BRITISH STANDARD

BS EN 1537:2000

Execution of special geotechnical work — Ground anchors

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The European Standard EN 1537:1999 has the status of a British Standard

ICS 93.020

National foreword

This British Standard is the official English language version of EN 1537:1999. It supersedes those parts of BS 8081:1989 that deal with the construction ('execution') of ground anchorages; these parts will therefore be declared obsolescent by amendment.

The harmonized European design of ground anchorages will be dealt with by EN 1997-1. Until it is published, the design parts of BS 8081:1989 apply, whereafter BS 8081:1989 will be declared obsolescent on its entirety.

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

— aid enquirers to understand the text;

— 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.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Summary of pages

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Execution of special geotechnical work – Ground anchors

Exécution des travaux géotechniques spéciaux – Tirant d'anchrage

Ausführung von besonderen geotechnischen Arbeiten (Spezialtiefbau) - Verpreßanker

This European Standard was approved by CEN on 20 February 1998.

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

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

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Central Secretariat: rue de Stassart, 36 B-1050 Brussels

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Contents

Foreword

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

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

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

The remit of CEN/TC 288 is the standardization of the execution procedures for geotechnical works (including testing and control methods) and of the required material properties. CEN/TC 288/WG 2 has been charged with the preparation of a standard in the subject area of ground anchors, which includes all anchors bonded to the ground by grout and are tensioned.

The document has been prepared to stand alongside ENV 1997-1-1 : Geotechnical Design, General Rules. Clause 7 "Design considerations" of this standard deals only with those matters which should be taken into account during the execution stage of ground anchor so that the design of the anchor system may be fulfilled. The standard, however, provides full coverage of the construction and supervision requirements. An informative Annex D provides a detailed treatment of ground anchor design.

The standard has been drafted by a working group comprising delegates from 10 countries and is based on the review of 10 national and international codes of practice.

1 Scope

This standard is applicable to the installation, testing and monitoring of permanent and temporary ground anchors where the load capacity is tested. An anchor consists of an anchor head, A free anchor length and a fixed anchor length which is bonded to the ground by grout. The term "ground" is taken to encompass both soil and rock.

The planning and design of ground anchors calls for experience and knowledge in this specialized field and although these topics are covered briefly in ENV 1997-1 Eurocode 7 : Geotechnical Design, Part 1 : General Rules a more detailed treatment of the design of ground anchors is included in an annex to this standard.

The installation and testing phases require skilled and qualified labour and supervision. This standard cannot replace the knowledge of specialist personnel and the expertise of experienced contractors required to apply the standard.

This standard does not address alternative systems of anchoring such as tension piles, screw anchors, mechanical anchors, soil nails, expander anchors or deadman anchors.

The standard establishes and defines principles with regard to anchor technology. Where anchor systems do not comply with the principles defined in the text, flexibility in the use of these systems is offered by written acceptance of the Client's Technical Representative.

2 Normative references

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

Exceptionally the list of normative references contains European Pre-standards which are at the draft stage. If any of these documents becomes a European Standard the reference shall be checked.

EN 45014, *General criteria for declaration of conformity*.

ENV 206, *Concrete - Performance, production, placing and compliance criteria.*

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

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

ENV 1992-1-5, *Eurocode 2 : Design of concrete structures - Part 1-5 : Structures with unbonded and external prestressing tendons.*

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

ENV 1994-1-1, *Eurocode 4 : Design of composite steel and concrete structures - Part 1-1 :- General rules and rules for buildings.*

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

prEN 445, *Grout for prestressing tendons - Test methods.*

prEN 446, *Grout for prestressing tendons - Grouting procedures.*

prEN 447, *Grout for prestressing tendons.*

prEN 10138, *Design of prestressing steel - Specification for common grout.*

3 Terms, definitions and symbols

3.1 Terms and definitions

The main terms are used in common with all Eurocodes. For the purposes of this standard the following definitions apply :

3.1.1
anchor
fr : tirant d'ancrage
de : Anker
an installation capable of transmitting an applied tensile load to a load bearing stratum

3.1.2
anchor head
fr : tête d'ancrage
de : Ankerkopf
the component of a ground anchor which transmits the tensile load from the tendon to bearing plate or structure

3.1.3
acceptance test
fr : essai de réception
de : Abnahmeprüfung
a load test to confirm that each anchor conforms with the acceptance criteria

3.1.4
apparent tendon free length
fr : longueur libre équivalente
de : Rechnerische freie Stahllänge
the length of tendon between the connection of the tendon to the stressing jack and a point along the tendon, deduced from load testing of an anchor

3.1.5
bleed
fr : ressuage
de : Absetzma
the separation of water from grout paste

3.1.6
borehole diameter
fr : diamètre de forage
de : Bohrlochdurchmesser
the diameter of a borehole as defined by the drill bit or casing diameter, excluding any enlargements

3.1.7
characteristic internal anchor resistance
fr : résistance interne caractéristique du tirant
de : Charakteristischer Innerer Ankerwiderstand
the characteristic load capacity of the anchor tendon

3.1.8
client's technical representative
fr : représentant technique du client
de : Technischer Bauherrnvertreter
represents the client and is fully acquainted with all aspects of the works related to the use of the anchors, including specialist knowledge of ground anchor technology

3.1.9
coupler
fr : coupleur
de : Koppelelement
a device for joining lengths of bar or strand which comprise an anchor tendon

3.1.10
creep limit
fr : vitesse limite de fluage
de : Grenzkriechmaβ
the maximum creep displacement rate permitted at a specific load level

3.1.11
critical creep load
fr : traction critique de fluage
de : Kritische Kriechkraft
the anchor load corresponding to the end of the first linear part of a plot of anchor load against creep rate

3.1.12
datum load
fr : traction de référence
de : Vorbelastung
the level of anchor load from which the anchor head displacement is measured during a stress test. In general, a value of 10 % proof load is adopted

3.1.13
encapsulation
fr : protection
de : Korrosionsschutzumhüllung
a corrosion protection applied at least to the tendon bond length

3.1.14
external anchor resistance
fr : résistance externe du tirant
de : Herausziehwiderstand des Ankers
the load resistance of an anchor at the interface between ground and fixed anchor length

3.1.15
fixed anchor length
fr : longueur de scellement du tirant
de : Krafteintragungslänge
the designed length of an anchor over which the load is transmitted to the surrounding ground, through a grout body

3.1.16
free anchor length
fr : longueur libre du tirant
de : Freie Ankerlänge
the distance between the proximal end of the fixed anchor length and the tendon anchorage at the anchor head

3.1.17
grout
fr : coulis
de : Verpreβmörtel
a setting material which transfers load from the tendon to the ground over the fixed anchor length, and which may fill the rest of the borehole and/or contribute to corrosion protection

3.1.18
investigation test
fr : essai préalable
de : Untersuchungsprüfung
a load test to establish the ultimate load resistance of an anchor at the grout/ground interface and to determine the characteristics of the anchor in the working load range

3.1.19
load loss limit
fr : pert de tension admissible
de : Grenzkraftabfall
the permitted cumulative loss of load at the end of a specified time period

3.1.20
lock-off load
fr : traction de blocage
de : Festlegekraft
the load transferred to an anchor head immediately on completion of a stressing operation

3.1.21
permanent anchor
fr : tirant d'ancrage permanent
de : Daueranker
an anchor with a design life which is in excess of two years

3.1.22
proof load
fr : traction d'épreuve
de : Prüfkraft
the maximum test load to which an anchor is subjected

3.1.23
suitability test
fr : essai de contrôle
de : Eignungsprüfung
a load test to confirm that a particular anchor design will be adequate in particular ground conditions

3.1.24
system test
fr : essai de système
de : Systemprüfung
a test which is carried out on an anchor system to verify its competence to perform as required

3.25
temporary anchor
fr : tirant d'ancrage provisoire
de : Kurzzeitanker
an anchor with a design life of less than two years

3.1.26
tendon
fr : armature
de : Zugglied
the part of a ground anchor that is capable of transmitting the tensile load from the fixed anchor length to the anchor head

3.1.27
tendon bond length
fr : longueur de scellement de l'armature
de : Verankerungslänge des Zuggliedes
the length of the tendon that is bonded directly to the grout and capable of transmitting the applied tensile load

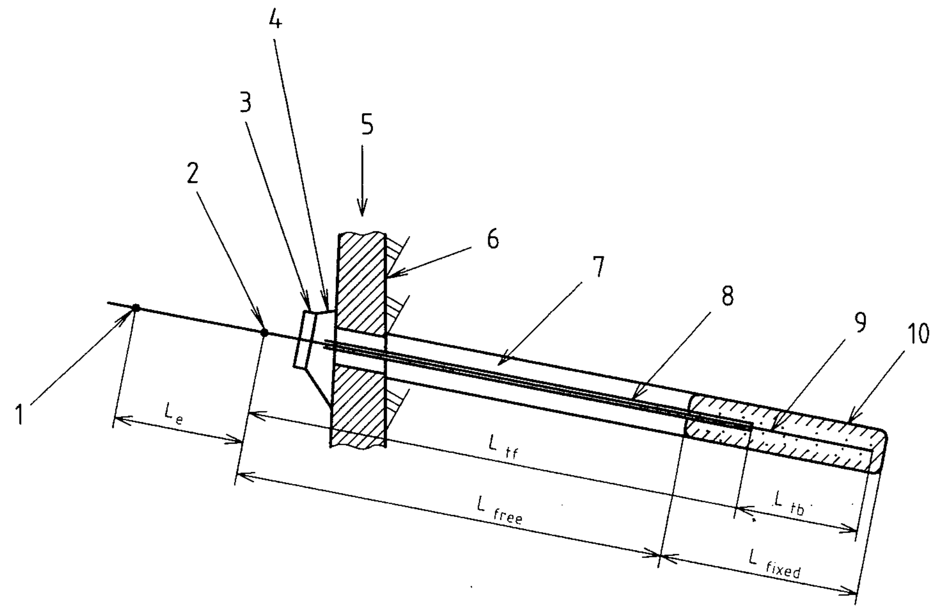
3.1.28
tendon free length
fr : longueur libre de l'armature
de : Freie Stahllänge
the length of tendon between the anchor head and the proximal end of the tendon bond length

A typical anchor is shown in Figure 1.

3.2 Symbols

A_t	Cross sectional area of anchor tendon
E_d	Design value of the effect of an action
$E_{d,dst}$	Design value of the effect of destabilising action
$E_{d,stb}$	Design value of the effect of stabilising action
E_t	Elastic modulus of anchor tendon
f	Friction loss as a percent of P_p
f_{tk}	Characteristic tensile strength of a tendon
$f_{t0,1k}$	Characteristic tensile stress at which there is a permanent strain of 0,1%
f_r	Relative area of ribs of ribbed or profiled wire or bar
k_s	Creep displacement rate
k_1	Load loss
L_{app}	Apparent tendon free length
L_e	External length of tendon measured from the tendon anchorage in the anchor head to the anchorage point in the stressing jack
L_{fixed}	Fixed anchor length
L_{free}	Free anchor length
L_{tb}	Tendon bond length
L_{tf}	Tendon free length
P	Anchor tendon load
P_a	Datum load
P_c	Critical creep load
P_c'	Approximation to critical creep load
P_o	Anchor lock-off load
P_p	Proof load
P_{tk}	Characteristic load capacity of tendon
$P_{t0,1k}$	Characteristic tensile load at which there is a permanent strain of 0,1 %
R_a	External anchor resistance
R_{ak}	Characteristic external anchor resistance
R_{ik}	Characteristic internal anchor resistance

R_d	Design resistance of an anchor
R_k	Lower of characteristic internal and external resistances
s	Anchor head displacement
t	Time from application of load increment or load lock-off
α	Slope of creep displacement/log time plot
ΔP	Difference between proof load and anchor datum load
Δs	Measured extension of anchor tendon under load increment ΔP
γq	Variation factor for anchor load
γ_R	Partial factor on anchor resistance



Key

1 Anchorage point at jack during stressing
2 Anchorage point at anchor head in service
3 Bearing plate
4 Lold transfer black
5 Structural element
6 Soll/rock
7 Borehole
8 Debonding sleeve
9 Tendon
10 Grout body

Figure 1 — Sketch of a ground anchor - Details of anchor head and head protection omitted

4 Specific needs

4.1 General

Ground anchors can only be designed efficiently on the basis of a sound knowledge of the construction project, of the structural requirements of the anchor and of the geotechnical properties of the ground. Anchor testing and the verification of design parameters are necessary elements in the construction procedure for economical installation of effective ground anchors.

The responsibilities of all parties involved in the design, execution, testing and maintenance of the ground anchors shall be defined. Table 1 shows, as a guide, an appropriate separation of design and execution activities.

Table 1 — Design and execution activities

Overall design activities	Specialist execution activities
1. Provision of site investigation data for construction of ground anchors	1. Assessment of site investigation data with respect to design assumptions.
2. Decision to use ground anchors, required trials and testing and provision of a specification	2. Selection of ground anchor components and details.
3. Acquisition of legal authorisation and entitlement to encroach on third party property	3. Determination of fixed anchor dimensions.
4. Overall design of anchored structure, calculations of anchor force required. Definition of safety factors to be employed.	4. Detailing of the corrosion protection system for the ground anchor.
5. Definition of ground anchor life (permanent/temporary) and requirement for corrosion protection.	5. Supply and installation of the ground anchor system.
6. Specification of anchor spacing and orientation, anchor loads and overall stability requirements.	6. Supply and installation of the ground anchor monitoring system.
7. Specification of minimum distance from the structure to mid fixed length to ensure stability of the structure.	7. Quality control of works.
8. Specification of load transfer mechanism from the anchor to the structure.	8. Execution and assessment of anchor tests.
9. Specification of any sequence of anchor loading required of the structure and the appropriate load levels.	9. Evaluation of on-site anchor tests.
10. Specification of systems for monitoring ground anchor behaviour and for interpretation of results.	10. Maintenance of ground anchor as directed.
11. Supervision of the works.	
12. Specification of maintenance for ground anchors.	
13. Instruction to all parties involved of key items in the design philosophy to which special attention should be directed.	

Sufficient information to assist in the design and installation of ground anchors should be provided prior to, and updated during, the execution of the works.

NOTE The whole design or some parts of the design may be performed by the client, the main contractor, a specialist contractor or by a consultant.

4.2 Planning of anchor works

The following shall be provided prior to the initial supply and installation of the ground anchor system :

— details of the ground anchor project and the construction sequence and programme ;

— a site investigation report incorporating a geotechnical classification and engineering properties of the ground in which the ground anchors are to be located ;

— information on all other boundary conditions, including underground services, existing foundations and requirements relevant to the location and performance of the ground anchors ;

— details of ownership of the ground into which the anchors are to be installed ;

— details of any agreement required to gain access to ground into which the anchors are to be installed.

The amount of investigative and design work depends upon the type and size of the project, the complexity of the ground and the degree of risk involved.

5 Site investigation

The ground is a vital element of the ground anchor system, therefore a good quality geotechnical investigation is essential. A common cause of individual anchor failure at the acceptance testing stage is the lack of accurate information on the ground conditions local to the anchor.

Since inclined ground anchors are installed as commonly as vertical anchors, lateral variations in ground properties should be investigated as thoroughly as the vertical variations.

All geotechnical investigation shall be undertaken in accordance with the requirements and recommendations of ENV 1997-1-1 Eurocode 7, Part 1.

Geotechnical investigation should be extended to site extremities so that the strata profile may be interpolated between the investigation locations rather than extrapolated outside the area investigated. Where possible it should be extended to include ground formations outside the actual site if stresses induced by anchors are extended there.

Depths of geotechnical investigation should be adequate to ensure that :

a) a known geological formation is proved ; or

b) no underlying stratum will affect design ; and

c) groundwater conditions are well defined.

In addition to the lithology and structure of the ground in accordance with ENV 1997-1 Eurocode 7, Part 1, the following shall also be known, where applicable :

a) for soils :

- soil description and classification (grading, moisture content, unit weight, relative density, Atterberg limits) ;
- shear strength, compressibility and radial stiffness ;
- permeability ;
- ground water conditions ;
- corrosion potential of soil and ground water ;
- existence of stray electric currents ;

b) for rocks :

- classification (geometry of discontinuities, unit weight, degree of weathering, index tests) ;
- rock stratification ;
- unconfined compression strength of intact rock ;
- shear strength and deformability of rock mass ;
- permeability ;
- ground water conditions ;

- corrosion potential of rock and ground water ;
- existence of stray electric currents.

From this information, it should be possible to determine the likelihood of difficulties relating to :

- potential obstructions to drilling ;
- the process of borehole drilling (drillability) ;
- borehole stability ;
- flow of ground water into the borehole ;
- loss of grout from the borehole.

6 Materials and products

6.1 General

Anchor systems shall be used for which successful experience with respect to performance and durability has been documented.

All anchor systems shall have been subjected to at least one system test to verify the competence of the system. The results of all tests shall be documented in detail.

The documented system test shall be approved by the Client's Technical Representative in accordance with principles stated in this standard.

All materials used shall be mutually compatible. This applies in particular to adjacent materials with a common interface. Material properties shall not change during the design life of the ground anchor in such a way that the anchor loses its serviceability.

Anchors involving the use of newly developed materials or methods of execution are permitted subject to the performance of the anchor and durability of the materials used being proven by system tests and approved by the Client's Technical Representative to ensure that the serviceability of the anchor system is maintained for the design life of the anchored structure.

6.2 Tendon

All steel tendons shall comply with the following European Standards :

Construction steel	- ENV 1993-1 : Eurocode 3 : Design of steel structures - Part 1 : General rules ;
Steel reinforcement	- ENV 1992-1-1 : Eurocode 2 : Design of concrete structures - Part 1 : General rules ;
Prestressing steel	- prEN 10138: Design of prestressing steel ;
	- prENV 1992-1-5 : Eurocode 2 Part 1- 5: The use of unbonded and external prestressing tendons.

Other tendon materials may only be used if their suitability as anchor components has been proven and they are approved by the Client's Technical Representative.

6.3 Anchor head

The anchor head shall allow the tendon to be stressed, proof loaded and locked-off and, if required, released, destressed and restressed. It shall be able to carry the characteristic tensile load of the tendon of 100 % P_{tk}.

The anchor head shall comply with ENV 1992-1 : Eurocode 2 unless the required deviation is justified. The anchor head shall be designed to tolerate angular deviations of the tendon from the direction normal to the head, up to a maximum of 3° at 97 % P_{tk} of the tendon.

The anchor head shall distribute the tendon load to the main structure or to the ground in accordance with the overall design of the structure through designed or tested components.

The anchor head (i.e. the connection between the anchor tendon and the structure) shall be able to adjust to deformations which may be expected during the design life of the structure.

6.4 Coupler

Couplers shall comply with ENV 1992-1-1 : Eurocode 2, and shall not compromise the required tensile strength of the tendon.

The tendon should not be coupled inside the bond length.

The free extension of a steel tendon shall not be compromised by restraint of the coupler.

The corrosion protection of the coupler shall be compatible with the corrosion protection provided to the tendon.

6.5 Tendon bond length

In order to anchor the tendon in the bond length, profiled or ribbed tendons, strands or compression tubes shall be used in this section.

As a guide the following types of steel tendon may be anchored by bond action :

- cold drawn wires profiled after drawing ;
- quenched and tempered wires ribbed during hot rolling ;
- ribbed bars ;
- seven wire strands.

The relative area, f_r, of the ribs of ribbed or profiled wires and bars shall be in accordance with ENV 1992-1: Eurocode 2.

Prestressing steels with a smooth surface with or without special proven anchoring devices may only be used with temporary anchors when approved by the Client's Technical Representative.

6.6 Spacer and other components in the borehole

All installed tendons and encapsulations shall be provided with a minimum of 10 mm grout cover to the borehole wall. This may be achieved by the use of spacers or centralizers.

Any component installed and remaining in the borehole should be spaced and located so that it does not reduce the bond capacity of the anchor. To ensure correct positioning of the tendon(s), the tendon components, the corrosion protection components and any other component in the borehole, spacers should be located such that minimum grout cover requirements and complete filling of open volume by grout are provided.

Spacers and centralizers shall not impede grout flow.

When used outside an encapsulation in a permanent anchor spacers should be manufactured from corrosion resistant materials.

The design of centralizers shall take into account the shape of the hole, e.g. the presence of underreamed bells, the weight of the tendon and the susceptibility of the ground to disturbance during insertion of the tendon.

6.7 Cement grout and admixtures

Cement grouts used in the encapsulation and in contact with prestressing steel tendons shall conform in general with prEN 445, prEN 446 and prEN 447. Where there is conflict between the provisions of this standard and prEN 445, prEN 446 and prEN 447, the provisions of this standard shall be adopted.

For cement grout used to encase a tendon within an encapsulation or to protect steel tubes, the properties should be controlled to prevent bleed and shrinkage. Water/cement ratios for anchor grouts outside the encapsulation but within the borehole should be chosen appropriate to the ground conditions.

High sulphide content cements shall not be used in contact with prestressing steel.

When selecting the type of cement for grout placed in contact with the surrounding ground, account shall be taken of the presence of aggressive substances in the environment, e.g. carbonic acid and sulphates, of the permeability of the ground and of the design life of the anchor. The aggressivity of the environment shall be defined in accordance with ENV 206.

Admixtures may be used for improving workability or durability, for reducing bleed or shrinkage, or for increasing rate of strength development. The use of admixtures with prestressing steel shall be approved by the Client's Technical Representative. Admixtures shall be free from any product liable to damage prestressing steel or the grout itself. No admixture that contains more than 0,1 % (by mass) of chlorides, sulphides or nitrates shall be used.

Where appropriate, inert fillers (i.e. sand) may be incorporated within the grout mix to reduce leakage away from the borehole.

Laboratory and field tests should be undertaken to verify mixture, mixing efficiency, setting times and performance. These tests should be undertaken in accordance with prEN 445 where applicable.

6.8 Resin grout

Resins and resin mortars may be used in ground anchor construction as an alternative to cement grout if their applicability has been proven by a system test appropriate to their application.

Laboratory and field tests should be undertaken to verify mixture, mixing efficiency, setting times and performance.

6.9 Corrosion protection of steel tendon and stressed steel components

6.9.1 General

There is no certain way of identifying corrosive circumstance with sufficient precision to predict corrosion rates of steel in the ground. All steel components which are stressed shall be protected against corrosion for their design life. Corrosion protection elements shall be capable of transmitting tendon loads, where required.

The standard of corrosion protection is classified by the anchor design life :

— temporary ground anchors are defined as those which are required to be in service no longer than two years ;

— permanent ground anchors are defined as those which are to have a design life of more than two years.

Table 2 — Examples of corrosion protection systems for temporary anchors

1. Tendon bond length
All installed tendons shall be provided with a minimum 10 mm cement grout cover to the borehole wall. Where aggressive ground conditions are known to exist, it may be appropriate to enhance the protection for example by the use of a single corrugated duct around the tendon(s).
2. Tendon free length
The protection system shall have low frictional properties and allow movement of the tendon within the borehole. This may be achieved by the provision of one of the following : a) plastic sheath surrounding each individual tendon, end sealed against ingress of water ; b) plastic sheath surrounding each individual tendon, completely filled with corrosion protection compound ; c) plastic or steel sheath or duct common to all tendons, end sealed against ingress of water ; d) plastic or steel sheath or duct common to all tendons completely filled with corrosion protection compound ; b) or d) is appropriate for extended temporary use or in aggressive conditions.
3. Transition between anchor head and free length (inner anchor head)
The free length sheath or duct may be sealed to the bearing plate/anchor head, or a metal sleeve or plastic duct may be sealed or welded to the bearing plate. It shall overlap the free length sheath or duct and for extended temporary use be filled with corrosion protection compound, cement or resin which is contained at the lower end.
4. Anchor head
Where the anchor head is accessible for inspection and possible re-coating the following protection is acceptable : a) a coating of non-fluid corrosion protection compound ; or b) a combination of corrosion protection compound and tape which is impregnated with corrosion protection compound. Where the anchor head is not accessible a metal or plastic cap shall be fitted and filled with corrosion protection compound for extended use. Where aggressive conditions are known to exist, a metal or plastic cap shall be filled with corrosion protection compound.

6.9.2 Temporary ground anchor

The steel components of a temporary ground anchor shall be provided with protection which will inhibit or prevent corrosion over a minimum design life of two years.

If there is a possibility that the design life of a temporary ground anchor is to be extended on a temporary basis or if the anchor is installed in ground conditions known to be corrosive then measures, approved by the Client's Technical Representative, shall be taken to protect all parts of the anchor from corrosion.

Examples of corrosion protection which may be considered to satisfy the above principles of protection to temporary anchors are described in Table 2.

6.9.3 Permanent ground anchor

The minimum corrosion protection surrounding the tendon(s) of the anchor shall be a single continuous layer of corrosion preventive material which does not degrade during the design life of the anchor.

The tendon(s) of a permanent ground anchor shall be provided with either :

a) two protective barriers to corrosion such that if one barrier is damaged during installation or anchor loading, the second barrier remains intact ; or

b) a single protective barrier to corrosion, the integrity of which shall be proven by testing each anchor insitu (see annex A) ;

c) a corrosion protection system provided by a steel duct tube-a-manchette type anchor (see 6.10.4 and 6.10.9) ;

d) a corrosion protection system provided by a corrugated plastic duct tube-a-manchette type anchor (see 6.10.4 and 6.10.9);

e) a corrosion protection system provided by a steel duct compression tube type anchor (see 6.10.4 and 6.10.6).

Examples of corrosion protection which may be considered to satisfy the above principles of protection to permanent anchors are described in Table 3.

6.10 Commonly used components and materials for corrosion protection barriers

6.10.1 Plastic sheaths and ducts

Plastic sheaths and ducts shall conform with relevant European product standards and in particular are required to be continuous, impermeable to water, resistant to age brittleness and resistant to ultra-violet radiation damage during storage, transportation and installation. Joints between plastic components shall be fully sealed against ingress of water by direct contact or by sealants. Where used, PVC shall be resistant to ageing and shall not produce free chlorides.

The minimum wall thickness of an external corrugated duct common to one or several tendons shall be :

— 1,0 mm for internal diameter ≤ 80 mm ;

— 1,5 mm for internal diameter > 80 mm but ≤ 120 mm ;

— 2,0 mm for internal diameter > 120 mm.

The minimum wall thickness of an external smooth common sheath or duct shall be 1 mm greater than that required for the corrugated ducts or it shall be reinforced.

The minimum wall thickness of an internal sheath shall be 1,0 mm and an internal corrugated duct shall be 0,8 mm.

NOTE Where two plastic barriers are provided some protection to the inner barrier is provided during installation by the outer barrier.

Where used for load transfer, plastic ducts shall be deformed or corrugated. The amplitude and pitch of the deformations or corrugations shall be related to the wall thickness and shall be able to transfer load in a manner not susceptible to creep losses.

Table 3 — Examples of corrosion protection systems for permanent anchors

<table>
<tr><td colspan="2">Verification of protection offered
a) All corrosion protection systems shall have been subjected to test(s) to verify the competence of the system. The results of all tests shall be well documented ;

b) the Client's Technical Representative will carry out a technical assessment of the results of the corrosion protection system tests in order to verify that the protection offered by each barrier in the system is achieved. It should be noted that in certain systems the integrity of the inner protective barrier itself depends on the maintenance of the integrity of the outer barrier ;

c) where only a single protective barrier is provided in the tendon bond length the integrity of this barrier may be checked by an insitu test such as an electrical resistivity test.</td></tr>
<tr><td>1. Tendon bond length

The encapsulation may consist of one of the following :</td><td>Protective barriers Offered insitu</td></tr>
<tr><td>a) a single corrugated plastic duct containing the tendon(s) and cement grout ;</td><td>a) one plastic duct</td></tr>
<tr><td>b) two concentric corrugated plastic ducts containing the tendon(s), fully pregrouted (with cement or resin) within the core and the annulus between the ducts prior to installation ;</td><td>b) two plastic ducts</td></tr>
<tr><td>c) a single corrugated plastic duct containing a bar tendon or tendons and pregrouted with cement grout. A minimum cover of 5 mm is provided between the duct and bar. The bar tendon(s) have a continuous ribbed outer surface. The crack width of the cement grout between the duct and the bar does not exceed 0,1 mm under service loading ;</td><td>c) internal cement grout and surrounding plastic duct ;</td></tr>
<tr><td>d) a single steel or corrugated plastic tube-a-manchette duct not less than 3 mm thick, surrounded by a minimum of 20 mm grout cover injected under a pressure of not less than 500 kPa at intervals along the tube-a-manchette no greater than 1 metre. A minimum cover of 5 mm is provided between the duct and the tendons. The crack width of this cement grout does not exceed 0,2 mm under service loading ;</td><td>d) internal cement grout and surrounding steel or plastic duct ;</td></tr>
<tr><td>e) a single corrugated steel duct (compression tube) closely surrounding a greased steel tendon. The duct and plastic cap at the restraining nut are protected by the surrounding cement grout having a thickness of not less than 10mm, and where the crack widths do not exceed 0,1 mm under service loading.</td><td>e) steel duct and surrounding cement grout</td></tr>
<tr><td colspan="2">2. Tendon free length

The protection system allows free movement of the tendon within the borehole. This may be achieved by one of the following :

a) a plastic sheath to individual tendon(s) filled completely with flexible corrosion protection compound plus the inclusion of A, B, C or D below ;
b) a plastic sheath to individual tendon(s) filled completely with cement grout plus A or B below ;
c) a common plastic sheath for multiple tendon(s) filled completely with cement grout plus B.
a) Common plastic sheath or duct filled with flexible corrosion protection compound ;
b) common plastic sheath or duct sealed at the ends against ingress of water ;
c) common plastic sheath or duct filled with cement grout ;
d) common steel duct filled with dense cement grout.

A lubricant or bond free contact is present within either the individual sheaths or the common sheath to ensure free movement of the tendon(s) during stressing.</td></tr>
<tr><td colspan="2">3. Transition between anchor head and free length
A coated, grouted or cast-in metal sleeve or fixed plastic duct is sealed or welded to the anchor head. It is sealed to the free length sheath or duct and filled with corrosion protection compound, cement or resin.</td></tr>
<tr><td colspan="2">4. Anchor head
A coated and/or galvanised metal cap with a minimum 3 mm wall thickness or a rigid plastic cap with a minimum 5 mm wall thickness is connected to the bearing plate and if removable it is filled with a flexible corrosion protection compound and sealed with a gasket. If non-removable it may be filled with cement or resin.</td></tr>
</table>

Where a corrugated duct, used for grout injection under pressure, is considered as a protective barrier then it should be demonstrated that the grout ports do not allow the ingress of water after grout injection.

The duct shall be not less than 3 mm thick and the pitch and amplitude of the corrugations shall be suitable for load transfer, proven by a system test (see 6.12).

The integrity of the protective barrier should also be demonstrated in the stressed state (see 6.12).

Where a single plastic duct forms the sole protective barrier of a permanent anchor an in situ test shall be carried out to verify the integrity of the plastic duct throughout the length of the anchor. This may be by electrical resistivity test and carried out after borehole grouting and after stressing to establish the complete isolation of the steel tendon from the ground. Details of an acceptable testing method are given in annex A to this standard.

6.10.2 Heat shrink sleeves

Heat shrink sleeves may be used to encapsulate corrosion protection compounds which cover the surface of a steel element.

The heat shall be applied during shrinking in such a way that other elements of the corrosion protection system remain within standard requirements, e.g. not deformed nor burnt by heat application or otherwise damaged to the impairment of serviceability.

The shrinkage ratio shall be such as to prevent any gaps from opening in the long term. The wall thickness of the sleeve after shrinkage shall be not less than 1 mm.

6.10.3 Seals

Mechanical joints are sealed with O-rings, gaskets or heat shrink sleeves.

The seal or other equivalent device shall prevent any leak of packing or any penetration of water from outside, whatever the subsequent relative movements between adjacent elements being sealed.

6.10.4 Cement grout

Cement grout injected into boreholes is permitted as temporary protection provided that the cover to the tendon is not less than 10 mm throughout its length.

Dense cement grout injected under factory or equivalent controlled conditions is permitted as one of two permanent protection barriers provided that the cover between the tendon and the outer barrier is not less than 5 mm, and provided that the crack width during serviceability loading has been proven not to exceed 0,1 mm (see 6.12).

In the case of tube-á-manchette type anchors where the steel or plastic corrugated duct is at least 3 mm thick, surrounded by a minimum of 20 mm grout cover injected under a pressure of not less than 500 kPa, then crack widths in the grout between the tendon and the duct shall be proven to be less than 0,2 mm wide under the serviceability loading condition.

The distribution of cracks and their widths may, in certain conditions, be controlled by the distribution of ribs on a bar tendon.

Quality control and volume checks should be made during encapsulation grouting.

6.10.5 Resins

Resin grouts injected or placed in a controlled manner with a minimum cover to the tendon of 5 mm are permitted as one permanent barrier providing they are contained, are unstressed and do not crack.

6.10.6 Corrosion protection compounds

Corrosion protection compounds based on petroleum waxes and greases are commonly used.

Guidelines for the acceptance criteria for viscous corrosion protection compounds and examples of test methods to measure properties of viscous corrosion protection compounds are given in annex C.

The properties of corrosion protection compounds should include stability against oxygen and resistance to bacterial and microbiological attack.

Corrosion protection compounds used for permanent corrosion barriers shall be contained within a robust moisture-proof sheath, duct or cap which itself shall be resistant to corrosion. In these circumstances such compounds also act as lubricants and void fillers which are able to exclude gas and water.

Non-contained corrosion protection compounds may be used as temporary corrosion barriers when applied effectively as a coating. Tape impregnated with corrosion protection compounds may only be used as temporary protection since there is a tendency for it to deteriorate whilst exposed to air or water.

6.10.7 Sacrificial metallic coating

Sacrificial metallic coatings shall not be applied to tendons.

Sacrificial metallic coatings may be used on other steel components such as bearing plates, caps and sleeves.

6.10.8 Other coatings on steel parts

Tar-epoxy, tar-polyurethane and fusion bonded epoxy coatings may be applied to steel surfaces which are sand blasted and free from any deleterious matter. They may be used as corrosion protection to tendons of temporary anchors if they are factory applied.

They are acceptable as a corrosion protection barrier for the tendon on a permanent anchor if the layer is applied in the factory and the thickness is not less than 0,3 mm and if application faults like pin holes are excluded by appropriate fabrication control.

Coatings are only permitted in the bond length if the bond and the integrity of the corrosion protection are verified by testing (see 6.12).

6.10.9 Steel tubes and caps

Steel parts may provide permanent corrosion protection barriers where they are themselves externally protected. Such protection may be provided by dense cement grout or concrete, by hot dip galvanising or by multiple application of coating materials approved by the Client's Technical Representative.

Steel parts with coatings which become stressed during anchor loading are only permitted if the bond and integrity of the corrosion protection are verified by testing (see 6.12).

Where a duct used for grout injection is considered as a protective barrier then it should be demonstrated that the grout ports do not allow the ingress of water after grout injection.

The duct shall be not less than 3 mm thick, surrounded by a minimum of 20 mm grout cover and the bond capacity and integrity of the corrosion protection verified by a system test (see 6.12).

Any potential degradation of the steel or coating shall be considered in the design of the anchor in the selection of element thickness and sizes.

6.11 Application of corrosion protection

6.11.1 General

The principles of protection are the same for all parts of the anchor but different detailed treatments are necessary for the tendon bond length, the tendon free length and the anchor head.

The protective system shall not restrict any stressing or destressing operation nor be damaged by it. A lubricant or bond free contact shall be present within either the individual sheaths or the common sheath to ensure free movement of the tendon(s) during stressing.

Particular care shall be taken to seal transition points from one protection component to another and at end points.

The ground anchor or any part of it shall be handled in such a way that the corrosion protection system is not damaged.

6.11.2 Tendon free and bond lengths

Tendons shall be free of corrosion, in particular pitting corrosion, when they are encapsulated by a corrosion protection system. Slight surface rust is permissible, providing it can be wiped off, and the surface is subsequently covered by cement grout.

Tendon protection to the free length of a temporary anchor may be applied in situ, on site, or prior to delivery.

Tendon protection to the bond length of a temporary anchor is generally applied in situ.

Where corrosion protection of permanent anchors is applied by means of plastic sheaths and ducts, permanent tendon sheaths, resin or cement grouts and corrosion preventive compounds prior to the installation of the tendon in the borehole, this should be done either under factory conditions or on site within specially constructed work areas where dry air and clean conditions can be assured. The environmental conditions shall be such that the application of corrosion protection may be undertaken in accordance with this standard.

Where corrosion protection of permanent anchors is applied in situ by means of plastic sheaths and ducts, permanent tendon sheaths, metal ducts, resin or cement grouts and corrosion preventive compounds, care should be taken to ensure that the tendon and metal duct are kept clean and free of corrosive materials during this operation.

Grouting of the encapsulation of permanent anchors shall be undertaken from the lower end of the sheath and shall be continuous until completed.

The tendon shall not be exposed to deleterious stray currents.

6.11.3 Anchor head

Where the environment is aggressive, early protection of the anchor head shall be applied to both temporary and permanent anchors.

The purpose of the inner head protection is to provide an effective overlap with the free length protection, to protect the short exposed length of tendon below and passing through the bearing plate.

Where injection techniques are employed, a lower injection pipe and upper vent pipe should be used to ensure complete filling of the void. Where no access for injection of the inner head is provided, a prepacked corrosion protection compound may be used.

Where restressability or load checking is not required, resins, grouts and other setting sealants may be used within the anchor cap. Where restressability or load checking is required the outer head protection including the anchor head cap and its contents shall be removable. It shall be possible to refill the cap with corrosion protection compound.

A suitable seal and mechanical coupling shall be provided between the cap and the bearing plate.

Where applied to permanent anchors the bearing plate and the other exposed steel components at the anchor head shall be protected in accordance with the relevant EN for the coating of steel structures prior to being brought onto site.

Steel caps for permanent anchors shall have a minimum wall thickness of 3 mm.

Reinforced plastic caps having a minimum wall thickness of 5 mm may be used, where approved by the Client's Technical Representative.

The protection system applied to the inner and outer anchor head shall be subjected to a system test (see 6.12).

6.12 Corrosion protection testing for permanent anchors with system tests

All corrosion protection systems shall have been subjected to at least one system test to verify the competence of the system. The results of all tests shall be documented.

The type of system test carried out for each anchor system shall be approved, in accordance with the principles stated herein, by the Client's Technical Representative who shall assess the documented results of the corrosion protection system tests in order to verify that the protection offered by each barrier in the system has been achieved.

The loading sequence shall comply with one of the three types of suitability tests in clause 9.

The confinement conditions in the test bond length shall simulate those encountered in the ground, be it rock or soil.

NOTE Either in situ tests or simulated laboratory tests are performed. Laboratory tests may include uniform stressing of encapsulated tendons as well as simulating the load transfer in the bond length.

Where an in situ test is undertaken the installation procedure shall simulate the procedure used with production anchors.

After loading the test anchors shall be uncovered with care in order to observe the effect of the stressed condition on the corrosion protection system.

The following properties of the corrosion protection system shall be assessed by inspection or measurement, where appropriate :

— wall thickness and integrity of plastic ducts ;

— integrity of joints and seals ;

— grout cover and performance of spacers and centralizers ;

— location and spacing of cracks in the cement grout where it serves as a corrosion protection barrier ;

— degree of filling of grout, resin and corrosion protection compound in ducts and volumes of containment ;

— damage to coatings ;

— degree of bond or debonding along interfaces ;

— dislocation of components during installation and loading.

It should be noted that in certain systems the integrity of the inner protective barrier depends on the maintenance of the integrity of the outer barrier.

Where plastic duct(s) are used as a protection barrier in the bond length of a permanent anchor the system test should demonstrate the integrity of the pregrouted encapsulation. The test should simulate the loading condition by preloading in an environment which approximates the ground conditions. The inspection of the plastic after the loading should prove that protection has not been impaired. A single documented test for a tendon arrangement in each particular duct size is sufficient in the simulated load condition. (An example of a test is described in annex B.)

Where a single plastic duct protection is supplemented by a crack controlled grout a system test should establish the crack spacing (in terms of cracks per metre) within the encapsulation. From the elastic properties of the tendon and the observed spacing of the cracks it should be shown that the crack width does not exceed 0,1 mm under service loading in the test undertaken. The inspection of the plastic after the loading should prove that protection has not been impaired. A single documented test for a tendon arrangement in each particular duct size should be sufficient in the simulated load condition (an example of such a test is described in annex B).

Where a single 3 mm thick steel or corrugated plastic tube-a-manchette duct is supplemented by a crack controlled grout and a minimum external grout cover of 20 mm, a system test should establish the crack spacing (in terms of cracks per metre) within the encapsulation. From the elastic properties of the tendon and the observed spacing of the cracks it should be shown that the crack width does not exceed 0,2 mm under service loading in the test undertaken. A single documented test for a tendon arrangement in each particular duct size should be sufficient in the simulated load condition.

7 Design considerations

This clause deals with those matters which should be taken into account in the execution stage of a ground anchor so that the design of the anchor system may be fulfilled.

For the detailed design of a ground anchor reference should be made to annex D of this standard. For the design of the structure as a whole reference should be made to ENV 1991-1-1 : Eurocode 1 Part 1-1 and ENV 1997-1 : Eurocode 7- Part 1.

Anchored structures can consist of the following types of structures :

— retaining structures ;

— embankment and slope stabilizing structures ;

— underground openings ;

— underground structures and basements subjected to uplift forces due to ground water ;

— structures transferring tensile loads generated by the superstructure or by actions on the superstructure, to the ground.

The following should be clearly shown on construction drawings, where appropriate :

— minimum cross-sectional dimensions and material characteristics of all elements within the anchor system ;

— dimensions of fixed and free anchor lengths ;

— angle of inclination of boreholes to accommodate the anchors ;

— tolerances on anchor dimensions, inclinations and anchor locations.

The design of the anchor system is based on soil parameters and the geometry of the anchor arrangement. Where changes in the anchor locations, spacings or inclinations are proposed, appropriate studies or proving tests should be undertaken to demonstrate the suitability of such an arrangement.

The design of the anchor should address the following :

— loads and constraints of loading imposed by the anchors on the overall structure as an assistance to the overall structural designer ;

— the way in which the loads will be applied to the anchor during its design life i.e. static or dynamic ;

— the load distribution of the anchor arrangement on the structure during stressing and during the design life of the structure ;

— the interface between the anchor and the structure to ensure structural stability at all times ;

— the consequence of anchor failure during stressing and thereafter, and the possibility of the allocation of reserve locations for replacement anchors, if required.

8 Execution

8.1 Drilling of holes

8.1.1 General

Holes for anchors shall be drilled to the tolerances specified.

NOTE 1 In the case of unforeseen conditions on site, design modifications or execution alternatives may be introduced. During execution the borehole diameter may be increased due to the necessary use of casing etc. Compliance with the positioning tolerance is important if the design of the anchored structure is to remain valid. In general horizontal boreholes are avoided because of problems in filling the borehole completely with grout.

The hole diameter shall provide for the specified grout cover to the tendons along the fixed anchor length.

Allowance for extra drilling depth should be added to the specified depth when detritus cannot be removed from the bottom of the hole.

Unless otherwise specified the choice and the set-up of the drilling equipment should satisfy the following conditions :

- the borehole collar axis at the anchor head should be positioned within a radial tolerance of 75 mm ;
- the initial alignment when setting up the drilling rig should not deviate by more than 2° from the specified axis of the borehole.

The deviation should be checked after the borehole has been advanced 2 m.

During drilling the overall borehole deviation tolerance should be limited to 1/30 of the anchor length. On occasion ground conditions may dictate the need for a relaxation of this tolerance.

NOTE 2 The drilling rig assembly and any working platform must be rigid if the desired borehole alignment is to be achieved. In case of doubt the positioning should be rechecked during drilling. Compliance with the angular tolerance is important in relation to the interaction between the fixed anchor lengths. Longer anchors may require smaller angular tolerances, if fixed anchor interference is to be avoided.

NOTE 3 Compliance with the deviation tolerance is important if difficult homing, undesired friction during stressing and interaction between fixed anchors are to be avoided. Measurement of borehole deviation is not common practice but in special cases inclinometer devices can be applied. Borehole deviation can be minimized by using rigid and large diameter drill rods and associated casing. Deviation of rigid systems usually results from obstructions or inclined bedding planes. Other means and procedures, not detailed here, are available to check and control misalignment.

8.1.2 Drilling methods

The drilling method shall be chosen with due regard to the ground conditions so as to cause either minimum ground modification or the modification most beneficial to the anchor capacity and to allow the design anchor resistance (R_d) to be mobilized.

NOTE 1 The reasons for minimum ground modification are :

- to prevent collapse of the borehole wall during drilling and tendon installation (where necessary a casing should be utilized) ;
- to minimize loosening of the surrounding ground in cohesionless soils ;
- to minimize change of ground water levels ;
- to minimize softening of the surface of the borehole wall in cohesive soils and degradable rocks.

The modification to the ground shall be limited in such a way as to reduce the negative effects e.g. splitting, preconsolidation, postconsolidation, associated with each operation. The drilling fluid and possible additives shall have no adverse effect on the tendon, tendon protection, the grout or on the borehole walls especially in the tendon bond length.

NOTE 2 The relationship between area of inlet of the drilling fluid, the annular area of flush return, the particle size and density of the drill spoil and the density of the drilling fluid are critical to the efficiency of the drilling system. The use of air flush with wet cohesive spoil may cause blockage and result in unnecessary disturbance of adjacent ground. Clays, marls and marly rock may be liable to swelling or softening if exposed to water flush for unnecessarily lengthy periods.

Special care should be taken when drilling through ground under artesian water pressure.

NOTE 3 Sands may be loosened and destabilized by adverse hydraulic gradients in the soil surrounding the borehole.

Techniques to counteract the water pressure and to prevent any blow-out, hole collapse and erosion during drilling, installation and grouting operations shall be identified in advance and implemented as and when required. In high water table situations it may be appropriate to use heavy drilling fluids.

NOTE 4 Possible preventative measures include :

- the use of special auxiliary drilling equipment such as seals or packers ;
- the lowering of the water table, after the risks of general settlement of the ground have been assessed ;
- pre-grouting of the ground.

Drilling operations should be conducted in such a way that any major variation in ground characteristics, from those on which the ground anchor design has been based, may be detected immediately.

An indicative drilling log should be established using simple practical identification data (e.g. class of ground, colour of flushing returns or loss of drilling fluid downhole), which can be easily recognized by the operator.

Any major deviation from the indicative log shall be reported immediately to the designer.

8.2 Manufacturing, transport, handling and installation of tendons

8.2.1 Manufacture

During manufacture and storage, the tendons and their components shall be kept clean and free from corrosion, mechanical damage and weld splash.

The tendons shall not be coiled to radii less than any minimum specified by the manufacturer.

Where tendons comprise pre-coated greased strand or wire, exposed elements in the tendon bond length shall be cleaned and degreased thoroughly using steam or solvents.

When solvents are used care to degrease the tendons shall be taken to ensure that they are not aggressive to any of the anchor components and that after application the tendon/grout bond is able to transfer the design tensile loads without creeping.

Centralizers capable of ensuring the required cover to the tendon should be firmly attached to the tendon.

NOTE The spacing of centralizers will primarily depend on the stiffness and weight per unit length of the tendon.

8.2.2 Transport, handling and installation

During loading, transporting and installation of the tendon, care shall be taken not to kink the tendon or cause damage to its components and corrosion protection elements.

Prior to tendon installation, the borehole should be checked for obstructions and cleanliness in addition to length. Tendon installation should be carried out in a controlled manner with care being taken to avoid relative displacement of the components. In upward inclined ground anchors the installed tendon should be securely fixed to prevent movement during grouting.

The time intervals between the different operations required for the construction of an anchor should be related to the properties of the ground. They should, however, be kept as short as possible.

NOTE Where there is a risk of ground swelling or softening, installation and grouting of the tendon should follow immediately after the drilling of the borehole. As a general rule, tendon installation and grouting should be carried out on the same day as drilling of the fixed anchor length. If a delay cannot be avoided, each hole should be plugged to prevent the entry of deleterious material.

8.3 Grouting

8.3.1 General

Grouting meets one or more of the following functions :

a) to form the fixed anchor length in order that the applied load may be transferred from the tendon to the surrounding ground ;

b) to protect the tendon against corrosion ;

c) to strengthen the ground immediately adjacent to the fixed anchor in order to enhance ground anchor capacity ;

d) to seal the ground immediately adjacent to the fixed anchor length in order to limit the loss of grout.

NOTE If a grout volume injected is in excess of three times the borehole volume at pressures not exceeding total overburden pressure, then general void filling is indicated which is beyond routine anchor construction. In such cases general void filling may be necessary before grouting the anchor. For functions c) and d) above only nominal grout consumptions should be expected.

In order to form the fixed anchor length without an uncontrolled loss of grout over this length, the following operations may be considered :

— borehole testing ;

— pregrouting ;

— anchor grouting.

8.3.2 Borehole testing

On completion of the borehole or during the grouting of the anchor measures shall be taken to ensure that the fixed length is fully grouted after the grout has set. This may be done for example, by water testing, falling head grout tests or by pressure grouting.

NOTE 1 Water Testing. - The likelihood of cement grout loss can be assessed in rock from an analysis of a water injection test. Routinely a falling head test is applied to the borehole or the fixed anchor length via a packer. Pregrouting is not usually required if leakage or water loss in the hole or fixed anchor length is less than 5 l/min at an excess head of 0,1 MPa measured over a period of 10 min.

NOTE 2 Falling Head Grout Test. - When pressure grouting of the fixed anchor length is not carried out as part of the routine anchor construction, the borehole may be pre-filled with grout and the grout level observed until it becomes steady. If the level continues to fall it should be topped up and after sufficient stiffening of the grout, the borehole should be redrilled and retested. The test may be applied to the entire borehole or restricted to the fixed anchor length by packer or casing over the free anchor length.

NOTE 3 Pressure Grouting. - For anchor types where grouting of the fixed anchor length is done under pressure, this activity is generally isolated during controlled withdrawal of the lining tube or by the use of a packer or tube-á-manchette system. During injection a controlled flow rate at a measured pressure indicates a satisfactory grouting operation. On completion of grouting of the fixed anchor length the efficiency of this phase can be checked by monitoring the response of the ground to further grout injection when the back pressure should be quickly restored.

8.3.3 Pregrouting

Pregrouting should be carried out by filling the borehole with cement based grout. Sand/cement grout is commonly employed in rock and very stiff to hard cohesive deposits with partially filled or open fissures and in permeable cohesionless soils to reduce grout consumption.

On completion of pregrouting the borehole should be retested and if necessary, the grouting process should be repeated after redrilling.

8.3.4 Pregrouting of rock

In soft rocks, the time of redrilling in relation to grout strength gain is critical to avoid problems of drilling alignment.

Chemical grouting should not be necessary in normal practice but, if employed, it should be established that the chemical will have no deleterious effect on the anchor or on the environment (i.e. contamination of soil and groundwater).

Where a water test indicates an hydraulic connection to an adjacent unstressed anchor, then stressing of that anchor should not be carried out before the grout has set.

8.3.5 Pregrouting of soil

Where borehole testing has identified that the soil is highly permeable or that the grout may be injected at a high flow rate without generating back pressure, pregrouting may be required. This may not be a routine procedure but a prudent precautionary measure if the above soil conditions are suspected to prevail.

In exceptional circumstances it may be necessary to carry out general void filling for overall ground strengthening. In this case such work should not be considered part of routine ground anchor construction.

8.3.6 Anchor grouting

Placement of grout should be carried out as soon as possible after completion of drilling.

When grouting by the tremie method, the end of the tremie pipe shall remain submerged in grout within the fixed anchor length and grouting shall continue until the consistency of the grout emerging is the same as that of the injected grout.

The grouting process should always start at the lower end of the section to be grouted. For horizontal and upward inclined holes, a seal or packer is required to prevent loss of grout from either the fixed anchor length or the entire hole.

Air and water shall be able to escape to permit complete grout filling.

When installing nearly horizontal anchors, special measures, such as multi-stage pressure grouting should be used to prevent any voids being left in the section to be grouted. When multi-sequence grouting along the fixed anchor length or regrouting is envisaged, a sleeve pipe (tube-á-manchette) system should be incorporated in the anchor assembly.

In certain ground conditions where the grout column is adequately confined in the free length some load can be transferred from the fixed length into the free length and onto the back of the structure. Where appropriate, one or more of the following actions may be taken :

— flush the grout out from behind the structure ;

— replace the free length grout with a non-load transferring material ;

— locate a packer at the proximal end of the fixed length.

High pressure multi-stage grouting may be used to increase anchor resistance by introducing further grout into the ground and raising the normal stresses at the ground/grout interface. This may be carried out before or after tendon installation.

Artesian water gain within a borehole should be counteracted by an excess head of grout or by pregrouting irrespective of the rate of the water gain.

8.4 Stressing

8.4.1 General

Stressing is required to fulfil the following two functions :

— to ascertain and record the load carrying behaviour of the anchor ;

— to tension the tendon and to anchor it at its lock-off load.

Stressing and recording shall be carried out by experienced personnel under the control of a suitably qualified supervisor, provided preferably by a specialist anchor contractor or stressing equipment supplier.

8.4.2 Equipment

Stressing equipment and load cells in regular use shall be calibrated at intervals not exceeding six months and the calibration certificate shall be made available for inspection on site at all times.

Stressing equipment for bar and strand tendon should tension the complete tendon as a single unit. Stressing equipment which tensions individual strands not simultaneously should be provided with or be supplemented by measuring devices which establish the total load in the multiple strands at any time during testing. Alternatively accurate lift-off checks should be undertaken.

NOTE The equipment should be capable of safely tensioning the tendon to the specified proof load within the rated pressure capacity of the pumping unit.

8.4.3 Stressing procedure

If the loading on the structure is required to control the sequence or the phase loading of the anchors then this shall be specified at the design stage.

The anchored structure should be designed to provide reaction to allow load testing of the ground anchors in accordance with clause 9.

The methods of stressing and load recording to be used in each testing or stressing operation should be detailed prior to any tensioning work.

The equipment should be used strictly in accordance with the manufacturer's operating instructions.

Stressing or testing should not be carried out until sufficient hardening of the grout in the fixed length has been achieved, which normally requires seven days.

In sensitive cohesive soils it may be appropriate to stipulate a minimum time period for soil recovery after completion of the ground anchor installation and prior to stressing.

During the testing or stressing of production anchors no indents resulting from tendon gripping should be formed in the tendon below the anchor head and no damage should be allowed to the corrosion protection.

9 Testing, supervision and monitoring

9.1 General

ENV 1997-1 recognizes 2 classes of anchor testing, namely assessment tests and acceptance tests. In this standard three classifications of on-site load test will be considered separately.

These are :

- investigation test ;
- suitability test ;
- acceptance test.

The first two classes can be considered subdivisions of the general category of Assessment tests.

Investigation tests establish in advance of the installation of the working anchors :

a) the resistance R_a of the anchor at the grout/ground interface ;

b) the critical creep load of the anchor system ; or

c) the creep characteristics of the anchor system at loads up to failure ; or

d) the load loss characteristics of the anchor system at the serviceability limit state P_0;

e) an apparent tendon free length L_{app}.

Suitability tests confirm, for a particular design situation :

a) the ability to sustain a proof load P_p ;

b) the creep or load loss characteristics of the anchor system up to proof load ;

c) an apparent tendon free length L_{app}.

Acceptance tests confirm, for each individual anchor :

a) the ability of the anchor to sustain a proof load ;

b) the creep or load loss characteristics at the serviceability limit state, when necessary ;

c) the apparent tendon free length L_{app}.

The supervision and assessment of all anchor tests shall be undertaken by a competent person experienced in anchor technology. The test methods prescribed for each test class shall apply to both temporary and permanent anchors.

On each project where encapsulations are grouted in the borehole a test involving the complete filling of the encapsulation with a quality grout in accordance with subclause 6.7 shall be undertaken by simulated operations under similar geometrical conditions prior to production anchor grouting. The test is carried out at the start of the works. Other system tests exist to verify the competence of the corrosion protection provided by the anchor system. These tests are described in clause 6.

9.2 Measurement accuracy

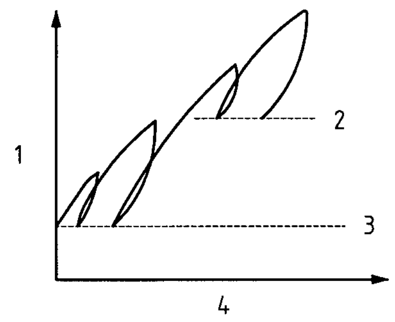
During hold periods where creep is measured in any test, the accuracy of displacement measurement shall be to 0,05 mm. Where no creep is to be measured, the accuracy of displacement measurement required is to 0,5 mm. The measuring equipment shall be able to resolve displacement of 0,01 mm when creep is being measured.

The measurement of loads in anchors shall be by hydraulic, electrical or mechanical load measuring device able to measure to an accuracy of better than 2 % of the maximum applied load during each test. Any load measuring device used for load loss tests shall be able to resolve loads to 0,5 % of the proof load.

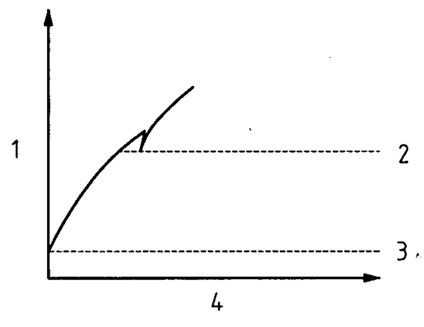
9.3 Datum Load

The datum load P_a adopted from which measurement commences, is normally about 10 % of the proof load.

Higher datum loads are permitted in cyclic loading tests after load cycles where unusually high tendon extensions occur, see Figure 2.



a) With load cycling



b) Without load cycling

Key

1 Anchor load

2 Optional higher datum load

3 Datum load P_a

4 Anchor displacement

Figure 2 — Loading procedures with increased datum load

9.4 Test methods

The Client's Technical Representative shall approve the test method and the associated interpretation system which shall be used in each test class. For each test class the ground anchor shall be loaded in stages in accordance with any procedure required for that test class.

Three examples of test methods applicable to each test class are given in annex E - these are :

a) **Test Method 1** : The anchor is loaded incrementally in one or more cycles from a datum load to a proof load. Displacement of the anchor head is measured over a time period at the maximum load in each cycle ;

b) **Test Method 2** : The anchor is loaded incrementally in cycles from a datum load to a proof load or to failure. The loss of load at the anchor head is measured over a period of time at the maximum load in each cycle ;

c) **Test Method 3** : The anchor is loaded in incremental steps from a datum load to a maximum load. The displacement of the anchor head is measured under maintained load at each loading step.

During all testing the load shall be applied and released smoothly so that the anchor is not subjected to any shock or dynamic loads.

9.5 Investigation test

Investigation tests may be required to establish for the designer, in advance of the installation of the working ground anchors, the ultimate load resistance in relation to the ground conditions and materials used, to prove the competence of the contractor and/or to prove a new type of ground anchor by inducing a failure at the grout/ground interface.

Investigation tests should be carried out where anchors are used in ground conditions not yet tested by previous investigation tests or with higher working loads than those already adopted in similar ground conditions.

Anchors used for investigation tests are loaded more rigorously than anchors in acceptance tests so it may be necessary to increase the size of the tendon to accommodate this. Anchors subjected to investigation tests shall not be used in the permanent works if they have been loaded to failure.

The diameter of the borehole and dimensions of other components, apart from the tendon, should be kept the same as the working anchor.

Where an increase in capacity of the tendon is not possible then a shorter fixed length may be tested in order to induce a grout/ground failure.

Where failure of a test anchor with a reduced fixed anchor length is attained an increase in load resistance directly proportional to the increase in fixed length should not be expected for anchors of longer fixed lengths.

If the diameter of the borehole is increased the behaviour of an anchor in an investigation test may not be compared directly to the behaviour of working anchors.

The anchor shall be loaded to failure (R_a) or to a proof load (P_p) which shall be limited to 0,80 P_{tk} or 0,95 $P_{t0,1k}$ whichever is the lower.

9.6 Suitability test

Prior to the execution of suitability tests full consideration of the benefits of investigation tests should be made and the results from any such tests should be assessed.

The objectives of the suitability test are as follows :

a) where investigation tests have been carried out suitability tests confirm either the acceptable creep or load loss characteristics at proof and lock-off load levels for future acceptance tests, or a critical creep load ;

b) where no investigation tests have been carried out and if no results of investigation tests on similar anchors in similar ground conditions are available, suitability tests demonstrate the characteristics as in a) above, and provide acceptance creep or load loss criteria at proof load level of acceptance tests, or provide the critical creep load ;

c) to determine the apparent tendon free length.

At least three suitability tests shall be carried out on anchors constructed under identical conditions to working anchors.

Where investigation tests have not been carried out the suitability test anchors may contain a tendon with a capacity higher than that of a working anchor.

9.7 Acceptance test

Each working anchor shall be subjected to an acceptance test.

The objectives of the acceptance test are as follows :

a) to demonstrate that a proof load, which will depend on the test method, can be sustained by the anchor ;

b) to determine the apparent tendon free length ;

c) to ensure that the lock-off load is at the designed load level, excluding friction ;

d) the creep or load loss characteristics at the serviceability limit state, when necessary.

9.8 Maximum lock-off load

If a creep or load loss limit is not exceeded, the maximum lock-off load (P_0) shall be limited to 0,60 P_{tk}.

If, in the case of either a suitability test or an acceptance test, the creep or load loss limit is exceeded, the lock-off load shall be reduced to a level where the creep or load loss criterion is satisfied.

9.9 Evaluation of the apparent tendon free length

The apparent tendon free length, L_{app}, is calculated from the measurement of the tendon extension Δs from the point of fixing the tendon to the jack or from a reference point coupled to the tendon. This measurement defines the location of a fictitious fixed anchor which is compared with the end of the tendon free length and the start of the tendon bond length.

NOTE The following equation is generally used to calculate the apparent tendon free length :

$$L_{app} = (A_t E_t \Delta s)/\Delta P$$

where

L_{app} is the apparent tendon free length ;

A_t is the cross-section of tendon ;

E_t is the elastic modulus of the anchor tendon ;

Δs is the elastic extension of the tendon ;

ΔP is the proof load minus datum load.

Limits within which L_{app} shall fall are :

— upper limit $L_{app} \leq L_{tf} + L_e + 0{,}5L_{tb}$;

$L_{app} \leq 1{,}10L_{tf} + L_e$;

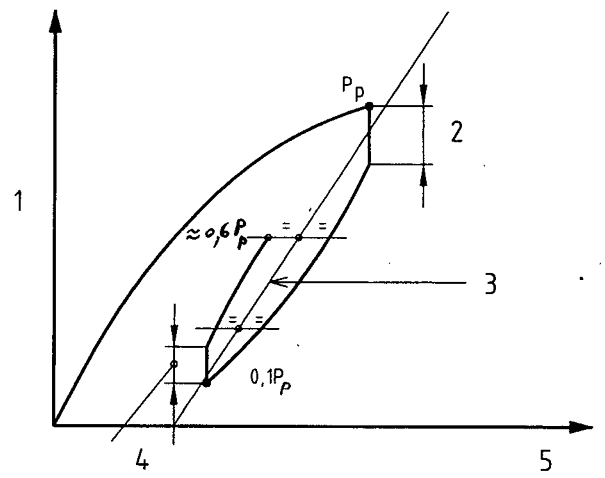
whichever is the larger ;

— lower limit $L_{app} \geq 0{,}80L_{tf} + L_e$.

Where there is significant friction in the free length the method shown in Figure 3 may be used, by considering the hysteresis loop between a load and an unload curve, to estimate the magnitude of apparent elastic stiffness of the free length ($\Delta P/\Delta s$).

NOTE If friction exceeds 5 % P_p then this may be taken into account in determining the minimum proof load or lock-off load. If necessary the proof load may be reduced.

Where the apparent tendon free length lies outside the limits the anchor may be subjected to repeated load cycles to P_p. If the anchor demonstrates repeatability of load/extension behaviour the anchor may be accepted by the designer.



Key

1 Anchor load (P)

2 Friction

3 Slope of load vs displacement curve $\Delta P/\Delta s$

4 Friction

5 Displacement (s)

Figure 3 — Estimate of elastic stiffness where there is significant friction

9.10 Supervision of construction and testing

The installation and testing of all anchors shall be supervised and records shall be made at the site (see clause 10).

If inspection reveals uncertainties with respect to the quality of installed anchors, additional investigations shall be carried out to determine the as-built conditions of the anchors.

9.11 Monitoring

Ground anchors can be installed with a monitoring facility. Where a structure is sensitive to changes in load or ground movement use can be made of this facility to monitor the behaviour throughout its design life.

The number of anchors to be monitored and the intervals between measurements shall be specified.

NOTE In certain cases due to structural movement, it may be necessary to restress the anchors periodically to keep the residual anchor force above the minimum required level.

The corrosion protection of the accessible parts of the anchor heads shall be inspected periodically and renewed, if necessary.

10 Records

An anchor installation plan shall be prepared and shall be available on site containing the technical specification related to the anchor system to be used.

NOTE An anchor installation plan may contain the following information, as appropriate :

- the anchor type with designation ;
- number of anchors ;
- the location and orientation of each anchor and tolerances in position ;
- free anchor length and fixed anchor length ;
- required anchor load carrying capacity and lock-off load ;
- installation technique (drilling, placing, grouting and stressing) ;
- known obstructions ;
- any other constraints on anchoring activities.

Records of anchor construction shall be compiled in accordance with ENV 1997-1-1, for future reference. These shall cover :

- the sequence of deliveries of all cementitious materials, resins and hardeners, cement and resin grouts ;
- site investigation ;
- drilling technique ;
- installation and geometry of anchor elements ;
- date and time of installation of each anchor ;
- for grouted anchors : - material, pressure, grouted volume, grouting length, grouting time ;
- installation of the chosen corrosion protection ;
- grouting ;
- stressing ;
- anchor testing.

A signed record shall be kept for each anchor installation. This record shall include any special features of construction. All installation and testing records shall be kept after the completion of the works. As-built plans shall be compiled after completion of the anchors and kept with the construction records. Any acceptance certificates issued by regulatory authorities for materials used in the anchor installation shall be held with the construction records.

Copies of all records described in this clause should be deposited such that they may be consulted by interested parties in the future.

Examples of suitable record sheets are given in annex F.

11 Special requirements

When executing anchor works all national standards, specifications or statutory requirements regarding :

— security of the site ;

— safety of the working procedures ; and

— operational safety of drilling and auxiliary equipment and tools should be complied with.

Particular attention shall be drawn to all processes requiring personnel operating alongside heavy equipment and heavy tools.

Nuisance and/or environmental damage that can be caused by the anchor work shall be kept to a minimum.

Such nuisance and/or environmental damage can be caused by :

— noise ;

— ground vibration ;

— ground pollution ;

— surface water pollution ;

— groundwater pollution ;

— air pollution.

During stressing safety precautions are essential.

Operatives and observers should stand to one side of the tensioning equipment and never pass behind when it is under load.

Notices should be displayed stating 'DANGER - Tensioning in Progress' or something similar.

Annex A
(informative)

Electrical testing of corrosion protection

A.1 General

This annex describes the measurement of electrical resistance between an anchor and surrounding soil or structure to determine the effectiveness of the applied corrosion protection system.

Two tests are described;- the first measures the isolation of the anchor from the soil and structure and the second measures the isolation of the head of the anchor from the structure alone.

A.2 Electrical resistance measurement I (ERM I)

For the method of execution of ERM I (Isolation of anchor from soil/structure) see Figures A.1a) and A.1b).

The following equipment specification is adopted :

— measurement voltage 500 V d.c ;

— measuring range > 10 kΩ (0,01 MΩ).

During measurement the anchor shall be connected to the positive pole with the earth connection at the negative pole of the measuring circuit. Generally, the moist soil of the site is used as the earth.

Lengths of reinforcing steel in reinforced concrete construction in contact with the soil, metallic pipes buried in the soil, or soil or rock nails may also be used as the earth connection.

During measurement the points of contact are kept clean.

The ERM I may be executed in two separate phases :

Phase a

This tests the integrity of a plastic sheath on the free anchor length and the bond length after the subsequent stages of the installation of the anchor i.e. before lock-off of the anchor :

This includes :

— after setting the anchor into the borehole ;

— after the primary grouting ;

— after a possible secondary grouting ;

— after the acceptance test.

The execution of the measurement in these stages is shown in Figure A.1a).

A measured electrical resistance between tendon and ground ≥ 0,1 MΩ demonstrates an acceptable level of plastic sheath integrity.

NOTE 1 A faultless watertight plastic sheath gives values of R_I > 100 MΩ.

NOTE 2 It is recommended that these measurements are used to observe the effects of the different actions during the installation of the anchor on the integrity of the plastic sheath.

Phase b

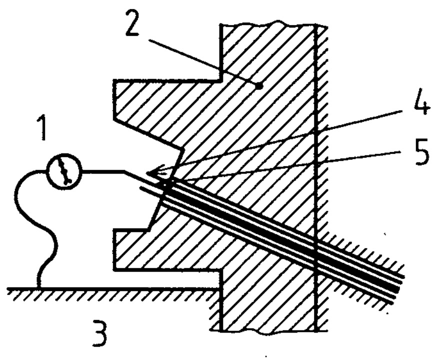
This tests the overall electrical isolation of the anchor from ground and structure :

This includes :

- after lock-off of the anchor ;
- after the anchor head injection ;
- at any time during the working life of the anchor.

A resistance R_I between anchor and ground/structure $\geq$ 0,1 MΩ demonstrates overall electrical isolation of the anchor from the ground and structure.

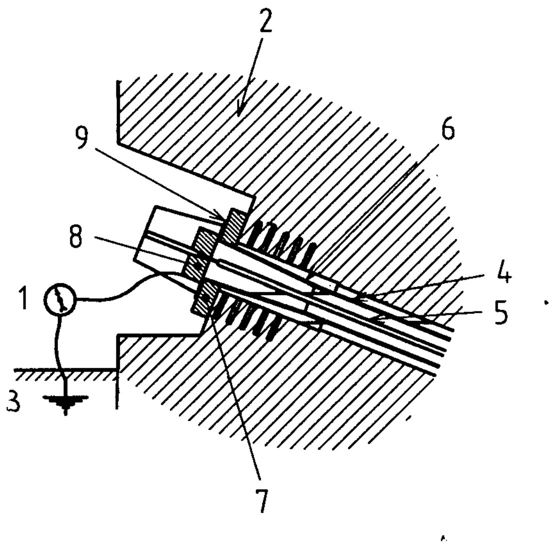
The execution of the measurement on the finished anchor is shown in Figure A.1b).



Key

1 Ohmmeter
2 Structure (concrete)
3 Ground
4 PE-sheath
5 Tendon

Figure A.1a) — ERM I before lock-off of the anchor
R_I between tendon and ground $\geq$ 0,1 MΩ

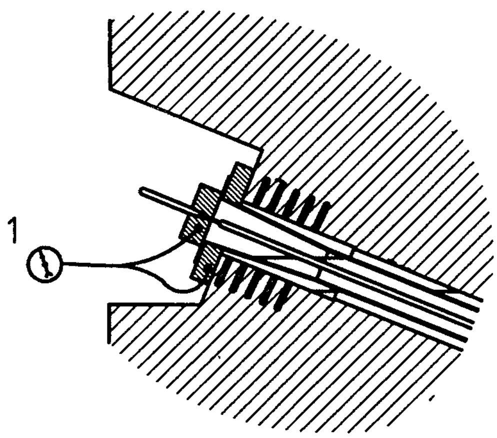


Key

1 Ohmmeter
2 Structure
3 Ground
4 PE-sheath
5 Tendon
6 PE-trumpet
7 Bearing plate
8 Anchor head
9 Isolating plate

NOTE The top of the PE Sheat shall be clean and dry

Figure A.1b) — ERM II after lock-off of the anchor R_I between anchor head and ground/structure $\geq$ 0,1 MΩ



Key

1 Ohmmeter

NOTE ERM II is only executed if R_I after lock off is lower than 0,1 MΩ.

Figure A.2 — ERM II after lock-off of the anchor R_{II} between the anchor head and the bearing plate≥0.1MΩ

A.3 Electrical resistance measurement II (ERM II)

This measurement is only executed if R_I after lock-off of the anchor is lower than 0,1 MΩ in order to prove that, at least, there is no direct contact between anchor head and reinforcing steel of the anchored structure.

ERM II is executed on the stressed anchor. For the method of execution see Figure A.2.

The following equipment specification is adopted :

— measurement voltage circa 40V a.c ;

— measuring range 0-200 kΩ (0-0,2 MΩ).

Generally, the bearing plate is used as the earth connection.

The steel in the anchored structure may be used if the bearing plate is coated by an electrically isolating material.

During measurement the anchor head and in particular the isolating plate between anchor head and bearing plate is kept dry. The electrical contacts are kept clean and the metal bare. In order to ensure good contacts either clamps or strong magnets are used. Pins are not used for this type of measurement.

Measurement ERM II is sensitive to climatic influences such as air humidity in the area of the anchor head and also possibly to stray currents in the ground.

If several measurements are carried out on an anchor then, given the correct execution of the measurement, the greatest resistance measurement should be adopted.

A resistance R_{II} between anchor head and bearing plate or reinforcing steel of the structure > 100 Ω demonstrates no direct contact between anchor head and reinforcing steel of the anchored structure.

Annex B
(informative)

Investigation testing of corrosion protection

This annex describes investigation methods for establishing the integrity of the corrosion protection of a prefabricated anchor encapsulation in a loaded or post-loaded condition. These tests are undertaken in a test frame. Figure B.1 shows the general arrangement of the test apparatus.

TEST A

This method involves the loading of an encapsulated tendon with the encapsulation unconfined.

The tendon, the encapsulation grout and the surrounding plastic duct(s) are subjected to loading conditions identical to those on a service anchor.

The anchor is loaded to the maximum load it will be subjected to during testing in situ.

The flexibility and crack resistance of the duct is observed externally during the loading of the anchor.

The tendon is subsequently unloaded to zero load.

A section of the outer plastic covering is removed and the tendon reloaded to the lock-off load in order to inspect the condition of the inner duct and to check the crack distribution and crack widths in the encapsulation grout.

TEST B

This method involves the loading of an encapsulated tendon in a confined and bonded state within a grouted split gunbarrel.

The loading condition simulates that applied to a service anchor.

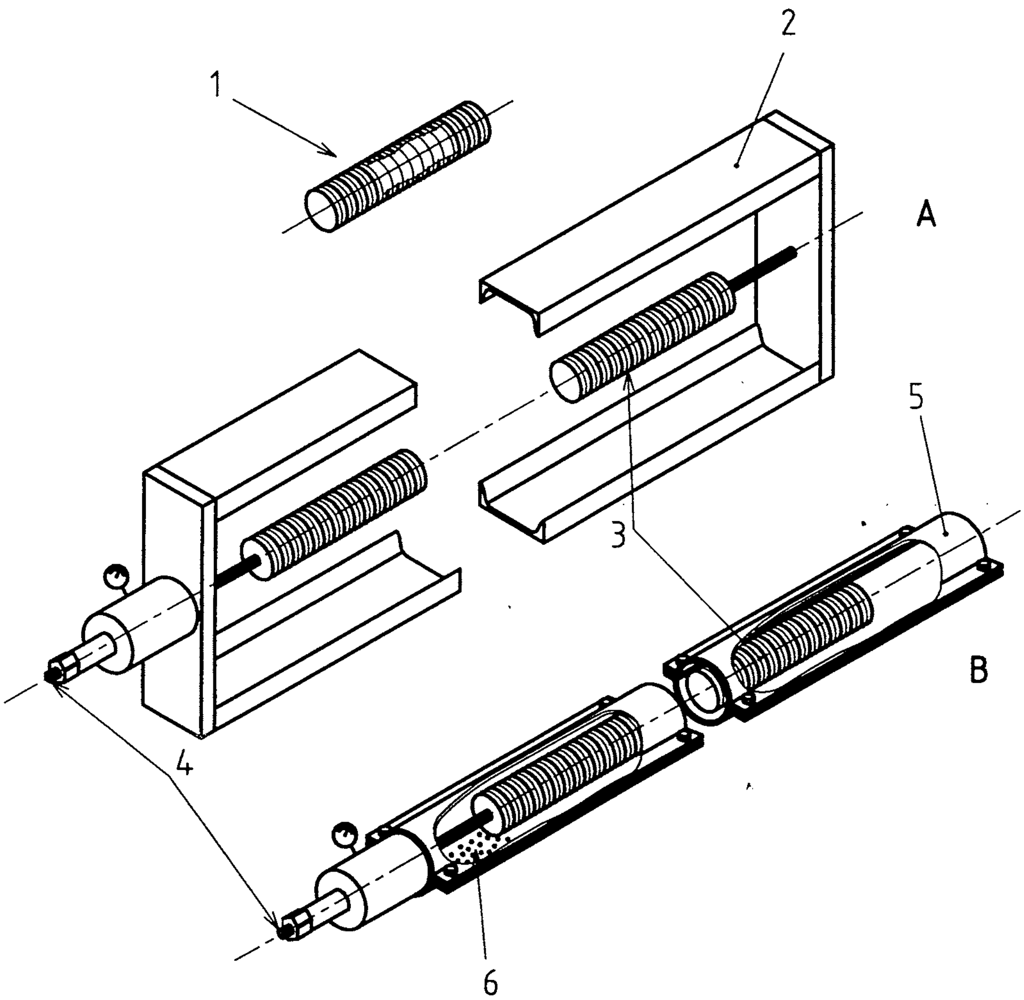
The anchor is loaded to the maximum load it will be subjected to during testing in situ.

The tendon is unloaded to zero load.

The gunbarrel is split open and the gunbarrel grout removed from the outer plastic duct. The integrity of the outer plastic duct is then proved by inspection.

On removal of the outer duct either the inner duct is inspected or, in the absence of an inner duct, the distribution of the cracks in the encapsulated grout is measured.

The tendon extension under the applied service load divided by the number of cracks observed is an indication of the average width of crack in the grout under service loading condition.



Key

1 Inspection of inner duct or grout crack distribution/carck width observed/measured in a loaded (Test “A”) or unloaded (Test “B”) condition at various locations

2 Test frame

3 Anchor encapsulation

4 Bar or multi-strand system

5 Split gunbarrel

6 Grout

A Test “A” Unconfined condition

B Test “B” Confined condition

Figure B.1 — Investigation testing of corrosion protection

Annex C
(informative)

Guidelines for acceptance criteria for viscous corrosion protection compounds and examples of standards for the testing of material properties

Table C.1 — Acceptance criteria for viscous corrosion protection compounds

Property	Units	Acceptance values
Content of free sulphur, sulphates and sulphides	ppm	≤ 50
Content of ionic chlorides, nitrites, nitrates, rhodanites	ppm	≤ 50
Spec. resistivity	Ω*cm	≥ 10^9
Water absorption 0,1N KOH, after 30 days	%	≤ 2
Saponification (acidity)	mg KOH/gm	≤ 5
Deoiling on filter paper at 50 °C, 24 h : dia. of oil spot.	dia. mm	≤ 5
Penetration depth in deoiling test on hardened cement grout 5mm thick at 50 °C after 7 days	mm	≤ 2
Thermal stability, 24 h No oil droplet at sieve for temperature increase of 10 °C every 2 h.	°C Occurrence of oil droplets	≥ 40
Drop point	°C	≥ 60
Protection against rust - Marine fog: 5 % NaCl - 168 h at 35 °C	visual	Zero corrosion
Bleeding at 40 °C	%	≤ 5

Examples of standards for the testing of materials are :

DIN 51759 — Prüfung von flüssigen Mineralölerzeugnissen; Prüfung der Korrosionswirkung auf Kupfer; Kupferstreifen prüfung. (Testing of liquid mineral oil products; testing of corrosion related to copper; copper strip method).

DIN 51576 — Prüfung von Mineralöl-Kohlenwasserstoffen; Bestimmung des Salzgehaltes. (Testing of mineral oil hydrocarbons: determination of salt content).

DIN 53483 — Prüfung von Isolierstoffen; Bestimmung der elektrischen Eigenschaften: Teil 1, 2, 3. (Testing of insulating materials: determination of the di-electrical properties: part 1, 2, 3).

DIN 53495 — Prüfung von Kunsstoffen; Bestimmung der Wasseraufnahme. (Testing of plastics; determination of the water absorption).

DIN 53401 — Bestimmung der Verseifungszahl. (Test method for the determination of the saponification number).

DIN 51801 — Bestimmung des Tropfpunktes: Ubbelohde-Verfahren für bituminöse Bindemittel. (Test method for the determination of the drop point: Ubbelohde method for bitumen).

ASTM D-130-88 — Method for detection of copper corrosion from petroleum products by the copper strip tarnish test.

ASTM D-94-89 — Test method for saponification no. of petroleum products.

ASTM D-512-89 — Test methods for chloride ion in water.

Annex D
(informative)

Design of ground anchors

D.1 General

The recommendations of this annex apply to structures which are supported by ground anchors, defined in clause 1, transmitting a tensile force to a load-bearing formation of soil or rock.

Anchored structures can consist of the following types of structures :

— retaining structures ;

— embankment and slope stabilizing structures ;

— underground openings ;

— underground structures and basements subjected to uplift forces due to ground water ;

— structures transferring tensile loads generated by the superstructure or by actions on the superstructure, to the ground.

This annex deals with the design of ground anchors associated with structures taking into account the behaviour and the requirements of the structures. For the design of the structure as a whole reference should be made to ENV 1991-1-1 : Eurocode 1: Part 1-1 and ENV 1997-1: Eurocode 7 - Part 1-1.

D.2 Limit states

A list of limit states which are to be considered should be compiled.

The minimum number of limit states to be considered for the design of an anchored structure is given in Eurocodes 1, 2, 7.

In addition the following limit states should be considered for anchored structures :

— failure of the ground anchor by tension ;

— structural failure of the ground anchor due to shear forces, distortion at the anchor head or corrosion ;

— loss of anchor load due to excessive displacements of the anchor head or by creep and relaxation ;

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

For all types of anchored structures consideration should be given to combinations of the limit states above as these apply to the entire structure itself.

D.3 Actions, ground properties, geometrical data and design situations

In the selection of actions for the calculation of limit states, consideration should be given to the actions listed according to clause 2.4.2 of ENV 1997-1:1994.

NOTE 1 An analysis of the interaction between the structure, anchor and ground may be required in order to determine the actions from the structure to be adopted in the design of the ground anchor.

Anchor loads are usually considered as actions.

NOTE 2 Anchor loads usually act in a favourable manner. The anchor load is, in this case, taken as a lower value, i.e. less than that which is calculated to occur based on the analysis undertaken in accordance with D.4. Where, however, the anchor load is unfavourable, an upper value is adopted in the design.

Appropriate design situations should be selected in accordance with the principles stated in clause 2.2 of ENV 1997-1:1994

The design situations should consider the environmental conditions in accordance with clause 2.3 of ENV 1997-1:1994

Transient design situations associated with the construction should be considered.

NOTE 3 When selecting the design situations for anchored structures it is important to assess the level of the groundwater table and the water pressures in confined aquifers.

Design values for ground properties and geometrical data should be derived in accordance with the principles stated in clauses 2.4.3 and 2.4.5 of ENV 1997-1:1994.

D.4 Design methods

The design of anchored structures should be undertaken in accordance with the requirements of Eurocodes 1, 2, 4, 7 depending of the type of structure under consideration. Design verifications which take into account the effect of anchor loads on the structure should be undertaken in accordance with this annex.

For the design of an individual anchor the following verifications and design calculations are necessary :

— verification of the internal anchor resistance ;

— verification of the external anchor resistance ;

— verification of the serviceability and durability of the anchor ;

— calculation of the necessary free anchor length ;

— determination of the anchor lock-off load.

Steel strands and bars used for ground anchors should be designed according to the principles contained in ENV 1992-1-1.

The external anchor resistance should be determined on the basis of the results of investigation or suitability tests (see clause 9), the results of site investigation or from experience in similar ground conditions.

The minimum free anchor length and the anchor lock-off load are derived from the design of the anchored structure.

The determination of the anchor lock-off load P_0 should be such that the anchor load P during the design life of the structure remains below the limit :

$$P \leq 0{,}65\, P_{tk}$$

where

P_{tk} is the characteristic load capacity of the tendon.

The anchor lock-off load should be :

$$P_0 \leq 0{,}60\, P_{tk}$$

D.5 Ultimate limit state design

D.5.1 Principles and requirements

Each anchored structure should be checked at the ultimate limit state using the design actions and design situations appropriate to that state, as specified in clause D.3. All ultimate limit states which apply to the anchored structure should be considered.

When considering a limit state of static equilibrium or gross displacements of the structure as a rigid body (overall stability), it should be verified that :

$$E_{d,dst} \leq E_{d,stb}$$

where

$E_{d,dst}$ is the design value of the effect of destabilising actions ;

$E_{d,stb}$ is the design value of the effect of stabilising actions.

When considering a limit state of rupture or excessive deformation of a section, anchor or connection, it should be verified that :

$$E_d \leq R_d$$

where

E_d is the design value of the effect of actions, such as anchor force ;

R_d is the corresponding design resistance, associating all structural properties with the respective design values.

The design value of the effect of stabilising actions $E_{d,stb}$ and the design resistance of the anchored structure R_d should be calculated using the design strengths for the ground as specified in clause 2.4.3 of ENV 1997-1:1994, together with design strengths for structural materials as specified in ENV 1992-1-1 and ENV 1993-1-1.

The assessment of design strengths of different materials should take into account the compatibility of their stress-strain behaviour when they are considered together in a design.

Upper or lower design values should be used for the strength of the ground, whichever is more adverse.

The design resistance R_d of the anchor depends on the manner in which the anchor is being stressed in the limit mode under consideration.

If the anchor is stressed only by tension :

$$R_d = R_k/\gamma_R$$

where

R_k is the lower value of the characteristic internal or external anchor resistance ;

γ_R is the partial factor for anchor resistance.

The partial factor for anchor resistance γ_R takes into account :

— the variations of ground properties within a distinct ground area ;

— the variations of dimensions and properties of the components of the anchors ;

— the variations in the execution of the anchor works.

If the anchor is not only subjected to tension, but also to shear and bending :

$$R_d = \gamma_q P_0$$

where

γ_q is the variation factor for the anchor load.

The variation factor for anchor load γ_q considers the changes of the anchor load during the time between the initial lock-off of the anchor and the occurrence of the considered limit mode due to :

— relaxation of the tendon ;

— creep of fixed anchor length ;

— displacements of the structure at the anchor head ;

— displacements of the structure as a rigid body in the limit mode considered.

The factor for anchor load γ_q usually varies between the following limits :

$$0{,}8 \leq \gamma_q \leq 1{,}1$$

but can take higher values.

For all anchors the partial factor γ_R should be :

$$\gamma_R \geq 1{,}35$$

NOTE Typical examples of limit modes where anchors are not directly pulled out are shown in Figures D.1a) and D.1b). Considering the limit mode shown in Figure D.1a), the design resistance of the anchor cannot be higher than the actual anchor force, because pull-out failure of the anchor occurs only after a gross displacement of the structure.

D.5.2 Characteristic internal anchor resistance

The characteristic internal anchor resistance, R_{ik} is the characteristic load capacity of the tendon :

$$R_{ik} = P_{tk} = A_t f_{tk}$$

where

A_t is the cross sectional area of tendon ;

f_{tk} is the characteristic tensile strength of tendon.

The design, construction and execution of anchors should ensure that the failure resistance of the anchor head and the failure resistance of bond at internal interfaces (tendon-grout and, where relevant, grout-encapsulation) are equal to or higher than P_{tk}. (see 6.3).

D.5.3 Characteristic external anchor resistance

The external anchor resistance R_a is the failure resistance of the anchor at the grout-ground interface. R_a is equal to the load at which there is continuous displacement of the fixed anchor length, and at which after a period of time pull-out of the fixed anchor length will occur.

The characteristic external anchor resistance R_{ak} is derived from values of R_a which should be evaluated from the results of load tests (see clause 9).

NOTE 1 For practical purposes the external anchor resistance R_a is defined as the load causing a creep displacement rate k_s, α or load loss k_l. (See annex E).

When deriving the characteristic anchor resistance R_{ak} from values of R_a measured in the Investigation Tests, R_{ak} should be not greater than the lowest value of R_a.

NOTE 2 If a value of R_{ak} is adopted which is greater than the lowest measured value of R_a, then this shall be justified. It may be necessary to provide further evidence by undertaking additional Investigation Tests.

The characteristic external anchor resistance is normally taken is be equal to or higher than the characteristic internal anchor resistance :

$$R_{ak} \geq R_{ik}$$

D.6 Serviceability limit state design

Design and verification of anchored structures at serviceability limit state should be executed by checking the appropriate design situations, as specified in D.3, using characteristic values of actions, ground properties and geometrical data. Limiting values of the allowable displacement and deformation of the structure and the ground adjacent to anchored structures should be established in accordance with clause 2.4.6 of ENV 1997-1:1994, taking into account the tolerance of supported structures to displacement and distortion.

Estimates of the distortion and displacement of the anchored structure and the effects on supported structures and services should be made on the basis of comparable experience. These estimates should include the effects of construction of the anchored structure. It should be verified that the estimated displacements do not exceed the limiting values.

If the estimated displacements exceed the limiting values, the design should be justified by a more detailed investigation including displacement calculations.

If the estimated displacements exceed 50 % of the limiting values, a more detailed investigation including displacement calculations should be undertaken in the following situations :

— where nearby structures and services are unusually sensitive to displacement ;

— where the anchored structure is supported by soft clay within its height or beneath its base ;

— where comparable experience is not well established.

Displacement calculations should take account of the stiffness of the ground, the anchors and other structural elements and the sequence of construction.

NOTE The material behaviour assumed in the calculation of structural displacements should be calibrated against known displacement models. Appropriate structural and ground stiffnesses should be adopted for the magnitude of deformation anticipated. Non-linear ground behaviour should be taken into account if necessary.

For the verification of a structure at serviceability limit state the effect of an anchor should be considered as an action or as a prestressed elastic spring.

When considering the effect of the anchor as an action, either the minimum or the maximum anchor force occurring during the lifetime of the structure, whichever is the more adverse, should be used.

The effect of the proof load on the structure during anchor testing, should be considered.

When considering the anchor as a prestressed elastic spring, the worst combination of the minimum or the maximum anchor stiffness and minimum or maximum prestress should be considered.

Account should be taken of the effect of the imposed anchor prestress force on the deformations of the structure.

The relevance of the anchor head displacements increases when the tensile force exerted on the anchor exceeds the anchor load.

For anchored structures transferring tensile loads generated by a superstructure or by actions on the superstructure, to the ground the anchor load should always be higher than the effect of the tensile load on the anchor. This applies also to uplift anchors.

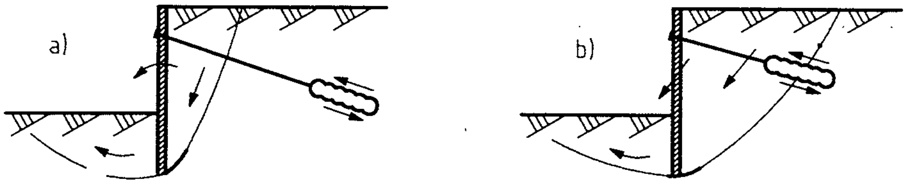


Figure D.1 — Examples of limit modes for failure by pull-out of anchors

Annex E
(informative)

Examples of anchor testing methods

E.1 General

In clause 9 reference was made to the three classes of test commonly adopted in connection with anchors. These are :

a) **Test Method 1** : The anchor is loaded in incremental cycles from a datum load to a maximum test load. Displacement of the anchor head is measured over a time period at the maximum load in each incremental cycle ;

b) **Test Method 2** : The anchor is loaded in incremental cycles from a datum load to a maximum test load or to failure. The loss of load at the anchor head is measured over a period of time at the lock-off load and at the maximum load in each incremental cycle ;

c) **Test Method 3** : The anchor is loaded in incremental steps from a datum load to a maximum test load. The displacement of the anchor head is measured under maintained load at each loading step.

The essential loading procedures for Test Methods 1, 2 and 3 are shown in Figures E.1, E.2 and E.3.

E.2 Test Method 1

E.2.1 Investigation Test - Loading Procedure

The anchor should be loaded to failure (R_a) or to a proof load (P_p) which should be limited to 0,80 P_{tk} or 0,95 $P_{t0,1k}$ whichever is the lower.

The anchor should be loaded to the maximum test load in a minimum of six cycles, see Figure E.1.

The load cycles and minimum periods of observation are given in Table E.1.

Where creep displacements are monitored the maximum load in each cycle should be held for a minimum of 15 min for loads less than P_p and 60 min at P_p in non-cohesive soils or 180 min in cohesive soils. This time should be extended until the creep displacement rate at that load is approximately constant.

E.2.2 Suitability Test - Loading Procedure

The proof load required for the working anchor should be :

$P_p \geq 1{,}25 P_0$ or $P_p \geq R_d$

whichever is greater.

The load in the tendon should not exceed 0,95 $P_{t0,1k}$.

The load cycles and minimum periods of observation are given in Table E.1.

The anchor may be loaded to the maximum test load in a minimum of five load cycles by the omission of the first cycle in Table E.1.

The maximum creep displacement rate, k_s, at proof load should be no greater than 1 mm, where Investigation Tests have been carried out. Where failure (defined as k_s = 2 mm) has not been confirmed by Investigation Tests then the value of k_s at proof load should not exceed 0,8 mm.

E.2.3 Acceptance Test - Loading Procedure

The anchor should be loaded to proof load (P_p) by a minimum of three equal increments. The anchor should then be unloaded to a datum load P_a and again reloaded to lock-off load (P_0). The proof load should be a minimum of 1,25 P_0 but should be no greater than 0,9 $P_{t0,1k}$.

NOTE The load-extension curves may provide additional information about the ground and behaviour of the anchor components in the ground.

The monitoring period should be not less than 5 min at proof load.

The following limit should apply :

— the creep displacement rate k_s should not exceed 0,8 mm at proof load and 0,5 mm at lock-off load.

Higher values of k_s (up to 1 mm at proof load) are recommended if they have been proven to be acceptable by previous Investigation Tests.

E.2.4 Measurement of Creep Characteristics

The increment of anchor head displacement relative to a fixed point should be measured at the end of specified time intervals for load increments indicated in Table E.1. The creep rate should be determined after a constant creep displacement rate, k_s, is measured over two time intervals.

k_s is defined as follows :

$$k_s = (s_2-s_1)/\log(t_2/t_1)$$

where

s_1 is the head displacement at time t_1 ;

s_2 is the head displacement at time t_2 ;

t is the time after application of load increment.

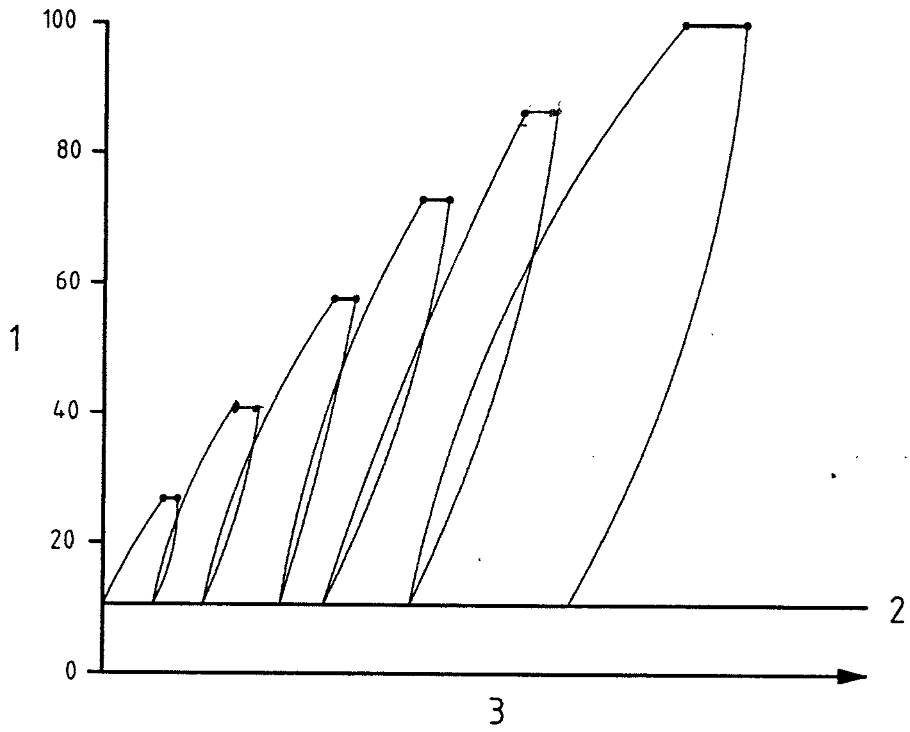
The creep rate limit is the maximum displacement creep rate permitted at the specified load level (see E.2.2 and E.2.3).

Measurements of anchor head displacement should be made, at the times indicated below while maintaining a constant load.

The successive monitoring times (in minutes) at the maximum cycle load levels as shown in Table E.1 are as follows :

1 → 2 → 3 → 5 → 10 → 15 → 20 → 30 → 45 → 60.

Where periods of observation are shorter than 60 min the sequence is curtailed as indicated in the Table E1.



Key

1 Applied load in % P_p

2 Datum load P_a

3 Anchor Displacement

Figure E.1 — Loading procedure for Test Method 1

E.3 Test Method 2

E.3.1 Investigation Test - Loading Procedure

The anchor should be loaded to failure (R_a) or to a proof load (P_p) which should be limited to 0,80 P_{tk} or 0,95 $P_{t0,1k}$ whichever is the lower.

The anchor should be loaded to the maximum test load in a minimum of six cycles, see Figure E2.

The load cycles and periods of observation are given in Tables E.1 and E.2.

If the cumulative load loss, at the proposed lock-off load, after 7 time periods (3 days) does not exceed the allowable and the load loss per time interval is not increasing then the test may terminate and the load cycling of the anchor be continued to P_p or, to failure. Should the allowable loss of load be exceeded and/or the load loss per time interval be increasing the observation period may be extended to the eighth period (10 days) or longer until stability is achieved. If stability is not achieved the applied load is too high for a serviceability condition but the test should be continued to determine the failure load.

E.3.2 Suitability Test - Loading Procedure

The proof load required for the working anchor should be :

$P_p \geq 1{,}25 P_0$ or $P_p \geq R_d$

whichever is greater.

The load in the tendon should not exceed 0,95 $P_{t0,1k}$.

The anchor may be loaded to the maximum test load in two load cycles of approximately 10 %P_p - 25 %P_p –50 %P_p - 75 %P_p – 100 %P_p – 75 %P_p – 50 %P_p - 10 %P_p and then to the lock-off load P_0.

Periods of observation for are given in Table E.2.

The load loss (k_l) at the lock-off load P_0 should not exceed the limits specified in Table E.2 over seven time periods (3 days).

E.3.3 Acceptance Test - Loading Procedure

The anchor should be loaded to proof load (P_p) by a minimum of three equal increments. The anchor should then be unloaded to a datum load P_a and again reloaded to lock-off load (P_0). The proof load should be a minimum of 1,25 P_0 but should be no greater than 0,9 $P_{t0,1k}$.

NOTE The load-extension curves may provide additional information about the ground and behaviour of the anchor components in the ground.

Behaviour under lock-off load should be observed over 3 time periods (50 min) and the load loss should not exceed the cumulative figure shown in Table E.2. If the loss is greater than the limit the test should be extended until stability is achieved and an acceptable load loss is measured.

If the monitoring system accuracy does not comply with 9.2 in terms of load loss tests but does comply with clause 9.2 using lift-off tests then acceptance may be established by lift-off after 6 time periods (1 day) showing cumulative load loss k_l less than 6 %.

The following limit should apply at the lock-off load :

a) the load loss k_l should not exceed 3 % P_0 in 50 min ; or

b) the load loss k_l should not exceed 6 % P_0 in 24 h.

E.3.4 Measurement of Load Loss Characteristics

At lock-off load the anchor head displacement relative to the structure should be held constant and the load should be monitored. The anchor head should be fixed against a load cell or an inactive jack and the load loss should be monitored at the end of each time interval for up to ten days to determine k_l, the percentage load loss.

The load loss limit is the maximum cumulative load loss recommended at the specified load level at the end of a number of time periods.

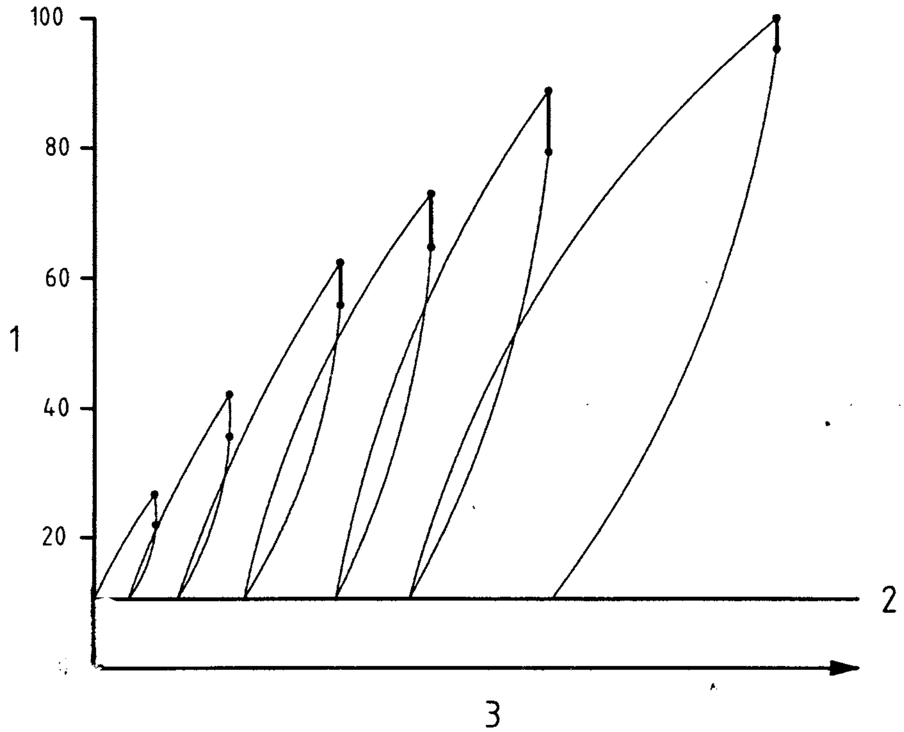
Measurement of load loss as required in E.3.4 should be made at times shown in Table E.2. The minimum duration of observation is as follows :

— investigation Test - 7 periods (3 days) ;

— suitability Test - 7 periods (3 days) ;

— acceptance Test - 3 periods (50 min).

Load loss characteristics are representative of true load loss as applied to the structure via the anchor head. If used to interpret actual creep displacement of the fixed anchor then allowance must be made for the influence of the anchor free length, i.e. the longer the free length the smaller the load loss effect from the same absolute creep displacement of the fixed anchor.



Key

1 Applied load in %P_p

2 Datum load P_a

3 Anchor displacement

Figure E.2 — Loading procedure for Test Method 2

E.4 Test Method 3

E.4.1 Investigation Test - Loading Procedure

The anchor should be loaded to failure (R_a) or to a proof load (P_p) which should be limited to 0,80 P_{tk} or 0,90 $P_{t0,1k}$ whichever is the lower.

The anchor should be loaded to the maximum test load by a minimum of six load steps, see Figure E.3.a).

The load steps and minimum periods of observation are given in Table E.3.

The minimum periods of observation can be reduced to 30 min if no significant creep occurs.

E.4.2 Suitability Test - Loading Procedure

The proof load required for the working anchor should be :

$P_p \geq 1{,}25\ P_0$ or $P_p \geq R_d$

whichever is greater.

The load in the tendon should not exceed 0,90 $P_{t0,1k}$.

The anchor may be loaded to the maximum test load in a minimum of five steps by the omission of the first step in Figure E.3b).

The load steps and minimum periods of observation are given in Table E.4.

The maximum creep displacement (α) at the proof load level of Suitability Tests should be less than 0,8 mm per log. cycle of time (see Figure E.4) where Investigation Tests have not been carried out. Where Tests have been carried out then α at the proof load level of the Suitability Test should be less than :

— 1,2 mm/log time for a temporary anchor ;

— 1,0 mm/log time for a permanent anchor.

In any case the proof load level of the Suitability Test for the project anchors should be not greater than P_c.

E.4.3 Acceptance Test - Loading Procedure

The anchor should be loaded from the datum load P_a to proof load P_p of 1,25 P_0 or R_d in a minimum of four increments. Then the proof load is maintained constant for at least 15 min.

After the proof load has been maintained for the desired period the contractor can carry out a partial or total unloading-loading cycle, see Figure E.3c).

NOTE The load-extension curves may provide additional information about the ground and behaviour of the anchor components in the ground.

Where Test Method 3 is used in accordance with 9.4, the apparent tendon free length may be calculated from the datum load to the proof load curve using the method shown in Figure E.3c). Where there is significant friction in the free length a partial cycle may be performed and the apparent tendon free length calculated from the established no-friction curve to determine ΔP and Δs.

The displacement due to creep at proof load should be measured between the 3rd and 15th min.

The corresponding α should be less than :

— 1,2 mm for permanent or temporary anchors without Investigation Tests ;

— 1,5mm for permanent anchors with Investigation Tests ;

— 1,8 mm for temporary anchors with Investigation Tests.

E.4.4 Measurement of Creep and Characteristic Load

Creep and characteristic loads should be measured and evaluated as follows :

— the increment of anchor head displacement relative to a fixed point should be measured at each step of loading at different times ;

— the creep displacement α should be determined at each step of loading as indicated in Figure E.4. The creep displacement α is defined as the slope of the anchor head displacement versus log. time curve at the end of each loading step ;

— the anchor resistance R_a is the load corresponding to the vertical asymptote of the α versus load curve. If the asymptote cannot be determined, it is considered that R_a is the load corresponding to an α value equal to 5 mm, see Figure E.5 ;

— the critical creep load P_c should be determined as indicated on Figure E.5. The critical creep load is the load corresponding to the end of the first linear part of the α versus load curve. Where it is difficult to determine P_c accurately an alternative resistance $P_{c'}$ is determined as indicated in Figure E.5 and P_c is defined by :

$P_c = 0{,}9\ P_c'$

Measurement of creep displacement should be made at the times indicated below, after each change in load. The periods of observation for each step are :

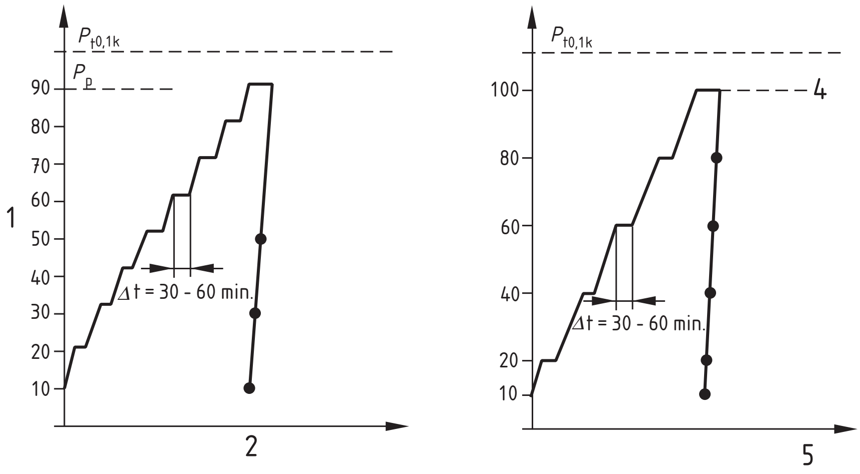
— investigation test - 30 min or 60 min ;

— suitability test - 30 min or 60 min ;

— acceptance test - not less than 15 min at proof load.

The successive monitoring times (in minutes) at each step are as follows :

$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 7 \rightarrow 10 \rightarrow 15 \rightarrow 20 \rightarrow 30 \rightarrow 45 \rightarrow 60$



a) Investigation test b) Suitability test

Key

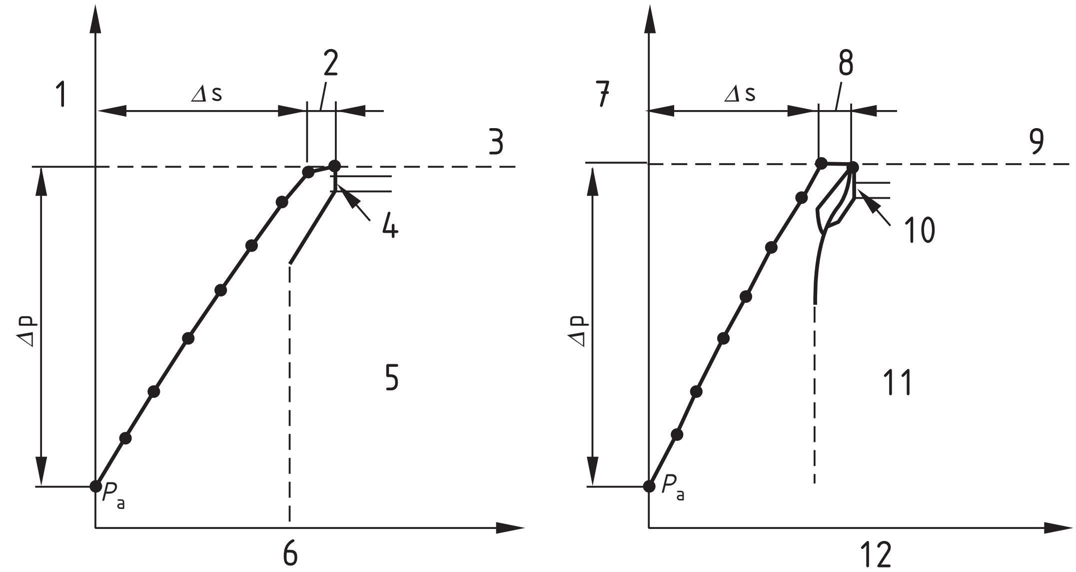
1 Applied load in % of $P_{10.1k}$

2 Anchor displacement

3 Applied load in % of P_p

4 Proof load

5 Anchor displacement



c) Acceptance test

Key

1 Applied Load

2 Creep

3 Proof load

4 Friction f as proportion $p_f P_p$

5 Without cycle

6 Anchor displacement

7 Applied load

8 Creep

9 Proof load

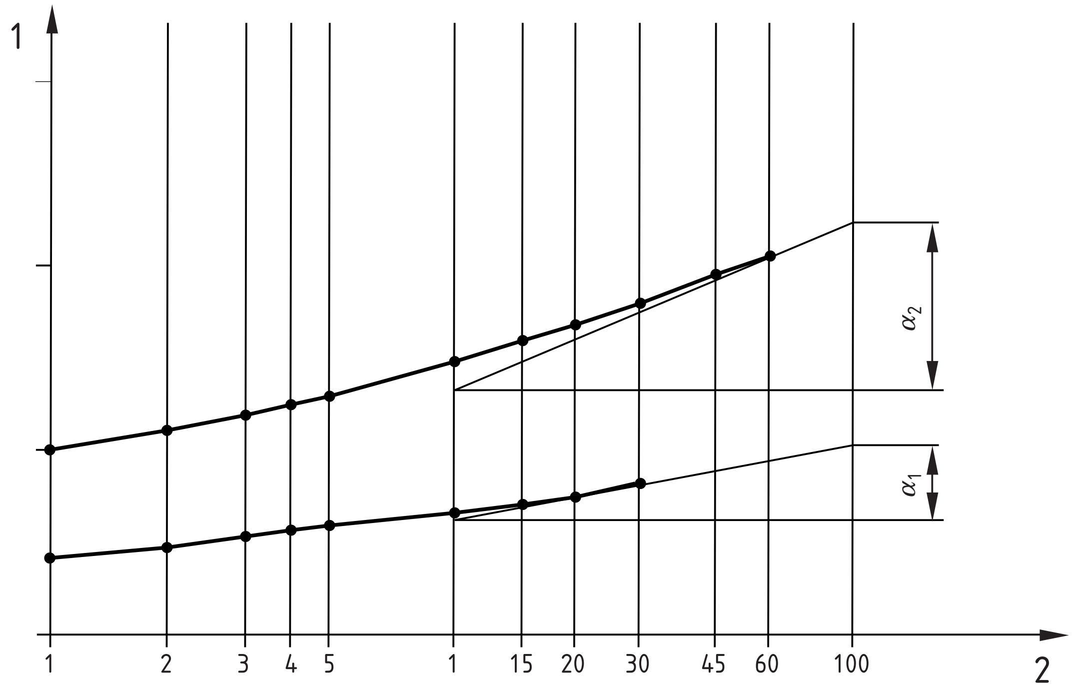
10 Friction f as proportion $p_f P_p$

11 With partial cycle

12 Anchor displacement

$$L_{app} = A_t \,.\, E_t \,.\, \Delta s \;\; / \;\; \Delta P \, (1 - f)$$

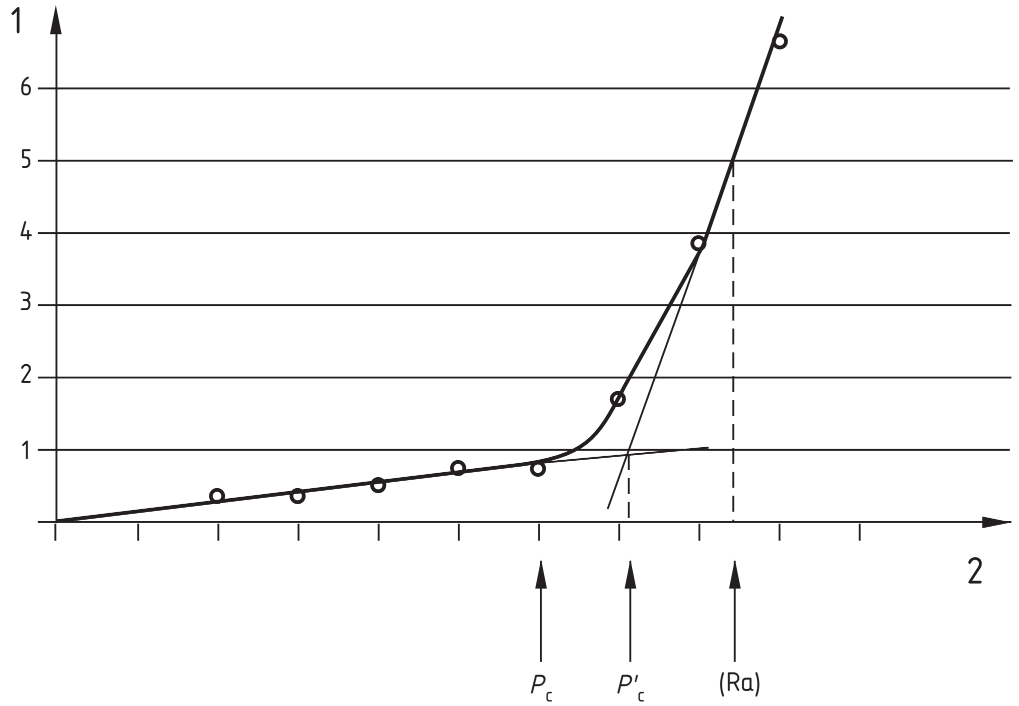
Figure E.3 — Loading procedures for Test Method 3



Key

1 Creep displacement

Figure E.4 — Creep displacement vs log time and slope α_n for Test Method 3



Key

1 Slope

2 Applied Load

Figure E.5 — Creep vs applied load for Test Method 3

E.5 General tables for loading procedure. Test methods 1, 2, and 3

Table E.1 — Load cycles and minimum periods of observation for Investigation and Suitability tests on anchors, Test Methods 1 and 2

Load levels %P_p						Minimum period of observation in minutes (Test Method 1 only)
cycle 1	cycle 2	cycle 3	cycle 4	cycle 5	cycle 6	
10	10	10	10	10	10	1
	25	40	55	70	85	1
25	40	55	70	85	100*	15 (60 or 180[1)])
	25	40	55	70	85	1
10	10	10	10	10	10	1

1) In Test Method 2, where the peak load is the lock-off load P_0 the period of observation is extended - see Table E.2.

Table E.2 — Times and periods of observation and acceptance criteria for load loss, Test Method 2

Time of observation in minutes	Time period number	Permissible cumulative loss of load k_l (% Applied Load)
5	1	1
15	2	2
50	3	3
150	4	4
500	5	5
1 500 (approx 1 day)	6	6
5 000 (approx 3 days)	7	7
15 000 (approx 10 days)	8	8

Table E.3 — Load steps and minimum periods of observation for Investigation Tests on anchors, Test Method 3

Load increments %$P_{t0,1k}$ [1) 2) 3)]									
Datum load	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step number
10	20	30	40	50	60	70	80	90	% $P_{to,1k}$
0	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	Period of observation (minutes)

1) Commence at Datum Load $P_a = 0{,}1 P_{t0,1k}$.

2) $P_{max} \leq 0{,}9 P_{t0,1k}$.

3) Example given for 8 steps.

Table E.4 — Load steps and minimum periods of observation for Suitability Tests on anchors, Test Method 3

Load increments $\%P_p$ for working anchors [1] [2]							
Datum Load	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**Step number**
10	25	40	55	70	85	100	% of P_p
0	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	Period of observation (minutes)

[1] Commence at Datum Load P_a = 0,1P_p

[2] Example given for 6 steps

Annex F
(informative)

Examples of record sheets

	RECORD SHEET FOR ANCHORS			Doc.		
01) Contract 02) Location						
03) Anchor Type/DWG						
04) Anchor No.						
Drilling	101 Entry position X/Y	m				
	102) Entry Level Z	m				
	103) Direction N/E	°				
	104) Inclination (Horiz)	°				
	105) Drill method					
	106) Hole diameter	mm				
	107) Overall length	m				
	108) Cased from/to	m				
	109) Flushing medium					
	110) Ground water level	m				
	111) Ground characteristics					
	112) Pregrouting (if any)					
	113) Testing					
	114)					
	115) Drill date					
Tendon	201) Tendon types					
	202) No./D	/mm				
	203) Tendon area A_t	mm^2				
	204) Steel strength f_{pk}	N/mm^2				
	205) Elastic Modulus E_t	N/mm^2				
	206) Fixed length L_{fixed}	m				
	207) Free length L_{free}	m				
	208) Jacking over length	m				
	209) Overall length L	m				
	210) Protection L_{fixed}					
	211) Protection L_{free}					
	212) Spacers L_{fixed}					
	213) Spacers L_{free}					
	214) Grouting ducts					
	215)					
	216)					
Grouting	301) Cement type					
	302) Admixtures					
	303) W/C					
	304) Cement consumption	kg				
	305) Grouting pressure	MPa				
	NOTES :					
	Operators:					

	STRESSING RECORD FOR ANCHOR	Doc.

01) Contract:	Construction Details - Sheet:........................
4. STRESSING EQUIPMENT	**5. STRESSING REFERENCES**
401) Head type DWG	501) Test type: INVESTIGATION/ SUITABILITY/ACCEPTANCE
402) Jack capacity/stroke kN/mm	502) Test specification
403) Jack ref:	503) Ultimate tensile load P_{tk} kN
404) Load cell type No.	504) Design resistance R_d kN
405) Pressure gauge No.	505) Proof load P_p kN
406) Displacement measuring system	506) Working load P kN
407)	507) Lock-off load P_o kN
408)	508) Datum load P_a kN
409)	509)
410) Stressing Date	510)

6. STRESSING DATA

Cycle No.	Pressure p MPa	Load P kN	P/R_d %	Displacement at 0 min mm	Displacement at 1 min mm	Head Displacement mm	Corrected Displacement mm	Time h.min	Remarks

NOTES :

Operators: