INTERNATIONAL STANDARD

ISO 22966

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Execution of concrete structures

Exécution des structures en béton

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22966 was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and prestressed concrete*, Subcommittee SC 3, *Concrete production and execution of concrete structures*.

Introduction

This International Standard applies to the execution of concrete structures to achieve the intended levels of reliability and serviceability that are given in ISO 2394[3] and in standards for the design of concrete structures.

This International Standard has three functions:

— to transfer the requirements set during design from the designer to the constructor, i.e. to be a link between design and execution;

— to give a set of standardized technical requirements for the execution when ordering a concrete structure;

— to serve as a check list for the designer to ensure that he provides the constructor with all relevant technical information for the execution of the structure; see Annex A.

In order to achieve these objectives, it is necessary that the designer prepare a set of documents and drawings giving all information required for the execution of the work in accordance with the plans. This set of documents is in this International Standard referred to as the “execution specification”. This International Standard leaves a number of items open that can be decided by the execution specification.

It is necessary that the execution specification refer to national provisions in areas where these apply.

It is recognized in this International Standard that areas such as detailed requirements for competence of personnel and details related to quality management are within the competence of the member states.

A national annex can refer to national standards approved and published by an ISO member body and that supplement this International Standard; alternatively, the supplementing rules can be given directly in the national annex.

Execution of concrete structures

1 Scope

This International Standard gives common requirements for the execution of concrete structures and applies to both *in-situ* works and construction using prefabricated concrete elements.

This International Standard requires that the execution specification state all the specific requirements relevant to the particular structure.

This International Standard is applicable to temporary as well as permanent concrete structures.

Additional or different requirements can be considered and, if required, given in the execution specification when using

— lightweight aggregate concrete;

— other materials (e.g. fibres) or constituent materials;

— special technologies/innovative designs.

This International Standard does not apply to the following:

a) concrete members used only as equipment or construction aids for the execution;

b) specification, production and conformity of concrete;

c) production of precast concrete elements made in accordance with product standards;

d) safety and health aspects of execution, or third-party safety requirements;

e) contractual issues or responsibilities for the identified actions.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6934 (all parts), *Steel for the prestressing of concrete*

ISO 6935-1, *Steel for the reinforcement of concrete — Part 1: Plain bars*

ISO 6935-2, *Steel for the reinforcement of concrete — Part 2: Ribbed bars*

ISO 15630-1, *Steel for the reinforcement and prestressing of concrete — Test methods — Part 1: Reinforcing bars, wire rod and wire*

ISO 17660-1, *Welding — Welding of reinforcing steel — Part 1: Load-bearing welded joints*

ISO 17660-2, *Welding — Welding of reinforcing steel — Part 2: Non-load-bearing welded joints*

ISO 22965-1, *Concrete — Part 1: Methods of specifying and guidance for the specifier*

ISO 22965-2, *Concrete — Part 2; Specification of constituent materials, production of concrete and compliance of concrete*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
back-propping
propping installed at levels below the slab that supports the falsework in order to distribute the load to suitable support

3.2
chair for reinforcement
device used to secure the position between reinforcement layers, e.g. supporting top reinforcement in a slab

3.3
construction works
everything that is constructed or results from construction operations

NOTE The term covers both building and civil engineering works. It refers to the complete construction comprised of both structural and non-structural components.

3.4
constructor
organization executing the works

3.5
erection specification
documents covering all drawings, technical data and requirements required for the safe erection of precast elements

3.6
execution
all activities carried out for the physical completion of the work, i.e. procurement, scaffolding, formwork, reinforcing, concreting, curing, erection of precast elements, etc., and the inspection and documentation thereof

3.7
execution class
classified set of requirements specified for the execution of the works as a whole or an individual component

3.8
execution specification
documents covering all drawings, technical data and requirements necessary for the execution of a particular project

NOTE The execution specification is not one document but signifies the total sum of documents required for the execution of the work as provided by the designer to the constructor and includes the project specification prepared to supplement and qualify the requirements of this International Standard, as well as referring to the national provisions relevant in the place of use.

3.9
falsework
temporary support for a part of a structure while it is not self-supporting and for associated service load

3.10
formwork
structure, permanent or temporary, for containing poured concrete, moulding it to the required dimensions and supporting it until it is able to support itself

NOTE Formwork consists of the face contact material and the bearers directly supporting the face contact material.

3.11
inspection
conformity evaluation by observation and judgment accompanied as appropriate by measurement, testing or gauging

[ISO 9000:2005[6], 3.8.2]

3.12
method statement
documentation describing the methods and procedures that shall be used to perform the work

3.13
permitted deviation
permitted algebraic differences between the limits of size and the corresponding reference size

[Adapted from ISO 1803:1997[1], 3.8.]

3.14
precast concrete element
concrete element cast and cured in a place other than the final location of use (factory produced or site manufactured)

NOTE Precast concrete element manufactured in compliance with the relevant international product standard is called a “precast concrete product.” In this International Standard, the shorter terms “precast element” and “precast product” are used.

3.15
project specification
project-specific document describing the requirements applicable for the particular project

3.16
quality plan
document specifying which procedures and associated resources shall be applied by whom and when to meet the requirements of the specific project

NOTE Guidance can be found in ISO 9000[6] concerning the content of a quality plan.

3.17
reference line
line defined in the execution specification to which positions are related

3.18
secondary line
any line used for the purpose of setting-out the proposed building and for checking the compliance of the building or building parts

[ISO 4463-1:1989[2], 4.4]

3.19
spacer
device used to secure correct spacing between the formwork and the reinforcement

3.20
surface finish
description of the appearance of the concrete surface including aspects of geometry, texture, colour etc.

3.21
temporary structure
structure designed for a short design working life

3.22
tolerance
difference between upper limit of size and the lower limit of size

[Adapted from ISO 1803:1997[1], 3.11.]

NOTE 1 Geometrical tolerances for precast concrete elements are subdivided as follows:

— production tolerances;

— erection tolerances, i.e. geometrical tolerances relating to location, verticality, horizontality or other characteristics of the construction assembly;

— construction tolerances, i.e. geometrical tolerances that are a combination of production, site construction and erection tolerances.

NOTE 2 Tolerance is an absolute value without sign, it is however commonly expressed by “the sum of the positive and negative permitted deviation” so that the value of the tolerance is implicit.

3.23
normal tolerance
basic limit for geometrical deviations that ensures that the structure

— satisfies the design assumptions;

— achieves other functional requirements of the construction works.

NOTE In this International Standard, normal tolerances are referred to as tolerance class 1.

3.24
special tolerance
tolerance other than normal tolerance

3.25
works
those parts of the construction works that are structural concrete work and are described in the execution specification

4 Execution management

4.1 Assumptions

4.1.1 This International Standard assumes the following:

— availability of a comprehensive design of the structure;

— project management in charge of the supervision of the works that can enable the execution of a conforming structure;

— site management that can take charge of the organization of the works and enable the correct and safe use of the equipment and machinery, the required quality of materials, the execution of a conforming structure and its safe use up to the delivery of the works.

4.1.2 When precast elements are used, the following additional assumptions are made:

— availability of a specific design of the precast elements conforming to the relevant standards;

— availability of design coordination between precast elements and site manufactured components;

— technical specification of the precast structure with instructions for installation;

— availability of an erection management to direct the erection team.

4.1.3 This International Standard presupposes that the work is carried out with the necessary skill and adequate equipment and resources to perform the work in accordance with this International Standard and the requirements of the execution specification.

NOTE In some countries, there are special requirements regarding the level of knowledge, training and experience of personnel involved in the various tasks.

4.1.4 It is assumed that the constructor will comply with national regulations and standards, e.g. with respect to

— quality management;

— qualifications for the personnel doing the various activities covered by this International Standard;

— health and safety aspects of construction;

— environmental aspects.

4.1.5 This International Standard assumes that the structure after completion is used as intended in the design and submitted to the planned inspection and maintenance necessary to achieve the intended design working life and to detect weaknesses or any unexpected behaviour.

4.2 Documentation

4.2.1 Execution specification

4.2.1.1 Before commencement of the execution of any part of the works, the execution specification relevant to that part of the works shall be complete and available.

4.2.1.2 The following items shall be included in the execution specification:

— reference to this International Standard and, if published, its national annex;

— reference to other relevant International Standards and national technical approvals;

— reference to relevant national regulations and standards;

— project specification giving information and requirements for the particular project prepared to supplement and qualify the requirements of the above-listed documents;

— drawings and other technical documents needed for the execution.

Annex H gives guidance on the content of a national annex to this International standard; a national annex may cover any of the areas indicated as open for specification by the execution specification.

NOTE Table A.1 contains a checklist of requirements and information that it can be necessary to include in the execution specification, as appropriate.

4.2.1.3 In addition, where relevant, procedures shall be established for

— making alterations to previously agreed requirements;

— distribution, filing and recording of technical documents used for the works.

4.2.2 Quality plan

4.2.2.1 Where a quality plan is required by the execution specification, it shall be available on site.

4.2.2.2 There may be one quality plan covering all activities or one overall plan supplemented by separate plans for the various phases and activities to be performed.

4.2.3 Execution record documentation

A record shall be made giving the required information as specified for the execution class in Tables 1, 2 and 3.

4.2.4 Special record documentation

If special documentation is required, the type and extent of the documentation shall be stated in the execution specification.

4.3 Quality management

4.3.1 Execution classes

4.3.1.1 Supervision and inspection of the work shall ensure that the construction is completed in accordance with the execution specification.

4.3.1.2 Inspection in this context refers to verifying conformity of the properties of products and materials being used as well as inspection of the execution of the works.

4.3.1.3 Requirements for quality management are specified using one of the following three classes, for which the required strictness increases from class 1 to class 3:

— execution class 1;

— execution class 2;

— execution class 3.

4.3.1.4 The execution class may refer to the complete structure, to components of the structure or to certain materials/technologies used for the execution.

4.3.1.5 The execution class being used shall be stated in the execution specification.

4.3.1.6 This International Standard does not deal with provisions related to degree of independence of the personnel performing the inspection.

4.3.1.7 Further detailing of the requirements for the quality management regime in excess of what is given in this International Standard may be stated in the execution specification.

NOTE Annex B gives guidance on quality management.

4.3.2 Inspection of materials and products

The inspection requirements for conformity with the execution specification are given in Table 1.

Table 1 — Inspection for materials and products

Subject	Execution class 1	Execution class 2	Execution class 3
Materials for scaffold, formwork and falsework[a]	In accordance with 5.1 and 5.2		
Reinforcing steel[a]	In accordance with 6.2		
Prestressing system components[a]	Shall not be used in this class	In accordance with 7.2	
Fresh concrete, ready-mixed or site-mixed[ac]	In accordance with 8.1 and 8.3 At reception of ready-mixed concrete a delivery ticket shall be present		
Other items[ab]	In accordance with the execution specification		
Precast elements[a]	In accordance with 9.2 and 9.3		
Inspection report	Not required	Required	

[a] Products bearing a recognized quality mark or certified by an approved certification body shall be checked against the delivery ticket and visually inspected. In cases of doubt, further inspection shall be undertaken to check that the product conforms to its specification. Other products shall be subject to inspection and acceptance testing as defined in the execution specification.

[b] For example, items such as embedded steel components, etc.

[c] If prescribed concrete is used, the relevant properties shall be checked by tests.

4.3.3 Inspection of execution

The inspection requirements for conformity with the execution specification are given in Tables 2 and 3.

Table 2 — Inspection requirements

Subject for inspection of execution	Execution class 1	Execution class 2	Execution class 3
Scaffolding, formwork and falsework	According to requirements given in Clause 5		
Embedded items	According to requirements given in 5.6		
Ordinary reinforcement	According to requirements given in Clause 6		
Prestressing reinforcement	Shall not be used in this class	According to requirements given in Clause 7	
Site transport and casting and curing of concrete	According to requirements given in Clause 8		
Erection of precast elements	According to requirements given in Clause 9		
As-built geometry	Not required	According to execution specification	

Table 3 — Type and documentation of inspection

	Execution class 1	Execution class 2	Execution class 3
Type of inspection	Visual inspection and random measurements	Visual inspection and systematic and regular measurements of major works	Visual inspection Detailed inspection of all works which are significant for the load-bearing capacity and durability of the structure
Party which carries out the inspection	Self inspection	Self inspection Inspection in accordance with the procedures of the constructor Possible additional requirements by execution specification	Self inspection Inspection in accordance with the procedures of the constructor Additional requirements by project execution specification
Extent	All works	In addition to the self inspection, there shall be a systematic and regular inspection of the works	In addition to the self inspection, there shall be a systematic and regular inspection of the works
Inspection report	Not required	Required	
As-built geometry	Not required	According to execution specification	

4.4 Action in the event of a non-conformity

4.4.1 Where inspection reveals a non-conformity, appropriate action shall be taken to ensure that the structure is able to perform as designed.

4.4.2 The following aspects shall be investigated in the listed order:

a) implications of the non-conformity on further execution and fitness for intended design purpose;

b) measures necessary to make the component acceptable;

c) necessity of rejection and replacement of the non-repairable component.

4.4.3 If required in the execution specification, the rectification of non-conformity shall be in accordance with a procedure stated in the execution specification or as agreed upon.

5 Falsework and formwork

5.1 Basic requirements

5.1.1 Falsework and formwork including their supports and foundations shall be designed and constructed so that they are

— capable of resisting any foreseeable action to which they are submitted during the construction process;

— stiff enough to ensure that the tolerances specified for the structure are satisfied and the integrity of the structural member is not affected.

5.1.2 The form, function, appearance and durability of the permanent works shall not be impaired or damaged due to the performance of the falsework, formwork and back-propping or their removal.

5.1.3 Falsework and formwork shall comply with this International Standard and the relevant International Standard, if available, or be demonstrably fit for the intended use.

NOTE 1 Annex C gives guidance on falsework and formwork.

NOTE 2 Falsework and formwork that comply with International Standards prepared for systems for temporary equipment can be deemed to satisfy this International Standard.

5.2 Materials

5.2.1 General

Any material may be used provided that its use fulfils the criteria for the structure given in 5.1 and Clause 8. The material should comply with the relevant product standard or, where none exists, the material may be used provided that the characteristics of the material are taken into account.

5.2.2 Release agents

5.2.2.1 Release agents, where used, shall be selected and applied in such a way that they are not harmful to concrete, reinforcing steel, prestressing steel or formwork and in such a way that they have no detrimental effects on the permanent structure.

5.2.2.2 Release agents shall have no unintended effect on the colour, surface quality of the permanent structure or specified subsequent coatings.

5.3 Design and installation of falsework

5.3.1 A method statement, where required by the execution specification, shall give the design parameters/class adopted and describe the method of erection and dismantling of temporary structures including back-propping. It shall specify the requirements for handling, adjusting, intentional precambering, loading, unkeying, striking and dismantling.

5.3.2 The design of the falsework shall take into account the deformation during and after concreting to prevent deleterious cracking in the young concrete.

5.3.3 The layout of falsework shall not restrain the elastic deformation of the concrete during post-tensioning.

5.3.4 Where the design of the finished permanent structure requires support of part of the structure until further parts or supporting structures, including backfilling, are completed, such requirements shall be stated in the execution specification.

5.4 Design and installation of formwork

5.4.1 A method statement, where required by the execution specification, shall describe the methods of support, erection and dismantling. It shall specify the requirements for handling, adjusting, tying, intentional precambering, loading, unkeying, striking and dismantling.

5.4.2 Formwork shall keep the concrete in its required shape until it is sufficiently hardened.

5.4.3 Formwork and joints shall be sufficiently tight so as to minimize loss of fines.

5.4.4 Formwork likely to absorb significant amounts of water from the concrete or facilitate evaporation shall be suitably treated to reduce water uptake from the concrete, unless intended specifically for that purpose.

5.4.5 The internal surface of the formwork shall be clean. If the formwork is required by the execution specification to produce visible concrete surfaces, the treatment of the formwork surfaces shall be such that the specified finish is achievable.

5.4.6 Where the design of the finished permanent structure requires a particular surface finish, it shall be stated in the execution specification.

5.4.7 Where the design of the finished permanent structure requires temporary support and/or specific deflection criteria, it shall be stated in the execution specification.

5.4.8 The formwork shall not restrain the elastic deformation of the concrete during post-tensioning.

5.4.9 When using slipforming, the design of the system shall take into account the properties of the formwork material and make provision for controlling the geometry of the works.

5.5 Special formwork

Requirements shall be given in the execution specification.

5.6 Inserts in formwork and embedded components

5.6.1 General

Temporary inserts to keep the formwork in place, such as bars, ducts and similar items, being cast within the section and embedded components shall

— be fixed robustly enough to ensure that they keep their prescribed position during concreting;

— be provided with adequate corrosion protection;

— be of sufficient strength and stiffness to preserve their shape during the concreting operation;

— be given the specified concrete cover unless surface treated;

— not introduce unacceptable actions on the structure;

— not react harmfully with the concrete, the reinforcement or prestressing steel;

— not produce blemishes to the specified surface finish;

— not impair the functional performance and the durability of the structural member;

— not prevent adequate placing and compaction of the fresh concrete.

5.6.2 Making good of temporary recesses and holes

Recesses and holes used for temporary works shall be filled and finished with a material similar in characteristics to the surrounding concrete, or as given by the execution specification.

5.7 Removal of formwork and falsework

5.7.1 Falsework, back-propping and formwork shall not be removed until the concrete has gained sufficient strength

— to resist damage to surfaces that can arise during the striking;

— to carry the actions imposed on the concrete member at that stage;

— to avoid deflections beyond the specified deviation in this International Standard and the execution specification;

— to avoid damage due to climatic effects.

5.7.2 Striking shall be made in a manner that does not subject the structure to impact, overload or damage the permanent structure.

5.7.3 The loads in falsework shall be released in a sequence that ensures that the other falsework members and any supporting permanent constructions are not subject to excessive loads. The stability of falsework and formwork shall be maintained when loads are released and during dismantling.

5.7.4 The sequence of removal, where back-propping and/or re-propping of the structure is used, shall be detailed in a method statement or the execution specification.

5.7.5 If formwork is part of the curing system, the timing of its removal shall be taken into account in accordance with the requirements of 8.5.

6 Reinforcement

6.1 General

Provisions given in 6.2 to 6.6 apply to pre-fabricated and site-fabricated reinforcement.

NOTE Annex D gives guidance on reinforcement.

6.2 Materials

6.2.1 Reinforcing steel shall conform to ISO 6935-1 and ISO 6935-2, and be in accordance with the requirements given in the execution specification. Reinforcement made from stainless steel shall be in accordance with requirements given in the execution specification.

6.2.2 Each product shall be clearly identifiable.

6.2.3 Anchorage devices and couplers shall be used as specified by the execution specification.

6.2.4 The surface of the reinforcement shall be free from loose rust and deleterious substances that can adversely affect the steel, concrete, or the bond between them. Light surface rust is acceptable.

6.2.5 When galvanized reinforcement is used, the zinc coating shall be sufficiently passive to avoid chemical reactions with the cement or the concrete shall be made with cement that has no detrimental effect on the bond to the galvanized reinforcement.

NOTE Natural passivization of zinc coating can be achieved by storing the zinc-coated products outdoors for a time. Normally about four weeks is enough. Instant passivization can be achieved by dipping the coated product in passivization solution.

6.2.6 Materials other than steel used as reinforcement, such as composite carbon-, glass- or aramid-fibre bars, shall have an established suitability and be in accordance with the requirements given in the execution specification.

NOTE Suitability can be established by compliance with International Standards, national standards or national provisions in the place of use.

6.2.7 Chairs and spacers shall be suitable for achieving the specified cover to the reinforcement. Concrete and cementitious spacers should have at least the same strength and should give at least the same corrosion protection as the concrete in the structure.

NOTE Steel spacers are permitted to be in contact with the concrete surface only in a dry environment, i.e. exposure class X0 and XC1 of ISO 22965-1.

6.3 Bending, cutting, transport and storage of the reinforcement

6.3.1 The cutting and bending of reinforcing steel shall conform to the execution specification; bent bars shall be without cracks and other damage. The following requirements apply.

— Bending shall be done in one operation. When using automated bending machines, it may be continuous or incremental.

— Bending of steel at temperatures below −5 °C is permitted only if allowed by the execution specification and provided the procedure conforms to given additional precautions.

— Unless permitted by the execution specification, bending by heating the bars is not permitted.

NOTE It is recommended that bar schedules for cutting and bending of reinforcement conform to ISO 3766[4].

6.3.2 For bending bars, the diameter of the mandrel used shall be in accordance with the execution specification.

NOTE The mandrel being used is specified based on the following considerations:

— the bending properties of the steel;

— the bearing strength of the concrete in the bend;

— geometry of the structure.

6.3.3 For welded reinforcement and fabric bent after welding, the diameter of the mandrel used shall be in accordance with the execution specification.

6.3.4 Steel reinforcing bars, welded fabric and prefabricated reinforcement cages shall not be damaged during transporting, storing, handling and placing into position and shall be stored clear of the ground.

6.3.5 Straightening of bent bars is not allowed unless permitted by the execution specification and, in such cases,

— the mandrel used for the original bend is at least two times the minimum mandrel allowed for that steel, unless a smaller mandrel diameter is documented by a rebend test in accordance with ISO 15630-1;

— if a smaller mandrel diameter is documented by a rebend test in accordance with ISO 15630-1, the actual bending diameter should be not less than 1,3 times the test diameter in the rebend test;

— special equipment to limit local stresses is used;

— a procedure for straightening has been prepared;

— straightened bars are inspected visually for cracks or other damage.

NOTE The requirements above do not exclude the use of type-tested products where the original bend is that which can be documented by a test of tensile strength, demonstrating a tensile strength as required for the actual grade of steel, after a procedure of bending, aging and straightening.

6.3.6 Reinforcement from coils shall not be used unless appropriate equipment is available and the straightening procedures are in accordance with the manufacturer's instructions. The de-coiled and straightened bars shall meet the requirements for the reinforcement given in the relevant standards, after straightening, and tested as specified in ISO 6935-1 and ISO 6935-2.

6.4 Welding

6.4.1 Welding is permitted only on reinforcing steel classified as weldable, unless specified in the execution specification.

6.4.2 Welding of reinforcing steel and welding of reinforcing steel to structural steel in loadbearing joints shall be performed as specified in the execution specification, and in accordance with ISO 17660-1, unless otherwise specified.

6.4.3 Spot welding of non-loadbearing welds performed in accordance with ISO 17660-2 is permitted, unless otherwise specified in the execution specification.

6.5 Joints

Bars shall be jointed, by laps, couplers or welding, in accordance with the execution specification.

6.6 Assembly and placing of the reinforcement

6.6.1 The reinforcement shall be placed according to the execution specification, which gives details of cover, spacing, joints, overlaps, lap lengths and layout of bars.

Special attention should be given to reinforcement and cover at the location of holes of small dimensions which are not considered in the structural design.

6.6.2 Where permitted by the execution specification, the reinforcement may be placed as “running metres”. In this case, the laps shall be well distributed, with a maximum 25 % lapped in the same section, and the longitudinal distance between two adjacent laps should not be less than the lap length. The minimum lap length shall be stated.

NOTE This system is used only in cases where the actual positions of overlapping joints are not of importance, i.e. secondary reinforcement in walls and slabs, but not in beams or columns or joints between structural members.

6.6.3 The reinforcement shall be fixed and secured so that its final position is within the tolerances given in this International Standard. The assembly of reinforcement may be done with tie wire or spot welding; see 6.4.3. Unless otherwise specified, overlapping bars should be placed in contact; in beams and columns, the laps should, in general, be tied.

6.6.4 The specified cover applies to the nominal value, c_{nom}, and applies to the surface of any reinforcement including possible assembly reinforcement.

7 Prestressing

7.1 General

7.1.1 The requirements in 7.2 to 7.6 apply to prestressed concrete construction including

— bonded, pre-tensioned construction;

— bonded, post-tensioned construction;

— unbonded, post-tensioned, internal or external construction.

NOTE Annex E gives guidance on prestressing.

7.1.2 This International Standard assumes that the work is performed by adequately experienced specialist companies; additional requirements for the installation of post-tensioning kits for prestressing of structures and qualification of the specialist company and its personnel may be stated in the execution specification.

NOTE Guidance can be found in specialist literature; one alternative is CEN Workshop Agreement CWA 14646[5].

7.2 Materials for prestressing

7.2.1 Post-tensioning systems

7.2.1.1 Post-tensioning systems shall hold a national technical approval or equivalent and be in accordance with the requirements given in the execution specification.

7.2.1.2 All parts of the post-tensioning system shall be compatible, e.g. from the same prestressing system.

NOTE A post-tensioning system includes all those parts that are relevant for the particular application, such as anchorages, couplings, sheets, filling material, special accessories, etc., including tensile elements, whether these are proprietary or of a general make.

7.2.2 Sheaths

7.2.2.1 Steel strip sheaths shall conform to a national standard or national technical approval or equivalent.

7.2.2.2 Sheaths of materials other than steel shall be in accordance with the national technical approval or equivalent for the prestressing system.

NOTE The term “duct” is also used instead of “sheath”.

7.2.3 Tensile elements

7.2.3.1 The prestressing steel (wires, strands, bars) shall conform to ISO 6934 (all parts) and be in accordance with the requirements given in the execution specification.

7.2.3.2 Materials other than steel used for prestressing shall be in accordance with the requirements given in the execution specification.

NOTE At the time of publishing of this International Standard, there are no International Standards covering the design, specification and application for materials other than steel, e.g. carbon, glass or aramid fibres.

7.2.4 Anchorage elements and accessories

Anchorage components for the prestressing system shall be those specified in the national technical approval or equivalent.

7.2.5 Tendon supports

7.2.5.1 Tendon supports shall

— not be deleterious to either steel or concrete;

— be stiff enough to ensure a stable fixing of the tendons in their required position during concreting;

— not damage the sheaths.

7.2.5.2 The spacing of the tendon supports shall be such as to ensure that the sheaths conform to the required line and level.

7.2.6 Cement-based grout

Grout for filling ducts and anchorages shall conform to a national standard, the national technical approval or equivalent.

NOTE A new work item is being proposed to prepare an ISO International Standard for grout and grouting of prestressing tendons.

7.2.7 Grease, wax or other products

Grease or wax for filling ducts and anchorages of unbonded tendons shall be as specified in the national technical approval or equivalent.

7.3 Transport and storage

7.3.1 Materials sensitive to corrosion, e.g. prestressing steel, sheaths, anchorage devices, couplers, prefabricated tendons and tendons fabricated on site, shall be protected from harmful influences during transport and storage and also whilst placed in the structure prior to permanent protection. Materials that have corroded to an extent that is likely to impair their performance shall be replaced by conforming materials.

The supplier should provide instructions related to transportation, storage and handling as appropriate.

7.3.2 Materials for grout shall be protected from water and moisture during delivery and storage on site and shall be used within the specified shelf life.

7.4 Installation of tendons

7.4.1 General

7.4.1.1 The prestressing tendons shall be assembled, placed and secured in accordance with the national technical approval and as specified in the execution specification, and follow a smooth line without sags or kinks and within the permissible tolerances; see 10.6.

7.4.1.2 The type and class of prestressing steel and source documentation for all components shall be recorded in the inspection record documentation.

7.4.1.3 Welding of prestressing steel or anchorages is not permitted. Oxygen cutting or welding of steel in the vicinity of prestressing steel is not permitted unless under conditions stated in the execution specification. Welding of local anchorage-zone reinforcement, anchor plates and spot welding of perforated plates is not permitted unless under conditions stated in the execution specification.

7.4.1.4 All joints in sheaths, anchorages and couplers shall be sealed against the ingress of water.

7.4.1.5 Care shall be taken to prevent twisting or crossing of strands both in assembly and installation.

7.4.2 Pre-tensioned tendons

Any debonded lengths of the prestressing steel shall be adequately protected against corrosion.

7.4.3 Post-tensioned bonded tendons

7.4.3.1 Vents shall be provided on the sheaths at both ends and at the points of the tendon where air or water can accumulate. Vents or inlets are normally required at intermediate positions.

7.4.3.2 Vents shall be properly marked to identify the cable.

7.4.3.3 The sheaths and vents shall be secured to withstand the effects of placing and compacting of the concrete.

7.4.4 Internal and external unbonded tendons

Unbonded tendons shall be adequately sealed against penetration of moisture throughout their length.

7.5 Tensioning

7.5.1 General

7.5.1.1 Tensioning shall conform to a prearranged and approved tensioning programme. Force (pressure) and elongation shall be recorded in an inspection record document.

The national technical approval or equivalent should specify the maximum force for the system.

7.5.1.2 Written instructions for the tensioning shall be available on site.

7.5.1.3 Jacking anchorages as well as dead-end anchorages shall be as shown in the drawings.

7.5.1.4 Stressing equipment shall be selected from those permitted by the national technical approval, or equivalent, for the system.

7.5.1.5 The valid calibration records for the force measuring devices shall be available on site before the tensioning starts.

7.5.1.6 Application and/or transfer of prestressing to a structure is allowed only when the concrete strength is equal to or greater than the minimum compressive strength specified in the execution specification.

7.5.1.7 The results of the tensioning programme and its conformity or non-conformity to the requirements shall be recorded in an inspection report.

NOTE Guidance on common practice is given in E.3.

7.5.2 Pre-tensioned tendons

7.5.2.1 If during the stressing of pre-tensioning tendons to the specified force, the actual elongation of the group of all tendons at a particular cross-section of the structure is not within ± 3 % of the calculated elongation, or that of a single tendon is not within ± 5 % of the calculated elongation, action shall be taken in accordance with the execution specification.

7.5.2.2 If the fresh concrete cannot be cast in due time after tensioning, temporary protective measures that do not have a detrimental effect on the steel and/or the concrete shall be taken. It shall be verified that any reduction of bond due to the temporary protective measure is acceptable for the design of the structure.

7.5.3 Post-tensioned bonded tendons

7.5.3.1 If, during the stressing of post-tensioning tendons to the specified force, the actual elongation of the group of all tendons at a particular cross-section of the structure is not within ± 5 % of the calculated elongation, or that of a single tendon in a group is not within ± 15 % of the calculated elongation, action shall be taken in accordance with the execution specification.

7.5.3.2 In the case of deviation from the planned performance during tensioning, the cutting off of tendon ends or grouting is not permitted. Work that can impair the re-tensioning shall not be carried out. Such work shall be postponed until the causes have been investigated and a revised tensioning report has been approved.

7.5.4 Internal and external unbonded tendons

The provisions in 7.5.3 apply.

7.6 Protective measures (grouting, greasing)

7.6.1 General

7.6.1.1 Written instructions shall be provided for the preparation and execution of the protective measures, for example, against corrosion, frost and mechanical damages.

7.6.1.2 Grouting equipment shall be suitable for the grouting operations and selected from those permitted by the national technical approval or equivalent.

7.6.1.3 Results from the inspection and whether the work conforms to the requirements for protection shall be recorded in the inspection report; see 4.3 and Annex E.

7.6.1.4 Anchorage areas and end caps, as well as the tendons, shall be protected.

7.6.1.5 If permanent protection cannot be applied within due time after installation or tensioning of the tendons, temporary protective measures shall be taken; see Annex E.

7.6.2 Pre-tensioned tendons

The ends of the tendons shall be protected against corrosion under service.

7.6.3 Post-tensioned bonded tendons

Grouting of post-tensioned, bonded tendons shall conform to a national standard or the national technical approval, or be specified by the execution specification.

7.6.4 Internal or external unbonded tendons

7.6.4.1 Where external tendons are protected by grout, the grout and grouting shall conform to 7.6.3.

7.6.4.2 In other cases, the sheaths and anchorages of the tendons shall be filled by the specified method with a non-corrosive grease or wax conforming to the national technical approval, or be specified by the execution specification.

7.6.5 Grouting operations

7.6.5.1 The mixing process (batching, water/cement ratio, procedure, time) shall be in accordance with a national standard or the national technical approval, or be specified by the execution specification.

7.6.5.2 Grouting shall be performed in accordance with a national standard or the national technical approval, or be specified by the execution specification.

7.6.5.3 If grouting cannot be performed in due time after tensioning, temporary protective measures that do not have a detrimental effect on the prestressing steel and/or the grout shall be taken. It shall be verified that any reduction of bond due to the temporary protective measure is acceptable for the design of the structure.

7.6.6 Greasing operations

7.6.6.1 Injection of grease or wax shall be carried out at a continuous and steady rate.

7.6.6.2 The volume injected shall be comparable with the theoretical free volume in the duct. The change of volume with temperature shall be taken into account.

7.6.6.3 After the injection is complete, unintended loss of grease or wax from the ducts shall be prevented by sealing them under pressure.

7.6.6.4 Materials, connections and equipment shall be suitable for the temperature range needed for injection of grease or wax. Special safety precautions can be necessary for works at elevated temperatures.

7.6.7 Sealing

7.6.7.1 Anchorages shall be sealed after grouting to assure a corrosion protection equivalent to that provided along the tendon (e.g., sufficient depth of dense, low permeability concrete, or cap, or combination of measures).

7.6.7.2 Anchorage zones shall be protected from drainage water.

7.6.7.3 All vents and grout inlets and outlets shall be suitably sealed and protected.

8 Concreting

NOTE Annex F gives guidance on concreting.

8.1 Specification of concrete

8.1.1 Concrete and its specification shall comply with ISO 22965 (all parts).

8.1.2 The concrete specification shall include requirements given in the execution specification and requirements related to the actual method of execution.

8.1.3 The actual upper sieve size D of the aggregate being used in the concrete shall not be less than that given in the execution specification.

NOTE "D" represents a sieve size through which at least 80 % to 85 % but not more than 99 % of the sample can pass.

8.1.4 Information on concrete strength development shall be obtained from the concrete producer when required for the execution of the concrete works, e.g. in deciding curing class.

8.2 Pre-concreting operations

8.2.1 A concreting plan shall be prepared where required by the execution specification.

8.2.2 Initial testing of concreting by trial casting shall be performed where required by the execution specification. The results of these tests shall be documented before the start of execution.

8.2.3 All preparatory works shall be completed, inspected and documented as required for the actual execution class before the casting is initiated.

8.2.4 Construction joints shall be prepared in accordance with the requirements given in the execution specification; they shall be clean, free of laitance and wetted to a damp condition.

8.2.5 The form should be free of detritus, ice, snow and standing water.

8.2.6 Where concrete is placed directly against ground, the fresh concrete shall be protected against intermixing with the substrate.

8.2.7 Where there is risk that rain or other flowing water can wash out the cement and fines of the fresh concrete during casting, precautions shall be planned to protect the concrete against damaging effects.

8.2.8 Ground, rock, formwork or structural parts in contact with the section being cast shall have a temperature that does not result in freezing of the concrete before it has sufficient strength to resist the effects of freezing.

8.2.9 Where the ambient temperature is low, or forecast to be low during the time of casting or the curing period, precautions shall be taken to protect the concrete against damage due to freezing.

8.2.10 Where the ambient temperature at the time of setting and curing is likely to be high, precautions shall be taken to protect the concrete against damaging effects.

8.3 Delivery, reception and site transport of fresh concrete

8.3.1 The receiving inspection shall be comprised of a check of the delivery ticket prior to discharge.

8.3.2 The concrete shall be visually inspected during unloading. Unloading shall be stopped if the appearance, judged by experience, is not normal.

8.3.3 Detrimental changes of the fresh concrete, such as segregation, bleeding, paste loss or any other changes shall be minimized during loading, transport and unloading, as well as during conveyance on site.

8.3.4 Where required by the execution specification, samples for testing shall be taken at the point of placing, or, in the case of ready-mixed concrete, at the point of delivery if permitted by the execution specification.

NOTE 1 The requirements in this International Standard are for the concrete as it is placed in the structure; tests taken as part of the documentation of the concrete as delivered by the ready-mix producer at the point of delivery can, however, be accepted as documentation of the concrete as placed in the structure, when permitted by the execution specification.

NOTE 2 Test methods and criteria for determining the identity and conformity of concrete to ISO 22965-2 are given therein.

8.3.5 Fresh concrete shall not come into contact with aluminium alloy, unless permitted by the execution specification and unless gas generation is not considered a problem.

8.4 Placing and compaction

8.4.1 General

8.4.1.1 The concrete shall be placed and compacted in order to ensure that all reinforcement and cast-in items are properly embedded and that the concrete achieves its intended strength and durability.

8.4.1.2 Particular care in ensuring proper compaction is required at changes in cross-sections, in narrow locations, at box-outs, at congested reinforcement arrangements and at construction joints.

8.4.1.3 The rate of placing and compaction shall be high enough to avoid cold joints and low enough to prevent excessive settlements or overloading of the formwork and falsework.

NOTE A cold joint can form during casting if the concrete on the casting front sets before placing and compaction of the next layer of concrete. Particular attention is required when revibration of the joint is not possible.

8.4.1.4 Additional requirements on the placing method and rates of placing can be needed where there are special requirements for the surface finishes.

8.4.1.5 Segregation shall be minimized during placing and compaction.

8.4.1.6 The concrete shall be protected against adverse effects of solar radiation, strong wind, freezing, water, rain and snow during placing and compaction. During hot-weather concreting, the temperature of the fresh concrete, embedded material, materials that the fresh concrete is cast against, etc., shall be controlled to protect the hardening concrete from thermal cracking and extreme peak curing temperatures.

8.4.2 Lightweight aggregate concrete

Where lightweight aggregate concrete is being pumped, documentation shall be available showing that pumping has no significant effect on the strength of the hardened concrete.

NOTE A strength loss can reflect a weakening of the transition zone between the paste and the lightweight aggregates due to water squeezed in and out of the aggregate during and after pumping. A remixing of the concrete after pumping can compensate for the effect.

8.4.3 Self-compacting concrete

By the use of concrete described as self-compacting concrete (SCC), the compaction of the fluid concrete is achieved due to the effect of gravity. Working procedures for the actual cast shall be established, based on the constructor's experience and/or pretesting, to enable obtaining the required compaction. Requirements in addition to those given in ISO 22965 (all parts) for the fresh concrete properties and its conformity criteria, if any, shall be agreed with the producer.

8.4.4 Sprayed concrete

For concrete placed by spraying, the execution of the work shall comply with the requirements given in national standards and be as specified by the execution specification.

Technical requirements should be included in the execution specification, as appropriate for the works.

8.4.5 Slipforming

8.4.5.1 Concrete for slipforming shall have an appropriate consistency and set. Slipforming shall be performed with equipment and methods appropriate to ensure that the specified cover to the reinforcement, concrete quality and surface finish are achieved.

8.4.5.2 The execution specification, for instance the detailing of the reinforcement, and the actual slipforming equipment shall be compatible.

8.4.6 Underwater concreting

8.4.6.1 Underwater concreting shall be executed with equipment and methods adequate to ensure that the requirements specified in the execution specification are fulfilled.

8.4.6.2 The execution specification, for instance the detailing of the reinforcement, and the actual method of concreting shall be compatible.

8.5 Curing and protection

8.5.1 Concrete, in its early life, shall be cured and protected

— to minimize plastic shrinkage;

— to ensure adequate surface strength;

— to ensure adequate surface-zone durability;

— from harmful weather conditions;

— from freezing;

— from harmful vibration, impact or damage.

8.5.2 If it is necessary to protect concrete in its early life against harmful contact with aggressive agents (e.g. chlorides), such requirements shall be stated in the execution specification.

8.5.3 Either the methods of curing shall achieve low evaporation rates from the concrete surface or the surface shall be keep permanently wet; guidance is given in Annex F.

Natural curing is sufficient when conditions throughout the required curing period are such that evaporation rates from the concrete surface are low, e.g. in damp, rainy or foggy weather.

8.5.4 On completion of compaction and finishing operations on the concrete, the surface shall be cured without delay. If necessary to prevent plastic shrinkage cracking on free surfaces, temporary curing shall be applied prior to finishing.

8.5.5 If concrete with a low bleeding tendency is used, e.g. high-strength concrete and self-compacting concrete, special considerations shall be given to prevent plastic shrinkage cracking. This applies also for concreting under weather conditions that cause strong evaporation, such as hot or windy weather, as well as in cold, dry air.

8.5.6 The duration of applied curing shall be a function of the development of the concrete properties in the surface zone.

This development is described by curing classes defined by a curing period or percentage of the specified characteristic 28 day compressive strength, according to Table 4.

Table 4 — Curing classes

	Curing class 1	Curing class 2	Curing class 3	Curing class 4
Period (hours)	12[a]	NA	NA	NA
Percentage of specified characteristic 28 days compressive strength	Not applicable (NA)	35 %	50 %	70 %

[a] Provided the set does not exceed 5 h, and the surface concrete temperature is equal to or above 5 °C.

8.5.7 The curing class that shall be used shall be stated in the execution specification.

8.5.8 Special curing requirements (higher than 70 %) may be given in the execution specification.

8.5.9 Recommendations on minimum curing times are given in Annex F.

8.5.10 Curing compounds are not permitted on construction joints, on surfaces that shall be treated or surfaces to which it is required to bond other materials, unless the compounds are fully removed prior to the subsequent operation, or they are proven to have no detrimental effects on the subsequent operations.

8.5.11 Curing compounds shall not be used on surfaces with special requirements for the surface finish unless they are proven to have no adverse effects.

8.5.12 The concrete surface temperature shall not fall below 0 °C until the concrete surface compressive strength has reached a minimum value of 5 MPa.

8.5.13 Unless specified otherwise, the peak temperature of the concrete within a component exposed to a wet or cyclicly wet environment shall not exceed 70 °C, unless data are provided to prove that, with the combination of materials used, higher temperatures have no significant adverse effect on the service performance of the concrete.

NOTE If concrete is exposed to high temperature over a certain period in its early life, delayed ettringite formation can occur depending on humidity and concrete mix design (alkali content, chemical composition of cement, use of additions, etc.).

8.5.14 Requirements related to accelerated curing by the application of external or internal heat are not given in this International Standard.

8.5.15 It is necessary to take into account a possible strength loss when high-temperature curing is used.

8.5.16 The execution specification may include requirements to reduce the possibility of early-age thermal cracking, e.g. use of low-heat cement, cooling pipes, insulation, etc.

8.6 Post-concreting operations

8.6.1 After form striking, all surfaces shall be inspected in accordance with the execution class for conformity to the requirements.

8.6.2 The surface shall not be damaged or disfigured during construction.

8.7 Concreting of composite structures

Concreting of composite structures shall conform to this International Standard.

8.8 Surface finish

Requirements, if any, for the finish of formed and unformed surfaces shall be given in the execution specification.

9 Execution with precast concrete elements

9.1 General

9.1.1 Clause 9 gives requirements for the construction operations involving structural precast elements from their reception at the site or, in the case of site-manufactured elements, from the removal from the forms, until the completion of their installation and final acceptance.

9.1.2 Precast elements shall be used as specified in the execution specification and the design coordination between them and the structural performance of the overall structure shall be verified.

9.2 Factory produced precast elements

9.2.1 The factory-produced precast elements, up to the receipt of the elements at the site, can be within the scope of national or international product standards (precast products).

9.2.2 The provisions of this International Standard shall apply to the manufacturing of precast elements not conforming to a national or international product standard.

9.3 Site-manufactured precast elements

9.3.1 Site-manufactured elements may be treated as precast products if they conform to a national or international product standard.

9.3.2 Site-manufactured elements that do not conform to any product standard shall not be considered as precast products; their manufacture is covered by this International Standard.

9.3.3 The requirements for operations following the production of site-manufactured precast elements are the same as for factory-produced precast elements.

9.4 Handling and storage

9.4.1 General

9.4.1.1 Handling, storage and protection of the precast elements shall be carried out in accordance with the execution specification.

9.4.1.2 The total mass shall be available for each precast element.

9.4.1.3 Marking for product identification shall be available on each precast element and, where required by the execution specification, the relevant position of each precast element within the works.

9.4.2 Handling

A lifting scheme defining the suspension points and forces, the arrangement of the lifting system and, where necessary, any special provisions shall be available.

9.4.3 Storage

Storage instructions for the precast element shall define the storage position and the permissible support points, the maximum height of the stack, the protective measures and, where necessary, any provisions required to maintain stability.

9.5 Placing and adjustment

9.5.1 General

9.5.1.1 Requirements for the placing and adjustment of the precast elements shall be given in the erection specification.

9.5.1.2 Before the delivery of any precast element, the erection specification necessary for its handling and possible on-site storage shall be available on site.

9.5.1.3 The work programme with the sequence of on-site operations shall be available on site.

9.5.1.4 Erection shall not be started until the above items are satisfactorily verified.

9.5.2 Placing

9.5.2.1 The erection specification shall define the arrangement of the supports, the necessary props and, where necessary, the temporary stability provisions.

9.5.2.2 Where necessary, the access and work positions shall be shown in the erection specification for the guiding of any precast element and the reach and capacity of lifting devices.

9.5.2.3 The applied construction measures shall ensure that supports remain stable during construction and that they minimize the risk of damage to such supports.

Special advice can be required to ensure safe installation and to avoid accidental damage. For beams and slabs, minimum support lengths and edge distances should be specified in a manner that facilitates both easy installation and easy inspection.

9.5.2.4 The erection of the precast elements shall conform to the erection and execution specification and the operation sequence of the work programme.

9.5.2.5 During installation, the correct position of the precast elements, the dimensional accuracy of the supports, the conditions of the joints and the overall arrangement of the structure shall be checked and any necessary adjustments made.

9.6 Jointing and completion works

9.6.1 General

9.6.1.1 An inspection of the erection shall be carried out before the execution of jointing and before any completion works.

9.6.1.2 The completion work shall be carried out on the basis of the requirements given in the erection specification and taking climatic conditions into account.

9.6.2 *In-situ* works

9.6.2.1 The placing of any additional reinforcement for the completion of the structure shall conform to Clauses 6 and 7.

9.6.2.2 The *in-situ* concreting shall conform to Clause 8.

9.6.3 Structural connections

9.6.3.1 Connections of any type shall be used in accordance with the manufacturer's instructions.

9.6.3.2 Threaded and glued connections shall be executed according to the specific technology of the materials used.

9.6.3.3 The execution specification should contain requirements to ensure that

— joints have a size compatible with the sealing method;

— steel inserts of any type, used for joint connections, are properly protected against corrosion and fire by an appropriate choice of materials or covering;

— welded structural connections are made with compatible weldable materials and are inspected.

10 Geometrical tolerances

10.1 General

10.1.1 The completed structure shall be within the maximum allowable deviations to avoid detrimental effects in terms of

a) mechanical resistance and stability in transient and in service stages;

b) service performance during the use of the construction works;

c) placing compatibility for the erection of the structure and its non-structural components.

Deviations from the specified tolerance range shall be handled in accordance with 4.4. Small deviations that have no significant consequence on the performance of the finished structure may be ignored.

10.1.2 Clause 10 contains the types of geometrical deviations relevant to building structures. They may be applied also for civil engineering works, as relevant, or amended in the execution specification. Numerical values are given for structural tolerances, i.e. tolerances that influence structural safety. Two structural tolerance classes are identified for geometrical tolerances. Unless otherwise stated in the execution specification, tolerance class 1 applies.

NOTE Tolerance class 1 is considered as applying to normal tolerances (see 3.23) and achieves the design assumptions for the normally required level of safety. These are considered essential for the mechanical resistance and stability of structures in order to fulfil the provisions of 10.1.1 a).

10.1.3 Values for permitted geometrical deviations in terms of service performance and placing compatibility may be given in the execution specification. Recommended values are given in Annex G. Unless otherwise specified, the tolerances given in Annex G should apply.

10.1.4 Any requirements for special tolerances shall be identified in the execution specification and the following information shall then be given:

— any amendments to the permitted deviations given in this International Standard;

— any further type of deviation that it is necessary to control, together with the defined parameters and permitted values;

— whether these special tolerances apply to all relevant components or to only particular components that are identified;

— if the “box principle” shall be applied, and what deviation is permitted; see 10.1.5.

10.1.5 The “box principle” requires that all points of the structure are within the specified theoretical position with a margin in any direction corresponding to the permitted deviation. A recommended value when applying the box principle is ± 20 mm.

10.1.6 Tolerances for surfaces between components where it is intended to transmit forces by full-contact bearing between the surfaces are not defined in this International Standard. Any requirements for such surfaces shall be stated in the execution specification.

10.1.7 Tolerances for components cast under water are not given in this International Standard.

10.1.8 If a certain geometrical deviation is covered by different requirements, the strictest tolerance is applicable.

10.1.9 The requirements of Clause 10 relate to the completed structure. Where components are incorporated in a structure, any intermediate checking of such components shall be subordinate to the final checking of the completed structure.

10.1.10 This International Standard does not give requirements for the combination of construction tolerances and structural deformations. Permitted deviations are valid for the situation before deformations caused by loading and time dependent effects unless otherwise specified in the execution specification; see 10.1.4.

10.2 Reference system

10.2.1 Tolerances of position in plane refer to the secondary lines in plane.

10.2.2 Tolerances of position in height refer to the secondary lines in height, e.g. a transferred bench mark.

10.2.3 Any requirement for the secondary lines shall be stated in the execution specification.

NOTE ISO 4463-1[2] gives guidance for setting-out the secondary lines.

10.3 Base supports (foundations)

Base supports may be direct foundations on the ground, pile caps, etc. Recommended values for the position of the centres of the base supports are given in Figure G.1.

Foundation on the ground may be either cast directly or made from precast concrete elements. Tolerance requirements for deep foundations, such as piles, slurry walls, diaphragms, special anchorage, etc., are not given in this International Standard.

10.4 Columns and walls

Values for permitted structural deviations for columns and walls are given in Figure 1.

NOTE Guidance for permitted deviations for the positions of columns and walls measured relative to the secondary lines is given in Figure G.2.

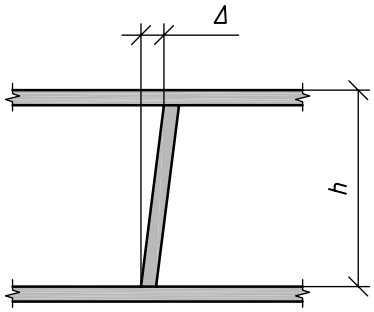
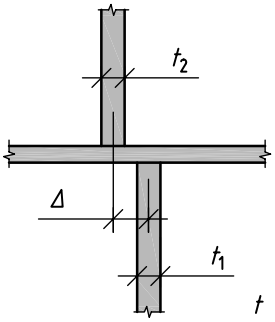
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	 h is the free height, expressed in metres	Inclination of a column or wall at any level in a single- or a multi-storey building $h \leqslant 10$ m $h > 10$ m	The larger of 15 mm or (h/400) m 25 mm or (h/600) m
B		Deviation between centre	The larger of (t/30) mm or 15 mm, but not more than 30 mm NOTE $t = (t_1 + t_2)/2$

Figure 1 (*continued*)

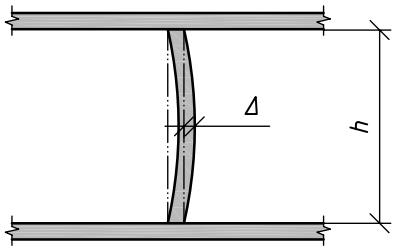
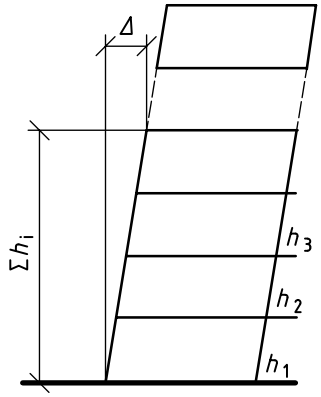
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
C		Curvature of a column between adjacent storey levels	The larger of (h/300) m or 15 mm, but not more than 30 mm
D	 $\sum h_i$ is the sum of height of storeys considered	Location of a column or a wall at any storey level, from a vertical line through its intended centre at base level in a multi-storey structure n is the number of storeys for n >1	The smaller of 50 mm or $\sum h_i / \left(200 n^{1/2}\right)$

Figure 1 — Permitted vertical deviations for columns and walls

10.5 Beams and slabs

10.5.1 The given deviations for the line and level of beams and slabs also apply to other horizontal and sloping structural components.

10.5.2 Values for permitted structural deviations for beams and slabs are given in Figure 2.

10.5.3 Tolerances for bearing length of precast beams and slabs are not given in this International Standard; they shall be given in the erection specification or by technical information on the precast element.

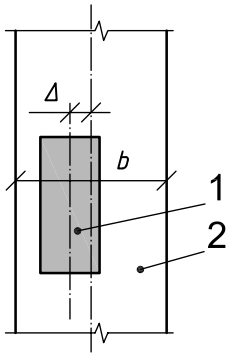
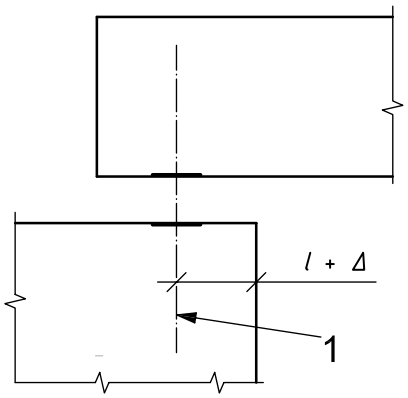
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	 **Key** 1 beam, section 2 column, elevation	Location of a beam-to-column-connection measured relative to the column b is the dimension of column in the same direction as Δ	The larger of $\pm b/30$ or $\pm$ 20 mm
B	 **Key** 1 actual bearing axis of support	Position of bearing axis of support when structural bearings are used l is the intended distance from edge	The larger of $\pm l/20$ or $\pm$ 15 mm

Figure 2 — Permitted deviations for beams and slabs

10.6 Sections

10.6.1 The dimensions of cross-section, the cover and position of reinforcement and prestressing reinforcement shall not deviate more from the nominal values than given in Figure 3.

The values for deviations given do not apply to precast products, which should conform to the relevant product standard.

10.6.2 Conformity with the cover requirements shall be assessed for each individual reading unless provisions valid at the construction site permit a statistical approach.

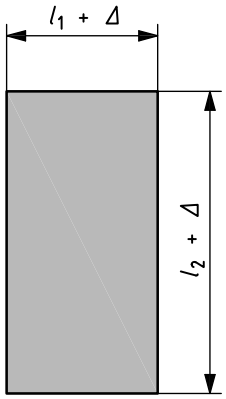
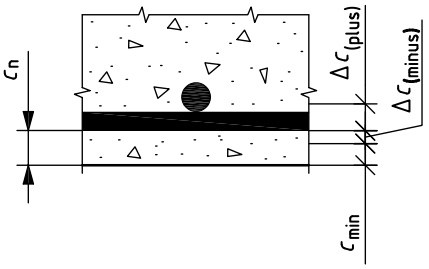
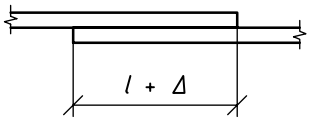
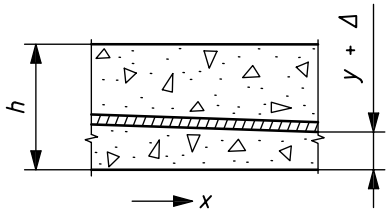
No.	Type of deviation	Description	Permitted deviation[a] Δ	
			Tolerance class 1[b]	Tolerance class 2[b]
A	 **Key** l_1, l_2 are the lengths of the cross-sectional dimension	Cross-sectional dimensions Applicable to beams, slabs and columns For l_1 or $l_2 < 150$ mm l_1 or $l_2 = 400$ mm l_1 or $l_2 \geqslant 2\,500$ mm with linear interpolation for intermediate values	 ± 10 mm ± 15 mm ± 30 mm	 ± 5 mm ± 10 mm ± 30 mm
B	Cross-section  Requirement: $c_{nom} + \Delta c_{(plus)} > c > c_{nom} - \lvert\Delta c_{(minus)}\rvert$ where c_{min} is the required minimum cover; c_{nom} is the nominal cover, equal to $c_{min} + \lvert\Delta c_{(minus)}\rvert$; c is the actual cover; Δc is the permitted deviation from c_{nom}; h is the height of cross-section.	Location of ordinary reinforcement $\Delta c_{(plus)}$ $h \leqslant 150$ mm $h = 400$ mm $h \geqslant 2\,500$ mm with linear interpolation for intermediate values $\Delta c_{(minus)}$	 + 10 mm + 15 mm + 25 mm[c] Δc_{dev}[d]	 + 5 mm + 10 mm + 20 mm Δc_{dev}[d]

Figure 3 (*continued*)

No.	Type of deviation	Description	Permitted deviation[a] Δ	
			Tolerance class 1[b]	Tolerance class 2[b]
C	 l is the lap length	Lap joints	$-0{,}06\ l$	—
D	 Longitudinal section; y is the nominal position normally a function of position x along the prestressing tendon	Location of prestressing reinforcement[e] For $h \leqslant 200$ mm For $h > 200$ mm Concrete cover measured to sheath $\Delta c_{(\text{minus})}$	 $\pm$ 6 mm The smaller of $\pm 0{,}03\ h$ or $\pm$ 30 mm Δc_{dev}[f]	—

[a] For foundations, permitted positive deviations shall be stated in the execution specification, if required. Minus-deviations are as stated.

[b] Tolerances for special geotechnical concrete members cast directly into the ground, e.g. slurry-walls, bored piles, etc., are not covered by this International Standard. However, ordinary, normal foundations cast directly onto the ground are covered (i.e. blindings, etc.).

[c] Permitted positive deviations for cover to reinforcement for foundations and concrete members in foundations may be increased by 15 mm. The given negative deviations apply.

[d] Δc_{dev} may be given in the national annex. Unless otherwise specified, $\Delta c_{\text{dev}} = 10$ mm. The execution specification may state whether a statistical approach allowing a certain percentage of values with covers less than c_{min} is permitted.

[e] The values given apply to thickness and transverse direction. For transverse direction, h is the width of the element. For tendons in slabs deviations larger than $\pm$ 30 mm may be permitted if necessary to avoid small openings, ducts, chases and inserts. The tendon profile of such deviations shall be smooth.

[f] Permitted negative deviation, Δc_{dev}, as for ordinary reinforcement; see case B.

Figure 3 — Permitted sectional deviations

10.7 Surfaces and edge straightness

Recommended values for deviations for surfaces and straightness are given in Figure G.5.

10.8 Tolerances for holes and inserts

Recommended values for deviations for holes and inserts are given in Figure G.6.

Annex A
(informative)

Guidance on documentation

A.1 Guidance on 4.2.1 — Execution specification

The execution specification should include

— a description of all products being used with any requirement for the application of the products; this information should be given on the drawings and/or in the project specification;

— a project specification, which is the document that describes the execution classes being applied, any special tolerance, requirements for the properties of surface finish, etc.; a checklist for information that should be included is given in Table A.1; the project specification should also include all requirements for execution of the work, i.e. sequence of operations, temporary supports, work procedures, etc.;

— construction drawings, giving all necessary information, such as

  — geometry of the structure,

  — amount and position of reinforcing and prestressing steel,

  — for precast concrete elements, lifting devices, masses, inserts, etc.;

— where relevant, an erection specification for precast concrete elements, which should include

  — installation drawings consisting of plans and sections showing the positions and the connections of the elements in the completed works,

  — installation data with the required *in-situ* material properties and inspections,

  — installation instructions with the necessary data for the handling, storing, setting, adjusting, connection and completion works; see 9.4, 9.5 and 9.6.

Table A.1 gives a summary of the information that should be included in the execution specification, as relevant, to conform with this International Standard.

Table A.1 — Checklist of information for inclusion in the execution specification

Clause	Clause	Text
1 Scope	1	Specify all the specific requirements relevant for the particular structure.
	1	If required, specify any additional requirements regarding lightweight concrete, other materials or special technology.
	1	State any requirements on concrete members used as equipment for the execution.
2 Normative references	2	Add all relevant national standards or provisions valid at the construction site.
3 Terms and definitions	3.17	Define the reference line for setting out.
4 Execution management	4.1.3	Specify requirements related to qualifications of personnel.
	4.1.4 and 4.2.1.2	Specify national provisions that it is necessary to respect.
	4.2.1.3	Include procedure for altering execution specification.
	4.2.1.3	State requirements for document distribution.
	4.2.2.1	State if quality plan is required.
	4.2.4	State extent of special documentation, if required.
	4.3.1.5	Specify execution class and define who is responsible for the inspection.
	4.3.1.6	Specify provisions related to inspection personnel.
	4.3.1.7	If necessary, specify further requirements for the quality management regime.
	4.3.2, Table 1	Define inspections and acceptance testing of products without a recognized quality marking or third-party certification.
	4.3.3, Tables 2 and 3	Check if the scopes of these inspections are adequate: if not, give additional requirements.
	4.4.3	If required, specify rectification of possible non-conformances.
5 Falsework and formwork	5.3.1 and 5.4.1	If required specify if method statement shall be worked out.
	5.3.4	Specify requirements to temporary support structures, if any.
	5.4.5	Specify any requirements for surface finish.
	5.4.6	Specify any requirements for special finishes or trial panels.
	5.4.7	Specify any requirement for temporary support of the permanent structure.
	5.5	Specify any requirements for special formwork.
	5.6.2	State requirements for filling temporary holes, etc.
	5.7.1	State requirements for removal of falsework and formwork to avoid deflections.
	5.7.4	If relevant, specify sequence of removal, where back-propping and/or re-propping of the structure is used.

Table A.1 (*continued*)

Clause	Clause	Text
6 Reinforcement	6.2.1	Specify types of reinforcement.
	6.2.3	Specify permitted types of anchorages or couplers.
	6.2.6	State requirement for reinforcement materials other than steel, if used.
	6.3.1	Provide cutting and bending schedules or identify that this is a task for the constructor.
	6.3.1	State if bending at temperatures below –5 °C is permitted and, if so, specify the precautions that it is necessary to take.
	6.3.1	State if bending by heating is permitted.
	6.3.2	Specify mandrel diameter for bending bars.
	6.3.3	Specify mandrel diameter for welded reinforcement and fabric bent after welding.
	6.3.5	Specify any requirements for straightening bent bars.
	6.4.1 and 6.4.2	State provisions for the welding of reinforcement.
	6.4.3	Specify if spot welding is not permitted.
	6.5	State provisions for joints of reinforcement.
	6.6.1	Specify the position of reinforcement, including cover, the position of laps and joints, etc.
	6.6.2	Specify if reinforcement by “running meters” is permitted.
	6.6.3	Specify special requirements, if any.
	6.6.4	Specify nominal concrete cover, i.e. the required minimum cover and the numerical value of the permitted negative deviation; see Figure 3, case B).
7 Prestressing	7.1.2	State requirements for installation of post-tensioning kits and qualification of personnel to perform the installation.
	7.2.1.1	State requirements for the post-tensioning system.
	7.2.3.1	Specify requirements for the prestressing steel.
	7.2.3.2	State if alternatives to prestressing steel are permitted, and the requirements.
	7.2.5.2	Describe the tendon support.
	7.4.1.1	State provisions for assembling the prestressing tendons.
	7.4.1.3	Specify if welding of local anchorage zone reinforcement, anchor plates and spot welding of perforated plates is permitted.
	7.5.1.6	State requirement relating to the minimum compressive strength of concrete when applying or transferring prestressing force to the structure.
	7.5.2.1	State actions that it is necessary to take when the accuracy of elongation of pre-tensioning tendons cannot be achieved.
	7.5.3.1	State actions that it is necessary to take when the accuracy of elongation of post-tensioning tendons cannot be achieved.
8 Concreting	8.1.1	Check that all the required concrete properties have been specified according to ISO 22965 (all parts) and national standards or provisions valid in the place of use of the concrete.
	8.1.3	State the minimum upper sieve size, D, for the concrete.
	8.2.1	State if a concreting plan is required.
	8.2.2	State if a trial casting is required.

Table A.1 (*continued*)

Clause	Clause	Text
	8.2.4	State requirements for construction joints, where relevant.
	8.2.6	State if an increased cover to the reinforcement is needed when casting directly on ground.
	8.3.4	State if samples shall be taken.
	8.4.4	If sprayed concrete is applied, the execution specification shall give requirements for the execution.
	8.4.5.2	If slipforming is applied, the detailing and the equipment used shall be compatible.
	8.4.6.1	Specify special requirements to underwater casting, methodology, etc., if any.
	8.4.6.2	If the concrete is being cast under water, the detailing and the concreting method shall be compatible.
	8.5.2	Specify if there is any requirement to protect the concrete in its early age from aggressive agents.
	8.5.7	Specify the curing class being applied.
	8.5.8	Specify if there are any special curing requirements.
	8.5.16	Specify if special measures are required to reduce the risk of thermal cracking.
	8.8	Specify possible surface finish requirements.
9 Execution with precast concrete elements	9.1.2	Specify the precast concrete elements being used.
	9.4.1.1	Specify special requirements for handling, storage, protection and position.
	9.4.1.3	Specify requirements for product identification.
	9.5.1.1	State requirements for placing and adjustments.
	9.5.2.4	Give input for the erection, if relevant.
	9.6	State *in situ* works required for completion.
	9.6.3.1	State detailing of structural connections.
	9.6.3.2	Specify acceptable specific technologies.
	9.6.3.3	Specify requirements for connections, inserts for joint connections and welded structural connections.
10 Geometrical tolerances	10.1.2	Specify whether tolerance class 2 applies (and where).
	10.1.2 and 10.1.4	Specify any special tolerances and the elements to which they apply.
	10.1.3	Specify whether the tolerance requirements in Annex G do not apply.
	10.1.4 and 10.1.5	Specify whether the “box-principle” applies and with what tolerance, if different from $\pm$ 20 mm.
	10.1.6	State any requirements for surfaces with full contact bearing.
	10.1.7	Specify tolerances for sections that are being cast under water.
	10.1.10	State possible requirements for the combination of construction tolerances and structural deflections.
	10.2.3	State any requirements for the secondary lines.

A.2 Guidance on 4.2.3 — Execution record documentation

The following subjects should be considered for inclusion in the execution record documentation:

— sources of materials, material test reports and/or suppliers' declaration of conformity;

— applications for variations and the responses;

— as-built drawings or sufficient information to enable the production of as-built drawings for the entire structure, including any precast elements;

— description of non-conformities and, where applicable, the corrective actions taken;

— record of accepted changes to the project specification;

— records of any dimensional checks at hand-over;

— documentation of the inspections;

— events of significance for the properties of the finished structure;

— weather conditions during casting and curing.

Annex B
(informative)

Guidance on quality management

B.1 Guidance for 4.3.1 — Execution classes

B.1.1 Supervision and inspection are parts of the quality management.

B.1.2 The three execution classes give the option to specify the required level of quality management based on the importance of the component/structure and the criticality of the execution for its ability to fulfil its function.

Execution class 1 should be used only for structures where consequences in case of failure are small or negligible.

B.1.3 The execution classes are comprised of requirements for inspection and are dependant on the relevant National Annex, or the execution specification, requirements for quality planning focusing on organizational measures and allocation of resources and personnel.

B.1.4 The three execution classes given in 4.3.1 are connected to the three levels of reliability differentiation indicated in ISO 2394:1998[3], 4.2.3.

B.1.5 The extent of inspection applied shall be in accordance with national regulations and shall be stated in the execution specification by the selection of the appropriate “execution class”.

B.2 Guidance for 4.3.2 and 4.3.3 — Inspection of materials and products and inspection of execution

B.2.1 An inspection plan should, for each inspection point, state

— the requirements;

— the references to the standard and the execution specification;

— the method of inspection, monitoring or testing;

— the definition of inspection section;

— the frequency of inspection, monitoring or testing;

— the acceptance criteria;

— the documentation;

— the responsible inspector;

— the possible involvement of other parties in the inspection.

B.2.2 An inspection plan may be prepared as a summary table with references to the inspection procedures and inspection instructions giving the details of inspection, monitoring and testing.

B.2.3 An inspection as described in this subclause and in B.2.4 to B.2.6 normally satisfies the requirements of this International Standard with respect to the extent of inspection.

— Inspection for execution class 1 is an inspection that can be carried out by the operator that performed the work. This implies that the inspection is carried out on all work done, i.e., self inspection.

— For inspection for execution class 2, there should, in addition to the self inspection, be an internal systematic and regular inspection with fixed routines within the company that performed the work, i.e., an internal systematic inspection.

— For inspection for execution class 3, an extended inspection according to national regulations and/or the execution specification can be required, in addition to the self inspection and the internal systematic inspection performed by the constructor themselves. This extended inspection may be performed by another company, i.e., an independent inspection.

B.2.4 For structures in execution class 3, the internal systematic inspection should include any concrete works of significance for the load-bearing capacity and durability of the structure. This includes inspection of formwork, reinforcement, cleaning before casting, concrete, concreting and curing, prestressing, injection, etc.

In case an extended (or independent) inspection is required, this should have at least an extent similar to that described for the internal systematic inspection in execution class 2; see B.2.5.

B.2.5 For structures in execution class 2, the internal systematic inspection should include an inspection of all concrete and reinforcement works for important structural members, such as columns and beams. For other structural members, inspection by spot checks should be carried out to an extent depending on the significance of the structural members for the load-bearing capacity and durability.

B.2.6 For structures of precast concrete elements, all load-bearing supports and joints in the load-bearing system should be inspected.

Annex C
(informative)

Guidance on falsework and formwork

C.1 Guidance for 5.1 — Basic requirements

C.1.1 The principal actions that it is necessary to take into account in the design are the governing combinations of

— selfweight of formwork, reinforcement and concrete;

— pressure on formwork, taking into account concrete type (including possible uplift);

— construction loads (crew, equipment, etc.), including static and dynamic effects of placing, compacting and construction traffic;

— wind and snow loads;

— particular actions at the place of execution, such as provision for earthquakes.

NOTE The consequence of an earthquake is normally not considered for temporary works like formwork and falsework.

C.1.2 The provision of adequate bracing and the means of its connection are important.

C.2 Guidance for 5.3 — Design and installation of falsework

C.2.1 Wedges for the correct adjustment of falsework supports shall be properly secured against slippage during concreting.

C.2.2 Differential settlements should be taken into account, for example when propping off the ground.

C.2.3 Prevention of deleterious cracking in young concrete may be achieved by

— limiting the deflection and/or settlement;

— controlling the casting sequence and/or concrete specification.

C.3 Guidance for 5.4 — Design and installation of formwork

C.3.1 A closable window (opening) at the bottom of the form can be helpful when cleaning out the forms.

C.3.2 Considerations for slipforming include the following.

a) The form should have adequate batter to limit the form friction on the young concrete.

b) A continuous guidance system between the reinforcement and the form should be used to ensure that the required concrete cover is within the tolerances given in Clause 10.

C.4 Guidance for 5.5 — Special formwork

C.4.1 When proprietary formwork systems are used, the manufacturer's requirements should be adhered to.

C.4.2 Permeable formwork lining can be used to improve the quality of the concrete in the cover zone and significantly reduces the number and size of blowholes.

C.5 Guidance for 5.6.1 — Inserts in formwork and embedded components — General

C.5.1 When aluminium or galvanized steel inserts are being used, special measures should be taken to avoid chemical reactions between the metal and the concrete.

C.5.2 Metallic materials of different electrical potential should not be connected to form a complete conductive circuit.

C.6 Guidance for 5.7 — Removal of formwork and falsework

Where guidance on the required strength for removal of formwork and falsework is not given in the formwork or falsework design or the execution specification, then the following are suggested:

— concrete strength of 5 MPa to resist damage to surfaces that can arise during the striking;

— back-propping or other support that can be used to carry the actions imposed on the concrete member at that stage;

— protection that can be used to avoid surface damage due to weather until the concrete has achieved the design strength.

Annex D
(informative)

Guidance on reinforcement

D.1 Guidance on 6.2 — Materials

D.1.1 Reinforcement steel shall be specified in accordance with a national standard or ISO 6935-1 and ISO 6935-2. ISO 6935-1 and 6935-2 cover eleven steel grades that are intended for welding (symbol WR) and ten steel grades not intended for welding (symbol R). These parts of ISO 6935 give four ductility classes (A, B, C, D) with Class D as the most ductile steel, and three classes of characteristic yield strength (300 MPa, 400 MPa, 500 MPa), except for ductility class D, which also has two additional strength classes (350 MPa and 420 MPa).

D.1.2 In the selection of suitable chairs and spacers, consideration of the loading during placing of the reinforcement and casting of the concrete should be taken into account. The chairs and spacers should not lead to enclosure of air, crack formation, penetration of water or damage the reinforcement over the design service life of the structure. Long, continuous chairs that can be crack initiators are generally not suitable in a corrosive environment.

D.2 Guidance on 6.3 — Bending, cutting, transport and storage of the reinforcement

D.2.1 Measures should be taken to avoid

— mechanical damage, e.g. notches or dents;

— rupture of welds;

— reduction of the section through corrosion.

D.2.2 The actual bending diameter shall be as specified in the execution specification, taking account of the requirements to avoid damage to the reinforcement and to concrete in the bend, e.g. $\phi_{actual} \geqslant \phi_{m,min}$.

The use of mandrels in the Renard series with the following diameters, expressed in millimetres, is recommended: 16, 20, 25, 32, 40, 50, 63, 80, 100, 125, 160, 200, 250, 320, 400, 500, 630.

D.2.3 The minimum mandrel diameter from the point of the bending properties of the reinforcement should be sufficiently larger then the test mandrel used when testing bending properties, typically by a factor of 1,3 to 2,0. For reinforcement in accordance with ISO 6935-1 and 6935-2, the values in Table D.1 may be applied, unless other values are specified. The lower line applies to reinforcement that is bent and later rebent or straightened, while the other values are for reinforcement bent only once and in one continuous operation.

Table D.1 — Minimum permissible mandrel diameter to avoid damage to the reinforcement

Reinforcement diameter	6	8	10	12	14	16	20	25	28	32	40
Test mandrel diameter according to ISO 6935-1 and ISO 6935-2, ϕ_{test}	$3d$						$6d$				$7d$
Minimum permissible mandrel diameter, ϕ_{min}[a]	$4d$						$7d$				$10d$
Recommended minimum mandrel diameter according to Renard series	25	32	40	50	63	80	160	200	200	250	450
Rebending or straightening of bars Recommended minimum mandrel diameter according to Renard series	50	63	80	100	125	160	320	400	400	500	—

[a] National standards or provisions in the place of use can require larger mandrel sizes for bending of reinforcement.

D.2.4 Unless otherwise specified when bending inside the heat affected zone (HAZ) for welded reinforcement and fabric bent after welding, the mandrel should not be less than five times the bar diameter in cases where the welded bar is on the inside of the bend, and twenty times the bar diameter if the weld is on the outside of the bend of the mandrel diameter.

D.2.5 The following conditions should be satisfied when cold bending reinforcing steel:

— The shape and actual mandrel diameter are specified in the execution specification.

— The execution specification states if rebending at the same point is permitted.

— Boxes used to cover reinforcing bars for later connection should be designed so as not to adversely affect the load-bearing capacity of the concrete section or the corrosion protection of the reinforcement.

Annex E
(informative)

Guidance on prestressing

E.1 Guidance on 7.3 — Transport and storage

E.1.1 Prestressing steel, anchorages, couplers and ready-made tendons should be transported on carriages that are clean and free from chemical substances aggressive to the steel. Any contact with detrimental substances should be avoided by special packing at the mill or by supporting the steel in such a way that it is prevented from coming into contact with the carriage surfaces.

E.1.2 Transport by water should not be allowed without suitable protection.

E.1.3 The bar diameters that can be transported and stored as coils should be approved.

E.1.4 Prestressing steel should not be stored in contact with the ground nor exposed to rain. Prestressing steel should preferably be stored in closed rooms at a relative humidity of less than 60 %.

E.1.5 Ready-made tendons within sheaths should be protected at their ends against the penetration of moisture, against condensation, and supported at distances that do not impair the stability and tightness of the sheaths.

E.1.6 Corrosion of prestressing components should be avoided, if possible. Light rusting on tensile elements is generally acceptable if it can be removed by a soft cloth. More significant rust can generally be accepted on the external surfaces of anchorage castings.

E.2 Guidance on 7.4 — Installation of the tendons

E.2.1 Connections to anchorages and other connections should meet the same requirements as the sheaths.

E.2.2 Tapes for sealing the sheaths should be free of chloride.

E.2.3 Prestressing steel should be cut with a disk cutter.

E.2.4 For post-tensioned tendons, resistance against buckling of sheaths can be achieved by using a sufficiently stiff sheath or with temporary support from a polythene tube or similar.

E.3 Guidance on 7.5 — Tensioning

E.3.1 Guidance on 7.5.1 — General

Tensioning is a complex operation working with high forces on the jacks and the prestressing tendons. It is an operation that requires suitable safety measures and supervision by experienced personnel.

E.3.2 Guidance on 7.5.2 — Pre-tensioned tendons

E.3.2.1 In addition to the requirements in 7.5.1 and 7.5.2, the tensioning programme should specify

— any special sequence of tensioning;

— the jack pressure and its equivalent jack force that is attained;

— the minimum and maximum permissible tension in the tendons and their seating in the anchorages;

— the required concrete strength at the time of releasing the prestressing force.

E.3.2.2 The operational suitability of reusable anchorage components should be proven by a check.

E.3.3 Guidance on 7.5.3 — Post-tensioned bonded tendons

E.3.3.1 In addition to the requirements in 7.5.1 and 7.5.3, the tensioning programme should specify

— the prestressing system being used;

— the type and grade of prestressing steel;

— the number of bars, wires or strands in each tendon;

— the required concrete strength for the application of tension;

— the order in which it is necessary to tension successive tendons and any requirements for phased tensioning on a tendon;

— the calculated tensioning and jacking force as well as the elongation of the tendons;

— the anticipated seating at the anchorage;

— any necessary partial or full release of the falsework.

E.3.3.2 The following should be recorded:

— verification of the required concrete strength for the tensioning;

— type of prestressing jack used;

— measured jack force and the elongation of the tendon at each stage of tensioning;

— observed seating;

— any severe deviation from the calculated tensioning force or elongation;

— if specified, the release of falsework.

E.3.4 Guidance on 7.5.4 — Internal and external unbonded tendons

E.3.3.1 and E.3.3.2 apply.

E.4 Guidance on 7.6.1 — Protective measures — General

E.4.1 If the penetration of water or excessive humidity can be prevented, and if provisions valid at the construction site do not specify otherwise, the following construction periods are recommended:

— maximum of 12 weeks between fabrication of tendons and grouting;

— maximum of 4 weeks in the formwork before casting of concrete;

— approximately 2 weeks in the tensioned condition before applying the protective measures in severe exposure conditions/environment; in benign exposure conditions/environments, this period may be extended to 4 weeks.

E.4.2 If the period above between tensioning and grouting is exceeded, temporary protection should be maintained by an approved method. Application of approved, water-soluble oils or flushing of the ducts at appropriate intervals with dried air can provide suitable means of protection.

Annex F
(informative)

Guidance on concreting

F.1 Guidance on 8.1 — Specification of concrete

ISO 22965-1 defines concrete as " … mixing cement, coarse and fine aggregate and water …".

Standards on aggregates may define coarse aggregates as aggregate with $D \geqslant 4$ mm or 5 mm where D is the actual upper sieve size of the aggregate. Included in this definition are both a maximum and a minimum percentage passings on sieve size D. The term D_{max} normally defines the "maximum nominal upper aggregate size", which is selected to ensure a proper casting, taking into account the cover and free spacing between the reinforcement bars. In principle, any value of D less than D_{max} satisfies a requirement related to D_{max}.

Concrete with aggregates of upper size D in the range from 4 mm to 12 mm might not support the design assumptions, e.g. aggregate interlock, shear capacity, stiffness, fracture energy. ISO 22965-1 therefore states in a note that in concrete for general purpose the coarse aggregate should normally have a minimum size of 16 mm.

To ensure compatibility with the design assumptions, the actual maximum size of the aggregate being used should be specified, in particular if D smaller than 16 mm is allowed.

F.2 Guidance on 8.2 — Pre-concreting operations

F.2.1 Construction joints should not be made at critical places.

F.2.2 Structural elements should be isolated from the ground by a blinding layer of at least 50 mm unless the concrete cover to the reinforcement is increased correspondingly.

F.2.3 Concreting onto frozen ground should not be permitted unless special procedures are followed.

F.2.4 The surface temperature at the construction joint should be above 0 °C at the time of concreting.

F.2.5 The execution specification may define ambient temperatures above which it is necessary that precautions be planned to protect the concrete against damaging effects.

F.3 Guidance on 8.3 — Delivery, reception and site transport of fresh concrete

F.3.1 The receiving inspection should be documented by signing the delivery ticket, when relevant.

F.3.2 For SCC, receiving inspection should include testing of fresh state properties.

F.4 Guidance on 8.4.1 — Placing and compaction — General (for ordinary vibrated concrete)

F.4.1 Compaction should be performed by internal vibration, unless otherwise agreed.

F.4.2 Concrete should be placed as near as practical to its final location. Vibration should be used to compact the concrete and not as a means of moving the concrete long distances.

F.4.3 Vibration by poker or surface vibrator should be applied systematically after placing until the expulsion of entrapped air has practically ceased. Excessive vibration, which can promote weak surface layers or segregation, should be avoided.

F.4.4 Normally the thickness of the concrete layer placed should be less than the length of the poker vibrator. Vibration should be systematic and include re-vibration of the top of the previous layer.

F.4.5 Where permanent formwork is incorporated in the structure, its energy absorption should be taken into account when deciding the method of compaction and consistency of the concrete.

F.4.6 In deep sections, re-compaction of the surface layer is recommended to prevent plastic settlement below horizontal top reinforcement.

F.4.7 Where only surface vibrators are used, the layer of concrete after compaction should, in normal situations, not exceed 100 mm unless proved acceptable by trial castings. Additional vibration near the supports can be required to obtain adequate compaction.

F.4.8 Surface finishing by screeding, trowelling or floating should be carried out in a manner and in the time necessary to achieve the specified surface finish.

F.4.9 Surface finishing should not result in laitance.

F.4.10 Water, cement, surface hardeners or other materials should not be added during the finishing operations unless specified or agreed.

F.4.11 When placing and compacting fresh concrete near prestressing tendons, it is necessary to take special care in order not to damage or displace the tendons.

F.5 Guidance on 8.4.3 — Placing and compaction — Self-compacting concrete

F.5.1 SCC mix design should comply with specific requirements in the fresh state depending on the type of application, and especially on

— confinement conditions related to the concrete element geometry and the quantity, type and location of reinforcement, inserts and recesses;

— placing equipment (pump, truck-mixer, skip, etc.);

— placing methods (number of delivery points);

— finishing method.

F.5.2 The provisions in F.5.1 can be expressed and justified in terms of

— flowability and filling ability;

— viscosity (measure of the speed of flow);

— passing ability, (flow without blocking);

— segregation stability.

F.5.3 The required consistence retention time depends on the transportation and placing time. This should be determined and specified.

F.5.4 Self-compacting concrete should, as much as possible, be placed in one continuous pour so delivery rates should be matched to placing rate. The maximum allowed period of time between successive concrete layers should be declared and not exceeded.

F.5.5 Free-fall and horizontal flow of SCC should be limited in order to avoid any adverse effect on concrete quality and homogeneity.

F.5.6 Vibration of SCC should generally be avoided as it is likely to result in significant segregation of the coarse aggregate. A carefully controlled and light vibration may be used if it is demonstrated that there is no adverse effect on concrete quality and homogeneity.

NOTE 1 At the time of publishing this International Standard, ISO has not completed its work to standardize test methods characterizing the properties of SCC nor additional provisions for its specification in ISO 22965 (all parts). Till such provisions are available, the constructor and the concrete producer can find guidance in national and international guidelines published by other bodies.

NOTE 2 Guidance regarding limitation of free-fall and horizontal flow can be found in published guidelines (e.g. RILEM SCC Technical Committee report).

F.6 Guidance for curing and protection

F.6.1 The following methods are suitable for curing used separately or in sequence:

— keeping the formwork in place;

— covering the concrete surface with vapour-proof sheets, which are secured at the edges and joints to prevent draughts;

— placing of wet coverings on the surface and protection of these coverings against drying out;

— keeping the concrete surface visibly wet with suitable water;

— application of a curing compound of established suitability.

Other curing methods of equal effectiveness may be used.

NOTE At the time of publishing this International Standard, standardized test methods characterizing the properties of curing compounds are not available.

F.6.2 The development of properties in the surface zone should be based on the relationship of compressive strength to maturity.

F.6.3 Detailed estimates of the development of concrete properties may be based on one of the following methods:

— maturity calculation from temperature measurements taken at a maximum depth of 10 mm below the surface;

— maturity calculation based on the daily average air temperature;

— temperature-matched curing;

— rebound hammer testing (after calibration on relevant concrete test sample);

— other methods of established suitability.

F.6.4 Maturity calculations should be based on an appropriate maturity function, proven for the type of cement or combination of cement and addition in use.

F.6.5 Tables F.1 to F.3 give the duration of curing, expressed in number of days, deemed to satisfy curing class 2 to curing class 4, respectively, and should be used in the absence of a more accurate method for determining concrete strength in the cover zone.

Table F.1 — Minimum curing period for curing class 2 corresponding to a surface concrete strength equal to 35 % of the specified characteristic strength

Surface concrete temperature t °C	**Minimum curing period for concrete strength development**[ab] $r = (f_{cm2}/f_{cm28})$ days[c]		
	rapid $r \geqslant 0{,}50$	medium $0{,}50 > r \geqslant 0{,}30$	slow $0{,}30 > r \geqslant 0{,}15$
$t \geqslant 25$	1,0	1,5	2,5
$25 > t \geqslant 15$	1,0	2,5	5
$15 > t \geqslant 10$	1,5	4	8
$10 > t \geqslant 5$[d]	2,0	5	11

[a] The concrete strength development is the ratio of the mean compressive strength after 2 days to the mean compressive strength after 28 days determined from initial tests or based on known performance of concrete of comparable composition; see ISO 22965-2.

[b] For very slow concrete strength development, special requirements should be given in the execution specification.

[c] Plus any period of set exceeding 5 h.

[d] For temperatures below 5 °C, the duration should be extended for a period equal to the time below 5 °C.

Table F.2 — Minimum curing period for curing class 3 corresponding to a surface concrete strength equal to 50 % of the specified characteristic strength

Surface concrete temperature t °C	**Minimum curing period for concrete strength development**[ab] $r = (f_{cm2}/f_{cm28})$ days[c]		
	rapid $r \geqslant 0{,}50$	medium $0{,}50 > r \geqslant 0{,}30$	slow $0{,}30 > r \geqslant 0{,}15$
$t \geqslant 25$	1,5	2,5	3,5
$25 > t \geqslant 15$	2,0	4	7
$15 > t \geqslant 10$	2,5	7	12
$10 > t \geqslant 5$[d]	3,5	9	18

[a] The concrete strength development is the ratio of the mean compressive strength after 2 days to the mean compressive strength after 28 days determined from initial tests or based on known performance of concrete of comparable composition; see ISO 22965-2.

[b] For very slow concrete strength development, special requirements should be given in the execution specification.

[c] Plus any period of set exceeding 5 h.

[d] For temperatures below 5 °C, the duration should be extended for a period equal to the time below 5 °C.

Table F.3 — Minimum curing period for curing class 4 corresponding to a surface concrete strength equal to 70 % of the specified characteristic strength

Surface concrete temperature t °C	Minimum curing period for concrete strength development[ab] $r = (f_{cm2}/f_{cm28})$ days[c]		
	rapid $r \geqslant 0{,}50$	medium $0{,}50 > r \geqslant 0{,}30$	slow $0{,}30 > r \geqslant 0{,}15$
$t \geqslant 25$	3	5	6
$25 > t \geqslant 15$	5	9	12
$15 > t \geqslant 10$	7	13	21
$10 > t \geqslant 5$[d]	9	18	30

[a] The concrete strength development is the ratio of the mean compressive strength after 2 days to the mean compressive strength after 28 days determined from initial tests or based on known performance of concrete of comparable composition; see ISO 22965-2.

[b] For very slow concrete strength development, special requirements should be given in the execution specification.

[c] Plus any period of set exceeding 5 h.

[d] For temperatures below 5 °C, the duration should be extended for a period equal to the time below 5 °C.

F.6.6 The choice of curing class is dependant on exposure classes, choice of concrete composition and choice of concrete cover to the reinforcement. Climatic conditions and size of elements are also important parameters.

F.6.7 Curing compounds can penetrate the surface and make removal very difficult; therefore, grit blasting or high-pressure water jetting normally is necessary if it is necessary to remove them.

F.6.8 The use of a curing compound containing a dye makes verification of application simple.

F.6.9 Possible adverse effects of high concrete temperatures during curing include

— delayed ettringite formation,

— significant reductions of strength,

— significant increase in porosity,

— increase in the temperature difference between the cast element and previously cast restraining elements.

F.7 Guidance for surface finish

F.7.1 The following requirements should be given as appropriate for each finish:

— formwork face material: acceptability of face material leaving an imprint on the concrete that is not specifically part of the finish; the constructor's freedom to use different face materials to give greater re-use of the form face;

— colour: no requirements for colour consistency or shade unless using special coloured materials;

— blowholes: limits on size, depth and frequency should be given where visual effects are important;

— abrupt and gradual irregularities: size and frequency should be given; these irregularities are independent of any tolerance deviation allowed in the element and should encompass formwork face irregularities only.

— making good: whether making good is permitted to improve the finish.

F.7.2 A typical use of the finish types is given in Table F.4 to indicate the requirements for an execution specification.

Table F.4 — Types of surface finish

Type	Normal application	Example
Formed surfaces		
Basic finish	Where no particular requirement is needed	Foundations
Ordinary finish	Where not of visual importance or to receive applied finishes	Areas with applied render finish or unseen surfaces such as inside ducts or lift shafts
Plain finish	Where visual effect is of some importance	Areas seen occasionally and areas that are prepared, direct painted areas where there are some particular requirements
Special finish	Where special requirements have to be given	Areas where surface regularity and/or colour are important
Unformed surfaces		
Basic finish	A closed uniform surface produced by levelling No further work is required	Area to receive a screeded finish or other applied finishes
Ordinary finish	A level uniform surface produced by floating or similar process	Area for false floor and other applied floorings
Plain finish	A dense smooth surface produced by trowelling or similar	Normal warehouses and factories, areas of plant rooms and work areas with no finish other than paint
Special finish	A surface where special requirements have to be given for further working of another finish	Areas of warehouse floors for special trafficking

Annex G
(informative)

Guidance on geometrical tolerances

G.1 Guidance on 10.1 — Geometrical tolerances — General

In this annex, guidance is given for permitted geometrical deviations in terms of service performance placing compatibility. These are tolerances for geometrical quantities that are considered to have small structural influence.

G.2 Guidance on 10.3 — Geometrical tolerances — Base supports (foundations)

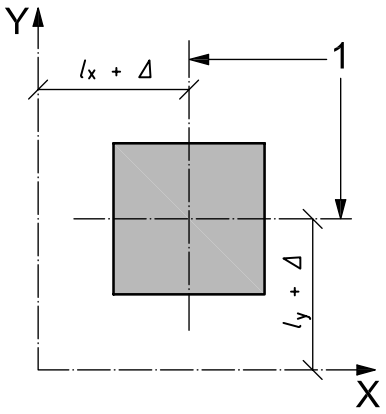
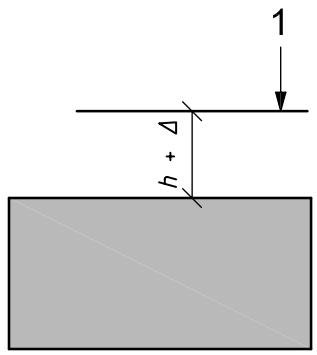
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	 **Key** X secondary line in the x direction Y secondary line in the y direction 1 support centre lines (horizontal section)	Position in plan of a base support relative to the secondary lines	± 25 mm
B	 **Key** 1 secondary level (vertical section) h intended distance	Position in vertical direction of a base support relative to the secondary level	± 20 mm

Figure G.1 — Permitted deviations for the position of base supports (foundations)

G.3 Guidance on 10.4 — Geometrical tolerances — Columns and walls

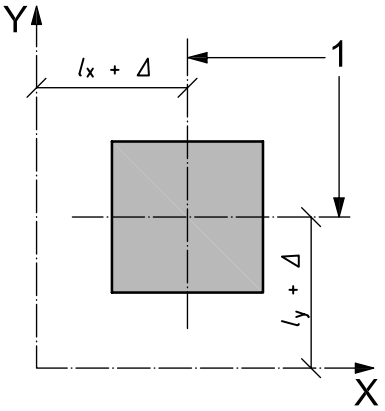
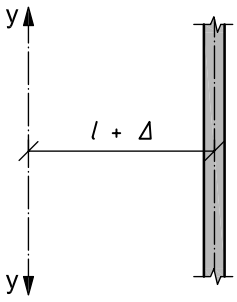
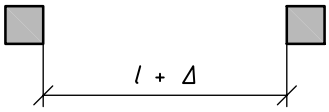
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	 **Key** X secondary line in the x direction Y secondary line in the y direction 1 column centre lines (horizontal section)	Position in plane of a column relative to the secondary lines	± 25 mm
B	 secondary line in y direction	Position in plane of a wall relative to the secondary line	± 25 mm
C		Free space between adjacent columns or walls	The larger of ± 20 mm or ± *l*/600 but not larger than 60 mm[a]
[a] Stricter values can be needed for beams supporting precast elements for the required support length.			

Figure G.2 — Permitted deviations for position of columns and walls, horizontal sections

G.4 Guidance on 10.5 — Geometrical tolerances — Beams and slabs

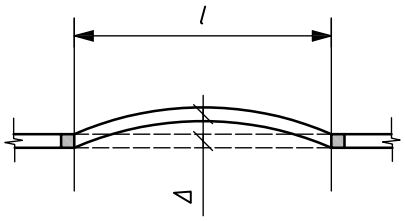
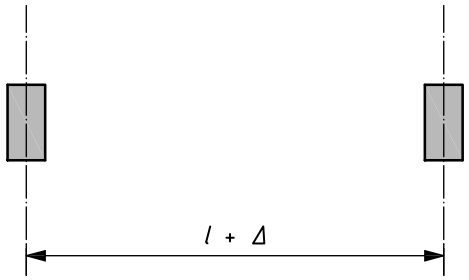
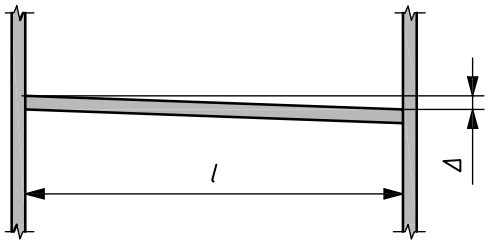
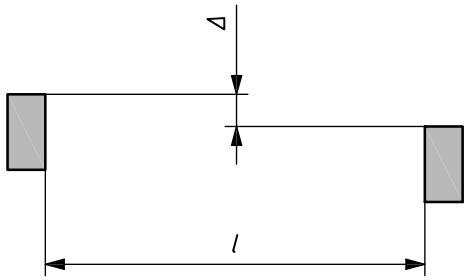
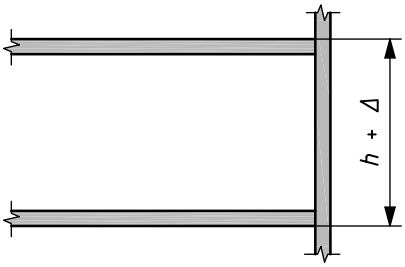
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A		Horizontal straightness of beams	The larger of ± 20 mm or ± *l*/600
B		Distance between adjacent beams, measured at corresponding points	The larger of ± 20 mm or ± *l*/600 but not more than 40 mm[a]
C		Inclination of a beam or a slab	± (10 + *l*/500) mm
D		Level of adjacent beams, measured at corresponding points	± (10 + *l*/500) mm
E		Levels of adjacent floors at supports	± 20 mm

Figure G.3 (*continued*)

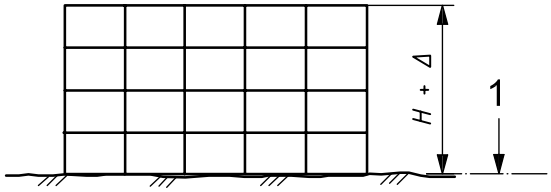
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
F	 **Key** 1 secondary level	Level of upper floor measured relative to the secondary system $H \leqslant 20$ m 20 m < H	± 20 mm ± 0,5 (H + 20) mm but not more than 50 mm
a Stricter position tolerances can be required for beams supporting precast elements depending on the length tolerance of the supported member and required support length.			

Figure G.3 — Permitted deviations for beams and slabs

G.5 Guidance on 10.6 — Geometrical tolerances — Sections

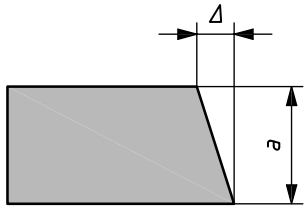
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	 a length of cross-sectional dimension	Orthogonality of a cross-section	The larger of ± 0,04 a or ± 10 mm, but not more than ± 20 mm

Figure G.4 — Permitted cross-sectional deviations

G.6 Guidance on 10.7 — Geometrical tolerances — Surfaces and edge straightness

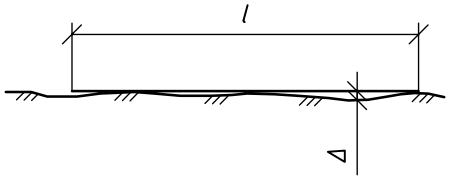
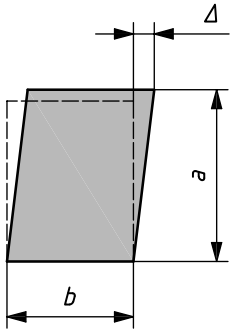
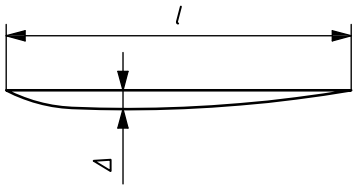
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	Flatness	Flatness	
	Surface moulded or smoothed		
	global	l = 2,0 m	9 mm
	local	l = 0,2 m	4 mm
	Surface not moulded		
	global	l = 2,0 m	15 mm
	local	l = 0,2 m	6 mm
			
B		Skewness of cross-section	The greater of $\pm a/25$ or $\pm b/25$, but not more than $\pm$ 30 mm
C		Edge straightness For lengths: $l \leqslant$ 1 m $l >$ 1 m	 $\pm$ 8 mm $\pm$ 8 mm/m, but not more than $\pm$ 20 mm

Figure G.5 — Permitted deviations for surfaces and edges

G.7 Guidance on 10.8 — Geometrical tolerances — Tolerances for holes and inserts

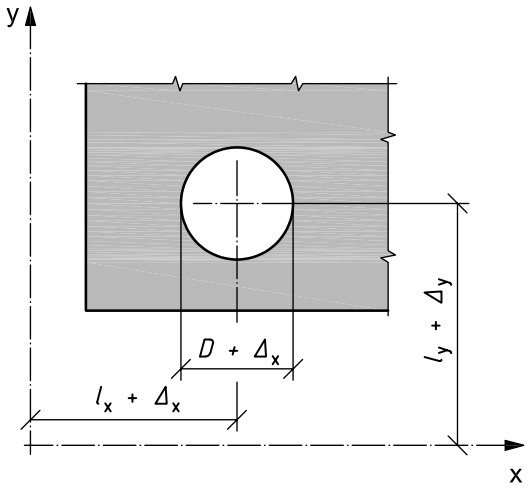
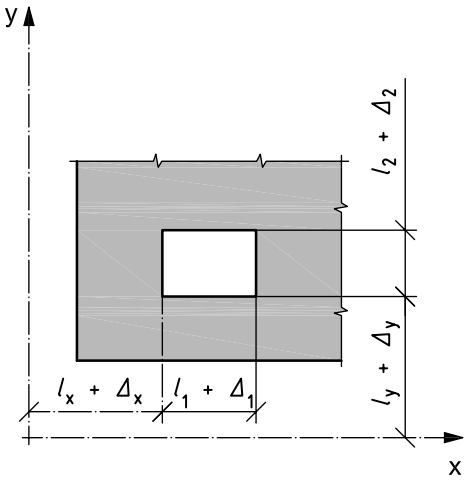
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
A	 Δ_x and Δ_y deviation from secondary line in x- and y-direction Δ_D deviation on diameter	Holes and conduit inserts Δ_x and Δ_y Δ_D	 ± 25 mm ± 10 mm unless otherwise stated in the execution specification
B	 Δ_x and Δ_y deviation from secondary line in x- and y-direction Δ_1 and Δ_2 deviations on block-out Alternatively measured to centrelines as in A.	Blockout and recesses Δ_x, Δ_y, Δ_1, Δ_2	 ± 25 mm unless otherwise stated in the execution specification

Figure G.6 (*continued*)

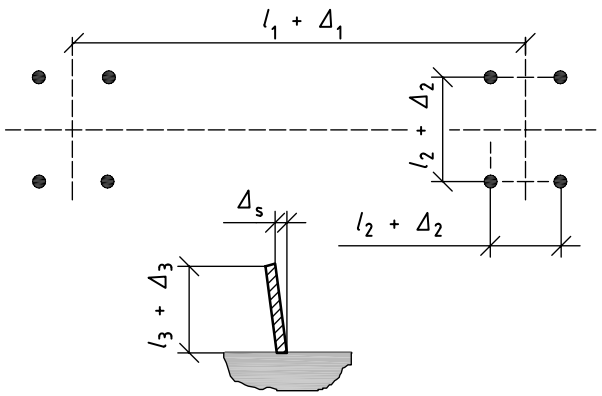
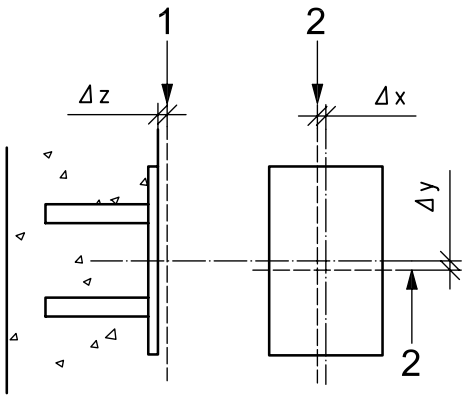
No.	Type of deviation	Description	Permitted deviation for tolerance class 1 Δ
C	 l_1 distance between bolt groups l_2 distance between bolts within group l_3 free length of bolt	Anchor bolts and similar inserts Placing of bolts and centre of a bolt group Internal distance between bolts in a group Protrusion Inclination	 $\Delta_1 = \pm 10$ mm $\Delta_2 = \pm 3$ mm $\Delta_3 = {}^{+25}_{-5}$ mm Δ_s is equal to the greater of 5 mm or $l_3/200$ unless otherwise stated in the execution specification
D	 **Key** 1 nominal position in depth 2 nominal position in plane	Anchoring plates and similar inserts Deviation in plane Deviation in depth	 $\Delta_x, \Delta_y = \pm 20$ mm $\Delta_z = \pm 10$ mm unless otherwise stated in the execution specification

Figure G.6 — Permitted deviations for holes and inserts

Annex H
(informative)

Guidance on national annex

H.1 Guidance on a National Annex

A number of clauses in this International Standard refer to requirements that should be given in the execution specification. These requirements may be project-execution-specific but in many situations such requirements can be given on a national basis either in national regulations or as national standards. It is foreseen that the use of a national annex to this International Standard can be helpful, either by referring to national requirements or alternatively by giving the national provisions directly on any of the areas that are referred to as open for specification by the execution specification.

A national annex to this International Standard may include or give reference to national requirements on items such as the following:

a) execution management: requirements related to the organization of construction works and the competence of the personnel performing the various tasks;

b) project documentation: minimum requirements for documentation and records that should be prepared and stored;

c) quality management: requirements related to the use of execution classes and the extent and type of inspection required; see Table 3 and Annex B;

d) reinforcement: provisions regarding applicable types, such as yield strength, ductility, bending properties, relative rib area, weldability, fatigue properties, etc.;

e) concreting: provisions regarding requirements related to minimum D (upper sieve size of the coarse aggregate), curing and selection of curing classes;

f) surface finish: provisions regarding reference to systems for surface finish descriptions;

g) geometrical tolerances: provisions for tolerance to minimum cover to the reinforcement in accordance with national design standards, for values for tolerance class 2 where such values are not given, and for special structures (e.g. bridges, silos).

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[3] ISO 2394:1998, *General principles on reliability for structures*

[4] ISO 3766, *Construction drawings — Simplified representation of concrete reinforcement*

[5] BS CWA 14646:2003, *Requirements for the installation of post-tensioning kits for prestressing of structures and qualification of the specialist company and its personnel*

[6] ISO 9000:2005, *Quality management systems — Fundamentals and vocabulary*

[7] Final Report of RILEM TC 188-CSC, Casting of Self Compacting Concrete, Ed. Å. Skarendahl and Peter Billberg

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