Eurocode 8 Part 3:
Assessment and retrofitting of buildings

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Urgency of guidance documents for assessment and retrofit

- Worldwide growth of urbanisation and industrialisation in seismically active regions, without proper consideration of the seismic hazard
- Relatively recent realisation of the extent of the risk in terms of expected human and economic losses: Loma Prieta (1989), Kobe (1995), Koaceli(1999),…
- Reduction of the present level of risk is a long-term objective; availability of effective technical regulations is the only tool for rational planning

Reasons for the delayed appearance of assessment documents

- Late realisation of the conceptual and practical difference with respect to new design codes consisting in:
    - uncertain knowledge of the actual resisting system
    - greater sophistication in the analysis, due to likely presence of unfavourable, difficult to analyse mechanisms
    - poor knowledge on the ultimate behaviour of old-type, non seismically detailed, elements
- All existing documents (USA, Japan, New Zealand) are in the form of Reccomendations.

The structure of Eurocode 8 Part 3

Type: Displacement and Performance-based

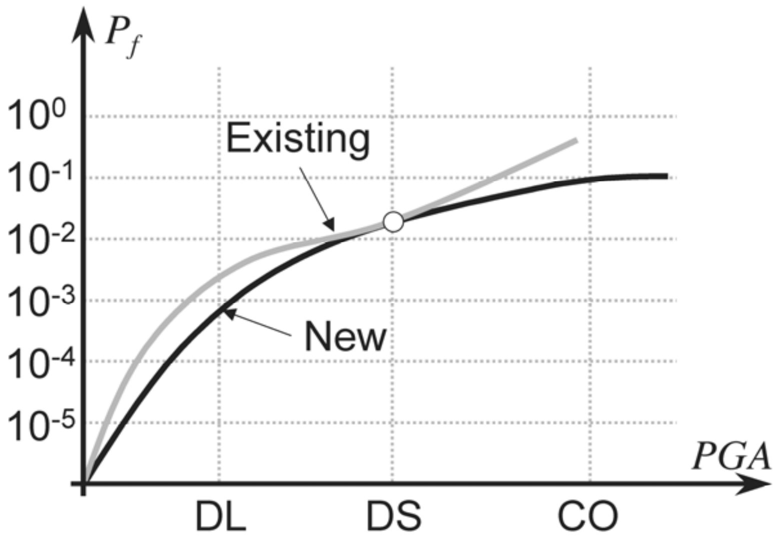
- Seismic action and corresponding performance levels: three
- Seismic action: elastic 5% damping response spectrum
- Analysis: essentially based on the *equal displacement rule* (except for non-linear dynamic) to estimate deformation demands in *ductile* structural members, and corresponding force demands in *brittle* members
- Verifications: additional safety factors called *confidence factors*
  original formulations for: ultimate flexural deformations of concrete elements, shear strength

Performance requirements

Hazard (return period of the design spectrum)	Required performance
$T_R = 2475$ years (2% in 50 years)	Near Collapse (very heavy damage, large permanent drift, but still standing)
$T_R = 475$ years (10% in 50 years)	Significant damage (damage to structural and non-strutural members, uneconomic to repair but has residual stiffness/strength)
$T_R = 225$ years (20% in 50 years)	Limited damage (damage to non-structural components only)
TR values above same as for new buildings. National authorities may select lower values, and require compliance with only two limit-states	

Motivation for the use of a 3rd, higher level of hazard

Contrary to new, code designed, buildings, existing ones may not have adequate margins to resist seismic actions higher than the design one



The additional "point check" is intended to ensure that "new" and "existing" have the same "total risk"

Safety format: components of the reliability framework

- Probabilistic definition of the seismic action
- Use of 'mean' or 'best estimate' values of the material properties, affected by the usual 'partial factors' (as for new designs)
- Introduction of an additional factor accounting for the 'level of knowledge' in: *geometry, details, material properties*
    - Three 'levels of knowledge' and corresponding 'confidence factors' (CF) values are defined (The CF's enter in the verification of the structural members

Knowledge levels (KL) and Confidence factors (CF)

<table>
<tr><th>Knowledge Level</th><th>Geometry</th><th>Details</th><th>Materials</th><th>Analysis</th><th>CF</th></tr>
<tr><td>KL1</td><td rowspan="3">From original outline construction drawings with sample visual survey
or
from full survey</td><td>Simulated design in accordance with relevant practice
and
from limited in-situ inspection</td><td>Default values in accordance with standards of the time of construction
and
from limited in-situ testing</td><td>LF-MRS</td><td>CF_{KL1}</td></tr>
<tr><td>KL2</td><td>From incomplete original detailed construction drawings with limited in-situ inspection
or
from extended in-situ inspection</td><td>From original design specifications with limited in-situ testing
or
from extended in-situ testing</td><td>All</td><td>CF_{KL2}</td></tr>
<tr><td>KL3</td><td>From original detailed construction drawings with limited in-situ inspection
or
from comprehensive in-situ inspection</td><td>From original test reports with limited in-situ testing
or
from comprehensive in-situ testing</td><td>All</td><td>CF_{KL3}</td></tr>
</table>

Methods of analysis: possible choices

• Linear static	applicable to buildings that are 'regular' in elevation, with a period T_1<2s, and T_1<4T_C (corner period of the spectrum) and **satisfy 'uniform strength conditions'**
• Linear dynamic	as above
• Non-linear static	EC8 standard assessment method, applicable without restrictions
• Non-linear dynamic	applicable in all cases

Methods of analysis: linear methods

- Linear displacemet-based methods have been under development in the USA and in Europe in the last decade
- Actual displacements are obtained by applying correction factors to the displacements from a linear analysis of the structure subjected to the unreduced seismic action
- Condition for applicability: ratio between demand D_i and capacity C_i, $\rho_i = D_i / C_i$ sufficiently uniform across all primary resisting memebers, e.g.:

$$\rho_{max} / \rho_{min} \leq 2 \div 3$$

(Very useful also for detecting a number of inadequate members)

Methods of analysis: non-linear static 1/2

Specifications for use within EC8:

- No limitations related to regularity of the building
- Two patterns of lateral forces, corresponding to a 'rigid' and a 'first-mode' deformed shape
- Consistent transformation factor for the 'capacity curve'
  - Base shear $\Gamma = \sum m_i \phi_i / \sum m_i \phi_i^2 \qquad F^* = F_b / \Gamma$
  - Top displacement $d^* = d_{top} / \Gamma$
- Determination of the response by entering the design elastic displacement response spectrum at the period *T** from the bilinearised (F_y*, d_y*) 'capacity curve'

Methods of analysis: non-linear static 2/2

- Modification of the elastic response in the short-period range (T<=Tc)

$$d^{**} = \frac{d^*}{q_u}\left[1-(q_u-1)\frac{T_C}{T^*}\right]$$

where q_u = equivalent ductility $= S_e(T^*)m^*/F_y^*$

$(S_e(T^*) = \text{elastic spectral ordinate})$

- Combination of the effects of the two horizontal components of the seismic action
    - Conventional Ex+0.30Ey; Ey+0.3Ex
    where Ex, Ey are the effects of the full action along X and Y, respectively

Member verifications: demand quantities

- **Ductile members** (beam-columns and walls in flexure)
  the demand quantity is the chord-rotation at the ends, as obtained from the analysis, either linear or non-linear

- **Brittle mechanisms** (shear)
  the demand quantity is the force acting on the mechanism

  - Linear analysis: the ductile transmitting mechanisms can be:

    - below yielding: the force is given by the analysis

    - yielded: the force is obtained from equilibrium conditions, with the capacity of the ductile elements evaluated using **mean values** of the mech. prop.'s **multiplied** by the CF's

  - Non-linear analysis: forces as obtained from the analysis

Member verifications: capacities

- **Ductile members** (beam-columns and walls in flexure)
  expressions of the ultimate chord-rotations are given for the three performance levels, the values of the mech. properties are the **mean values**, **divided** by the CF's.

- **Brittle mechanisms** (shear)
  expressions for the ultimate strength are given for the NC performance level, the values to be used for the mechanical properties are the **mean values**, **divided** by both the usual partial factors and the CF's

Member verifications: synopsis

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Linear Model (LM)</td><td colspan="2">Non-linear Model</td></tr>
<tr><td>Demand</td><td>Capacity</td><td>Demand</td><td>Capacity</td></tr>
<tr><td rowspan="7">Type of elment or mechanism (e/m)</td><td rowspan="4">Ductile</td><td colspan="2">Acceptability of Linear Model
(for checking of $\rho_i = D_i/C_i$ values)</td><td rowspan="7">From analysis.
Use mean values of properties in model.</td><td rowspan="4">In terms of deformation.
Use mean values of properties divided by CF.</td></tr>
<tr><td>From analysis.
Use mean values of properties in model.</td><td>In terms of strength.
Use mean values of properties</td></tr>
<tr><td colspan="2">Verifications (if LM accepted)</td></tr>
<tr><td>From analysis.</td><td>In terms of deformation.
Use mean values of properties divided by CF.</td></tr>
<tr><td rowspan="3">Brittle</td><td colspan="2">Verifications (if LM accepted)</td><td rowspan="3">In terms of strength.
Use mean values of properties divided by CF and by partial factor.</td></tr>
<tr><td>If $\rho_i \leq 1$: from analysis.</td><td rowspan="2">In terms of strength.
Use mean values of properties divided by CF and by partial factor.</td></tr>
<tr><td>If $\rho_i > 1$: from equilibrium with strength of ductile e/m.
Use mean values of properties multiplied by CF.</td></tr>
</table>

Capacity models for RC members: flexure

• Mechanically-based models capable of accounting for all internal deterioration mechanisms that develop in inadequately detailed RC members are not available

• Resort has been made to a large database collecting tests made in the past in order to derive empirical expressions.

•Example:

$$\theta_{um} = 0.01(0.3)^{\nu}\left[\frac{\max(0.01;\omega')}{\max(0.01;\omega)} f_c\right]^{0.225}\left(\frac{L_s}{h}\right)^{0.35} 25^{\alpha\rho_{sx}\frac{f_{yw}}{f_c}} 1.25^{100\rho_d}$$

where ν = normalised axial force

ω, ω' = mech. reinforc. ratio of compression and tension reinf.

L_s = shear span

h = net height of the section

α = confinement effectiveness factor

ρ_{sx}, ρ_{dx} = transverse and diagonal reinforcement ratio

Capacity models for RC members: shear

The well-known three-terms additive format for the shear strength has been retained. The expressions for the three contributions have been derived using the same database as for the flexural capacity, augmented by test results of specimen failing in shear after initial flexural yielding:

$$V_R = 0.85\left[\frac{h-x}{2L}\min(N;0.55A_c f_c) + \left(1-0.55\min\left(5;\mu_\Delta^{pl}\right)\right)\times \right.$$

$$\left. \times 0.16\max(0.5;100\rho_{tot})\left(1-0.16\min\left(5;\frac{L_s}{h}\right)\right)\sqrt{f_c} + V_w\right]$$

where x = neutral axis depth

N = compressive axial force (= 0 if tensile)

A_c = cross-section area

μ_Δ^{pl} = plastic part of ductility demand

ρ_{tot} = total longitudinal reinf. ratio

V_w = contribution of transverse steel

$$\frac{V_{R,predicted}}{V_{R,experimental}} = 1$$

$$CoV = 15\%$$

Capacity models for strengthened members

The section covers traditional strengthening techniques, such as concrete and steel jacketing, as well as the use of FRP plating and wrapping, for which results from recent research are incorporated. Guidance in the use of externally bonded FRP is given fo the purposes of:

- increasing shear strength (contribution additive to existing strength)
- increasing ductility of critical regions (amount of confinement pressure to be applied, as function of the ratio between target and available curvature ductility)
- preventing lap-splice failure (amount of confinement pressure to be applied, as function of the bar diameters and of the action already provided by existing closed stirrups)

Concluding remarks

- Eurocode 8 Part 3: Assessment and retrofitting of buildings is the latest addition to a small set of international documents dealing with the dramatic issue of the high seismic risk of existing buildings
- The best of the Codes cannot solve the problems by itself, it is however a necessary prerequisite, and the absence of assessment documents until very recently has contributed to delay the planning of measures of risk mitigation
- Preparation of EC8/3 has revealed lack of fundamental knowledge in a number of areas, most notably the deformation and strength properties of old-type elements, on which fresh research is needed
- The practicality, as well as the ability of EC8/3 to provide consistent measures of the level of safety of existing buildings, needs to be confirmed through extensive applications.