Structural Eurocodes

EN 1990 - Basis of Structural Design

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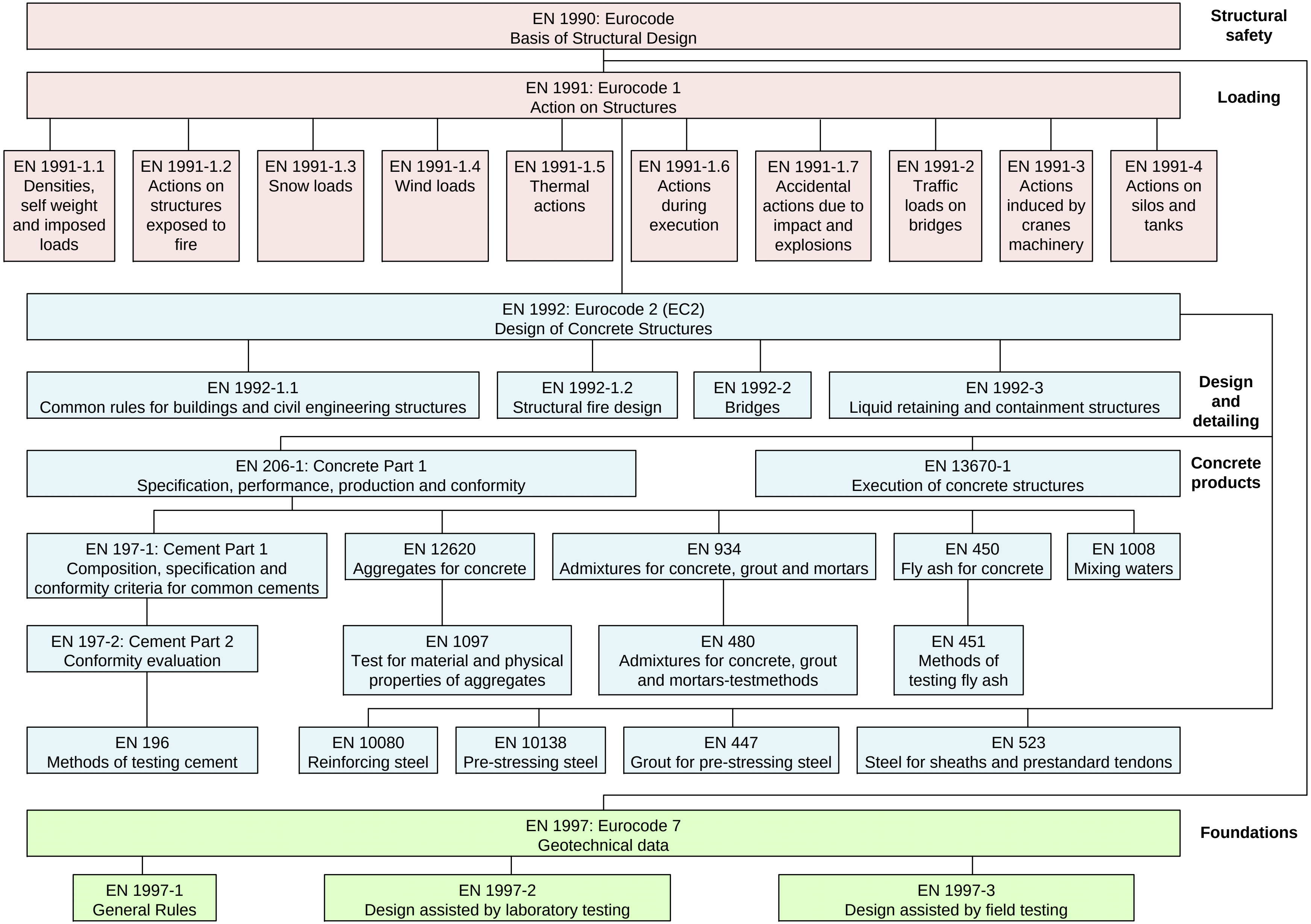
Structural Eurocodes



Structural safety

EN 1990: Eurocode
Basis of Structural Design

Loading

EN 1991: Eurocode 1
Action on Structures

EN 1991-1.1
Densities, self weight and imposed loads

EN 1991-1.2
Actions on structures exposed to fire

EN 1991-1.3
Snow loads

EN 1991-1.4
Wind loads

EN 1991-1.5
Thermal actions

EN 1991-1.6
Actions during execution

EN 1991-1.7
Accidental actions due to impact and explosions

EN 1991-2
Traffic loads on bridges

EN 1991-3
Actions induced by cranes machinery

EN 1991-4
Actions on silos and tanks

Design and detailing

EN 1992: Eurocode 2 (EC2)
Design of Concrete Structures

EN 1992-1.1
Common rules for buildings and civil engineering structures

EN 1992-1.2
Structural fire design

EN 1992-2
Bridges

EN 1992-3
Liquid retaining and containment structures

Concrete products

EN 206-1: Concrete Part 1
Specification, performance, production and conformity

EN 13670-1
Execution of concrete structures

EN 197-1: Cement Part 1
Composition, specification and conformity criteria for common cements

EN 12620
Aggregates for concrete

EN 934
Admixtures for concrete, grout and mortars

EN 450
Fly ash for concrete

EN 1008
Mixing waters

EN 197-2: Cement Part 2
Conformity evaluation

EN 1097
Test for material and physical properties of aggregates

EN 480
Admixtures for concrete, grout and mortars-testmethods

EN 451
Methods of testing fly ash

EN 196
Methods of testing cement

EN 10080
Reinforcing steel

EN 10138
Pre-stressing steel

EN 447
Grout for pre-stressing steel

EN 523
Steel for sheaths and prestandard tendons

Foundations

EN 1997: Eurocode 7
Geotechnical data

EN 1997-1
General Rules

EN 1997-2
Design assisted by laboratory testing

EN 1997-3
Design assisted by field testing

Eurocode 1: Actions on Structures

EN 1991-1-1	General actions – Desities, self-weight, imposed loads for buildings : 2002 + Correction AC:2009
EN 1991-1-2	General actions – Actions due to fire : 2003
EN 1991-1-3	General actions – Snow loads : 2003 + AC:2009
EN 1991-1-4	General actions – Wind actions : 2005(E) Amendment A1:2010 Correction AC:2010
EN 1991-1-5	General actions – Thermal actions : 2003 Correction AC:2009
EN 1991-1-6	General actions, Actions during execution : 2005 Correction AC:2008
EN 1991-1-7	General actions – Accidental actions : 2006 Correction AC:2010
EN 1991-2	Traffic loads on Bridges : 2004
EN 1991-3	Actions induced by cranes and machinery : 2006
EN 1991-4	General actions – Silos and tanks : 2006

Objectives of EN 1990

EN 1990 describes the Principles and requirements for safety, serviceability and durability of structures. It is based on the limit state concept used in conjunction with a partial factor method.

Overview

Risks in Civil Engineering

Measures of Reliability in a Probabilistic Concept

Reliability Verification in EN 1990

Partial Factor Concept in EN 1990

Limit States

- **Ultimate Limit State – ULS**
- **Serviceability Limit State - SLS**

Conclusions

Actions on Structures – EN 1991

Risks in Civil Engineering

Storm

Earthquake

Fire

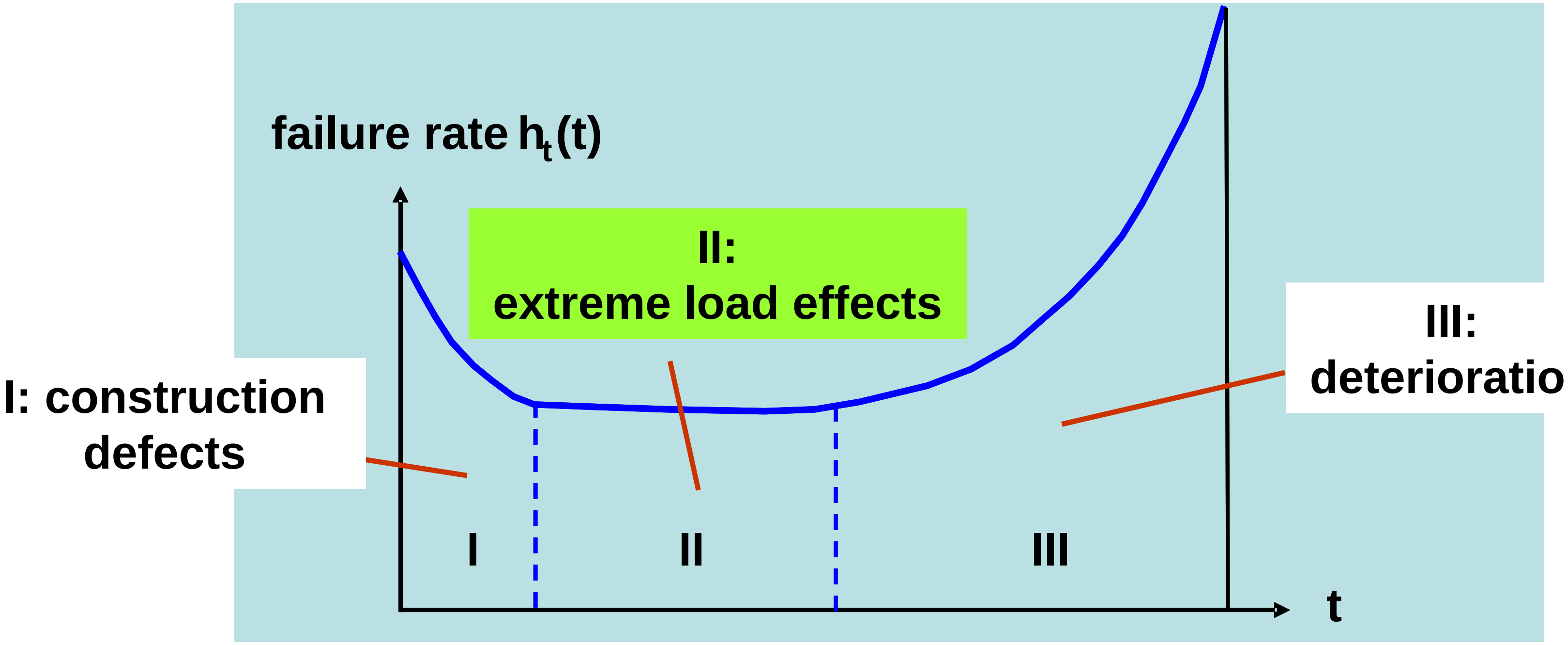
Water

Risks in Civil Engineering

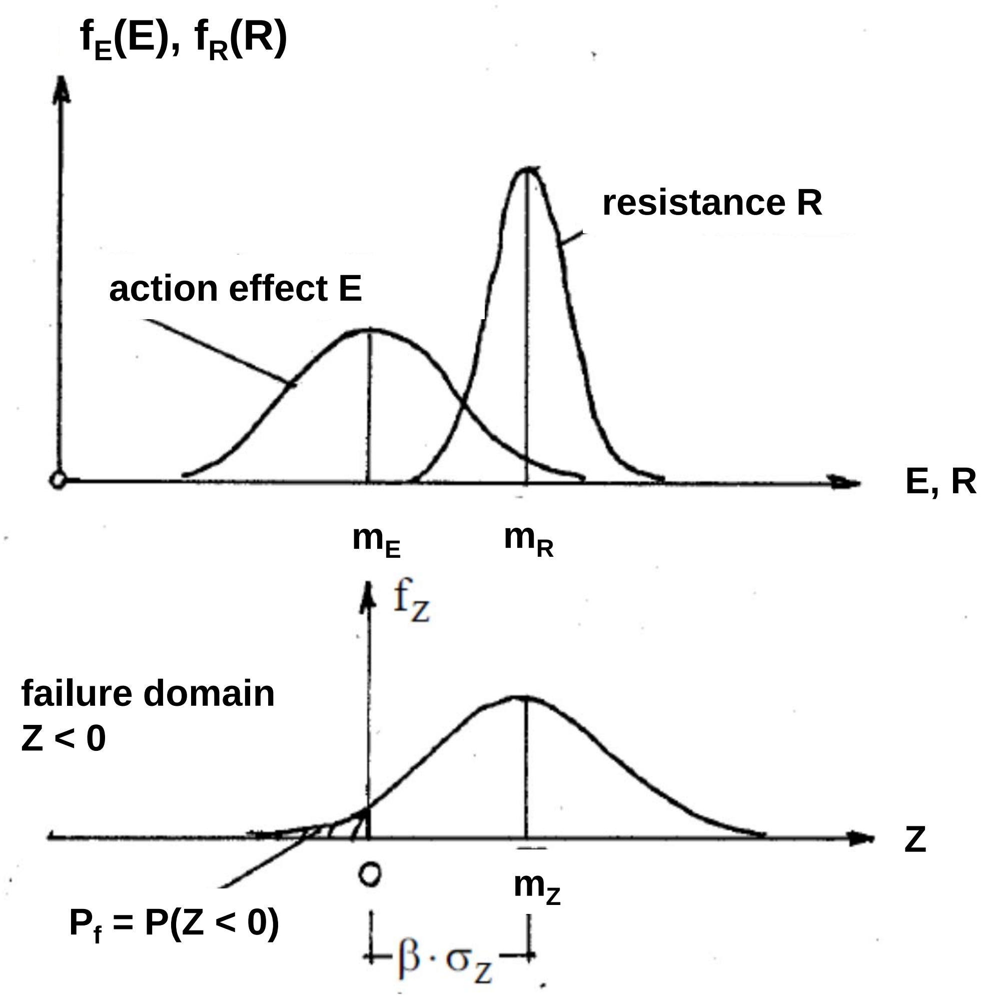
Failure Rate:

$$h_t(t) = \frac{P(T_L \le t + \Delta t \mid T_L > t)}{\Delta t}$$

T_L – design life, t - time



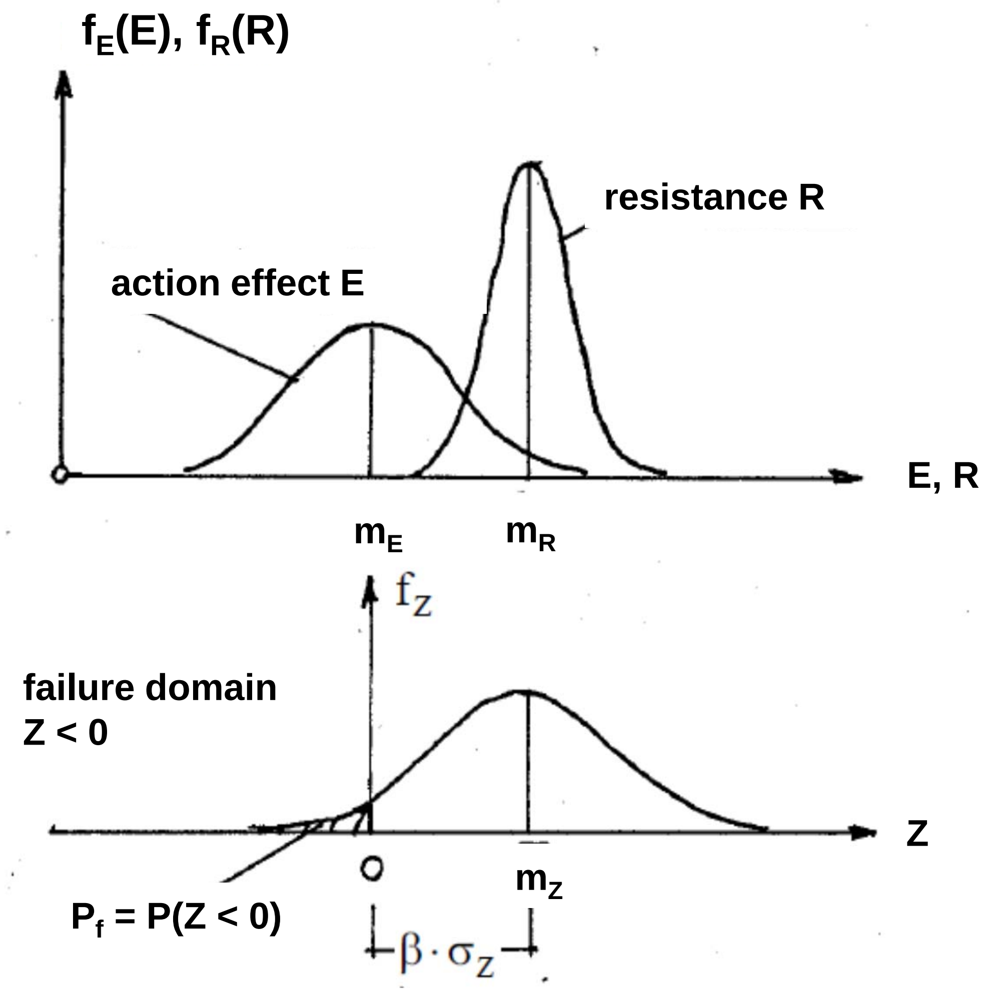
Measures of Reliability



safety zone: $Z = R - E$
with mean m_Z, stand. dev. σ_Z

survival: $Z > 0$; failure: $Z \leq 0$

Measures of Reliability

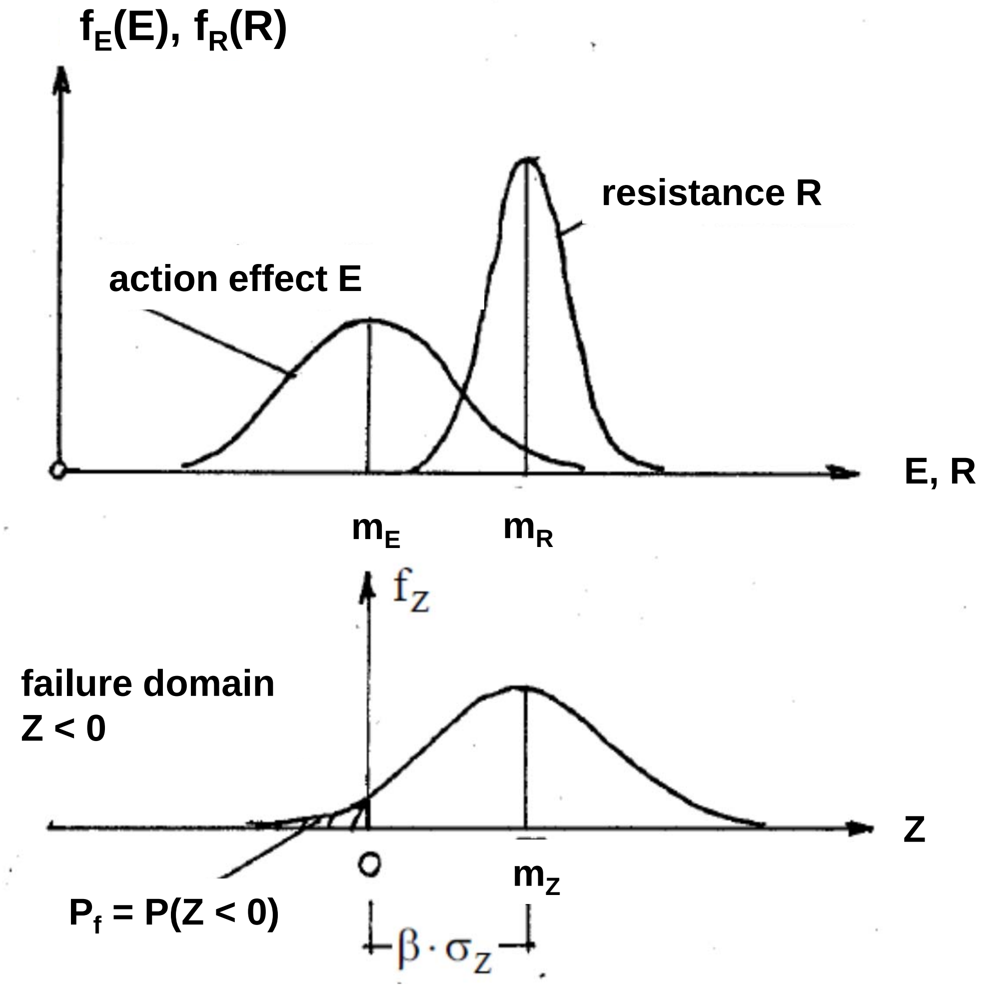


safety zone: $Z = R - E$
with mean m_Z, stand. dev. σ_Z

survival: $Z > 0$**; failure:** $Z \leq 0$

probability of failure P_f
$$P_f = P(Z \leq 0)$$

Measures of Reliability



safety zone: $Z = R - E$
with mean m_Z, stand. dev. σ_Z

survival: $Z > 0$; failure: $Z \leq 0$

probability of failure P_f

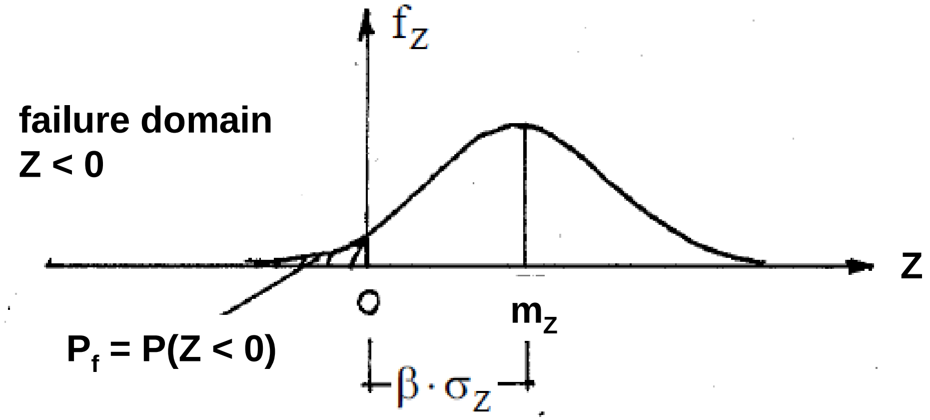
$$P_f = P(Z \leq 0)$$

reliability index β

$$m_Z = \beta \cdot \sigma_Z$$

A reliability index of $\beta = 0$ corresponds to a failure probability of $P_f = 0.5$!

Measures of Reliability



The reliability index β is applied in EN 1990 for reliability verifications. It is related to the probability of failure, P_f, by

$$P_f = \Phi(-\beta)$$

where Φ is the cumulative probability function of the Gaussian distribution

Table C1 - Relation between β and P_f

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	1,28	2,32	3,09	3,72	4,27	4,75	5,20

Reliability Verification in EN 1990

Design values of Action Effect, E_d and Resistance, R_d

Given are: target reliability index β

mean resistance m_R
standard deviation σ_R

mean action effect m_E
standard deviation σ_E

design requirement:

$$m_Z = \beta \cdot \sigma_Z$$

Replacing Z by E and R:

$$m_R - m_E = \beta(\alpha_R \cdot \sigma_R - \alpha_E \cdot \sigma_E)$$

where α are linear weight factors with ranges:

$$-1 \leq \alpha_E < 0$$

$$0 \leq \alpha_R \leq 1$$

Design verification using design values E_d and R_d:

$$m_R - \beta\alpha_R \cdot \sigma_R = m_E - \beta\alpha_E \cdot \sigma_E$$

$$R_d = m_R - \beta\alpha_R \cdot \sigma_R \geq E_d = m_E - \beta\alpha_E \cdot \sigma_E$$

Reliability Verification in EN 1990

Target values of Reliability

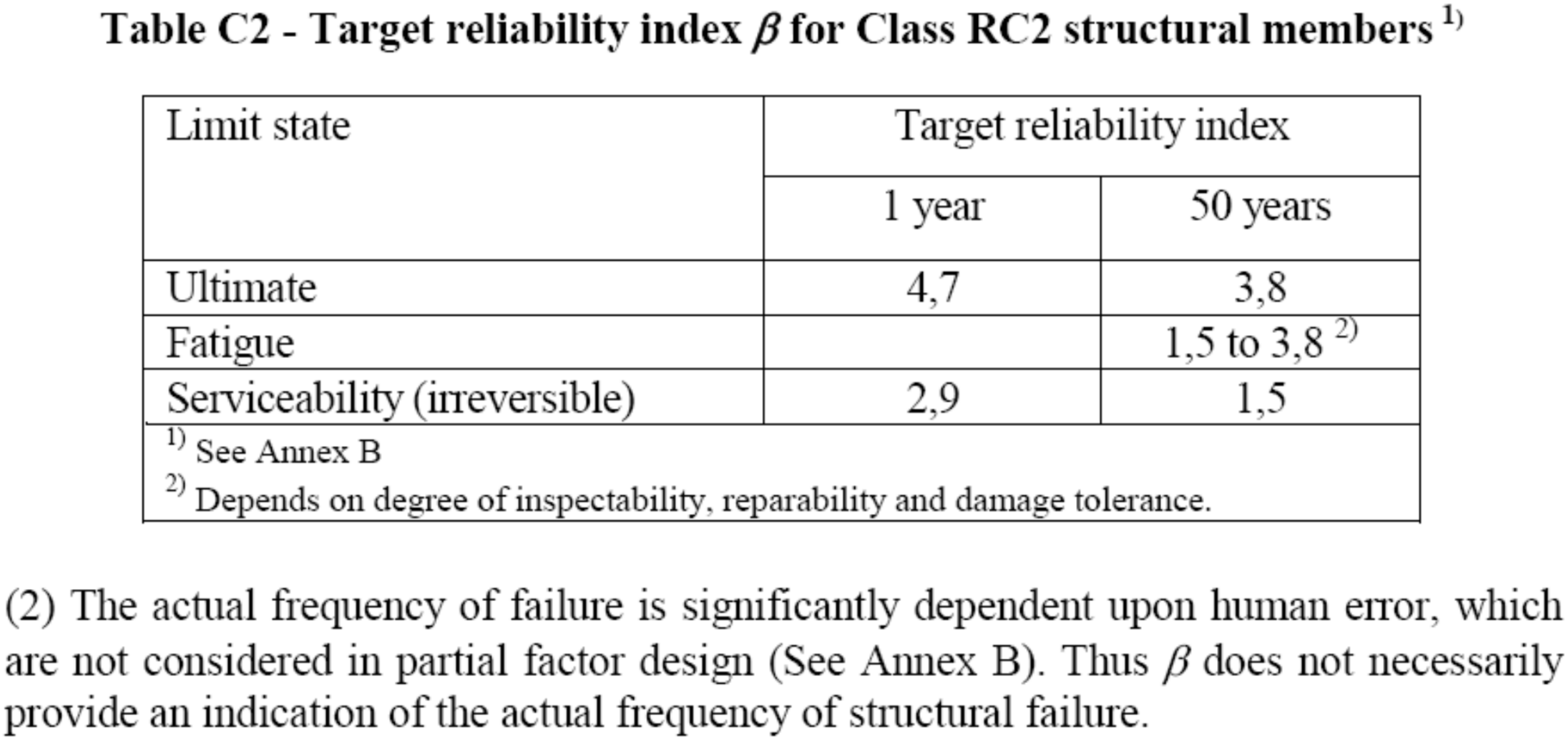


Table C2 - Target reliability index β for Class RC2 structural members [1)]

Limit state	Target reliability index	
	1 year	50 years
Ultimate	4,7	3,8
Fatigue		1,5 to 3,8 [2)]
Serviceability (irreversible)	2,9	1,5

[1)] See Annex B

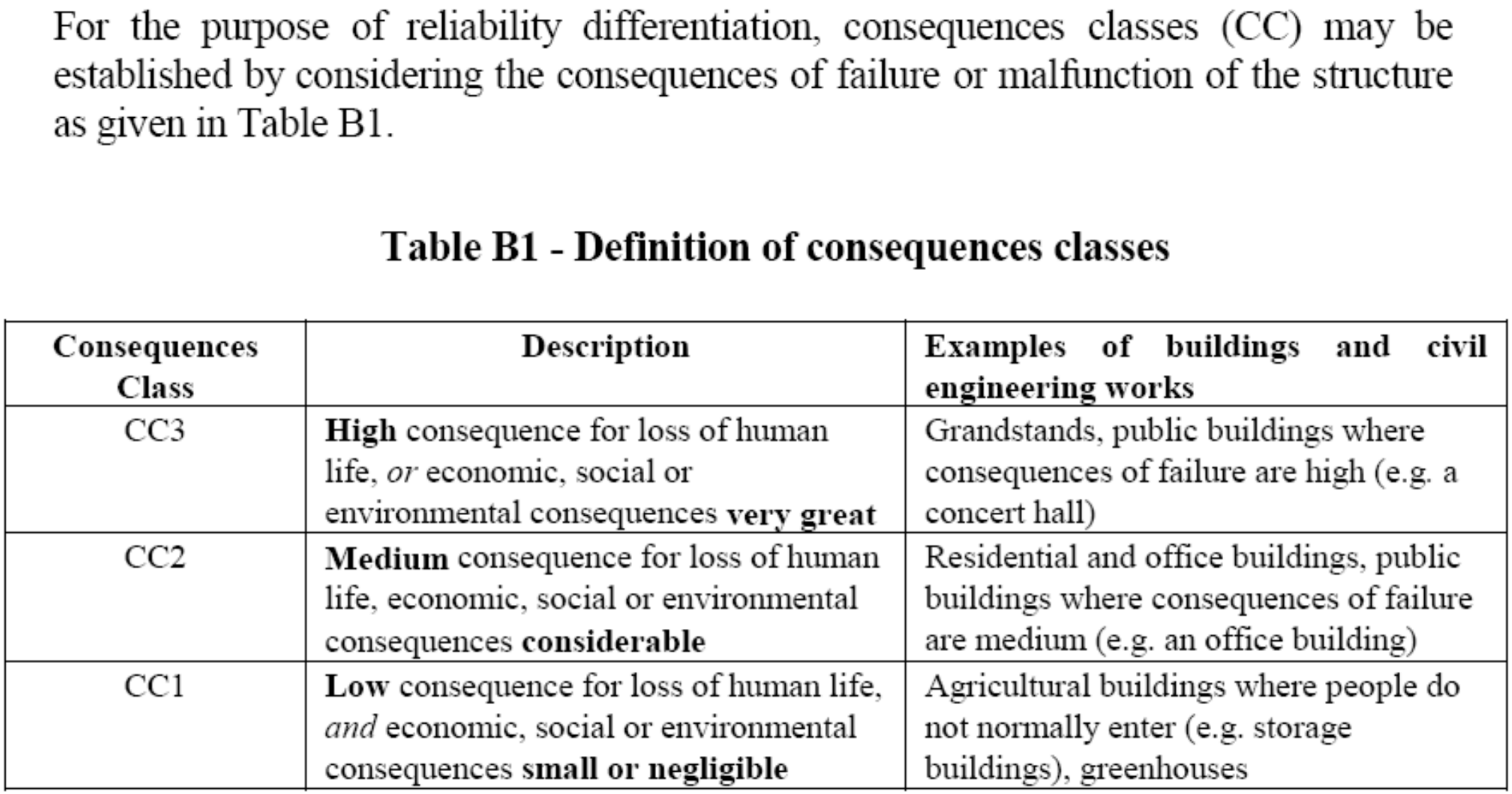
[2)] Depends on degree of inspectability, reparability and damage tolerance.

(2) The actual frequency of failure is significantly dependent upon human error, which are not considered in partial factor design (See Annex B). Thus β does not necessarily provide an indication of the actual frequency of structural failure.

The target values of reliability are operational, indicative numbers

Reliability Verification in EN 1990

Reliability Differentiation in EN 1990



For the purpose of reliability differentiation, consequences classes (CC) may be established by considering the consequences of failure or malfunction of the structure as given in Table B1.

Table B1 - Definition of consequences classes

Consequences Class	**Description**	**Examples of buildings and civil engineering works**
CC3	**High** consequence for loss of human life, *or* economic, social or environmental consequences **very great**	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)
CC2	**Medium** consequence for loss of human life, economic, social or environmental consequences **considerable**	Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)
CC1	**Low** consequence for loss of human life, *and* economic, social or environmental consequences **small or negligible**	Agricultural buildings where people do not normally enter (e.g. storage buildings), greenhouses

Reliability Verification in EN 1990

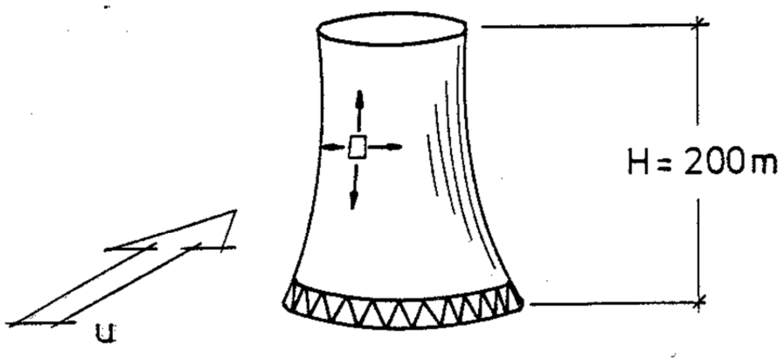
(2) Three reliability classes RC1, RC2 and RC3 may be associated with the three consequences classes CC1, CC2 and CC3.

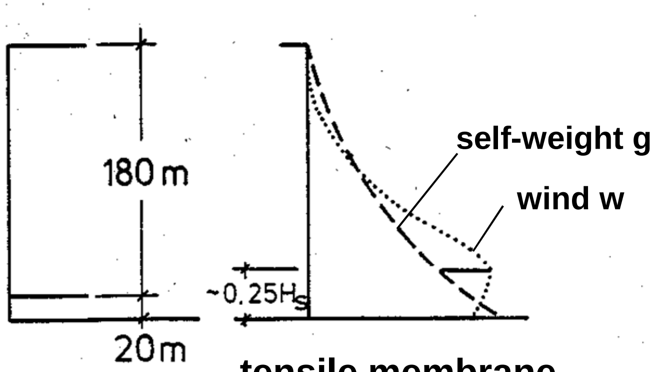
Table B2 - Recommended minimum values for reliability index β (ultimate limit states)

Reliability Class	**Minimum values for β**	
	1 year reference period	**50 years reference period**
RC3	5,2	4,3
RC2	4,7	3,8
RC1	4,2	3,3

NOTE A design using EN 1990 with the partial factors given in annex A1 and EN 1991 to EN 1999 is considered generally to lead to a structure with a β value greater than 3,8 for a 50 year reference period. Reliability classes for members of the structure above RC3 are not further considered in this Annex, since these structures each require individual consideration.

Partial Factor Concept in EN 1990





tensile membrane force n at the windward meridian

Actions: self weight g, wind load w

Resistance: yield strength of the reinforcement $A_s \cdot \beta_s$

Global safety factor γ_{tot} applied to design the shell for tensile strength:

$$\gamma_{tot} \cdot (n_w - n_g) \leq A_s \cdot \beta_s$$

Self-weight is compressive, it diminishes the tensile wind force:
The shell cannot carry $\gamma_{tot} \cdot w$ when designed with a global factor.

Such a goal would be achieved by the following design equation:

$$\gamma_{tot} \cdot n_w - n_g \leq A_s \cdot \beta_s$$

5.11.1965

In a strong gale, three Cooling Towers at the Ferrybridge Power Station, UK, collapse due to tensile failure of the reinforcement at the windward side

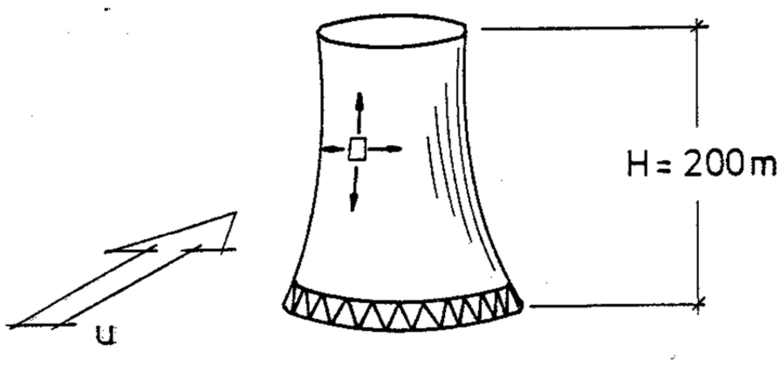
Principal failure causes

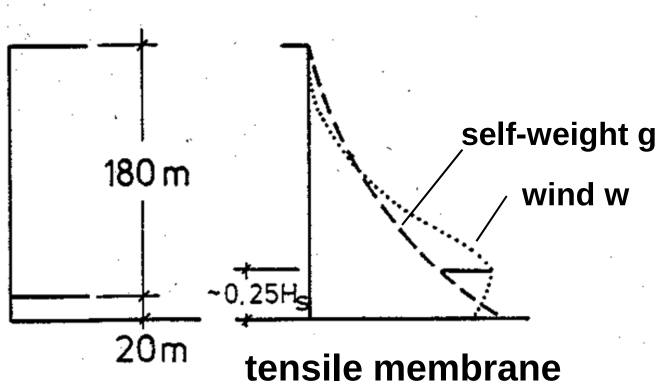
(1) Small shell bending stiffness due to *Single layer reinforcement*, low natural frequencies, increase of resonant response to turbulence;

2) *Load amplification due to flow Interference;*

(3) Unified safety factor instead of partial concept

Partial Factor Concept in EN 1990





tensile membrane force n at the windward meridian

Concept of partial safety factors

$$\gamma_W \cdot n_w - \gamma_G \cdot n_g \leq A_s \cdot \beta_s / \gamma_M$$

VGB-BTR 2005: $1{,}6 \cdot n_w - 1{,}0 \cdot n_g \leq A_s \cdot \beta_s / 1{,}15$

The shell is now designed to carry 1,6-times the nominal wind load against 1/1,15 times the nominal tensile strength.

Partial Factor Concept in EN 1990

EN 1990 does not apply directly the ***design values*** but utilises the ***partial factor design*** consisting of the following steps:

(1) **Characteristic values** of the basic variables actions F_k, and of the material properties X_k are introduced.

Characteristic values are typically:

- for variable actions Q:	Q_k is the 0,98-quantile of the yearly extremes;
- for permanent actions G:	G_k is the mean value;
- for accidental actions A:	A_d is a nominal value used as design value;
- for strength of materials X:	X_k is the 5%-quantile.

(2) **Design values of actions F** are specified by using partial load factors γ_F:

$F_d = \gamma_F F_k$ for a leading action, or

$F_d = \gamma_F \cdot \psi \cdot F_k$ for an accompanying action;

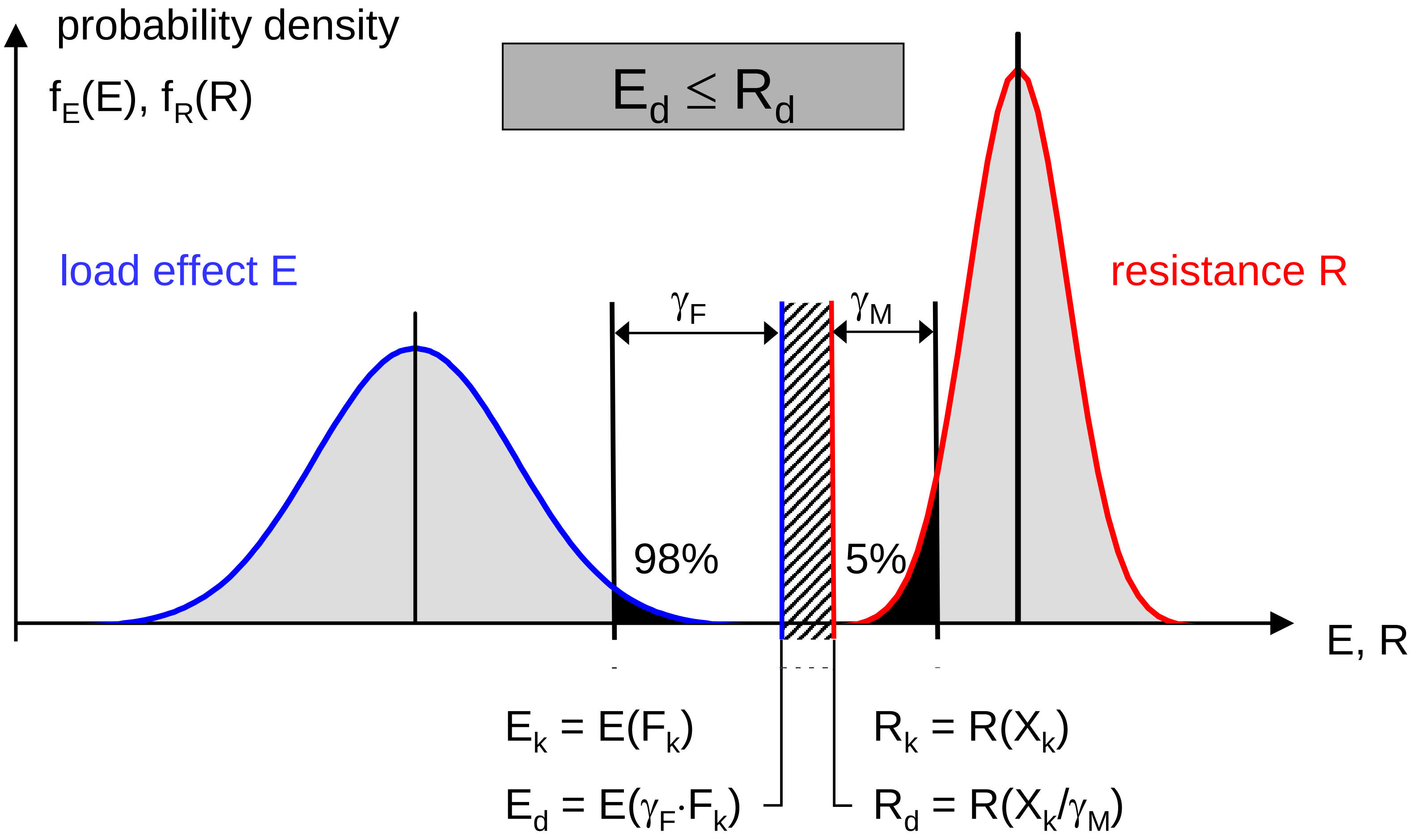
Design values of material properties X are specified by partial material factors γ_m : $X_d = X_k / \gamma_m$

(3) The **design values of action effect and resistance** are calculated as

$$E_d = E\{\gamma_F \cdot F_k;\ \gamma_F \cdot \psi \cdot F_k\} \ \leq \ R_d = R\{X_k/\gamma_m\}$$

Partial Factor Concept in EN 1990

Summary of Verification Procedure



$E_k = E(F_k)$

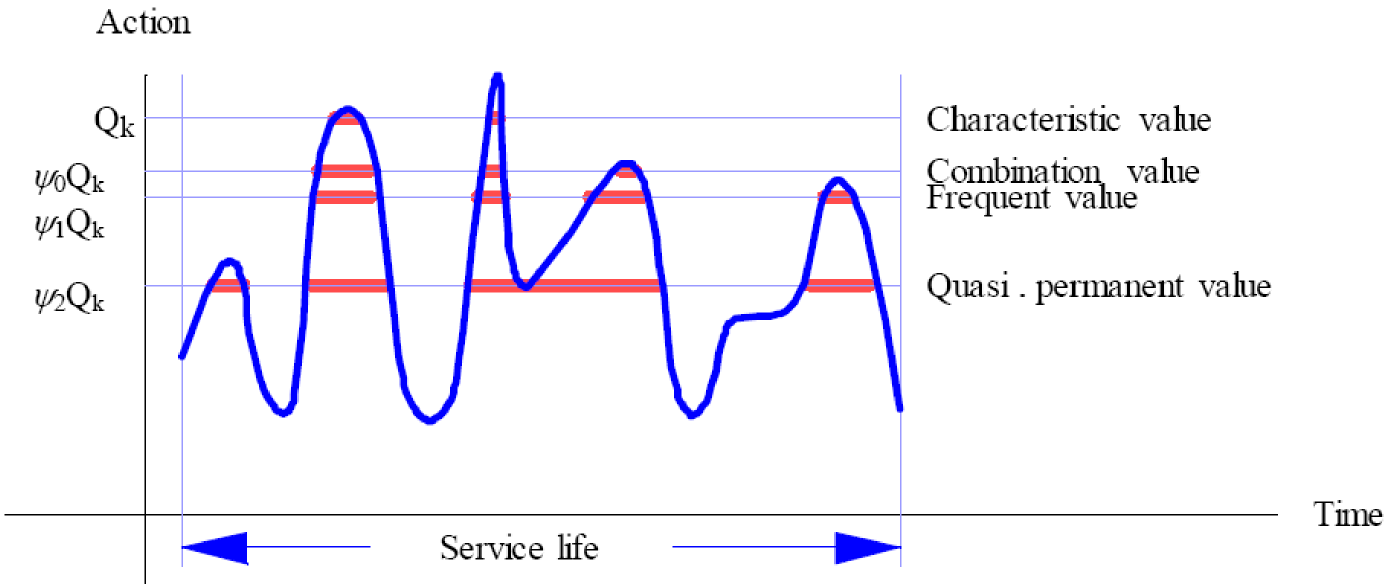
$E_d = E(\gamma_F \cdot F_k)$

$R_k = R(X_k)$

$R_d = R(X_k / \gamma_M)$

Partial Factor Concept in EN 1990

If **several variable actions** have to be considered, the combination of actions consists of the **leading action Q_{k1}** and the **accompanying actions $\psi \cdot Q_{kj}$,** where ψ is the factor for accompanying actions, $\psi \leq 1$

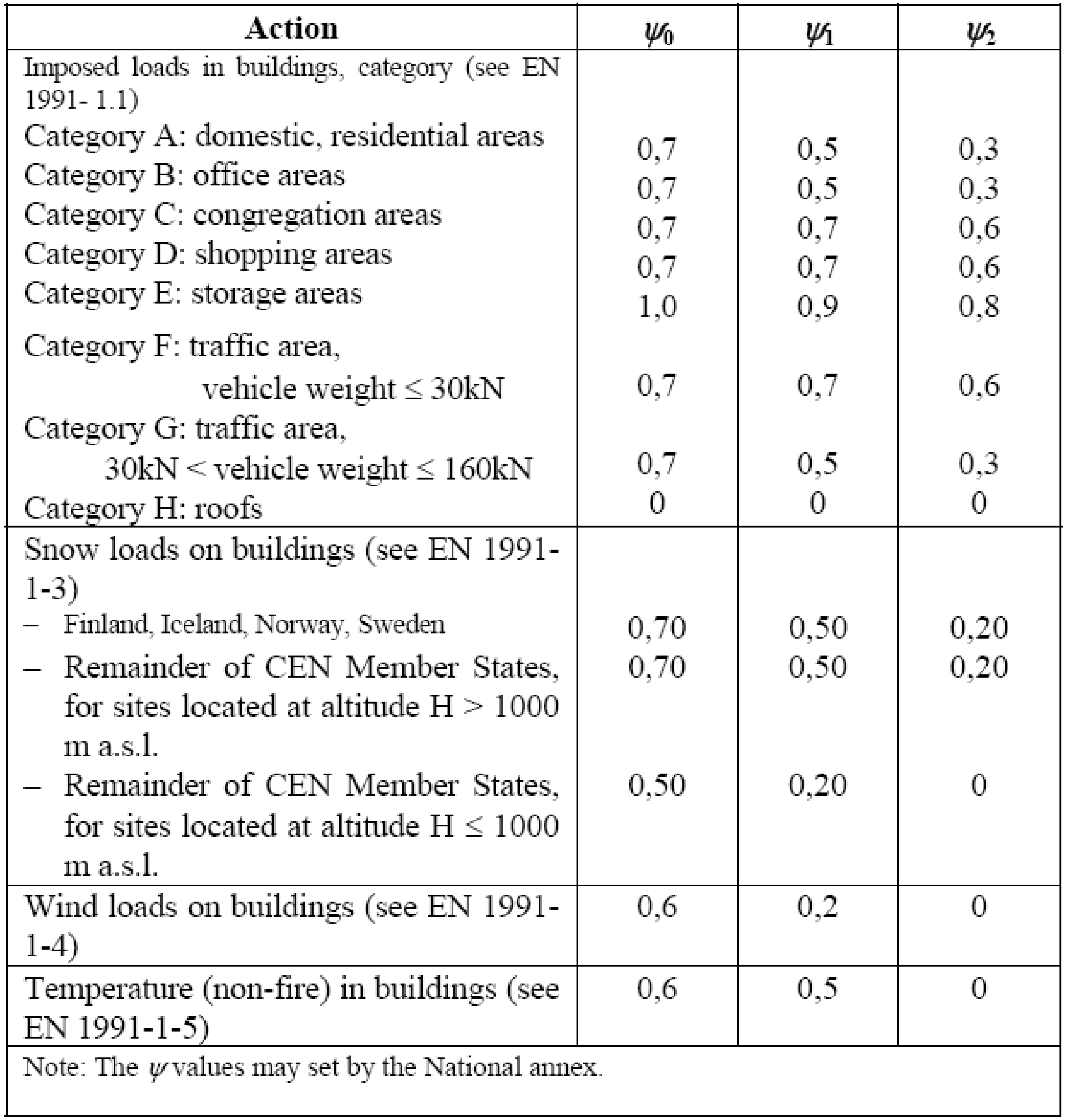


The factor ψ, covers the following situations:

- the combination value of a variable action	$\psi_0 \cdot Q_k$
- the frequent value of a variable action	$\psi_1 \cdot Q_k$
- the quasi-permanent value of a variable action	$\psi_2 \cdot Q_k$

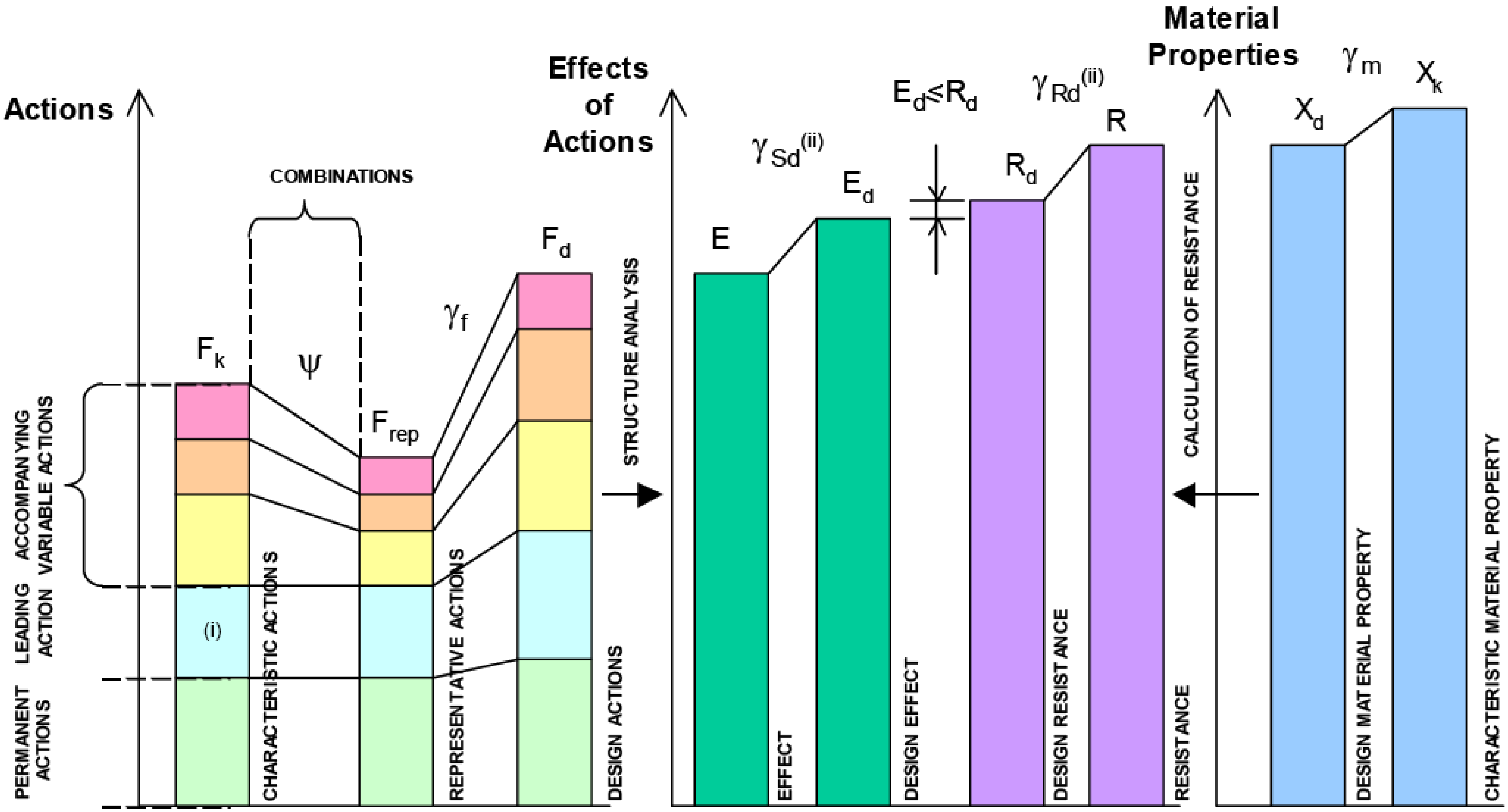
Partial Factor Concept in EN 1990

Variable loads and related ψ-factors



Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991- 1.1)			
Category A: domestic, residential areas	0,7	0,5	0,3
Category B: office areas	0,7	0,5	0,3
Category C: congregation areas	0,7	0,7	0,6
Category D: shopping areas	0,7	0,7	0,6
Category E: storage areas	1,0	0,9	0,8
Category F: traffic area, vehicle weight ≤ 30kN	0,7	0,7	0,6
Category G: traffic area, 30kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H: roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)			
– Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
– Remainder of CEN Member States, for sites located at altitude H > 1000 m a.s.l.	0,70	0,50	0,20
– Remainder of CEN Member States, for sites located at altitude H ≤ 1000 m a.s.l.	0,50	0,20	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0
Note: The ψ values may set by the National annex.			

Partial Factor Concept in EN 1990



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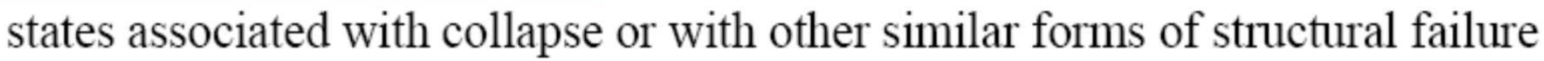
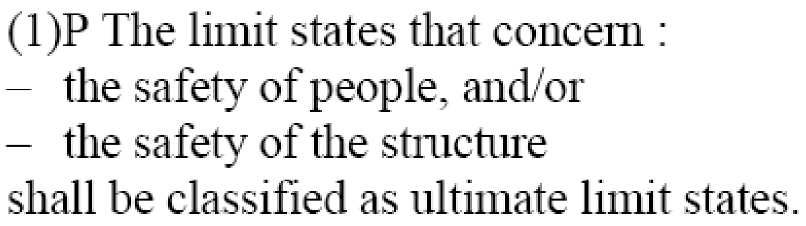
Limit States

Ultimate Limit State – ULS



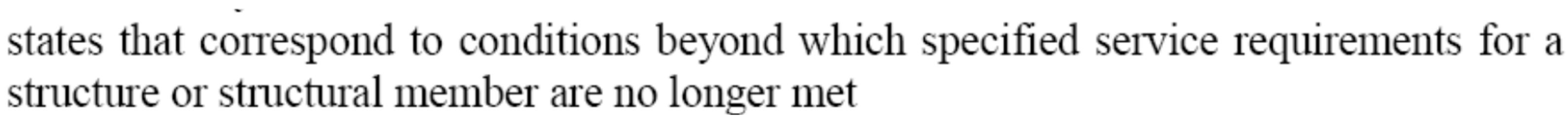
states associated with collapse or with other similar forms of structural failure



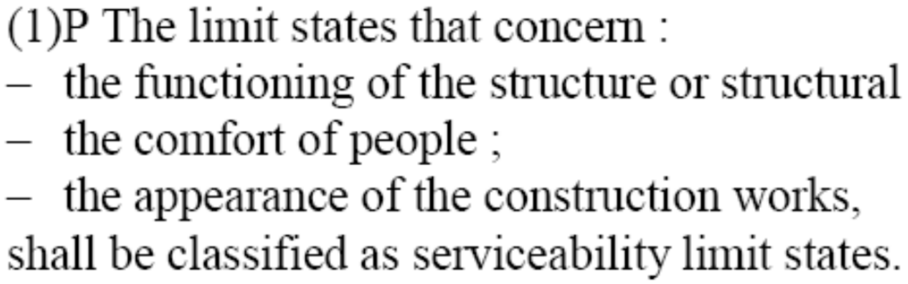
(1)P The limit states that concern :
- the safety of people, and/or
- the safety of the structure

shall be classified as ultimate limit states.

Serviceability Limit State – SLS



states that correspond to conditions beyond which specified service requirements for a structure or structural member are no longer met

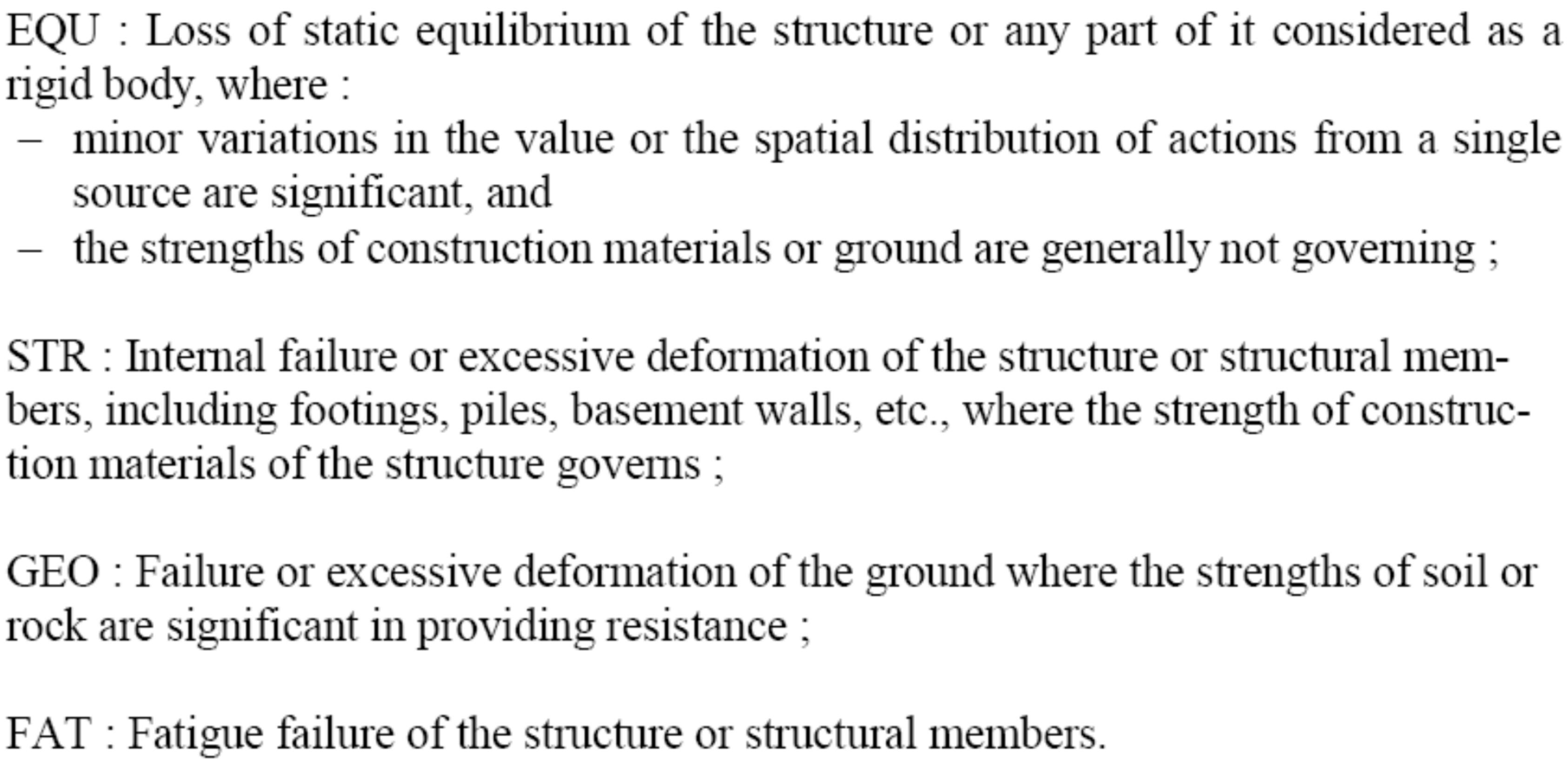


(1)P The limit states that concern :
- the functioning of the structure or structural members under normal use ;
- the comfort of people ;
- the appearance of the construction works,

shall be classified as serviceability limit states.

Limit States: Ultimate Limit States

ULS in EN 1990



EQU : Loss of static equilibrium of the structure or any part of it considered as a rigid body, where :

- minor variations in the value or the spatial distribution of actions from a single source are significant, and
- the strengths of construction materials or ground are generally not governing ;

STR : Internal failure or excessive deformation of the structure or structural members, including footings, piles, basement walls, etc., where the strength of construction materials of the structure governs ;

GEO : Failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance ;

FAT : Fatigue failure of the structure or structural members.

FAT load combinations are given in the design codes EN1992 – EN1996

Ultimate Limit States: Static Equilibrium

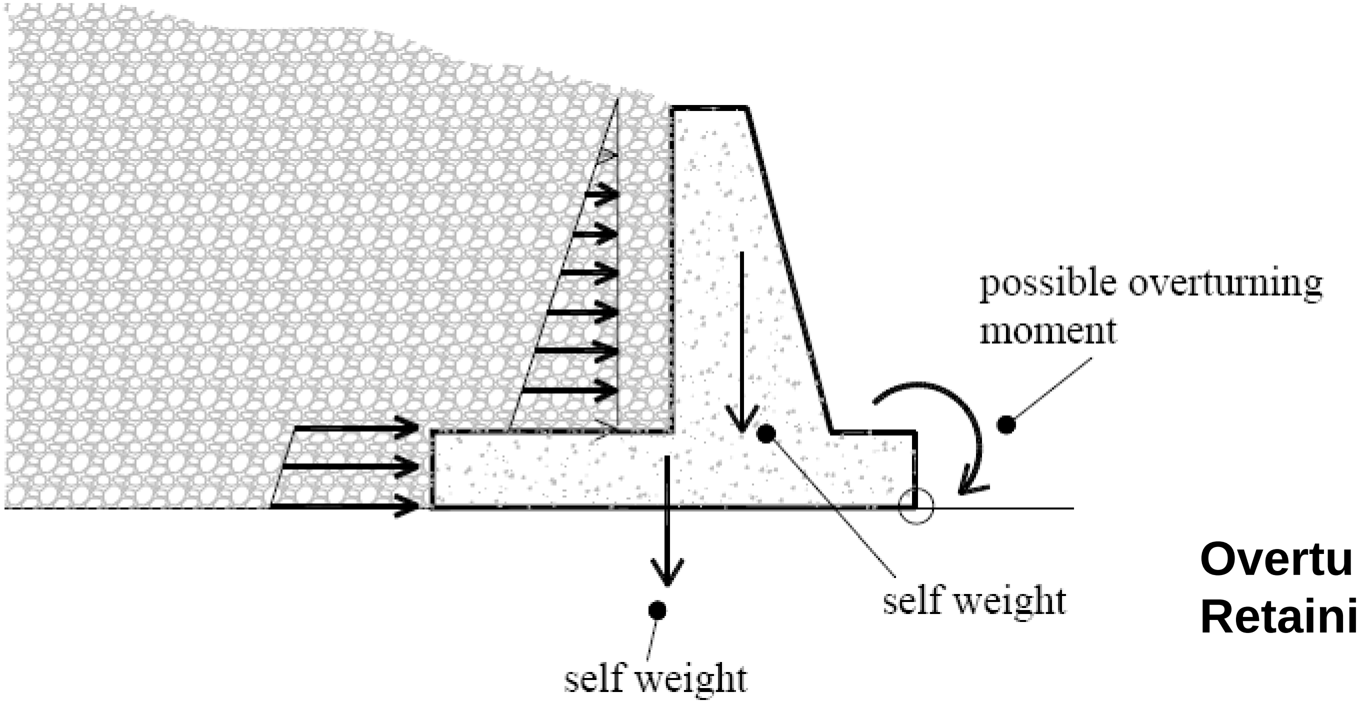
Verifications of static equilibrium

$$E_{d,dst} \leq E_{d,stb}$$

where :

$E_{d,dst}$ is the design value of the effect of destabilising actions ;

$E_{d,stb}$ is the design value of the effect of stabilising actions.

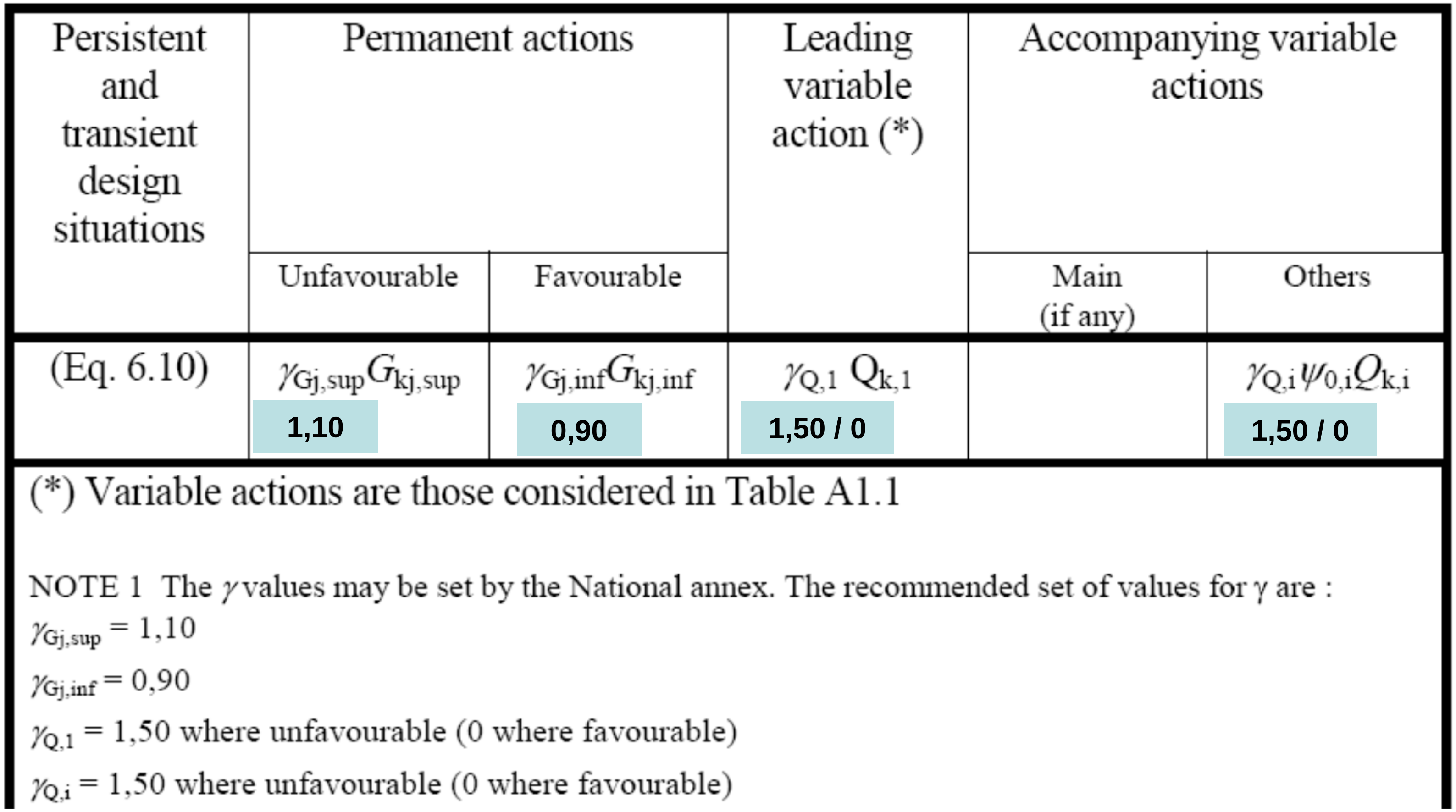


Overturning of a Retaining Wall

Static Equilibrium Limit States

$$E_{d,dst} \leq E_{d,stb}$$

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} "+" \gamma_P P "+" \gamma_{Q,1} Q_{k,1} "+" \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$



Persistent and transient design situations	Permanent actions		Leading variable action (*)	Accompanying variable actions	
	Unfavourable	Favourable		Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup}G_{kj,sup}$ **1,10**	$\gamma_{Gj,inf}G_{kj,inf}$ **0,90**	$\gamma_{Q,1}$ $Q_{k,1}$ **1,50 / 0**		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$ **1,50 / 0**

(*) Variable actions are those considered in Table A1.1

NOTE 1 The γ values may be set by the National annex. The recommended set of values for γ are :

$\gamma_{Gj,sup} = 1,10$

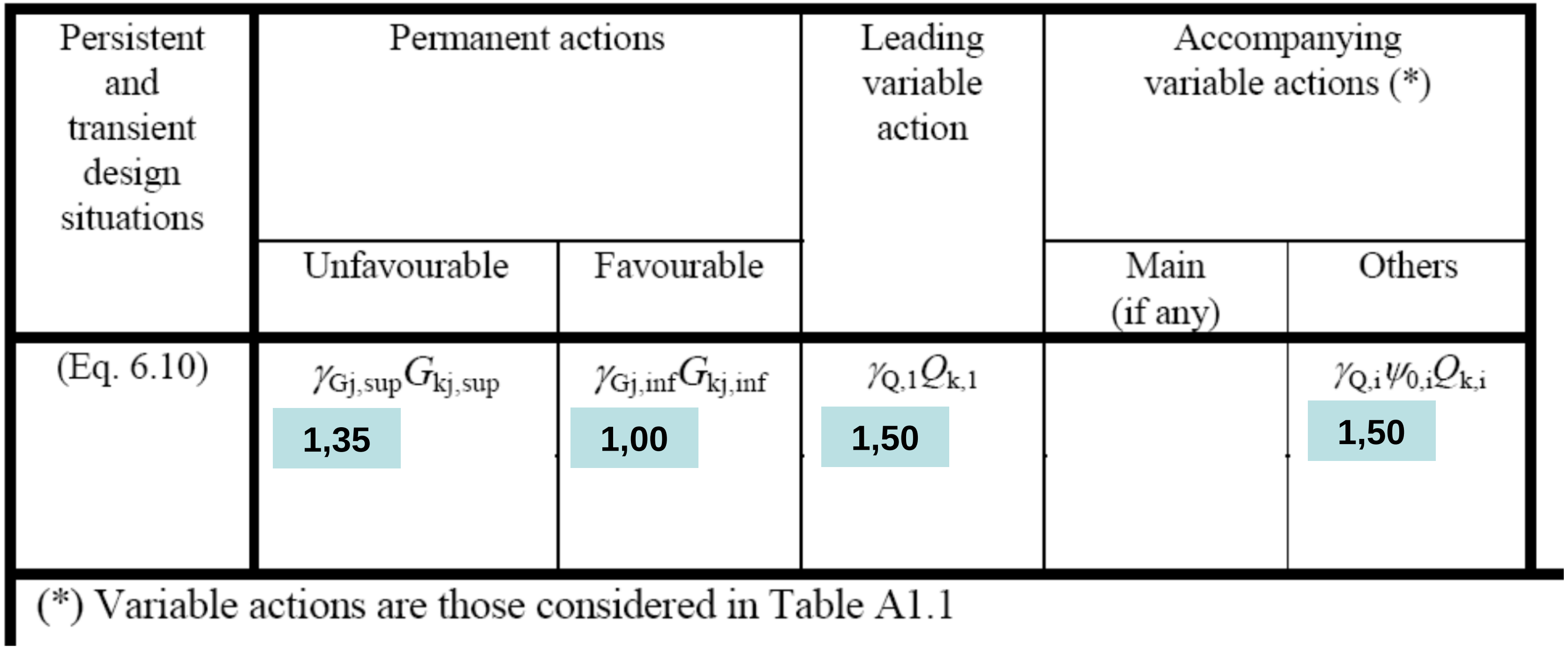
$\gamma_{Gj,inf} = 0,90$

$\gamma_{Q,1} = 1,50$ where unfavourable (0 where favourable)

$\gamma_{Q,i} = 1,50$ where unfavourable (0 where favourable)

Structural Failure Limit States

$$\sum_{j\geq1} \gamma_{G,j} G_{k,j} "+" \gamma_P P "+" \gamma_{Q,1} Q_{k,1} "+" \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$



Persistent and transient design situations	Permanent actions		Leading variable action	Accompanying variable actions (*)	
	Unfavourable	Favourable		Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup} G_{kj,sup}$ **1,35**	$\gamma_{Gj,inf} G_{kj,inf}$ **1,00**	$\gamma_{Q,1} Q_{k,1}$ **1,50**		$\gamma_{Q,i} \psi_{0,i} Q_{k,i}$ **1,50**

(*) Variable actions are those considered in Table A1.1

Note regarding permanent actions resulting from **one** source:

The partial factor 1,35 applies for all actions originating from **self-weight** if the resulting total effect is unfavourable. Similarly, γ_{inf} = 1.00 is valid if the resulting total effect is favourable. This also applies if different materials are involved.

Structural Failure Limit States

$$\sum_{j\geq 1}\gamma_{G,j}G_{k,j}\text{"+"}\gamma_{P}P\text{"+"}\gamma_{Q,1}Q_{k,1}\text{"+"}\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} \tag{6.10}$$

or, alternatively for STR and GEO limit states, the less favourable of the two following expressions:

$$\begin{cases}\displaystyle\sum_{j\geq 1}\gamma_{G,j}G_{k,j}\text{"+"}\gamma_{P}P\text{"+"}\gamma_{Q,1}\psi_{0,1}Q_{k,1}\text{"+"}\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} & \text{(6.10a)}\\ \displaystyle\sum_{j\geq 1}\xi_{j}\gamma_{G,j}G_{k,j}\text{"+"}\gamma_{P}P\text{"+"}\gamma_{Q,1}Q_{k,1}\text{"+"}\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} & \text{(6.10b)}\end{cases}$$

Where :

"+ "	implies "to be combined with"
Σ	implies "the combined effect of"
ξ	is a reduction factor for unfavourable permanent actions G

Structural Failure Limit States

$$\sum_{j\geq 1}\gamma_{G,j}G_{k,j}\text{"+"}\gamma_{P}P\text{"+"}\gamma_{Q,1}Q_{k,1}\text{"+"}\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} \qquad (6.10)$$

or, alternatively for STR and GEO limit states, the less favourable of the two following expressions:

$$\left\{\begin{array}{ll}\displaystyle\sum_{j\geq 1}\gamma_{G,j}G_{k,j}\text{"+"}\gamma_{P}P\text{"+"}\gamma_{Q,1}\psi_{0,1}Q_{k,1}\text{"+"}\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} & \qquad (6.10a)\\ \displaystyle\sum_{j\geq 1}\xi_{j}\gamma_{G,j}G_{k,j}\text{"+"}\gamma_{P}P\text{"+"}\gamma_{Q,1}Q_{k,1}\text{"+"}\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} & \qquad (6.10b)\end{array}\right.$$

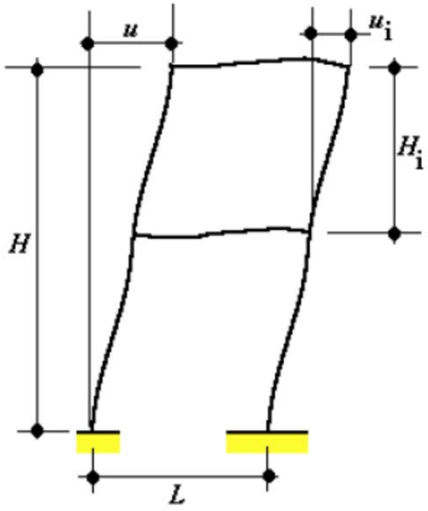
Where :

"+ "	implies "to be combined with"
Σ	implies "the combined effect of"
ξ	is a reduction factor for unfavourable permanent actions G

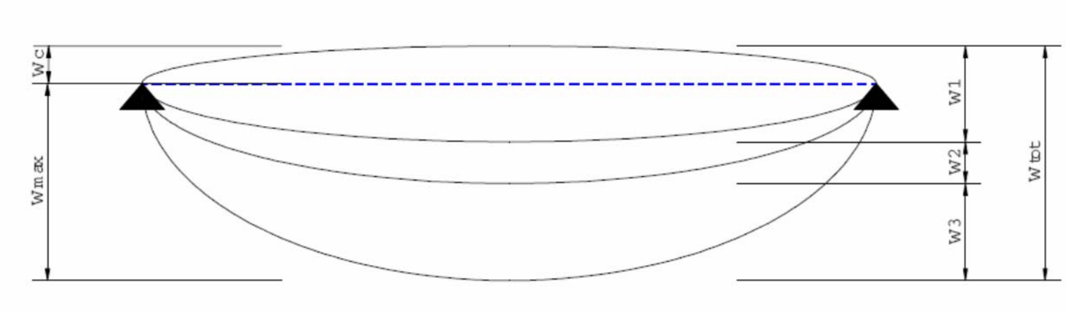
Serviceability Limit States

(1) Serviceability limit states in buildings should take into account criteria related, for example, to floor stiffness, differential floor levels, storey sway or/and building sway and roof stiffness. Stiffness criteria may be expressed in terms of limits for vertical deflections and for vibrations. Sway criteria may be expressed in terms of limits for horizontal displacements.

(2) The serviceability criteria should be specified for each project and agreed with the client.

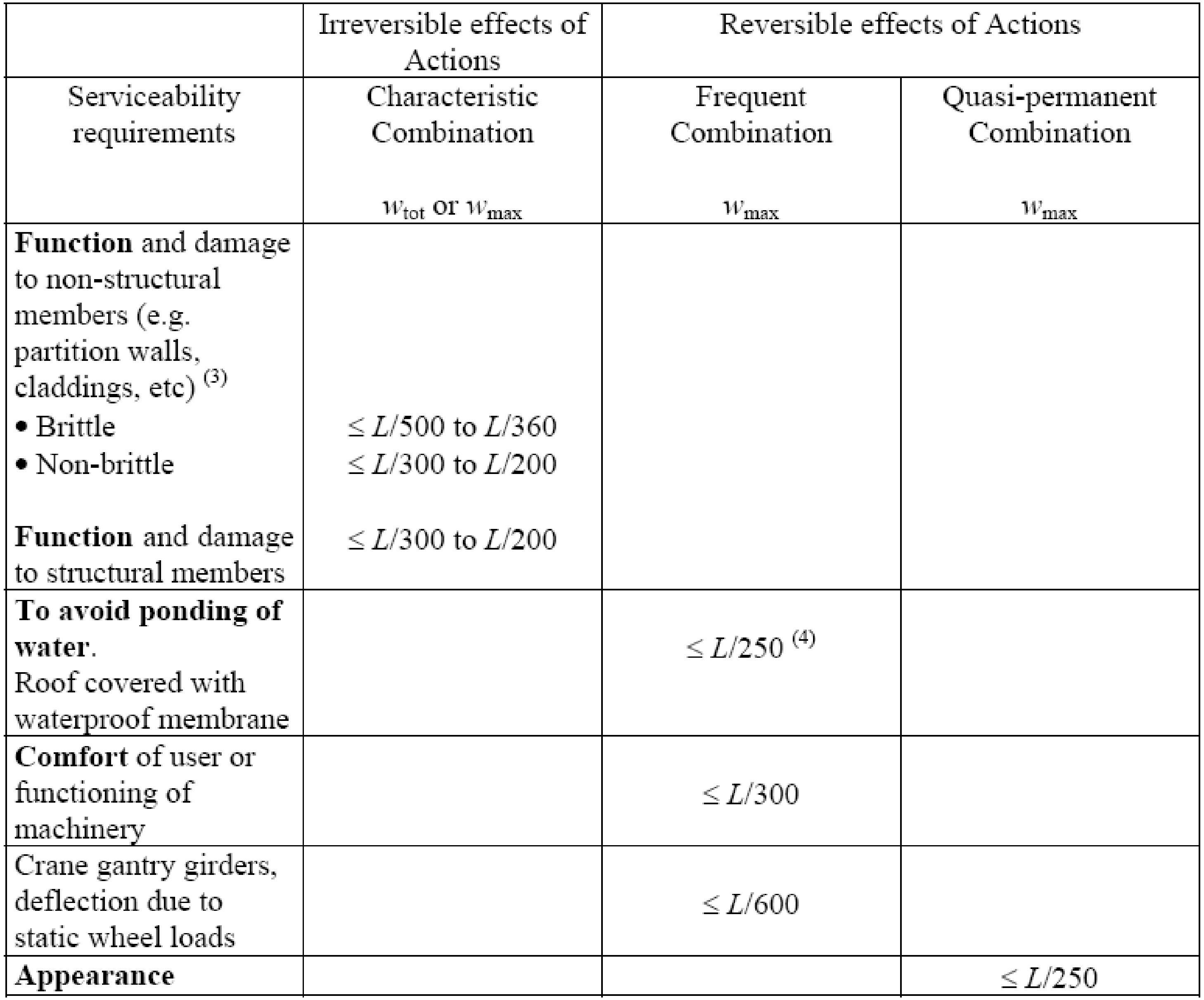


Horizontal Displacements



Vertical Deflections

Serviceability Limit States

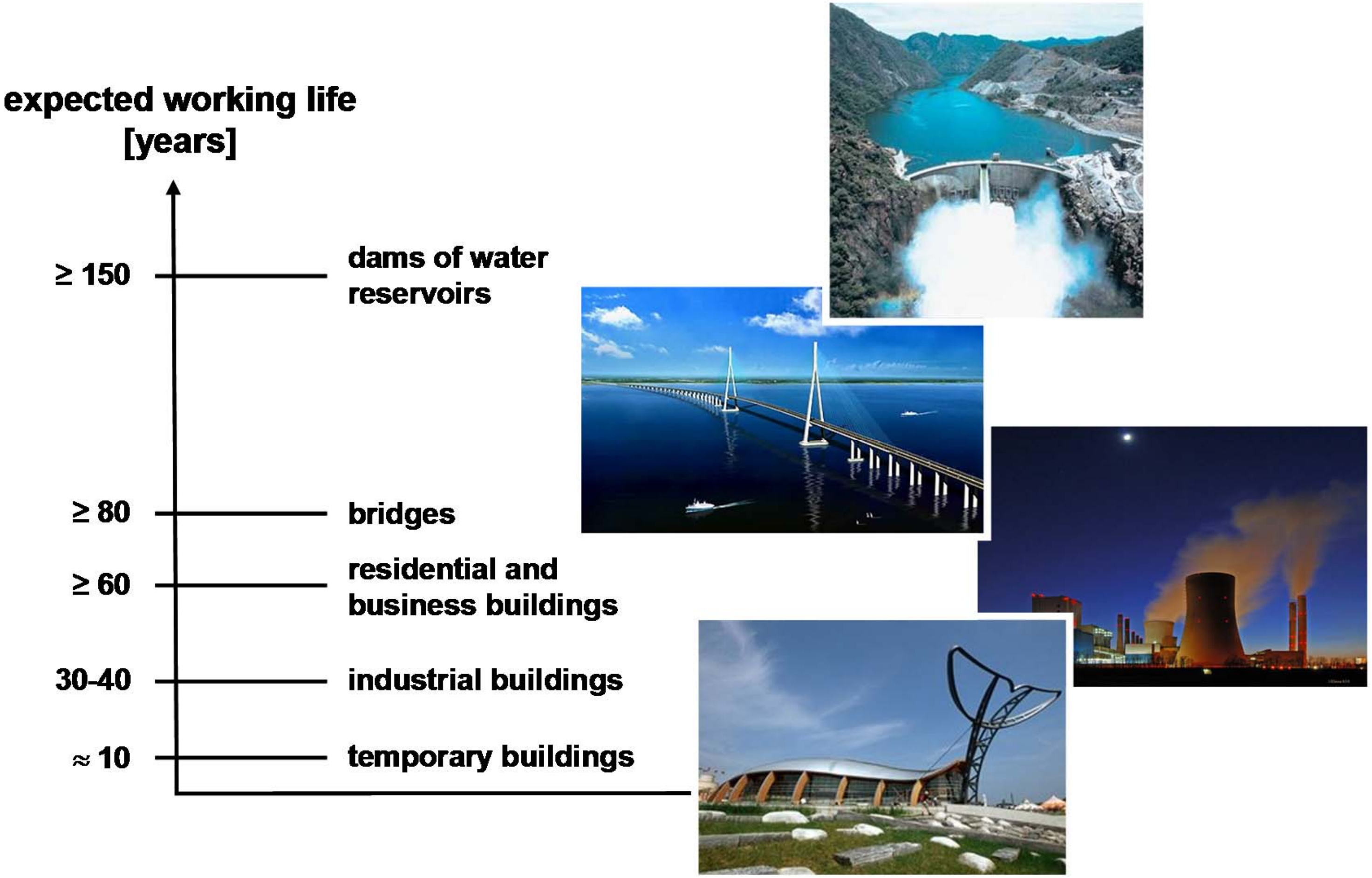


	Irreversible effects of Actions	Reversible effects of Actions	
Serviceability requirements	Characteristic Combination w_{tot} or w_{max}	Frequent Combination w_{max}	Quasi-permanent Combination w_{max}
Function and damage to non-structural members (e.g. partition walls, claddings, etc) (3)			
• Brittle	$\leq L/500$ to $L/360$		
• Non-brittle	$\leq L/300$ to $L/200$		
Function and damage to structural members	$\leq L/300$ to $L/200$		
To avoid ponding of water. Roof covered with waterproof membrane		$\leq L/250$ (4)	
Comfort of user or functioning of machinery		$\leq L/300$	
Crane gantry girders, deflection due to static wheel loads		$\leq L/600$	
Appearance			$\leq L/250$

Design working life

Definition in EN 1990

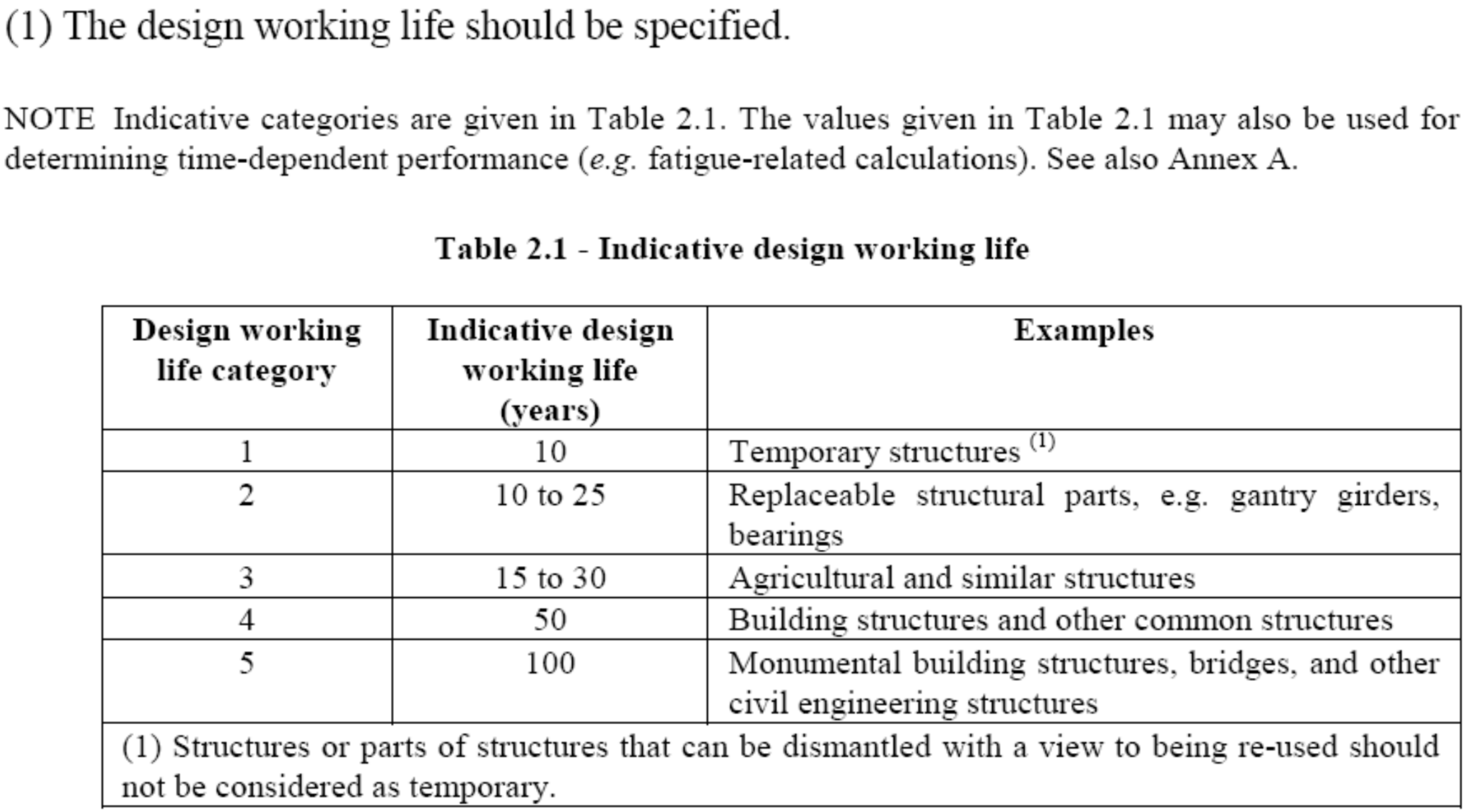
assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary



expected working life [years]

- **≥ 150** – **dams of water reservoirs**
- **≥ 80** – **bridges**
- **≥ 60** – **residential and business buildings**
- **30-40** – **industrial buildings**
- **≈ 10** – **temporary buildings**

Design working life



(1) The design working life should be specified.

NOTE Indicative categories are given in Table 2.1. The values given in Table 2.1 may also be used for determining time-dependent performance (*e.g.* fatigue-related calculations). See also Annex A.

Table 2.1 - Indicative design working life

Design working life category	**Indicative design working life (years)**	**Examples**
1	10	Temporary structures (1)
2	10 to 25	Replaceable structural parts, e.g. gantry girders, bearings
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures
(1) Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.		

Design working life