Second Generation of Eurocode 8

EN1998-3: Assessment and Retrofit of Steel Structures

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Contains rules for assessment & retrofitting of steel and composite-steel concrete structures

- Section 9.1 scope
- Section 9.2 Identification of geometry, details and materials
- Section 9.3 Structural modelling
- Section 9.4 Resistance and deformation models for assessment
- Section 9.5 Verification of limit states
- Section 9.6 Resistance models for retrofitting

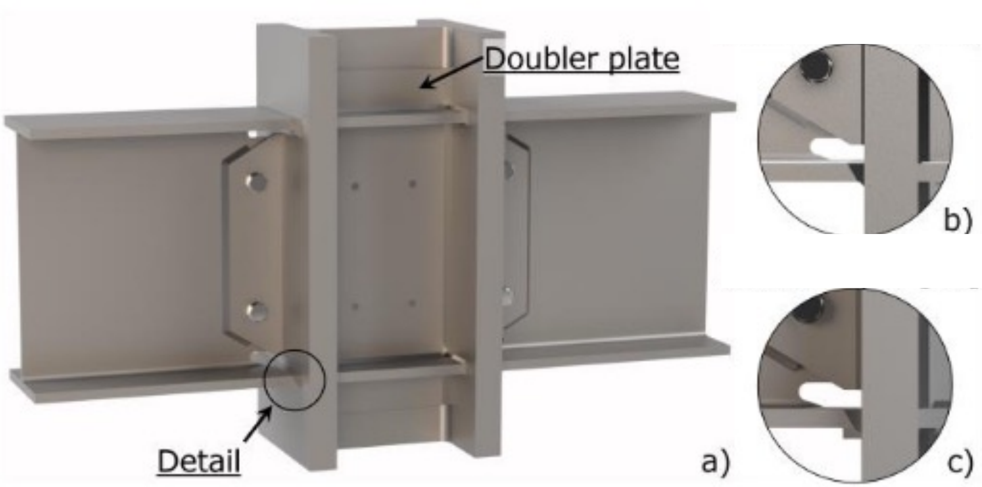
Section 9.2: Identification of geometry, details and materials

9.2.2 Geometry

- Identify the lateral load resisting systems
- Size and thickness of connecting elements (e.g., beams, columns, bracings)
- Cross-sectional / member geometry
- Possible eccentricities between
  - beams and column axes,
  - bracing end connections
- Base metal and connector materials

Section 9.2: Identification of geometry, details and materials

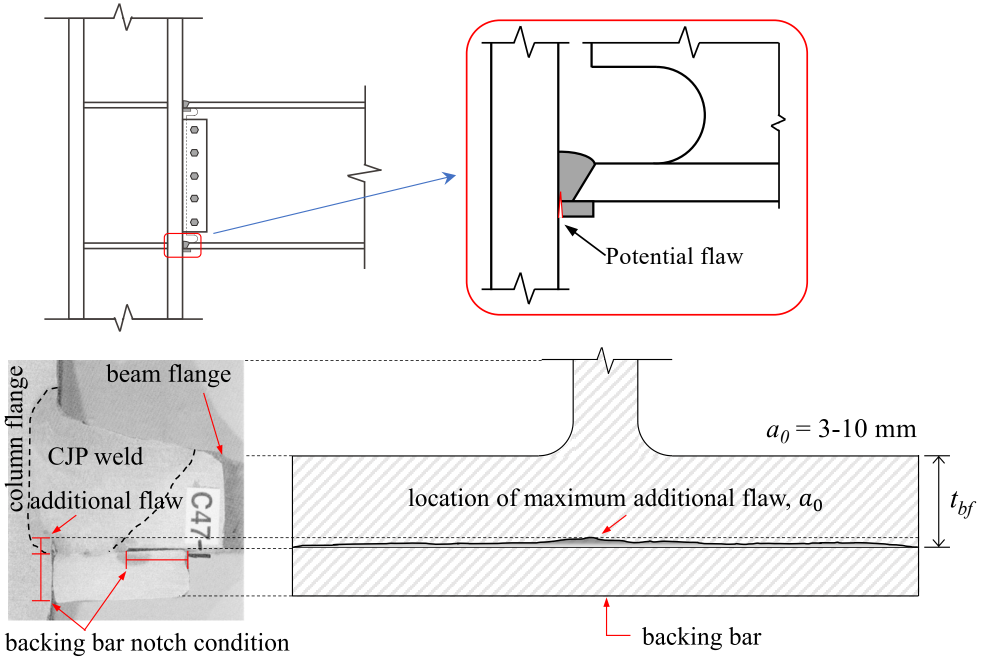
9.2.3 Details



Source: Skiadopoulos and Lignos (2023)

Section 9.2: Identification of geometry, details and materials

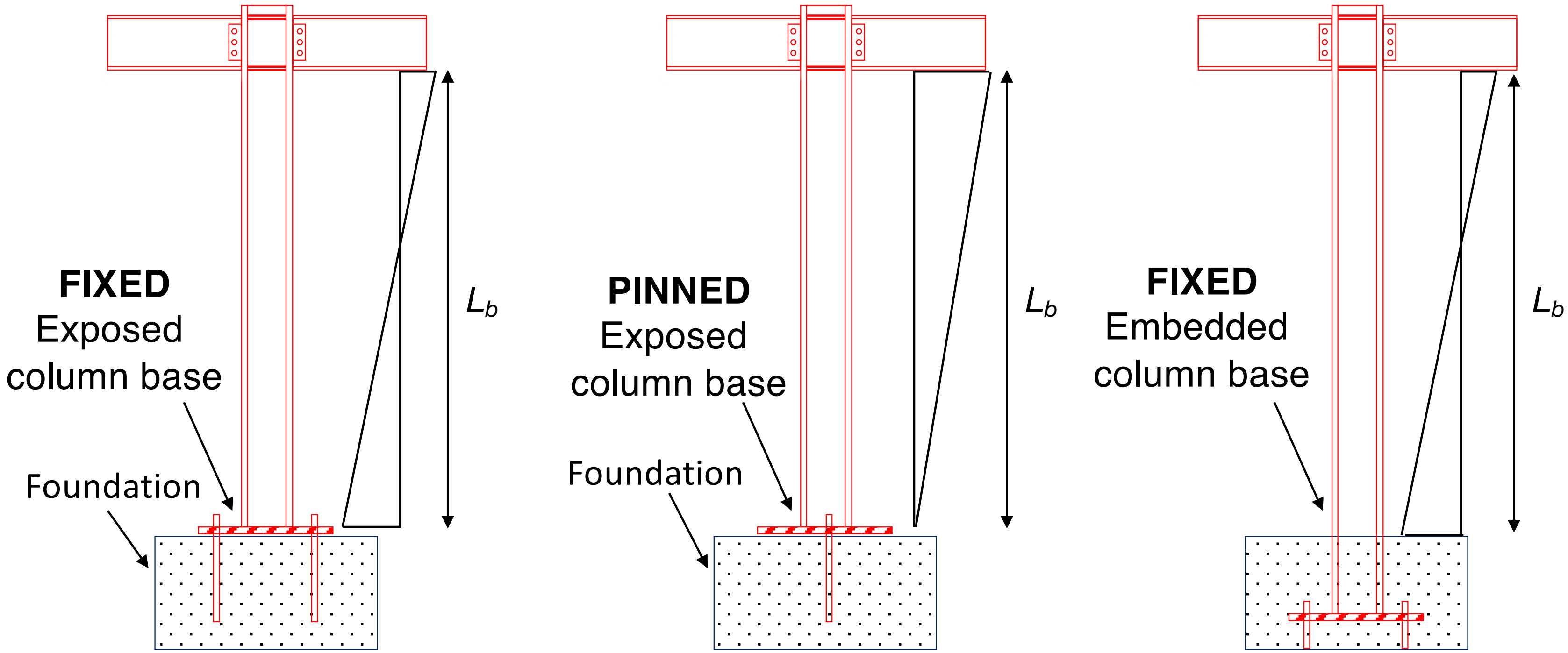
9.2.3 Details (2)



Source: Skiadopoulos and Lignos (2022)

Section 9.2: Identification of geometry, details and materials

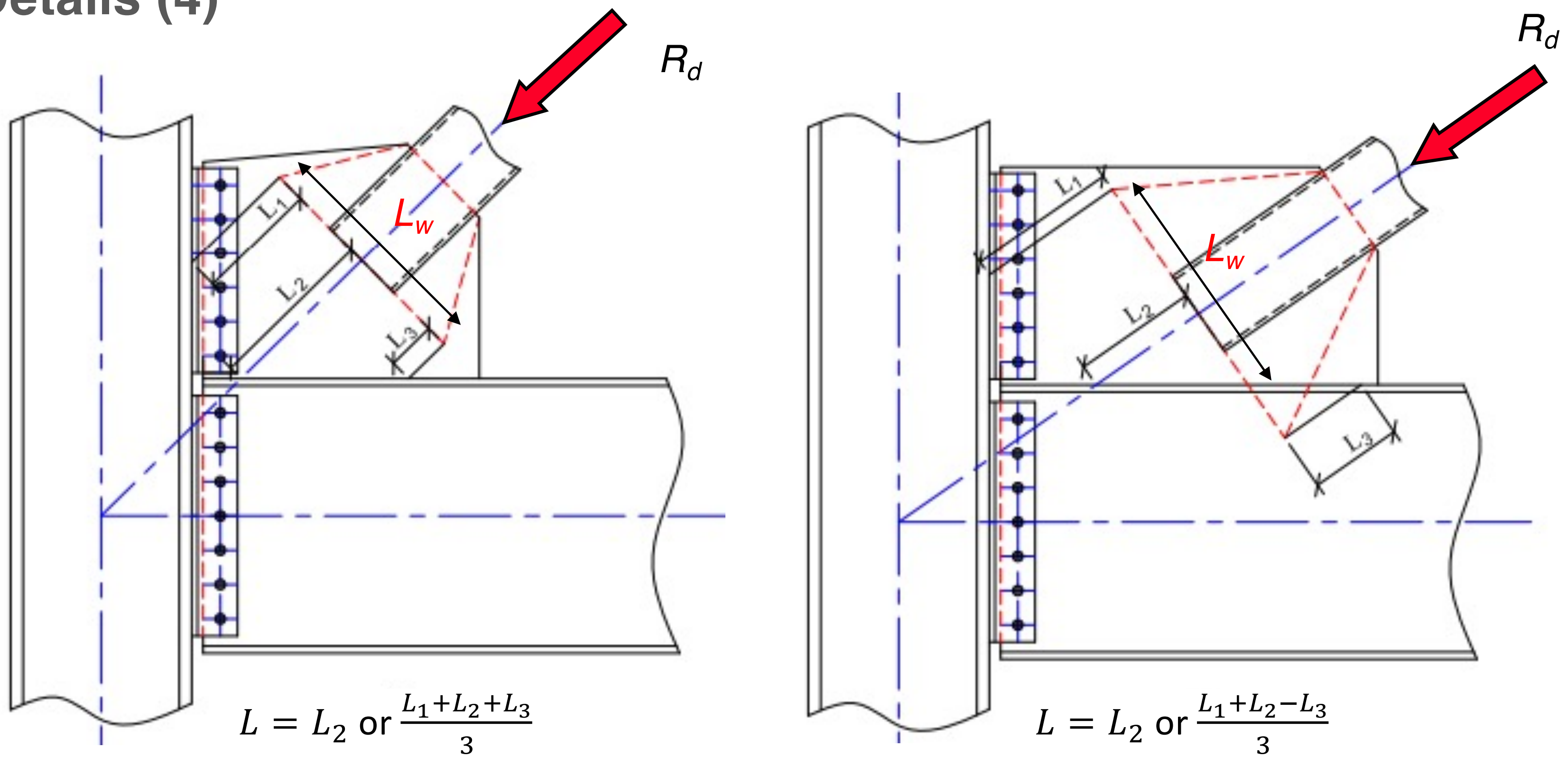
9.2.3 Details (3)



Source: Lignos (2016)

Section 9.2: Identification of geometry, details and materials

9.2.3 Details (4)



$L = L_2$ or $\frac{L_1+L_2+L_3}{3}$

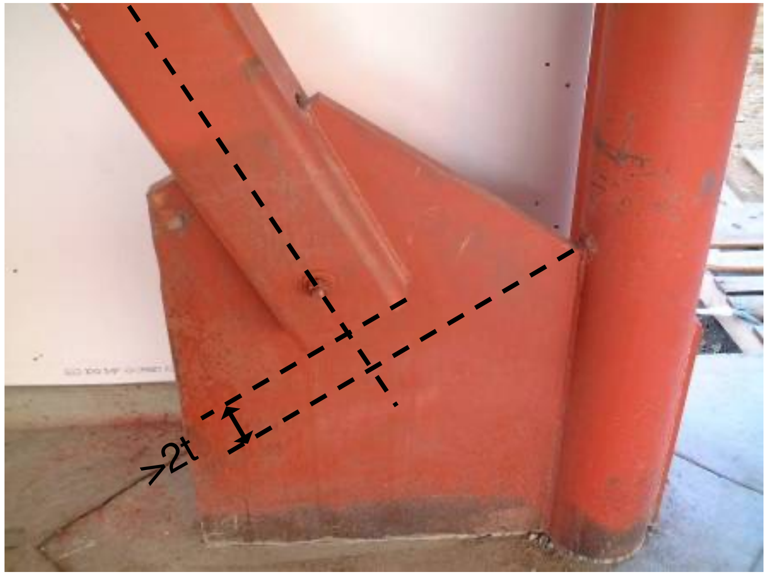
$L = L_2$ or $\frac{L_1+L_2-L_3}{3}$

Source: Lignos (2016)

Section 9.2: Identification of geometry, details and materials

9.2.3 Details (5)

Consistent with new Annex E (EN1998-1-2:2022)



Eccentric bracing-end connections

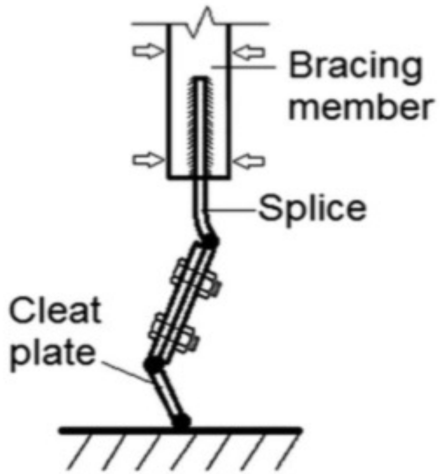


Image courtesy of Prof. Robert Tremblay, EPM

Image courtesy of Prof. Dimitrios Lignos, EPFL

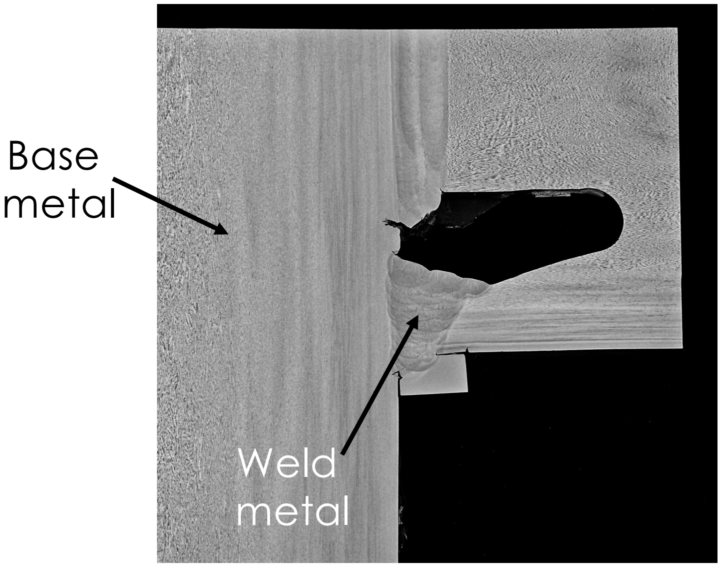
Section 9.2: Identification of geometry, details and materials

9.2.3 Details (6) – Examples on deficient details in bracing end connections

Images courtesy of Prof. Dimitrios Lignos, EPFL
(Lignos et al. 2012)

Section 9.2: Identification of geometry, details and materials

9.2.4 Materials

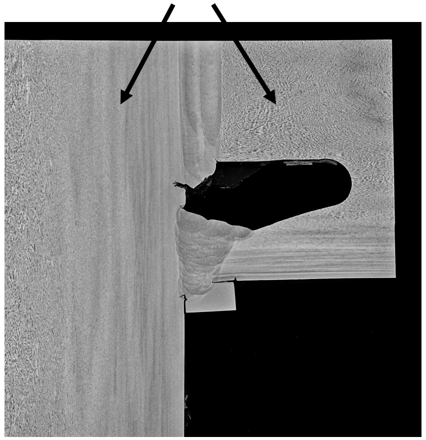


@Skiadopoulos et al. (2023)

@Prof. Lignos, Riveted bridge, CH

Section 9.2: Identification of geometry, details and materials

9.2.4 Structural steel (base metal)



@Skiadopoulos et al. (2023)

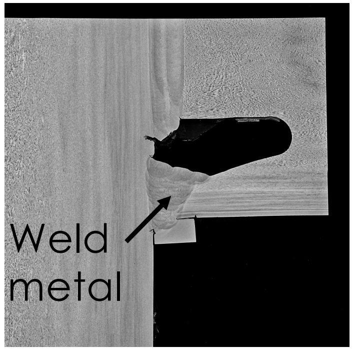
Table 9.3 Nominal yield and ultimate tensile strength for steel materials

Date of Production	Material Grade	Nominal yield strength, f_y [MPa]	Nominal tensile strength, f_u [MPa]
Before 1901	Pre-standardized structural steel	70	120
1850-1900	Wrought iron and homogeneous iron	220	320
Before 1920	Cast iron	Not applicable	Not applicable
1900-1940	Homogeneous iron	235	335
1925-1955	Mild steel	235	360
1993 - current	S235	According to EN1993-1-1:2023 (see Table 5.1)	According to EN1993-1-1:2023 (see Table 5.1)
	S275		
	S355		
	S420		
	S460		
1993 - current	S260	According to EN1993-1-1:2023 (see Table 5.2)	According to EN1993-1-1:2023 (see Table 5.2)
	S315		
	S355		
	S420		

Section 9.2: Identification of geometry, details and materials

9.2.4 Weld Metal

Table 9.4 Default ultimate tensile strength for existing welds



Listing in Design Documents	Construction Date	Default Value
Filler metal listed	Any	The specified minimum tensile strength for the filler metal classification according to prEN 1993-1-8:2020, **6**.
Filler metal not listed	1980 or later	460 MPa
	Prior to 1980	400 MPa

@Skiadopoulos et al. (2023)

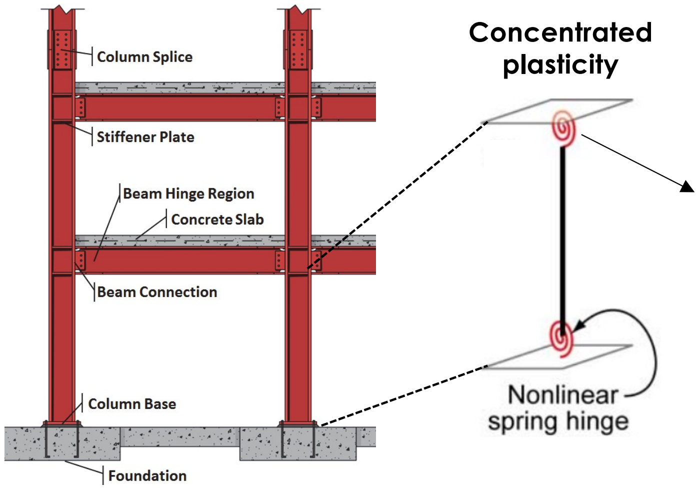
Section 9.2: Identification of geometry, details and materials

9.2.4 Weld Metal (2)

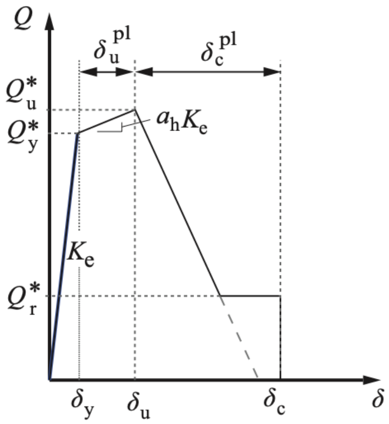
Table 9.5 Default CVN toughness for existing welds

Listing in Design Documents	Filler Metal Properties	Default Value
Filler metal listed	The filler metal classification has specified CVN toughness requirements	The specified minimum CVN notch toughness for the filler metal classification
	The filler metal met the requirements of EN 1090-2: 2018 for a demand critical weld	50 Joules at 21°C
	The filler metal classification has no specified minimum CVN toughness requirements	14 Joules at 21°C
Filler metal not listed	Any	14 Joules at 21°C

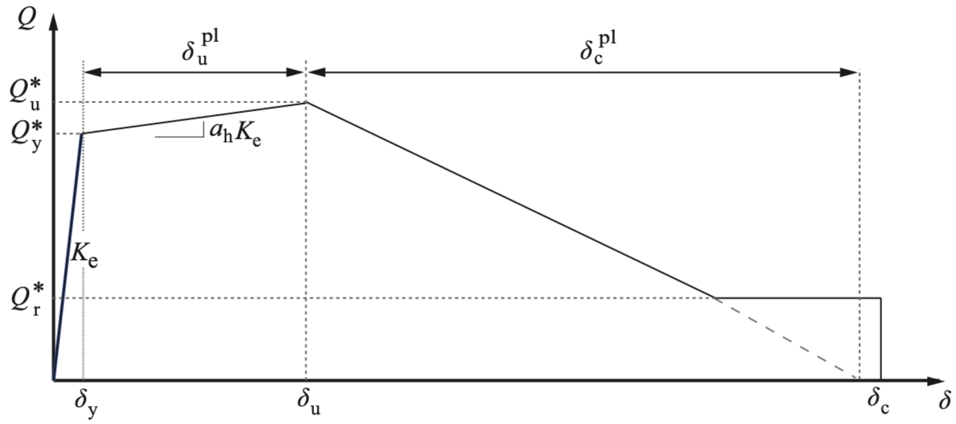
Section 9.3: Structural modelling



General definition of piecewise linear load-deformation relationship



Limited ductile behaviour



Ductile behaviour

EN1998-1-1:2022 (Clause 7.3)

- Structural elements according to DC2 and DC3 are covered in EN1998-1-1:2022 (Clause 7.3)
- prCEN/TS 1998-1-101 (Technical specification for loading protocols and acceptance criteria)

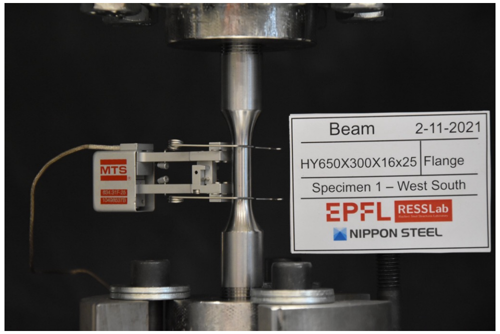
Section 9.4: Resistance and deformation models for assessment

- 9.4.2 Beams and columns under flexure with or without axial load
- 9.4.3 Steel bracings
- 9.4.4 Links in frames with eccentric bracings
- 9.4.5 Buckling-restrained bracings
- 9.4.6 Steel column and beam splices
- 9.4.7 Beam-to-column web panel joint
- 9.4.8 Bracing-end connections

Section 9.4: Resistance and deformation models for assessment

-The models are based on more than 1500 collected experiments

Material scale (over 10 steel grades)

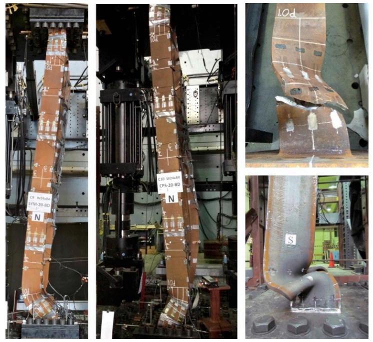


Hartloper et al. (2023)

Steel beam-to-column joints

Lignos and Krawinkler (2011)

I- H- shaped steel columns

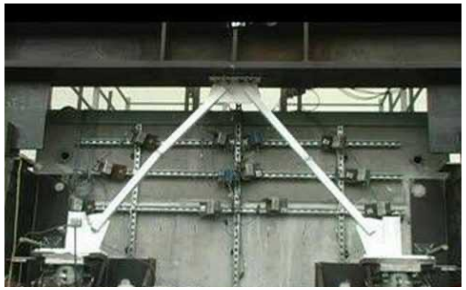


Elkady and Lignos (2018)

Hollow structural steel columns

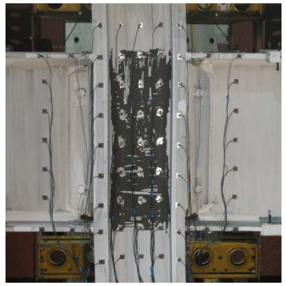
Lignos and Krawinkler (2010)

Steel braces (HSS, round HSS, I-shaped, L-shaped)



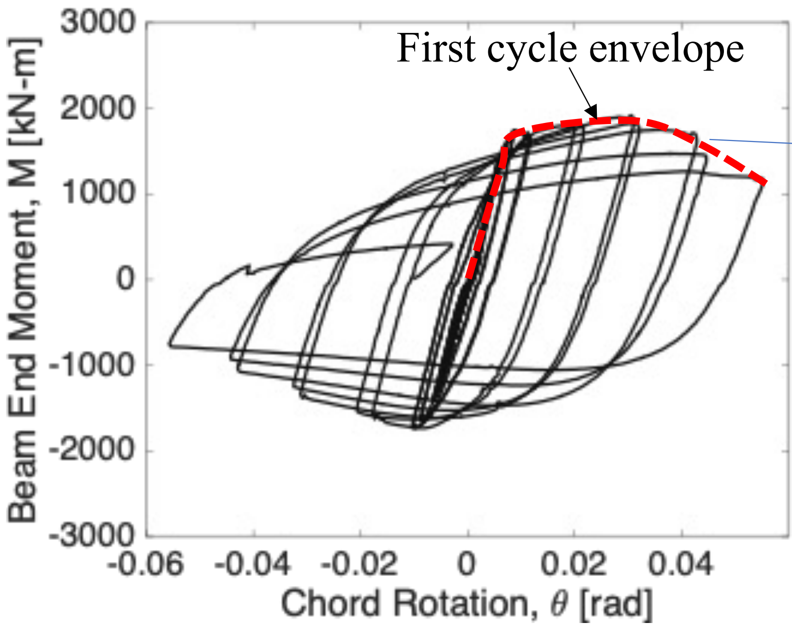
Karamanci and Lignos (2014)

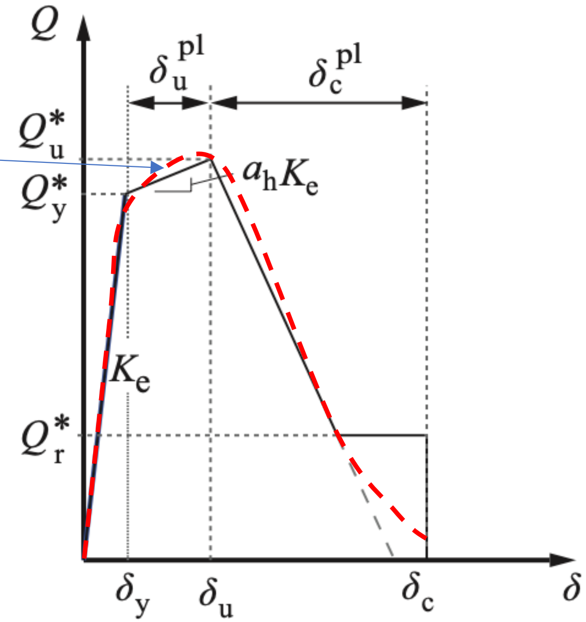
Beam-to-column web panel



Skiadopoulos and Lignos (2021)

Section 9.4: Resistance and deformation models for assessment
-Methodology





Section 9.4: Resistance and deformation models for assessment

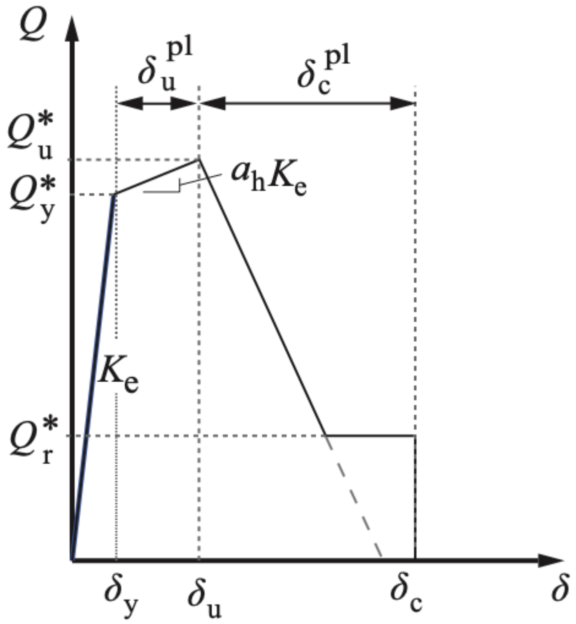
-9.4.2 Beams and columns under flexure with or without axial load

Table 9.8 Steel beam-to-column joint types

Joint Type	Description	Rigidity	Resistance
Welded unreinforced flange bolted web	Full penetration butt welds between beam and column flanges, bolted web	Rigid	Full-strength
Bolted end plate-stiffened	Stiffened end plate welded to beam and column flange	Rigid	Full-strength
Reduced beam section (RBS)	Connection in which the beam flange is reduced to force plastic hinging away from column face	Rigid	Full-strength
Bolted end plate – Unstiffened*	Unstiffened end plate welded to beam and bolted to column flange	Semi-rigid	Partial strength
Top and bottom seat-angle	Clip angle bolted or riveted to beam flange and column flange	Semi-rigid	Partial strength
Double split Tee (T-stub)	Split tees bolted or riveted to beam flange and column flange	Semi-rigid	Partial strength
Bolted flange plate	Bolted to both the beam and girder webs	Flexible	Partial strength
Simple shear tab	Simple connection with bolted shear tab	Flexible	Partial strength
* Depending on the end plate thickness, bolted end plate beam-to-column joints may be classified as rigid and full-strength connections according to EN 1993-1-8.			

Section 9.4: Resistance and deformation models for assessment

-9.4.2.2.2 Steel beams with non-compliant seismic weld detailing



Resistance models

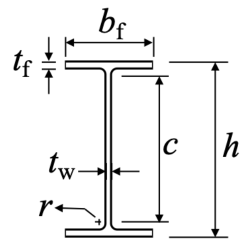
$$M_y^* = 1{,}1\, W_{el} f_y$$

$$M_u^* = M_y^* + a_h K_e \delta_u^{pl} \qquad (a_h = 0{,}03)$$

Deformation models

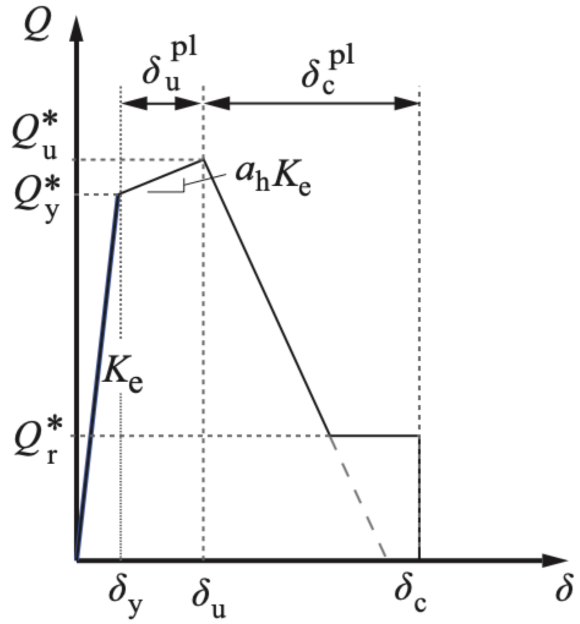
$$\delta_u^{pl} = 0{,}048 - 0{,}000433\, h$$

$$\delta_c = 0{,}056 - 0{,}000433\, h$$



Section 9.4: Resistance and deformation models for assessment

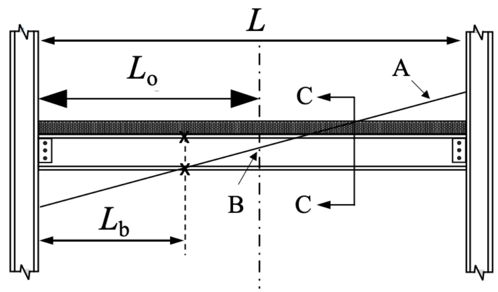
-9.4.2.2.1 Steel beams with compliant seismic weld detailing (in DC2 or DC3)

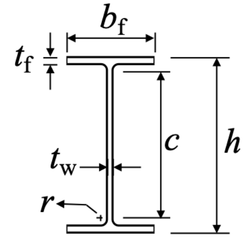


Resistance models

$$M_y^* = 1{,}1\omega_{rm} M_{Rk}$$

$$M_u^* = 1{,}1 M_y^*$$





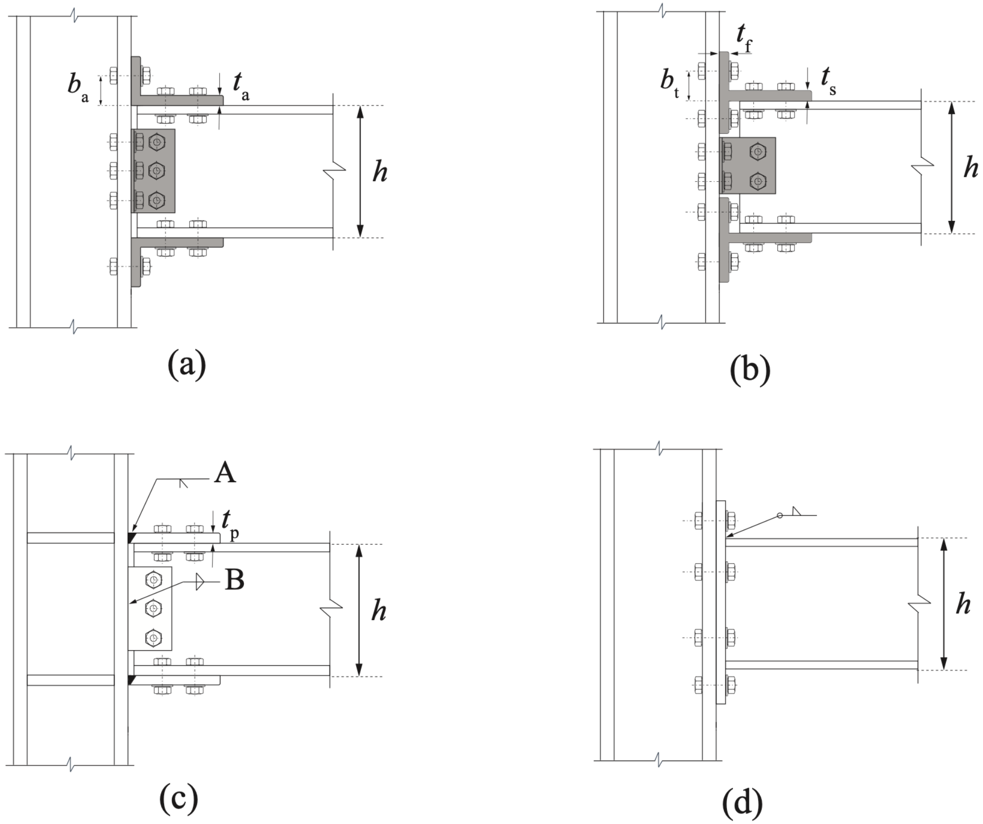
Deformation models

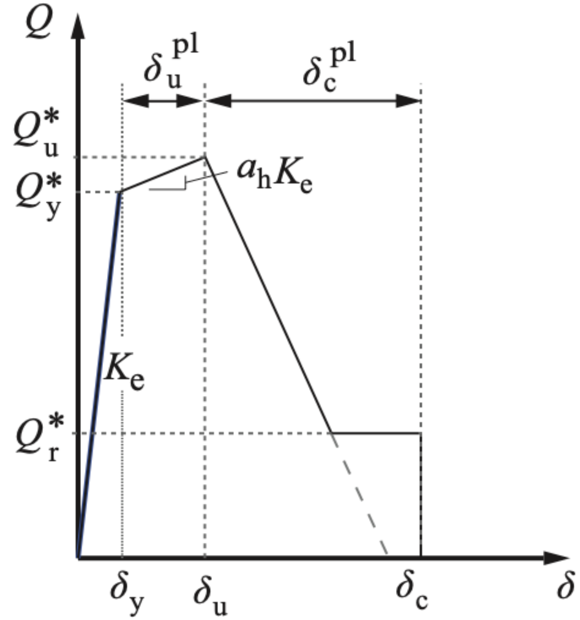
$$\delta_u^{pl} = 0{,}50\left(\frac{c}{t_w}\right)^{-0{,}9}\left(\frac{b_f}{2t_f}\right)^{-1{,}1}\left(\frac{L_b}{i_z}\right)^{-0{,}2}\left(\frac{L_o}{h}\right)^{-1{,}1}\left(\frac{E}{\omega_{rm} f_y}\right)^{0{,}2}$$

$$\delta_c^{pl} = 6{,}4\left(\frac{c}{t_w}\right)^{-0{,}9}\left(\frac{b_f}{2t_f}\right)^{-0{,}2}\left(\frac{L_b}{i_z}\right)^{-0{,}5}\left(\frac{E}{\omega_{rm} f_y}\right)^{0{,}1} \leq 0{,}05 \text{ rad}$$

Section 9.4: Resistance and deformation models for assessment

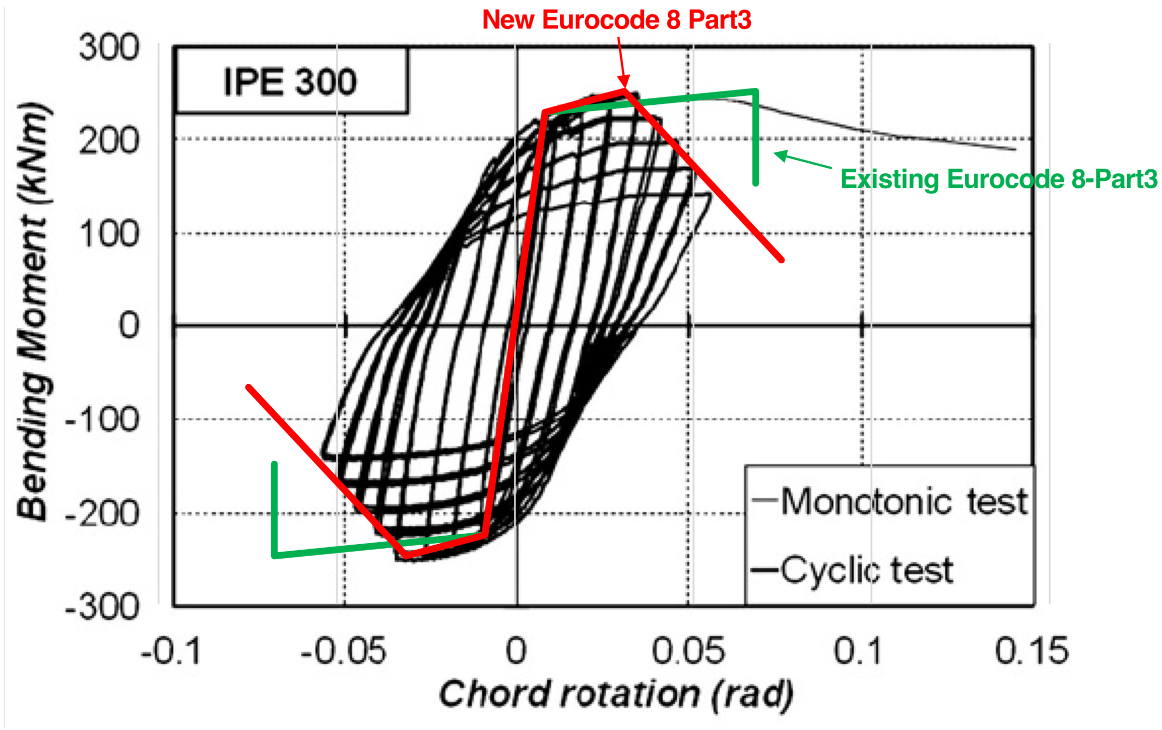
-9.4.2.4.2 Steel beams in partial-strength beam-to-column joints





Section 9.4: Resistance and deformation models for assessment

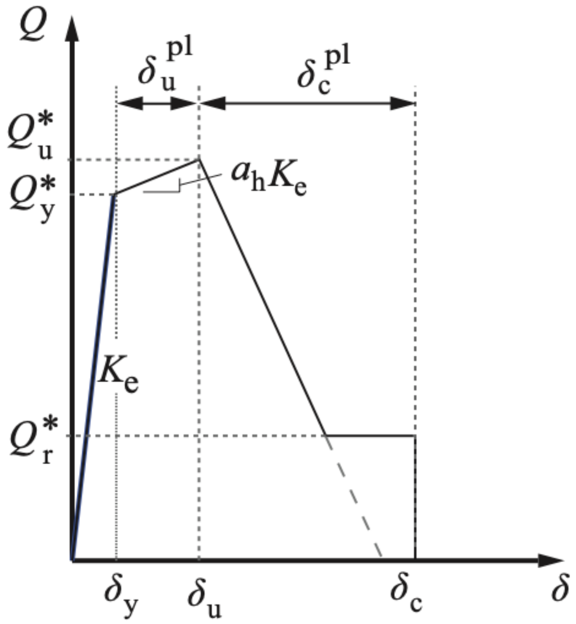
-Example and comparison with existing Eurocode 8-Part3



Cantilever steel beam test data (D'Aniello et al. 2012)

Section 9.4: Resistance and deformation models for assessment

-9.4.2.2.1 I- and H-shaped steel columns



Resistance models

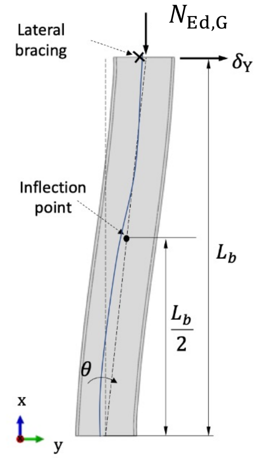
$$M_y^* = 1{,}15\omega_{rm}\left(1 - \frac{N_{Ed,G}}{\chi_z N_{Rk}/\gamma_{M1}}\right)\chi_{LT} M_{y,Rk}/\gamma_{M1}$$

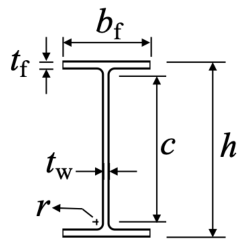
$$M_u^* = M_y^* + a_h K_e \theta_u^{pl}$$

Deformation models

$$\delta_u^{pl} = 7{,}37\left(\frac{c}{t_w}\right)^{-0{,}95}\left(\frac{L_b}{i_z}\right)^{-0{,}5}\left(1 - \frac{N_{Ed,G}}{N_{pl,e}}\right)^{2{,}4} \leq 0{,}15\text{rad}$$

$$\delta_c = 20\left(\frac{c}{t_w}\right)^{-0{,}9}\left(\frac{L_b}{i_z}\right)^{-0{,}5}\left(1 - \frac{N_{Ed,G}}{N_{pl,e}}\right)^{3{,}4} \leq 0{,}07\text{rad}$$

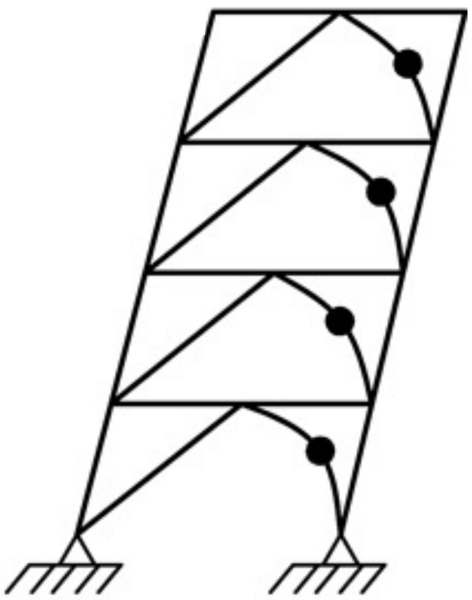


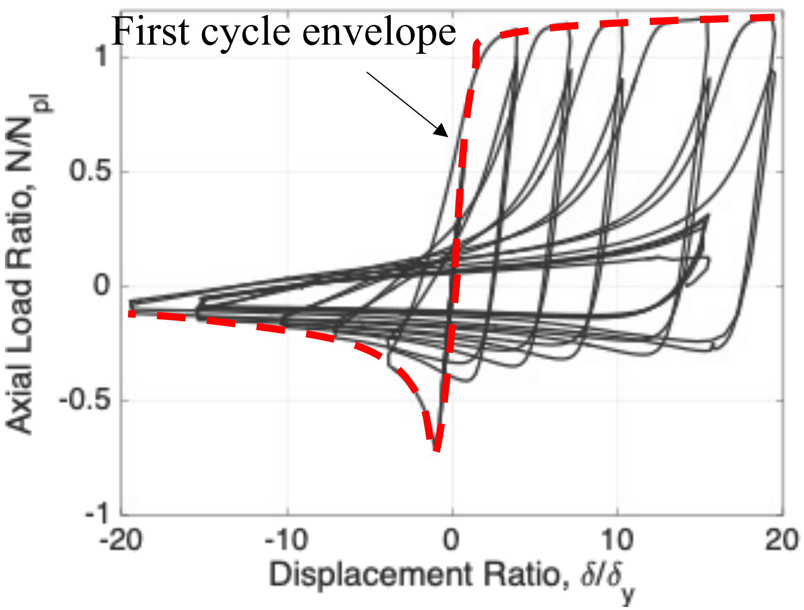


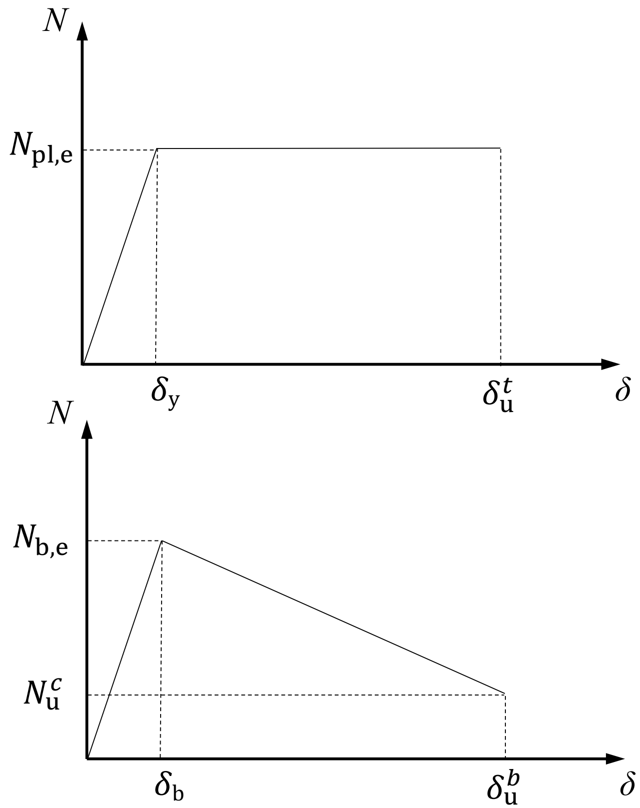
Source: Lignos et al. (2019)

Section 9.4: Resistance and deformation models for assessment

-9.4.3 Steel bracings (see also EN1998-1-1:2022, Clause 7.3.3)

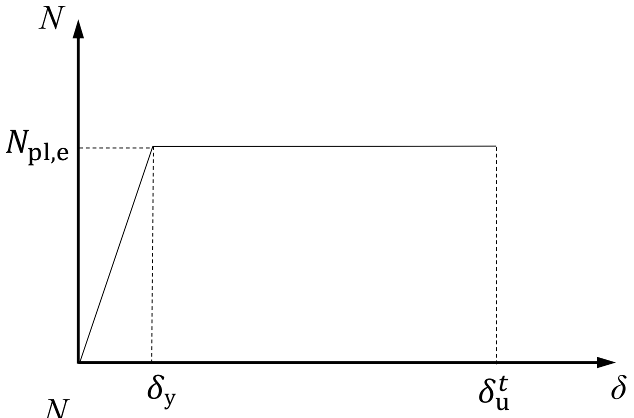


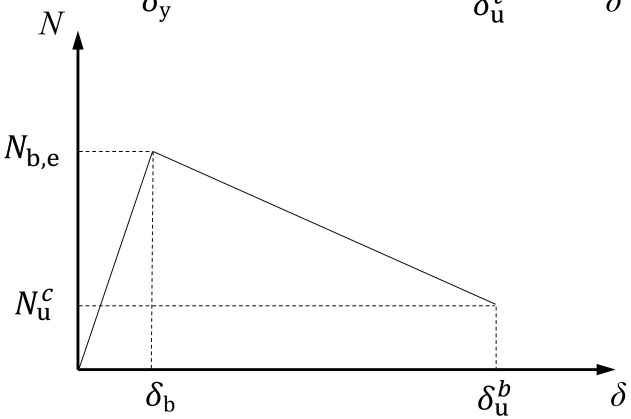




Section 9.4: Resistance and deformation models for assessment

-9.4.3 Steel bracings (see also EN1998-1-1:2022, Clause 7.3.3)





Resistance models

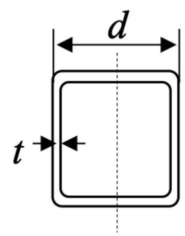
$N_{pl,e} = \omega_{rm} f_y A, \qquad N_u^t = N_{pl,e}$ **(tensile load)**

$N_{b,e} = \omega_{rm} N_{b,Rd}, \qquad N_u^c = 0{,}20\, \omega_{rm} N_{b,Rd}$ **(compressive load)**

Deformation models (example hollow structural steel sections)

$$\delta_u^c = 3{,}75 \left(\frac{\lambda_f}{\lambda_{Cl.1}}\right)^{-1{,}0} \left(\frac{L_{cr}}{i}\sqrt{\frac{\omega_{rm} f_y}{E}}\right)^{0{,}4} \delta_b$$

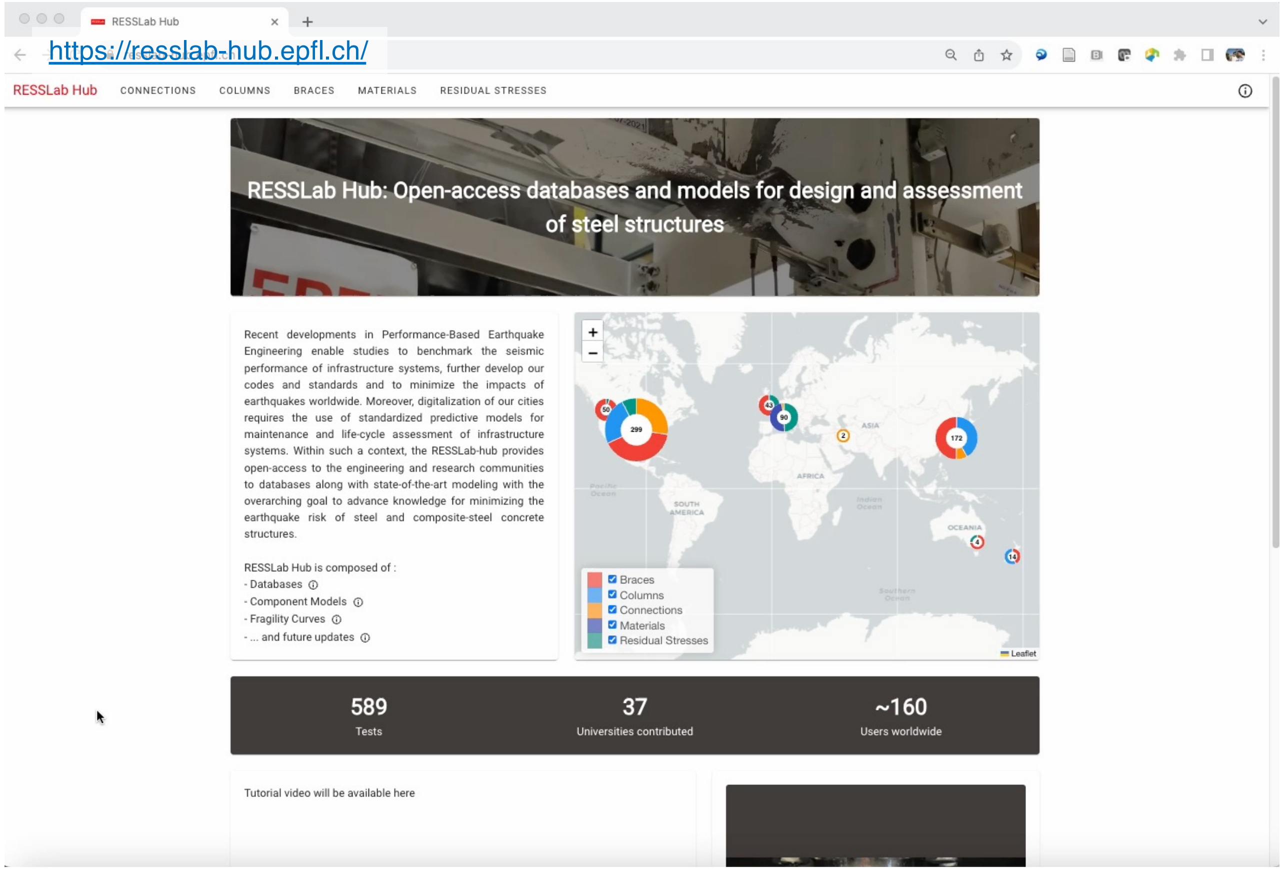
$$\delta_u^t = 5{,}8 \left(\frac{\lambda_f}{\lambda_{Cl.1}}\right)^{-1{,}0} \left(\frac{L_{cr}}{i}\sqrt{\frac{\omega_{rm} f_y}{E}}\right)^{0{,}24} \delta_y$$



Source: Lignos (2023)

Section 9.4: Resistance and deformation models for assessment

-Developed web-based interfaces for exploitation of models & data



Q-R code

Section 9.5: Verification of limit states

Deformation capacity of a primary or secondary structural element (Near Collapse)

$$\delta_{\mathrm{NC}} = \frac{\delta_{\mathrm{u(or\ c)}}}{\gamma_{\mathrm{Rd}}}$$

$\delta_{\mathrm{u(or\ c)}}$ → From section 9.4 (depending on the element)

γ_{Rd} → From section 9.5.2 to 9.5.7 (depending on the element)

Column Type	Dominant KL	1	2	3
Steel I- or H-shaped	G	1,15	1,10	1,10
Steel hollow structural steel (HSS)	G	1,05	1,00	1,00
Encased composite	G	1,05	1,00	1,00
Filled composite	G	0,90	0,90	0,90
Reinforced concrete	According to **8.5.1.1** or **8.5.2.1**, whichever is applicable			

Section 9.5: Verification of limit states

Deformation capacity of a primary or secondary structural element (Significant Damage)

$$\delta_{SD} = \frac{\delta_y + \alpha_{SD,\theta}\delta_{u(or\ c)}}{\gamma_{Rd}}$$

→ $\alpha_{SD,\theta}$ from EN1998-1-1:2022

→ depends on the element

Deformation capacity of a primary or secondary structural element (Damage Limitation)

$$\delta_{DL} = \frac{\delta_y}{\gamma_{Rd}}$$

→ From section 9.4 (depending on the element)

→ 1,1 (primary) or 1,0 (secondary)

Non-dissipative connections (or joints)

$$Q_{NC} = \frac{Q_R^*}{\gamma_{Rd}}$$

→ From section 9.4 (depending on the element)

→ May be considered as constant (equal to 1,1)

Section 9.6: Resistance models for retrofitting

- 9.6.1 General
- 9.6.2 Weld retrofits
- 9.6.3 Retrofitting with stiffener or doubler plates
- 9.6.4 Beam-to-column joint retrofitting with haunched stiffeners
- 9.6.5 Retrofitting with encased composite columns
- 9.6.6 Retrofitting riveted or bolted connections and joints

Thank you for your kind attention!

Questions?

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