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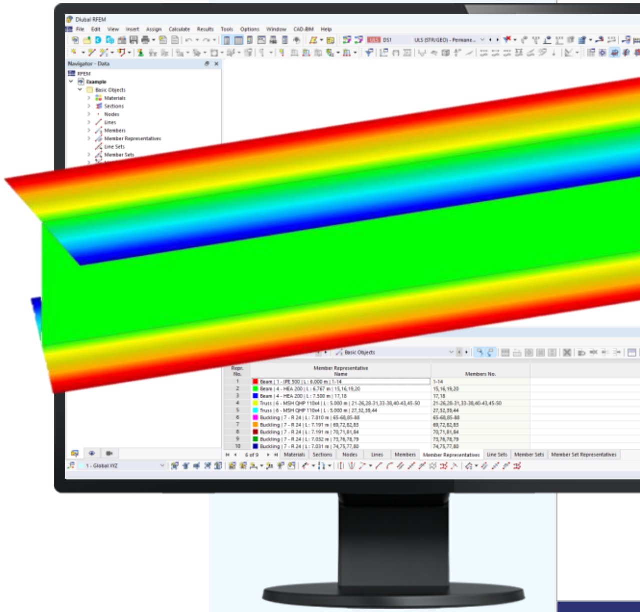
Webinar

Consideration of Torsional Warping in RFEM 6 and RSTAB 9



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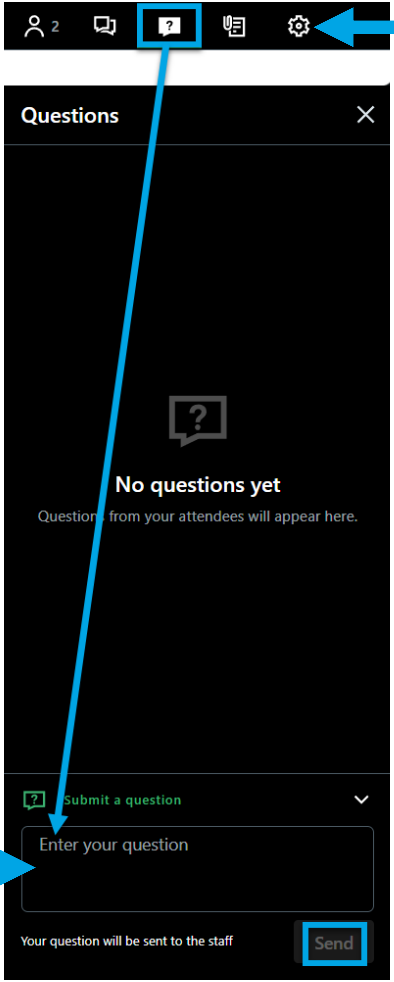

Ask questions

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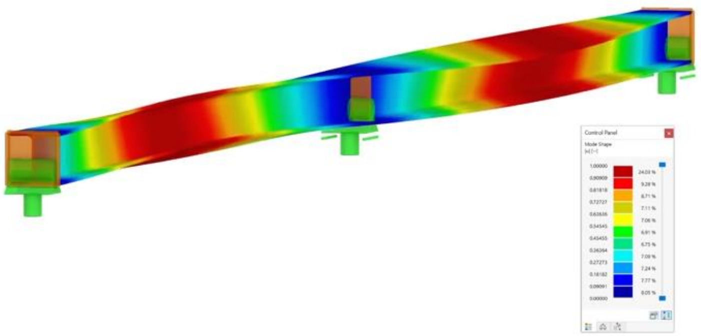
Content

01 Basics of Torsional Warping

02 Things to consider for a 7 DOF calculation in RFEM 6 and RSTAB 9

03 Influence of Torsional Warping on selected structures



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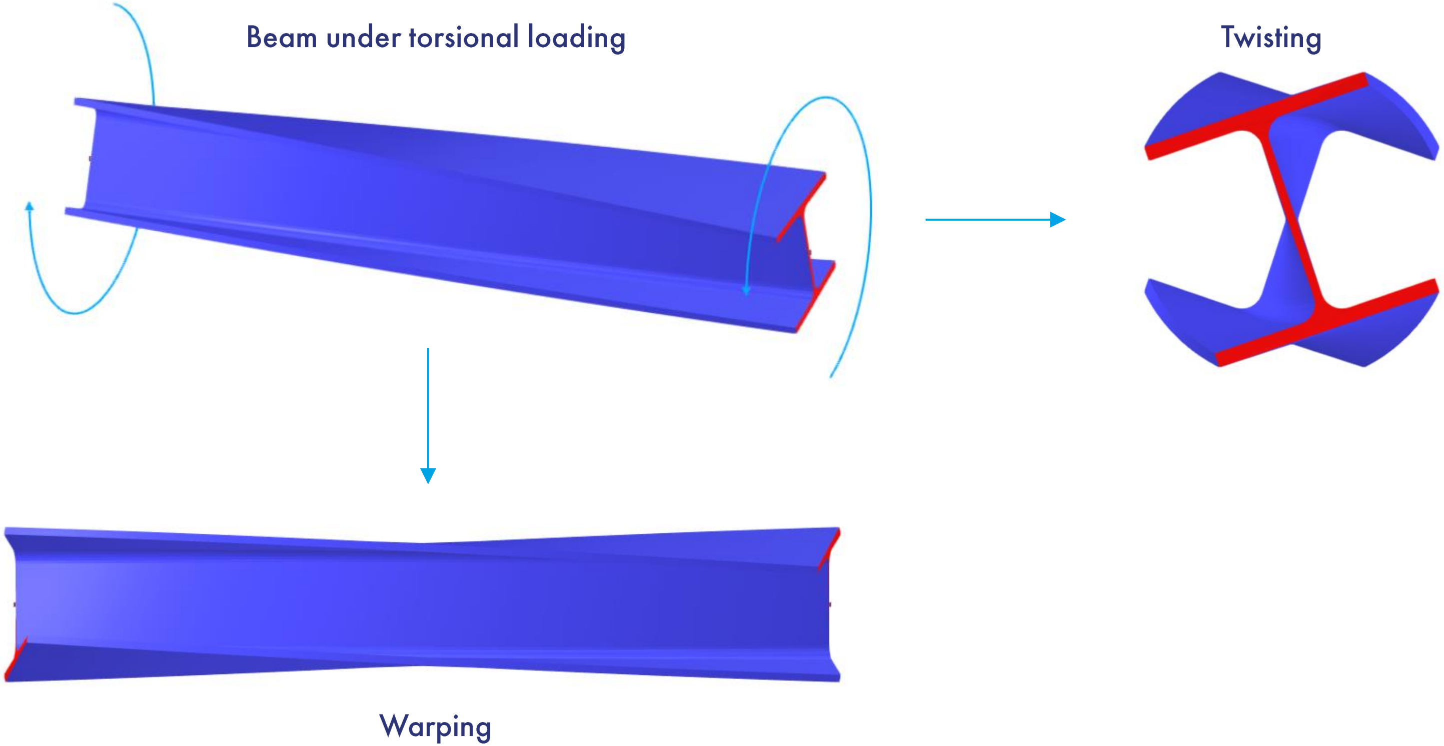
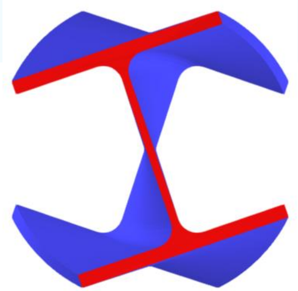
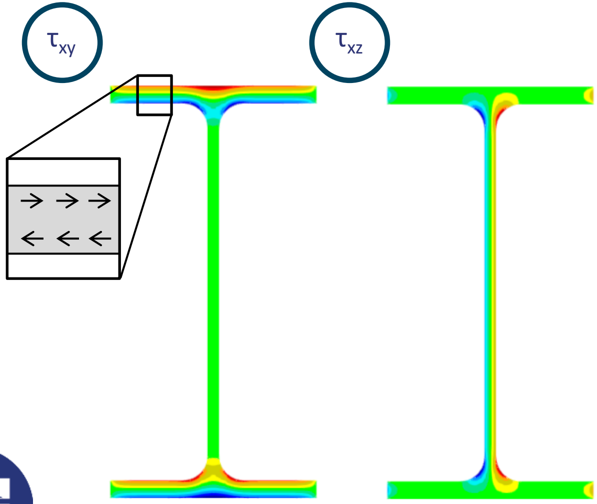
General Case: Mixed Torsion



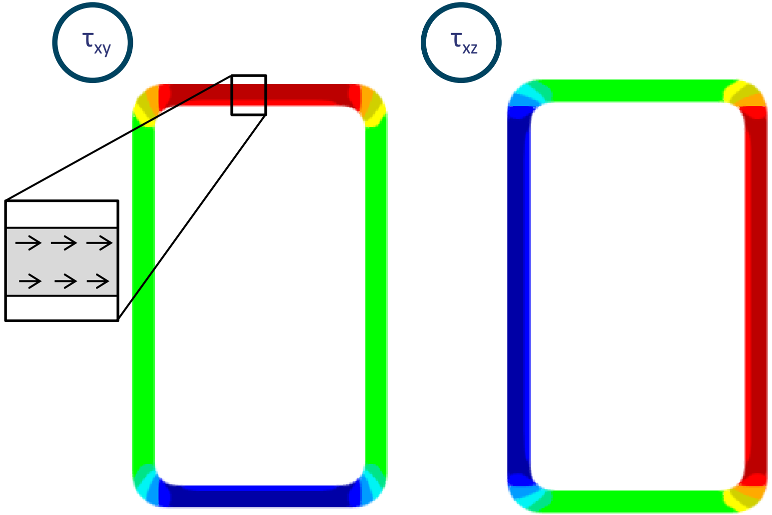


St. Venant Torsion (6 DOF)

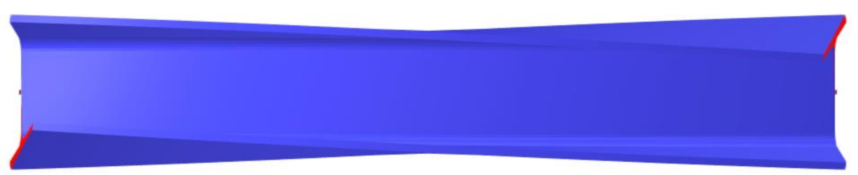
- Pure section rotation due to primary / St. Venant /pure torsion
- St. Venant torsion generates (primary) shear stresses
- Integral of primary shear stresses is equal to the primary / St. Venant torsional moment $M_{T,pri}$



Primary shear stresses for an **open** Section

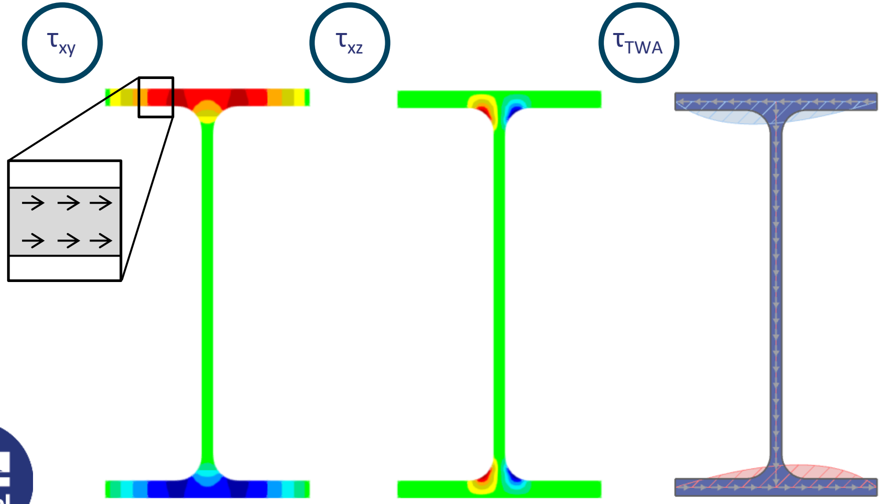


Primary shear stresses for a **closed** Section

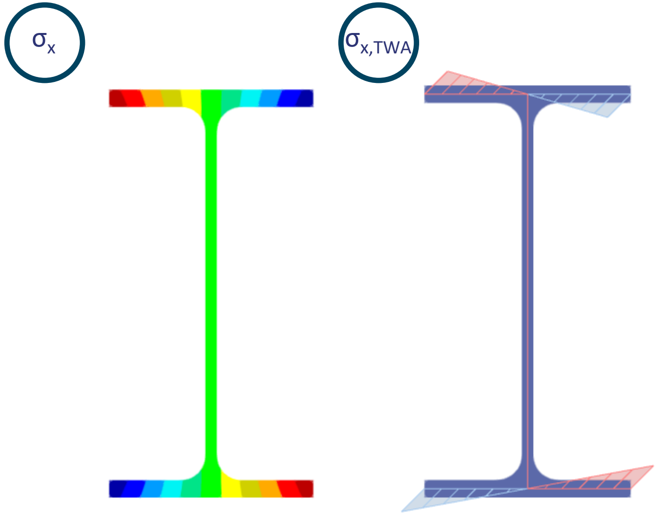


Warping Torsion (7 DOF)

- Section warping (non uniform elongation of the section fibres)
- Restraint warping generates axial warping stresses and for equilibrium reasons (secondary) shear stresses
- Integral of the axial warping stresses is equal to the warping moment Mω [Force x Area, e.g. kNm²]
- Integral of secondary shear stresses is equal to the secondary torsional moment $M_{T,sec}$
- Relation between warping moment and secondary torsional moment $M_{\omega}' = M_{T,sec}$ (Analogy to bending theory e.g. $M_y' = V_z$)



Secondary shear stresses for an **open** Section



Warping stresses for an **open** Section

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Essential equations

- Torsional differential equation

$$M_T = M_{T,pri} + M_{T,sec}$$

$$M_T = \underbrace{G * I_t}_{\text{Torsional stiffness}} * \varphi'_x + \underbrace{E * I_\omega}_{\text{Warping stiffness}} * \varphi'''_x$$

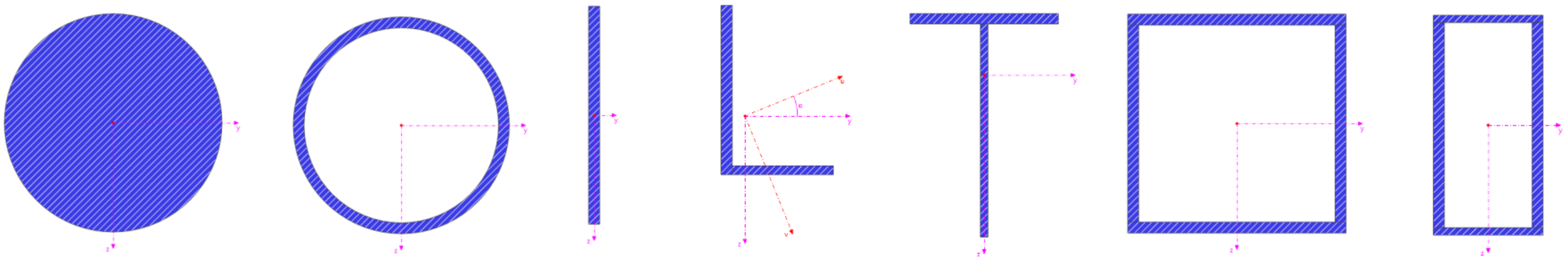
- Member constant for torsion

$$\varepsilon_t = L * \sqrt{\frac{GI_t}{EI_\omega}}$$

G	Shear modulus
E	Modulus of elasticity
I_t	Torsional constant
I_ω	Warping constant
φ_x	Beam rotation
φ'_x	Beam twist
L	Member length

Influence of the section shape

1. Category: **Warping-free** Sections
   - Circular hollow/solid section
   - Thin-walled cross sections whose profile centre lines meet at one point
   - Quadratic hollow section with constant thickness
   - Special case: Rectangular hollow section with specific dimensions



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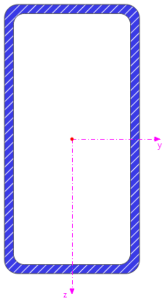
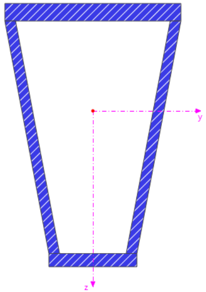
Influence of the section shape

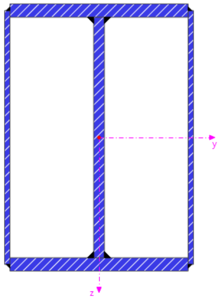
1. Category: **Warping-free** Sections
2. Category: Cross sections with **minor Warping**
   - All closed sections (one or multiple cells)
   - Solid sections (with exceptions)
   - Common assumption [4]: $\varepsilon_t > 10$



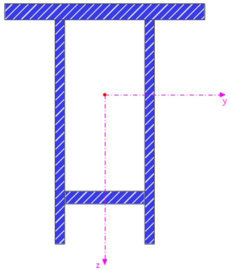
$\varepsilon_t \approx 29$



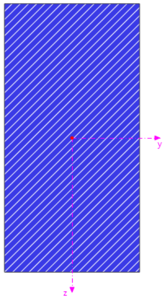
$\varepsilon_t \approx 27$



$\varepsilon_t \approx 32$



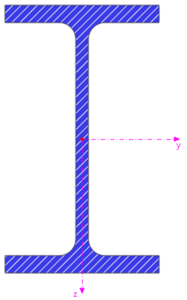
$\varepsilon_t \approx 13$



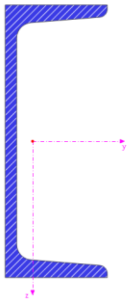
$\varepsilon_t \approx 40$

Influence of the section shape

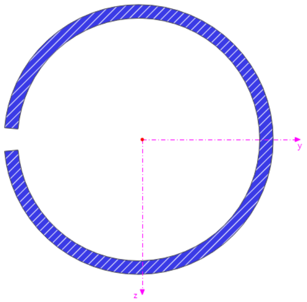
1. Category: **Warping-free** Sections
2. Category: Cross sections with **minor Warping**
3. Category : **Non-warping-free** Sections
   - All open sections that do not fit into 1. Category



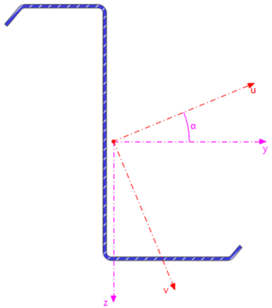
$\varepsilon_t \approx 1{,}4$



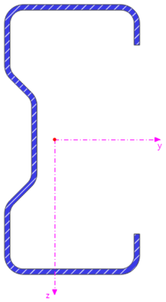
$\varepsilon_t \approx 2{,}2$



$\varepsilon_t \approx 0{,}6$



$\varepsilon_t \approx 0{,}2$

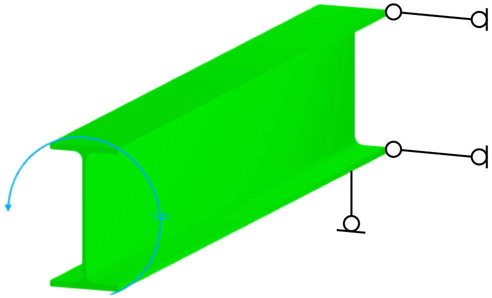


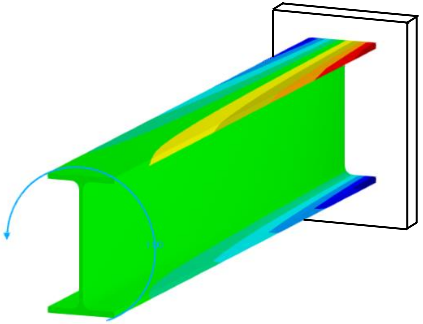
$\varepsilon_t \approx 0{,}4$

Types of warping restraint

Free warping is restrained in case...

... warping boundary conditions are introduced



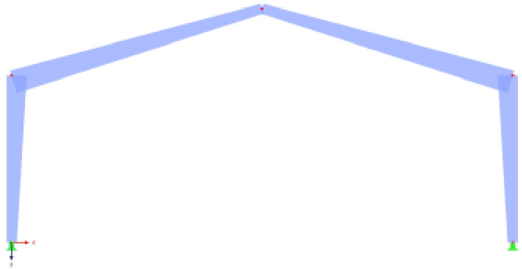


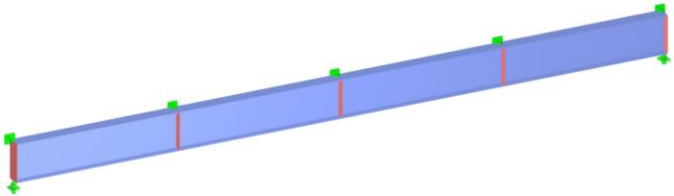
Types of warping restraint

Free warping is restrained in case...

... warping boundary conditions are introduced

... the torsional / warping stiffness changes along a member





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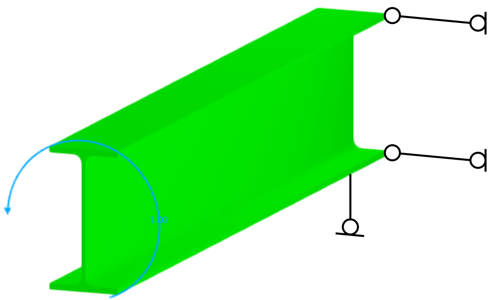
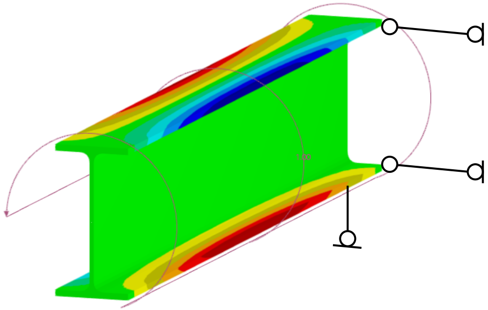
Types of warping restraint

Free warping is restrained in case...
... warping boundary conditions are introduced
... the torsional / warping stiffness changes along a member
... the torsional moment is not constant

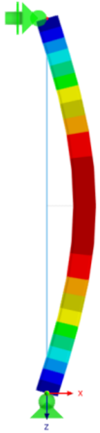
$\left.\right\} \quad \varphi'_x \neq \text{const}$





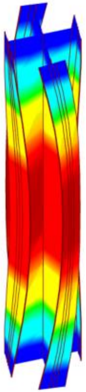
Warping torsion is relevant for **non-warping-free** sections that are **loaded in torsion** and have some type of **warping restraint**!

Stability modes of beams



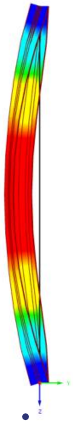
Flexural buckling

$N_{cr,y/z}$



Torsional buckling

$N_{cr,T}$



Flexural-torsional Buckling

Lateral-torsional Buckling

$N_{cr,LTB}$; M_{cr}

Warping torsion required to account for those modes in static / stability analysis!

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Summary

- In the general case, two types of torsion load bearing mechanisms are observed in members loaded in torsion
- Warping torsion is relevant for ...
  - ... non-warping-free Sections ...
  - ... with warping restraint ($\varphi_x' \neq$ const).
- In this case, the consideration of warping torsion has an effect on:
  - Deformations
  - Stresses
  - Internal Forces
- Only with 7 DOFs and under consideration of II./III. Order theory, the relationship between bending and torsion is correctly considered. "Indirect" torsion from biaxial bending is not captured with 6 FG, nor are the stability cases of torsional and lateral-torsional buckling
- Important when using the Add-On „Torsional Warping" in RFEM 6 und RSTAB 9:
  - By default, loads and boundary conditions act in the centre of gravity of a section
  - By default, warping is not assumed to be continuous when connecting members (warping hinge)
  - Discrete warping restraints/-springs can be considered by defining transverse stiffeners on members/member sets
  - More information is given in our >>Online Manual<<

Further reading

[1] Educational videos ETH Zürich: https://youtu.be/TjO7WFzdqPE?feature=shared

[2] E-Learning platform TU Graz: https://www.tugraz.at/institute/isb/lehre/e-learning

[3] Hughes et. al.: Design of Steel Beams in Torsion, SCI Publication P385, 2011

[4] Kindmann & Kraus.: Steel Structures – Design using FEM, 2011

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All you need to know for a start!

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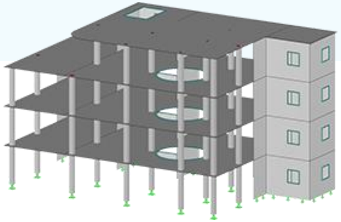

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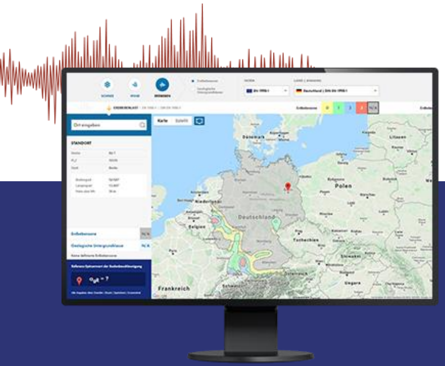

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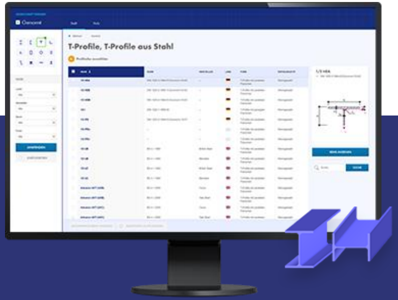

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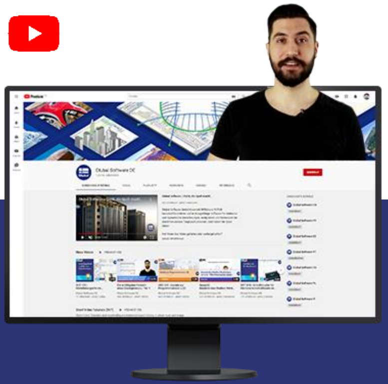

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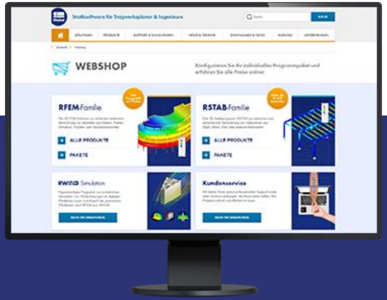

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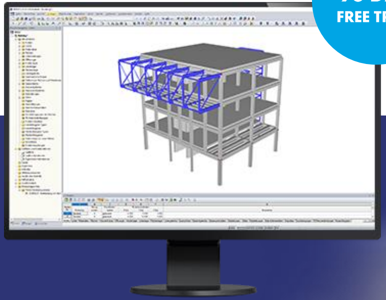

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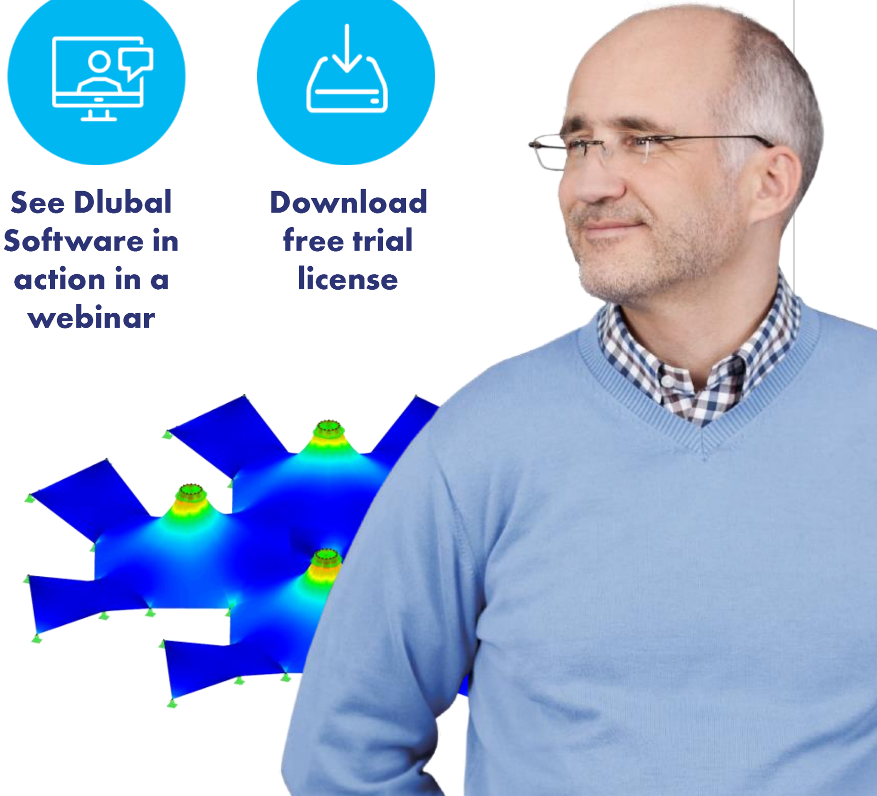

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