EUROCODES
Building the Future

Eurocodes
Building the future in the Euro-Mediterranean area

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WORKSHOP
on the use of the Eurocodes in the Mediterranean Countries
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Eurocode 8
and other seismic design codes

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Seismic Codes in the USA

- Seismic design: according to building design code covering also non-structural aspects (architectural, mechanical, electrical, building equipment, etc.).
- Traditionally, large fragmentation in Code development:
  - International Conference of Building Officials (ICBO): Uniform Building Code (UBC, last one 1997), used mainly in the Western USA.
  - Building Officials and Code Administrators International, Inc. (BOCA): National Building Code (NBC), used mainly in the Northeast & in Central US.
  - Southern Building Code Congress International, Inc. (SBCCI): Standard Building Code (SBC), adopted primarily in the Southeastern USA.
  - International Code Council (ICC): International Building Code (IBC 2000, 2003), gradually being adopted throughout the USA.
  - National Fire Prevention Association (NFPA): National Fire Prevention Association code (NFPA500 2003), competing with IBC 2003. As a result, some states (e.g., Ca) did not adopt either and stayed with UBC 1997.
- Local Authorities (States, counties, cities) formally adopt a code, adapting to local traditions/conditions (some rural areas: no formal building code).

Seismic Codes in the USA *(cont'd)*

- Seismic design provisions for new buildings developed by:
  - the Building Seismic Safety Council (BSSC): "NEHRP Recommended Provisions for the Development of Seismic Regulations for Buildings and Other Structures" (last one: 2003), reflected with some time-lag in (but not fully adopted by) the NBC and the IBC, or
  - the Structural Engineers Association of California (SEAoC): "SEAoC Recommended Lateral Force Requirements", reflected with some time-lag in the UBC.

Seismic Codes in the USA *(cont'd)*

- Seismic design rules refer to, or use as a source document, codes of material organizations:
  - ACI 318-H for concrete,
  - AISC-Seismic Provisions for steel and composite,
  - ACI 530/ASCE 5/TMS 402 for masonry,
  - but not so for timber,

  often under the coordination of a BSSC Provisions Update Committee.
- BSSC Provisions Update Committees also take care of:
  - foundations (retaining structures not covered),
  - seismic isolation and energy dissipation, or
  - some types of structures other than buildings.
- Full harmonisation: not yet.

Seismic Codes in the USA *(cont'd)*

Coverage of "non-buildings structures":

- Towers;
- Tanks;
- Underground structures;

- is elementary – by reference to provisions for buildings;
- does not take into account their particularities and special performance requirements.

For Comparison:

EN 1998-4: Silos, Tanks and Pipelines

1. General
2. General Principles and Application Rules
3. Specific Principles and Application Rules for Silos
4. Specific Principles and Application Rules for Tanks
5. Specific Principles and Application Rules for Above-ground Pipelines
6. Specific Principles and Application Rules for Buried Pipelines

EN1998-6: Towers, Masts and Chimneys

1. General
2. Performance Requirements and Compliance Criteria
3. Seismic Action
4. Design of Earthquake Resistant Towers, Masts and Chimneys
5. Specific Rules for Reinforced Concrete Chimneys
6. Special Rules for Steel Chimneys
7. Special Rules for Steel Towers
8. Special Rules for Guyed Masts

Seismic Codes in the USA *(cont'd)*

- Actions separated from design and detailing rules. Seismic actions: ASCE 7 Committee on Minimum Design Loads for Buildings and Other Structures (ASCE 2002) publishes loading criteria for seismic design on the basis of US Geological Survey (USGS) work.
- 1997 NEHRP Provisions include USGS national Seismic Hazard maps: 5%-damped elastic spectral acceleration at the acceleration-controlled (T=0.2s) & the velocity-controlled (T=1s) part of the spectrum over firm rock (ground type A).
  - National maps (1:5000000) for 10%/50yr (475yr) & 2%/50yr (2475yr) values.
  - National and regional maps (1:500000 to 1:2000000) also for "Maximum Considered Earthquake" (MCE), corresponding to 1.5 times the characteristic event produced by clearly identified, well known seismic sources. (The smaller of the MCE & of the 2%/50yr event is used, e.g. for "Collapse Prevention").
- Factors & expressions cover:
  - the other (4) standard ground types;
  - different hazard levels (2%-10% /50yr);
  - damping other than 5%.

For Comparison: Seismic Action in EN1998-1

- The Design Seismic action is defined as the one for which the No-(life-threatening-)collapse requirement is verified
- The Reference Return Period of the Reference Seismic action is a NDP (recommended value: 475yrs - Reference Probability of Exceedance in the structure's design life of 50yrs: 10%).
- The Reference Seismic action is described (in the national zonation maps) in terms of a single parameter: the Reference Peak Ground Acceleration on Rock, a_{gR}.
- The design ground acceleration on rock, a_g, is the reference PGA times the importance factor: $a_g = \gamma_I a_{gR}$
- In addition to the Reference Peak Ground Acceleration on Rock, the Reference Seismic action is defined in terms of the Elastic Response Spectrum for 5% damping, which is NDP.

Performance-based Seismic Design of Buildings

- Design for different "Performance Levels" at different Seismic Hazard levels
- "Basic Objective" (ordinary buildings):

Performance Level	Hazard Level	
Operational	Frequent EQ	(25-72 yrs)
Immediate occupancy	Occasional EQ	(72-225 yrs)
Life-safety	Rare EQ	(475 yrs)
Collapse prevention	Very rare EQ	(800-2500 yrs)

- Safety-critical facilities: "Enhanced Objective“

➢ Better property protection; flexibility in conceptual design. But, onerous design process.

IN EUROPE, SINCE '60s (also in seismic codes)

- Instead of "Performance Level":
- "Limit State" (LS) = state of unfitness to (intended) purpose:
  - ULS (Ultimate LS): safety of people and/or structure;
  - SLS (Serviceability LS): operation, damage to property.
- LS concept:
  - Adopted in 1985 CEB seismic Model Code;
  - Continued & expanded in 1994 ENV (prestandard) EC8;
  - According to EN 1990 (Basis of structural design): LS-design is the basis for all Eurocodes (including EC8).

EN 1998: Adaptation of L.S. Design of new buildings, towers, tanks, pipelines, chimneys or silos to Performance-based concept:

- Verify explicitly No-life-threatening-collapse requirement ("Life Safety" performance level) for "rare" Earthquake (recommended NDP-reference seismic action for structures of ordinary importance: 475 years).

- Limit damage, through damage limitation check for "frequent" Earthquake (recommended NDP-reference EQ for structures of ordinary importance: 95 yrs).

- Prevent collapse under any conceivable Earthquake, through generalised application of Capacity Design.

➢ **Safety-critical or large occupancy facilities:** Multiply seismic action by importance factor γ_I

EN 1998: Design of foundations, bridges, retaining structures, masts:

- Verify explicitly only No-(life-threatening) collapse requirement under "rare" Earthquake (recommended NDP-reference seismic action for structures of ordinary importance: 475 years).
- No Serviceability or Damage Limitation checks for "frequent" Earthquake
- For some types of structures: Prevent collapse under any conceivable Earthquake through "Capacity Design”

➢ **Safety-critical facilities:** Multiply seismic action by importance factor γ_I

EN 1998-3: Assessment and retrofitting of buildings: EXPLICIT PERFORMANCE-BASED APPROACH:

Assessment & Retrofitting for different Limit States under different Seismic Hazard levels

- **<u>Limit States</u> (Performance Levels)**
  - Damage Limitation (: Immediate Occupancy)
  - Significant Damage (: Life Safety)
  - Near Collapse.
- Flexibility for countries, owners, designers:
  - How many & which Limit States will be met and for what Hazard Level:
    - to be decided by country, or
    - (if country doesn't decide in National Annex) by owner/designer
  - Hazard Levels: NDPs - No recommendation given
    Noted that Basic Objective for ordinary new buildings is:
    - Damage Limitation: Occasional EQ (225yrs)
    - Significant Damage: Rare EQ (475yrs)
    - Near Collapse: Very rare EQ (2475yrs)
- **Safety-critical or large occupancy facilities:** Multiply seismic action by importance factor γ_I

For Comparison:
Performance requirements of US codes for new buildings and non-building structures

- Verify explicitly No-life-threatening-collapse requirement ("Life Safety" performance level) for “design" Earthquake:
  - for buildings of ordinary importance: 2/3 x MCE (Maximum Considered Earthquake);
  - for large occupancy buildings : 5/6 x MCE;
  - for safety-critical facilities: MCE.
- Limited application of Capacity Design to prevent collapse under any conceivable Earthquake.

EN1998-1: LINEAR ANALYSIS FOR DESIGN SEISMIC ACTION –
ULS MEMBER VERIFICATION - COMPLIANCE CRITERIA FOR LIFE SAFETY

- Reference approach:
  Force-based design with linear analysis:
- Linear modal response spectrum analysis, with design response spectrum (elastic spectrum reduced by behaviour-factor q):
  - Applies always (except in seismic isolation with very nonlinear devices)
- If:
  - building regular in elevation &
  - higher modes unimportant (fundamental T <4T_c & <2sec, T_C: T at end of constat spectral acceleration plateau):

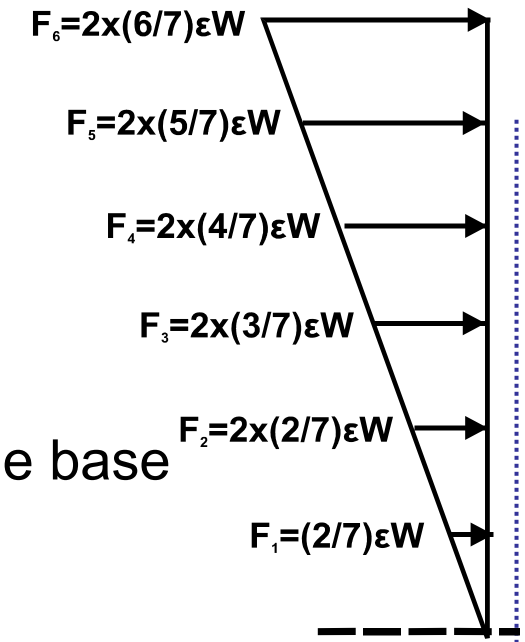
  (linear) Lateral force procedure emulating response-spectrum method:
  - T from mechanics (Rayleigh quotient);
  - Reduction of forces by 15% if >2 storeys & T<2T_c

– Member verification at the Ultimate Limit State (ULS) for "Life-Safety" EQ in terms of forces (resistances)

EN1998-1: LINEAR ANALYSIS FOR DESIGN SEISMIC ACTION *Cont'd*

- Reference approach is **modal response spectrum analysis**, with design spectrum:
  - Number of modes taken into account:
    - All those with modal mass ≥ 5% of total in one of the directions of application of the seismic action;
    - Sufficient to collectively account for ≥ 90% of total mass in each direction of application of the seismic action.
  - Combination of modal responses:
    - CQC (Complete Quadratic Combination);
    - SRSS (Square-Root-of-Sum-of-Squares) if ratio of successive modal periods > 0.9 & < 1/0.9.

- **Lateral force procedure**:
  - Static lateral forces on storey or nodal masses proportional to the mass times its distance from the base (inverted triangular heightwise distribution).



For Comparison:

LINEAR ANALYSIS IN US CODES

Reference analysis:

Linear lateral force procedure, w/ design response spectrum (elastic spectrum divided by Force Reduction factor R, equivalent to q-factor):

- Applies always except:
  - If design PGA or 1sec spectral acceleration are >0.2g for ordinary importance structures or >0.133g for higher importance ones, and
    - $T > 3T_c$ or;
    - the building is irregular in plan or in elevation.
- T is obtained from empirical conservative formulas
  - T from mechanics not to exceed empirical value by more than a certain percentage (40%, 50% or 70%, if the 1sec spectral acceleration ≥0.3g, 0.2g or 0.1g, respectively in NHERP, or lower values in SEAoC).

Comparison: LINEAR ANALYSIS IN US CODES *Cont'd*

- Reference approach: **Lateral force procedure** w/ static lateral forces on storey or nodal masses:
  - in NEHRP: proportional to the mass times its distance from the base to a power k (k=1 for T≤0.5s to k=2 for T≥2.5s);
  - In SEAoC: concentrated force at the top for T>0.7s, equal to 0.07T (≤0.25) times the base shear; the rest follows inverted triangular heigthwise pattern of response accelerations.
- **Modal response spectrum analysis** emulates lateral force procedure:
  - It is a lateral force analysis, w/ lateral storey forces derived from response accelerations computed via SRSS (or CQC) combination of modal storey accelerations.
  - If the base shear derived from modal combination is <85% (90% for regular structures, 100% for irregular ones in SEAoC) of that from the lateral force procedure on the basis of the upper-bound-value of T (: multiple of empirical T), the modal analysis results are scaled up by the ratio of base shears.

EN1998-1: REGULARITY OF BUILDINGS IN ELEVATION

(APPLICABILITY OF LATERAL FORCE PROCEDURE & FOR VALUE OF BEHAVIOUR FACTOR, q)

- Qualitative criteria, can be checked w/o calculations:
- Structural systems (walls, frames, bracing systems): *continuous to the top (of corresponding part)*.
- Storey *K* & *m:* *constant or gradually decreasing to the top*.
- Individual floor setbacks on each side: *< 10% of underlying storey.*
- Unsymmetric setbacks: *< 30% of base in total.*
- Single setback at lower 15% of building: *< 50% of base.*
- In frames (incl. infilled): *smooth distribution of storey overstrength.*

- Heightwise irregular buildings: q-factor reduced by 20%

EN1998-1: REGULARITY OF BUILDINGS IN PLAN

(FOR ANALYSIS OF TWO SEPARATE PLANAR/2D MODELS)

Criteria can be checked before any analysis:

- *K* & *m* ~ symmetric w.r.to two orthogonal axes.
- Rigid floors.
- Plan configuration compact, w/ aspect ratio ≤ 4;
  any recess from convex polygonal envelope: < 5% of floor area.
- In both horizontal directions:
  - r *(torsional radius of struct. system)* $\geq l_s$ *(radius of gyration of floor plan)*:
    Translational fundamental T(s) > torsional.
  - e_o *(eccentricity between floor C.S. & C.M.)* ≤ 0.3 r:
    Conservative bound to satisfactory performance (element ductility demands ~ same as in torsionally balanced structure).

Alternative for buildings ≤ 10m tall:

- In both horizontal directions: $r^2 \geq l_s^2 + e_o^2$

For Comparison:
REGULARITY OF BUILDINGS IN ELEVATION IN US CODES

- Semi-quantitative criteria, checking may need calculation:

FOR APPLICABILITY OF LATERAL FORCE ANALYSIS IN MODERATE OR HIGH SEISMICITY (design PGA or 1s Spect. Acc. >0.2g for ordinary importance or >0.133g for higher importance):

– Storey *m:* *does not exceed by >50% that of adjacent storey*.
– Storey *K:* *≥70% of K of storey above, <u>and</u> ≥80% of average K in 3 storeys above.*
– Floor setbacks, total on both each sides: *≤30% of adjacent storey.*

TO ALLOW HIGH IMPORTANCE BUILDING IN VERY HIGH SEISMICITY: (1s Spect. Acc. of MCE >0.75g)

– Storey strength*:* *≥80% of strength of storey above.*
– Storey *K:* *≥60% of K of storey above, <u>and</u> ≥60% of average K in 3 storeys above.*

For Comparison:
REGULARITY OF BUILDINGS IN PLAN IN US CODES

- Quantitative criteria, checking after an analysis:

FOR APPLICABILITY OF LATERAL FORCE ANALYSIS IN MODERATE OR HIGH SEISMICITY (design PGA or 1s Spect. Acc. >0.2g for ordinary importance or >0.133g for higher importance), AND

FOR AMPLIFICATION OF ACCIDENTAL & NATURAL ECCENTRICITY BETWEEN CENTRES OF STIFFNESS & MASS (w/ iterations):

– maximum storey drift exceeds by <20% mean storey drift.

TO ALLOW HIGH IMPORTANCE BUILDING IN VERY HIGH SEISMICITY:

(1s Spect. Acc. of MCE > 0.75g)

– maximum storey drift exceeds by <40% mean storey drift.

THANK YOU!