

Execution of special geotechnical work — Sheet pile walls

ICS 93.020

National foreword

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The UK participation in its preparation was entrusted to Technical Committee B/526, Geotechnics, which has the responsibility to:

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- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 55 and a back cover.

Amendments issued since publication

Amd. No.	Date	Comments

This British Standard, having been prepared under the direction of the Sector Committee for Building and Civil Engineering, was published under the authority of the Standards Committee and comes into effect on 15 August 1999

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ISBN 0 580 32288 2

Foreword

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

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 1999, and conflicting national standards shall be withdrawn at the latest by August 1999.

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

The present standard expands on design only when necessary, but provides full coverage of the execution and supervision requirements for sheet pile wall structures.

It has been drafted on the basis of existing Codes of Practice and general available expertise which can be found in specialized literature.

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1 Scope

This standard specifies requirements, recommendations and information concerning the execution of permanent or temporary sheet pile wall structures in accordance with 2.4 of ENV 1991-1:1994 and the handling of equipment and materials.

It does not give requirements and recommendations for the installation of specific parts of the structure such as ground anchorages and piles which are covered by other codes.

It applies only to steel sheet pile walls, combined walls and wooden sheet pile walls.

Composite structures such as Berliner walls and sheet pile walls in combination with shotcrete, are not the subject of this standard.

2 Normative references

This 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 standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 287-1:1992 + A1:1997, *Approval testing of welders — Fusion welding — Part 1: Steels.*

EN 288-2:1992 + A1:1997, *Specification and approval of welding procedures for metallic materials — Part 2: Welding procedures specification for arc welding.*

EN 288-3:1992 + A1:1997, *Specification and approval of welding procedures for metallic materials — Part 3: Welding procedure tests for the arc welding of steels.*

EN 499:1994, *Welding consumables — Covered electrodes for manual metal-arc welding of non-alloy and fine grain steels — Classification.*

EN 996:1995, *Piling equipment — Safety requirements.*

prEN 1537, *Execution of special geotechnical work — Ground anchors.*

ENV 1991-1:1994, *Eurocode 1: Basis of design and actions on structures — Part 1: Basis of design.*

ENV 1992-1-1:1994, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules and rules for buildings.*

ENV 1993-1-1:1994, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings.*

ENV 1993-5:1998, *Eurocode 3: Design of steel structures — Part 5: Piling.*

ENV 1997-1:1994, *Eurocode 7: Geotechnical design — Part 1: General rules.*

EN 10020:1988, *Definitions and classification of grades of steel.*

EN 10079:1992, *Definition of steel products.*

EN 10219-1:1997, *Cold formed structural welded hollow sections of non-alloy and fine grain steels — Part 1: Technical delivery requirements.*

EN 10219-2:1997, *Cold formed welded structural hollow sections of non-alloy and fine grain steels — Part 2: Tolerances, dimensions and sectional properties.*

EN 10248-1:1995, *Hot rolled sheet piling of non-alloy steels — Part 1: Technical delivery conditions.*

EN 10248-2:1995, *Hot rolled sheet piling of non-alloy steels — Part 2: Tolerances on shape and dimensions.*

EN 10249-1:1995, *Cold formed sheet piling of non-alloy steels — Part 1: Technical delivery conditions.*

EN 10249-2:1995, *Cold formed sheet piling of non-alloy steels — Part 2: Tolerances on shape and dimensions.*

EN 24063:1992, *Welding, brazing, braze welding and soldering of metals — Nomenclature of processes and reference number for symbolic representation on drawings.*

(ISO 4063:1990)

EN 25817:1992, *Arc-welded joints in steel — Guidance on quality levels for imperfections.*

(ISO 5817:1992)

EN 29692:1994, *Metal-arc welding with covered electrode, gas-shielded metal-arc welding and gas welding — Joint preparations for steel.*

(ISO 9692:1992)

ISO 1106-1:1984, *Recommended practice for radiographic examination of fusion welded joints — Part 1: Fusion welded butt-joints in steel plates up to 50 mm thick.*

3 Definitions

For the purposes of this standard, the following definitions apply.

3.1

anchorage

anchoring system for the sheet pile wall, for example anchor plates or anchor walls including the connecting rods (tie rods), screw anchors, ground and rock anchors, driven ground anchors, anchoring piles and anchors with grouted or expanded bodies

3.2

auxiliary structures

all structures necessary for the proper and safe execution of the sheet piling works

3.3

bracing

a system of walings and struts to support the structure

3.4

combined wall

retaining wall composed of primary and secondary elements. The primary elements can be steel tubes, beams, or box piles. The secondary elements are normally U or Z-shaped steel sheet piles.

Figure 1 shows examples of combined walls

3.5

comparable experience

documented, or other clearly established information related to the ground and installation conditions, involving similar types of soil and rock and for which similar behaviour is expected. Information gained locally is considered to be particularly relevant

3.6

cushion

material, fitted into a recess in the driving cap, which smoothes the impact force of the falling hammer on the driving cap and on the head of the sheet pile (see Figure 2)

3.7

de-clutching

disconnection of the interlock during sheet pile driving

3.8

de-clutching detector

instrument for determining whether or not the interlocks of adjacent sheet piles are fully engaged during driving

3.9

driving cap

device, placed on the top of the sheet pile which transmits the blow of the hammer evenly, thereby preventing damage of the sheet pile head (see Figure 2)

3.10

driving

any method of installing the sheet piles to the required depth

3.11

driving method

method of driving such as panel driving, pitch and drive, staggered driving by means of impact, vibration pressing or by a combination of these

3.12

driving assistance

method to reduce the penetration resistance during driving, such as jetting or pre-augering

3.13

fish plate, splice plate

steel plate which joins two lengths of sheet pile together (see Figure B.2)

3.14

guide frame

frame consisting of one or more stiff guide beams, normally of steel or wood, to position and maintain the alignment of sheet piles during pitching and driving

3.15

hammer

part of piling equipment for driving sheet piles by percussion impact

3.16

leader

beam or similar, attached to the driving rig to lead the sheet pile and the hammer (or the vibrator) during driving (see Figures 2, 3 and 5)

3.17

leader slide

guiding device connecting the drive cap and/or the hammer to the leader (see Figures 2 and 3)

3.18

leading system

whole system to guide the sheet pile and the hammer (or the vibrator) during driving (see Figure 3)

3.19

rock dowel

rod protruding from the toe of the sheet pile, used for fixing sheet piles to the bed-rock (see Figure 13)

3.20

screw anchor

rod with a screw blade at the end, which is rotated into the natural ground behind the sheet piles to provide an anchorage

3.21

shackle

device for lifting sheet piles from the ground and placing them in the vertical position (see Figure A.7)

3.22

sheet pile

individual element of a sheet pile wall (single, double or multiple sheet pile)

3.23

sheet pile wall

screen of sheet piles which forms a continuous wall. For steel sheet piles continuity is provided by interlocking of the joints, fitting of longitudinal grooves or by means of special connectors and for timber sheet piles, by tongue and groove

3.24

sheet pile wall structure

structure, consisting of sheet piles, soil and rock, anchorages, bracings and walings, which retains ground and water. The elements are shown in Figure 4

3.25

site inspection

inspection of the construction site and its surroundings

3.26

site investigation

geotechnical investigations on and near the construction site

3.27

slippage

relative longitudinal displacement between the interlocks of adjacent sheet piles

3.28

strut

long compression member, usually of steel, wood or reinforced concrete, for the support of the sheet pile walls and normally connected to the walings

3.29

template

specific type of guide frame, used for positioning curved or angled sheet pile walls. They often incorporate a working platform or access staging for piling operatives

3.30

threader

device fixed to the toe of a sheet pile in order to guide the sheet pile into the interlock of a sheet pile already placed in the guide frame (see Figure A.8)

3.31

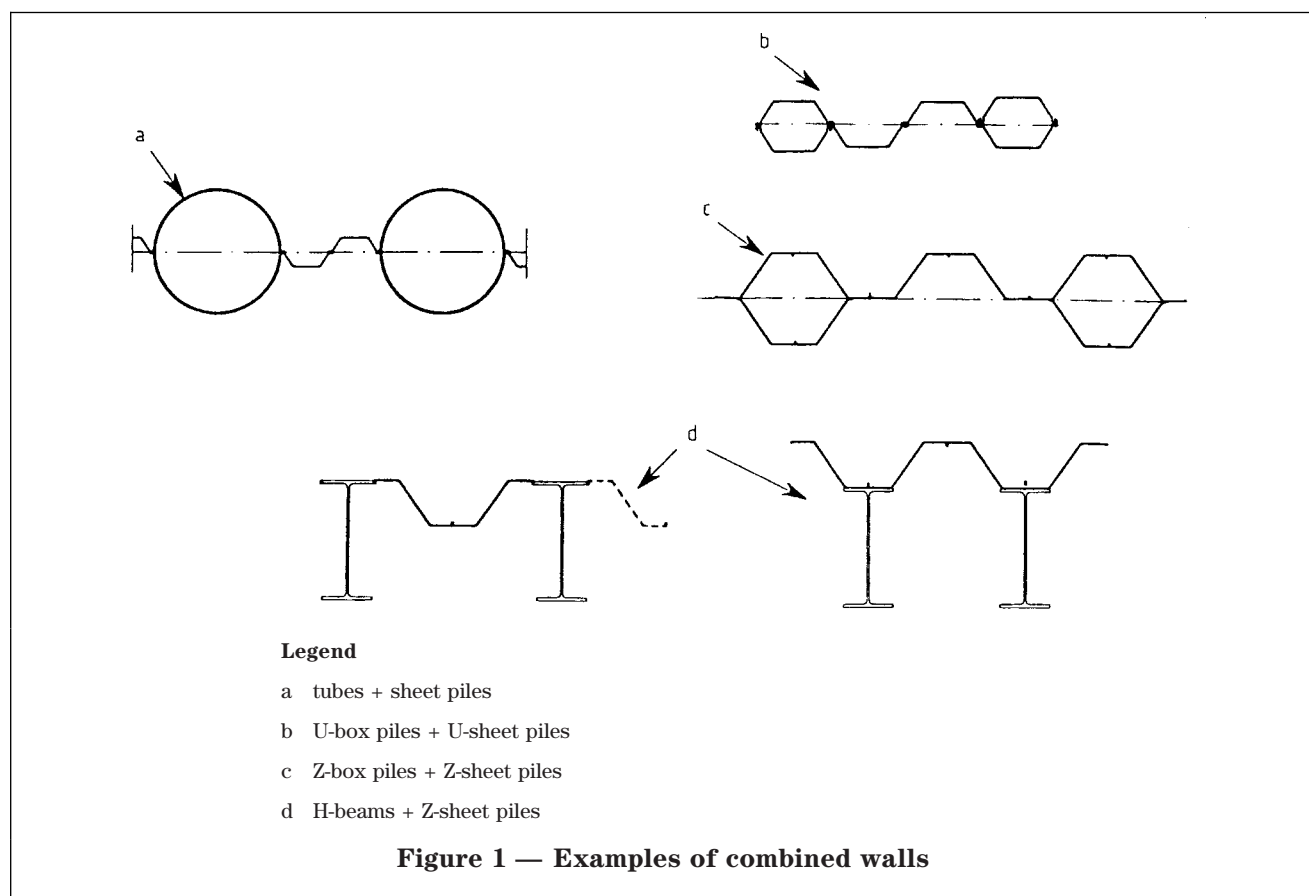
vibrator

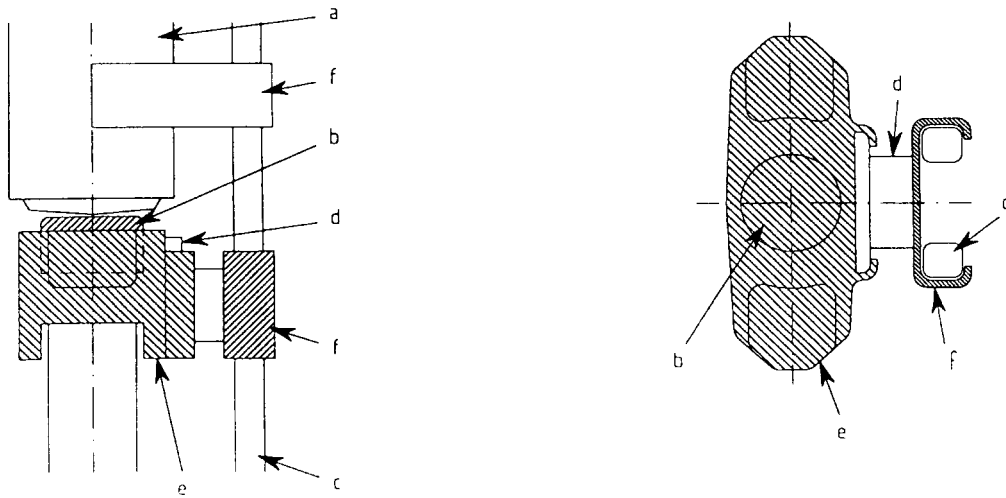
vibrating unit for the driving and extraction of the sheet piles and the primary and secondary elements of a combined wall

3.32

waling

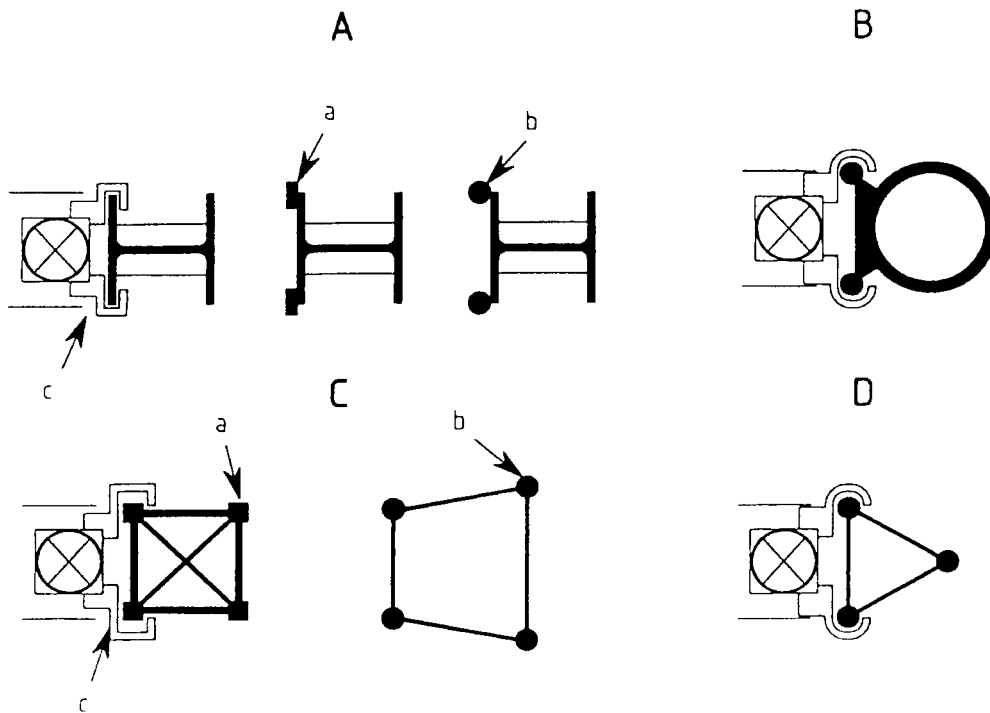
horizontal beam, usually of steel or reinforced concrete, fixed to the sheet pile wall and connected to the anchorage or struts, in order to distribute the applied anchor or strut forces equally over the sheet pile wall





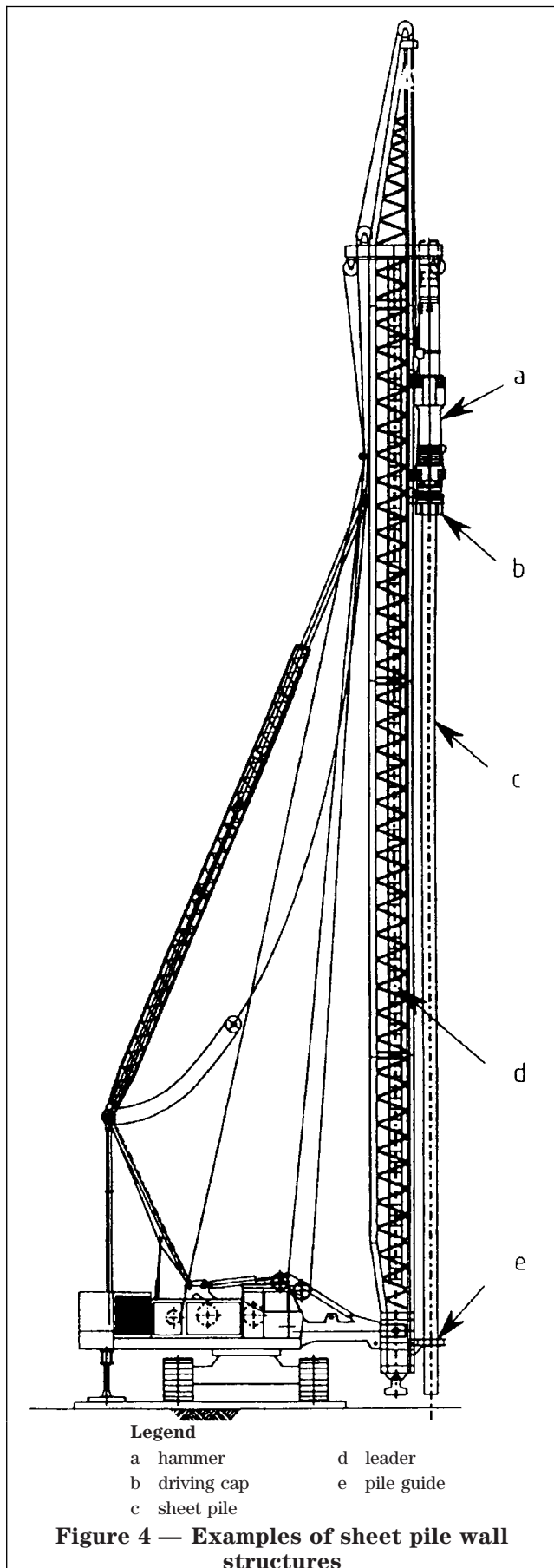
- Legend**
- | | |
|-----------|-----------------|
| a hammer | d sliding guide |
| b cushion | e driving cap |
| c leader | f leader slide |

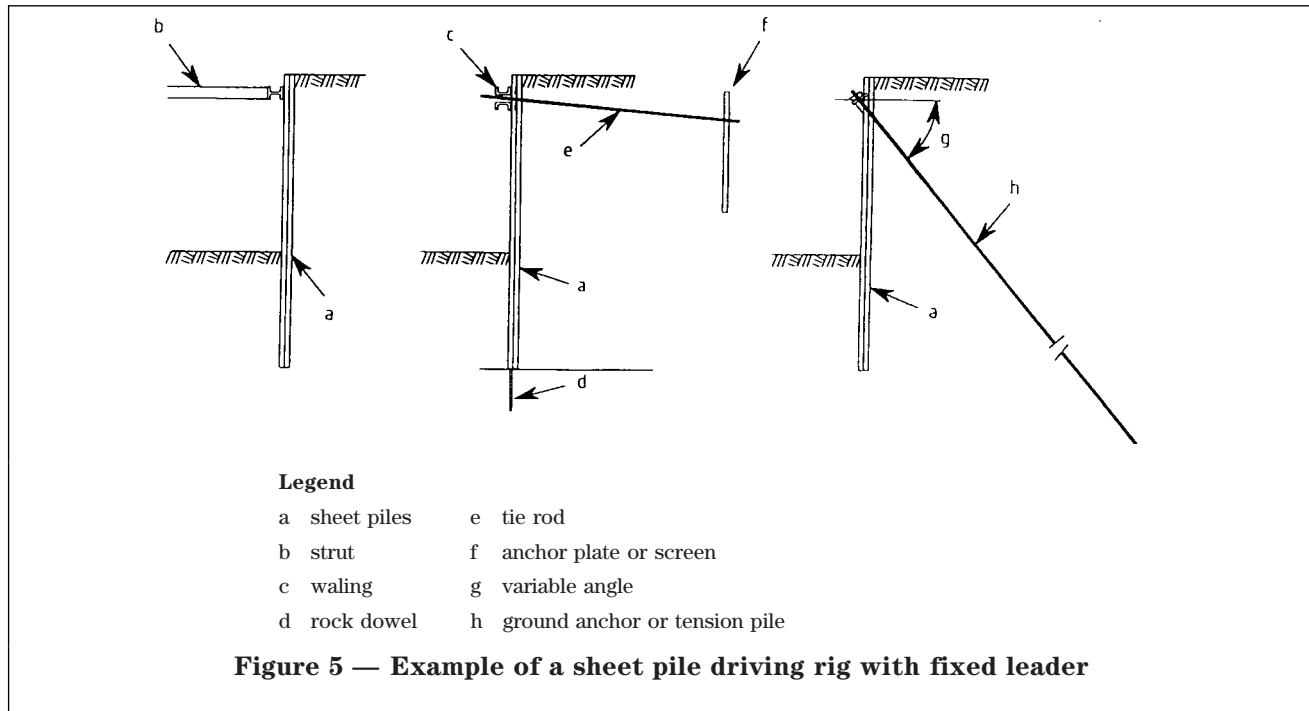
Figure 2 — Example of a driving cap



- Legend**
- | | |
|---------------------|----------------|
| A H-beam lead | a square tube |
| B pile leader | b round tube |
| C truss leader | c leader slide |
| D triangular leader | |

Figure 3 — Examples of leading systems





4 Information needed for the execution of sheet pile walls

4.1 General

The following information shall be made available before the execution of the sheet pile wall structure commences:

- location maps of the construction site, including access roads and possible hindrances;
- level and position of fixed reference points at or near the construction site;
- limitations concerning the access for equipment and materials;
- location of all services such as electricity, telephone, water and gas supply pipes and sewers;
- geotechnical data of the construction site;
- composition and stratification of the ground and its variation across the site;
- strength and deformation properties of the soil and rock layers;
- the possible presence of stones and boulders in the ground;
- the possibility of cohesive soils adhering to the piles when extracted (see 8.11);
- hydrogeological data of the area in which the construction site will be situated;
- specifications of the sheet pile walls, including all details such as type, profile, grade, protection and preservation systems and also whether any fixings of the interlocks are required to ensure transmission of the longitudinal shear forces;
- presence of sensitive buildings and/or installations in the vicinity of the construction site;
- restrictions concerning noise and vibrations;
- restrictions concerning driving method and driving assistance;
- restrictions regarding the permeability of the sheet pile wall for water or other fluids;

- various stages of the execution of the sheet pile wall structure required by the design;
- in the case of waterfront structures; the water levels and their fluctuations (amplitude, frequency and the cause of the fluctuations, e.g. discharge of a barrage, tide etc.);
- data regarding possible soil contamination;
- a list of any identified specific items to be investigated (see 4.2).

4.2 Specific

4.2.1 The following specific information shall be made available before the beginning of the works:

- all specific design information which is important to the execution;
- restrictions related to the presence, at or near the site, of ground anchors, cathodic protection devices and similar;
- the history of the building site: presence of foundation remnants or other artificial elements in the ground.

4.2.2 Information about the following matters should be made available before the beginning of the work:

- special aspects particular to the project, such as corrosion and abrasion problems;
- comparable experience from works in the neighbourhood or from similar works carried out under similar conditions;
- the condition of nearby buildings, structures or installations and the nature and depth of their foundation;
- data about adverse weather conditions, for example, wind conditions and frequency;
- severe frost action in the ground, where this can lead to overstressing of the sheet pile wall.

5 Site investigations

5.1 Soils and rock investigation

When additional soils and rock data are required for the selection of driving methods, procedures, equipment, auxiliary structures etc. or for checking the execution, the investigation shall comply with clause 3 of ENV 1997-1:1994.

5.2 Driveability of sheet piles

5.2.1 When driveability is investigated, account shall be taken of any restrictions in the design regarding techniques to assist driving (for instance jetting or pre-augering).

5.2.2 When no comparable experience exists, it is recommended that one or more driving tests are carried out before the sheet pile work commences.

NOTE The driving data obtained from the test is used to improve the efficiency of the driving operations and to confirm the choice of the profile. It indicates if driving assistance is necessary and what the influence on soil properties and other important matters might be. A driving test can also indicate if it is possible to use rock dowels.

6 Materials and products

6.1 Steel sheet piles

6.1.1 New sheet piles shall comply with EN 10248-1:1995 and EN 10248-2, EN 10249-1:1995 and EN 10249-2:1995 and EN 10079:1992.

6.1.2 Re-used sheet piles shall, as a minimum, comply with the design specifications concerning type, size, quality and steel grade.

6.1.3 Tubes used for primary elements of a combined wall shall comply with EN 10219-1:1997 and EN 10219-2:1997.

6.1.4 Special connectors such as those shown in Figure B.4, shall comply with EN 10248-1:1995 and EN 10248-2:1995.

6.2 Timber sheet piles

Permanent timber sheet pile wall structures in water bearing soils shall be of a high durability class such as tropical hard wood and pine wood which is impregnated (see annex F).

6.3 Other materials and products

All other materials and products (including the backfill), shall meet the design specifications.

6.4 Corrosion protection for steel sheet piles and preservation of wooden sheet piles

Paints, coatings and other means of corrosion protection of the steel elements and the preservation treatment of wooden sheet piles, shall comply with the design specifications.

6.5 Sealings for interlocks

6.5.1 Sealing materials for reducing the permeability of the interlocks when required, shall comply with the design specifications.

6.5.2 When permeability requirements are very strict it should be demonstrated by realistic tests on sealed interlocks, that the proposed product satisfies the design specifications.

7 Design considerations

7.1 General

The basis standards for the design of all elements of sheet pile wall structures are:

— ENV 1991-1:1994, Eurocode 1 — *Basis of design and actions on structures — Part 1: Basis of design*;

— ENV 1992-1-1:1994, Eurocode 2 — *Design of concrete structures — Part 1-1: General rules and rules for buildings*;

— ENV 1993-1-1:1994, Eurocode 3 — *Design of steel structures — Part 1: General rules and rules for buildings*;

— ENV 1993-5:1998, Eurocode 3 — *Design of steel structures — Part 5: Piling*;

— ENV 1997-1:1994, Eurocode 7 — *Geotechnical design — Part 1: General rules*.

7.2 Selection of sheet pile

7.2.1 The selection of sheet pile types, profile and quality, as well as the dimensions of the primary elements of combined walls shall, as a minimum, comply with the general design considerations.

For steel sheet piles account shall be taken of the cross-section classification in accordance with ENV 1993-5:1998.

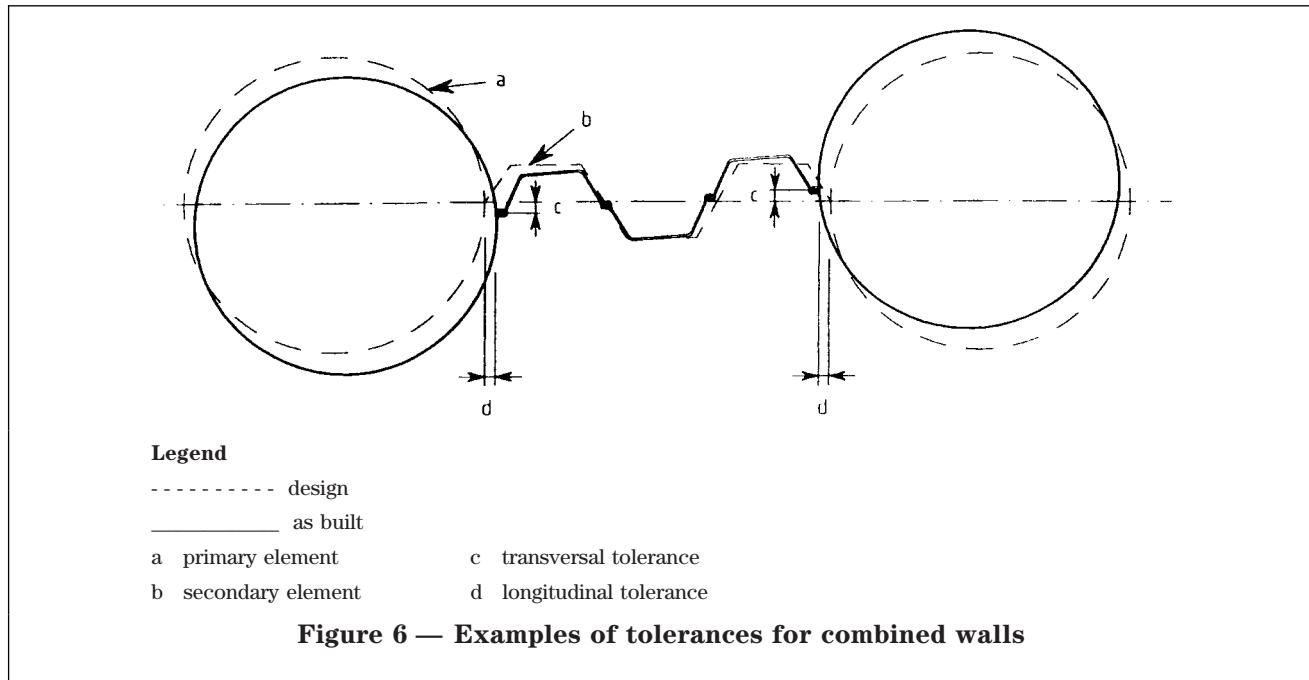
The selection shall ensure adequate driveability as established in 5.2.

7.2.2 When shear forces cannot fully be transmitted by the interlocks, this shall be taken into account in accordance with ENV 1993-5:1998 when selecting the sheet pile profiles.

7.2.3 In the case of combined walls the sheet pile profile for the secondary elements shall be selected not only on the basis of strength considerations but also on flexibility and driveability. Account shall be taken of the tolerances which can occur after driving the primary elements, as indicated in Figure 6 (see 8.6.2).

NOTE The danger of de-clutching depends mainly on the following conditions:

- accuracy of positioning and verticality of the primary elements;
- soil conditions;
- the deformation behaviour of the sheet piles.



7.3 Other structural elements

7.3.1 In addition to the sheet pile wall itself, the selection of the elements which are necessary for the sheet pile wall structure, such as anchorages, struts and walings, shall take account of adverse loading and site conditions.

7.3.2 Ground anchorages shall comply with prEN 1537.

7.4 Sequence of execution

7.4.1 The various stages of the works shall be established in accordance with the design.

7.4.2 The criteria for progressing from one stage to the next shall be defined.

As a minimum for each stage of the execution works, this involves the following:

- the levels and tolerances for filling and excavation;
- the levels and tolerances of the groundwater and the free water;
- the characteristics of the materials and the quality of the fill along both sides of the sheet pile wall and in front of the anchor plates;
- the displacements of the sheet pile wall, as anticipated at the end of the various stages;
- restrictions regarding surcharges.

7.5 Specific design considerations

The following matters should be specified in the design if appropriate:

- method of fixing the interlocks;
- method of attaching the connectors to the primary elements of a combined wall, taking into consideration Table 15 of EN 10248-2:1995;
- quality of the weldings;
- method of cutting steel elements;

— method to assist driving and the depth to which it may be applied;

— shape of rock shoe and other measures necessary to secure the toe of the sheet piles in the bed-rock;

— in soft clays, overlying bed-rock, the method of preventing the clay from squeezing through the gap between the pile toe and the bed-rock;

— quality of the backfill or the method of placement thereof;

— pre-stressing of the struts or anchorages in order to reduce displacements in the ground behind the sheet pile wall;

— time restraints during critical execution sequences;

— methods and levels of de-watering;

— type, kind and method of coating steel elements and preserving wooden parts;

— cathodic protection methods;

— compatibility of the interlock sealant and the coating material;

— special requirements regarding the permeability of the sheet pile wall, including performance criteria for materials, procedures and testing;

— the method to secure the position of the toe of sheet piles when close excavation in rock is carried out;

— consequences of extracting the sheet piles on adjacent buildings, installations and services, on settlements of the soil surface and on the creation of a link between soil layers with different groundwater regimes;

— measurements needed to check settlements, displacements and vibrations.

8 Execution of sheet pile wall structures

8.1 General

8.1.1 The sequence of executing the sheet pile wall structure shall be carried out in accordance with 7.4.

8.1.2 If the agreed sequence of the works cannot be maintained, a revision that meets the requirements of 7.4 shall be established in compliance with the design.

8.1.3 Each sheet pile should be referenced.

8.2 Site preparation

8.2.1 The site shall be prepared in such a way that operations can be carried out safely and efficiently.

8.2.2 The execution and use of auxiliary structures shall be in accordance with 7.3.

NOTE Access roads and mooring facilities to the construction site may have to comply with special regulations of the statutory authority.

8.3 Storage and handling of the sheet piles

Information regarding the storage and handling of steel sheet piles is given in annex A.

8.3.1 Handling and storage of the sheet piles on the site shall be carried out in such a way that significant damage to the straightness of the sheet piles, to the interlocks and to the coatings, does not occur.

8.3.2 The specific directives given by the sheet pile suppliers for handling and storing the sheet piles should be followed.

8.3.3 Sheet piles should be stored in such a way that they can be lifted easily in the sequence of use.

8.3.4 Sheet piles of different types and steel grade shall be stored separately and marked properly.

8.3.5 Storage and handling of straight web sheet piles shall be carried out with utmost care in order to avoid distortion of the profiles.

8.3.6 When storing pre-coated steel sheet piles, spacers shall be inserted between the individual sheet piles in a stack (see annex A).

8.3.7 Primary elements for a combined sheet pile wall shall be stored and supported on wood or a similar soft material placed between the elements in order to avoid permanent distortion of the profiles.

8.3.8 Primary elements of a combined wall should be handled using non-metallic straps or slings in order to prevent damage to the coating and to the connectors fixed to these elements.

8.3.9 The length and stiffness of the individual sheet piles shall be taken into account when assessing the number and positions of the supports to a stack of sheet piles to avoid sagging which may cause permanent deformations.

8.3.10 Special devices for lifting and positioning the sheet piles should be used, such as shackles, welded lifting hooks and similar, in order to avoid damage to the sheet piles and in particular to the interlocks.

8.3.11 When remote release shackles for lifting the sheet piles are used, their operation shall be verified before use.

8.3.12 Friction grip devices can release unexpectedly and therefore shall not be used for the handling of sheet piles unless additional safety measures are taken.

8.3.13 If preservation or corrosion treatment of sheet piles and other elements is carried out at the construction site, precautions shall be taken to ensure that storage and application of products and materials shall be in accordance with local regulations on health, safety and environmental aspects.

8.4 Welding and cutting of steel elements

Information regarding welding is given in annex B.

8.4.1 Welding and cutting of sheet piles and the preparation of primary elements for combined walls shall comply with the quality specified in the design.

8.4.2 Edge preparation and cutting of the steel elements shall be carried out in such a manner that embrittlement due to flame cutting does not have a significant adverse effect on the quality of the joint. The dimensional tolerances of EN 29692:1994, or in Figure 7j shall be complied with. The prepared piles shall be in accordance with EN 10248-2:1995, EN 10249-2:1995 and EN 10219-2:1997.

8.4.3 Unless specified otherwise, joint preparation, welding processes and the description or the qualification of the welding procedure shall be in accordance with Table 1.

For tubular primary elements it shall be ensured that the distance between the connector and a longitudinal seam of the element is ≥ 300 mm and that the circular and spiral seams on the elements are levelled at the position of the connector.

Table 1 — Welding requirements for steel sheet piles

Welding						Testing and inspection of welds			
Type of welded assembly	Type of joint	Type of weld	Joint preparation	Allowable welding processes	Description/qualification of welding procedure		Quality level according to EN 25817:1992	Type of testing	Extent of testing [%]
					BS (EN 10248-1:1995) ²⁾ S235 JRC, S275 JRC, S355 JOC according to EN 10249-1:1995 and grades according to EN 10219-1:1997 ³⁾	QS (EN 10248-1:1995) ⁴⁾ and grades given in EN 10219-1:1997 according to ⁵⁾			
Lengthened piles — straight web pile	butt-joint ¹⁾ (see Figure 7a)/ lap-joint (see Figure 7b)	EN 29692:1994	EN 29692:1994	⁶⁾	—	EN 288-2:1992 + A1:1997	D	visual	100
	butt-joint ¹⁾ (see Figure 7c)/ lap-joint (see Figure 7d)	EN 29692:1994	EN 29692:1994	⁶⁾	— ⁷⁾	EN 288-2:1992 + A1:1997 ⁷⁾	D ⁸⁾	visual ⁹⁾	100 ⁹⁾
— bending resistant pile	(see Figure 7c)/ lap-joint (see Figure 7d)		EN 29692:1994						
Strengthened piles	lap-joint (see Figure 7e)	EN 29692:1994	EN 29692:1994	⁶⁾	—	—	D	visual	100
Junctions/junction piles — all, except straight web junction piles	(oblique) T-joint (see Figure 7f + 7g)/ corner-joint (see Figure 7h)/ lap-joint (+ butt-joint) (see Figure 7i)	EN 29692:1994	EN 29692:1994	⁶⁾	— ⁷⁾	EN 288-2:1992 + A1:1997 ⁷⁾	D ⁸⁾	visual ⁹⁾	50 ⁹⁾
	(oblique) T-joint (see Figure 7j)	half V-weld/double half V-weld	according to Figure 7j	⁶⁾	EN 288-3:1992 + A1:1997	EN 288-3:1992 + A1:1997	D ⁸⁾	US + visual	10 (US) ¹⁰⁾ + 100 (visual)
Box piles — contiguous interlock	butt-joint (see Figure 7k)	butt-weld between curved elements	—	⁶⁾	—	EN 288-2:1992 + A1:1997	D	visual	100
— connected interlock	lap-joint (see Figure 7l)	EN 29692:1994	—	⁶⁾	—	EN 288-2:1992 + A1:1997	D	visual	100
— others	T-joint (see Figure 7m) lap-joint (see Figure 7n)	EN 29692:1994	EN 29692:1994	⁶⁾	—	EN 288-2:1992 + A1:1997	D	visual	100

Table 1 — Welding requirements for steel sheet piles (continued)

Welding					Testing and inspection of welds				
Type of welded assembly	Type of joint	Type of weld	Joint preparation	Allowable welding processes	Description/qualification of welding procedure		Quality level according to EN 25817:1992	Type of testing	Extent of testing [%]
					BS (EN 10248-1:1995) ²⁾ S235 JRC, S275 JRC, S355 JOC according to EN 10249-1:1995 and grades according to EN 10219-1:1997 ³⁾	QS (EN 10248-1:1995) ⁴⁾ and grades given in EN 10219-1:1997 according to ⁵⁾			
Welded interlocks (fixing, sealing)	butt-joint (see Figure 7o)	butt-weld between curved elements	—	⁶⁾	—	EN 288-2:1992 + A1:1997	D	visual	100

¹⁾ For different thicknesses, the shape of the butted ends shall be in accordance with the design specifications.
²⁾ BS = Base Steel according to **5.1.1** of EN 10020:1998.
³⁾ Steel grades according to Tables A.1, B.1 and B.2, except S420xxx and S460xxx.
⁴⁾ QS = Quality Steel according to **5.1.2** of EN 10020:1988.
⁵⁾ Steel grades S420xxx and S460xxx.
⁶⁾ All processes described in 111, 114, 121, 122, 131, 135 and 136 of EN 24063:1992, are permitted.
⁷⁾ In the case of acceptance class C, EN 288-3:1992 + A1:1997 shall be applied.
⁸⁾ Acceptance class C if requested by the design.
⁹⁾ In the case of acceptance class C, one X-ray test according to ISO 1106-1:1984 on 10 % of the sheet piles or primary elements and 100 % visual inspection or US tests on 10 % of the sheet piles or primary elements over the whole length of the weld and 100 % visual inspection.
¹⁰⁾ 10 % of the sheet piles or primary elements over the whole length of the weld.

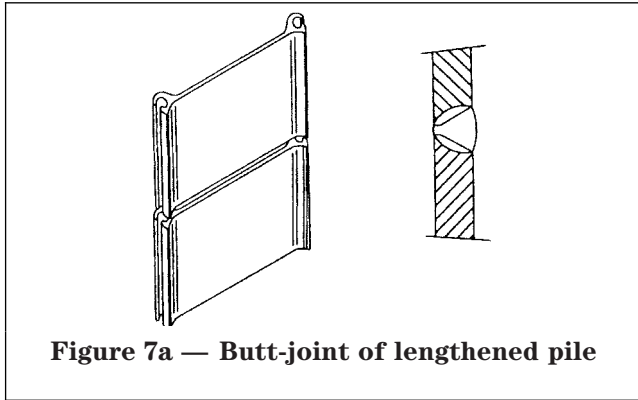


Figure 7a — Butt-joint of lengthened pile

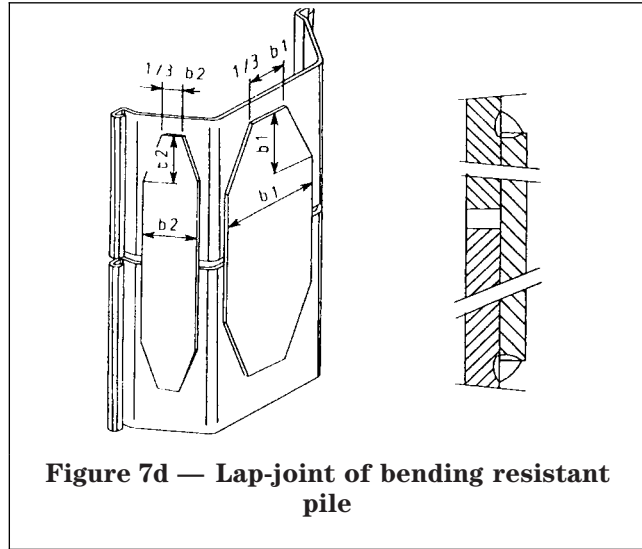


Figure 7d — Lap-joint of bending resistant pile

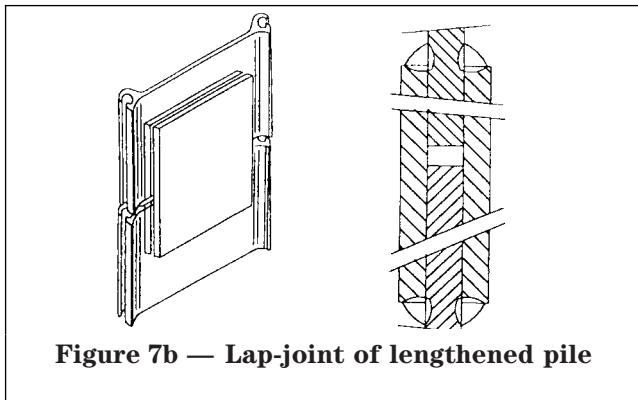


Figure 7b — Lap-joint of lengthened pile

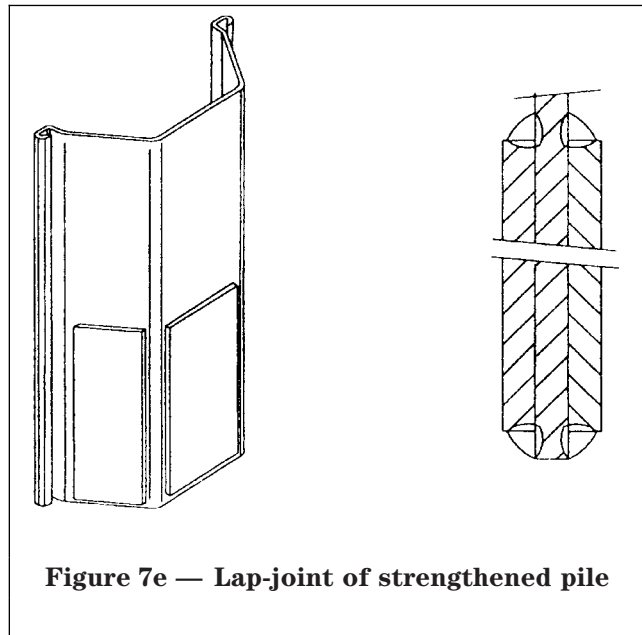


Figure 7e — Lap-joint of strengthened pile

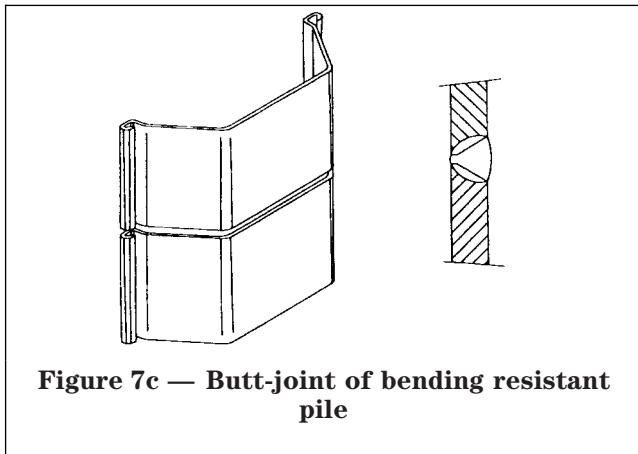


Figure 7c — Butt-joint of bending resistant pile

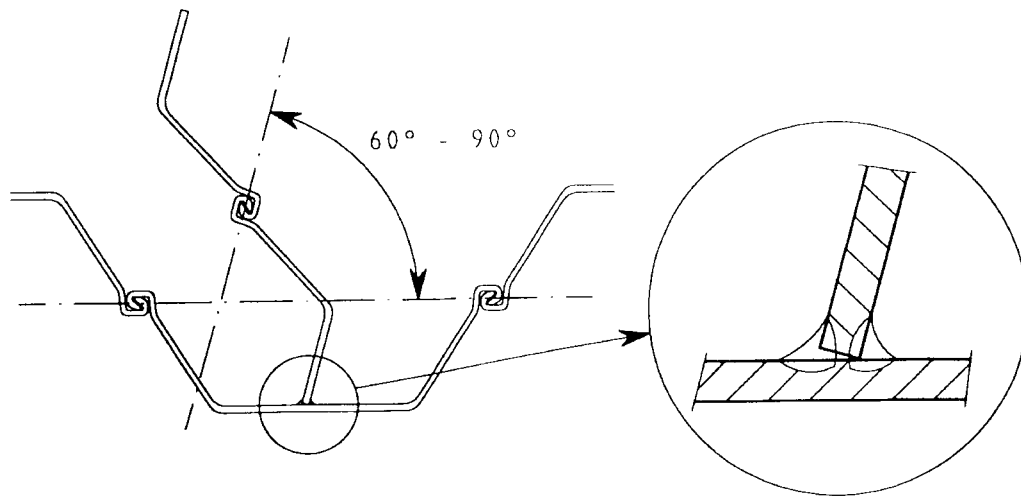


Figure 7f — Oblique T-joint of function pile

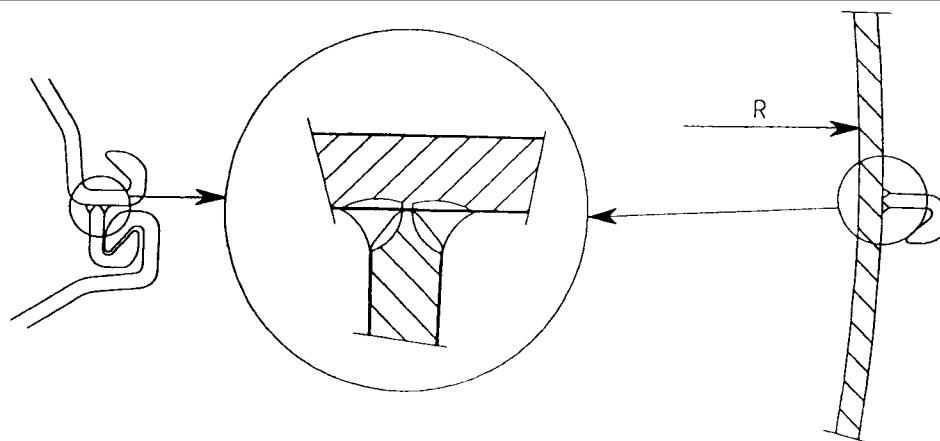


Figure 7g — T-joint junction

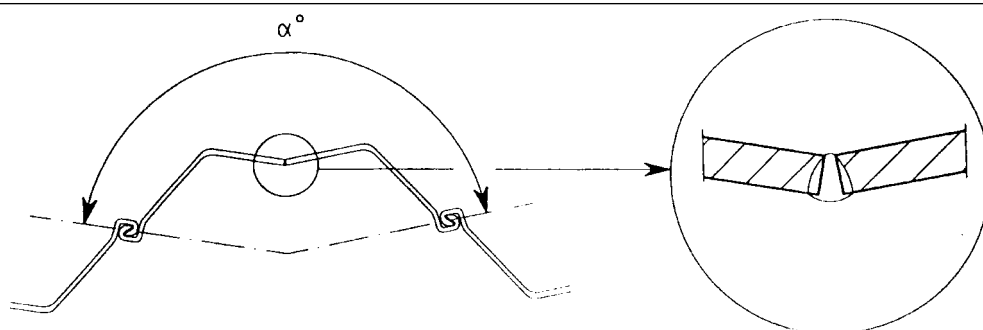


Figure 7g — Corner joint junction pile

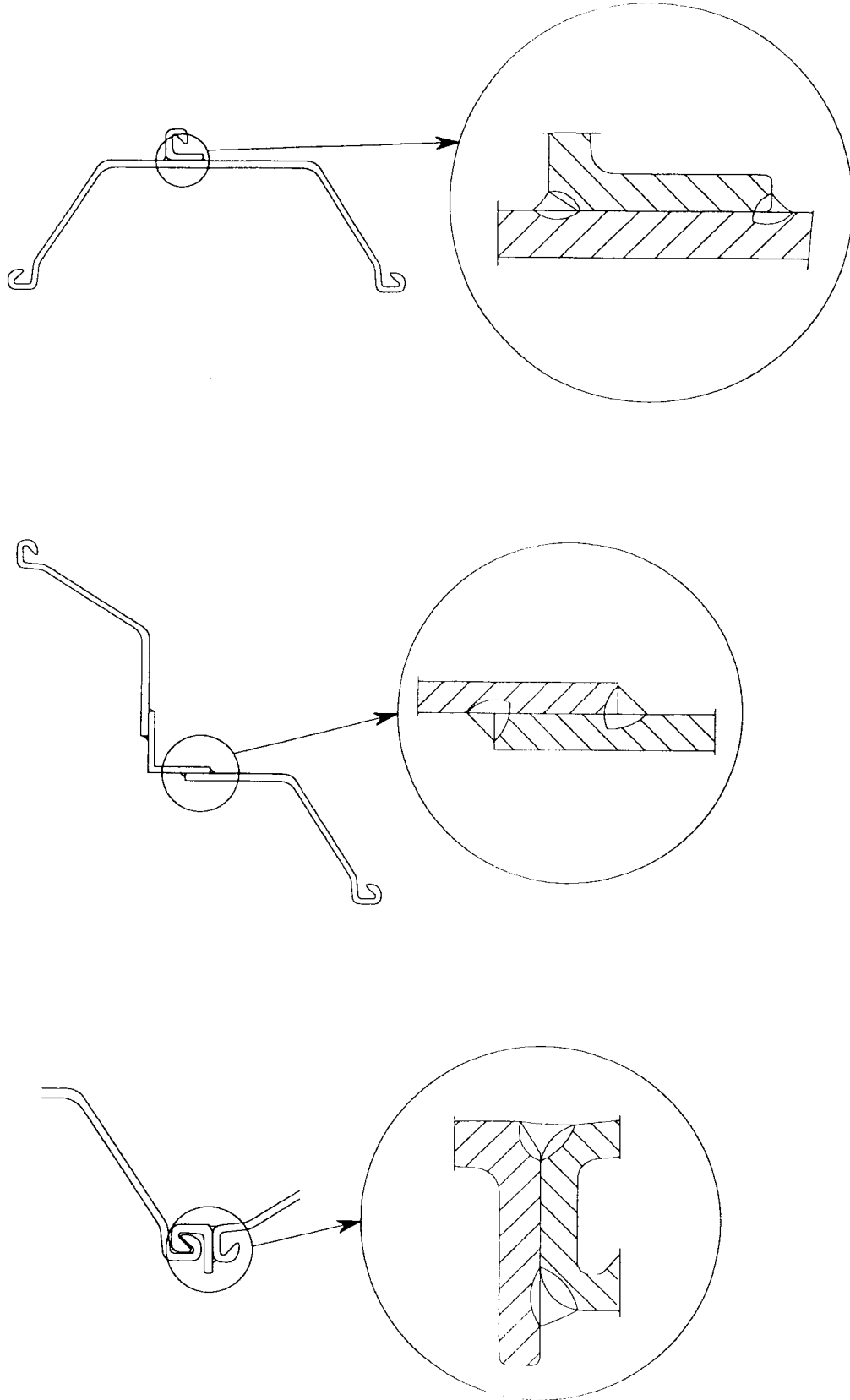


Figure 7i — Lap-joint (+ butt-joint) of junction pile

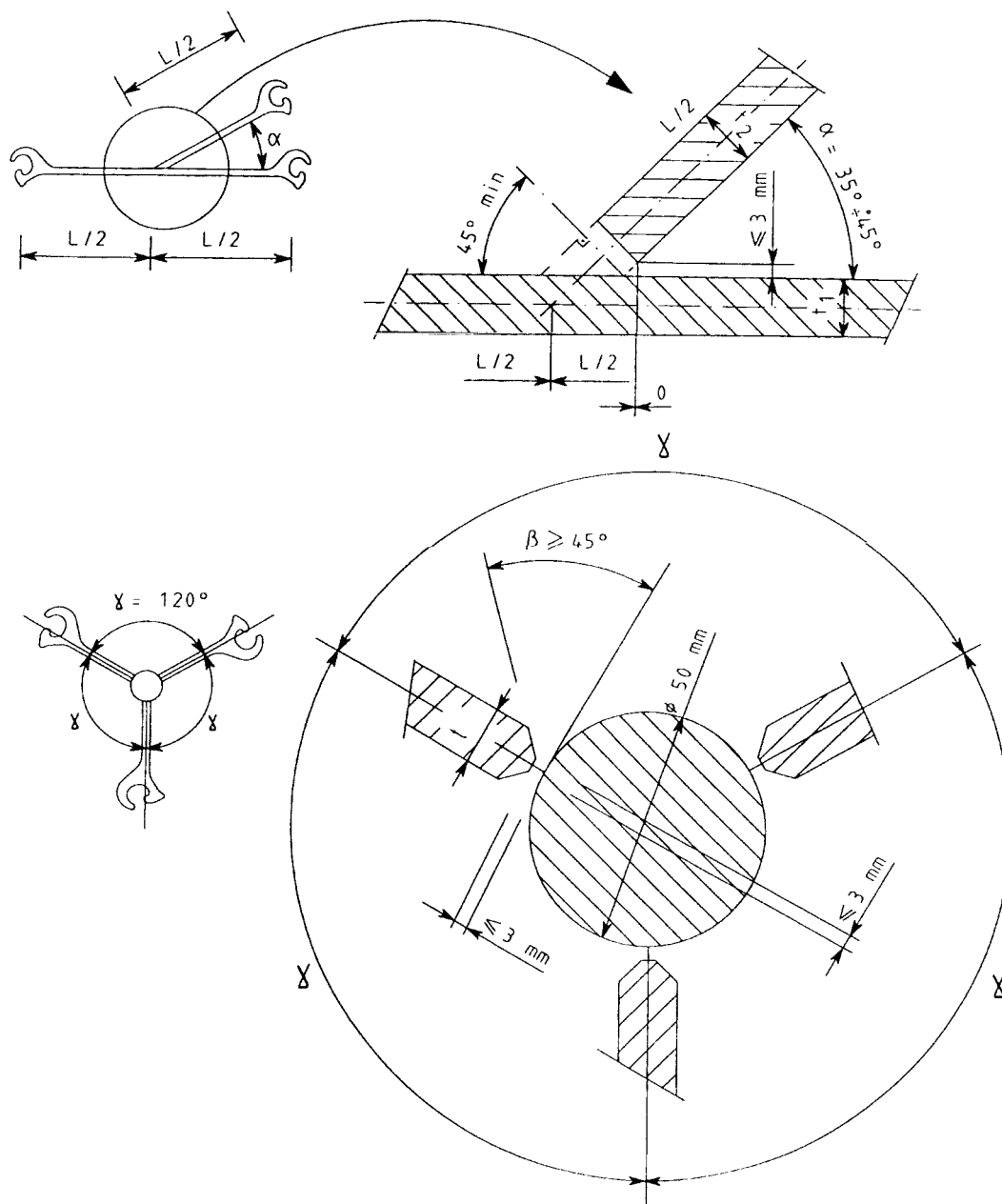


Figure 7j — Oblique T-joint of straight web junction pile

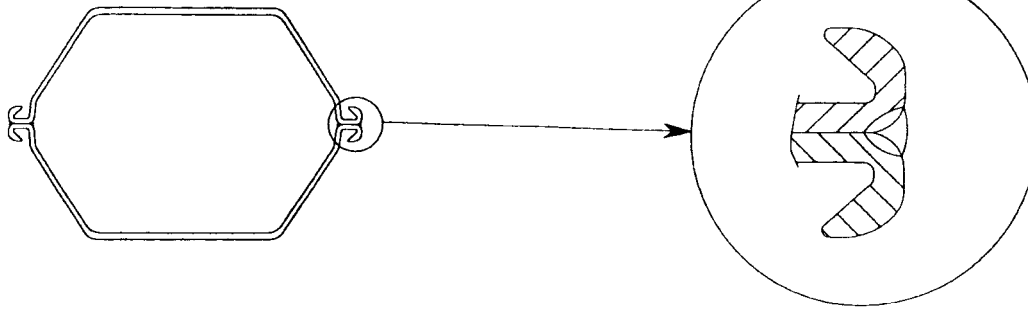


Figure 7k — Butt-joint of box pile

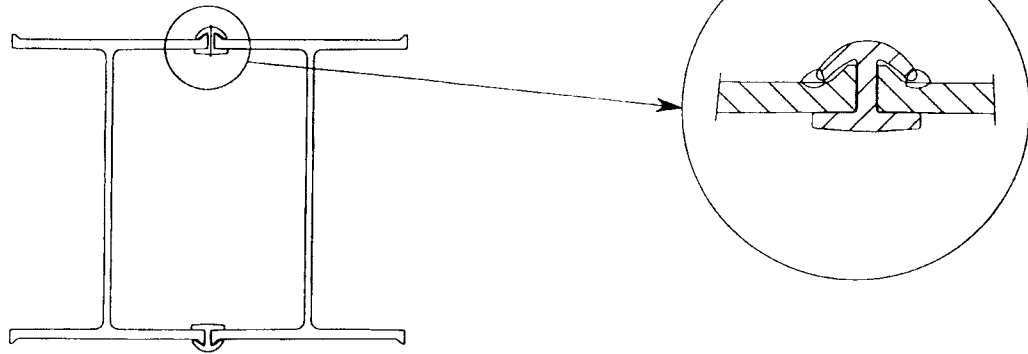
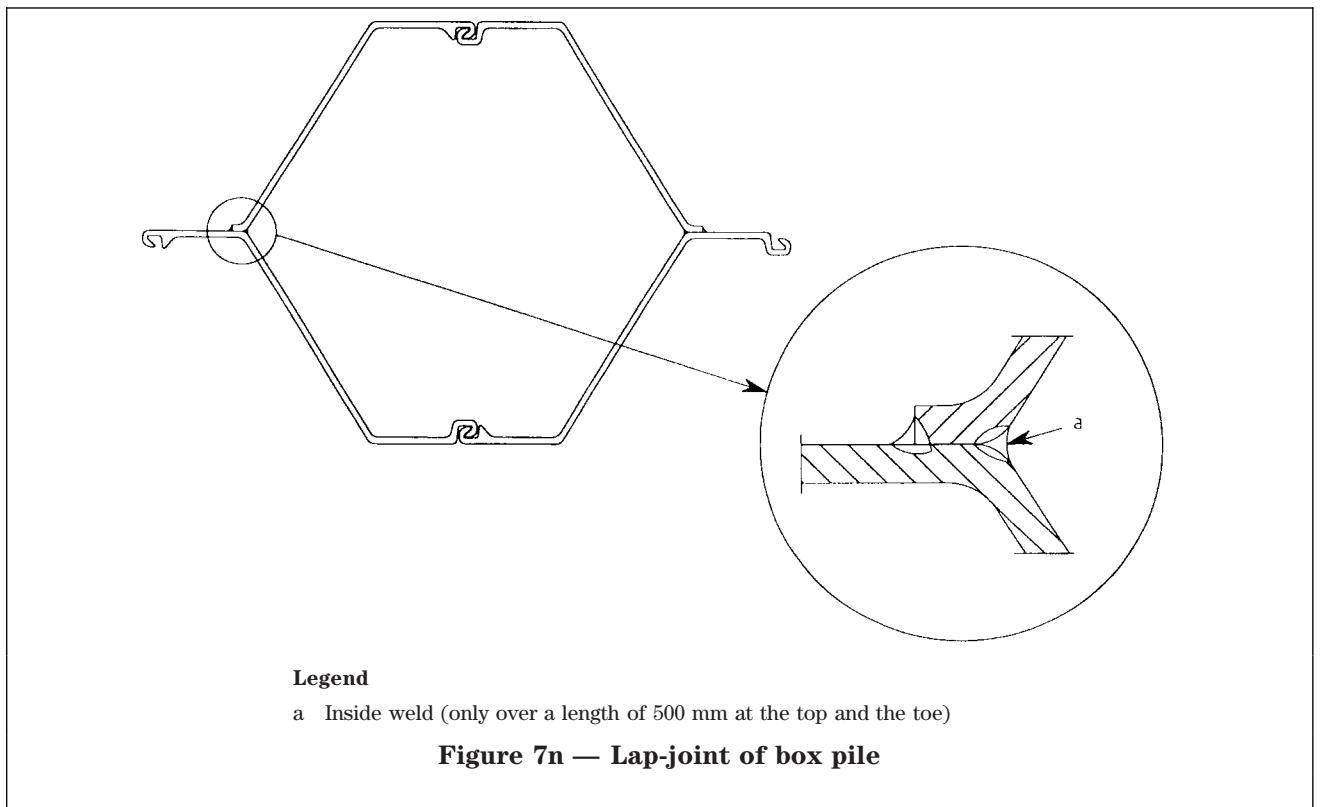
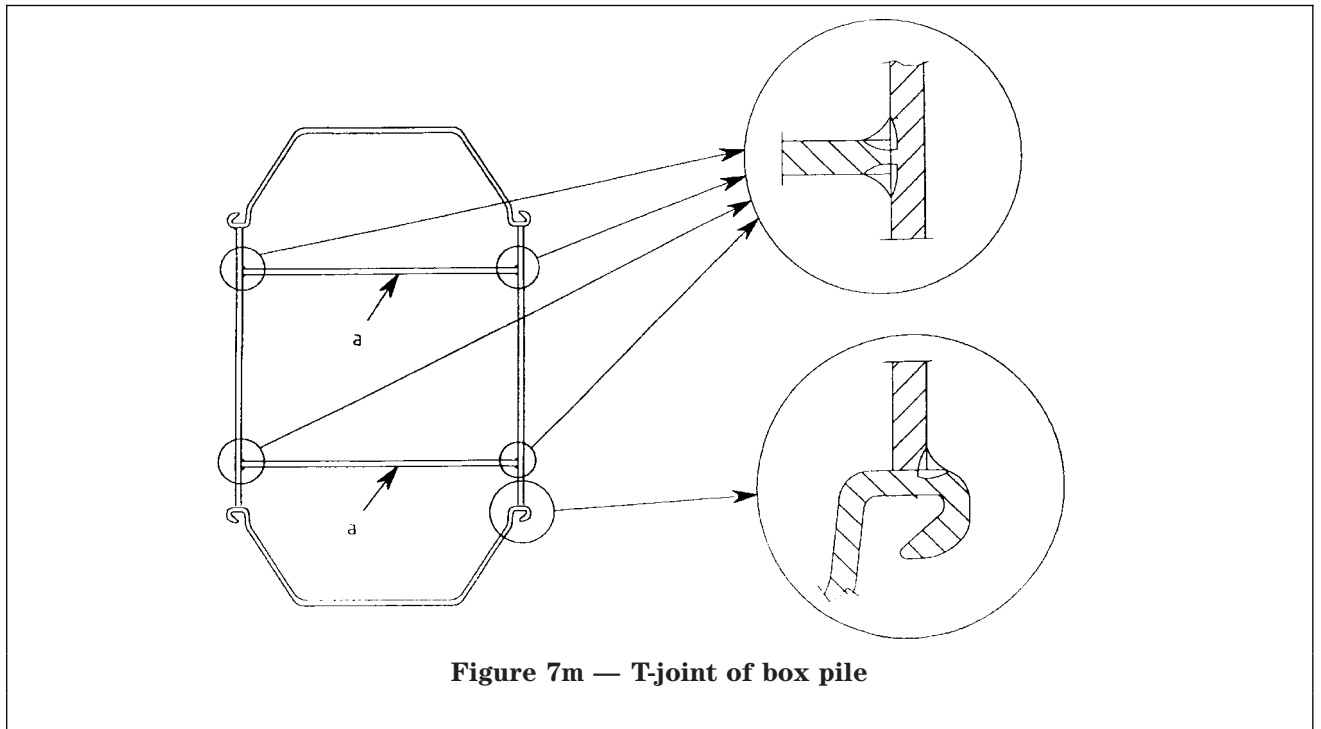


Figure 7l — Lap-joint of box pile



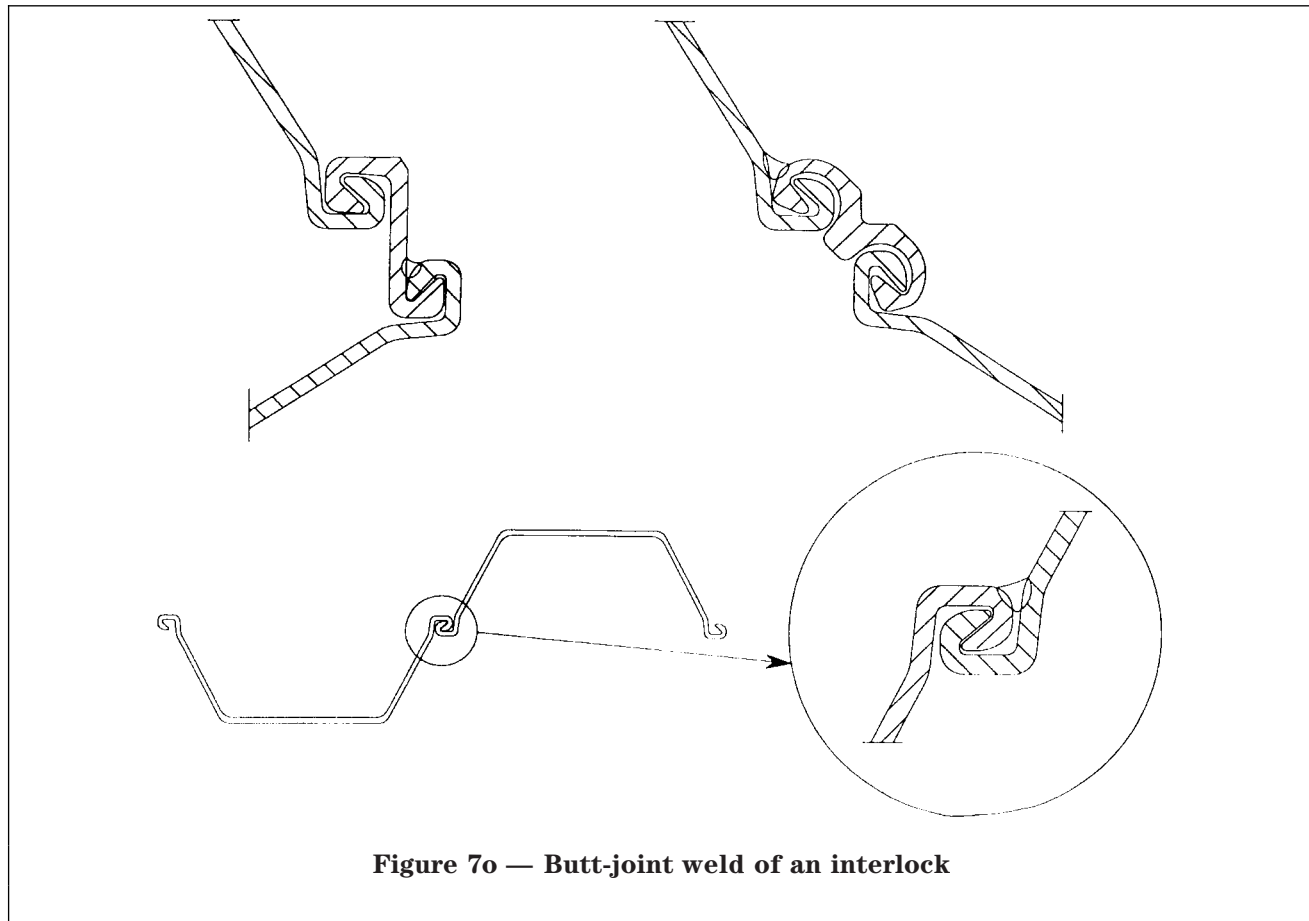


Figure 7o — Butt-joint weld of an interlock

8.4.4 After welding the procedure for checking the position of the connectors on tubular primary elements shall be as follows (see Figure 8):

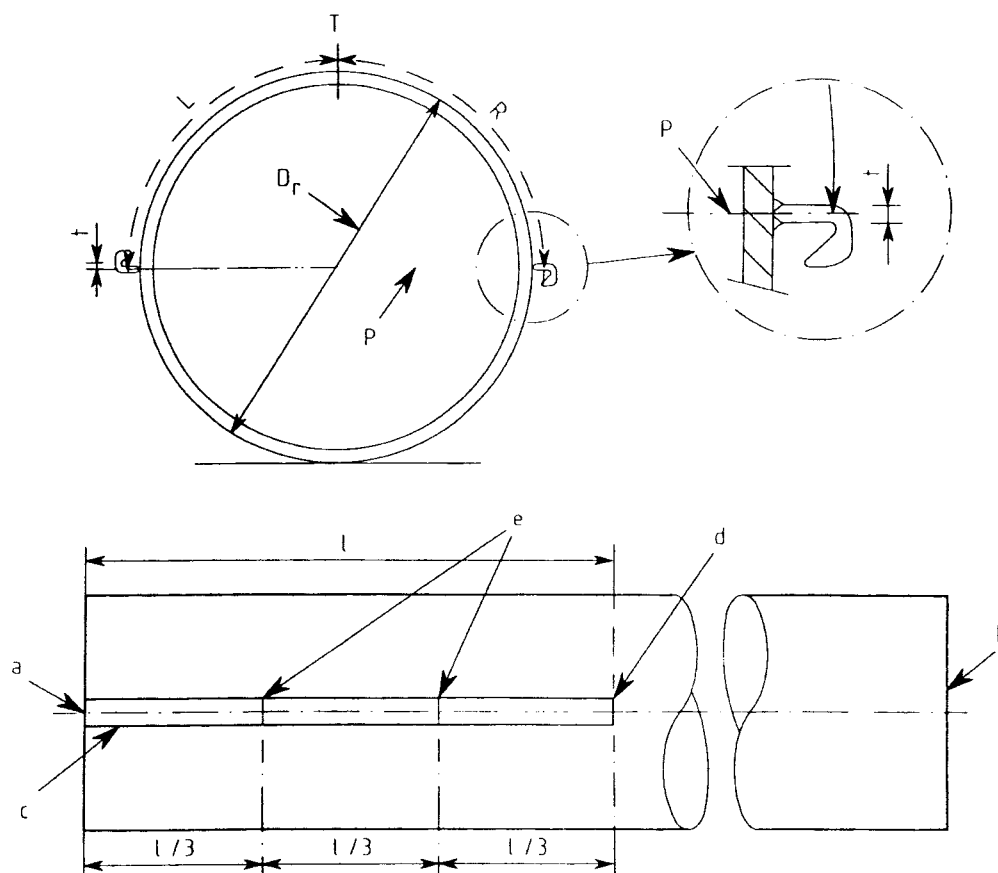
- position the element on a horizontal plane and rotate it such that line P at top end of the element is horizontal;
- by using levelling techniques mark the position T on the element at the third points along the length and at the lower end of the connectors as indicated in Figure 8;
- check compliance with the following tolerances at the top end, the third points and the lower end of the connector:

$$L = (\pi D_r) / (4 \pm 10) \text{ mm};$$

$$R = (\pi D_r) / (4 \pm 10) \text{ mm};$$

L and R are measured along the outer circumference of the element;

D_r is the outside diameter of the primary element at the checked sections.



Legend

- a top of the element and connectors
- b toe of the element
- c connector
- d toe of the connectors
- e third points on the connectors
- l length of the connectors
- T top of the element as established by levelling
- P line connecting the centres of both connectors at top end of the element

Figure 8 — Position of check-points and tolerances of welded connector on a tubular primary element

8.4.5 Electrodes shall be in accordance with EN 499:1994.

8.4.6 The metal deposited by welding shall, as a minimum, have the mechanical characteristics equivalent to those of the base material.

8.4.7 Quality Steel (QS) according to EN 10248-1:1995 and steel grades S420xxx and S460xxx according to EN 10219-1:1997, shall be welded using basic filler metals with low hydrogen. The level of hydrogen in the deposited metal shall be ≤ 10 ml/100 g.

8.4.8 In order to prevent all risks of cracking, preheating temperatures shall take account of the steel carbon equivalent, the welding process and the type of joint.

The temperature of a weld shall be ≤ 250 °C before the next welding pass is started.

Preheating shall extend for at least 75 mm on each side of the weld.

NOTE Preheating temperatures for different thicknesses and steel grades are given in Table B.3.

8.4.9 Special care shall be taken in order to ensure that the stresses and distortion due to the welding are minimized.

8.4.10 Welds of acceptance class D according to EN 25817:1992, shall be carried out by experienced operatives.

8.4.11 Welds of acceptance class C according to EN 25817:1992, shall be carried out by operatives qualified in accordance with EN 287-1:1992 + A1:1997.

8.4.12 The tolerances of sheet piles and primary piles lengthened either by butt welds or by splice plates shall be in accordance with EN 10248-2:1995, EN 10249-2:1995 or EN 10219-2:1997 referred to in clause 2.

8.4.13 The tolerances of strengthened sheet piles and primary elements shall be in accordance with EN 10248-2:1995, EN 10249-2:1995 or EN 10219-2:1997.

8.4.14 The tolerances of corner piles, straight web junction piles, box piles and fabricated primary elements shall be in accordance with EN 10248-2:1995, EN 10249-2:1995 or EN 10219-2:1997.

8.4.15 Where steel sheet piles are to be spliced by butt welding, the interlock may be left unwelded, unless a seal weld is required or if it is specified in the design.

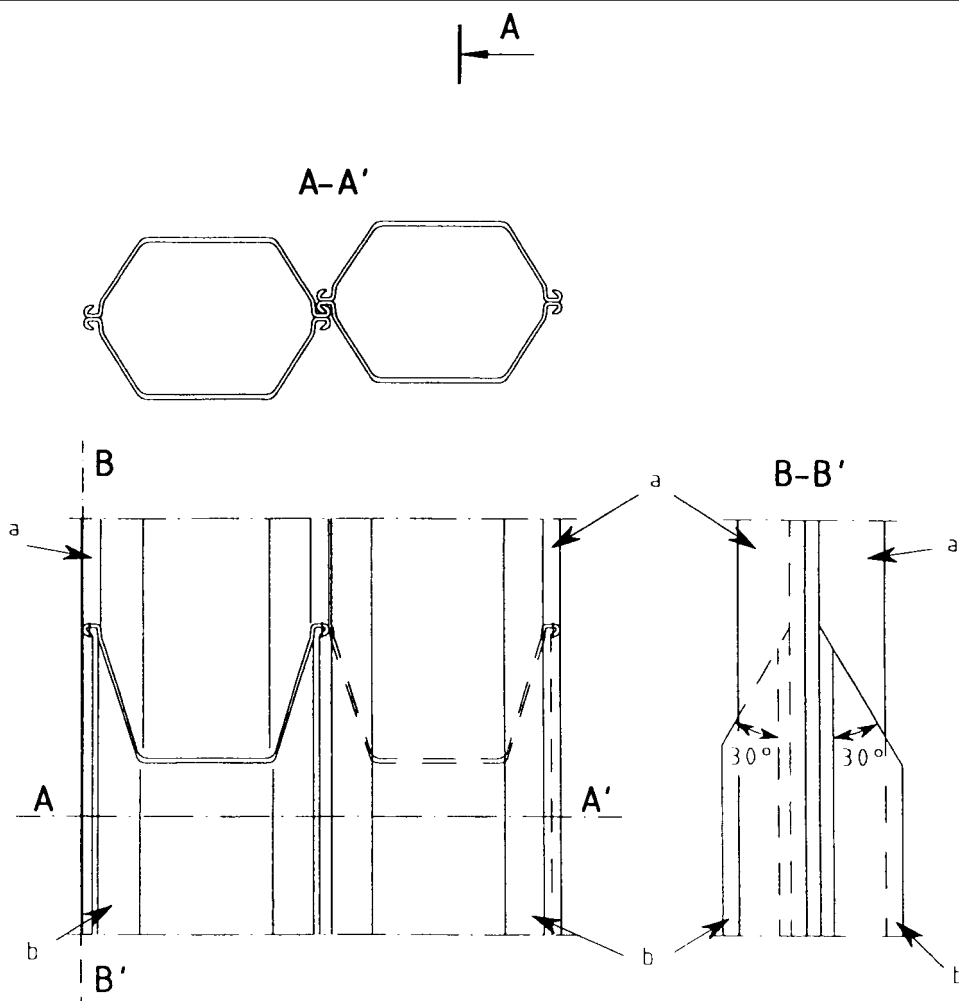
8.4.16 Where possible, butt welds should be located at a position in the pile length which is well removed from the location of the maximum bending-moment section. In addition butt weld positions in adjacent piles should be staggered by at least 0,5 m in the driven wall.

8.4.17 Sheet piles shall not have sudden variations of the section in the longitudinal direction of the pile. Plates, strips, splice plates and partial sheet piles for strengthening, shall be chamfered (see Figure 9).

8.4.18 Testing and inspection of welds shall be in accordance with Table 1.

8.4.19 If strengthening of the sheet pile is specified, the method should take account of the expected driving conditions.

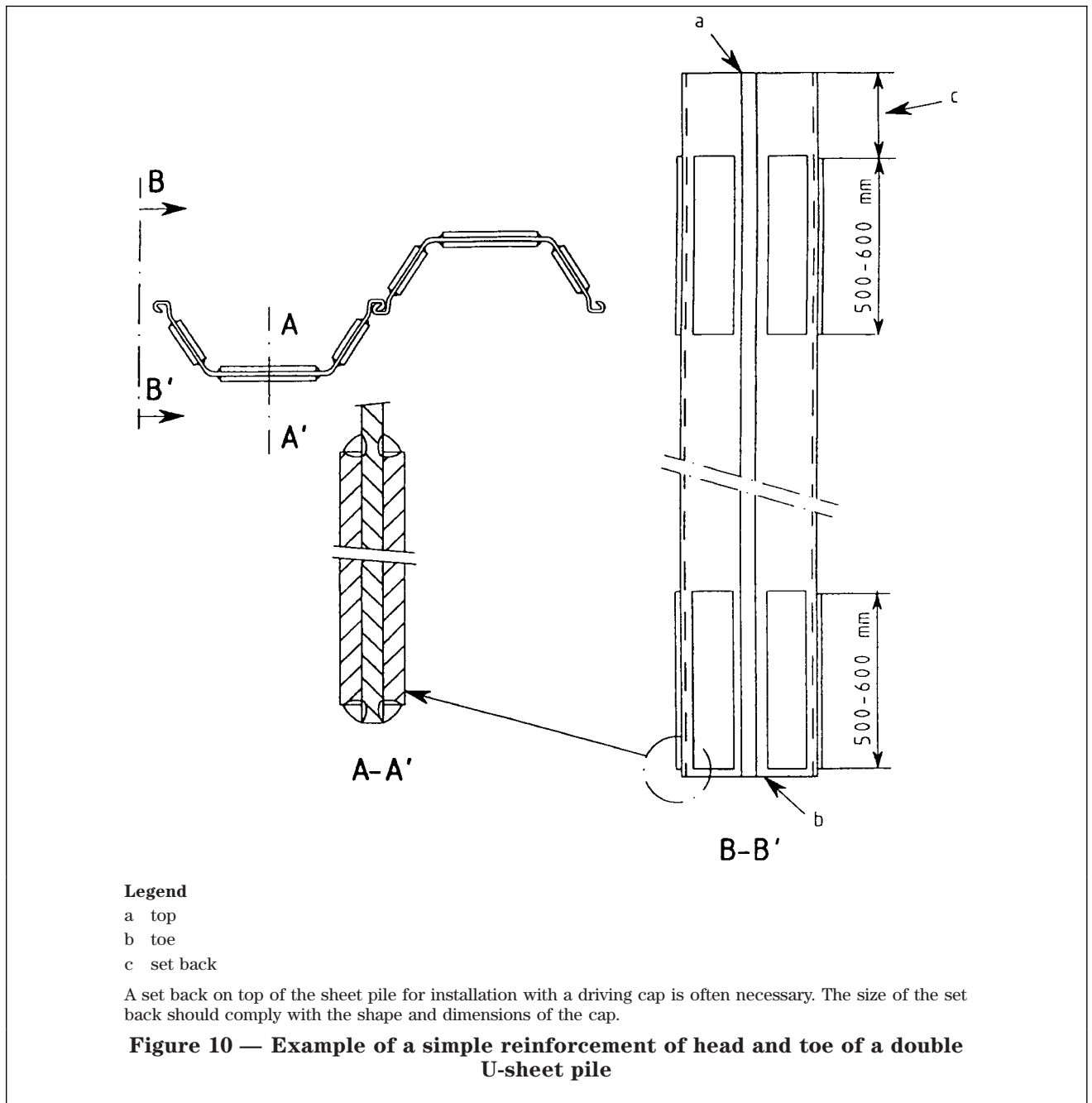
NOTE The strengthening details depend mainly on the presence of obstructions in the soil. Figure 10 gives an example of a simple strengthening method for the head and toe of a double U-pile.



Legend

- a pair of strength sheet piles
- b chamfered partial sheet piles

Figure 9 — Example of strengthening using a chamfered partial sheet pile



8.5 Driving of the sheet piles

8.5.1 The driving method, equipment and assistance shall be selected on the basis of comparable experience and shall comply with the design of the section according to 7.2.1.

8.5.2 When comparable experience does not exist or is considered to be insufficient, driving tests or a mathematical analysis of the driving process should be adopted in order to select the correct driving method (see annex C).

8.5.3 When pressing the sheet piles into the ground, it shall be shown that the capacity of the press and the holding capacity of the previously driven sheet piles (which must deliver the necessary reaction forces) are sufficient. This can be demonstrated either by comparable experience or by tests or analysis on the basis of soils data.

8.5.4 All piling equipment shall comply with EN 996:1995.

8.5.5 It should be verified, either by tests or analysis, that the selected driving method does not cause damage to adjacent buildings and installations (see annex C).

8.5.6 Jetting, pre-drilling or blasting techniques applied to assist driving, shall be carried out in such a way that damage to adjacent buildings, installations and services and to the work itself is unlikely to occur (see annex D).

8.5.7 A suitable driving method shall be selected which ensures that the requirements of the design with respect to the tolerances of the sheet pile wall after driving, will be obtained.

NOTE The following aspects are important:

- achieving the required toe level;
- keeping the plan position and verticality in accordance with 8.6;
- avoiding significant damage to sheet piles and interlocks (de-clutching);
- obtaining the required coefficient of permeability;
- ensuring that the driving forces act along the neutral axis of the sheet piles and the primary elements;
- maintaining the sequence of driving the primary elements for a combined wall;
- obtaining the required vertical bearing capacity, if applicable;
- specifying templates for combined walls and straight web piles.

(see also annex D).

8.5.8 Sheet piles should be guided at one or more levels during driving.

8.5.9 Guide frames should be stable and robust and positioned at such levels so as to ensure the horizontal and vertical alignment of the piles during driving. The guiding system should be designed to avoid damage to the coating on the sheet piles (for example by using guide rolls).

8.5.10 The piles in the driving rig or the guide frame shall be positioned with an accuracy which ensures that the specified tolerances are complied with.

8.5.11 In the case of a closed sheet pile wall, special care shall be taken of the plan position and the verticality of the closing sheet piles.

8.5.12 The sequence for driving primary elements should be selected so that the elements will meet the conditions of 8.6.1.

8.5.13 Driving caps should fit closely to the profile of the pile. Cushion fillings should be checked regularly in accordance with manufacturers' recommendations or the proven experience with the applied materials.

8.5.14 If lubricants or bentonite are used to facilitate driving, the local environmental regulations shall be followed.

8.5.15 Because of the possible considerable reduction of the interlock tensile strength of straight web piles, lubricants shall not be used.

8.5.16 If lubricants are used in the interlocks, they shall be in accordance with the design (see 7.2.2).

8.5.17 In the case of sheet piles having tongue and claw type interlocks, the sheet pile should be driven with the tongue at the leading end (see Figure 11).

8.6 Tolerances regarding plan position and verticality

8.6.1 The plan position and the verticality of the sheet piles after installation should be in accordance with the recommended values given in Table 2. This table gives values for normal cases.

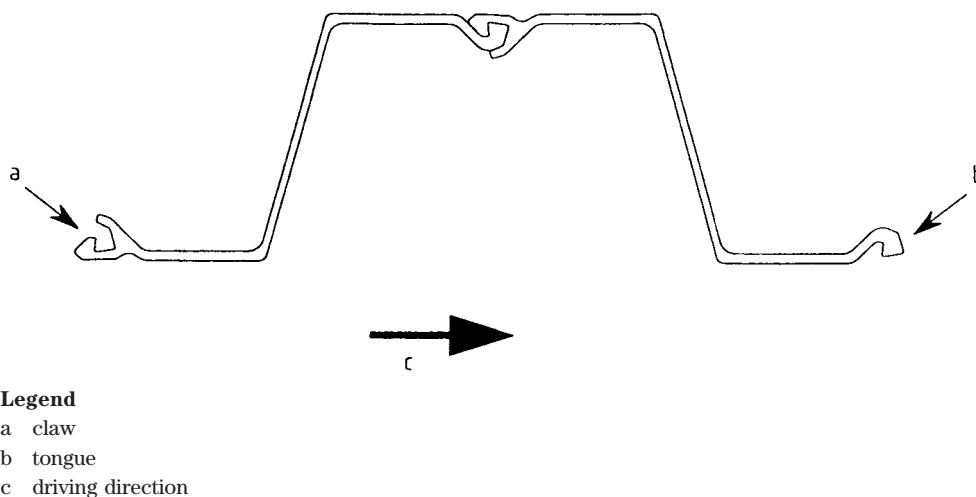


Figure 11 — Driving direction for Z-sheet piles with tongue and claw interlocks

Table 2 — Tolerances of plan position and verticality of the sheet piles after installation

Type of wall	Situation during execution	Plan position of pile top mm	Verticality ²⁾ measured over the top 1 m
			%
			all directions
Sheet pile ⁴⁾	on land over water	≤ 75 ¹⁾ ≤ 100 ¹⁾	≤ 1 ³⁾ $\leq 1,5$ ³⁾
Primary element of combined wall		depending on soil conditions and on length, shape, size and number of secondary elements, these values should be established in each case in order to ensure that de-clutching is not likely to occur	

¹⁾ Perpendicular to the wall.
²⁾ Where the design requires piles to be driven at an inclination, the tolerances specified in the table are with respect to that direction.
³⁾ May amount to 2 % in difficult soils, provided that no strict criteria regarding for example watertightness are specified and de-clutching is not considered to become a problem after excavation.
⁴⁾ Excluding straight web piles.

NOTE The tolerances regarding the position and the verticality may be additive.

8.6.2 For combined walls the requirements with respect to the plan position and verticality of the primary elements are generally very strict and consequently, special measures such as rigid and stable guide frames should be applied.

8.6.3 If the toe levels of the sheet piles and of the primary and secondary elements of a combined wall after driving differ more than 250 mm from the levels specified in the design, it shall be demonstrated that the performance requirements of the design are still satisfied.

8.6.4 If the head levels of sheet piles and of primary and secondary elements after driving differ more than 50 mm from the level which is specified in the design, it should be demonstrated that the performance requirements (e.g. connections with other elements), are still satisfied. If this is not the case, the sheet piles should be made good in accordance with the execution demands.

8.7 Corrections of sheet pile position during driving

8.7.1 When driving in very hard soil layers, the stiffness and stability of the guide frame should receive special attention in order to keep transverse and longitudinal leaning and horizontal displacements of the driven sheet piles within the tolerances given in **8.6.1**.

8.7.2 Chamfering or partial cutting the toe of a steel sheet pile to prevent longitudinal leaning should not be carried out, because of the risk of de-clutching.

8.7.3 If transverse leaning and rotation of a sheet pile occurs during driving, it should be extracted and re-driven unless other measures are sufficient.

8.7.4 If longitudinal leaning of the sheet piles occurs during driving, immediate action to counteract this should be taken, for example by pushing or pulling.

8.8 Installation of anchorages

8.8.1 The position, direction and execution of the anchorages including the connection to the walings shall correspond with the specifications in the design.

8.8.2 The nature of the material and the compaction of fill shall correspond with the requirements of the design and shall be in accordance with clause 5 of ENV 1997-1:1994.

8.8.3 Ground anchorages shall be installed in accordance with the specification given in prEN 1537.

8.8.4 If tension piles are used for the anchorage of a sheet pile wall, the execution shall be in accordance with **7.7.2.2** of ENV 1997-1:1994.

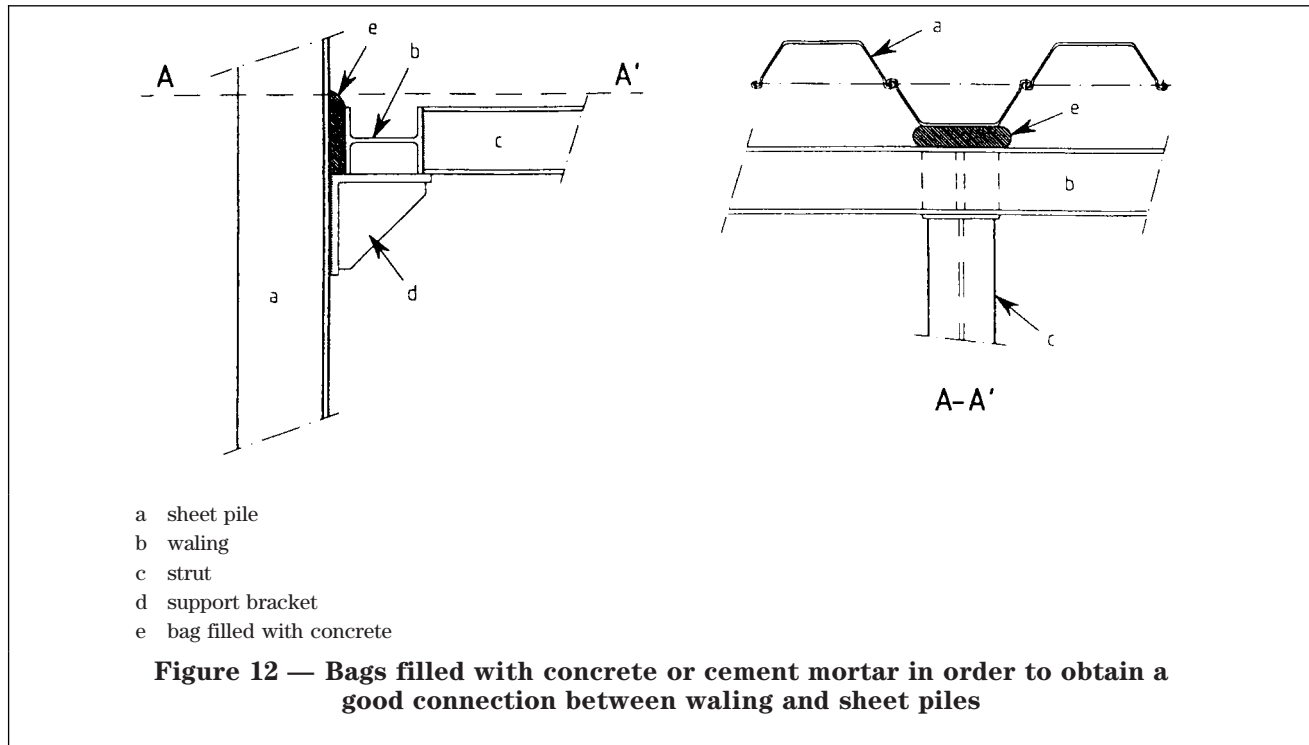
8.8.5 Consideration shall be given to sealing the anchorage holes in the sheet piles to prevent loss of soil and seepage of water.

8.9 Walings and struts

8.9.1 Walings and struts shall be constructed and installed to comply with **7.3.1**.

8.9.2 Gaps which occur between the sheet piles and waling shall be filled to ensure uniform load distribution to the waling.

NOTE Fillings between sheet pile and waling may be plates or wedges of steel, wood or plastic. Bags filled with concrete or cement mortar may also be used (see Figure 12).



8.10 Excavation, filling, drainage and de-watering

8.10.1 Excavation, filling, draining and de-watering shall be carried out with appropriate care and shall be in accordance with the design specifications.

NOTE In the case of excavation by dredging, the tolerances in the levels can be rather large. The dredging accuracy depends on the following:

- type of dredger;
- type of soil;
- water depth and wave characteristics.

De-watering prior to sheet pile driving introduces higher effective stresses in the soil which may adversely affect the subsequent installation.

8.10.2 The excavation and filling shall not cause damage to the parts of the sheet pile wall structure already installed.

8.11 Extraction of sheet piles

8.11.1 When extracting sheet piles the following shall be considered:

- vertical and horizontal deformations in the surrounding ground;
- the possibility of short cutting different groundwater regimes.

NOTE In particular, cohesive soils can adhere to the pile sides thereby creating voids in the ground when the piles are extracted.

In loose sands and silts, vibrations and voids may cause ground displacements which can cause damage to nearby buildings and installations. Such ground displacements and possible links between groundwater regimes can be avoided by injecting the voids with cement-grout or similar, simultaneously with pulling.

8.11.2 Where sheet piles are close to sensitive structures, chemical plants, sensitive infra-structural services, underground railways etc., the extraction shall be carried out with particular care.

8.11.3 The handling and transport of sheet piles to be re-used, shall be in accordance with the requirements of 8.3.

8.12 Rock dowels and anchor bolts

Examples of rock dowels and anchor bolts are shown in Figure 13.

8.12.1 When the application of rock dowels is necessary, a suitable tube shall be properly attached to the piles to ensure the correct positioning of the dowel in the rock.

8.12.2 The bottom 0,5 m of the installation tube should be protected or strengthened to avoid deformations.

8.12.3 The installation tube for the rock dowel shall end 50 mm above the toe of the sheet pile.

8.12.4 The tube shall be closed at the bottom end by a plug, normally of concrete.

8.12.5 The dowel shall be anchored to the rock by grouting the hole.

8.12.6 To verify that rock dowels will meet the requirement of the design, the gap between the toe of the sheet pile and the rock level shall be determined with an accuracy of 40 mm.

8.12.7 If rock excavation is carried out close to the toe of the sheet piles, the toe shall be secured in accordance with the design or by other measures, such as inclined anchor bolts as shown in Figure 13.

8.13 Sealing

When soft clay overlies bed-rock, the openings between the toe of the sheet piles and the rock shall be sealed in accordance with the design requirements.

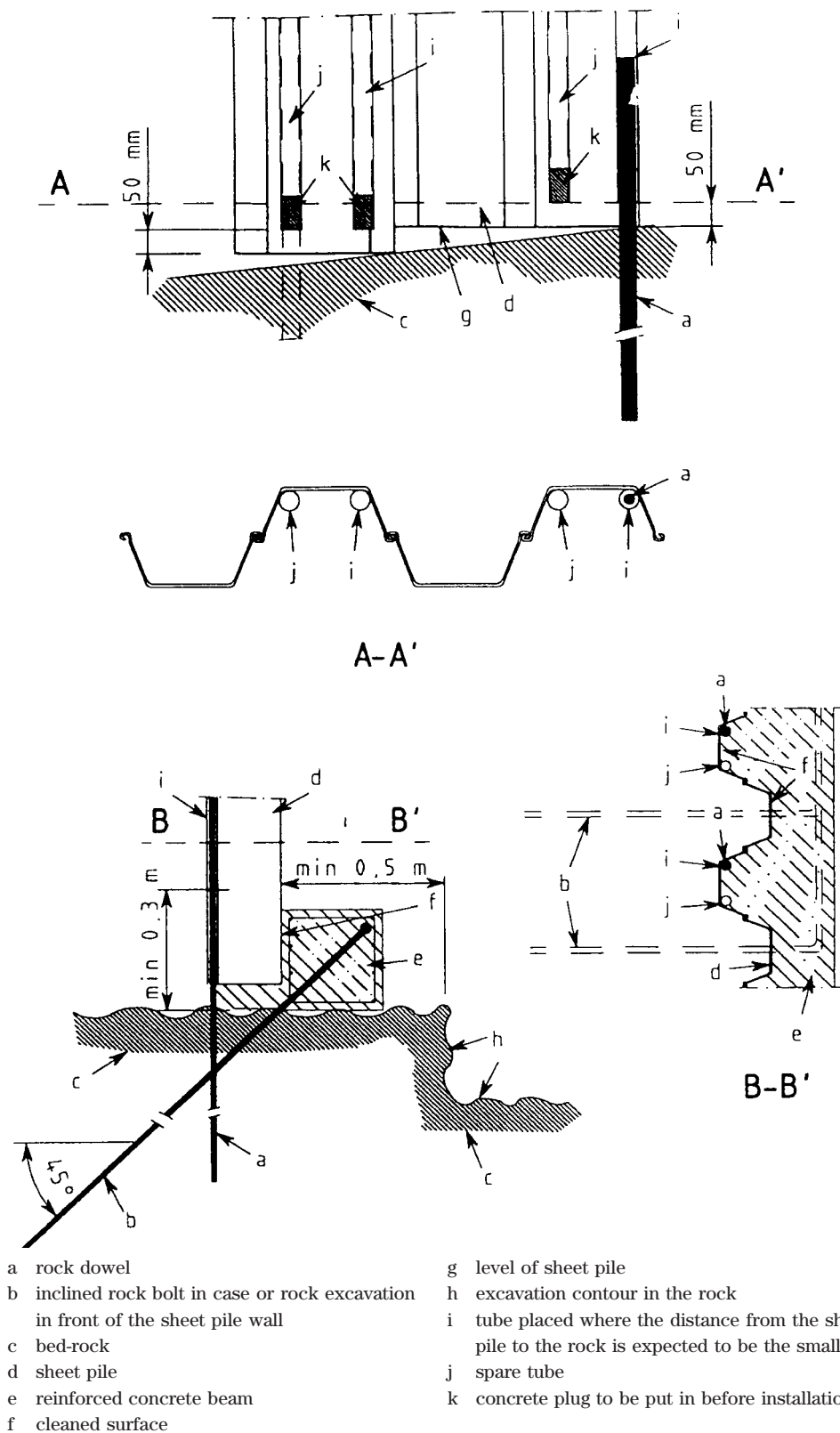


Figure 13 — Example of a rock dowel with and without an inclined rock anchor bolt

9 Supervision, testing and monitoring

9.1 Supervision

9.1.1 A schedule for the supervision should be available at the construction site. In this schedule as a minimum the following shall be noted:

- frequency of the different checks;
- critical values of the deformations, forces and water levels.

9.1.2 As a minimum the supervision of all works connected with the execution of the sheet pile wall structure shall be in accordance with clause 4 of ENV 1997-1:1994.

9.1.3 Supervision shall also include, if applicable, the following checks and observations:

- are site conditions, soils, groundwater and free water in accordance with the data of the design;
- are there any obstructions in the ground which hinder the sheet pile driving and which were unforeseen at the design stage;
- is the driving method capable of installing the sheet piles in accordance with the design and environmental requirements;
- does the sequence and method of execution comply with the execution scheme and are the criteria regarding the progression from one stage to the next as stated in the scheme (see 7.4);
- are the primary and secondary elements for a combined wall properly stored and handled;
- do the sheet piles, primary and secondary elements and all other structural elements for a combined wall fulfil the requirements referred to in clause 6;
- are treatments, materials and products used for protection of the steel elements and the preservation of wooden parts, in accordance with 6.4;
- are templates and other devices for guiding the piles during driving, well positioned and sufficiently stable to ensure that the piles will meet the tolerances specified in 8.6;
- is the verticality during positioning and driving of the primary elements of a combined wall checked with sufficiently accurate instruments;
- are sheet piles, primary and secondary elements for a combined wall within the tolerances specified in 8.6;
- are the positions of the elements of the anchorages in accordance with the design;
- are the surcharges behind the sheet pile wall within the calculated limits at all stages of the execution;
- is there any damage to nearby buildings, installations or underground services which could be attributed to the execution works;
- during the execution works, have any events occurred which have an adverse effect on the quality of the structure?

9.2 Testing

9.2.1 Soil tests shall be carried out in accordance with clause 3 of ENV 1997-1:1994.

9.2.2 Load tests on sheet piles, primary and secondary elements, should comply with 7.5 of ENV 1997-1:1994.

9.3 Monitoring

9.3.1 The rate of penetration of at least some of the piles should be recorded in order to establish whether the soil conditions comply with those assumed in the design.

9.3.2 Where piles are designed to carry vertical loads, the rate of penetration shall be recorded over at least the last metre of driving, unless the sheet piles are placed in or on bed-rock. In that case, in order to establish that the sheet piles have reached the required depth, monitoring shall be carried out in accordance with the requirements of the design.

9.3.3 If groundwater and free water levels are critical parameters according to the design, they shall be monitored at time intervals which are short enough to obtain a reliable pattern of these levels.

9.3.4 It is recommended that the monitoring of the groundwater levels or pore pressures are continued after the completion of the works until it is established that no adverse effects will occur.

9.3.5 Where the project is situated in a built-up area, the vibration and noise levels at the construction site and at the most exposed buildings should be recorded periodically. Such measurements should be done in accordance with local practice in order to compare the results with criteria which are appropriate for the area.

9.3.6 The horizontal displacements of the top of the sheet pile wall should be periodically measured with appropriate accuracy at predefined points in such a way that the results can be compared with the expected design values.

9.3.7 Where sensitive buildings or installations are close to the sheet pile wall structure, in addition to the measures described in 9.3.6, at least the following should be considered:

- displacement measurements at selected depth;
- settlement measurements of these buildings and installations;
- anchor force measurements.

9.3.8 When driving a combined wall, de-clutching detectors should be applied to at least some of the secondary elements. This should be done in combination with recording the rate of penetration over the full depth such that the driving diagram can be used as a control to check possible de-clutching.

NOTE Monitoring the rate of penetration of the sheet piles under difficult circumstances often gives only an approximate indication regarding possible de-clutching. De-clutching detectors can be useful to verify the integrity of the sheet pile wall after completion.

9.3.9 During the extraction of sheet piles or primary elements, the extraction time should be recorded for each pile or element. For some of them the ground displacements should be measured.

10 Site records

10.1 Records in connection with the execution

For permanent sheet pile wall structures, site records concerning all particulars during the supervision, testing and monitoring as described in clause 9, shall be available at the construction site.

10.2 Records at completion of the execution works

In the final site records the following shall be included:

- the “as built” position of the sheet pile wall structure relative to fixed reference points or lines including auxiliary structures which remain in the ground;
- list with important information regarding use, maintenance and inspection of the structure;
- information prescribed in the design report with respect to groundwater levels and pore-water pressures;
- particular directives regarding management after completion of the work if deemed necessary because of observations made during the execution;
- directives for the maintenance of drainage systems, methods to be used and frequency;
- surcharge restrictions behind the wall;
- displacements of the sheet pile wall during execution;
- events which had an adverse effect on the execution and how these effects were dealt with;
- damage records of nearby buildings;
- driving and load test results.

11 Special requirements

11.1 Safety

11.1.1 During the execution of the sheet pile wall structure, the European and national standards, specifications or statutory requirements regarding safety, shall be respected.

11.1.2 Equipment shall be in accordance with EN 996:1995.

11.2 Impact on the surrounding buildings and installations

When in the vicinity of the construction site, there are structures and installations which are vulnerable to constructional damage, the conditions of these structures shall be carefully observed and documented prior to the execution works.

During sheet pile driving or extraction by impact or vibrators, the relevant buildings shall be monitored regularly.

11.3 Noise hindrance

Special precautions shall be taken to ensure that the noise loads do not exceed the limit prescribed by international or national directives.

11.4 Permeability of sheet pile walls

11.4.1 Procedures for reducing the permeability of sheet pile walls and the tests, if required, shall be selected in accordance with the design.

11.4.2 When very strict requirements regarding the permeability of the sheet pile walls are specified in the design, it shall be shown that all activities, materials and procedures, deemed necessary to satisfy these requirements, are in conformity with the performance criteria specified in the design. When no comparable experience is available, representative tests on sealed interlocks shall be carried out, demonstrating that the proposed method satisfies the specified discharge requirements (see annex E).

Annex A (informative)

Handling and storage of sheet piles

A.1 General

Inappropriate handling and inadequate storage of sheet piles, especially of straight web piles are often the cause of problems during installation. Misuse may also cause damage to pre-coatings on sheet piles. When installing sheet piles safe access should be provided for a site operative to guide the toe of the pile being pitched into the top of the previously installed pile.

The use of threading devices which enable the piles to be interlocked without the assistance of persons on the top level is advised.

A.2 Hoisting

In Figure A.1 some examples are given of hoisting and placing nested stacks of sheet piles (single and pairs) at the storage area.

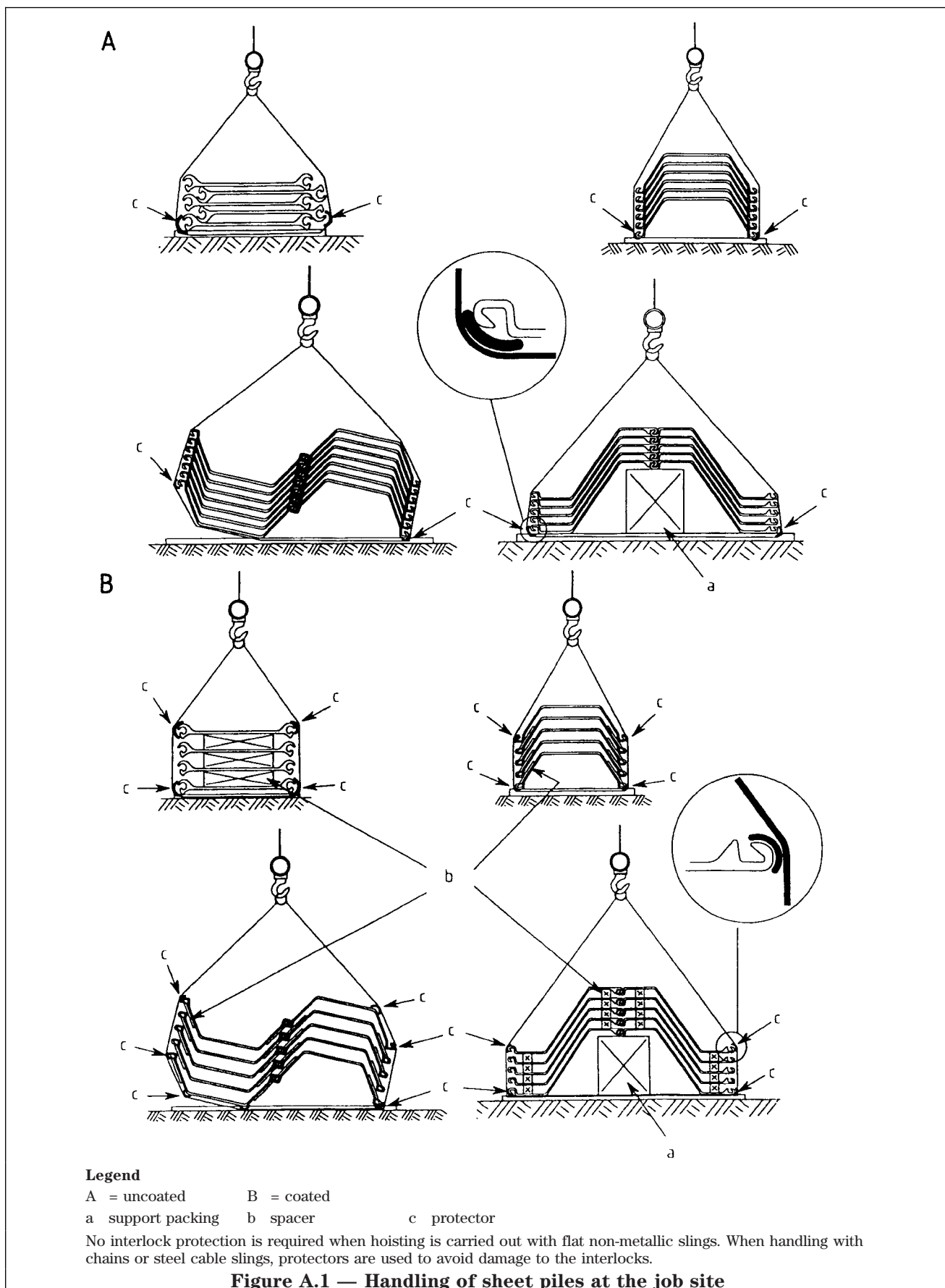
Figures A.2 to A.4 show examples of how to lift sheet piles from a nested stack.

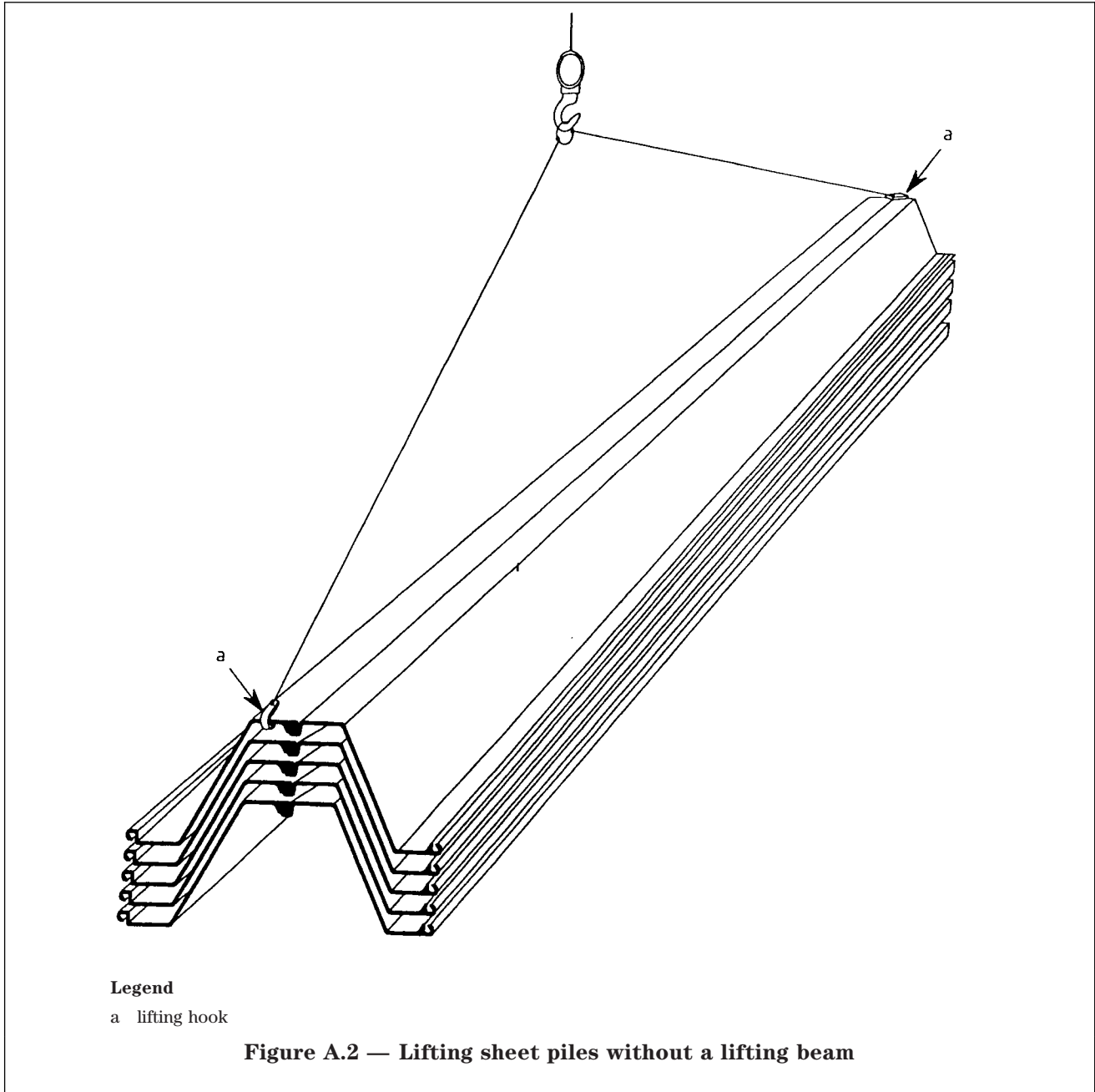
A.3 Storage

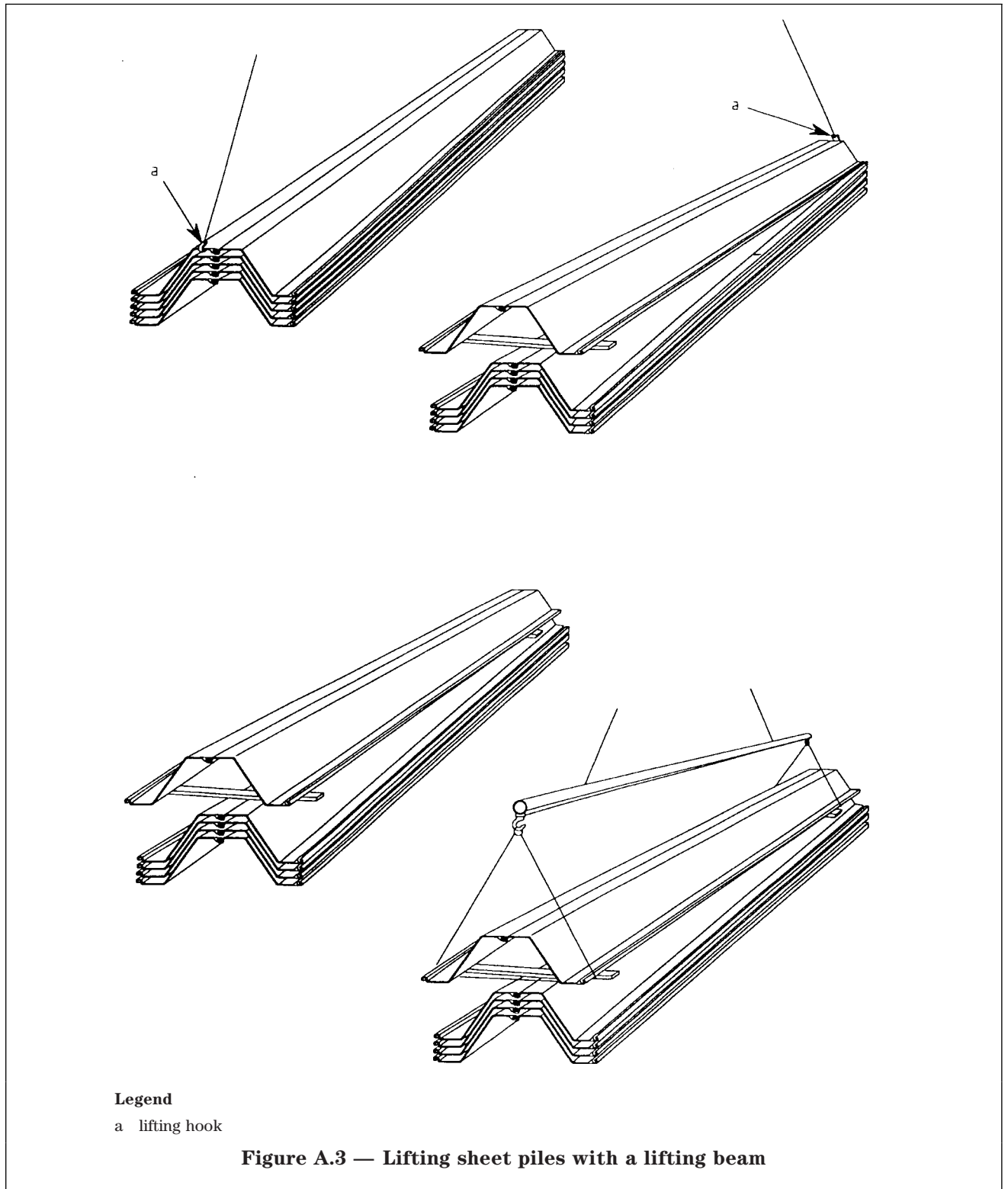
Figures A.5 and A.6 give examples of how to stack sheet piles at the storage area. If the ground surface of the storage area is not level and firm, the stacks should be supported adequately on timber dunnage or similar devices, in order to minimize sagging.

A.4 Special devices

Figure A.7 shows an example of the use of a shackle for lifting a sheet pile from a stack. Figure A.8 shows an example of the use of a sheet pile threader for pitching a sheet pile in the interlock of the previously pitched pile at high level when panel driving. This process eliminates the requirement for a man at the top of the panel to pitch the piles.

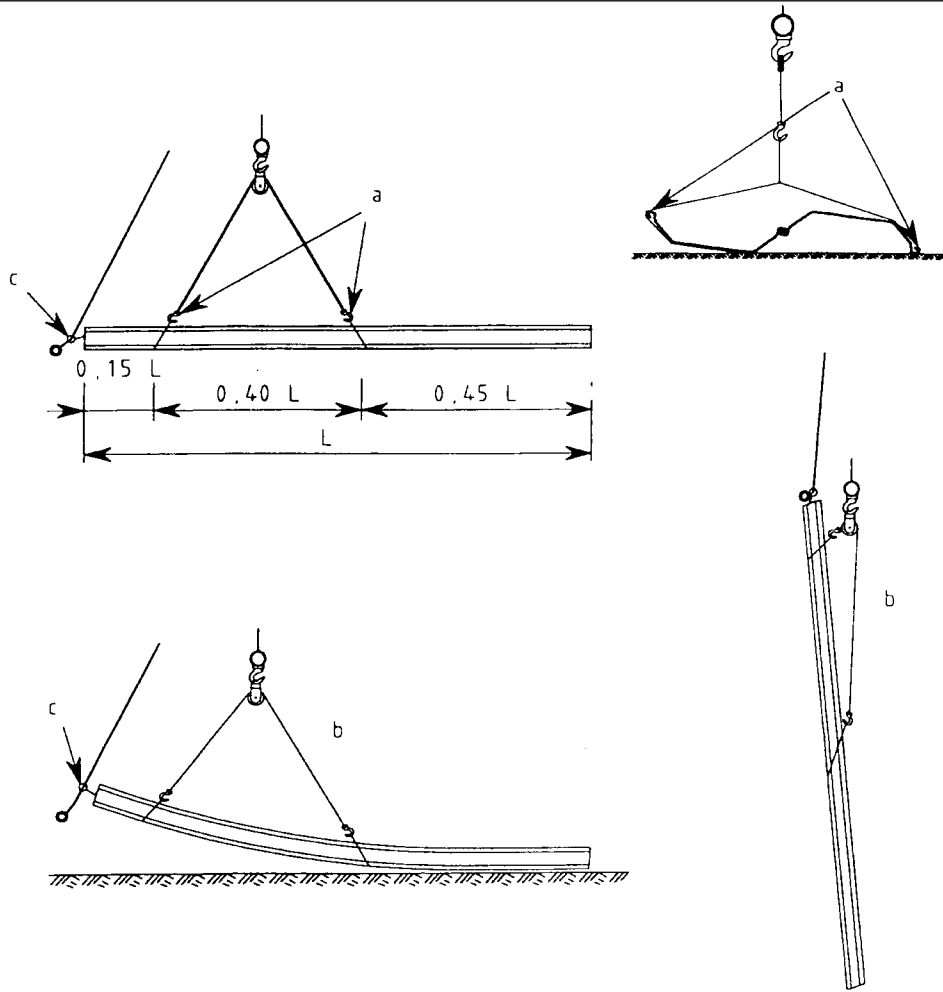






Legend
a lifting hook

Figure A.3 — Lifting sheet piles with a lifting beam

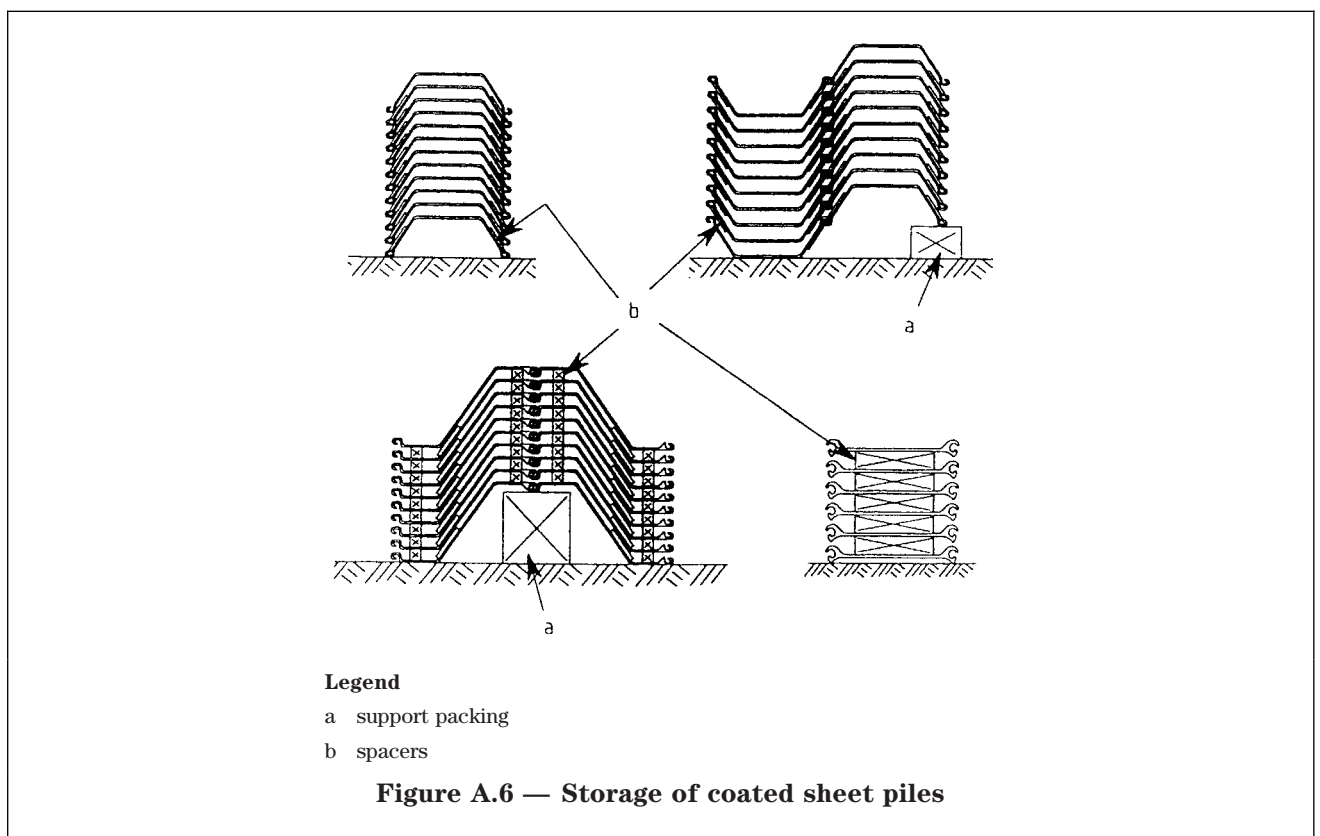
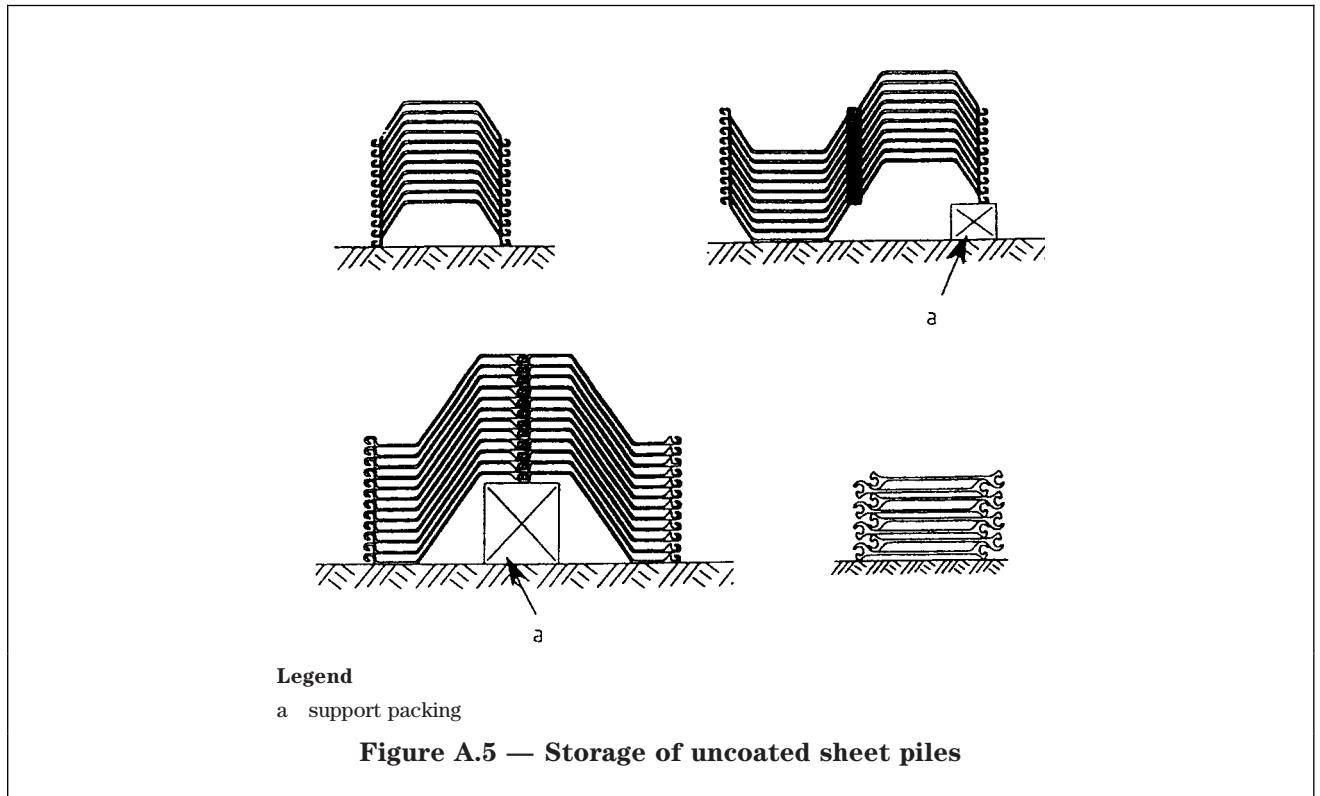


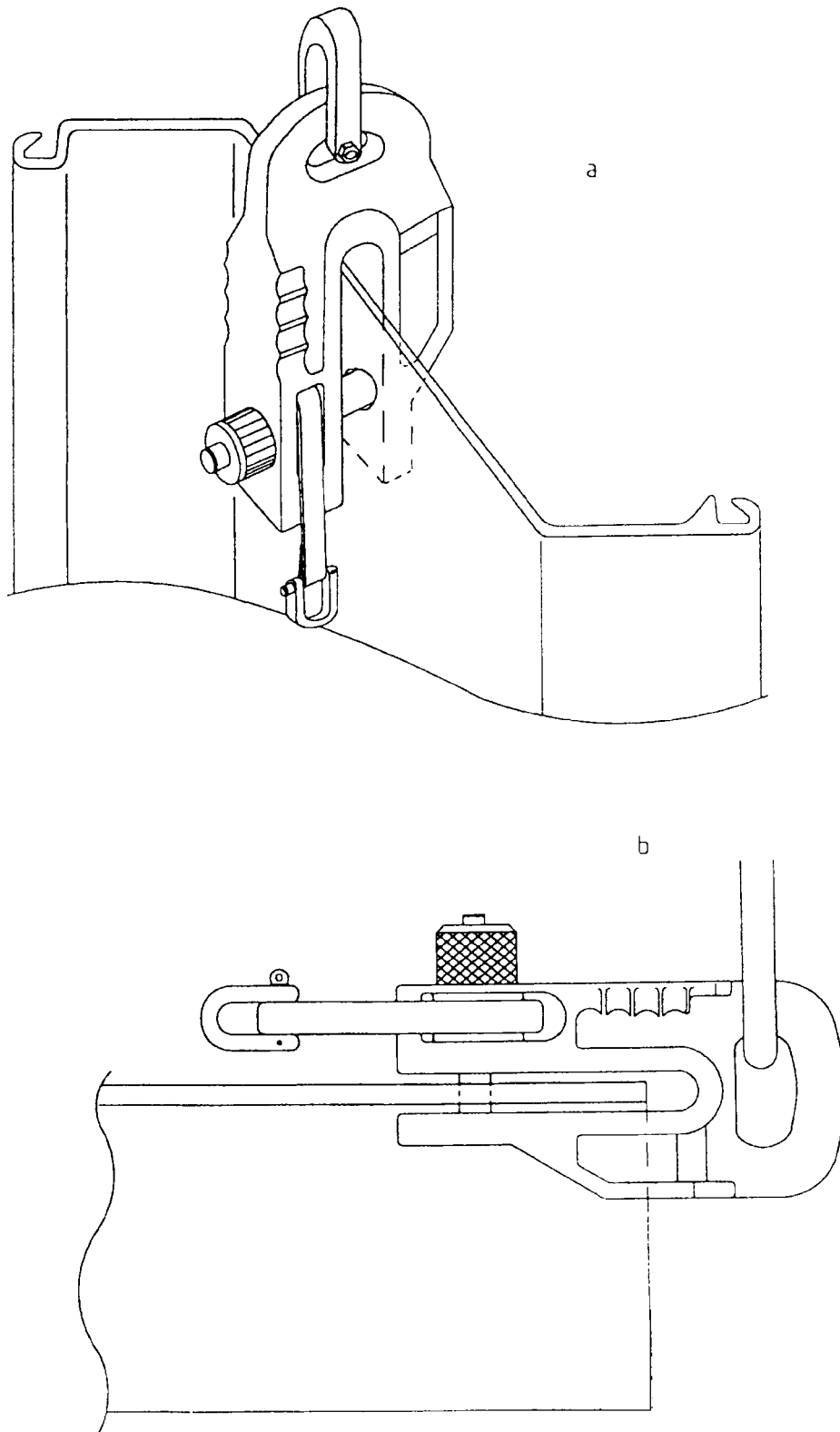
Legend

- a points of support
- b lifting operation
- c fastening in the handling hole

Two hoist lines are needed

Figure A.4 — Lifting procedure for long sheet piles of low section modulus

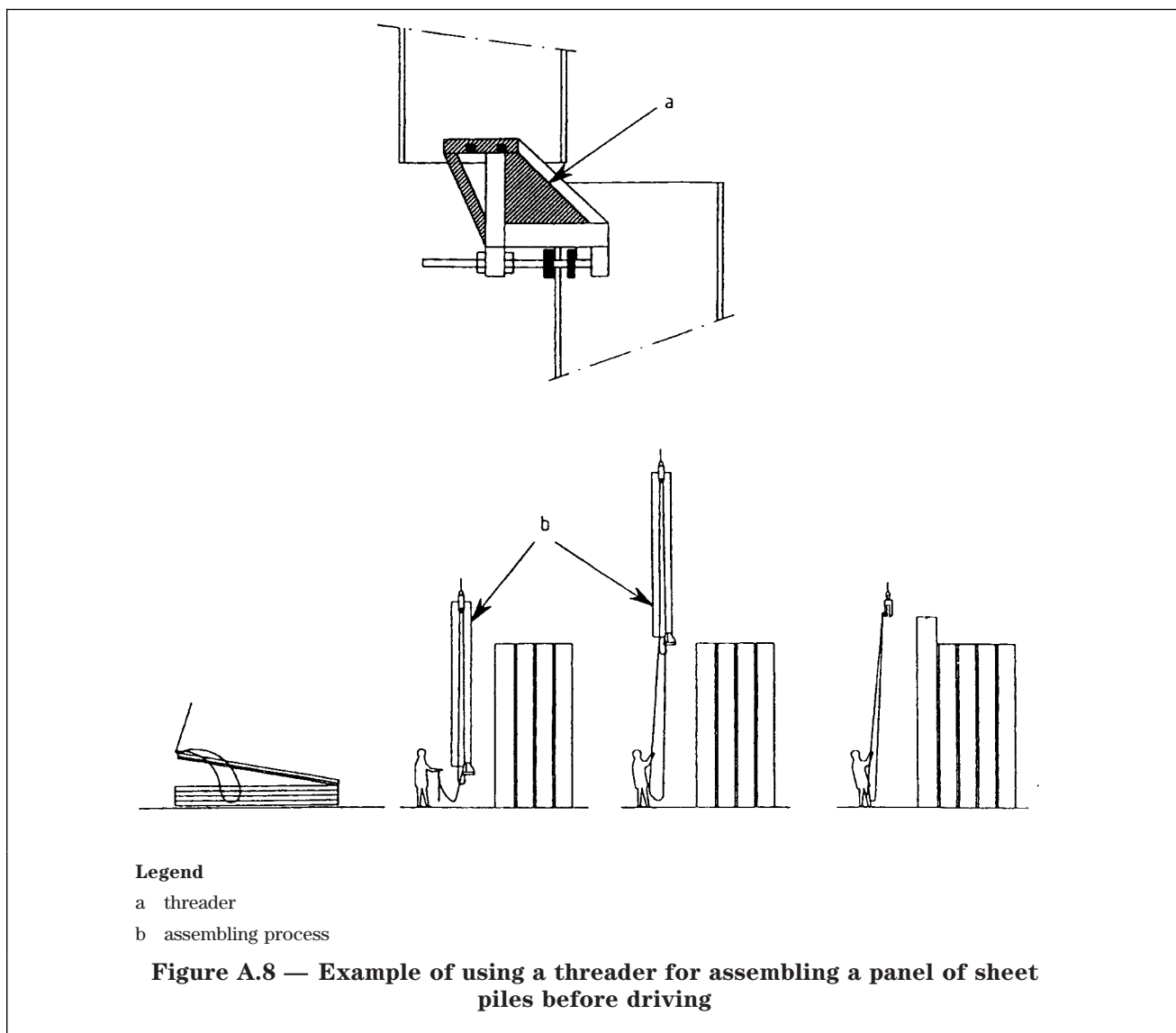




Legend

- a lifting axially
- b lifting at an angle of 90° to the axis of the sheet pile

Figure A.7 — Example of using a shackle for lifting a sheet pile from a stack



Annex B (informative)

Welding of sheet piles

B.1 General

During the execution of a sheet pile wall structure, welding will be frequently used at the site for joining steel elements together.

Information regarding the following important items is given in this annex:

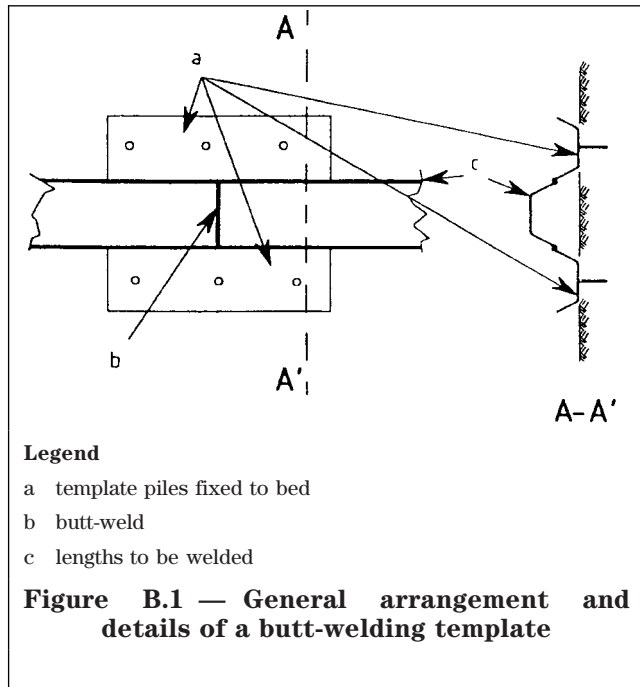
- butt-welding multiple lengths;
- splicing with plates (fish plates);
- junction piles for joining a part wall element to the main wall;
- special corner piles;
- straight web junction piles;
- box piles;
- sealing welds.

B.2 Butt-welding multiple lengths

The preparation of normal butt-joints is carried out in accordance with 8.4.

Manufacturing tolerances mean that piles of the same section size can have several millimetres difference in width and height. Care is necessary to ensure that interlocks are aligned at the joints. Alignment can be achieved by construction of a template into which the ends of piles to be joined can be entered prior to welding. The laying out bed should also be provided with supports to ensure overall straightness of the resulting spliced pile. In Figure B.1 the general arrangement and the detail of a butt-welding template is shown.

The welds are completed across the full width of the pile except for the interlocks. The pile is then removed from the template so that the welds can be completed. It is important to avoid weld metal being deposited on the inner faces of the interlocks. This should be carefully checked before the piles are used.



B.3 Welding multiple lengths by splicing with plates

When lengthening is carried out by means of plates, which are welded to the ends of both sheet piles, it is important to ensure that the forces that have to be transmitted, are distributed as evenly as possible over the cross-section of the sheet piles.

Figure B.2 shows two examples for splicing a double Z-pile and a single U-pile. The use of tapered plates reduces the risk of cracking at sharp edges due to stress concentrations.

The splice plates must be welded around their entire perimeter. It is necessary to check that this is carried out in accordance with the requirements of 8.4.

B.4 Junction piles (U and Z-piles) for joining a part wall element to the main wall

B.4.1 General

Figure B.3 shows a junction pile consisting of a double Z-sheet pile with a sheet pile off-cut.

The inserted angle section as shown in the figure, may alternatively be omitted.

B.4.2 Type of welding

Welds D.1 and D.2 are intermittent welds with an effective weld thickness a_{eff} of 5 mm to 6 mm, the total length of the intermittent weld being 30 % of the pile length, meaning 3 welds of 100 mm each per metre.

When there exists a possibility of serious corrosion, a continuous sealing weld may be necessary between the intermittent welds.

B.4.3 Assembly and welding procedure for the junction pile

- prepare and straighten the off-cut clutch; assemble the off-cut clutch and angle section on horizontal supports;
- tack weld over the whole length;
- apply the final welds (100 mm in length), commencing in the centre of the assembly (over a distance of about 1 m), then apply the final welds at both ends of the assembly over a distance of about 1 m;
- apply the final welds (100 mm in length) in the intermediate portions of the assembly in a back step procedure, starting from the centre and moving towards the ends;
- during welding operations welds D.1 and D.2 are applied in a staggered sequence as indicated in Figure B.3;
- if the off-cut clutch deforms during welding, straighten it prior to subsequent operations with a torch or a press;

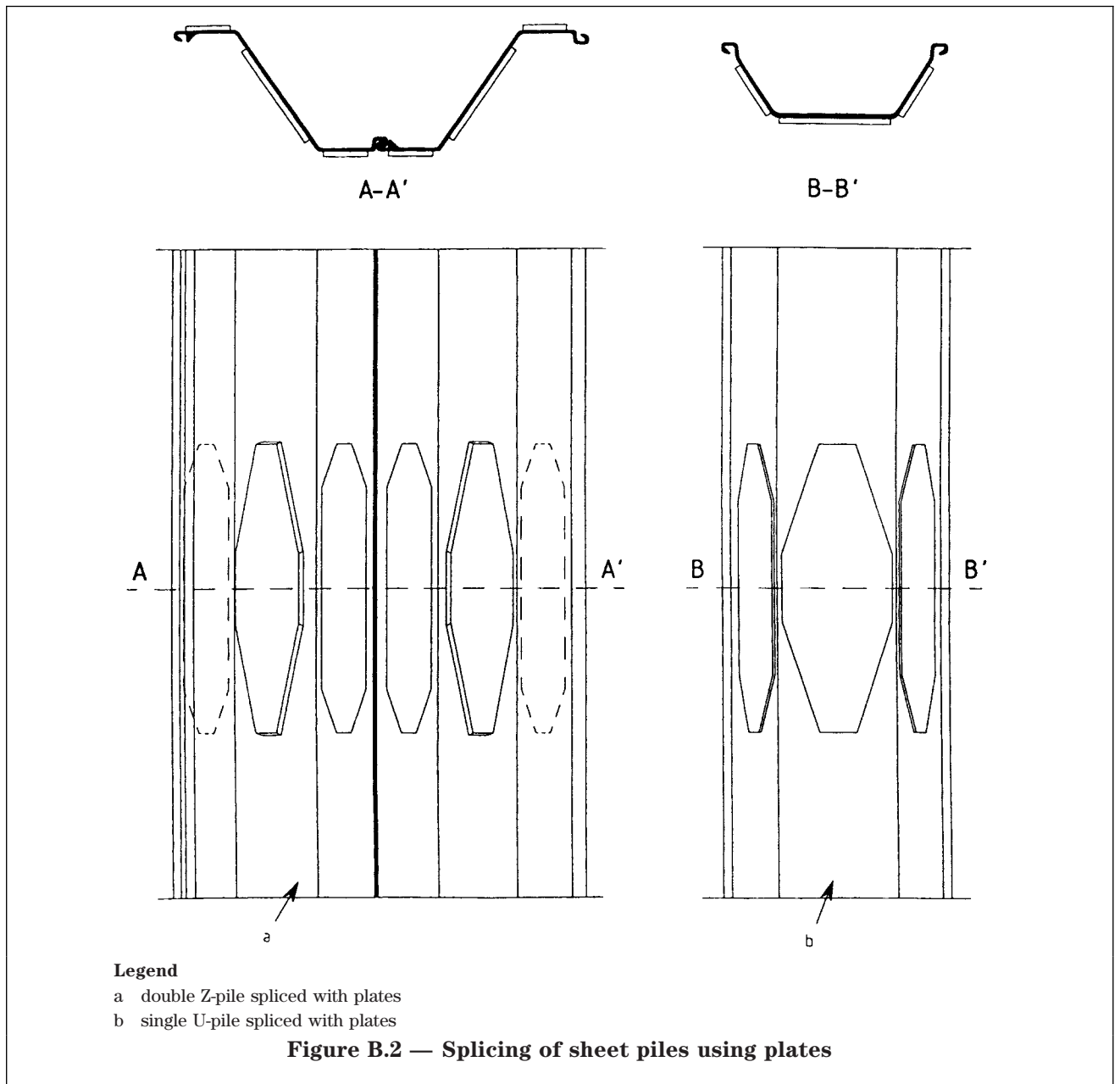
— assemble the off-cut clutch/angle section connector and the sheet pile on horizontal supports. Generally the welded on section does not extend to the top of the special pile to allow for pile driving using a cap or clamps;

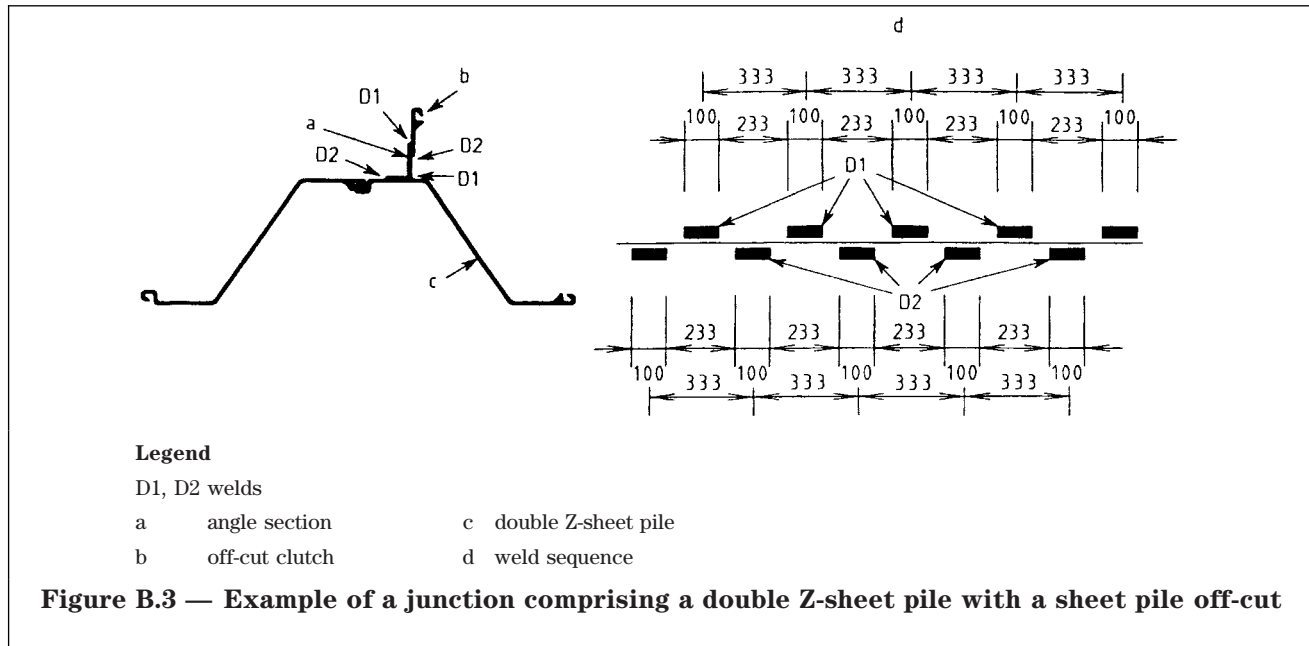
- tack weld over the whole length;
- apply the final welds (100 mm in length) commencing in the centre of the assembly (over a distance of about 1 m), then apply the final welds at both ends over a distance of about 1 m;
- apply the final welds (100 mm in length) in the intermediate portions of the assembly in a back step procedure starting from the centre and moving towards the ends of the pile;
- during the welding operations welds D.1 and D.2 are applied in a staggered sequence as indicated in Figure B.3;
- if the pile deforms during welding, straighten it with a torch or a press.

B.4.4 Welding filler materials

In 8.4 the characteristics of the selected filler metals are given.

For guidance on gas-shielded metal-arc welding and submerged arc welding, see Tables B.1 and B.2.





B.5 Special corner piles

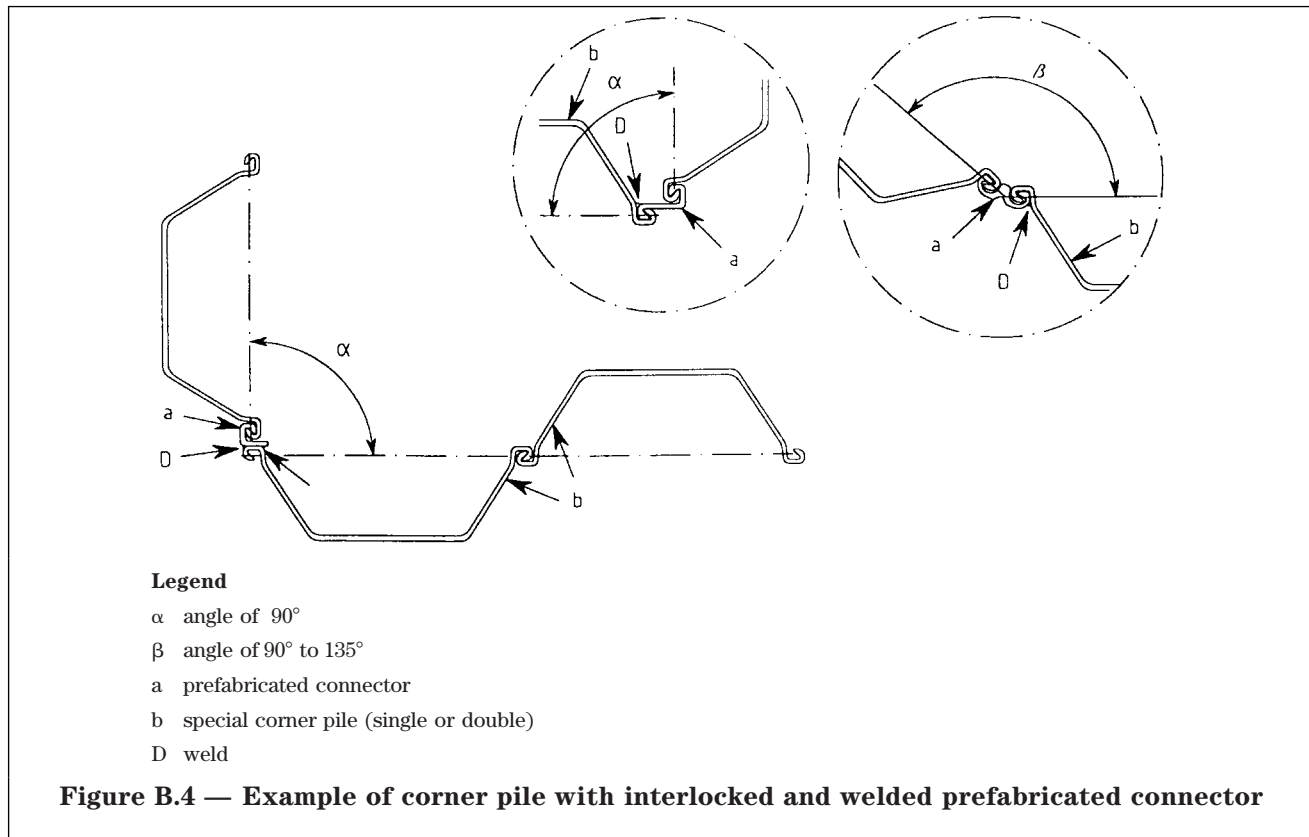
B.5.1 General

Figure B.4 shows examples of the construction of special corner piles by welding a prefabricated connector to the sheet pile.

B.5.2 Type of welding

Weld D: intermittent weld with an effective weld thickness a_{eff} of 5 mm to 6 mm. Total length of the intermittent weld being 30 % of the sheet pile length meaning three welds of 100 mm each per metre of sheet pile.

When there exists a possibility of serious corrosion, a continuous sealing weld may be necessary between the intermittent welds.



B.5.3 Assembly and welding procedure for the corner pile

- assemble the prefabricated connector and the sheet pile on horizontal supports. Generally the corner sections do not extend to the top of the special pile in order to allow for driving with a cap or clamps;
- position the connector at the appropriate angle (possible angles are 90° or from 90° to 135°);
- tack weld over the whole length;
- apply the final welds according to the procedure described for the junction pile.

B.5.4 Welding filler metals

As for junction piles (according to B.4.4).

B.6 Straight web junction piles**B.6.1 General**

Fabrication of straight web junction piles is carried out by welding, special connectors or by bolting.

Figures B.5 and B.6 show examples of the fabrication by welding and special connectors.

B.6.2 Type of welding for straight web junction piles

The weld is continuous with an effective weld thickness as shown in Figure B.5.

B.6.3 Assembly and welding procedure for the straight web junction pile

The working procedure is as follows (see Figure B.5):

- prepare and straighten either one or the three sheet pile off-cut(s). Generally the width of the off-cut(s) is half the width of a complete sheet pile;
- when necessary chamfer the off-cut(s);
- assemble the off-cut(s) and a complete sheet pile or the round bar on horizontal supports. The connecting angle α is normally 35° to 45°, the angle γ , 120°;
- tack weld the off-cut(s) over the whole length of the complete sheet pile or the round bar;
- weld P₁: first weld at both ends, then in the centre of the junction pile length (over a length of about 1 000 mm). Then start the intermediate weld P₁ at the centre and move by the back step method towards the ends of the junction pile (length of each pass about 1 000 mm);
- first weld P₂: weld each off-cut over the whole length at one side and then over the whole length at the opposite site;
- if the junction pile deforms during welding, straighten it with a torch or a press.

B.6.4 Welding filler materials

According to B.4.4 (junction piles).

B.7 Box piles**B.7.1 General**

Figure B.8 shows an example of a box pile made out of two U-type sheet piles.

B.7.2 Type of welding

Weld “C”: external continuous longitudinal weld with an effective weld thickness which is in accordance with the design ($a_{\text{eff}} \geq 5$ mm to 9 mm, depending on the thickness of the sheet pile section).

Weld “R”: internal longitudinal weld with an effective weld thickness $a_{\text{eff}} \geq 5$ mm normally over a length of 500 mm at the top and bottom of the box pile.

B.7.3 Assembly and welding procedure for a box pile

Stages for assembling and welding are:

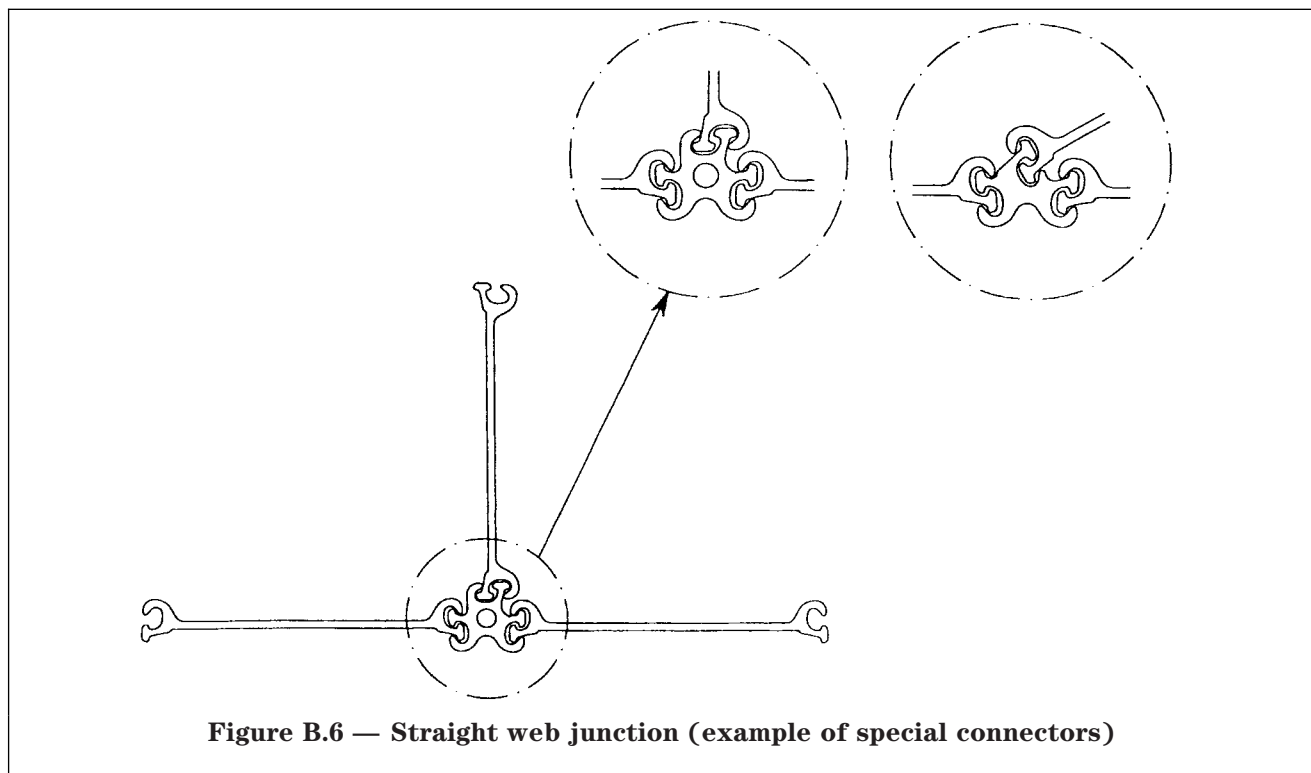
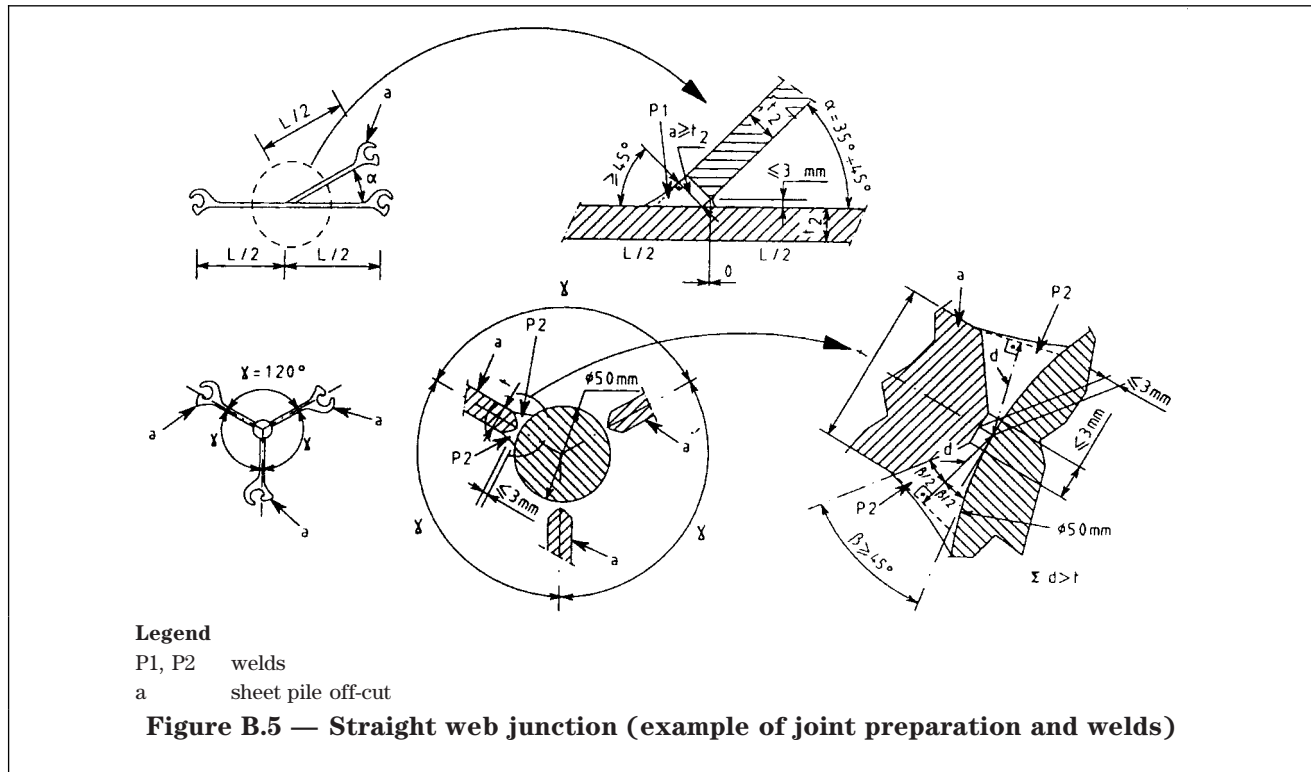
- assemble the two single piles on horizontal supports;
- adjust any differences in width of the sheet piles with a chain-wrench or other means (see Figure B.7);
- tack weld over the whole length;
- apply welds “R” at both ends of the box pile (see Figure B.8);
- apply welds “C” over a length of about 1 000 mm, first at each end, then in the centre of the box pile (see Figure B.8);
- finish weld “C” by the back step method from the centre towards the ends of the box pile (length of each pass about 1 m);
- if the box pile deforms during welding, straighten it with a torch or a press.

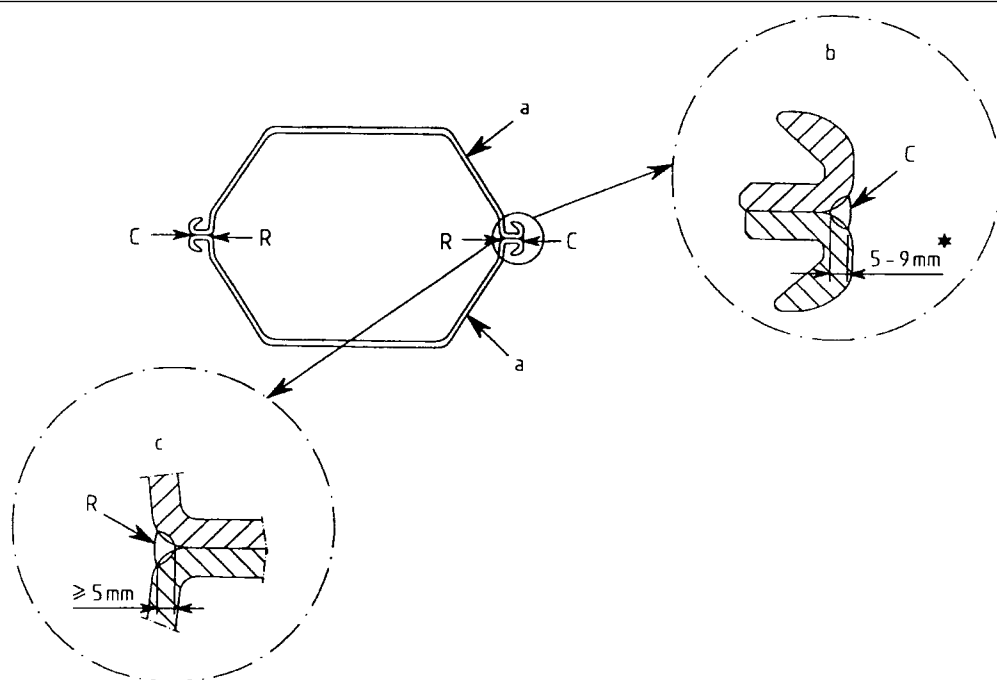
B.7.4 Welding filler metals

As for junction piles in accordance with B.4.4.

B.8 Sealing welds

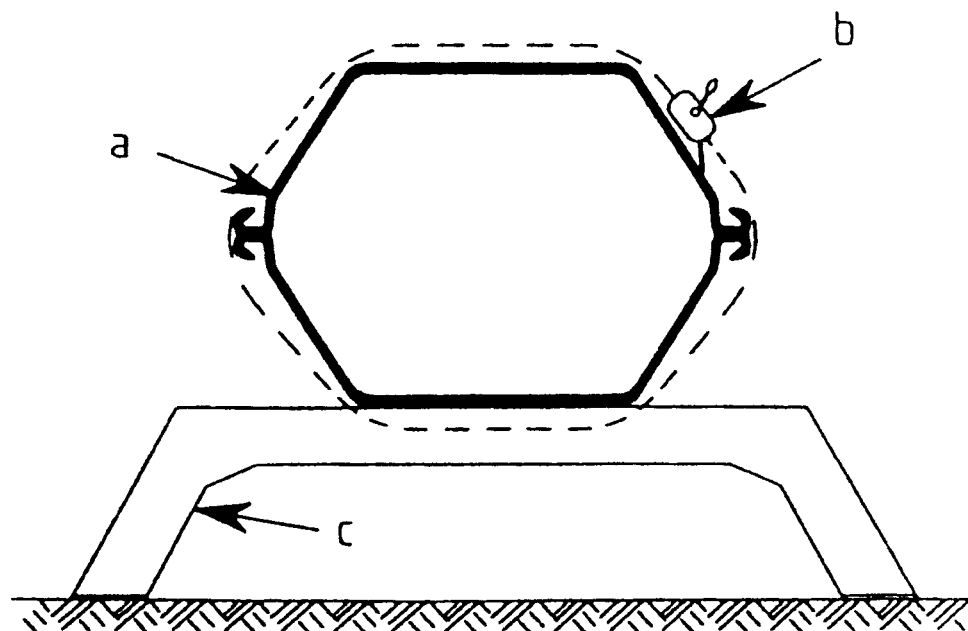
An example of sealing by welding is shown in Figure B.9.





- a U-box pile
- b chain pull
- c assembling support

Figure B.7 — Example of normal assembly equipment for U-box piles



Legend

- * in accordance with the design
- a single pile
- b detail of "C" weld
- c detail of "R" weld (length: normally 500 mm on top and toe)

Figure B.8 — Box pile contiguous interlocks

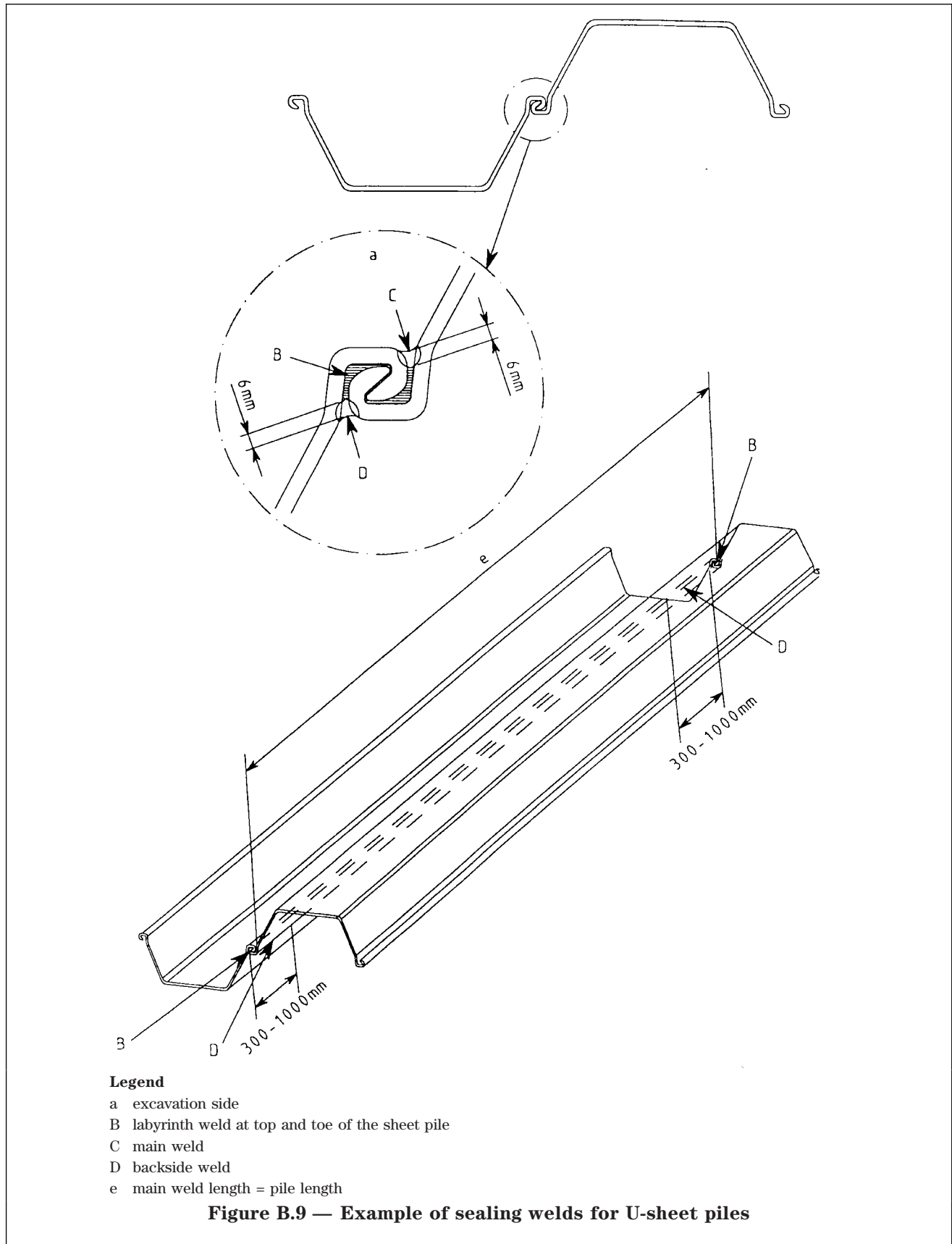


Table B.1 — Recommended filler metal for gas-shielded metal-arc welding

Steel grade hot-rolled EN 10248-1:1995	Steel grade cold formed EN 10249-1:1995	Steel grade tubes for primary elements EN 10219-1:1997, Tables A.1, B.1 and B.2	EN 440:1994
S240GP S270GP S320GP S355GP S390GP S430GP	S235JRC S275JRC S355JOC	S235xxx S275xxx — S355xxx — S420xxx S460xxx	G2Si G2Si G2Si G2Si G3Si1 G3Si1 G3Si1

Table B.2 — Recommended filler metal for submerged arc welding

Steel grade hot rolled EN 10248-1:1995	Steel grade cold formed EN 10249-1:1995	Steel grade tubes for primary elements EN 10219-1:1997, Tables A.1, B.1 and B.2	EN 756:1995
S240GP S270GP S320GP S355GP S390GP S430GP	S235JRC S275JRC S355JOC	S235xxx S275xxx — S355xxx — S420xxx S460xxx	S1 S1 S2 S2Si S4 S2Ni 1

Table B.3 — Preheating temperature for the welding of steel sheet piles (°C)

Steel grades acc. to EN 10248-1:1995 EN 10249-1:1995	S 240 GP S 270 GP S 235 JRC S 275 JRC	S 320 GP S 355 GP S 355 JOC		S 390 GP S 430 GP	
EN 10219-1:1997	S 235xxx S 275xxx	S 355xxx		S 420xxx S 460xxx	
Welding energy	≥ 15 < 25 kJ/cm	15 kJ/cm	25 kJ/cm	15 kJ/cm	25 kJ/cm
Thickness of the product (mm)					
8	5	5	5	5	5
10	5	5	5	5	5
12	5	5	5	5	5
14	5	5	5	50	5
16	5	5	5	90	5
18	5	30	5	110	5
20	5	60	5	130	5
22	5	85	5	150	30
24	5	100	5	155	55
26	5	110	5	160	75
28	5	120	5	165	90
30	5	130	5	170	95

Annex C (informative)

Driving of sheet piles

Sheet piles are installed in the ground by one or a combination of the following methods:

- impact;
- vibration;
- pressing.

Vibrating is in many circumstances the most efficient method. In combination with leader guiding it is also a very accurate method of driving sheet piles to the required depth. However, if very dense sands and gravel above groundwater level or stiff clay layers have to be driven through, vibrating may be ineffective. In these cases either driving assistance or impact driving may be required. When obstacles are present and cannot be removed, either pre-drilling or careful impact driving are the best methods to be used.

Generally driving with a vibrator causes a higher level of vibration in the surrounding ground than impact driving. High frequency vibrators, where the eccentricity of the rotating mass can be varied during the start up and stop phases of the driving process, can considerably reduce the adverse vibrations of the process on the surrounding ground.

Vibratory driving generally reduces the tendency for piles to lean during driving when compared to impact driving. The main cause of longitudinal leaning is friction in the interlock between the pile being driven and the adjoining pile. This friction causes an eccentricity of the force acting on the sheet pile which cannot normally be adequately corrected by moving the centre of impact of the hammer. Reducing the friction in the free leading interlock is normally a better alternative. Friction reduction can be obtained by various means such as lubricants or by keeping the space in the leading interlock filled with bentonite or cement-bentonite during the driving process (see also 8.5.7 and 8.5.8). Also soil can be prevented from entering the interlock by closing off the interlock at the pile toe.

Vibrations from impact hammers and vibratory drivers are normally considerable and can travel over relatively long distances. Foundations which are subjected to vibration will pick up part of these vibrations and transfer them to the various elements of the supported structure. As a result damage can be caused to sensitive buildings near to the source of the vibrations. Special care is necessary if such structures are founded on loose sand, especially if it is saturated, because it is subject to sudden settlement resulting from vibrations in the ground.

Where vibration or noise is considered a problem, pressing the sheet piles into the ground may be a solution. Normally pressing is effective in cohesive soils. In difficult soil conditions pre-boring and sometimes water jetting can be effective in assisting the sheet pile to reach the required depth (see annex D for more information).

Different types of pile driving equipment suitable for the installation of the sheet piles are available. The most common types are:

- free falling hammers;
- diesel hammers;
- hydro hammers;
- air hammers;
- high and low frequency vibrators;
- high frequency vibrators with a variable eccentricity of the rotating mass;
- high frequency vibrator with continuously variable eccentricity and resonance free start and stop phases;
- pressing systems.

Specifications for these devices can be found in handbooks and producers manuals.

Theoretical analysis (e.g. wave equations) of the driving conditions can help with the selection of the pile driving equipment.

Annex D (informative)

Installation and driving assistance

D.1 Driving method

In the “pitch and drive” method a single or double sheet pile, is driven to full depth before pitching the next one. This simple procedure has the advantage that the top of the sheet pile has only to be lifted a distance equal to the length of the pile above the ground surface. Moreover, it can easily be guided manually into the interlock of the sheet pile which has already been driven.

In the case of dense sands, stiff cohesive soils and in soils containing obstructions, the “pitch and drive” method can lead to de-clutching problems in the free leading interlock and occasionally to rather large deviations from the required position.

“Panel driving” and “staggered panel driving”, enables better control of the position of the sheet piles along the wall length. At the same time the danger of de-clutching is minimized.

As a whole panel is pitched it is not necessary to drive all the sheet piles to full depth in order to maintain sheet piling operations. If obstructions are encountered, individual sheet piles can be left high without disruption to the installation process.

“Staggered driving” is a particular form of “panel driving” which may be applied when difficult soil conditions are encountered. The sheet piles in the panel are driven in a sequence indicated in Figure D.1. The disadvantage of the “panel driving” method is that interlocking the sheet piles requires individual piles to be lifted to twice their length.

Driving the primary elements of a combined wall causes local compaction of the soil. This can cause problems when driving adjacent primary elements and it should therefore be taken into account when selecting the driving sequence.

To reduce the likelihood of de-clutching, the primary elements of a combined wall are driven in sequence to the design depth of the secondary elements. Having completed this successfully, the secondary elements can be pitched and driven. Thereafter the primary elements are driven to the full depth.

D.2 Driving assistance

It is often necessary to loosen very dense sand layers. Normally applied methods are:

- a) low pressure jetting with low water volumes:
 - pressure: 1,5 MPa to 2,0 MPa;
 - discharge: 2 l/s to 4 l/s per tube;
 - diameter of pipes: approx. 25 mm;
 - number of pipes: 1 to 2 per sheet pile.

The pipes are welded to the sheet piles and left in situ.

b) high pressure jetting:

- pressure: 25 MPa to 50 MPa (at pump outlet);
- discharge: 1 l/s to 2 l/s;
- pipe diameter: 20 mm to 30 mm;
- nozzle diameter: 1,5 mm to 3,0 mm.

c) pre-drilling, with or without cement-bentonite.

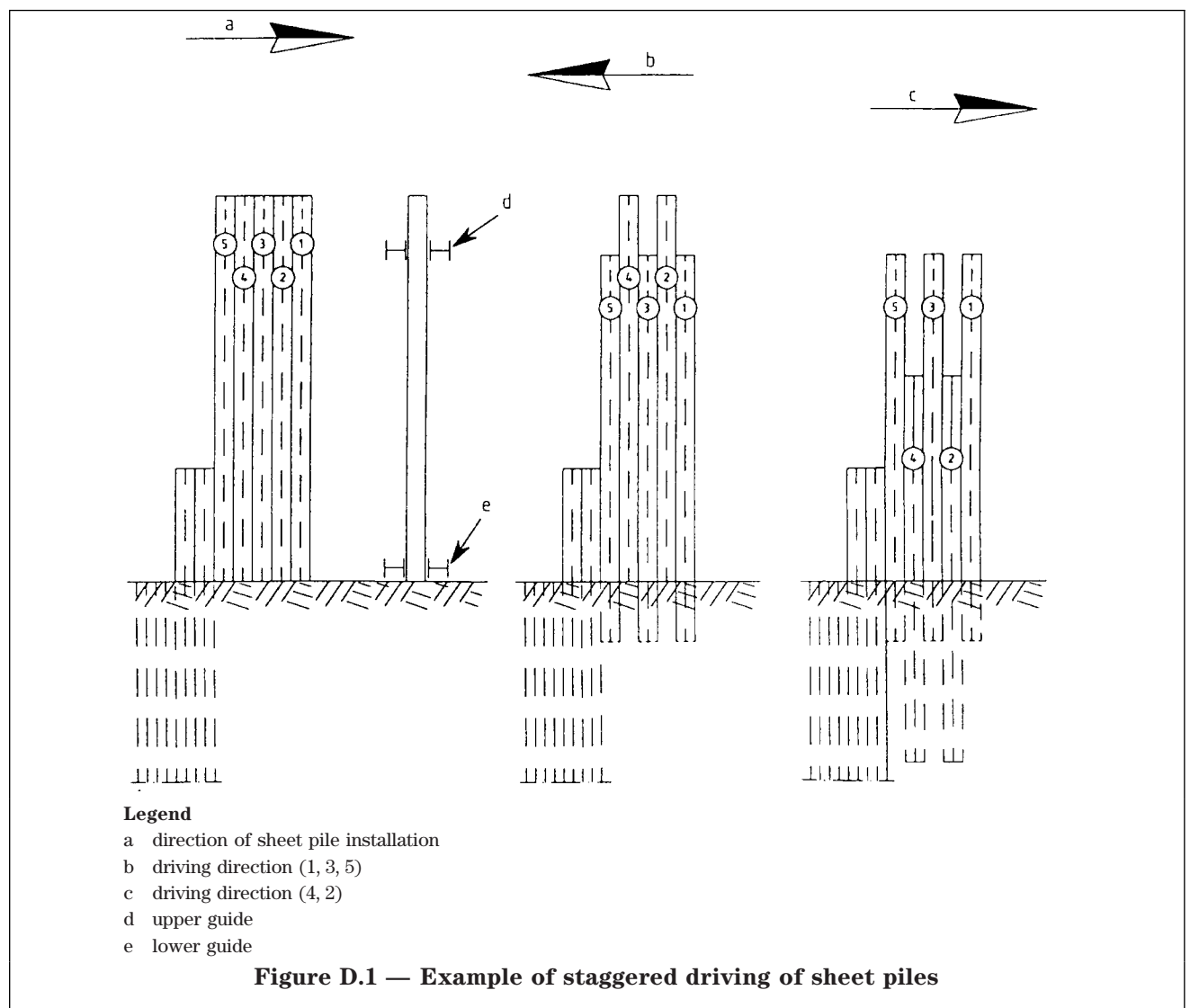
d) blasting in special cases.

Low pressure jetting is mainly used in dense non-cohesive soils.

Low pressure jetting with low water volumes, in combination with a vibrator, enables sheet piles to penetrate very dense soils. In general the soil characteristics are only slightly modified and there is practically no settlement, although special care has to be taken when the sheet piles have to carry vertical loads.

This method, especially in combination with high frequency vibration is recommended.

In addition, low pressure jetting is sometimes used for pre-treatment of the soil prior to pile driving.



Low pressure jetting with high water volumes is rather crude, especially when the tubes are not fixed to the sheet piles, and is therefore not recommended.

High pressure jetting or fluidization can be very effective in very dense soil layers.

Limited amounts of jetting fluid, water or sometimes cement-bentonite, are introduced into the ground through nozzles fixed to the sheet pile at a short distance above its tip. As a result of the limited water consumption this method permits effective control of the pile. The soil properties are only adversely effected in a limited area around the sheet piles. The overall performance will not be significantly influenced.

Pre-drilling is sometimes carried out prior to the sheet pile driving. The soil is locally loosened by this process. Normally flight auger drills are used.

Pre-drilling is often carried out at the positions of the fixed interlock of a double sheet pile, but it can be more effective to pre-drill at the free interlock positions. If extreme difficulties with driving are expected or when there are special requirements regarding the water-tightness of the sheet pile wall, it is convenient to use the flight auger to exchange a column of soil at the interlock positions and replace it by cement-bentonite.

Fracturing by blasting is normally carried out if the sheet piles have to pass hard obstructions in the soil or if they must penetrate bed-rock.

Annex E (informative)

Water-tightness of interlock sealings

E.1 General considerations

If sheet pile walls are being used to retain the earth at the sides of deep excavations in which a low groundwater level has to be maintained, the hydro-geological situation can be adversely affected. In this case very often special requirements regarding the water-tightness of these sheet pile walls are demanded.

This implies that the sheet piles have to be driven to sufficient depth in an impervious soil stratum. However, this is not always sufficient as the leakage of water from an aquifer through the interlocks may still exceed the permissible groundwater flow.

Prevention of leakage through the interlocks is a difficult problem if the permissible flow is limited to very low values.

In severe cases additional measures may therefore be needed to reduce leakage through the interlocks.

Possibilities are:

- the application of special filling fluids or mastics in the interlock space;
- the application of water swelling sealing materials or elastomeric seals;
- welding of the interlocks, if possible;
- injection of the free interlocks with cement-bentonite or swelling and hardening chemical fluids during the installation of the sheet piles;

— filling holes which are bored at the locations of the interlocks before driving with cement-bentonite slurry;

— placing the steel sheet pile wall in a trench which is filled with cement-bentonite slurry;

— installing a separate impervious screen behind the sheet pile wall;

— combination of two techniques as “special interlock filling” and “pre-bored holes filled with bentonite”.

Treatment of the interlocks with a bituminous filler will normally be sufficient. In the case of severe permeability requirements, expanding fillers, an elastic, moulded seal or the combination of two methods, may be appropriate.

A unique method for the definition of the permeability of a steel sheet pile wall does not exist. This also applies to methods for testing the effectiveness of the sealing technique. It is recommended to describe the permeability in terms of the so called inverse resistance

which is

$$q_z = \rho \frac{\Delta p_z}{\gamma_w}$$

where

q_z the discharge per unit of the joint length at level z in cubic metres per second per metre ($\text{m}^3/\text{s}/\text{m}$);

Δp the pressure drop at level z in kilo Pascals (kPa);

ρ the inverse joint resistance in metre per second (m/s);

γ_w the unit weight of water in kilonewton per cubic metre (kN/m^3).

The discharge per unit length of the joint can be established by testing a specimen of the sealed interlock in the laboratory or by tests in prototype situations in a specially equipped test-pit.

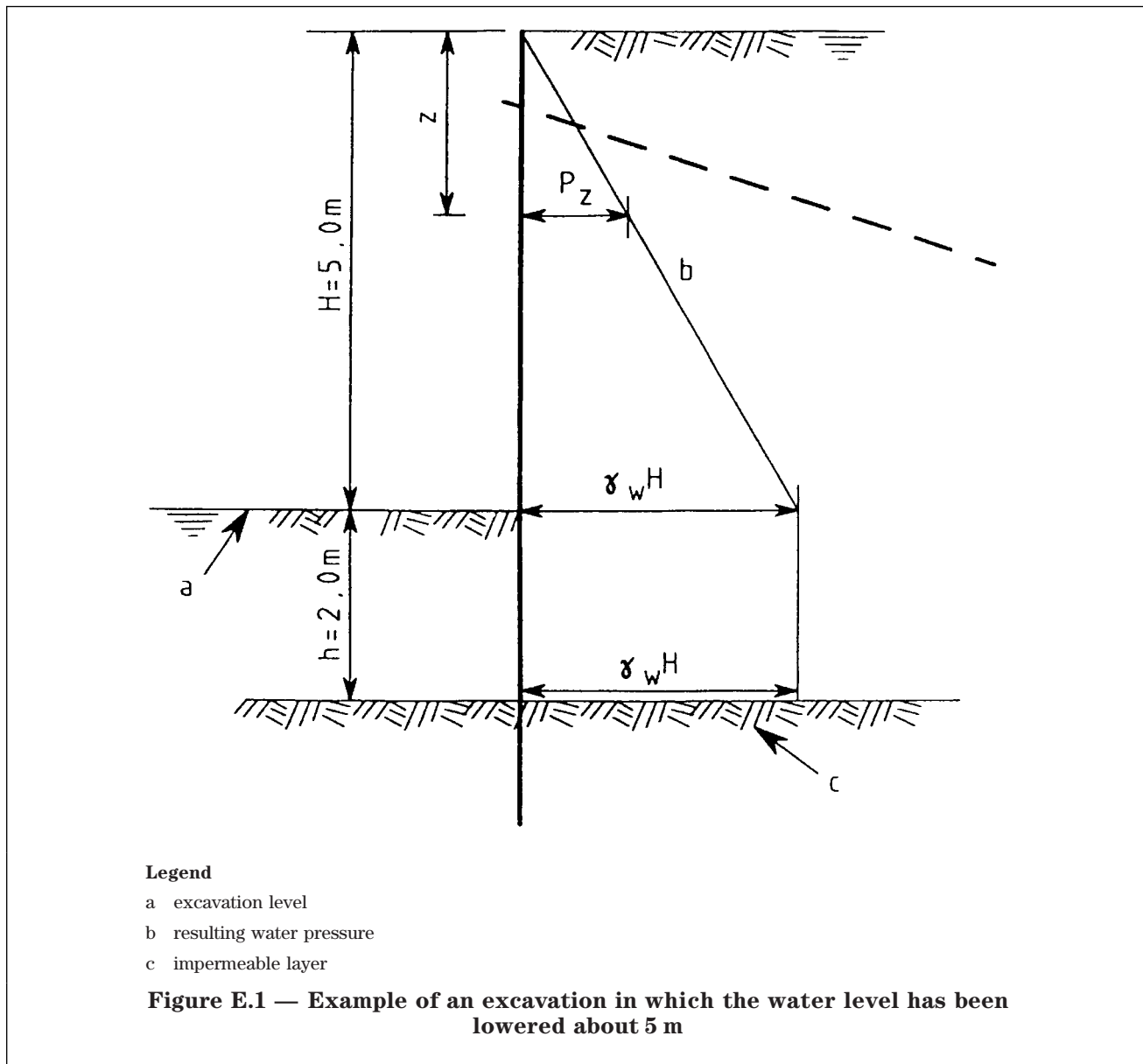
The large scattering in the results of this type of permeability testing is taken into account by applying a factor of safety in the order of 10 to the average of the testing results.

E.2 A simple case of assessing the discharge through a steel sheet pile wall

In Figure E.1 the data for the assessment of the discharge through the wall is shown. The sheet pile wall penetrates some distance into an impervious soil stratum.

Consequently the flow around the pile toe is neglected.

The resulting hydrostatic pressure diagram is drawn. The maximum pressure drop is at the bottom of the excavation and stays constant thereafter.



The maximum pressure drop is:

$$\Delta p_{\max} = \gamma_w H$$

The total discharge through one joint is:

$$Q_1 = \int_0^{h+H} q_z (dz) = \left(\frac{\rho}{\gamma_w} \right) \int_0^{h+H} \Delta p_z dz$$

with a pressure drop of:

$$\Delta p = \gamma_w z \text{ for } z \leq H;$$

$$\Delta p = \gamma_w H \text{ for } H < z \leq H + h.$$

Thus, the integral yields the area in the pressure diagram and the equation becomes:

$$Q_1 = \rho H(0,5H + h)$$

The total number of interlocks in the sheet pile wall for the excavation is:

$$n = L/b$$

where

L is the length of the perimeter of the excavation in metres; [m]

b is system width of the sheet piles in metres. [m]

The total discharge into the building pit is:

$$Q = n Q_1$$

Q represents a safe approximation for the discharge as certain favourable aspects have been neglected, for example the influence of the flow pattern on the geometry of the water table in the vicinity of the wall.

E.3 Worked example

For an excavation with a circumference of 180 m, constructed of 600 mm wide sheet piles:

$$b = 0,6 \text{ m};$$

$$H = 5 \text{ m and } h = 2 \text{ m.}$$

The interlock with filler is fully described by the inverse joint resistance:

$$\rho = 5 \times 10^{-10} \text{ m/s.}$$

The number of interlocks is:

$$n = 180/0,6 = 300.$$

Discharge per interlock:

$$Q_1 = 5 \times 10^{-10} \times 5 \times (0,5 \times 5 + 2) = 1,125 \times 10^{-8} \text{ m}^3/\text{s}.$$

And the total inflow into the building pit is:

$$Q = 300 \times 1,125 \times 10^{-8} = 3,375 \times 10^{-6} \text{ m}^3/\text{s or } 12 \text{ l/h}$$

Annex F (informative)

Timber sheet piles and walings

F.1 General

The terminology for timber and imperfections in sawn timber are given in EN 844-1:1995, EN 844-3:1995, EN 844-7:1997 and EN 844-9:1997 as.

Timber for sheet piles and walings in permanent sheet pile wall structures is normally of high durability.

Tropical hardwood normally meets this requirement without any preservation. However, coniferous species when used in waterfront structures, need to be impregnated by a preservation fluid pressed into the wood under vacuum conditions.

EN 335-1:1992 and EN 335-2:1992 provide a general decision-making procedure for arriving at the hazard class and the associated biological agents in order to determine the preservation treatment.

Cutting, boring and similar operations should preferably be carried out in the factory before the timber is impregnated. When impregnated timber is subsequently cut, bored or similarly re-shaped, it is necessary to treat the affected area with special protecting liquid.

F.2 Delivery of timber sheet piles and walings

Orders for timber sheet piles, walings and timber anchoring plates, normally cover the following aspects:

- wood species (strength requirements);
- the nominal values of thickness and length;
- the shape and dimensions of the tongue and groove joints;
- the shape and size of the splice joint in the waling;
- the shape and size of the bevelling at the toe of the sheet piles if required (see Figure F.3);

- the nominal dimensions of the special sheet piles as for example corner piles;
- the type and method of applying the preservative treatment.

Normally these aspects are checked at delivery to the site.

F.3 Quality requirements

Table F.1 gives quality requirements for sheet piles and walings of sawn soft wood and hardwood.

The main testing criteria are for:

- imperfections;
- dimensional tolerances;
- straightness in the longitudinal and transverse direction.

F.4 Transport and storage

Normally timber sheet piles and walings are delivered in packages. These packages are stored on a flat surface not in contact with the ground. Tropical hardwood sheet piles and walings are stapled one on the other. This prevents loss of moisture, warping, twisting and cracking. Because of the durability treatment, pinewood is stacked with spacers between the individual elements.

It is recommended to leave the staples intact as long as possible and to protect them from direct sun radiation by covering with a sheet.

To avoid mixing, packages of treated timber sheet piles, walings and other timber parts stored on the construction site are labelled according to:

- timber which will be underground;
- timber which will be applied in fresh water under fully submerged conditions;
- timber which will be applied in salt and brackish water.

F.5 Tolerances

Criteria for the maximum distortions (warp, cup and twist) are given in Table F.1.

The maximum allowed variations from the nominal dimensions are presented in Table F.2.

F.6 Joints

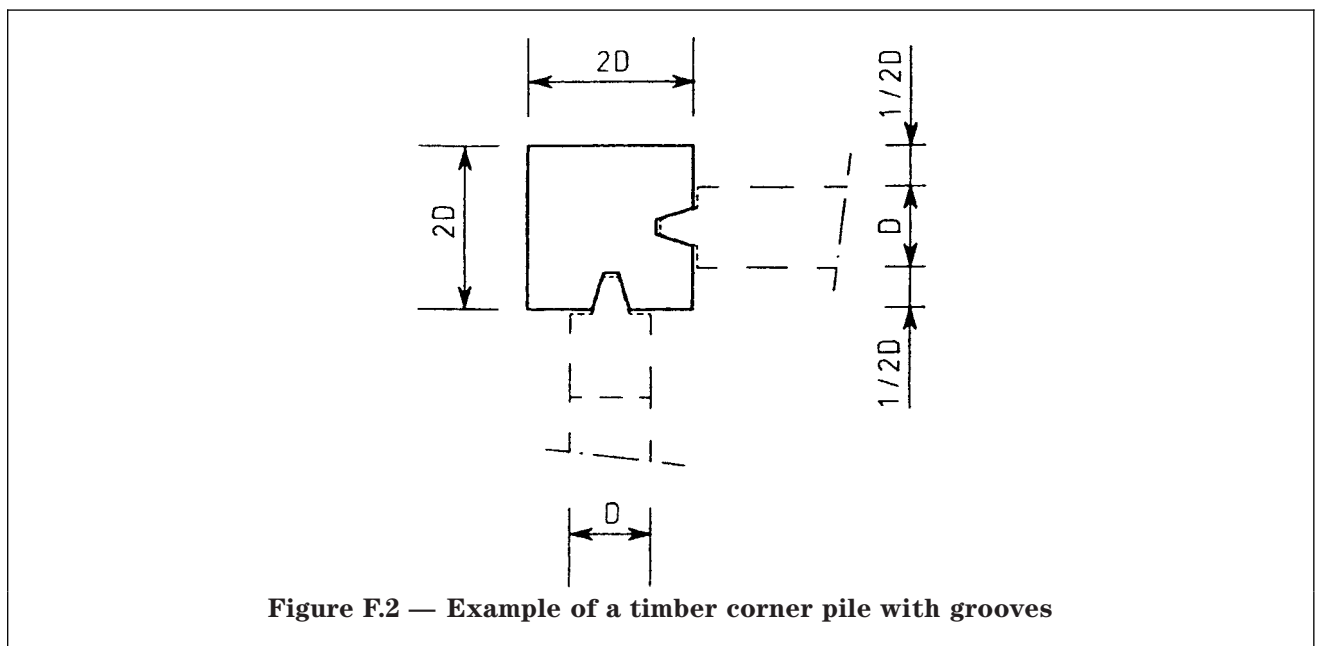
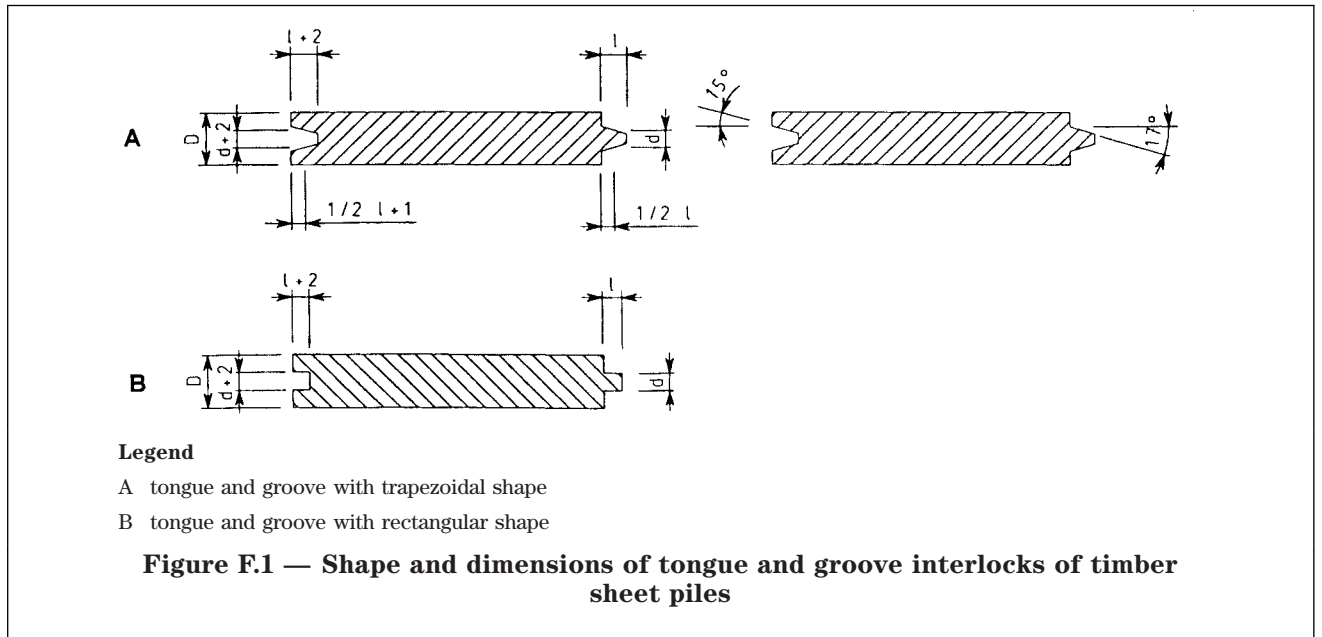
Normally timber sheet piles are jointed by tongue and groove type interlocks of a trapezoidal shape. However, a rectangular shape is also used.

Table F.3 gives recommendations regarding shape and dimensions of the tongue.

The dimensions of the tongue determine the size of the groove as shown in Figure F.1.

F.7 Corner sheet piles

Corner sheet piles generally have a square cross-section with grooves to connect the adjacent sheet piles (see Figure F.2).



F.8 Execution

Normally timber sheet piles are only used in retaining structures with a limited retained height. Typical uses are:

- vertical or nearly vertical embankments along canals and ditches;
- small quays in yachting harbours and similar.

Driving is usually carried out with light driving equipment. If a free falling mass is used the height of the drop should not exceed 2,5 m.

When a vibrator is used, panels of several piles are driven as units.

In order to keep the sheet piling in the correct position, a guide frame is used.

Low pressure water jetting is often used to assist driving work in sand layers.

In order to ascertain a proper tongue and groove connection, the sheet piles are often bevelled at the “free” side of the toe as shown in Figure F.3.

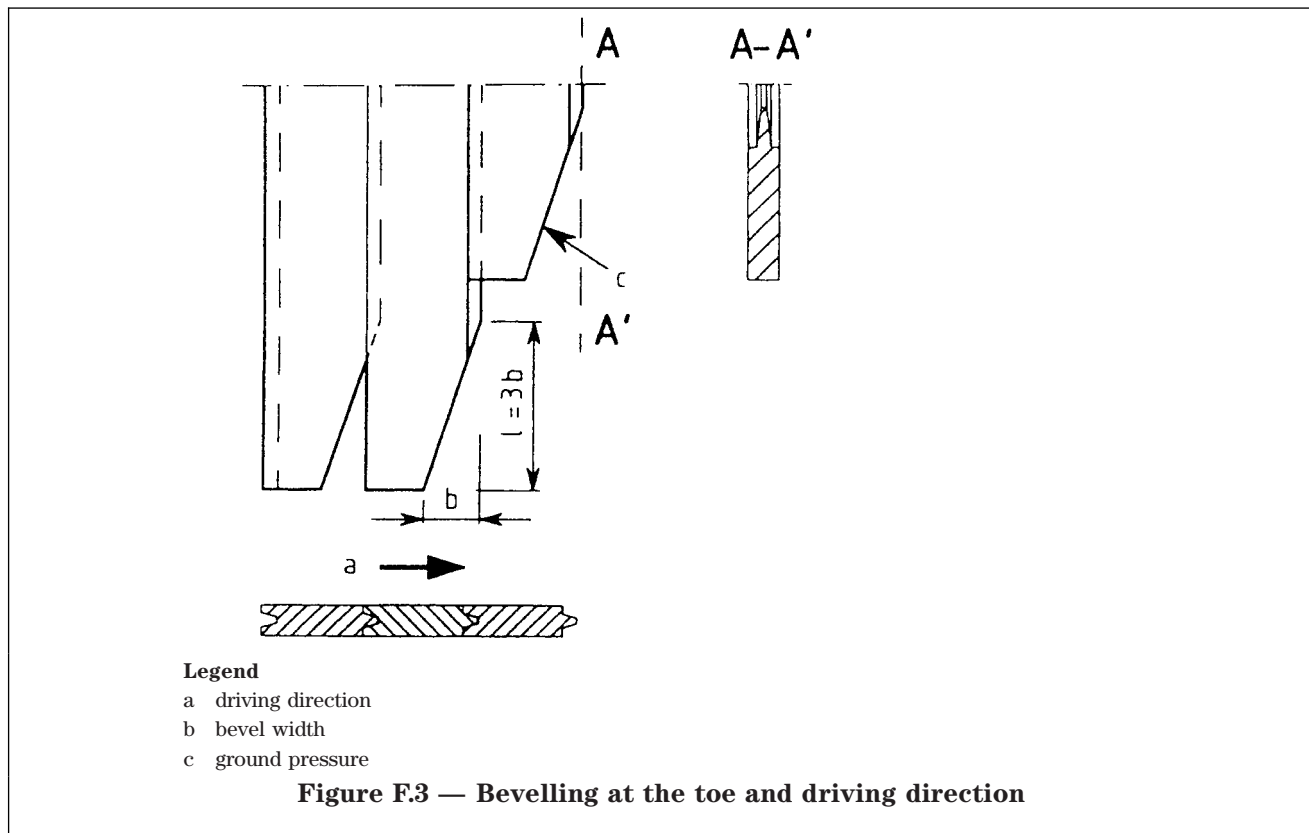


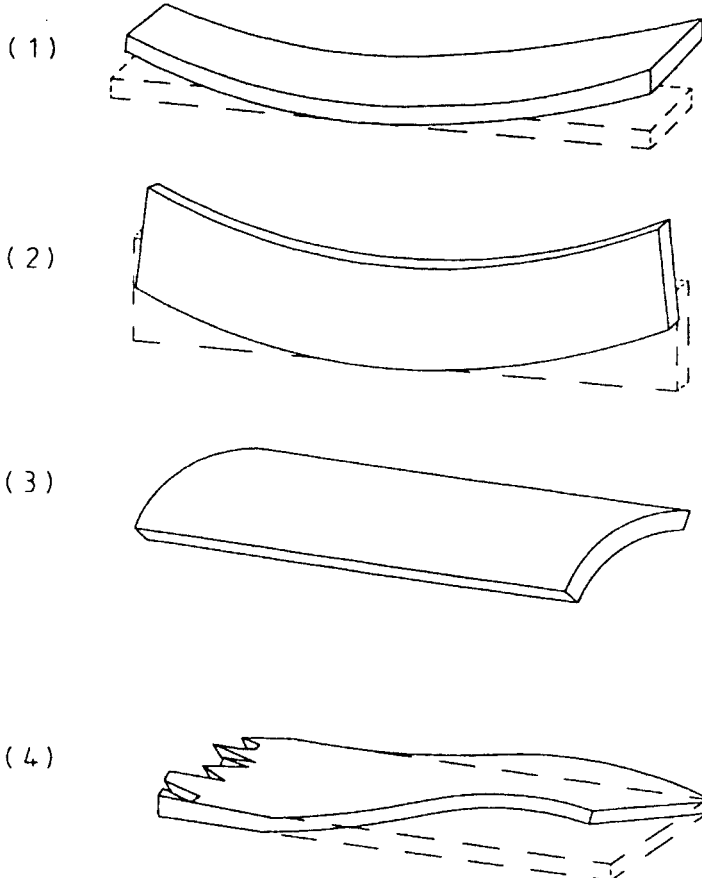
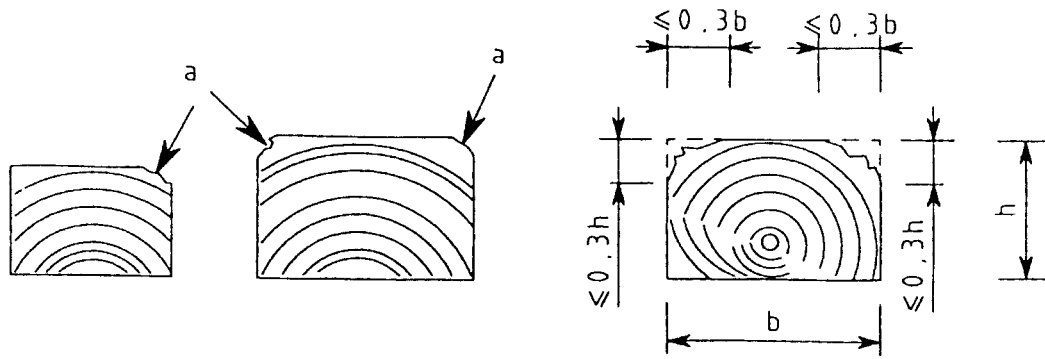
Table F.1 — Delivery conditions for sheet piles and walings of sawn softwood and hardwood and for the execution of timber sheet pile walls

Imperfections		Soft wood	Hardwood
worm holes	no probability of extension	*	*
	probability of extension	*	*
compression cracks		*	*
heartwood		*	*
bark pockets		*	*
knots in sheet piles and walings	hard knots	fixed	*
		loose	*
	soft knots		*
	knots disturbing the fitting		*
	percentage of knots, max.		*
	diameter max.		*
			*
cracks	fissures		*
	face shakes		*
	end shakes		*
	clefts		*
	heart shakes		*
sapwood		*	*
fungous affects		*	*
		*	*
		*	*
Wane (see Figure F.4)	sheet piles ¹⁾	*	*
	walings	two edges: max. 0,3 × width, resp. thickness of timber	not acceptable
mechanical damages		loose or broken fibers acc. to depth into the wood < 0,1 × thickness of the wood constricted parts resulting from steel bands acc. provided that the fibres are not damaged.	
warping of sheet piles ²⁾	max. bow per metre (see Figure F.4)	4 mm	3 mm
	max. spring per metre (see Figure F.4)	2 mm	max. 1/3 of the length of the tongue
	max. cup over 100 mm width (see Figure F.4)	2 mm	no requirement
	max. twist per metre (see Figure F.4)	2 mm	not acceptable
warping of walings ²⁾	max. bow per metre (see Figure F.4)	4 mm	at the retaining side: 1 mm; at the other side: 4 mm
	max. spring per metre (see Figure F.4)		
	max. cup over 100 mm width (see Figure F.4)	2 mm	no requirement
	max. twist per metre (see Figure F.4)	4 mm	not acceptable

* To be stated by the design.

¹⁾ A small wane is acceptable over a length of max. 250 mm from the bottom end of the timber sheet pile, provided that it does not harm a proper fitting of the tongue and groove connection.

²⁾ Deformations over the full length of the timber sheet pile or the waling.



Legend

- a wane
- b width of the waling
- h height of the waling

- (1) bow
- (2) spring
- (3) cup
- (4) twist

Figure F.4 — Definition of various distortions

Table F.2 — Maximum allowable difference of the actual dimensions with respect to the nominal values in mm

	Sheet piles		Walings	
	Individual	Average	≤ 105 ¹⁾	> 105 ¹⁾
length	±100	≥ 0	+50 -25	+50 -25
width	—	—	±2	+2 -3
thickness	±2	±0,5	±2	±2

¹⁾ Thickness of the waling perpendicular to the sheet pile wall.

Table F.3 — Dimensions of tongues in sheet piles

		Length of tongue (mm)						
		Soft wood	Length of sheet pile of tropical hardwood (m)					
Thickness of the sheet pile (mm)	Thickness of the tongue (mm)		< 3,5	3,6 to 4,5	4,6 to 5,5	5,6 to 6,5	6,6 to 7,5	7,6 to 8,5
30	10	11	11	13	15	—	—	—
40	13	13		13	15		—	—
50	16	17			15	18	22	—
60	19	18				18	22	24
70	23	22				18	22	24
80	26	24						24
90	29	24						24
100	33	24						24
110	36	24						24
120	39	24						24

Annex G (informative)

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