

Eurocode 3 — Design of steel structures —

Part 5: Piling

ICS 91.010.30; 91.080.10

National foreword

This British Standard is the UK implementation of EN 1993-5:2007, incorporating corrigendum May 2009. It partially supersedes BS 449-2:1969 and BS 5950-1:2000, which will be withdrawn by March 2010.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by CEN corrigendum May 2009 is indicated in the text by **AC1** **AC1**.

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials: concrete, steel, composite concrete and steel, timber, masonry and aluminium; this is to enable a common date of withdrawal (DOW) for all the relevant parts that are needed for a particular design. The conflicting national standards will be withdrawn at the end of the coexistence period, after all the EN Eurocodes of a package are available.

Following publication of the EN, there is a period allowed for national calibration during which the National Annex is issued, followed by a coexistence period of a maximum 3 years. During the coexistence period Member States are encouraged to adapt their national provisions. Conflicting national standards will be withdrawn by March 2010 at the latest.

The UK participation in its preparation was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/31.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Where a normative part of this EN allows for a choice to be made at the national level, the range and possible choice will be given in the normative text, and a note will qualify it as a Nationally Determined Parameter (NDP). NDPs can be a specific value for a factor, a specific level or class, a particular method or a particular application rule if several are proposed in the EN.

To enable EN 1993-5 to be used in the UK, the NDPs will be published in a National Annex, which will be made available by BSI in due course, after public consultation has taken place.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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English Version

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Eurocode 3 - Calcul des structures en acier - Partie 5:
Pieux et palplanches

Eurocode 3 - Bemessung und Konstruktion von
Stahlbauten - Teil 5: Pfähle und Spundwände

This European Standard was approved by CEN on 12 June 2006.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

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Contents

Page

Foreword	4
1 General	7
1.1 Scope	7
1.2 Normative references	8
1.3 Assumptions	8
1.4 Distinction between principles and application rules	9
1.5 Definitions	9
1.6 Symbols	9
1.7 Units	10
1.8 Terminology	11
1.9 Convention for sheet pile axes.....	19
2 Basis of design	20
2.1 General	20
2.2 Ultimate limit state criteria	20
2.3 Serviceability limit state criteria	21
2.4 Site investigation and soil parameters	21
2.5 Analysis	22
2.6 Design assisted by testing.....	23
2.7 Driveability	24
3 Material properties.....	25
3.1 General	25
3.2 Bearing piles	25
3.3 Hot rolled steel sheet piles.....	25
3.4 Cold formed steel sheet piles.....	25
3.5 Sections used for waling and bracing	26
3.6 Connecting devices.....	26
3.7 Steel members used for anchors	26
3.8 Steel members used for combined walls	26
3.9 Fracture toughness.....	27
4 Durability	28
4.1 General	28
4.2 Durability requirements for bearing piles.....	29
4.3 Durability requirements for sheet piling.....	30
4.4 Corrosion rates for design.....	30
5 Ultimate limit states.....	32
5.1 Basis	32
5.2 Sheet piling	32
5.3 Bearing piles	46
5.4 High modulus walls	48
5.5 Combined walls	49
6 Serviceability limit states	52
6.1 Basis	52
6.2 Displacements of retaining walls.....	52
6.3 Displacements of bearing piles	52
6.4 Structural aspects of steel sheet piling.....	52
7 Anchors, walings, bracing and connections	54
7.1 General	54

7.2	Anchorage	54
7.3	Walings and bracing	56
7.4	Connections	56
8	Execution	64
8.1	General	64
8.2	Steel sheet piling	64
8.3	Bearing piles	64
8.4	Anchorage	64
8.5	Walings, bracings and connections	64
A	[normative] - Thin walled steel sheet piling	65
A.1	General	65
A.2	Basis of design	66
A.3	Properties of materials and cross-sections	66
A.4	Local buckling	70
A.5	Resistance of cross-sections	72
A.6	Design by calculation	76
A.7	Design assisted by testing	77
B	[informative] - Testing of thin walled steel sheet piles	79
B.1	General	79
B.2	Single span beam test	79
B.3	Intermediate support test	80
B.4	Double span beam test	81
B.5	Evaluation of test results	82
C	[informative] - Guidance for the design of steel sheet piling	84
C.1	Design of sheet pile cross section at ultimate limit state	84
C.2	Serviceability limit state	87
D	[informative] - Primary elements of combined walls	89
D.1	I-sections used as primary elements	89
D.2	Tubular piles used as primary elements	91

Foreword

This European Standard EN 1993-5, “Eurocode 3: Design of steel structures: Part 5 Piling”, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

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 August 2007, and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-5:1998.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom..

Background to the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980's.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement¹ between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links de facto the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN 1990	Eurocode: Basis of structural design
EN 1991	Eurocode 1: Actions on structures
EN 1992	Eurocode 2: Design of concrete structures
EN 1993	Eurocode 3: Design of steel structures
EN 1994	Eurocode 4: Design of composite steel and concrete structures
EN 1995	Eurocode 5: Design of timber structures
EN 1996	Eurocode 6: Design of masonry structures
EN 1997	Eurocode 7: Geotechnical design
EN 1998	Eurocode 8: Design of structures for earthquake resistance
EN 1999	Eurocode 9: Design of aluminium structures

¹ Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of Eurocodes

The Member States of the EU and EFTA recognise that Eurocodes serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 – Mechanical resistance and stability - and Essential Requirement N°2 - Safety in case of fire;
- as a basis for specifying contracts for construction works and related engineering services;
- as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents² referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standard³. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving a full compatibility of these technical specifications with the Eurocodes. The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National Annex (informative).

The National Annex (informative) may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e.:

- values for partial factors and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- geographical and climatic data specific to the Member State, e.g. snow map,
- the procedure to be used where alternative procedures are given in the Eurocode,
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

2 According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for hENs and ETAGs/ETAs.

3 According to Art. 12 of the CPD the interpretative documents shall:

- (a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary;
- (b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc.;
- (c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.

The Eurocodes, de facto, play a similar role in the field of the ER 1 and a part of ER 2.

Links between Eurocodes and product harmonised technical specifications (ENs and ETAs)

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works⁴. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

Additional information specific to EN 1993-5

EN 1993-5 gives design rules for steel sheet piling and bearing piles to supplement the generic rules in EN 1993-1.

EN 1993-5 is intended to be used with Eurocodes EN 1990 - Basis of design, EN 1991 - Actions on structures and Part 1 of EN 1997 Geotechnical Design.

Matters that are already covered in those documents are not repeated.

EN 1993-5 is intended for use by

- committees drafting design related product, testing and execution standards,
- clients (e.g. for the formulation of their specific requirements)
- designers and constructors
- relevant authorities.

Numerical values for partial factors and other parameters are recommended as basic values that provide an acceptable level of safety. They have been selected assuming that an appropriate level of workmanship and quality management applies.

Annex A and Annex B have been prepared to complement the provisions of EN 1993-1-3 for class 4 steel sheet piles.

Annex C gives guidance on the plastic design of steel sheet pile retaining structures.

Annex D gives one possible set of design rules for primary elements of combined walls.

Reference should be made to EN 1997 for geotechnical design which is not covered in this document.

National Annex for EN 1993-5

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-5 should have a National Annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1993-5 through clauses:

3.7 (1)	5.2.2 (13)	7.2.3 (2)
3.9 (1)P	5.2.5 (7)	7.4.2 (4)
4.4 (1)	5.5.4 (2)	A.3.1 (3)
5.1.1 (4)	6.4 (3)	B.5.4 (1)
5.2.2 (2)	7.1 (4)	D.2.2 (5)

⁴ See Art. 3.3 and Art. 12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

1 General

1.1 Scope

- (1) Part 5 of EN 1993 provides principles and application rules for the structural design of bearing piles and sheet piles made of steel.
- (2) It also provides examples of detailing for foundation and retaining wall structures.
- (3) The field of application includes:
 - steel piled foundations for civil engineering works on land and over water;
 - temporary or permanent structures needed to carry out steel piling work;
 - temporary or permanent retaining structures composed of steel sheet piles, including all kinds of combined walls.
- (4) The field of application excludes:
 - offshore platforms;
 - dolphins.
- (5) Part 5 of EN 1993 also includes application rules for steel piles filled with concrete.
- (6) Special requirements for seismic design are not covered. Where the effects of ground movements caused by earthquakes are relevant see EN 1998.
- (7) Design provisions are also given for walings, bracing and anchorages, see section 7.
- (8) The design of steel sheet piling using class 1, 2 and 3 cross-sections is covered in sections 5 and 6, whereas the design of class 4 cross-sections is covered in annex A.

NOTE: The testing of class 4 sheet piles is covered in annex B.

- (9) The design procedures for crimped U-piles and straight web steel sheet piles utilise design resistances obtained by testing. Reference should be made to EN 10248 for testing procedures.
- (10) Geotechnical aspects are not covered in this document. Reference is made to EN 1997.
- (11) Provisions for taking into account the effects of corrosion in the design of piling are given in section 4.
- (12) Allowance for plastic global analysis in accordance with 5.4.3 of EN 1993-1-1 is given in 5.2.

NOTE: Guidance for the design of steel sheet pile walls allowing for plastic global analysis is given in Annex C.

- (13) The design of combined walls at ultimate limit states is covered in section 5 including general provisions for the design of primary elements.

NOTE: Guidance for the design of both tubular piles and I-sections used as primary elements is given in Annex D.

1.2 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 1990	Eurocode:	Basis of structural design
EN 1991	Eurocode 1:	Actions on structures
EN 1992	Eurocode 2:	Design of concrete structures
EN 1993	Eurocode 3:	Design of steel structures
	Part 1.1:	General rules: General rules and rules for buildings;
	Part 1.2:	General rules: Structural fire design;
	Part 1.3:	General rules: Supplementary rules for cold formed thin gauge members and sheeting;
	Part 1.5:	General rules: Plated structural elements;
	Part 1.6:	General rules: Strength and stability of shell structures
	Part 1.8:	General rules: Design of joints
	Part 1.9:	General rules: Fatigue
	Part 1.10:	General rules: Material toughness and through-thickness properties
	Part 1.11:	General rules: Design of structures with tension components made of steel
EN 1994	Eurocode 4:	Design of composite steel and concrete structures
EN 1997	Eurocode 7:	Geotechnical design
EN 1998	Eurocode 8:	Earthquake resistant design of structures;
EN 10002		Metallic materials; tensile testing;
EN 10027		Designation systems for steel;
EN 10210		Hot finished structural hollow sections of non-alloy fine grain structural steels;
EN 10219		Cold formed structural hollow sections of non-alloy fine grain structural steels;
EN 10248		Hot rolled sheet piling of non alloy steels;
EN 10249		Cold formed sheet piling of non alloy steels;
EN 1536		Execution of special geotechnical work - Bored piles;
EN 1537		Execution of special geotechnical work - Ground anchors;
EN 12063		Execution of special geotechnical work - Sheet-pile walls;
EN 12699		Execution of special geotechnical work - Displacement piles;
EN 14199		Execution of special geotechnical work - Micro piles;
EN 10045		Metallic materials; Charpy impact test;
EN 1090-2		Execution of steel structures and aluminium structures, Part 2: Technical requirements for steel structures.

1.3 Assumptions

- (1) In addition to the general assumptions in EN 1990 the following assumptions apply:

Installation and fabrication of steel piles and steel sheet piles are in accordance with EN 12699, EN 14199 and EN 12063.

1.4 Distinction between principles and application rules

(1)P Reference shall be made to 1.4 of EN 1990.

1.5 Definitions

For the purpose of this standard, the following definitions apply:

1.5.1 foundation: Part of a construction work including piles and possibly their pile cap.

1.5.2 retaining structure: A construction element including walls retaining soil, similar material and/or water, and, where relevant, their support systems (e.g. anchorages).

1.5.3 soil-structure interaction: The mutual influence of deformations on soil and a foundation or a retaining structure.

1.6 Symbols

(1) In addition to those given in EN 1993-1-1, the following main symbols are used:

c Slant height of the web of steel sheet piles, see Figure 5-1;

α Inclination of the web, see Figure 5-1.

(2) In addition to those given in EN 1993-1-1, the following subscripts are used:

red Reduced.

(3) In addition to those given in EN 1993-1-1, the following major symbols are used:

A_v Projected shear area, see Figure 5-1;

F_{Ed} Design value of the anchor force;

$F_{Q,Ed}$ Additional horizontal force resulting from global buckling to be resisted by the toe of a sheet pile to allow for the assumption of a non-sway buckling mode, see Figure 5-4;

$F_{t,Rd}$ Design tension resistance of an anchor;

$F_{t,Ed}$ Design value of the circumferential tensile force in a cellular cofferdam;

$F_{t,ser}$ Axial force in an anchor under characteristic loading;

$F_{ta,Ed}$ Design tensile force in the arc cell of a cellular cofferdam;

$F_{tc,Ed}$ Design tensile force in the common wall of a cellular cofferdam;

$F_{tg,Rd}$ Design tensile resistance of shafts of anchors;

$F_{tm,Ed}$ Design tensile force in the main cell of a cellular cofferdam;

- $F_{ts,Rd}$ Design tensile resistance of simple straight web steel sheet piles;
- $F_{tt,Rd}$ Design tensile resistance of threads of anchors;
- $R_{c,Rd}$ Design resistance of a sheet pile to a local transverse force;
- $R_{tw,Rd}$ Design tensile resistance of the webs of a sheet pile to the introduction of a local transverse force;
- $R_{Vf,Rd}$ Design shear resistance of the flange of a sheet pile to the introduction of a local transverse force;
- $p_{m,Ed}$ Design value of the internal pressure acting in the main cell of a cellular cofferdam;
- r_a Initial radius of the arc cell in a cellular cofferdam;
- r_m Initial radius of the main cell in a cellular cofferdam;
- t_f Nominal flange thickness of a steel sheet pile;
- t_w Nominal web thickness of steel sheet piles;
- β_B Factor accounting for the possible reduction of the section modulus of U-piles due to insufficient shear force transmission in the interlocks;
- β_D Factor accounting for the possible reduction of the bending stiffness of U-piles due to insufficient shear force transmission in the interlocks;
- β_R Factor accounting for the interlock resistance of straight web steel sheet piles;
- β_T Factor accounting for the behaviour of a welded junction pile at ultimate limit states;
- $\beta_{o,I}$ Factor accounting for the reduction of the second moment of area about the wall axis due to the ovalisation of the tube;
- ρ_P Factor accounting for the effects of differential water pressure on transverse local plate bending.

(4) Further symbols are defined where they first occur.

1.7 Units

- (1) S.I. units should be used in accordance with ISO 1000.
- (2) The following units are recommended for use in calculations:
- forces and loads: kN, kN/m, kN/m²;
 - unit mass: kg/m³;
 - unit weight: kN/m³;
 - stresses and strengths: N/mm² (MN/m² or MPa);
 - bending moments: kNm;
 - torsional moments: kNm.

1.8 Terminology

For the purposes of this Standard, the following terminology is used:

NOTE: Figure 1-1 to Figure 1-10 are only examples and are provided in order to enhance the understanding of the wording of the terminology used. The examples are by no means exhaustive and they do not represent any preferred detailing.

1.8.1 Anchorage

The general expression used to describe the anchoring system at the back of a retaining wall, such as dead-man anchors, anchor plates or anchor screens, screw anchors, ground anchors, anchor piles and expanded bodies. Examples of connections between anchors and a sheet pile wall are shown in Figure 1-1.

1.8.2 Anchored wall

A wall whose stability depends upon penetration of the sheet piling into the ground and also upon one or more anchor levels.

1.8.3 Bearing piles

Structural elements (hollow type, H-type, cruciform or X-type cross-sections) incorporated into the foundations of building or civil engineering works and used for resisting axial compressive or tensile forces, moments and transverse (shear) forces (see Table 1-1). The bearing resistance is achieved by base resistance or shaft friction or a combination of both.

1.8.4 Bracing

Struts perpendicular or at an angle to the front face of a retaining wall, supporting the wall and usually connected to the walings (see Figure 1-2).

1.8.5 Cantilever wall

Wall whose stability depends solely upon the penetration of the sheet piling into the ground.

1.8.6 Cellular cofferdams

Cofferdams constructed of straight web profiles with interlock tensile strength sufficient to resist the circumferential tension developed in the cellular walls due to the radial pressure of the contained fill (see Figure 1-3). The stability of these cells is obtained by the self-weight of the fill. Two basic types of cellular cofferdams are:

- Cellular cofferdams involving circular cells: This type of cofferdam consists of individual cells of large diameter connected together by arcs of smaller diameter (see Figure 1-4a);
- Cellular cofferdams involving diaphragm cells: This type of cofferdam consists of two rows of circular arcs connected together by diaphragms perpendicular to the axis of the cofferdam (see Figure 1-4b).

1.8.7 Combined walls

Retaining walls composed of primary and secondary elements. The primary elements are normally steel tubular piles, I-sections or built up box types, spaced uniformly along the length of the wall. The secondary elements are generally steel sheet piles of various types installed in the spaces between the primary elements and connected to them by interlocks (see Figure 1-5).

1.8.8 Double U-pile

Two threaded single U sheet piles with a crimped or welded common interlock allowing for shear force transmission.

1.8.9 Driveability

The ability of a sheet pile or bearing pile to be driven through the ground strata to the required penetration depth without detrimental effects.

1.8.10 Driving

Any method for installing a pile into the ground to the required depth, such as impact driving, vibrating, pressing or screwing or by a combination of these or other methods.

1.8.11 High modulus wall

A high strength retaining wall formed by interlocking steel elements that have the same geometry. The elements may consist of fabricated profiles, see Figure 1-6, to obtain a high section modulus.

1.8.12 Interlock

The portion of a steel sheet pile or other sheeting that connects adjacent elements by means of a thumb and finger or similar configuration to make a continuous wall. Interlocks may be described as

- Free: Threaded interlocks that are neither crimped nor welded;
- Crimped: Interlocks of threaded single piles that have been mechanically connected by crimped points;
- Welded: Interlocks of threaded single piles that have been mechanically connected by continuous or intermittent welding.

1.8.13 Jagged wall

Special sheet pile wall configuration in which the single piles are arranged either to enhance the moment of inertia of the wall (see example in Figure 1-7) or to suit special applications (see example in Figure 1-8).

1.8.14 Pile coupler

A mechanical friction sleeve used to lengthen a steel tubular or X shaped pile.

1.8.15 Propped wall

A retaining wall whose stability depends upon penetration of the sheet piling into the ground and also upon one or more levels of bracing.

1.8.16 Soldier or king pile wall

Soldier or king pile walls consist of vertical piles (king, master or soldier piles) driven at intervals, supporting intermediate horizontal elements (boarding, planks or lagging), see Figure 1-9. The king or master piles may be rolled or welded I-sections, tubular or box sections.

1.8.17 Steel box piles

Piles with a non-circular hollow shape formed from two or more hot-rolled sections continuously or intermittently welded together in longitudinal direction (see Table 1-1).

1.8.18 Steel tubular piles

Piles of circular cross-section formed by the seamless, longitudinal or helical welding processes (see Table 1-1).

1.8.19 Steel sheet pile

The individual steel elements of which a sheet pile wall is composed. The types of steel sheet piles covered in this Part 5 are given in Table 1-2: Z-shaped, U-shaped and straight web profiles, and in Table A-1 of

Annex A for cold formed sheet piling. The interlocks of the Z-piles are located on the extreme fibres of the wall, whereas the interlocks of U-shaped and straight web profiles are located on the axis of the retaining wall.

1.8.20 Steel sheet pile wall

The screen of sheet piles that forms a continuous wall by threading of the interlocks.

1.8.21 T-connection

Special element, see Figure 1-10, to connect two cellular cofferdams by arcs of smaller diameter, see Figure 1-3.

1.8.22 Triple U-pile

A sheet pile consisting of three threaded single U sheet piles with two crimped or welded common interlocks allowing for shear force transmission.

1.8.23 Waling

Horizontal beam, usually of steel or reinforced concrete, fixed to the retaining wall and used to transmit the design support force for the wall into the tie rods or struts.

Table 1-1: Examples of cross-sections of steel bearing piles

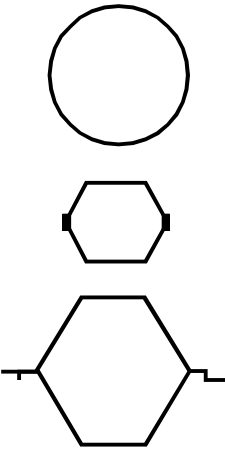
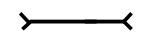
Type of cross-section	Representation
Hollow type (examples), <i>see Note</i>	
H type	
X type	
Note: Reference should be made to EN 12699 and EN 14199 for execution details.	

Table 1-2: Steel sheet piles

Type of cross-section	Single pile	Double pile
Z - profiles		
U - profiles		
Straight web profiles		
Note: Reference should be made to EN 10248 for details of the interlocks.		

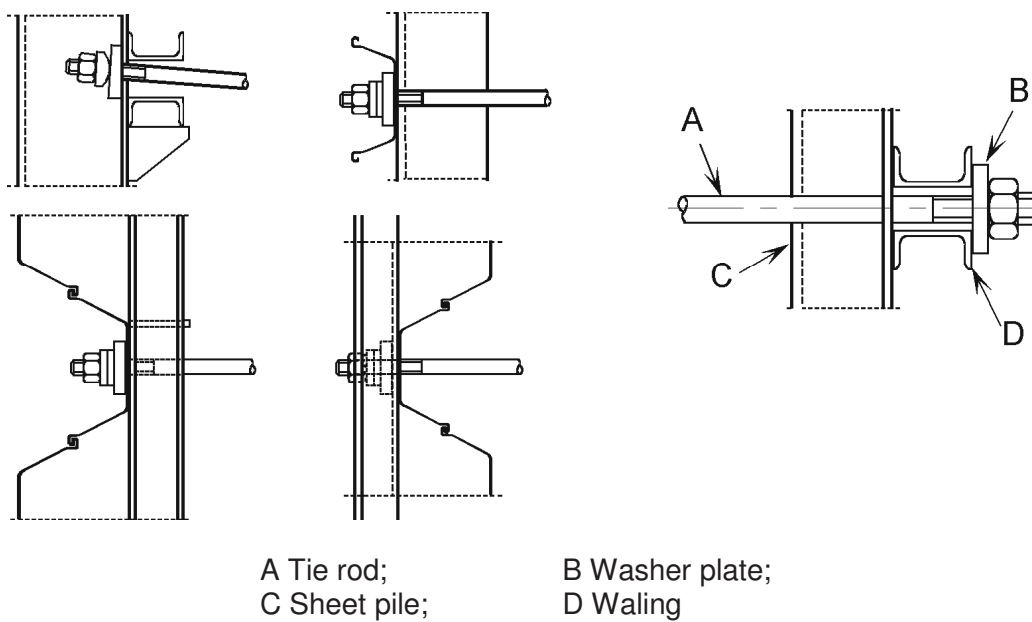
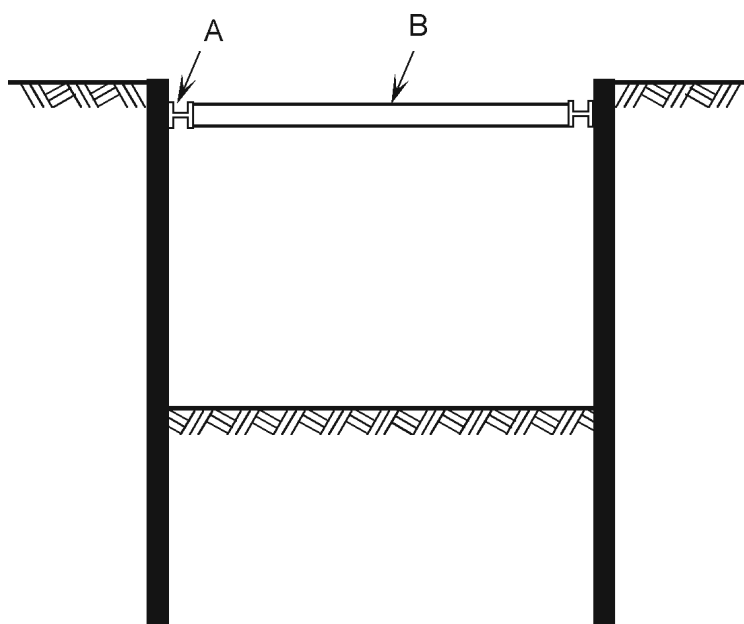
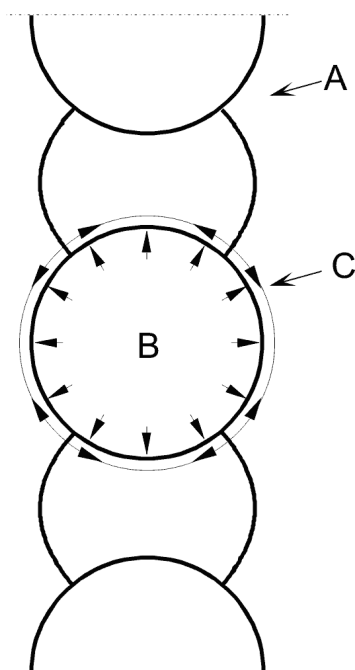


Figure 1-1: Examples of connections between anchors and sheet pile walls



A Waling; B Strut

Figure 1-2: Example of bracing



A T-junction;
B Internal pressure;
C Circumferential tensile force

Figure 1-3: Cellular cofferdams

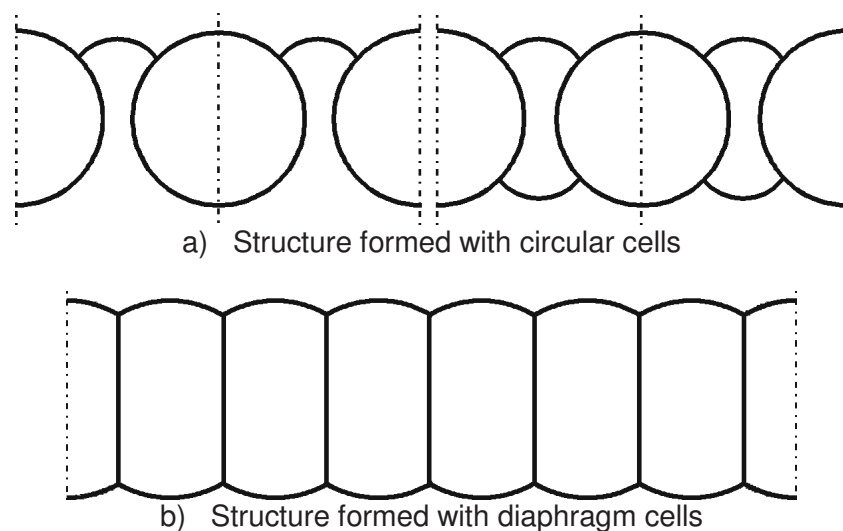


Figure 1-4: Examples of cellular structures

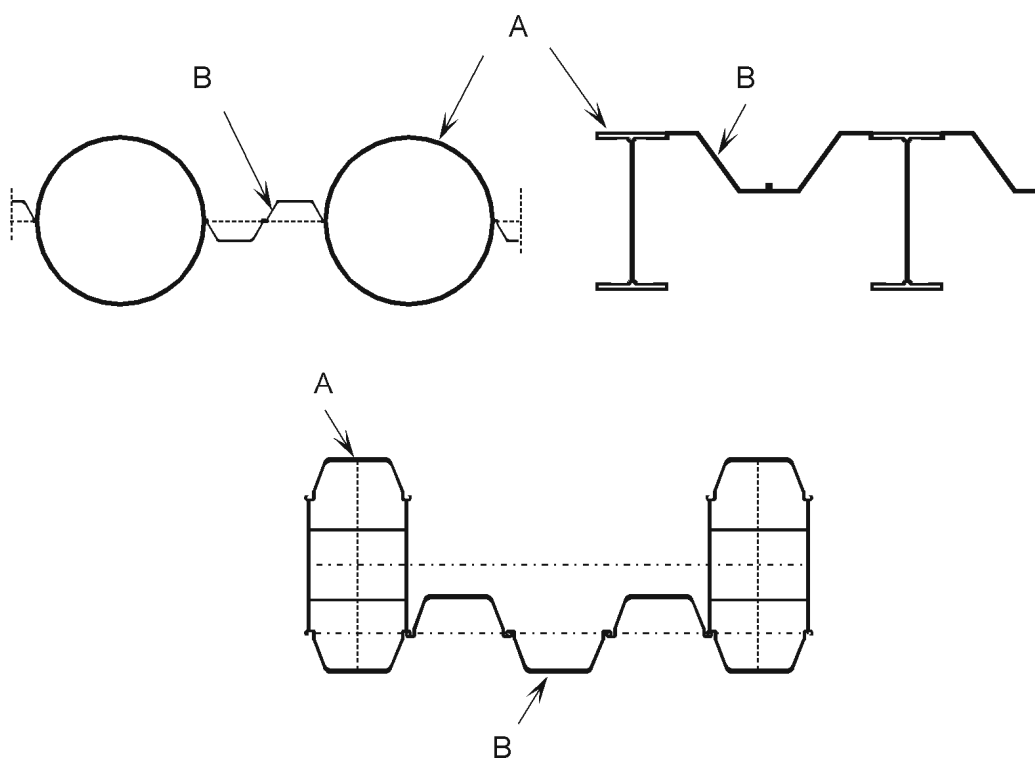
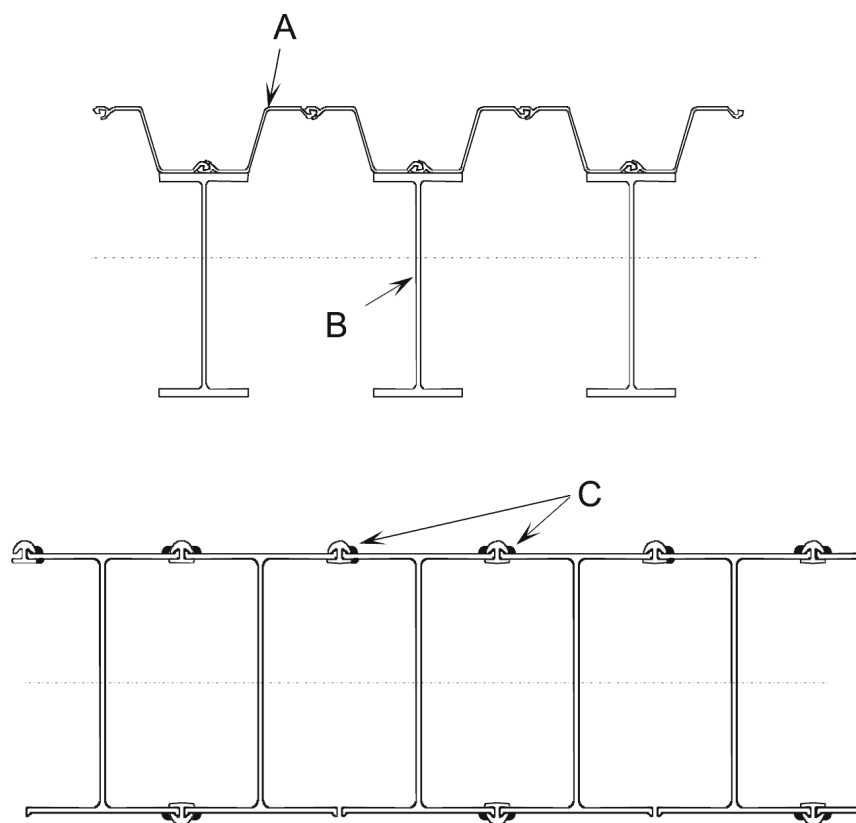
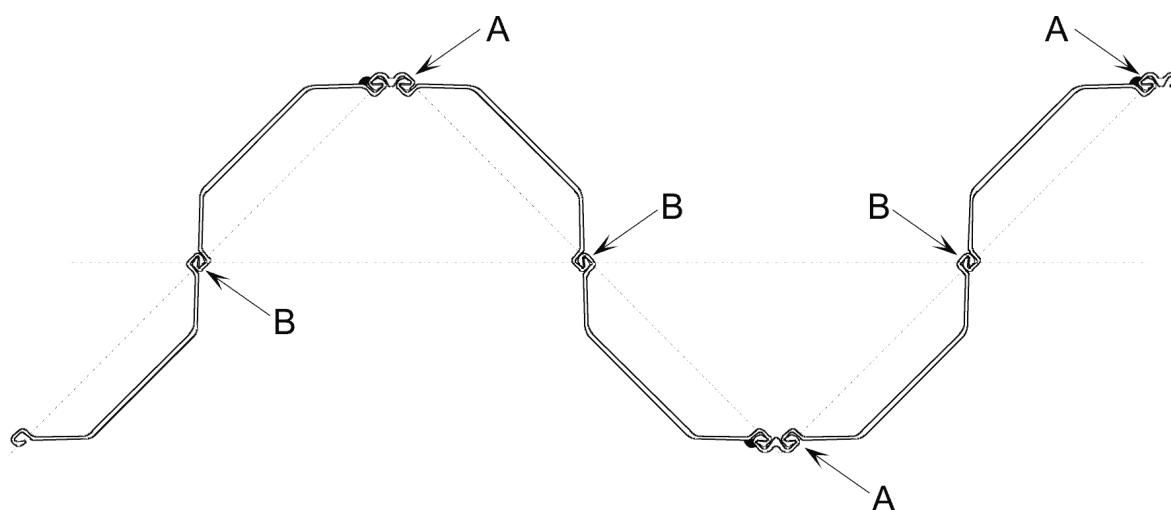


Figure 1-5: Examples of combined walls



A Sheet pile welded to I-Section;
B I-section;
C Connector welded to I-Section

Figure 1-6: Examples of high modulus walls

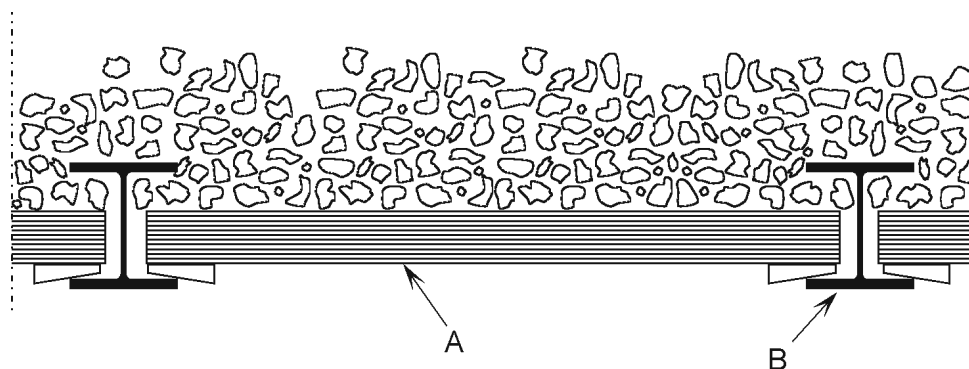


A Connector welded to one double pile; B Crimped Interlock

Figure 1-7: Example of a jagged wall formed from U-profiles



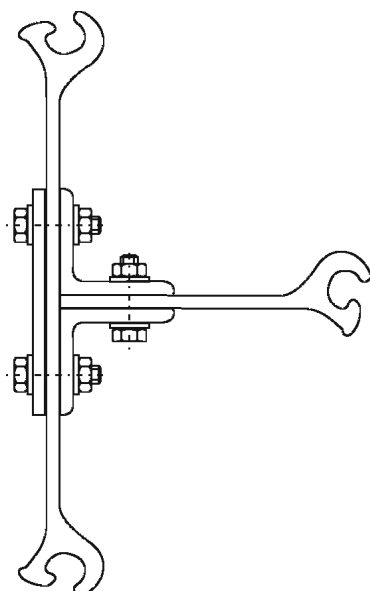
Figure 1-8: Example of a jagged wall formed from Z-profiles



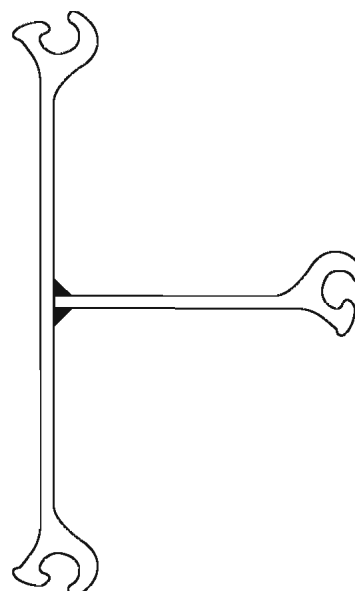
A Lagging, boarding, planks;

B Soldier, king or master pile

Figure 1-9: Example of a soldier pile wall



a) Bolted



b) Welded

Figure 1-10: Examples of T-connections

1.9 Convention for sheet pile axes

(1) For sheet piling the following axis convention is used:

- generally
 - $x - x$ is the longitudinal axis of a pile;
 - $y - y$ is the cross-sectional axis parallel to the retaining wall;
 - $z - z$ is the other cross-sectional axis;
- where necessary
 - $u - u$ is the principal axis nearest to the plane of the retaining wall if this does not coincide with the $y - y$ axis;
 - $v - v$ is the other principal axis if this does not coincide with $z - z$.

NOTE: This differs from the axis convention used in EN 1993-1-1. Care therefore needs to be taken when cross-reference is made to Part 1.1.

2 Basis of design

2.1 General

- (1)P For the design of bearing piles and sheet piling, including the design of walings, bracing and anchorages, the provisions of EN 1990 apply, except where different provisions are given in this document.
- (2) In the following, specific provisions are given for the design of bearing piles and sheet piling to fulfil the safety and durability requirements for both serviceability and ultimate limit states.
- (3) The bearing resistance of the ground should be determined according to EN 1997-1.
- (4)P All design situations, including each stage of execution and use, shall be taken into account, see EN 1990.
- (5) The driveability of bearing piles and sheet piles should be taken into account in the design of the structure, see 2.7.
- (6) The provisions given in this document apply equally to temporary and permanent structures, unless otherwise stated, see EN 1990.
- (7) In the following distinction is made between bearing piles and retaining walls where relevant.
- (8) For provisions regarding walings, bracing, connections and anchors, reference should be made to section 7.

2.2 Ultimate limit state criteria

- (1)P The following ultimate limit state criteria shall be taken into account:

- a) failure of the construction by failure in the soil (the soil resistance is exceeded);
- b) structural failure;
- c) combination of failure in the soil and structural failure.

NOTE: Failure of adjacent structures may be caused by deformations resulting from excavation. If adjacent structures are sensitive to such deformations, recommendations for dealing with the situation can be given for the project.

- (2) Verifications related to ultimate limit state criteria should be carried out in accordance with EN 1997-1.

- (3) Depending on the design situation the resistance to one or more of the following modes of structural failure should be verified:

- for bearing piles:
 - failure due to bending and/or axial force;
 - failure due to overall flexural buckling, taking account of the restraint provided by the ground and by the supported structure at the connections to it;
 - local failure at points of load application;

- fatigue.
- for retaining walls:
 - failure due to bending and/or axial force;
 - failure due to overall flexural buckling, taking account of the restraint provided by the soil;
 - local buckling due to overall bending;
 - local failure at points of load application (e.g. web crippling);
 - fatigue.

2.3 Serviceability limit state criteria

(1) Unless otherwise specified, the following serviceability limit state criteria should be taken into account:

- for bearing piles:
 - limits to vertical settlements or horizontal displacements necessary to suit the supported structure;
 - vibration limits necessary to suit structures directly connected to, or adjacent to, the bearing piles.
- for retaining walls:
 - deformation limits necessary to suit the serviceability of the retaining wall itself;
 - limits to horizontal displacements, vertical settlements or vibrations, necessary to suit structures directly connected to, or adjacent to, the retaining wall itself.

(2) Values for the limits given in (1), in relation to the combination of actions to be taken into account according to EN 1990, should be defined for each project.

(3) Where relevant, values for limits imposed by adjacent structures should be defined for the project. Guidance for determining such limits is given in EN 1997-1.

NOTE: Serviceability criteria may be the governing criteria for the design.

2.4 Site investigation and soil parameters

(1)P Parameters for soil and/or backfill shall be determined from geotechnical investigation in accordance with EN 1997.

2.5 Analysis

2.5.1 General

- (1) Global analysis should be carried out to determine the effects of actions (internal forces and moments, stresses, strains and displacements) over the whole or part of the structure. Additional local analyses of the structure should be carried out where necessary, e.g. load application points, connections etc.
- (2) Analyses may be carried out using idealisations of the geometry, behaviour of the structure and behaviour of the soil. The idealisations should be selected with regard to the design situation.
- (3) Except where the design is sensitive to the effects of variations, assessment of the effects of actions in piled foundations and in sheet pile walls may be carried out on the basis of nominal values of geometrical data.
- (4) Structural fire design should be taken into account through the provisions of EN 1993-1-2 and EN 1991-1-2.

2.5.2 Assessment of actions

- (1) Where relevant, actions should be taken from EN 1991, otherwise they should be defined for the project and agreed with the client.
- (2) In the case of piled foundations, actions due to vertical or transverse ground movements (e.g. down-drag, etc.) should be assessed in accordance with EN 1997-1.
- (3) The actions transmitted to the structure through the soil should be assessed by using models selected in accordance with EN 1997-1, or defined for the project and agreed with the client.
- (4) Where necessary, the effects of actions resulting from variations in temperature with time, or from special loads not specified in EN 1991, should be taken into account.

NOTE 1: It may be necessary to take into account temperature effects, for example on struts, if there are likely to be large variations in temperature. The design may prescribe measures to reduce the influence of temperature variations.

NOTE 2: Examples of special loads are:

- loads due to falling objects or swinging buckets;
- loads from excavators and cranes;
- imposed loads such as pumps, access ways, intermediate struts, staging for materials or stacking of bundles of steel reinforcement.

(5) Unless otherwise specified, for retaining walls subject to loads from a road or a railway track, simplified models for such loads (for example uniformly distributed loads) derived from those defined for bridges may be used, see EN 1991-2.

2.5.3 Structural analysis

2.5.3.1 General

- (1) The analysis of the structure should be carried out using a suitable soil-structure model in accordance with EN 1997-1.
- (2) Depending on the design situation, anchors may be modelled either as simple supports or as springs.
- (3) If connections have a major influence on the distribution of internal forces and moments, they should be taken into account in the structural analysis.

2.5.3.2 Ultimate limit states

- (1) The structural analysis of piled foundations for ultimate limit states may be based on the same type of model as used for serviceability limit states.
- (2) Where accidental situations need to be taken into account, the assessment of effects of actions in the piles in a foundation may be carried out on the basis of a plastic model, both for the whole structure and for the soil-structure interaction.

NOTE: An example of an accidental situation is a ship collision against a bridge pier.

- (3) Assessment of the effects of actions in sheet pile retaining walls should be carried out on the basis of the relevant failure mode for ultimate limit state verifications, using a soil structure interaction model as defined in 2.5.3.1 (1).

2.5.3.3 Serviceability limit states

- (1) For sheet pile retaining walls, and also for piled foundations, the global analysis should be based on a linear elastic model of the structure, and a soil-structure model as defined in 2.5.3.1(1).
- (2) It should be shown that no plastic deformations occur in the structure as a result of serviceability loading.

2.6 Design assisted by testing

2.6.1 General

- (1) The general provisions for design assisted by testing given in EN 1990, EN 1993-1-1 and EN 1997-1 should be satisfied.

NOTE: Guidance on the determination of design resistance from tests is given in Annex D of EN 1990.

2.6.2 Bearing piles

(1) For guidance on the testing of bearing piles, reference should be made to EN 1997-1, EN 12699 and EN 14199.

2.6.3 Steel sheet piling

(1) The assumptions made in the design of sheet piling may be verified in stages by on-site testing during execution of the work (for instance in the case of an excavation procedure).

(2) Reference should be made to EN 1997-1 for calibration of a calculation model and modification of the design during execution.

2.6.4 Anchorages

(1) The general provisions for design assisted by testing given in EN 1997-1, EN 1537 and EN 1993-1-11 should be followed for anchorages.

2.7 Driveability

(1)P In the design of all piles (bearing piles or sheet piles), the practical aspects of installing the piles to the required penetration depth shall be taken into account. Reference shall be made to EN 12063 and to EN 12699 and EN 14199.

(2) The type, size and detailing of the piles should be chosen, in combination with the effectiveness of the piling plant used for installation and extraction, and the driving procedure (driving parameters), to be suitable for the ground conditions through which the piles have to be driven.

(3) If pile points, stiffeners or friction reducers are used as an aid to driving or to strengthen the piles during installation, their effects on the performance of the piles under service conditions should be taken into account.

3 Material properties

3.1 General

(1)P This Part 5 of EN 1993 shall be used for the design of piles and retaining walls fabricated from steel conforming with the standards referred to in 3.2 to 3.9.

(2) This document may also be used for other structural steels, provided that adequate data exist to justify application of the relevant design and fabrication rules. Test procedures and test evaluation should conform with section 2 of EN 1993-1-1 and EN 1990 and the test requirements should align with those given in the relevant standards mentioned in 3.2 to 3.9.

(3)P Re-used and second quality piles shall as a minimum comply with the requirements concerning geometrical and material properties specified in the design and shall be free from damage and deleterious matters that would affect strength and durability.

3.2 Bearing piles

(1) Reference should be made to EN 1993-1-1 for steel properties.

(2) For the properties of steel piles fabricated from steel sheet piles see 3.3 or 3.4.

3.3 Hot rolled steel sheet piles

(1)P Hot rolled steel sheet piles shall be in accordance with EN 10248.

(2) Nominal values of the yield strength f_y and the ultimate tensile strength f_u for hot rolled steel sheet piles may be obtained from Table 3-1, which are the minimum values given in EN 10248-1.

(3) Reference should be made to 3.2.2 of EN 1993-1-1 for ductility requirements.

NOTE: The steel grades listed in Table 3-1 are accepted as satisfying these requirements.

Table 3-1: Nominal values of yield strength f_y and ultimate tensile strength f_u for hot rolled steel sheet piles according to EN 10248-1

Steel name to EN 10027	f_y [N/mm ²]	f_u [N/mm ²]
S240 GP	240	340
S270 GP	270	410
S320 GP	320	440
S355 GP	355	480
S390 GP	390	490
S430 GP	430	510

3.4 Cold formed steel sheet piles

(1)P Cold formed steel sheet piles shall be in accordance with EN 10249.

(2) Nominal values for the basic yield strength f_{yb} and the ultimate tensile strength f_u for cold formed steel sheet piles may be obtained from Table 3-2 which is in accordance with EN 10249-1.

NOTE: The basic yield strength f_{yb} is the nominal yield strength of the basic steel used for cold forming.

(3) Reference should be made to A.3.1 for ductility requirements.

Table 3-2: Nominal values of basic yield strength f_{yb} and ultimate tensile strength f_u for cold formed steel sheet piles according to EN 10249-1

Steel name to EN 10027	f_{yb} [N/mm ²]	f_u [N/mm ²]
S235 JRC	235	340
S275 JRC	275	410
S355 JOC	355	490

3.5 Sections used for waling and bracing

(1) Reference should be made to 3.1 and 3.2 of EN 1993-1-1 for properties of steels used for walings and bracing.

3.6 Connecting devices

(1) Reference should be made to EN 1993-1-8 for properties of bolts, nuts and washers and of welding consumables.

3.7 Steel members used for anchors

(1) Reference should be made to EN 1537 for anchors made from high strength steel with a specified minimum yield strength $f_{y,spec}$, which should not be higher than $f_{y,spec,max}$.

NOTE: The value $f_{y,spec,max}$ may be given in the National Annex. The value $f_{y,spec,max} = 500 \text{ N/mm}^2$ is recommended.

(2) Reference should be made to 3.2.1, 3.2.2 of EN 1993-1-1 and 3.9 of EN 1993-5 for the material properties of anchors made of non-high strength steel.

3.8 Steel members used for combined walls

(1)P Steel properties of special I-section piles used as the primary elements of combined walls shall be in accordance with EN 10248.

(2)P Tubes used as the primary elements in combined walls shall conform with EN 10210 or EN 10219.

(3) Steel properties of built up box piles used as the primary elements of combined walls should satisfy the requirements given in 3.2.

(4) Steel properties of the secondary elements used for combined walls should satisfy the requirements given in 3.3 or 3.4 respectively.

(5)P Hot rolled connecting devices for sheet piles shall be in accordance with EN 10248.

3.9 Fracture toughness

(1)P The material shall have sufficient toughness to avoid brittle fracture at the lowest service temperature expected to occur within the intended life of the structure.

NOTE: The lowest service temperature to be taken into account may be given in the National Annex.

(2) For sheet piling with a flange thickness not more than 25mm, steels with values of T_{27J} according to Table 3-3 may be used, provided that the lowest service temperature is not lower than -30°C .

NOTE 1: For other cases reference can be made to EN 1993-1-10.

NOTE 2: The T_{27J} value is the test temperature at which an impact energy $K_V(T) > 27$ Joule is required to fracture a Charpy-V-notch specimen. For the test see EN 10045.

Table 3-3: Test temperature T_{27J} for fracture toughness of steel piles

Yield strength f_y [N/mm^2]		240	270	320	355	390	430
Values of T_{27J}	for lowest service temperature of -15°C	35°	35°	35°	15°	15°	15°
	for lowest service temperature of -30°C	20°	20°	20°	0°	0°	0°

Notes:

- 1) If there are holes (e.g. for anchors) in a flange stressed in tension, the reduction of the cross-sectional resistance should be taken into account by using a reduced yield strength or an effective cross-sectional area.
- 2) These values have been calculated for a lowest service temperature and a flange thickness of not more than 25mm without taking into account dynamic effects. For a flange thickness $25 < t_f \leq 30$ mm the values given in the table for T_{27J} should be reduced by 5° for lowest service temperature of -15°C and by 10° for lowest service temperature of -30°C .
- 3) Higher toughness requirements may be necessary if driving of the piles is foreseen in hard soils at temperatures below -10°C .

4 Durability

4.1 General

(1)P Dependant upon the aggressiveness of the media surrounding the steel member, measures against corrosion effects shall be taken into account if substantial losses of steel thickness are to be expected.

(2) If corrosion is to be taken into account in the design by a reduction of thickness, reference should be made to 4.4.

(3) Consideration should be given to the following measures to prolong the life of the structure:

- the use of additional steel thickness as a corrosion allowance;
- statical reserve;
- the use of protective coatings (usually paints, grouting or galvanizing);
- the use of cathodic protection, with or without protective coatings;
- providing a concrete, mortar or grout protection in the zone of high corrosion.

(4) If the required design working life is longer than the duration of the protective effect of a coating, the loss of thickness occurring during the remaining design working life should be taken into account in serviceability limit state and ultimate limit state verifications.

NOTE 1: A combination of different protective measures may be useful to obtain a high design working life. The whole protective system can be defined taking into account the design of the structure and of the protective coating as well as the feasibility of inspection.

NOTE 2: Special care is necessary in areas where poorly isolated sources of direct current are likely to produce stray currents in the soil.

(5) The possibility that corrosion may not be uniform over the whole length of a pile may be taken into account, allowing an economic design to be achieved by selection of a moment distribution adapted to the corrosion distribution, see Figure 4-1.

(6) The required design working life for sheet piling and bearing piles should be given for each project.

(7) The loss of thickness due to corrosion may be neglected for a required design working life of less than 4 years, unless a different period is given for the project

(8) Corrosion protection systems should be defined for each project.