SECTION 5 EXECUTION

EXECUTION

CHAPTER XIII

Article 65 Falsework, formwork and moulds

The falsework, formwork and moulds, and the joints between the various elements, should have sufficient strength and rigidity to ensure compliance with all dimensional tolerances and to resist, without any detrimental settlement or deformation, those actions of any kind to which they may potentially be subjected as a result of the concreting operation, and especially under the pressure of the fresh concrete or the effects of the compaction method used. Such conditions shall be maintained until the concrete has acquired sufficient strength to withstand, with a suitable safety margin, the stresses to which it will be subjected during the removal of formwork, moulds or falsework.

These elements shall be placed in such a way as to prevent any damage to structures that have already been built.

The supplier shall justify and guarantee the properties of the shoring and shall specify the conditions under which the same is to be used.

The use of aluminium for moulds that have to get in contact with the concrete is expressly forbidden.

The formwork and moulds shall be sufficiently tightness, with respect to the compaction method employed, to avoid any appreciable losses of cement slurry or mortar, and to obtain a fully formed concrete surfaces.

Wooden formwork and moulds shall be wetted prior to use, in order to prevent them from absorbing the water contained in the concrete. Additionally, wooden elements shall be arranged in such a way that they are able to swell, without the risk of the production of any abnormal stresses or strains.

The inner surfaces of formwork and moulds shall be clean when the concrete is placed and in such a condition that guarantees that they can be freely separated from the concrete, thus preventing the appearance of cracking in the surfaces of the members. In order to facilitate cleaning at the bottom of columns and walls, temporary openings shall be provided in the lower part of the corresponding formwork.

In the case of prestressed concrete, the falsework, formwork and moulds shall provide adequate resistance to any redistribution of loads that may occur during the prestressing of the reinforcement, as a result of the transfer of prestress to the concrete. In addition, they shall allow the deformation of the members cast inside them, particularly elongation, shortening and contra-flexure, which shall not be restricted.

These elements shall be designed in order to allow the reinforcement and prestressing tendons to be correctly positioned and the concrete to be suitably compacted.

It shall be possible for both formwork and moulds to be struck without causing any impact or damage to the concrete.

The use of products to facilitate the removal of formwork or moulds from members requires, in all cases, the express authorisation of the Works Manager. Such products shall not leave any traces or have any damaging effect on the concrete surface, and they shall not run down the vertical or sloping surfaces of either the moulds or the formwork. Additionally, they shall not prevent the subsequent coatings or the construction of any concrete joints, especially in the case of those elements that are subsequently to be joined together to function as a single element.

The approved formwork or mould release agents shall be applied in continuous and uniform layers on the inner surface of the formwork or mould, and the concrete shall be placed during the period that these products remain effective.

Fuel oil, ordinary grease or any other similar product shall not be used; instead, non-stick varnishes composed of silicones or preparations based on water or soluble oils or dilute grease may be employed.

COMMENTS

For the purposes of this Instruction, formwork is the component employed in on-site concreting of any section of the structure, and mould is the term used for the same object, but when the concreting takes place at a manufacturing plant or workshop and not on site.

The Project specifications shall establish the maximum movements that may be produced in the falsework, formwork and moulds. As a guideline, five millimetres may be fixed for local movements and one thousandth of the span for those of the entire structure.

The falsework, formwork and moulds shall be designed so that they are able to withstand the most unfavourable combination of its own weight, reinforcement weight, pressure and weight of the fresh concrete, construction and wind loading, together with the combined accidental dynamic effects produced by placing, vibration and compaction of the concrete.

As is well known, the static pressure produced by the concrete on the formwork or moulds increases with the height of the fresh mass of the concrete they contain. Furthermore, the speed of placing, the vibration applied in order to compact the concrete, the use of certain admixtures (plasticisers, setting delay agents, etc.) lead to additional pressure, which should be taken into account when employing formwork and moulds so that their rigidity may be guaranteed and the appearance of all unwanted deformation may be avoided.

When the span of an element exceeds six metres, it is recommended that the falsework, formwork and moulds be arranged in such a manner that once they have been removed and the member has been loaded, the latter presents a slight contra-flexure (in the order of thousandths of the span) in order to produce an attractive appearance.

Article 66 Bar bending and the placement of steel reinforcement

66.1 General

For bar bending and the placement of steel reinforcement, the provisions given in UNE 36831:97 shall be followed.

Steel reinforcement shall be free from paint, grease or any other harmful substance that could adversely affect the steel, the concrete or the bonding between them. They shall be placed according to the project indications, secured and fixed so that their specified position will not vary during transport, assembly and placing of concrete, and to enable concrete to surround them without leaving any air cavities.

If the steel reinforcement has an excessive level of oxidation, which could affect its bonding properties, a check shall be made to ensure that these properties have not undergone a significant alteration. For this reason, the reinforcement shall be cleaned with a wire brush and a check shall be carried out to guarantee that any weight loss does not exceed 1% and that the height of the ribs, in the case of ribbed steel, lies within the limits specified in 31.3.

The reinforcement elements shall be secured inside the formwork or moulds to prevent any type of displacement (movement), and their positions shall be checked before concreting.

In beams and similar elements that are subjected to bending, bent bars shall be adequately surrounded by links or stirrups in the region of the bend. This disposition is always recommended, no matter what type of element is employed. When many bars are simultaneously bent , it is recommended that the diameter of the stirrups in this region be increased or their spacing reduced.

Reinforcement elements may be welded together provided that the operation is performed in accordance with the procedures laid down in UNE 36832:97, that the steel is of a weldable type, and that it be carried out in a workshop with a fixed industrial installation. Only in those specific cases mentioned in the project, and with specific authorisation from the Works Manager, may steel reinforcement be welded on site.

The links in columns or stirrups in beams shall be fixed to the main bars using simple wire ties or other suitable procedures, however, once the steel is inside the moulds or formwork any fixing by means of spot-welding is expressly forbidden.

The simultaneous use of steels with different yield strengths should be avoided Nevertheless, in those situations where there is no possible danger of confusion, two different types of steel may be used for the steel reinforcement within the same element: one for the main reinforcement and the other for the stirrups.

In those exceptional cases where it is not possible to avoid the use of two steels with differing yield strengths with the same structural function in the same section of an element, the provisions contained in 38.3 shall apply.

In the works execution, the provisions given in 66.5 and 66.6 shall be complied with in all cases.

COMMENTS

The bars of different types should be stored separately. To prevent any possible confusion, the bars shall be colour-coded following a pre-established colour code that has been approved by the Works manager.

66.2 Spacer distribution

The positions that are specified for steel reinforcement and particularly the minimum cover indicated in 37.2.4 shall be guaranteed by using the appropriate elements (spacers or chairs) placed on site. These elements shall comply with the provisions of 37.2.5, and shall be distributed in accordance with the specifications given in Table 66.2.

Table 66.2
Spacer distribution

Element		Maximum distance
Broad horizontal elements (slabs, floor slabs, footings, raft foundations, etc.).	Lower grid	50 Ø ≤ 100 cm
	Upper grid	50 Ø ≤ 50 cm
Walls	Each grid	50 Ø or 50 cm
	Grid separation	100 cm
Beams [1]		100 cm
Columns [1]		100 Ø ≤ 200 cm

[1] At least three planes of spacers shall be employed per bay, in the case of beams, and per length, in the case of columns, and which are connected to the links or stirrups.

Ø The diameter of the reinforcement to which the spacer is connected.

66.3 Steel reinforcement bending

Reinforcing bars shall be bent in accordance with the project drawings and instructions. In general, this operation shall be performed cold by mechanical means at a uniform rate with the aid of mandrels, so that the curvature is constant throughout the area.

Bends, including those supplied, shall not be straightened, unless this operation can be carried out without any immediate or potential future damage to the corresponding bar.

Should be absolutely necessary to straighten bent bars on site, as for example, in the case of certain starter bars, it shall be performed in accordance with proven procedures or criteria and the reinforcing bars shall then be checked for the presence of fissures or fractures. If any are discovered, the damaged elements shall be replaced. If the straightening operation is carried out hot, suitable measures shall be adopted to prevent the concrete being damaged due to the high temperatures.

The minimum bending diameter for a bar shall be such that it does not produce excessive compression and cracking of the concrete in the region of the bend, and the bending shall not cause any fracturing of the bar itself.

In addition, a large number of bars shall not be bent in the same section of the member, in order to avoid producing a stress concentration within the concrete that could become dangerous.

Unless the project indicates otherwise, bars shall be bent around mandrels with a diameter no smaller than those diameters given in Table 66.3.

Table 66.3
Minimum diameter mandrels for bars

Ribbed bars	Hooks, bends and loops (See Figure 66.5.1.a).		Bent bars and other curved bars	
	Bar diameter in mm		Bar diameter in mm	
	Ø < 20	Ø≥20	Ø≤25	Ø > 25
B 400 S	4Ø	7Ø	10Ø	12Ø
B 500 S	4Ø	7Ø	12Ø	14Ø

Links or stirrups with a diameter equal to, or less than, 12 mm may be bent to smaller diameters than those given in the above table, provided that this does not cause them to become cracked. To prevent such cracking, the diameter used shall be no less than 3 times the diameter of the bar or 3 centimetres, whichever is the larger.

In the case of wire fabrics, the limitations given above will also apply, provided that the bending is performed at a distance equal to, or greater than, four bar diameters from the closest node or weld. If this is not the case, then the minimum bending diameter shall not be less than 20 times the diameter of the reinforcement.

COMMENTS

Bending rate should take into account the type of steel and the surrounding temperature. low temperatures may lead to fragile breakage due to shock or bending.

ending at heavily stressed areas, or with smaller diameters than those prescribed in the article, shall be studied in order to establish the minimum value that may be assigned to these diameters without producing any danger of damage to the concrete corresponding to the change of reinforcement direction. The most detrimental effect of tensile stresses, that tend to split the concrete, than compressive stresses produced by the bend should be taken into account. In such cases, it is always necessary to surround the bent bars with links or stirrups in those areas corresponding to the bends.

With respect to the bending of links or stirrups, particularly if they are made from special steel, emphasis is placed on the risk involved in carrying out this operation with small diameters, due to the potential for the formation of the beginning of a crack, whether visible or not, with the consequent danger of the future corrosion of the bar. An identical risk is involved when straightening a bend.

66.4 Spacing between reinforcing bars

Steel reinforcement shall be distributed in such a way as to permit that all the bars, or bundles of bars, are completely surrounded by the concrete.

When the bars are placed in separate, horizontal layers, the bars in each layer shall be vertically aligned over those in the layer below so that there is sufficient space between the resulting columns of bars to allow for the insertion of an internal vibrator.

The following requirements apply to ordinary on-site concreting work. With provisional works, or in special cases requiring very careful execution (precast elements, for example), the minimum spacing, as indicated in the following sub-sections, may be reduced if it is previously justified.

COMMENTS

Areas having a high reinforcement density, such as the crosses of structural elements, anchoring zones etc, constitute a special case where the minimum distances as indicated in this section may be reduced, always provided that particular care is taken with the execution. In other words, whenever correct concreting of the member can be guaranteed, so that all the bars are completely surrounded by concrete.

It is often a good practice to pair up the stirrups and even the longitudinal reinforcement when the separation is small in order to facilitate the passing of the concrete.

66.4.1 Individual bars

Except as indicated in 66.4.2, the horizontal and vertical free distance between two consecutive individual bars shall be equal to, or greater than, the greater of the following three values:

a) two centimetres;
b) the diameter of the largest;
c) 1.25 times the maximum aggregate size (see 28.2).

COMMENTS

where there are several layers of bars for reinforcement, it is recommended that the minimum separation given in the article be prudently increased.

66.4.2 Bundles of bars

The term “bundle of bars” is applied to two or more ribbed bars placed in contact.

As a general rule, bundles of up to three bars may be used as the main reinforcement. In the case of compressed members that are concreted in a vertical position, having dimensions that do not require the use of couplers in the reinforcement, bundles of up to four bars may be used.

In determining the depth of covering and the free distances between neighbouring reinforcement elements for bundles of bars, the diameter of each bundle shall be taken as being that of the circular section with an equivalent area to the sum of the areas of the bars that it consists of. The covering and free distances shall be measured from the true outline of the bundle.

In bundles, the number and diameter of bars shall be such that the equivalent diameter of the bundle, as defined in the previous paragraph, is no greater than 50 mm, except in the case of compressed members that are concreted in a vertical position, for which this limit may be increased to 70 mm. In lap joint regions, the maximum number of bars in contact in the connection area shall be four

66.5 Anchorage of reinforcing bars

66.5.1 General

The basic anchorage lengths (l_b), as defined in 66.5.2, will depend on the bonding properties of the bars, and the position they occupy within the concrete member, among other factors.

With regards to the position that is occupied by the bar in the member, the following cases can be distinguished:

a) Position I, well bonded, for reinforcement which during concreting, forms an angle of between 45° and 90° with the horizontal, or if it forms an angle of less than 45° it should be located in the lower half of the section or at a distance equal to, or greater than, 30 cm from the upper surface of a concrete layer.

b) Position II, deficient bonding, for reinforcement that does not fall into any of the previous cases during the concreting operation.

In those cases where there could be dynamic effects, the anchorage lengths indicated in 66.5.2 should be increased by 10 ∅.

The anchorage length as defined in 66.5.2 and 66.5.4, shall not have any values that are smaller than the largest of the following three values:

a) 10 ∅;
b) 15 cm;
c) one third of the basic anchorage length for tension bars and two thirds of this length for compression bars.

The ends of the bars may be anchored by the standard procedures described in Figure 66.5.1 or any other mechanical procedure that has been proven by testing that can guarantee the transfer of stresses to the concrete endangering it.

In order to take into account the effect of diagonal cracking, due to shear stress, in the tension bar anchorage the envelope of bending moments shall be assumed to be shifted parallel to the main axis of the member by an amount equal to S_d in the most unfavourable direction, as indicated in 44.2.3.4.2.

At least one third of the reinforcement that is required to resist the maximum positive moment shall continue as far as the supports in the case of beam end supports, and at least one quarter in the case of intermediate supports. This reinforcement shall continue beyond the support axis by a distance that is equal to the corresponding anchorage length.

COMMENTS

The articulate limits the minimum value for the net anchorage length defined in 66.5.2 and 66.5.4 because this is, generally, a quantity smaller than the anchorage basic length. Nevertheless, where only the latest is needed, as is the case of overlapping bundles of bars defined in 66.6.3, it must be considered a basic anchorage length not lower than 10 times the diameter, and no less than 15 cm.

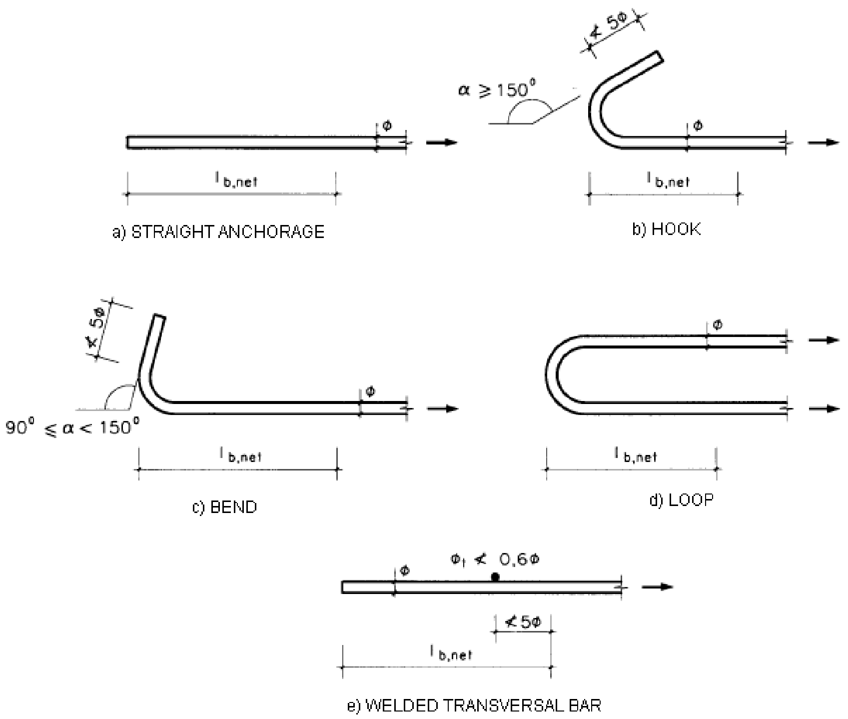


Figure 66.5.1

66.5.2 Anchorage of ribbed bars

This section refers to ribbed bars that comply with the essential requirements established in Article 31.

The basic straight anchorage length in position I is that necessary for anchoring a force $A_s f_{yd}$ of a bar assuming constant bonding stress. Among other factors, for ribbed bars this value will depend on the diameter of the bar, the quality of the concrete and the anchorage length itself; formulation is therefore complex and the following simplified formulation is employed instead.

For bars in position I:

$$l_{bl} = m\phi^2 \not< \frac{f_{yk}}{20}\phi$$

For bars in position II:

$$l_{bl} = 1.4\, m\phi^2 \not< \frac{f_{yk}}{14}\phi$$

where:

- Ø Bar diameter in centimetres;
- *m* A numerical coefficient, with the values given in Table 66.5.2.a in accordance with the type of steel, and calculated using the experimental results obtained from the bar bonding test.
- f_{yk} Guaranteed yield stress steel, in N/mm^2.

The anchorage length is defined as follows:

$$l_{b,neta} = l_b \, \beta \, \frac{A_s}{A_{s,real}}$$

where β is the reduction factor defined in table 66.5.2.b. Under no circumstances shall this value be less than that given in 66.5.1

Table 66.5.2.a

Characteristic concrete strength (N/mm²)	***m***	
	B 400 S	**B 500 S**
25	12	15
30	10	13
35	9	12
40	8	11
45	7	10
50	7	10

Table 66.5.2.b
Values of β

Type of anchorage	**Tension**	**Compression**
Straight prolongation	1	1
Hook, bend and loop	0.7 (*)	1
Welded transverse bar	0.7	0.7

(*) If the concrete covering perpendicular to the plane of bending is greater than 3ø. Otherwise β=1.

COMMENTS

Values obtained in the articulate for basic anchorage lengths l_{bI} and 1_{bII} are in cm.

66.5.3 Special rules for bundles of bars

Wherever possible, the bars in a bundle shall have straight anchorages.

When all the bars in a bundle become unnecessary in the same section, the anchorage length for the bars shall be at least:

1.3 l_b for bundles of 2 bars.
1.4 l_b for bundles of 3 bars.
1.6 l_b for bundles of 4 bars.

where l_b is the anchorage length that corresponds to a single bar.

When the bars in a bundle become unnecessary in different sections, each bar shall be provided with its own anchorage length in accordance with the following criteria:

1.2 l_b if there is 1 other bar in the section where it becomes unnecessary;
1.3 l_b if there are 2 other bars in the section where it becomes unnecessary;
1.4 l_b if there are 3 other bars in the section where it becomes unnecessary;

always taking into account the fact that the ends of the bars shall never be within a length l_b of each other (Figure 66.5.3).

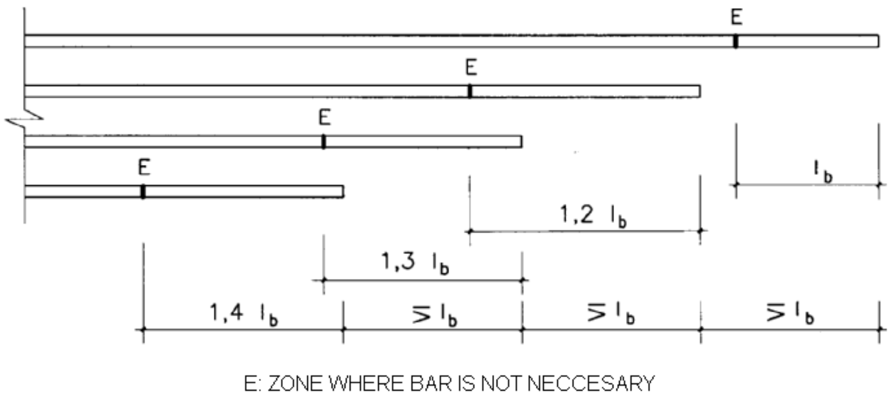


Figure 66.5.3

66.5.4 Anchorage for wire fabrics

The anchorage length of ribbed wire fabrics shall be determined using the following formula:

$$l_{b,neta} = l_b \frac{A_s}{A_{s,real}}$$

where l_b is the value given in the formulae in 66.5.2.

If there is one or more welded transverse bars in the anchorage zone, the net anchorage length shall be reduced by 30 per cent.

In all cases, the anchorage length shall never be less than the minimum values as stated in 66.5.1.

COMMENTS

That stated in 66.5.3 shall be applied in those cases of double bars when there is no specific experimental data or more precise criteria available.

66.6 Reinforcement splices

66.6.1 General

Bar splices shall be designed to guarantee that forces are transmitted from one bar to another without causing any spalling or other types of damage in the concrete next to the region (area) of the splice.

No splices other than those shown in the drawings, together with those authorised by the Works Manager, may be implemented. Splices shall be located, whenever possible, away from zones where the reinforcement is subjected to maximum loads.

Splices may be lapped or welded. Other types of splice may also be acceptable provided that the tests carried out on them demonstrate that the yield strength of the splice is permanently not less than that of the smaller of the two spliced bars and that the relative slip of the spliced bars does not exceed 0.1 mm (a highly improbable situation).

As a general rule, splices of the various tensile bars in a member shall be staggered so that there is a distance between their centres that is equal to, or greater than, l_b, measured in the direction of the bars (Figure 66.6.1).

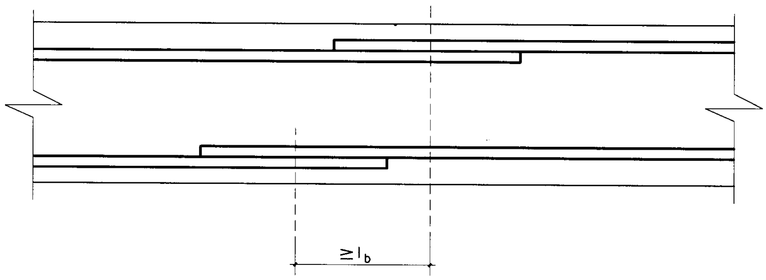


Figure 66.6.1

66.6.2 Splices by overlapping of bars

This type of splice is achieved by locating the bars side by side with a maximum clear spacing between them of 4ø. For tensile reinforcement, this spacing shall not be less than that specified in 66.4.

The lap length shall be made equal to:

$$l_s = \alpha \, l_{b,neta}$$

where $l_{b,net}$ is the value of the anchorage length as defined in 66.5.2, and α is the coefficient as defined in Table 66.6.2,which is a function of the percentage of lapped reinforcement in a section with regards to the total steel area in the same section, the transverse spacing between laps (as defined in Figure 66.6.2), and the type of stress in the bar.

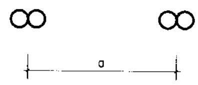


Figure 66.6.2

Table 66.6.2
Values of α

Distance between the closest laps (Figure 66.6.2.a)	Percentage of lapped bars under tension compared with the total area of steel					Lapped bars normally working under compression at any percentage
	20	25	33	50	>50	
$a \leq 10\ \varnothing$	1.2	1.4	1.6	1.8	2.0	1.0
$a > 10\ \varnothing$	1.0	1.1	1.2	1.3	1.4	1.0

In the case of bars with a diameter greater than 32 mm, lapped joints are acceptable only if it can be shown that they perform adequately in each case, on the basis of special studies.

Transverse reinforcement shall be located in the lap zone, with cross-sections that are equal to, or larger than, the cross-section of the largest lapped bar.

COMMENTS

Very careful attention shall be paid during concreting in order to guarantee that this is performed in a suitable fashion in the bar splice zones.

The lack of experience and the absence of the necessary studies on the measures to be taken in order to guarantee the correct behaviour of lapped joints employing bars having a diameter greater than 32 mm, make it necessary to advise the use of other types of splices in these cases, especially those that are made using mechanical devices such as sleeves.

66.6.3 Lapping of bundles of bars

For a lapped splice employing a bundle of bars, an extra bar having a diameter that is equal to the largest of the bars in the bundle shall be added along the whole region affected by the bar splices. The end of each bar shall be abutted against the bar it is to splice. The distance between the various splices and the end of the extra bar should be $1.2l_b$ or $1.3l_b$ depending on whether the bundles consist of two or three bars (Figure 66.6.3).

Lapped splices in four-bar bundles are forbidden.

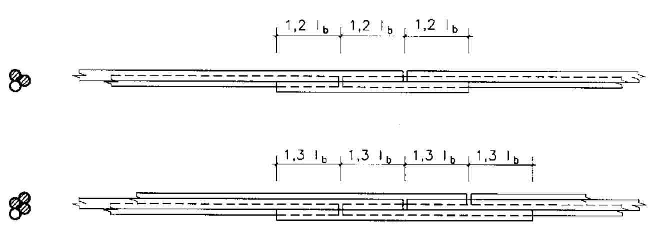


Figure 66.6.3

66.6.4 Lapping of wire fabrics

Two lap positions will be considered, in accordance with the wire fabric arrangement: intermeshed (Figure 66.6.4.a) and layered (Figures 66.6.4.b and c).

A) Intermeshed lap:

The lap length shall be $\alpha l_{b,neta}$, where $l_{b,neta}$ is the value given in 66.5.4 and α is the coefficient provided by Table 66.6.2.

For static loads, 100 per cent of the reinforcement may be lapped in the same section. For dynamic loads, 100 per cent may be lapped only if all the reinforcement is arranged in one layer; otherwise, only 50 per cent may be lapped. In the latter case, the laps shall be staggered by a length of $l_{b,net}$.

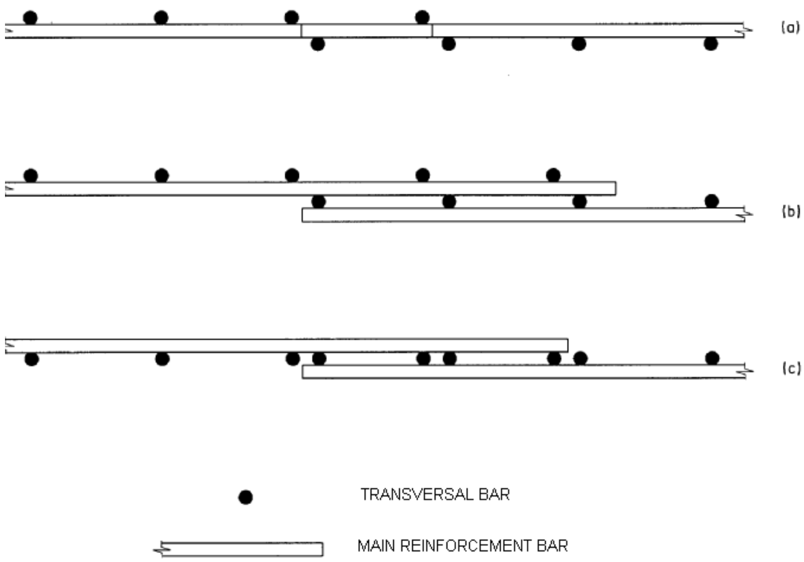
B) Layered lap

The lap length shall be 1.7 l_b when the spacing between lapped elements is greater than 10∅, increasing to 2.4 l_b when the gap is less than 10∅.

In all cases, the minimum lap length shall not be less than the greater of the following values:

a) 15∅
b) 20 cm

Whenever possible all laps shall be located in regions where the stresses in the reinforcement do not exceed 80 per cent of their maximum values. The proportion of elements that may be lapped should be 100 per cent when there is only one layer of fabric, and 60 per cent if there are more than one. In this case, the laps shall be staggered by at least $1.5 l_b$. With double bars of ∅ > 8.5 mm, only a maximum of 60 per cent of the reinforcement may be lapped.



Figures 66.6.4

66.6.5 Welded splices

Welded splices shall be performed in accordance with the welding procedures described in UNE 36832:97, and shall be carried out by duly qualified welders.

The surfaces to be welded shall be dry and free from any material that might affect the quality of the weld.

The welding of galvanised or epoxy-coated reinforcement is expressly forbidden.

Welded splices shall not be employed in strongly curved parts of the reinforcement profile.

Bars of different diameters may be butt-welded together provided that the difference between their diameters is less than 3 millimetres.

Welding shall not be carried out during strong winds, rain or snow, unless suitable precautions are taken, such as the provision of protective screens or covers, and the welds are adequately protected in order to avoid rapid cooling. Under no circumstances shall welding be carried out on a surface that is at a temperature of 0°C or less immediately before the welding operation.

COMMENTS

Since welding is a delicate job, it is recommended that the welders who are to carry out the welding operations are previously required to demonstrate their ability by being subjected to the tests as specified in UNE EN 287, Part 1:92.

The same precautions shall be taken, together with the employment of the same welding parameters and the same welding types, whether the welds are load-bearing or not, unless there are other specific instructions.

66.6.6 Splices by mechanical devices

Splices that are made using mechanical devices shall be carried out in accordance with the procedures established by the manufacturers.

Connecting devices shall have at least the same strength capacity as the smallest of the bars to be connected and shall not permit a relative displacement of more than 0.1 mm under service stress levels.

All splices of this type may be concentrated in a single section provided that this does not affect the placing of the concrete.

COMMENTS

Mechanical connections are employed when lap joints are impractical due to the lack of space in heavily reinforced members. This operation is carried out by employing members known as couplers, which have a prismatic or cylindrical shape, that enable two bars to be connected by their ends and transmit the force from the first bar to the second.

When this type of connection is employed, it should be taken into account that a local reduction in ductility may occur within the region of the splice. This reduction will depend on the type and dimensions of the splice. Special conditions may be established in the plastic structural design, when the splices are located in areas where the design has made provision for the implementation of plastic joints. For a linear elastic design with limited plastic redistribution (for example, 15% of the elastic moments) any type of connection may be employed.

Article 67 Placing and tensioning of prestressing steel

67.1 General

Depending on the manner in which it is located inside the members, three types of prestressign steel may be distinguished:

a) bonded reinforcement;
b) reinforcement in sheaths or ducts with bonding grout;
c) reinforcement in sheaths or ducts with non-bonding grout.

When it is placed, prestressing steel shall be perfectly clean, without any traces of rust, grease, oil, paint, dust, soil or any other material that may be detrimental to its conservation or bonding. It shall not reveal any signs of corrosion, apparent surface defects, welds, kinks or folds

The on-site straightening of prestressing steel is forbidden.

Prestressing steels with different properties shall not be used in the same tendon unless it has been demonstrated that there is no risk of electrolytic corrosion in the steels.

COMMENTS

The protection of tendons against corrosion is normally achieved by inserting them in ducts containing injected cement grout or other protective agents such as grease or wax.

67.2 Placing of prestressing steel

The actual profile of tendons shall be in conformity with the requirements (provisions) defined in the project by means of supports that maintain prestressing steel and sheaths in the correct positions. The spacing between supports should be such as to ensure the compliance with the profile tolerances, given in Article 96.

The supports does not lead to cracks or infiltration once the concrete has hardened.

Additionally, prestressing steel or sheaths should be secured to prevent them from moving during concreting. The use of welding for this purpose is strictly forbidden.

The tendons shall be located in the correct positions within their sheaths or ducts, and if necessary, spacers shall be used to ensure this.

When pre-tensioned reinforcement is used, they shall be slightly stressed previously, in order to verify that the spacers and end blocks, together with the wires, are correctly aligned and that the wires have not become caught up on anything or tangled.

Before the concreting operation is authorised and once the reinforcement has been located and tensioned where necessary, it should be checked to ensure that the position of the reinforcement, sheaths, anchorages and other elements is in accordance with that shown in the drawings and that the supports are sufficient to guarantee that these positions will not change during concreting. Corrections may be made where the same are necessary.

COMMENTS

Any irregularity in the reinforcement profile with respect to its correct position will modify the load distribution in the cross section of the member and could lead to stresses that were not included in the design, and which could cause cracking or other damage to the concrete and also affect the friction value between tendons and sheaths.

For this reason, it is necessary to know all the necessary data, in order to provide the correct reinforcement profile and to carry out all checks that are required during the construction phases in order to guarantee that this profile is maintained.

In order to be able to guarantee the profile conditions imposed by the project, a specific study shall be performed that will indicate the number and lay-out of the supports.

The prior tensioning that is recommended for applying to pre-tensioned reinforcement may be evaluated as being 2.25 kN per wire for diameters of up to 5 mm and as 4.5 kN for wires having a larger diameter. This load is generally sufficient to be able to consider that the wires are straight.

67.3 Prestressign steel spacing

The spacing between the prestressing ducts or tendons shall be sufficient to allow the concrete to be adequately cast and compacted and to ensure proper bonding between the tendons or sheaths and the concrete.

67.3.1 Pre-tensioned reinforcement

Pre-tensioned reinforcement shall be located separately. The minimum free spacing between individual tendons, both horizontally and vertically, shall be equal to, or greater than, the largest of the following values (see Figure 67.3.1).

a) Twenty millimetres in horizontal spacing and ten millimetres vertical.
b) The diameter of the largest;
c) 1.25 times the maximum size of the aggregate for horizontal spacing and 0.8 times for vertical (see 28.2).

COMMENTS

In the special case of particularly careful execution (for example, precast elements with very strict control), the previous minimum distances may be reduced with prior special justification.

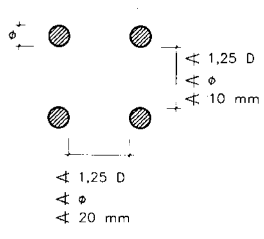


Figure 67.3.1

67.3.2 Post-tensioned reinforcement

In general, various sheaths may be placed in contact to form a group, limited to two horizontally and no more than a total of four. This requires ribbed sheaths, and sufficient space shall be left on each side of the group for the insertion of a normal internal vibrator.

The free spacing between sheaths or groups of sheaths in contact or between these sheaths and any other reinforcement shall be at least equal to the largest of the following values.

In the vertical direction:

a) The sheath diameter;
b) The vertical dimension of the sheath or group of sheaths.
c) 5 centimetres.

In the horizontal direction:

a) The sheath diameter;
b) The horizontal sheath dimension.
c) 4 centimetres.
d) 1.6 times the largest dimension of the individual sheaths that constitute a sheath group.

COMMENTS

The spacing between reinforcement that is estimated as being necessary for the insertion of a normal internal vibrator, without any risk, is 6 cm.

67.4 Bonding of prestressing steel to the concrete

The transmission length of a tendon may be defined as the length required for transferring through the bond the prestressing force , , to the concrete.The anchorage length is that required to guarantee the bonding strength of the anchorage up to the rupture point of the steel. The transmission and anchorage lengths are generally established experimentally.

COMMENTS

The transmission and anchorage lengths due to bonding of prestressing steel basically depends on three factors:

- diameter.
- surface characteristics.
- concrete strength.

when specific experimental data is not available, the transmission length may be estimated as follows:

$$l_{bpt} = \alpha_1\ \alpha_2\ \alpha_3\ \varnothing\ \ \alpha_{pi} / (4f_{bpd}\ (t))$$

where:

α_1 A coefficient having a value of 1.00 when the prestress is gradually applied or 1.25 when rapidly applied.
α_2 A coefficient having a value of 0.50 for Service Limit State verification or 1.00 for Ultimate Limit State verification.

$\varnothing$ The wire or nominal strand diameter.
α_3 A coefficient having a value of 0.50 for strands and 0.70 for indented wires.
α_{pi} The wire or strand tension when the prestress is applied.

$f_{bpd}(t)$ The design bonding tension when the prestress is applied. Table 67.4 contains the design bonding tension values at 28 days. For different ages, the design bonding tension value should be estimated in accordance with the tensile strength growth speed of the concrete (30.4.c). When the reinforcement is located in position II (see 66.5.1), the value of f_{bpt} from the table should be multiplied by 0.7.

Table 67.4
design bonding tension f_{bpd} [N/mm^2] for strands and indented wires.

Type of reinforcement	f_{bpd}(N/mm^2					
	25	30	35	40	45	50
Strands	1.4	1.6	1.8	1.9	2.1	2.2
Indented wires	1.6	1.8	2.0	2.2	2.4	2.6

and the anchorage length in accordance with the following expression:

$$l_{bpd} = l_{bpt} + \alpha_4 \varnothing (\alpha_{pd} - \alpha_{pcs}) / (4 f_{bpd})$$

where:

α_4 A coefficient having a value of 0.8 for strands or 1.0 for indented wires.
σ_{pd} The tension of the prestressing steel to be anchored.
σ_{pcs} The tension in the prestressing steel at the time of verification, taking any losses that have occurred into account.

67.5 Prestressing steel splices

Splices shall be made in the sections as stated in the project and shall be located inside suitable hollows/places of sufficient length to enable them to move freely during tensioning.

In general, couplers shall be located away from intermediate supports, and shall not be placed in more than half the tendons of a single cross-section.

COMMENTS

When couplers are employed, they shall be located by taking the interference they cause into consideration, so that the load carrying capacity of the member is not affected, and so that whatever provisional anchorage is required during construction may be satisfactorily inserted

67.6 Location of anchorage devices

All anchorage devices shall be assembled in accordance with the instructions of the supplier.

Anchor-bearing plates shall be located perpendicular to the tendon profile so that the jacks can be correctly positioned later. Any geometric deviations in the anchorages shall be corrected to avoid an abrupt change of direction of the tendons.

It should be possible to effectively fasten the anchorage devices to the formwork or mould so that they are not displaced when the member is concreting; and they should also be correctly connected to the sheaths or ducts in order to prevent any leakage of grout through the joints.

Before tensioning, all parts of the anchorage shall be thoroughly cleaned to remove any substance (grease, paint, etc.) that might be detrimental to its effective performance.

When concrete is cast around the anchorage points, it is important to compact carefully in order to avoid any cavities or air-pockets and to ensure that all the anchorage elements are both well covered and protected.

COMMENTS

As a general rule, suitable blocks shall be employed in the formwork coinciding with the points where the anchorage is to be located so that they form a box to provide support for the anchorage and facilitate the location of the material that is to be used to protect the anchoring device once the tensioning and injection have been carried out.

67.7 Placing of deflectors

The deflectors employed in internal non-bonded prestressing systems shall satisfy the following requirements:

- They shall be able to withstand the longitudinal and transverse forces transmitted to them by the tendons and then transmit these forces to the structure.

- They shall be able to guarantee continuity between two straight lengths of tendon without any unacceptable angular discontinuities.

Deflectors shall be located by following the instructions of the supplier.

COMMENTS

On design it is permitted tendon deviation, without any special support plate, up to an angle of 0.02 radians.

The forces that are produced by the deviation shall be taken into account in the project design.

67.8 Tensioning of prestressing steel

67.8.1 General

Tensioning shall be performed in accordance with an established programme in which the recommendations of the manufacturer of the employed system are taken into account. In particular, special care shall be taken to ensure the jack is centrally supported and perpendicular to the anchorage.

Tensioning shall be carried out by qualified personnel who possess all the necessary skills and experience. This operation shall be carefully supervised and controlled, and all necessary safety measures shall be adopted in order to prevent any personal injury.

Tensioning shall be applied at either one or both ends of the element, in accordance with the established schedule, and this shall be carried out in such a way that the stresses slowly and progressively increase until they reach the established design value.

Low-temperature tensioning requires special precautions.

If one or more of the elements making up the reinforcement should break during tensioning, the total prestressing force needed may still be reached by increasing the stress in the remaining ones, always provided that this does not require raising the stress in each individual element by more than 5% of the initially-planned value. The application of greater stresses would require a new study of the original design, which should be carried out on the basis of the mechanical properties of the materials that are actually used. In all such cases, it would be necessary to perform the corresponding verification of the structural member or element being prestressed, and to take the new conditions affecting it into account.

The complete loss of the prestressing force caused by the breaking of irreplaceable reinforcement elements should never exceed 2% of the total prestressing force as defined in the design.

COMMENTS

The final reinforcement tension force depends on the order of loading (tensioning), since the member will become progressively deformed during the application of the prestressing force.

It should always be checked that the tensioning of the first reinforcement elements does not cause any abnormal deformation in the member.

The value of movement caused by the wedge draw-in, where this type of anchorage is employed, should be carefully measured by a responsible person and recorded in the tensioning table.

Under no circumstances should any personnel, other than those required for the prestressing operation, be allowed in the area where the prestressing operation is to take place. Strong protection should be placed behind the jacks and nobody should be permitted to pass between this protection and the jacks during the prestressing operation.

In the case of prestressed reinforcement, it is recommended that a sign indicating its maximum design load be located on the stirrups of the prestressing beds.

In order to prevent the reinforcement from being thrown into the air in the event that it breaks during the prestressing operation, the following measures are recommended: the use of spacers or perforated plates for passing the wires; the use of stirrups surrounding the reinforcement; covering them with heavy boards, or wrapping them in jute bags.

67.8.2 Tensioning programme

The tensioning programme should specifically include the following:

A) Pre-tensioned reinforcement:

- The tensioning order of the reinforcement; and possibly the successive partial stages of tensioning.
- The pressure or force that should not be exceeded by the jacks.
- The value of the prestress loading on the anchorages.
- The elongation that is to be achieved, taking wedge draw-in movements into account when necessary.
- The method and sequence that is to be followed when releasing the tendons.
- The concrete strength required to transfer of prestressing.

B) Post-tensioned reinforcement:

- The tensioning order of reinforcement.
- The pressure or force to be produced by the jack.
- The expected elongation and maximum wedge draw-in.
- The time of removal of falsework during tensioning, where applicable.
- The concrete strength required before tensioning.
- The number, type and location of the couplers.

Tensioning shall not start without the prior authorisation of the Works Manager, who shall verify the suitability of the proposed tensioning programme and the concrete strength that should be equal to, or greater than, that established in the project design in order to commence this operation .

COMMENTS

In the event the tensioning operation is to be performed in successive stages, the need for some form of temporary protection should be examined. Where bond is required, f the protective material shall not affect it or have a detrimental affects on the steel or the concrete.

Informative testing shall be performed on specimens that have been conserved in conditions similar to those of the works, in order to verify whether the concrete has reached the necessary strength for commencing the tensioning.

67.8.3 Maximum permissible initial stress in the reinforcement

In order to reduce the possible number of hazards during construction (breaking of prestressing steel, stress corrosion, personal injuries, etc.), the maximum initial stress applied to the reinforcement, σ_{p0} before it is anchored shall not exceed the values given in 20.2.1.

COMMENTS

Since the monitoring of the stress produced in the reinforcement requires measurement of the elongation, it is essential that prestressing steel remain at all times in the elastic deformation zone.

It should be taken into account that the established limits are the maximum permissible values. Consequently, once these limits have been reached, no over-stress is acceptable, even in special cases (accidental breakage of wires, etc.).

67.8.4 Tensioning control. Elongation

The magnitude of the applied prestressing force shall be monitored by simultaneously measuring the stress exerted by the jack and the elongation produced in the reinforcement.

The tensile stress exerted by the jack shall be equal to that indicated on the prestressing programme that forms part of the project documentation. The tensioning devices and measuring instruments employed shall be able to guarantee that the prestressing force applied to the reinforcement does not vary from that indicated in the prestressing programme, by more than 5%.

The elongation values shall be measured with a precision of no less than 2% of the total length; and they should not vary from the values established in the prestressing programme by more than 15% for a particular tendon and 5% for the sum of the values for all the tendons in the same section. Where this difference is exceeded, suitable actions should be taken to correct this situation.

All the measuring instruments used shall be verified as frequently as necessary in order to guarantee that, at any given time, the precision of the measurements taken meet the criteria provided in the preceding paragraphs.

Control will be facilitated by the use of a printed prestressing table, together with a corresponding data sheet; on one side all the data of the prestressing programme planned in the project shall be recorded , together with the details required for tendon identification, and on the other the results taken during tensioning shall be recorded .

During tensioning, the actual results obtained (i.e., the readings recorded by the instruments used to measure the applied force and the corresponding elongation), shall be recorded in the appropriate boxes in the table opposite the corresponding theoretical values, to facilitate a quickly and easily verification. Likewise, any incidents that might occur during tensioning shall also be recorded.

COMMENTS

Whenever possible, the instrument used to measure the applied prestressing force should be independent of that used for the prestressing jack, except in the case of short tendons, where the elongation may not be so significant.

Initial deformation values (for small stresses) should be determine experimentally, especially when dealing with cables. It should be taken into account that, sometimes, this initial elongation in which the coupling of the various elements that make up the cable, may be significant. It is recommended that these first elongation values be evaluated by commencing the measurements as from a sufficient high stress value (for example, one tenth of the total) and extrapolating the diagram from this first reading to the deformation axis.

If any discrepancies with respect to the planned value are noted, it is recommended that the following be checked:

- whether the measuring instruments are correctly calibrated;
- the true reinforcement cross section;
- the modulus of elasticity of the prestressing stell;
- the condition of the anchorages; and
- if there any circumstances that might modify the forecast value of friction.

In all cases, it is the Works Manager who will decide what measures should be taken in order to correct any abnormalities that are observed during the prestressing operation.

67.8.5 Re-tensioning of post-tensioned reinforcement

Re-tensioning is any tensioning operation that is performed on a tendon after its initial tensioning.

This is only justified when it is seen as being necessary in order to make the stresses uniform in the various tendons of a single element, or when tensioning is performed in successive stages in accordance with the programme established in the project.

Re-tensioning should be avoided when its only objective is to reduce time-dependent prestress losses, unless it is specifically required under special circumstances.

COMMENTS

Tensioning in successive stages has the inconvenience of forcing a delay in the injection operation, which increases the risk of corrosion under tension in the prestressing reinforcement.

67.8.6 Stress transfer in pre-tensioned reinforcement

Stress transfer is the operation of transferring prestress from the reinforcement to the concrete in the case of pre-tensioned reinforcement, and is performed by releasing the reinforcement from its provisional end anchorage.

Before the transfer can begin, it shall be verified that the concrete has reached the necessary strength to withstand the stresses transmitted by the reinforcement, and any obstacles that might prevent free movement of the concrete members shall be removed.

If the transfer is performed on an element-by-element basis, the operation shall be carried out in a prearranged order to prevent any asymmetry that could be detrimental in the prestress.

Suitable mechanisms shall be foreseen to allow the transfer to be carried out slowly, gradually and evenly, without any sudden jolts (beatings).

Once the reinforcement has been released from its end attachments and any existing restraints between the successive members on each stressing bed have also been removed, the reinforcement ends shall be cut off where they project from the member heads if these heads are to remain exposed and not embedded in the concrete.

COMMENTS

Emphasis is placed on the danger involved in premature stress transfer due to the high prestressing force losses that could be produced as a result of significant rheological deformation occurring in the concrete if it is loaded at a very young age.

A brusque stress transfer would cause abnormal forces in the members, together with an increase in the transmission and anchorage length of the reinforcement and the risk of slipping of them.

Article 68 concrete composition

The concrete composition shall be determined in accordance with the methods considered most suitable, and taking into account the following limitations:

a) The minimum cement content per cubic metre of concrete shall be that as specified in section 37.3.2.

b) The maximum cement content per cubic metre of concrete is established as being 400 kg. This amount may be exceeded in exceptional cases where there is a prior experimental justification, together with express authorisation from the Works Manager.

c) A water/cement ratio that exceeds the maximum value established in 37.3.2 shall not be employed.

Among the factors that are to be taken into consideration on concrete composition are not only the mechanical strength and consistency that is to be obtained, but also the type of environment to be subjected with regards to any possible risk of deterioration of concrete or reinforcement due to attack by external agents.

In general, when determining the composition (or compositions, if various types of concrete are required), initial testing shall be performed by the contractor to provide a concrete that achieves the requirements established in Articles 30 and 37, together with those specified in the Project Specifications.

In those cases where the constructor is able to justifi by means of documents that with the proposed materials, composition and execution process it is possible to obtain a concrete that meets all the above-mentioned requirements, especially strength, the above-mentioned initial testing may be omitted.

COMMENTS

In order to determine the most suitable concrete composition, certain important factors, associated with productionshall not be forgotten, such as:

- properties of the materials;
- the required workability;
- special placing requirements, such as pumping;
- the required surface finishing;
- susceptibility to bleeding, slump and loss of slurry, etc.

Independently of the method that is to be employed to determine the composition, it is always advisable to carry out a prior study of the constituent materials, together with their proportions, to provide a concrete that complies with all the previously established requirements.

The following parameters should be analysed and determined:

- aggregate grading;
- composition of the compound aggregate;
- cement content and water/cement ratio;
- admixture and/or addition content.

The minimum cement content per cubic metre is particularly dependent on the aggregate size, being higher as this size decreases and lower as this size increases.

Even is exceptional cases, a cement content higher than 500 kg/m^3 is not recommended.

The danger of using very rich cement compositions lies in the high values that shrinkage and setting temperature can reach at the beginning in such cases. Nevertheless, if careful attention is paid to other factors that also influence in these phenomena, such as the type and class of cement, the water/cement ratio, the curing process etc, it is possible to employ higher cement proportions by carrying out the corresponding experimental verifications. In special circumstances, a figure of 400 kg/m^3 may be used in which, as occurs in certain precast situations, all details with regards to materials, grading, composition, execution and final curing are maximally controlled.

The water/cement ratio is an important factor in concrete durability, and should therefore, be as low as possible, and never higher than those values established for durability reasons. However, low water/cement ratios should be compatible with adequate concrete workability, that will permit adequate compaction and minimise segregation phenomena, which occasionally require the use of higher cement contents than those that are strictly necessary or the use of water reducing admixtures.

Article 69 Production and concrete transport to site

69.1 General requirements.

The production of concrete requires:

- Storage of constituent materials.
- Batching equipment.
- Mixing equipment.

The constituent materials shall be stored and transported in such a way as to prevent any intermixing, contamination, deterioration or any other significant alteration of the properties. The provisions of Articles 26, 27, 28 and 29 shall be taken into account in these cases.

The cement and, where appropriate, the additions, shall be batched by weight. In all cases, the quantity of each material shall comply with the specification in order to achieve a suitable degree of uniformity within batches.

The constituent materials shall be mixed in such a way that they are thoroughly and uniformly blended together, with the aggregate being well covered in the cement paste. The concrete homogeneity shall be verified in accordance with the procedure laid down in 69.2.5.

COMMENTS

It is not recommended that the aggregates be batched by volume due to the strong dispersion that usually occurs with this procedure.

The properties that allow to evaluate the quality of a concrete are homogeneity (the maintaining of similar characteristics within the same batch) and uniformity (the maintaining of similar characteristics within different batches). These properties may be verified by the weight per cubic metre, the air content, the consistency index and the compressive strength.

Concrete produced al plant is characterized, apart from its production specifications, by a higher homogeneity and uniformity, a fact which is presumable *a priori*, and which may be evaluated during the production quality assurance process. However, concrete that has been produced by any other procedure could present high dispersion, both of homogeneity and uniformity, and it is therefore recommended that the concrete be produced at plant by following the specifications given in section 69.2.

Homogeneity is analysed by evaluating the dispersion that exists between the properties of various samples taken from the same batch, which allows to verify of the suitability of the batching, mixing and transport processes.

Uniformity is analysed by evaluating by means of the variation coefficient the dispersion that exists between similar properties of several batches. This is normally carried out using the compressive strength values at 28 days.

69.2 Concrete produced at plant

69.2.1 General

A production plant for concrete is a set of facilities and equipment that complies with the specifications given in the following sections and consists of:

- Storage of constituent materials.
- Batching equipment.
- Mixing equipment.
- Transport equipment, where applicable.
- Production control.

There should be a suitably qualified and experienced person at each plant, who is responsible for production and who remains present during the production process, and this should not be the same person who is in charge of production control.

The plant may or may not form part of the on-site installations.

In order to be able to distinguish between these two cases within the framework of this Instruction, the term ready-mixed concrete is to refer to concrete made at a plant which does not form part of the on-site installations and which is on the Industrial Register in accordance with Section 4 of Industry Law 21/1992 dated the 16th of July and Royal Decree 697/1995 dated the 28th of April, with the corresponding entry being available to the client and the relevant Administrations.

69.2.2 Storage of constituent materials.

Cement, aggregates and additions, if any, shall be stored in accordance with 26.3, 28.5 and 29.2.3, respectively.

If there are any facilities for the storage of water or admixtures, they shall be of a type that prevents all forms of contamination.

Powdered admixtures should be stored under the same conditions as the cements.

Liquid admixtures and powdered admixtures diluted in water should be stored in frost-proof vessels fitted with stirrers to maintain the solids in suspension.

COMMENTS

On-site piling of aggregates (see 28.5) should be made over an anti-contaminant base that prevents any contact with the ground. The mixing of piles of different grades is avoided by using separating walls or by leaving sufficient space between them.

Wind action should be taken into consideration, especially with piles of fine aggregate, in order to prevent any segregation.

In order to achieve stable surface humidity (6 to 8 per cent of the weight of the aggregate) in fine aggregate, the pile should be maintained in position for the length of time required for drainage.

69.2.3 Batching equipment.

The batching equipment shall be equipped with silos with suitable separate compartments for each of the required aggregate fractions. Each silo compartment should be designed and assembled so that it may be effectively unloaded into hopper of the weighing equipment without any blockages and with minimal segregation.

All necessary controls should be available so that the flow of these materials into the hopper of the weighing equipment may be shut off at the precise moment when the required quantity is reached.

The hopper of the weighing equipment should be constructed so that they are able to completely unload all the material that has been weighed.

All instrument gauges should be in full view and close enough for the operator to be able to read them precisely while loading the hopper of the weighing equipment. The operator shall have easy access to all controls.

Under static loads, the weighing equipment shall have an accuracy of 0.5 per cent of the total capacity of the weighing scale. A suitable set of standard weights should be available for calibration purposes.

All the supports, linkages and similar parts of the weighing machines should be maintained absolutely clean.

The water measuring equipment shall have an accuracy that prevents the batching tolerance established in 69.2.4 from being exceeded.

Admixture dispensers shall be designed and marked in such a way as to allow the clear measurement of the quantity of admixture corresponding to 50 kilograms of cement .

COMMENTS

A separate dispenser is recommended for each type of admixture. If this is not the case, then the dispenser system should be thoroughly cleaned, except in those cases, where the various admixtures are compatible with each other.

69.2.4 Storage of constituent materials.

69.2.4.1 Cement

The cement shall be batched by weight, using weighing equipments and scales that are different to those used for the aggregates. The tolerance by weight of the cement should be ± 3 per cent.

COMMENTS

The production plant should be equipped with a sufficient number of weighing machines to guarantee that, under no circumstances should cement quantities be batched that are less than 10 per cent of the total scale of the weighing equipment being employed. In certain cases, it is sufficient to have loading cells with various ranges that may be interchanged whenever necessary.

The batching system shall be designed so that any uncontrolled variation in the cement content may be detected prior to entry into the mixer in order to avoid, as far as possible, the existence of batches with a cement content outside of the previously stated tolerance values.

69.2.4.2 Aggregates

Aggregates shall be batched by weight, taking into account any necessary corrections for moisture. The plant shall be equipped with devices to automatically measure the surface moisture.

The aggregate shall be composed of at least two grading fractions for maximum sizes equal to, or less than, 20 mm, and three grading fractions for greater maximum sizes.

If a graded aggregate is supplied for use, then the producer shall provide information on its grading and production tolerances, so that probable grading limits may be defined for use in controlling the aggregates in the mix design.

The tolerance by weight for the aggregates should be ± 3 per cent, whether separate weighing equipments are used for each aggregate grade or whether batching is carried out cumulatively.

COMMENTS

The production plant shall be equipped with a sufficient number of weighing equipments to guarantee that, under any circumstances, no aggregate quantities are batched that are less than 10 per cent of the total scale of the weighing equipment being employed in order not to exceed the established tolerance values. In certain cases, it is sufficient to have loading cells with various ranges that may be interchanged whenever necessary.

69.2.4.3 Water

The mixing water basically consists of; water added directly to the mix, that contained in the aggregate and on the surface of the aggregate, plus water in liquid admixtures, if any.

The water that is directly added to the mix shall be measured by weight or by volume, with a ± 1% tolerance.

In the case of transit mixers (truck mixers), any rinsing water that remains in the mixer should be exactly measured for use in the following batch. If this is impossible in practice, the rinsing water shall be removed before the next batch of concrete is loaded.

The total water shall be determined with a tolerance of 3% of the total specified amount.

COMMENTS

The total amount of water in a concrete batch consists of the water added directly to the mixture, the water contributed by the moisture contained in the aggregate (both absorbed and surface water), any water that might be remaining in the mixer after rinsing, together with water contributed by the admixtures, and this is the amount that will be employed in order to determine the water/cement ration of the concrete.

In order to maintain aggregate batches constant, these should have been studied with consideration to the material being saturated and with a dry surface.

The amount of water to be directly added to the mixture to obtained the specified consistency will depend on the amount of water contributed by the aggregates and on the retention capacity of the various fractions. It is, therefore, very important to know the surface water contributed by the aggregates, especially that of the sand. As far as the absorption water and retention capacity are concerned, these should be determined for each grade fraction by means of initial tests.

69.2.4.4 Admixtures

Powdered admixtures shall be measured by weight, and paste or liquid admixtures by weight or volume.

In both cases, the tolerance is ± 5% of the required weight or volume.

69.2.4.5. Additions

When employed, additions shall be batched by weight, using weighing equipments and scales other than those used for the aggregates. The tolerance by weight of the additions should be ± 3 per cent.

69.2.5 Mixing equipment

This equipment may consist of fixed or transit mixers designed to mix the concrete components in such a way as to obtain a homogeneous and thoroughly-mixed batch that will satisfy both requirements in Group A and at least two of those in Group B in Table 69.2.5.

This equipment shall be inspected as often as necessary to reveal the existence of hardened concrete or mortar residues, as well as for defects or wear in the blades or in the inner surface; where necessary it should then be verified to ensure that the above-mentioned requirements are met.

Both fixed and transit mixers should bear a metal plate in a prominent position on which the following information is specified:

- for fixed mixers, the mixing speed and the maximum capacity in terms of the mixed concrete volume;
- for transit mixers, the total volume of the mixer, its maximum capacity in terms of the mixed concrete volume, and the maximum and minimum rotation speeds.

Table 69.2.5
Verification of concrete homogeneity. Satisfactory results should be obtained in both tests in group A and in at least two of the four in group B

TESTS		Maximum permissible difference between the test results for two concrete samples taken during unloading (at 1/4 and 3/4 of the unloading)
Group A	**1. Consistency (UNE 83313:90)**	
	If the average slump is equal to or less than 9 cm	3 cm
	If the average slump is greater than 9 cm	4 cm
	2. Strength (*)	
	As percentages of the average	7.5 %
Group B	**3. Concrete density (UNE 83317:91)**	
	in kg/m^3	16 kg/m^3
	4. Entrained air (UNE 83315:96)	
	As a percentage of the concrete volume	1 %
	5. Coarse aggregate content (UNE 7295:76)	
	As a percentage of the sample weight	6 %
	6. Grading modulus of the aggregate (UNE 7295:76)	0.5

(*) For each sample Two specimens (15 cm in diameter and 30 cm in height) shall be tested at 7 days in accordance with UNE 83304:84. Specimens shall be made and stored in accordance with UNE 83301:91. The result for each of the two samples shall be taken as a percentage of the overall average.

COMMENTS

Fixed mixers shall be equipped with a suitable timer in order to prevent it from being unloaded before the prescribed mixing time.

69.2.6 Mixing

The concrete shall be mixed by using one of the following procedures:

- the entire operation takes place in a fixed mixer;
- started in a fixed mixer and completed in a transit mixer, before being transported;
- in a transit mixer, before being transported.

COMMENTS

The duration of the mixing operation depends on the type and composition of the concrete, together with the mixing conditions. The mixing time should be sufficient for obtaining a uniform concrete, but should not lead to aggregate breakdown.

Where possible, the concrete temperature should be equal to, or less than, 30ºC, or greater than 5ºC in cold weather or frosts. Frozen aggregates should be completely thawed before or during mixing.

69.2.7 Transport

The methods used for the transport of the concrete should guarantee that the mix arrives at the delivery site in the specified conditions, without undergoing any appreciable variation in the properties it had while freshly mixed.

The time that elapses between the addition of the mixing water to the cement and aggregate and the placing of the concrete shall not be more than one and a half hours. In hot weather, or under conditions that lead to rapid concrete setting, the time limit shall be less, unless special measures are adopted to extend the setting time without affecting the quality of the concrete.

When the concrete is fully mixed at the plant and is transported in transit mixers, the volume of the transported concrete shall not exceed 80% of the total mixer volume. When the concrete mixing is carried out entirely or is finished in a transit mixer, the volume shall not exceed two thirds of the total volume of the mixer.

Transport shall be free from hardened concrete or mortar residues, and will therefore, require careful cleaning before being filled with another fresh load of concrete. Additionally, there should not be any defects or wear and tear on the blades or the inner surface that might affect the homogeneity of the concrete and prevent compliance with the specifications contained in 69.2.5.

The concrete may be transported in transit mixers, at mixing speed, or by transport with or without agitators, provided that such equipment has smooth and rounded surfaces, and is capable of maintaining the homogeneity of the concrete during transport and unloading.

69.2.8 Designation and properties

Concrete produced at plant may be specified as prescribed concrete or designed concrete.

In both cases, at least the following shall be specified:

- The consistency.
- The maximum aggregate size.
- The type of environment to which the concrete is to be exposed.
- The characteristic compressive strength (see 39.1), for designed concrete .
- The cement content, in kilos per cubic metre (kg/m^3), for prescribed concrete .
- An indication as to whether it is to be used as mass, reinforced or prestressed concrete.

In the case of designed concrete , the supplier should establish the concrete composition, and should provide the client with a guarantee in respect of the specified properties of maximum aggregate size, consistency and characteristic strength, together with the limitations deriving from the type of specified environment (cement content and water/cement ratio).

Designation of designed concrete should be performed in accordance with that established in 39.2.

In the case of prescribed concrete , the client is responsible for the suitability of the specified properties of maximum aggregate size, consistency and cement content per cubic metre of concrete, and the supplier should guarantee the same, stating the water/cement ratio used.

When the client orders concrete with special properties or other, in addition to those mentioned above, the guarantees and specific information that the supplier is to provide shall be specified before the supply begins.

Before supply commences, the client may require that the supplier provides a satisfactory demonstration that the constituent materials to be used fully comply with the requirements established in Articles 26, 27, 28 and 29.

Under no circumstances shall additions be used without the prior knowledge of the client and authorisation from the Works Manager.

COMMENTS

The composition of designed concrete should comply with all the stated requirements, whereby the quantities of each component are resolved in favour of the strictest criterion. Similarly, the client should request a set of congruent properties, in other words, characteristic strengths and consistencies compatibles with the minimum requirements for cement content and water/cement ratio as specified in 37.3.2 for the type of environment that it is to be exposed to.

69.2.9 Delivery and acceptance

69.2.9.1 Documentation

Each load of concrete produced at plant, whether or not the production plant forms part of the on-site installations, shall be accompanied by a delivery ticket which shall be available to the Works Management at all times and containing at least the following information:

1. Name of the concrete production plant.
2. Delivery ticket serial number.
3. Delivery date.
4. Names of the client and person responsible for acceptance, in accordance with 69.2.9.2.
5. The concrete specifications.
   a) Designated concrete:
      - Designation in accordance with section 39.2
      - Cement content, in kilos per cubic metre (kg/m^3), with a tolerance of ± 15 kg.
      - Water/cement ratio with a tolerance of ± 0.02.

      Prescribed concrete:
      - Cement content, in kilos per cubic metre of concrete.
      - Water/cement ratio with a tolerance of ± 0.02.
      - The environment type in accordance with Table 8.2.2.

   b) Type, class and mark of cement.

c) Consistency.
d) The maximum aggregate size.
e) Type of admixture, in accordance with UNE-EN 934-2:98, if any, or a declaration that it does not contain any.
f) Source and amount of addition (fly-ash or microsilica) (29.2), if any, that it does not contain any.

6. Specific delivery site (name and place).
7. The amount of concrete making up the load, expressed in cubic metres of fresh concrete
8. The identification of the transit mixer (or other means of transport), together with the name of the person responsible for unloading, in accordance with 69.2.9.2.
9. The time limit for use of the concrete.

COMMENTS

The measurement of a load in cubic metres is obtained by dividing the weight of this load by the weight of a cubic metre of fresh concrete in accordance with UNE 83317:91.

In order to establish the weight of the supplied load, the vehicle should be weighed both before and after unloading, using the same weighing machine.

69.2.9.2 Acceptance

The moment when the concrete starts to be unloaded at the delivery site marks the beginning of the time of delivery and acceptance of the concrete, which will last until the unloading is completed.

The Works Manager, or a person delegated by him, is responsible for ensuring that the acceptance controls are effected, by taking the necessary samples, performing the required control tests, and following the procedures established in Chapter XV.

Any rejection of concrete that is based on the results of consistency tests (and tests for entrained air, where applicable) shall take place during delivery. No concrete shall be rejected for these reasons without the relevant tests having been carried out.

The addition of any amount of water or other substances to the concrete that could modify the original composition is expressly forbidden. However, if the result of a slump test is less than that established in 30.6, the supplier may add a plasticizer admixture to increase the slump until it reaches the correct consistency, without exceeding the tolerances stated in the above-mentioned section. For this reason, the transport (truck mixer) shall be equipped with the corresponding admixture dispenser and the concrete should be re-mixed until the added admixture is thoroughly dispersed. The re-mixing time should be at least 1 min/m^3 and under no circumstances should it be less than 5 minutes altogether.

The responsibility of the supplier ends once the concrete has been delivered and all acceptance tests are completed satisfactorily.

In any agreements between client and supplier, the time that may elapse between the concrete production and placing should be taken into account in each case.

COMMENTS

The delivery site is understood as being the work site established by the client and approved by the supplier for the acceptance of concrete.

This instruction expressly forbids the addition of water or any other product, during the acceptance of the concrete that could have a negative effect on the same, and which has not been previously established in the supply contract conditions. The Works Management should have prior knowledge of these conditions, where applicable. In order to eliminate this practice, the constructor should establish a specific control system. The Works Management and the independent control organisation are responsible for checking the existence of this control, and for verifying its operation.

As a rule of good practice, it is advisable that a sufficient reserve quantity of plasticizer admixture, approved by the Works Management, be available for use when necessary.

69.3 Concrete not produced at plant

The means for producing concrete consist of:

- Storage of constituent materials.
- Batching equipment.
- Mixing equipment.

Variations in the quality of the concrete, common to this production system, make its general use inadvisable. When it is employed, extreme care should be taken in batching, production and control.

When storing constituent materials, the provisions of Articles 26, 27, 28 and 29 shall be taken into consideration.

The cement shall be batched by weight, with the aggregates being batched by weight or by volume. The latter procedure is not recommended because of the wide range of variations that are frequently produced.

Mixing shall be performed for no less than ninety seconds at standard speed.

The producer of this type of concrete shall provide full information on the composition used, which shall be expressly accepted by the Works Manager. The producer is similarly responsible for ensuring that the operatives in charge of the batching and mixing operations are suitably qualified and experienced.

A book shall be maintained on site by the concrete producer and made available to the Works Management, containing the nominal compositions to be used in the work, together with any corrections performed during the process, with the corresponding justification. The book shall also contain a list of the suppliers of the constituent materials that are used in the manufacture of the concrete, a description of the equipment used, and a reference to the calibration document for the weighing equipment used for cement batching. In addition, a record of the number of batches used in each lot shall be maintained and the dates of concreting, together with the results of any tests carried out, where applicable.

Article 70 Concreting

70.1 Placing

Under no circumstances shall concrete be placed once it has begun to set.

During placing, even when this operation is done continuously with the use of suitable channelling, adequate precautions should be taken to prevent segregation of the concrete.

Concrete should not be placed in layers or beds which are of a thickness which prevents the concrete from being fully compacted.

Concreting should not be carried out until the Project Manager's agreement has been obtained, and once it has been verified that the reinforcement steel has been placed in its final location.

The concreting of each element should be carried out in accordance with an established plan, by which the expected formwork and falsework deformations are taken into account.

COMMENTS

The thickness of concrete layers depends on the method and efficiency of the employed compaction procedure. In general, this thickness should lie between 30 and 60 centimetres.

The placing of large piles with posterior spreading by vibrators is in no way recommendable since this produces a notable segregation of the concrete mass.

Special care should be taken to avoid any movement of the reinforcement steel, prestressing ducts, anchorages and formwork, and also to prevent any form of damage to the latter, especially when the concrete is allowed to fall freely.

When the concrete is permitted to fall freely from a height exceeding two metres, unavoidable segregation of the concrete occurs, and may even damage formwork surfaces or move them and the reinforcement steel or prestressing ducts, so that it is necessary to adopt suitable measures to prevent this.

70.2 Compaction.

Concrete shall be compacted on site by means of procedures that are suitable for the consistency of the mixes, so that cavities are eliminated and the concrete is fully consolidated, without any occurrence of segregation. Compaction should be allowed to continue until the paste flows to the surface and air no longer escapes.

When surface vibrators are employed, the thickness of the layer after compacting should not exceed 20 centimetres.

The use of mould or formwork vibrators shall be subject to study, so that the vibration transmitted through the formwork is sufficient to produce an adequate level of compaction and prevent the formation of cavities and weaker layers.

The re-vibration of the concrete requires prior approval from the Works Manager.

COMMENTS

Inadequate concrete compaction on site may lead to defects (for example, excessive permeability in the case of insufficient compaction, or, in the case of excessive compaction, the formation of a weak surface layer) which is not sufficiently reflected in the compressive strength value, but which may significantly alter other properties, such as permeability.

Concrete compaction becomes more difficult when the aggregate is prevented from achieving the level of order corresponding to maximum compaction that is compatible with its grading. For this reason compaction should be carried out right up to the formwork bottoms and sides, and in particular in the vertices and corners, although without coming into contact with the vibrator, and until all air cavities are eliminated.

The compaction procedure that best adapts to the particular conditions of the mass should be employed in accordance with the concrete consistency and workability in addition to the type of structural element. Table 70.2 contains the most recommended means of compaction in accordance with the concrete consistency.

Table 70.2

Consistency (Section 30.6)	Type of compaction
Dry	Energetic vibration
Plastic	Normal vibration
Soft	Normal vibration or bar stirring
Fluid	Bar stirring

70.3 Special techniques

If the concretes are transported, placed or compacted by means of the use of special techniques, the procedures should be carried out in accordance with the codes of good practice for such techniques.

Article 71 Construction joints

Construction joints, that in general shall be planned in the project design, shall be located as close as possible at right-angles to the direction of the compressive stresses at points where their effect will be least detrimental; they shall therefore be located away from regions where the reinforcement is subjected to strong tensions. They shall be shaped in such as way as to provide the closest possible bond between the old and new concretes.

construction joints not included in the project design, shall be positioned at locations previously approved by the Works Manager and preferably above the props of the falsework. Further concreting shall not take place there until the joints have been examined and approved, where applicable, by the Works Manager.

If a joint plane is poorly oriented, part of the concrete shall be demolished as required in order to give the surface a suitable direction.

Before further concreting the mortar, of the surface shall be removed to leave the aggregate exposed and the joint should be cleaned to remove any dirt or loose aggregate. Under no circumstances shall the cleaning method employed cause any appreciable changes in the bond between the cement paste and coarse aggregate. The use of corrosive products to clean joints is expressly forbidden.

The placing of concrete directly on or against concrete surfaces that have suffered the effects of frost exposure is also forbidden. In such cases, any parts frost-damaged shall be previously removed .

The Project Specifications may authorise the use of other techniques for executing joints (for example, impregnation with suitable products), provided that prior justification of the same exists, by means of the sufficiently guaranteed tests, whereby such techniques are shown to be capable of producing results that are at least as effective as those obtained through the use of traditional methods.

COMMENTS

Construction joints should be kept to the minimum necessary, since this could lead to a lower tensile and shear strength, which in turn, would reduce the load capacity in the immediate area, with the subsequent risk that, in the event of a careless execution, watertight properties would not be able to be guaranteed, thereby reducing the protection of the steel reinforcement against corrosion. Whenever possible, this type of joint should be restricted to areas that are subject to significant loads or where the joint is required because of other motives.

In order to guarantee adequate bonding between the new and old concrete, all grouting existing on the hardened concrete should be eliminated, and where it is dry, it should be first wetted before placing the fresh concrete. The joint should not be soaked, and it is recommended that the hardened concrete should have a wet internal core, in other words saturated, but with a dry, slightly absorbent surface.

As far as the concrete is concerned, it is recommended that all contact between calcium aluminate cement concretes and Portland cement concretes be avoided, especially if the latter is alkali-rich and there is the possibility of moisture reaching the contact zone between them.

Article 72 Cold weather concreting

The concrete temperature ,when it is cast into the mould or formwork, shall not be less than 5°C.

It is forbidden to place the concrete onto elements (reinforcements, moulds, etc.) if their temperature is less than 0ºC.

In general, concreting shall be stopped whenever it is expected that the ambient temperature may fall below 0ºC within the following forty-eight hours.

In cases when it is absolutely necessary concreting in freezing conditions, specific measures shall be taken to ensure that, during the setting and early hardening of the concrete, no local deterioration is caused in the elements involved, nor any appreciable permanent losses in the strength properties of the material. In the event that damage is caused, the necessary information tests (Article 89) shall be carried out in order to assess the strength actually achieved, prior to the adoption of the appropriate measures.

The use of freezing-point depressant admixtures requires the express authorisation of the Works Manager in all cases. Products that are liable to attack the reinforcement, especially those containing chloride ions, shall not be employed under any circumstances.

COMMENTS

Cold weather is taken as being a period of time during which the following conditions exist for more than three days:

- the average daily air temperature is below 5ºC;
- the air temperature does not exceed 10ºC during more than half the day.

The hydration of the cement paste is delayed during periods of cold temperature. In addition, frost can permanently damage concrete that is only partially hardened if the water content in the pores freezes and breaks the material. Consequently, the necessary measures should be adopted to ensure that the hardening speed is suitable and that frost damage does not occur.

Among those measures that may be adopted on concrete composition, is that of employing the lowest possible water/ cement ratio, and employing greater cement contents or cements with higher strength category. This will produce an acceleration in the hardening process, increase its temperature and reduce the risk of frost damage.

When there is a risk of ice or prolonged frost, the fresh concrete should be protected through the use of some form of covering or insulation, or by enclosures for heating the air that surrounds the recently concreted structural element, in which case other measures should be adopted to maintain an adequate level of humidity.

Article 73 Hot weather Concreting

When concreting is carried out in hot weather, the appropriate specific measures shall be taken in order to prevent the evaporation of the mixing water, especially while the concrete is being transported, and to reduce the concrete temperature.

For this reason, the constituent materials and the formwork or moulds shall be shaded from the sun.

Once the concrete has been cast, it should be protected from the sun, and especially the wind, in order to prevent it from drying out.

If the ambient temperature is above 40°C or if it is too windy, concreting operations shall be suspended, unless special measures are adopted with the express authorisation of the Works Management.

COMMENTS

The content of this article should make clear that a hot weather is that in which any combination of high temperatures, low relative humidity and high wind speed are produced, which tend to reduce the quality of the concrete or produce unwanted properties.

The properties of the concrete may be adversely affected in an unfavourable manner during hot weather. The high temperatures of the fresh concrete accelerate the setting process, increase the hydration speed and increase water requirements, leading to a lower final strength. Additionally, concreting conditions are made more difficult and the appearance of plastic shrinkage cracking is increased.

Consequently, the concrete temperature on placing should be less than 35ºC in the case of normal structures, and less than 15ºC in the case of very large masses of concrete.

Article 74 Concrete curing

During the setting and the first hardening period of the concrete, this should be maintained wet by means of a suitable curing process. This should be maintained as long as necessary in accordance with the type and class of cement, the temperature and level of humidity in the environment, etc.

Curing may be carried out by maintaining the surfaces of the concrete elements wet by watering them directly, provided that this does not wash away any material. The water employed in these operations should be of the quality as required by Article 27 of this Instruction.

Wet Curing may be substituted by surface protection using plastic sheets or by other suitable means, provided that such methods, especially in the case of dry mixes, can sufficiently guarantee that the initial moisture in the mix is retained during the early period of hardening, and do not contain any substances that might be harmful to the concrete.

If curing is carried out by means of special techniques (steam curing, for example), the codes of good practice for such techniques should be followed, with the prior authorisation of the Works Manager.

COMMENTS

Of the various operations required for the execution of a concrete member, the curing process is one of the most important because of its decisive influence on strength and other qualities of the resulting concrete.

The main methods employed in concrete curing are as follows:

-
- Protection with plastic sheets.
- protection with wet materials (burlap, sand and straw etc).
- Watering.
- The application of curing compounds that form protective membranes.

All these methods may be used separately or in combination. Not all curing methods are equally efficient. In general, those methods in which water is added produce a denser pore structure than those that simply prevent the concrete from drying out.

In order to estimate the minimum curing duration *D*, in days, the following expression may be employed:

$$D = K\ L\ D_0 + D_1$$

where:

D is the minimum curing duration in days.
K the environmental weighting factor in accordance with Table 74.4.
L the thermal weighting factor in accordance with Table 74.5.
D_0 is the basic curing parameter in accordance with Table 74,1.
D_1 is a parameter that is a function of the type of cement in accordance with Table 74.3.

In a situation where the environmental conditions during curing (sun, humidity and wind speed) do not exactly correspond with any of the cases, A, B, C, of Table 74.1, then the D_0 parameter may be determined by taking the values in the table as guidelines.

The concrete strength development may be determined as a function of the class of cement employed and of the water/cement ratio, in accordance with that established in Table 74.2.

In the event that silica fume is used as an addition in the production of the concrete, the curing operation should be performed with special care.

In the event that fly ash is used as an addition to the concrete, the value of D_1 should be one of the following:

$D_1 = 1$, if $F \leq 28\%$
$D_1 = 2$, if $28\% < F \leq 35\%$
$D_1 = 4$, if $F > 35\%$

where *F* is the percentage of fly ash employed, in relation to the mass of the cement.

In those cases where special techniques are used, the rules of good practice for such techniques should be followed, because they are processes in constant evolution and is very difficult to provide general rules.

Table 74.1

The determination of the basic curing parameter D_0

Environmental conditions during curing	Concrete strength development			
	Very fast	Fast	Average	Slow
-A- - Not exposed to the sun - Not exposed to wind - Relative humidity in excess of 80%	1	2	3	4
-B- - Exposed to sun with average intensity - Average wind speed - Relative humidity between 50% and 80%	2	3	4	5
-C- - Strong sun - High wind speed - Relative humidity below 50%	3	4	6	8

Table 74.2
Concrete strength development speed

Cement class	Water/cement ratio		
	A/C < 0.50	0.50 ≤ A/C < 0.60	A/C > 0.60
52.5 R, 52.5 and 42.5 R	Very fast	Fast	Slow
42.5 and 32.5 R	Fast	Average	Slow
32.5	Average	Slow	Slow
22.5	Slow	Slow	Slow

Table 74.3
Determination of the D_1 parameter

Type of cement	D_1 values
Portland: CEM I	0
With additions: CEM II CEM II-S CEM II-D CEM II-P CEM II-V CEM II-L	1
Blastfurnace: CEM III/A CEM III/B	 3 4
Pozzolanic CEM IV	2
Composite: CEM V	4
Special uses: ESP VI-1 ESP VI-2	 4 4
Calcium aluminate: CAC/R	(*)

(*) In accordance with 26.1, when calcium aluminate cements are employed, each individual case should be subjected to a special study.

Table 74.4
Environmental weighting factor K

Exposure class		K value
I II	- Non aggressive - Normal	1.00
III IV H	- Marine - With chlorides having an origin other than the marine environment - Frosts without de-icing agents	1.15
Q F	- Chemically aggressive - Frosts and de-icing agents	1.30

Table 74.5
Thermal weighting factor L

Temperature $T_{average}$ during curing (in ^oC)	Factor L
$T_{average} < 6^oC$	1.7
$6^oC \leq T_{average} < 12^oC$	1.3
$T_{average} \geq 12^oC$	1.0

Article 75 Removal of formwork, falsework and moulds

The various elements that make up the moulds, formwork (walling and decking etc.), props and falsework shall be removed without any shaking or jolting of the structure, and it is recommended that, for significant elements, wedges, sand boxes, jacks or other similar devices should be used in order to bring the supports down in a uniform fashion.

The previously-mentioned operations shall not be carried out until the concrete has reached the required strength to withstand, without any excessive deformation, the stresses to which it will be subjected during and after the removal of formwork, falsework or moulds.

In the case of significant works when no experience of similar cases is available, or when serious losses would result from premature cracking, information tests (Article 89) may be carried out in order to assess the actual strength of the concrete and to determine a suitable time for striking the formwork, moulds or centring,

Weather conditions (for example, frosts) should be taken into consideration, together with the need to adopt protection measures once the formwork or moulds have been removed.

Special attention should be paid to the timely removal of any formwork or mould element that could hinder the free movement of contraction, settlement or expansion joints or that of pinned joints, if applicable.

With prestressed concrete elements, it is essential that the falsework is struck in accordance with the programme established for this purpose in the project design. This programme should coincide with the one established for the prestressing process.

To facilitate the striking of formwork, especially where moulds are employed, it is recommended that they be coated with a release agent that complies with the conditions contained in Article 65

COMMENTS

Emphasis is placed on the fact that new concrete has not only a reduced value of strength, but also of modulus of elasticity, which may exert a great influence on any possible consequent deformation.

At times, it is useful to measure the deflection during the removal of falseword in certain elements, as a reference for deciding whether to continue the operation or not and also if it is necessary to carry out load tests on the structure.

Removal of falsework should be carried out in accordance with a carefully designed programme in order to prevent the structure from being subjected to stresses that have not been taken into consideration by the project and could be harmful, even if only on a temporary basis, during the execution process.

the following points should be taken into account during removal of falsework:

a) The weight of the concrete, especially if this represents a greater part of the total project loading.
b) The imposed loads, for example, the action of falsework of other upper elements and the execution overloads, etc.
c) The sequence of removal and any possible temporary effects of jacks and temporary supports.
d) The need to maintain certain elements to reduce any time-dependent deformation (for example, intermediate shoring) or in order to guarantee structure stability (for example, reinforcement against wind effects).
e) Tensioning and injection operations.
f) Specific removal operations, for example, parts of the entry angle in the formwork.

g) The environmental conditions to which the concrete is to be exposed once the formwork has been removed, above all if this is serving as a curing system.
h) Any possible requirements for later surface treatments.

Among others, the minimum de-centring period will depend on the evolution of strength and the modulus of deformation of the concrete, on the curing conditions, on the specifications of the structure and the dead load fraction that is acting in that moment. An approximate value for the minimum strength that the concrete should have reached to remove the falsework, may be obtained by verifying Limit State compliance under the load conditions present at this moment in time.

As a guideline, the formwork or falsework removal periods given by the following formula may be indicated:

$$j = \frac{400}{\left(\frac{Q}{G} + 0,5\right)(T + 10)}$$

where:

j is the number of days.

T the average temperature of the daily maxima and minima during the *j* days in degrees centigrade.

G the load acting on the element during removal of falsework (including its own weight).

Q the load acting later (*Q* + *G* = maximum total load).

This formula is only applicable to those reinforced concrete elements that are manufactured with Portland cement, and where it was hardened under ordinary conditions.

It is recommended that safety procedures should never be inferior to those established for the works in service.

When sufficient data is not available, and where normal-hardening cement has been employed, the minimum formwork and falsework removal periods for reinforced concrete given in Table 75 may be taken as a reference.

Table 75
Minimum formwork striking and fasework removal periods for reinforced concrete elements.

Surface temperature of the concrete (ºC)	≥ 24º	16º	8º	2º
Vertical formwork	9 hours	12 hours	18 hours	30 hours
Slabs Formwork bases Shoring	 2 days 7 days	 3 days 9 days	 5 days 13 days	 8 days 20 days
Beams Formwork bases Shoring	 7 days 10 days	 9 days 13 days	 13 days 18 days	 20 days 28 days

If the values recommended in the table for vertical formwork are applied, then the necessary measures for guaranteeing adequate curing and protection of the concrete should be implemented immediately after formwork striking.

If periods of frost occur during curing, then the values provided by the table should be suitably incremented.

The employment of special formwork, for example, slipforms, or the use of accelerated curing processes, will enable the recommended periods to be reduced. In a similar way, these periods may be increased in those cases where there are special conditions that require cracking to be limited during the early stages (for example, elements having different thickness or temperatures), or where it is necessary to reduce the deformation due to creep.

Article 76 Surface finishes

Once the formwork or moulds have been removed, the visible surfaces of members or structures shall not show any evidence of cavities or irregularities that could be detrimental to their performance or external appearance.

When a particular grade or type of finish is required for practical or aesthetic reasons, the requirements shall be specified either directly or by means of surface standards.

The mortars used for covering or filling anchorage points, orifices, cut-outs and recesses etc, a task which should be carried out once the members have been finished, should in general, be made from mortars similar to those used in the concreting of the members, but from which any aggregate that is larger than 4 mm has been removed. All mortar surfaces should be finished in an adequate manner

Article 77 Continuity joints between precast elements

The joints between the various precast members that make up a structure or between these members and the other structural elements constructed *in situ* shall be capable of guaranteeing the correct transfer of stresses.

These joints shall be constructed in such a way that they are able to absorb the normal pre-cast dimensional tolerances without creating any additional stresses or a concentration of stresses in the - precast elements.

The heads of those elements that are to remain in contact shall not show any irregularities that could prevent compression from being transmitted evenly over their whole area. The permissible limit for such irregularities depends on the type and thickness of the joint; and no attempt should be made to correct them by facing the heads with cement mortar, or any other material that cannot guarantee adequate transmission of stresses without undergoing excessive deformation.

When joints are welded, care shall be taken to ensure that any heat given off does not damage the concrete or the reinforcement within the members.

Joints constructed with post-tensioned reinforcement require the adoption of special precautions if this reinforcement is short. This method is recommended for making nodes rigid and is especially indicated for structures that have to withstand earthquakes.

COMMENTS

From the point of view of the strength, durability and deformation of the structure, the joints always constitute specific points that require special attention and a complete study in order to guarantee:

- that the joint is capable of accommodating any necessary relative movement in order to mobilise its strength.
- that it is capable of withstanding all action resulting from the analysis of the structure as a whole, together with those from the analysis of the individual elements.
- that the resistance and deformation of the joint guarantee the stable behaviour of the structure as a whole.
- that both fire and corrosion resistance are suitable.

During the design of the joint, both tolerance and adjustment requirements should be taken into account, along with the construction requirements for the achievement of a good finish and to allow later conservation or inspection work.

Special attention should be paid to joint details during execution, in order to avoid cracking or chipping of the concrete at the ends of precast elements.

Since post-tensioned reinforcement employed in continuity joints are generally very short, any variation in its path, length or anchorage slip could lead to significant variations in its stress. This is why it is extremely important to carefully control the location of this reinforcement and the behaviour of the anchorage. The length of the joint tendons should be at least equal to the anchorage lengths of the bonding reinforcement steel in the jointed members in order to prevent fragile breakage due to bonding failure. In addition, the strong curves that the paths of this type of reinforcement usually follow, can lead to significant stress losses due to friction, a fact which should be considered during the design stage.

Article 78 Grouting

78.1 General

The main objectives of grouting tendons are the prevention of corrosion of the prestressing steel and the provision of an effective bond between the concrete and the steel.

In order to meet these objectives, it is fundamental that all the spaces in the sheaths or ducts and anchorages are filled with a suitable grouting material (see Article 36), which meets the necessary strength and bonding requirements.

The grouting operation should be carried out as soon as possible after tensioning. If, due to construction motives, this has to be delayed, the reinforcement should be temporary protected by means of some method or material which will not prevent the tendons from subsequently bonding with the grout.

In addition, in order to guarantee that the tendons are grouted correctly and safely, the following should be available:

- Qualified personnel that are trained in the technique to be employed.
- Safe equipment that has been correctly serviced, calibrated and is in perfect working order.
- Written instructions and prior organisation of all the materials to be used and the grouting procedure to follow.
- The adoption of safety precautions that are suited to each individual case.

COMMENTS

The maximum period of time that is normally considered to be permissible, from the finishing of tensioning to injection, is one month.

In order to verify that the sheaths or ducts are completely full, it is recommended that the volume of cavities to be filled is compared with the actual amount of injected mixture. This will require suitable control devices at both the injection entry and exit sites.

78.2 Preparation of the grout mixture

The solid materials employed in making the grout should be measured out by weight.

The materials should be mixed in a mixing machine capable of preparing a grout of uniform consistency which is, where possible, colloidal in nature. Hand mixing is not permitted.

The mixing time will depend on the type of mixer and should be adopted in accordance with the instructions of the manufacturer. Under no circumstance, should it be less than 2 minutes or more than 4 minutes.

After mixing, the product should be kept in continuous movement until it such time as they are ready for injection. It is essential for the product to be lump-free at this point.

In the case of vertical sheaths or ducts, the water/cement ratio of the mix should be slightly greater than in grouts employed for injecting horizontal sheaths.

COMMENTS

The mixer, the agitator, if any, and the injection pump should be driven by independent motors and each one should also be controlled separately.

The injection pump should be fed by gravity and not by suction, since the latter method tends to introduce air into the mixture, which should be avoided.

The order for batching materials into the mixer should be as follows: first the water, then the cement followed by the aggregate, if used. If additions are employed, these should be added at the moment and in the manner described in the corresponding instructions for use.

It is recommended the use of delaying agents when a period of time exceeding 30 minutes is to elapse between mixing and grouting.

To avoid lumps, it is recommended that the product be passed through a sieve during the injection process, which, at the same time, will eliminate any impurities. The sieve mesh should by 2 mm for mortar and 0.125 mm for grout. Any other efficient procedure that produces the desired effect may also be employed.

78.3 Grouting programme

The grouting programme should include at least the following points:

- The properties of the grout being used, together with its usage time and hardening time.
- The injection equipment specifications, including pressures and injection speed.
- Ducts cleaning.
- The grouting operation sequence and the tests to be carried out on the fresh grout (fluidity and segregation, etc.).
- The manufacture of specimens (for bleeding, shrinkage and strength, etc.).
- Volume of grout to be prepared.
- Instructions with regards to the action to be taken in the case of any incidents (for example, equipment failure during injection) or adverse weather conditions (for example, during and after periods with temperatures of below 5°C).

78.4 Grouting execution

Before grouting begins, a check should be effected to ensure that the following conditions have been met:

- That the injection equipment is fully operational and that an auxiliary injection pump is available in order to avoid any interruptions in the event of a breakdown.
- There are permanent supplies of pressurised water and compressed air
- That more than sufficient materials for mixing the grout are available.
- The sheaths are free from any harmful materials, such as water or ice
- The ends of the ducts to be grouted have been correctly prepared and identified.
- That all the grout control tests have been prepared.

Grout injection should be continuous and without interruption, and should progress at a rate of between 5 and 15 metres per minute. The maximum injected length should not exceed 120 metres.

The use of compressed air during the grouting operation is forbidden.

Whenever possible, grouting should commence at the lower anchorage or the bottom vent pipe of the duct.

Grouting should continue being injected until the consistency of the mix that emerges at the free end of the duct is the same as that being injected, and once the injecting process stops, all necessary measures should be taken to prevent any loss of grout from the duct.

In the case of vertical sheaths or ducts, a small reservoir full of grout should be maintained at the upper end in order to compensate for any reduction of volume that might occur. It is important for this reservoir to be centred over the duct so that any water that bleeds upwards will mix with the grout in the reservoir and not accumulate in the upper end of the sheath, which could be harmful to the tendon protection and the corresponding anchorage.

Special precautions should be taken in cold weather, and especially during freezing periods, to ensure that there is no ice in the ducts when the grouting operation commences. Hot water may be injected to accomplish this, but never steam.

If the temperature is not forecast to fall below 5°C within the 48 hours following the grouting operation, then grouting may continue by using a product that is not too sensitive to frost, containing from 6 to 10% entrained air and which satisfies the conditions of Article 36, or alternatively by heating the element of the structure so that its temperature does not descend below 5°C during this period.

When the ambient temperature is above 35°C, it is recommended that the mixing water be cooled.

In all cases, once grouting has finished, all the orifices and vents should be hermetically sealed to prevent water or any other agent that is corrosive to the reinforcement from entering inside the ducts. Additionally, the equipment should be cleaned as quickly as possible after the grouting operation, and then the pump, mixer and piping should be thoroughly dried.

If there is a possibility that large areas have not been grouted, then suitable steps should be taken to grout them afterwards. Whenever any doubt exists, a check may be made with an endoscope or by making vacuum in it.

COMMENTS

pumps may be driven by motors or hand operated. They should be fitted with safety devices that prevent overpressures. The use of hand-operated pumps is not recommended for long vertical sheaths.

The duct should be thoroughly cleaned using compressed air before commencing grouting. Using compressed air to clean the ducts will also detect any interior blockages.

Water should be injected into sheath-less ducts (concrete walls) in order to wet the concrete. Then compressed air, or any other suitable method, should be employed to expulse any excess water.

The injection process should take place at constant rate, sufficiently fast to prevent segregation in areas that are difficult to pass, but slow enough in ribbed sheaths to prevent air being included in the downward grout flow.

It is also recommended that the injection be as low as possible, with normal values varying between 3 and 7 atmospheres. These values should be reached progressively, without any sudden jumps.

The injection should be performed as slow as possible to prevent the segregation of the mixture.

The joint between the duct being injected and the tube employed for the injection should be leak-tight to prevent air being dragged into the mixture.

Very long ducts or those having a large diameter may require the injection to be repeated after a period of two hours in order to compensate for any eventual reduction in volume.

When long, ondulating cables are to be injected, where a high pressure is required, the end at which the injection is initiated may be closed off and then the injection process may be continued via successive purge tubes.

When the injection is carried out at low temperatures, it may be protected against frost effects by suitably heating the sheaths, and of course, the water.

Once the grouting has been completed, it is recommended that the exit tubes be doubled over and tied off in the same fashion as a football valve.

78.5 Inspection

A report shall be prepared for each grouting, and should include the following information: the grout properties, the ambient temperature at the time of injection, the type of cement employed, the type and proportion of admixture, if any, , the water/cement ratio, the type of mixer, the mixing time, and the specimens that were made to check the conditions specified in Article 36.

The grouting reports should form part of the construction documentation.

COMMENTS

For control purposes, it is recommended that the product fluidity be measured on site in accordance with 36.2.

78.6 Safety measures

During duct grouting, all nearby workers should be provided with protective goggles or a transparent screen, in case any grout injected under pressure should escape.

Nobody should be allowed to look down pipes used as vents or overflows in order to check the progress of the grout.

When grouting is carried out on site close to trafficked areas, all necessary precautions should be taken to prevent any escaping grout from causing damage.

COMMENTS

A jet of pressurised injection product can cause serious injury, especially if it strikes the eyes. It is possible for the injected mixture to become temporarily blocked, only to become suddenly released as continuous pressure is applied, this would produce jets from the vents or the opposite end of the sheath and could cause serious injury.

Article 79 General observations with regards to the execution

79.1 Making the construction process conform to the project

All necessary measures should be adopted to guarantee that the construction arrangements and execution procedures fully conform with the provisions contained in the project.

In particular, special care should be taken to ensure that all such arrangements and procedures are compatible with the design hypotheses, especially with regards to connections (fixed, pinned and simply supported joints, etc.) and the magnitude of the actions imposed during the execution of the structure.

All temporary operations and situations, especially transport, assembly and placing of precast members, should be subjected to a prior study. It is also required that it be guaranteed that all the necessary measures have been taken to ensure that the members have been placed safely and precisely and maintained in their correct final positions before and during the execution of joints that are constructed on site and where appropriate, during hardening of the same. If any significant modifications are made to the construction process, it should be included in the corresponding additional documentation.

79.2 Mechanical actions during execution

During execution, the application of any static or dynamic loads that might cause damage to already-concreted elements should be avoided.

When the construction of the works leads to successive stages of removal of falsework, prestressing or load transfer, it may be necessary to determine the stresses corresponding to a certain number of these phases.

COMMENTS

The premature action of excessively large static or dynamic loads could lead to various types of damage which are usually manifested in the form of unacceptable cracking or deformation in the already-concreted elements, which should be avoided. The accumulation of materials (the stacking of bricks on floor slabs, for example), together with the vibration produced by certain work site machinery, are two of the causes that may potentially cause such damage in those elements acted directly upon by these loads, especially where these elements have not yet reached their design strength.