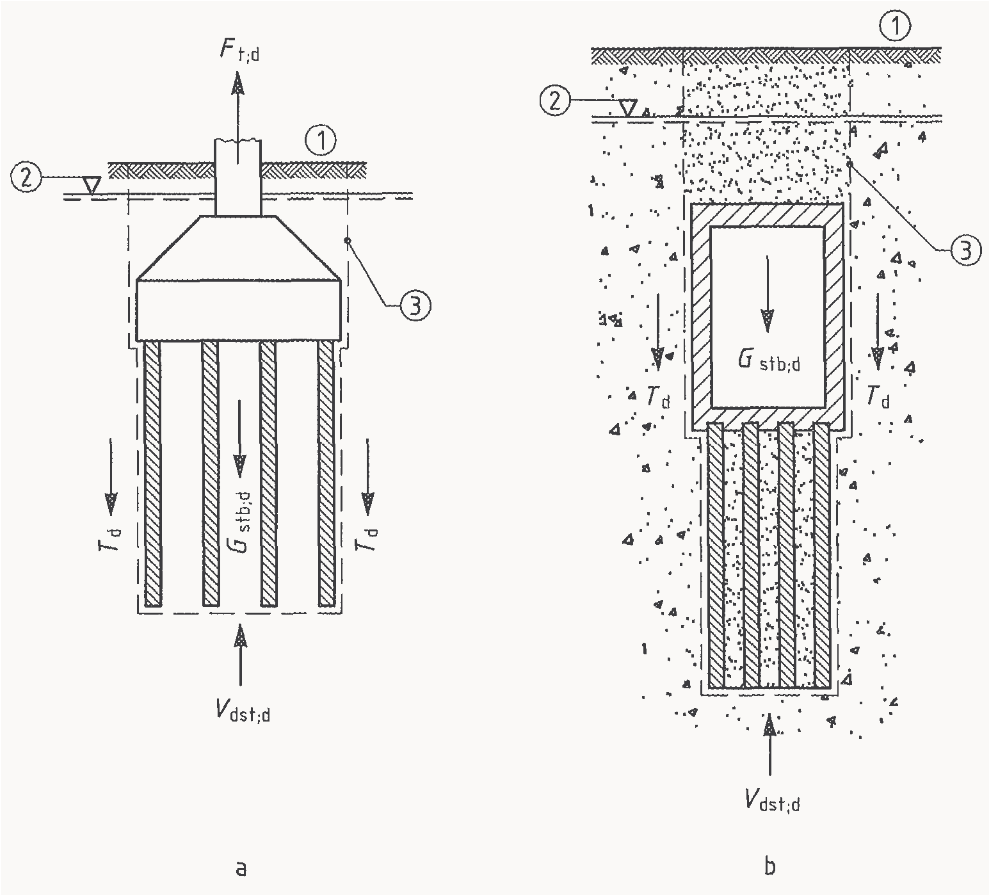

1 ground surface

2 ground-water level

3 side of the 'block', where resistance T_d develops

Figure 7.1 — Examples of uplift (UPL) of a group of piles

(3) Normally when piles are to be loaded in tension, it should be specified that more than one pile should be tested. In the case of a large number of tension piles, at least 2 % should be tested.

(4)P The records of the installation of the test pile(s) shall be checked and any deviation from the normal construction conditions shall be accounted for in the interpretation of the pile load test results.

(5)P The characteristic value of the pile tensile resistance shall be determined by:

$$R_{t;k} = \text{Min}\left\{ \frac{(R_{t;m})_{mean}}{\xi_1} ; \frac{(R_{t;m})_{min}}{\xi_2} \right\} \tag{7.14}$$

where ξ_1 and ξ_2 are correlation factors related to the number of piles tested, n, and are applied respectively to the mean $(R_{t;m})_{mean}$ and the lowest $(R_{t;m})_{min}$ value of the measured tensile resistances.

NOTE The values of the correlation factors may be set by the National annex. The recommended values are given in Table A.9.

7.6.3.3 Ultimate tensile resistance from ground test results

(1)P Methods for assessing the tensile resistance of a pile foundation from ground test results shall have been established from pile load tests and from comparable experience as defined in 1.5.2.2.

(2) A model factor may be introduced as described in 2.4.1(9) to ensure that the predicted tensile resistance is sufficiently safe.

(3)P The design value of tensile resistance of a pile, $R_{t;d}$, shall be derived from:

$$R_{t;d} = R_{t;k} / \gamma_{s;t} \tag{7.15}$$

where:

$$R_{t;k} = R_{s;k} \tag{7.16}$$

NOTE The values of the partial factor may be set by the National annex. The recommended values for persistent and transient situations are given in Tables A.6, A.7 and A.8 .

(4)P The characteristic value $R_{t;k}$ shall either be determined by:

$$R_{t;k} = \mathrm{Min}\left\{ \frac{(R_{s;cal})_{mean}}{\xi_3} ; \frac{(R_{s;cal})_{min}}{\xi_4} \right\} \tag{7.17}$$

where ξ_3 and ξ_4 are correlation factors that depend on the number of profiles of tests, n, and are applied respectively to the mean $(R_{s;cal})_{mean}$ and to the lowest value $(R_{s;cal})_{min}$ of $R_{s;cal}$, or by the method given in 7.6.3.3(6).

NOTE The values of the correlation factors may be set by the National annex. The recommended values are given in Table A.10.

(5)P The systematic and random components of the variation in the ground shall be recognised in the interpretation of the calculated tensile resistance.

(6) The characteristic value of tensile resistance may be obtained by calculating:

$$R_{t;k} = \sum_{i} A_{s;i} \cdot q_{s;i;k} \tag{7.18}$$

where $q_{s;i;k}$ are characteristic values of shaft friction in the various strata obtained from values of ground properties.

NOTE If this alternative procedure is applied, the value of the partial factor $\gamma_{s,t}$ recommended [AC1) in (AC1] Annex A, may need to be corrected by a model factor larger than 1,0. The value of the model factor may be set by the National annex.

(7)P If Design Approach 3 is used, the characteristic values of ground parameters shall be determined according to 2.4.5; partial factors shall then be applied to these characteristic values to obtain design values of the ground parameters to calculate the design values of the pile resistance.

(8) The assessment of the validity of a model based on ground test results should be in accordance with 7.6.2.3(10).

7.6.4 Vertical displacements of pile foundations (Serviceability of supported structure)

7.6.4.1 General

(1)P Vertical displacements under serviceability limit state conditions shall be assessed and checked against the requirements given in 2.4.8 and 2.4.9.

(2) When calculating the vertical displacements of a pile foundation, the uncertainties involved in the calculation model and in determining the relevant ground properties should be taken into account. Hence it should not be overlooked that in most cases calculations will provide only an approximate estimate of the displacements of the pile foundation.

NOTE For piles bearing in medium-to-dense soils and for tension piles, the safety requirements for the ultimate limit state design are normally sufficient to prevent a serviceability limit state in the supported structure.

7.6.4.2 Pile foundations in compression

(1)P The occurrence of a serviceability limit state in the supported structure due to pile settlements shall be checked, taking into account downdrag, where probable.

NOTE When the pile toe is placed in a medium-dense or firm layer overlying rock or very hard soil, the [AC1) partial factors (AC1] for ultimate limit state conditions are normally sufficient to satisfy serviceability limit state conditions.

(2)P Assessment of settlements shall include both the settlement of individual piles and the settlement due to group action.

(3) The settlement analysis should include an estimate of the differential settlements that may occur.

(4) When no load test results are available for an analysis of the interaction of the piled foundation with the superstructure, the load-settlement performance of individual piles should be [AC1) assessed on the basis of (AC1] empirically established safe assumptions.

7.6.4.3 Pile foundations in tension

(1)P The assessment of upward displacements shall be in accordance with the principles of 7.6.4.2.

NOTE Particular attention should be paid to the elongation of the pile material.

(2)P When very severe criteria are set for the serviceability limit state, a separate check of the upward displacements shall be carried out.

7.7 Transversely loaded piles

7.7.1 General

(1)P The design of piles subjected to transverse loading shall be consistent with the design rules given in 7.4 and 7.5, where applicable. Design rules specifically for foundations involving piles subjected to transverse loading are presented below.

(2)P To demonstrate that a pile will support the design transverse load with adequate safety against failure, the following inequality shall be satisfied for all ultimate limit state load cases and load combinations:

$$F_{tr;d} \leq R_{tr;d} \qquad (7.19)$$

(3) One of the following failure mechanisms should be considered:

— for short piles, rotation or translation as a rigid body;

— for long slender piles, bending failure of the pile, accompanied by local yielding and displacement of the soil near the top of the pile.

(4)P The group effect shall be considered when assessing the resistance of transversely loaded piles.

(5) It should be considered that a transverse load applied to a group of piles may result in a combination of compression, tension and transverse forces in the individual piles.

7.7.2 Transverse load resistance from pile load tests

(1)P Transverse pile load tests shall be carried out in accordance with 7.5.2.

(2) Contrary to the load test procedure described in 7.5, tests on transversely loaded piles need not normally be continued to a state of failure. The magnitude and line of action of the test load should simulate the design loading of the pile.

(3)P An allowance shall be made for the variability of the ground, particularly over the top few metres of the pile, when choosing the number of piles for testing and when deriving the design transverse resistance from load test results.

(4) Records of the installation of the test pile(s) should be checked, and any deviation from the normal construction conditions should be accounted for in the interpretation of the pile load test results. For pile groups, the effects of interaction and head fixity should be accounted for when deriving the transverse resistance from the results of load tests on individual test piles.

7.7.3 Transverse load resistance from ground test results and pile strength parameters

(1)P The transverse resistance of a pile or pile group shall be calculated using a compatible set of structural effects of actions, ground reactions and displacements.

(2)P The analysis of a transversely loaded pile shall include the possibility of structural failure of the pile in the ground, in accordance with 7.8.

(3) The calculation of the transverse resistance of a long slender pile may be carried out using the theory of a beam loaded at the top and supported by a deformable medium characterised by a horizontal modulus of subgrade reaction.

(4)P The degree of freedom of rotation of the piles at the connection with the structure shall be taken into account when assessing the foundation’s transverse resistance.

7.7.4 Transverse displacement

(1)P The assessment of the transverse displacement of a pile foundation shall take into account:

— the stiffness of the ground and its variation with strain level;

— the flexural stiffness of the individual piles;

— the moment fixity of the piles at the connection with the structure;

— the group effect;

— the effect of load reversals or of cyclic loading.

(2) A general analysis of the displacement of a pile foundation should be based on expected degrees of kinematic freedom of movement.

7.8 Structural design of piles

(1)P Piles shall be verified against structural failure in accordance with 2.4.6.4.

(2)P The structure of piles shall be designed to accommodate all the situations to which the piles will be subjected. These include:

— the circumstances of their use e.g. corrosion conditions;

— the circumstances of their installation e.g. adverse ground conditions such as boulders, steeply inclined bedrock surfaces;

— other factors influencing driveability, including quality of joints;

— for precast piles, the circumstances of their transportation to site and installation.

(3)P During structural design, construction tolerances as specified for the type of pile, the action components and the performance of the foundation shall be taken into account.

(4)P Slender piles passing through water or thick deposits of [AC1) extremely low strength fine (AC1] soil shall be checked against buckling.

(5) Normally a check for buckling is not required when the piles are contained by soils with a [AC1) characteristic (AC1] shear strength, c_u, that exceeds 10 kPa.

7.9 Supervision of construction

(1)P A pile installation plan shall form the basis for the piling works.

(2) The plan should give the following design information:

— the pile type;

— the location and inclination of each pile, including tolerances on position;

— pile cross-section;

— for cast-in-situ piles, data about the reinforcement;

— pile length;

— pile number;

— required pile load carrying capacity;

— pile toe level (with respect to a fixed datum within or near the site), or the required penetration resistance;

— installation sequence;

— known obstructions;

— any other constraints on piling activities.

(3)P It shall be specified that the installation of all piles is monitored and records are made as the piles are installed.

(4) The record for each pile should include aspects of construction covered in the relevant execution standards, EN 1536:1999, EN 12063:1999, EN 12699:2000, [AC1) EN 14199:2005, (AC1] such as the following:

— pile number;

— installation equipment;

— pile cross-section and length;

— date and time of installation (including interruptions to the installation process);

— concrete mix, volume of concrete used and method of placing for cast-in-situ piles;

— weight density, pH, Marsh viscosity and fines content of bentonite slurry (when used);

— for continuous flight auger piles or other injection piles, volumes and pumping pressures of the grout or concrete, internal and external diameters, pitch of screw and penetration per revolution;

— for displacement piles, the values of driving resistance measurements such as weight and drop or power rating of hammer, blow frequency and number of blows for at least the last 0,25 m penetration;

— the power take-off of vibrators (where used);

— the torque applied to the drilling motor (where used);

— for bored piles, the strata encountered in the borings and the condition of the base if the performance of the pile toe is critical;

— obstructions encountered during piling;

— deviations of position and direction and as-built elevations.

[AC1) *Note deleted* (AC1]

(5) Records should be kept for at least a period of five years after completion of the works. As-built records should be compiled after completion of the piling and kept with the construction documents.

(6)P If site observations or inspection of records reveal uncertainties about the quality of installed piles, investigations shall be carried out to determine their condition and if remedial measures are necessary. These investigations shall include either performing a static pile load or integrity test, installing a new pile or, in the case of a displacement pile, re-driving the pile, in combination with ground tests adjoining the suspect pile.

(7)P Tests shall be used to examine the integrity of piles for which the quality is sensitive to the installation procedures if the procedures cannot be monitored in a reliable way.

(8) Dynamic low strain integrity tests may be used for a global evaluation of piles that might have severe defects or that may have caused a serious loss of strength in the soil during construction. Defects such as insufficient quality of concrete and thickness of concrete cover, both of which can affect the long term performance of a pile, often cannot be found by dynamic tests and other tests, such as sonic tests, vibration tests or coring, may be needed in supervising the execution.

A1 Section 8 Anchors

8.1 General

8.1.1 Scope

(1)P This Section shall apply to the design of temporary and permanent anchors used e.g.:

— to support a retaining structure;

— to ensure the stability of slopes, cuts or tunnels;

— to resist uplift forces on a structure;

— to prevent sliding or tilting;

— to restrain tension cables;

by transmitting a tensile force to a load resisting formation of soil or rock.

(2)P This section shall be used for the design of anchors covered by EN 1537 and other anchors that are consistent with 8.1.2.1, such as screw anchors and expander anchors with a free length.

(3)P Tension members without a free length (such as tension piles) shall be designed using the principles given in Section 7 'Pile foundations'.

(4)P Walls providing fixity for dead-man anchors shall be designed using the principles given in Section 9, 'Retaining structures'.

(5) This section does not cover the design of soil nails or rock bolts.

8.1.2 Definitions

8.1.2.1
anchor
installation capable of transmitting an applied tensile load through a free length to a load bearing stratum

8.1.2.2
grouted anchor
anchor that uses a bonded length formed of cement grout, resin or similar material to transmit the tensile force to the ground

NOTE A 'grouted anchor' in EN 1997–1 is termed a 'ground anchor' in EN 1537.

8.1.2.3
permanent anchor
anchor with a design life which is in excess of two years

8.1.2.4
temporary anchor
anchor with a design life of 2 years or less

8.1.2.5
tendon
part of an anchor that is capable of transmitting the tensile load from the anchor head to the resisting element in the ground

8.1.2.6
anchor fixed length
designed length of an anchor over which the load is transmitted to the surrounding ground A1

A1 **8.1.2.7**
anchor free length
length of the anchor between the anchorage point at the anchor head and the proximal end of the anchor fixed length

8.1.2.8
tendon bond length for grouted anchors
length of the tendon that is bonded directly to the grout and capable of transmitting the applied tensile load

8.1.2.9
tendon free length
length of the tendon between the anchorage point at the anchor head and the proximal end of the tendon bond length

8.1.2.10
apparent tendon free length
length of tendon which is estimated to be fully decoupled from the surrounding grout and is calculated from the load-elastic displacement data following testing

8.1.2.11
investigation test
load test to establish the geotechnical ultimate resistance of an anchor and to determine the characteristics of the anchor in the working load range

8.1.2.12
suitability test
load test to confirm that a particular anchor design will be adequate in particular ground conditions

8.1.2.13
acceptance test
load test to confirm that an individual anchor conforms with its acceptance criteria

8.2 Limit states

(1)P The following limit states (both individually and in combination) shall be considered for all anchors:

— structural failure of the tendon or anchor head, caused by the applied stresses;

— failure of the connection between the tendon and the resisting element in the ground;

— loss of anchor force and excessive displacements of the anchor head due to creep and relaxation;

— failure or excessive deformation of parts of the anchored structure due to the applied anchor force;

— loss of overall stability of the retained ground and the retaining structure (see Section 11);

— limit states in supported or adjacent structures, including those arising from pre-stressing forces;

— instability or excessive deformation of the zone of ground into which tensile forces from a group of anchors are to be transferred;

— failure at the interface between the resisting element and the ground.

(2)P In addition to the limit states listed in 8.2(1)P, the following limit states (both individually and in combination) shall be considered for all grouted anchors:

— failure at the interface between the body of grout and the ground;

— failure of the bond at the interfaces of tendon, encapsulation and grout;

— failure of the bond between the tendon and the grout. A1

A1) (3) For a group of anchors, the most critical failure surface should be considered.

NOTE Depending on spacing and the profile of ground strength, this can involve displacement of part or all of the block contained by the anchors, often combined with pull-out of the distal ends of the anchors.

8.3 Design situations and actions

(1)P Design situations shall be selected in accordance with 2.2.

(2)P In addition, consideration shall be given to:

— all pertinent limit states listed in 8.2 and their combinations;

— chemical components of ground or groundwater that can adversely affect the durability of the anchor.

(3)P The design value of the anchor load shall be derived from the design of the anchored structure, taking into consideration ultimate and serviceability limit states.

8.4 Design and construction considerations

(1)P Anchors shall not be used unless their design and construction have been verified by investigation or suitability tests in accordance with EN ISO 22477-5 or by comparable experience (as defined in 1.5.2.2) and have been shown to have the required performance and durability, which have been documented.

(2)P Account shall be taken of the effects of any deformations imposed on adjacent structures when installing the anchor and by the anchor pre-stress force.

(3) The zone of ground into which tensile forces are to be transferred should be included in site investigations whenever possible.

(4)P For pre-stressed anchors, the anchor head shall be designed to allow the tendon to be stressed, proof-loaded and locked-off and, if required, released, de-stressed and re-stressed.

(5)P The anchor head shall be designed to tolerate angular deviations of the anchor force, and to be able to accommodate deformations that can occur during the design life of the structure.

(6)P Since the effectiveness of an anchor depends on its free length, the anchor force shall act in ground that is sufficiently distant from the anchored structure such that no additional force is applied on it. The necessary anchor free length shall be determined in the design of the anchored structure.

NOTE The method of determining the necessary free length may be set in the National Annex.

(7)P Measures shall be taken to avoid adverse interactions between anchors that are located close to each other.

NOTE The criteria for the necessity to check the group effects may be set in the National Annex.

(8)P The direction of the anchor should normally be chosen to enable self-stressing under deformation. If this is not feasible, the adverse effects of potential failure mechanisms shall be taken into account.

(9)P A sufficient lock-off force shall be used to ensure that the anchor resistance under serviceability limit state conditions will be mobilised with tolerable head displacements.

(10) If the anchor is analysed as a spring, its stiffness should be selected to achieve compatibility between calculated displacements of the retained structure and the displacement and elongation of the anchor, including displacement of the fixed anchor length. (A1

A1 (11)P Corrosion protection of anchors that have a tendon made of steel shall be designed taking into account the type of steel and the aggressiveness of the ground environment.

(12)P For grouted anchors, corrosion protection shall be in accordance with EN 1537.

8.5 Limit state design of anchors

8.5.1 General

(1)P The design value of the geotechnical ultimate limit state resistance of an anchor, $R_{ULS;d}$, shall satisfy the following inequality:

$$E_{ULS;d} \leq R_{ULS;d} \tag{8.1}$$

where:

$$E_{ULS;d} = \max\left(F_{ULS;d}; F_{Serv;d}\right) \tag{8.2}$$

and where:

$$F_{Serv;d} = \gamma_{Serv} \times F_{Serv;k} \tag{8.3}$$

NOTE 1 The value of partial factor γ_{Serv} may be set by the National Annex. The recommended value for persistent and transient situations is given in Table A.18.

NOTE 2 Formulae (8.1) to (8.3) are also applicable to uplift calculations (UPL).

NOTE 3 It is assumed in Section 8 that all partial factors and correlations factors for serviceability limit states are unity unless symbols are specifically included. The values for additional partial factors and correlation factors for serviceability limit states may be set in the National Annex.

(2)P When a separate evaluation of the serviceability limit state of the anchor is required the evaluation shall be carried out using Formula (8).4).

$$F_{Serv;k} \leq R_{SLS;d} \tag{8.4}$$

NOTE 1 The National Annex may set whether a separate evaluation of the serviceability limit state of the anchor is required.

NOTE 2 The National Annex may set whether the verifications for ultimate limit state and serviceability limit state are to be carried out separately or in a combined procedure.

8.5.2 Geotechnical ultimate limit state resistance

(1)P The measured geotechnical ultimate limit state resistance of an anchor as defined in 8.5.2(2)P shall be determined from a number of investigation or suitability tests (n) carried out in accordance with EN ISO 22477-5.

NOTE The test method to be used to determine the measured resistance and the number of tests n may be set in the National Annex.

(2)P The measured ultimate limit state resistance of an anchor $R_{ULS;m}$ shall be determined by load tests as the lesser of the proof load or the load causing a limiting condition (R_m). The limiting condition depends on the test method and may be: A1