



BSI Standards Publication

Eurocode 3 — Design of steel structures

Part 5: Piling

National foreword

This British Standard is the UK implementation of EN 1993-5:2025. It supersedes BS EN 1993-5:2007, which will be withdrawn on 30 March 2028.

The UK participation in its preparation was entrusted to Technical Committee CB/203, Design & execution of steel structures.

A list of organizations represented on this committee can be obtained on request to its committee manager.

National choice is allowed in this standard where explicitly stated within notes. The National Annex to this standard contains the national choices to be used for buildings and civil engineering works constructed in the UK.

The first generation of EN Eurocodes was published between 2002 and 2007, with conflicting British Standards withdrawn in 2010. This document forms part of the second generation of EN Eurocodes.

The second generation of EN Eurocodes is expected to be published between 2023 and 2026. These documents are being published as soon as they are available. This is being done to enable users to prepare for the transition from the first generation to second generation of EN Eurocodes.

UK adoptions of the first generation of EN Eurocodes will be withdrawn by BSI on 30 March 2028. Until that date, the first generation documents should be considered as the applicable standards for buildings and civil engineering works constructed in the UK unless otherwise specified by the relevant authority or in the specification for a particular project.

This standard is intended to be used with its National Annex and other referenced documents, including other second generation Eurocodes, as an interdependent suite of documents.

While the use of provisions in this standard in conjunction with first generation Eurocodes is not precluded, it should be undertaken with care and should only be done when users are satisfied that it will not result in a lower level of reliability than the minimum level set in the first generation Eurocodes and associated UK National Annexes.

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Date

Text affected

English Version

Eurocode 3 - Design of steel structures - Part 5: Piling

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

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

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (EN 1993-5:2025) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

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 September 2027, and conflicting national standards shall be withdrawn at the latest by March 2028.

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

This document supersedes EN 1993-5:2007.

EN 1993-5:2025 includes the following significant technical changes with respect to EN 1993-5:2007:

- the methods for the structural analysis were harmonized with EN 1993-1-1 and summarized in a flowchart;
- the terminology for anchors and tension piles, their material properties and their durability have been clarified;
- design by FEM modelling has been included as a way for verification with requirements for particular use for piling;
- the classification of Z-piles has been updated;
- a new method for the design of semi-compact sections (Class 3) has been implemented for Z-, U-piles and tubular piles (Annex E);
- default values for reduction factors β_B and β_D taking into account lack of shear force transmission in the interlocks of U-piles have been introduced as NDP;
- rules on king piles of combined walls have been extended.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland,

Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom

0 Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of Parts:

- EN 1990 Eurocode — Basis of structural and geotechnical 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
- EN 19100 Eurocode 10 — Design of glass structures
- New parts are under development, e.g. Eurocode for design for fibre-polymer composite structures and design of tensioned membrane structures

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1993 (all parts)

EN 1993 (all parts) applies to the design of buildings and civil engineering works in steel. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EN 1990 – *Basis of structural and geotechnical design*.

EN 1993 (all parts) is concerned only with requirements for resistance, serviceability, durability and fire resistance of steel structures. Other requirements, e.g. concerning thermal or sound insulation, are not covered.

EN 1993 is subdivided in various parts:

EN 1993-1-1, *Eurocode 3 — Design of Steel Structures — Part 1-1: General rules and rules for buildings*;

EN 1993-1-2, *Eurocode 3 — Design of Steel Structures — Part 1-2: Structural fire design*;

EN 1993-1-3, *Eurocode 3 — Design of Steel Structures — Part 1-3: Cold-formed members and sheeting*;

NOTE Cold-formed hollow sections supplied according to EN 10219 (all parts) are covered in EN 1993-1-1.

EN 1993-1-4, *Eurocode 3 — Design of Steel Structures — Part 1-4: Stainless steel structures*;

EN 1993-1-5, *Eurocode 3 — Design of Steel Structures — Part 1-5: Plated structural elements*;

EN 1993-1-6, *Eurocode 3 — Design of Steel Structures — Part 1-6: Strength and stability of shell structures*;

EN 1993-1-7, *Eurocode 3 — Design of Steel Structures — Part 1-7: Plate assemblies with elements under transverse loads*;

EN 1993-1-8, *Eurocode 3 — Design of Steel Structures — Part 1-8: Joints*;

EN 1993-1-9, *Eurocode 3 — Design of Steel Structures — Part 1-9: Fatigue*;

EN 1993-1-10, *Eurocode 3 — Design of Steel Structures — Part 1-10: Material toughness and through-thickness properties*;

EN 1993-1-11, *Eurocode 3 — Design of Steel Structures — Part 1-11: Tension components*;

EN 1993-1-12, *Eurocode 3 — Design of Steel Structures — Part 1-12: Additional rules for steel grades up to S960*;

EN 1993-1-13, *Eurocode 3 — Design of Steel Structures — Part 1-13: Beams with large web openings*;

EN 1993-1-14, *Eurocode 3 — Design of Steel Structures — Part 1-14: Design assisted by finite element analysis*;

EN 1993-2, *Eurocode 3 — Design of Steel Structures — Part 2: Bridges*;

EN 1993-3, *Eurocode 3 — Design of Steel Structures — Part 3: Towers, masts and chimneys*;

EN 1993-4-1, *Eurocode 3 — Design of Steel Structures — Part 4-1: Silos*;

EN 1993-4-2, *Eurocode 3 — Design of Steel Structures — Part 4-2: Tanks*;

EN 1993-5, *Eurocode 3 — Design of Steel Structures — Part 5: Piling*;

EN 1993-6, *Eurocode 3 — Design of Steel Structures — Part 6: Crane supporting structures*;

EN 1993-7, *Eurocode 3 — Design of Steel Structures — Part 7: Sandwich panels* (under preparation).

All subsequent parts EN 1993-1-2 to EN 1993-1-14 treat general topics that are independent from the structural type like structural fire design, cold-formed members and sheeting, stainless steels, plated structural elements, etc.

All subsequent parts numbered EN 1993-2 to EN 1993-7 treat topics relevant for a specific structural type like steel bridges, towers, masts and chimneys, silos and tanks, piling, crane supporting structures, etc. EN 1993-2 to EN 1993-7 refer to the generic rules in EN 1993-1 and supplement, modify or supersede them, where relevant.

0.3 Introduction to EN 1993-5

EN 1993-5 gives design rules for steel sheet piling and bearing piles to supplement the generic rules in the parts of EN 1993-1. The focus in EN 1993-5 is on design rules that supplement, modify or supersede the equivalent provisions given in the parts of EN 1993-1.

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

0.4 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National annex for EN 1993-5

National choice is allowed in this document where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing EN 1993-5 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

When no national choice is given, the default choice given in this document is to be used.

When no national choice is made and no default is given in this document, the choice can be specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

National choice is allowed in EN 1993-5 through notes to the following clauses:

4.1.3(2)	4.6.1(2)	4.6.2(2) – 2 choices	5.2.6(1)
5.4.2(2)	6.4.1(1)	6.4.4(1)	7.4(3)
8.2(1)	8.2(2)	8.2(3)	8.3.1(2)
8.11.2(1)	9.4(4)		

National choice is allowed in EN 1993-5 on the application of the following informative annex:

Annex F

The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of EN 1993-5

(1) This document provides rules for the structural design of bearing piles and sheet piles made of steel.

(2) This document provides rules for the structural design of steel elements for foundations and retaining structures constructed using steel piles.

(3) This document is applicable to:

- steel piled foundations for civil engineering works on land and over water;
- temporary or permanent structures needed to carry out steel piling work;
- temporary and permanent retaining structures made of continuous steel piling.

(4) This document does not apply to:

- offshore platforms;
- dolphins;
- ground reinforcing elements.

NOTE Ground reinforcing elements include rock bolts, soil nails, sprayed concrete, wire mesh and facing elements.

(5) This document does not cover the following aspects:

- geotechnical design;
- seismic design.

NOTE 1 For geotechnical design, see EN 1997 (all parts).

NOTE 2 For the effects of ground movement caused by earthquakes, see EN 1998 (all parts).

(6) This document provides methods for design by calculation and for design assisted by testing.

1.2 Assumptions

(1) Unless specifically stated, EN 1990, EN 1991 (all parts), EN 1993-1 (all parts) and EN 1997 (all parts) apply.

(2) The design methods given in EN 1993-5 are applicable if

- the execution quality for steel piles is as specified in EN 12063, EN 12699, EN 14199; and
- the execution quality for associated steel elements (such as bracing, anchors, waling, etc.) is as specified in EN 1090-2, EN 1537; and
- the execution quality for concreting of bearing piles is as specified in EN 1536; and
- the construction materials and products used are as specified in the relevant parts of EN 1993 (all parts), or in the relevant material and product specifications.

(3) The methods for design by calculation apply only within the stated ranges of material properties and geometric proportions, for which sufficient experience and test evidence is available. These limitations do not apply to design assisted by testing.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. in 'should' clauses), permissions ('may' clauses), possibilities ('can' clauses), and in notes.

EN 1090-2, *Execution of steel structures and aluminium structures — Part 2: Technical requirements for steel structures*

EN 1536, *Execution of special geotechnical work — Bored piles*

EN 1537, *Execution of special geotechnical works - Ground anchors*

EN 1990:2023,¹ *Eurocode — Basis of structural and geotechnical design*

EN 1991 (all parts), *Eurocode 1 — Actions on structures*

EN 1992-1-1:2023, *Eurocode 2 - Design of concrete structures - Part 1-1: General rules and rules for buildings, bridges and civil engineering structures*

EN 1993, (all parts), *Eurocode 3 — Design of steel structures*

EN 1997 (all parts), *Eurocode 7 — Geotechnical design*

EN 10210 (all parts), *Hot finished steel structural hollow sections*

EN 10219 (all parts), *Cold formed welded steel structural hollow sections*

EN 10248 (all parts), *Hot-rolled steel sheet piles*

EN 10249 (all parts), *Cold formed steel sheet piling*

EN 12063, *Execution of special geotechnical work - Sheet pile walls, combined pile walls, high modulus walls*

EN 12699, *Execution of special geotechnical works - Displacement piles*

EN 14199, *Execution of special geotechnical works - Micropiles*

¹ As impacted by EN 1990:2023/prA1:2024.

3 Terms, definitions, symbols

3.1 Terms and definitions

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

NOTE Figures 3.1 to Figure 3.7 are only examples and are provided 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.

3.1.1 Terms and definitions for piles

3.1.1.1

bearing pile

pile that transmits forces to the ground either by compression through end bearing or by friction between the surface of the pile and the adjacent ground or a combination of both

Note 1 to entry: See examples in Figure 3.1 a).

3.1.1.2

box pile

non-circular hollow pile fabricated from any combination of sheet pile and plate continuously or intermittently welded together in longitudinal direction

Note 1 to entry: See Figure 3.1.

3.1.1.3

bracing

system of walings and struts to support the structure

Note 1 to entry: See examples of retaining walls shown in Figure 3.2.

3.1.1.4

cantilever wall

wall whose stability depends solely upon embedment of the piles (sheet piles, combi-wall or high-modulus wall) made of steel into the ground

Note 1 to entry: See Figure 3.2 a).

3.1.1.5

cellular structure

retaining structure whose stability depends upon the self weight of the fill

Note 1 to entry: These structures are typically constructed from straight web sheet piles with sufficient interlock resistance to resist the circumferential tension developed in the walls due to the radial pressure of the contained fill (see Figure 3.4).

3.1.1.6

circular cell wall

wall constructed of individual cellular structures connected by arcs of smaller diameter

Note 1 to entry: See Figure 3.3 e).

3.1.1.7**combined wall**

embedded retaining wall composed of connecting primary and secondary elements

Note 1 to entry: The primary elements are normally steel tubular piles, H-piles or 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 (see Figure 3.3 c)).

3.1.1.8**connector**

hot rolled or fabricated device that connects adjacent piles by means of a thumb and finger or similar configuration to make a continuous wall

Note 1 to entry: Connectors perform the same function as interlocks but are fabricated separately and not as an integral part of the pile.

3.1.1.9**diaphragm cell wall**

wall constructed of special cellular structures using two rows of circular arcs connected together by diaphragms perpendicular to the axis of the structure

Note 1 to entry: See Figure 3.3 f).

3.1.1.10**double U-pile**

two threaded single U-piles with shear connections

3.1.1.11**driveability**

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

3.1.1.12**driving**

method, or combination of methods, for installing a pile into the ground to the required depth

- EXAMPLE
- 1 impact
 - 2 vibrating
 - 3 pressing
 - 4 resonance
 - 5 screwing

3.1.1.13**foundation**

construction for transmitting forces to the supporting ground

3.1.1.14**ground structure interaction**

mutual influence of deformations on ground and a foundation or a retaining structure

3.1.1.15

high modulus wall

retaining wall formed by connecting primary steel elements that have the same geometry

Note 1 to entry: See Figure 3.3 b).

3.1.1.16

interlock

portion of a steel sheet pile that connects adjacent elements by means of a thumb and finger or similar configuration to make a continuous wall

Note 1 to entry: Interlocks can 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 to form a shear connection;
- welded: interlocks of threaded single piles that have been mechanically connected by continuous or intermittent partial penetration butt welds to form a shear connection.

3.1.1.17

jagged wall

special sheet pile wall configuration in which the single piles are arranged either to enhance the moment of inertia of the wall or to suit special applications

Note 1 to entry: See Figure 3.3 d).

3.1.1.18

junction pile

special element connecting primary and secondary cells or adjacent diaphragm cells

Note 1 to entry: See Figure 3.5 for examples for junction piles and Figures 3.3 e) and 3.3 f) for examples of pile configurations for retaining walls.

3.1.1.19

micropile

drilled pile which has a diameter smaller than 300 mm

Note 1 to entry: If not otherwise specified, all design provisions in this document relating to piles also apply to micropiles.

3.1.1.20

pile

slender structural member, substantially underground, intended to transmit forces from above ground and/or forces caused by retaining of soil, into load-bearing strata below the surface of the ground

3.1.1.21

pile coupler

mechanical sleeve used to lengthen a steel tubular pile

3.1.1.22

piled foundation

foundation that incorporates one or more piles

3.1.1.23**propped wall**

retaining wall whose stability depends upon embedment of piles into the ground and upon one or more levels of support

Note 1 to entry: See Figure 3.2 b). Support systems can include bracing, struts, props or floors.

3.1.1.24**reinforced shoulder**

transition zone between web and flange characterized by additional external material with a width b_s of at least 5 mm

3.1.1.25**retaining structure**

construction element including walls retaining ground, similar material and/or water, and, where relevant, their support systems (e.g. anchors)

3.1.1.26**shear connection**

any mode of connection preventing the relative displacement of piles at the interlocks when loaded

Note 1 to entry: Shear connections are typically fabricated by crimping or partial penetration butt welding the interlocks together. Shop crimping can be double or triple points. Shop or site welding can be continuous or intermittent.

3.1.1.27**sheet pile**

product obtained by hot rolling or cold forming steel to a shape such that, by interlocking of the joints or fitting of longitudinal grooves or by means of special fasteners, it forms partitions or continuous walls

Note 1 to entry: The types of steel sheet piles covered in this Part 5 are shown in Figure 3.1 b).

3.1.1.28**sheet pile wall**

line of sheet piles that forms a continuous wall by threading of the interlocks

Note 1 to entry: For typical examples see Figure 3.3.

3.1.1.29**soldier wall****Berlin wall**

wall composed of vertical piles installed at intervals supporting intermediate horizontal elements

Note 1 to entry: See Figure 3.3 g). Intermediate horizontal elements can be boarding, planks or lagging.

3.1.1.30**straight web sheet pile**

flat or slightly bent section with interlocks working in tension only

Note 1 to entry: See Figure 3.1 b).

3.1.1.31**triple U-pile**

sheet pile consisting of three threaded single U-piles with shear connections

3.1.1.32

tubular pile

pile of circular cross-section manufactured in a factory under controlled processes using seamless, longitudinal or helical welding processes

Note 1 to entry: See Figures 3.1 a) and 3.1 c).

3.1.2 Terms and definitions relating to anchors, tension piles and waling

3.1.2.1

anchor

structural element capable of transmitting an applied tensile load from the anchor head through a free anchor length to a resisting element and finally into the ground

Note 1 to entry: See Figure 3.2 c).

3.1.2.2

anchor head

element of an anchor which transmits tensile load to the structure

Note 1 to entry: For examples of typical anchor heads see Figure 3.6.

3.1.2.3

anchored wall

retaining wall whose stability depends upon embedment of the piles into the ground and also upon one or more levels of tensile restraint

Note 1 to entry: Restraint can be provided by tension elements including anchors and tension piles, see Figure 3.2 c).

3.1.2.4

deadman

discrete passive structural element buried in or secured to the ground for the purpose of providing anchorage for tie rods through passive earth pressure and friction

Note 1 to entry: Deadman anchorage can also be continuous, e.g. anchor sheet pile wall, ground beams, etc.

3.1.2.5

grouted anchor

anchor that uses a bonded length formed of cement grout, resin or similar material to transmit the tensile force to the ground

3.1.2.6

permanent anchor

anchor with a design service life which is in excess of two years

3.1.2.7

prestressed anchor

anchor which is stressed and locked off after installation, but before load enters the anchor (e.g. due to excavation, ground water lowering or service loads)

Note 1 to entry: Not all anchors are pre-stressed. Anchors are pre-stressed to limit deformation of the anchored structure. Prestressed anchors are also termed active anchors, whereas non-prestressed anchors are also termed passive anchors.

3.1.2.8**temporary anchor**

anchor with a design service life of two years or less

3.1.2.9**tendon**

part of an anchor that is capable of transmitting tensile load from the anchor head to the resisting element in the ground

EXAMPLE 1 solid steel rod or reinforcing steel bar

 2 hollow bar

 3 strand

3.1.2.10**tension pile**

pile that transfers tension load to the ground by friction between the surface of the pile and the adjacent ground

Note 1 to entry: See Figure 3.2 c).

3.1.2.11**tie rod****tie bar**

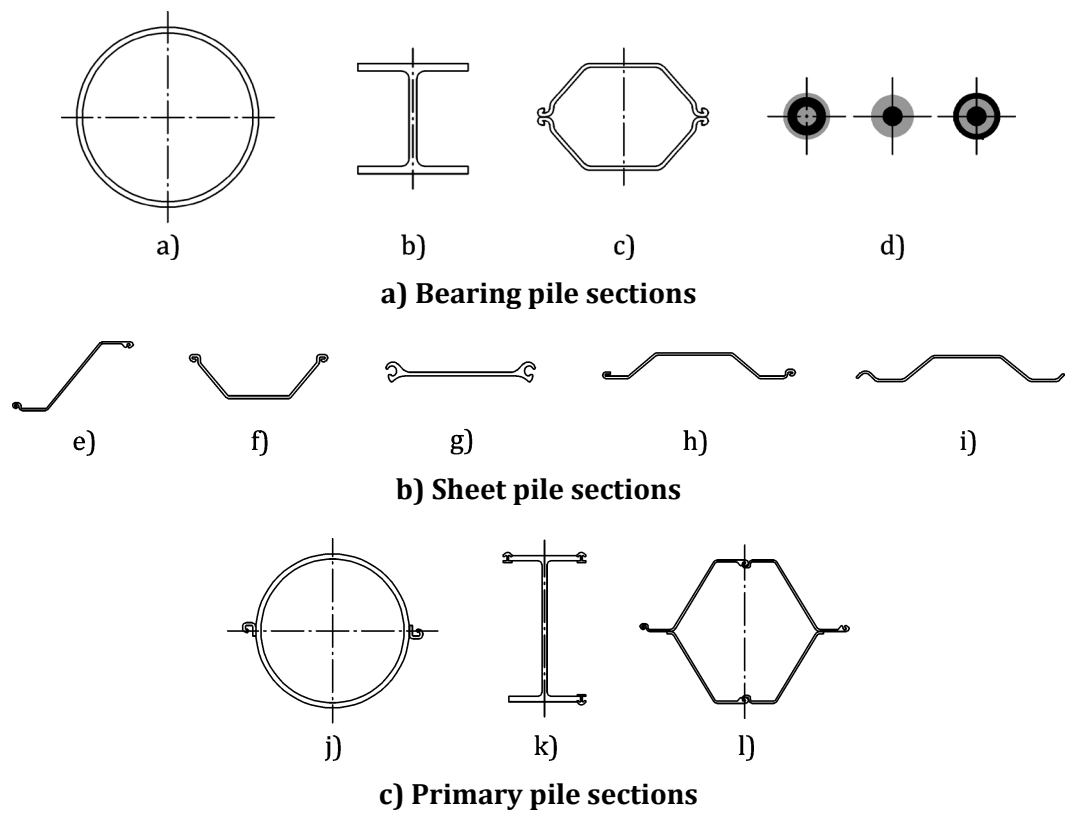
circular solid steel rod (bar) with terminations transmitting tensile load from the anchor head to a deadman or anchor wall

Note 1 to entry: Tie rods are considered part of an anchor in this document.

3.1.2.12**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 anchors, tension piles or struts

Note 1 to entry: See Figures 3.2 and 3.6.

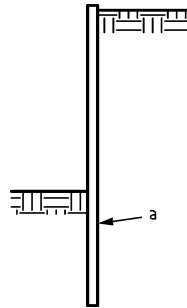


Key

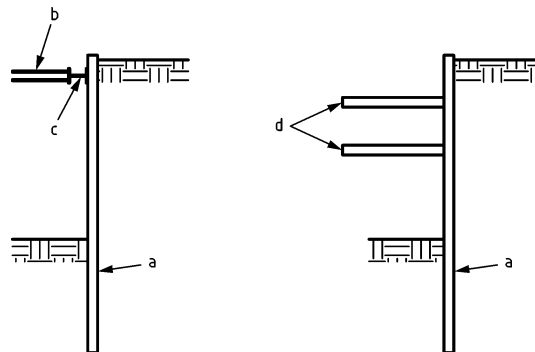
a	tubular pile	e	Z-pile	i	trench pile
b	H-pile	f	U-pile	j	tubular pile
c	box pile	g	Straight web sheet pile	k	H-pile
d	micropiles	h	Ω-pile (Omega pile)	l	box pile

NOTE Ω-piles and trench piles are dealt with in Annex A.

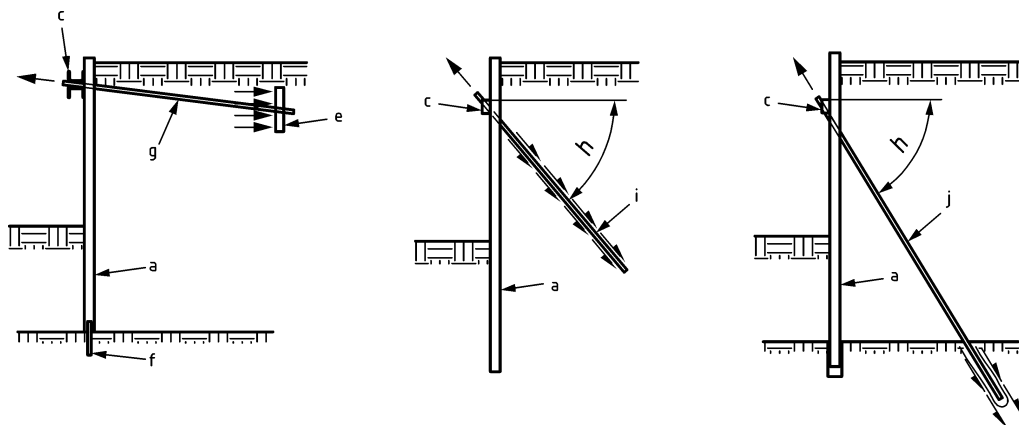
Figure 3.1 — Examples of typical pile sections



a) Cantilever retaining wall



b) Propped retaining wall

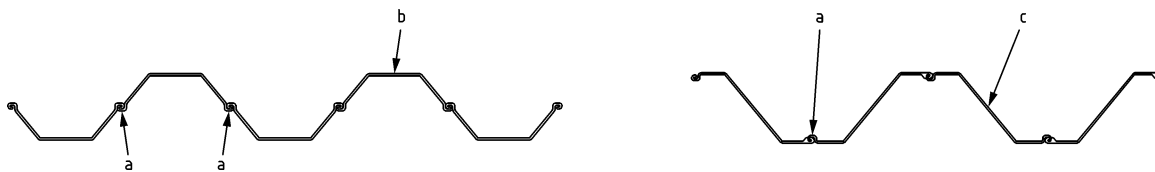


c) Anchored retaining wall

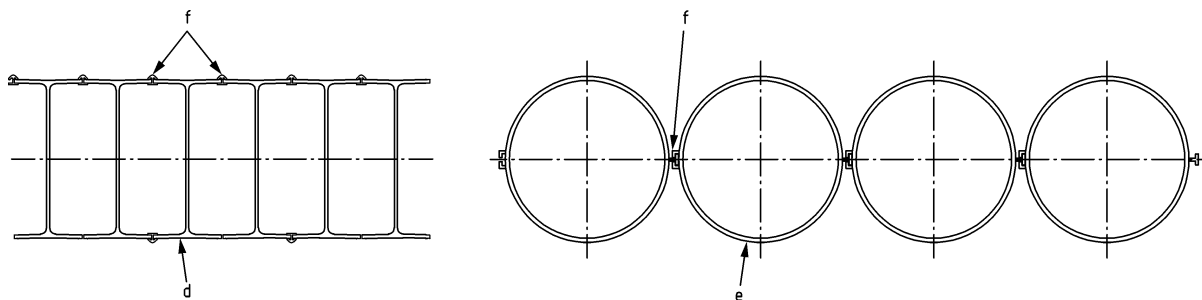
Key

- | | | | |
|---|--------------------------|---|-----------------------------|
| a | sheet pile wall | f | rock dowel (where required) |
| b | strut / prop | g | tie rod anchor |
| c | waling | h | variable angle |
| d | floor | i | tension pile |
| e | deadman (anchor or wall) | j | grouted anchor |

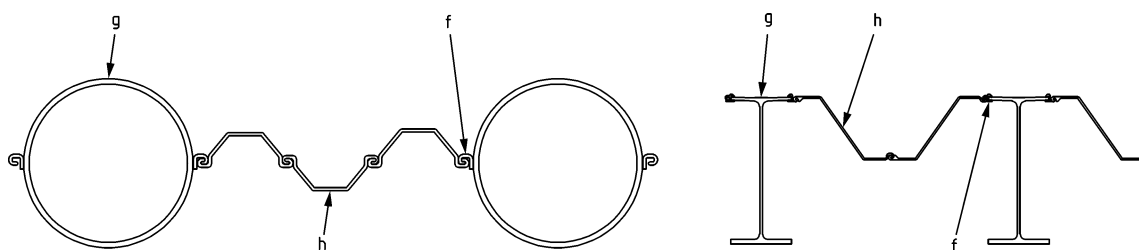
Figure 3.2 — Schematic examples of retaining walls



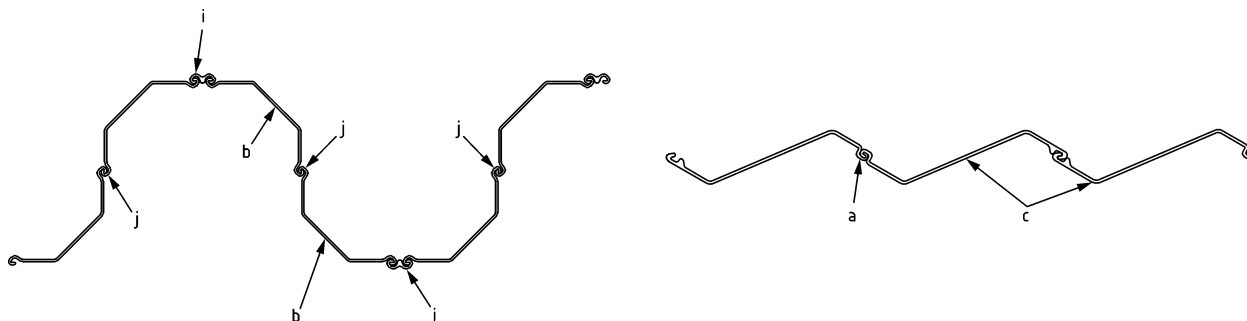
a) Sheet pile wall



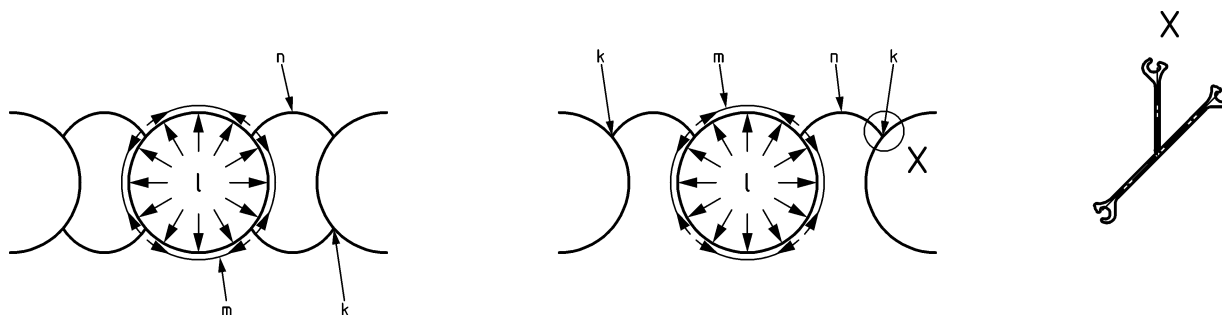
b) High modulus wall



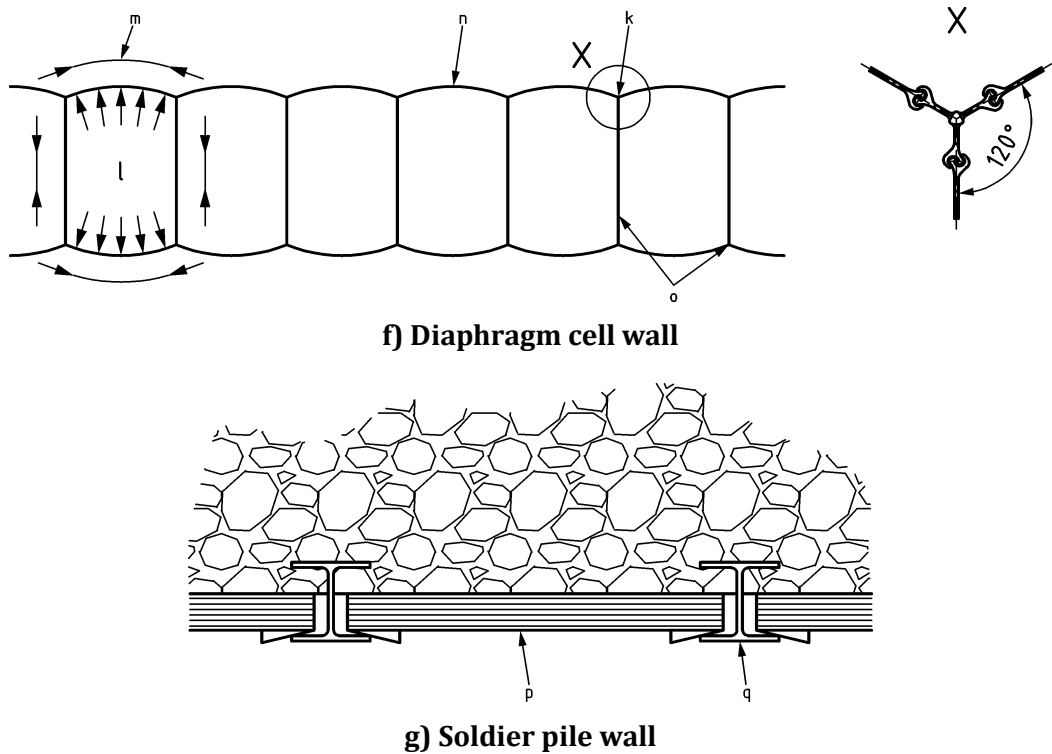
c) Combined wall



d) Jagged wall

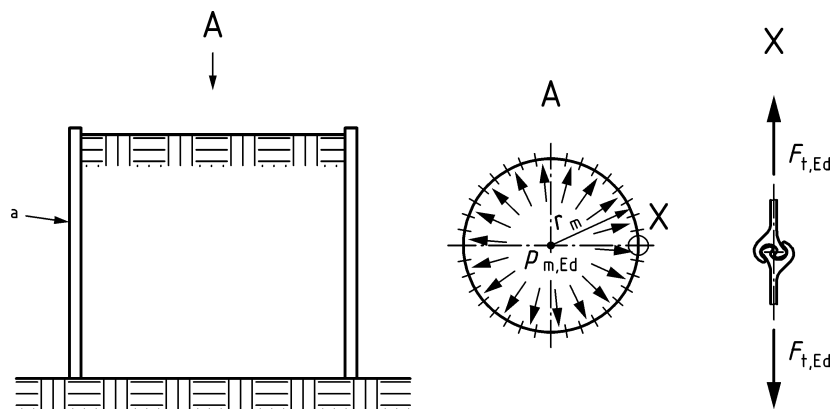


e) Circular cellular wall



Key		
a interlock	g primary elements	m circumferential tensile force
b U-pile	h secondary elements	n arc
c Z-pile	i welded connector	o diaphragm wall
d H-pile	j crimped interlock	p lagging, boarding, planks, steel plates
e tubular pile	k junction pile	q soldier-pile
f connector	l internal pressure	

Figure 3.3 — Examples of pile configurations for retaining walls



Key	
a	straight web sheet piles

Figure 3.4 — Cellular structure

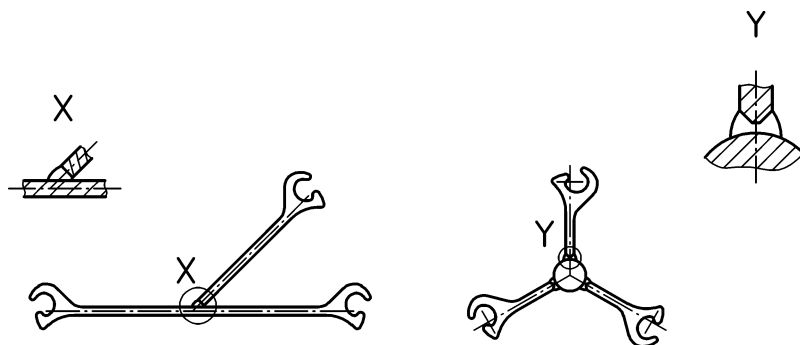


Figure 3.5 — Example junction piles

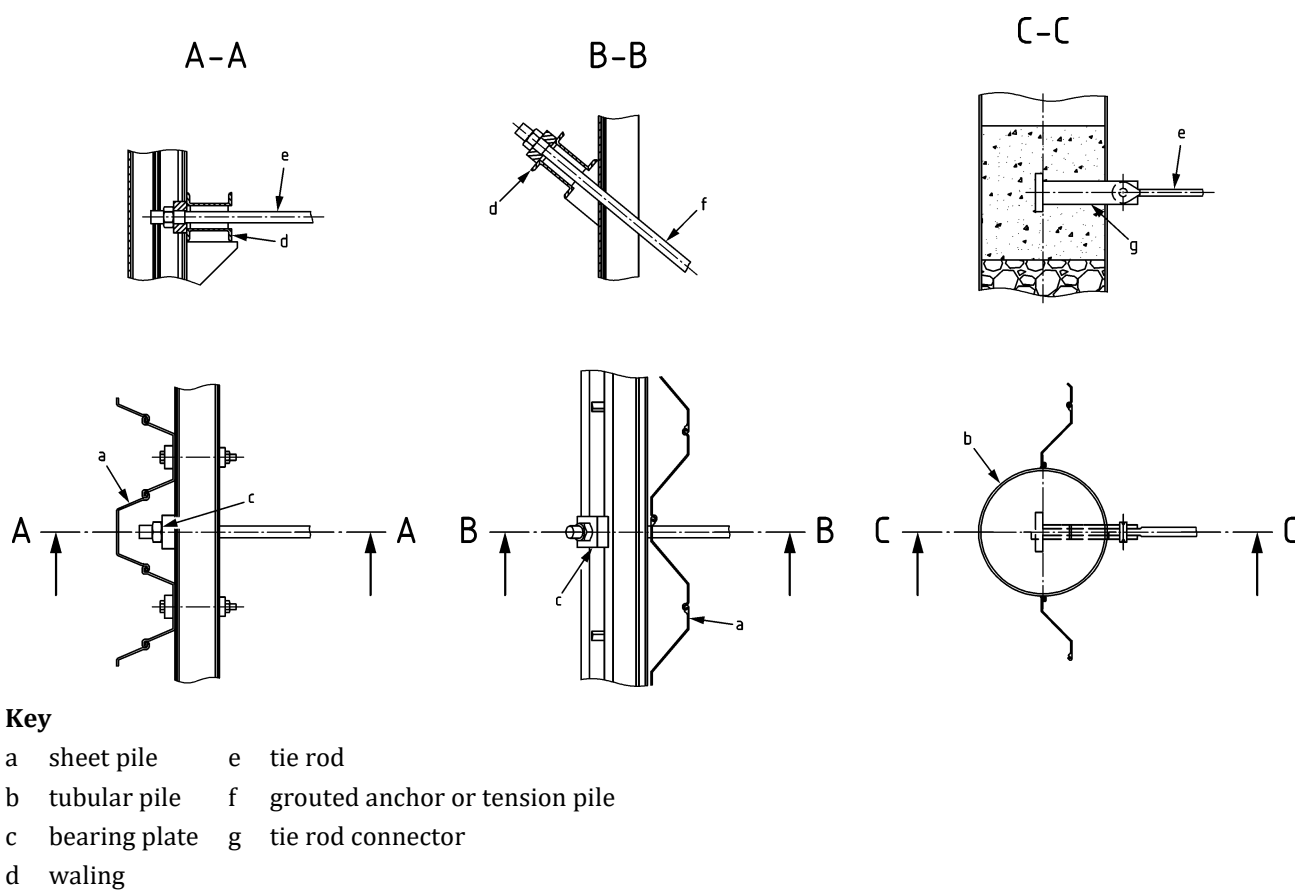


Figure 3.6 — Examples of anchorage head connections

3.2 Symbols

3.2.1 General

(1) For the purposes of this document, the following symbols apply.

3.2.2 Latin upper-case symbols

A	cross-sectional area
A_{cf}	cross-sectional area of the compression flange
A_g	gross cross-sectional area of the tension element
A_n	nominal metallic cross-sectional area of reinforcing steel
A_s	tensile stress area of the tension element at the termination
A_{tf}	cross-sectional area of the tension flange
A_v	projected shear area, see Figure 8.1
A_w	web area
B	(effective) width of the pile, in contact with soil
$B_{p,Rd}$	design punching shear resistance of the anchor head and the nut
C	member curvature
C_{cr}	critical curvature
C_y	curvature at the point of first yield
C_θ	non-dimensional rotational flexibility
D	diameter or width of pile
E	modulus of elasticity
E_p	horizontal passive earth pressure resultant
$(EI)_{eff}$	effective flexural stiffness
EI_{red}	reduced flexural stiffness
Ei_w	stiffness of the rotational spring representing the web
$E_{soil\ fill}$	deformation modulus of the soil
F_d	design force
F_{Ed}	design value of the local transverse force applied through the flange
Fe_d	applied design transverse 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
F_{SLS}	axial force under characteristic loading
$F_{t,Ed}$	design value of the circumferential tensile force in a cellular cofferdam
$F_{ta,Ed}$	design tensile force in the arc cell of a cellular cofferdam
$F_{tm,Ed}$	design tensile force in the main cell of a cellular cofferdam
$F_{ts,Rd}$	design tensile resistance of simple straight web steel sheet piles
G	shear modulus

H_A	fictitious horizontal load applied at the level of the anchor or support structure
I	second moment of area
I_D	relative density of soil
I_T	torsion constant
$I_{T,eff}$	torsional moment of inertia of partially welded double H-section
$I_{T,D}$	torsional moment of inertia of a continuously welded double H-section
I_y	moment of inertia (second moment of area) about y-y axis
I_z	moment of inertia (second moment of area) about z-z axis
I_ω	warping constant
K	lateral rigidity of the anchor or support structure
$K_V(T)$	impact energy
K_1	parameter depending on category of cross-sections
L	length of the pile
L_a	length of intermittent weld
L_B	fraction of the distance between the toe and the horizontal support
L_c	weak axis free length of a partially embedded H-pile above a weaker soil layer
L_{cr}	buckling length
$L_{cr,LT}$	lateral torsional buckling length
$L_{cr,y}$	buckling length in y direction
$L_{cr,z}$	buckling length in z direction
L_f	free length of a partially embedded pile
$L_{f,y}$	L_f in the y direction
$L_{f,z}$	L_f in the z direction
$L_{f,z}$	weak axis free length of a partially embedded H-pile, i.e. pile support to top of coarse soil layer
L_{Mmax}	length from the point of introduction of the external vertical load to the level of maximum design bending moment
L_s	height of the system
$L_{w end}$	applied continuous weld seam length at the end of the pile
M_A	absolute value of the maximum bending moment of the wall
M_B	absolute value of the intermediate maximum bending moment in the embedded part of the wall
M_{cr}	equivalent elastic critical moment
$M_{c,Rd}$	design moment resistance of the cross-section
$M_{c,Rk}$	characteristic moment resistance of the cross-section
M_{Ed}	design value of bending moment
ΔM_{imp}	additional bending moment due to sway imperfection

$M_{Ed}^{N=0}$	design bending moment assuming zero external vertical load and no sway imperfection
$M_{N,Rd}$	reduced design moment resistance allowing for the axial force
$M_{m,Rd}$	resistance for longitudinal moment
$M_{pl,Rd}$	design value of plastic bending moment resistance
M_{Rk}	characteristic value of the bending moment resistance
$M_{V,Rd}$	reduced design plastic moment resistance allowing for the shear force
$N_{cf,Ed}$	normal force acting on the compression flange
N_{cr}	elastic critical force for the relevant buckling mode of the sheet pile wall or other piling construction
$N_{cr,sw}$	elastic critical buckling load for sway mode
N_{Ed}	design value of the compression force
$N_{m,Rd}$	resistance for longitudinal normal force
$N_{pl,Rd}$	design value of plastic compression resistance
N_{Rd}	design value of the resistance to axial force
N_{Rk}	characteristic value of the compressive resistance
P_p	proof load
Q	manufacturing tolerance class parameter
$R_{c,Rd}$	design resistance of a sheet pile to a local transverse force
R_d	design value of a resistance
$R_{e,Rd}$	elastic design resistance to the local transverse force
$R_{GEO,d}$	design ultimate geotechnical resistance of an anchor or tension pile
R_k	characteristic resistance of the crimped point determined by testing
$R_{k,s}$	characteristic interlock resistance of straight web sheet piles
$R_{p,Rd}$	plastic design resistance to the local transverse force
$R_{STR,d}$	design value of the structural ultimate limit state resistance of an anchor or tension pile
$R_{tg,d}$	design tensile resistance of the gross cross-section of the tension element shaft
$R_{tt,d}$	design tensile resistance at the termination, or coupling, of the tension element
$R_{tt,Md}$	design tensile resistance at the termination, or coupling, of the tension element allowing for any bending effects
$R_{tw,Rd}$	design tensile resistance of the webs of a sheet pile to the introduction of a local transverse force
$R_{ULS,d}$	design value of the geotechnical ultimate limit state resistance of an anchor or tension pile
$R_{w,Rd}$	design value of the resistance of the web to transverse forces
$R_{w,Rk}$	characteristic in-plane resistance of the web
$R_{Vf,Rd}$	design shear resistance of the flange of a sheet pile to the introduction of a local transverse force

S_n	nominal metallic cross-sectional area of prestressing steel
$S_{y,cf}$	first moment of area of the compression flange with respect to the centroid of the full cross-section
$S_{y,tf}$	first moment of area of the tension flange with respect to the centroid of the full cross-section
T	design service life
T_{27}	test temperature
$V_{b,Rd}$	design value of the shear buckling resistance
V_{Ed}	design value of shear force
$V_{pl,Rd}$	design value of plastic shear resistance
W_{ep}	elasto-plastic section modulus for semi-compact sections
W_{el}	elastic section modulus determined about the wall axis, with full shear transfer
W_{pl}	plastic section modulus determined about the wall axis, with full shear transfer
X_n	nominal value of a basic variable

3.2.3 Latin lower-case symbols

a	ovalization of tube
b	width of flange for a Z pile
b_a	width of bearing plate
b_f	width of the flat portion of the flange
b_s	width of a reinforced shoulder
c	width or depth of a part of a cross-section for U, Z and Ω piles it is the slant height of the web of steel sheet piles
c_1	rotational stiffness of connecting beam (at node 1)
d	outer diameter of a tube
d_y	d in the y direction
d_z	d in the z direction
e	eccentricity of the force introduced into the web
$f_{p0.1k}$	characteristic proof strength at 0,1 % strain for prestressing steel
$f_{0.2k}$	characteristic proof strength at 0,2 % strain for reinforcing steel
f_{bv}	shear buckling strength
f_{pk}	characteristic tensile strength for prestressing steel
f_{tk}	characteristic tensile strength for reinforcing steel
f_u	ultimate tensile strength
f_y	nominal value of the yield strength
$f_{y,red}$	reduced yield strength
f_{yb}	nominal yield strength of the basic steel used for cold forming

h	depth of a cross-section
h_a	length of bearing plate
h_f	internal lever arm between the centroids of the flanges
h_w	height of the web between flange midlines
k	lateral linear subgrade reaction of the soil to the bearing pile
k_c	slenderness correction factor for moment distribution between restraints
k_{gr}	lateral linear subgrade reaction of coarse granular soil to a bearing pile
k_{fi}	lateral linear subgrade reaction of fine cohesive soil to a bearing pile
k_1	translational stiffness (at node 1)
k_{B0}	reference value of the lateral subgrade reaction multiplied with the pile width
k_t	reduction factor for anchor tension elements in tension
k_b	reduction factor for anchor tension elements in bending
k_{yy}	interaction factor for flexural member buckling
l	length
l_y	effective bearing length
n	ratio between load and critical buckling force
n_{Ed}	design value of transversal normal force
n_{Rd}	resistance for transversal normal force
n_z	ratio of design axial force to design value of the buckling resistance of a member in compression for buckling about z-z axis according to EN 1993-1-1
m_A, m_B	circumferential bending moment at location A or B, etc.
m_{Ed}	design value of transversal bending moment
m_{Rd}	resistance for transversal bending moment
m_M	circumferential bending moment caused by longitudinal moment M
$m_{x,Ed}$	transversal bending moment in interlock
$p_{m,Ed}$	design value of the internal pressure acting in the main cell of a cellular cofferdam
$q_{y,Ed}$	horizontal force in interlock, in y-direction
r	midline radius of the corners between the webs and the flanges
r_a	initial radius of the arc cell in a cellular cofferdam
r_t	mid-line radius of the tube
r'	radius of the circular tube in ovalized state
r_0	outside radius of the corner between flange and web
r_m	initial radius of the main cell in a cellular cofferdam
s_s	length of stiff bearing
t_f	nominal flange thickness of a steel sheet pile
t_{min}	lesser of t_f or t_w for a Z pile

t_{red}	reduced plate thickness
t_w	nominal web thickness of a steel sheet pile
$t_{w,i}$	varying web thicknesses
ν	Poisson's ratio

3.2.4 Greek symbols

α	angle of inclination of the web
α_e	buckling parameter in the elastic range
α_G	factor accounting for the effect of the tube length
α_I	factor accounting for the effect of imperfections
α_T	coefficient of linear thermal elongation
α_1	stiffness factor of the lateral resistance of the embedded part of the pile, defined at surface level
β	ratio between the lateral linear subgrade reaction of the soil and flexural rigidity of the pile
β_p	buckling parameter in the plastic range
β_a	reduction factor accounting for effect of the decrease of the diameter
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_c	modification factor of equivalent compression flange in accordance with EN 1993-1-1:2022, Formula (8.87)
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_m	reduction factor accounting for transverse shell bending
β_{ov}	over-design factor of anchors, struts, walings and connections in the transient and persistent design situations
$\beta_{\text{soil fill}}$	reduction factor of transverse shell bending to account for soil fill
β_p	plastic range factor
β_T	factor accounting for the behaviour of a welded junction pile at ultimate limit states
β_w	degree of welding in zone of intermittent welding
β_0	critical length coefficient for weak axis buckling, i.e. ratio between the critical length and the free length of a partially embedded pile
β_1	critical length coefficient for weak axis buckling, for a partially embedded pile in uniform dense soil
β_2	critical length coefficient for weak axis buckling, for a partially embedded pile in uniform soft soil
β_3	critical length coefficient for weak axis buckling, for a fully embedded pile in uniform soft soil
γ_{FE}	model factor covering the uncertainties of the numerical model and the executed analysis type

γ_m	partial factor for resistance
γ_{M0}	partial factor for resistance of cross-sections
γ_{M1}	partial factor for resistance of members to instability assessed by member checks
γ_{M2}	partial factor for resistance of cross-sections in tension to fracture
$\gamma_{M3,ser}$	partial factor for resistance of connection cross-sections in tension at serviceability limit state
$\gamma_{Mt,A}$	partial factor for resistance of reinforcing or prestressing steel in tension to fracture
γ_s	partial factor for resistance of cross-sections in reinforcing or prestressing steel
Δ	verification of cross-section
δ	web area factor to determine $M_{N,Rd}$
δ_A	horizontal displacement at the level of the anchor or support structure due to H_A , relative to the bottom end of the member
δ_y	imposed in-plane displacement on secondary piles caused by misalignment of primary piles
δ_z	maximum relative deflection of a sheet pile wall occurring between the supports according to a first order analysis
Δh	differential water head
Δl	additional pile length
ΔM_{imp}	additional bending moment due to sway imperfection
$\Delta t_{d,mw}$	total loss of thickness due to corrosion caused by mechanical wearing during the design service life
Δw_k	characteristic imperfection amplitude
ε	material parameter
ε_{mp}	maximum plastic strain
η	interaction exponent
η_{sys}	factor for differences in behaviour under test and service conditions
η_w	factor for the effect of degree of welding on the effective torsional stiffness
n_z	axial force utilization
Υ	verification of rotation capacity
ϕ	is the initial sway imperfection
θ	yield angle in the cross section
ϕ_{Cd}	design plastic rotation angle provided by the cross-section
ϕ_{Ed}	maximum design rotation angle demand for the actual design case
ϕ_k	characteristic value of the internal friction angle of the fill material
$\phi_{rot,Ed}$	design angle at ultimate limit state
$\phi_{y,Ed}$	rotation angle corresponding to the reduced plastic moment resistance $M_{pl,Rd}$
λ	non-dimensional slenderness factor
$\bar{\lambda}$	web slenderness, shell slenderness

$\bar{\lambda}_w$	slenderness according to EN 1993-1-5
$\bar{\lambda}_0$	squash limit relative slenderness
$\bar{\lambda}_{c,z,mod}$	modified relative slenderness of the equivalent compression flange according to EN 1993-1-1
$\bar{\lambda}_p$	plastic limit relative slenderness
ν	Poisson's ratio
ξ	parameter to determine β_0
ξ_1	parameter to determine β_1
ξ_2	parameter to determine β_2
ρ	reduction factor to determine reduced design values of the resistance to bending moments making allowance for the presence of shear forces
ρ_c	reduction factor
ρ_p	factor accounting for the effects of differential water pressure on transverse local plate bending
ρ_s	unit mass
ρ_1	stiffness factor of the rotational resistance of the embedded part of the pile
ρ_2	stiffness factor of the rotational resistance of the beam or deck.
c	buckling coefficient
χ	reduction factor due to global flexural buckling
$\chi_{c,z}$	reduction factor for flexural buckling of the equivalent compression flange about the weak axis of the section
χ_h	hardening limit
Ω	dimensionless length of a tube
ω	dimensionless length

3.3 Convention for sheet pile axes

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

- Generally
 - $x - x$ is the longitudinal axis of a pile;
 - $y - y$ is the principal 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 $z - z$
- for tubular piles

- $m - m$ is the meridional axis;
- $c - c$ is the circumferential axis;
- $r - r$ is the radial axis.

See Figure 3.7.

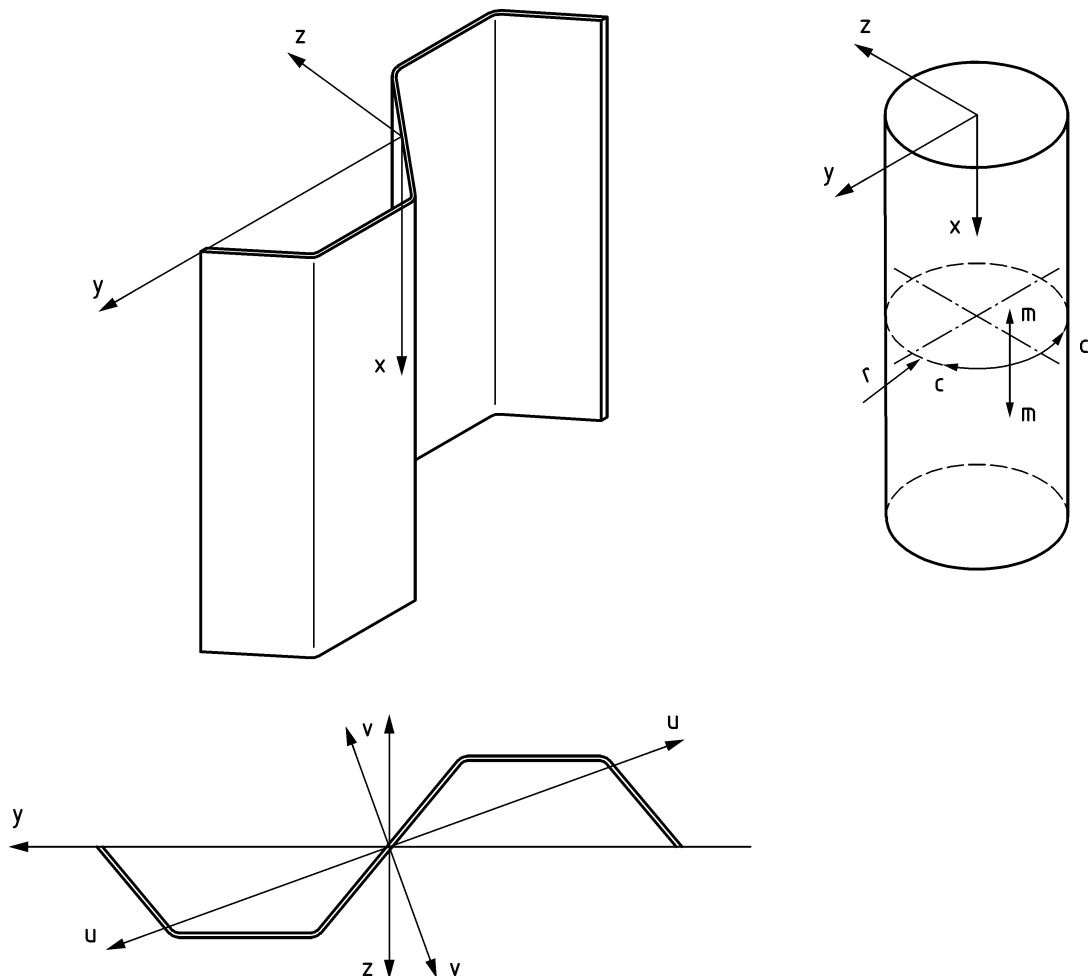


Figure 3.7 — Convention for sheet pile and tubular pile axes

4 Basis of design

4.1 General rules

4.1.1 Basic requirements

- (1) The design of piling structures shall be in accordance with the general rules given in EN 1990 and EN 1991 (all parts) and the specific design provisions for steel structures given in EN 1993-1 (all parts).
- (2) Geotechnical actions and resistances shall be in accordance with EN 1997 (all parts).
- (3) Piling structures designed according to this document shall be executed according to
 - EN 12063 for sheet pile walls, combined pile walls, high modulus walls;
 - EN 12699 for displacement piles;

- EN 14199 for micropiles;
- EN 1090-2 for walings, bracings, struts, connecting parts and structural steel parts of anchors and tension piles;
- EN 1537 for grouted anchors;
- EN 1536 for concreting of bearing piles

with construction materials and products used as specified in the relevant parts of EN 1993, or in the relevant material and product specifications.

NOTE The scope of EN 1090-2 does not include steel sheet piles.

4.1.2 Structural reliability and consequences of failure

(1) To obtain the reliability of the completed works required according to EN 1990, an appropriate execution class shall be selected in accordance with EN 1993-1-1:2022, Annex A for steel piles executed according to EN 12063, EN 12699 and EN 14199 and for associated steel structures (waling, bracing, connections, etc.) executed according to EN 1090-2.

(2) If different levels of reliability are required, they should be achieved by an appropriate choice of quality management measures in design and execution according to EN 1990, and relevant execution codes mentioned in 4.1.1 (3).

(3) Consequence classes should be determined according to EN 1990 and EN 1997 (all parts).

4.1.3 Robustness

(1) To achieve the required level of robustness according to EN 1990 and EN 1997-3, retaining walls, walings, anchors, struts and connections should at least comply with paragraphs (2), (3) and (4). Additional measures and strategies of design should be taken in accordance with EN 1997-1 where needed.

(2) Retaining walls, walings, anchors, struts and connections should be designed against progressive collapse to achieve the required level of robustness according to EN 1990 and EN 1997-3 either by

- designing for a failing structural element, e.g. a failing anchor or strut using the loads and factors of the accidental design situation (method 1) or by
- over-designing of anchors, struts, walings and connections with a factor β_{ov} in the transient and persistent design situations (method 2).

NOTE 1 The choice of method can be given in the National Annex. The value of $\beta_{ov} = 1,25$ for anchors and connections, unless the National Annex specifies a different value.

NOTE 2 Robustness can be achieved in different ways. Prevention of accidental situations is an important consideration.

NOTE 3 Designing the walings as continuous in tension and/or bending can enhance the resistance in case of a failing anchor or strut.

(3) In cases with risk of (ship or vehicle) impacts detailing for anchor heads should provide adequate protection. Protrusion of anchor heads should be avoided.

(4) The design of the pile structure shall be checked and modified (if necessary) to account for any significant variations encountered during installation.

4.1.4 Design service life

(1) The required design service life of a piling structure should be specified according to EN 1990. According to the specific needs the required design service life may be specified by the relevant authority or, where not specified, as agreed for a specific project by the relevant parties.

NOTE Guidance on the design service life of specific geotechnical structures is given in EN 1997-3.

4.1.5 Durability

(1) Depending upon the type of action affecting the design service life (see EN 1990), piling structures shall be:

- designed for the effects of corrosion (see Clause 6);
- designed for driveability (see 4.5);
- designed for accidental actions (see EN 1991-1-7);
- designed for the effects of fatigue where relevant (see EN 1993-1-9);
- inspected and maintained.

(2) The durability requirements stated in this document shall be followed, see Clause 6.

4.1.6 Sustainability

(1) Piling structures should be designed for sustainability according to EN 1990.

4.2 Principles of limit state design

4.2.1 Design situations

(1) All design situations, including each stage of execution and use, shall be taken into account.

NOTE For the selection of design situations, see EN 1990.

4.2.2 Ultimate limit state criteria

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

- failure of the system or component of the system, by exceedance of the resistance of the ground, or by other geotechnical failure mechanisms, see EN 1997-3;
- structural failure of any component of the system and/or connections of the components;
- combination of failure in the ground and structural failure.

(2) Verifications related to ultimate limit state criteria should be carried out in accordance with EN 1997-1 and EN 1997-3.

(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, walings, bracings and struts:
 - failure due to bending and/or axial force;
 - failure due to overall flexural buckling, taking account of the restraint provided by the ground;
 - local buckling due to overall bending;
 - local failure at points of load application (e.g. web crippling);
 - fatigue.
- for anchors and tension piles:
 - structural failure caused by the applied force;
 - structural failure caused by loads arising from prestressing or proof loading during testing;
 - structural failure caused by deformation of surrounding ground during the service life of the structure, such as settlements;
 - fatigue.

(4) For the verification of ultimate limit states, the effects of actions on the walings and bracing should be determined for all relevant design situations.

4.2.3 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, walings, bracings and struts:
 - 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.
- for anchors and tension piles:
 - deformation limits necessary to suit the serviceability of the retaining wall.

(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 specified.

(3) Where relevant, values for limits imposed by adjacent structures should be specified.

NOTE 1 Guidance for determining such limits is given in EN 1997-1, EN 1997-3 and EN 1990.

NOTE 2 Serviceability criteria can be the governing criteria for the design.

4.3 Basic variables

4.3.1 Actions and environmental influences

(1) Parameters for ground and/or backfill shall be determined from geotechnical investigation in accordance with EN 1997-2.

(2) Where relevant, actions should be taken from EN 1991, otherwise they should be specified by the relevant authority or, where not specified, as agreed for a specific project by the relevant parties.

(3) In the case of piled foundations, actions due to vertical or transverse ground movements (e.g. down-drag, passive loading due to horizontal movement, etc.) should be assessed in accordance with EN 1997-1 and EN 1997-3.

(4) The actions transmitted to the structure through the ground should be assessed by using models selected in accordance with EN 1997-1 or EN 1997-3.

(5) Where necessary, the effects of actions resulting from variations in temperature with time, should be taken into account. The design may prescribe measures to reduce the influence of temperature variations.

NOTE Examples for which temperature effects are likely are struts and bracings.

(6) Where necessary, the effects of actions resulting from special loads not specified in EN 1991 (all parts), should be taken into account.

NOTE 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.

(7) Unless otherwise specified, for retaining walls subject to traffic load, simplified models for such loads (for example uniformly distributed loads) derived from those defined for bridges may be used, see EN 1991-2.

(8) Where applicable, seismic actions should be considered in accordance with EN 1998 (all parts).

4.3.2 Material and product properties and geometrical data

(1) The material properties for steels and other construction products and the geometrical data to be used for design should be those specified in the relevant EN and EN ISO product standards, unless otherwise indicated in Clause 5.

NOTE A transparent and reproducible assessment that complies with all the requirements of a European Assessment Document (EAD) or European Technical Approval (ETA) can provide appropriate material and geometrical properties specific to piling applications.