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Izvedba posebnih geotehniļ nih del - Diafragme

Execution of special geotechnical works - Diaphragm walls

Ausführung von besonderen geotechnischen Arbeiten (Spezialtiefbau) - Schlitzwände

Exécution de travaux géotechniques spéciaux - Parois moulées

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EUROPEAN STANDARD
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English version

Execution of special geotechnical works - Diaphragm walls

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Central Secretariat: rue de Stassart, 36 B-1050 Brussels

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Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 288 "Execution of special geotechnical works", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2000, and conflicting national standards shall be withdrawn at the latest by July 2000.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The general scope of TC 288 is the standardisation of the execution procedures for geotechnical works, including testing and control methods, and of the required material properties. WG1 has been charged with the subject area of both retaining and cut-off diaphragm walls. The present Standard excludes the execution of barrettes, which is covered by prEN 1536 Execution of Special Geotechnical Works : Bored Piles.

The document has been prepared to stand alongside ENV 1997 Eurocode 7 Part 1 : Geotechnical Design, General Rules. Clause 8 of this Standard covers design aspects of retaining structures and gives guidance on supervision. The present Standard expands on design only where necessary (e.g. the detailing of reinforcement) but provides full coverage of the construction and supervision requirements.

This document has been drafted by a working group comprised of delegates from 10 countries and is based on the review of 7 national or international codes of practice.

1 Scope

This European Standard specifies the execution of diaphragm walls and the practical aspects which must be taken into account in the production of the working drawings. Diaphragm walls can be permanent or temporary structures. The following types are concerned :

a) retaining walls : usually made to support the sides of an excavation in the ground. They include :

   1) cast in situ concrete diaphragm walls ;

   2) precast concrete diaphragm walls ;

   3) reinforced slurry walls ;

b) cut-off diaphragm walls : usually made to prevent migration of groundwater, clear or polluted, or of other liquids present in the ground. They include :

   1) slurry walls (possibly with membranes or sheetpiles) ;

   2) plastic concrete walls.

The design, planning and execution of diaphragm walls call for experience and knowledge in this specialized field. The execution phase requires skilled and qualified personnel and this document cannot replace the know-how of specialist personnel and the expertise of experienced contractors.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies.

EN 10080, *Steel for the reinforcement of concrete, weldable ribbed reinforcing steel B500 — Technical delivery conditions for bars, coils and welded fabric.*

ENV 197, *Cement — Composition, specifications and conformity criteria.*

ENV 206:1990, *Concrete — Performance, production, placing and compliance criteria.*

ENV 1991, *Eurocode 1 : Basis of Design and Actions on Structures.*

ENV 1992, *Eurocode 2 : Design of Concrete Structures.*

ENV 1994, *Eurocode 4 : Design of Composite Steel and Concrete Structures.*

ENV 1997, *Eurocode 7 : Geotechnical Design.*

ENV 1998, *Eurocode 8 : Earthquake Resistant Design of Structures.*

ISO 9690, *Production and control of concrete — Classification of environmental exposure conditions for concrete and reinforced concrete structures.*

3 Terms and definitions

For the purposes of this European Standard, the following terms and definitions apply :

3.1
cast in situ concrete diaphragm wall
fr : paroi moulée en béton
de : Ortbetonschlitzwand
wall made of plain concrete or reinforced concrete, which is constructed in a trench excavated in the ground. The concrete is placed through concreting pipes, beneath the supporting fluid in the case of liquid-supported trenches or in some cases, in dry conditions

3.2
precast concrete diaphragm wall
fr : paroi préfabriquée en béton
de : Fertigteilschlitzwand
wall made of precast elements which are lowered into a trench containing a self-hardening slurry

3.3
reinforced slurry wall
fr : paroi moulée en coulis armé
de : Bewehrte Einphasenschlitzwand
wall made from a self-hardening slurry reinforced by steel beams, steel mesh or other suitable means

3.4
slurry wall
fr : paroi moulée en coulis
de : Einphasenschlitzwand
wall made from a self-hardening slurry. In most cases, the excavation is carried out using a self-hardening slurry as the supporting fluid. Sealing elements such as membranes or sheetpiles may be inserted

3.5
plastic concrete wall
fr : paroi moulée en béton plastique
de : Tonbetonschlitzwand
wall made of plastic concrete, which is constructed in a trench in the ground. The concrete is placed beneath the supporting fluid using concreting pipes in liquid-supported trenches, or in some cases, in dry conditions

3.6
panel
fr : panneau
de : Schlitzwandelement
section of a diaphragm wall which is concreted as a single unit. A diaphragm panel may be linear, T-shaped, L-shaped, or of other configuration

3.7
guide-walls
fr : murettes-guides
de : Leitwände
small, parallel temporary walls which are used to provide a guide for the excavating tool and to secure the sides of the trench against collapse in the vicinity of the fluctuating level of the supporting fluid

3.8
concreting pipe
fr : tube plongeur
de : Betonierrohr
pipe used for placing concrete beneath the supporting fluid, to avoid contamination and segregation

3.9
supporting fluid
fr : fluide d'excavation
de : Stützende Flüssigkeit
fluid used during excavation to support the sides of the trench. It is usually a bentonite suspension, a polymer solution or a self-hardening slurry

3.10
self-hardening slurry
fr : coulis autodurcissant
de : Selbsterhärtende Suspension
slurry which hardens with time. The slurry is a suspension which contains cement or another binder, and additional materials such as clay (bentonite), ground granulated blast furnace slag (GGBFS) or pulverized fuel ash (PFA), fillers, and admixtures

3.11
plastic concrete
fr : béton plastique
de :Tonbeton
a low strength, high plasticity concrete. Here, high plasticity means the ability to sustain larger strains than normal concrete. It is usually made with a low cement content, containing bentonite and/or other clay materials. It may also include other materials such as PFA and admixtures

4 Information required for the execution of the work

The following information is required for the production of the working drawings and the execution of the work :

— site topography ;

— previous use of site ;

— geotechnical information and data as specified in clause 5 ;

— information on the adjacent roads and structures, in particular the type of foundation and precautions necessary to ensure their stability ;

— location, type and condition of services (gas, electricity, sewers ...) ;

— presence of obstructions in the ground (old masonry ...) ;

— presence of archeological remains ;

— presence of polluted ground ;

— working restrictions if any (vibrations, noise, headroom, working area ...) ;

— all necessary information for the production of the working drawings ;

— any specific requirements for the diaphragm wall, in particular those pertaining to tolerances, quality of materials, watertightness, and type of joints ;

— environmental requirements ;

— when available, previous experience with diaphragm walls or underground works on or adjacent to the site.

For cut-off walls, permeability, strength and deformation properties of the wall material, together with testing methods, shall be specified.

Diaphragm walls cannot be expected to be completely watertight, since leakage can occur at joints, at recesses or through the wall material. Damp patches and droplets of water on the surface of the wall cannot be avoided under normal circumstances.

Continuity of reinforcement between the cages and across the joints is not normally required, but may be specified in exceptional circumstances.

5 Site investigation

5.1 General

Site investigations for the design and execution of diaphragm wall shall be made according to the general rules given in ENV 1997.

All information from the site investigation shall be made available in accordance with the requirements of clause 4.

5.2 Specific aspects

Particular attention shall be paid to the following aspects, which are relevant to the execution of diaphragm walls :

— piezometric levels of all water-tables and permeability of the soils ;

— presence of coarse, highly permeable soils or cavities (natural or artificial), which may cause sudden losses of supporting fluid and instability of the trench, and thus may require special measures ;

— presence, strength and deformation characteristics of soft soils, such as very soft clay or peat, which may cause difficulties during excavation (deformation or instability) ;

— presence of boulders or obstructions which may cause difficulties during excavation and, when possible, an assessment of their size and frequency ;

— presence, position, strength and hardness of rock or other hard materials which may cause difficulties during excavation and may require the use of special tools ;

— detrimental chemistry of groundwater, soil and rock, and water temperatures if required (see ISO 9690) ;

— detrimental chemistry of waste materials (see ISO 9690) ;

— presence of pretreated soil, which may have an adverse effect during excavation.

The piezometric levels of the various water-tables existing on the site shall be monitored separately and over a sufficient period of time to estimate the highest piezometric levels which may occur during construction of the diaphragm wall. Particular attention shall be paid to artesian conditions.

The strength of the soils and rocks shall be determined by laboratory tests and/or in situ tests over the full depth of the diaphragm wall and to a certain depth below the base depending on the nature of the ground and the function of the wall.

The grain-size distribution of cohesionless soils shall be determined.

When diaphragm walls are required to reach or penetrate into rock, the level of the rock surface shall be determined in both the longitudinal and transverse directions along the length of the diaphragm wall. The properties of the rock, including the degree of weathering and the extent of fissuring shall also be determined.

6 Materials

6.1 General

Unless otherwise stated in this European Standard, the materials used shall comply with other relevant European Standards.

6.2 Constituents

Bentonite is used in supporting fluids, either as a bentonite suspension or as an addition to polymers. It is also used as a constituent part of self-hardening slurries.

Bentonite is a clay containing mainly the mineral montmorillonite or similar minerals. A distinction should be made between calcium bentonite, natural sodium bentonite and activated bentonite, which is a sodium bentonite produced from natural calcium bentonite by ion exchange.

Bentonite used in bentonite suspensions shall not contain harmful constituents in such quantities as may be detrimental to reinforcement or concrete.

The chemical and mineralogical composition of the bentonite shall be supplied.

The type of cement to be used shall take into account the aggressiveness of the soil and groundwater. Cement for concrete shall comply with 4.1 of ENV 206.

6.3 Supporting fluids

This subclause covers only bentonite suspensions, polymer solutions and self-hardening slurries.

6.3.1 Bentonite suspensions

A bentonite suspension shall be prepared with either natural or activated sodium bentonite.

In certain cases, e.g. when the density of the suspension has to be increased, suitable inert materials may be added.

A self-hardening slurry may be prepared with calcium bentonite or natural or activated sodium bentonite.

Under normal circumstances, the bentonite suspension shall meet the conditions shown in Table 1.

The values in Table 1 may be modified in special circumstances, for example in the case of :

— soils or rock with high permeability or cavities where loss of bentonite may occur ;

— high piezometric levels (artesian conditions) ;

— very soft soils ;

— salt water conditions.

Table 1 — Characteristics for bentonite suspensions

Property	Stages		
	Fresh	Ready for re-use	Before concreting
Density in g/ml	< 1,10	< 1,25	< 1,15
Marsh value in s	32 to 50	32 to 60	32 to 50
Fluid loss in ml	< 30	< 50	n.a.
pH	7 to 11	7 to 12	n.a.
Sand content in %	n.a.	n.a.	< 4
Filter cake in mm	< 3	< 6	n.a.
n.a. : not applicable			

At the stage "before concreting", an upper limit value between 4 % and 6 % for sand content may be used in special cases (e.g.: non load bearing walls, unreinforced walls).

In order to keep the sand particles in suspension and to reduce penetration into the ground, it is necessary to have a bentonite suspension with sufficient gel strength.

When deemed to be necessary, the gel strength can be checked by using rotational viscometers or other suitable equipment.

The Marsh value, the fluid loss, the sand content and the filter cake can be measured, for example, using the tests described in the American Petroleum Institute document "Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids" (reference: American Petroleum Institute Recommended Practice 13B-1, June 1, 1990).

The Marsh value is the time required for a volume of 946 ml to flow through the orifice of the cone. A volume of 1 000 ml may be used, but in this case, the Marsh values given in table 1 shall be adjusted.

The duration of the fluid loss test may be reduced to 7,5 min. for routine control tests. However, in this case, the values for fluid loss and filter cake shall be adjusted. The fluid loss for the 7,5 min. test will be approximately half of the value obtained in the 30 min test.

NOTE Sand content is the percentage by volume, and not by weight, of particles larger than 74 µm, which is the mesh size of the sand content set.

6.3.2 Polymer solutions

Polymer solutions, possibly with the addition of bentonite, may be used as supporting fluids on the basis of previous experience in similar or worse geotechnical conditions, or after full-scale trial trenches on the site. A reasonable extrapolation of previous experience may be made with the support of laboratory tests and theoretical analysis.

6.4 Self-hardening slurries

Self-hardening slurries are generally used in the precast concrete diaphragm wall technique, for reinforced slurry walls and slurry cut-off walls. They serve as the supporting fluid during excavation, and, together with the fines from the natural ground, form the final, hardened material. The characteristics of the slurry must be suitable to ensure satisfactory performance during execution. Admixtures may have to be used to adjust workability during excavation and the insertion of elements, as well as setting time taking into account the possible effects of temperature and chemical components of the soil and groundwater. The characteristics of the hardened material, as needed for the particular applications (e.g. permeability, strength and deformation properties), together with testing methods, must be specified to satisfy the functional requirements of the wall.

6.5 Concrete

6.5.1 General

Unless otherwise stated, the concrete used in cast in situ concrete diaphragm walls or in precast concrete diaphragm walls shall comply with ENV 206.

The following subclauses of this section apply to cast in situ concrete and deal only with the properties required for correct execution. The concrete shall be designed to avoid segregation during placing, to flow easily around the reinforcement, and when set, to provide a dense and watertight material. The specified properties of the hardened concrete, related to strength and durability, shall be compatible with the workability requirements.

6.5.2 Aggregates

In order to avoid segregation, the aggregates shall be well-graded. The maximum particle size shall not exceed 32 mm or 1/4 of the clear space between the longitudinal bars, whichever is the smaller.

In the case of a maximum aggregate size of 32 mm, the concrete mix shall have the following characteristics :

— sand content greater than 40 % by weight of the total aggregate ;

— silt size particles in the concrete mix (including cement and other fine materials) between 400 kg/m^3 and 550 kg/m^3. These particles are those between 2 µm and 63 µm and they include cement and other fine materials.

6.5.3 Cement

The minimum cement content shall be related to the maximum aggregate size in accordance with Table 2 .

Part of the cement can be replaced by additions such as pulverized fuel ash (PFA) or ground granulated blast furnace slag (GGBFS).

Table 2 — Minimum cement content

Maximum grain size (mm)	Minimum cement content (kg/m^3)
32	350
25	370
20	385
16	400

6.5.4 Water/cement ratio

The water/cement ratio should not exceed 0,6.

This value may have to be modified if additions are included in the mix.

6.5.5 Admixtures

In order to ensure that the concrete has the properties required for placing by concreting pipes, admixtures may be used as follows :

— water reducing and plasticizing admixtures including superplasticizers to avoid bleeding or segregation which might occur in some situations ;

— retarding admixtures to prolong the workability as required for the duration of the concreting process and to cater for any interruptions.

6.5.6 Fresh concrete

The consistency of the fresh concrete just before concreting shall correspond to a slump value between 160 mm and 220 mm. A value between 180 mm and 210 mm is recommended.

The flow table test may be used instead of the slump test. In this case, the consistency of the fresh concrete just before placing shall correspond to a flow value between 520 mm and 630 mm. A value between 550 mm and 600 mm is recommended.

6.6 Plastic concrete or plastic mortar

Plastic concretes or mortars are used for cut-off walls when, in addition to low permeability, high deformability is required. Their constituent parts are :

— clay or bentonite ;

— cement or another binder ;

— well-graded aggregates ;

— additives ;

— water ;

— and possibly additions and admixtures.

The term "plastic mortar" applies when the size of the aggregates is limited to that of sand. The mix shall be designed in order to obtain the required deformability and permeability, together with adequate workability and strength.

Typical compositions for plastic concrete and plastic mortar using bentonite, are given in annex A.

6.7 Steel

The reinforcement steel used in diaphragm walls shall comply with EN 10080. Unless special precautions are taken, other metallic elements used in cast in situ diaphragm walls, such as tubes, plates, connectors, etc. shall not be made of galvanized steel or other metals which may produce electrostatic effects resulting in a buildup of bentonite cake or may cause electrochemical corrosion of the reinforcement.

7 Design considerations

7.1 General

The terminology used to define the dimensions and details of panels is shown on Figures 1 and 2.

Design shall take into account tolerances given in 8.2.

The panel dimensions should take into account the dimensions of available excavating equipment, the method and sequence of excavating, panel stability during excavation and concrete supply, as well as the appropriate information in clause 4.

The design wall thickness is equal to the width of the excavating tool. A larger wall thickness may be taken into account provided it is justified by site measurements.

The panels shall be designed as vertical elements, normally with the same horizontal cross-section throughout their depth. In some cases, the horizontal cross-section may be reduced below a certain depth.

The design of the wall shall take into account the discontinuity of the reinforcement at the joints between the panels and between adjacent cages in the same panel. Sufficient space shall be allowed between reinforcement cages of adjacent panels to accommodate the type of joints to be made and to take account of the construction tolerances.

A reinforced concrete capping beam is usually constructed along the top of reinforced concrete diaphragm walls, where it is necessary to distribute loads or minimize differential displacements. In rare cases where it is necessary to provide structural continuity across the joints, special techniques are available.

7.2 Panel stability during excavation

The length of the panels shall be such as to ensure the stability of the trench during excavation.

The trench stability during excavation includes two aspects :

— the stability of the soil grains at the walls of the trench ;

— the overall stability of the excavation.

The trench remains stable as a result of the stabilizing forces of the supporting fluid acting against the walls of the trench. In the case of bentonitic suspensions, the supporting effect in fine-grained soils is due to the formation of a filter cake. In coarser soils, this effect is caused by stagnation of the bentonitic suspension after a limited penetration into the pores of the soil. In the case of polymer solutions, the supporting effect is caused by the seepage pressure of the liquid flowing into the soil. The penetration depth, which increases with time, is significant in the case of silty or sandy soils, but remains small in the case of clayey soils.

The main factors affecting the stability which can be controlled during the execution are :

- the properties of the supporting fluid ;
- the level of the supporting fluid ;
- the length of the panels ;
- the time during which the trench is left open, relative to the soil and groundwater conditions (possible loss of shear strength of the soil with time).

The excavation tools or procedures, especially where chiselling or blasting are used, may have an influence on the stability of the trench.

The stability of the trench shall be determined on the basis of comparable experience, stability calculations, or trial excavation(s) on site. When the comparable experience is considered to be insufficient, the second or third option shall be adopted.

Comparable experience is defined as experience which relates to similar works in similar conditions. In particular, the following items shall be considered in the comparison :

- soil and rock properties ;
- groundwater pressures ;
- adjacent structures ;
- construction methods.

This experience shall be well documented or otherwise clearly established. Experience gained locally is considered to be particularly relevant.

The stability calculations shall take account of the following factors :

- stabilizing forces due to the supporting fluid ;
- groundwater pressures ;
- earth pressures, including the three-dimensional geometry of the problem ;
- shear strength parameters of the soils ;
- effects of adjacent loads.

In the case of trial excavation(s), an adequate safety margin shall be allowed in the design of the diaphragm wall trench.

The level of the supporting fluid shall be adjusted with respect to the highest piezometric level anticipated during excavation, and shall always remain at least 1 m above the highest piezometric level.

In the case of very soft soils, it may be necessary to raise the level of the supporting fluid and/or to increase its density during excavation, and to minimize the time during which the trench is left open.

In the case of highly permeable, coarse soils or where there are voids in the ground, loss of supporting fluid may occur and, as a consequence, special measures should be adopted, for example :

- increasing the shear strength of the fluid by increasing the bentonite content in the suspension ;
- adding a filler material to the bentonite suspension, either at the mixing plant or directly in the trench ;
- in the case of voids, filling the trench to an appropriate depth with lean mix concrete or other suitable material, and re-excavating ;

— grouting the layers concerned before excavating the trench.

7.3 Socketting into rock

Where diaphragm walls are required to be socketted into bedrock, the following shall be taken into account in the design :

— the function of the wall ;

— the properties of the rock such as strength, structure (fissuring, bedding, etc.), degree of weathering, and possibly permeability ;

— the slope of the rock surface both in transverse and longitudinal directions of the diaphragm wall ;

— the ability to penetrate the rock with the tools to be used.

The design may need to include special solutions such as :

— variable depths along the base of individual panels or between panels ;

— doweling into the rock at the base of panels with steel bars, tubes, beams, etc.;

— base grouting.

7.4 Reinforcement cages

7.4.1 General

This subclause applies to reinforcement cages inserted into cast in situ concrete diaphragm walls, where reinforcement is required by the design.

The reinforcement within a panel may comprise one or more cages within the panel length.

The design of the reinforcement cage(s) shall be made in accordance with ENV 1992. The design shall provide not only adequate strength for the final wall, but also adequate strength and stiffness during construction, in particular for the handling and concreting phases. It shall also allow the fresh concrete to flow easily around each of its components.

The vertical length of a reinforcement cage shall be such that the distance between its base and the bottom of the excavation is at least 0,2 m.

The reinforcement cage shall include :

— vertical reinforcement, usually arranged in either one or two layers on each face of the wall ;

— horizontal reinforcement in the form of links, stirrups or other suitable shapes ;

— suspension and lifting bars.

and when necessary :

— special reinforcement for anchors, props or other structural elements connected with the diaphragm wall ;

— bracing bars to improve the stiffness of the cage for the handling operations ;

— formwork for recesses or tubes for anchors, services ... ;

— vertical tubes for grouting, dowel bars, control tests, etc..

In the case of welding, only electric welding is permitted, provided that the steel quality is suitable.