Second Generation of Eurocode 8

EN1998-1-2:2022: Composite Steel-Concrete Buildings

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Contains rules for the design and verification of composite steel-concrete buildings in seismic regions

- Section 12.1 General
- Section 12.2 Basis of design
- Section 12.3 Materials

Mostly the same with EN1998:2004

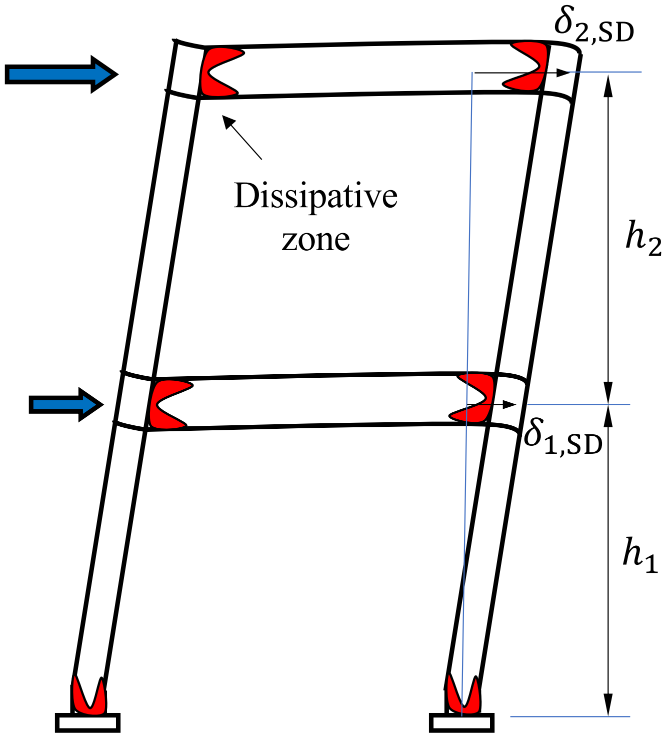
- Section 12.4 Structural types, behaviour factors, limits of seismic action & drift limits
- Section 12.5 Structural analysis
- Section 12.6 Verification to limit states
- Section 12.7 Design rules for DC1 behaviour
- Section 12.8 Design rules for dissipative (DC2, DC3) structural behaviour
- Section 12.9 Composite moment resisting frames in DC2 and DC3
- Section 12.10 Composite frames with concentric bracings in DC2 and DC3
- Section 12.11 Composite frames with eccentric bracings in DC2 and DC3
- Section 12.12 Composite frames with buckling restrained bracings
- Section 12.13 Composite dual frames in DC2 and DC3
- Section 12.14 Structural wall systems (RC & composite with structural steel elements)
- Annexes E, G (composite joints), H (column bases) , I (design of slabs)

Section 12.4: Structural types and behaviour factors

Structural type	Ductility Class					
	DC2			DC3		
	q_D	q_R	q	q_D	q_R	q
a) Composite moment resisting frames (CMRFs) Full-strength connections Portal frames and single-storey CMRFs with class 3 and 4 cross sections Portal frames and single-storey CMRFs with class 1 and 2 cross sections Multi-storey CMRFs Types above without or with unconnected interacting infills	See Table 11.2					
b) CMRFs with dissipative partial-strength connections	2,3	1,0	3,5	-	-	-
c) Composite frames with concentric bracings	See Table 11.2					
d) Composite frames with eccentric bracings	See Table 11.2					
e) Composite inverted pendulum	See Table 11.2					
f) Composite dual frames CMRFs with concentric bracings CMRFs with eccentric bracings CMRFs with buckling restrained braces	See Table 11.2					
g) Composite structural wall systems Composite walls (Type 1 and 2) Composite or concrete walls coupled by steel or composite beams (Type 3)	 2,2 2,2	 1,0 1,0	 3,5 3,5	 3,0 3,3	 1,0 1,0	 4,5 5,0

Section 12.6: Verification to limit states

- Limitation of interstorey drift angle at Significant Damage (SD) limit state:

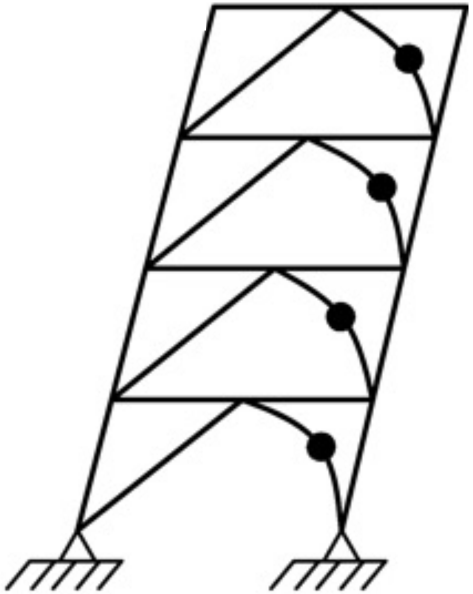


Composite moment resisting frames & dual frames
(Full or partial-strength connections)

$$d_{r,\text{SD}} = \frac{\delta_{r,\text{SD}} - \delta_{r-1,\text{SD}}}{h_s} \leq 0{,}02$$

Section 12.6: Verification to limit states (Cont.)

- Limitation of interstorey drift angle at Significant Damage (SD) limit state:



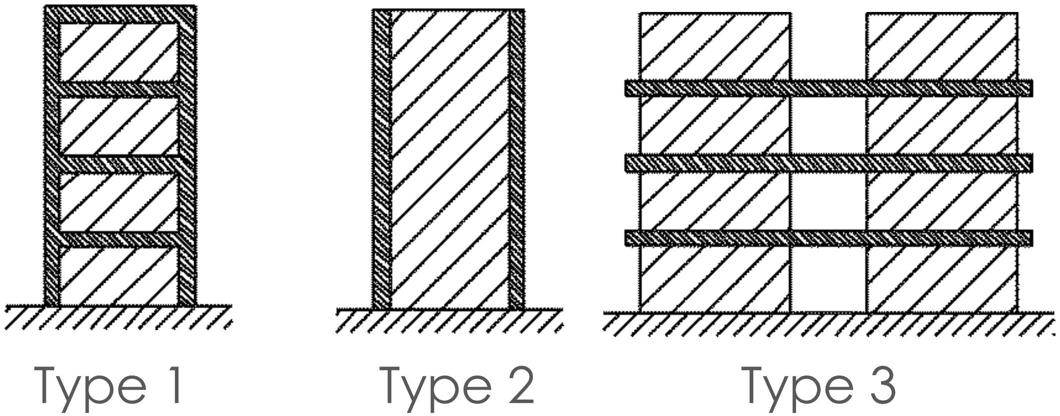
Composite frames with concentric/eccentric bracings

$$d_{r,\mathrm{SD}} = \frac{\delta_{r,\mathrm{SD}} - \delta_{r-1,\mathrm{SD}}}{h_s} \leq 0{,}015$$

Section 12.6: Verification to limit states (Cont.)

- Limitation of interstorey drift angle at Significant Damage (SD) limit state:

Composite structural wall systems of Type 1, 2 and 3



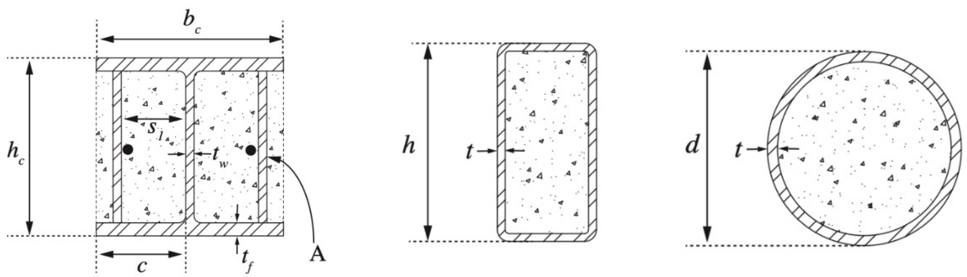
$$d_{r,\mathrm{SD}} = \frac{\delta_{r,\mathrm{SD}} - \delta_{r-1,\mathrm{SD}}}{h_s} \leq 0{,}017$$

Section 12.8: Design rules for dissipative (DC2, DC3) behaviour

- Local slenderness of cross sections within dissipative zones should be restricted
- For dissipative steel members 11.8.3 should be applied (Table 11.5)
- Encased or filled composite members under compression and/or bending:

Table 12.4

Ductility class	DC2		DC3
Reference value of behaviour factor	$q = 1,5$	$1,5 < q \leq 3,5$	$q > 3,5$
Partially or fully encased H- or I-cross section: c/t_f limits:	20ε	14ε	9ε
Filled rectangular cross section: h/t limits:	70ε	52ε	35ε
Filled circular cross section: d/t limits:	$125\varepsilon^2$	$90\varepsilon^2$	$80\varepsilon^2$



Local buckling

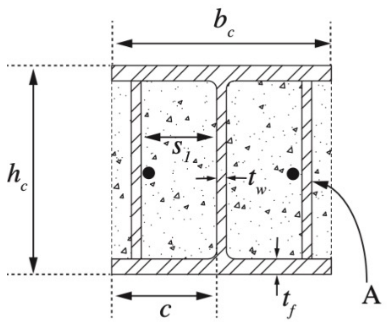
Farahi et al. 2022

Fracture

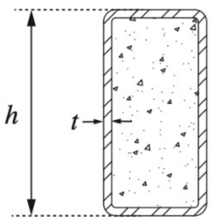
Silva et al. 2016

Section 12.8: Design rules for dissipative (DC2, DC3) behaviour (Cont.)

- Encased or filled composite members under compression and/or bending:



(a)



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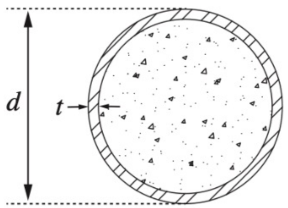


(c)

EN1998:2004

Ductility class	DCM		DCH
Reference value of behaviour factor	$q = 1{,}5$	$1{,}5 < q \leq 4$	$q > 4$
Partially or fully encased H- or I-cross section: c/t_f limits:	20ε	14ε	9ε
Filled rectangular cross section: h/t limits:	52ε	38ε	24ε
Filled circular cross section: d/t limits:	$90\varepsilon^2$	$85\varepsilon^2$	$80\varepsilon^2$

EN1998-1-2:2022

Ductility class	DC2		DC3
Reference value of behaviour factor	$q = 1{,}5$	$1{,}5 < q \leq 3{,}5$	$q > 3{,}5$
Partially or fully encased H- or I-cross section: c/t_f limits:	20ε	14ε	9ε
Filled rectangular cross section: h/t limits:	70ε	52ε	35ε
Filled circular cross section: d/t limits:	$125\varepsilon^2$	$90\varepsilon^2$	$80\varepsilon^2$

Section 12.8.5: Verification of members in DC2 and DC3

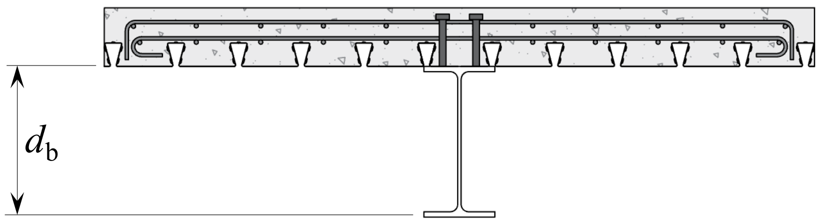
- In DC2, the resistance and stability of members defined by structural type should be verified according to,

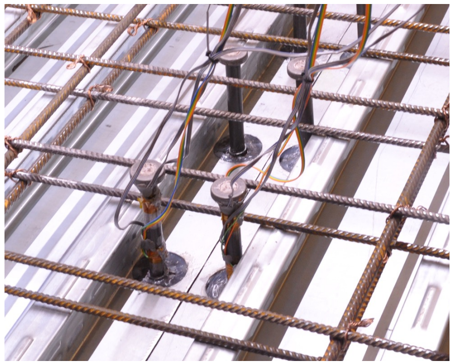
$$N_{\mathrm{Ed}} = N_{\mathrm{Ed,G}} \text{ "+" } \Omega \; N_{\mathrm{Ed,E}} \qquad M_{\mathrm{Ed}} = M_{\mathrm{Ed,G}} \text{ "+" } \Omega \; M_{\mathrm{Ed,E}} \qquad V_{\mathrm{Ed}} = V_{\mathrm{Ed,G}} \text{ "+" } \Omega \; V_{\mathrm{Ed,E}}$$

Structural types	Ω	Members
Composite moment resisting frames (CMRFs): With full-strength connections	See Table 11.6	Columns
With partial-strength connections	2,0	Columns
Composite frames with concentric bracings	See Table 11.6	Beams and columns
Composite frames with eccentric bracings	See Table 11.6	Beams outside the link, braces and columns
Composite inverted pendulum structures	See Table 11.6	Columns
Composite dual frames CMRFs with concentric bracings CMRFs with eccentric bracings	See Table 11.6	Beams and columns of the concentric bracing; columns of the CMRF Beams outside the link, braces and oclumns of the eccentricl bracing; columns of the CMRF
Composite structural wall systems Types 1, 2 and 3	2,0	None None

Section 12.8.6: Verification of composite beams in DC2 and DC3

- Composite beams in dissipative zones may be designed with full or partial shear connections in accordance with EN1994-1-1:2022 and a degree of composite action of at least 80%





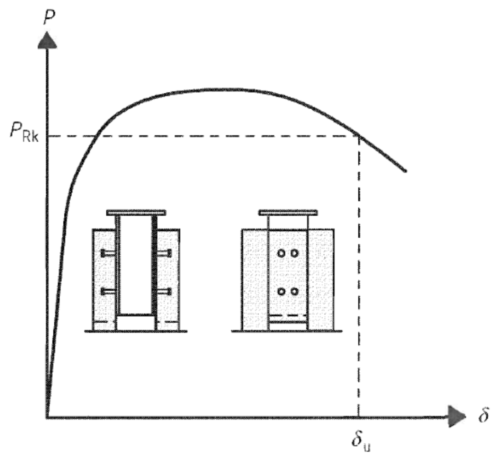
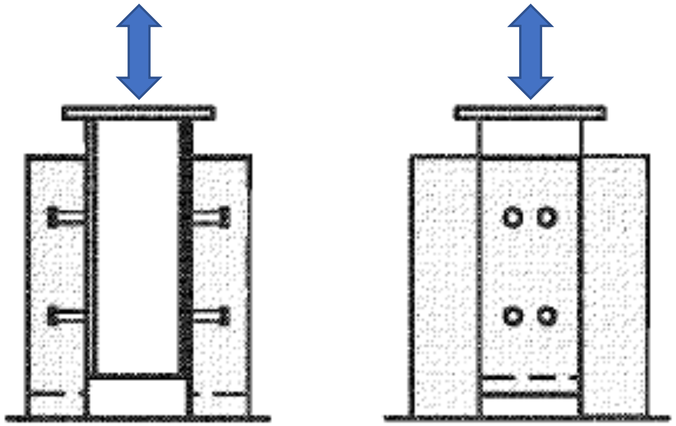


Image courtesy of Prof. Dr. D. Lignos

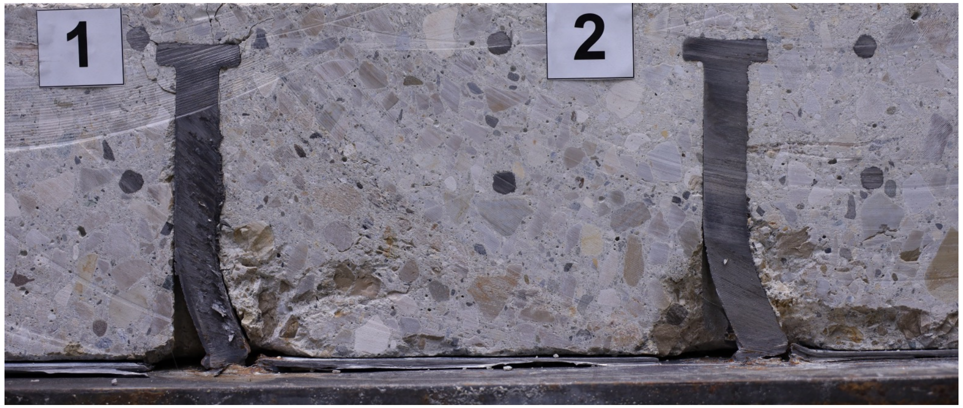
- Composite beams with $d_b \leq 500mm$: The 25% reduction on shear resistance is neglected

Section 12.8.6: Verification of composite beams in DC2 and DC3 (Cont.)

- Shear resistance of connectors



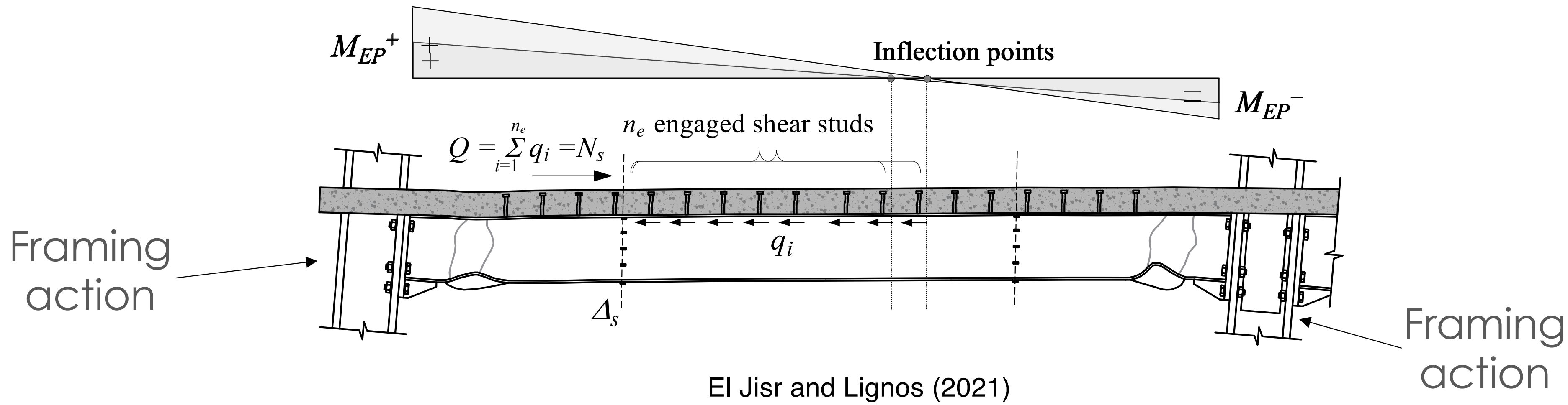
Standard push-out test



El Jisr and Lignos (2021)

Section 12.8.6: Verification of composite beams in DC2 and DC3 (Cont.)

- Shear resistance of connectors



El Jisr and Lignos (2021)

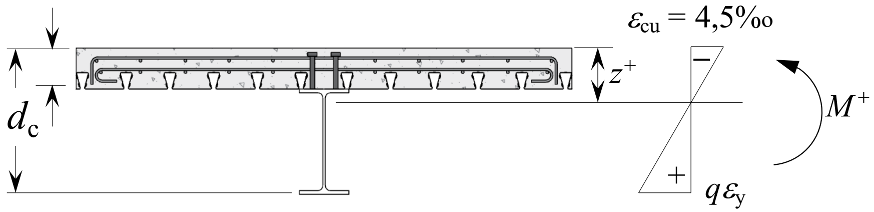
Section 12.8.6: Verification of composite beams in DC2 and DC3 (Cont.)

- Shear resistance of connectors

(El Jisr and Lignos, 2021)

Section 12.8.6: Verification of composite beams in DC2 and DC3 (Cont.)

- Ductility requirements in composite steel beams in dissipative zones (positive bending)



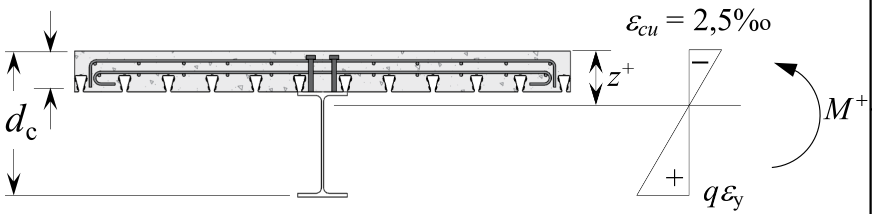
$$\frac{z^+}{d_c} \leq \frac{\varepsilon_{cu}}{\varepsilon_{cu} + q \cdot \varepsilon_y}$$

ε_{cu} (considers confinement)

Ductility class	***q***	f_y **(N/mm²)**	z^+/d_c **upper limit**
DC2	$1,5 < q \leq 3,5$	355	0,45
		275	0,50
		235	0,55
DC3	$3,5 < q \leq 5,0$	355	0,35
		275	0,40
		235	0,45
	$q > 5,0$	355	0,30
		275	0,35
		235	0,40

Section 7.6.2 in EN1998:2004: Verification of composite beams

- Ductility requirements in composite steel beams (EN1998:2004)



$$\frac{z^+}{d_c} \leq \frac{\varepsilon_{cu}}{\varepsilon_{cu} + q \cdot \varepsilon_y}$$

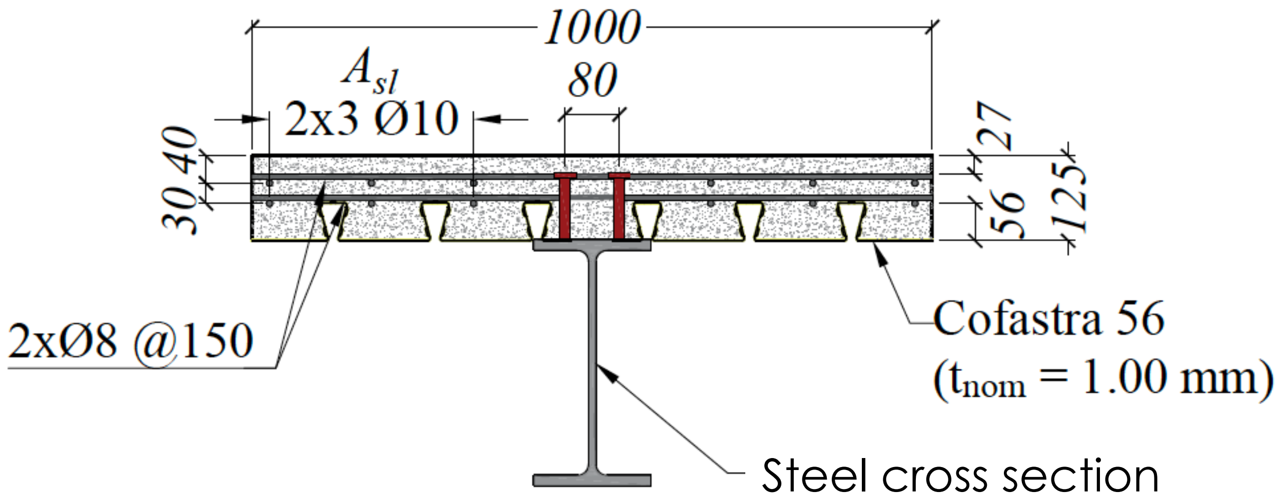
Table 7.4

Ductility class	q	f_y (N/mm²)	z^+/d_c upper limit
DCM	$1{,}5 < q \leq 4$	355	0,27
		275	-
		235	0,36
DCH	$q > 4{,}0$	355	0,20
		275	-
		235	0,27

ε_{cu} (does not consider confinement)

Some remarks regarding ductility requirements for composite steel beams

- For a typical composite steel (S355) beam (f_{cd}=20MPa)



Some remarks regarding ductility requirements for composite steel beams

EN1998:2004

Fully Composite Beam

q	L [mm]	z/d								Limit
		IPE270	IPE300	IPE330	IPE360	IPE400	IPE450	IPE500	IPE550	
1.5	5000	0.336	0.317	0.315	0.345	0.387	0.414	0.439	0.457	0.50
	6000	0.332	0.313	0.297	0.284	0.332	0.368	0.400	0.424	0.50
	7000	0.327	0.309	0.294	0.281	0.277	0.323	0.361	0.391	0.50
	8000	0.322	0.305	0.290	0.278	0.262	0.277	0.322	0.358	0.50
	9000	0.318	0.301	0.287	0.275	0.259	0.242	0.284	0.325	0.50
2	5000	0.336	0.317	0.315	0.345	0.387	0.414	0.439	0.457	0.43
	6000	0.332	0.313	0.297	0.284	0.332	0.368	0.400	0.424	0.43
	7000	0.327	0.309	0.294	0.281	0.277	0.323	0.361	0.391	0.43
	8000	0.322	0.305	0.290	0.278	0.262	0.277	0.322	0.358	0.43
	9000	0.318	0.301	0.287	0.275	0.259	0.242	0.284	0.325	0.43
3.5	5000	0.336	0.317	0.315	0.345	0.387	0.414	0.439	0.457	0.30
	6000	0.332	0.313	0.297	0.284	0.332	0.368	0.400	0.424	0.30
	7000	0.327	0.309	0.294	0.281	0.277	0.323	0.361	0.391	0.30
	8000	0.322	0.305	0.290	0.278	0.262	0.277	0.322	0.358	0.30
	9000	0.318	0.301	0.287	0.275	0.259	0.242	0.284	0.325	0.30
5.5	5000	0.336	0.317	0.315	0.345	0.387	0.414	0.439	0.457	0.21
	6000	0.332	0.313	0.297	0.284	0.332	0.368	0.400	0.424	0.21
	7000	0.327	0.309	0.294	0.281	0.277	0.323	0.361	0.391	0.21
	8000	0.322	0.305	0.290	0.278	0.262	0.277	0.322	0.358	0.21
	9000	0.318	0.301	0.287	0.275	0.259	0.242	0.284	0.325	0.21
6.5	5000	0.336	0.317	0.315	0.345	0.387	0.414	0.439	0.457	0.19
	6000	0.332	0.313	0.297	0.284	0.332	0.368	0.400	0.424	0.19
	7000	0.327	0.309	0.294	0.281	0.277	0.323	0.361	0.391	0.19
	8000	0.322	0.305	0.290	0.278	0.262	0.277	0.322	0.358	0.19
	9000	0.318	0.301	0.287	0.275	0.259	0.242	0.284	0.325	0.19

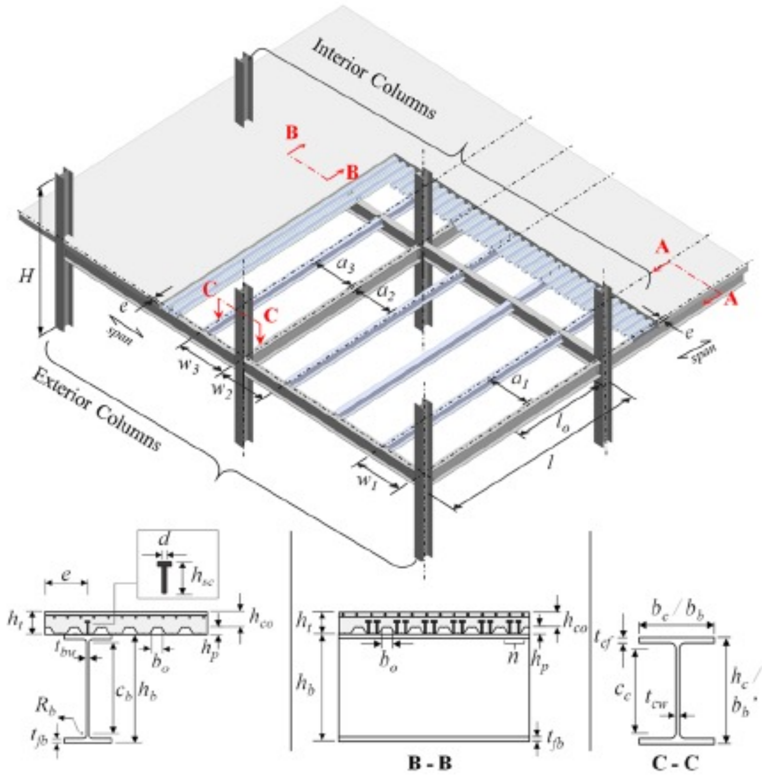
EN1998-1-2:2022

Fully Composite Beam

q	L [mm]	z/d								Limit
		IPE270	IPE300	IPE330	IPE360	IPE400	IPE450	IPE500	IPE550	
1.5	5000	0.338	0.318	0.337	0.364	0.403	0.428	0.451	0.467	0.64
	6000	0.334	0.315	0.299	0.311	0.358	0.390	0.418	0.440	0.64
	7000	0.330	0.312	0.296	0.283	0.312	0.352	0.386	0.412	0.64
	8000	0.326	0.308	0.293	0.280	0.266	0.313	0.354	0.385	0.64
	9000	0.322	0.305	0.290	0.278	0.262	0.275	0.321	0.357	0.64
2	5000	0.338	0.318	0.337	0.364	0.403	0.428	0.451	0.467	0.57
	6000	0.334	0.315	0.299	0.311	0.358	0.390	0.418	0.440	0.57
	7000	0.330	0.312	0.296	0.283	0.312	0.352	0.386	0.412	0.57
	8000	0.326	0.308	0.293	0.280	0.266	0.313	0.354	0.385	0.57
	9000	0.322	0.305	0.290	0.278	0.262	0.275	0.321	0.357	0.57
3.5	5000	0.338	0.318	0.337	0.364	0.403	0.428	0.451	0.467	0.43
	6000	0.334	0.315	0.299	0.311	0.358	0.390	0.418	0.440	0.43
	7000	0.330	0.312	0.296	0.283	0.312	0.352	0.386	0.412	0.43
	8000	0.326	0.308	0.293	0.280	0.266	0.313	0.354	0.385	0.43
	9000	0.322	0.305	0.290	0.278	0.262	0.275	0.321	0.357	0.43
5.5	5000	0.338	0.318	0.337	0.364	0.403	0.428	0.451	0.467	0.33
	6000	0.334	0.315	0.299	0.311	0.358	0.390	0.418	0.440	0.33
	7000	0.330	0.312	0.296	0.283	0.312	0.352	0.386	0.412	0.33
	8000	0.326	0.308	0.293	0.280	0.266	0.313	0.354	0.385	0.33
	9000	0.322	0.305	0.290	0.278	0.262	0.275	0.321	0.357	0.33
6.5	5000	0.338	0.318	0.337	0.364	0.403	0.428	0.451	0.467	0.29
	6000	0.334	0.315	0.299	0.311	0.358	0.390	0.418	0.440	0.29
	7000	0.330	0.312	0.296	0.283	0.312	0.352	0.386	0.412	0.29
	8000	0.326	0.308	0.293	0.280	0.266	0.313	0.354	0.385	0.29
	9000	0.322	0.305	0.290	0.278	0.262	0.275	0.321	0.357	0.29

Section 12.8.6: Slab effective width for plastic bending resistance calculations

- Partial effective width $b_{eff,Rd}$ of slab for evaluation of M_{Rd}



(El Jisr and Lignos, 2019)

Table 7.5 (EN1998:2004)

Sign of bending moment M	Location	Transverse element	b_e for M_{Rd} (PLASTIC)
Negative M	Interior column	Seismic re-bars	$0{,}1\ l$
Negative M	Exterior column	All layouts with re-bars anchored to façade beam or to concrete cantilever edge strip	$0{,}1\ l$
Negative M	Exterior column	All layouts with re-bars not anchored to façade beam or to concrete cantilever edge strip	0,0
Positive M	Interior column	Seismic re-bars	$0{,}075\ l$
Positive M	Exterior column	Steel transverse beam with connectors. Concrete slab up to exterior face of column of H section with strong axis oriented as in Fig. 7.5 or beyond (concrete edge strip). Seismic re-bars	$0{,}075\ l$
Positive M	Exterior column	No steel transverse beam or steel transverse beam without connectors. Concrete slab up to exterior face of column of H section with strong axis oriented as in Fig. 7.5, or beyond (edge strip). Seismic re-bars	$b_b/2 + 0{,}7\ h_c/2$
Positive M	Exterior column	All other layouts. Seismic re-bars	$b_b/2 \leq b_{e,max}$ $b_{e,max} = 0{,}05l$

Section 12.8.6: Slab effective width for plastic bending resistance calculations

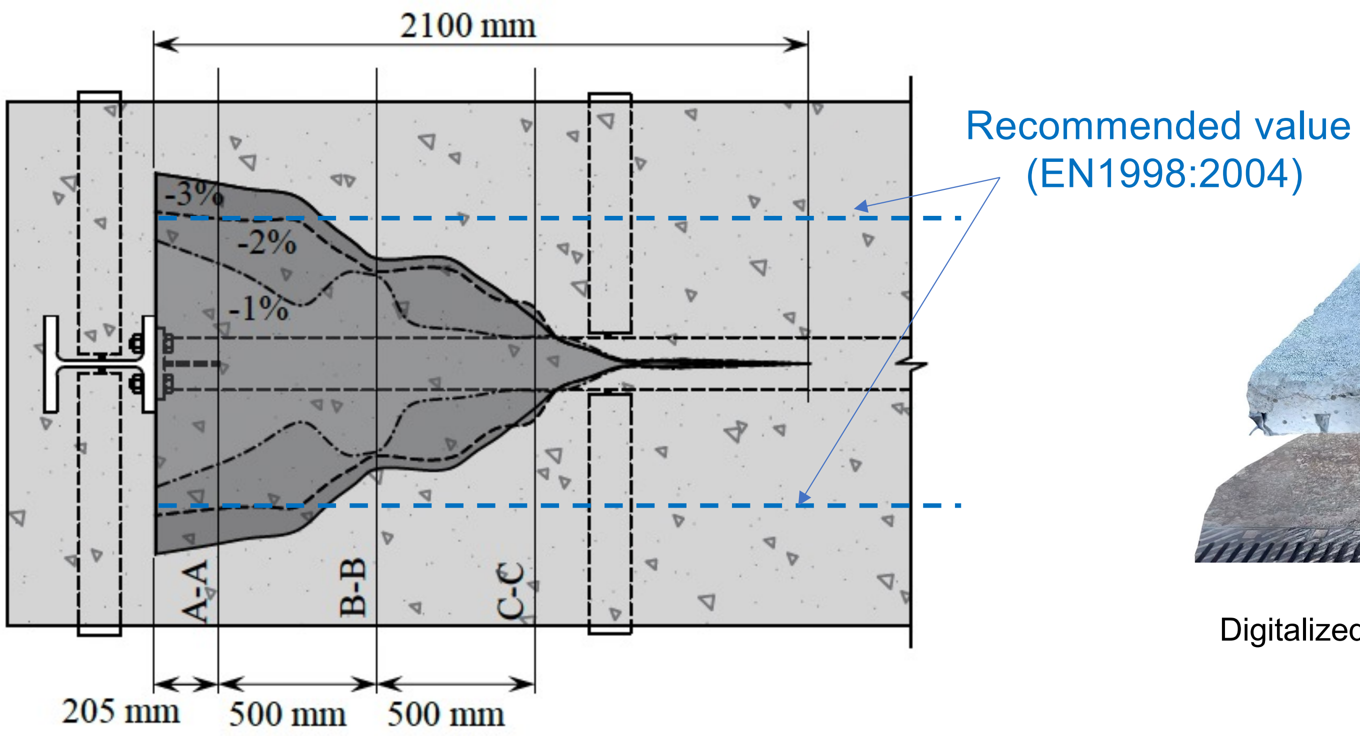
- Partial effective width $b_{eff,Rd}$ of slab for evaluation of M_{Rd}

Table 12.7

Stresses in slab	**Column location**	**Transverse element**	$\boldsymbol{b_{eff,Rd}}$
Tensile	Interior	With seismic re-bars	b_{eff}
Tensile	Exterior	With re-bars anchored to façade beam or to concrete cantilever edge strip. With seismic rebars	b_{eff}
Tensile	Exterior	With re-bars not anchored to façade beam or to concrete cantilever edge strip. With seismic rebars	0,0
Compressive	Interior/Exterior	Transverse beam with connectors and rigidly connected to column. With seismic re-bars	b_{eff}
Compressive	Interior/Exterior	No transverse beam with connectors. With seismic re-bars	b_c+0,7h_c
Compressive	Exterior (perimeter frame)	No transverse beam with connectors. With seismic re-bars	b_c

Section 12.8.6: Slab effective width for plastic bending resistance calculations

- Benchmarking of partial effective width $b_{eff,Rd}$ of slab for evaluation of M_{Rd}



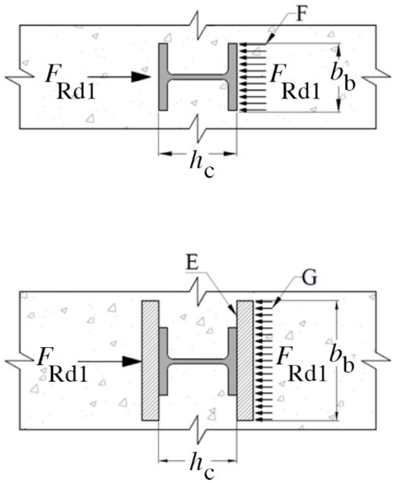
Digitalized transverse section of composite steel beam

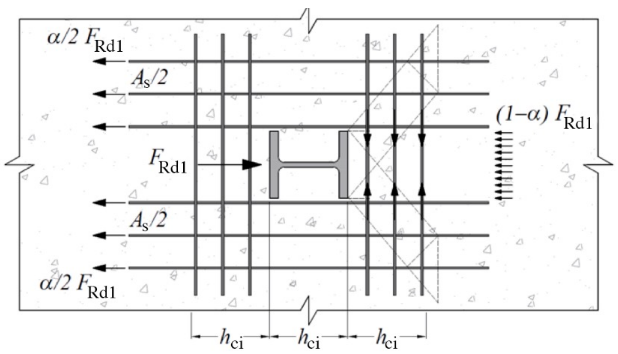
El Jisr and Lignos (2021)

Section 12.8.8: Verification of composite joints in dissipative zones

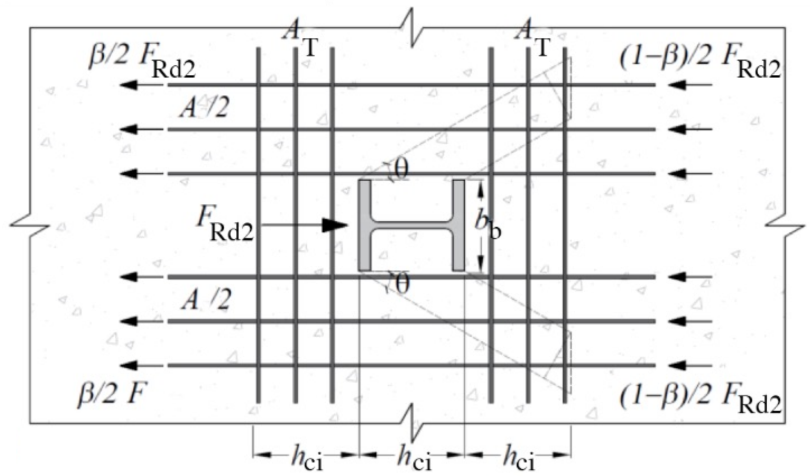
- The integrity of the concrete in compression should be maintained; yielding should be limited to the steel cross section(s)

- Reinforcing rebars in the joint region according to Annex I for slabs





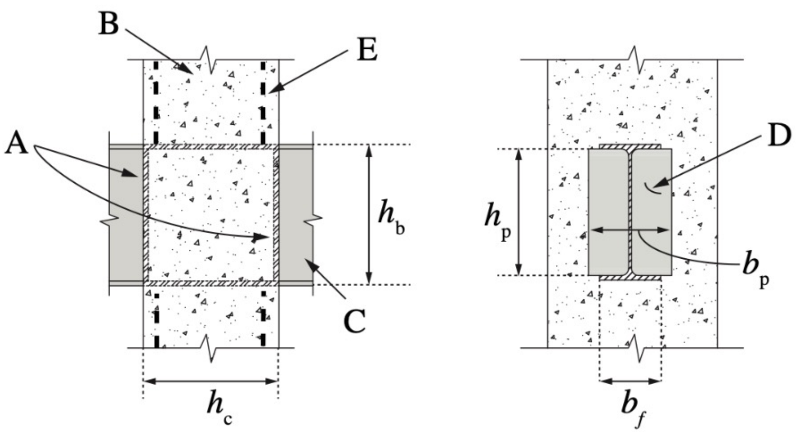
Mechanism I



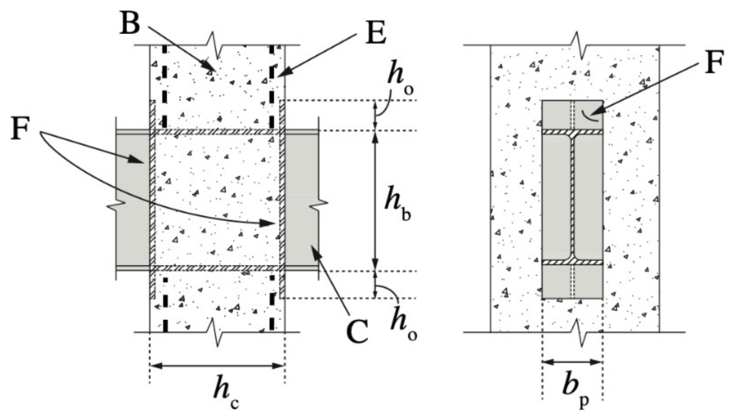
Mechanism II

Section 12.8.8: Verification of composite joints in dissipative zones (Cont.)

- Joints between steel and reinforced concrete columns according to Annex G (G.5)



Wide face bearing plates

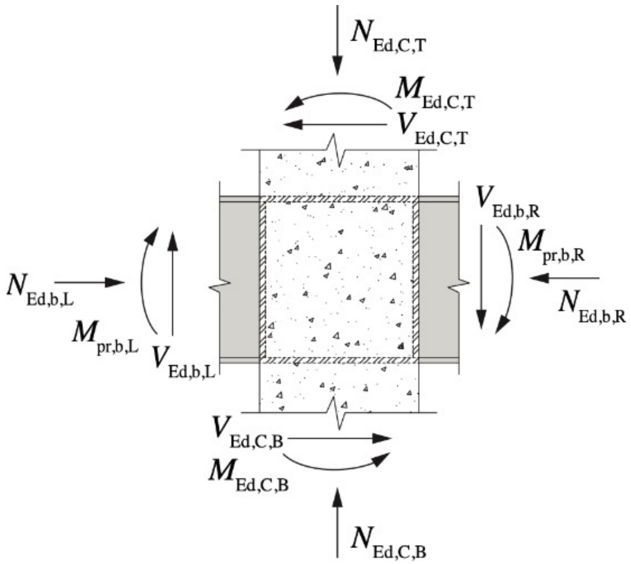


Extended face bearing plates

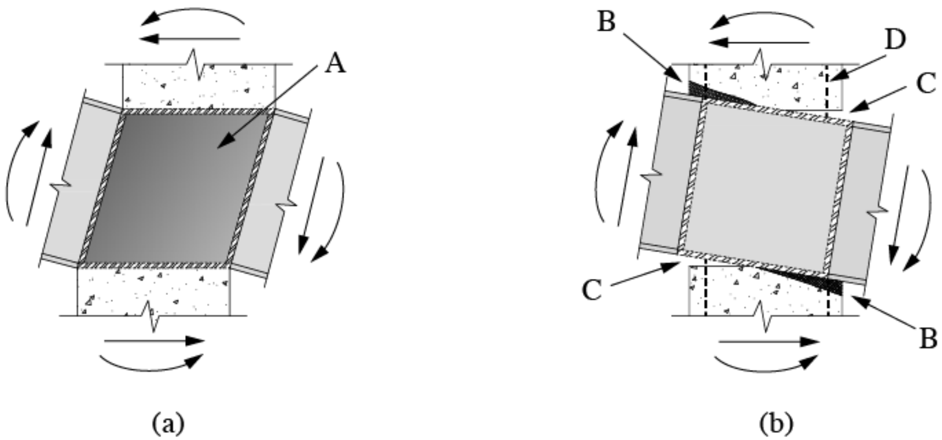
Section 12.8.8: Verification of composite joints in dissipative zones (Cont.)

- Joints between steel and reinforced concrete columns according to Annex G (G.5)

Joint forces



Joint failure modes

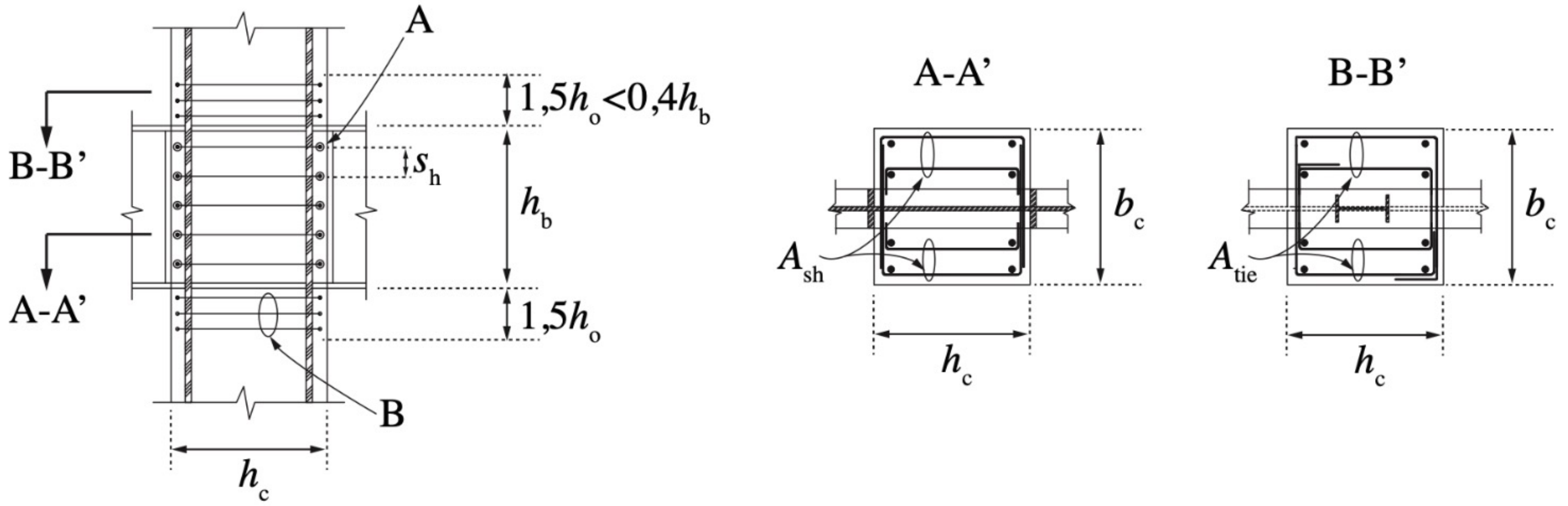


Web panel shear

Vertical bearing

Section 12.8.8: Verification of composite joints in dissipative zones (Cont.)

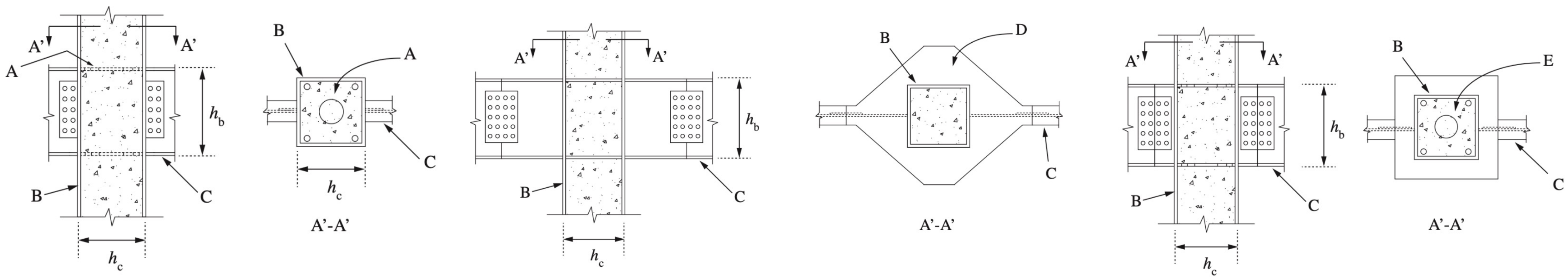
- Joints between steel and reinforced concrete columns according to Annex G (G.5)
- Column horizontal and vertical reinforcing details



Section 12.8.8: Verification of composite joints in dissipative zones (Cont.)

- Joints using diaphragm plates according to Annex G (G.6)

- Composite joints using diaphragm plates should be designed as full strength with all plastic deformations localised in the composite steel beam



Internal External Through

Section 12.9: Composite moment resisting frames in DC2 and DC3

- Generally, follow the design provisions in 11.9
- Provisions on columns in DC3 (12.9.4):

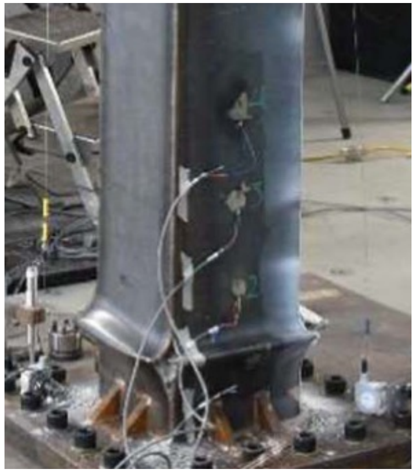
H-, I-shaped or HSS

$$\frac{N_{\mathrm{Ed,G}}}{N_{\mathrm{pl,Rd}}} \leq 0{,}30$$

Suzuki and Lignos (2015)

Encased, partially encased or filled composite

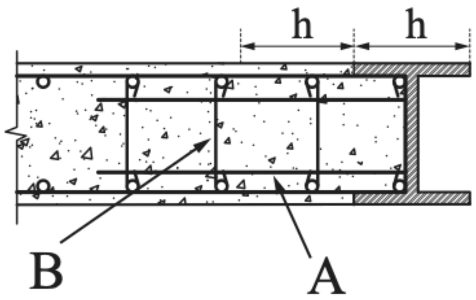
$$\frac{N_{\mathrm{Ed}}}{N_{\mathrm{pl,Rd}}} \leq 0{,}75$$

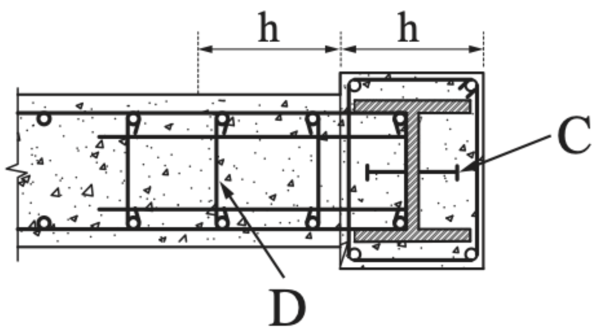


Farahi et al. (2022)

Section 12.14: Composite walls in DC2 and DC3

- In primary seismic walls, the normalised design axial load $v_{\mathrm{d,c}}$ should be limited





For DC2

$$v_{\mathrm{d,c}} = \frac{N_{\mathrm{Ed}}}{f_{\mathrm{cd}}[A_{\mathrm{c}} + n_{\mathrm{o}}(A_{\mathrm{s}} + A_{\mathrm{a}})]} \leq 0{,}40$$

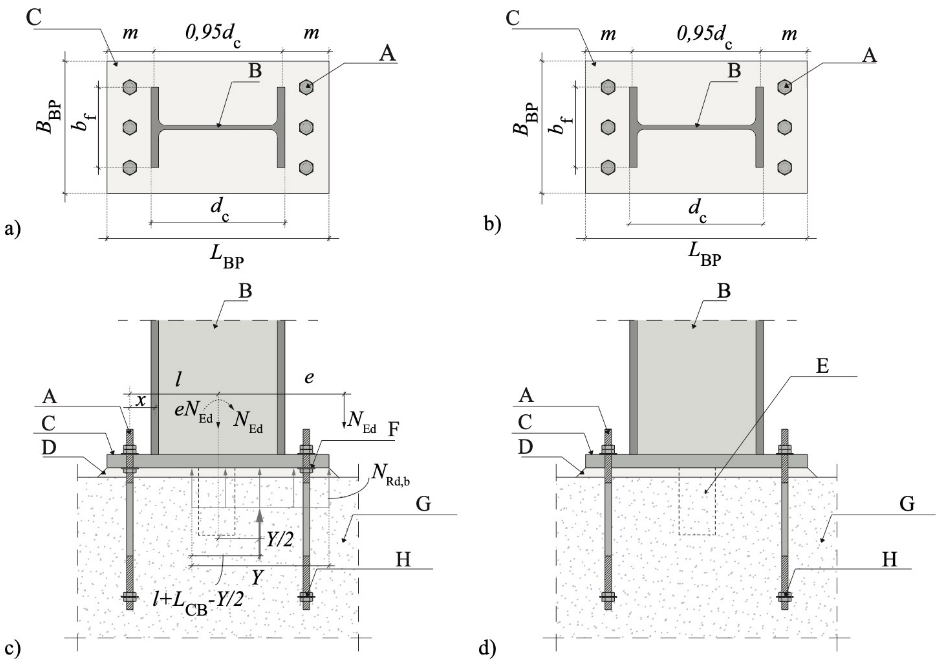
For DC3

$$v_{\mathrm{d,c}} = \frac{N_{\mathrm{Ed}}}{f_{\mathrm{cd}}[A_{\mathrm{c}} + n_{\mathrm{o}}(A_{\mathrm{s}} + A_{\mathrm{a}})]} \leq 0{,}35$$

Section 12.9.7: Verification of column base joints

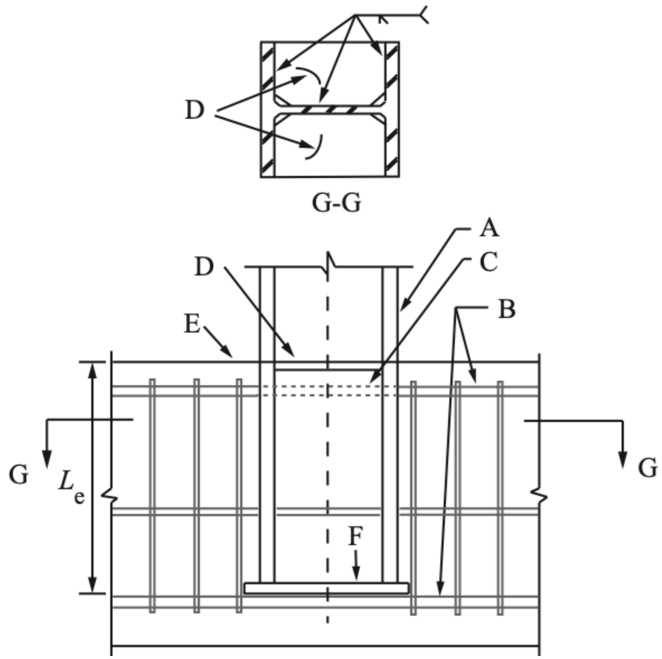
- 11.9.5 and Annex H should be applied

Annex H, H4 (EN1998-1-2:2022)



Exposed column bases

Annex H, H5 (EN1998-1-2:2022)



Embedded column bases

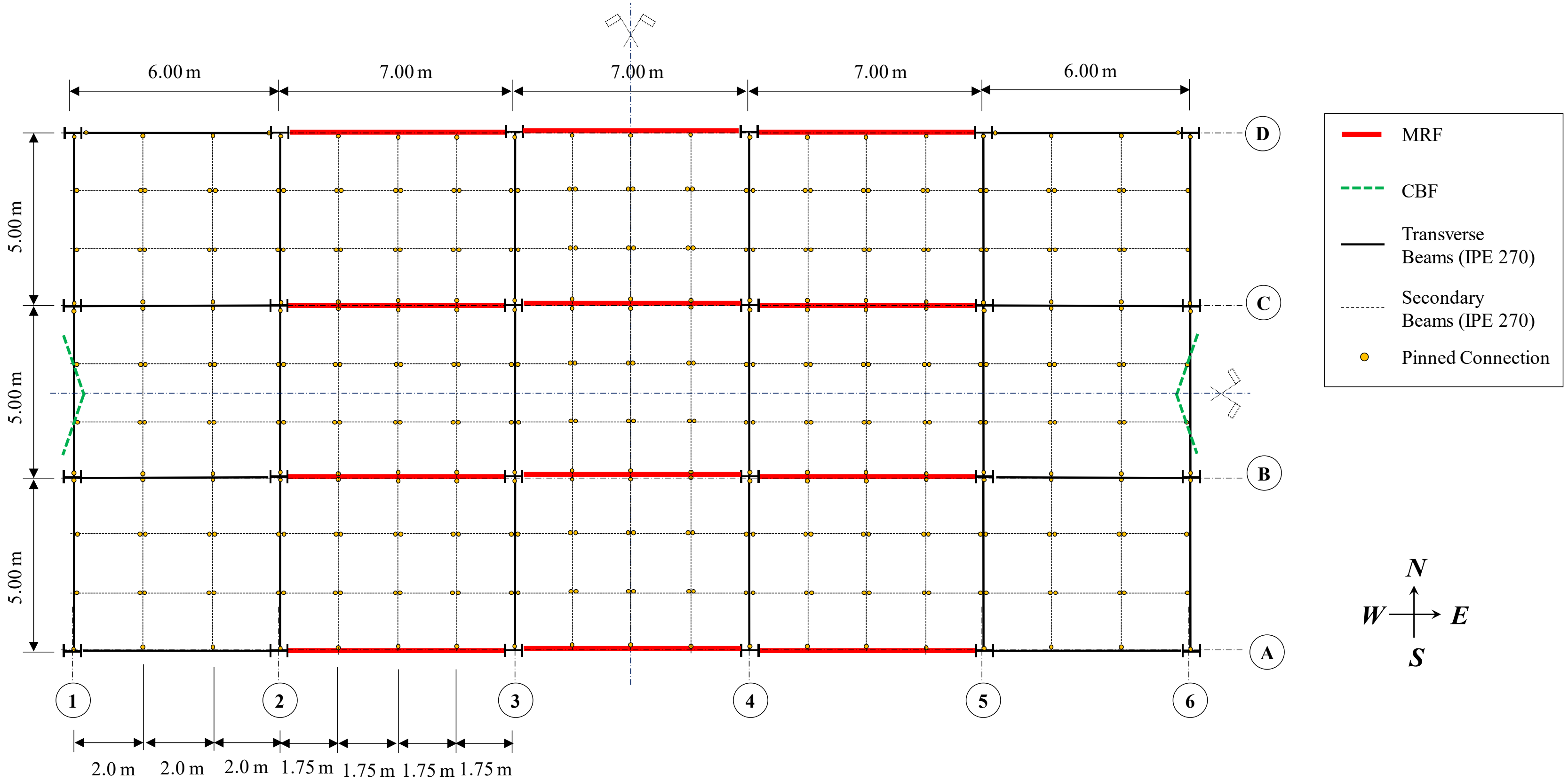
Overview of design examples

- Comparisons between DC2 (EN1998-1-2:2022) and DCM (EN1998:2004)

- Prototype 6-storey building
  - 3-bay composite-steel MRFs and composite steel frames with bracings
  - Site Class D, a_g = 0,22g (Katerini, GR, Braila, RO, Rimini, IT, Sion, CH)
  - Same design spectrum & snow, wind conditions

- Two different designs
  - Composite steel beams with n=100% and n=80%
  - q=3 (for both DC2 and DCM)

Overview of design examples (Cont.)



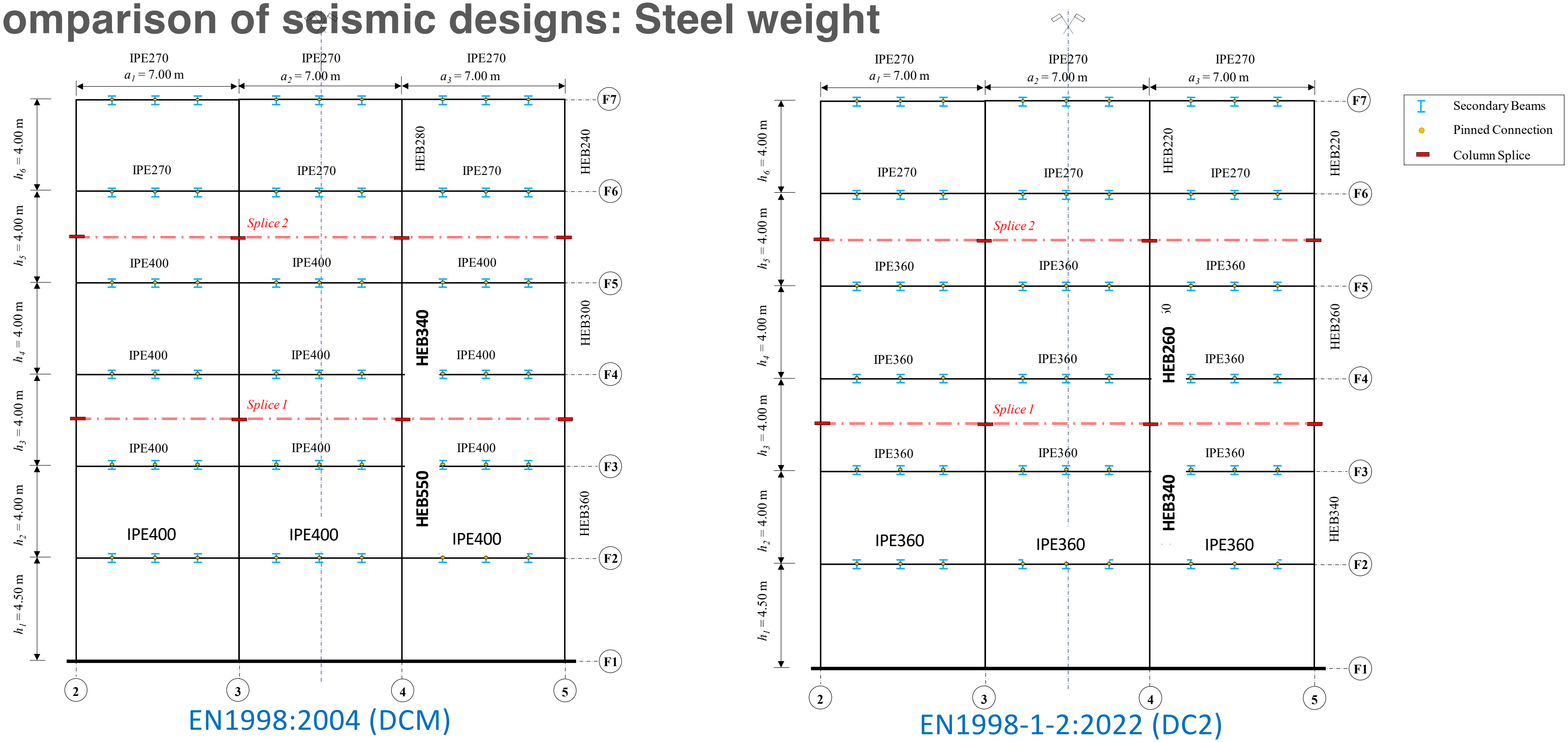
Source: El Jisr and Lignos (2020)

Comparison of seismic designs: First mode periods

	DCM EN1998:2004 T_1 [sec]	DCH EN1998-1-2:2022 T_1 [sec]
Degree of composite action, η=100%	1.63	2.07
Degree of composite action, η=80%	1.67	2.13

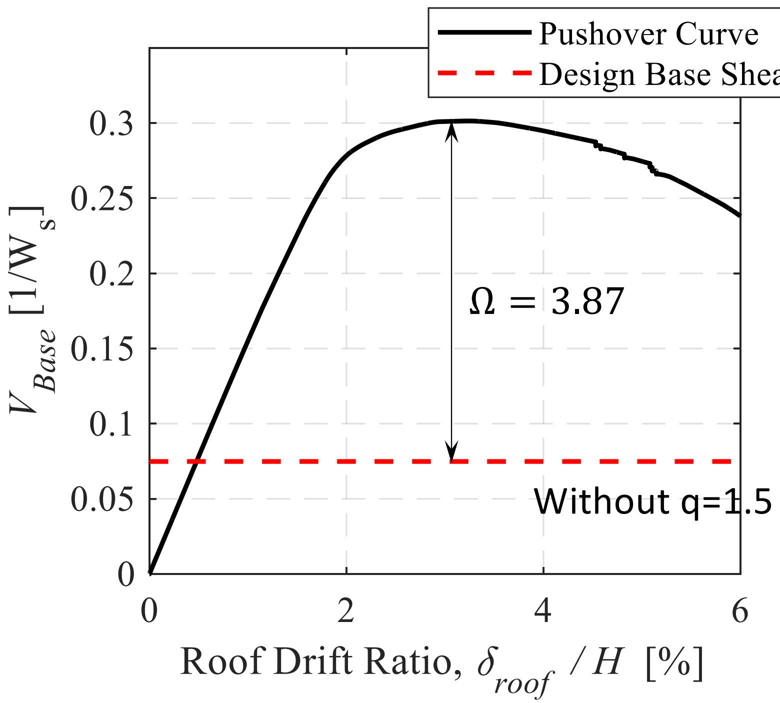
Source: El Jisr and Lignos (2020)

Comparison of seismic designs: Steel weight

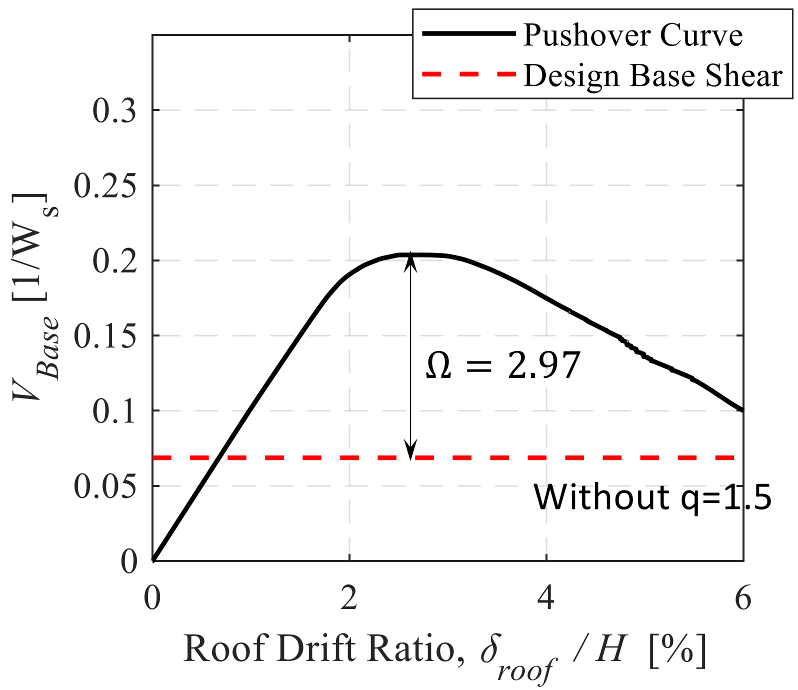


Source: El Jisr and Lignos (2020)

Comparison of seismic designs: Pushover analysis



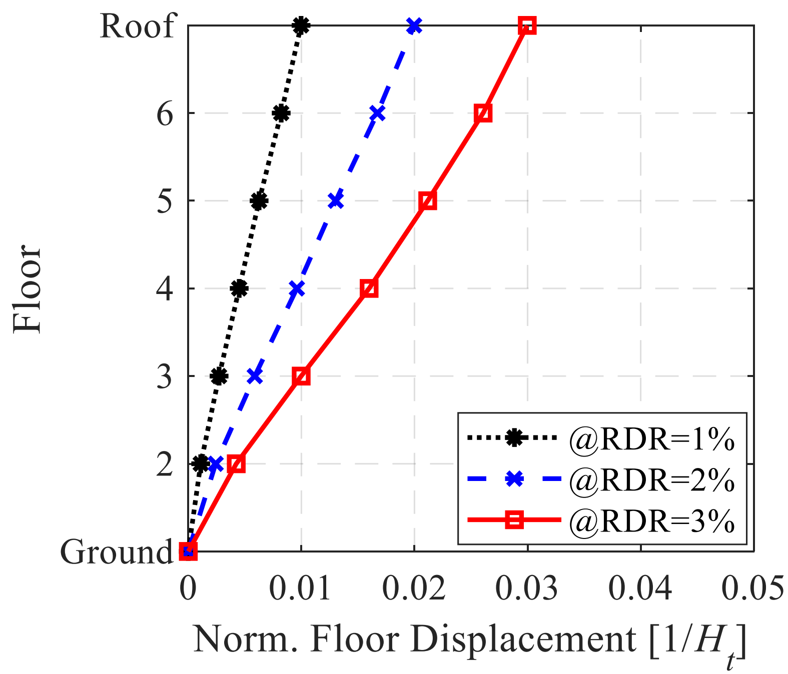
EN1998:2004 (DCM)



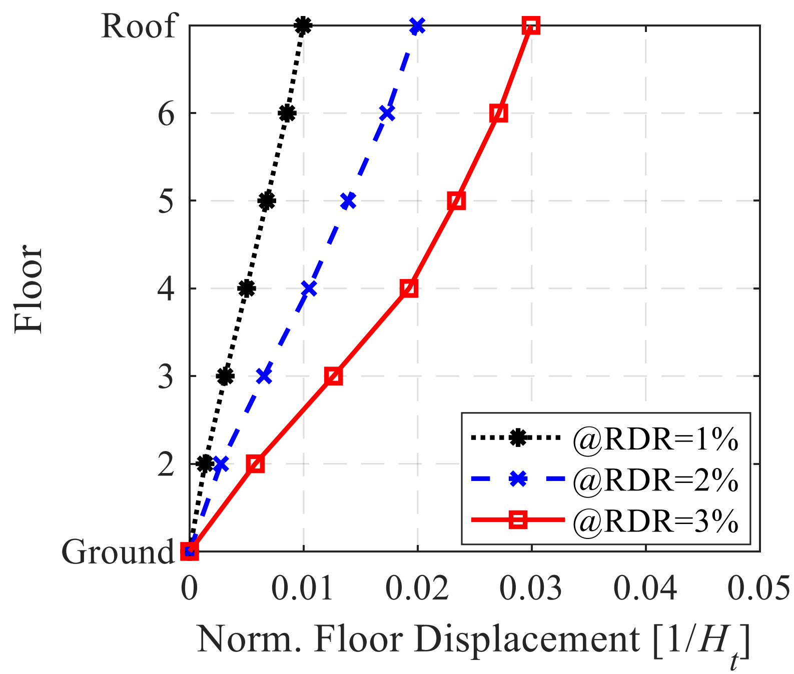
EN1998-1-2:2022 (DC2)

Source: El Jisr and Lignos (2020)

Comparison of seismic designs: Pushover analysis



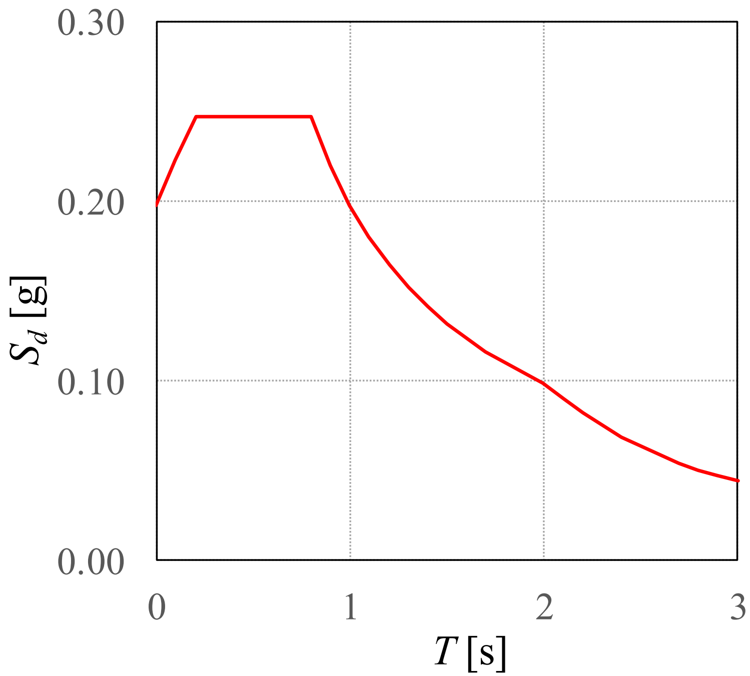
EN1998:2004 (DCM)

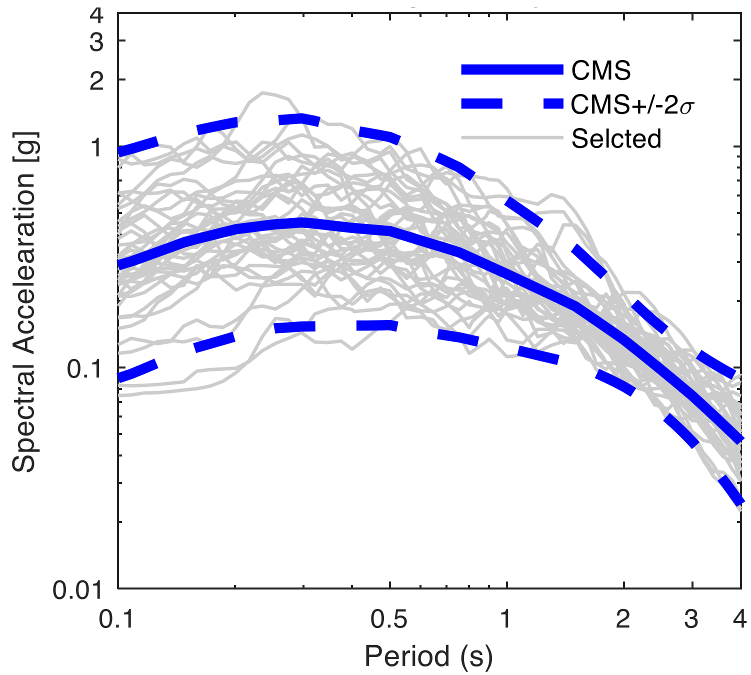


EN1998-1-2:2022 (DC2)

Source: El Jisr and Lignos (2020)

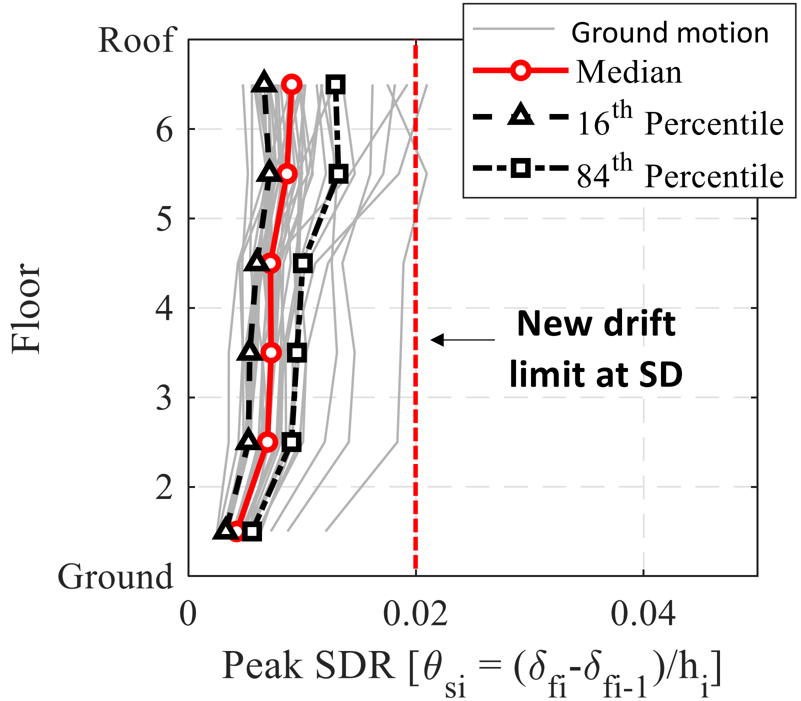
Comparison of seismic designs: Nonlinear response history analyses



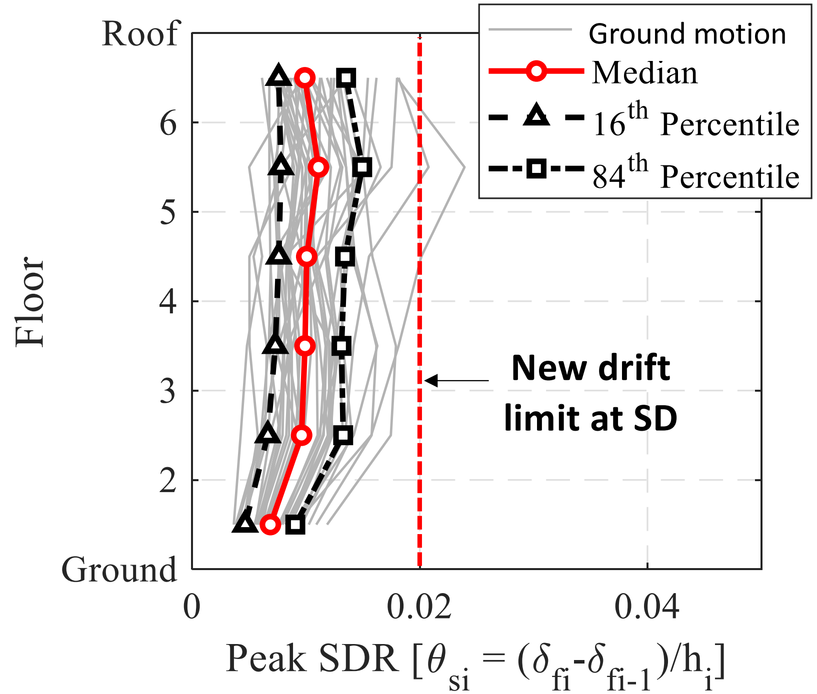


Source: El Jisr and Lignos (2020)

Comparison of seismic designs: Nonlinear response history analyses



EN1998:2004 (DCM)



EN1998-1-2:2022 (DC2)

Source: El Jisr and Lignos (2020)

Thank you for your kind attention!

Questions?

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