Durability

CHAPTER VII

Article 37 Durability of concrete and reinforcements.

37.1 General

The durability of a concrete structure refers to its ability to withstand the physical and chemical conditions to which it is exposed, throughout its design service life, which may cause it to deteriorate as a result of the various effects of the loads and stresses considered in structural analysis.

A durable structure must be achieved through a strategy which takes into account all possible degradation factors and acts accordingly during every stage of design, execution and use of the structure.

A correct durability strategy should take into account the fact that inside a single structure there may be various structural elements subject to different types of environment.

COMMENTS

The article sets out a method directed towards achieving a suitable durability in the case of conventional structures that are not subjected to out-of-the-ordinary aggressive situations. In other cases, it might be advisable to employ other durability methods, based on performance criteria.

The durability does not only involve the structural elements. At times, it is the non-structural elements that involve significant durability problems. These problems may consist of the deterioration of the actual element itself (for example, degradation of bridge sidewalk), or they may be the consequence of unsuitable performance (for example, the incorrect operation of the drainage of a bridge).

37.1.1 The consideration of durability on design.

The design of a concrete structure must include the necessary measures for the structure to last throughout its intended service life in accordance with the aggressiveness of the environment and the type of structure. For this reason, a durability strategy shall be included, in accordance with the criteria set out in 37.3.

The aggressiveness to which the structure is exposed shall be identified by the type of environment, in accordance with 8.2.1.

The choice of exposure classes considered for the structure shall be justified in the Project Description. In addition, the type of environment for which each element has been designed shall be included on the drawings.

The design shall define structural forms and details that facilitate the removal of water and which are effective against any mechanisms that might damage the concrete.

Since equipment, such as supports, joints , drains etc. may have a shorter life-span than the structure itself, design measures should be employed where appropriate to facilitate maintenance and replacement of such elements during the stage of use.

COMMENTS

In the protection against aggressive physical and chemical agents, preventive methods are usually more efficient and less costly. For this reason, durability is a quality that should be taken into account during the project design stage, by studying the nature and predicted potential intensity of the aggressive environment and choosing the structural forms, materials, dosages and execution procedures that are the most suitable in each particular situation.

The choice of environmental type should take into account the existence of a series of factors that are capable of modifying the degree of aggressiveness which, a priori, should be considered as a characteristic of the geographic area where the structure is located. In this way, relatively close locations may have different classes of exposure in function of the altitude, the general orientation of the structure, the nature of the terrain surface (vegetation coverage, rocky, etc.), the existence of urban zones , the proximity of a river, etc.

37.1.2 The consideration of durability during the execution.

A good quality in the execution, especially during the curing process, have a decisive influence to obtain a durable structure.

The specifications related to durability shall be fully complied during execution. It is forbidden to compensate for the effects that derive from the non-compliance of any of them.

COMMENTS

In accordance with the article, the use of a less permeable concrete (with a smaller water/cement ratio) should not be acceptable for alleviating the possible effect of incorrectly positioned reinforcement with concrete covers that are inferior to those indicated for the project.

37.2 Durability strategy.

37.2.1 General requirements.

In order to satisfy the requirements established in Article 5, it is necessary to adopt a strategy that takes all possible degradation mechanisms into consideration, and employs specific measures in accordance with the aggressiveness to which each element is exposed.

The durability strategy shall include the following aspects, at least :

a) Selection of suitable structural forms, in accordance with 37.2.2.

b) The obtaining of a suitable quality of concrete, especially in the outer layer, in accordance with 37.2.3.

c) The choice of a suitable cover to protect the reinforcement, in accordance with 37.2.4 and 37.2.5.

d) The control of maximum crack width, in accordance with 37.2.6.

e) The use of surface protection in the case of highly aggressive environments, in accordance with 37.2.7.

f) The adoption of anti-corrosion measures for the reinforcement, as indicated in 37.4.

37.2.2 The selection of structural form.

The design shall define structural layouts, geometric forms and details that are compatible with the achievement of sufficient durability for the structure.

The use of structural designs with particular sensitivity to water action should be avoided whenever possible.

Direct contact between concrete surfaces and water should be reduced to a minimum (e.g., through the provision of water drips).

Furthermore, the necessary elements to provide the rapid removal of water shall be incorporated into the design, including suitable channelling and drainage systems (drain-holes, gutters etc). It is particularly important to prevent water from passing over areas of joints and seals as far as is possible.

Wherever possible, the inclusion of surfaces subject to splashing or soaking in water shall be avoided.

When the structure has sections containing hollows or cavities, provision should be made for the necessary systems to ventilate and drain these areas.

Except in projects of lesser importance, provision shall be made for access to all the s elements of the structure as far as this is possible, studying the opportunity of providing specific systems to facilitate inspection and maintenance during the stage of use.

COMMENTS

A basic principle for obtaining a durable structure is the achievement of maximum isolation from water, as far as possible.

Most attacks suffered by concrete are water-related. In some case, these come through dissolved substances that penetrate through the concrete (for example, chemical attack). On other occasions, it is the water itself which is the cause of the deterioration (for example, in freezing-thawing mechanisms). Finally, there are times when, although the water is not the only or sufficient cause, it is still a necessary element for the development of the degradation processes (for example, in corrosion).

37.2.3 Requirements in relation to the quality of the concrete

A strategy which focuses on the durability of a structure should achieve suitable concrete quality, especially in more superficial areas where deterioration processes may occur.

A concrete of suitable quality is understood as meeting the following conditions.

- A choice of constituents in accordance with Articles 26 to 36.
- A suitable composition, as indicated in 37.3.1 and Article 68.
- Correct placing, in accordance with Article 70.
- Curing of the concrete in accordance with Article 74.
- Strength in accordance with the expected structural performance and consistent with the durability requirements.
- Performance meeting the requirements of 37.3.1.

37.2.4 Cover to reinforcement

The concrete covering is the distance between the outer surface of the reinforcement (including transverse reinforcement as links or stirrups) and the nearest concrete surface.

In the case of reinforcing bars or pretensioned prestressing reinforcement, the following cover shall be employed.

a) In the case of main bars, the cover should be equal to, or greater than, the diameter of the bar (or equivalent diameter in the case of a group of bars) and 0.80 times the maximum size of aggregate, unless the arrangement of the reinforcement, with regard to the faces of the element, makes it difficult for the concrete to pass, in which case the value of 1.25 times the maximum size of aggregate shall be used (see 28.2).

b) For any type of reinforcing bars (including stirrups) or pre-tensioned prestressing reinforcement, the cover shall not be less, at any point, than the minimum values given in Table 37.2.4 in accordance with the environmental exposure class (as indicated in 8.2.1). To ensure these minimum values, a nominal concrete cover r_{nom} shall be prescribed in the design, where:

$$r_{nom} = r_{mín} + \Delta r$$

where:

r_{nom} is the nominal concrete cover
$r_{mín}$ is the minimum concrete cover
Δr Margin of covering, which depends on the level of inspection of execution.

The nominal concrete cover is the value that shall be prescribed in the design and shown on the drawings, and used to define the spacers.

The minimum concrete cover is the value that shall be guaranteed at any point of the element; and is given in Table 37.2.4.

The margin of covering is a function of the level of inspection of execution , and should be:

- 0 mm in precast elements manufactured with a high level of inspection of execution

- 5 mm in the case of in situ elements with a high level of inspection of execution, and
- 10 mm in all other cases.

Table 37.2.4 Minimum cover to reinforcement

Characteristic strength of concrete. [N/mm^2]	Type of Element	MINIMUM CONCRETE COVER [mm] IN ACCORDANCE WITH THE EXPOSURE CLASS (**)									
		I	IIa	IIb	IIIc	IIIb	IIIc	IV	Qa	Qb	Qc
$25 \le f_{ck} < 40$	general	20	25	30	35	35	40	35	40	(*)	(*)
	precast elements and shells	15	20	25	30	30	35	30	35	(*)	(*)
$f_{ck} \ge 40$	general	15	20	25	30	30	35	30	35	(*)	(*)
	precast elements and shells	15	20	25	25	25	30	25	30	(*)	(*)

(*) The designer shall establish the concrete cover to provide sufficient guarantee that the reinforcement is protected against aggressive environmental action.

(**) In the case of H, F or E exposure classes, the concrete cover is not affected.

In the case of elements (joists or slabs) that are precast on factory for reinforced or prestressed concrete one-way floor slabs, the designer may add to the actual concrete cover the thickness of any finished, permanent floor slab facings that are compact and impermeable in order to meet the requirements of Table 37.2.4. In such cases, however, the actual concrete cover shall never be less than 15 mm.

c) The concrete cover over bent bars shall not be less than two diameters, as measured perpendicularly to the plane of the bend.

d) If, due to any reason (durability, fire protection or the use of groups of bars), the concrete cover were to be greater than 50 mm, it may be recommendable to place some distribution fabric in the middle of the thickness of cover in the tension zone, with a geometrical percentage of reinforcement (reinforcing ratio) of 0.05% of the cover area for bars or groups of bars of diameter (or equivalent diameter) equal to, or less than, 32 mm, and 1% for diameters (or equivalent diameters) greater than 32 mm.

e) In members concreting against ground the minimum concrete cover shall be 70 mm, unless the ground has been previously prepared and blinding concrete laid, in which case Table 37.2.4 applies. This case is not governed by the provisions of sub-section d).

In the case of post-tensioned reinforcement, the concrete cover (Figure 37.2.4.a) shall be at least equal to the largest of the following limits.

- in the vertical direction:
  - 4 cm;
  - the horizontal dimension of the sheath or group of sheaths in horizontal contact;
- in the horizontal direction:
  - 4 cm;

- half the vertical dimension of the sheath or the group of sheaths in contact;
- the horizontal dimension of the sheath or group of sheaths in horizontal contact.

In specific cases of strongly aggressive atmospheres or special fire hazard, the concrete cover indicated in this article shall be increased.

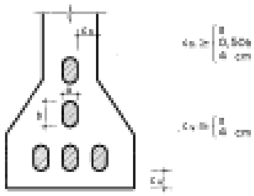

Figure 37.2.4.a

COMMENTS

The concrete cover thickness is a very important parameter in the achievement of suitable reinforcement protection during the service life of the structure . The period of time during which the concrete of the cover protects the reinforcement is a function of the square of the concrete cover thickness. This means that a reduction of the cover to one half of its nominal thickness may translate into the reduction of the reinforcement protection period to one quarter.

The values given in Table 37.2.4. are the absolute minimum, that may not be reduced any further under any circumstances, and to which the margin of covering indicated in the article shall be added, which will result in the nominal cover prescribed for the project. When the concrete cover is monitored after the placing and hardening of the concrete, the average values shall exceed, at all points, the minimum covers given in the table.

In the case of standard beams, the application of the article leads to an arrangement of the distribution fabric A_s as indicated in Figure 37.2.4.b, where A_r is the cover area (shaded zone).

In the case of highly aggressive environments, the value of the concrete covers and other project provisions shall be established, with prior consultation of specialised technical literature, in accordance with the nature of the environment, the type of structural element being dealt with etc.

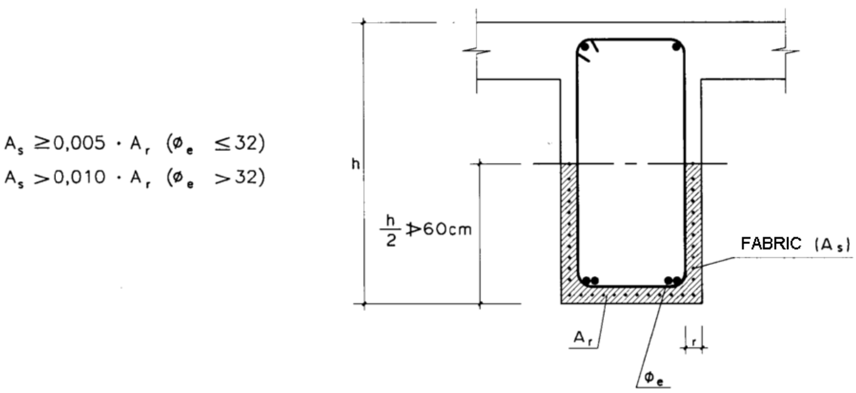

Figure 37.2.4.b

37.2.5 Spacers

The concrete cover shall be guaranteed through the arrangement of appropriate spacing elements placed on site.

These chairs or spacers shall be arranged in accordance with the provisions of 66.2. They shall be made of materials able to withstand the alkalinity of the concrete and which do not induce corrosion in the reinforcement. They shall be at least as impermeable to water as the concrete itself and able to withstand any chemical attacks to which the same concrete may be subjected.

Regardless of whether they are temporary or permanent, they shall be made of concrete, mortar, rigid plastic or any similar material and should have been specifically designed for this purpose.

If the spacers are made of concrete, this should have a comparable quality, with regards to strength, permeability, hygroscopicity , thermal expansion etc, to that employed in the construction of the member. Similarly, if they are made of mortar, they should have a quality similar to that of the mortar content in the concrete of the member.

When spacers are employed that are made of a material that does not contain cement, they shall have holes with a total cross-sectional area equivalent to at least 25% of the surface area of the spacer to guarantee a good adhesion to the concrete of the member.

The use of wood, together with any construction residue, even brick or concrete, is forbidden. In those cases where these remain visible, the use of metal materials is also forbidden.

COMMENTS

The article requires the use of elements specifically designed, by their strength, rigidity and permeability, as spacers.

It is recommended that the constituents of the spacers do not contain asbestos.

The spacers or chairs may be individual elements or in the form of specific spacer systems that facilitates their placing.

37.2.6 Maximum crack width

Durability, together with functional and appearance considerations, are some of the criteria on which the need to limit crack width is based. The maximum width values to be considered, depending on the environmental exposure class, are those indicated in 49.2.4

COMMENTS

In the case of reinforced concrete structures, the influence of crack width on reinforcement corrosion may be relatively small, always provided that this width remains within a range of sufficiently low values. To a large extent, this is due to the tendency of self-sealing, which prevents any acceleration of the processes involved in corrosion.

Longitudinal cracking in the reinforcement is of greater significance than that in a horizontal direction, since its effects are more generalised and, additionally, it leads to a higher probability of covering loss.

37.2.7 Special protection measures.

In cases of highly aggressive environments, in which normal protection measures are not considered sufficient, special protection systems may be employed.

These additional protective measures may even have a shorter service life than that of the structural element itself. In such cases, the design shall include maintenance strategies of the protection system.

COMMENTS

Some examples of special protection measures are given below:

- The application of surface layers with specific products for concrete protection.
- The protection of the steel reinforcement using paint or coverings.
- Cathodic protection of steel reinforcement.

37.3 Concrete durability

The concrete durability is its ability to perform satisfactorily in the presence of aggressive physical or chemical actions and to provide adequate protection of the reinforcement and other metal elements embedded in the concrete during the service life of the structure.

The choice of constituents and concrete composition shall always be made taking into account the particular characteristics of the works, or the part of the same that is under consideration, and the nature of the actions or attacks that might be expected in each case.

37.3.1 Composition and performance requirements of concrete

The following requirements shall be satisfied in order to achieve adequate durability of concrete:

a) General requirements:
- Maximum water/cement ratio, in accordance 37.3.2.
- Minimum cement content, in accordance with 37.3.2.

b) Additional requirements:
- Minimum content of entrained air, where applicable, according to 37.3.3
- Sulphate resistance, where applicable, according to 37.3.4.
- Sea-water resistance, where applicable, according to 37.30,5.
- Erosion resistance, where applicable, in accordance with 37.3.6.
- Alkali-aggregate reaction resistance, where applicable, in accordance with 37.3.7.

COMMENTS

In some environments where their aggressive nature is related to chemical processes, the use of a suitable type of cement contribute to obtain a durable concrete. In these cases, it is especially advisable to follow the guidance for the use of cement given in Annex 3 of this Instruction.

37.3.2 Limitations to water and cement contents

The requirements given in Table 37.3.2.a shall be met in accordance with the exposure classes to which the concrete will be subjected, as defined by 8.2.2 and 8.2.3.

When the type of environment includes one or more specific exposure classes, the most demanding criterion ,among those established for the classes in question, shall be used for each parameter.

Where additions are used in concrete, they may be taken into account in the concrete composition with respect to the cement content and water/cement ratio. For such purposes, the cement content C (kg/m3) shall be replaced in Table 37.3.2.a by C + KF, and the A/C ratio shall be replaced by A/(C + KF), where F (kg/m3) is the addition content and K is its coefficient of effectiveness.

In the case of fly-ash, a value of K not greater than 0.30 shall be adopted. The Project Manager may allow a higher value of K than that indicated, but no higher than 0.40 for building work or 0.50 for public works, provided that the value is obtained from the results of an exhaustive experimental study carried out in advance, in which the aspects taken into consideration included not only strength, but also durability.

In the case of silica fume, a value of K not greater than 2 shall be adopted, except in concretes with a water/cement ratio greater than 0.45 that are to be subjected to exposure classes H or F, in which case K shall have a value of 1.

Where additions are used, the cement content shall not be less than 200, 250 or 275 kg/m3, for mass, reinforced or prestressed concrete respectively.

An experimental way of indirectly confirming that the requirements for minimum cement content and maximum water/cement ratio are met, is to check the permeability of the concrete to water by means of the method of determining the depth of penetration of water under pressure, in accordance with UNE 83309:90 EX. Its objective is to validate compositions, in accordance with Article 85.

This check shall be carried out when, in accordance with 8.2.2, the general exposure classes are III or IV, or when the environment has any specific exposure class.

A concrete is considered sufficiently impermeable to water when the results of the water penetration test meet both the following conditions

- The maximum depth of water penetration is less than, or equal to, 50 mm.
- The average depth of water penetration is less than, or equal to, 30 mm.

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

	Type of concrete	EXPOSURE CLASS I	IIa	IIb	IIIa	IIIb	IIIc	IV	Qa	Qb	Qc	H	F	E
maximum water/cement ratio	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
	prestressed	0.60	0.60	0.55	0.50	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
	prestressed	275	300	300	300	325	350	325	325	350	350	300	325	300

Table 37.3.2.b Minimum strengths compatible with durability requirements

	Type of concrete	EXPOSURE CLASS I	IIa	IIb	IIIa	IIIb	IIIc	IV	Qa	Qb	Qc	H	F	E
Minimum strength (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
	prestressed	25	25	30	30	35	35	35	30	35	35	30	30	30

COMMENTS

One method of guaranteeing concrete durability, together with its protection of the steel reinforcement against corrosion, is to obtain a concrete with reduced permeability. In order to obtain this, it is essential to select s sufficiently low water/cement ratio, a suitable concrete compaction, cement content, together with sufficient hydration of the latter, achieved through careful curing. Minima cement contents established in the article are absolute values. Design mix tolerances specified in 69.2.4.1 and 69.2.9.1 must fulfil these values.

It is pointed out that the maximum cement content in the concrete is limited to 400 kg/m^3 (article 68), except in exceptional cases.

The mechanical strength of concrete shall not be used as a determining factor of suitability against durability, nor as substitute for the stated composition requirements. However, the specifications for the water/cement ratio and cement content condition the specification of a concrete where the mechanical characteristics shall be coherent with the prescribed parameters. For purely information purposes, and in order to encourage this coherence, Table 37.3.2.b gives minimum strength categories that may be taken as being compatible with the given specifications for each environmental exposure class.

The most suitable method of reducing attacks on the concrete is to reduce at minimum the volume of pores forming a capillary network with a very little connections. This objective is traying to be obtained through the requirements for the water and cement contents given in the article. Since there are no standard methods to control these contents, it is necessary to employ other indirect means through performance tests, such as that for water penetration as described in the article.

The impermeability of the concrete to water is considered as being a necessary condition, although not the only one, for achieving suitable behaviour against aggressive attacks. On the other hand, permeability is not the only mechanism in the processes of concrete degradation, since there are others that are linked to water absorption and gas and ion diffusion phenomena.

37.3.3 Frost resistance of concrete.

When concrete is subjected to exposure class F, it shall have a content of entrained air not less than 4.5% , determined in accordance with UNE 83315:96.

COMMENTS

When the concrete is subject to H or F exposure classes, it is recommended that the Project Specification includes compliance of the requirements in relation to aggregate stability against sodium or magnesium solution (see 28.3.2).

37.3.4 Concrete resistance to sulphate attack.

where sulphates are present with a content equal to, or greater than, 600 mg/l in the case of water, or equal to, or greater than, 3000 mg/kg in the case of soil, the cement shall have the additional property of sulphate resistance in accordance with UNE 80303:96, .

37.3.5 Resistance of concrete to seawater attack

where a structural element is exposed to an environment that includes a general class type IIIb or IIIc, the cement to be used shall have the additional property of seawater resistance, in accordance with UNE 80303:96.

COMMENTS

The type of attack suffered by concrete due to sea water action is basically that of the combined sulphate and magnesium ion action. Independently of their effect on the steel reinforcement, the presence of chlorides will noticeably reduce sulphate action.

37.3.6 Erosion resistance of concrete

When concrete is to be subjected to exposure class E, an erosion resistant concrete shall be used. For this purpose, the following shall be adopted.

- Minimum cement content and maximum water/cement ratio in accordance with Table 37.3.2.a.
- Minimum concrete strength of 30 N/mm^2.
- The fine aggregate should be quartz or another material of at least the same hardness.
- The coarse aggregate shall have a Los Angeles coefficient of less than 30.
- The cement content indicated below for each maximum upper 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

- Curing duration at least 50% longer than that for concrete not subject to erosion, with all other conditions being equal.

37.3.7 Resistance to alkali-aggregate reactivity

Alkali-aggregate reactions can occur where the environment is wet, the concrete has a high alkali content and aggregates containing reactive components have been employed.

For the purposes of this article, wet environments are those with a general exposure class other than I or IIb in accordance with 8.2.2.

The following measures shall be adopted to prevent alkali-aggregate reactions.

a) Non-reactive aggregates shall be employed, in accordance with 28.3.1.
b) The use of cements with an alkali content, expressed as sodium oxide equivalent (0.658 K_2O + Na_2O), of less than 0.60% by mass .

Where it is not possible to use constituents that meet the above requirements, a specific experimental study shall be carried out to establish the suitability of adopting one of the following measures.

a) The use of blended cements with additionsother than lime fillers, in accordance with UNE 80301:96 and UNE 80307:96.
b) The use of additions to concrete, as specified in 29.2

In these cases, the suitability of adopting further protective measures by surface waterproofing methods may also be studied.

COMMENTS

Alkali-aggregate reactions take place between the alkalis present in the water within the concrete pores and certain reactive components that exist in certain aggregates. As a consequence of this process, compounds are produced that have an expansive nature and which can lead to cracking occurring in the concrete.

Various types of attacks may be produced, depending on the type of reactive component in the aggregate.

- An alkali-silica reaction, when the aggregate contains amorphous, micro-crystalline or slightly crystallised silica or with undulating extinction.
- An alkali-carbonate reaction, when the aggregates have a dolomite nature.

37.4 Steel Reinforcement corrosion

The steel reinforcement shall remain free from corrosion throughout the service life of the structure. The aggressiveness of the environment in relation to reinforcement corrosion is defined by the general exposure classes in accordance with 8.2.2.

In order to prevent corrosion, all the considerations with regards concrete cover indicated in 37.2.4 should be taken into account.

In relation to the materials used, it is forbidden to allow the steel reinforcement to come into contact with other metals of varying galvanic potential.

In addition, the ban on the use of constituent materials containing depassivating ions, such as chlorides, sulphides and sulphates, in proportions that are greater than those indicated in articles 27, 28 and 29 should be noted.

COMMENTS

Steel Reinforcement embedded in Portland cement concrete may be maintained corrosion free indefinitely, due to the alkaline protection effect provided by the cement on hydration. This protection is lost when the alkalinity is neutralised, as a result of the penetration of atmospheric carbon dioxide through the concrete pores (carbonation), or by the action of chloride ions. These latter components may come from the constituents used in the concrete, or they may penetrate from the outside (for example, in a marine environment):

Additionally, corrosion may be produced in the steel reinforcement due to corrosion phenomenon under stress or hydrogen brittleness in the case of prestressed concrete, when a specific aggressive medium and a determined level of stress.

Under no circumstance, whether due to conditions of formation or due to its very nature, will the corrosion products guarantee the final protection of the steel reinforcement, so that once the corrosion process has been initiated, it will progress continually, as long as the originating cause persists. In addition to this, the corrosion products form with an expansive nature, and produce high pressures that may produce the cracking of concrete, close to the reinforcement, and the opening of further channels for the aggressive agents penetration. This shows the great importance of compactness and concrete covers in the protection of steel reinforcement.

37.4.1 Reinforcement corrosion

In addition to the specific limitation on chloride ion content for each constituent material, the total chloride ion content in concrete containing reinforcement shall be below the following limits:

- reinforced concrete works or mass concrete works that contain reinforcement to reduce cracking: 0.4% of the weight of the cement

37.4.2 Prestressing reinforcement corrosion

In the case of prestressed structures, the use of any substance that might catalyse the absorption of hydrogen by the steel is forbidden.

In addition to the specific limitation on chloride ion content for each constituent material, the total chloride ion content in prestressed concrete shall not exceed 0.2% of the mass of the cement.

The use of couplers (connections) or grips (links) made of metals other than steel is forbidden, which also applies to cathodic protection.

In general, the use of steels with protective metal coatings is not allowed. The Project Manager may allow their use in a situation where an experimental study has shown that their performance is suitable for the particular case of each project.

COMMENTS

In prestressed structures, there is a special risk of corrosion in prestressing reinforcement, whereby microscopic fissures appear which provoke brittle breakage.

These failures are due to the propagation resulting from the tensional state of the existing micro-fissures in the steel These may have their origin in the actual material itself (under-stress corrosion) or be the consequence of hydrogen absorption by the steel under certain conditions (hydrogen brittleness). The precautions that are recommended in order to avoid these phenomena are as follows:

- To comply with the requirements given in this Instruction for harmful substances that may favour the appearance of corrosion, with special emphasis on the control of chlorides, sulphates and sulphites.
- Avoid the use of those types of additions that could cause the freeing of hydrogen capable of penetrating into the steel.
- Not employing steel that has been protected with a metal covering, except in the case of phosphate treatments.

The environmental aggressiveness and alternate or repeated forces make up an additional danger factor for this type of phenomena.

One test that could be performed in order to determine the sensitivity of the steel to corrosion under stress due to the fissuring action of hydrogen is the ammonia thyocyanate test (UNE 36464:86). In this test, the resistance to corrosion under stress of a prestressed steel is considered to be sufficient, if the minimum and average duration of a group of at least six test bars meet the requirements given in Table 37.4.2.

Table 37.4.2

Type of reinforcement	Minimum failure time (hours)	Average failure time (hours)
Wires	1,5	4
Strands	1,5	4
Bars from 16 to 25 mm diameter	60	250
Bars with a diameter exceeding 25 mm	100	400

37.4.3 Protection and maintenance of prestressing reinforcement and anchorages

During the storage and placement of active reinforcement and afterwards, the necessary precautions shall be taken to prevent any damage, particularly notching or local heating, which could modify its properties or lead to a process of corrosion.

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