CHAPTER 7

DURABILITY

Article 37. Durability of concrete and reinforcements

37.1 General

The durability of a concrete structure is its capacity to withstand, for the duration of its designed service life, the physical and chemical conditions to which it is exposed, and which could cause it to deteriorate as a result of effects other than the loads and stresses considered in its structural analysis.

A durable structure shall be created using a strategy which is able to take account of all the possible deterioration factors and consequently take place during each of the design, construction and use phases of the structure; the Designer shall therefore establish a durability strategy that takes account of the specifications in this Chapter. Alternatively, the Durability Limit State may be verified with regard to the corrosion processes of reinforcements, as indicated in Section 1 of Annex 9.

A correct strategy for durability shall take account of the fact that a structure may have various structural elements submitted to different types of environment.

37.1.1 Consideration of durability at the design stage

The design of a concrete structure shall include the measures necessary so that the structure has the useful service life determined as indicated in Article 5, as a function of the environmental aggressivity conditions to which it may be subjected. A durability strategy shall therefore be included in accordance with the criteria set out in paragraph 37.2. If, due to the structure's characteristics, the Designer deems it appropriate for the structure's useful life to be estimated by verifying its Durability Limit State, the methods indicated in Annex No. 9 of this Code may be used.

The aggressivity to which the structure is subjected shall be identified using the environment type, according to 8.2.1.

The document shall include supporting evidence for the exposure classes selected for consideration for the structure. The drawings shall also show the type of environment for which each element has been designed.

The design shall define the structural shapes and details which facilitate water drainage and which are efficient in the light of the possible concrete deterioration mechanisms.

Equipment elements, such as supports, joints, drains, etc., may have a shorter service life than the structure itself; where appropriate, the adoption of design measures which facilitate the maintenance and replacement of these elements during the use phase shall be therefore examined.

37.1.2 Consideration of durability during the construction phase

High quality on-site work, in particular curing, has a decisive influence on ensuring a durable structure is built.

The specifications relating to durability shall be satisfied in their entirety during the construction phase. Offsetting of the effects of a failure to comply with these specifications

shall not be permitted unless this is justified by satisfying, where appropriate, the Durability Limit State set out in Annex 9.

37.2 Durability strategy

37.2.1 General requirements

In order to satisfy the requirements set out in Article 5, a strategy which encompasses all the possible deterioration mechanisms will need to be followed, and special measures adopted, depending on the degree of aggressivity to which each element is to be subjected.

The durability strategy shall at least include the following aspects:

a) Selection of suitable structural shapes, in accordance with the provisions in 37.2.2.
b) Ensuring suitable concrete quality and, in particular, its outer layer, in accordance with the provisions in 37.2.3.
c) Adopting a suitable cover thickness for the protection of reinforcements, according 37.2.4 and 37.2.5.
d) Checking the maximum crack width value, in accordance with 37.2.6.
e) The provision of surface protections in highly aggressive environments, according to 37.2.7.
f) Adoption of corrosion protection methods in accordance with the provisions in 37.4.

37.2.2 Selection of structural shapes

The design shall specify the structural layouts, the geometric shapes and details that are compatible with ensuring suitable durability of the structure.

The use of structural designs which are particularly vulnerable to the effects of water shall be avoided and, wherever possible, direct contact between water and concrete shall be minimised.

The design shall also include the details necessary to facilitate rapid water elimination and include suitable systems for its control and drainage (outlets, ducting, etc.) In particular, the passage of water across joints and sealed areas shall be avoided wherever possible.

Suitable systems shall be provided to prevent surfaces being subjected to splashes or soaking.

If the structure includes sections comprising internal hollows or cavities, the necessary systems for their ventilation and drainage shall be provided.

Wherever possible, access shall be provided, apart from in small scale structures, to all the structure's elements, and the appropriateness of providing special systems to facilitate inspection and maintenance during the service phase, in accordance with the provisions in Chapter 17 of this Code, shall be examined.

37.2.3 Concrete quality requirements

A strategy based on the durability of a structure must ensure suitable concrete quality, in particular in the more superficial areas, where damage can occur.

A suitable quality concrete is a concrete which satisfies the following requirements:

- The selection of raw materials in accordance with the provisions in Articles 26 to 35.
- Suitable mix proportioning, as indicated in paragraph 37.3.1, and sub-paragraph 37.3.2.
- Correct placing, as indicated in Article 71.
- Curing of the concrete, as indicated in sub-paragraph 71.6
- Strength in accordance with expected structural performance and durability requirements.
- Performance in accordance with the requirements in sub-paragraph 37.3.1.

37.2.4 Coverings

The concrete covering is the distance between the external surface of the reinforcement (including hoops and stirrups) and the nearest concrete surface.

For the purposes of this Code, the minimum covering of a passive reinforcement is a covering depth maintained at every point on the reinforcement. In order to ensure these minimum values, a nominal cover value of r_{nom}, defined as follows shall be set out in the design document:

$$r_{nom} = r_{min} + \Delta r$$

In which:

r_{nom} Nominal cover

r_{min} Minimum covering

Δr Covering margin, as a function of its execution control level and whose value shall be:

0 mm in pre-cast elements subject to intense execution inspection

5 mm in the case of in situ elements subject to intense execution inspection, and

10 mm in all other cases

Nominal cover is the value to be shown in drawings, and used to define the spacers. The minimum covering is the value which shall be guaranteed at any point in the element and which is checked in accordance with the provisions in Article 95.

In special cases where a severely aggressive atmosphere obtains or where particular fire risks obtain, the coverings indicated in this Article shall be increased.

37.2.4.1 Specifications for coverings for passive and active pre-tensioned reinforcements

The minimum coverings for passive and active pre-tensioned reinforcements shall satisfy the following:

a) The covering of main reinforcements shall be at least the diameter of the bars concerned (or their equivalent diameter in the case of bundled bars) and at least 0.80 times the maximum size of the aggregate, unless the arrangement of reinforcements relative to faces renders the placing of concrete difficult; in this case, a figure of 1.25 times the maximum aggregate size, as defined in paragraph 28.3, shall be used.

b) No point in the covering of any grade of passive reinforcement (including stirrups) or of any pre-tensioned active reinforcement shall be less than the minimum values indicated in tables 37.2.4.1 .a, 37.2.4.1 .b and 37.2.4.1 .c.

c) In order to comply with the requirements in sub-paragraph c) above, designers of pre-cast elements (secondary beams or plates) for one-way reinforced or pre-stressed concrete slabs in fixed industrial installations shall be able to include, as well as the concrete thickness, the thickness of the slab's coverings, if these are compact, impermeable, definitive and permanent. In these situations, the actual concrete covering shall never be less than 15 mm. Annex 9 includes a few recommendations for calculating the contribution referred to in this sub-paragraph if covering mortars are used.

d) Bent bars shall have a covering of at least two diameters, measured in a direction perpendicular to the curve plane.

e) The covering of concreting boundary surfaces, if reinforcements are permanently embedded in the body of the concrete, shall not be less than the diameter of the bars concerned or their equivalent diameter, in the case of

bundled bars, or less than 0.8 times the maximum aggregate size.

If, for any reason (durability, fire protection or the use of bundled bars) the covering needs to be more than 50 mm, the potential advantage of installing a distribution mesh halfway down the thickness of the covering in its tensile stressed area shall be considered using a geometric ratio of 5 per millimetre of the covering area, in the case of bars or bundled bars with a diameter (or equivalent diameter) of 32 mm or less and 10 per millimetre in the case of diameters (or equivalent diameters) of more than 32 mm.

The minimum covering for members concreted against the ground shall be 70 mm unless the ground has been prepared and blinding concrete laid; the provisions in the paragraph above shall not be applicable in this case.

Table 37.2.4.1.a Minimum coverings (mm) for general exposure classes I and II

Exposure class	Type of cement	Characteristic strength of the concrete [N/mm^2]	Useful life of the structure (tg), (years)	
			50	100
I	Any	$f_{ck} \geq 25$	15	25
II a	CEM I	$25 \leq f_{ck} < 40$	15	25
		$f_{ck} \geq 40$	10	20
	Other types of cement or if the concrete contains additives	$25 \leq f_{ck} < 40$	20	30
		$f_{ck} \geq 40$	15	25
II b	CEM I	$25 \leq f_{ck} < 40$	20	30
		$f_{ck} \geq 40$	15	25
	Other types of cement or if the concrete contains additives	$25 \leq f_{ck} < 40$	25	35
		$f_{ck} \geq 40$	20	30

Table 37.2.4.1.b Minimum covering (mm) for general exposure classes III and IV

Concrete	Cement	Useful structural life (t_g) (years)	General exposure class			
			IIIa	IIIb	IIIc	IV
Reinforced	CEM III, CEM IV, CEM II/B-S, B-P, B-V, A-D or concrete with micro-silica	50	25	30	35	35
		100	30	35	40	40
	Other useable cements	50	45	40	*	*
		100	65	*	*	*
Pre-stressed	CEM II/A-D or with silica fume additive of more than 6%	50	30	35	40	40
		100	35	40	45	45
	Other useable cements according to Article 26	50	65	45	*	*
		100	*	*	*	*

* These situations will require excessive coverings, thus making it difficult to make the element and are therefore inadvisable. It is therefore recommended that their Durability Limit State is verified, as indicated in Annex 9, based on the concrete's characteristics, ad set out in the Project's Technical Specifications.

In the case of deterioration mechanisms other than corrosion of reinforcements, the values in table 37.2.4.1.c shall be used.

Table 37.2.4.1.c Minimum coverings for specific exposure classes

Exposure class	Type of cement	Characteristic strength of the concrete [N/mm^2]	Useful life of the structure (t_g), (years)	
			50	100
H	CEM III	$25 \leq f_{ck} < 40$	25	50
		$f_{ck} \geq 40$	15	25
	Other types of cement	$25 \leq f_{ck} < 40$	20	35
		$f_{ck} \geq 40$	10	20
F	CEM I I/A-D	$25 \leq fck < 40$	25	50
		$fck \geq 40$	15	35
	CEM III	$25 \leq fck < 40$	40	75
		$fck \geq 40$	20	40
	Other types of cement or, if the concrete contains additives	$25 \leq fck < 40$	20	40
		$fck \geq 40$	10	20
E (1)	Any	$25 \leq fck < 40$	40	80
		$fck \geq 40$	20	35
Qa	CEM III, CEM IV, CEM II/B-S, B-P, B-V, A-D or concrete containing more than 6% micro silica or more than 20% fly ash		40	55
	Other usable cements	-	*	*
Qb, Qc	Any	-	(2)	(2)

(*) These situations would require excessive coverings

(1) These values are for moderately severe abrasion conditions. If severe abrasion is anticipated, a detailed study will need to be carried out.

(2) The Designer shall set these minimum covering values, and as appropriate, additional measures, in order to suitably guarantee the concrete's protection and the reinforcement's protection in the specific chemically aggressive situation concerned.

The minimum covering values in tables 37.2.4.1.a, 37.2.4.1.b and 37.2.4.1.c are associated with the simultaneous compliance with the mix proportioning specifications for concrete, indicated in 37.3 for the various exposure classes. If experimental data concerning the aggressivity of the environment in similar structures located in adjoining areas, and with the same degree of exposure are available, or if it is decided to adopt more stringent concrete characteristics in the design than those indicated in the articles, the Designer shall be able

to check compliance with the Durability Limit State in accordance with the provisions in Annex 9.

If the Designer sets out therein the adoption of special protection measures from corrosion for the reinforcements (cathodic protection, galvanised reinforcements or the use of corrosion inhibitors in the concrete) certain reduced minimum coverings may be provided for general classes III and IV, which shall correspond to those indicated in this Article for general class IIb, provided that the necessary measures are taken to ensure the effectiveness of these special measures for the entire useful service life of the structure, and specified in the design.

37.2.4.2 Coverings for post-tensioned active reinforcements

The minimum coverings for post-tensioned active reinforcements in the horizontal and vertical directions (Figure 37.2.4.2) shall be at least the following limits, and never exceed 80 mm:

- 40 mm;
- the greater of the following values; the smaller dimension or half the bigger dimension of the sheath or sets of sheaths in contact.

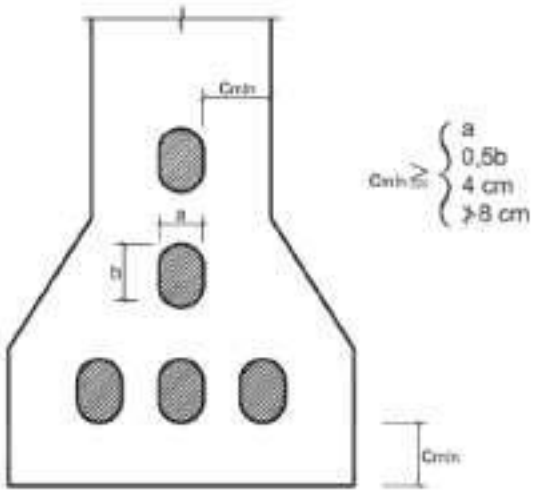

Figure 37.2.4.2

37.2.5 Spacers

Coverings shall be assured by arranging the corresponding spacer elements installed in situ.

These blocks or spacers shall be arranged in accordance with the provisions in 69.8.2. They shall comprise materials that resist the concrete's alkalinity, and shall not cause corrosion in the reinforcements. They shall be at least as impermeable to water as the concrete, and resist any chemical attacks to which they may be subject.

Irrespective of whether they are temporary or definitive, they must be made from concrete, mortar, rigid plastic or a similar material, and have been specially designed for this purpose.

Concrete spacers, as regards their strength, permeability, hygroscopicity, thermal expansion, etc., shall be of a quality comparable to that of the concrete used to make the element. Similarly, if they are made from mortar, they shall be of a similar quality to that of the mortar contained in the structure's concrete.

In order to ensure that spacers made from other materials that do not contain cement bond well with the member's concrete, they shall have openings whose total cross-section shall be at least 25% of the spacer's total surface area.

The use of wood and any other construction residual material, whether brick or concrete is prohibited. The use of metal in visible spacers is also prohibited. In any case the material of the spacers will not contain asbestos.

37.2.6 Maximum values for crack openings

Durability is, along with functional and appearance considerations, one of the reasons why crack widths need to be controlled. The maximum values used shall be as indicated in table 5.1.1, as a function of environmental exposure classes.

37.2.7 Special protection methods

Special protection systems may be adopted in particularly aggressive environments, when normal protection measures are deemed insufficient, such as:

- Applying surface coverings, using specific products for concrete protection (paints or coatings), in accordance with the standards in the UNE-EN 1504 series, as applicable.
- Protection of the reinforcements using coatings (i.e. galvanised reinforcements).
- Cathodic protection of reinforcements using sacrificial anodes or applied current, according to UNE-EN 12696.
- Stainless steel reinforcements, according to UNE 36067.
- Active corrosion inhibitors.

Additional protections may have a useful life shorter than that of the structural element. The design shall therefore include schedules for the appropriate maintenance of these protection systems.

37.3 Durability of concrete

The durability of concrete is its capacity to perform satisfactorily when exposed to physical loads or aggressive chemicals and suitably protect its reinforcements and other metal elements embedded in it for the duration of the structure's service life.

Choosing raw materials and composing the concrete mix shall always be undertaken in the light of the special characteristics of the structure or a constituent part, as well as the nature of the loads or attacks that can be anticipated in each case.

37.3.1 Mix proportions and concrete performance

The following requirements shall be satisfied In order to ensure suitable durability of the concrete,:

a) General requirements:
   - Maximum water/cement ratio, according to 37.3.2.
   - Minimum cement content, according to 37.3.2.

b) Additional requirements:
   - Minimum occluded air, as appropriate, according to 37.3.3.
   - Use of sulphate-resistant cement, as appropriate, according to 37.3.4.
   - Use of sea water-resistant cement, as appropriate, according to 37.3.5.
   - Erosion resistance, as appropriate, according to 37.3.6.
   - Alkali-aggregate reaction resistance, as appropriate, according to 37.3.7.

37.3.2 Limitations on water and cement content

Depending on the exposure classes to which the concrete is to be subjected, as defined in 8.2.2 and 8.2.3, the specifications indicated in table 37.3.2.a shall be satisfied.

If the environment includes one or more specific exposure classes, the most severe criteria of those set out for the classes in question, shall be set for each parameter.

If additions are used to make the concrete, these may be taken into consideration for the purposes of calculating the cement content and water/cement ratio. The cement content C (kg/m^3) in table 37.3.2.a shall therefore be replaced by C+KF, and the A/C ratio replaced by A/ (C+KF) where F(kg/m^3) is the addition content and K is its coefficient of efficiency.

In case of flying ashes, a value of K not greater than 0.20 will be adopted when using a cement CEM I 32.5, neither greater than 0.40 with cements CEM I with other strength categories. The Project Manager may allow, at his responsibility, higher values of the efficiency coefficient, but not greater than 0.65, provided the deduction as a centred estimation in median of the real characteristic value, defined as the 5% quartile of the K distribution function. That estimation would be based in an experimental study previously validated by the concrete certification entity in which not only strength aspects, but also durability aspects are considered.

A value of K not exceeding 2, shall be adopted for silica fumes, apart from in concretes with a water/cement ratio of more than 0.45, which are to be subjected to exposure classes H or F, when a value of 1 shall be adopted for K.

The cement contents, when additives are used, may not be less than 200, 250 or 275 kg/m^3, depending on whether the concrete is mass, reinforced or pre-stressed concrete.

37.3.3 Resistance to water penetration

An experimental check can be undertaken on a completed porous structure, to see if its concrete is sufficiently impermeable for the environment in which it is going to be located, by verifying the concrete's water impermeability, using the low pressure water penetration depth determination method, according to la UNE 12390-8.

This verification shall be undertaken when, in accordance with 8.2.2, the general exposure classes are either III or IV, or if the environment represents any particular exposure class.

A concrete shall be deemed to be sufficiently water impermeable if the results from the water penetration test satisfy all of the following:

Environmental exposure class	Specification for the maximum depth	Specification for an average depth
IIIa, IIIb, IV, Qa, E, H, F, Qb (in the case of mass concrete or reinforced concrete elements)	50 mm	30 mm
IIIc, Qc Qb (only in the case of pre-stressed concrete elements)	30 mm	20 mm

Table 37.3.2.a Maximum water/cement ratio and minimum cement content

Mix proportioning parameter	Type of concrete	EXPOSURE CLASS												
		I	IIa	IIb	IIIa	IIIb	IIIc	IV	Qa	Qb	Qc	H	F	E
Maximum ratio a/c	mass	0,65	-	-	-	-	-	-	0,50	0,50	0,45	0,55	0,50	0,50
	reinforced	0,65	0,60	0,55	0,50	0,50	0,45	0,50	0,50	0,50	0,45	0,55	0,50	0,50
	pre-stressed	0,60	0,60	0,55	0,45	0,45	0,45	0,45	0,50	0,45	0,45	0,55	0,50	0,50
Minimum cement content (kg/m^3)	mass	200	-	-	-	-	-	-	275	300	325	275	300	275
	reinforced	250	275	300	300	325	350	325	325	350	350	300	325	300
	pre-stressed	275	300	300	300	325	350	325	325	350	350	300	325	300

Tabla 37.3.2.b Minimun strength recommended according to exposure classes (*)

Mix proportioning parameter	Type of concrete	EXPOSURE CLASS												
		I	IIa	IIb	IIIa	IIIb	IIIc	IV	Qa	Qb	Qc	H	F	E
Minimun stregth (N/mm^2)	mass	20	-	-	-	-	-	-	30	30	35	30	30	30
	reinforced	25	25	30	30	30	35	30	30	30	35	30	30	30
	pre-stressed	25	25	30	30	35	35	35	30	35	35	30	30	30

(*) These values are the generally expected strengths when using good quality aggregates and the strict specifications of durability included in this Code. It is an orientative table, to help for coherence between durability and strength specifications. In this sense, it must be remembered that in some geographic zones where aggregates only can fulfill strictly the specifications defined in this Code, it could be not easy to reach these values.

37.3.4 Frost-resistance of concrete

When a concrete is subjected to an exposure class F, a minimum occluded air content of 4.5%, determined in accordance with UNE-EN 12350-7 shall be adopted.

37.3.5 Sulphate-resistance of concrete

Where sulphate is present, the cement shall have additional sulphate resistance characteristics according to the current Code for the acceptance of cements, wherever the sulphate content of the surrounding water is 600 mg/l or more, or where the surrounding medium is soil, the sulphate content is 3,000 mg/kg or more (apart from in the case of seawater whose chloride content is more than 5,000 mg/l, when the provisions in 37.3.6 shall apply.

37.3.6 Seawater-resistance of concrete

If a structural element is subject to an environment which includes a general class of type IIIb or IIIc, the cement used shall have an additional seawater-resistance characteristic according to the Code in force for the acceptance of cements

37.3.7 Erosion-resistance of concrete

If a concrete is to be subjected to an exposure class E, an erosion-resistant concrete should be sought. The following measures shall therefore be adopted:

- Minimum cement contact and maximum water/cement ratio, according to table 37.3.2.a.
- Minimum strength of concrete of 30 N/mm^2.

- The fine aggregate shall be quartz or another material which has at least the same hardness.
- Coarse aggregate shall have a Los Angeles coefficient of less than 30.
- The cement contents indicated below for each maximum aggregate size *D* shall not be exceeded:

D	Maximum cement content
10 mm	400 kg/m^3
20 mm	375 kg/m^3
40 mm	350 kg/m^3

- Prolonged curing, lasting at least 50% longer, shall be adopted as shall the remaining requirements for a concrete not subject to erosion.

37.3.8 Alkaline-aggregate reactivity resistance

Alkaline-aggregate reactions may occur simultaneously with the presence of a humid atmosphere, the presence of a high alkaline content in the concrete and the use of aggregates containing reactive constituents.

For the purposes of this Article, damp environments shall be deemed to be environments whose general exposure class, according to 8.2.2, are other than I or IIb.

In order to prevent alkaline-aggregate reactions, one of the following measures shall be adopted:

a) The use of non-reactive aggregates, according to 28.7.6.
b) The use of cements with an alkaline content expressed as equivalent sodium oxide ($0.658\ K_2O + Na_2O$) less than 0.60% of the weight of the cement.

If the use of raw materials that satisfy the aforementioned requirements is impossible, an individual experimental study shall be conducted on the suitability of adopting one of the following measures:

a) Use of cements containing additives, apart from lime, stone filler, according to la UNE 80301 and UNE 80307.
b) Use of additives in the concrete, according to the specifications in 30.

In these situations, the suitability of adopting an additional protection in the form of surface waterproofing may also be examined.

37.4 Corrosion of reinforcements

The reinforcements shall be corrosion-free for the entire service life of the structure. The corrosion aggressivity of the environment for the reinforcements is defined using the general exposure classes, according to 8.2.2.

In order to prevent corrosion, all the considerations relating to covering thicknesses, indicated in 37.2.4 shall be taken into consideration.

Unless cathodic protection systems are used, reinforcements shall not be allowed to come into contact with other metals with a very different galvanic potential.

This Code covers the option to use systems for protecting reinforcements from corrosion in accordance with the provisions in 37.2.7.

Similarly, the use of constituent materials that contain depassivating ions, such as chlorides, sulphides or sulphates in proportions greater than those indicated in Articles 27, 28, 29 and 30, is also prohibited.

37.4.1 Corrosion of passive reinforcements

In addition to the specific restriction on the chloride ion content for each of the content's constituent materials, the total chloride content in a concrete containing passive reinforcements shall be less than the following limits:

- Reinforced concrete structures or mass concrete structures containing reinforcements to prevent cracking: 0.4% of the cement weight

37.4.2 Corrosion of active reinforcements

The use in pre-stressed structures of any substance that catalyses the absorption of hydrogen by the steel is prohibited.

In addition to the specific limitation on the chloride ion content for each of its constituent materials, the total chloride content of a pre-stressed concrete shall not exceed 0.2% of the cement weight.

Splices or fixings made from metals other than steel and cathodic protection are prohibited.

Metal coated steel shall generally not be used. The Project Manager shall permit this form of protection to be used use if an experimental study confirming its performance as suitable for each specific structure is carried out.

37.4.3 Protection and conservation of active reinforcements and anchorages

The precautions necessary to prevent active reinforcements being damaged, particularly notches forming or local temperature rises being generated that could modify their characteristics or lead to incipient corrosion during their storage, installation, or following their incorporation in the structure, shall be adopted.