Dlubal

Structural Analysis & Design Software

www.dlubal.com

Dipl.-Ing. (FH) Andreas Hörold
Organizer

Marketing & Public Relations
Dlubal Software GmbH

Dr.-Ing. Jonas Bien
Co-Organizer

Product Engineering & Customer Support
Dlubal Software GmbH

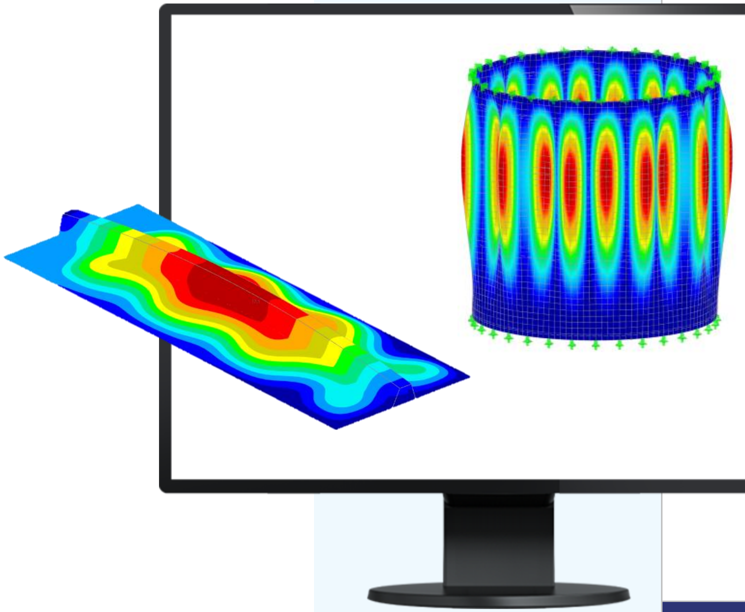
Dipl.-Ing. Oliver Metzkes
Co-Organizer

Product Engineering & Customer Support
Dlubal Software GmbH

Dlubal

Webinar

Buckling Analysis in RFEM 6



Questions During the Presentation

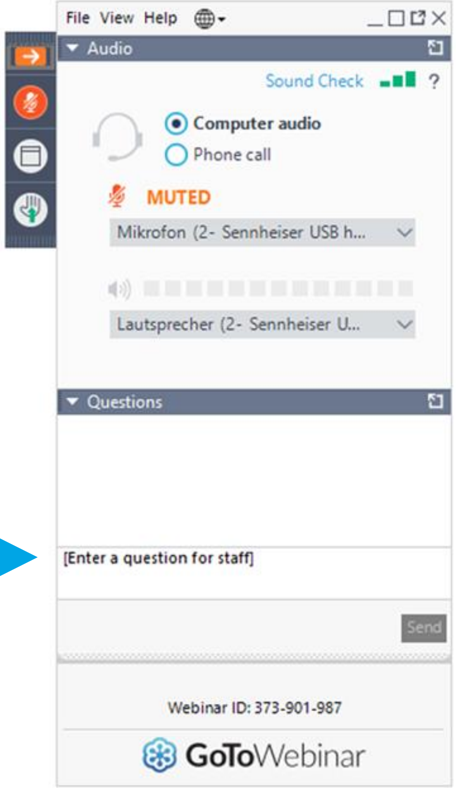
GoToWebinar Control Panel
Desktop

E-mail: **info@dlubal.com**

Show or hide control panel

Adjust audio settings

Ask questions

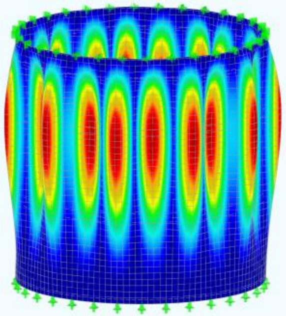


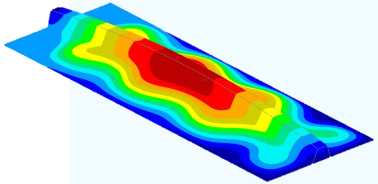
Webinar

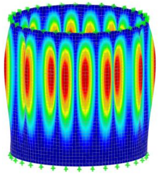
CONTENT

01 Analysis for shell buckling using global MNA and LBA calculations according to EN 1993-1-6

02 Analysis for plate buckling using GMNIA method according to EN 1993-1-5







Buckling Analyses of Steel Shell Structures acc. to EN1993-1-6

Stress-based buckling analysis

- Simple application for expert engineers
- Low requirements for computer technology (often hand calculation formulas used)
- Economic results difficult to achieve for load situations significantly differing from conventional buckling shapes

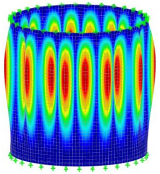
Design by global numerical MNA/LBA analysis

- More background knowledge for shell stability required
- Higher requirements for computer technology (materially nonlinear analysis (MNA), linear elastic bifurcation analysis (LBA))
- Computer technology using FE analysis consequently applied

Design by global numerical GMNIA analysis

- Excellent background knowledge for shell stability required (e.g. correct application of imperfections (pre-forming) is complex)
- Considerable requirements for computer technology

Example: Shell Buckling Design by Global Numerical MNA/LBA Analysis acc. to [3]



Technical data

Liquid: γ = 10 kN/m³

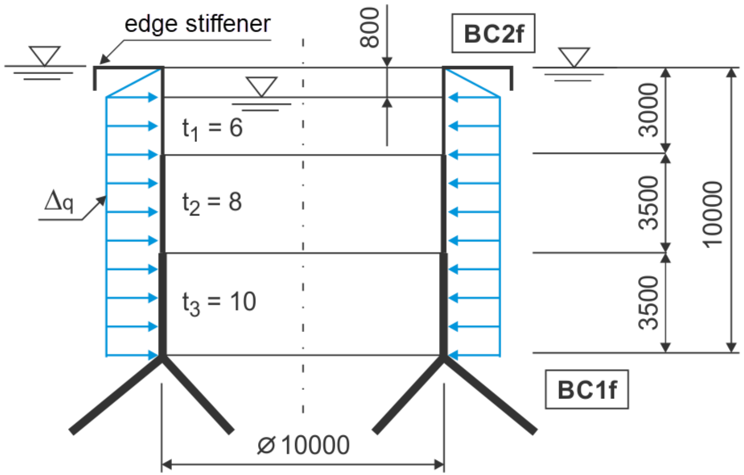
Material: S 235

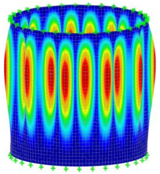
Manufacturer quality: class A

Load (1.0 x differential pressure)

Δq_d = 8.0 kN/m²

System





Analysis

Elastic critical buckling resistance ratio

r_{Rcr} = 1.504 (FE eigenvalue analysis (LBA) in RFEM)

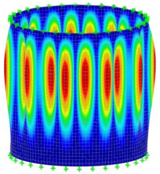
Plastic reference resistance ratio ([2], Eq. 8.24)

$$r_{Rpl} = t \cdot f_{yk} \,/\, \sqrt{n^2_{x,Ed} - n_{x,Ed} n_{\theta,Ed} + n^2_{\theta,Ed} + 3n^2_{x\theta,Ed}}$$

The lowest value of plastic resistance ratio so calculated should be taken as the estimate of the plastic reference resistance ratio r_{Rpl}.

NOTE: A safe estimate of r_{Rpl} can usually be obtained by applying expression (8.24) in turn at the three points in the shell where each of the three buckling-relevant membrane stress resultants attains its highest value, and using the lowest of these three estimates as the relevant value for r_{Rpl}. [2]

Dlubal



Analysis

$r_{Rpl} = 35.6$ (materially non-linear analysis (MNA in RFEM)

Overall relative slenderness ([2], Eq. 8.25)

$$\bar{\lambda}_{ov} = \sqrt{r_{Rpl}/r_{Rcr}}$$

$$\bar{\lambda}_{ov} = \sqrt{35.6/1.504}$$

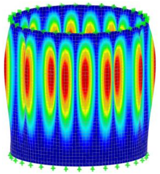
$$\bar{\lambda}_{ov} = 4.87$$

Circumferential elastic imperfection reduction factor ([2], Tab. D.5)

$$\alpha_{ov} = \alpha_{\theta} = 0.75$$

Plastic range factor ([2], D.26)

$$\beta = 0.60$$



Analysis

Plastic limit relative slenderness ([2], Eq. 8.16)

$$\bar{\lambda}_p = \sqrt{\alpha/(1-\beta)}$$

$$\bar{\lambda}_p = \sqrt{0.75/0.40)}$$

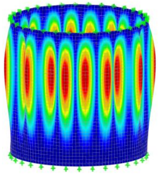
$\bar{\lambda}_p = 1.37 << 4.87$ → pure elastic buckling

Buckling reduction factor ([2], Eq. 8.15)

$$\chi_{ov} = {}^{\alpha}/_{\bar{\lambda}^2}$$

$$\chi_{ov} = {}^{0.75}/_{4.87^2}$$

$$\chi_{ov} = 0.0316$$



Analysis

Characteristic buckling resistance ratio ([2], Eq. 8.26)

$$r_{Rk} = \chi_{ov} \cdot r_{Rpl}$$

$$r_{Rk} = 0.0316 \cdot 35.6$$

$$r_{Rk} = 1.125$$

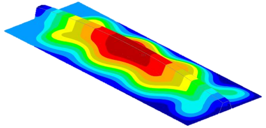
Design buckling resistance ratio ([2], Eq. 8.27)

$$r_{Rd} = {}^{r_{Rk}}/_{\gamma_{M1}}$$

$$r_{Rd} = {}^{1.125}/_{1.1}$$

$r_{Rd} = 1.02 > 1$ → design fulfilled

→ Another example available in Knowledge Base



Example: (Buckling) Verification of a stiffened Plate using GMNIA

Plate

Material: S 355

Thickness: t = 14 mm

Plate loading

$\sigma_1 = \sigma_2 = 21{,}0\ kN/cm^2$

$\tau = 1{,}0\ kN/cm^2$

Trapezoidal Stiffener

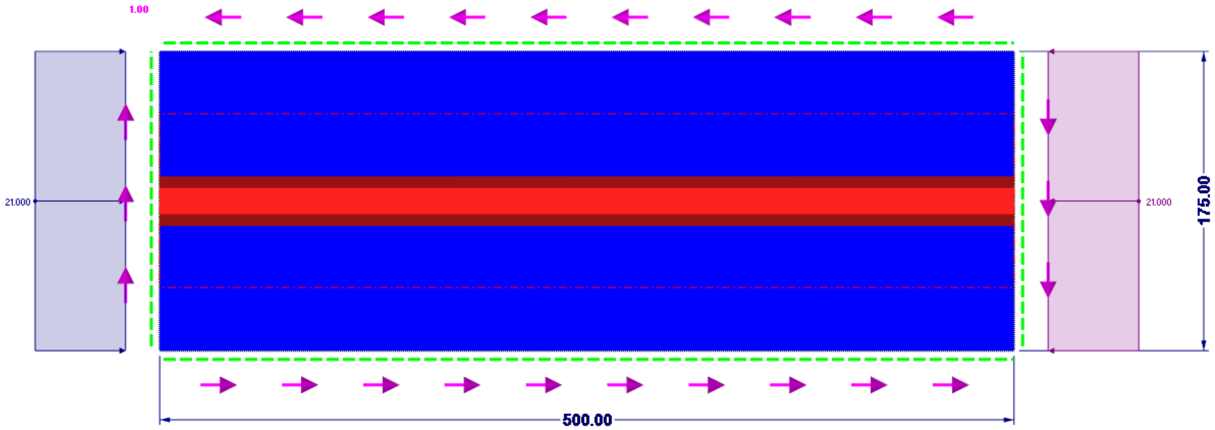
Material: S 355

h = 200 mm

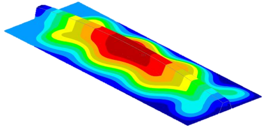
$b_u / b_o = 300\ mm\ /\ 150\ mm$

t = 6 mm

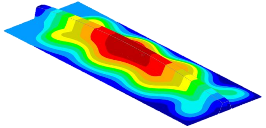
System



What are the characteristics of a GMNIA?



Analysis type	Deformations	Material	Geometry
Linear elastic analysis (**LA**)	linear	linear elastic	perfect
Linear bifurcation (eigenvalue) analysis (**LBA**)	eigenshape	linear elastic	perfect
Materially non-linear analysis (**MNA**)	linear	elastic-plastic	perfect
Geometrically non-linear analysis (**GNA**)	nonlinear	linear elastic	perfect
Geometrically and materially non-linear analysis (**GMNA**)	nonlinear	nonlinear	perfect
Geometrically non-linear elastic analysis with imperfections (**GNIA**)	nonlinear	linear elastic	imperfect
Geometrically and materially non-linear analysis with imperfections (**GMNIA**)	nonlinear	nonlinear	imperfect

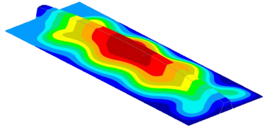


Buckling Analyses of Steel Plates According to EN1993-1-5

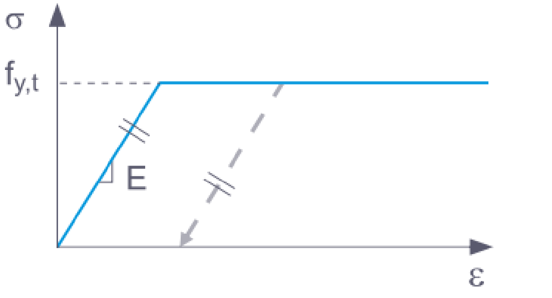
Method of effective cross-sections
([1], Sec. 4-7)

Reduced stress method
([1], Sec. 10)
- **PLATE-BUCKLING**

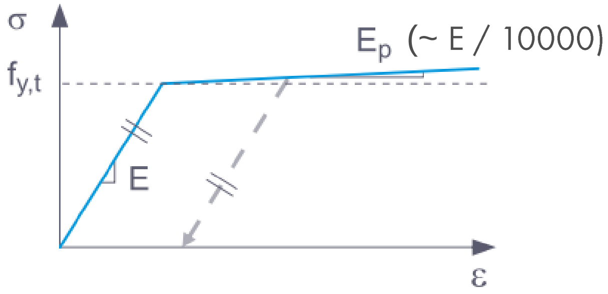
Analyses using Finite Element Method
([1], Annex C)
- **RFEM 6**
  GMNIA on the surface model



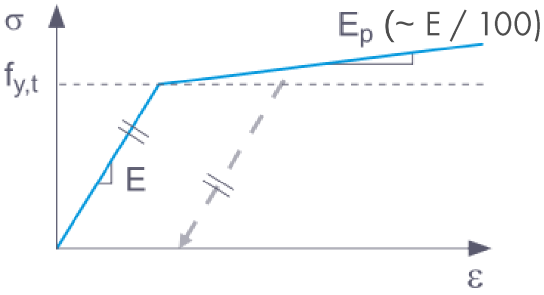
Nonlinear Material Models



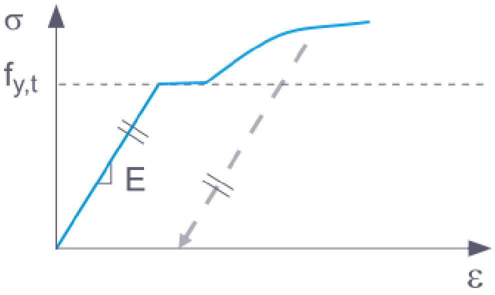
a) linear elastic – perfectly plastic



b) linear elastic – perfectly plastic with pseudo-hardening

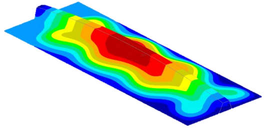


c) linear elastic – linear hardening

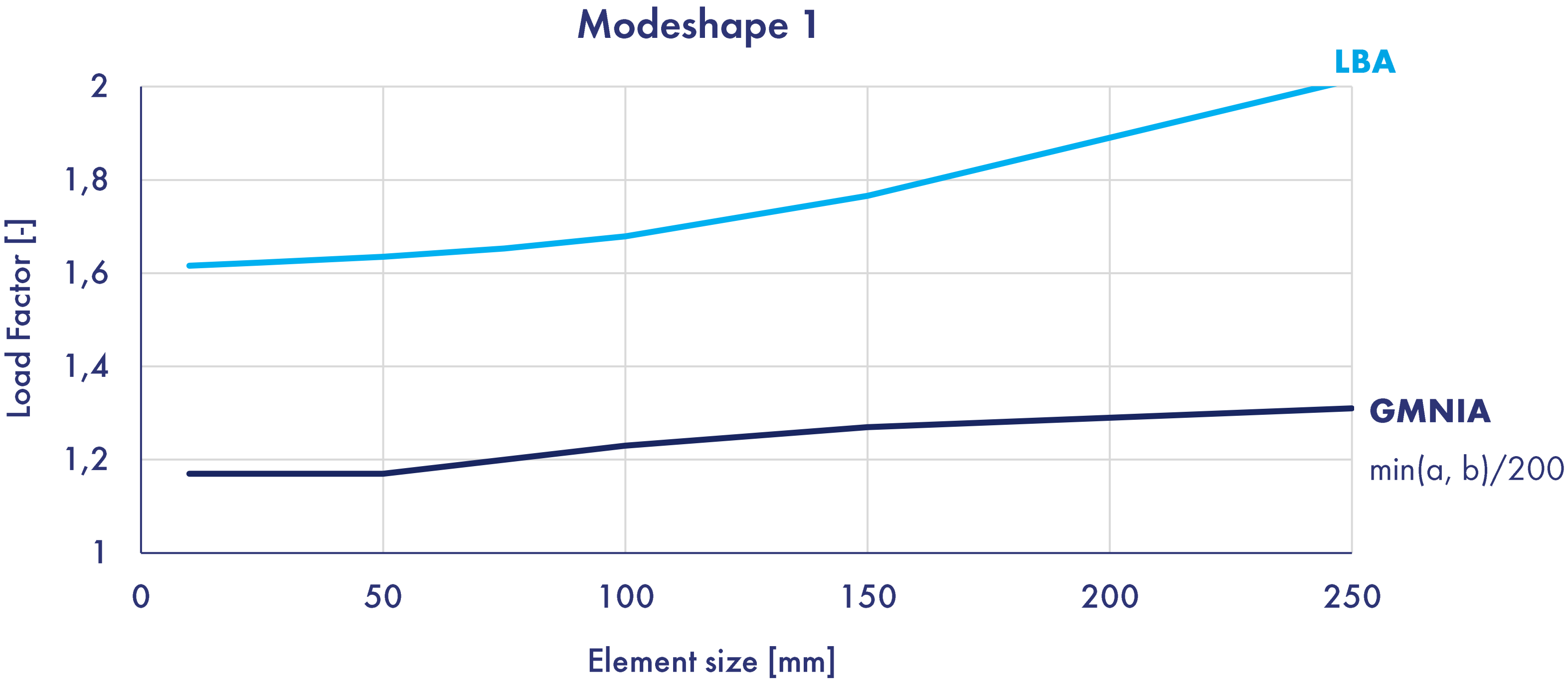


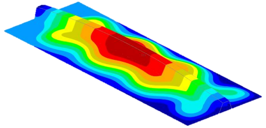
d) true stress-strain curve

EN 1993-1-5:2019, Section C.6

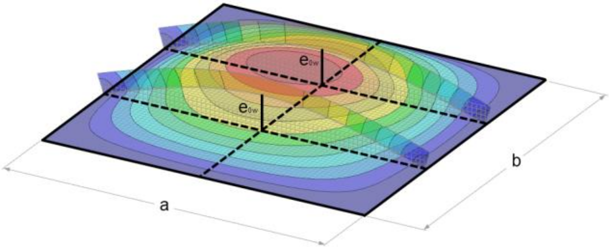
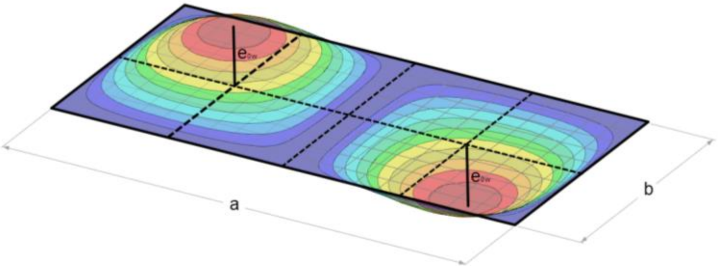


Mesh convergence study



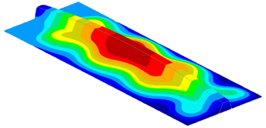


Imperfections

Type of Imperfection	Component	Shape	Magnitude
global, longitudinal stiffener with length a		bow	min(a, b) / 400
local, panel or sub-panel		buckling shape	min(a, b) / 200

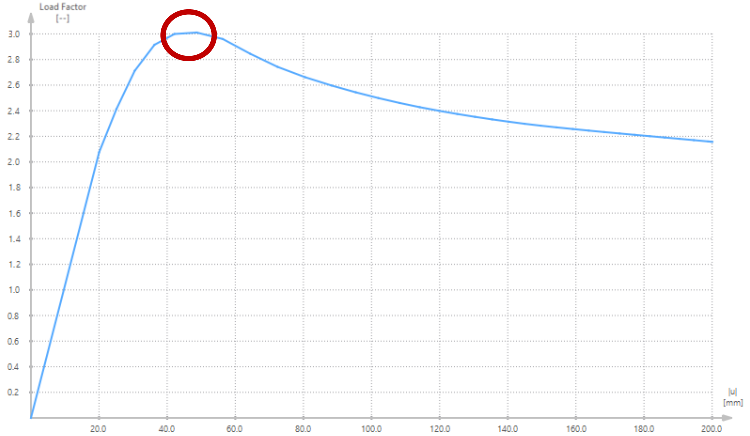
EN 1993-1-5:2019-10, Section C.5

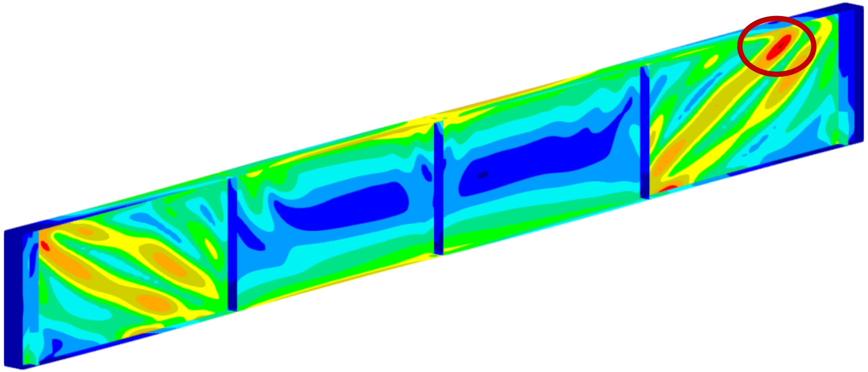
Limit states and verification



Maximum load level of the computed load-deformation path $\propto_{u,1}$

Load level $\propto_{u,2}$ when reaching largest tolerable principal plastic membrane strain (5%)





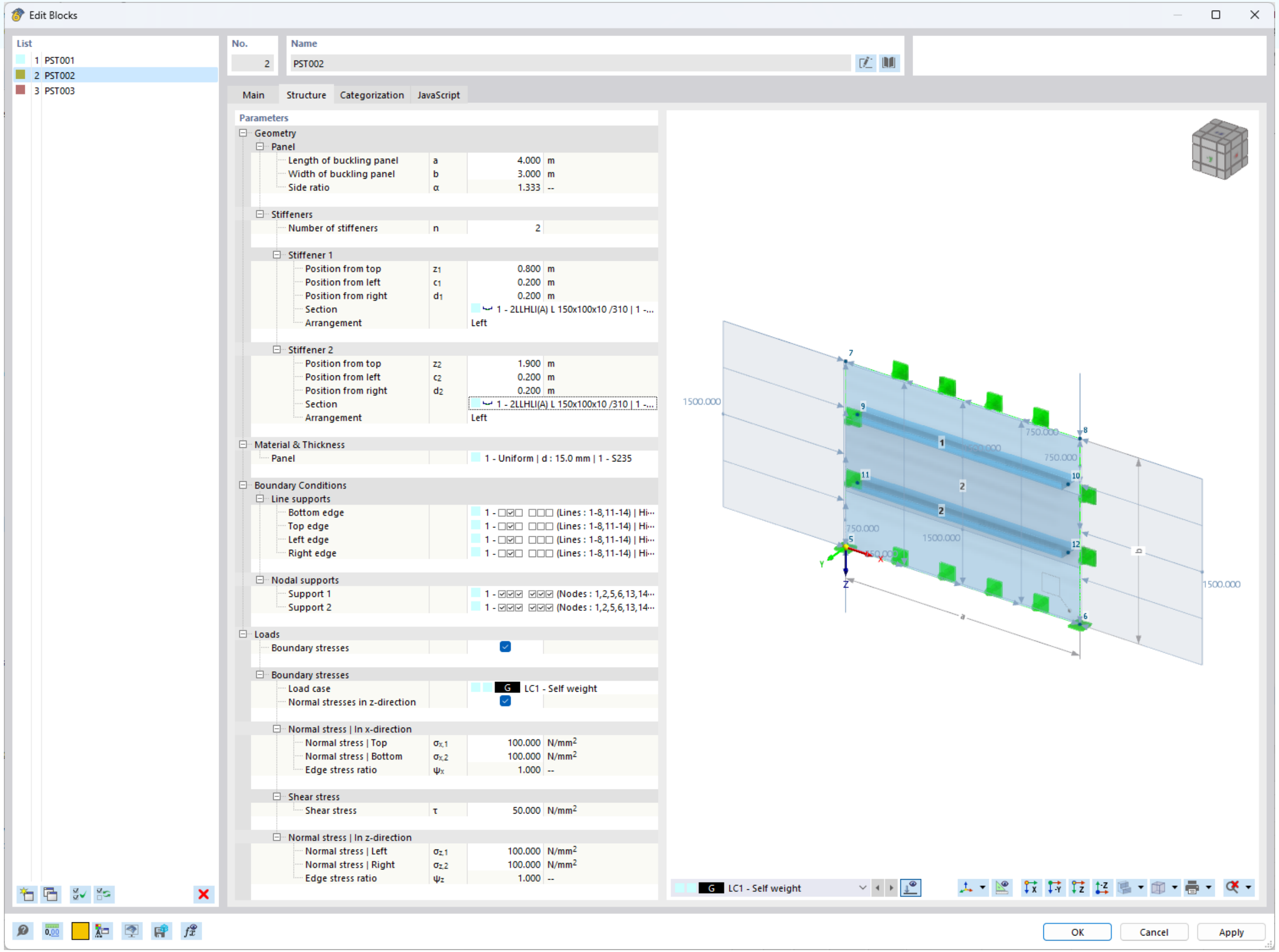
$min(\propto_{u,1}, \propto_{u,2}) = \propto_u > \propto_1 \propto_2$ → Uncertainty of load and resistance models:
Recommendation : γ_{M1} for stability / γ_{M2} for material failure

↓ Uncertainty of numerical model
Recommendation NA: $\propto_1 = 1,05$

EN 1993-1-5:2019-10, Section C.8/9

Webinar

Outlook



Webinar

Bibliography

[1] Eurocode 3: Design of steel structures – Part 1-5: General rules – Plated structural elements; EN 1993-1-5:2006 (E)

[2] Eurocode 3: Design of steel structures – Part 1-6: Strength and stability of shell structures, EN 1993-1-6:2007 (E)

[3] Schmidt H.: Beulsicherheitsnachweise für Schalen nach dem neuen Eurocode EN 1993-1-6 – Ein Überblick mit Beispielen aus der Anwendungspraxis, Referat beim 27. Stahlbau-Seminar in Neu-Ulm und Wien, 2005

[4] ECCS Handbook: Design of steel plated structures with finite elements, 2023

Book your free Online Appointment!

Get valuable insights from one of our experts

Dipl.-Ing. (FH) Dipl.-Wirtschaftsing. (FH) Christian Stautner
Head of Sales

Bastian Ackermann, M.Sc.
Sales

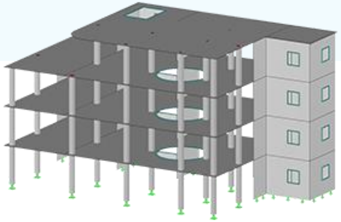
Daniel Dlubal, M.Sc.
COO of Dlubal Software GmbH

Dipl.-Ing. (FH) Michael Hansen
Sales & Marketing

Dlubal

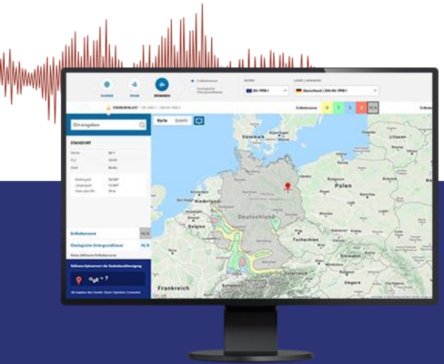
→ Contact Our Sales Team

Free Online Services



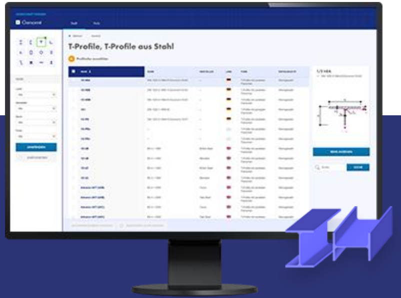
Geo-Zone Tool

Dlubal Software provides an online tool with snow, wind and seismic zone maps.



Cross-Section Properties

With this free online tool, you can select standardized sections from an extensive section library, define parametrized cross-sections and calculate its cross-section properties.



FAQs & Knowledge Base

Access frequently asked questions commonly submitted to our customer support team and view helpful tips and tricks articles to improve your work.

Models to Download

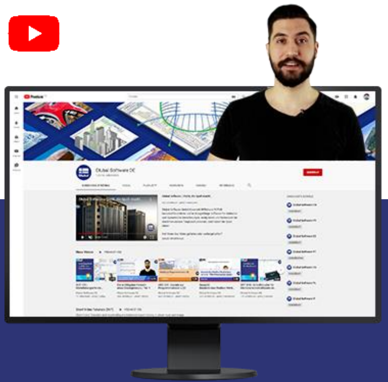
Download numerous example files here that will help you to get started and become familiar with the Dlubal programs.

Free Online Services

We offer free support via email and chat

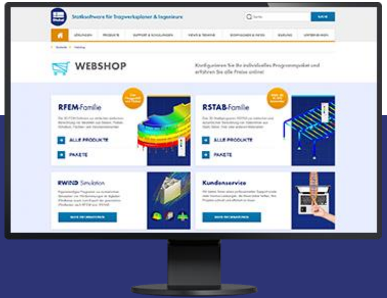
Youtube Channel - Webinars, Videos

Videos and webinars about the structural engineering software.



Webshop with Prices

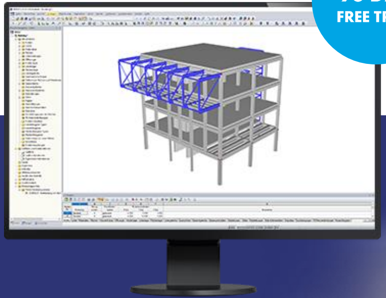
Configure your individual program package and get all prices online!



Trial Licenses

The best way how to learn using our programs is to simply test them for yourself. Download a 90-day free trial version of our structural analysis & design software.

90-DAY FREE TRIAL



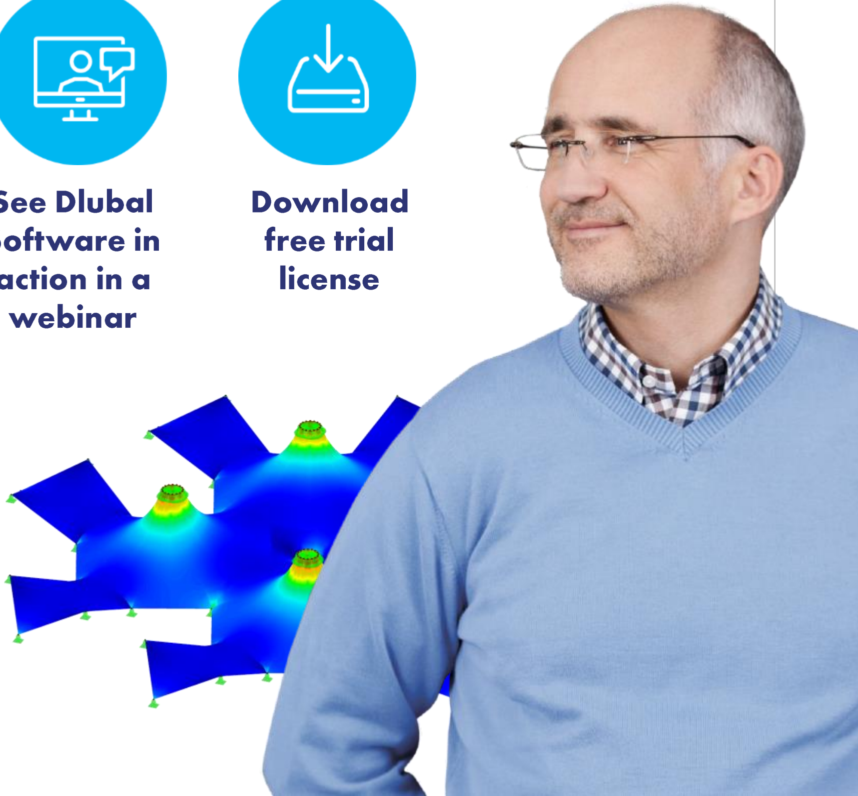
Get Further Details About Dlubal

Visit website
www.dlubal.com

- Videos and recorded webinars
- Newsletters
- Events and conferences
- Knowledge Base articles

See Dlubal Software in action in a webinar

Download free trial license



Dlubal Software GmbH
Am Zellweg 2,
93464 Tiefenbach, Germany

Phone: +49 9673 9203-0
E-mail: info@dlubal.com

Dlubal

www.dlubal.com