SECTION 1, DESIGN BASIS

General Principles and the Limit State Method

CHAPTER II

Article 5 Essential Requirements

A structure should be designed and constructed so that, within an acceptable margin of safety, it is able to withstand all the actions that may act upon it during construction and the designed service life-span and also the aggressiveness of the environment.

A structure should also be designed in such a way that it is not damaged by the consequences of exceptional actions, such as explosions or impacts, together with the results of errors to an extent which is disproportionate to the original cause.

In summary, the minimum essential requirements that a structure fulfil are: mechanical strength and stability, fire safety, hygiene, health and environmental, in addition to safety during use.

The previous requirements are satisfied through a correct design which includes a suitable choice of structural solution and construction materials, careful execution in accordance with the design, suitable design, execution and operation control, together with appropriate use and maintenance.

COMMENTS

The service life of a structure is understood to be the period of time from when it is put into service, during which it should maintain certain acceptable conditions of safety, functionality and aspect. During this period, it shall require normal conservation work, but not rehabilitation operations.

The service life of a project is a magnitude that should be established by the owner prior to the project initiation.

Article 6 Safety criteria

6.1 Principles

The safety of a structure when threatened by some form of risk may be expressed in terms of the overall probability of failure, which is linked to a particular reliability index.

The required reliability is guaranteed in this Instruction by the adoption of the Limit State Method (Article 8). This method provides a simple way of taking into account the random nature of the variables of actions, strength and dimensions that are involved in the design. The design value for a variable is obtained by weighting its main representative value with the corresponding partial safety factor.

Partial safety factors do not take into consideration the influence of any possible gross human errors. These failures must be avoided by means of suitable quality control mechanisms which should cover all activities in relation to the design, execution, use and maintenance of a structure.

COMMENTS

The limit state procedure, based on the prior determination of partial safety factors, corresponds to a level 1 reliability method.

There are basically two procedures for determining the partial safety factors:

a) Through a calibration with the design values of the variables employed in the calculation of existing structures.
b) Through the statistical evaluation of experimental data within the scope of application of probabilistic methods.

The partial safety factors in this Instruction are based on method a), with certain exceptions based on method b). Reliability may be defined as the ability of the structure to comply with a function in determined conditions, with a predefined probability. To a certain extent, this corresponds to the probability of a lack of failure and may be quantified using the reliability index, β.

The reliability index β is linked to the overall failure probability p_f in accordance with the expression:

$$\psi(\beta) = 1 - p_f$$

where $\psi(\beta)$ is the standard normal distribution law.

As values that are indicative of the overall failure probability pf and of the corresponding failure index β for normal distribution, and accepted as valid for most cases, those given in Table 6.1 may be considered.

Table 6.1

Limit State	Failure probability p_f	Reliability index β
Ultimate	$7.2 \cdot 10^{-5}$	3.8
Service	$6.7 \cdot 10^{-2}$	1.5

This overall failure probability does not correspond to the true frequency of structural failures. The values given in the table should be taken as nominal safety values, serving as guideline base for the development of strict, coherent rules for the dimensioning of structures.

6.2 Structural verification through calculation procedures

Structural verification through calculation is one possible method for guaranteeing the safety of a structure and is the system proposed in this Instruction.

6.3 Structural verification through testing methods

In those situations where the rules given in this Instruction are insufficient or where test results may lead to significant economic savings in a structure, there is also potential to afford structural design through testing.

This procedure is not explicitly developed in this Instruction and specialised literature should therefore, be consulted for further information.

Article 7 Design situations

The considered design situations are given below:

- Persistent situations, corresponding to the structure's normal conditions of use.
- Transient situations, such as those produced during structure construction or repair.
- Accidental situations, corresponding to exceptional conditions applicable to the structure.

Article 8 Design basis

8.1 The Limit State Method

8.1.1 Limit States

Limit States are defined as those situations which, when exceeded, the structure may be considered as not meeting one or more of the functions for which it was designed.

In general, Limit States are classified as:

- Ultimate Limit States
- Serviceability Limit States

Checks should be made to ensure that a structure does not exceed any of the Limit States as defined above in any of the design situations given in Article 7, with regards to the design values of the actions, material properties and geometric data.

The verification procedure for a particular Limit State consists of deducing both the effect of the actions applied to the structure or a part of it, together with the response of the structure to this specific limit situation. The Limit State will be guaranteed if it is found that the structural response is not less than the effect of the applied actions, with acceptable reliability.

In order to determine the effect of the actions, the design actions shall be considered in combination in accordance with the criteria stated in Chapter III, together with the geometric data as defined in Article 16. A structural analysis should be carried out in accordance with the criteria given in Chapter V.

In order to determine the structure's response, the various criteria defined in Section 4 shall be considered and the design values for materials and geometric data as given in Chapter IV shall be taken into account.

The definitions of the actions acting on the structures are given in the relevant instructions, regulations and basic standards etc, in relation to the actions. Since they are essential to the use of this Instruction, in general, it establishes rules for the definition of the design values of the actions and their combinations, provided that the corresponding action instructions do not indicate otherwise.

COMMENTS

Through its history, a structure undergoes various phases that are characterised by the type and value of the loads it has to support, and eventually by the structural pattern (static and sectional) adopted by the structure (Article 7). These phases therefore, refer to a determined structural state, including those of construction.

It shall be necessary to carry out checks of the various Limit States in each phase, considering at least the following:

1) Construction phase
   a) Various construction phases.
   b) In the case of prestressed concrete, the phase or phases of prestress force application would be of particular significance.

2) Serviceability phases

It may be necessary to analyse various phases during the structure serviceability situation, ifs, for example, it is put into service before certain time-dependent actions have reached their final values.

8.1.2 Ultimate Limit States

The Ultimate Limit State designation applies to all those conditions that place the structure out of service, whether due to the collapse or breakage of all or part of it.

The following should be considered as Ultimate Limit States:

- failure through excessive plastic deformations, breakage or loss of stability of the whole structure or part of the same;
- loss of equilibrium of the structure or part of it, considered as a rigid solid;
- failure through the accumulation of deformations or progressive cracking under repeated loads.

The following condition shall be satisfied in the verification of Ultimate Limit States with regards to the breakage of a section or element.

$$R_d \geq S_d$$

where:

R_d The structural response design value.
S_d The action effect design value.

For the evaluation of the Equilibrium Limit State (Article 41), the following condition shall be satisfied:

$$E_{d,estab} \geq E_{d,desestab}$$

where:

$E_{d,\,estab}$ The stabilising action effect design value.
$E_{d,\,desestab}$ The destabilising action effect design value.

The Fatigue Limit State (Article 48) is related to the damage that a structure may suffer as a consequence of repeated varying loads.

For the evaluation of the Fatigue Limit State, the following condition shall be satisfied:

$$R_F \geq S_F$$

where:

R_F Design fatigue strength value.
S_F The fatigue action effect design value.

COMMENTS

The Ultimate Limit States included in this Instruction are as follows:

- Equilibrium Limit State. It is studied for the whole structure level or for each structural element.
- Breakdown Limit State (studied at a sectional level):
  - by axial and bending action effects
  - by shear
  - by torsion
  - by punching
  - by shear at the interface
- Instability Limit State. It is studied for the whole structure level or for each structural element.
- Fatigue Limit State. It is studied at a sectional level

8.1.3 Serviceability Limit States

Serviceability Limit States include all those structural situations for which the requirements of functionality, comfort, durability or appearance are not met.

The fulfilment of Serviceability Limit States means that the following condition shall be satisfied:

$$C_d \geq E_d$$

where:

C_d The admissible limiting value for the Limit State to be verified (deformations, vibrations, cracking, etc.).
E_d Action design effect (stresses, vibration level, crack width, etc.).

COMMENTS

The Serviceability Limit States included in this Instruction are as follows:

- Deformation Limit State. This is produced by deformations that may affect the applied actions, the appearance or the use of the structure, or produce damage to non-structural elements.
- Vibration Limit State. This is produced by vibrations that may be unpleasant or cause disturbance to the users or cause damage to structure or equipment.
- Cracking Limit State. This is produced when cracking in the concrete due to tensile stress can affect the durability, impermeability or appearance of the structure. Micro-cracking in the concrete due to excessive compression may also affect durability.

8.2 Durability-orientated design basis

Before commencing the design, the type of environment that defines the aggressiveness affecting each structural element shall be identified.

In order to achieve a suitable durability, a design strategy depending on the type of environment should be established, in accordance with the criteria given in Chapter VII.

8.2.1 Definition of the environment type

The type of environment to which a structural element is subject can be defined by the set of physical and chemical conditions to which it is exposed, and which might cause its degradation as a consequence of effects other than the loads and stresses considered in the structural analysis.

The environment type is defined by a combination of:

- one of the general exposure classes against reinforcement corrosion, in accordance with 8.2.2.
- the specific exposure classes in relation to other degradation processes that are relevant in each case, among those defined in 8.2.3.

In the situation where a structural element is subject to some specific class of exposure, the designation of the environment type should reflect all the classes, linked by plus "+" signs.

When a structure contains elements with different environmental types, the designer shall define some groups of structural elements that have similar characteristics of environmental exposure. In order to achieve this, whenever possible, elements of the same type are grouped together (for example, pillars, roof beams, and foundations, etc.), ensuring at the same time, that the criteria followed are compatible with any peculiarities of the execution phase.

For each group, the class or, where applicable, the combination of classes that define the environmental aggressivness to which the elements are subjected, shall be identified.

COMMENTS

The proposed methodology for defining the environmental type distinguishes between exposure classes in relation to reinforcement corrosion and other classes in relation to other degradation processes. The former are identified as general classes, whereas the latter are defined as specific ones. This is not intended to reflect any type of hierarchy between the various processes that affect the durability, but only to be a procedure for defining the proposed methodology. Consequently, under no circumstances should it be assumed that processes such as freezing-thawing, chemical attack, etc. are less important than reinforcement corrosion in relation to the durability of the structural element.

8.2.2 General environmental exposure classes in relation to reinforcement corrosion

All structural elements are subject to a single general exposure class or subclass.

In relation to this Instruction, general exposure classes are defined as those exclusively referring to reinforcement corrosion processes , and which are included in Table 8.2.2

COMMENTS

In accordance with Table 8.2.2, plain concrete structural elements always belong to general exposure class I (non-aggressive), since the lack of reinforcement prevents any possibility of corrosion, but these may be subject, where applicable, to the specific classes defined in 8.2.3.

The normal general class, designated as II, basically corresponds to corrosion problems that might be produced in the reinforcement as a consequence of concrete carbonation, although it also includes the case of buried foundations. For this reason, it has been decided to indicate the process type as *Corrosion with an origin other than chlorides*.

Concrete internal humidity is a critical factor in the diffusion of carbon dioxide in the pore structure. When the humidity is high (class IIa), process is difficult and the internal gas transport mechanism is slower, being this exposure conditions less aggressive than those in humid environments (class Iib).

The subclass aerial marine, designed as IIa, is exclusively devoted to external elements exposed to salt deposits in a distance less than 5 km of thecoastline.

8.2.3 Specific environmental exposure classes in relation to degradation processes other than that of corrosion

In addition to the classes included in 8.2.2, another series of specific exposure classes is established that are related to concrete degradation processes other than that of reinforcement corrosion (Table 8.2.3.a).

An element may be subject to none, one or more specific exposure classes relating to other processes of concrete degradation.

However, an element may not be simultaneously subjected to more than one of the subclasses defined for each specific exposure class.

In the case of those structures subject to chemical attack (class Q), the aggressiveness will be classified according to the criteria provided in Table 8.2.3.b.

Table 8.2.2. General Exposure Classes in relation to reinforcement corrosion

GENERAL EXPOSURE CLASS				DESCRIPTION	EXAMPLES
Class	**Subclass**	**Designation**	**Process type**		
non aggressive		I	none	- interiors of buildings, not subject to condensation - plain concrete elements	- building interiors, protected from the weather
normal	**high humidity**	IIa	Corrosion origin other than that of chlorides	- interiors subject to medium-to-high humidity (>65%) or exterior condensation without chlorides, exposed to rain in areas with average annual precipitation over 600 mm. - buried or submerged elements.	- unventilated basements - foundations - bridge decks and piles in areas with an average annual rainfall in excess of 600 mm - concrete building roof elements
	medium humidity	IIb	Corrosion origin other than that of chlorides	- exteriors without chlorides, subject to rainwater action in areas with an average annual precipitation of under 600 mm	- exterior structures protected from the rain - bridge decks and piles in areas with an average annual rainfall less than 600 mm
marine	**aerial**	IIIa	Chloride corrosion	- marine structure elements above high tide level - structures located near the coastline (less than 5 km)	- buildings near the coast - bridges near the coast - aerial parts of dikes, sea-walls and other coastal defence elements - port installations
	submerged	IIIb	Chloride corrosion	- marine structure elements that are permanently submerged below minimum low tide level	- submerged parts of dikes, sea-walls and other coastal defence works - bridge foundations and submerged piles in the sea
	in tidal zones	IIIc	Chloride corrosion	- marine structure elements situated in the tidal flow zone	- - areas located between high and low tide levels of dikes, sea-walls and other coastal defences - - areas of bridge piles in the sea located between high and low tide levels
with chloride origin other than that of the marine environment		IV	Chloride corrosion	- non-waterproofed installations in contact with water with high chloride content unrelated to the marine environment - non-waterproofed surfaces exposed to de-icing salts.	- swimming pools - overpass or footbridge piles in snowy areas - water treatment plants.

Table 8.2.3.a Specific exposure classes in relation to degradation processes other than that of corrosion

SPECIFIC EXPOSURE CLASS				DESCRIPTION	EXAMPLES
Class	**Subclass**	**Designation**	**Process type**		
Aggressive chemical	**weak**	Qa	chemical attack	- elements located in environments with chemical content capable of producing slow changes in the concrete (see Table 8.2.3.b)	- industrial installations, with slightly aggressive substances in accordance with Table 8.2.3.b. - constructions near slightly aggressive industrial areas in accordance with table 8.2.3.b.
	medium	Qb	chemical attack	- elements in contact with seawater - elements located in environments with chemical content capable of producing medium-rate changes in the concrete (see Table 8.2.3.b)	- blocks and other dike elements - marine structures in general - industrial installations with moderately aggressive substances in accordance with Table 8.2.3.b. - constructions near moderately aggressive industrial areas in accordance with Table 8.2.3b. - installations for the channelling and treatment of waste water with medium aggressive substances in accordance with Table 8.2.3.b.
	strong	Qc	chemical attack	- elements situated in environments with chemical content capable of producing rapid changes in the concrete (see Table 8.2.3.b)	- industrial installations, with highly aggressive substances in accordance with Table 8.2.3.b. - installations for the channelling and treatment of waste water with highly aggressive substances in accordance with Table 8.2.3.b.
with frost	**Without de-icing salts**	H	freeze-thaw attack	- elements in frequent contact with water or located in areas with average environmental relative humidity in winter in excess of 75% and with an annual probability exceeding 50% of temperatures dropping to below –5°C at least once	- constructions in high mountain areas - winter sports resorts
	With de-icing salts	F	de-icing salt attack	- elements intended for vehicular or pedestrian traffic in areas with more than 5 days of snow per year or with an average minimum temperature in the winter months of under 0ºC	- bridge or footbridge decks in high mountain areas
erosion		E	cavitation abrasion	- elements subject to surface wear - hydraulic structure elements in which the pressure level may fall below the water vapour pressure	- bridge piles in strongly-flowing river beds - elements of dikes, sea-walls and other coastal defence works subject to heavy wave action - concrete pavements - high-pressure piping

Table 8.2.3.b. Aggressive chemical classification

TYPE OF AGGRESSIVE MEDIUM	PARAMETERS	EXPOSURE TYPE		
		Qa	Qb	Qc
		WEAK ATTACK	MEDIUM ATTACK	STRONG ATTACK
WATER	pH VALUE	6.5 – 5.5	5.5 – 4.5	< 4.5
	AGGRESSIVE CO_2 (mg CO_2/ l)	15 - 40	40 - 100	> 100
	AMMONIA ION (mg NH_4^+ / l)	15 - 30	30 - 60	> 60
	MAGNESIUM ION (mg Mg^{2+} / l)	300 - 1000	1000 - 3000	> 3000
	SULPHATE ION (mg SO_4^{2-} / l)	200 - 600	600 - 3000	> 3000
	DRY RESIDUE (mg / l)	75-150	50 - 75	< 50
SOIL	BAUMANN-GULLY DEGREE OF ACIDITY	> 20	(*)	(*)
	SULPHATE ION (mg SO_4^{2-} / kg of dry soil)	2000 - 3000	3000 - 12000	> 12000

(*) These conditions do not exist in practice

COMMENTS

The example in the table 8.2.2.a. corresponding to class F refers to the case of bridges or footbridges decks in high mountain environment and not properly waterproofed. In case of correct waterproofing (material, thickness and installation) it must be considered as not corresponding to F class.

In accordance with the articles, a structural element is subjected to an environment defined by the combination of a series of exposure classes, one of which is general and the others specific. Several examples are given below:

- The piles of an overpass located in a high mountain area.
  - General exposure class: IV (with non-marine chlorides)
  - Specific exposure classes: F (with frosts and de-icing salts)
  - Environment type: IV+F
- Uncovered piles forming the supports for a building in an area with a benign climate and far from industrial zones.
  - General exposure class: IIb (normal medium)

- Specific exposure classes: none
- Environment type: IIb

- Bridge decks, 200 metres from the coast in non-chalk bearing soils.
    - General exposure class: IIIa (aerial marine)
    - Specific exposure classes: none
    - Environment type: IIIa
- Prefabricated reinforced concrete floating structures for the construction of a port dike , which is floated to its definitive location and then sunk.
    - General exposure class: IIIb (submerged marine)
    - Specific exposure classes: Qb (aggressive chemical medium)
    - Environment type: IIIb + Qb
- Mass concrete blocks for port breakwater.
    - General exposure class: I (plain concrete, non-aggressive)
    - Specific exposure classes: Qb (aggressive chemical medium) + E (erosion)
    - Environment type: I + Qb + E

- The determination of the parameters established in Table 8.2.3.b. is carried out in accordance with the UNE 7234:71, UNE 7131:58, UNE 7130:58 standards and Appendix 5.