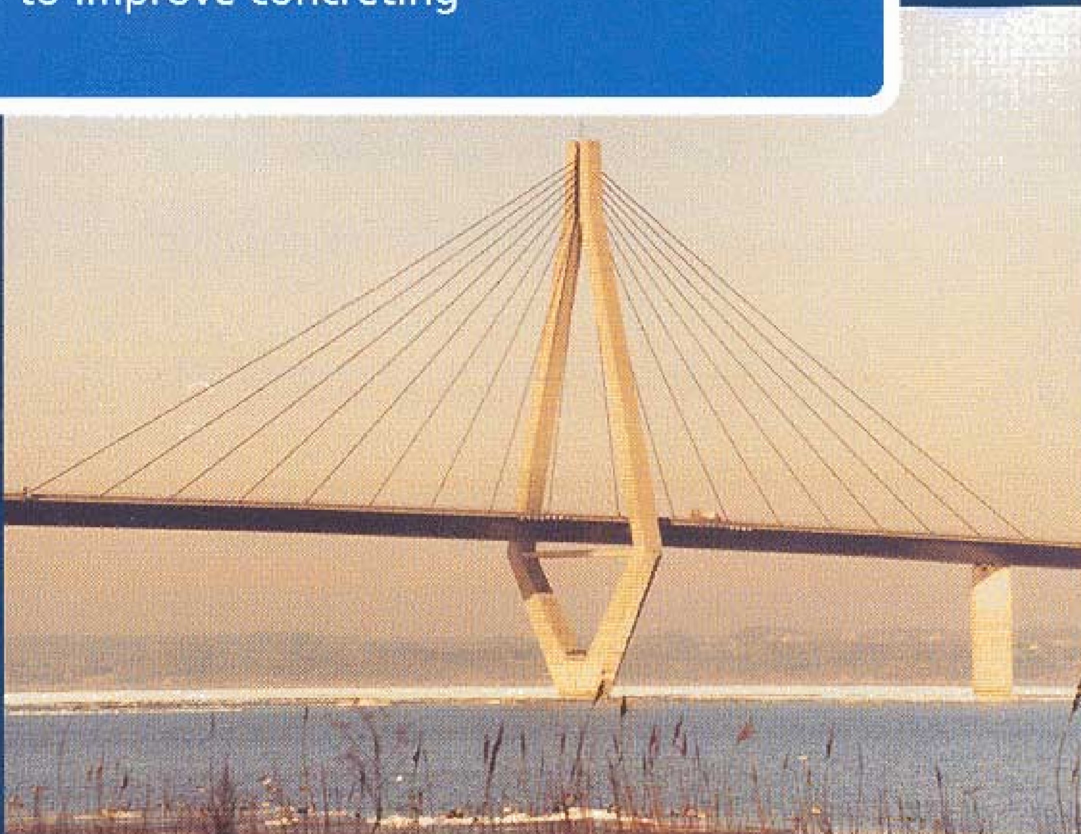
HETEK

Guidelines for structural detailing to improve concreting



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Abstract

This report forms a part of the Danish Road Directorate's research programme called High Performance Concrete - The Contractor's Technology (abbreviated to HETEK). HETEK is divided into eight parts where part no. 5 concerns compaction as well as structural detailing.

The guidelines for structural detailing to improve concreting is prepared on basis of the recommendations given in the State of the Art report.

Front page photo: The front page photo shows the pylons of the Faroe Bridge between Faroe and Falster, Denmark. The pylons are cast against inclined formwork.

Contents

0. Preface

The design and execution of reinforced concrete structures is a segment of the development project "High Performance Concrete - The Contractor's Technology", abbreviated to HETEK (an acronym for Højkvalitetsbeton, Entreprenørens Teknologi).

High performance concrete is concrete with a design service life of at least 100 years in an aggressive environment.

The HETEK project is divided into the following eight segments.

- Chloride penetration
- Frost resistance
- Autogenous shrinkage
- Curing technology
- Compaction and structural detailing to improve concreting
- Protection against drying out
- Pre-Testing of concrete properties and workmanship
- Repairs

The project put out to tender by the Road Directorate is financed by the Ministry of Commerce, Committee for Development Contracts. The technical project manager is Erik Stoklund Larsen (Road Directorate) in collaboration with the managers of each of the segments of HETEK.

The segment on structural detailing to improve concreting was carried out by:

The Danish Concrete Institute A/S, represented by:

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- Erik Andersen
- Arne Steen Jacobsen
- Bjarne Chr. Jensen
- Alex Kjær
- Flemming Pedersen
- Steen Rostam
- Erik Skettrup

Hans Henrik Orbesen (Pihl & Son A/S) took part as consultant.

The segment is divided into four phases:

Phase 1: Classification of problems, preparation of a memorandum
Phase 2: State of the art
Phase 3: Draft guide in Danish
Phase 4: Guide in English

This is the Phase 4 report.

The structural features that involve difficult casting have been identified by a working group consisting of:

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- Niels Coff, Armton/NCC
- Jan Gråbæk, Monberg & Thorsen A/S
- Gunnar Holm, Jorton A/S
- Arne Steen Jacobsen, COWI
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The guidelines deal with the features identified by the working group.

For each structural feature, the difficulties involved in execution are described. Several difficult features are often found in combination, e.g. openings, dense reinforcement and cast-in components; the increased difficulty and risk of error must be evaluated on the basis of the various difficulties involved.

The report has been reviewed by Reidar Kompen (Norwegian Road Directorate), who is a member of HETEK's technical committee.
The steering group wishes to express their thanks to Reidar Kompen and other contributors for their active participation.

1. Introduction

The lifetime of reinforced concrete structures is in focus. Increased awareness of the dependence of durability on the composition of the concrete has resulted in the development of so-called high performance concretes, that meet the expectation of a long lifetime.

When cast in geometrically simple forms with a moderate amount of reinforcement, high performance concretes will have great resistance to mechanisms of deterioration resulting from the accelerated environmental loadings prescribed by the usual testing methods. The aim is to achieve the same degree of resistance in structural concrete in general. This means that certain requirements for design and execution must be met.

The design must be such as to ensure that, provided that the execution is error-free, the expected lifetime will be achieved. These guidelines do not directly deal with the design of structures.

Complicated structural components with difficult geometry and/or closely spaced reinforcement make execution problematic. The risk of making a mistake during casting is increased, even when it is carried out carefully in accordance with accepted methods. Methods of execution adapted to complicated structures are primarily aimed at avoiding gross errors. These methods therefore differ from the usual ones and frequently involve a reduction in the quality of the structure. The object of avoiding features that make casting difficult is thus not merely to make the work easier for the contractor.

1.1 Aims

The aim of these guidelines is to point out structural features that involve an increased risk of error in the execution of the concrete work, even when the latter is carried out carefully and according to recognized methods. Where possible, alternative methods are given.

As it may not be possible to use the suggested alternative method, the guidelines give, where possible, proposals for design aids and the best execution procedure.

The guidelines have been prepared with cast in-situ structures of high performance concrete in an aggressive environment in mind. These structures are frequently more complex than typical concrete structures. The guidelines can also be used with advantage for traditional types of structure.

1.2 Background

The background material comprises the investigations carried out in Phases 1, 2 and 3 as mentioned in the preface.

2. Geometry

Structures with vertical and horizontal surfaces give the best results.

It is not always possible to follow this simple rule, one reason being that rapid rainwater runoff is also important for the durability of concrete structures. Inclined surfaces will therefore often be necessary.

2.1 Inclined surfaces

There are two basic types of inclined surface, shown in Figures 1 and 2.

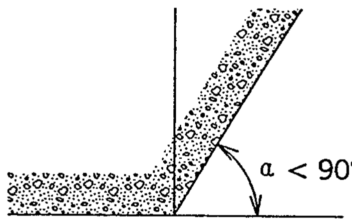


Fig. 1. Vertical section
Inclined surface with
angle α < 90°.

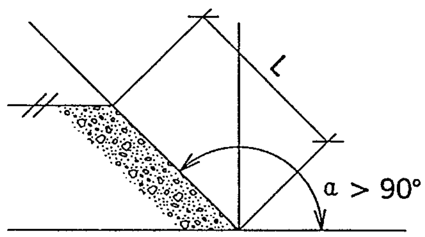


Fig. 2. Vertical section.
Inclined surface with
angle α > 90°.

Inclined surfaces with angles a < 90° - see Fig. 1 - can usually be cast without difficulty.

Problem (90° > α).
Inclined surfaces with angles α > 90° - see Fig. 2 - are usually cast in-situ against formwork. Effective vibration under inclined formwork is difficult, especially when the length L of the section is considerable.

The problem is that air bubbles and any excess water rise to the surface of the form during vibration. The need for an adequate amount of air in the concrete of structures that will be exposed to frost limits the extent of vibration. All the air pockets under the upper form will therefore not disappear if the normal and recommended amount of vibration is used. The result is a surface with "air holes" that are often 0.5 to 1 cm deep. This in turn means local reductions in the concrete cover. Water which possibly contains aggressive materials may settle in the holes and accelerate the deterioration.

The extent of such defects increases as a increases beyond 90°.

For structures that can be prefabricated, these problems can be avoided. For example, the box profile shown in Figs. 5a and 5b can be cast "on end" against vertical formwork. However, as the units must be transported and "turned" prior to final positioning, this procedure is usually adopted only for smaller structures.

Remedial measures - structural detailing (α > 90°)
It is best to avoid inclined surfaces, but if this is not possible, the following measures can improve the quality/lifetime:

- increased concrete cover (see also Sect. 4.1)
- the use of form textiles

Remedial measures - execution (α > 90°)
To ensure good vibration of the concrete under the form, vibrator guides can be used, as shown in Fig. 3. The guides can consist, for example, of 5 Ø8 longitudinal smooth bars with welded rings of a suitable diameter.

The use of a poker vibrator in the concrete cover layer is not advisable. Shallow casting layers can improve the result.

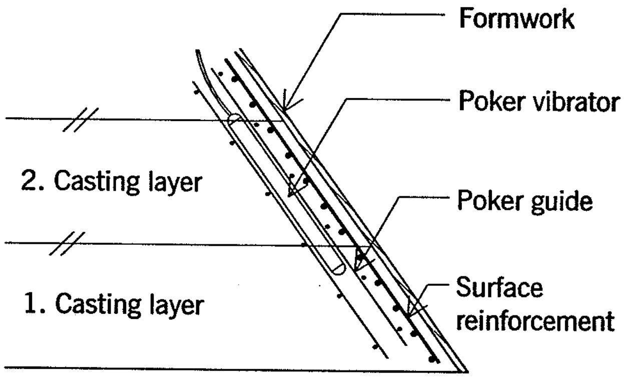


Fig. 3. Vibration of concrete under an inclined form

Problem (α > approx. 160°)
When the angle of inclination a exceeds about 160°, it is not possible to cast in-situ concrete against a continuous form. This is because satisfactory vibration with a poker vibrator cannot be achieved, even with the use of a vibrator guide.
Vibration must therefore be carried out either without an over-form or with an over-form with openings large enough (100 x 100 mm) to permit a poker vibrator to pass through.

None of these methods ensures effective vibration. Casting without an over- form involves a risk of the concrete slipping, with possible inhomogeneity as a result. Casting against a form with openings involves a risk of large air pockets under the form.

Remedial measures - structural detailing (α > approx. 160°)
The closer a approaches 180°, the smaller is the problem of achieving effective vibration without an over-form. A design with an almost horizontal surface should therefore be aimed at. However, a slope that permits adequate water runoff is also necessary.

Example 1: Foundations
Fig. 4a shows a frequently used type of foundation slab with an inclined top surface. The risk of defects when casting without an over-form is greatly reduced if the design shown in Fig. 4b is used, in which the slope is 30‰. If water runoff is not necessary the top surface may be horizontal.

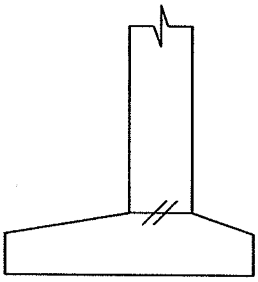


Fig. 4a Foundation slab traditional design

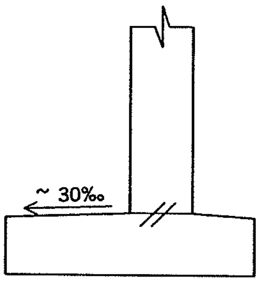


Fig. 4b Foundation slab with slightly inclined top surface

Only if the construction joint is placed as shown is there any advantage in the design shown in Fig. 4b. If the wall, or a part of it, is to be cast simultaneously with the foundation slab, an over-form ("skirt") may be needed; see Sect. 2.4.

Example 2: Box profiles
Fig. 5a shows a traditional box profile design with strengthening of the transition zone between base slab and wall. The strengthened parts have inclined surfaces of the type discussed.

The risk of defects in casting without the use of an over-form is considerably reduced if the design shown in Fig. 5b is used.

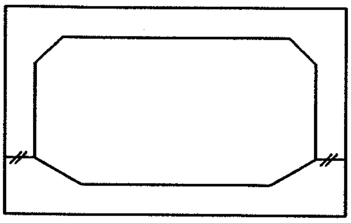


Fig. 5a Box profile with strengthening of transition zone slab/wall.

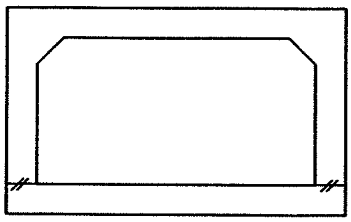


Fig. 5b Box profile. Base slab with horizontal top.

As in Example 1, the advantage of the design shown in Fig. 5b can be obtained only if the construction joint is placed as shown. Environmental conditions may necessitate placing of the joint at a higher level.

Remedial measures - execution (α > approx. 160°)
The traditional methods are casting either with an over-form with openings that permit the passage of a poker vibrator or by placing over-form sections each time a new casting layer is commenced. For almost horizontal surfaces (a > 170°) the concrete can be cast without an over-form by "careful" vibration, so that slipping of the concrete is avoided. Pre-testing could be performed - see [2].

2.2 Drainage profiles

As mentioned in Sect. 2.1, a design with almost horizontal surfaces will reduce the risks involved in casting without an over-form. Special circumstances in connection with complex profiles can, however, involve an increased risk. An example is shown in Fig. 6.

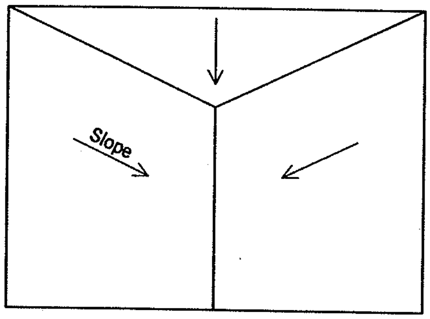


Fig. 6. Concrete surface with complex drainage profile. Plan.

Problem (drainage profiles)
It is difficult to cast surfaces with the prescribed geometry even when guides and smoothing edges are used. The difficulties result in an increased risk of inhomogeneity, especially near the surface. If the main reinforcement is in this zone (Fig. 7a), the corrosion protection is reduced.

Remedial measures - structural detailing (drainage profiles)
Slabs with drainage profiles are usually cast without horizontal construction joints (Fig. 7a).

To reduce the risk of defects near the surface, casting with horizontal construction joints, as shown in Fig. 7b, is preferable, as the main reinforcement is outside the inclined surface zone. The top layer should be reinforced to avoid shrinkage cracks, but a light reinforcement net suffices.

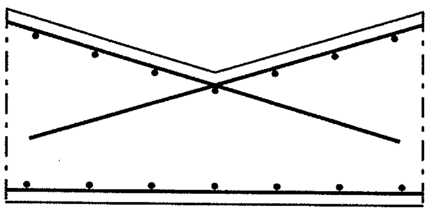


Fig. 7a Floor slab with drainage profile cast as one unit.

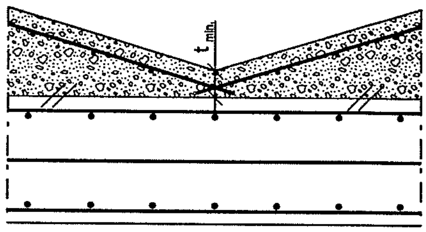


Fig. 7b Floor slab with drainage profile. Separate top layer cast against construction joint. t_{min} = 3 times max. particle size.

Experience shows that the top layer (Fig. 7b) has a tendency to "break away" from the construction joint. This can result in the penetration of water into the joint and subsequent deterioration of the slab concrete. Both methods thus have disadvantages.

The usual method shown in Fig. 7a is generally recommended. As mentioned, it is difficult to carry out. The design should therefore not have features that make casting even more difficult. To compensate for the possibility of poor quality concrete cover, an increase in the thickness of the cover should be considered. See also Sect. 4.1.

Remedial measures - execution (drainage profiles)
To avoid settlement cracks, the top layer around and above the reinforcement should be cast after the underlying concrete has settled. Vibration of the top layer should be carried out with a beam vibrator, which moves on rigidly supported guides. If the reinforcement is very rigid, the beam vibrator can be provided with attachments, e.g. rectangular profiles welded to the underside. The height of the attachments shall correspond to the thickness of the cover. When the attachments are in contact with the reinforcement bars, the cover thickness will be correct. If the surface is to be smoothed, this should be carried out manually using the vibrator beam as access bridge and working platform. Experience shows that mechanical smoothing equipment ("helicopter") increases the risk of inhomogeneity and reduced strength in the cover layer.
Pre-testing could be performed - see [2].

2.3 Wall dimensions

Difficulty in casting walls can be due to inadequate thickness or excessive height.

2.3.1 Wall thickness

Problem (wall thickness)
Casting concrete in thin walls with two layers of reinforcement or one layer in the middle can be difficult. Casting tubes and/or pumping pipes must be able to pass between the reinforcement nets. Pumping pipes are usually 125 or 100 mm.

Remedial measures - structural detailing (wall thickness)
To ensure free passage of the casting tube or pumping pipe, the wall thickness shall be such that the clear distance between the reinforcement nets is at least 150 mm.

If the wall top is bevelled or strengthened with edge profiles, the clear distance between the triangular mouldings or edge profiles shall likewise be at least 150 mm. (See Sect. 2.7 and 3.1).

Remedial measures - execution (wall thickness)
Pumping pipes of diameter 75 mm are available. However, experience with these shows that there is a considerable risk of a stoppage, especially when pumping concrete containing 25 or 32 mm aggregate. Flexible tubes of textile, e.g. fire hoses, can deform and pass through smaller openings. The flexible tube can be attached to the pumping pipe.

When casting with a flexible tube it is important that the nozzle always be held above the concrete already cast. If the nozzle is in the concrete the pressure can become so high that the tube bursts.

2.3.2 Wall height

Problem (wall height)
Casting and compacting concrete in high walls is difficult. A uniform depth of casting layers and correct positioning of poker vibrators can be very difficult as it is impossible to get a clear view from the wall top.
The poor visibility is rendered even worse if the wall is thin, inclined or contains complicated reinforcement. In addition, experience shows that it is difficult to obtain the required air content in the lowest zone in high walls because the pressure is high.

Remedial measures - structural detailing (wall height)
To reduce the risk of casting defects and inadequate air content, the following maximum casting heights (total wall height or distance between construction joints) are recommended:

H_{max} = 8 m for wall thickness over 0.6 m, vertical form and appropriate reinforcement[1)].

H_{max} = 6 m for wall thickness over 0.6 m, inclined form and/or inappropriate reinforcement[1)].

H_{max} = 6 m for wall thickness 0.4-0.6 m, vertical form and appropriate reinforcement.

H_{max} = 5 m for wall thickness 0.3-0.4 m, vertical form and appropriate reinforcement.

H_{max} = 4 m for wall thickness under 0.6 m, inclined form and/or inappropriate reinforcement.

Note 1. Appropriate reinforcement is such that the space between the reinforcement nets and between the nets and the form is visible.
Inappropriate reinforcement can be closely spaced stirrups and/or horizontal lapping bars at the top of the wall. It may also be ducts for prestressing steel.

Remedial measures - execution (wall height)
Ensuring uniform thickness of casting layers is difficult in high walls. The layer thickness to be aimed at is determined on the basis of [1] and [2]. The distance between the points at which the pumping pipe is lowered must be carefully determined on the basis of the concrete's slump. The distance should not exceed 2 m. The period in which concrete is pumped at each point is adjusted to obtain the required layer thickness.

If the thickness of the casting layer is not under control and the visibility is poor, it is impossible to place the poker vibrator correctly.

Poor visibility can be remedied to some extent by arranging "windows" in the form. See Fig. 8.
Pre-testing could be performed.

Fig. 8. Form with openings "windows" for vibration.

2.4 Construction joints

The positioning of construction joints can have a great influence on the concrete work.

As mentioned in Sect. 2.3, casting layers in walls should not be too high, as this

involves risk of error due to poor visibility. Very high walls should therefore be divided into sections of suitable height by means of planned construction joints.
Other considerations apply to the transition between two different cross-sections. The transition wall/foundation in the transverse and longitudinal directions is given in the following.

Problem (cross-section wall/foundation)
The joint between foundation slab and wall is often placed a certain distance above the top of the foundation, as in Fig. 9a.

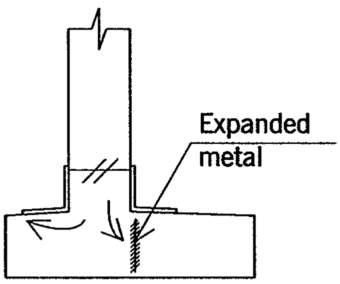


Fig. 9a Construction joint in wall above foundation.

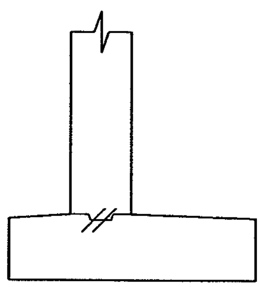


Fig. 9b Construction joint at top of foundation.

In casting the part of the wall below the construction joint, the concrete pressure may cause movement in the upper part of the foundation slab. This can give rise to inhomogeneities. The greater the height of the construction joint above the foundation, the greater the risk.

Remedial measures - structural detailing (cross-section wall/foundation)
The problem can be remedied by placing the construction joint at the top of the foundation, as shown in Fig. 9b.

Remedial measures - execution (cross-section wall/foundation)
The movements in question can be hindered by placing an over-form ("skirt") on the foundation, as shown in Fig. 9a. However, this will result in the surface being "holed" by rising air bubbles, as mentioned in Section 2.1. Another possibility is to place expanded metal in the foundation, as shown in Fig. 9a. Expanded metal, however, is flexible and therefore should only be used if the pressure from concrete and vibration is not very high (the construction joint should not be more than 0.5 m above tht top of the foundation). Expanded metal can result in cracking; the use of an over-form is therefore generally preferable.

Problem (longitudinal section wall/foundation)
If the foundation depth is variable, the foundation and construction joint are sometimes given a uniform fall, as shown in Fig. 10a.

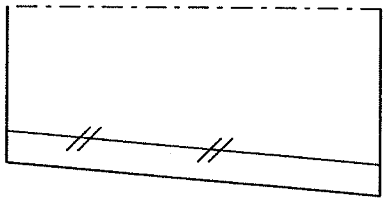


Fig. 10a Foundation with uniform longitudinal fall.

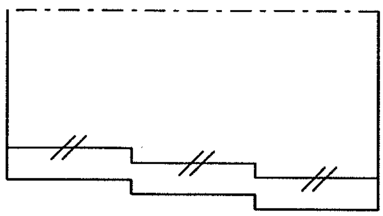


Fig. 10b Stepped foundation.

This can result in problems with inclined surfaces, as described in Section 2.1. The zone around the construction joint is especially problematic, as the lapping bars projecting from the foundation make smoothing difficult. If a jointing profile is to be placed, the difficulties are further increased - see Sect. 3.4.

Remedial measures - structural detailing (longitudinal section wall/foundation)
The difficulties can be avoided by stepping the foundation as shown in Fig. 10b.

Remedial measures - execution (longitudinal section wall/foundation)
No special remedial measures can be identified.

2.5 Openings

Openings generally interfere with the casting process and increase the risk of errors. The most significant factors are:

- The geometry of the openings
- The position of the openings
- Reinforcement
- Joint profiles

These factors are discussed in the following.

2.5.1 Opening, geometry

Problem (opening, geometry)
The main problem with openings is to ensure correct casting under the opening. Furthermore, the lower surface of the opening, which is covered by an over-form, will be vulnerable to holes from rising air bubbles. Complex reinforcement increases the difficulties.

Remedial measures - design (opening, geometry)
The problems are greatest for openings with a large horizontal dimension. This dimension should therefore be limited. The maximum dimension depends on the position of the opening - see section 2.5.2.

From the casting point of view, circular, oval and rhombus-shaped openings are preferable to square and rectangular ones, because the rising air bubbles can escape more easily. However, the reinforcement arrangement is more complex for the former type of opening, as the bars differ from those in the main reinforcement net. There can thus be up to four layers of reinforcement in each side of the wall locally around the opening. Circular, oval and rhombus-shaped openings are therefore advantageous only for relatively thick walls and beams.

Openings for circular pipes are often square. After the pipe has been placed, the space between pipe and opening is filled in. If the wall is sufficiently thick (see above-mentioned reinforcement problem), it may be an advantage to turn the opening through 45°, as shown in Fig. 11b. This also makes the subsequent filling-in around the pipe easier.

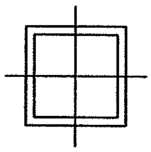


Fig. 11a Square opening, traditional orientation.

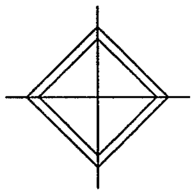


Fig. 11b Square opening turned through 45°. an advantage in relatively thick walls.

To reduce the number of air holes in the lower surface of rectangular openings, the use of form textiles can be specified.

Remedial measures - execution (opening, geometry)
Casting under openings is best carried out as shown in Fig. 12. To reduce the number of air holes in the lower surface of rectangular openings, form textiles can be used.

If the opening has a large horizontal dimension (over 1 m), casting can be carried out through a pipe passing through the opening, as shown in Fig. 13. The distance between pipes depends on the consistency of the concrete, but should not exceed 1.0 m. Pre-testing could be performed - see [2].

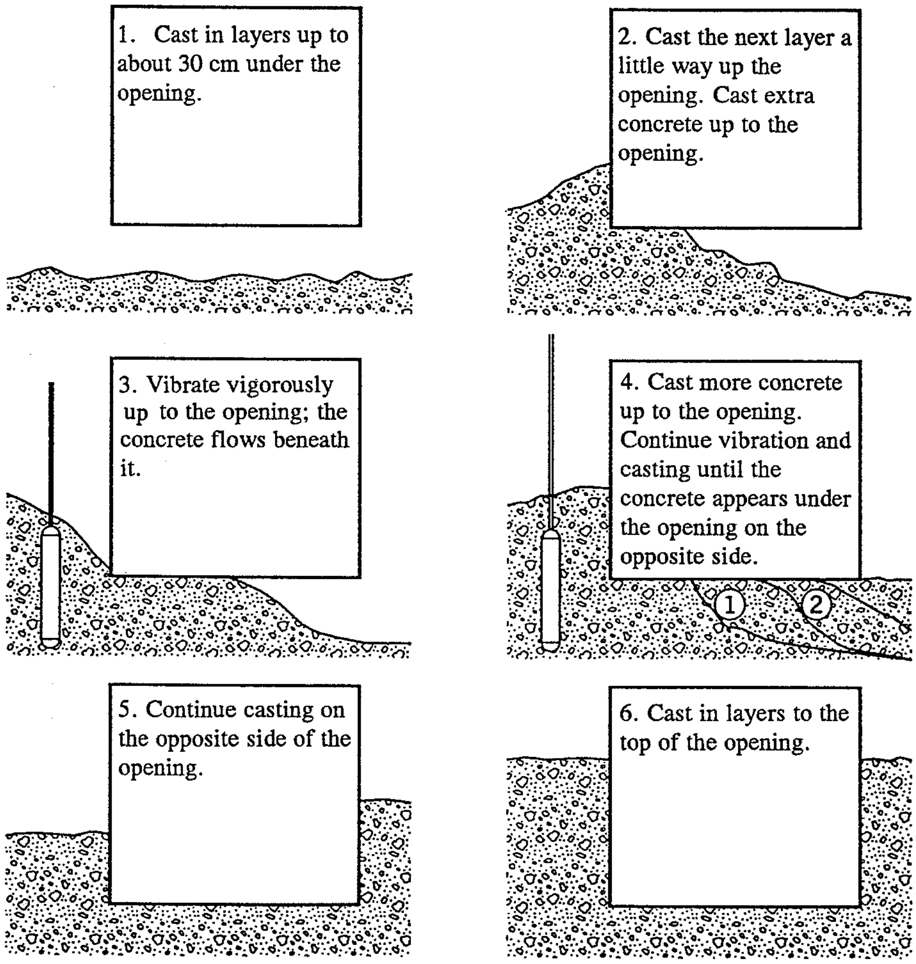


Fig. 12. Casting concrete under an opening.

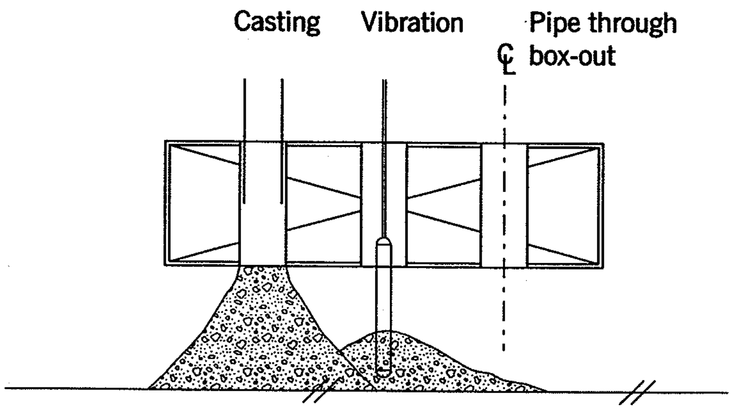


Fig. 13. Casting and vibration of concrete under an opening with large horizontal dimension.

2.5.2 Opening, position

Problem (opening, position)

The previously described difficulties are greatly increased if the distance from the underside of the opening to the construction joint below it is small.

Remedial measures - structural detailing (opening, position)

To ensure acceptable working conditions, the distance from the underside of the opening to the construction joint below should not be less than half the length of the opening. Fig. 14a shows an inappropriate position of both construction joint (see Sect. 2.4) and opening. The 1.0 m long opening is placed 0.2 m above the construction joint, less than half the length of the opening.

By moving the joint to the top of the foundation as shown in Fig. 14b, the recommended distance (0.5 m) between joint and opening is achieved. The most favourable position for the joint is obtained at the same time.

Alternatively, the height of the opening (Fig. 14a) can be increased by 200 mm. The opening will then extend down to the joint and casting under the opening will be unnecessary.

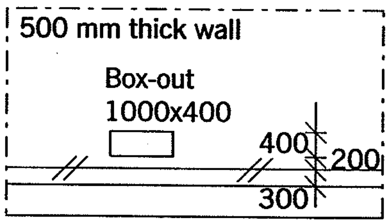


Fig. 14a. 1 m long opening placed 200 mm above construction joint.

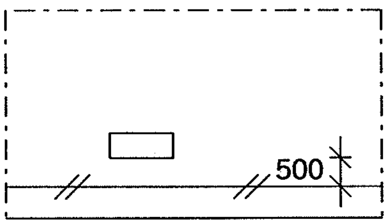


Fig. 14b. The same opening placed 0.5 m above the joint.

Remedial measures - execution (opening, position)

Good workmanship can be achieved by using a casting tube through the opening. See Fig. 13.

2.5.3 Opening, reinforcement and jointing profile

Problem (opening, reinforcement and jointing profile)

Supplementary reinforcement is normally placed along the edges of the opening. If the opening, after casting, is subjected to hydraulic pressure, casting in of a jointing profile at the centre of the opening may be necessary.

In some cases, where a subsequent casting can be carried out, it may be necessary to provide the opening with lapping bars.

All these circumstances, singly or in combination, may make it impossible to cast through tubes, as shown in Fig. 13. It may be possible only with very thick walls.

Remedial measures - structural detailing (opening, reinforcement and joint profile)
The reinforcement arrangement around long openings (over 1 m) shall be such that it is possible to pass a casting tube through the opening as shown in Fig. 13. The supplementary reinforcement should therefore - as far as possible - be placed along the sides of the wall, preferably in the same directions as the ordinary reinforcement (i.e. without inclined bars).

If lapping is necessary, reinforcement couplers may be required.

Joint profiles should be avoided and alternative methods considered, e.g. the use of bentonite, which expands and forms a watertight seal when in contact with water.

If the required measures become complicated, it may be preferable to cast in the component for which the opening is intended. Cast-in pipes can be provided with watertight flanges and possibly with injection ducts for subsequent injection.

Remedial measures - execution (opening, reinforcement and joint profile)
If casting through a tube is not possible due to reinforcement, etc., a hole can be cut in the wall-form itself. This will give access to the opening box and the concrete can be cast through temporary openings in the bottom of the opening box. This solution is not realistic when steel forms and system formwork are used.

2.6 Recesses

Problems with the casting and compaction of concrete under recesses as shown in Fig. 15 are similar to those mentioned in Section 2.5. The deeper the recess, the greater the similarity.

Fig. 15. Recess with holes from rising air bubbles.

Problem (recesses)
The general problem is that rising air bubbles collect under the lower horizontal recess form - see Fig. 16a. After removal of the form, the lower surface is frequently pitted with holes caused by air bubbles.

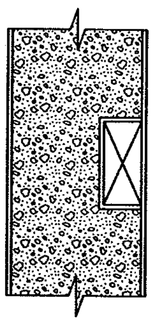


Fig. 16a Recess with horizontal underside.

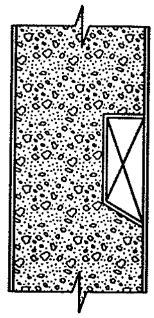


Fig. 16b Recess with inclined underside.

Remedial measures - structural detailing (recesses)
The extent of pitting in the lower horizontal surface can be reduced by casting the surface with a slope, as shown in Fig. 16b. Further reduction can be achieved by prescribing the use of form textile on that surface.

Remedial measures - execution (recesses)
The extent of pitting in the lower horizontal surface can be reduced by the use of form textile.

2.7 Bevelled edges

Bevelled edges are formed by triangular profiles fixed to the form - see Fig. 16a. Bevelled edges reduce the cross-section locally and thus can lead to design and execution problems. The latter are mainly connected with bevelling at the top of walls. These problems are discussed below.

Problem (bevelling)
The wall in Fig. 17a has triangular profiles that are large in relation to the wall thickness. The profiles reduce the clear opening through which casting is to be carried out. If the opening is too small, the traditional method of pumping cannot be used.

If the reinforcement is placed in such a way that the cover to the horizontal surface is c, the cover under the bevel - with a small bending radius - can be less than c.

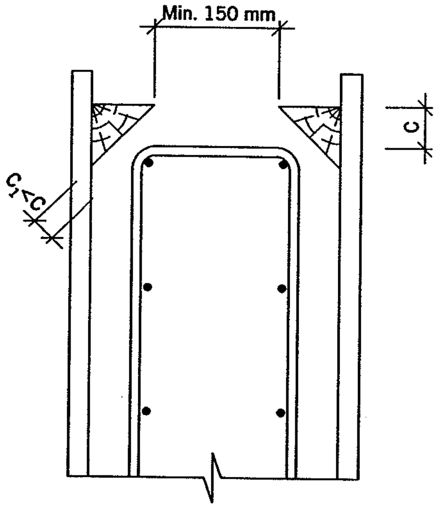


Fig. 17a Wall with bevelled edges. Reduced cover under the bevel.

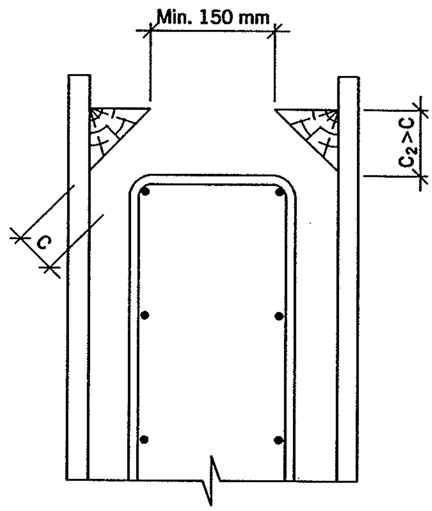


Fig. 17b Wall with bevelled edges. Increased cover at the wall top.

Remedial measures - structural detailing (bevels)
The clear distance between the profiles and between the reinforcement nets must be at least 150 mm. To ensure that the cover under the bevel is equal to c, the reinforcement can be placed as shown in Fig. 17b. This involves a deeper cover over the horizontal reinforcement at the wall top.

Remedial measures - execution (bevels)
If the clear distance between the bevels is less than 150 mm, flexible tubes can be used. See Section 2.3.

2.8 Trapezoidal grooves and drip traps

Construction joints are sometimes provided with trapezoidal grooves (Fig. 18) and with drip traps. These are formed by fixing profiles to the form.

Problem (trapezoidal grooves and drip traps)
Slender profiles have a tendency to twist and warp. When the profile is flexible, there is a risk of deformation even when the distance between nails is small. The result can be that the grooves have incorrect dimensions or jagged edges.

Remedial measures - structural detailing (trapezoidal grooves and drip traps)
Grooves and drip traps should have sufficient depth and width. The depth should be at least 20 mm. Profiles of this thickness are sufficiently rigid.

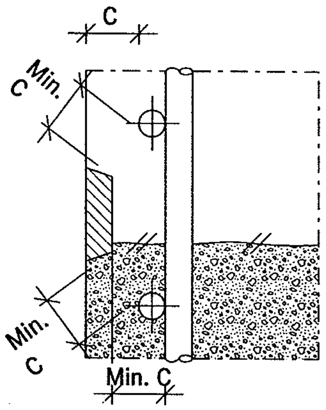


Fig. 18. Design of trapezoidal groove and the reinforcement around it.

To ensure that the cover is at least c, the following conditions must be met:

- The outermost reinforcement bars must be parallel to the groove.
- The distance from the groove to the nearest bars must exceed c.

If these conditions cannot be met, the cover can be increased (see Section 4.1).

Remedial measures - execution (trapezoidal grooves and drip traps)
No special measures can be identified other than having a very small distance between nails when using slender profiles.

3. Cast-in components

Cast-in components usually make casting and compaction more difficult.
The larger and more complex the components, and the greater their number, the greater the risk of casting defects.

For components with horizontal surfaces there is a risk of air pocket formation, with reduced bond as a result. Inclined and concave surfaces reduce the risk. In addition, the following principle applies:

Components that do not project beyond the surface of the concrete in which they are cast give the best conditions for casting good concrete.

If the geometry or mode of operation does not permit the complete casting-in of a component, it is preferable to make a recess or opening and to cast the component in later.

Problems that arise with frequently used components are discussed in the following.

3.1 Steel edge profiles

Edges of structures that may be exposed to shocks or impacts are often reinforced with edge profiles.

Problem (edge profiles)
Wide profiles at the top of walls and beams can reduce the clear opening through which casting is to be carried out. The problem is identical with that in bevelled edges (Section 2.7).

Remedial measures - structural detailing (edge profiles)
The clear distance between edge profiles at the top of walls and beams should be at least 150 mm.

Remedial measures - execution (edge profiles)
Remedial measures are identical with those for bevelled edges (Section 2.7).

3.2 Cavity tubes

In some structures cavity tubes are used to reduce the dead load. The tubes used are a hindrance for casting and vibration and can result in serious defects. Fig. 19 shows the casting of a slab using cavity tubes.

Fig. 19. Casting of prestressed slab with corrugated cavity tubes.

Problem (cavity tubes)
There is a risk that the cavity tubes will deform during casting under the pressure of the concrete, and that the buoyancy effect will cause movement of the tubes.
The conical ends of the tubes are especially difficult to anchor. Deformations and movement can change the longitudinal fall of the tubes, resulting in water pockets and the risk of accelerated deterioration. Furthermore, it is difficult to cast effectively under the tubes.

Remedial measures - structural detailing (cavity tubes)
The use of cavity tubes must be considered carefully. To minimize the risk of deformation the wall thickness of the tubes should be specified. The tubes should be provided with drainage outlets (drip-tubes).

To achieve effective casting under the cavity tubes, the clear distance between tubes should not be less than 0.7 times the tube diameter.

The arrangement of reinforcement, prestressed as well as non-prestressed, between the tubes must permit adequate visibilty and the entry of poker vibrators.

Remedial measures - execution (cavity tubes)
To ensure good casting, the following should be observed:

- The cavity tubes must be anchored along their entire length to prevent movement resulting from buoyancy.
- The conical ends of the tubes must be firmly attached to the base of the form.

When the cavity tubes have been firmly fixed, casting can begin. In casting, it is important to ensure that the spaces under the tubes are filled. This is best achieved by working systematically from one side of the cross-section to the other, so that the space below each tube is filled on one side of the tube before concrete is cast on the other side.

In the longitudinal direction casting can be carried out in two ways:

a. Horizontal casting layers

Casting is carried out from each side alternately, with casting layers of varying thickness, as shown in Fig. 20. This reduces the horizontal force on the tube. A pause may be necessary when the concrete has reached a height corresponding to the centre-line of the tube (layer No. 3 in Fig. 20). This reduces the buoyancy effect. When this concrete has become sufficiently cohesive, the remaining concrete is cast.

A pause in the casting may mean that the normally accepted maximum periods in which concrete surfaces can be exposed without protection against drying out will be exceeded. At worst, there can be a "cold construction joint".

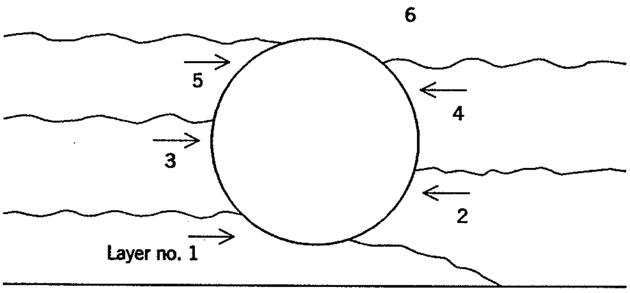


Fig. 20. Casting around a cavity tube.
Horizontal casting layers.

b. Inclined casting layers

In this method, which can be necessary for major casting operations, the concrete is cast in the longitudinal direction with an inclined front extending over the entire cross-section (Fig. 21).

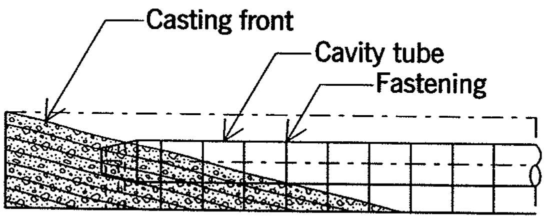


Fig. 21. Casting around cavity tube.
Inclined casting layers.

The concrete in the first layers cast will be so cohesive that no buoyancy effect will arise. Furthermore, the concrete above the tubes will act as a counterweight for the tube sections that are subjected to buoyancy. The favourable effect is greatest when casting is carried out slowly in thin layers. This method requires subsequent vibration to prevent settlement cracks above the tubes and voids under them.

3.3 Cooling pipes

Temperature-regulating measures that reduce the risk of cracking in the hardening phase are increasingly used. Maximum permissible temperatures and temperature differences are frequently specified.

Massive structures develop much heat, and it can be necessary to lower the temperature e.g. by cooling the hardening concrete with cold water, circulated in the structure by means of cast-in pipes of plastic or steel. When a massive structure is cast against another that has ambient temperature, it can be difficult to meet the requirement for the maximum temperature difference between the two castings. In such cases it is not always sufficient to cool the section cast last [3]. The cold section may have to be heated, e.g. by circulating warm water in the pipes used for cooling it in the hardening phase.

Cooling by cooling pipes is the most effective method of temperature regulation, but cast-in pipes hamper casting and compaction of the concrete.

Problem (cooling pipes)
The pipes are usually placed in the central part of structures, as it is most difficult to remove heat from this region.

In massive structures of considerable volume the pipes must often be placed in layers approx. 0.5 m apart, with the same distance between the pipes in each layer.

It can also be necessary to use cooling pipes in thin walls, if they are to be cast against walls cast earlier, that have cooled to the temperature of the surroundings. Pipes placed at the centre-line of a wall can hamper casting and compaction.

Remedial measures - structural detailing (cooling pipes)
Massive structures of large volume should be avoided if possible. The required maximum difference in mean temperatures is very difficult to meet if such a structure is to be cast against a cold structure. However, stress calculations can be carried out, see [3].

Because of the required temperature difference between cast sections, the position of the construction joint is critical for the total amount of cooling needed. Similarly, the planned casting sequences is critical for the temperature of the section to be cast against. The optimum solution should take both these factors into account. Constructive collaboration on hardening problems in the planning phase is therefore important.

Remedial measures - execution (cooling pipes)
Only the measures needed to ensure satisfactory casting and effective vibration will be mentioned.

Cooling pipes in walls are placed on the centre-line, where the temperature would otherwise be highest. If the pipes are placed horizontally, the clear opening through which casting and vibration are to be carried out is reduced - see Fig. 22. The clear opening should be at least 150 mm.

If this is not possible, the pipes can be placed vertically with horizontal connections uniformly distributed at the top and bottom. In this way there will be uniformly distributed openings of sufficient width.

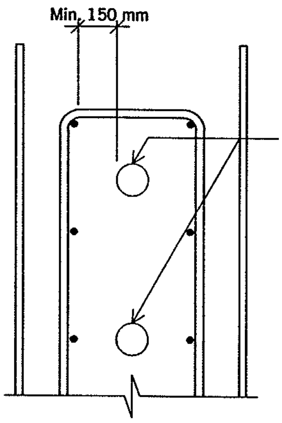


Fig. 22. Cooling pipes at the centre-line of a wall.

Cooling pipes should not be placed where there is dense reinforcement, as effective vibration would be rendered even more difficult. It is particularly important not to place cooling pipes close to the anchorage zone of prestressed reinforcement.

3.4 Joint profiles

Construction joints in structures subject to hydraulic pressure are often provided with joint profiles. PVC profiles are usually used. The profile is placed either at the centre of the joint, or close to the side exposed to hydraulic pressure. See Figs. 23 and 24.

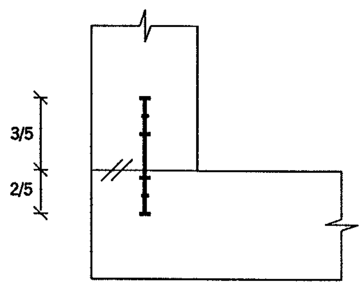


Fig. 23 Profile placed at the centre of the construction joint.

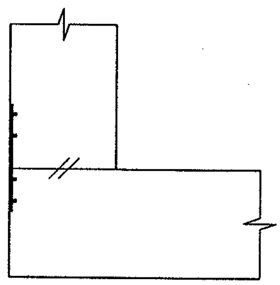


Fig. 24 Profile placed at one side of the construction joint.

Problem (joint profile)

PVC profiles become soft when warmed by the sun. The deformations can result in folding, in which case there is a risk that the profile will not be positioned as shown in Figs. 23 and 24. The casting of the lower section in which the profile is placed is hampered by the presence of the profile, especially when it is centrally placed (Fig. 23). This can result in the cast-in width of profile being less than the recommended (2/5). If there is through-going horizontal reinforcement in the topside of the lower structural section, the profile cannot be cast in with the recommended width.

Profiles in slabs are especially problematic (Fig. 26). Here there is a risk that the concrete under the horizontal profile will not completely surround the profile. Rising air bubbles may be the cause of this. The construction joint will then not be watertight, despite the joint profile.

Remedial measures - structural detailing (joint profile)
The type of profile to be used should be carefully considered. To counteract the reduction of concrete cover by deformation of the profile placed on one side (Fig. 24), an increased cover (e.g. +10 mm) can be specified (see also Section 4.1). If there is through-going horizontal reinforcement in the topside of the lower structural section, a centrally placed profile can be positioned correctly only if the construction joint is placed a little way up the wall, as shown in Fig. 25. This creates further complications in casting, cf. Section 2.4. Another type of profile is available, consisting of bentonite, which expands when in contact with water and prevents its further penetration. This type of profile is less likely to be incorrectly positioned and its use gives less risk of inhomogeneities in the concrete.

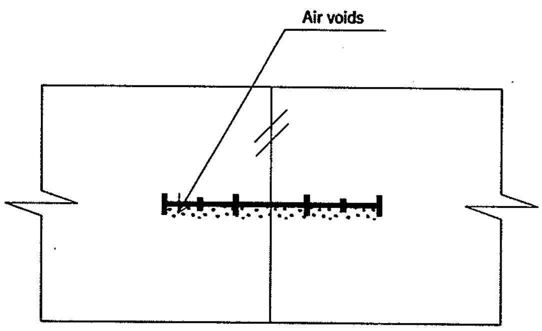


Fig. 25. Joint profile in construction joint of slab.

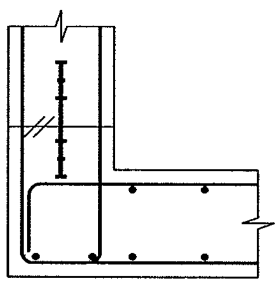


Fig. 26. Joint profile in construction joint with through-goint reinforcement in the topside of the slab.

Remedial measures - execution (joint profile)
To ensure that the profile is correctly placed when in the position shown in Fig. 24, it can be fixed to a 2 mm steel plate placed against the form.

4. Non-prestressed reinforcement

If the reinforcement in a concrete structure is to act throughout the expected service life of the structure, it must be effectively protected against corrosion. The depth and quality of the concrete cover is therefore of great importance.

4.1 Concrete cover

"Anvisning i brug af højkvalitetsbeton til udsatte anlægskonstruktioner" [4] gives a detailed description of the factors in design and execution that influence the quality of the cover.

The cover must have a minimum thickness c_o, that depends on the environmental class. The specified cover c is given by the minimum thickness + a tolerance allowance Δc. In stress calculations, c is taken to be equal to $c_o + \Delta c$.

In Denmark, the main reinforcement must be placed with an accuracy corresponding to the drawing dimension ± 10 mm. The permissible deviations are:

For tolerance allowance $\Delta c > 10$ mm: ± 10 mm

For tolerance allowance $\Delta c < 10$ mm: + 10 mm/-Δc

Problem (cover thickness)

Small tolerance allowances, e.g. $\Delta c = 5$ mm, mean that the reinforcement must be placed with an accuracy corresponding to the drawings +10/-5 mm, and must remain in that position during and after casting.

Placing the reinforcement with such an accuracy can be extremely difficult and in some cases virtually impossible. This applies to surfaces that are not cast against a form and even more to profiled surfaces - see Section 2.2. To ensure that the reinforcement gets at least the prescribed minimum cover, it is often placed with an increased cover.

Remedial measures - structural detailing (cover thickness)

Large tolerance allowances increase the probability of achieving the minimum cover. Eurocode 2 gives the tolerance allowance for structures cast in-situ as 5-10 mm. The Danish code of practice DS 411 states that the allowance should not be less than 5 mm. DIN 1045 gives 10 mm, and in Norway [5] 10-15 mm is used.

Admittedly, an increase in the tolerance allowance involves an increase in the amount of reinforcement. If the stresses under service loads are governing, an increase in the allowance from 5 to 15 mm for a Ø20 mm reinforcement bar with 40 mm minimum cover will increase the amount of reinforcement by approx. 5% when DS 411 is used. If the supplement is increased from 5 to 10 mm, the reinforcement increase will be only about 3%.

The reinforcement increases are thus modest, and larger tolerance supplements are recommended for structures that are difficult to cast, e.g. surfaces not cast against forms. This increases the likelihood of achieving the minimum cover and takes a realistic evaluation of the accuracy of reinforcement placing into account.

If the minimum cover c_o is increased e.g. due to local reductions in the cross-section e.g. from cast-in profiles or grooves, this will also involve a small increase in the amount of reinforcement if the service state governs the dimensions.

Remedial measures - execution (cover thickness)
To ensure that the bars in the topside of a floor slab remain in the correct position, spacers bars must be placed between the upper and lower reinforcement nets. The distance between spacer bars must not be too great, as loads on the net in the construction phase could deform the reinforcement. Spacer blocks are placed under the lower reinforcement net; they ensure that the net is given the required cover and transfer load from the spacer bars to the form.

To obtain the correct cover, the spacer bars and spacer blocks must be made with great accuracy. The tolerance for the blocks should be -0/+5 mm. Loads on the upper reinforcement net in the construction phase should be distributed by means of planks or boards.

4.2 Distance between reinforcement bars

A small distance between bars makes effective vibration difficult.

Problem (distance between reinforcement bars)
Standards prescribe a minimum clear distance between reinforcement bars in the same layer; this distance depends on the diameter of the bars and the maximum aggregate size. In practice the distance is typically 50 mm (for Ø25 mm bars and max. aggregate size 32 mm) according to DS 411, but only 37 mm according to Eurocode 2.

Small clear distances in wall reinforcement can result in the compaction effect of poker vibrators being impeded and failing to reach the cover layer. There is also a risk of a "sieve effect" - the larger particles in the aggregate being held back. Experience shows that there is a risk of large particles "building a bridge" when the clear distance between bars is less than 3 times the maximum particle size.

The risk of inhomogeneous concrete and other casting defects increases with decreasing clear distance.

In slabs with several layers of crossing bars, clear openings of 50 x 50 mm (DS 411) or even 37 x 37 mm (Eurocode 2) are quite inadequate for casting with a 125 mm pumping pipe or for correct placing and effective use of poker vibrators.

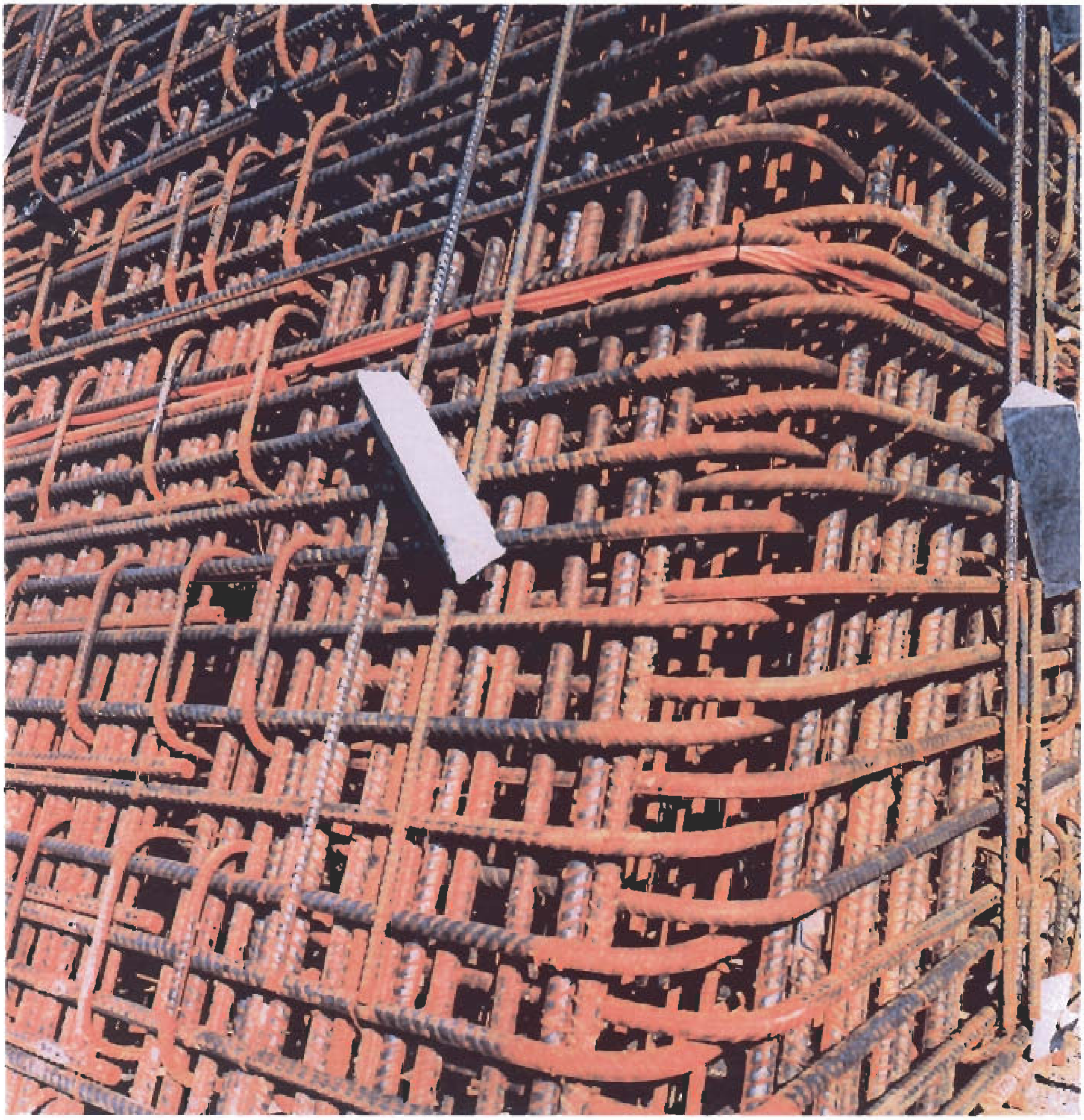


Fig. 27. Dense reinforcement.

Remedial measures - execution (distance between reinforcement bars)
For satisfactory casting the following principles can be recommended:

- Reinforcement near surfaces should have a minimum clear distance of 50 mm in both directions between bars, laps and bundles of bars. Bars should, where possible, be tied in bundles to facilitate placing and compaction of the concrete.

- A high reinforcement percentage with non-bundled bars and small diameters makes vibration difficult. In such cases, bars of larger diameter should be used.

- For walls and slabs, two or three layers of reinforcement are better than one layer with a shorter distance between bars. A greater distance enables larger aggregate particles to pass through and facilitates the use of a poker vibrator.

The arrangement shall ensure that the concrete can be placed in its final position without large horizontal movement during vibration, and that there is room to insert a poker vibrator - see Fig. 28.

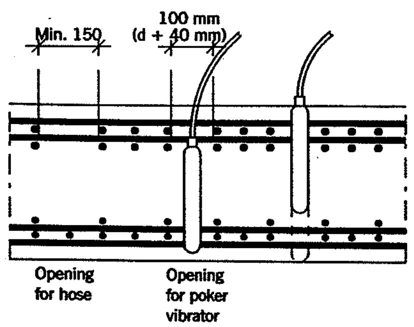


Fig. 28. Openings for pumping pipe and poker vibrators.

Openings for pumping pipes or casting tubes are necessary when the height of the structure exceeds 1 m, as this is the normal limit for the free fall of concrete. At openings, the clear distance between bars should be at least 150 x 150 mm. The maximum distance between such openings depends on the consistency of the concrete, but should not exceed 2 m.

The clear distance between bars at openings for poker vibrators should be at least d + 40 mm, where d is the diameter of the poker vibrator. The distance between openings depends on the complexity of the reinforcement and the diameter of the vibrator. See "Recommendation for poker vibration" [2].

Remedial measures - execution (distance between reinforcement bars)
Accurate reinforcement work will reduce the risk of local reduction of the clear distance between bars.

To obtain the required number of openings for casting tubes and poker vibrators (Fig. 26), the bars can be displaced and/or arranged in groups. This must only be done by agreement with the design engineer.

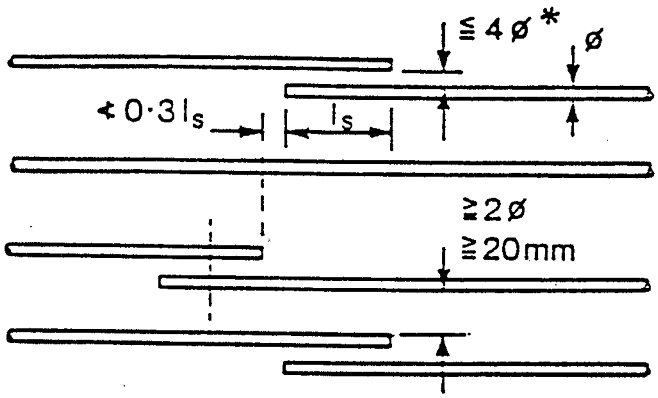
For very complex reinforcement, casting a representative test specimen is advisable [2].

4.3 Laps and anchorages

Laps and anchorages increase the density of the reinforcement and create additional difficulties for casting.

Problem (laps and anchorages)

The problems are the same as those mentioned in Section 4.2. Eurocode 2 gives rules for the clear distance between lapped bars (both horizontal and vertical) as shown in Fig. 29.



* Otherwise the lap length must be increased by a length equal to that by which the clear distance exceeds 4ø.

Fig. 29. Closely spaced laps.

Fig. 30 shows an example of closely spaced anchored bars. The casting in such zones can be extremely difficult.

Remedial measures - structural detailing (laps and anchorages)

The general principles given in Section 4.2 also apply here. In addition, the following can be mentioned:

- Staggered laps should be used, as the reinforcement density is thereby reduced.
- The clear distance between laps, Fig. 29, should be as great as possible.
- The use of reinforcement couplings reduces the reinforcement density.

Remedial measures - execution (laps and anchorages)

To obtain better casting around reinforcement in zones with closely spaced laps and anchorages, concrete with maximum particle size 16 mm can be used. Reducing the aggregate content of the concrete mix may be a further help.

Fig. 30. Closely spaced anchored bars

5. Prestressed reinforcement

Anchorage zones in prestressed concrete can be difficult to cast.

Problem (anchorages)
The concrete behind anchorages is reinforced with a closely spaced net - or a spiral. These zones, in which ordinary reinforcement bars are also present, can be difficult of access for a poker vibrator.

Prestressed reinforcement in walls makes casting and vibration difficult. The problem is analogous to that with cooling pipes - see Section 3.3.

Remedial measures - structural detailing (anchorages)
The general principles given in Sections 4.2 and 4.3 should be followed. Net reinforcement is preferable to spiral reinforcement, as vibration is easier with the former.

Cooling pipes should be placed at least 1 m from the anchorage zone.

Remedial measures - execution (anchorages)
In casting anchorage zones with dense reinforcement, it is recommended that the concrete be placed outside the zone, and vibrated in towards the anchorages as shown in Fig. 31. This procedure is a departure from the generally accepted methods of casting.

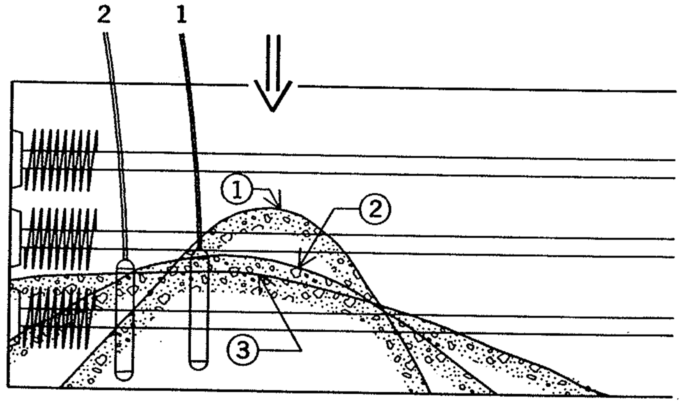


Fig. 31. Casting of anchorage zone with dense reinforcement.

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