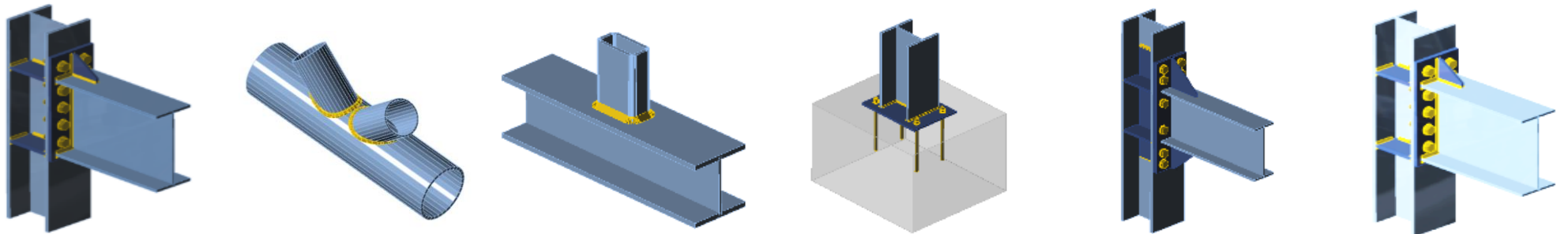# Connection design
by Component Based Finite Element Method

Lecture 3
Joint of hollow to open section

List of lectures

1) Beam to column moment connection
2) Hollow section joints
3) **Joint of hollow to open section**
4) Column base
5) Seismically qualified joints
6) Joints at elevated temperature

Aims and objectives

- Provide information on modeling hollow section connections

- Provide an online training to students and engineers

- Illustrate the differences between numerical simulation and numerical calculation, e.g., between research-oriented FEM and design-oriented FEM.

- Show the process of Validation & Verification

- Offer a list of references relevant to the topic

Lecture 4

Joint
of hollow to open section

František Wald, Marta Kuříková, Martin Kočka, Abhishek Ghimire, Lubomír Šabatka, Jaromír Kabeláč, Drahoš Kojala

Tutorial

o This lecture describes the principles of FEM modeling of hollow section joints using Component Based FEM (CBFEM).

o Failure mode models are presented for one of the simplest cases on hollow to open section joints.

o An overview of both simple and FEM analysis and modeling is presented.

o Validation, verification and benchmark cases using Component Based Finite Element Method are presented.

Motivation

o The purpose of this lecture is to explain the design of connections of hollow sections to open sections, as a simple case of a very large subject.
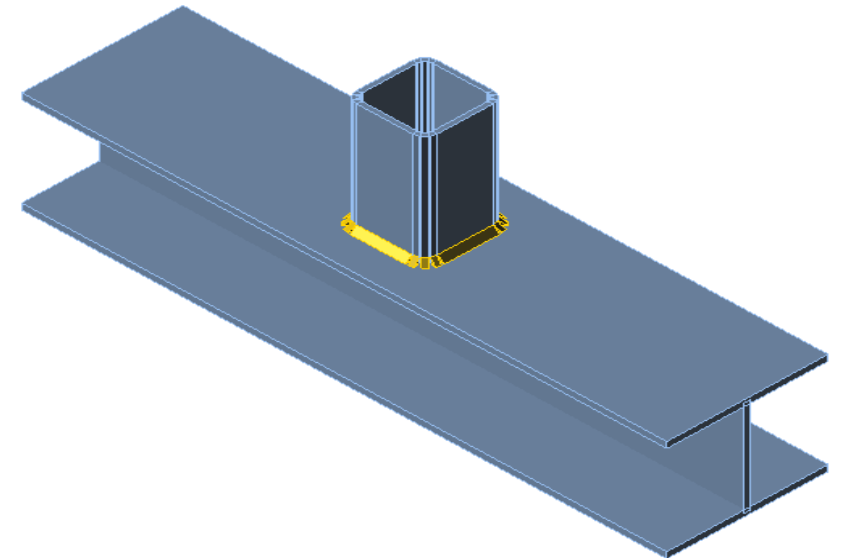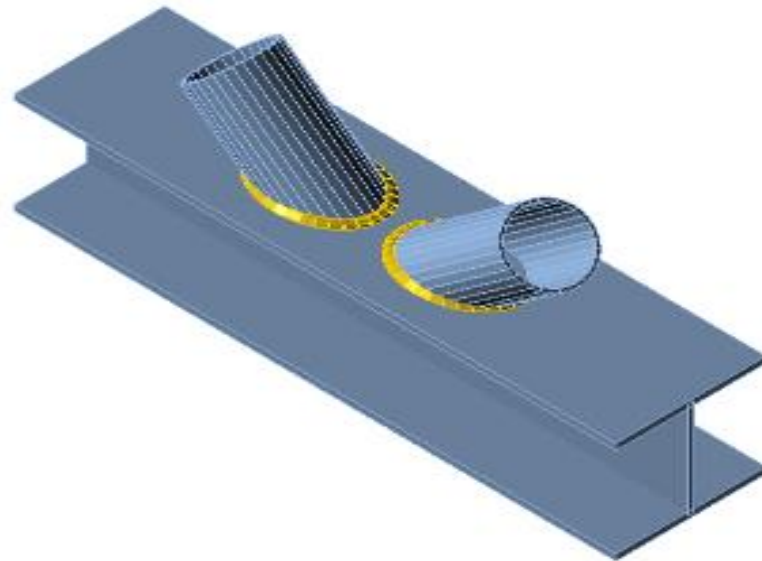
Outline of the lecture

- Introduction - hollow section joints
- **Failure mode method**
    - General
    - Influencing joint parameters
    - Component method
    - Hollow to open joints
    - Assessment I
- **Component based FE method**
    - Principles
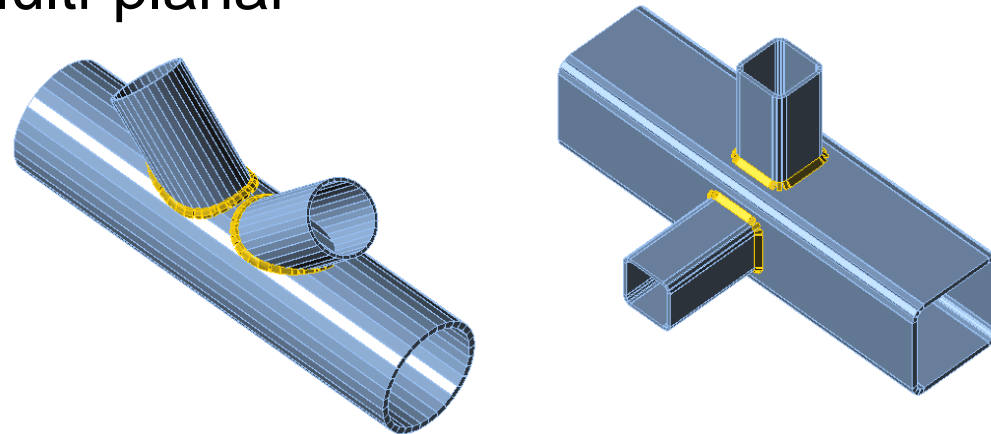   - Validation
    - Verification
    - Benchmark case
    - Assessment II
- Summary

Hollow section joints

Lecture 4

Joint of hollow to open section

Geometry

○ The welded joints of circular, square or rectangular hollow sections can be either:

    ○ Uni-planar

    ○ Multi-planar

○ The combination of hollow sections with open sections are used in the uni-planar joints.
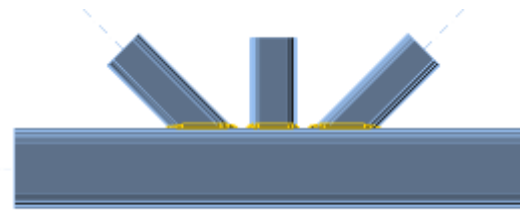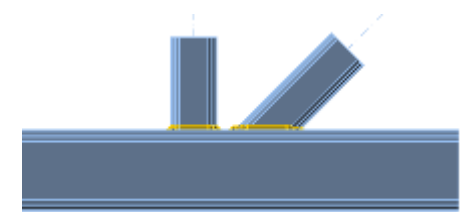
Basic geometrical types

o The typical uni-planar joints
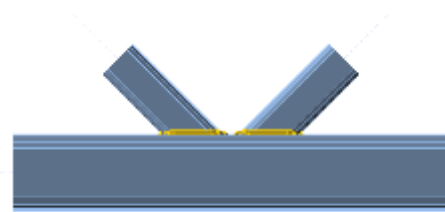
K joint

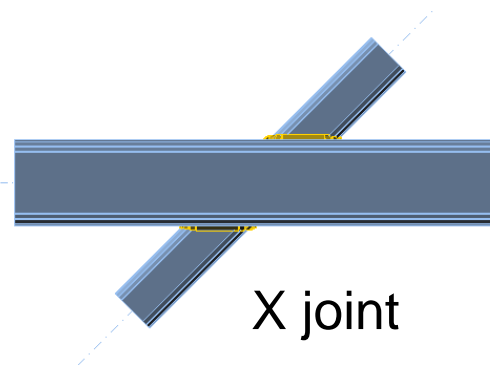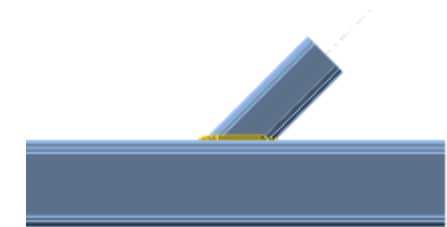KT joint

N joint

T joint

X joint

Y joint
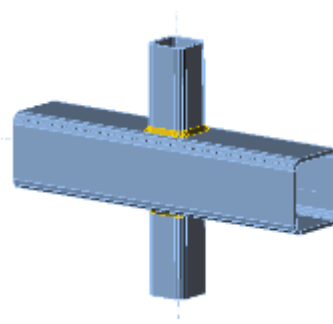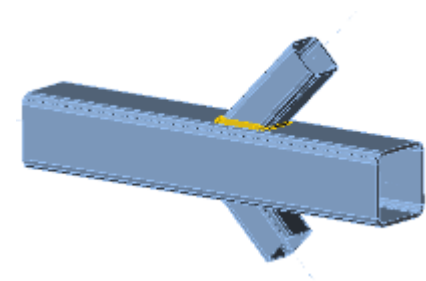
10

Basic geometrical types

o The typical multi-planar joints
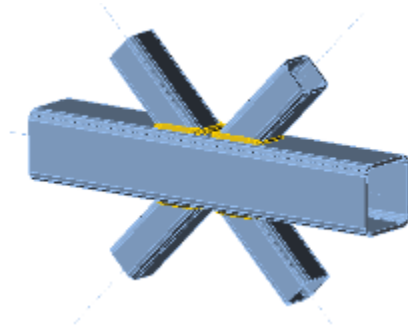
DK joint

X joint

DY joint
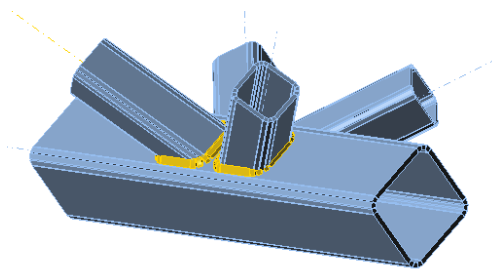
KK joint

TT joint

XX joint

Loading

o The design resistance of the joint is expressed as maximum axial or moment resistances for the brace.
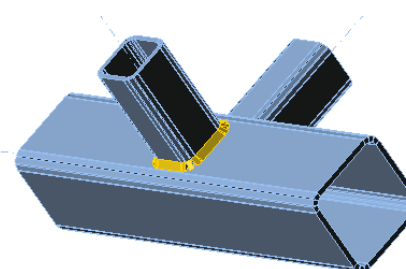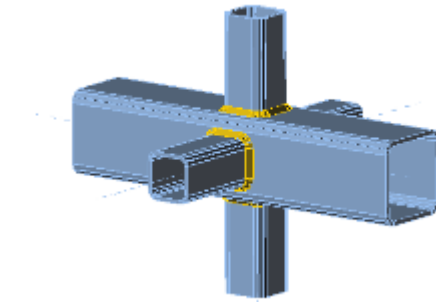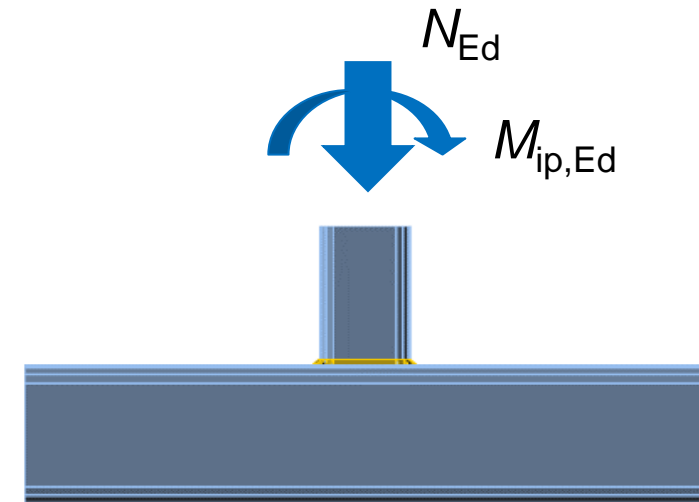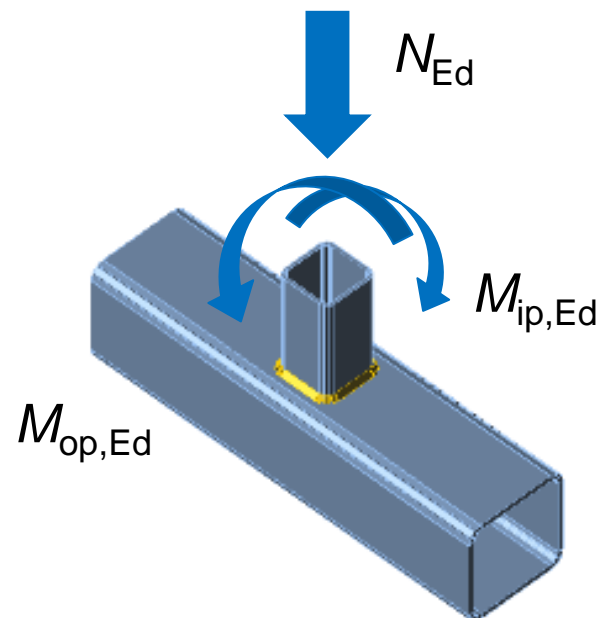
o The moment resistance can be reached for in-plane or out-of-plane loading.

N_{Ed}

$M_{ip,Ed}$

$M_{op,Ed}$

N_{Ed}

$M_{ip,Ed}$

Design of welds

o The welds are preferably designed for full resistance of joint not be the weakest part. I.e. the design resistance of the weld, per unit length of perimeter of a brace member, should not normally be less than the design resistance of the cross-section of that member per unit length of perimeter.

o **The full seam butt weld** is recommended for $t_i > 8$ mm
with $a = t_i$

o **The fillet welds** are recommended only for members thickness t_i ⬚ 8 mm
with the weld effective thickness a for element thickness t_i and for steel

S 235 as $a = 0,92\ t_i$

S 275 as $a = 0,96\ t_i$

S 355 as $a = 1,10\ t_i$
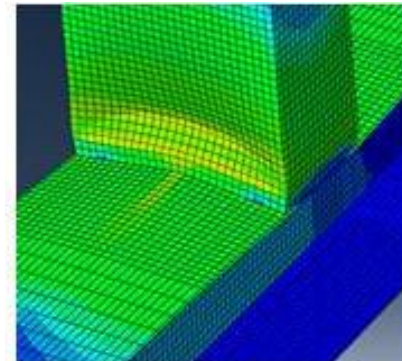
S 420 as $a = 1,42\ t_i$

S 460 as $a = 1,48\ t_i$

Design methods

Design resistance of joints may be determined by:

- **Failure mode method** based on
  - Curve fitting procedures with derived joint parameters based on analytical models

- **Component method**
  - Using lever arms and component resistances determined according to a failure mode procedure

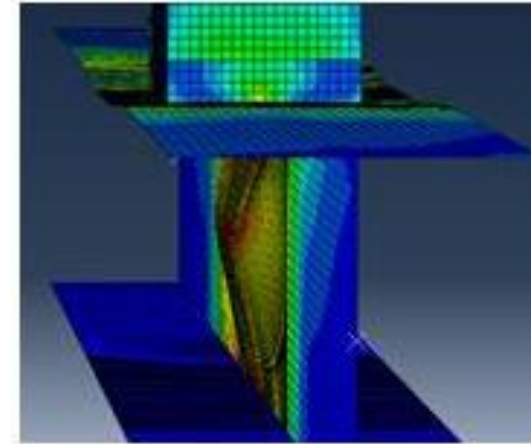- **Finite element method**

Finite element method

o **Research oriented model** by numerical experiments with geometric and material non-linear analysis with imperfections and evaluation of safety as mechanical experiments according to EN1990.

o **Design oriented model** with geometric and material non-linear analysis using design material model.

o The **Component based FEM (CBFEM)** is design procedure combining analytical models for components and FE analysis of plates.

Failure mode model

Lecture 4

Joint of hollow to open section

Failure modes on chord
demonstrated on rectangular hollow sections (RHS)

Chord face failure
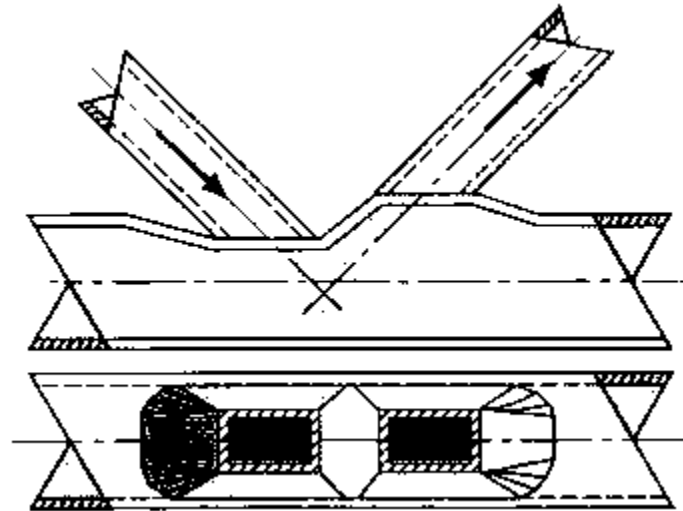
Punching shear failure
of the chord face

Overall shear
failure of the chord
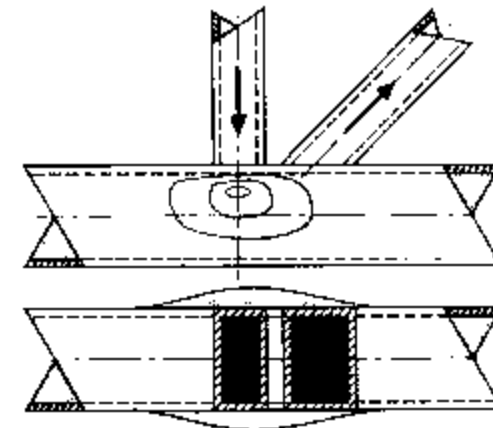
Chord side wall failure

Failure modes on brace
demonstrated on rectangular hollow sections (RHS)

Brace failure

Local buckling
of the brace member

Local buckling of the chord face

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Excluded modes of failure

o Weld failure
  - o Excluded by use efficient throat thickness of the welds

o Lamellar tearing
  - o Excluded by material properties

o Local buckling of the chord or brace sections
  - o Excluded by using sections with can be classified to a maximum cross section class 2
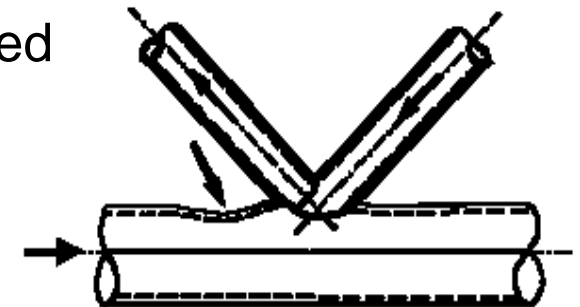
Design principle

- **Welds** are designed for full sectional resistance.

- **Geometrical types** are selected.

- **Range of validity** is prepared based on available experiments for each geometrical type.
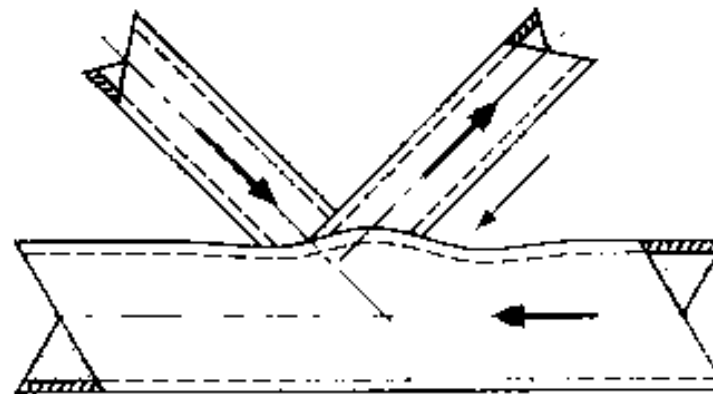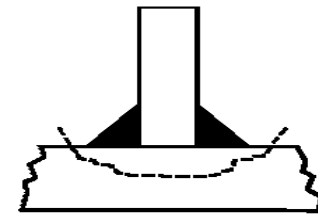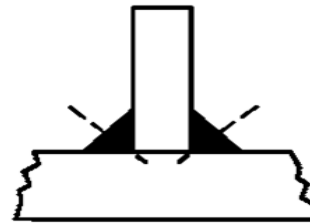
- Limited number of **failure modes** is possible by each geometrical type.

- For each geometrical type is prepared for each failure mode a **curve fitting prediction** of resistance.

- The **influencing joint parameters** are derived based on five **analytical models.**

Experiments and design resistance by curve fitting procedures

The design resistance is derived from experiments from

o   Ultimate load   (in EN1993-1-8:2005)

o   Deformation limit   (in prEN1993-1-8:2017)
    o   chord width as $b_0/300$
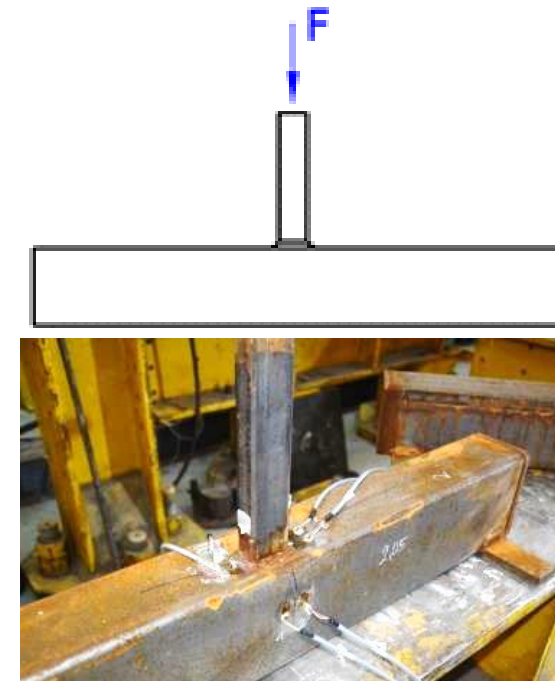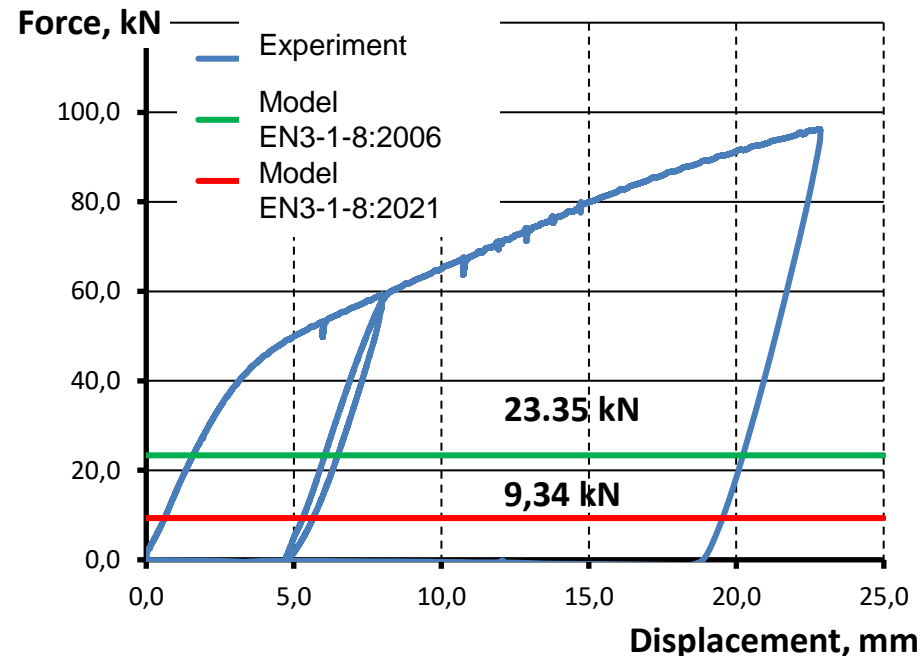
Example behaviour and curve fitting predictions of joint with RHS chord 150 x 100 x 4 mm and brace 50 x 30 x 4 mm

General limits of application

o The members of lattice structures should satisfy the requirements:

o Class 1 (or Class 2) cross-section only

o The angle between the brace and the chord should be larger than 30°
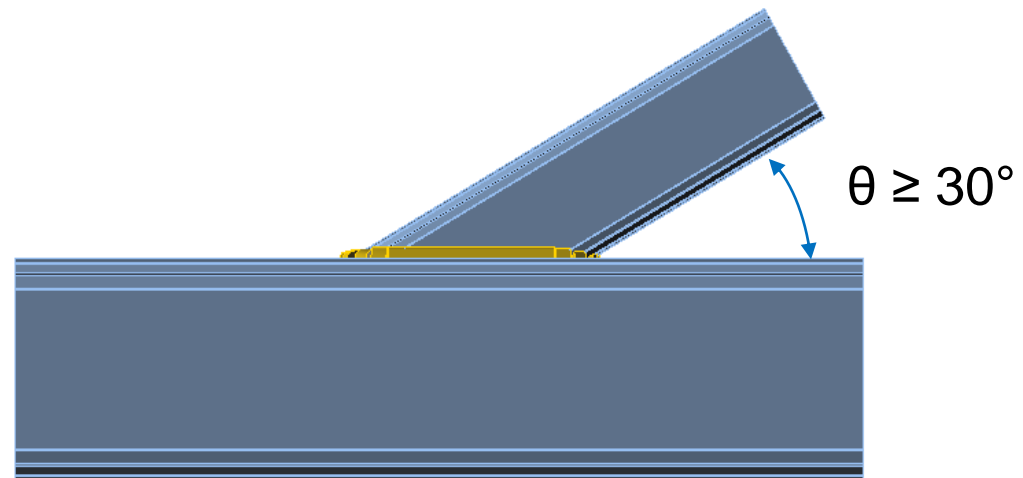
$\theta \geq 30°$

Analytical Models
for determination of influencing joint parameters

o The curve fitting procedure is used for evaluation of joint´s resistance on each possible failure mode.

o For the determination of **the influencing joint parameters** of welded joints between rectangular hollow sections are used analytical models:

- o Yield line
- o Punching shear
- o Brace effective width
- o Chord side wall bearing or buckling
- o Chord shear

Yield line model
for the influencing joint parameters

o The typical case of searching for influencing parameters by yield line model is chord face failure, as is shown below on deformed shape of K joint of RHS after experiment and its cut.
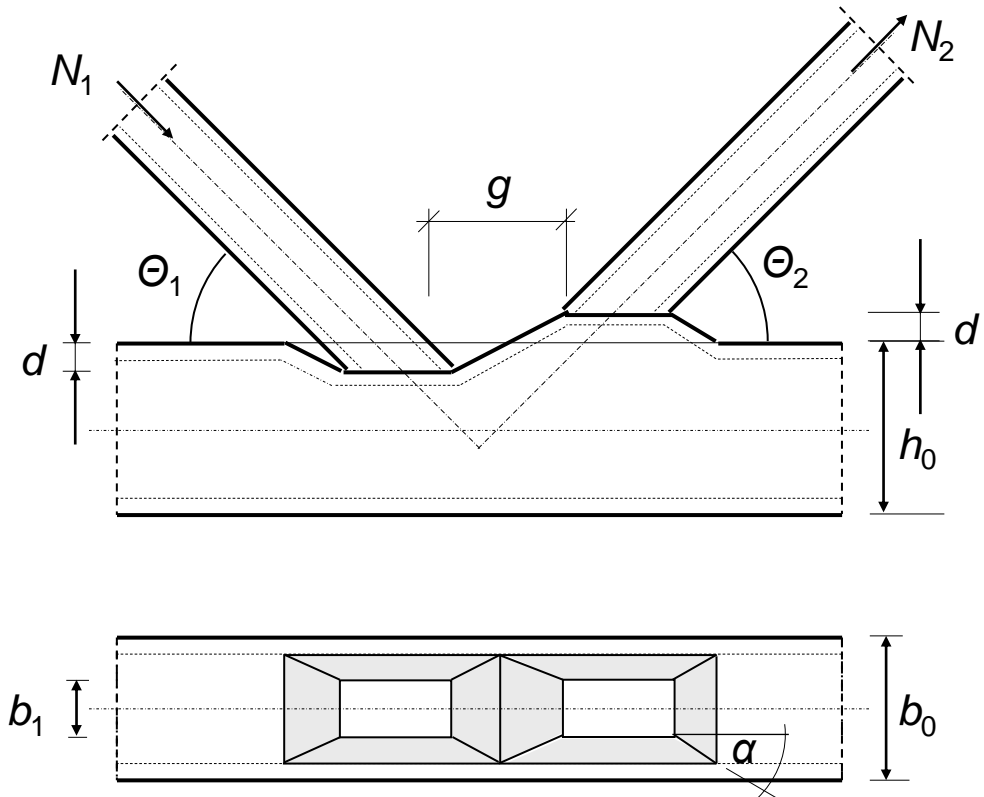
Geometry
of K shape joint of rectangular hollow section

o In principle, the yield line model is an upper bound approach

o Various yield line pattern have to be examined in order to obtain the lowest capacity

o Strain hardening effects and membrane action not considered

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Limits of application of Yield line model

For joints with

o   small β ratios the deformations may be too high to realise the yield line pattern

o   medium β ratios the yield line model gives a good   estimate of the chord face plastification capacity

o   high β ratios prediction of an infinite strength

where β is the ratio of the mean diameter or width of the brace members, to that of the chord.
For T, Y and X joints it is
$$d_1/d_0; \ d_1/b_0 \ \text{or} \ b_1/b_0.$$
brace diameter/chord diameter; brace diameter/chord width or brace width/chord width

Geometry of punching shear model
for the influencing joint parameters

N_1

h_1

Θ_1

t_0

$0,5 \cdot b_e$,

$0,5 \cdot b_e$,

$h_1/\sin\Theta_1$
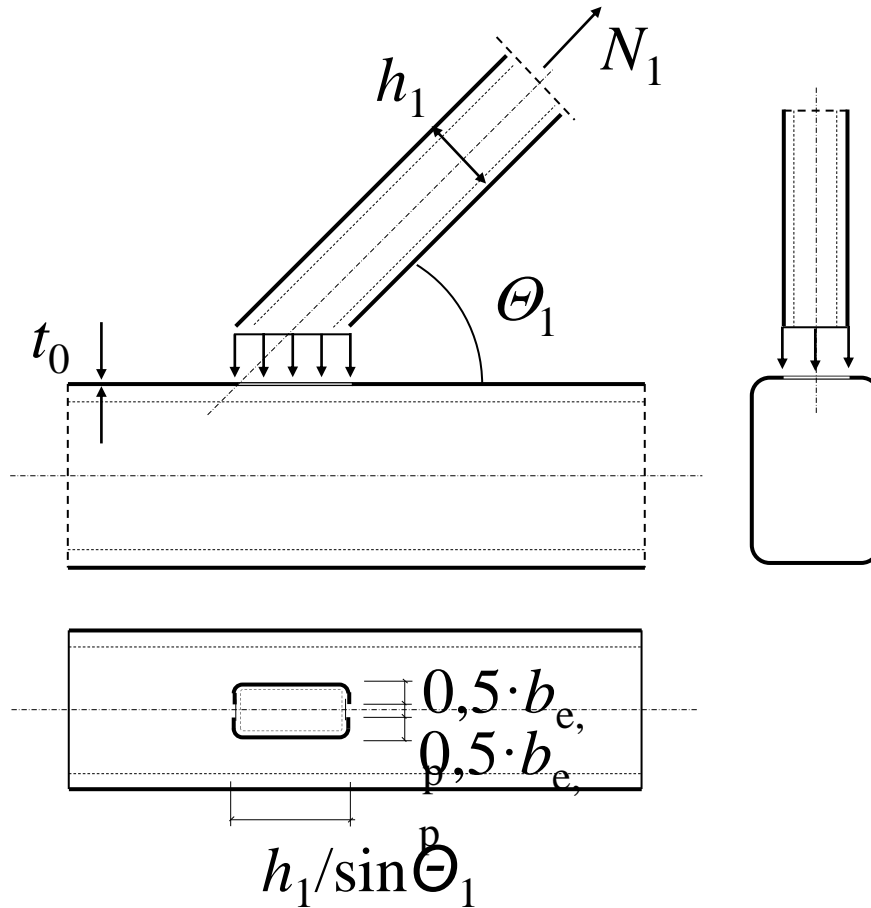
Very small gap
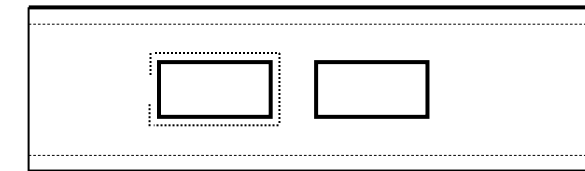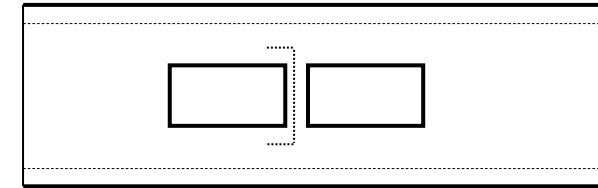
$g = b_0 - b_2$

Big gap

$h_2 / \sin\Theta_2$

Punching shear model
for the influencing joint parameters

o Punching shear is caused by the brace load component perpendicular to the chord face.

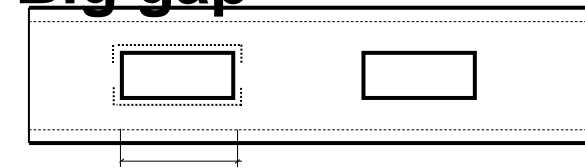o Since of the non-uniform stress distribution at connection and not sufficient deformation capacity may be available, only parts of connection perimeters are effective for punching shear failure.

o Therefore the punching shear criterion is

$$N_1 = \frac{f_{y0}}{\sqrt{3}}\, t_0 \left(\frac{2h_1}{\sin\Theta_1} + 2b_{e,p} \right) \frac{1}{\sin\Theta_1}$$
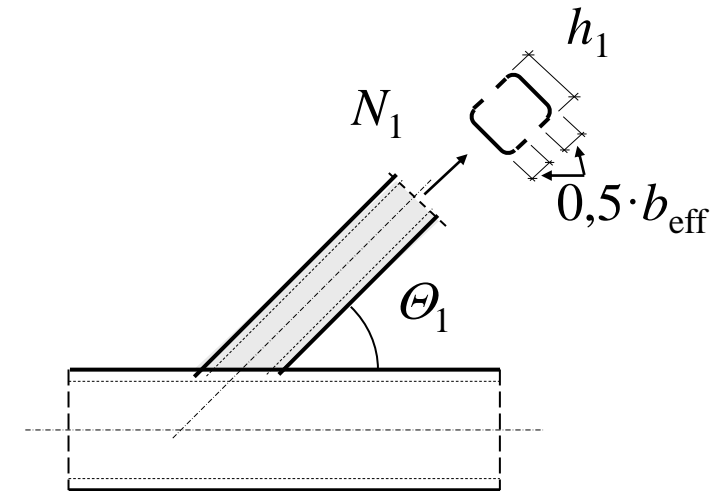
Brace effective width model
for the influencing joint parameters

o Similar to punching shear failure but the complete brace load has to be taken into account.

o For a T, Y and X joint, the effective width criterion is

$$N_1 = f_{y1}\ t_1\ (2h_1 + 2b_e - 4t_1)$$

o As for punching shear failure the gaps are important for the effective lengths.

Brace effective width model
for the influencing joint parameters

o For K-joints with gaps in the allowed range the brace effective width criterion is

$$N_2 = f_{y2}\, t_2\, (2h_2 + b_2 + b_e - 4t_1)$$

o No regulations for small gaps available

o For big gaps the criterion for T-, Y- and X-joints can be used
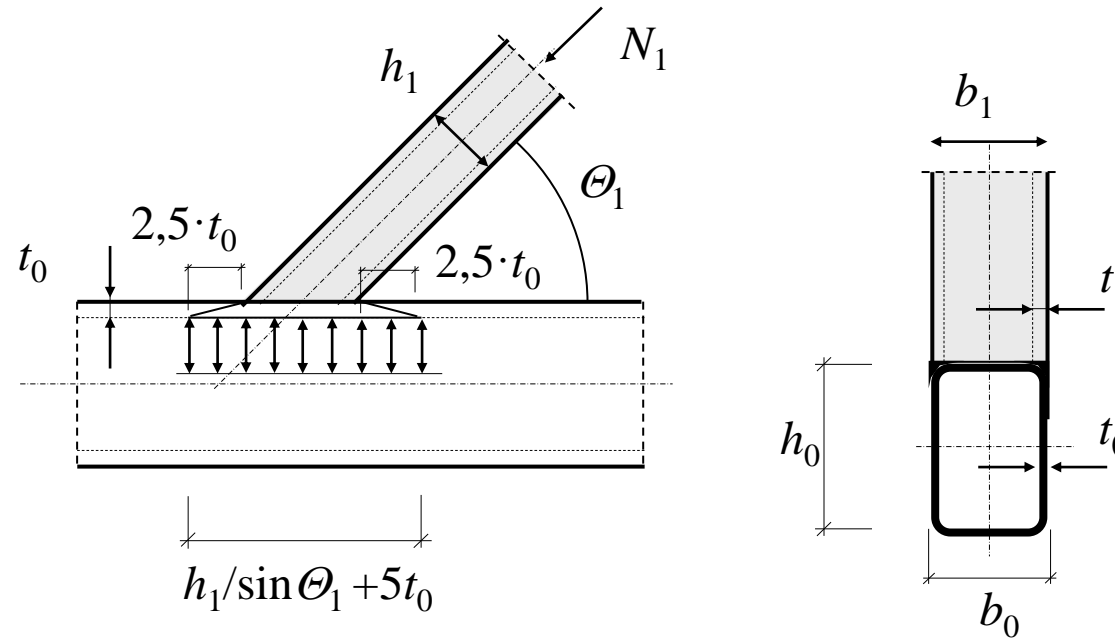
Chord side wall bearing/buckling model
for the influencing joint parameters

○ T, Y and X joints with a high β ratio generally fail by yielding or buckling of the chord side walls.

○ For joints with $\beta = 1,0$ the yield capacity of the chord webs is determined as

$$N_1 = 2f_{y0} \cdot t_0 \left(\frac{h_1}{\sin\Theta_1} + 5t_0 \right) \cdot \frac{1}{\sin\Theta_1}$$

Chord side wall bearing/buckling model
for the influencing joint parameters

- For slender walls the yield stress f_{y0} is replaced by a buckling stress f_k which is obtained from the European buckling curve *a*

- For a Euler strut with a buckling length of $h_0 - 3t$
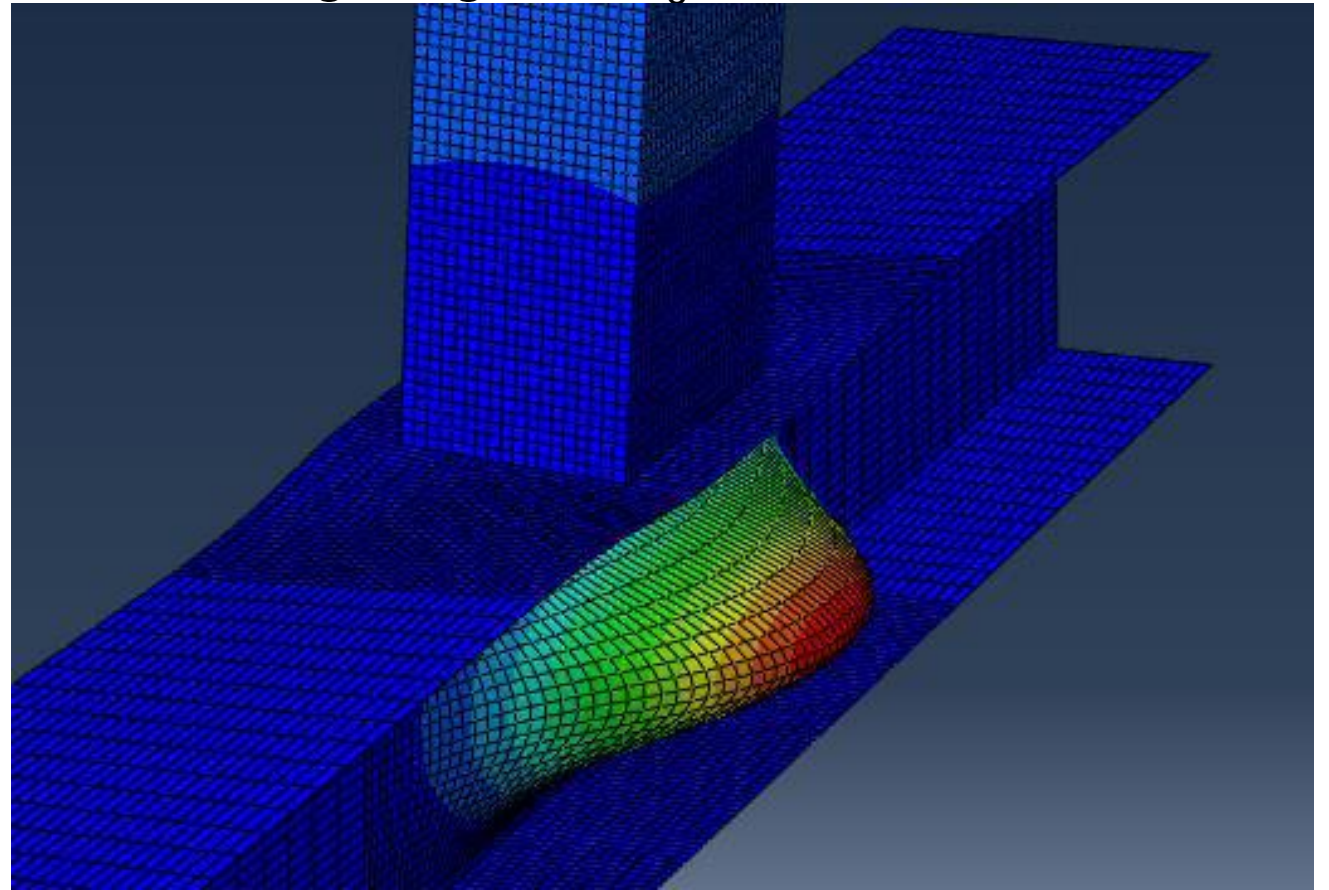
Chord shear model
for the influencing joint parameters
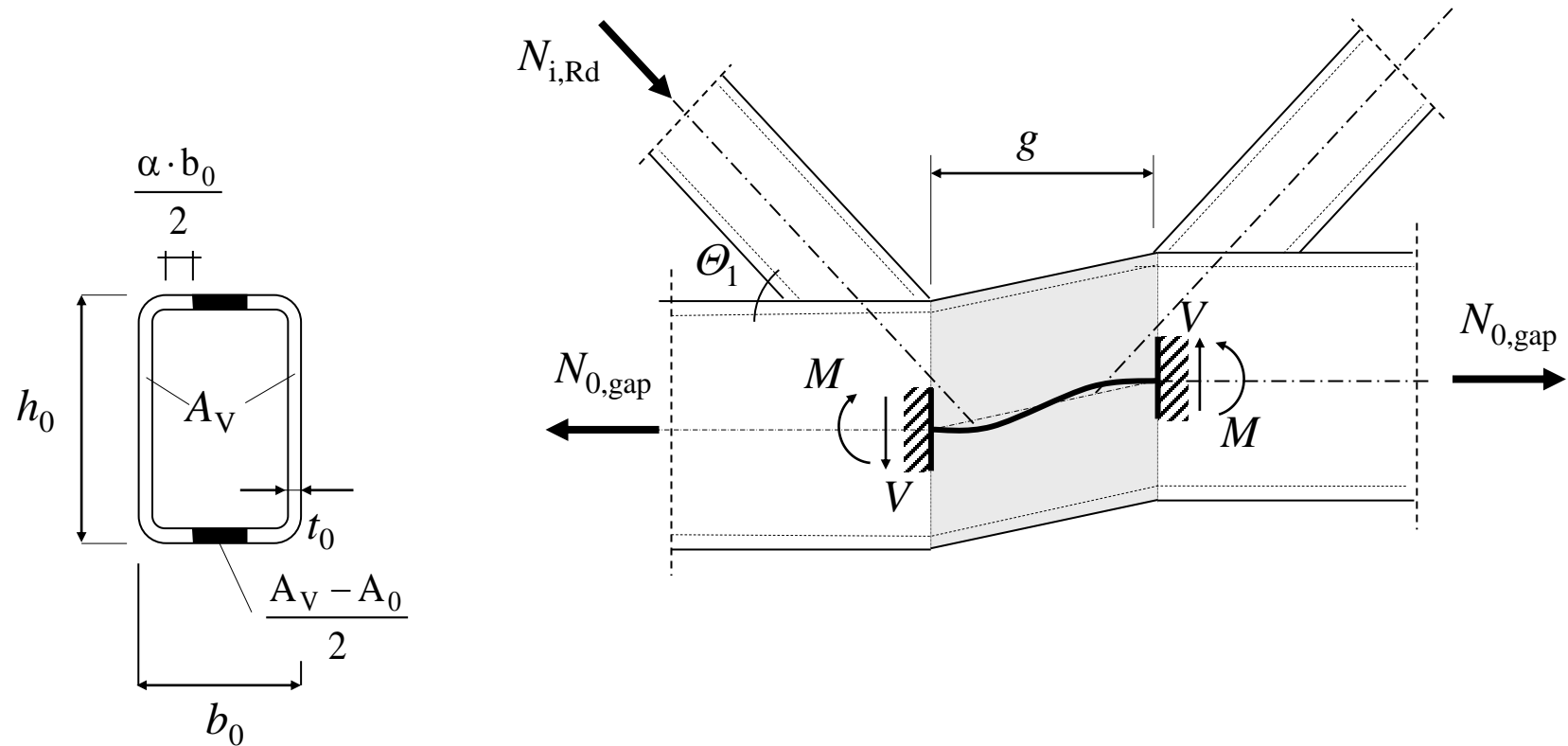
o Resistance is calculated
based on the basic formulae for plastic design.

Chord shear model
for the influencing joint parameters

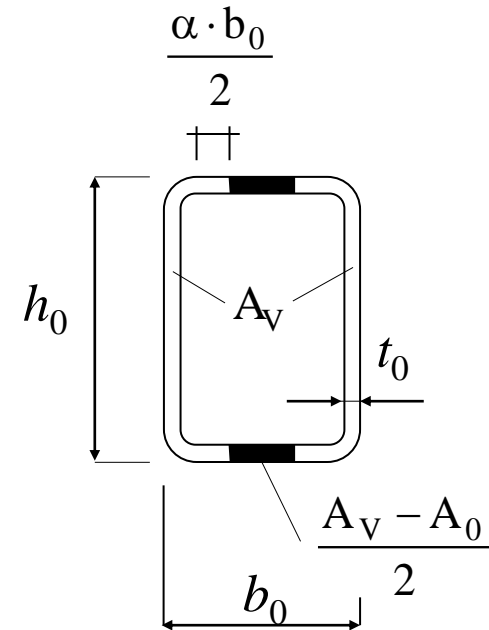o The plastic shear load capacity is

$$V_{pl} = \frac{f_{y0}}{\sqrt{3}} \cdot A_v$$

with an effective shear area

$$A_V = (2h_0 + \alpha \cdot b_0)\, t_0$$

o Based on
the Huber Hencky-Von Mises criterion the following interaction
formula for shear resistance of the chord web

$$N_{o.gap} \leq (A_0 - A_V)\, f_{y0} + A_V\, f_{y0} \sqrt{1\left(\frac{V_{Sd}}{V_{pl}}\right)^2}$$

Component based approach for hollow section joints

Lecture 4

Joint of hollow to open section

Principle

o Component based approach for hollow section design is formal reorganisation of equations to be engineering user friendly.

o Failure modes are represented as components.

o The same equations are used by curve fitting approach but in different formulation.

Joint configuration

Joint 2 — Brace 2 — θ_2

Joint 1 — Brace 1 — θ_1

Chord
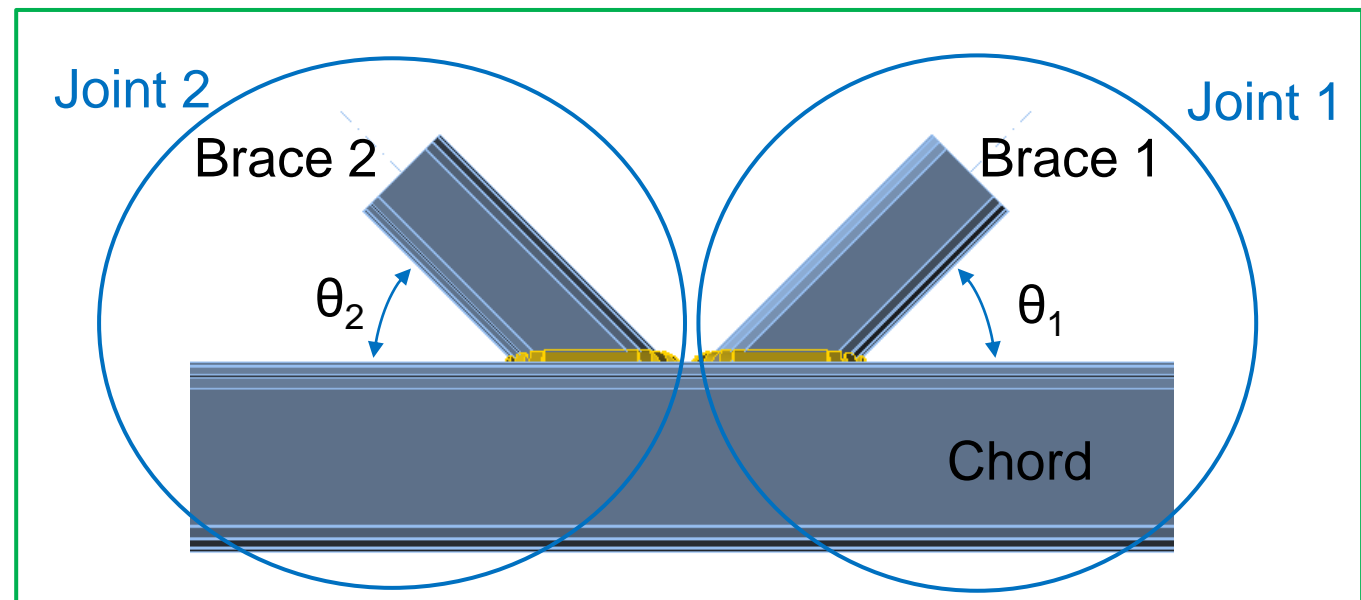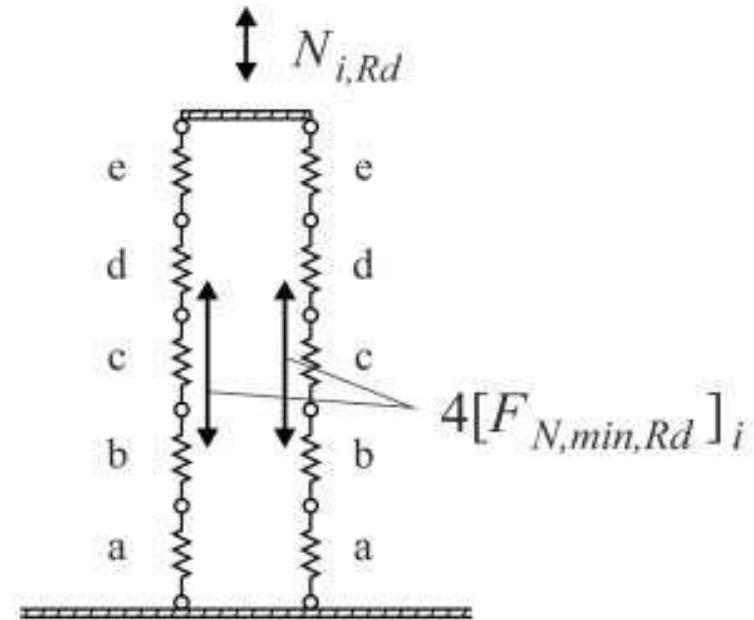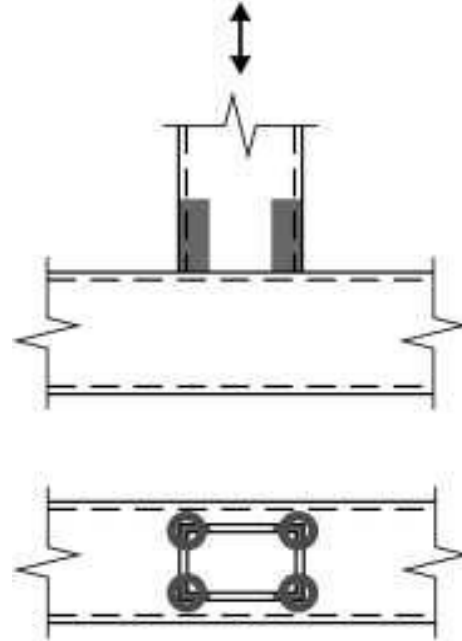
Defined lever arms and components (failure modes)

○ k_{fa} factors transferred to

   ○ b_{eff} effective widths

   ○ r_a lever arm

○ The interaction of load limits the application.

7 failure modes are modelled as 7 components
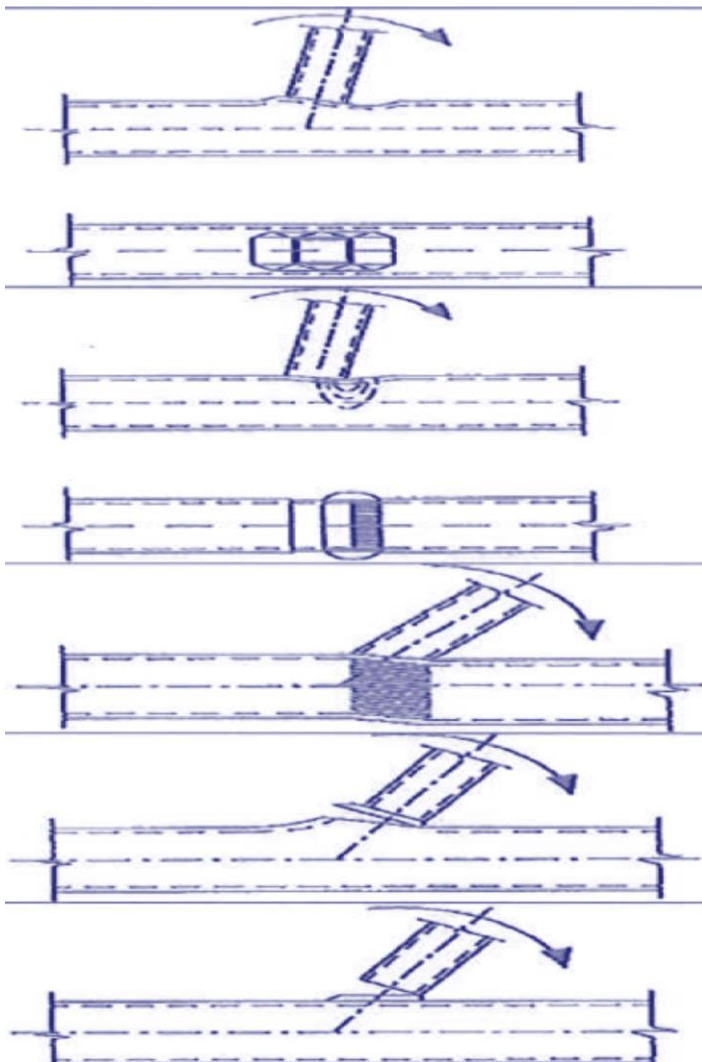
1) Chord face in bending

2) Chord side wall
   in tension/ compression

3) Chord side wall in in shear

4) Chord face under punching shear
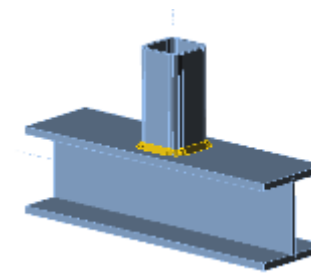
5) Brace flange and web
   in tension/compression

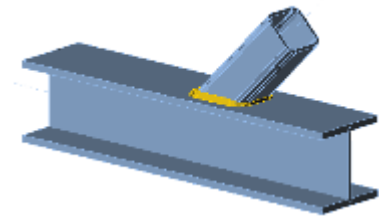# Application of principles to hollow to open joints

Lecture 4

Joint of hollow to open section

Hollow to open joints as example of application

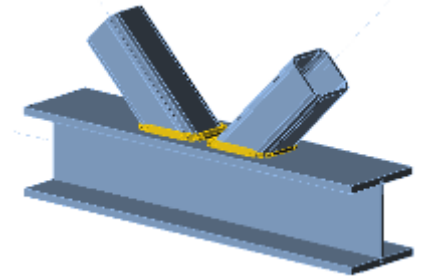o Types of joint available in failure mode method
  - o T, Y, X, K and K gap joint

o Two failure modes only
  - o Brace failure
  - o Chord web failure
  - o Chord shear failure (only for K joint)

o Range of validity
  - o Class 1 and 2 with limited flange width

o Influencing parameters
  b_{eff} brace effective width
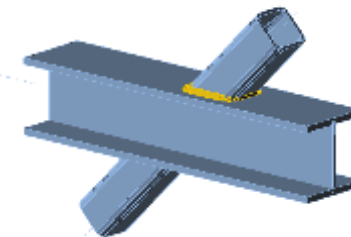 b_w chord web effective width

T joint

Y joint

K joint

X joint

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Design resistance

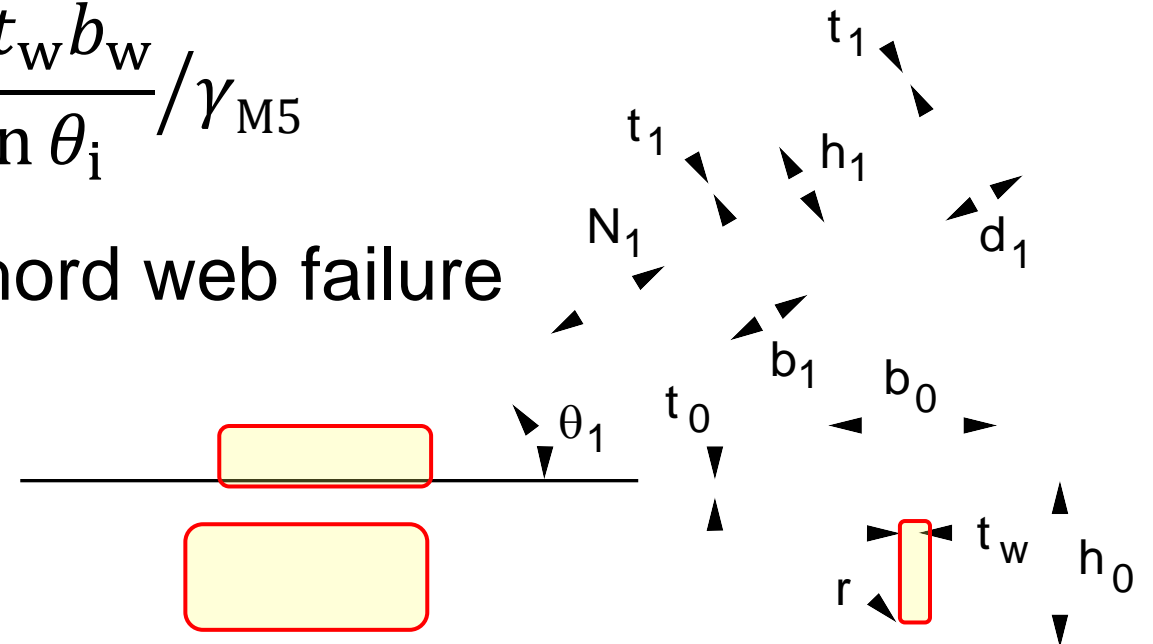**of welded joints between RHS or CHS brace members and I or H section chords by failure mode method**

o Brace failure

$$N_{i,Rd} = 2C_f f_{yi} t_i b_{eff} / \gamma_{M5}$$

o Chord web failure

$$N_{i,Rd} = \frac{f_{y0} t_w b_w}{\sin \theta_i} / \gamma_{M5}$$

o For K gap joints also chord web failure

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Design resistance

of welded joints between RHS or CHS brace members and I or H section chords by failure mode method

Chord shear failure for K gap joints and for X joints with $\cos\theta_i > h_i/h_0$ use $\alpha = 0$

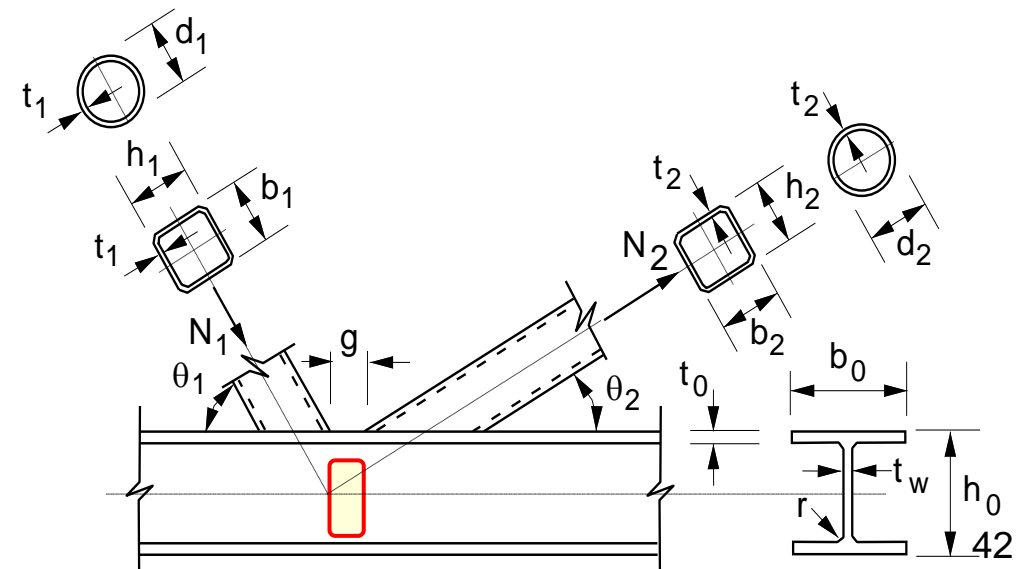$$N_{i,Rd} = \frac{f_{y0}A_{V,0,gap}}{\sqrt{3}\sin\theta_i}/\gamma_{M5}$$

$$N_{0,gap,Rd} = \left[(A_0 - A_{V,0,gap})f_{y0} + A_{V,0,gap}f_{y0}\sqrt{1 - \left(\frac{V_{0,gap,Ed}}{V_{0,gap,pl}}\right)^2}\right]\Big/\gamma_{M5}$$

$$A_{V,0,gap} = A_0 - (2-\alpha)b_0 t_0 + (t_w + 2r)t_0$$

$$\alpha = \sqrt{\frac{1}{1 + (4g^2)/(3t_0^2)}}$$

$$V_{0,gap,pl} = \frac{f_{y0}}{\sqrt{3}}A_{v,0,gap}$$

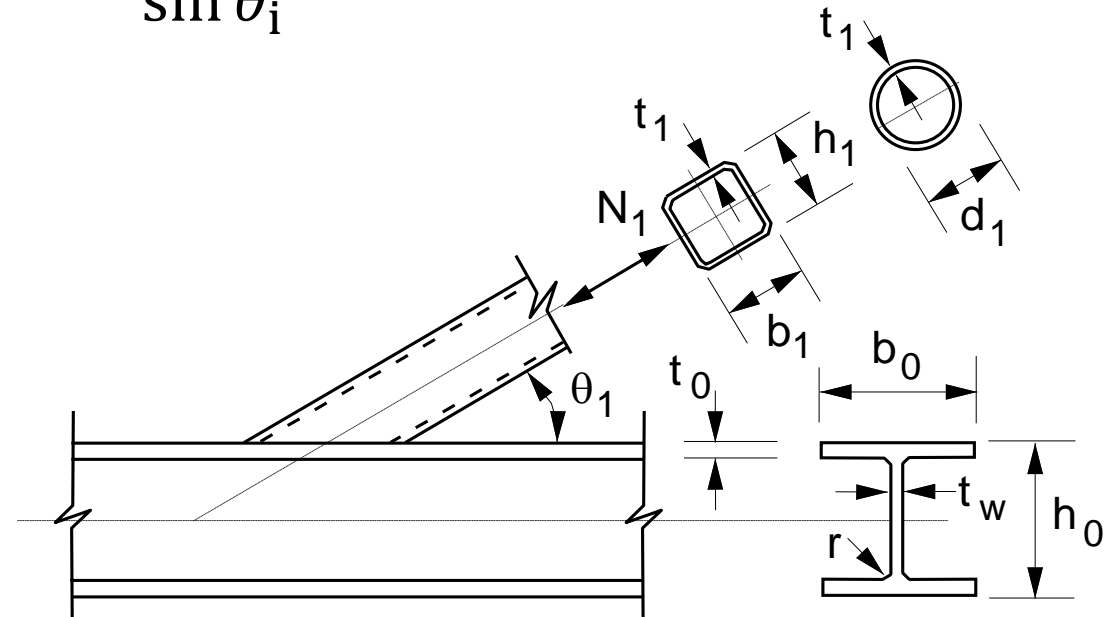$$V_{0,gap,Ed} = \left(N_{i,Ed}\sin\theta_i\right)_{max}$$

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Effective width

of welded joints between RHS or CHS brace members and I or H section chords for failure mode method

For RHS braces

$$b_{\text{eff}} = t_{\text{w}} + 2r + 7t_0 \frac{f_{\text{y0}}}{f_{\text{yi}}} \text{ but } \leq b_{\text{i}} + h_{\text{i}} - 2t_{\text{i}}$$

$$b_{\text{w}} = \frac{h_{\text{i}}}{\sin \theta_{\text{i}}} + 5(t_0 + r) \text{ but } \leq \frac{2t_{\text{i}}}{\sin \theta_{\text{i}}} + 10(t_0 + r)$$


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Range of validity

**for welded joints between CHS or RHS brace members
and I or H section chord members for failure mode method**

Type of joint	Joint parameters					
	Chord web width d_w	b_i/t_i and h_i/t_I or d_i/t_i		h_i/b_i	b_0/t_0	Gap
		Compression	Tension			
X	Class 1 and $d_w \leq 400$ mm	Class 1 or 2 and $\dfrac{h_i}{t_i} \leq 35$	$\dfrac{h_i}{t_i} \leq 35$ $\dfrac{b_i}{t_i} \leq 35$ $\dfrac{d_i}{t_i} \leq 50$	$0{,}5 \leq h_i/b_i \leq 2{,}0$	Class 1 or 2	–
T or Y	Class 1 or 2 and $d_w \leq 400$ mm	$\dfrac{b_i}{t_i} \leq 35$ $\dfrac{d_i}{t_i} \leq 50$				
K gap						$g \geq t_1 + t_2$
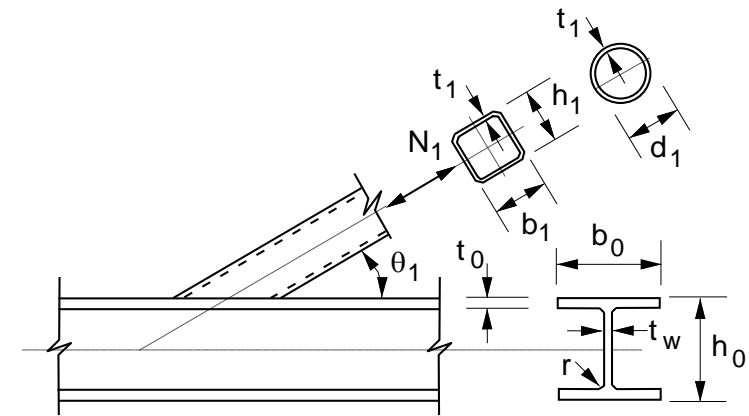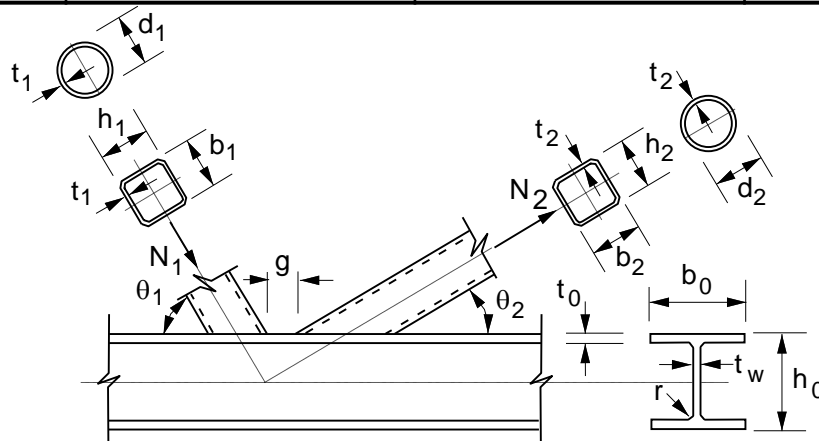
Component approach
of welded joints between RHS or CHS brace members and I or H section chords by failure mode method

Brace failure from failure mode method

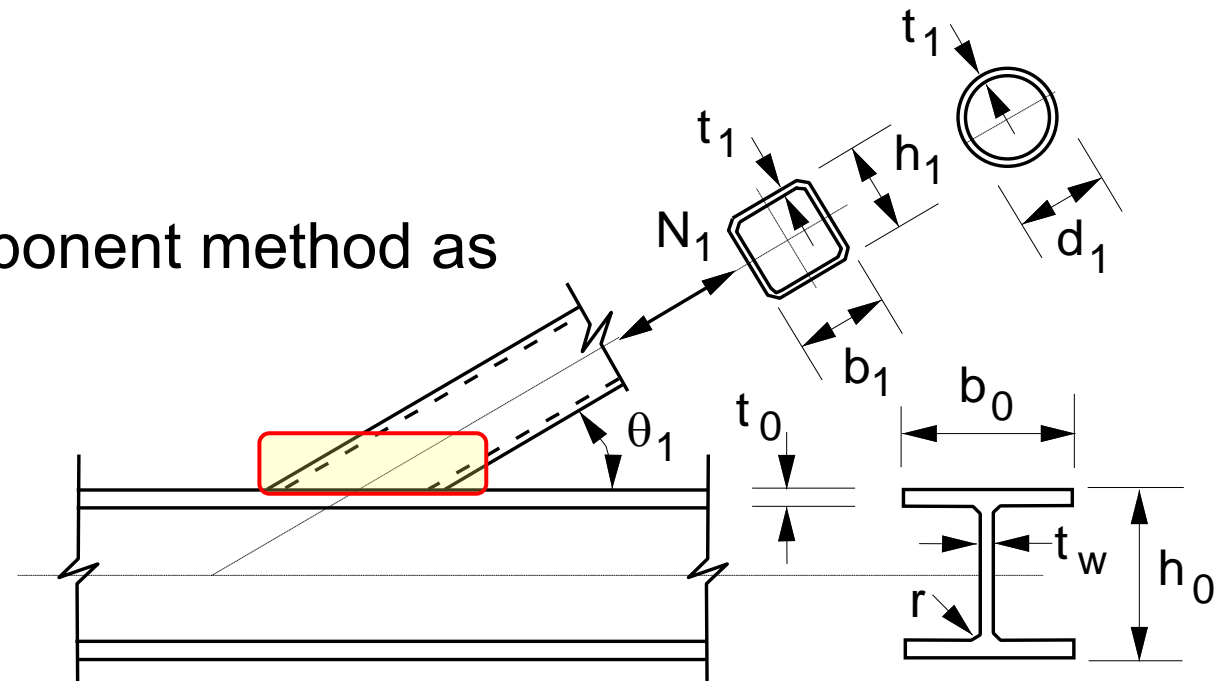$$N_{i,Rd} = 2C_f f_{yi} t_i b_{eff} / \gamma_{M5}$$

$$b_{eff} = t_w + 2r + 7t_0 \frac{f_{y0}}{f_{yi}} \text{ but } \leq b_i + h_i - 2t_i$$

can be overwritten for component method as

$$F_{e,Rd} = C_f f_{yi} t_1 b_{eff} / \gamma_{M5}$$

$$N_{1,Rd} = 4[F_{N,min,Rd}]$$

$$b_{eff,e} = 0,5 b_{eff}$$

45

Component approach
of welded joints between RHS or CHS brace members and I or H section chords by failure mode method

Chord web failure from failure mode method

$$N_{\mathrm{i,Rd}} = \frac{f_{\mathrm{y0}} t_{\mathrm{w}} b_{\mathrm{w}}}{\sin \theta_{\mathrm{i}}} / \gamma_{\mathrm{M5}}$$

$$b_{\mathrm{w}} = \frac{h_{\mathrm{i}}}{\sin \theta_{\mathrm{i}}} + 5(t_0 + r) \quad \text{but} \quad \leq \frac{2t_{\mathrm{i}}}{\sin \theta_{\mathrm{i}}} + 10(t_0 + r)$$

$$K_{\mathrm{N,ch,b}} = 1{,}0; K_{\mathrm{b,ch,b}} = 1{,}0; t_0 = t_w/2$$

can be overwritten for component method as

$$N_{\mathrm{1,Rd}} = 2\, K_{\mathrm{N,ch,b}} K_{\mathrm{N,ch,b}} \frac{f_{\mathrm{y0}} t_0 b_{\mathrm{w}}}{\sin \theta_{\mathrm{i}}} / \gamma_{\mathrm{M5}}$$

$$N_{\mathrm{1,Rd}} = 4[F_{\mathrm{N,min,Rd}}]$$

$$b_{\mathrm{eff},e} = b_w / \sin \theta_{\mathrm{i}}$$
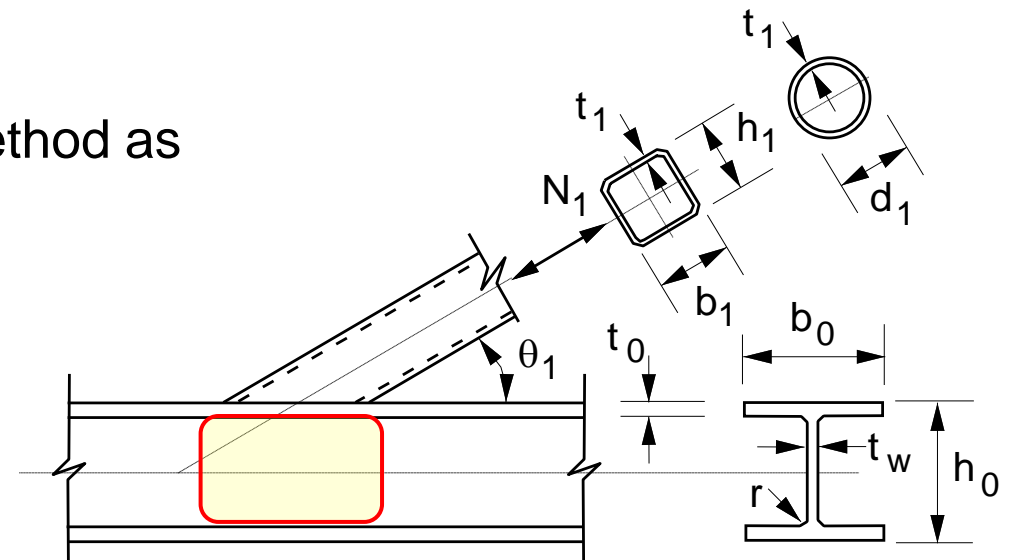
Assessment I

o What limits the application of the component method to the design of hollow section connections?

o How are the analytically derived parameters applied in the failure mode design procedure?

o Which failure modes are excluded and how?

o Why are validity ranges used?

o Is the failure mode method the curve fitting method?

o What is the principle of the component method prepared on the basis of the failure mode method?

o What failure modes can be observed at joints between hollow and open sections?

Component Based
Finite Element Method

Lecture 3

Joint of hollow to open section

Material

○ Bilinear ideal elastic plastic diagram is used in design oriented models as CBFEM according to Ch. 7 in EN 1993-1-5:2006 and the slope of plastic branch is due to numerical stability E/1000.

○ Plastic strain in plates is limited by 5%.

○ In research oriented models is calculated the true stress-strain diagram from the material properties obtained in tensile tests, which is taking into account the necking of the coupon during its yielding before rupture.
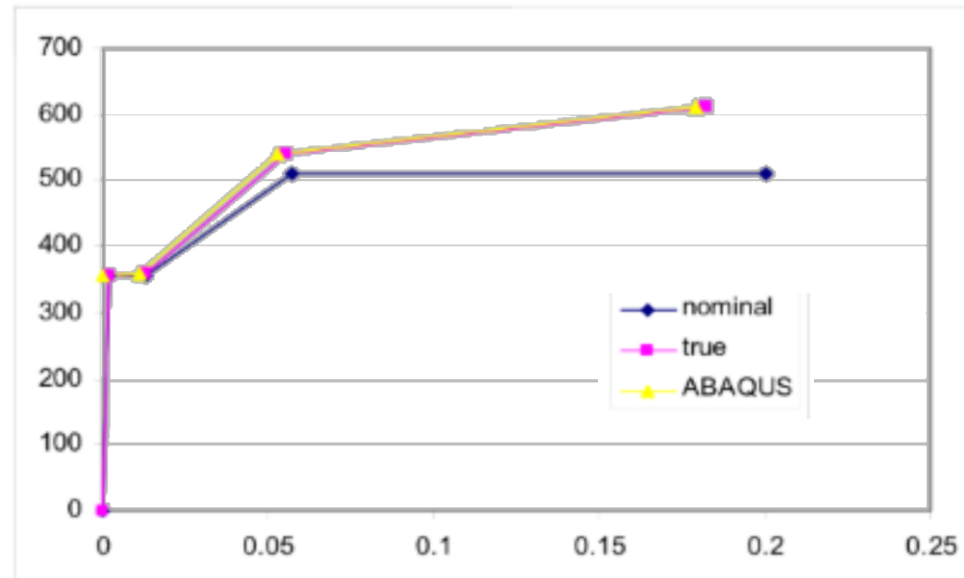
Plate and cross sections

○ For modelling of plate are applied four node quadrangle shell elements with six degrees of freedom.
I.e. there are three translations and three rotations in every node.
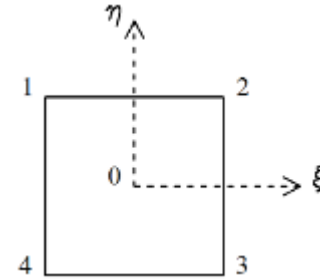
○ The cross section is build from plates with independent meshes, which are connected by constraints, to simplify the meshing procedure.
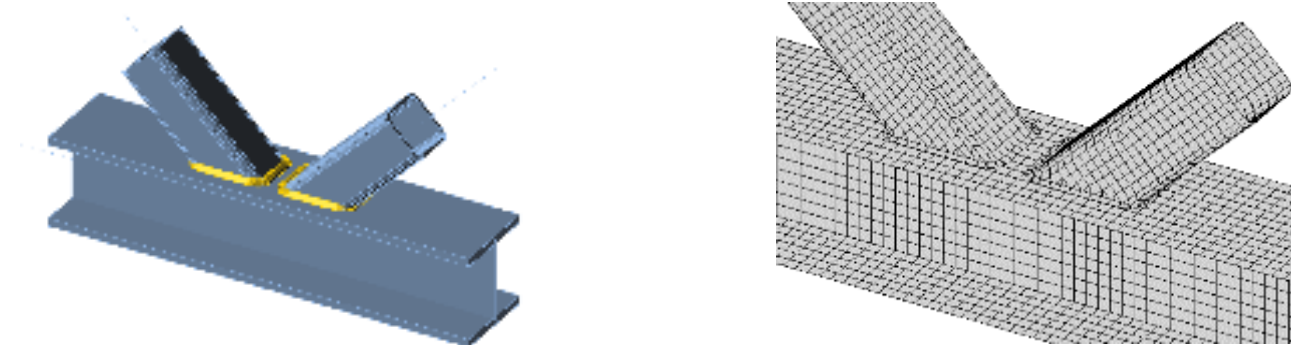
50

Welds

o   Filled weld is modelled by equivalent solid elastoplastic element, which is added between plates to express the weld behaviour, see Fig. below.

o   The element respects the weld throat thickness, position, and orientation to assure a good representation of weld deformation stiffness, resistance and deformation capacity.

o   The plastic strain in weld is limited to 5% as in basic material.
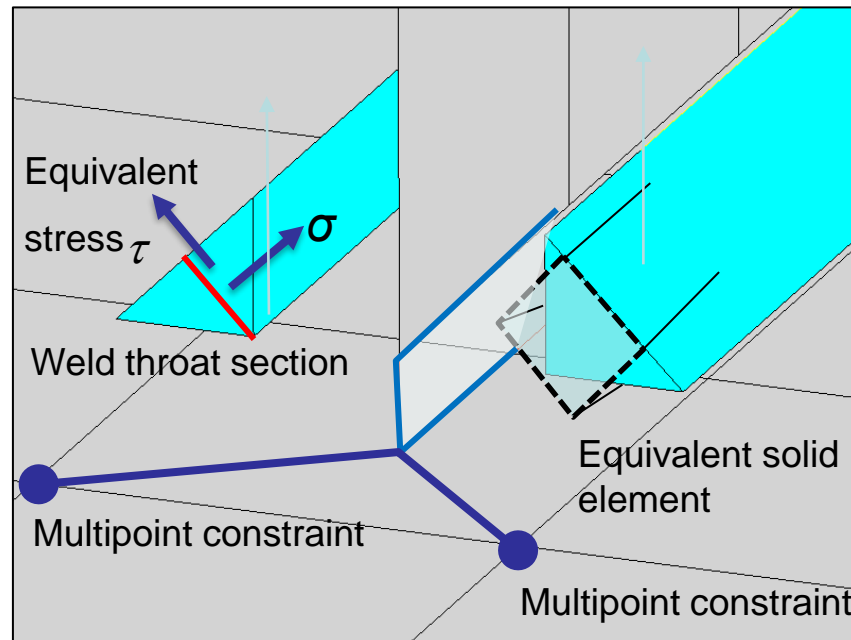
Wald et al. (2016)

Verification & Validation

o The need and position of Verification & Validation in prediction of the reality is demonstrated on the diagram below
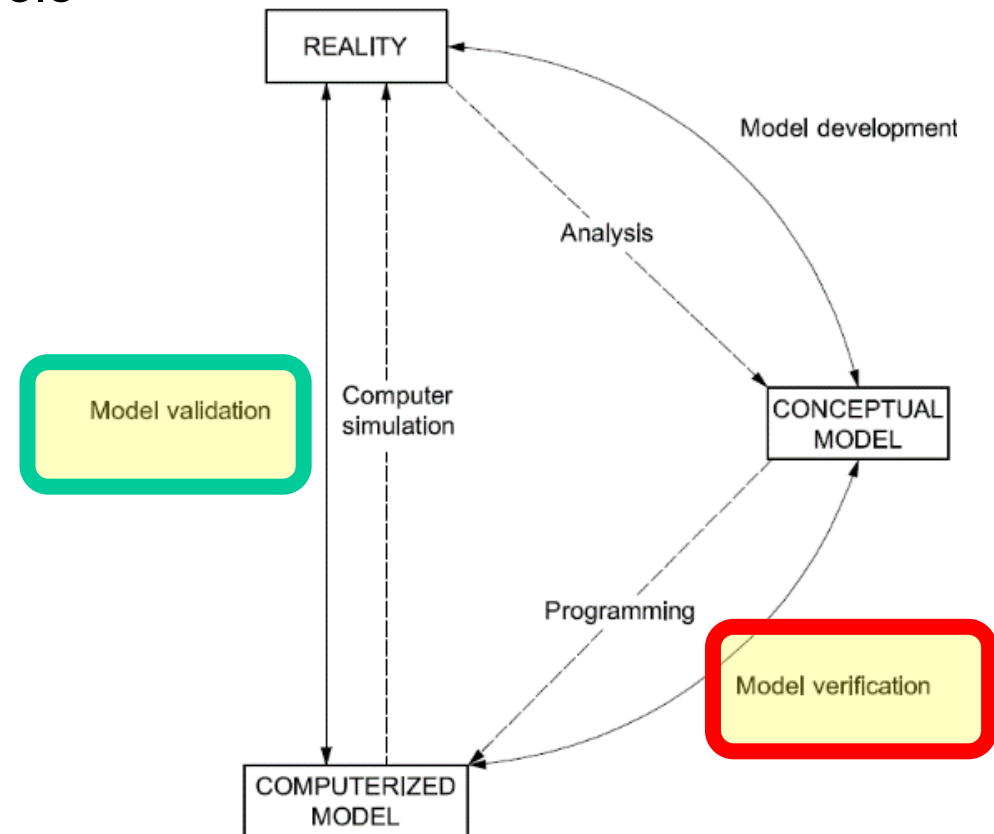
ISO/FDIS 16730
Fire safety engineering - Assessment, verification and validation of calculation methods, Geneva, 2008.

Design and research oriented model

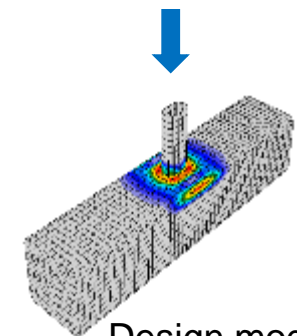Current approval of design models consist of

1) **Experiments**

o **Research oriented FE model** (ROFEM)

2) **Validated** on experiments

3) Numerical experiments

o **Design numerical model** (DOFEM)

4) **Verified** to numerical experiments and/or another design models

5) Sensitivity study

6) Validity range

o **Benchmark case** (BC)

7) To help the users of model to check up its correctness and proper use

Experiment

Research model

Design model

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Experiments with
T joint of hollow to open section

o In compression

o In bending

54

Experiments in compression

o Geometry

Specimen number	Chord (mm)						Brace (mm)			
	b_0	h_0	t_f	t_w	r	L_0	h_1	b_1	t_2	L_1
A1	140	133	8,5	5,5	12	1050	150	100	12,5	500
A2	140	133	8,5	5,5	12	1050	150	100	5	500
A3	140	133	8,5	5,5	12	1050	80	140	4	500
A4	135	270	10,2	6,6	15	1050	150	100	12,5	500

o Failure modes

A3 - Brace failure   A1 - Chord web failure

55

Results of experiments in compression

Resistance	A1	A2	A3	A4
Failure	Chord web	Brace	Brace	Chord web
$F_{peak\ load}$ [kN]	775,14	620,01	355,24	780,7:
$F_{3\%b0}$ [kN]	643,99*	590,04	354,60	644,23
$F_{\varepsilon 5\%}$ [kN]	646,08	540,36	324,83	685,2:

* decreasing load after reaching the peak load
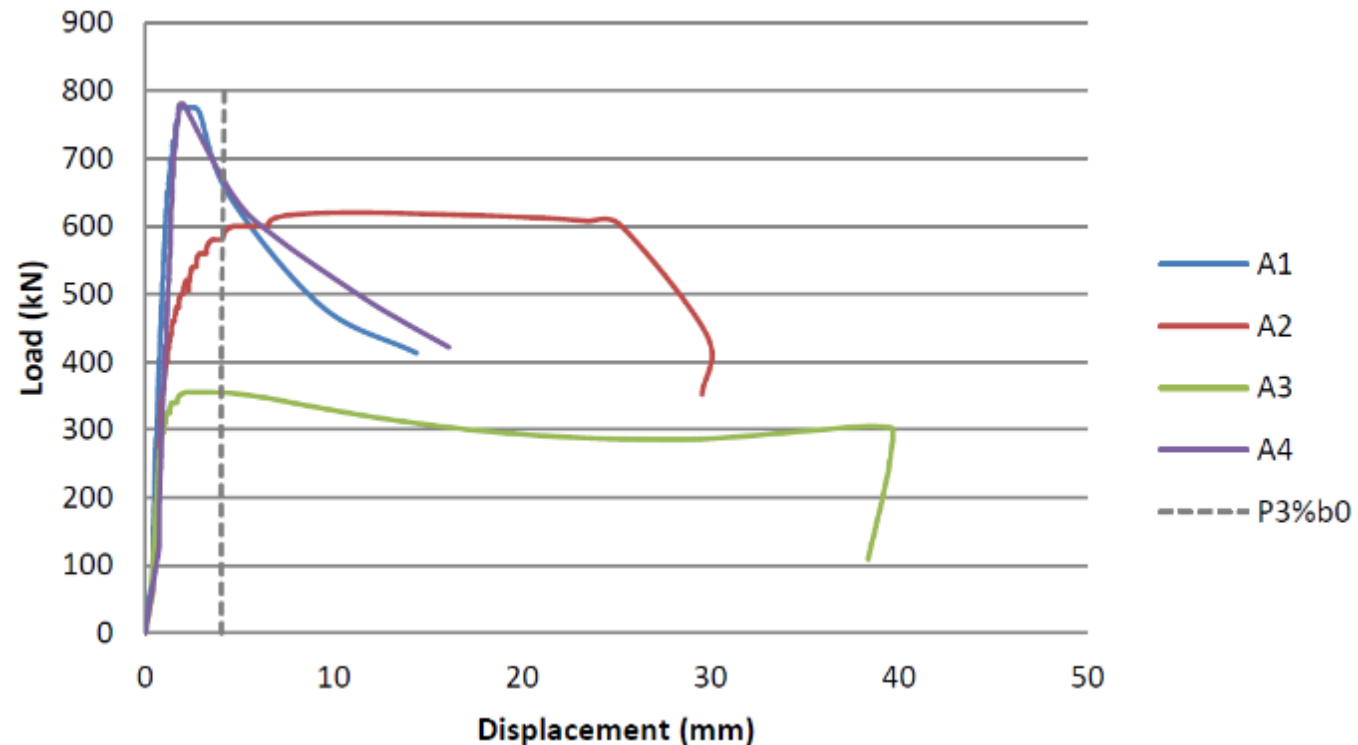
Research oriented FEM

- ABAQUS 6.13

- Solid quadratic element (20-node brick, C3D20)
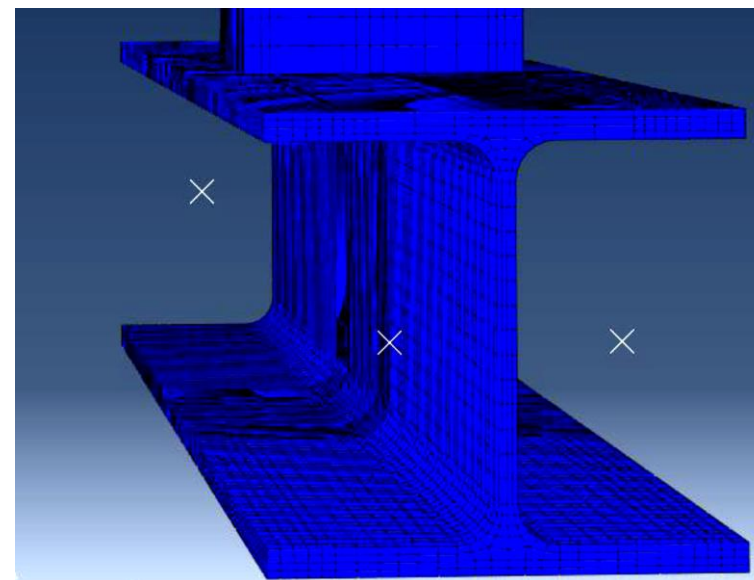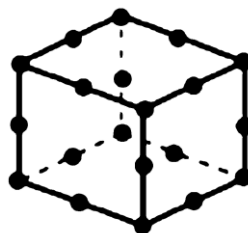
- True stress-strain multilinear material model

HEA140		IPE270		RHS150X100X5		RHS150X100X12.5		RHS140X80X4	
σ_{true} [MPa]	$\varepsilon_{plas,true}$	σ_{true} [MPa]	$\varepsilon_{plas,true}$	σ_{true} [MPa]	$\varepsilon_{plas,true}$	σ_{true} [MPa]	$\varepsilon_{plas,true}$	σ_{true} [MPa]	$\varepsilon_{plas,true}$
0	0	0	0	0	0	0	0	0	0
386,44	0	448,36	0	519,89	0	579,93	0	357,84	0
389,92	0,009	452,45	0,009	524,54	0,009	583,57	0,006	361,59	0,010
601,86	0,060	603,43	0,046	580,85	0,028	675,93	0,034	538,71	0,054
678,36	0,179	689,40	0,179	676,20	0,179	781,56	0,179	611,04	0,179

Boundary conditions for research oriented FEM

- Bottom flange boundary condition
  - Rotation and translation restrain in all axis

- Load point
  - Coupling to top of braces edges
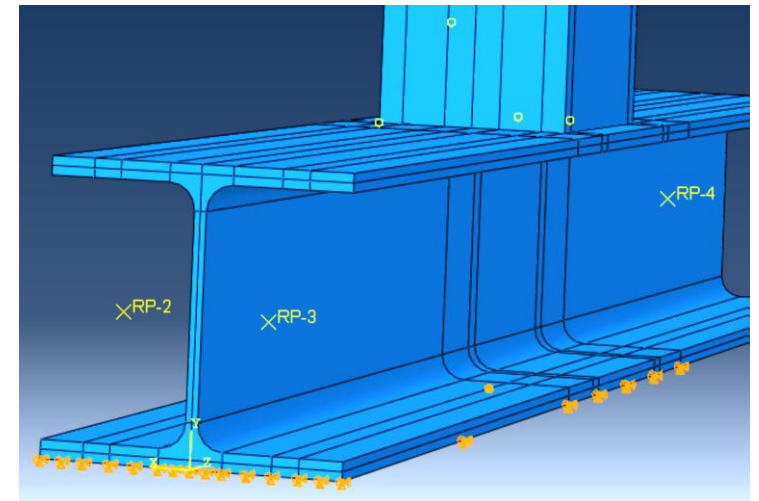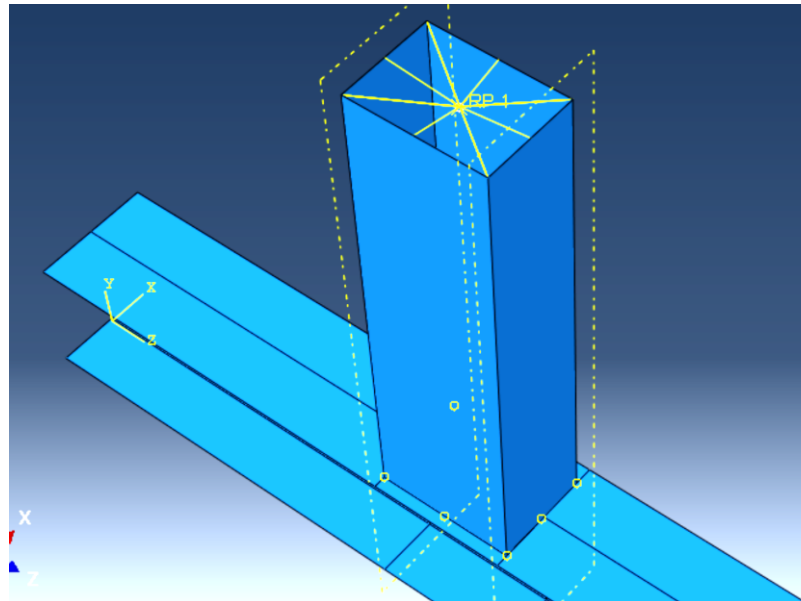
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Validation of failure modes

o Both failure modes were well predicted

Resistance	A1	A2	A3	A4
Failure	Chord web	Brace	Brace	Chord web
$P_{peak\,load}$ [kN]	775,14	620,01	355,24	780,71
$P_{3\%b0}$ [kN]	643,99*	590,04	354,60	644,23*
$P_{\varepsilon 5\%}$ [kN]	646,08	540,36	324,83	685,24

o Failure of chord web, experiment A1
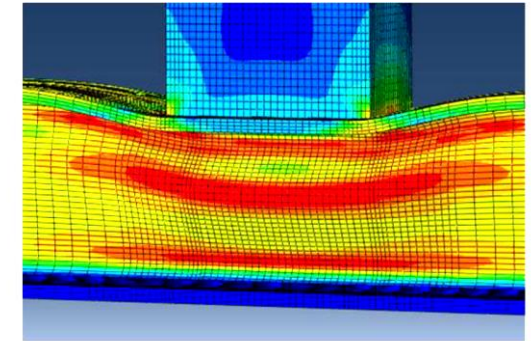
o Failure of brace, experiment A2
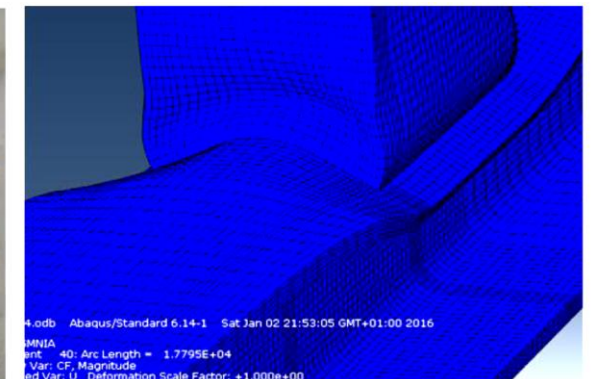
59

Mesh sensitivity study

o The Figure below shows the importance of the mesh size to the prediction of behaviour of joint
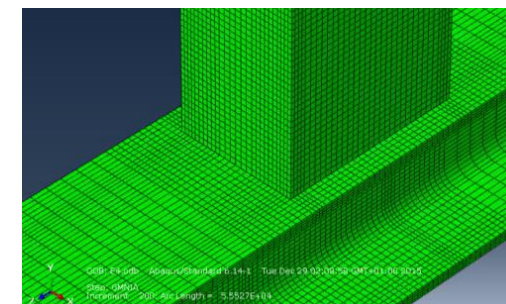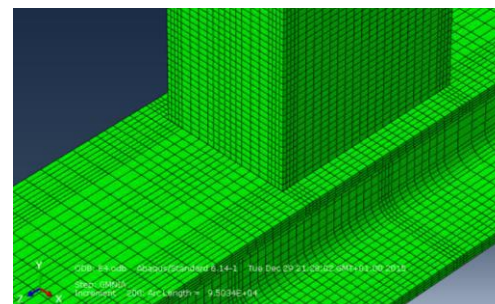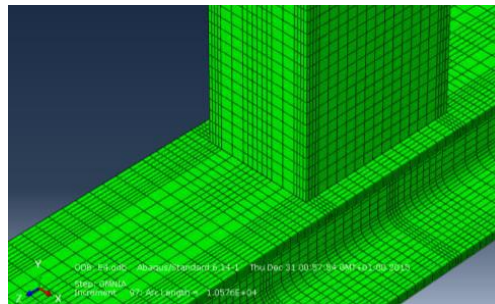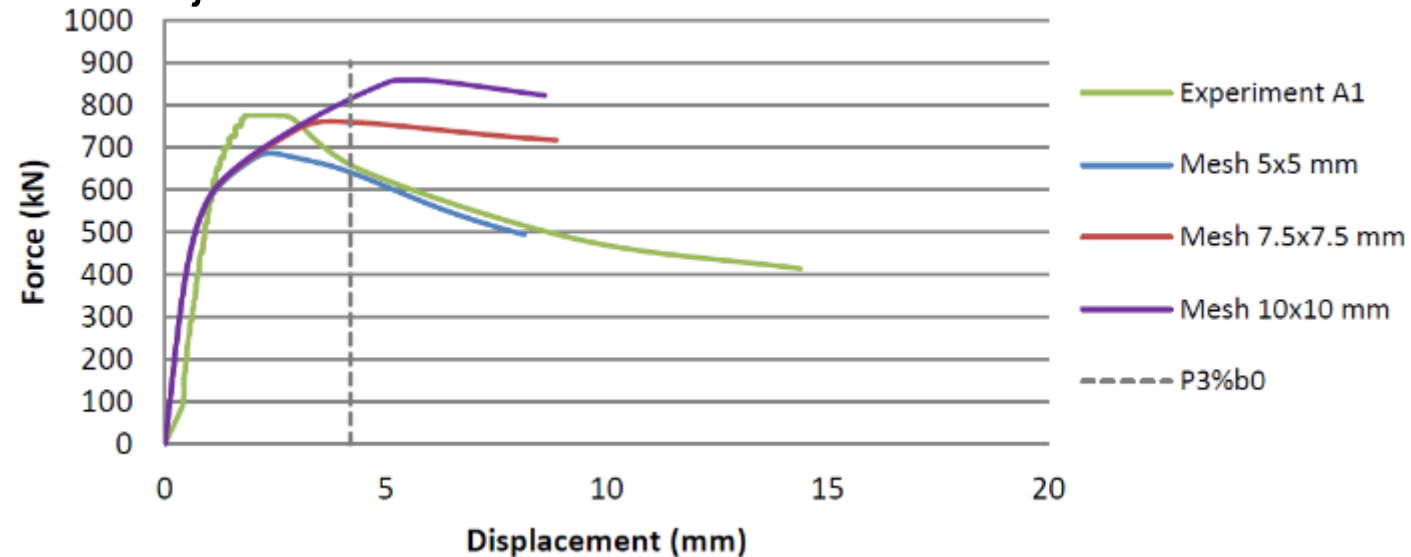
Description of local and global behaviour

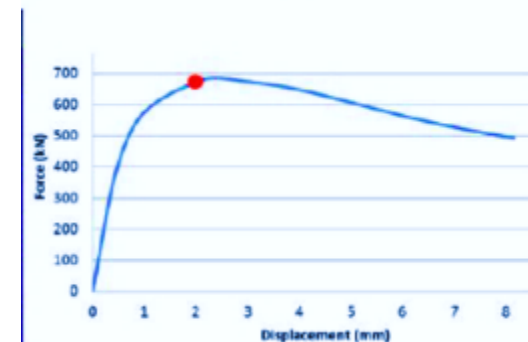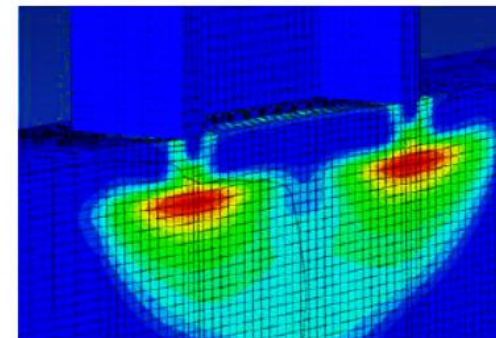## Development of plastic zones

o The first yielding
in the chord web
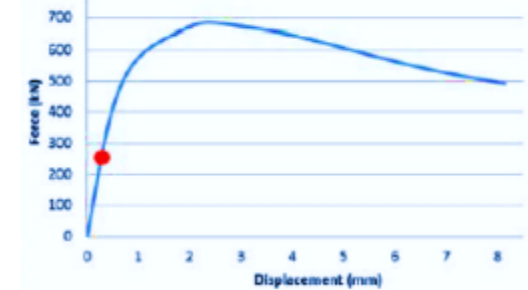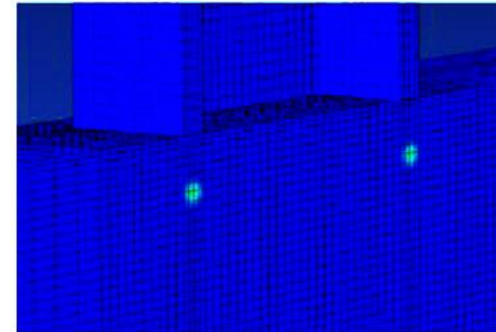
o 5% strain
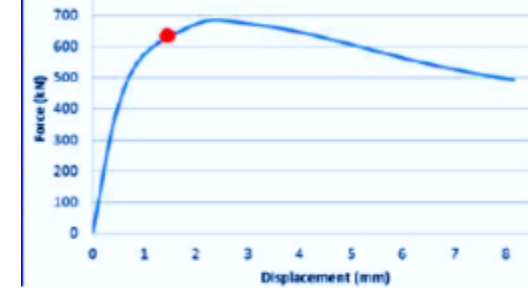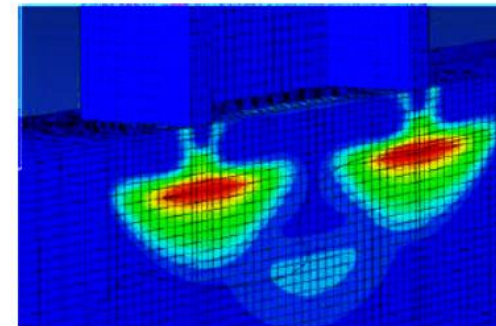
o Full plasticity
at the peak load

Quality of prediction of resistance

o The validation should answer the quality of prediction on global behaviour namely in important points of design.

o Table below shows the prediction of resistance by deformation of upper surface $b_0/300$ (used by curve fitting models) and 5% of strain (used by numerical models) for experiment in compression A1 with failure of chord web.

	Experiment A1	ROFEM	%
$P_{peak\ load}$ (kN)	775,1	686,0	*12%*
$P_{5\%\ strain}$ (kN)	646,1	683,9	*6%*
$P_{3\%b0}$ (kN)	620,3	638,3	*3%*

Verification of T-joint and K-joint
CBFEM model to failure mode procedure

o   A uniplanar T-joint and K-joint of a rectangular hollow section brace to an open section chord.

o   The brace section is RHS 140x70x10.

o   The chord sections are IPE, IPN, HEA a HEB.

o   The brace is loaded in tension/compression or by in-plane bending moment.
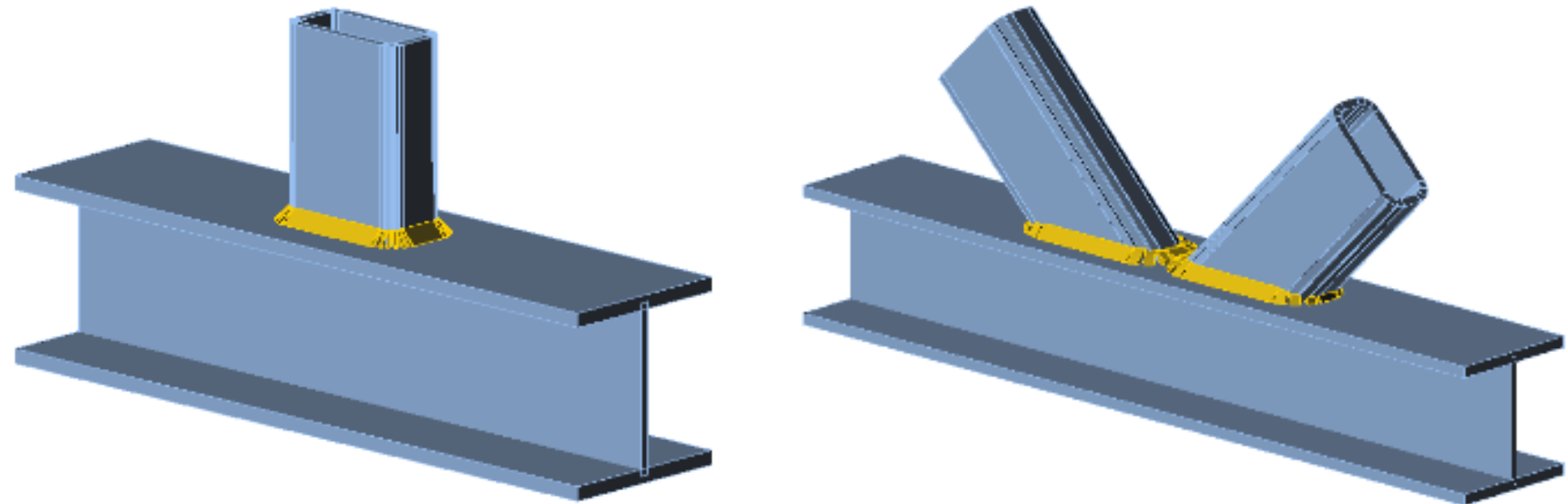
Verification of T-joint and K-joint in compression

o The prediction by component based finite element method (CBFEM) is verified with the failure modes (FM) implemented in EN 1993-1-8:2005.

o Three failure modes occur in joints of the welded rectangular hollow sections to the open sections, e.g. the local yielding of brace (brace failure), the chord web failure and the chord shear.
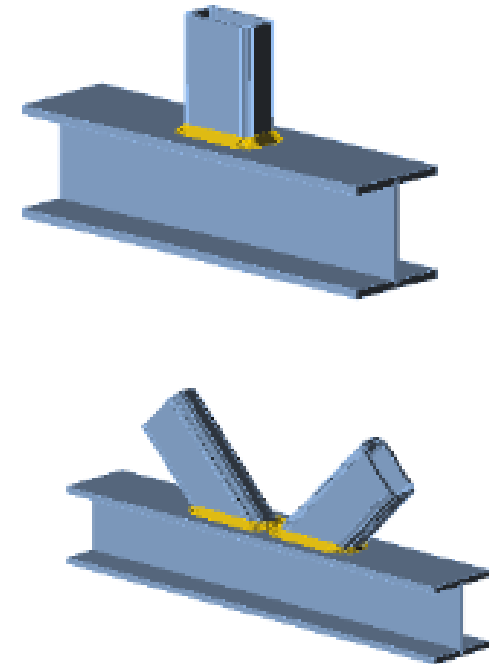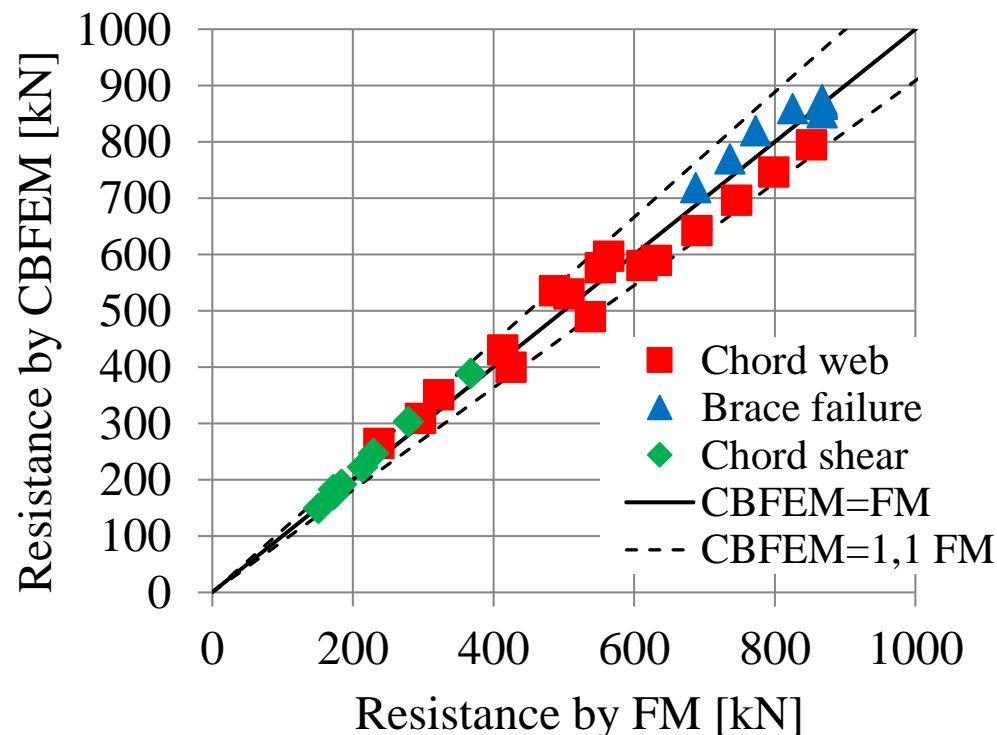
Verification of T-joint in bending

- The prediction by component based finite element method (CBFEM) is verified with the failure modes (FM) implemented in EN 1993-1-8:2005.

- Two failure modes occur in joints of the welded rectangular hollow sections to the open sections, e.g. the local yielding of brace (brace failure) and the chord web failure.
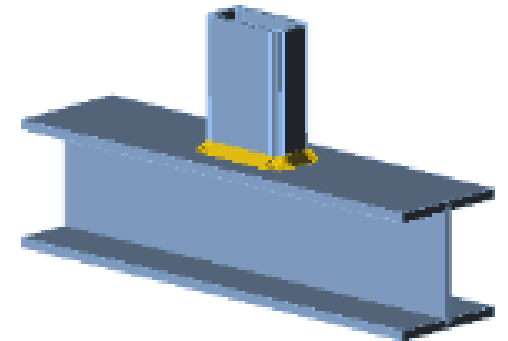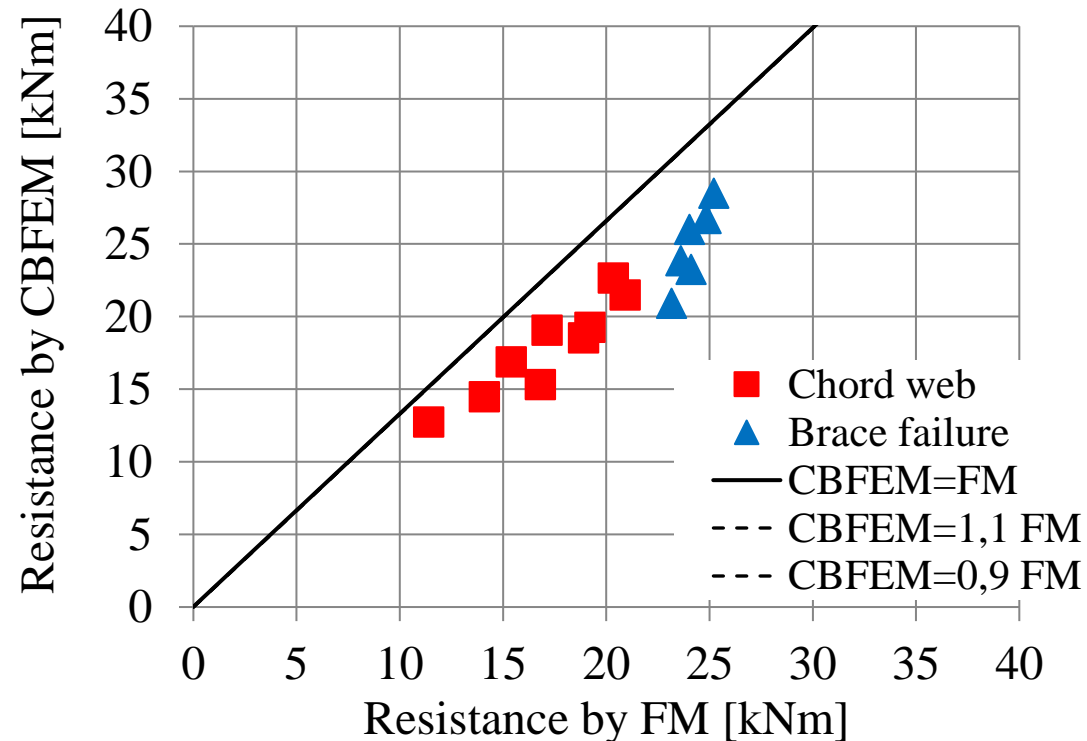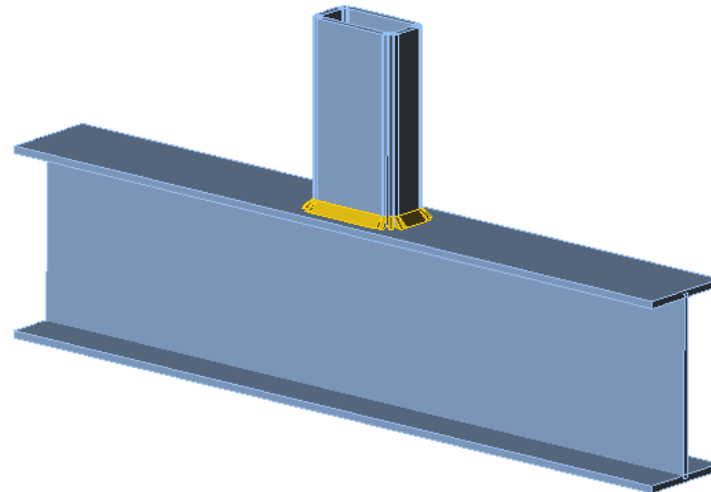
Benchmark case
Uniplanar T-joint between RHS brace and I chord

o **Input**

  o Chord: IPE270, Steel S235

  o Brace: RHS 140x70x10, Steel S235

  o Weld: Throat thickness a_w = 10 mm, Fillet weld around the brace

o **Output**

  o Design resistance in compression/tension $F_{c,Rd}$ = 431 kN

  o Collapse mode is full yielding of the chord web
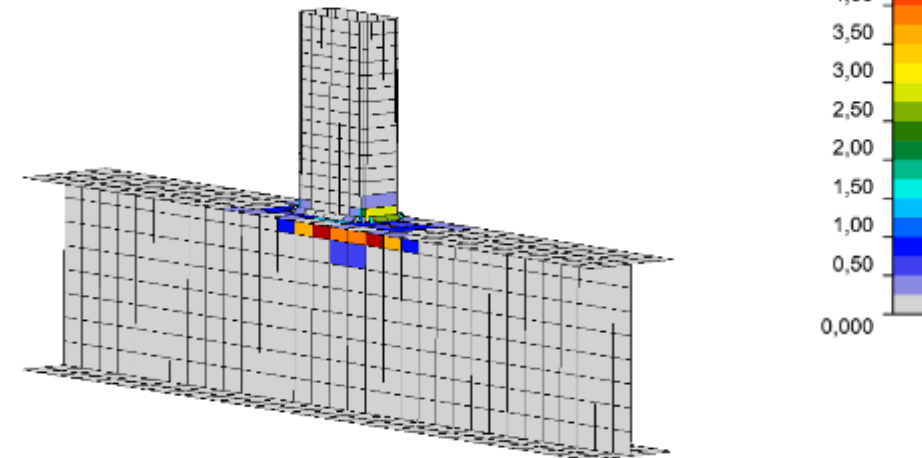
Plastic strain [%]

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Assessment II

o How is modelled the material for research and how for design models?

o What elements are recommended for plates?

o How are modelled welds?

o What is expected to be the accurate solution in mesh sensitivity study?

o How differs validation from verification?

o What are two major purposes of benchmark cases in application of FEA analyses?

Summary

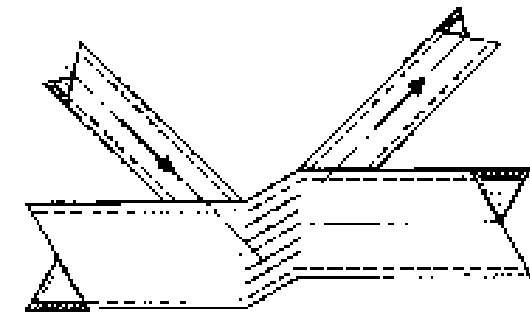Lecture 3

Joint of hollow to open section

Summary

○ The hollow sections to open sections joints belongs to family of hollow section joints.

○ There are three failure modes

  ○ Brace failure

  ○ Chord web failure

  ○ Chord web shear failure in case of gap
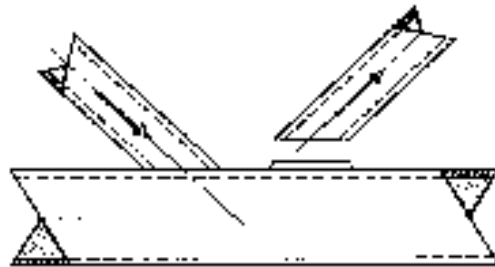
Brace failure
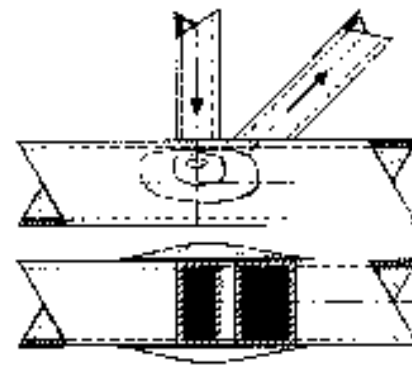
Chord web failure

Shear failure of the chord

Summary

o The curve fitting methods are used to evaluate design resistances for each possible failure mode.

o The range of validity limits the application of the expressions to experimentally verified solutions only.

o The component-based approach is a great simplification for the design of some rectangular hollow sections.

o For design of circular hollow sections brings unpleasant complexity.

o It cannot be used for complex joints in general.

Prediction of global and local behaviour

T joint of RHS brace and HEA chord

o Chord HEA180

o Brace RHS 180x100x8.8

o Steel S355

o Weld throat thickness 11 mm
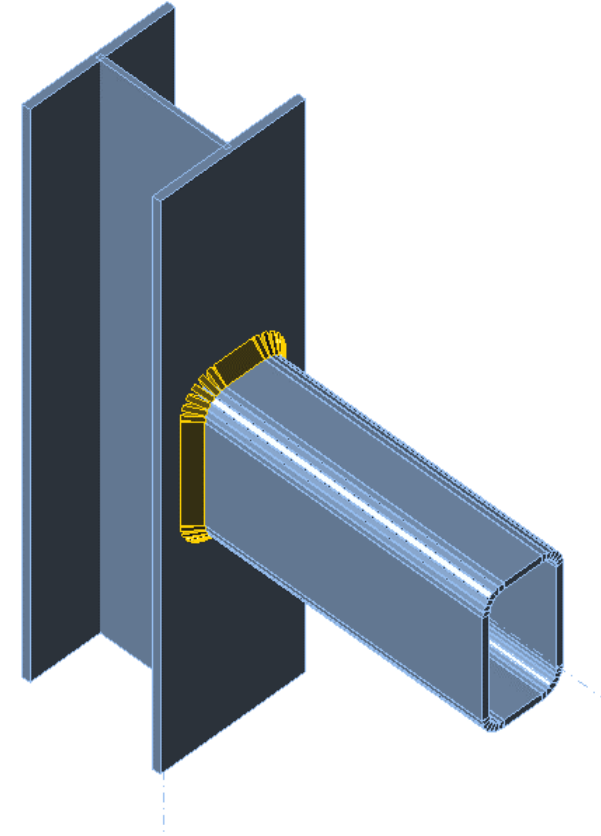
Global and local behaviour

Elastic stage
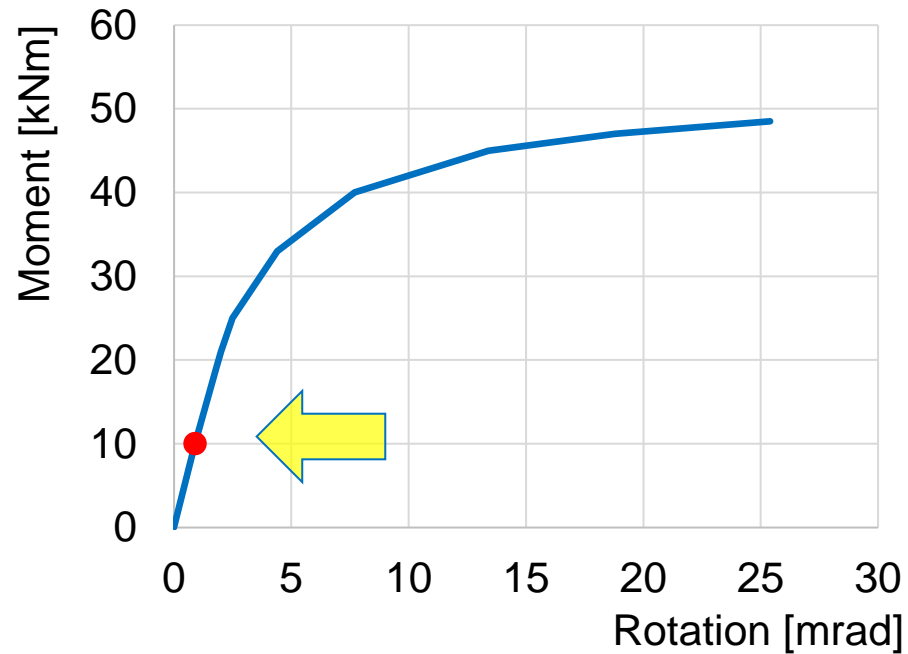
$M = 10$ kNm

$\varphi = 0{,}9$ mrad

$S_j = 10{,}7$ MNm/rad
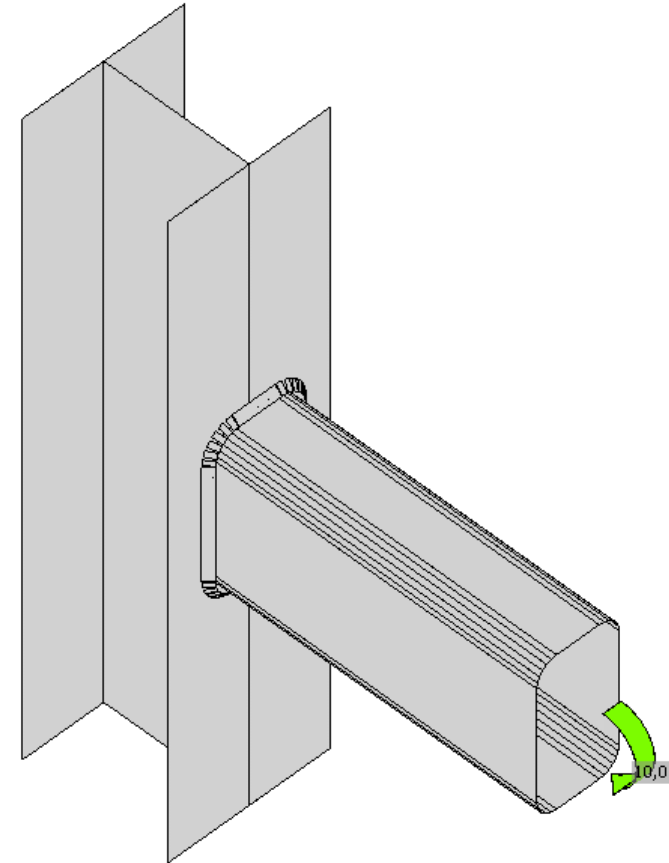
Global and local behaviour

Plastification of the upper flange of RHS brace

M = 19 kNm

φ = 1,8 mrad

S_j = 10,7 MNm/rad

Global and local behaviour

Initial plastification in the open section web

$M = 21$ kNm

$\varphi = 2{,}0$ mrad

$S_j = 10{,}6$ MNm/rad

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Global and local behaviour

Initial plastification in the weld

$M = 25$ kNm

$\varphi = 2{,}5$ mrad

$S_j = 10{,}0$ MNm/rad

Global and local behaviour

Initial plastification in the open section flange

M = 33 kNm

φ = 4,4 mrad

S_j = 7,6 MNm/rad

Global and local behaviour

Initial plastification in the RHS brace roundings

M = 40 kNm

φ = 7,7 mrad

S_j = 5,3 MNm/rad

Global and local behaviour

Full plastification through the open section web

$M = 47$ kNm

$\varphi = 18{,}8$ mrad

$S_j = 2{,}6$ MNm/rad
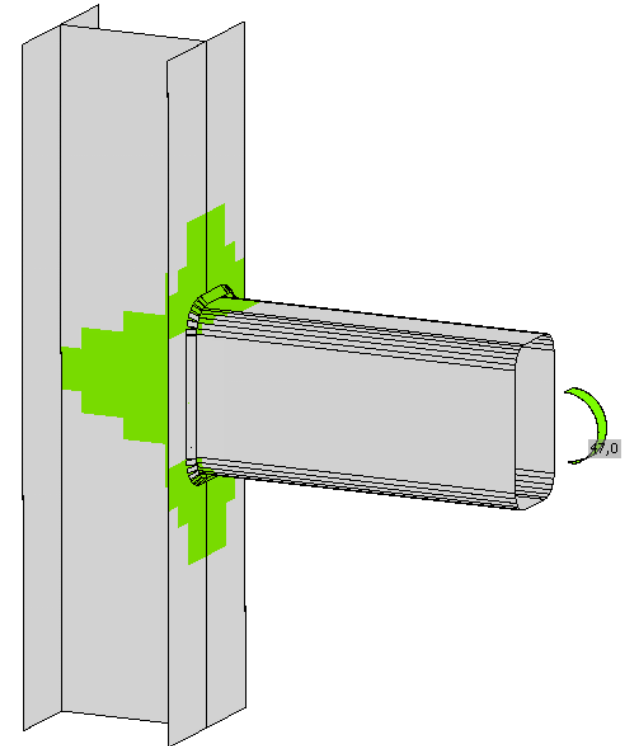
Global and local behaviour

The open section web reaches plastic strain 5%
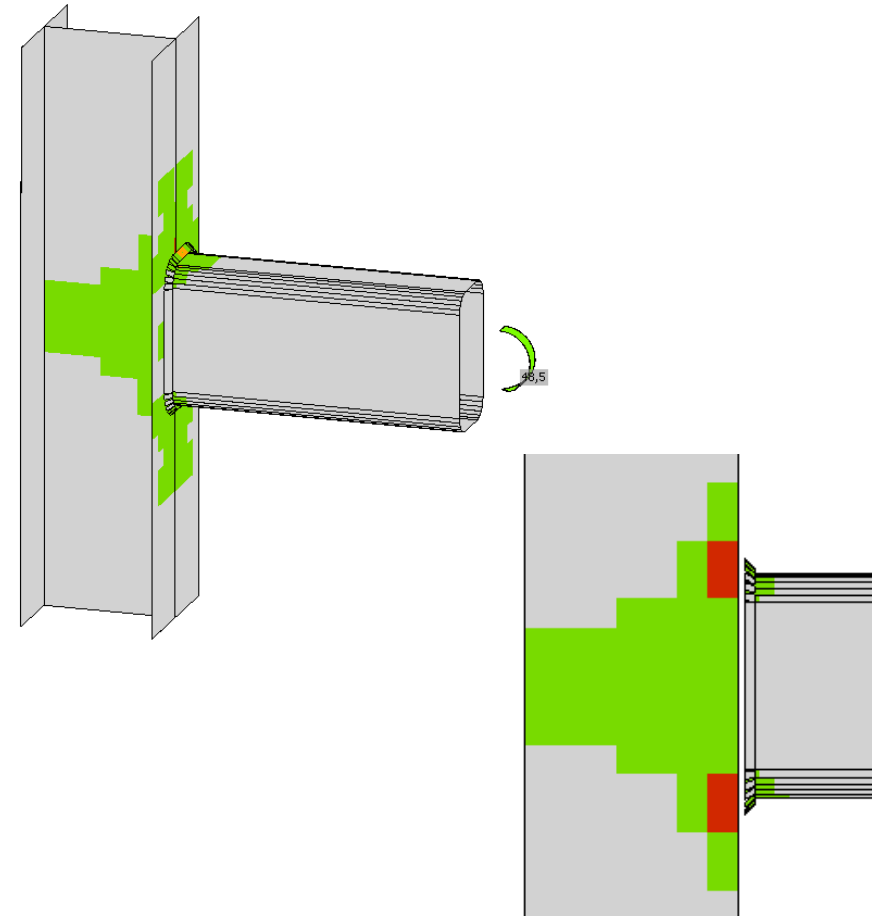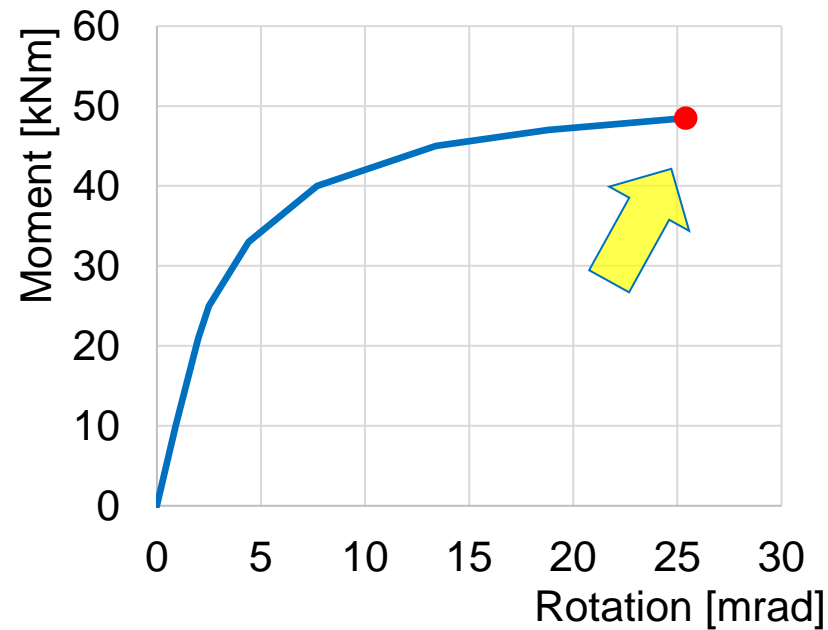
$M = 48{,}5$ kNm

$\varphi = 25{,}4$ mrad

$S_j = 2{,}2$ MNm/rad

What is the major reason

of using CBFEM for Hollow section joints ?

o **The design resistance of generally loaded complex hollow section joints** may be by failure mode method only estimated.

o The example of design procedure by CBFEM is shown below.
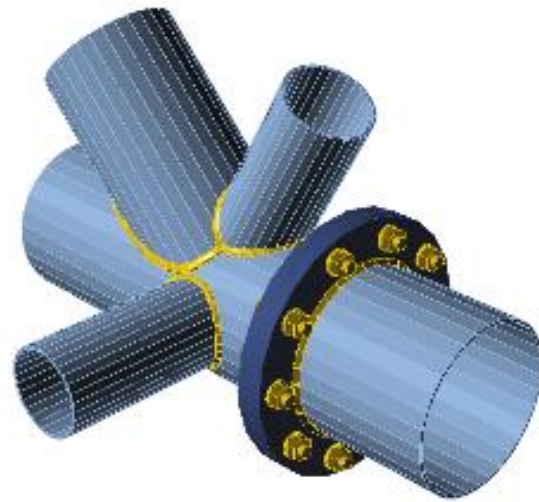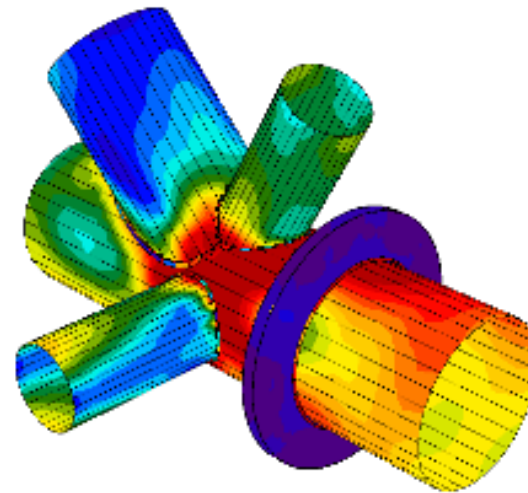
3D model　　　Finite element analyses　　　Design check
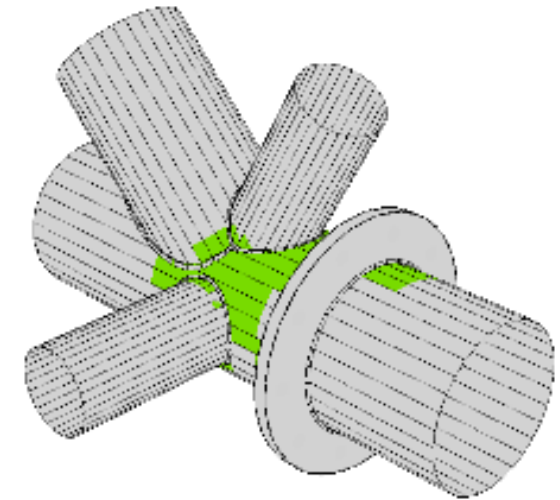
Design tips

o The most economical and common way to connect hollow sections to open sections is by direct connection, without the use of cross plates or gussets, which is also the most efficient method for protection and maintenance.

o Connections between hollow and open sections are easy to make because the connectors have only straight end cuts.
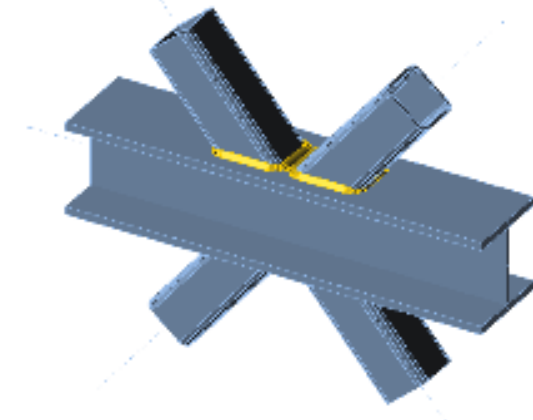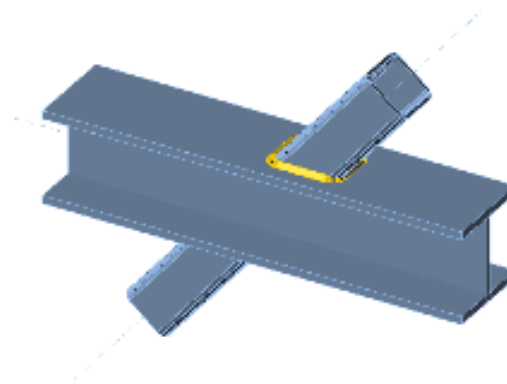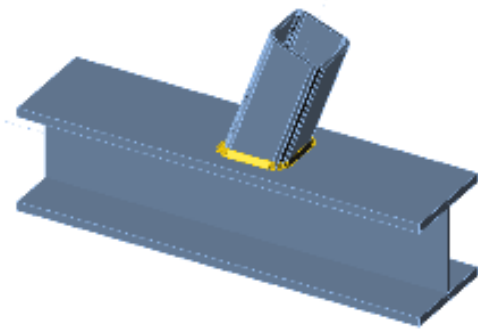
Design tips

o Tips to optimize design

  o Select relatively stocky chord

  o Select relatively thin brace
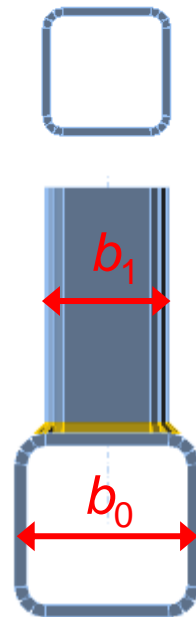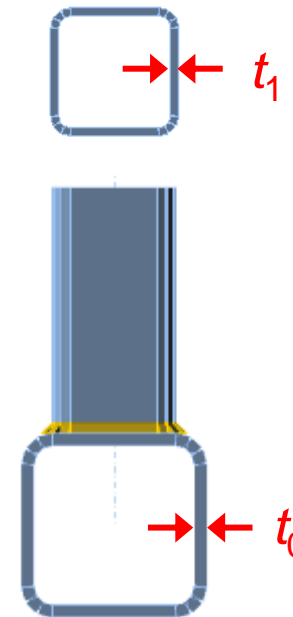
b_1/b_0 as high as possible t_1/t_0 as low as possible

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Design tips

o Tips to optimize joint design

  o Consider virtues of <u>gapped</u> K-connections
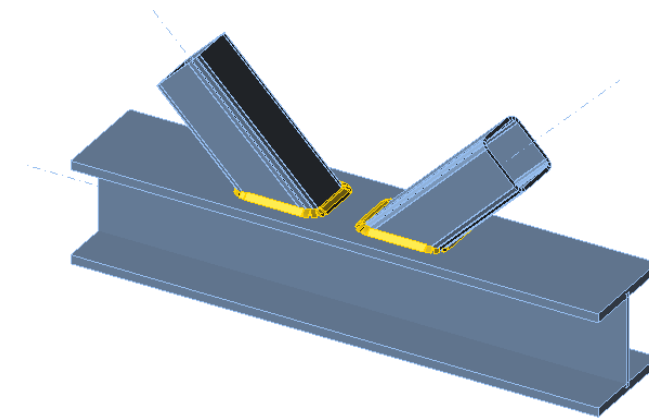
  o Gapped joints are easier and cheaper to fabricate.
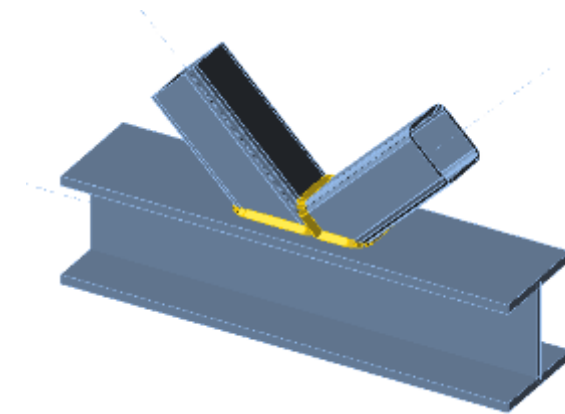
  o Overlapped joints have higher static and fatigue strength and produce stiffer truss (reduced truss deflections).

Thank your for attention

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Notes to users of the lecture

- Subject Design of hollow section joints of steel structures.

- Lecture duration 60 mins.

- Keywords Civil Engineering, Structural design, Steel structure, Trusses, Truss girder, Joint, Hollow section joint, Hollow to open section joint, Component Method, Component based Finite Element Method, Eurocode.

- Aspects to be discussed Curve fitting models of joints, Failure mode models of joints, FE models of joints, Failure modes, Component method principle, Application of analytical modelling

- Further reading relevant documents in references and relevant European design standards, Eurocodes including National Annexes.

- Preparation for tutorial exercise see examples in References.

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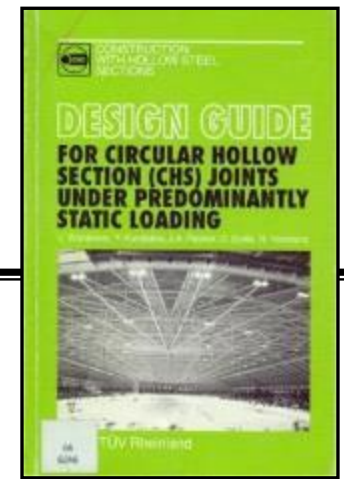
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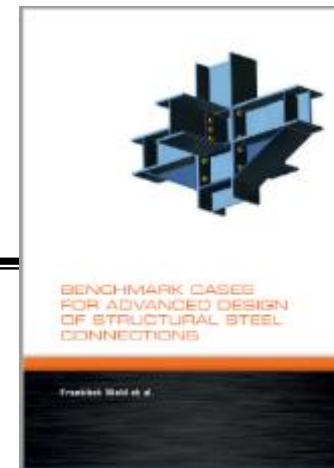
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