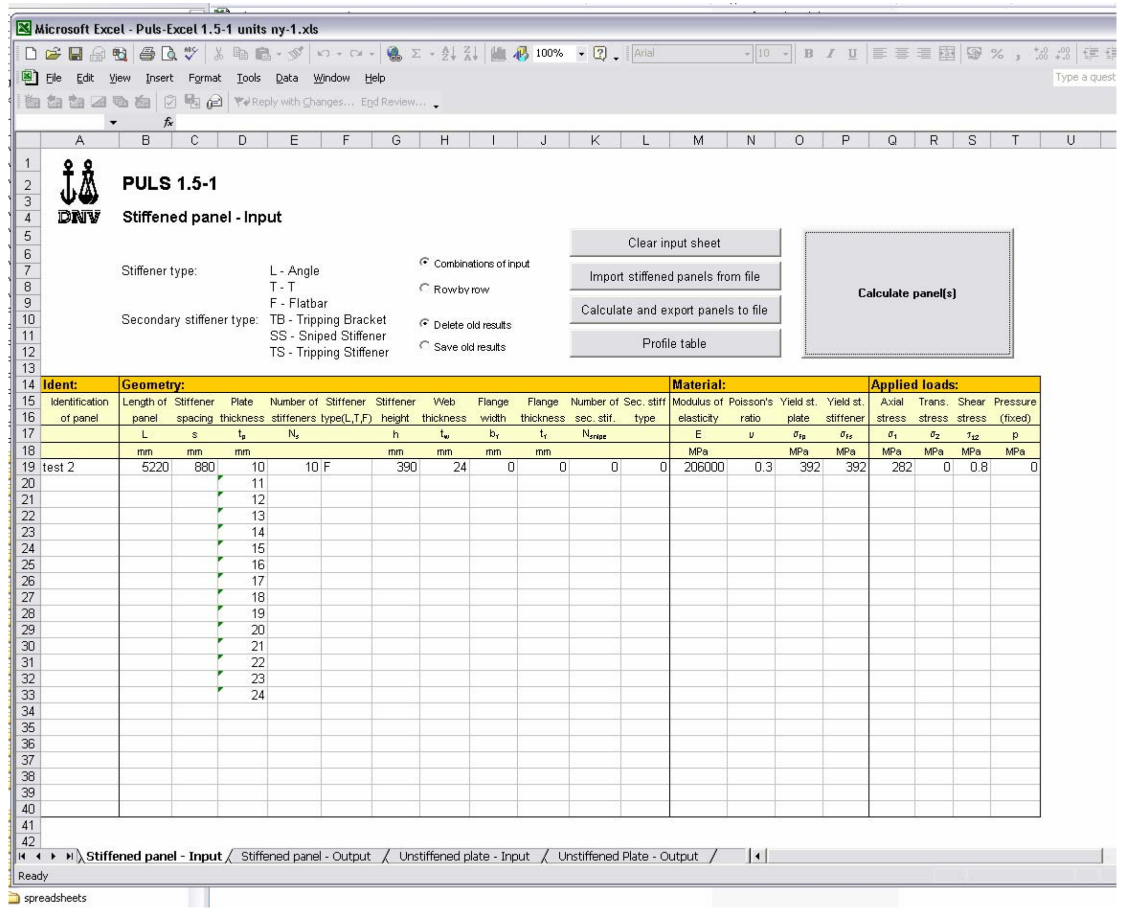
Dutput:

) Elastic buckling stresses (LEB and GEB; igenmodes)

) ULS strengh (max capacity)

i) Local ULS membrane stresses

v) Single parameter strength evaluation : sage factor



Menu: Panel/Secondary stiffeners

PULS Excel Application

Parameter study using PULS

PULS 1.5-1

Stiffened panel - Results

Show all results

Hide non-essential results

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	T	U	V	W	AD	AE	AF
UT:																				PULS:		
t.	Geometry:											Material:				Applied loads				ULS:		
cation	Length of panel	Stiffener spacing	Plate thick.	Number of stiffen	Stiffener type	Stiff. Height	Web thick.	Flange width	Flange thick.	Number of sn. stiffene	Secondary stiffener	Modulus of elasticity	Poisson's ratio	Yield stress plate	Yield stress stiffener	Axial stress	Trans. stress	Shear stress	Pressure (fixed)	Axial stress	Trans. Stress	Shear stress
d	L	s	t	N_s		h	t_w	b_f	t_f	N_{snipe}		E	ν	σ_{Fp}	σ_{Fs}	σ_1	σ_2	τ_{12}	p	σ_1	σ_2	τ_{12}
1	5150	900	24	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	236	79	94
2	5150	900	22	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	231	77	92
3	5150	900	20	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	230	77	92
4	5150	900	18	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	223	74	89
5	5150	900	16	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	215	72	86
6	5150	900	14	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	197	66	79
7	5150	900	12	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	169	56	67
8	5150	900	10	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	142	47	57
9	5150	900	8	6	T	300	14	150	16	0	0	210000	0.3	355	355	150	50	60	0	119	40	48

ging thickness, all other parameters fixed

Change in usage factor due to thickness chang

PULS 2.0 versus 1.5

Improvements:

• Automatic smoothening routine of Capacity Curves/Surfaces for bi-axial compression (reduce "bumps"

• Modified lateral pressure model, minor changes

• Increased slenderness range of stiffener web and flange (h/t_w < 90 (80), f_f/t_f < 15 (10))

New technical features:

• S2 stiffened plate element renamed S3 with new features

• S3: Linearly varying stress perpendicular to primary stiffeners

• S3: Boundary conditions: Option for free to pull in edges (non-linear effect - minor interest for normal ship scantlings

• U1 unstiffened plate renamed U3 with new features

• U3: Boundary conditions; Option for clamped or rotational restrained edges

• New element T1: Non-regular stiffening arrangement, triangular plates etc.

PULS 2.0

New software features, Explorer user interface:

• S3: Visualization of secondary stiffeners (run perpendicular to main stiffeners)

• S3, U3: Extra tab strip for boundary conditions

• S3, U3: Improved pressure plot of plate and stiffener deflections

•S3: Weakest link: identfies max. deflections in plates and stiffeners – useful design info

•S3, U3 : New Excel Report generator, summarize input and output results

New software features, Excel user interface:

• S3: Optimisation of stiffener/plate geometry, fixed weight/cross-sectional area

• S3: Weakest link: identfies max. deflections in plates and stiffeners – useful design info

PULS 2.0 download and installation

- Go to the internet page: http://www2.dnv.com/software/Products/Nauticus/puls/puls.htm
- Click on ”Download PULS”
- Write in name etc., and click ”Download PULS”
- Choose ”Save”, pick a directory for the download, and click ”Close” when download is complete
- Go to your PULS directory, and unpack the .zip-file
- Start the installation by double-clicking the setup.exe-file
- Execute PULS from the Start-meny