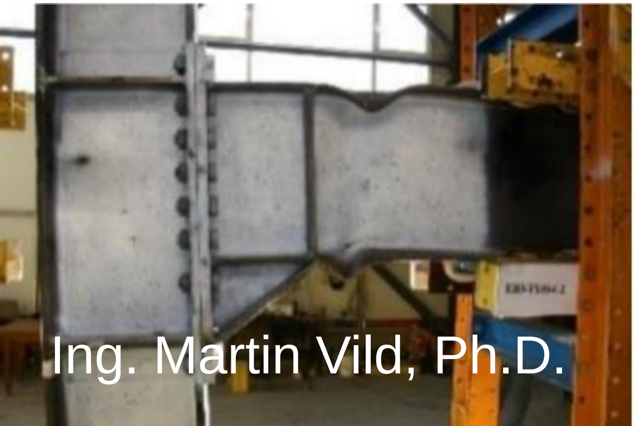
BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF CIVIL ENGINEERING

CAPACITY DESIGN USING CBFEM



Ing. Martin Vild, Ph.D.

18th April 2019

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    - Seismic loads
- Capacity design
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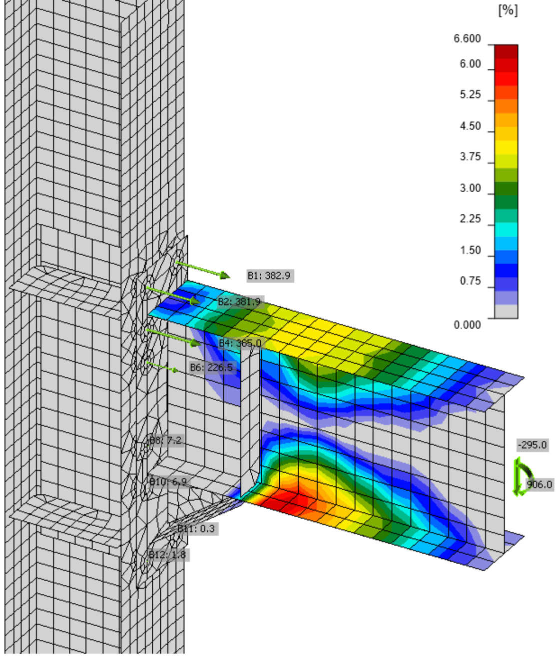
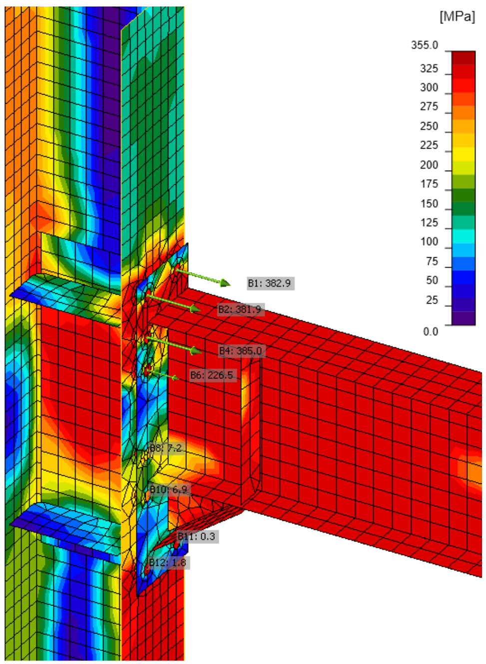
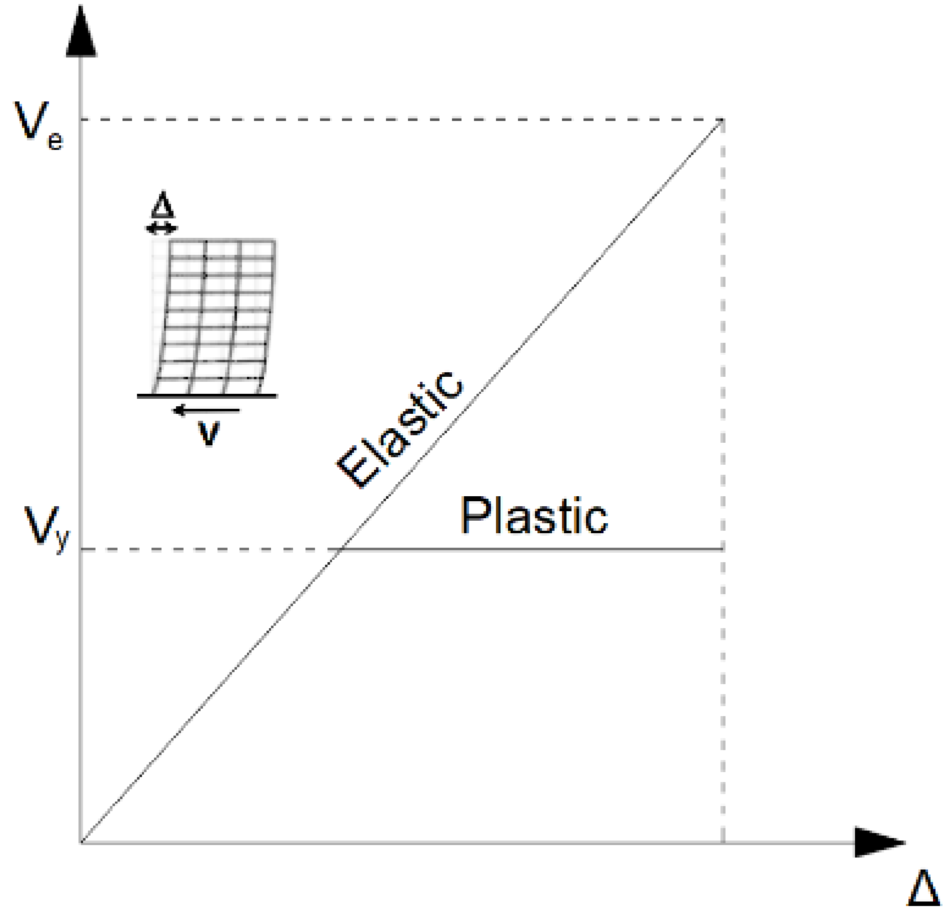




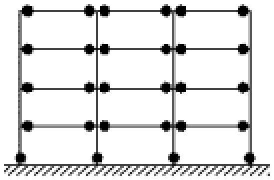
Seismic design

- Seismic loads may be very high
- Using dissipative structural behavior, loads may be decreased
- Ductility must be ensured

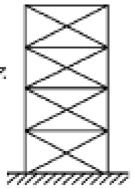


Structural types

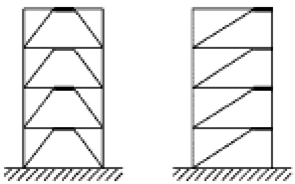
- Moment resisting frames (MRF)



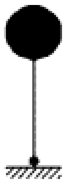
- Frames with concentric bracings (CBF)



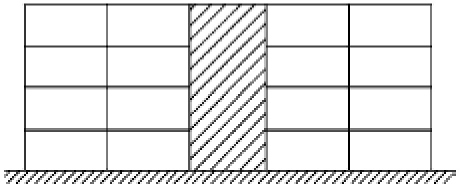
- Frames with eccentric bracings (EBF)



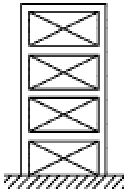
- Inverted pendulum structures



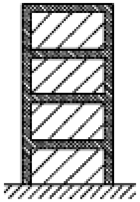
- Steel structures associated to concrete cores or concrete walls



- Dual frames made of moment resisting frames combined with braced frames

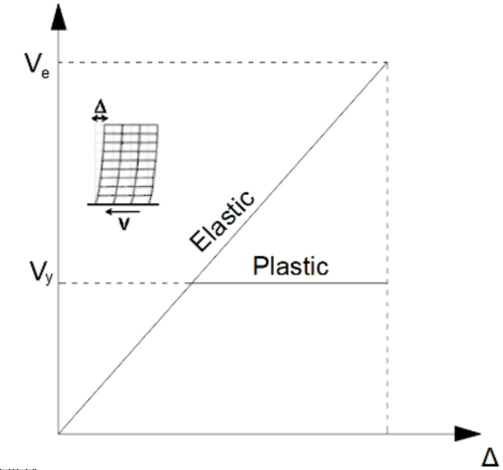


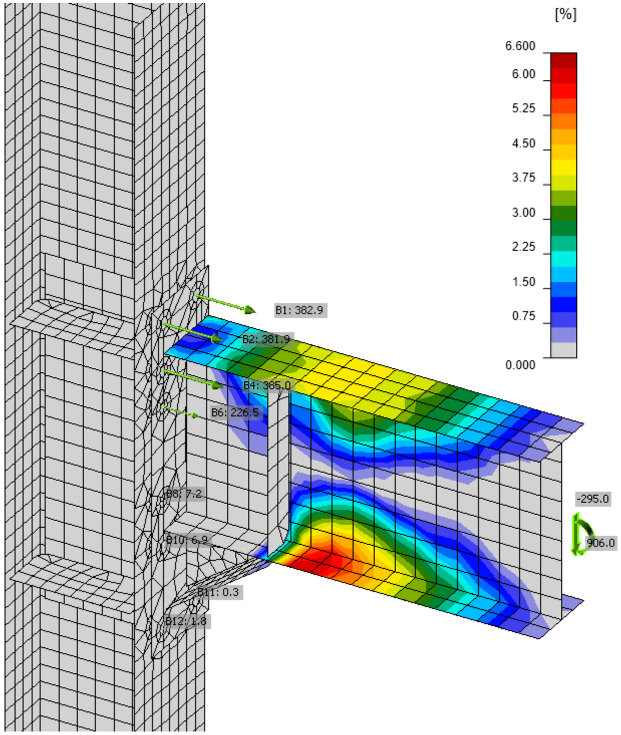
- Moment resisting frames combined with reinforced concrete infills



Seismic loads

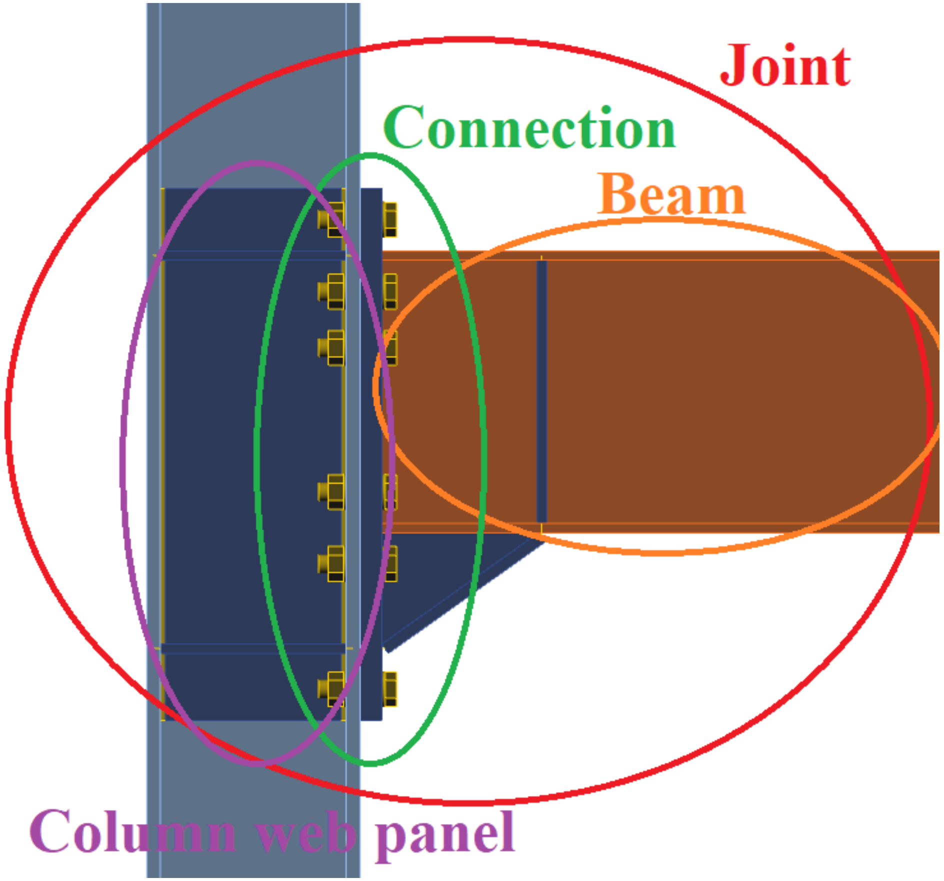
1. Seismic load combination
   - decreased by behavior factor *q*
2. Capacity design
   - Selected element(s) yield while other elements are strong
   - Required for ductility class medium and high





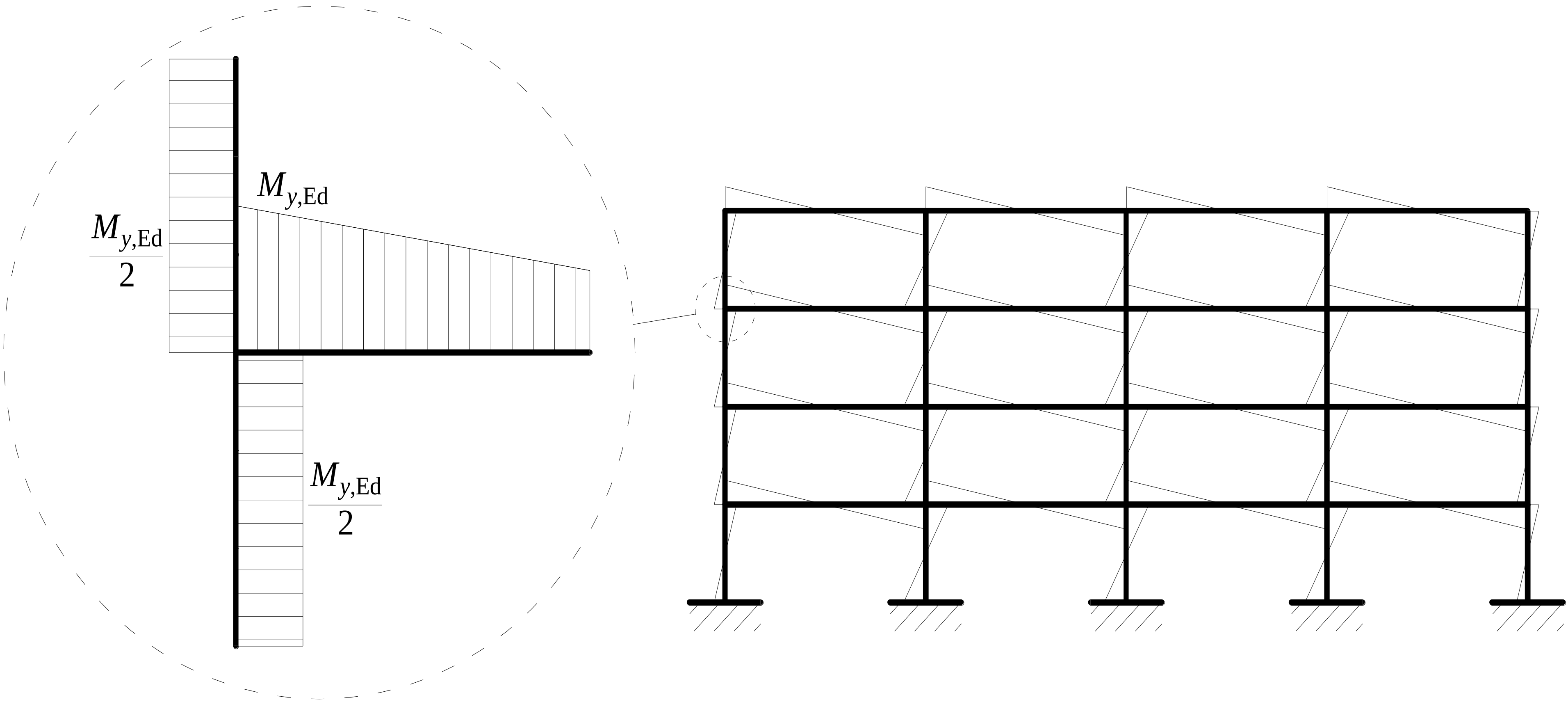
Capacity design

- Aim is to prove that the structure has sufficient ductility
- Proven:
  - structural type
  - joint type
  - detailing

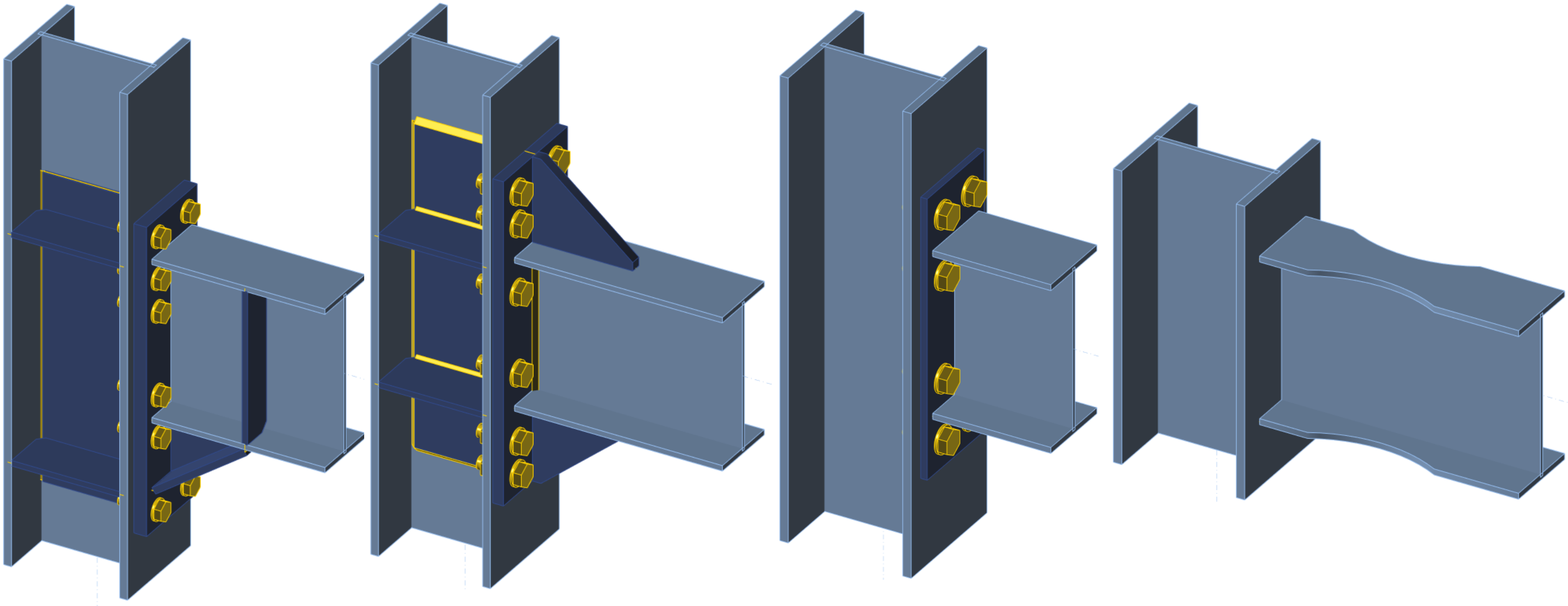


Capacity design – loads

- Plastic hinge at the end of each beam



Joint types



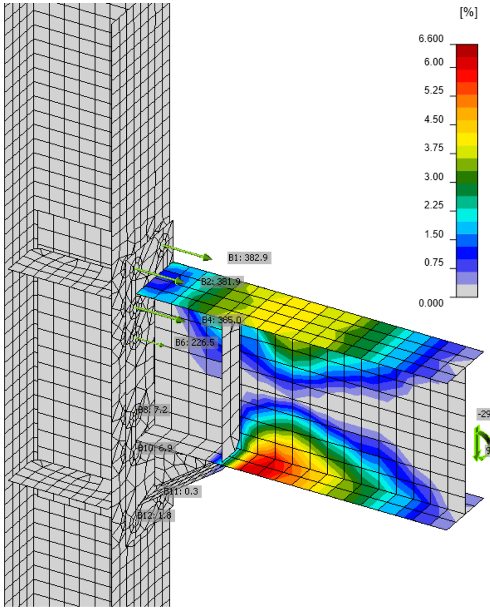
Haunched

Extended unstiffened end-plate

Extended stiffened end-plate

Reduced beam section

Overstrength



Select the location of plastic hinge

Traditionally, in the beam

$f_{y,max} = \gamma_{ov} \cdot \gamma_{sh} \cdot f_y$

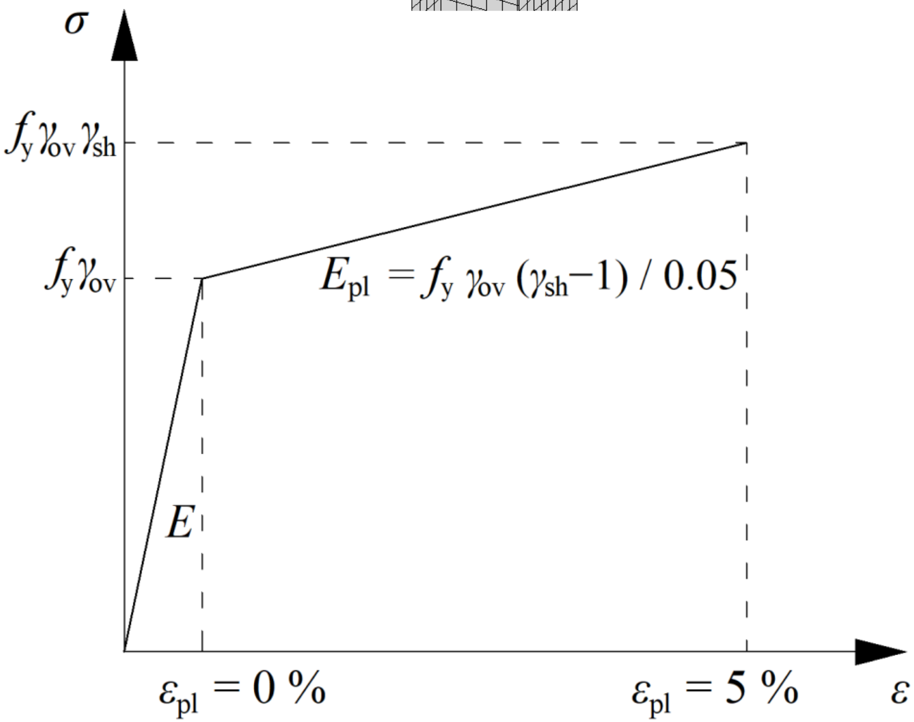
overstrength factor

$\gamma_{ov} = 1.25$

strain-hardening factor

$\gamma_{sh} = 1.1$ ... EN 1998-1

$\gamma_{sh} = 1.2$ ... EN 1993-1-8



Capacity design – Loads

- Load in plastic hinge:

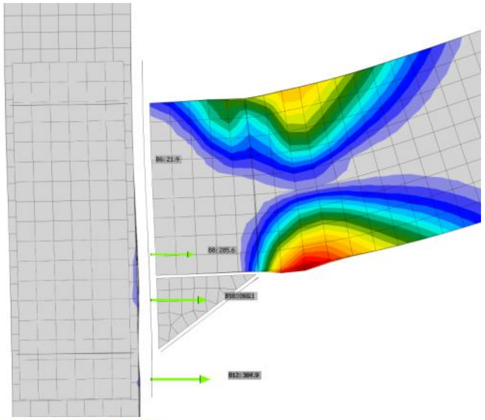
$$M_{\mathrm{Ed}} = W_{\mathrm{pl}} \cdot \gamma_{\mathrm{ov}} \cdot \gamma_{\mathrm{sh}} \cdot f_{\mathrm{y}}$$

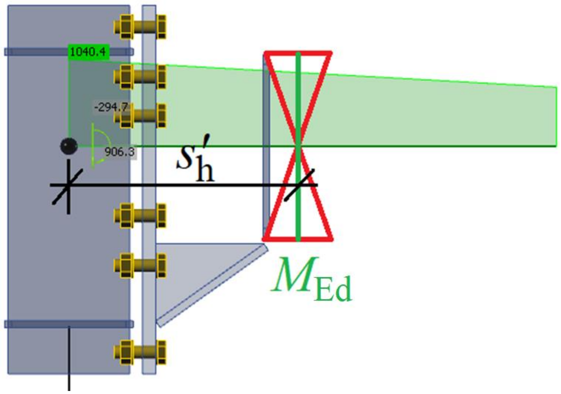
$$V_{\mathrm{Ed}} = \frac{2M_{\mathrm{Ed}}}{L_{\mathrm{h}}} + V_{\mathrm{grav}}$$

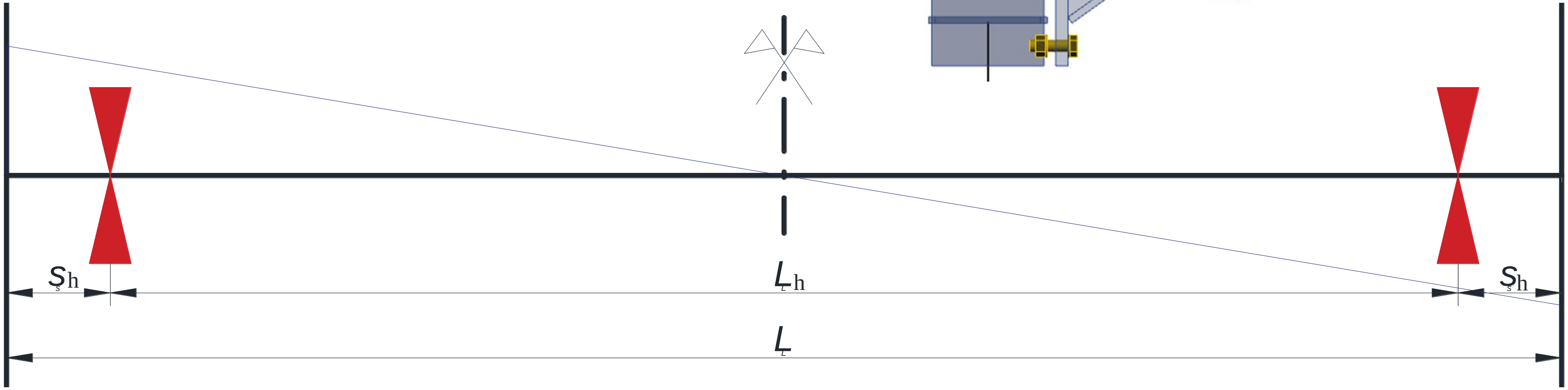
- Load in connection:

$$M_{\mathrm{c,Ed}} = M_{\mathrm{Ed}} + V_{\mathrm{Ed}} \cdot s_{\mathrm{h}}$$

$$V_{\mathrm{c,Ed}} = V_{\mathrm{Ed}}$$

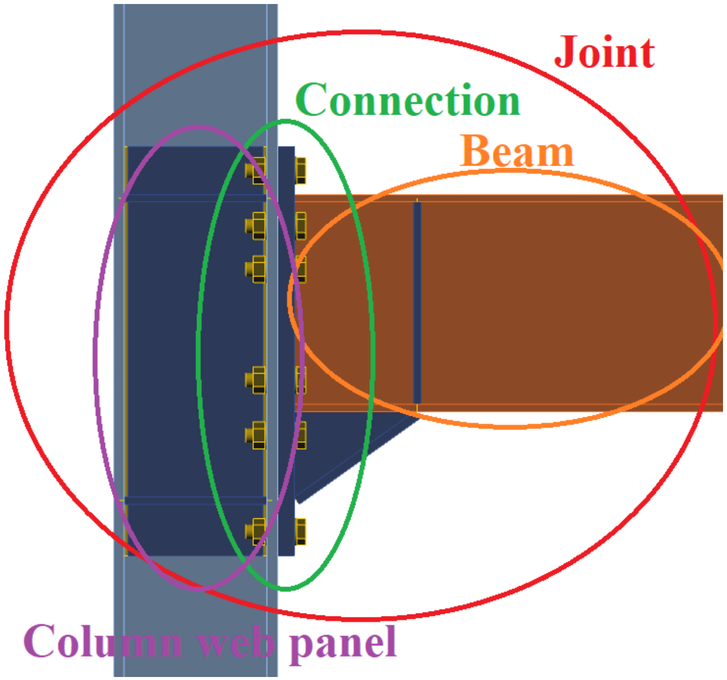






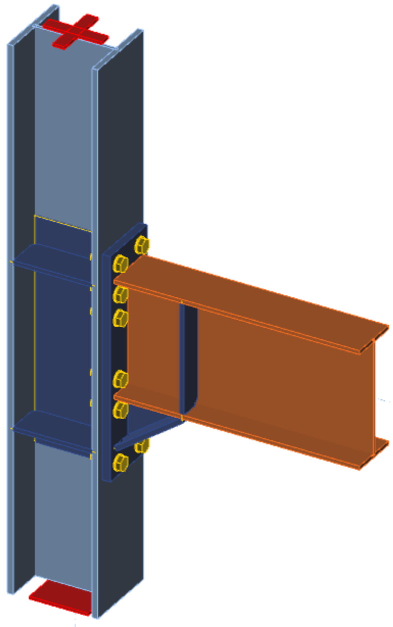
Joint strength classification

1. Full strength
   - plastic demand is concentrated in the beam
   - $\alpha \geq \gamma_{\mathrm{ov}} \cdot \gamma_{\mathrm{sh}}$
2. Equal strength
   - in the beam and connection and/or column web panel
   - $\alpha \approx 1$
3. Partial strength
   - in the connection or column web panel
   - $\alpha < 1$



Three macro-components

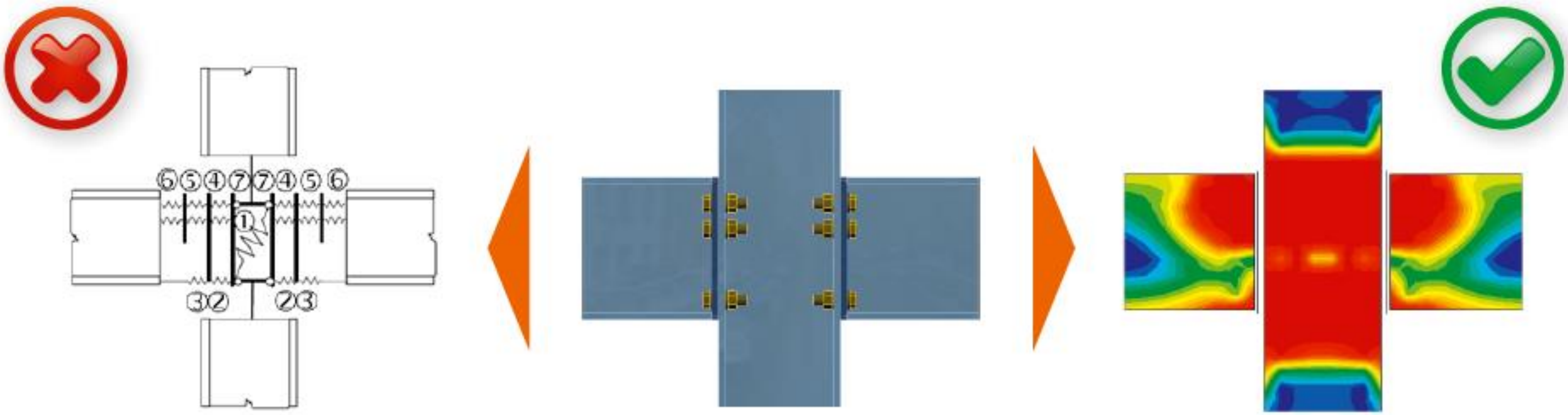
CBFEM



Component Based Finite Element Method

IDEA StatiCa®

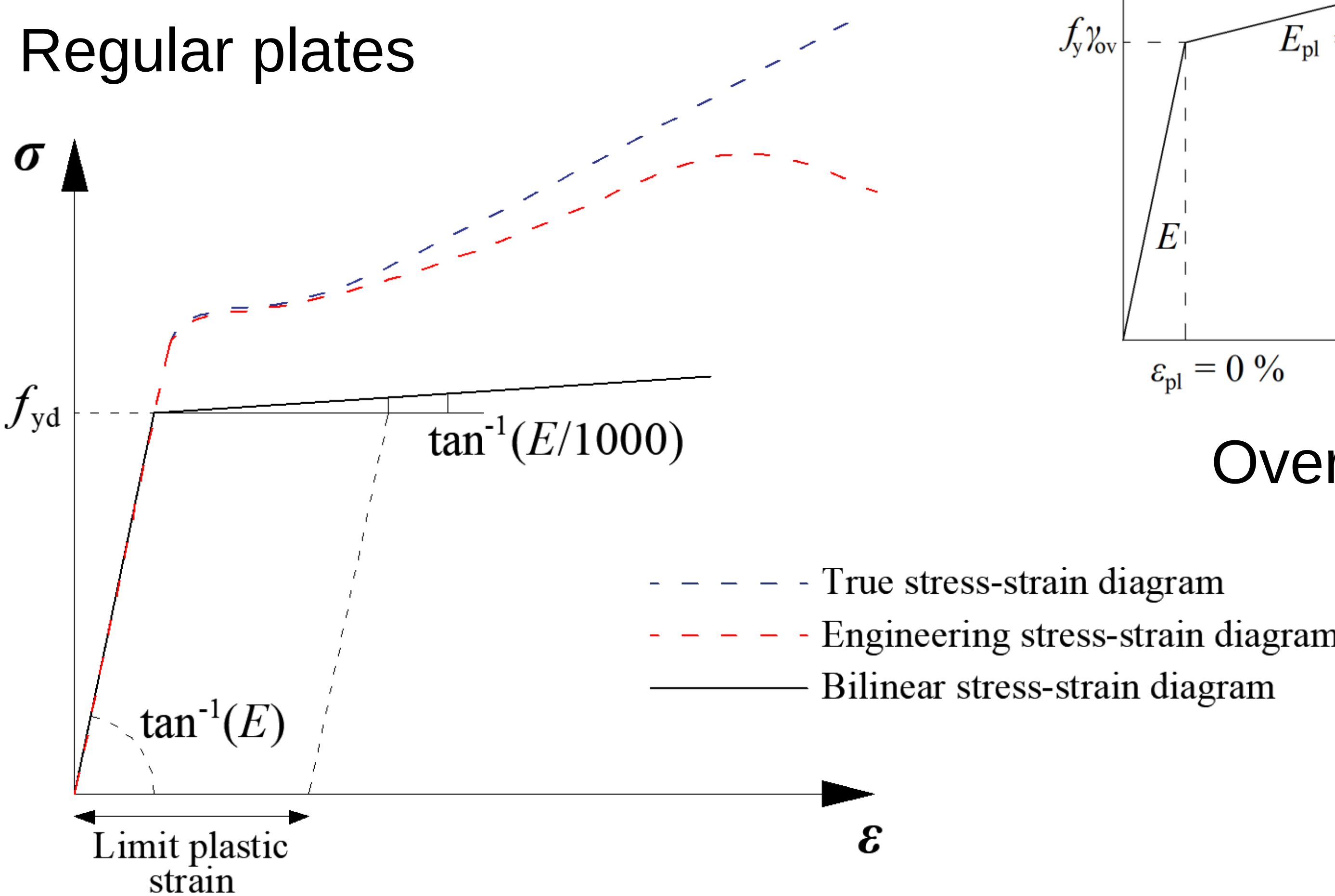
Calculate yesterday's estimates

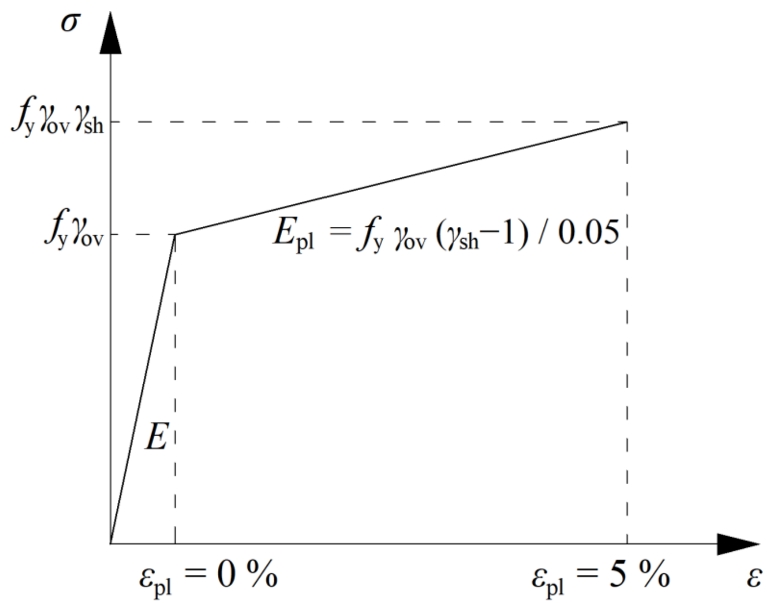


Component model | Bolted joint | CBFEM model

Plates

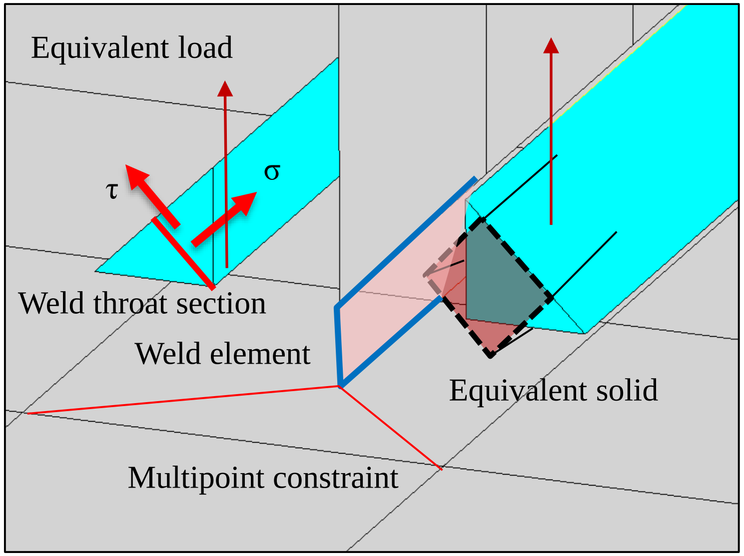
Regular plates

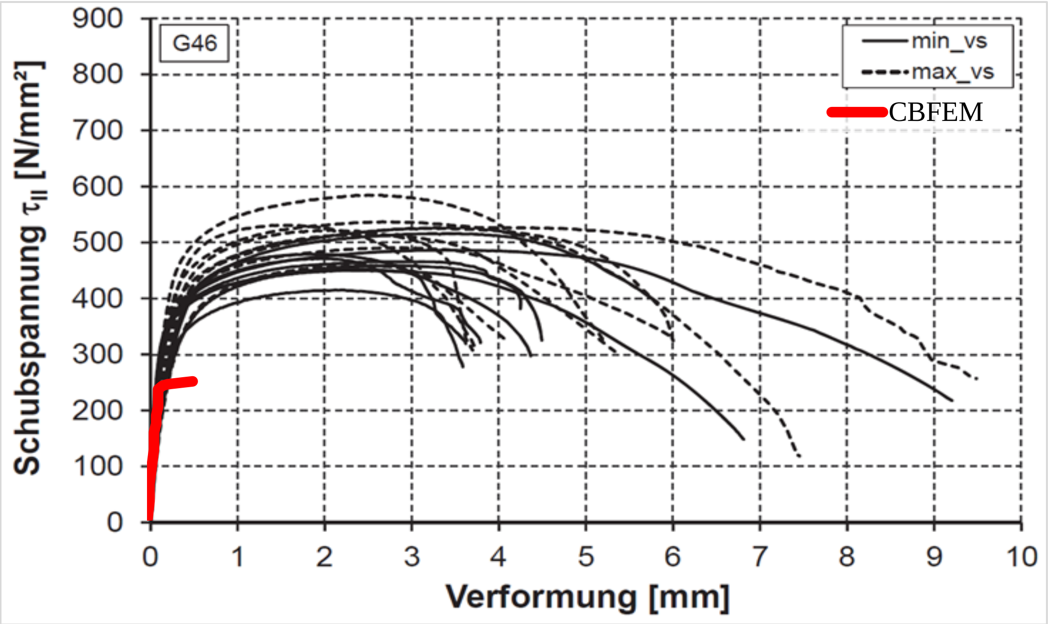




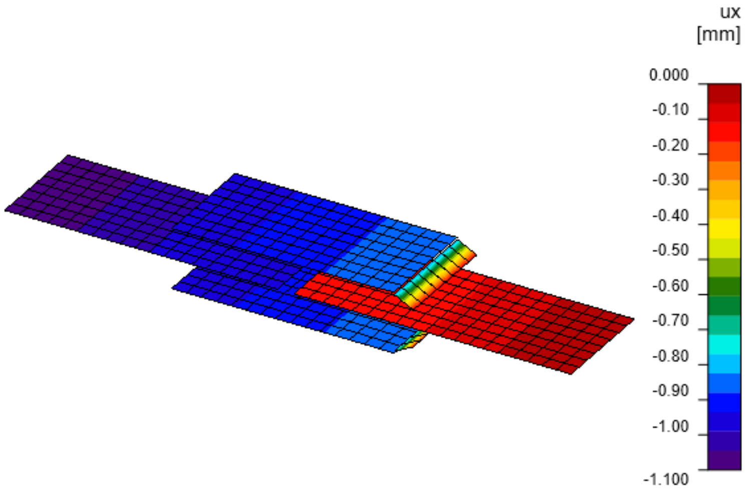
Overstrength

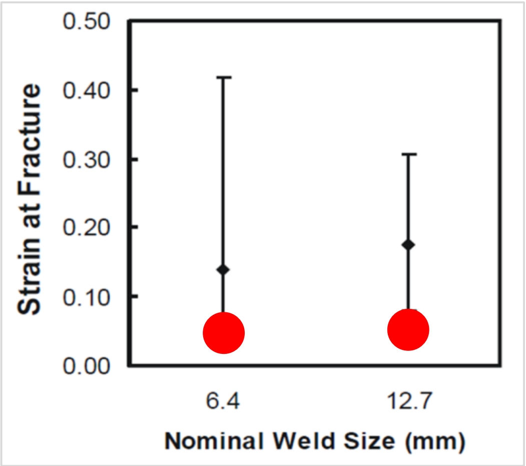
Welds





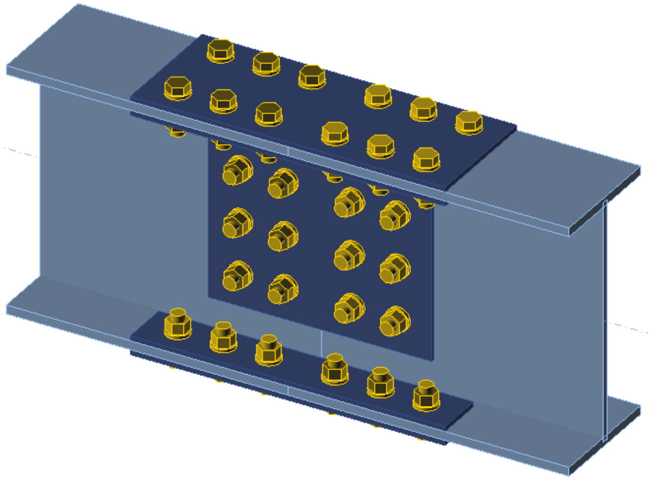
Kleiner
Stuttgart University

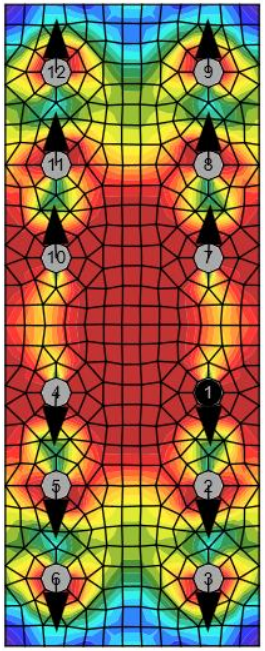


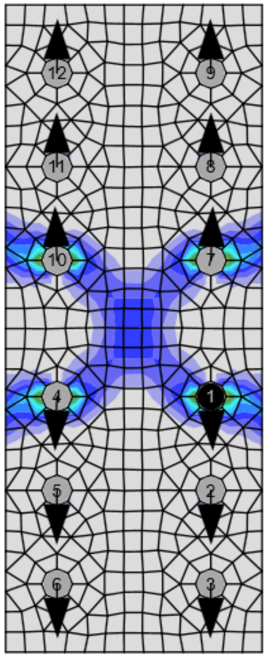


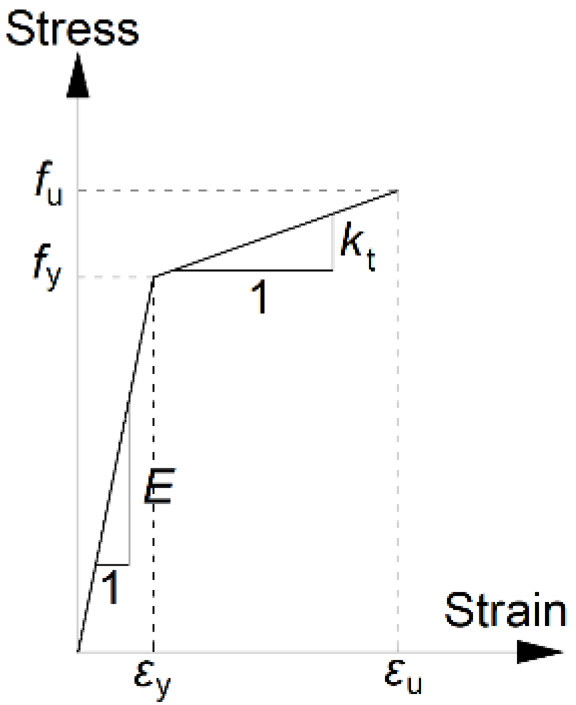
Ng, Driver, Grondin
University of Alberta

Bolts

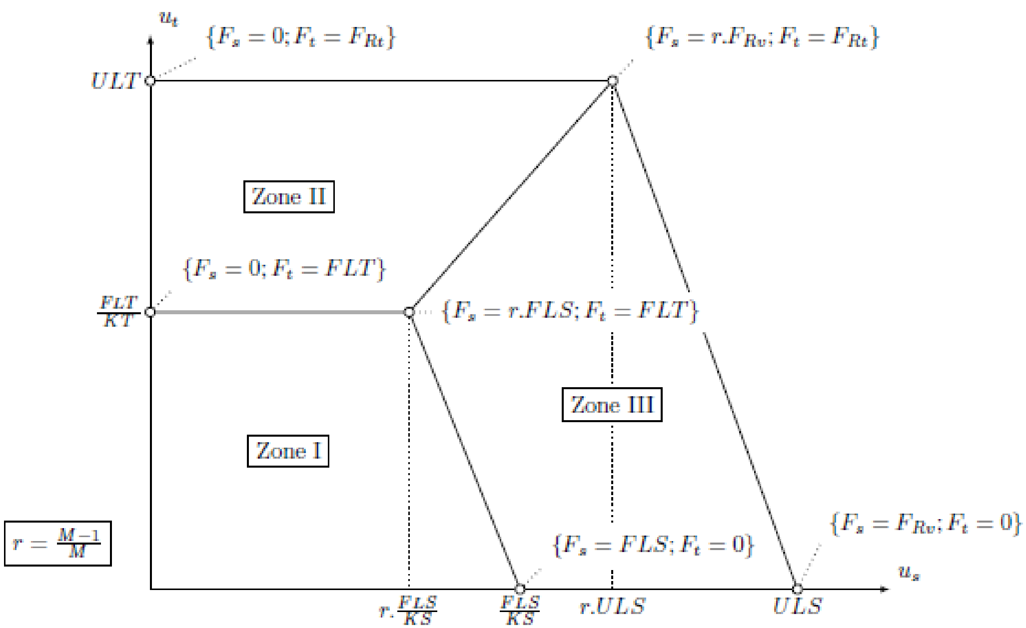






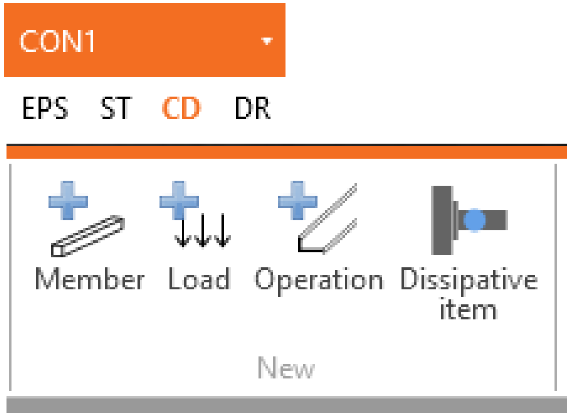


Stress
f_u
f_y
k_t
1
E
1
Strain
ε_y
ε_u



u_t
$\{F_s = 0; F_t = F_{Rt}\}$
$\{F_s = r.F_{Rv}; F_t = F_{Rt}\}$
ULT
Zone II
$\{F_s = 0; F_t = FLT\}$
$\frac{FLT}{KT}$
$\{F_s = r.FLS; F_t = FLT\}$
Zone III
Zone I
$r = \frac{M-1}{M}$
$\{F_s = FLS; F_t = 0\}$
$\{F_s = F_{Rv}; F_t = 0\}$
u_s
$r.\frac{FLS}{KS}$
$\frac{FLS}{KS}$
$r.ULS$
ULS

CBFEM – new feature in v.10



Dissipative components

DISS1

DISS1 [Dissipative item]

Properties

Strain hardening γsh	1.2
Items	IPE450

General

Name	S 355

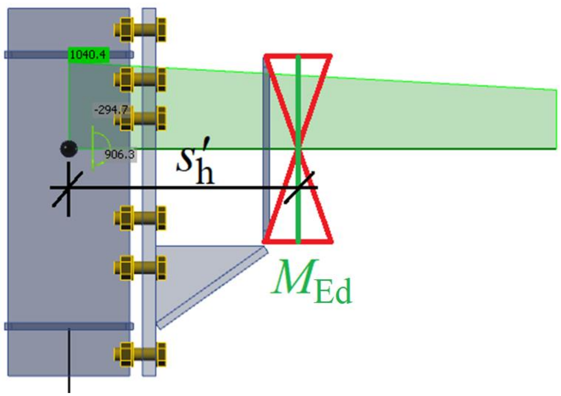
Physical properties

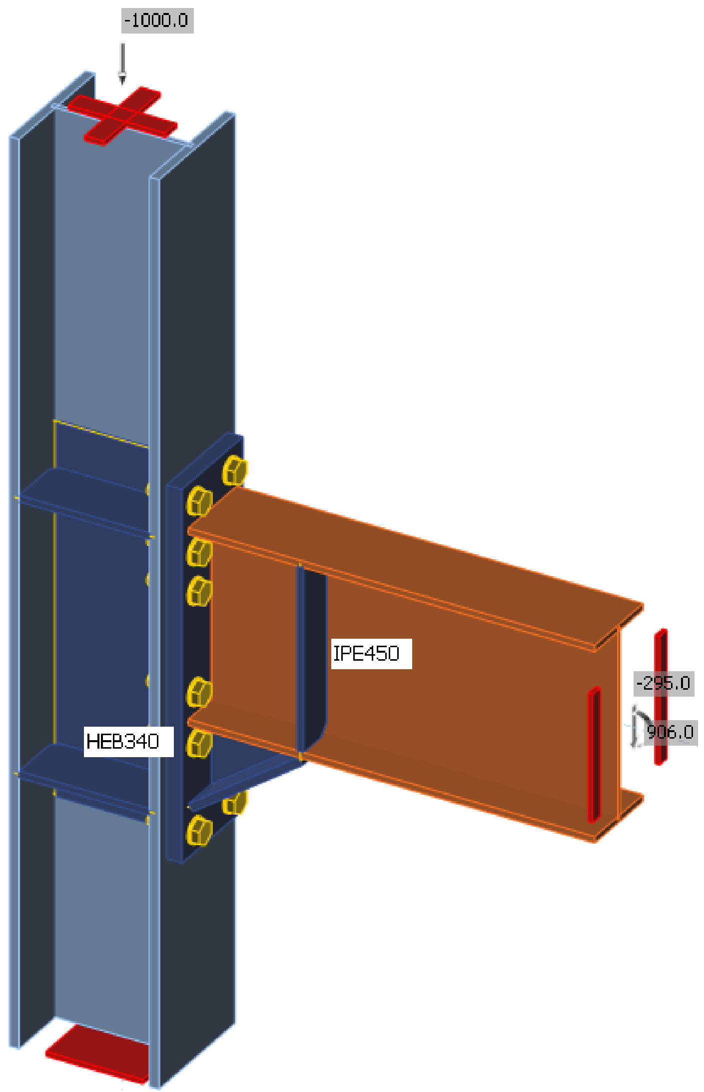
m [kg/m3]	7850
E [MPa]	210000.0
ν	0.3
G [MPa]	80769.2
α [1e-6/K]	12
λ [W/(m.K)]	50
c [kJ/(kg.K)]	0.49

Properties specific to European standard

fu [MPa]	490.0
fy [MPa]	355.0
fu,40 [MPa]	470.0
fy,40 [MPa]	335.0
γov,fu [-]	1.25
γov,fy [-]	1.25

CBFEM – Loads





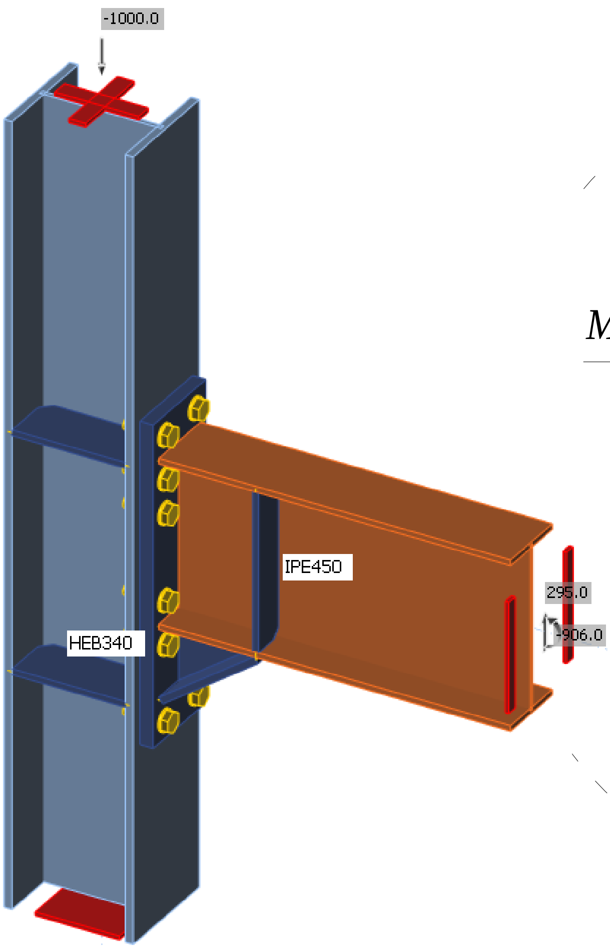
Model

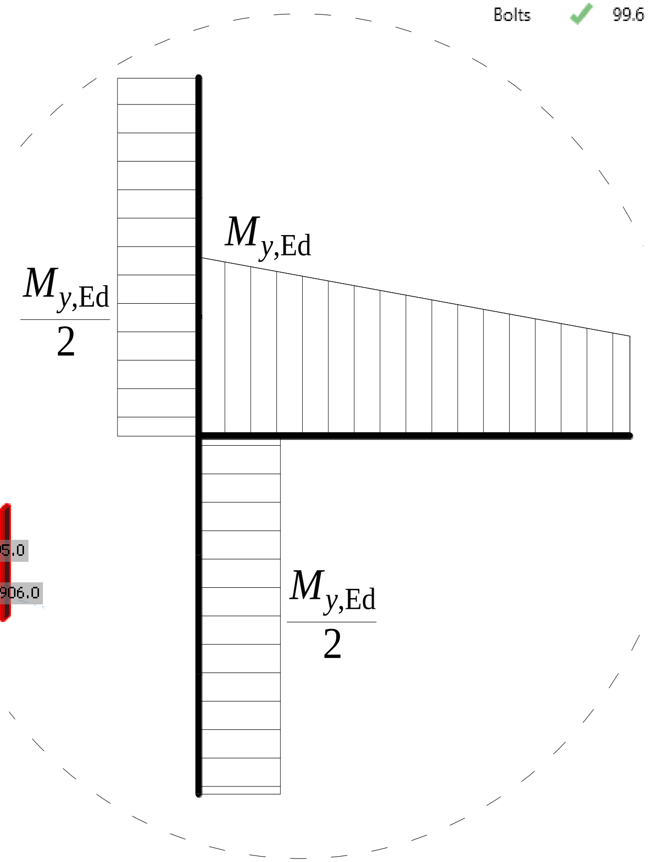
Model type	N-Vz-My
Forces in	Position
X [mm]	455

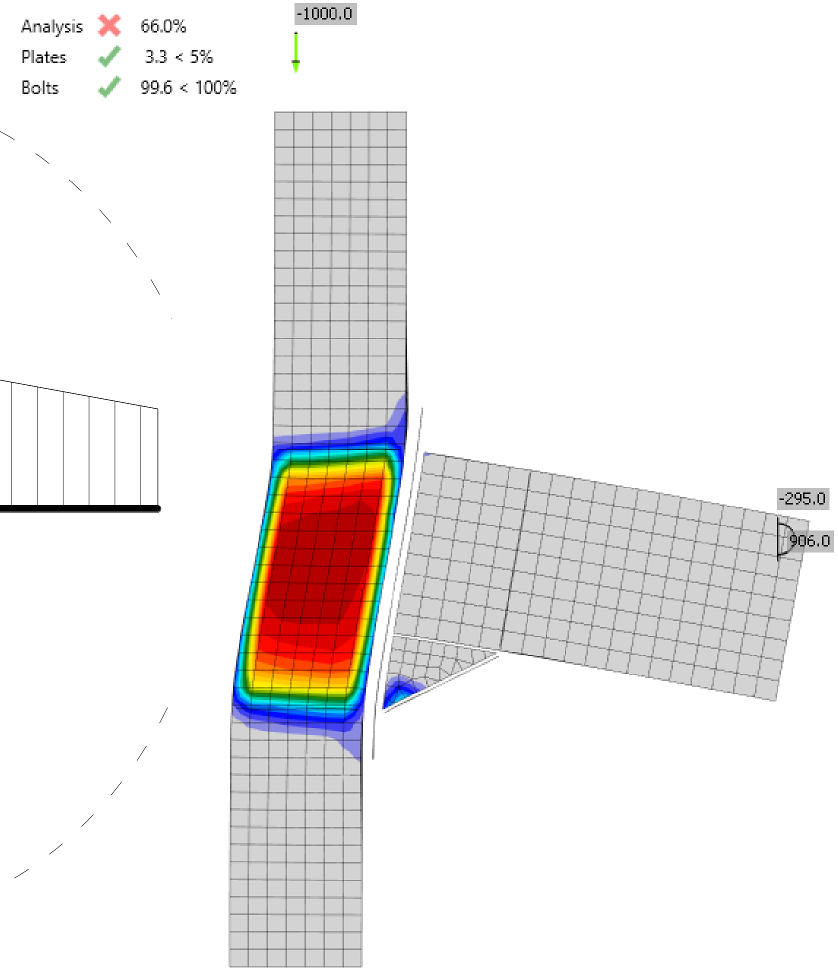
	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
	HEB340 / End	-1000.0	0.0	0.0	0.0	0.0	0.0
>	IPE450 / End	0.0	0.0	-295.0	0.0	906.0	0.0

	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
	HEB340 / End	-1000.0	0.0	0.0	0.0	0.0	0.0
>	IPE450 / End	0.0	0.0	295.0	0.0	-906.0	0.0

CBFEM – Model type





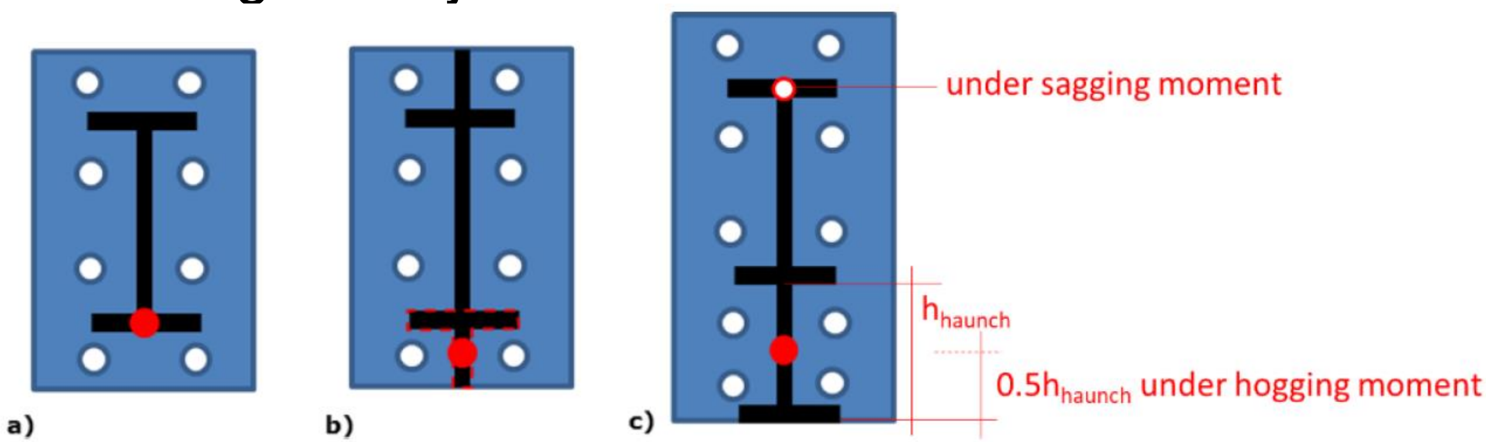


Verification

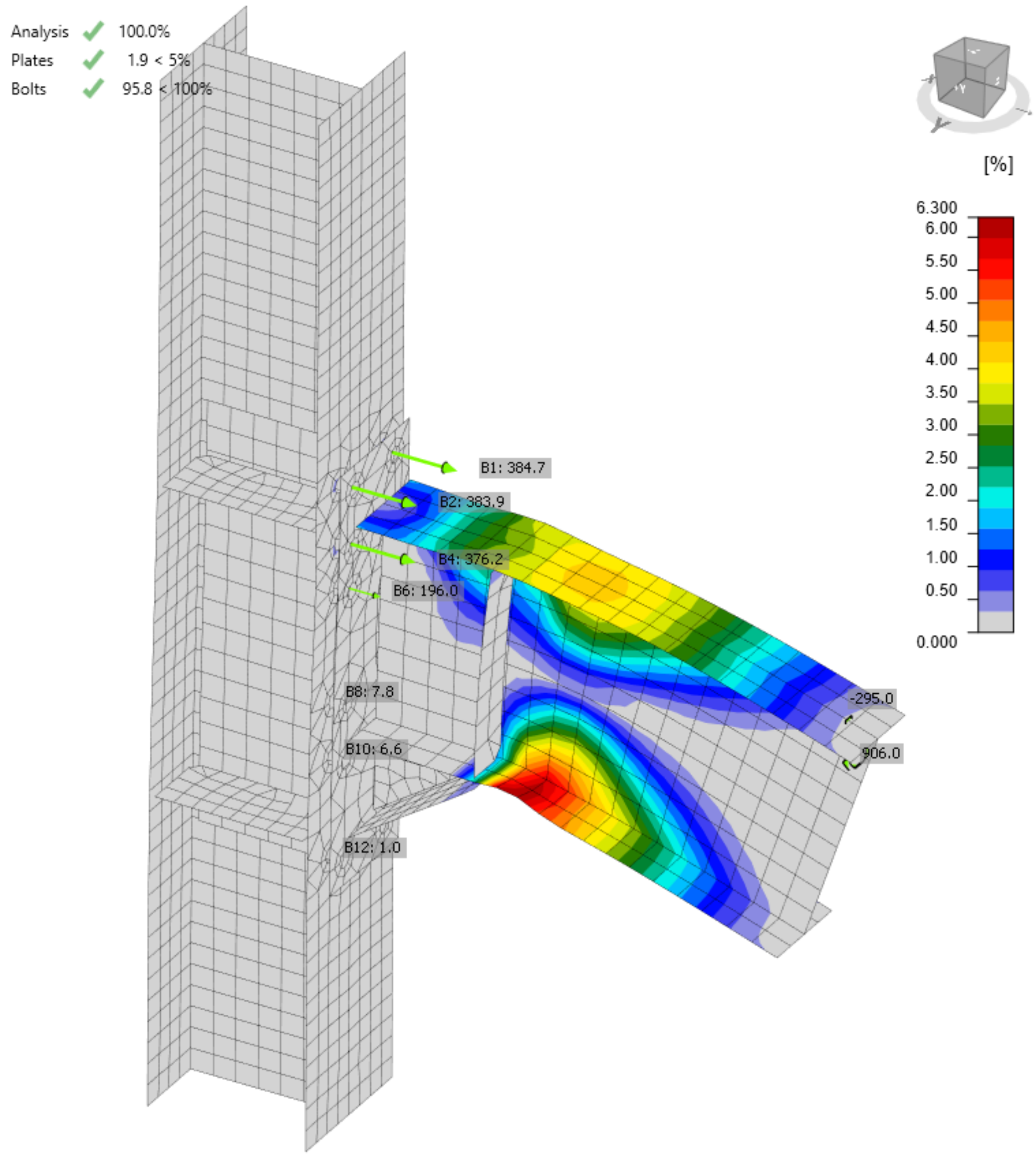
EN 1998-1: "Use EN 1993-1-8 if not specified otherwise"

Equaljoints: Detailed design guides for:

- Haunched joints
- Stiffened extended end-plate joints
- Unstiffened extended end-plate joints
- Dog bone joints

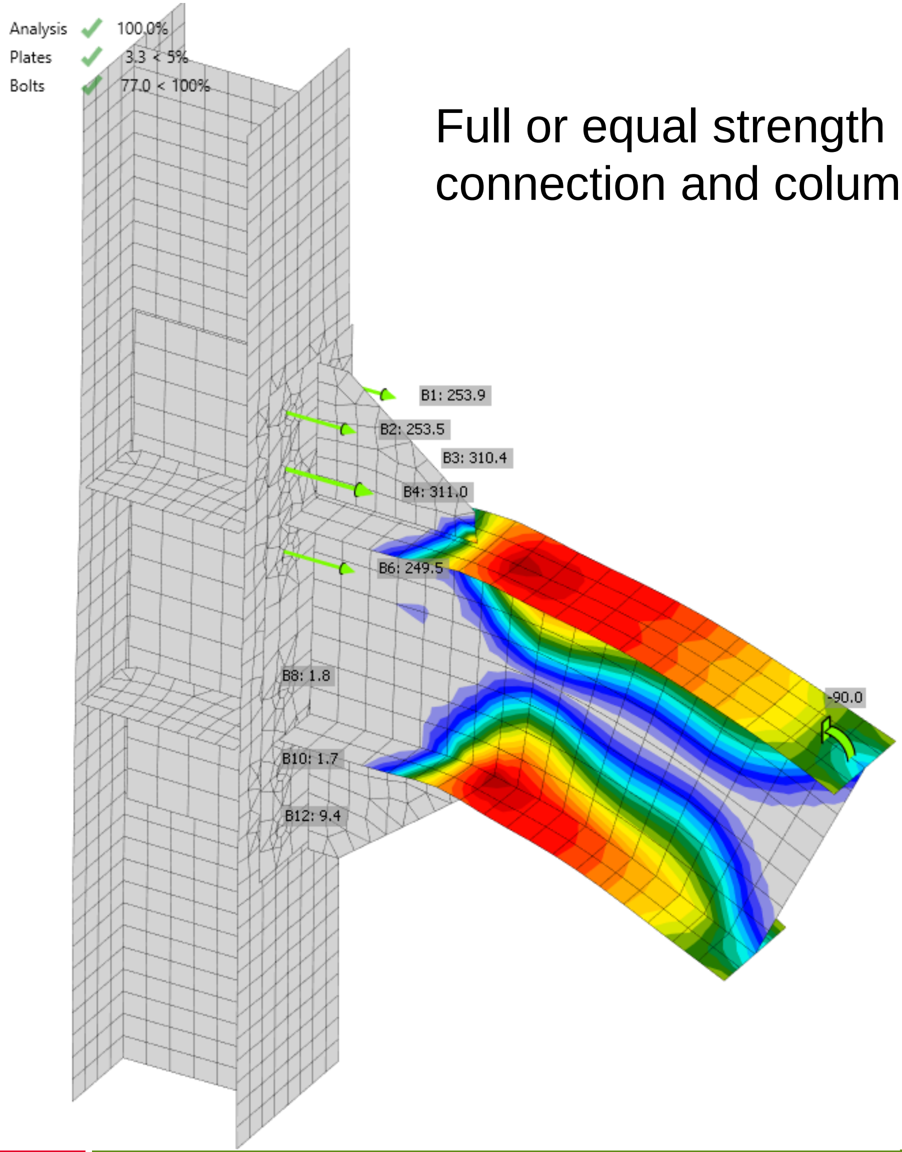


Haunched joint



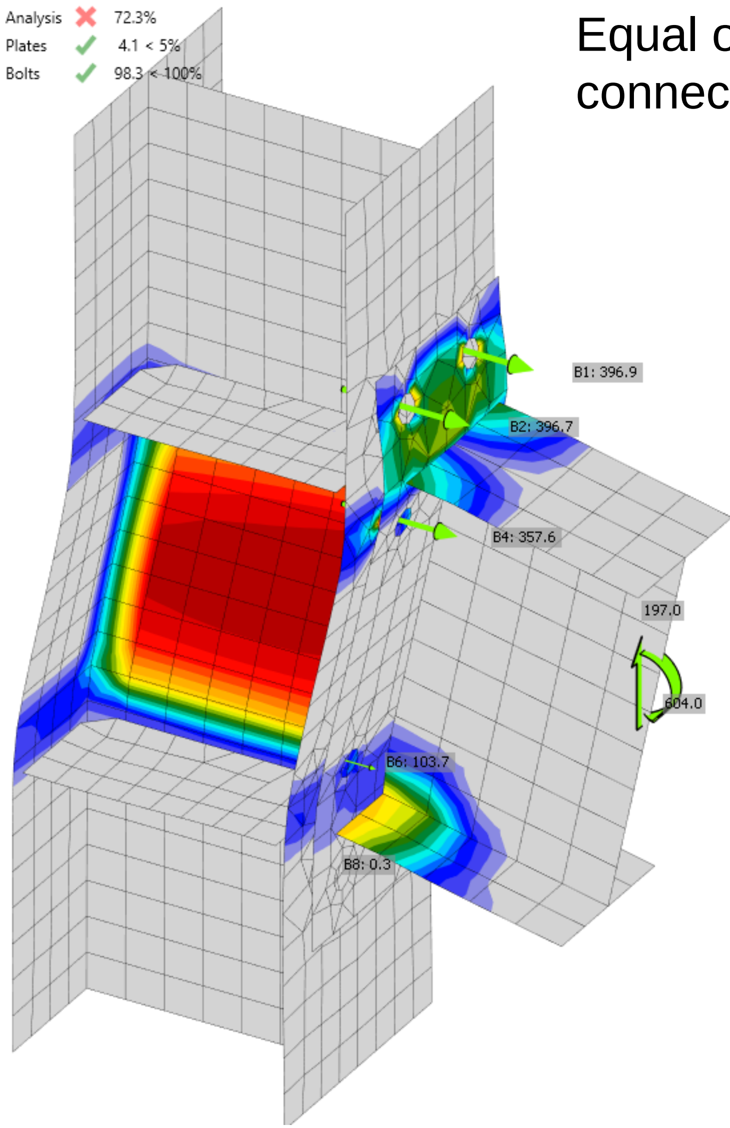
Usually full strength connection and column web panel

Stiffened extended end-plate



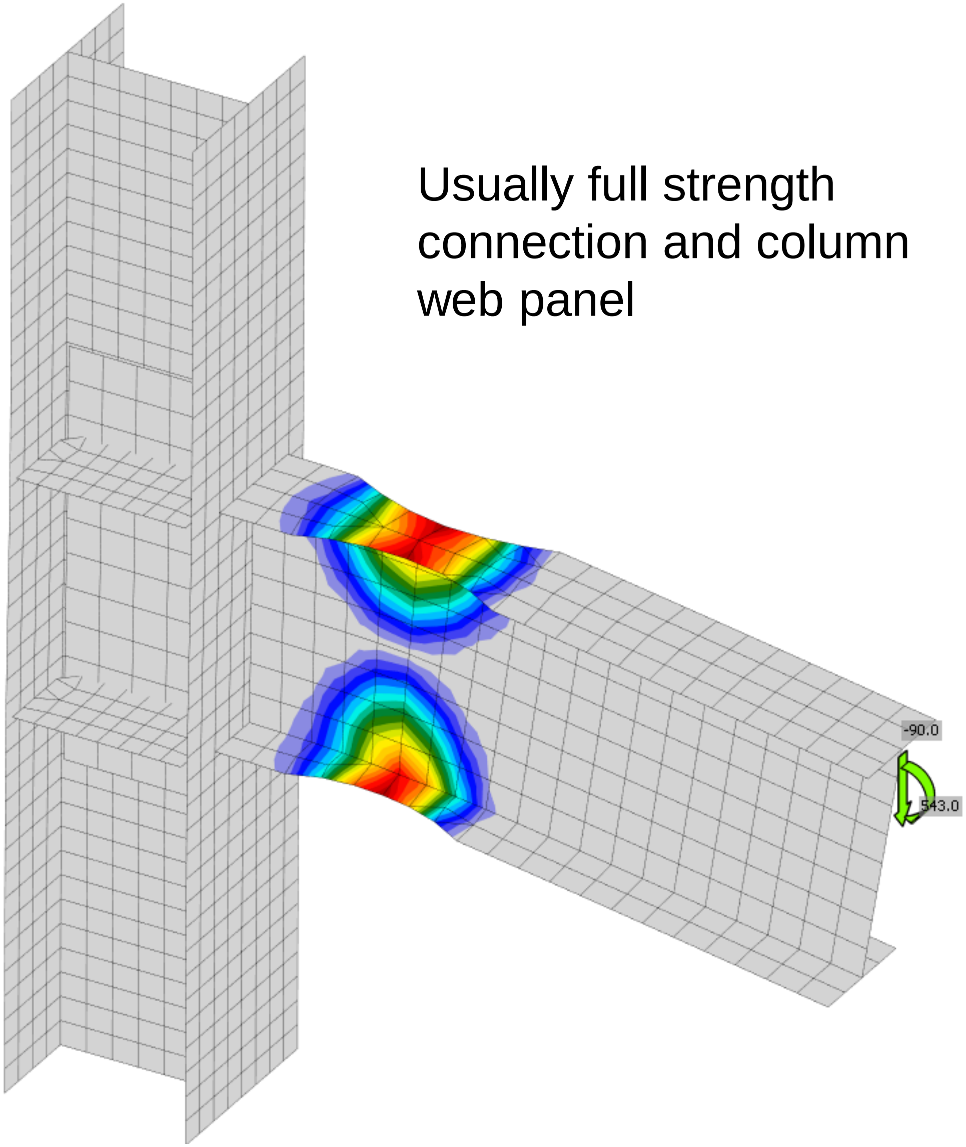
Full or equal strength
connection and column web panel

Unstiffened extended end-plate

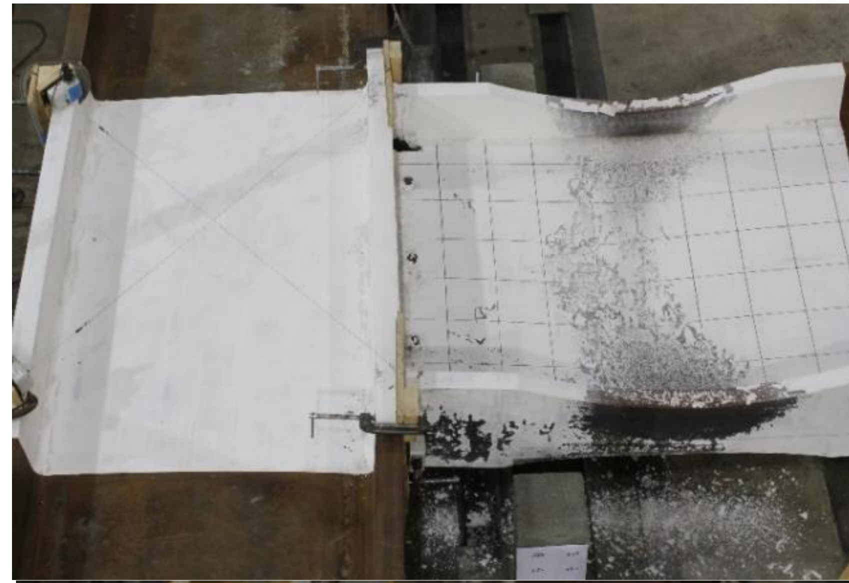


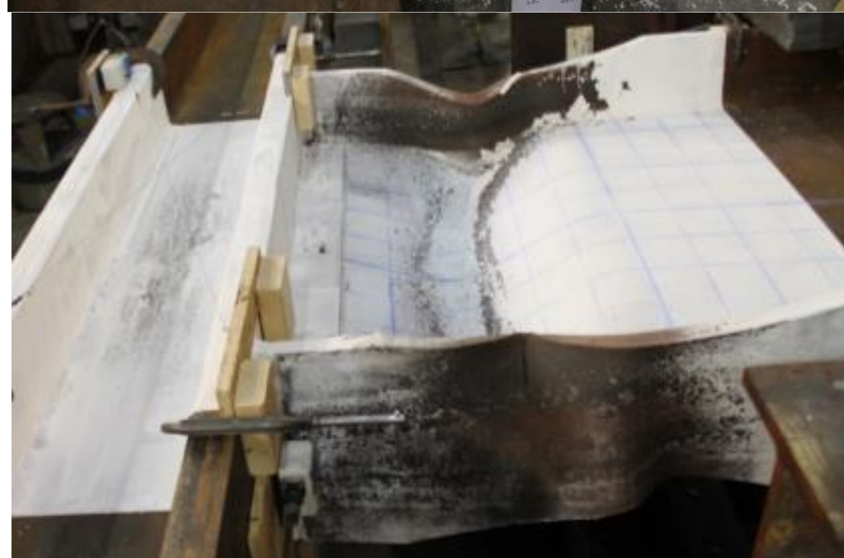
Equal or partial strength
connection and column web panel

Dog bone joint

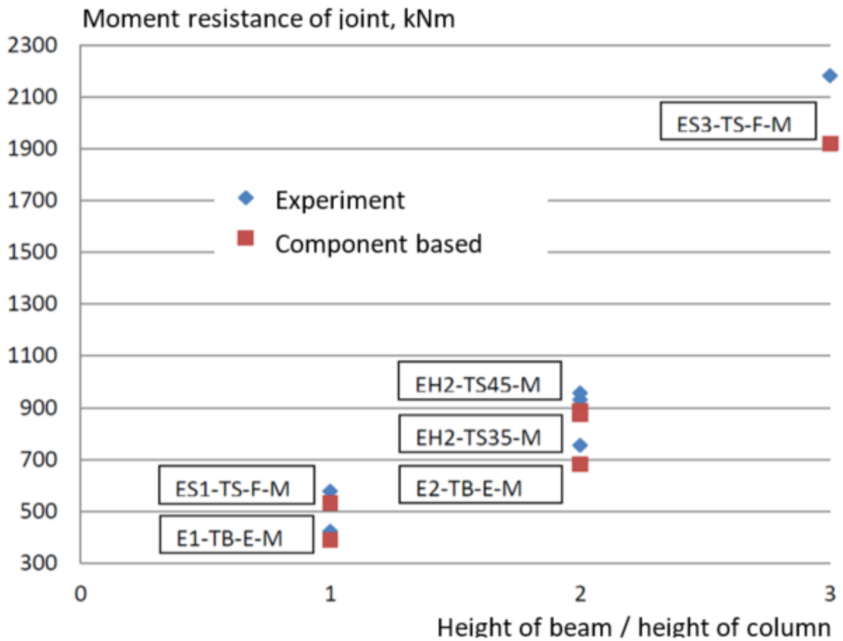


Usually full strength connection and column web panel

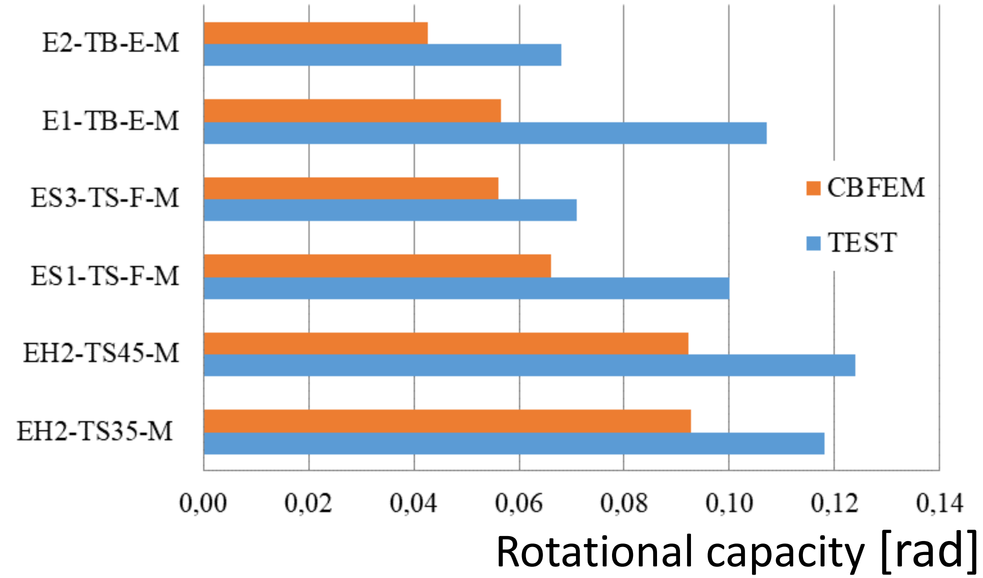




Validation



Resistance

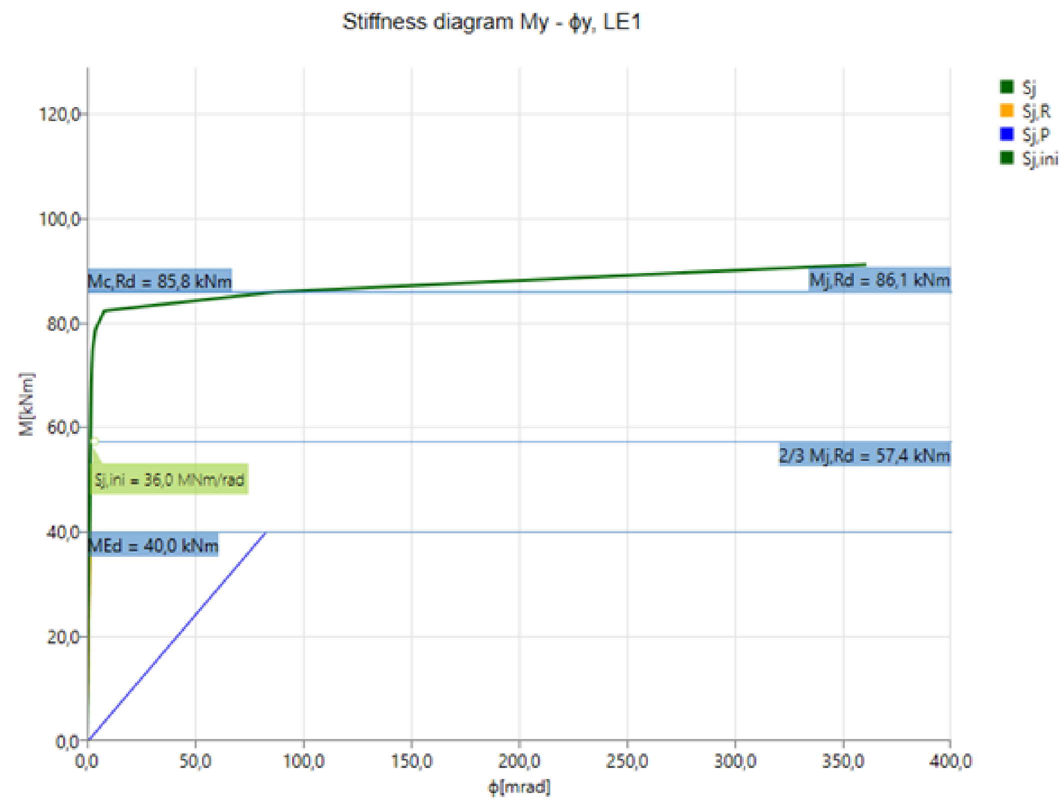


Rotational capacity

Rotational capacity

Stiffness analysis

Rotational capacity at 15 % plastic strain of plates bolts and welds must be stronger

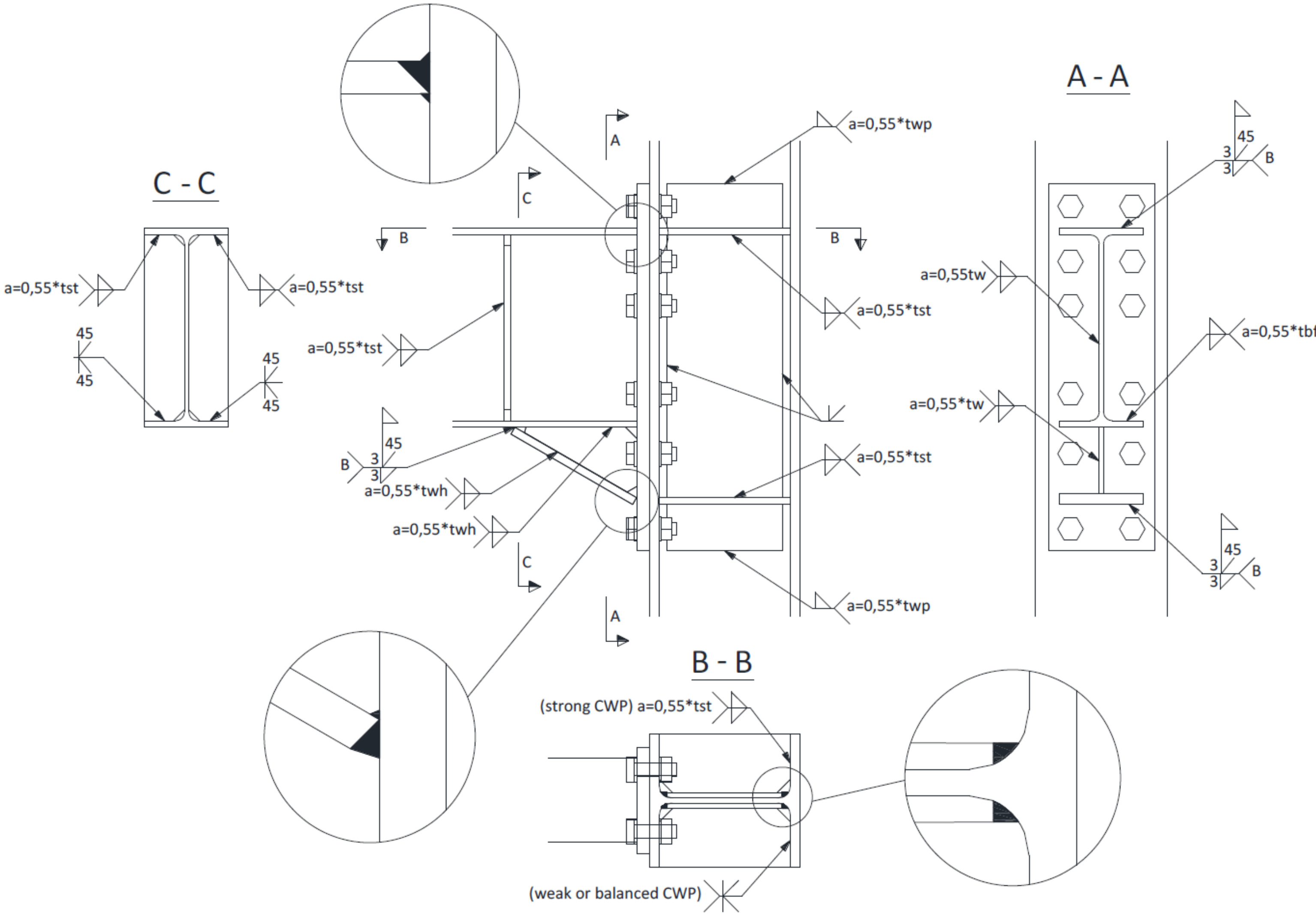


Summary | Rotational stiffness

Rotational stiffness of joint component

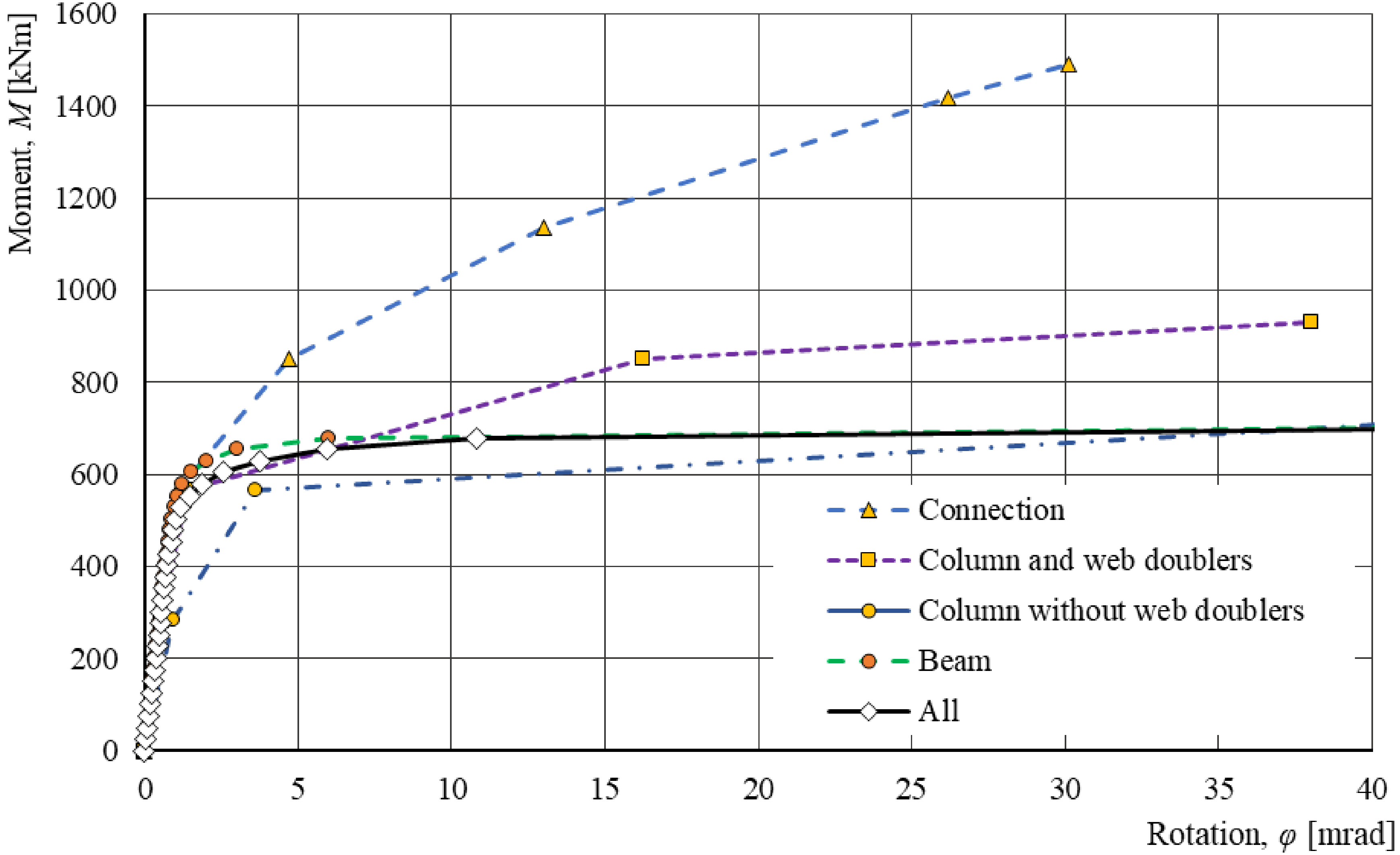
Item	Comp.	Loads	M [kNm]	Mj,Rd [kNm]	Sj,ini [MNm/rad]	Sjs [MNm/rad]	Φ [mrad]	Φc [mrad]	L [m]	Sj,R [MNm/rad]	Sj,P [MNm/rad]	Class
B	My	LE1	40,0	86,1	36,0	36,5	1,1	361,0	6,00	24,3	0,5	Rigid

Weld detailing



NOTE:
1. All full-penetration welds shall be quality level B acc. EN ISO 5817 and EN 1090-2:2008.
2. All welds shall be quality level C unless otherwise specified on drawings.

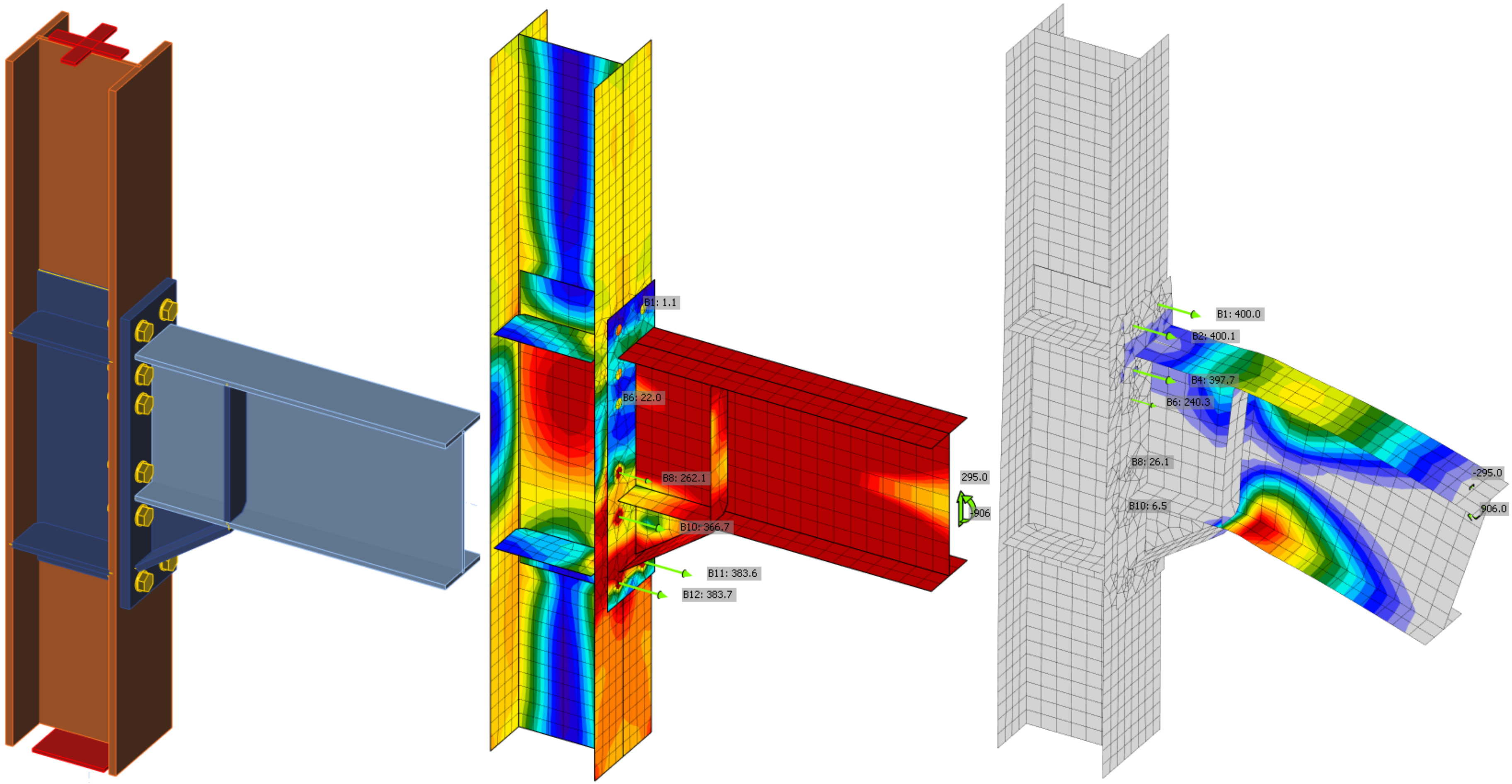
Individual macro-components



Life demonstration

IDEA StatiCa®

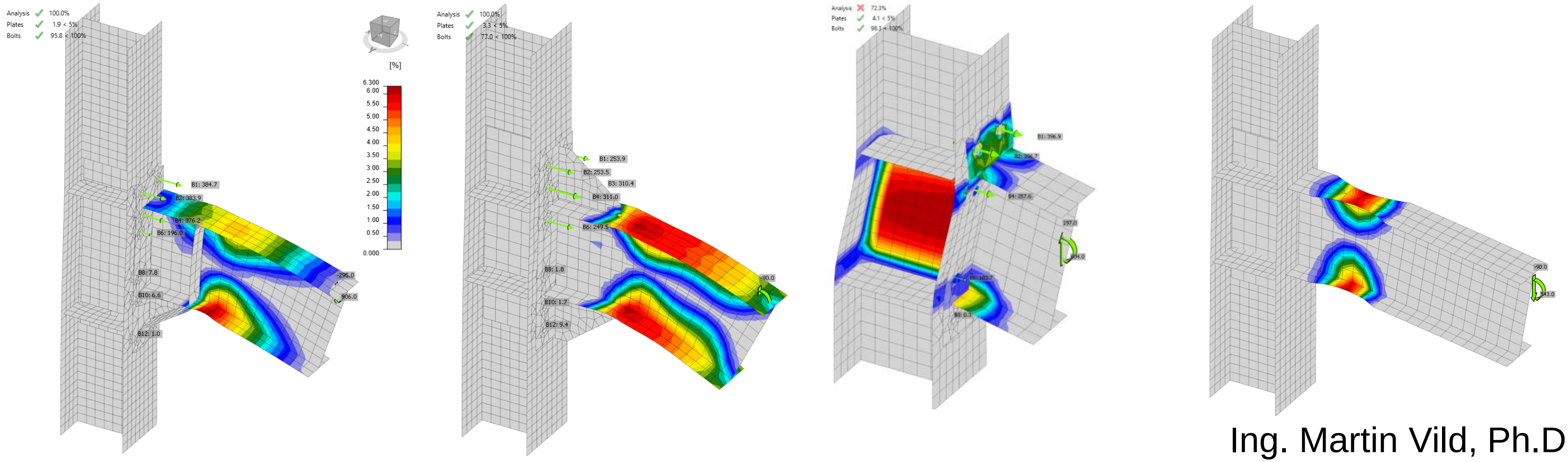
Calculate yesterday's estimates



Capacity design – Summary

- Necessary for ductility class medium and high
- Rules in EN 1993-1-8 still apply
- Detailing of welds is prescribed – no need to check
- Workflow:
  - Apply overstrength to member with plastic hinge
  - Set loads to create plastic hinge
  - Observe plastic hinge in the member – $\varepsilon_{\mathrm{pl}} \cong 5\ \%$
  - Standard check all other components

Thank you
for your attention



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