DEVELOPMENTS IN CODES FOR NEW AND EXSISTING STRUCTURES

Seismic design and assessment in MC 2020

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Model Code 2020: a fully comprehensive code for new and existing structures

- Based for new structures on 7.4.3 seismic design chapter of MC 2010
- To be extended for the assessment of existing structures
- To be complemented with some general information on seismic risk

Seismic Risk (R)

Estimation of global cost (human life, economical values, cultural values, structures and infrastructures) to be expected in a reference time in a predefined region

Probability to reach a predefined level of loss within a reference time interval

Seismic Risk

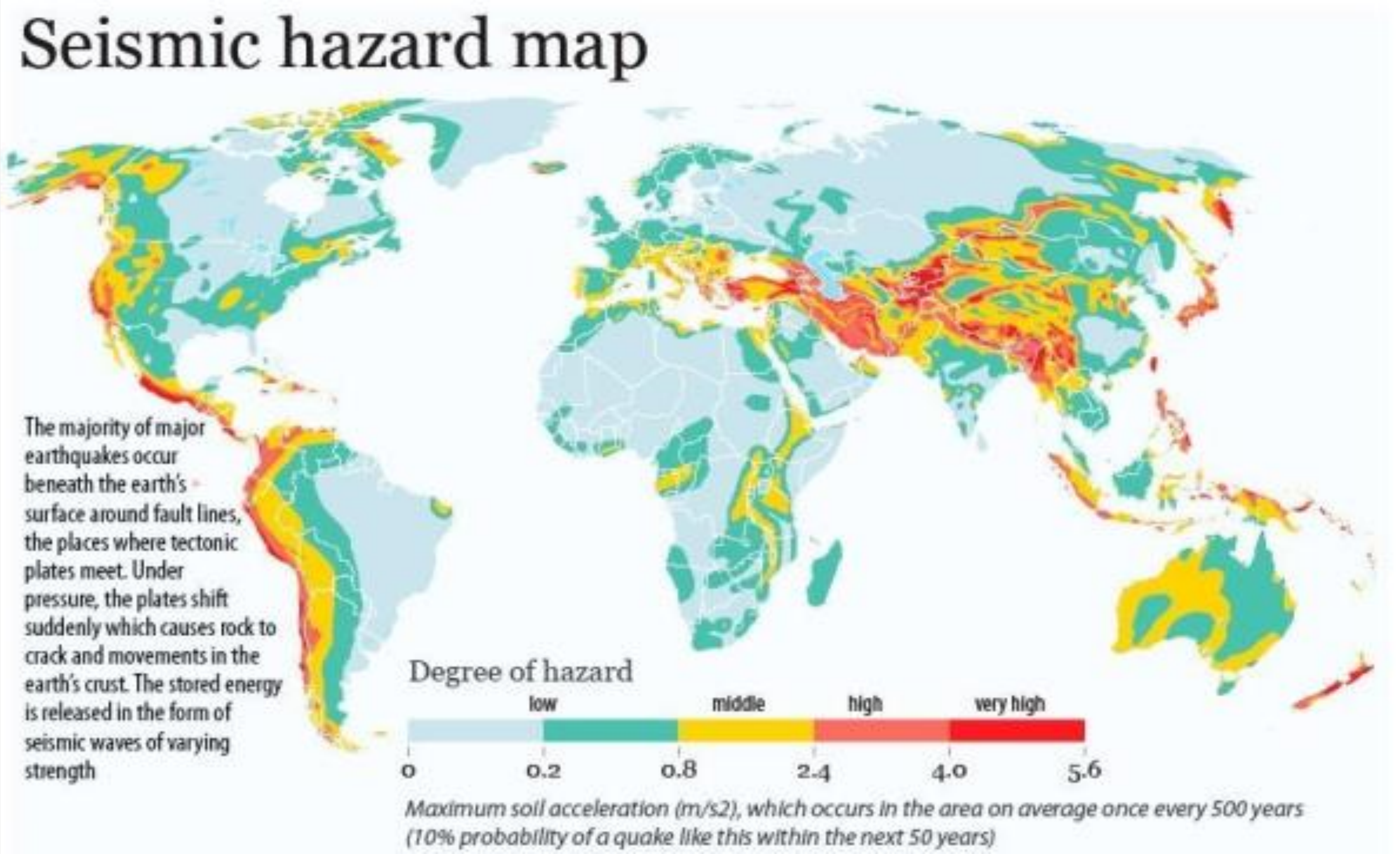
is a function of

Hazard (1)

Vulnerability (2)

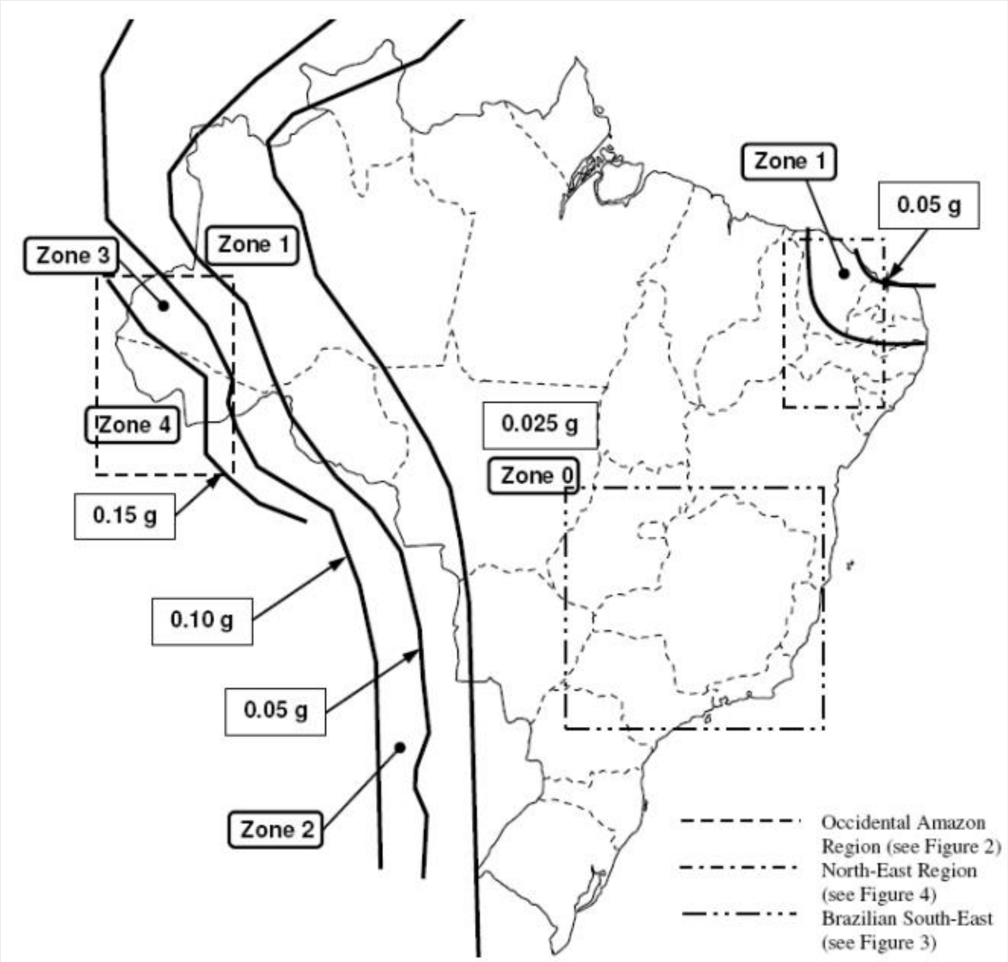
Exposition (3)

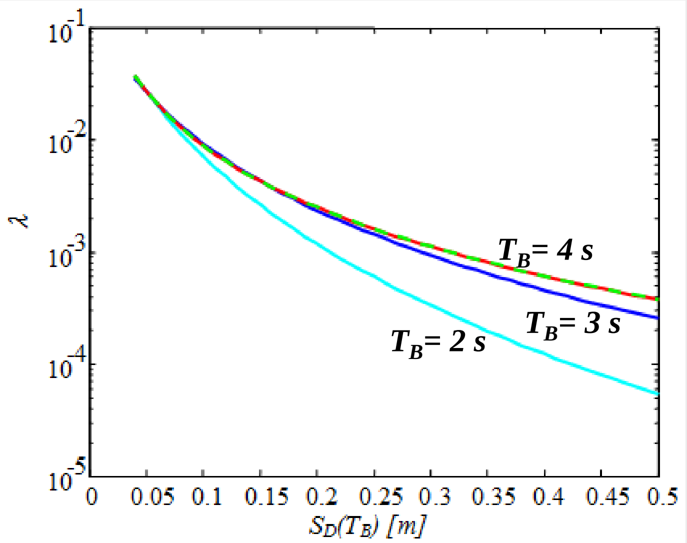
Generally: $R = H \times V \times E$


Seismic hazard map
The majority of major earthquakes occur beneath the earth's surface around fault lines, the places where tectonic plates meet. Under pressure, the plates shift suddenly which causes rock to crack and movements in the earth's crust. The stored energy is released in the form of seismic waves of varying strength
Degree of hazard
low
middle
high
very high
0
0.2
0.8
2.4
4.0
5.6
Maximum soil acceleration (m/s2), which occurs in the area on average once every 500 years
(10% probability of a quake like this within the next 50 years)

1 Hazard (H)

Depends on the physical parameters of the seismic event and on the local geological conditions (to be defined by the Authorities)

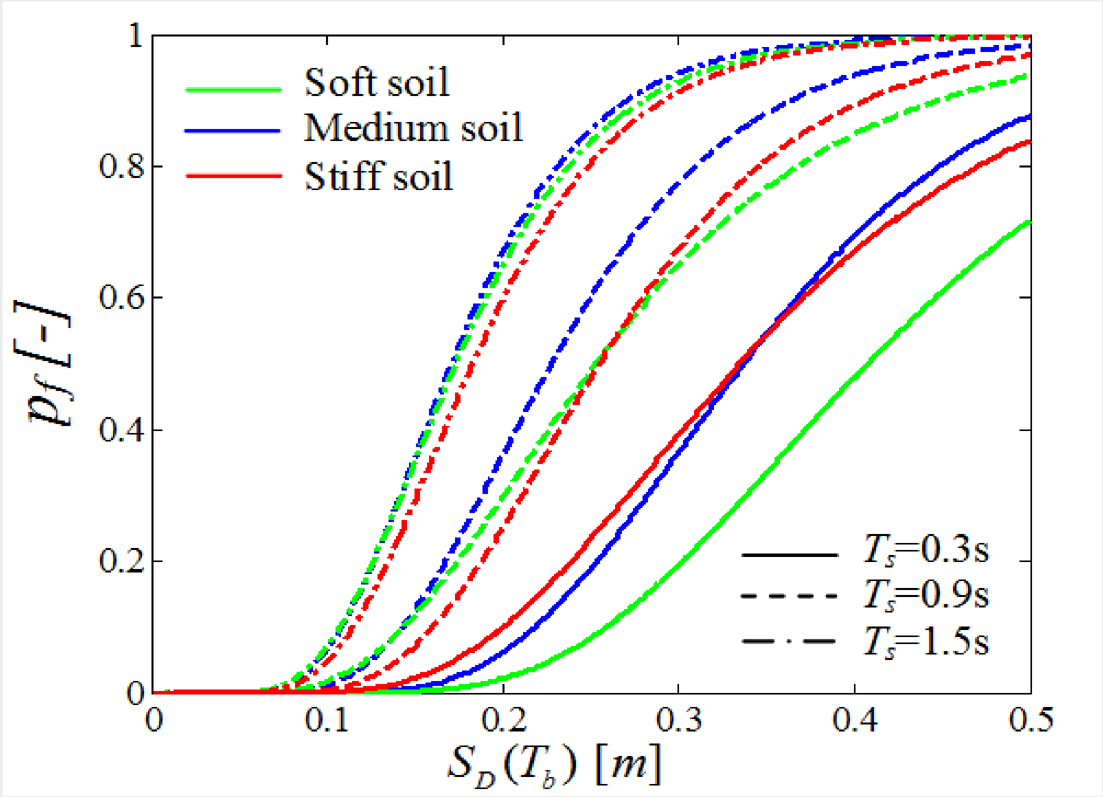




λ : Average annual rate exceeding the intensity measured levels

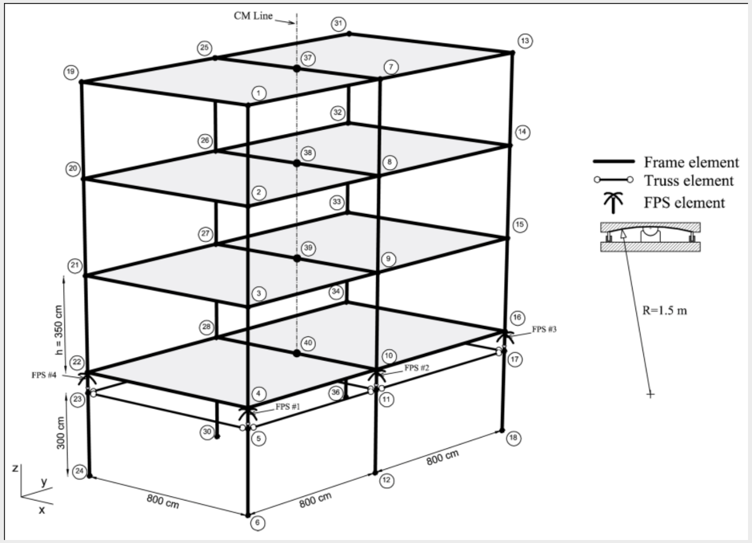
2 Vulnerability (V)

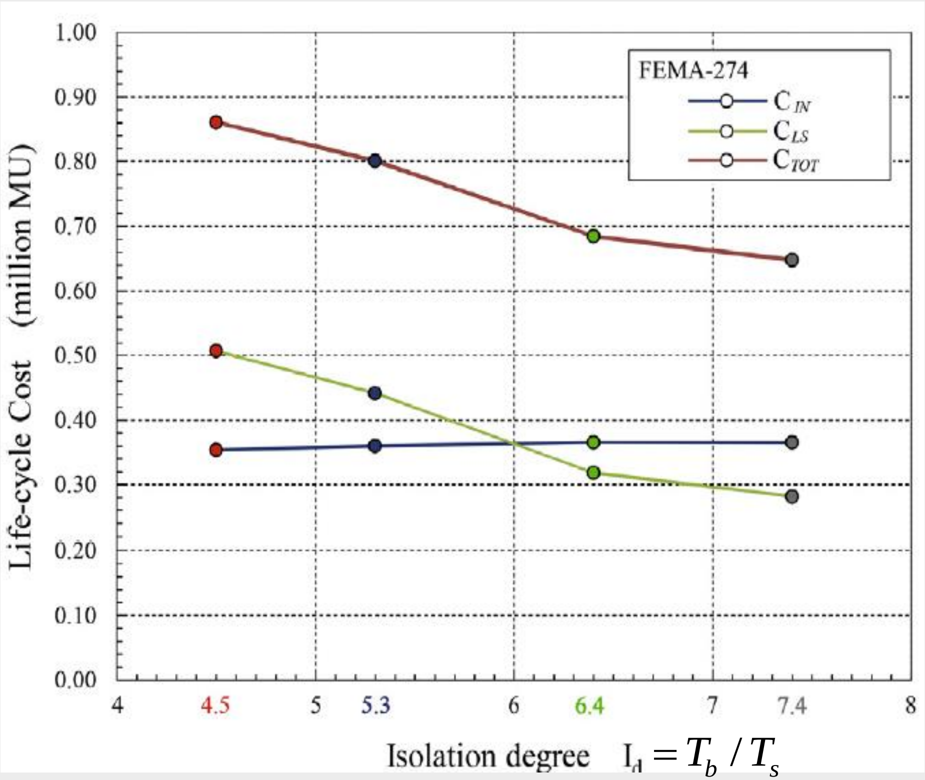
Depends on the sensitivity of a structure to be damaged by effect of a certain earthquake, at different levels of intensity (designer task)



3 Exposition (E)

Depends on nature/ quality/ value of potential losses, like buildings/economical activities/infrastructures/population density, …. (owner and designer task)





C_{IN}: the initial construction cost

C_{LS}: the limit states dependent cost

C_{TOT}: $C_{IN} + C_{LS}$

Within the field of

Limit State (LS) approach

Evaluation of P_f within a reference time

$$P_f = P(C \leq D)$$

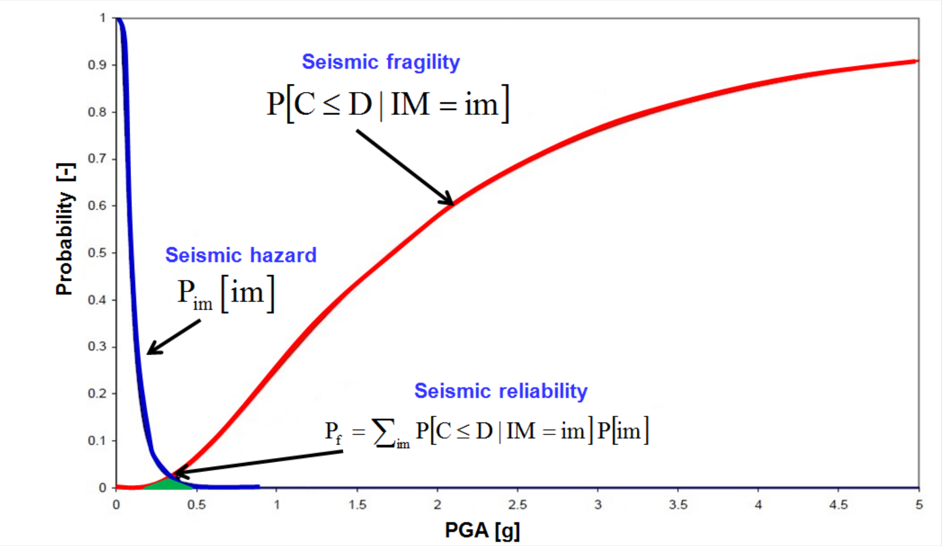
Where: C = non linear structure capacity

D = seismic demand

Cornell (2004)

Separation of structure capacity by probabilistic evaluation of seismic demand

$$P(C \le D) = \sum P(C \le D \mid IM = \alpha) \cdot P(\mathrm{IM} = \alpha)$$



$P(\mathrm{IM} = \alpha)$ → Probability to have an earthquake with magnitude $IM = \alpha$, to be evaluated by means of probabilistic analyses of the site

(PSHA → Probabilistic Seismic Hazard Analysis)

$P(C \leq D | IM = \alpha)$ → Structure fragility or failure probability for a certain IM, so describing the structure vulnerability

Exposition defined by means of an index I_e

$$I_e = I_u x\, I_f$$

Number of people expected to be present in the structure

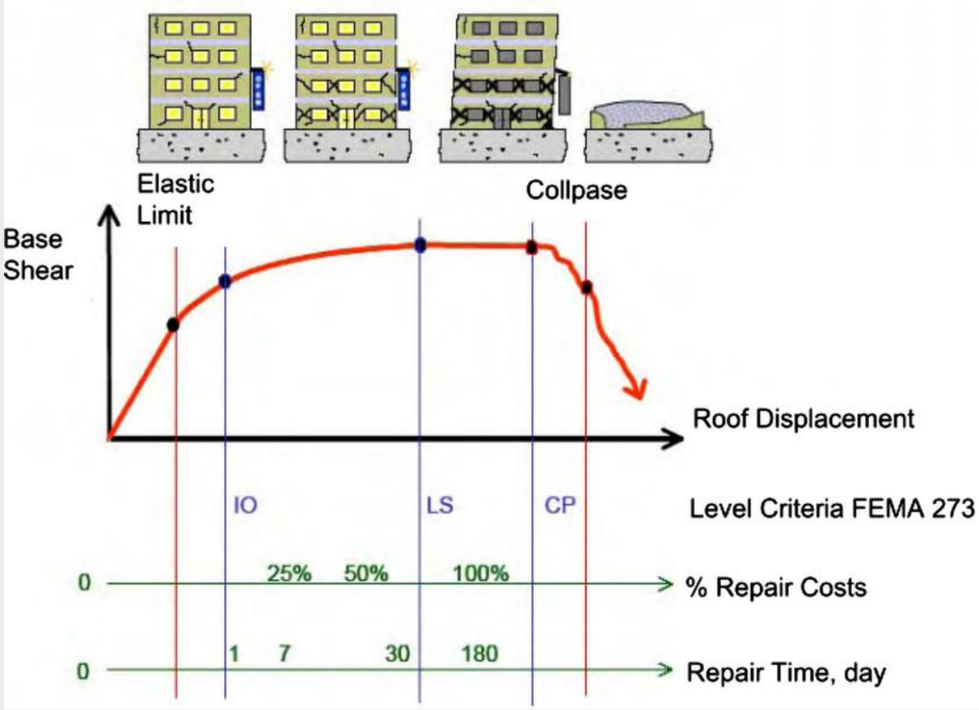
Accounts for reaction capacity of people

Activity expected within the building

Accounts for the actual period of use of structure with a given people density

Limit states to be considered within the approach of performance-based engineering

OPERATIONAL (OP) | **IMMEDIATE USE (IU)** | **LIFE SAFETY (LS)** | **NEAR COLLAPSE (NC)**



Seismic performance limit states in *fib* MC2010, with associated seismic hazard levels for ordinary facilities and member compliance criteria

Performance limit state	Facility operation	Structural condition	Deformation limit in *fib* MC2010	Seismic action per *fib* MC2010
Operational (OP)	Continued use; any non-structural damage is repaired later	No structural damage	Mean value of yield deformation	Frequent: ~70 % probability of being exceeded in service life
Immediate use (IU)	Safe; temporary interruption of normal use	Light structural damage (localized bar yielding, concrete cracking/spalling)	Mean value of yield deformation may be exceeded by a factor of 2.0	Occasional: ~40 % probability of being exceeded in service life
Life safety (LS)	Only emergency or temporary use; unsafe for normal use; no threat to life during earthquake; repair feasible but possibly uneconomic	Significant structural damage, no imminent collapse; capacity for quasi-permanent loads and sufficient seismic strength/stiffness for life protection until repair	Safety factor γ^*_R of 1.35 against lower 5 % fractile of plastic rotation capacity	Rare: 10 % probability of being exceeded in service life
Near collapse (NC)	Unsafe for emergency use; life safety during earthquake mostly ensured but not fully guaranteed (hazard from falling debris)	Heavy structural damage, on the verge of collapse; strength barely sufficient for quasi-permanent loads, but not for aftershocks	Lower 5 % fractile of plastic rotation capacity may be reached ($\gamma^*_R = 1$)	Very rare: 2–5 % probability of being exceeded in service life

(Fardis, 2013)

Format for verification

M.C. 2010 mainly conceived for framed structures

↓

Chord rotation is the governing parameter (ϑ_{pl}) including the contribution of **slippage** (ϑ_{slip})

OP	**IU**	**LS**	**NC**
↓	↓	↓	↓
ϑ_y	$2\vartheta_y$	$\vartheta_{pl,Ed}$	$\vartheta_{pl,u,k}$
		↓	
		$\vartheta_{pl,u,k}$ **/1,35**	

with $\vartheta_{pl,u,k} = \vartheta_{u,m} / \gamma_{Rd}$

The mean value of plastic contribution of ultimate chord rotation may be derived by a physical model, which assumes that the plastic part of curvature is uniform within the lenght of plastic hinge (L_{pl})

$$\vartheta_{u,m}^{pl} = (\varphi_u - \varphi_y) L_{pl} \left(1 - \frac{L_{pl}}{2L_s} \right) + \Delta \vartheta_{slip,u-y}$$

Where:

φ_u and φ_y are the ultimate and yield curvature

L_s is the shear span

Confinement effect should be considered for the evaluation of φ_u

↓

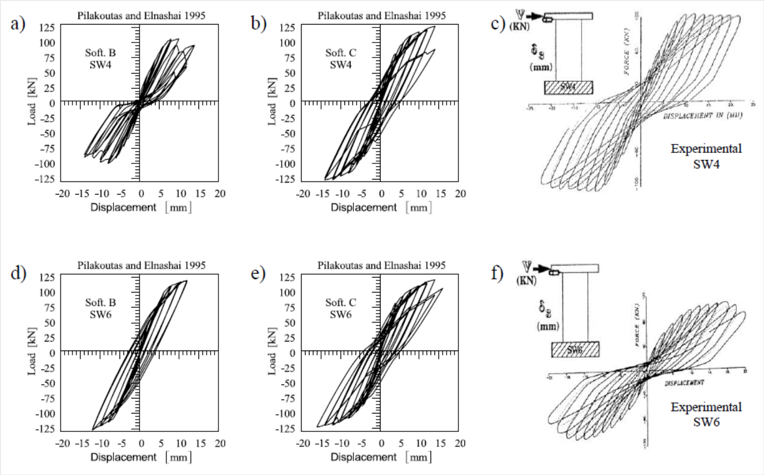
In **existing structures** generally this contribution is **negligeable**

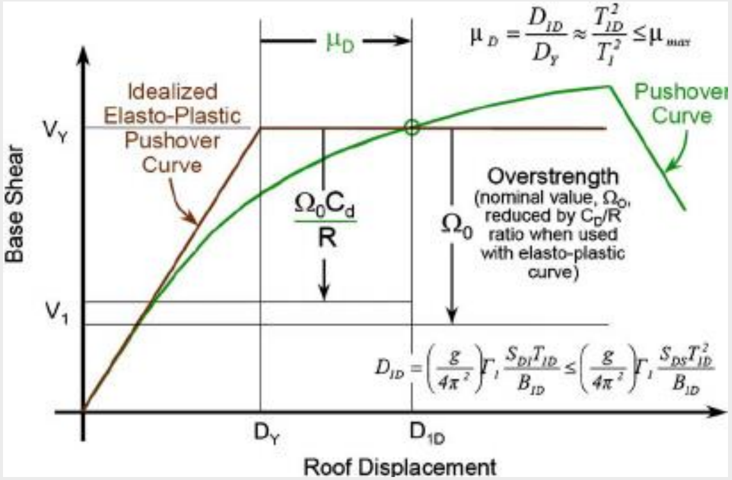
Remarks on γ^*_R=1.35

This value should be probabilistically calibrated considering the ***related model uncertainties****.*

$$\vartheta_{pl,u,d} = \frac{\vartheta_{pl,u,\mathrm{m}}}{\gamma_R \cdot \gamma_{Rd}}$$

Non-linear analysis

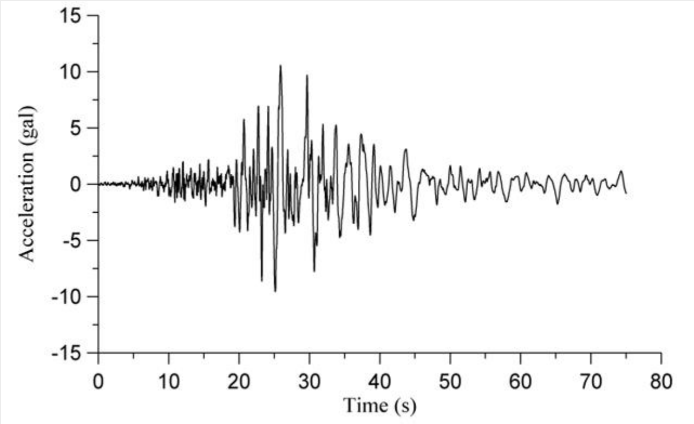


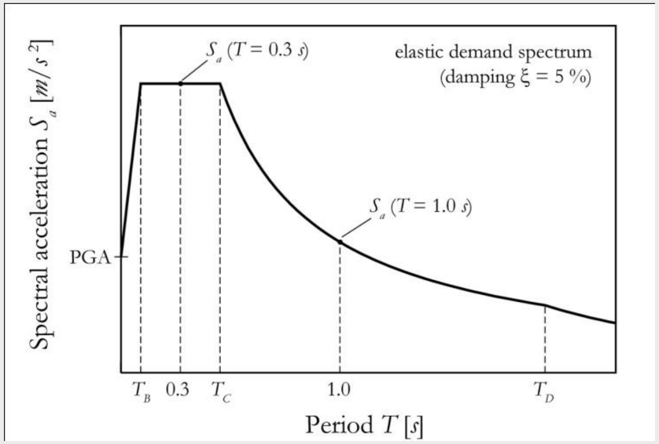


Safety format should be consistent with the recent issues and the remaining part of the code

Apply the **Global Safety Format (GSF)**

GSF can be applied in the field of **accelerations**!

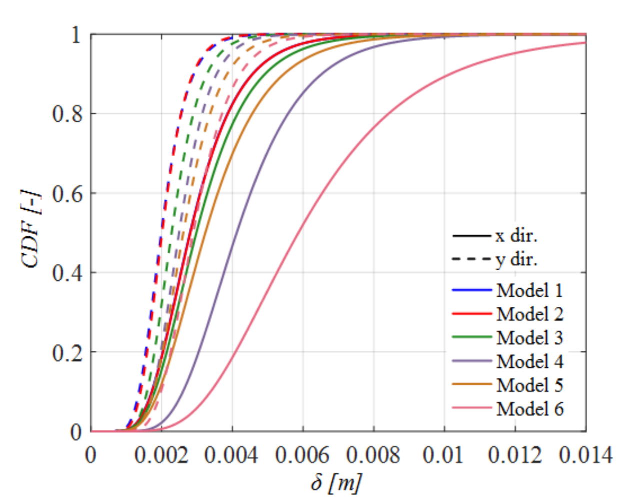


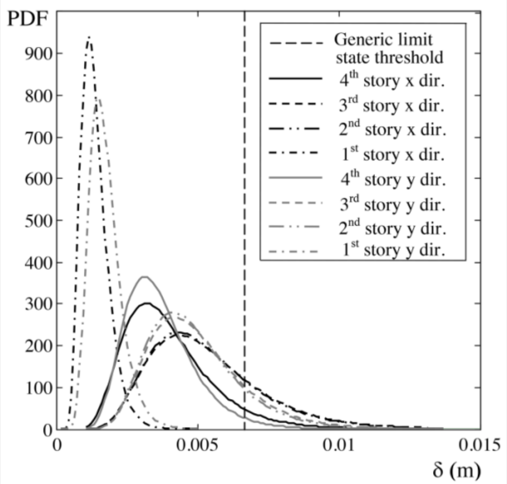


Perform the analysis with the mean values of mechanical parameters and then evaluate the **structural design deformation** as:

$$\vartheta_{pl,u,d} = \frac{\vartheta_{pl,u,\mathrm{m}}}{\gamma_R \cdot \gamma_{Rd}}$$

Being the materials described with lognormal PDFs, also the **structure response** is essentialy **lognormal**





Use a reduced Monte Carlo simulation to evaluate mean and COV of structural response

Derive <u>**analytically γ_R**</u>

- γ_{Rd} should cover the uncertainties due to use of non linear FEM

- Another γ_{Rd} should be considered in the evaluation of empirical formulas transferring the mean value of tests to the design ones (see positon paper)

For instance, for the empirical formulas proposed in MC 2010

$$\theta_{u,m}^{pl} = \alpha_{st}^{pl}(1-0{,}4a_{w,r})\left(1-\frac{a_{w,nr}}{4}\right)(0{,}25)^{\nu}\left(\frac{\max(0{,}01;\omega_2)}{\max(0{,}01;\omega_1)}\right)^{0,3} f_c^{\,0,2}\left(\frac{L_s}{h}\right)^{0,35} 25^{\left(\frac{\alpha\rho_w f_{yw}}{f_c}\right)} 1{,}275^{100\rho_d}$$

$$\theta_{u,m}^{pl} = \alpha_{st}^{hbw}\left(1-0{,}05\max\left(1{,}5;\min\left(10;\frac{h}{b_w}\right)\right)\right)(0{,}2)^{\nu}\left(\frac{\max(0{,}01;\omega_2)}{\max(0{,}01;\omega_1)}\frac{L_s}{h}\right)^{\frac{1}{3}} f_c^{\,0,2}\, 25^{\left(\frac{\alpha\rho_w f_{yw}}{f_c}\right)} 1{,}225^{100\rho_d}$$

A γ_{Rd} (γ_{Global}) value of **1.75** is proposed

There is the need to **split the** $\boldsymbol{\gamma_{Global}}$ **in** $\boldsymbol{\gamma_R}$ **and** $\boldsymbol{\gamma_{Rd}}$ to calibrate the best fitting of experimental tests in agreement with the position paper to be used all along the MC 2020

Starting from experimental tests, an empirical or semiempirical **Resisting Model** can be defined as:

Mean of the empirical coefficient defined after statistical calibration (best fitting)

Term including the deterministic part of the model (geometry,…)

$$R_m = C \cdot f(x_{1,m}, x_{2,m}, \dots, x_{n,m}) \cdot A$$

Mean of the experimental resistance

Function of considered variables with mean or nominal values

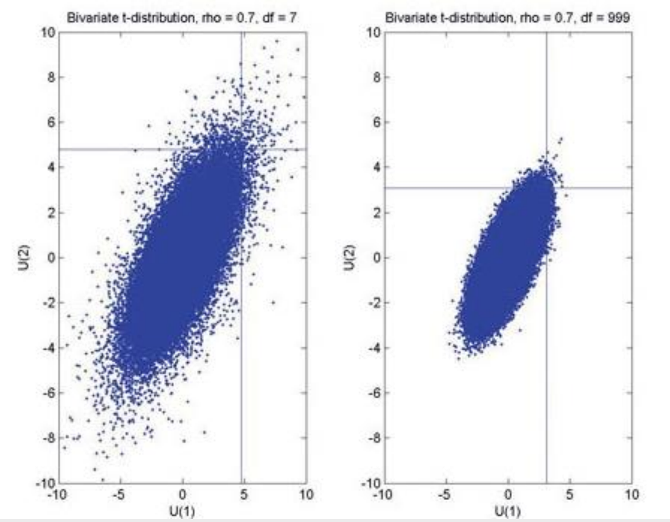
Probabilistic model

Definition of a set of random variables enriched by model uncertaintes ϑ calibrated on experimental results

$$x_1, x_2, \dots, x_n, \vartheta$$

$$R(x_1, x_2, \dots, x_n, \vartheta) = \vartheta \cdot C \cdot f(x_1, x_2, \dots, x_n) \cdot A$$

Monte Carlo simulation to define a PDF



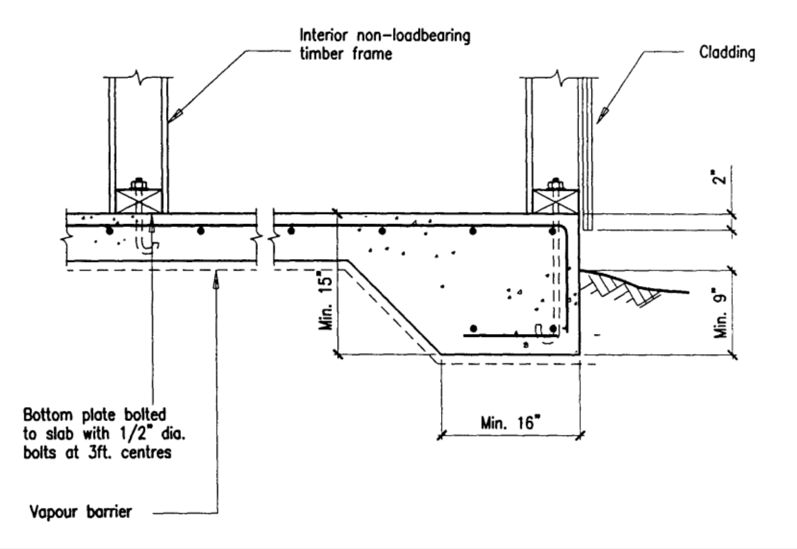
Evaluation of fractiles of resistance

$$R(x_1, x_2, \dots, x_n, \vartheta)$$

Assessment of existing structures

Structural knowledge

Geometry **Details** **Materials**



Knowledge levels

(EC8)

Limited *(KL1)*

Normal *(KL2)*

Full *(KL3)*

Confidence factors

1.35

1.20

1.00

To be applied to the material properties

Remarks

→ The definition of knowledge level is not objective and may produce discrepancies

→ The definition of KLi-th values is too empirical

→ It is not correct to mix the uncertainties of different nature (geometry/details/materials)

A more confident approach

Use a **Bayesian approach** to treat at the same level the different types od uncertaintes

(A) Random uncertainties → Frequentistic interpretation

(B) Epistemic uncertainties → Degree of believe interpretation

Random uncertainties

(Generally described by PDF and CDF)

Material properties

Seismic action

Model uncertainties in description of material properties and actions

Bayesian upgrading of old and new tests

Different probability of exceedance may be accepted

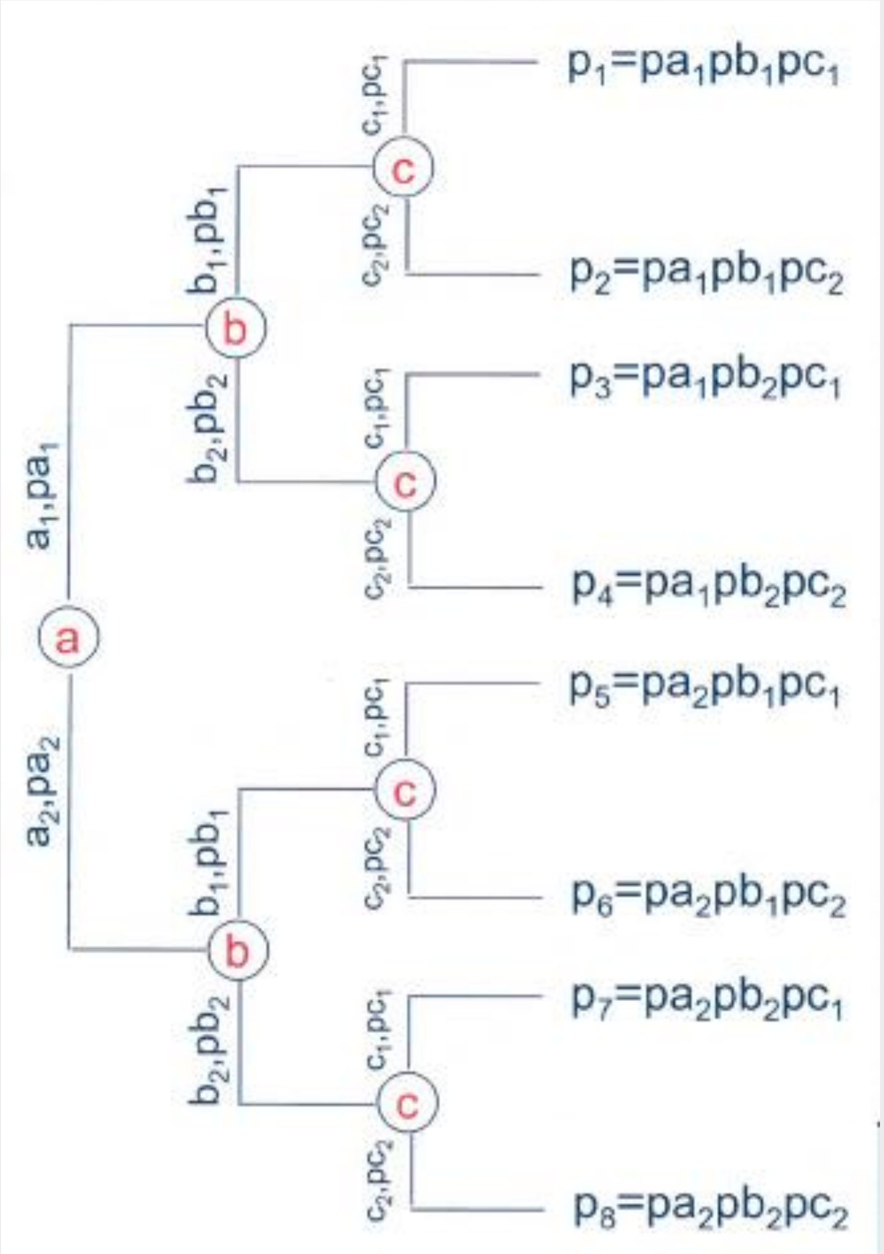
Partial or full improvement

Epistemic uncertainties

Lack of structural knowledge

Choice between alternative resisting models

Event tree approach



Variables a/b/c are supposed to be independent

Weighted mean of probability of different legs with probabilities p_i

Target reliability levels

↓

To be modified considering economical/social/sustainability aspects

↓

See *fib* bulletin 80

Partial factor methods for existing concrete structures

Applicability of procedures used for new structures design

In existing structures generally confinement is very poor

Maintaing the same procedure based on $\vartheta_{pl,u,d}$ as governing parameter

Mean value of yield deformation exceedance should be very limited (factor 5 to 10 respect to yield one), or alternatively with capacity design

$$q = 1.5 \div 2$$

Assessment procedure

→ Evaluation of hazard (seismic action)

→ Evaluation with a step by step procedure of maximum hazard level that can be reached

→ By comparison with the prescribed hazard: evaluation of probability of exceedance (≥ 10%)

Decision making for the upgrading, when necessary

Accept a limited upgrading with probability of exceedance higher than 10%

Full upgrading

Isolation

(q = 1)

Don't forget the **uncertainties related to the isolators**

Thank you for the kind attention