Workshop Implementation of the EC 8-3:2005
Assessment and interventions on buildings in earthquake prone areas

A pilot application of EC8-3.
Reflections and comparisons with the GCSI

Andreas J Kappos,
Professor of Civil Engineering,
City University London

Athens, 12 April 2013

Eurocode 8 – Part 3 Overview

- ❖ Relatively recent document, intended to be performance- and displacement-based
- ❖ 'Flexibility' to accommodate the large variety of situations arising in practice and in different countries
  - ➢ Arguably major advantage, also major weakness!..
- ❖ Logically structured, but (on drafters' own admission, see Pinto 2011) missing the support from extended use
  - ➢ improvements to be expected from future (and present?) experience
- ❖ Normative part covering only material-independent concepts and rules; verification formulae are in non-mandatory Informative Annexes
- ❖ Very limited application, mainly in academic/background studies
  - ➢ the GCSI has enjoyed much more extensive application

Performance requirements in EC8 – 3

Hazard (return period of the design spectrum)	**Required performance**
T_R=2475 years (2% in 50 years)	**Near Collapse (NC)** (heavily damaged, very low residual strength & stiffness, large permanent drift but still standing)
T_R=475 years (10% in 50 years)	**Significant damage (SD)** (significantly damaged, some residual strength & stiffness, non-strutural comp. damaged, uneconomic to repair)
T_R=225 years (20% in 50 years)	**Limited damage (LD)** (only lightly damaged, damage to non-structural components economically repairable)
T_R values above same as for new buildings. National authorities may select lower values, and require compliance with only two limit-states	

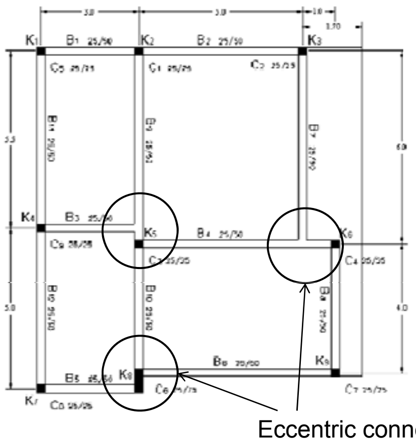
This presentation

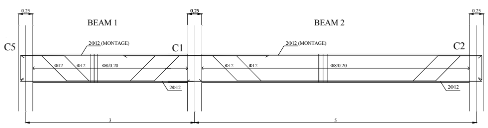
- ❖ Application of EC8-3 to a realistic building, representative of 1970's European practice
  - ➢ the 'SPEAR building' (designed by Fardis et al.)
- ❖ Application of all commonly used analysis methods for assessment
  - ➢ Lateral force (elastic) analysis
  - ➢ Multi-modal response spectrum analysis
  - ➢ q-factor approach
- ❖ Application also of GCSI provisions, wherever different (m-method)
- ❖ Identification of difficulties in implementing EC8-3
- ❖ Comparisons with the GCSI
- ❖ Conclusions and reflections on some issues and future trends

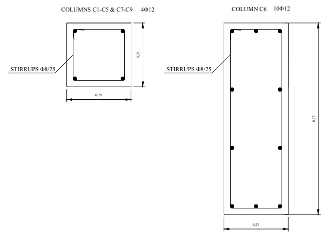
Key data for the building

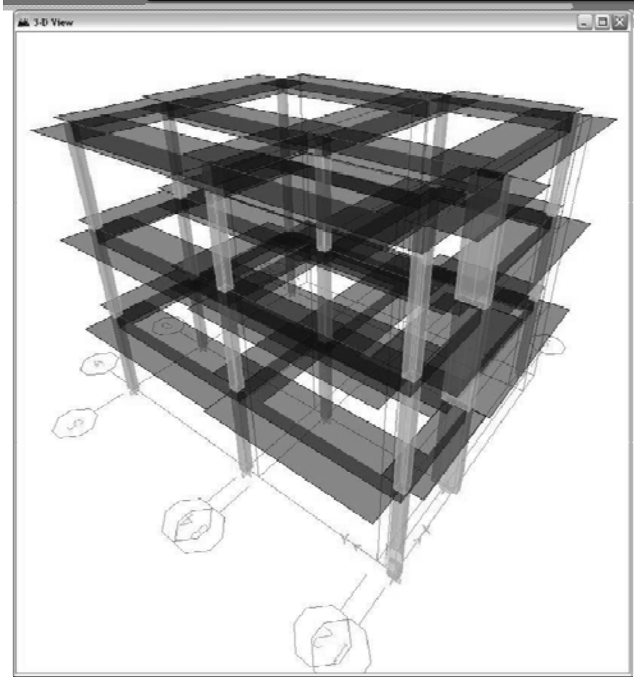
- ❖ Specimen tested within the frame of the SPEAR project
- ❖ 3-storey reinforced concrete (R/C) building
- ❖ Broadly based on Greek codes of 1954 and 1959
  - ➢ deemed representative of 1970's European practice
- ❖ Frame structure, no special seismic provisions and detailing
- ❖ Intentional weak points:
  - ➢ irregular in plan, torsion problem
  - ➢ indirect beam supports
  - ➢ eccentric connections at some joints

Key data for the building (contnd)









Building model in ETABS

Diploma thesis
Ch. Anastasiadou,
AUTh 2010

Performance requirements and seismic actions

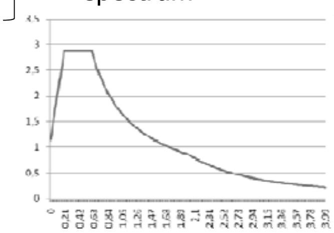
- Significant Damage ↔ 10% in 50 years seismic action
- Knowledge level: KL3 (full knowledge), not common in actual buildings (as opposed to Lab specimens)
  → confidence factor: $CF_{KL3}=1$
- Seismic hazard zone: I ($\alpha_g=0.16g$)
- Ground conditions: C (dense sand, gravel or stiff clay)
- Importance class: II ($\gamma_I=1.00$)

A pilot application of EC8-3. Reflections and comparisons with the GCSI

Assessment methods used

- Lateral force (elastic) analysis
- Multi-modal response spectrum analysis
- q-factor approach

(Lateral force and multi-modal analyses: Elastic response spectrum)



Seismic load combinations: $E_x+0.3E_y$, $E_y+0.3E_x$

Assumed stiffnesses: $EI_{ef}=0.50EI_g$ (EC8 §4.3.1 applies)

- important difference from GCSI (and ASCE 41-07)!
- ‘hidden’ in §A3.2.4(5) referring specifically to DL state (not SD), that if deformations are verified, then $EI_{ef}=M_yL_V/3\theta_y$

Lateral force (elastic) analysis

- Range of applicability (according to Eurocode 8 – Part 1):

  a) period criteria $T_1 \le \begin{cases} 4T_c = 2.4s \\ 2.0s \end{cases}$

  b) Regularity in elevation

  → Additional requirement in EC8–3: $\rho_i = D_i / C_i < 2.5$ for ductile members

Multi-modal response spectrum analysis

- No restrictions in Eurocode 8 – Part 1
- Additional requirement in EC8–3: $\rho_i = D_i / C_i < 2.5$ for ductile members

q-factor approach

- q= 1.5 for reinforced concrete buildings
- Verifications based on action effects derived by reduced (×1/q) spectrum, rather than on ρ_i
- Elastic static analysis

A pilot application of EC8-3. Reflections and comparisons with the GCSI

Flexure and shear verifications

- Brittle components/mechanisms

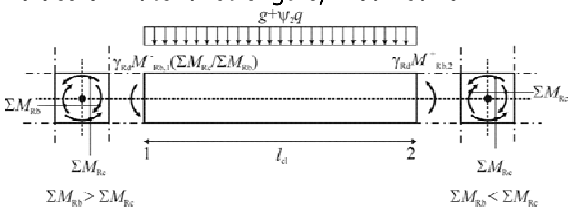
  $\rho_i = D_i / C_i < 1.0$, D_i → from analysis (V_{Ed})

  ➢ C_i based on mean values of material strengths (M_{Rm})

  $\rho_i > 1$, D_i from capacity design

  ➢ M_{Rd} based on mean values of material strengths, modified for CF_{KL3} and γ_M

$$M_{i,d} = \gamma_{Rd} M_{Rb,i} \min(1, \frac{\sum M_{Rc}}{\sum M_{Rb}})$$



- Ductile components/mechanisms

  → Verification based on deformations!

Simplified column check for biaxial flexure (M_y, M_z, N)

- biaxial flexure is reduced to uniaxial one [Eurocode 2 Handbook]

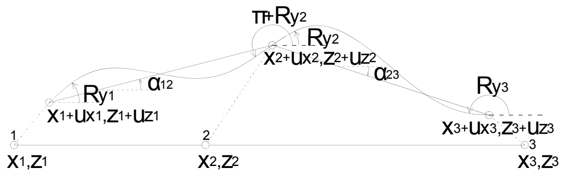
			z-axis	y-axis
$\frac{hM_{yi}}{bM_{xi}} \ge 5$ OR $\frac{hM_{yi}}{bM_{xi}} \le 0{,}2$	Consider both	(i)	0	M_y
		(ii)	M_z	0
In all other cases:	if $\frac{M_y \cdot h'}{M_z \cdot b'} \le 1$		$M_z + \frac{\beta h' M_z}{b'}$	0
	if $\frac{M_y \cdot h'}{M_z \cdot b'} \ge 1$		0	$M_z + \frac{\beta h' M_y}{b'}$

- the above M_y, M_z, are compared with corresponding (uniaxial) flexural strengths

Flexural verification based on deformations (§A.3.2.1)

❖ Existing software packages do not provide chord rotations (θ) as output

➢ how can θ be calculated from given joint rotations?



general case for calculating θ from joint rotations R_y on plane x-z

chord rotation at end i: $\theta_i = \left| R_{yi} - \alpha_{ij} \right|$ where:

$$\tan a_{ij} = \frac{z_j + u_{zj} - (z_i + u_{zi})}{x_j + x_{zj} - (x_i + u_{xi})} \Rightarrow a_{ij} = \arctan \frac{z_j + u_{zj} - (z_i + u_{zi})}{x_j + x_{zj} - (x_i + u_{xi})}$$

❖ Verification: checking of θ against fractions (dependent on PR) of

$$\theta_{um} = \frac{1}{\gamma_{el}} 0.016 \cdot (0.3^{\nu}) \left[\frac{\max(0.01;\omega')}{\max(0.01;\omega)} f_c \right]^{0.225} \left(\frac{L_V}{h} \right)^{0,35} 25^{\left(\alpha \rho_{sx} \frac{f_{yw}}{f_c}\right)} \left(1.25^{100\rho_d}\right)$$

Critical joint verification: Diagonal compression

a) For internal beam-column joints:

$$V_{jhd} = \gamma_{Rd}(A_{s1} + A_{s2})f_{yd} - V_c \leq \eta f_{cd}\sqrt{1 - \frac{v_d}{\eta}} b_j h_{jc}$$

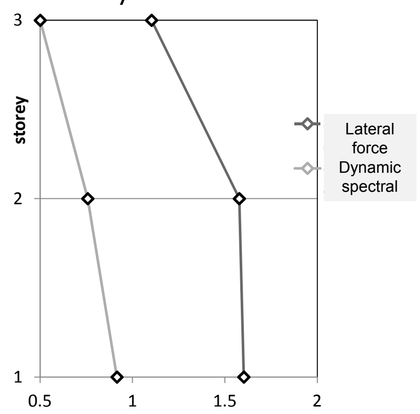
b) For external beam-column joints:

$$V_{jhd} = \gamma_{Rd} A_{s1} f_{yd} - V_c \leq 0.80\eta f_{cd}\sqrt{1 - \frac{v_d}{\eta}} b_j h_{jc}$$

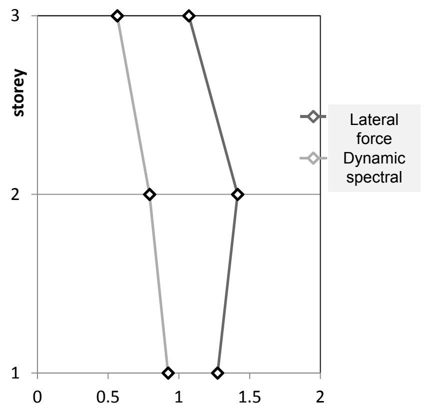
- Mean values of material strengths, modified for CF_{KL3} and γ_M

Results: Distribution of $\rho_i = D_i/C_i$ (flexure)

Ex+0.3Ey



Ey+0.3Ex



Ex+0.3Ey: Lateral force	Ex+0.3Ey: Dynamic response spectrum	Ey+0.3Ex: Lateral force	Ey+0.3Ex: Dynamic response spectrum
$min\rho_i$ = 0.015	$min\rho_i$ = 0.003	$min\rho_i$ = 0.015	$min\rho_i$ = 0.001
$max\rho_i$ = 18.37	$max\rho_i$ = 11.18	$max\rho_i$ = 7.17	$max\rho_i$ = 7.49

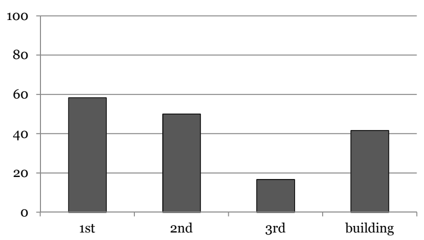
$\rho_{max}/\rho_{min} >> 2.5$ (ρ_{min}=1.002 for ρ>1) $\rightarrow$ elastic methods not allowed!

Summary of required verifications

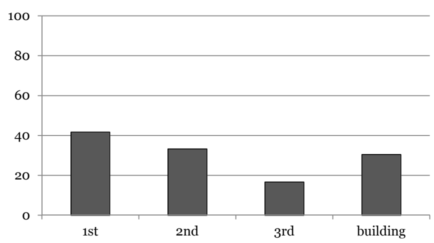
		Linear Model (LM) Demand	Linear Model (LM) Capacity	Nonlinear Model Demand	Nonlinear Model Capacity	*q*-factor approach Demand	*q*-factor approach Capacity
Type of element or mechanism (e/m)	Ductile	Acceptability of Linear Model (for checking of $\rho_i = D_i/C_i$ values): From analysis. Use mean values of properties in model.	In terms of strength. Use mean values of properties.	From analysis. Use mean values of properties in model.	In terms of strength. Use mean values of properties divided by CF and by partial factor.	From analysis.	In terms of strength. Use mean values of properties divided by CF and by partial factor.
		Verifications (if LM accepted): From analysis.	In terms of deformation. Use mean values of properties divided by CF.				
	Brittle	Verifications (if LM accepted): If $\rho_i \leq 1$: from analysis. If $\rho_i > 1$: from equilibrium with strength of ductile e/m. Use mean values of properties multiplied by CF.	In terms of strength. Use mean values of properties divided by CF and by partial factor.		In terms of strength. Use mean values of properties divided by CF and by partial factor	In accordance with the relevant Section of EN1998-1: 2004.	

% of beam failures in flexure (E_x+0.3E_y)

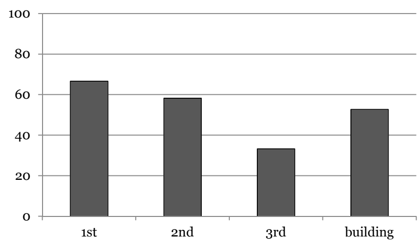
Lateral force (m-method)



Dynamic response spectrum (m-method)



q-approach

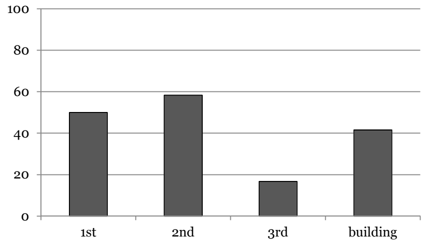


'θ-method' ($\theta_{req}<3/4\theta_u$, based on $EI_{ef}=0.50EI_g$)

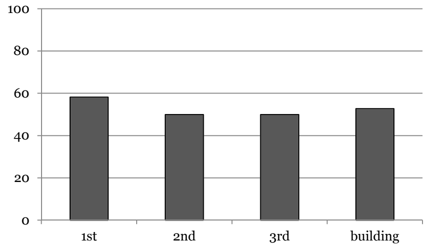
→ No failures!

% of beam failures in flexure (E_y+0.3E_x)

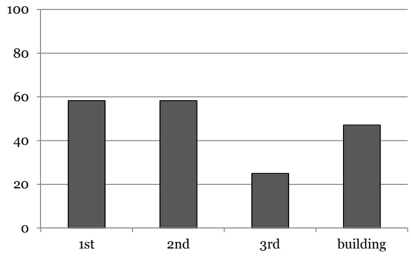
Lateral force (m-method)



Dynamic response spectrum (m-method)



q-approach

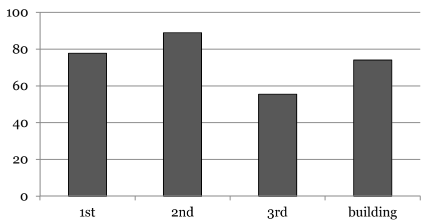


'θ-method' ($\theta_{req}<3/4\theta_u$)

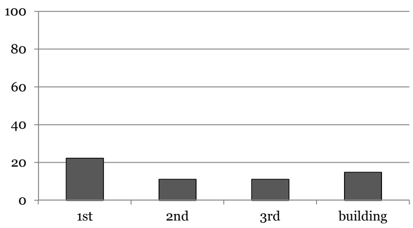
→ No failures!

% of column failures under M, N (E_x+0.3E_y)

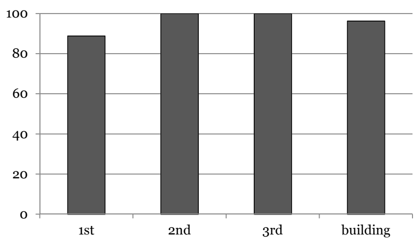
Lateral force (m-method)



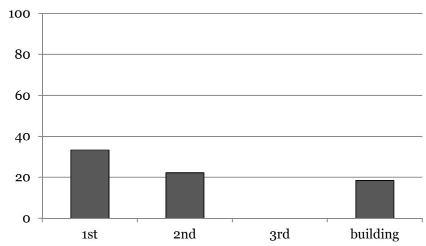
Dynamic response spectrum (m-method)



q-approach

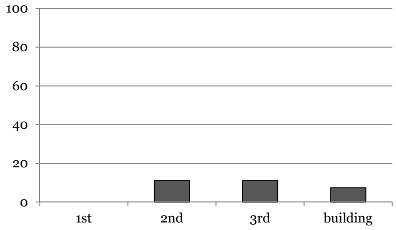


'θ-method'

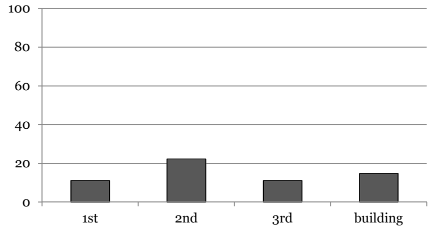


% of column failures under M, N (E_y+0.3E_x)

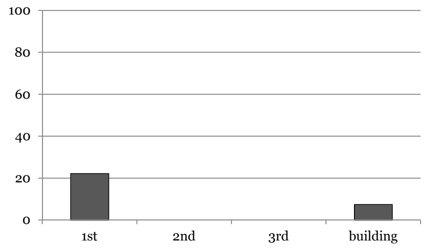
Lateral force



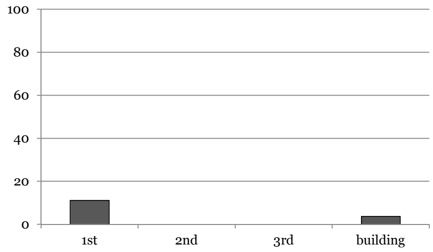
Dynamic response spectrum



q-approach

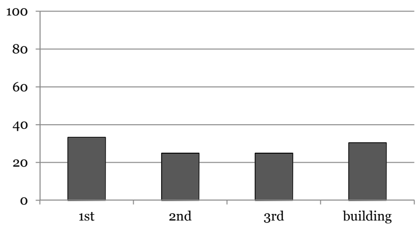


'θ-method'

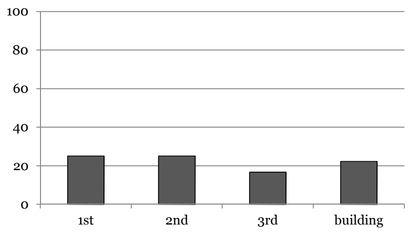


% of beam shear failures (E_x+0.3E_y)

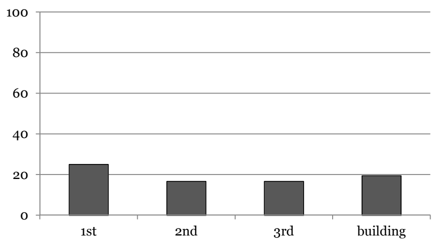
Lateral force

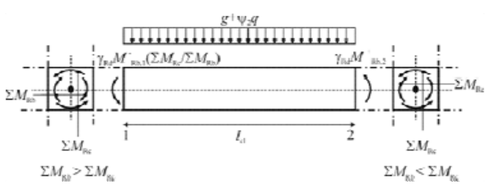


Dynamic response spectrum

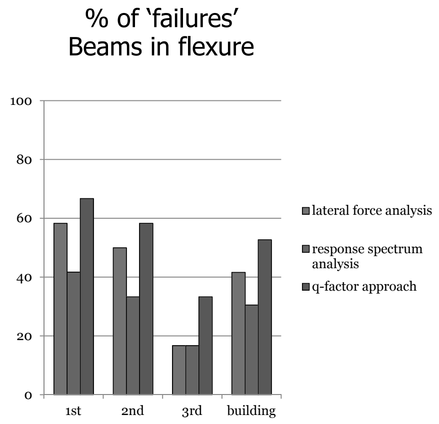


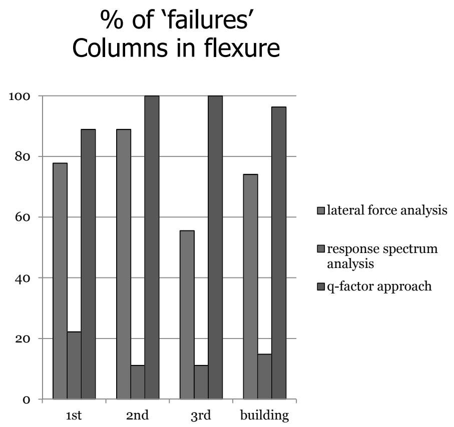
q-approach





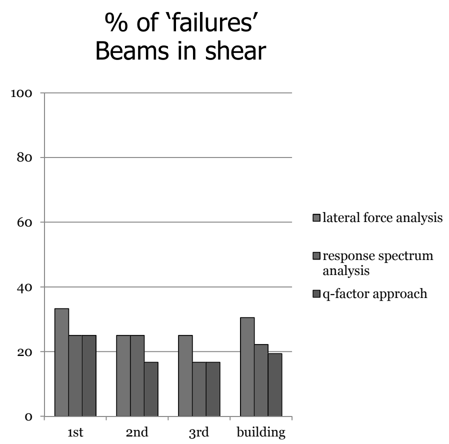
Comparative results for combination $E_x+0.3E_y$

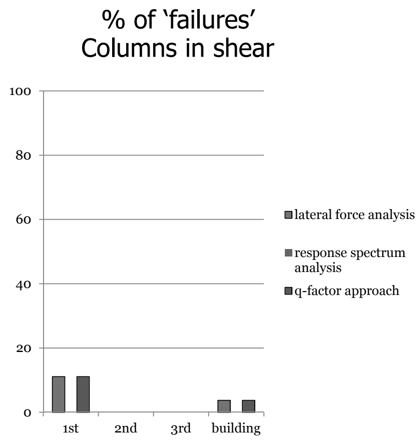




(lateral force and dynamic analysis based on m-method)

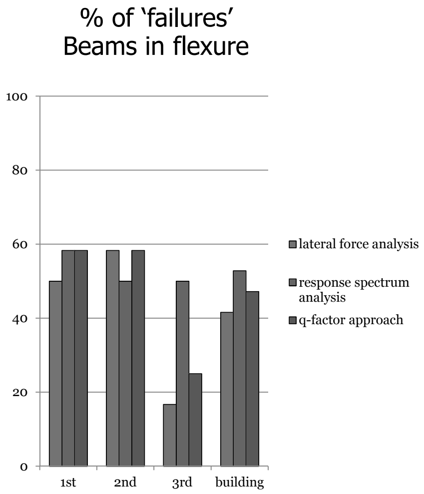
Comparative results for combination $E_x+0.3E_y$

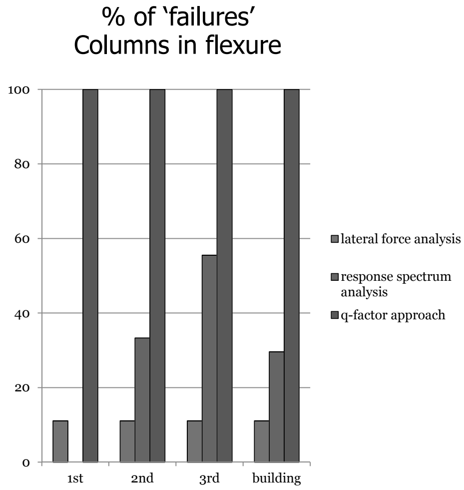




(lateral force and dynamic analysis based on m-method)

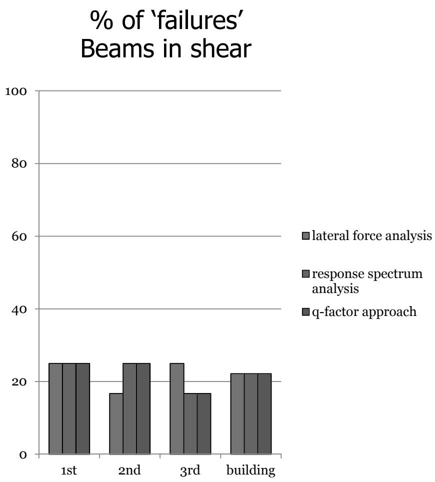
Comparative results for combination $E_y+0.3E_x$

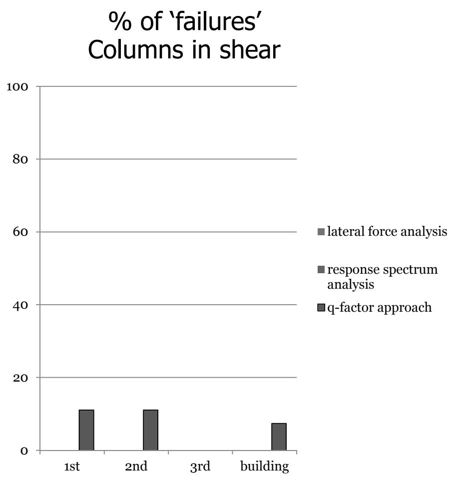




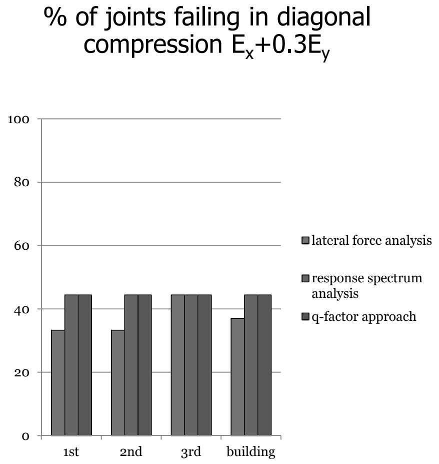
(lateral force and dynamic analysis based on m-method)

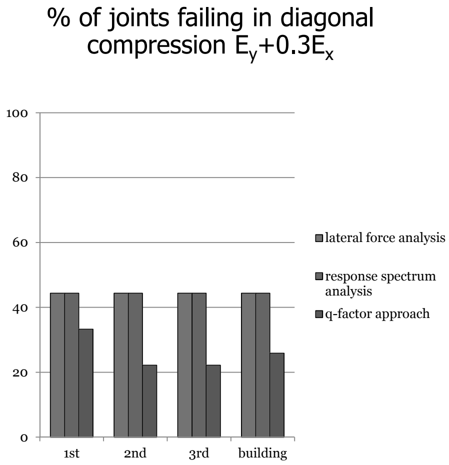
Comparative results for combination $E_y+0.3E_x$



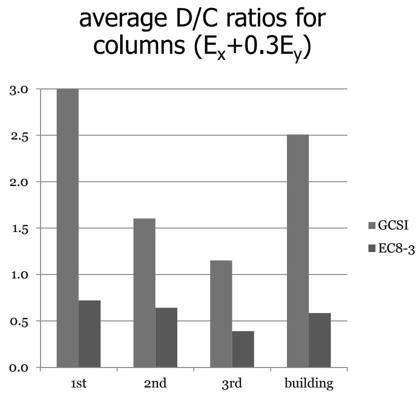


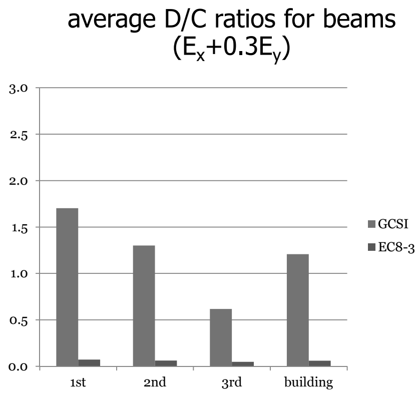
Beam-column joint verifications





Comparisons with the GCSI (θ vs. m method, lateral force)

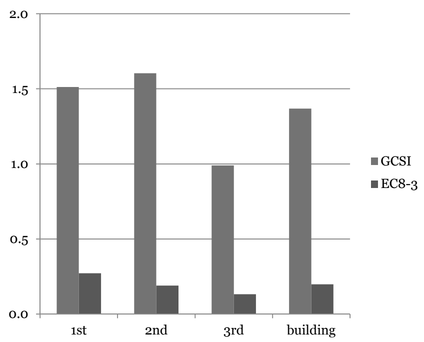




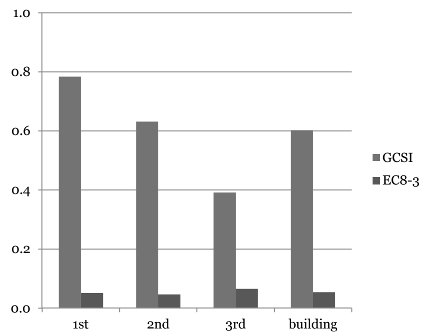
CGSI (and ASCE 41-06) m-method results in substantially more unfavourable results than EC8-3!

Comparisons with the GCSI
(θ vs. m method, response spectrum)

average D/C ratios for columns (E_x+0.3E_y)



average D/C ratios for beams (E_x+0.3E_y)



again, CGSI (and ASCE 41-06) m-method results in substantially more unfavourable results than EC8-3!

What are the reasons for the discrepancy?

- verifications should be carried out for stiffnesses compatible with θ_u, θ_y → important, since for old buildings EI_{ef}<<0.5EI_g (here 0.5EI_g was used in all cases, as allowed by §4.3 of EC8-3)
- different fractions of allowable deformation are specified by each code (e.g. for SD, $\theta_d=3/4\theta_u$ by EC8-3, $=0.5(\theta_u+\theta_y)/\gamma_{Rd}$ by GCSI)
- in calculating m approximate $L_V \cong L/2$ is assumed for beams and columns, whereas θ corresponds to the exact L_V
- m-factor used to reduce seismic action effects only, θ includes contribution from gravity loads as well
    - ➢ for same EI_{ef} and θ_d, the two procedures give the same outcome only in a cantilever, undeformed under gravity loads

Conclusions and reflections

- ❖ Analysis methods work as expected (same as in the GCSI)
  - ➢ Dynamic response spectrum method leads to most favourable results
  - ➢ q-approach leads to most unfavourable results
- ❖ Realistic structures do not satisfy ρ_i<2.5 requirement for elastic analysis (static+dynamic)
  - ➢ need for inelastic analysis! (this also true for the GCSI)
  - ➢ from GCSI based studies, pushover analysis more favourable results!
- ❖ Preferable to use procedures prescribed in more detailed and comprehensive codes (like the GCSI)
- ❖ Existing software packages do not provide chord rotations, while θ method (for flexure) is typically more favourable than m method!
- ❖ Shear verification (capacity-based) not influenced by analysis method
- ❖ Assessment becomes complicated (and perhaps error-prone) due to using different material strengths (with/without γ_M-factors)
  - ➢ things equally (actually, a bit more) complex in the GCSI!

A pilot application of EC8-3. Reflections and comparisons with the GCSI

Thank you,
hope I have stirred
some discussion!

websites: http://www.city.ac.uk/engineering-maths/staff/professor-andreas-kappos
http://ajkap.weebly.com/english.html
e-mail: Andreas.Kappos.1@city.ac.uk