EN 1998-1-2. Buildings.
General overview and new features

André Plumier
Leader of Project Team 2
Member of TC250 SC8 Management Group

24th January 2023

EN 1998-1-2:2022 Buildings

15 Chapters 399 pages

- 0. Introduction 1. Scope 2. Normative references 3. Terms, definitions and symbols
- 4. Basis of design
- 5. Modelling and structural analysis
- 6. Verifications of structural members to limit states
- 7. Ancillary elements
- 8. Base isolated buildings
- 9. Buildings with energy dissipation systems
- 10. Concrete buildings
- 11. Steel buildings
- 12. Composite steel–concrete buildings
- 13. Timber buildings
- 14. Masonry buildings
- 15. Aluminium buildings

this webinar

webinar 1-1.4

webinars 1-2.2 to 1.2-6

EN 1998-1-2:2022 Buildings 13 Annexes

7 Normative

- Floor accelerations for ancillary elements
- Buildings with energy dissipation systems
- Seismic design of connections for steel building
- Steel lightweight structure
- Design of connections of RC/composite columns for dissipative composite MRFs
- Design of the slab of composite beams at beam-column joints in MRFs
- F-D relationships of dissipative timber components. Resistances for N-L analyses

6 Informative

- Characteristics of earthquake resistant buildings and in-plan regularity
- Natural eccentricity and torsional radius
- Design of exposed&embedded steel & composite column base connection
- Drift limits for eccentrically loaded unreinforced masonry piers
- Simplified evaluation of drift demands in infilled frames
- Material or product properties in EN 1998-1-2

EN 1998-1-2:2022 Buildings Basis of design

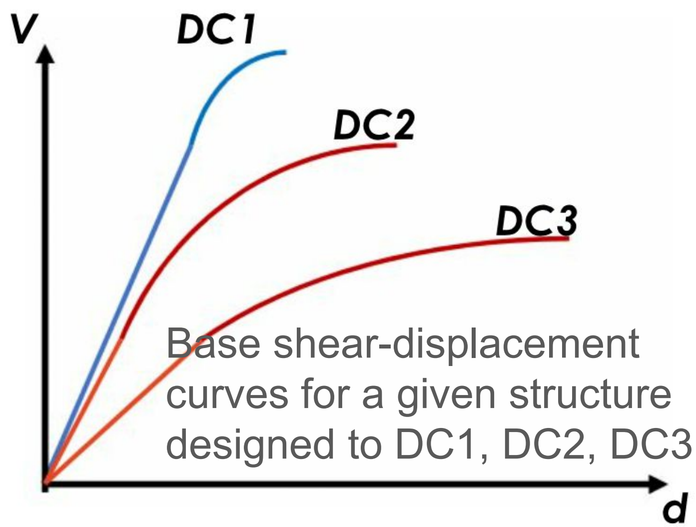
NOTE: in this presentation
NEW features in comparison to EN1998:2004 => **blue color**

Compliance criteria for new buildings

- 4 limit states envisaged: Operational OP Damage Limitation DL
  Significant Damage SD Near Collapse NC

- Verifications mandatory only for Significant Damage SD Limit State
  National Annex or contract may ask differently
  For most new structures, non-exceedance of SD avoids:
  ► *NC exceedance under a more severe seismic action than that of design*
  ► *DL exceedance under a seismic action less severe than that of design*

EN 1998-1-2:2022 Buildings Basis of design



Ductility classes

- 3 ductility classes: DC1 DC2 DC3
  partly different of DCL, DCM, DCH of EN1998:2004
- DC1 = DCL: overstrength
  no target plastic deformation capacity
  limits of application revised
- DC2: new class
  - local overstrength enforced by capacity design & plastic deformation criteria
  - control of global behavior by limitation of drift and of 2nd order effects
  - no criteria like "weak beams – strong columns" imposed
- DC3 ≈ DCM or DCH depending on material:
  - like DC2 + criteria for global plastic mechanism WBSC or else

EN 1998-1-2:2022 Buildings Basis of design

Reference seismic action: Webinar 1.1-2

- $S_{\alpha,475}$ reference parameter:
  max. 5% damped response spectral acceleration
  = constant acceleration range (plateau)
  for a 475 years earthquake return period
  on site category A (rock, flat)
  for consequence class CC2 (EC0 Table 4.11)
  PGA = $S_{\alpha,475}/F_A$ *with* $F_A = 2{,}5$ *(in general)*

- response on sites other than A
  CC other than CC2

$$S_\alpha = \gamma_{LS,CC} F_\alpha F_T S_{\alpha,475}$$

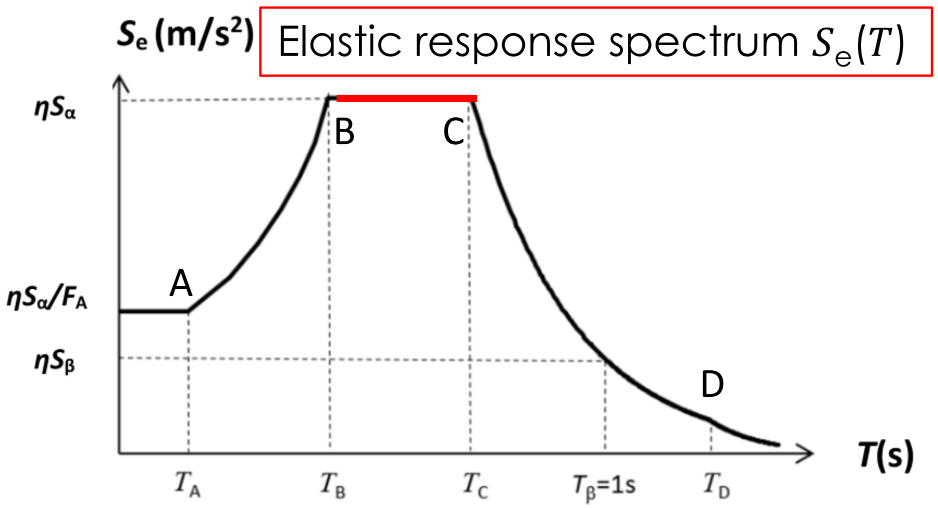
F_α : soil/site F_T : topography

- Damping other than 5% => ηS_α

Table 4.1 (NDP) — Qualification of consequence classes

Consequence class	Indicative qualification of consequences	
	Loss of human life or personal injury[a]	Economic, social or environmental consequences[a]
CC4 – Highest	Extreme	Huge
CC3 – High	High	Very great
CC2 – Normal	Medium	Considerable
CC1 – Low	Low	Small
CC0 – Lowest	Very low	Insignificant

[a] The consequence class is chosen based on the more severe of these two columns.



EN 1998-1-2:2022 Buildings
Basis of design

Seismic action

Table 4.3 (NDP) — Return period $T_{LS,CC}$ values, in years, for buildings

Limit state	Consequence class			
	CC1	CC2	CC3-a	CC3-b
NC	600	1600	2500	5000
SD	275	475	600	900
DL	100	115	125	140

Table 4.4 (NDP) — Performance factor $\gamma_{LS,CC}$ values for buildings

Limit state	Consequence class			
	CC1	CC2	CC3-a	CC3-b
NC	1,00	1,50	1,75	2,20
SD	0,80	1,00	1,10	1,25
DL	0,60	0,60	0,65	0,65

Table 4.1 (NDP) — Definitions of consequence classes CC3-a and CC3-b for buildings

CC3-a	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse (e.g. schools, assembly halls, cultural institutions)
CC3-b	Buildings of installations of vital importance for civil protection (e.g. hospitals, fire stations, and their equipment), and buildings which should remain operational at all times (e.g. communication centres, data centres, and their equipment)

NOTE Buildings that house very dangerous installations or materials are generally classified as CC4, which is not fully covered by this standard.

EN 1998-1-2:2022 Buildings Basis of design

A new parameter: the seismic action index S_δ

- Seismic action index $S_\delta = \delta\, F_\alpha\, F_T\, S_{\alpha,475}$
  δ: influence of Consequence Class (NDP)
- S_δ is used to define: seismic action classes: low – moderate – high
  limits of seismic action for given structural type/ductility class

- Evolution of S_δ from EC8:2004 to EC8:2023
  EC8:2004 in DCL: a "recommended" limit-all types PGA= 1 m/s² ⇔ S_δ = 2,5 m/s²

EC8:2023 DC1 <u>mandatory</u> limits of S_δ seismic action index
$S_\delta \leq$ 2,5 m/s² non ductile types e.g. RC MRF & flat slab structures
$S_\delta \leq$ 5 m/s² RC&composite walls metal structures

EC8:2023 DC2 & DC3: <u>mandatory</u> limits/type + some forbidden types

EN 1998-1-2:2022 Buildings Basis of design

Characteristics of earthquake resistant buildings. Conceptual design

- Classifications of structural types extended
  - ► *basic types*
  - ► *≠ dual types ⇔ relative contributions*
  - ► *new types e.g : RC flat slabs steel lightweight*
  - ► *hybrid structures: 2 or + structural types /materials in a same plane*

- Design for strength with force reduction factor $R_q(T)$ = 1,0 allowed
  - ► *if a ductile behaviour can hardly be conceived*
    is not supported by research reference
    e.g. concrete & steel domes
  - ► *if non-dissipative design can be safe/economical*
    e.g. steel K bracings, trussed beams/columns

EN 1998-1-2:2022 Buildings Basis of design

Characteristics of buildings. Primary and secondary seismic members

- Same principle: the contribution of lateral stiffness of secondary members should not affect significantly the dynamic behaviour of the structure

- It is the case if the total contribution to lateral stiffness of all secondary members is:
  a) ≤ 15% of that of all primary seismic members

  b) ≤ 30% of that of all primary seismic members and 2 analysis are performed:
    1) only with the primary members in the model
    2) with primary and secondary members in the model

and the most unfavourable effects from 1) and 2) are considered in the verifications

EN 1998-1-2:2022 Buildings Basis of design

Characteristics of buildings. Torsionally flexible buildings

- Cases which can be detected out of results of modal analysis
  a) in each main horizontal direction, the greatest effective modal mass is not the one of 1st or 2nd mode
  corresponds to a 1st mode in at least 1direction substantially influenced by torsion

  b) the period of the 1st predominant torsional mode is greater than the periods of the predominant translational modes in the 2 main horizontal directions

- General criteria: at each storey i: $r_i/l_{s,i} \geq 1{,}0$
  r_i min. torsional radius of the i-th floor; Annex B procedures to calculate r_{xi} & $r_{y,i}$
  $l_{s,i}$ radius of gyration of floor *I*

- Torsionally flexible buildings => q_R = 1,0 imposed

EN 1998-1-2:2022 Buildings Basis of design

Structural regularity

- For in-plan regularity: only guidance no rule
  the analysis takes in-plan irregularity into account

- Regularity in elevation requires :
  - continuous resisting system
  - progressive variation of mass & stiffness & resistance over height
    - *lateral stiffness and mass of the individual storeys decrease gradually by no more than 20% relative to the storey below*
    - *ratio of the actual storey resistance to the resistance required by the analysis does not vary by more than 30% between adjacent storeys*

EN 1998-1-2:2022 Buildings Modelling and structural analysis

Modelling

Table 5.1 — Minimum values of ϕ for calculating ψ_{Ei}

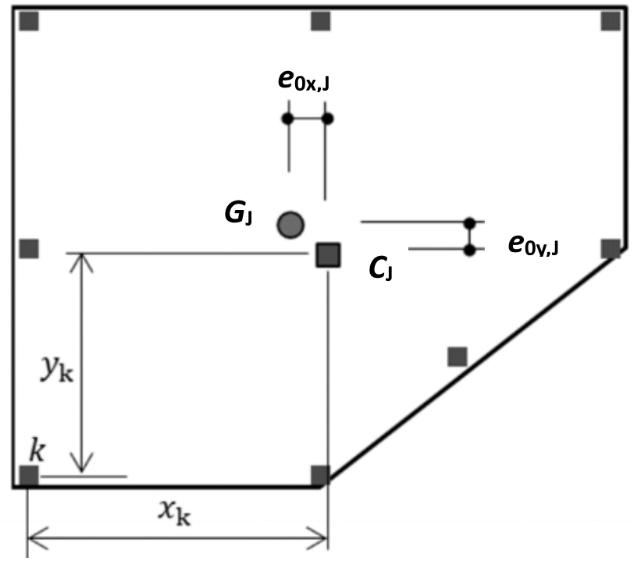
Type of variable action	ϕ
Categories* A and C	0,5
Other categories	1,0
* Categories as defined in prEN 1991-1-1, Table 8.1.	

- Masses: $\psi_{Ei} = \phi\ \psi_2$
- 2 planar models: only for low rise buildings (H ≤10 m, 1 storey) or (H ≤ 15m, 2 storey)
- Concrete, composite and masonry primary seismic members:

  Stiffness   consider cracking
  correspond to initiation of yielding of the reinforcement
  may be taken 0,5 times the stiffness of the uncracked member

EN 1998-1-2:2022 Buildings Modelling and structural analysis

Torsion



- Eccentricity of masses relative to G_j centre of torsion:
  - Natural eccentricity = G_jC_j $e_{0x,j}$&$e_{0y,j}$ projections of G_jC_j
  - Minimum design eccentricity $e_{min,i,j} = 0{,}05\ L_{i,j}$

    $L_{i,j}$ width of floors at level j
- Force-based approach => $M_{i,j} = e_{i,j} \times F_{i,j}$ at each storey j

  $F_{i,j}$ horizontal force on storey j in direction i;

  $e_{i,j}$ with planar models: $e_{i,j} = \max(e_{min,i,j}, e_{0,i,j})$

Note: amplification factors δ of EC8:2004 are deleted

- $e_{i,j}$ with 3D models if $e_{min,i,j} \leq e_{0,I,j}$ => $e_{i,j} = e_{0,i,j}$ if $e_{min,i,j} > e_{0,I,j}$ => $e_{i,j} = e_{min,i,j} - e_{0,i,j}$

Note: the addition of $e_{min,i,j}$ and $e_{0,i,j}$ effects of EC8:2004 is suppressed

- response-history analysis: storey mass such that $e_{0,i,j} \geq e_{min,i,j}$

EN 1998-1-2:2022 Buildings Modelling and structural analysis

Methods of analysis: Webinar 1.1-3

- Force-based approach
  - Lateral forces method of analysis
  - Response spectrum analysis
  - Linear response-history analysis

  with a linear analysis that implicitly/approximately accounts for the overstrength and the non-linear response through a behaviour factor q

- Force-based approach: reduced spectrum $S_r(T)$

  $S_r(T) = S_e(T)/R_q(T)$ $T > T_B$: $R_q(T) = q = q_R\, q_S\, q_D$ $T \leq T_A$: $R_q(T) = R_{q0} = q_R\, q_S$

  Lower bound for $S_r(T)$: $\beta S_{\alpha,475}(T) = 0{,}08\ S_{\alpha,475}(T)$

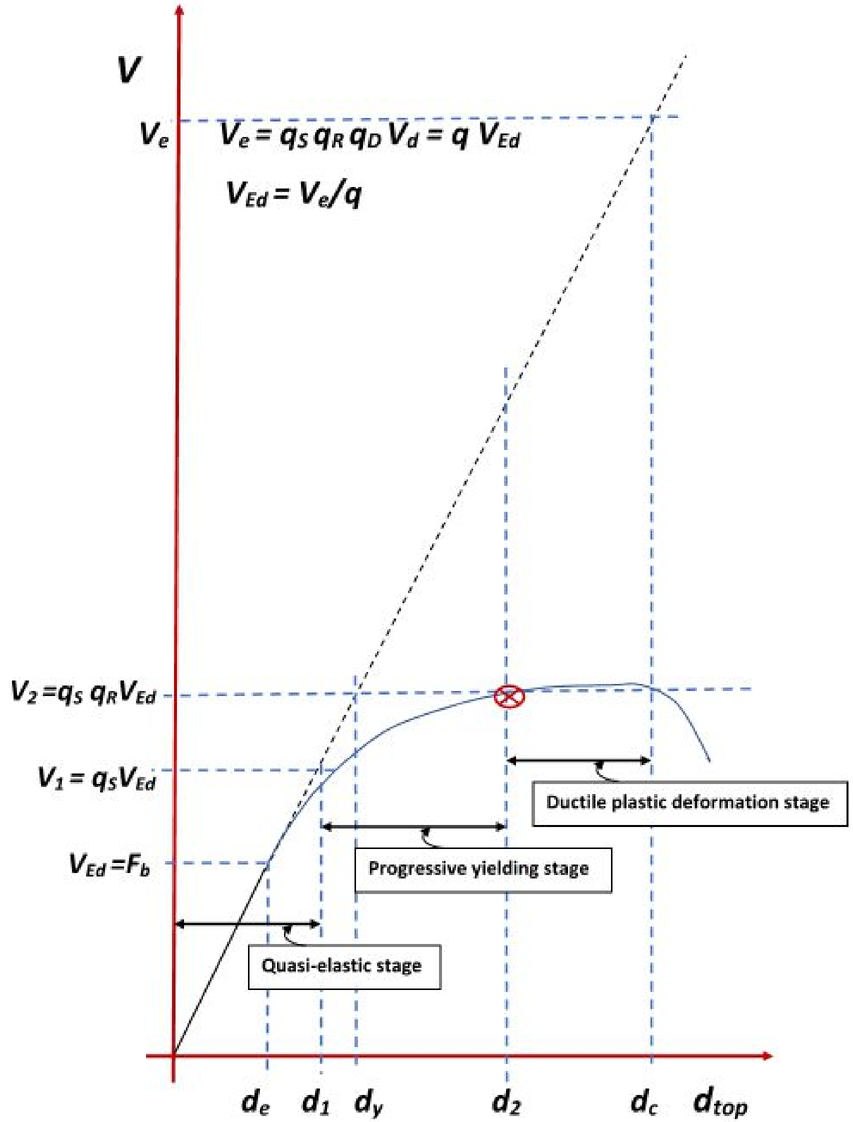
- Displacement-based approach
  - Non-linear static analysis
  - Non-linear response-history analysis

  explicitly accounts for the structural non-linear response

EN 1998-1-2:2022 Buildings
Modelling and structural analysis

Force-based approach

- Behaviour factor $q = q_R\ q_S\ q_D$
- q_R overstrength due to plastic
  redistribution of seismic action effects
  in the progressive yielding stage $q_R = a_u/a_1$
  redundant structures => $q_R \uparrow$
- q_D deformation capacity&energy dissipation
- q_S =1,5 overstrength due to all other sources
  (extra material strength, overdesign, ...)
- In 10 to 15 default values of q q_R q_D
  = upper bounds
  per material/structural type/ductility class



EN 1998-1-2:2022 Buildings Modelling and structural analysis

Force-based approach. Behaviour factor *q*.

- Buildings non-regular in elevation: $1 \leq q_D \leq 0{,}8$ x default value
- q may be different in 2 directions if primary structure/regularity in elevation are different in 2 horizontal directions, if the building is not torsionally flexible
- If primary structures of different types or materials are used to resist the seismic action in one direction => lowest q
- Primary bracings different in 2 directions: $q = 0{,}8$ x min(2 horiz. directions > $q_S = 1{,}5$
- Torsionally flexible buildings: $q_R = 1{,}0$

EN 1998-1-2:2022 Buildings Modelling and structural analysis

Lateral forces method of analysis

- Not for buildings H > 30 m or $T_1 > \min(4\,T_C;\ 1{,}5\ \mathrm{s})$
- Seismic base shear force: $F_b = \lambda\, m\, S_r(T_1)$

$S_r(T_1)$ ordinate of the reduced spectrum at period T_1, fundamental period of vibration of the building for lateral motion in the direction considered

m total mass of the building, above foundation or top of a rigid basement

$\lambda = 0{,}85$ if $T_1 < \min(2\,T_C;\ 1{,}2\ \mathrm{s})$ and more than 2 storeys $\lambda = 1{,}0$ otherwise

T_1 (s) either $$T_1 = 2\sqrt{\frac{\sum m_i s_i^2}{\sum m_i s_i}}$$ or approximate formula

m_i mass of the i-th storey

s_i displacement (in m) of i-th storey under g =9,81 m/s² applied horizontally

- Seismic action: horizontal forces F_i in each horizontal direction $F_i = F_b \dfrac{s_i m_i}{\sum s_j m_j}$

Response spectrum analysis

See Webinar 1-1.3 or prEN 1998-1-1:2022, 6.4.1 and 6.4.

EN 1998-1-2:2022 Buildings Modelling and structural analysis

Displacement-based approach. Non-linear static analysis

General

- Reference: Webinar 1-1.3 or prEN 1998-1-1:2022, 6.5
- The seismic action should be applied with both positive and negative signs; the most unfavourable seismic action effects resulting from the 2 cases should be used
- In low-rise wall buildings: if the bending moment effects in walls are low in comparison to shear action effects, each storey may be analysed independently

EN 1998-1-2:2022 Buildings Modelling and structural analysis

Non-linear static analysis. Construction of the capacity curve

- In Formula $\overline{F}_{\mathrm{i}} = m_{\mathrm{i}}\phi_{\mathrm{i}}$ of the normalized lateral force, the displacement ϕ_{i} of mode ϕ at the i-th node should be defined at the i-th storey
- If the lateral forces method is applicable, ϕ_{i} may be based on the displacement calculated with the horizontal forces of Formula $F_{\mathrm{i}} = F_{\mathrm{b}} \frac{s_{\mathrm{i}} m_{\mathrm{i}}}{\sum s_{\mathrm{j}} m_{\mathrm{j}}}$
- The $\overline{F}_{\mathrm{i}}$ should be applied at the centre of masses at each storey.
- The control displacement d_{n} should be the displacement at the centre of mass of the slab at the top of the building.

Non-linear static analysis. Seismic action effects.

- Correction factors $c_{\mathrm{P,k}}$ and $c_{\mathrm{E,i}}$ are given; they are ratio between normalised deformations obtained from the linear elastic analysis and from pushover analysis.
- $c_{\mathrm{P,k}}$ varies in plan; $c_{\mathrm{E,i}}$ varies in elevation of the building
- $c_{\mathrm{P,k}}$ &$c_{\mathrm{E,i}}$ primarily account for torsional effects and higher mode effects in elevation

Response-history analysis Webinar 1-1.3 or prEN 1998-1-1:2022, 6.6

EN 1998-1-2:2022 Buildings.

Verifications to SD Limit State in the force based approach

In the seismic design situation

- Equilibrium: the building structure should be stable – including overturning or sliding

- Resistance: for all structural members including connections and ancillary elements

$$E_{\mathrm{d}} \leq R_{\mathrm{d}}$$

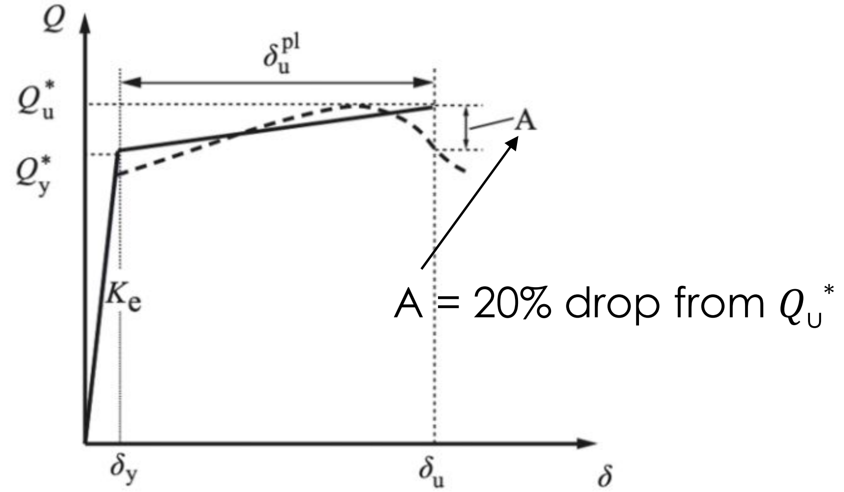
E_{d} design value of the action effect including influence of 2nd order effects

R_{d} design resistance calculated with the rules of the material used (characteristic values of material properties f_{k} and partial factor γ_{M}) and in accordance with chapters 10 to 15 by material

- $E_{\mathrm{d}} \leq R_{\mathrm{d}}$ expressed in terms of force or displacement
  - either generalised stresses - internal forces
  - or generalised strains like interstorey drifts, member chord rotations…

EN 1998-1-2:2022 Buildings.

Verifications to SD Limit State in the displacement-based approach



- Description of local mechanisms in EN1998-1-1 => Webinar 1.1-3
- "Resistance" of local ductile mechanisms:

$$\delta_{SD} = (\delta_y + \alpha_{SD,\theta}\, \delta_u^{pl})/\gamma_{Rd,SD,\theta}$$

$\alpha_{SD,\theta}$ portion of the plastic part of the ultimate deformation $\delta_u^{pl} = \delta_u - \delta_y$ that corresponds to the attainment of SD $\alpha_{SD,\theta} = 0{,}5$

δ_y local deformation of the member at yield;

δ_u ultimate local deformation in the ductile post-elastic mechanism;

$\gamma_{Rd,SD,\theta}$ partial factor on resistance at SD

NOTE: δ for moment frames is the chord rotation θ

- Resistance of local brittle mechanisms: $V_{R,SD} = V_R / \gamma_{Rd,SD}$

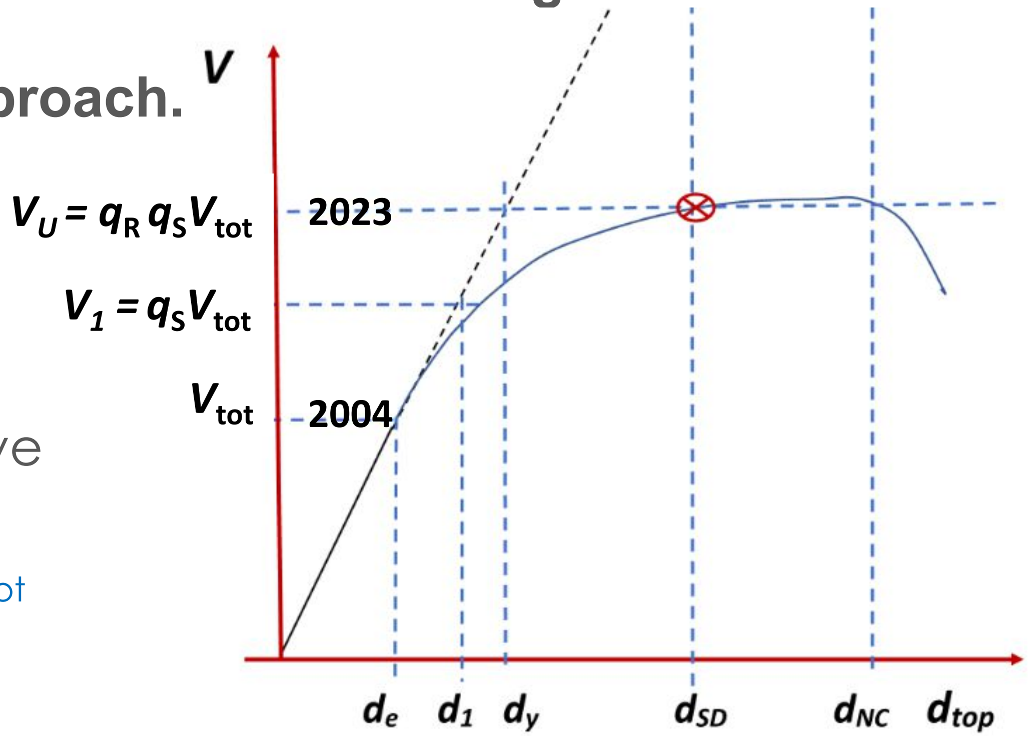
$\gamma_{Rd,SD}$ partial factor on resistance

EN 1998-1-2:2022 Buildings. Verifications in the seismic design situation.

Control 2nd order effects. Force based approach.

- θ interstorey drift sensitivity coefficient! calculated at each storey
- EN1998-1:2004 $\theta = (P_{tot}\, d_{r,SD})/(V_{tot}\, h_s)$
  $d_{r,SD} = q_{disp}\, d_e$
  V_{tot}&$d_{r,SD}$ not for the same point of V-d curve

- V & d both correspond to SD: $V_U = q_R\, q_S V_{tot}$
  $\theta = (P_{tot}\, d_{r,SD})/(q_R\, q_S V_{tot}\, h_s)$



- + standard rules: - $\theta \leq 0{,}10$ OK
  - $0{,}10 < \theta \leq 0{,}20$ => multiply seismic action effects by $1/(1-\theta)$
  - $0{,}20 < \theta \leq 0{,}30$ at any storey => 2nd order analysis
  - $\theta > 0{,}30$ not allowed, unless a 2nd order analysis is used

EN 1998-1-2:2022 Buildings. Verifications in the seismic design situation.

Control of second-order effects

- In the displacement-based approach $\theta = (P_{tot}\ d_{r,SD}) / (V_{s,SD}\ h_s)$
  $V_{s,SD}$ total storey shear at SD limit state from the analysis
- + standard rules on θ

Limitation of interstorey drift $d_{r,SD}$ at SD limit state

- $d_{r,SD} \leq \lambda_s h_s$ all ductility classes, all design approaches, all storeys
- $d_{r,SD}$ difference of the average lateral displacements d_s top and bottom of a storey
  $d_s = q_{disp}\ d_r$ d_r displacement under the reduced spectrum
  $q_{disp} = q = q_S\ q_R\ q_D$ if $T_1 \geq T_C$ $q_{disp} = 1 + (q - 1)\ T_C/T_1 \leq 3q$ if $T_1 < T_C$
  T_1 fundamental period of the structure in the considered direction
- h_s storey height
- λ_s given in chapter 10 to 15 per structural type/material for SD limit state

λ_s given in EN1998-1-1 for Damage Limitation DL limit state

EN 1998-1-2:2022 Buildings. Verifications in the seismic design situation

Capacity design in DC2

- Dissipative zones may be in structural members or in connections.
  => overstrength of non-dissipative zones Details in chapter 10 to 15
- In displacement-based design of MRFs: the plastic rotation demand θ_{SD} should nowhere exceed the corresponding resistance $\theta_{\mathrm{u}}^{\mathrm{pl}}$
- Prevention of soft-storey plastic mechanism in multi-storey buildings in DC2
  - ►Concrete wall systems & concrete wall-equiv. system dual with concrete or steel or composite structures
  - ►MRF&MRF equiv.: - regular in elevation
    - respect limit of seismic action index S_{δ}
    - respect interstorey drift limitation

  => no verification

Capacity design in DC3

Like DCH of EC8:2004. Conditions of DC2 + global criteria (for MRF: WBSC)

EN 1998-1-2:2022 Buildings. Verifications in the seismic design situation.

Diaphragms Foundation Seismic joint

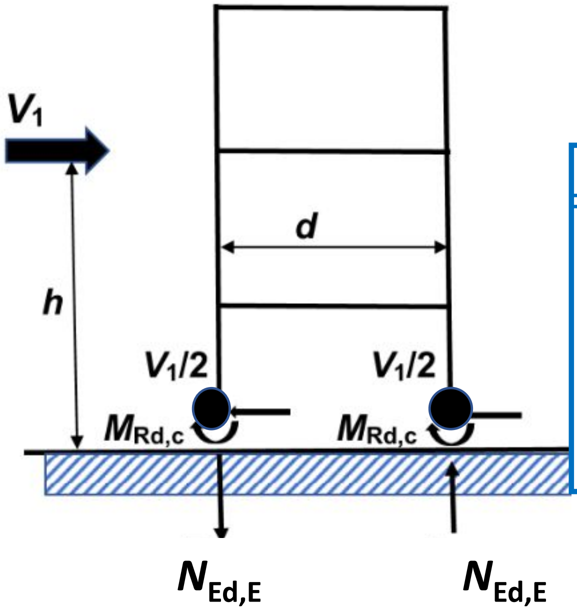
- Horizontal diaphragms and bracings: overstrength
- Foundation: overstrength, all rules in EN1998-5
- Underground basements all rules in EN1998-5
- Seismic joint conditions Unchanged from EC8:2004

EN 1998-1-2:2022 Buildings. Column axial force amplification factor Ω.

- Analysis of force based approach gives $M_{Ed,E}$ $N_{Ed,E}$ $V_{Ed,E}$ in columns
- 1st plastic hinges in columns under $V_1 = q_S V_{tot}$ $\quad V_1\, h = 2\, M_{Rd,c} + N_{Ed,E}\, d$
- Global mechanism under $V = V_U = q_R\, q_S V_{tot} = q_R V_1$ $\quad V_U\, h = 2\, M_{Rd,c} + N_{Ed,real}\, d$

=> At SD real $N_{Ed,E} = N_{Ed,real} > N_{Ed,E}$ => $N_{Ed} = \Omega\, N_{Ed,E}$

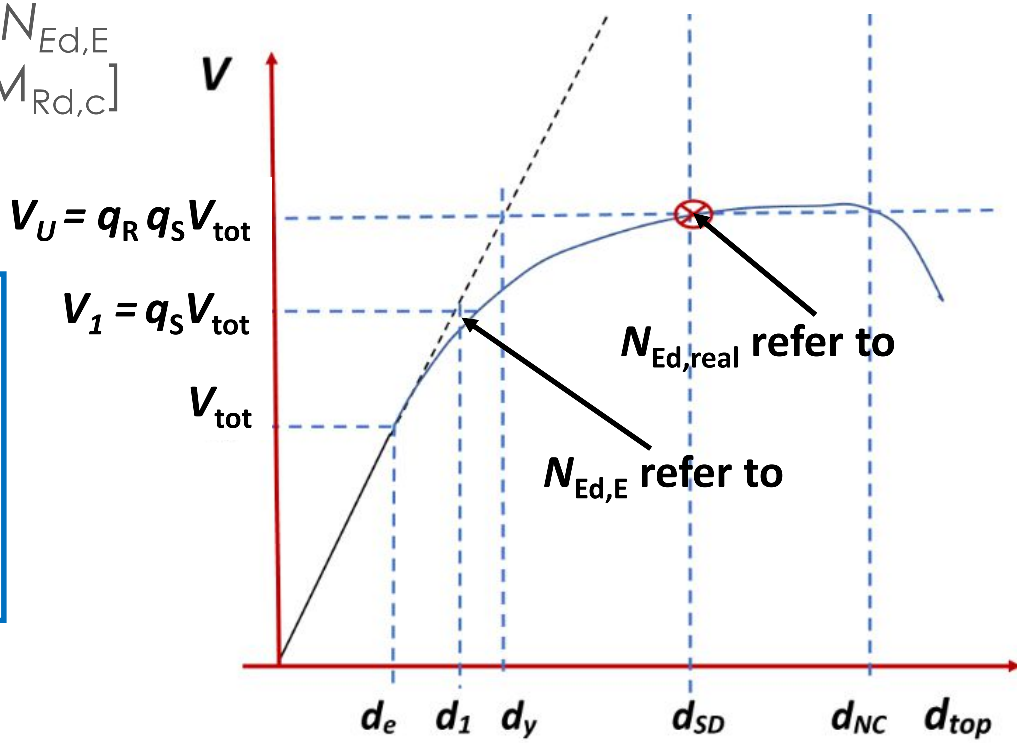
$$\Omega = N_{Ed,real}/N_{Ed,E} = (V_U\, h - 2\, M_{Rd,c})/[(V_U\, h/q_R) - 2\, M_{Rd,c}]$$



=> Design:

$$N_{Ed} = N_{Ed,G} + \Omega\, N_{Ed,E}$$

with $\Omega = 2$



EN 1998-1-2:2022 Buildings. Verifications in the seismic design situation.

Force transfer zones in DC2 and DC3

- Force transfer zones: zones where vertical components of the primary structure are interrupted for open spaces, car parks or setbacks

- Designed to resist with overstrength the action effects

  => $E_{Fd} = E_{F,G}$ "+" $1{,}25\ \Omega_d\ E_{F,E}$ with $\Omega_d \leq q$

  Ω_d ratio design resistance/action effect= R_{di}/E_{di} in the dissipative zone of member above transfer zone with highest influence on the members of transfer zone

  $\Omega_d = 1$ in RC walls

- Model for analysis: 3D explicit structural members of transfer zone and below it
- Analysis: response spectrum analysis 3D non-linear analysis

- If interstorey drift $d_{r,Sd,transfer\ zone} > 2\ d_{r,Sd,above\ transfer\ zone}$ => DC3 with $q \leq 2$

EN 1998-1-2:2022 Buildings. Verifications in the seismic design situation.

Force transfer zones in DC2 and DC3

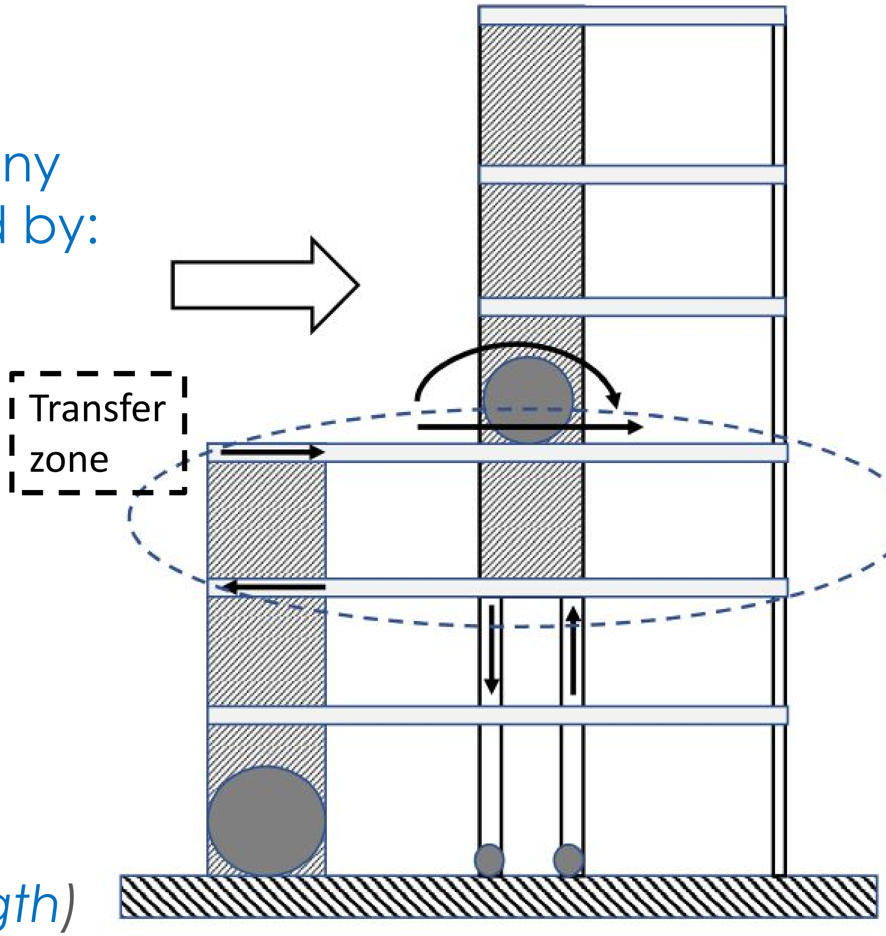
At the bottom of an interrupted wall/column at any level, resistance to M_{Ed}, N_{Ed} & V_{Ed} may be provided by:

a) 1 diaphragm at the level of interruption
+ a beam in the plane of the walls
+ supports by columns in the same plane

b) a couple of horizontal forces in 2 diaphragms

c) columns in the plane of an interrupted wall

NOTE:
No WBSC in transfer zones (because of overstrength)



EN 1998-1-2:2022 Buildings. Ancillary elements

Seismic action

- 2 orthogonal horizontal directions
- Analysis: a realistic model appropriate floor response spectrum
- $m_a/m_i > 0{,}01$ m_a ancillary component mass m_i floor mass
  => action effects in ancillary elements & structural members
  may be calculated taking into account their dynamic interaction
- Seismic action effects on ancillary elements: in plane & out-of-plane:
  horizontal force $F_{ap} = \gamma_{ap}\, m_{ap}\, S_{ap}/q_{ap}'$
  m_{ap} mass of the ancillary element
  q_{ap}' period dependent behaviour factor of the ancillary element, Annex C
  γ_{ap} performance factor of the element: NDP ≥ 1,0
  proposed for elements not participating to safety systems $\gamma_{ap} = 1{,}0$
  for safety equipment & anchorage of machinery $\gamma_{ap} = 1{,}5$
  S_{ap} value in the floor acceleration spectrum for T_{ap} and ξ_{ap}

EN 1998-1-2:2022 Buildings. Ancillary elements

Seismic action

- S_{ap} ?
- At level j if floor spectra are available: $S_{ap,j} = S_{floor,j}(T_{ap}, \xi_{ap})$
  T_{ap} natural period of the ancillary element;
  ξ_{ap} critical damping ratio of the ancillary element, may be taken equal to 2%
- At level j if floor spectra are not available,
  - for rigid ancillary element (cantilevering parapets or ornamentations, signs or billboards, chimneys or masts not taller than 4m) or those for which $T_{ap} \leq T_B$:

$$S_{ap,j} = \Gamma_1 \frac{z_j}{H} \frac{\eta S_\alpha}{q_D{}'} \geq \frac{S_\alpha}{F_A}$$

  H, height of the building, z_j height of floor j, Γ_1 participation factor of the fundamental mode of the building, N_s number of storeys, $q_D{}'$ period dependent behaviour factor related to q_D of the building
  - for other case: $S_{ap,j}$ in Annex C

EN 1998-1-2:2022 Buildings. Ancillary elements

Frames with interacting masonry infills

- Limitations of drift ⇔ masonry infill type

Table 7.1 — Limits of interstorey drift in % in buildings with masonry infills

Masonry Type	**Drift limits at OP [%]**	**Drift limits at DL [%]**	**Drift limits at SD [%]**
Ductile masonry infills as per 7.4.1 (4)	0,40	0,75	2,00
Unreinforced masonry with clay units in Groups 1, 2 or 3 with a thickness ≥ 200 mm and $f_k \geq 3$ MPa	0,25	0,45	1,40
Unreinforced masonry with units of Group 4	0,15	0,25	0,90

- with openings: limits reduced of at least 30%
- with confined/reinforced infills or with reinforcement: limits increased by1,20 at most

EN 1998-1-2:2022 Buildings. Ancillary elements . Frames with infills.

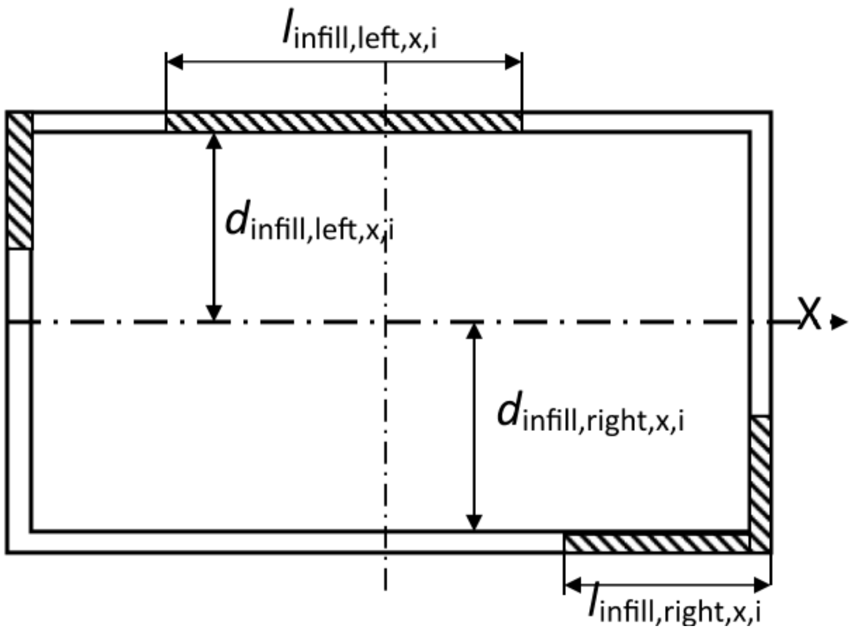
Analysis with a model of the bare frame only

- Horizontal regularity parameters $R_{\mathrm{sym,x}}$ $R_{\mathrm{sym,y}}$

  $R_{\mathrm{sym,x}} = \{\mathrm{ABS}\ [(\Sigma l_{\mathrm{infill,left,x,i}} d_{\mathrm{i}}^2 - \Sigma l_{\mathrm{infill,right,x,i}} d_{\mathrm{i}}^2)]\} / (\Sigma l_{\mathrm{infill,left,x,i}} d_{\mathrm{i}}^2 + \Sigma l_{\mathrm{infill,right,x,i}} d_{\mathrm{i}}^2)$

  => classification

very regular, R<0,2 => simplified method in Annex K
regular 0,2 ≤ R< 0,4 => action effects& drift X 1,3
irregular R ≥ 0,4 => model explicit interaction



- Vertical irregularity: if total cross-section area of infills is reduced by more than 30% in one or more consecutive storeys

=> EC8:2004 Formula: multiply by K_{IR} action effects calculated in the storey where infills are reduced

$$K_{\mathrm{IR}} = (1 + \Delta V_{\mathrm{Rw}}/\Sigma V_{\mathrm{Ed}}) \leq q$$

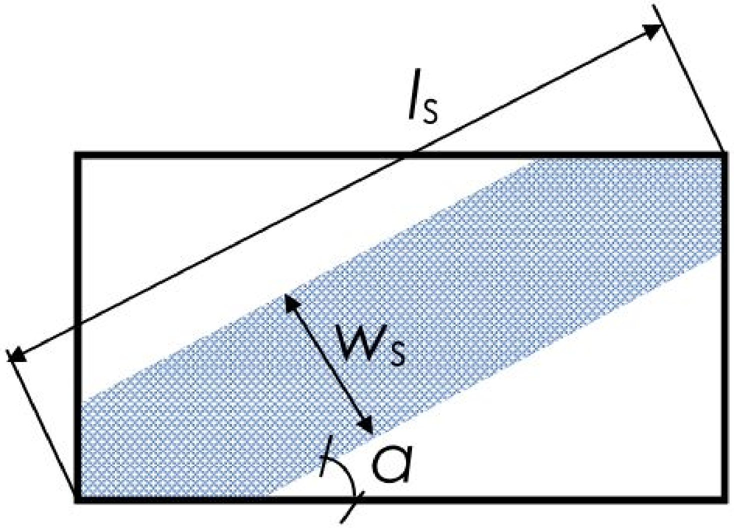
EN 1998-1-2:2022 Buildings. Ancillary elements. Frames with infills

Analysis with a model of the interaction between frame and infills

- Infill modelled as a strut:

  => Strut stiffness calculated with:
  width w_s = 0,25 l_s = 0,25 length of panel diagonal
  thickness t_p of the infill
  elastic modulus of the infilled masonry

- If openings: stiffness of infill panel x ρ_{op}



EN 1998-1-2:2022 Buildings. Ancillary elements. Frames with infills

Verification of columns adjacent to infills

- Entire length of columns = critical region
  In DC1, DC2 & DC3: ground floor columns
  In DC2 & DC3: if infill present over entire length on one side/no infill on the other
- Length l_{cs} of a column over which the diagonal strut force is applied: $l_{cs} = w_s/\cos \alpha$
  α : angle between infill panel diagonal and horizontal
- DC2 & DC3: if infill present on clear length l_{cl} top and bottom over l_{cs} should resist:
  $V_{Ed,infill} = \min (V_{ap,Rd}; V_{i,d})$ $V_{ap,Rd}$ horizontal component of strut force
  $V_{i,d}$ shear force ⇔ overstrength flexural capacity at 2 ends of contact length
- DC2 & DC3: if infill height smaller than l_{cl} of adjacent column:
  a) l_{cl} = critical region
  b) $V_{i,d}$ ⇔overstrength flexural capacity $\gamma_{Rd} M_{Rc,i}$ over height h_{op}
  c) If $h_{op} < 1{,}5h_c$ (h_c depth of column section)
  => diagonal reinforcement over $h_{op} + h_c$ above and below opening

EN 1998-1-2:2022 Buildings. Ancillary elements. Frames with infills

Verification of interacting masonry infills. In plane.

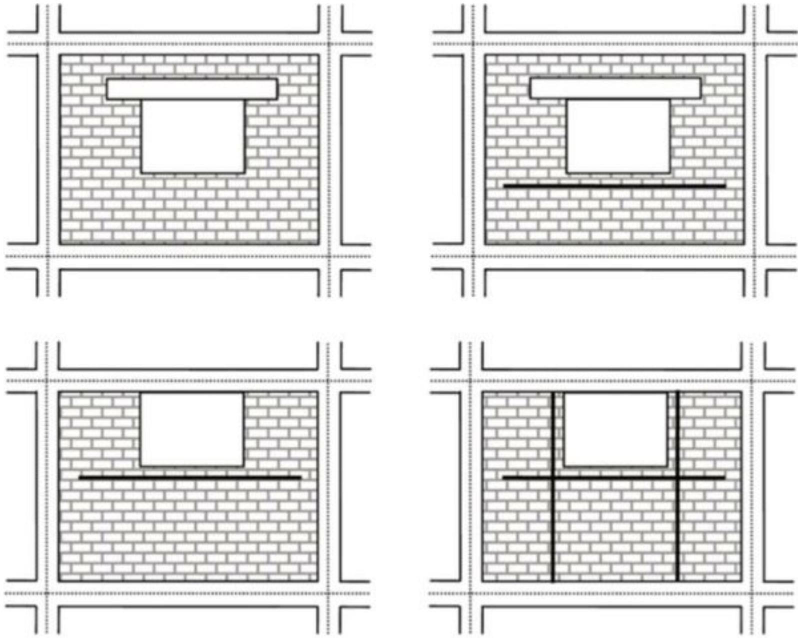
- drift demand ≤ drift capacity
- shear action effect ≤ design resistance

  $V_{ap,Ed} = F_{ap}/(h_{ap} \cdot l_{ap}) \leq V_{ap,Rd} = t_{ap} l_{ap} f_{vk0}$

  l_{ap} & h_{ap}: length & height of infill wall

  f_{vk0} characteristic initial shear strength of panel for 0 vertic. compression FprEN 1996-1-1:2021, 5.7.2.2
- If openings: $\rho_{op} = a \exp(b\, \alpha_a) + c \exp(d\, \alpha_l)$

  $\Rightarrow V_{ap,Ed} = F_{ap}/(h_{ap} \cdot l_{ap}) \leq \rho_{op} V_{ap,Rd}$



Partially reinforced

Reinforced

Table 7.2 — Coefficients *a, b, c* and *d* for the calculation of the shear resistance of panels with openings

Type of opening	*a*	*b*	*c*	*d*
Non reinforced	0,55	- 0,035	0,44	- 0,025
Partially reinforced	0,58	- 0,030	0,42	- 0,020
Reinforced	0,63	- 0,020	0,40	-0,010

$\alpha_a = l_{op} h_{op} / l_{ap} h_{ap}$

$\alpha_l = l_{op} / l_{ap}$

l_{op}&h_{op} = length & height of opening

EN 1998-1-2:2022 Buildings. Ancillary elements. Frames with infills

Verification of interacting masonry infills. Out-of-plane.

- Design lateral action effect per unit area:

  $$f_{a,p} = F_{ap}/(h_{ap} \cdot l_{ap})$$

  F_{ap} horizontal seismic force applied at the centre of the infill wall

  l_{ap} & h_{ap} respectively length & height of the infill wall

- Resistance = flexural or arching effect resistance in EN 1996-1-1:2022, 8.4.2 or 8.4.3.

- Condition: $f_{a,p} = F_{ap}/(h_{ap} \cdot l_{ap}) \leq 0,5$ flexural/arching resistance

  0,5 for interaction between in-plane & out-of-plane action effects

- Connections of infill to bounding frame:

  distributed regularly along infill perimeter

  designed to resist F_{ap}

EN 1998-1-2:2022 Buildings. Ancillary elements. Frames with infills.

Non-interacting infills

- Analysis: bare frame structure Infills = mass
- Design should be such that:
  a) contribution of infills to lateral stiffness and resistance may be neglected
  => Connection between bounding frame and infill panel:
  gap infill-frame closed by a force ≤ 20% shear resistance of adjacent column
  b) interaction infill-frame up to drift demand at SD may be neglected
  => Contribution of infill panel to lateral resistance
  ≤ 20% lateral resistance of bare frame
- Infills stable against out-of-plane/in-plane seismic action effects
- connections resist F_{ap}
  do not induce local failure of the infill walls
  accommodate design interstorey drift at SD

EN 1998-1-2:2022 Buildings. Ancillary elements. Claddings. Partitions

Structures with claddings

- Similar to infills
- Isostatic connection systems => non interacting claddings
- "integrated" claddings connection systems => interacting claddings
- Connections of integrated panels may be dissipative

Structures with partitions

- Out of plane collapse of partitions prevented at SD limit state.
- Out-of-plane resistance of partitions ≥ action effects due to f_{ap}
- Connections distributed regularly along the partition perimeter resist F_{ap}

EN 1998-1-2:2022 Buildings.

Thank you for your attention !

Questions ?