COMITÉ FRANÇAIS DE MÉCANIQUE DES SOLS ET DE GÉOTECHNIQUE

GROUND ANCHORS
TA 2020

PROFESSIONAL RULES
relative to design, construction, testing and monitoring of ground anchors

ENGLISH VERSION
2021
French version 2020

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PREFACE

Nearly 50 years after they were first published, the professional « TA2020 » rules are the worthy successors of the previous editions.

Written by the very best French experts, with some of them having also contributed to European documents about ground anchors, they naturally fully comply with the many French documents dealing with the execution, design and testing of ground anchors and their constitutive materials. We want to acknowledge the significant labour of synthesis produced by their writers, who have unfailingly fulfilled this difficult task.

But, way beyond this mandatory regulatory adequacy, this document benefits from the experience and know-how gained by French companies and design offices during decades, from all sorts of soil configurations, and sometimes outside our borders.

We can observe an evolution that is far from being solely semantic: while the previous editions were called « recommendations », the TA2020 benefit from a status of « professional rules », granted by the Agence Qualité Construction (construction quality agency*). This document is henceforth recognized as a reference text, written by all key players of the French geotechnical community: technical inspectors, companies, suppliers, design offices, prime contractors, and technical departments of the State.

Extremely thorough and educational, conceived for being used as a stand-alone document, TA2020 will be a prime reference of technical databases and will serve as a basis for many contracts.

CFMS extends warm thanks to all members of the drafting group for this important document, and in particular to its president and secretary Jean-Paul Volcke, whose efficiency, persistence and uprightness allowed this edition to be issued within a healthy work climate.

Nicolas Utter
Vice-president of CFMS

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FOREWORD

The present document replaces the recommendations called « Tirants d'Ancrage (TA) 95 », which were written by a working group under the auspices of the Comité Français de la Mécanique des Sols et des Travaux de Fondation (French Committee of Soil Mechanics and Foundation Works*, which was the denomination of CFMS at the time).

In line with the previous issues, it aims at addressing all aspects pertaining to the execution of ground anchors: design, construction, monitoring and maintenance. Through a decision notified on January 24 2020, the C2P biannual publication of July 2020 will record the approval by the C2P of the new edition of the text. It will also be made available on the AQC website.

It is based upon three different types of standards (execution, justification and testing), which it aims at synthesising for France.

Note : using the present rules within other countries compels to verify beforehand that these countries use the same frame of reference than France.

As such, the present document can be used autonomously and independently from standards in most frequent cases. However, if the standards are ones that have to be applied mandatorily (it is the case for Government procurement) and/or contractual ones, one should check beforehand that the normative references have not evolved beyond the present edition. The Developer, or its Project Manager, shall state whether he wants to keep the original text, or if he wants to revise the paragraph(s) concerned by the standard update.[1]

Note : decision was taken to write this document as a stand-alone one, and hence, several paragraphs mention excerpts of current standards without stating them comprehensively.

The hypotheses which the drafters of the technical body relied upon (which the present document is a part of), are reminded below :

- Data required for design are collected, recorded and interpreted by appropriately qualified and experienced personnel;
- Structures are designed by a personnel with the appropriate skill and experience;
- Adequate continuity and communication exist between the personnel involved in data-collection, design, verification and execution;
- An appropriate monitoring and quality control system is in place in factories, design offices, companies and on the field;
- The execution of works is carried out in accordance with the standards and their associated specifications by a personnel with the appropriate skill and experience;
- The construction materials and products are used in accordance with the specifications of the present document, or with the specifications specific to the materials or products being used;
- The structure is properly maintained, so that its stability and serviceability are guaranteed during its whole lifetime;
- The structure is adequately monitored in order to detect in advance any abnormal behaviour;
- The structure is used in accordance with the objectives defined when it was designed.

[1] The working group has generally adopted the codes and organisation of standards (see the ISO/CEI Directive - Règles de structure et de rédaction des publications, Rules for structuring and writing publications*).
A new tier, which was used within TA95, was added: the comment (sometimes called « remark »).
Comments are used for conciseness reasons. They aim at specifying, complementing, clarifying or illustrating the clauses to which they relate. Unlike notes (which are limited to reminders, clarifications or examples), they may contain requirements and recommendations.

CONTENTS

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1 SCOPE

1. SCOPE

The present guide can be fully applied to ground anchors that meet the following parameters (comment 1):

- They are constituted with a metallic reinforcement, in common steel, in steel for reinforced concrete, in steel with a high elastic limit or in a prestressing steel (see note 1 and comment 2)
- They are conventionally bonded into the ground by filling (« gravity injection »), then by injection (global and single, or repetitive and selective) (see comments 3 and 4);
- They feature a free part, because a mechanism constitutes a physical boundary between the anchor and the surrounding ground (comment 5);
- They are prestressed, or not;
- They are subject to systematic acceptance tests;
- They do not operate as a grid, even though, if required, a group effect shall be accounted for (see note 2).

Comment 1: regarding ground anchors having compression elements (in which forces are transferred through a non-adhesive tendon down to the borehole bottom, and then into the ground through a compression element and grout), most of the provisions of the present document are applicable, provided a few possible adaptations are made, EXCEPT for provisions relative to the geotechnical design, which may only be used with investigation tests.

Comment 2: there are other types of ground anchors being marketed (with tendons in composite materials for instance). You should use the provisions of geotechnical design (paragraphs 5.3.3 and 5.4.2), of tests and of monitoring (paragraphs 7.5.6 and 8) for these particular ground anchors. Provisions relative to restrictions on use, to conditions of use, to protection against corrosion, to durability and to structural design shall be specified by the supplier within the product specifications and/or under the form of an ATE or ETE[2].

Comment 3: single bore multiple anchors are not described in the present document. They shall be addressed with particular specifications.

Comment 4: ground anchors executed without injection (as defined in paragraph 7.3) can only be allowed with investigation tests (paragraph 8.3).

Comment 5: annex K provides recommendations for ground anchors having a free length not being materialised by a physical boundary.

Note 1: steels of the scope are described in paragraph 4.1.2.1

Note 2: the group effect is considered in paragraph 5.3.3.1; annex G recalls the method of TA 95 for slab ground anchors.

Annex A provides a few examples of use.

This guide may be applied to both bonds into soils and into rocky grounds. For rocky grounds, a few provisions of the present document shall be adapted.

Comment: adaptations for rocky grounds shall be analysed site by site. The following examples may be mentioned:

- Other failure phenomenons (such as the ones tied to discontinuities of the rock mass) may be added;
- Soil creep is rarely an issue for rocks: the scheduling and interpretation of failure tests may be modified;
- The loads on the tendons can sensibly differ from a simple tension, and require additional verifications;
- The issues of overall stability may be processed differently: the free part may be reduced.

Nailing, tension piles, screw anchors, mechanical anchoring, dead-man anchors and expander anchors do not fall within the scope of the present document.

Comment: there are different types of tensile geotechnical structures, and not all of them are ground anchors. The table below outlines the main differences for geotechnical structures that all act in tension and are not ground anchors:

	Noteworthy characteristics	Execution standard [a]	Justification standard [a]
Tension pile	Soil-structure interaction over its whole length	NF EN 12699 or NF EN 1536 or NF EN 14199	NF P 94-262
Dead-man anchor	The dead-man part is usually a geotechnical structure	May vary in function of the geotechnical structure	
	The tendon is a metallic structure		NF EN 1993-5
Nails and reinforced soils	Reinforced soil design	NF EN 14490 or NF EN 14475	NF P 94 270
Rock-nailed and bolts	The ground concerned by the structure comes under Rock Mechanics		NF EN 1997-1 [b]
[a] Only the standard deemed as being the most representative is provided as example [b] The 2004 version provides little indication about Rock Mechanics			

Table 1.1: list of tensile geotechnical structures

[2] Abbreviations are explained in 3.2.2

2 REFERENCES

2.1 STANDARDS

2.2 OTHER REFERENCES

2. REFERENCES

The documents referenced below were used to draft the present document, and may be used as additional information by the reader.

2.1 STANDARDS

This list is not comprehensive and it shall be appropriate, if needed, to consult the entirety of standards published by AFNOR.

NF EN 1997-1: 2004
Geotechnical design; part 1: general rules

NF EN 1997-1/A1: 2014
Geotechnical design; part 1: general rules; revision 1

NF EN 1997/AN: 2018
Geotechnical design; part 1: general rules; national annex to NF EN 1997-1

NF EN 1993-1-1: 2004
Design of steel structures; part 1-1: general rules and rules for buildings

NF EN 1993-5: 2004
Design of steel structures; part 5: piles and sheet piles

NF P 94 282: 2009
Geotechnical design; retaining structures; embedded walls

NF P 94 282/A1: 2015
Geotechnical design; retaining structures; embedded walls; amendment 1

NF EN 1537: 2013
Execution of special geotechnical works; ground anchors

NF EN ISO 22477-5 : 2018
Geotechnical investigation and testing; testing of geotechnical structures; testing of grouted anchors

NF P 94 500: 2013
Geotechnical engineering missions; classification and specification

NF EN 206/CN : 2014
Concrete; Specification, performance, production and conformity; national addition to standard NF EN 206

NF EN 934-2
Admixtures for concrete, mortar and grout; part 2: concrete admixtures, definitions, requirements, conformity, marking and labelling

NF EN 1090-2
Execution of steel structures and aluminium structures; part 2: technical requirements for steel structures

NF EN 10204
Metallic products; types of inspection documents

pr EN 10138-1
Prestressing steels; part 1: general requirements

Comment: standard EN 10138 is currently being drafted; standard ISO 6934 is not applicable in France, where the ASQPE certification (association for the qualification of prestressing and equipment of building and civil engineering structures*), or equivalent, is demanded.

NF EN 10080
Steels for the reinforcement of concrete; weldable reinforcing steels; general points

NF EN 10025-1
Hot rolled products of structural steels; part 1: general technical delivery conditions

NF EN 10083-1
Steels for quenching and tempering; part 1: general technical delivery conditions

NF EN ISO 12944-2
Paints and varnishes; corrosion protection of steel structures by protective paint systems; part 2: classification of environments

NF EN 447
Grout for prestressing tendons; requirements for common grouts

NF EN 445
Grout for prestressing tendons: test methods

NF EN 197-1
Cement; part 1: composition, specifications and conformity criteria for common cements

FD P 18-011
Concrete; definition and classification of chemically aggressive environments; recommendations for concrete mix design

2.2 OTHER REFERENCES

EAD 160004-00-0301
Post-tensioning kits for prestressing of structures

Commentaire : this document replaced ETAG13 in 2016.

Note : EOTA document (www.eota.eu)

Reference CSP AP Rc1 revision 6 of October 2015
Reference LDA CSP AP revision 3 of October 2015

Note : ASQPE documents (www.asqpe.fr)

GT8 R2F1
Design and execution of injection works in rocks and soils

Note : AFTES document (www.aftes.asso.fr)

LCPC newsletter n°140 of Nov-Dec 1985

3 TERMS, DEFINITIONS AND SYMBOLS

3.1 TERMS AND DEFINITIONS

3.2 ABBREVIATIONS AND SYMBOLS

3 TERMS, DEFINITIONS AND SYMBOLS

3.1 TERMS AND DEFINITIONS

3.1.1 GENERAL TERMS

3.1.1.1 GROUND ANCHOR

A ground anchor is a structural element capable of transferring a tensile force to a resistant ground layer through a free length. It includes the anchor head, the free length and the part bonded to the ground.

Note 1 : NF EN 1997-1 has retained « anchor » as an ellipsis in its section 8, which applies to grouted and expander anchors.

Note 2 : this definition is not a satisfying one under NF EN 1537 (see « bond-type ground anchor »)

3.1.1.2 BOND-TYPE GROUND ANCHOR

A bond-type ground anchor is a ground anchor for which the tensile load transfers to the resistant layer through a bond with a cement grout, a resin or any other similar material.

Note 1: NF EN 1997-1 used the ellipsis « bond-type anchor » in its section 8.

Note 2: this definition is the one of « ground anchor » in standard NF EN 1537.

3.1.1.3 GROUTED ANCHOR

Since the scope is restricted to grouted anchors, the abbreviation « ground anchor » within the present document implies grouted anchor.

3.1.1.4 ACTIVE GROUND ANCHOR = PRESTRESSED GROUND ANCHOR

The active ground anchor is an anchor for which the implementation ends up with stressing, at the prestressing value determined by the design.

Comment: the process that consists in applying a few kN of tension to the ground anchor in order to install the anchor system is not considered as being a prestressing process.

3.1.1.5 PASSIVE GROUND ANCHOR

The passive ground anchor is an anchor that is solely set in tension due to the application to the structure of the actions to which it is subject.

3.1.1.6 STRUCTURE GROUND ANCHOR = SERVICEABILITY GROUND ANCHOR = WORK GROUND ANCHOR = PRODUCTION GROUND ANCHOR

The structure ground anchor is a ground anchor integrated to the global structure, on a temporary or permanent basis. It shall not be used for failure tests.

Note : the 1st term is the recommended term.

3.1.1.7 TEST ANCHOR = NON-STRUCTURE GROUND ANCHOR

A test anchor is a sacrificial ground anchor installed with the exclusive purpose of carrying out tests.

Note 1: the 1st term is the recommended term.

Note 2: it is not necessarily a « non »-structure ground anchor: this expression only means that the test anchor does not contribute to the structure.

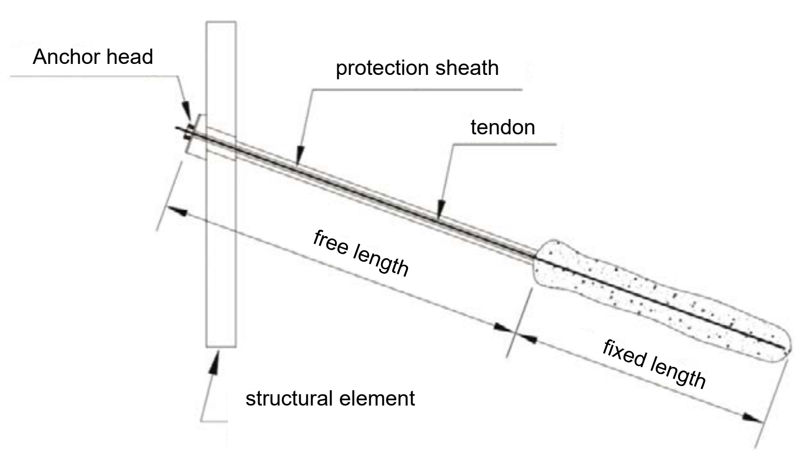


Figure 3.1: example of a ground anchor with its tendon directly bonded into the ground

3.1.1.8 SUITABILITY GROUND ANCHOR

The suitability ground anchor is a ground anchor executed within the contract framework in order to adjust the execution, monitoring and control procedures.

3.1.1.9 TEMPORARY GROUND ANCHOR

A temporary ground anchor is a ground anchor with a limited lifetime, usually exploited during the construction stages of the structure.

Comment: A temporary bond-type ground anchor with an operational lifetime beyond two years should be designed as a permanent one.

3.1.1.10 PERMANENT GROUND ANCHOR

A permanent ground anchor is a bond-type ground anchor with lifetime greater than 2 years, or more generally, one that is loaded during the whole lifetime of the structure.

3.1.2 TERMS RELATIVE TO THE STRUCTURE OF GROUND ANCHORS

3.1.2.1 TENDON

The tendon is the part of a ground anchor that is capable of transmitting the tension load from the anchor head to the resistant element into the ground.

3.1.2.2 SEALING

Sealing consists in embedding the anchor head into concrete, or any other sealed material, for the purpose of protecting the head against shocks.

3.1.2.3 PROTECTION CAP

The protection cap is the mechanism that ensures the anchor head protection against corrosion and shocks.

Note: when unequivocal, the term « anchor head » may include the protection cap.

Picture 3.1: example of a protection cap (© Sefi Intrafor)

3.1.2.4 SLEEVE GROUT

The sleeve grout is a cement grout, a resin or any other similar material that is set up during filling. It contributes to protecting the tendon against corrosion.

3.1.2.5 COUPLER

The coupler is a mechanism used to bind end-to-end the rods or strings of a ground anchor.

3.1.2.6 PROTECTION SHEATH

The protection sheath is any solution implemented to protect the tendon against corrosion (see section 6).

3.1.2.7 INJECTION

The injection is the operation of pouring, under pressure, a cement grout, a resin or any other similar material. This operation is solely dedicated to the bonded part.

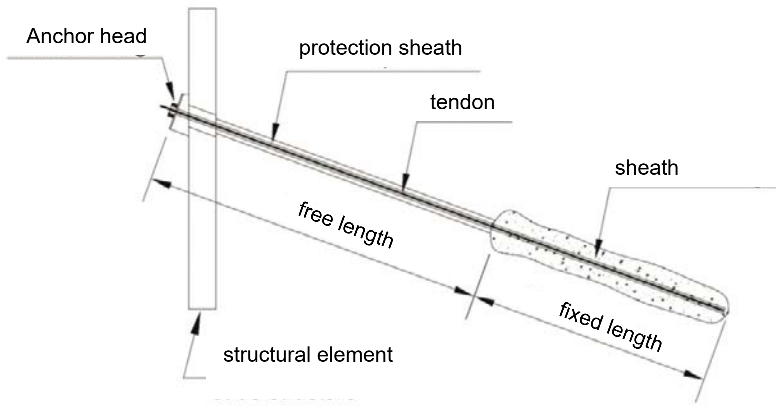


Figure 3.2: ground anchor with a tendon bonded into a sheath, which is itself bonded to the ground

3.1.2.8 GROUTING

This is an operation that aims at filling the borehole with a cement grout, a resin or any other similar material. It is carried out by gravity, or under low pressure, and involves the whole length of the ground anchor.

3.1.2.9 BONDING

The fixed length is the bonded part of a bond-type ground anchor, obtained after grouting and post-grouting.
By extension, bonding is the operation (or the set of operations) that leads to this result.

3.1.2.10 ANCHOR SYSTEM

The anchor system encompasses the components and specific materials that constitute, altogether, the ground anchor.

Comment: the following are part of the anchor system: the anchor head, the various elements of the tendon and the connecting devices between these elements. However, the bearing plate, the load-transfer block or the metallic waling do not belong to this system.

Note: this term is preferred to the one of ground anchor solely when the context may be misleading, or justifies such a degree of precision.

3.1.2.11 SUPPORT SYSTEM

The support system encompasses all elements (bearing plate, shims, bearing chair, metallic waling) found between the anchor head and the anchored structure.

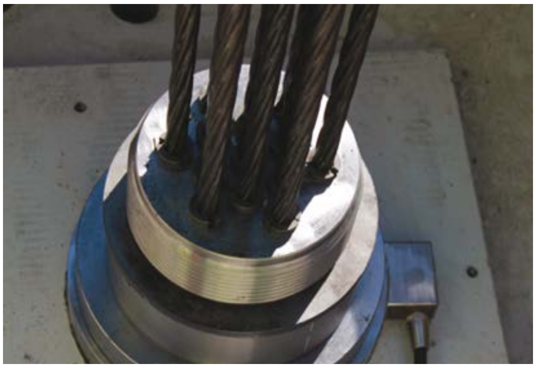
Comment: the support system is addressed within the present document only in terms of its expected requirements and properties, without entering the details of the justifications that should be stated.

Picture 3.2: Support system reduced to a load-transfer block (on a Lutetian pile) (© Freyssinet)

Picture 3.3: example of a support system (© Franki Fondation)

3.1.2.12 ANCHOR HEAD

The anchor head is the part of the anchor system that is in contact with the support system and guarantees that loads are transmitted to the tendon.



Picture 3.4a: Adjustable anchor head (© Freyssinet)

Picture 3.4b: Restressable anchoring block (© Freyssinet)

3.1.3 TERMS SPECIFIC TO TESTS, CONTROLS AND MONITORING

Annex B provides the comparison between tests in function of the frames of reference.

3.1.3.1 CONTROL DEVICES

Here, the term « control device » describes a fixed apparatus that displays (continuously or with periodic logs) the measures that allow assessing ground anchor parameters (in particular at its head level), e.g., dynamometric wedges and other tension-measuring cells.

3.1.3.2 INVESTIGATION TEST

An investigation test consists in carrying out a ground anchor loading test (during its design stage) to establish the ultimate geotechnical resistance and determine its service tension parameters.

Note: it is carried out on test anchors

3.1.3.3 CONFORMITY TEST

A conformity test consists in carrying out an anchor loading test during the execution stage, to establish and validate the ultimate geotechnical resistance and to determine or ascertain its service tension parameters.

Note 1: it is carried out on test anchors.

Note 2: it has sometimes been called design suitability test.

3.1.3.4 FAILURE TEST

A failure test consists in carrying out a loading test in stages, under the provisions recalled in annex J, with a proof load aiming at determining the ultimate geotechnical resistance.

Note: investigation tests and conformity tests are failure tests.

3.1.3.5 SUITABILITY TEST

A suitability test consists in carrying out a ground anchor loading test during the execution stage,

- to verify that the specific design of an anchor suits the particular conditions of the structure ground, and
- to control, with a proof load higher than the serviceability load, that the expected serviceability resistance is greater than the required service load.

Note: one may specify: « execution » suitability test

3.1.3.6 ACCEPTANCE TEST

An acceptance test consists in carrying out a ground anchor loading test to ascertain that the anchor meets the acceptance criteria.

3.1.3.7 « CREEP » RATE α

α is the slope of the displacement curve of the anchor head for a given loading stage, in function of the time logarithm, during a failure (investigation test or conformity), suitability or acceptance test.

Note : within NF EN 1997-1/A1, α is stated in mm because it results from the division of a displacement Δs by a time logarithm ;

The choice was made here to delete the unit (which is implicit) to avoid any possible confusion with TA 95, which was written with displacements in mm.

3.1.3.8 LOCK-OFF TEST

Lock-off test consists in measuring, by applying a force with a jack, the tension existing within a ground anchor subsequently to its implementation.

3.2 ABBREVIATIONS AND SYMBOLS

3.2.1 PREAMBLE

The notations of the text only (excluding annexes) are listed here.

Note: a notation specific to a paragraph is usually explained within the same paragraph.
Annex C provides a comparison between the main notations in function of the frames of reference.

Comment: annexes may include different notations (originating from the documents on which they are based). These particular notations are specified when being used.

3.2.2 ABBREVIATIONS AND ACRONYMS

AFTES Association Française des Tunnels et Espaces Souterrains (French association of tunnels and underground space*)

ATE French acronym for European technical approval

ASQPE Association pour la Qualification de la Précontrainte et des Equipements des ouvrages de bâtiment et de génie civil (association for the qualification of prestressing and equipment of building and civil engineering structures*)

CFMS Comité Français de Mécanique des Sols et de géotechnique (French committee of soils and geotechnics*)

CPT Cone penetration test (in-situ test, described in standard NF EN ISO 22476-12)

SLS serviceability limit state

ULS ultimate limit state

EQU is applied to an ultimate limit state relative to a loss of balance

ETE* French acronym for European technical assessment

GEO is applied to an ultimate limit state relative to failure or excess deformation, of a geotechnical origin

HYD is applied to an ultimate limit state relative to failure under the effect of hydraulic gradients

IGU French acronym for overall and one-phase injection

IRS French acronym for repetitive and selective injection

MISS French acronym for soil-structure interaction model (see NF P 94-282)

MEL French acronym for limit equilibrium model (see NF P 94-282)

PMT Ménard pressuremeter test (in-situ test, described in standard NF EN ISO 22476-4)

SPT Standard penetration test (in-situ test described in standard NF EN ISO 22476-3)

STR is applied to an ultimate limit state relative to failure or excess deformation, of a structural origin

UPL is applied to an ultimate limit state relative to an uplift caused by buoyancy or other vertical actions

3.2.3 GREEK LETTERS

α slope of the displacement curve in mm of the anchor head for a proof load stage in function of the time logarithm

$\Delta s_{t1\text{-}t2}$ measured displacement (of the end of the tendon) between times t1 and t2

$\gamma_{a,ELS}$ partial factor used to deduce the design resistance at serviceability limit state of an anchor from the characteristic resistance stemming from failure tests

$\gamma_{a,ELU}$ partial factor used to deduce the design resistance at ultimate limit state of an anchorage from the characteristic resistance stemming from failure tests

$\gamma_{a,rec,ELS}$ factor to be applied to the design service tension to obtain the proof load of an acceptance, or suitability, test

γ_{M0} partial factor for the elastic limit resistance of steel, under NF EN 1993-1-1

γ_{M2} partial factor for the tensile failure strength of steel, under NF EN 1993-1-1

γ_s partial factor for the elastic limit resistance of steel, under NF EN 1992-1-1

γ_{serv} partial factor for the effects of actions for ultimate limit states in transient and permanent design situations

ν number of ground anchors that simultaneously meet the same ground conditions and the same execution methodology

$\gamma_{Rd;GEO}$ partial factor of model for the geotechnical justification of the ground anchor

$\gamma_{Rd;STR}$ partial factor of model introduced in the structural justification of the ground anchor, to manage the distinction between temporary and permanent ground anchors

Π generic symbol for pressures measured on the stressing jack

Note : it may be used as a function: $\Pi(P)$ pressure on the jack corresponding to a tension P

ψ generic symbol for losses by friction

ξ_{ELU} correlation factor applicable within the framework of verification by test methods

3.2.4 LATIN LETTERS

A_s steel cross-section (if needed, at thread bottom), possibly reduced of a sacrificial thickness

E Young's modulus of the tendon

E_d design value of the effect of ULS actions to which the ground anchor has to resist (STR or GEO)

$f_{p0,1;k}$ characteristic value of a prestressing steel at a conventional elastic limit of 0.1%

Note : NF EN ISO 22477-5 uses the notation $f_{t0.1;k}$

$f_{t;k}$ characteristic value of steel failure resistance

Note : NF EN 1993-5 uses the notation $f_{u;a}$; NF EN ISO 22477-5 uses notations $f_{u;k}$ and Rm and NF EN 1992 uses $f_{p;k}$

$f_{y;k}$ characteristic value of the elastic limit of a construction steel, or one for quenching and tempering, and conventional at 0.2% of a steel for reinforced concrete

Note : NF EN ISO 22477-5 uses the notation $f_{t0.2;k}$

F_d design value of the strength required to avoid any ultimate limit state in the supported structure

F_k characteristic value of the anchor maximum strength, including the effect of the lock-off load, which will be sufficient to avoid a SLS in the supported structure. It is therefore the design value of the tension applied to the ground anchor in service conditions (see figure 5.1)

L_e extra length, length of the ground anchor part located between the point of application of the force and the base of the anchor head (see figure 7.12)

L_L theoretical free anchor length (measured from the outer side of the support apparatus, see figure 7.12)

L_S theoretical tendon bond length (see figure 7.12)

n minimum number of failure and suitability tests to be carried out to satisfy NF EN 1997-1/A1 8.5.2 (1)

N minimum number of failure tests for a series of ground anchors that simultaneously meet similar ground conditions and execution (ν)

P_0 lock-off load (at the end), residual tension (usually an assessed one) present in the tendon at the level of the anchor head immediately after the stressing operation (see figure 5.1)

P_a tension of initial reading, or reference tension: tension force prior to a test

P_b lock-off load (start), measured tension to which the ground anchor is subject to at the time of lock-off when it is implemented (see figure 5.1)

P_i minimum initial tension (also called prestressing) defined by design, which will exist in the ground anchor to guarantee the stability of the structure during the construction or serviceability stages (see figure 5.1)

P_P proof load: maximum tension to which a ground anchor is subject to during a test (see the example of figure 5.1)

$R_{cr;d}$ design value of the critical creep resistance of the anchor bond part

R_d design value of pull-out resistance of the anchor bond part

$R_{ELS;m}$ measured value of the critical creep resistance of the anchor bond part, resulting from failure tests of ground anchors

Note : $(R_{ELS;m})_{min}$ is the minimum value of $R_{ELS;m}$ observed during a series of tests

$R_{ELU;m}$ measured value of the critical creep resistance of the anchor bond part, resulting from failure tests of ground anchors

Note : $(R_{ELU;m})_{min}$ is the minimum value $R_{ELU;m}$ observed during a series of tests

R_k characteristic value of bond ULS resistance

R_{max} conventional limit resistance of the tendon

Comment : it is the maximum value of tension within the tendon during testing. It is a limitation of P_p

$R_{t;d}$ design value at ultimate limit state of the tensile strength of the ground anchor tendon

t_0 time from which the proof load is deemed as being reached (start of the trial stage)

4 MATERIALS AND PRODUCTS

4.1 ANCHOR SYSTEMS

4.2 OTHER ELEMENTS

4.3 OTHER COMPONENTS AND MATERIALS OF PROTECTION BARRIERS AGAINST CORROSION

4.4 CONSTITUENTS OF CEMENT GROUTS

4 MATERIALS AND PRODUCTS

4.1 ANCHOR SYSTEMS

4.1.1 GENERAL POINTS

The present document only describes the anchor systems that meet the requirement 6.1.1 of standard NF EN 1537, for which there is conclusive and documented testing, or for which there is a conclusive experience demonstrating their performance level.

Any other anchor system shall:

- have been the subject of pertinent studies that demonstrates its validity,
- have been evaluated in accordance with the principles described in standard NF EN 1537.

Note : annex D describes an evaluation procedure that satisfies these principles.

All materials used in the anchor system shall be compatible with each other.
For the planned lifetime of the ground anchor, the properties of the materials shall not vary up to a point where they would impact its proper functioning.

4.1.2 NATURE OF MATERIALS

4.1.2.1 STEELS

Steels shall comply with European standards when appropriate (see comment and table 4.1).

Category of tendon	Regulatory framework	Common labelling	Selected parameter	Acceptance criterion
Prestressing steel	ASQPE n°CSP AP Rc1 [a]	Strand	$f_{p;0,1,k}$ ≥1670 MPa $f_{t;k}$ ≥ 1860 MPa [b]	ASQPE [f] certified strand
		Bar (of prestressing)	$f_{p;0,1,k}$ ≥800 MPa	ASQPE [f] certified bar
Weldable steel for reinforced concrete	NF EN 10080	Hot-rolled full-length screw-on bar	$f_{y;k}$ ranging from 400 to 500 MPa [c]	Certification [g] and test programme with their anchor heads (see paragraph 4.1.3) and couplers (see paragraph 4.1.4) [h]
		Concrete reinforcement		
Construction steel	NF EN 10025	Hot-rolled full-length screw-on bar	$f_{y;k}$ ranging from 500 to 800 MPa	
		Other steels	$f_{y;k}$ ≤ 460 MPa	
		HEL steels	$f_{y;k}$ ≥ 460 MPa	
Steel for quenching and tempering	NF EN 10083	Cold-rolled threaded hollow bar	$f_{y;k}$ ≤ 700 MPa [e]	

[a] pending standard NF EN 10138 (in France, ISO 6934 is not applicable).
[b] standard prEN 10138 also mentions 1570/1770 steels, which are barely in use nowadays
[c] the maximum value may be pushed to 600 MPa if there is an anti-corrosion protection (which is deemed compliant with standard NF EN 1992-1-1 NA 3.2.2 (3)).
[d] threading carried out by cold-rolling.
[e] standard NF EN 10083 assumes greater resistances. In the current state of knowledge, it is recommended to only use these through an ATE or ETE, or after a test programme.
[f] i.e., shall have been subjected to a certification of compliance in regard to the ASQPE technical requirements for prestressing tendons.
[g] matter certificate 3.1 under standard NF EN 10204.
[h] the test programme :

- concerns the entire anchor system,
- includes the tests described in annex D,
- results in a report validated by an approved laboratory.

Table 4.1: usable steels for ground anchors

Comment: steels that pertain to standards other than the ones mentioned here are a priori not suitable for ground anchors.

In any case, the elastic limit that shall be taken into account is deduced from the identification sheet of steels.

The apparent elasticity modulus E of the tendon may differ from the one of its constitutive steel.

Comment: for prestressing tendons made of parallel bars or string/strand beams, the mean value of this modulus is $E = 2 \times 10^7$ N/cm2 = 2×10^5 MPa.

This value may vary within limits of ± 5 %, with the higher values corresponding to bars, and the lower values corresponding to strands.
The value of this modulus, previously given for guidance, shall be adjusted in function of the test reports for each batch supplied by the manufacturer. Attention is drawn on the fact that, for some bars threaded at their ends, the outlined cross-section is a bottom one, and not the current cross-section of the free part.

4.1.2.2 NON-METALLIC TENDONS

They are, e.g., tendons made of fiberglass, aramid, carbon, boron, etc.

Picture 4.1: On-site strand assembly (© Freyssinet)

It is pertinent to know the behaviour laws of these composite materials, and the data relative to their effective durability under stressing when these tendons are exposed to potentially aggressive environments, other than the ones considered as such for steels.

Comment: besides the clauses of paragraphs 5.3.2 and 5.4.1, impacted by these particular points, the remainder of the guide is fully applicable.

4.1.3 ANCHOR HEAD

The anchor head shall satisfy the requirements of the tests recalled in annex D, deemed as compliant with EAD 160004-00- 0301 (which replaces ETAG13 mentioned in standard NF EN 1537 6.2.2.3).

The tests shall be carried out with the tendon for which the anchor head is intended.

Comment: If the anchor head is subject to a CE marking, and/or belongs to an anchor system falling within an ATE or ETE, its compliance with the requirements of EAD 160004-00- 0301 is presupposed.

The mutual compatibilities of the materials of the anchor heads shall be guaranteed, as well as with the support system and the other components of the ground anchor, in order to avoid any effect of galvanic corrosion.

Note: galvanic corrosion is a local difference of electric potential that may cause electrochemical corrosion.

Comment: usually, the system supplier specifies the compatibility domain.

4.1.4 COUPLERS

Couplers shall comply with EN 1992-1-1, i.e. shall fall within an ETE or ATE for this use.

By default, they shall satisfy the requirements of the tests recalled in annex D, deemed compliant with EAD 160004-00-0301 (which replaces ETAG13 mentioned in standard NF EN 1537 6.2.2.3).

The tests shall be carried out with the tendon for which the coupler is intended.

Comment: If the coupler is subject to a CE marking, its compliance with the requirements of EAD 160004-00-0301 is presupposed.

Using couplers should be avoided in the bonded part. A steel tendon shall be capable of stretching freely, without being restricted by the presence of a coupler.

The coupler protection against corrosion shall be compatible with the tendon protection against corrosion.

4.2 OTHER ELEMENTS

4.2.1 SUPPORT SYSTEM

The support system shall be designed and installed according to the appropriate standards, and in such a way it will not produce parasitic forces within the ground anchor.

In particular, the connections between the various elements (chair/plate, plate/waling…) shall guarantee that motions (displacement, sliding, rotation) and deformations will be compatible with their use under the considered forces.

The compatibility of the materials of the support system with the other components of the ground anchor shall be guaranteed in order to avoid galvanic corrosion.

Note: galvanic corrosion is a local difference of electric potential that can cause electrochemical corrosion.

Picture 4.2: Outfitting a recess on a dam crest
(© Freyssinet)

For a support system made of steel, standard NF EN 1090-2 is applicable. Unless otherwise specified, the execution class to be selected is EXC2.

4.2.2 OTHER ELEMENTS SET IN THE BOREHOLE

All other elements that are permanently installed in the borehole shall be spaced and placed so that they do not reduce the performance of the bonded part of the anchor.

Spacers and centralizers should be set up so that the minimum coating requirements of the ground anchor are satisfied, that a full filling of the voids by grout is guaranteed and that the tendon and its anti-corrosion protective elements, or other elements in the borehole are properly positioned.

Spacers and centralizers shall be solidly fixed in order to avoid any motion within the borehole.

Note: the usual spacing between spacers or centralizers ranges from 2 to 3 m.

For a permanent ground anchor, when spacers and centralizers are used outside the protection, devices should be manufactured with anti-corrosion materials.
The design of centralizers shall take into account the borehole shape, for instance the occurrence of bell-shaped widenings, or the tendon weight and the sensitivity to soil remoulding during the installation of the tendon.

4.2.3 GROUND ANCHORS WITH COMPRESSION ELEMENTS

The compression element of an anchor with such elements shall be capable of fully transferring the tensile force to the bond grout, which shall be proven by documented studies, in compliance with article 6.1.1 of standard NF EN 1537.

The cover thickness of a compression element in a ground anchor with such elements shall be at least of 10 mm.
The bonded part of a compression element shall be verified by a documented study, in compliance with article 6.1.1 of standard NF EN 1537.

Picture 4.3: centralizers (grey) and tubes à manchettes (blue)
(© Spie Fondations)

Picture 4.4: spacers set on tubes à manchettes (© Freyssinet)

4.3 *OTHER COMPONENTS AND MATERIALS OF PROTECTION BARRIERS AGAINST CORROSION*

4.3.1 PLASTIC SHEATHS AND TUBES

4.3.1.1 GENERAL POINTS

Plastic sheaths and tubes shall comply with the European standards of the concerned product. In particular, they shall be continuous, waterproof and resistant to the brittleness caused by aging, by ultraviolet radiation during storing, by packing, by transportation and by installation.

The connections between elements shall be made waterproof by using adapted sealing products.

One should not use any PVC as an anti-corrosion barrier. Nonetheless, if this type of product has to be used, it should be age-resistant and not produce any free chloride.

4.3.1.2 MINIMUM THICKNESS

The minimum wall thickness of an outer corrugated tube, shared by one or several tendons, shall be of:

- 1,0 mm for an inner diameter ≤ 80 mm ;
- 1,2 mm for an inner diameter > 80 mm and ≤120 mm ;
- 1,5 mm for an inner diameter > 120 mm.

The minimum wall thickness of a sheath or of a shared outer smooth tube shall be 1.0 mm larger than the one advised for corrugated tubes, or this tube shall be reinforced.

When the protection consists in 2 plastic barriers, the minimum wall thickness of a sheath or of a corrugated inner tube shall be of 1.0 mm.

4.3.1.3 CASE OF TUBES SET IN THE BONDED PART

Plastic tubes shall be corrugated or crenelated (inside and outside) to guarantee the transmission of forces.

The tubes having parameters outlined in Table 4.2 are deemed as satisfying this requirement.

The other tubes shall be subject to a justification.

Note: it is reminded that the height and frequency of the corrugations or undulations are tied to the wall thickness, and in particular that the risk of load losses due to creep is part of the justification.

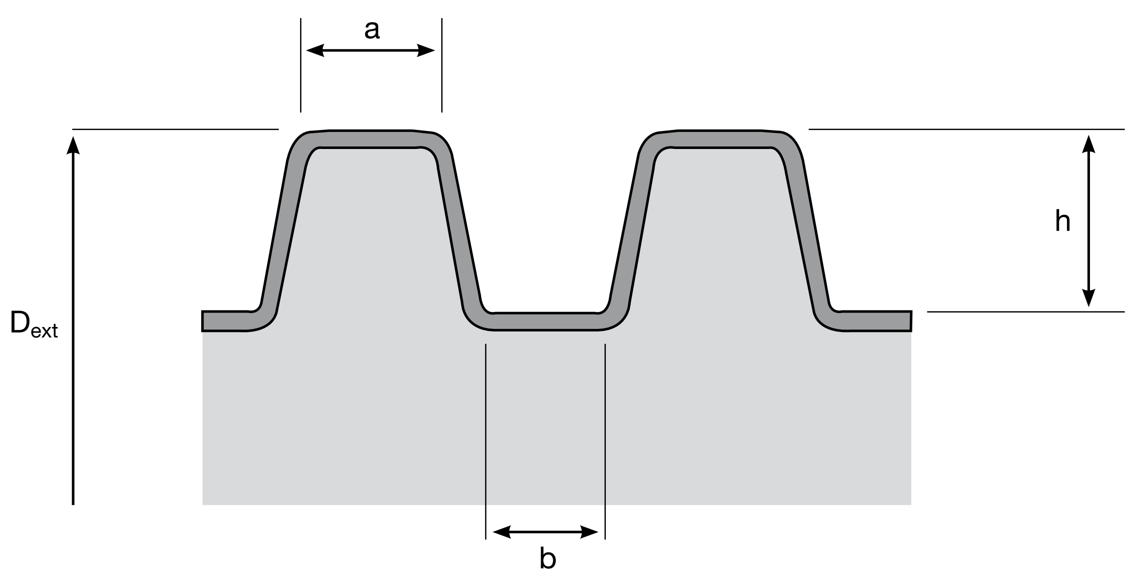


Figure 4.1: geometry of a corrugated plastic tube

	a	b	h
Inner D ≤ 80	3.0 to 6.0	1.5 to 5.0	2.0 to 6.0
80< inner D ≤120	3.5 to 7.0	2.0 to 7.0	3.0 to 8.0
Inner D > 120	5.0 to 12.0	4.0 to 9.0	5.0 to 12.0
Note 1: notations are explained on Figure 4.1 **Note 2:** data are in mm			

Table 4.2: corrugation parameters of a plastic tube

4.3.1.4 CASE OF A CORRUGATED TUBE USED FOR INJECTION

When a corrugated tube is used to inject grout under low pressure, and is considered as being a protection barrier, it is appropriate to demonstrate that, after the grout is injected, water cannot penetrate through the injection shutters.

The thickness of such a tube shall not be lower than 3.0 mm, and the height and frequency of the corrugations shall allow transmitting forces, which will be proved with appropriate studies on the pertinent components (see paragraph 6.1.1 of standard NF EN 1537).

The integrity of the protection barrier should be demonstrated under stressing (see paragraph 6.1.2 of standard NF EN 1537).

4.3.2 HEAT-SHRINKABLE SLEEVES

When it is required to cover the surface of a steel element, heat-shrinkable sleeves may be used if they are associated to anti-corrosion products.

Note: due to the anti-corrosion product, it is a priori not possible to use those on the fixed length.

The heating of the heat-shrinkable sleeve shall be carried out in such a way that the other elements of the anti-corrosion system remain compliant with the requirements of the standard, i.e., that they are neither deformed, or burned during heating, or damaged in other ways, with as a consequence a loss of their capacity to properly function.

The product technical sheet, which specifies in particular the diameter after shrinking (which will be in line with the element to be protected), and the conditions of use, shall be observed.

The wall thickness of the sleeves after shrinking shall not be lower than 1.0 mm.

The minimum overlap between two sleeves shall not be lower than 50 mm.

4.3.3 WATERPROOFING DEVICES

The water seals shall prevent any leaking of protection product or any entry of water, no matter what will be the relative subsequent motions between the connected elements.

Note: mechanical connections are made waterproof by using O-rings, water seals or heat-shrinkable sleeves.

4.3.4 METALLIC SHEATHS AND TUBES

Metallic sheaths and tubes shall comply with the European standard of the concerned product.

The compatibility between the metallic sheaths or tubes and the other components of the ground anchor shall be guaranteed in order to avoid any galvanic corrosion.

Note: galvanic corrosion is a local difference of electric potential that can cause electrochemical corrosion.

In particular, the metallic sheaths or tubes shall be continuous, waterproof and sufficiently solid to avoid being impaired during storing, transportation and installation.

The connections between the elements shall be made waterproof by using sealants or adapted solutions.

For ground anchors of the tube à manchettes type, it is appropriate to have a tube thickness not lower 3.0 mm.

Note: tubes with a lower thickness do not contribute to the anti-corrosion barrier.

When a tube is used to inject grout under pressure and is considered as being a protection barrier against corrosion, it should be demonstrated that, after the grout is injected, water cannot penetrate through the injection shutters.

4.3.5 PRODUCTS OF ANTI-CORROSION PROTECTION MADE OF PETROLEUM, WAX AND GREASE

The protection products used against corrosion and made of petroleum, wax and grease are common.

General rules regarding the acceptance criteria of anti-corrosion viscous products, as well as test methods to measure the properties of such products, are provided in annex B of standard NF EN 1537.

The properties of anti-corrosion products shall notably include stability in regard to oxidising and resistance to bacterial and microbiological attacks.

The products of protection against corrosion used as permanent barriers shall be confined within a solid moisture-proof sheath, a tube or a cap itself resistant to corrosion.

Note: within such conditions, these products also act as lubricants and as filling materials that prevent the entry of gas or water.

Unconfined anti-corrosion products may also be used as temporary protection barriers provided they are applied by coating.

Strips soaked with anti-corrosion products may only be used as a temporary protection within a non-aggressive environment.

Note: this is due to a risk of impairment under the effect of air or water.

4.3.6 METALLIC COATING USED AS PROTECTION

Metallic protective coating shall not be applied on prestressed tendons or prestressing steels.
Metallic protective coating may be used on other elements made of steel, such as bearing plates and caps.

No metallic coating should be used if it would lead to the production of a galvanic element that could damage the tendons.

4.3.7 OTHER COATING FOR STEEL PARTS

Coatings made of epoxy tar, of polyurethane tar, as well as fusion-bonded epoxy coatings are a priori not appropriate for bonding zones, except when manufactured according to NF EN ISO 12944-5 and subjected to the tests described in NF EN 1537.

Comment: products classified as carcinogenic, mutagenic and reprotoxic (CMR) should be avoided.

They shall be applied on sandblasted steel surfaces and free from any harmful foreign bodies.
They may be used as protection against corrosion for the tendons of temporary or permanent ground anchors, provided they were factory implemented in compliance with standard NF EN ISO 12944-5.
Using an asphalt-based paint is allowed on non-loaded elements of temporary ground anchors, when sandblasted and free from any harmful foreign bodies.

Note: e.g., it is the case of overlengths after stressing.

Using an asphalt-based paint is allowed on the free part of steel passive ground anchors (see Table 4.1), other than prestressing steels.
Using anti-corrosion paint is allowed, provided it remains compatible with the expected deformations of its support.

4.3.8 PROTECTION CAP

The minimum wall thickness of steel caps for ground anchors shall be of 3.0 mm.
Reinforced plastic caps shall have a flange with a minimum thickness of 10.0 mm, and a wall with a minimum thickness of 5.0 mm.

4.4 CONSTITUENTS OF CEMENT GROUTS

4.4.1 CEMENT GROUT

Cement grouts may either be part of a manufactured product (the ground anchor), or be made on-site for various uses (sleeve grout, injection grout, anti-corrosion protective grout).

Water/cement ratios and the cement resistances shall be chosen so that they are adapted to ground conditions and be sufficient to guarantee the load transfer.

The provisions of standard NF EN 447 shall be satisfied for grouts contributing to the anti-corrosion protection of permanent ground anchors in prestressing steel. Any other grout shall comply with the provisions of the present document.

Note: experience feedback on the execution and follow-up of ground anchors in France in the past decades show that a sulphide ratio lower than, or equal to, 0.15 % does not produce any harmful effect.

In-situ and laboratory testing shall be carried out to verify the mixture composition, the mixing efficiency, the setting times and the grout performances.
Such tests shall be carried out in compliance with standard NF EN 445, when applicable.

4.4.2 CEMENT

The cement shall comply with standard NF EN 197-1.

When choosing the cement type for grouts in contact with soils, the presence of aggressive matter in the environment, such as, for instance, carbonic acid or natural sulphate, ground permeability and the planned lifetime of the ground anchor shall be taken into account.

The environmental aggressivity shall be defined in compliance with Table 1 of standard NF EN 206 (recalled in annex E).
It is recommended to choose the cement in function of the environmental aggressivity, in compliance with the tables of fascicule FD P 18-011 (recalled in annex E).

4.4.3 ADJUVANTS AND ADMIXTURES

Adjuvants, as defined in standard NF EN 934-2, may be used to improve the workability or durability of the grout, or to reduce its bleeding, dewatering or shrinking, or to speed up setting.

Note: a bleeding value of 2 % at 3 hours, according to the AFTES protocol (GT8, R2F1 DESIGN AND EXECUTION OF INJECTION WORKS IN SOILS AND ROCKS) is usually a satisfying one.

Adjuvants shall be free of any element that could impair the prestressing steel or the grout itself.

Any adjuvant containing more than 0.1 % (of weight) either of chlorides or sulphates or nitrates shall not be used.
If needed, inert fillers (sand, for instance) can be incorporated to the grout in order to reduce grout losses in the borehole.

5 DESIGN PRINCIPLES

5.1 STUDY METHODOLOGY OF GROUND ANCHORS

5.2 SUCCESSIVE STAGES OF A GROUND ANCHOR LIFECYCLE

5.3 ULTIMATE LIMIT STATE JUSTIFICATION OF GROUND ANCHORS

5.4 SERVICEABILITY LIMIT STATE JUSTIFICATION OF GROUND ANCHORS

5 DESIGN PRINCIPLES

5.1 STUDY METHODOLOGY OF GROUND ANCHORS

5.1.1 GENERAL PRINCIPLES

It is reminded here that the structure study shall be achieved before the ground anchor study as such. Besides, it is advisable that investigation tests precede ground anchors design (see chapter 8).

Temporary ground anchors have justification rules that are different from the ones of permanent ground anchors.

Ground anchor design (for instance, within the framework of a design mission of standard NF P 94 500) shall take into account the results of the geological and geotechnical investigation campaign, as well as the available tests on ground anchors. This design can also rely on ground knowledge, resulting from previous works.

Besides, in cohesive soils that are likely to creep, for which the long-term behaviour is poorly known despite the many tests carried out since the first edition of the TA recommendations, it is mandatory to carry out failure tests as soon as during the design stage (« investigation tests »).

Note : cohesive soils that are likely to creep are ones with a plasticity index Ip greater than, or equal to, 20, and notably: clays, silts, marly clays and some marls (which have a $CaCO_3$ content lower than 30%).

Attention is drawn on the fact that in all cases, it is appropriate to comply with all steps and stages of standard NF P 94 500.

5.1.2 A FEW RULES OF GOOD PRACTICE

The global process of the design can be based upon the following schedule:

- Structure design:
    - Determining forces to be taken over,
    - Choosing ground anchor locations (levels, spacing, etc.) and successive execution stages (see comment 1),
    - Determining the reaction that the ground anchor will produce during the various execution stages,
    - Justifying the ground anchor resistance,
    - Justifying the internal stability of the structure,
    - Justifying the overall stability.
- Ground anchor design
    - Designing ground anchors incorporates the following parameters (see comment 2):
        - geometrical and topographical constraints of the site,
        - level(s) of the water table,
        - lifetime of the ground anchor,
        - nature and aggressivity of the environment (soil, water table, atmosphere…),
        - the resistance required in regard to the various limit states,
        - geological specificities, etc.
- The following points result from this:
    - determining the tendon in function of the expected resistance,
    - determining the expected level of protection against corrosion, as well as the nature of the protection and its execution,
    - choosing the procedure (drilling process, grouting type, etc.),
    - the possible provisions relative to monitoring and maintenance (accessibility of the anchor heads, possibility of subsequent operations, instrumentation).

Comment 1: any unfavourable interaction between the fixed lengths of the ground anchor should be appropriately avoided by keeping, when possible, an interval of at least 1.5 m between them (centre-to-centre distance).

Comment 2: the fixed length should be greater than 3 m, which is a value that usually protects against highly localised geotechnical anomalies and corresponds to a reasonable approach of the characteristic value of lateral friction.

5.2 SUCCESSIVE STAGES OF A GROUND ANCHOR LIFECYCLE

5.2.1 GENERAL PRINCIPLES

The various stages of a ground anchor lifecycle are:

a. drilling (see paragraph 7.1);
b. tendon installation (see paragraph 7.2);
c. ground anchor bonding, using grout or mortar (see paragraph 7.3);
d. suitability test, if the ground anchor belongs to a class that demands such a test (see paragraph 8.5);
e. ground anchor implementation, which entails the acceptance test and lock-off (see paragraph 7.4);
f. monitoring and regular survey of strength (using, for instance, a lift off device for lock-off test), if needed (see paragraph 8.6);
g. ground anchor destressing, or even, when needed, its extraction;
h. adjusting tension, if needed.

Note: depending on the ground anchor type, some of these operations above may not exist, or be bundled together.

Figure 5.1 below provides a simplified view of how the tension of a prestressed ground anchor evolves during steps e and f, for a case of retaining structure including several rows of ground anchors.

Note: steps a to c are carried out within the 0-ti duration of the figure. Evolutions beyond step f are only provided as examples.

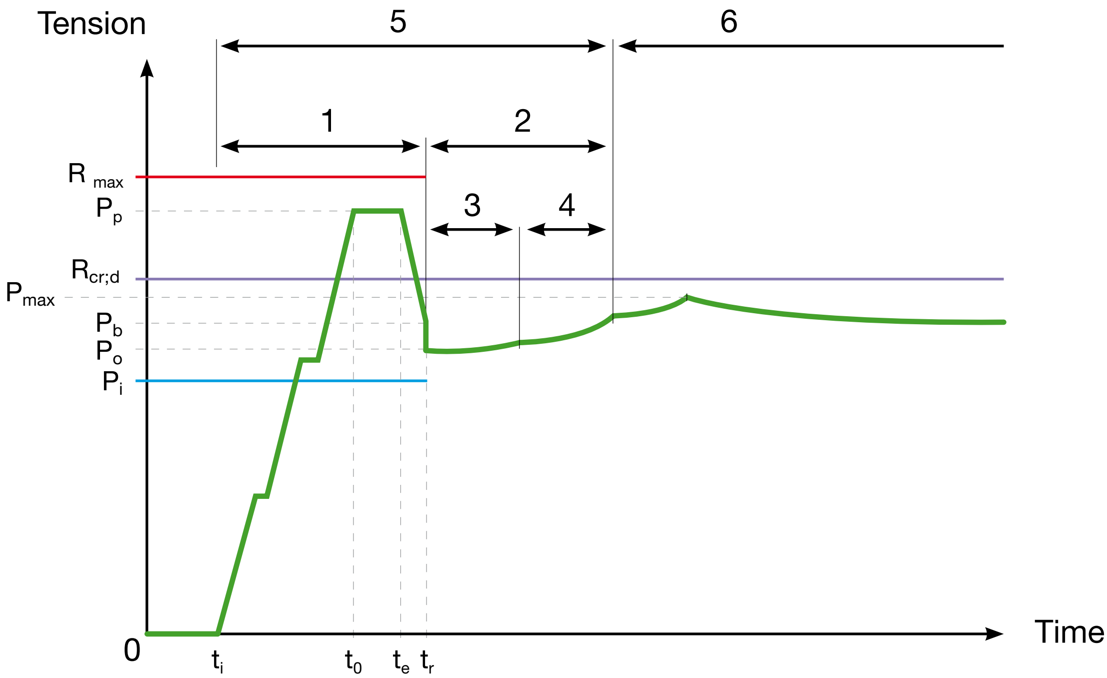


Figure 5.1: example of how tension evolves within a retaining wall anchor

Labels:
1: Ground anchor implementation
2: Execution of other works
3: Earthworks 1
4: Earthworks 2
5: Structure being constructed
6: Structure implementation

Step 1, between t_i and t_r , is the ground anchor implementation, and is the most critical one. It may be broken down into a certain number of basic stages:

- Firstly, during the acceptance test, the tension is brought to a value that will no longer be exceeded during the whole implementation process. This proof load value P_p (see note 1) is maintained over a certain time (t_e-t_0 sur la figure), which depends on the nature of the ground in which the bond is achieved (see note 2).
- Then, tension is being reduced down to the lock-off load value P_b (see note 3).
- Then, after the stage corresponding to the lock-off preparation, the lock-off as such is carried out, which may cause some tension loss during wedging. This loss is usually poorly known, except for ground anchors equipped with a control device. The tension P_0 that remains in the ground anchor is the post-lock-off load (see paragraph 7.4.8.4).
- The anti-corrosion protection of the anchor head is then achieved (see paragraph 7.4.10).

Note 1 : The value of P_p is indicated in paragraph 7.4.4.2.

Note 2 : The t_e-t_0 duration is stated in paragraphs 7.4.6.3 and 7.4.7.3.

Note 3 : the lock-off load P_b is estimated (see paragraphs 7.4.4.8 and 7.4.8.4) from the value of the initial tension P_i set by design.

The ground anchor is then mechanically complete, and is usually not subject to any other operation, besides the ones relative to a periodic monitoring (see paragraph 8.6), or if an anomaly occurs, due for instance to the structure behaviour.

What remains in the diagram translates how the tension evolves within the ground anchor during the successive work stages (execution of other ground anchors of the same row, digging to reach the next rows, execution of ground anchors on the new rowss, etc.) up to the final stage.

P_{max} is the limit service tension that truly remains in the ground anchor to guarantee the structure stability, as a result of design, under the most unfavourable loads that may occur during the whole lifetime of the structure. Its value can slightly differ from the theoretical value F_k, if only because of the uncertainties that bear on the assessment of tension losses (see paragraph 5.2.2).

5.2.2 TENSION LOSSES

5.2.2.1 ORIGINS

To assess loads within the tendons with the highest accuracy possible, it is critical to master the various losses that may occur during the ground anchor lifecycle.

Comment: assessing losses shall be handled with care, in order to avoid, as much as possible, an excessive over-assessment or under-assessment, which are both prejudicial to the safety of structures.

- Over-assessing losses leads to a permanent tension excess of the tendons, which may increase the risks of poor preservation of the tendon bond length (risk of creep) and of the structure (which will be necessarily oversized) over time.
- Under-assessing losses leads to a value of residual tension that will be too low. The structure is exposed to the risk of only finding its balance to the cost of deformations that are incompatible with its safety, or with its normal operational conditions.

Tension losses belong to three categories:

(1) Losses during stressing, which include:

- losses by friction in the jack $\psi_{vér}$ (which are usually well known),
- losses by friction of the tendon in the anchor head,
- losses by friction of the tendon in its sheath, over the free length (also called line losses), due to the possible curvature of the borehole, of the positioning of tendons, etc.

(2) Losses observed during the lock-off of the ground anchor. They are:

- losses due to the sliding of tendons in the anchor head ψ_t. They are also called anchor entries.
- the deformations of the bearing plate during the load transfer, which are added to the losses due to lock-off.

(3) Deferred losses, which may originate, for instance, from:

- the release of the prestressing tendons,
- the creep of ground,
- the motions of the support.

5.2.2.2 ASSESSING LOSSES DURING STRESSING

Losses by friction in the jack $\psi_{vér}$, besides a few exceptional cases for which losses are virtually constant, represent less than 4 % of the tension for the vast majority of jacks, depending on their types.

Losses by friction in the anchor head, in the bearing plate and in the trumpet tube represent less than 2 % of the tension (see comment).

Comment: In general, losses by friction of the tendon in the jack are not dissociated from the ones in the anchor head.
In order to determine their value, it is advised to consult the approval sheet of the prestressing process, or, by default, the manufacturer manual.
They may also be determined experimentally (see paragraph 7.4.4.7).

Losses by friction of the tendon in its sheath over the free length (or line losses) usually represent less than 4 % of the tension.

The aggregation of losses during stressing is usually evaluated as being between 5 and 10 % of the tension.

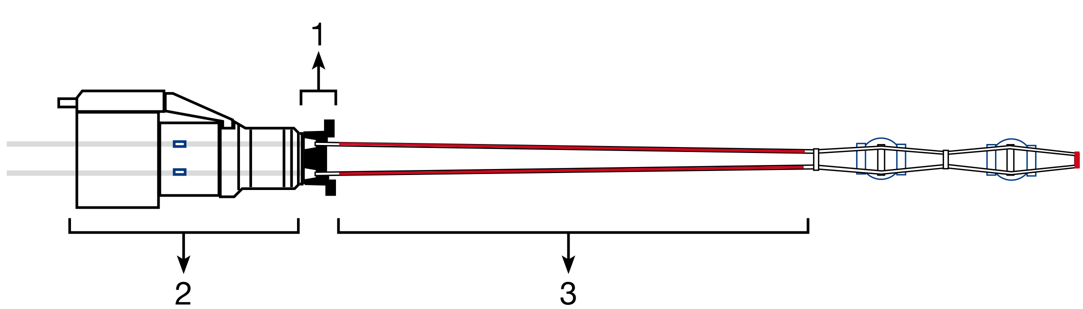


Figure 5.2: location of losses during stressing

Labels
1: losses in the anchor head
2: losses in the jack
3: line losses

5.2.2.3 ASSESSING LOSSES DURING GROUND ANCHOR LOCK-OFF

Anchor entries are usually provided by the holder of the prestressing process. They are expressed in mm and correspond to the set-up of the tendon into its anchor head during the load transfer from the jack to the head.

The design of the bearing plate shall be achieved in such a way that its deformations during the load transfer from the jack to the anchor head are negligible.

In the specific case of bars, ball nuts should be used in order to minimise losses.

5.2.2.4 ASSESSING DEFERRED LOSSES

Deferred losses stem from complex phenomenons such as slides and deformations at the bond level, ground creep, movements from the support, tendon release (usually provided by the supplier).

Note: The resulting loss, assessed in percentage of the final tension, notably depends on the relative proportions of the free length and of the loaded fixed length.
As an example, for common ground anchors into sandy-gravelly soils, with bonded lengths in an order of magnitude of 8 meters and free lengths of 12 to 15 metres, such losses represent around 2 to 3 % of the maximum tension.

5.2.2.5 MANAGEMENT OF LOSSES

All these losses do not simultaneously develop, and you should remain reasonable when managing the addition of these different losses.

When losses reach 12 to 15 % of the maximum tension, you should research their origin and verify if no anomaly has occurred.

Losses stemming from stressing and lock-off shall be taken into account during ground anchor implementation.

In the specific case where deferred losses are not negligible, they shall be taken into account during stressing, so that the selected lock-off load is revised upwards in regard to the design tension.

The monitoring interpretation takes deferred losses into account.

5.3 ULTIMATE LIMIT STATE JUSTIFICATION OF GROUND ANCHORS

5.3.1 CONTENT

The stability of a ground anchor in regard to structural failure, or to a failure due to a shortage of fixed length, shall be guaranteed during the construction stages and once the structure is built.

Only the justifications specific to ground anchors (ELU GEO/STR and ELS) are addressed here. You should refer to design standards (NF EN 1997-1, NF P 94 282, etc.) for larger justifications, of the EQU, UPL or HYD types.

Ground anchor free length should be sufficient to efficiently exert a prestressing force (minimising the losses due to the entry of lock-off devices, or due to the ground deferred deformations behind the wall, e.g.) and to avoid an interaction with the retaining wall.

In common cases, verifying that there is no interaction between the wall and the anchorage, under the specifications of annex F, is sufficient to define the minimum free length of the ground anchor.

Note: standard NF P 94 282 has set a minimum length of 5 m for the free length, which is usually appropriate for soils.

The verification of ground anchor resistance shall also include the resistance of the support system.

Note 1: this verification takes into account the execution tolerances of the various elements. Unless otherwise specified, this tolerance for steel structures is the one of the EXC2 class of standard NF EN 1090-2.

Note 2: this verification is carried out in compliance with the pertinent Eurocodes.

5.3.2 IN REGARD TO THE TENDON RESISTANCE

5.3.2.1 GENERAL CASE

In order to demonstrate that a ground anchor can bear a tensile force with a sufficient safety in regard to its structural failure, the following inequation shall be verified:

$$E_d \leq R_{t;d} / \gamma_{Rd;STR}$$

Note 1: the resistance of a retaining wall shall be verified in regard to the most unfavourable values stemming from a MISS design model, and a MEL design model when it is used to verify the ULS of abutment failure.

Note 2: when the effect of actions is deduced from a MISS design model, the characteristic value of this effect F_k is established by applying a partial safety factor equal to 1 to the actions and resistances, and its design value is determined from the relation (stemming from standard NF P 94 282, paragraph 10.2 (1)):

$$E_d = \gamma_{serv} \cdot F_k$$

with γ_{serv} = 1,35.

Note 3: the factor of model $\gamma_{Rd;STR}$ aims at taking into account, firstly, the brittleness of prestressing steels, and, secondly, the « parasitic » forces, which are unaccounted for in design models, e.g., bending for construction steels, which have an inertia that may not be disregarded.

It is appropriate to select a value of partial factor of model $\gamma_{Rd;STR}$ of :

- 1.05 for prestressing steels of a permanent ground anchor;
- 0.85 for prestressing steels of a temporary ground anchor;
- 1.0 for non-prestressing steels (e.g. construction or reinforced concrete steels).

Comment: given the partial factors specific to the various types of steels, and admitting:

$$E_d = 1{,}35 \cdot F_k$$

the result is a service tension stress, with a value that shall not be exceeded indicated in the table below:

	In prestressing steel	In reinforced concrete steel	In construction steel	In steels for quenching and tempering
Permanent ground anchor	0.6 $f_{p0,1;k}$	0.65 $f_{y;k}$	0.75 $f_{y;k}$	0.75 $f_{y;k}$ [a]
Temporary ground anchor	0.75 $f_{p0,1;k}$	0.75 $f_{y;k}$		
[a] : subject to proving the protection of the bonded part in the case of a prestressing ground anchor				

Table 5.1: workability of steels

When the risk of the ground anchor having a bending load or having shear (storing area at the top of the wall, quay walls, for instance) remains, you should favour construction provisions that minimise these effects. The justification of this type of limit state is beyond the scope of the present document.

5.3.2.2 CASE OF A TENDON IN PRESTRESSING STEEL

The design value of the tensile strength of a tendon $R_{t;d}$ in reinforced concrete steel is determined from the following formula:

$$R_{t;d} = f_{p0,1;k} \cdot A_s / \gamma_s$$

Note : in transient and durable project situations $\gamma_s = 1.15$

5.3.2.3 CASE OF A TENDON IN REINFORCED CONCRETE STEEL

The design value of the tensile strength of a tendon $R_{t;d}$ in reinforced concrete steel is determined from the following formula:

$$R_{t;d} = f_{y;k} \cdot A_s / \gamma_s$$

Note 1 : in transient and durable project situations $\gamma_s = 1.15$

Note 2 : if the ground anchor is not protected against corrosion (which is only possible with passive ground anchors), note that A_s is a cross-section reduced by sacrificial thickness (see paragraph 6.4.3).

5.3.2.4 CASE OF A TENDON IN CONSTRUCTION STEEL

The design value of the tensile strength of a tendon $R_{t;d}$ in construction steel is determined by considering the lowest of values:

- in the threaded part $R_{t;d} = k_t \cdot f_{t;k} \cdot A_s / \gamma_{M2}$
- in the non-threaded part $R_{t;d} = f_{y;k} \cdot A_g / \gamma_{M0}$

where A_g is the gross cross-section of the resistant part of the non-threaded part.

Note 1 : k_t is a coefficient with a value selected in standard NF EN 1993-5/NA (paragraph 7.2.3) of 0.6 if bending effects are disregarded (otherwise, this value is 0.9).

Note 2 : γ_{M2} is equal to 1.25 (NF EN 1993-1-1/NA, paragraph 6.1).

Note 3 : γ_{M0} is equal to 1.00 (NF EN 1993-1-1/NA, paragraph 6.1).

Note 4 : if the ground anchor is not protected against corrosion (which is only possible with passive ground anchors), note that A_s and A_g are cross-sections reduced by sacrificial thickness (see paragraph 6.4.3).

5.3.2.5 CASE OF A TENDON IN STEEL FOR QUENCHING AND TEMPERING

The design value of the tensile strength of a tendon $R_{t;d}$ in steel for quenching and tempering is determined by considering the lowest of values:

- in the threaded part $R_{t;d} = k_t \cdot f_{t;k} \cdot A_s / \gamma_{M2}$
- in the non-threaded part $R_{t;d} = f_{y;k} \cdot A_g / \gamma_{M0}$

where A_g is the gross cross-section of the resistant part of the non-threaded part.

Note 1 : k_t is a coefficient with a value selected in standard NF EN 1993-5/NA (paragraph 7.2.3) of 0.6, if bending effects are disregarded (otherwise, this value is 0.9).

Note 2 : γ_{M2} vis equal to 1.25 (NF EN 1993-1-1/NA, paragraph 6.1).

Note 3 : γ_{M0} is equal to 1.00 (NF EN 1993-1-1/NA, paragraph 6.1).

Comment: even though steels for quenching and tempering are not explicitly mentioned in standard NF EN 1993, in the absence of an ATE or ETE addressing such topics for an anchorage use, you should:

- apply the requirements and recommendations of standard NF EN 1993 (all parts);
- require a protection against corrosion as soon as the elastic limit stress $f_{y;k}$ of steel exceeds 500 MPa (see note).

Note : no cross-section reduction by sacrificial thickness on A_s and A_g may be substituted to the protection of threaded and non-threaded parts.

5.3.2.6 LIMIT CONVENTIONAL RESISTANCE

The limit conventional resistance R_{max} is determined as being the lowest of values between 95% of the « maximum elastic» tension and 80% of the « failure » tension,

- for a prestressing steel:
  $R_{max} = A_s \,.\, MIN\,(0{,}95 \,.\, f_{p0,1;k}\,;\, 0{,}8 \,.\, f_{t;k})$
- for a reinforced concrete steel:
  $R_{max} = A_s \,.\, MIN\,(0{,}95 \,.\, f_{y;k}\,;\, 0.8 \,.\, f_{t;k})$
- for a construction steel, or a steel for quenching and tempering:
  $R_{max} = MIN\,(0{,}95 \,.\, R_{t;d}\,;\, 0{,}8 \,.\, f_{t;k} \,.\, A_s)$

Comment: this value is used as a set limit for the proof load P_p :

$$P_p \leq R_{max}$$

5.3.3 IN REGARD TO THE PULL-OUT RESISTANCE

5.3.3.1 LIMITATIONS OF THE METHOD

The ground anchor justification described in this paragraph is founded on the hypothesis that the ground anchor is an isolated one.

Note: a ground anchor is considered as isolated when the shortest distance between its fixed part and the one of the adjacent ground anchor is greater than 1.5 m (centre-to-centre distance), for borehole diameters lower than 200 mm.

You should prefer solutions that distance the fixed lengths of the ground anchors from each other.

Note: e.g., boreholes may be inclined differently, or have azimuths that allow spacing the bonding zones. Another option consists in defining different free lengths.

Such provisions do not exempt professionals from keeping a critical eye on a possible group effect.

Note: standard NF P 94 262 outlines in its paragraph 10.3 a method to take the group effect into account. The annex G recalls the method of TA 95 for ground anchors under a slab. We remind you that the GEO justification shall also deal with the stability of the mass containing the anchorages which is not described here (you can see annexes F and G).

5.3.3.2 PRINCIPLES OF THE GEO-JUSTIFICATION

The only method allowed to justify bond-type ground anchors during the execution stage (mission G3 of standard NF P 94 500) is exploiting results from failure tests.

These tests may be carried out during all stages of the geotechnical missions (G2 AVP, G2 PRO, G2 DCE, G3, under NF P 94500), or even by benefitting from nearby operations, provided that the execution conditions (ground, intensity of tension, technology of execution) are similar to the ones of the structure ground anchors (see paragraph 8.1.2.2).

The number of failure and suitability tests (of article 8.5.2 (1) of standard NF EN 1997-1/A1) is defined as follows:

- N failure tests for each ground condition and ground anchor technology;
- Additionally, suitability tests at a rate of one for each series of 40 ground anchors, with a minimum number of 3 per site.

Note 1: the number of tests N is therefore not set, and varies with the total number of ground anchors. It may not be lower than 5 (2 failure tests and 3 suitability tests).

Note 2: the number of failure tests N is detailed in paragraphs 8.3.1 and 8.4.2

Besides, all ground anchors are subject to an acceptance test (see paragraph 7.4.6).

While awaiting failure tests, pre-design may be founded on charts (see annex H).

5.3.3.3 ULTIMATE LIMIT STATE JUSTIFICATION

In order to demonstrate that a ground anchor can bear a tensile force with a sufficient safety in regard to the pull-out of its bonded part, the following inequation shall be verified:

$$E_d \leq R_d \,/\, \gamma_{Rd;GEO}$$

Note 1 : the SLS verification relative to the critical creep load is usually more unfavourable for the design (see paragraph 5.4).

Note 2 : NF P 94 282: 2009 and NF P 94 282/A1: 2014 are no longer valid regarding this method.

A factor of model $\gamma R_{d;GEO}$ of 1.0 shall be used for the justification.

The failure tests described in paragraphs 8.1 to 8.4 allow setting the following characteristic value:

$$R_k = (R_{ELU;m})_{min} \,/\xi_{ELU}$$

with ξ_{ELU} = 1.0 (table A20 of standard NF EN 1997-1/A1)

The design value is then:

$$R_d = R_k \,/\gamma_{a;ELU}$$

Note : $\gamma_{a;ELU}$ is equal to 1.1 (table A19 of standard NF EN 1997-1/A1 and table A.2.3 of standard NF P 94 282; R2 approach)

Comment: the design models, such as the one displayed in annex H for ground anchors bonded to the ground by unitary global injection or by selective and repetitive injection, are only approved to assess the value of pull-out resistance at a pre-design stage.

5.4 SERVICEABILITY LIMIT STATE JUSTIFICATION OF GROUND ANCHORS

5.4.1 STIFFNESS OF GROUND ANCHORS

Usually (see notes 1 to 3), you should determine the stiffness K_{MA} of a ground anchor using the following expression:

$$K_{MA} = E \cdot A_s / (L_L + L_S / 2)$$

Note 1: the alternative would stem from the exploitation of ground anchor tests, but this data is usually produced late, except for investigation tests.

Note 2: this expression is usually only applied for grouted anchors with an injection under pressure into homogeneous soils. It is however allowed to use it to determine the stiffness of all ground anchors, provided a verification is made, or adjustments are carried out on the basis of representative tests.

Note 3: this formulation assumes there is no interaction between the anchorage and the main wall (see paragraph 5.3.1 and annex F), and may only be fully applied to common cases (one or two row(s) of ground anchors bonded into a compact ground). In more complex cases (multiple anchorages, short ground anchors, soil with poor compactness) the possibility of a global displacement of the soil mass behind the wall would be considered.

5.4.2 CRITICAL CREEP LOAD

In order to demonstrate that the loading stage of a ground anchor remains lower than its critical creep load during its lifetime, the following inequation shall be verified:

$$F_k \leq R_{cr;d}$$

Note 1: the tension value in serviceability conditions to be considered is the most unfavourable one of the values obtained by studying the various serviceability situations. It is equal to the corresponding characteristic value (partial factor of 1).

Note 2: as a reminder, the verifications shall be carried out in regard to design loads stemming from a MISS design model, and possibly from a MEL design model in the case of particularly simple structures (see article 10.1 (4) of standard NF P 94 282).

The failure tests described in 8.1 to 8.4 allow setting the following characteristics:

$$R_{cr;k} = (R_{ELS;m})_{min}$$

The design value is then:

$$R_{cr;d} = R_{cr;k} / \gamma_{a;ELS}$$

Note : $\gamma_{a;ELS}$ is equal to 1.1 for a temporary ground anchor, and to 1.2 for a permanent ground anchor.

Comment: when $R_{ELS;m}$ is not reached during the conformity tests, the value of $R_{cr;d}$ is conventionally used, as explained in paragraph 8.4.6.

Annex H defines the value of $R_{cr;d}$ deduced from charts, within the framework of a pre-design process.

6 PROTECTION AGAINST CORROSION

6.1 OVERVIEW

6.2 TYPE T GROUND ANCHORS

6.3 ADDITIONAL ELEMENTS FOR THE TYPE P PROTECTION

6.4 CASE OF GROUND ANCHORS IN COMMON STEEL

6 PROTECTION AGAINST CORROSION

6.1 *OVERVIEW*

6.1.1 PRINCIPLES

The steel of prestressed ground anchors and the ones with elastic limits greater than 500 MPa for all ground anchors (prestressed and passive) shall be protected against corrosion for their planned lifetime.

Note 1: the whole anchor system is addressed here: fixed part, free part and anchor head.

Note 2: only passive ground anchors in steel with an elastic limit lower than, or equal to, 500 MPa may remain unprotected (see paragraph 6.4)

Comment: the design and execution of the support system and of the control device (which are not part of the ground anchor) shall also be subject to anti-corrosion provisions, either with a lifetime protection equivalent to the one of ground anchors, or with appropriate measures (e.g., a maintenance programme).

Note 1: the protection system may be different from the one of the ground anchor, barring compatibility (in particular, and as a reminder, because of galvanic corrosion, i.e. a local difference of electric potential that may cause electrochemical corrosion).

Note 2: some provisions may have consequences on the anchor system design, for instance if the bearing plate and/or the control device are required to be accessible and/or removable, etc.

Picture 6.1: illustration of the effect of a protection defect at the anchor head level (©SMG)

6.1.2 LIFETIME AND DEGREE OF PROTECTION OF GROUND ANCHORS

The protection level against corrosion of the ground anchor notably depends on:

- the ground anchor lifetime (starting from its implementation), see comments 1 and 2;
- the aggressivity of the soils and ambiances in which it is executed, see comment 3;
- the requirements of the Developer.

Comment 1: if the ground anchor lifetime is likely to be unexpectedly extended, or if environmental conditions may modify the aggressivity of soils, appropriate periodic inspections and a monitoring of its behaviour during service shall be initiated to establish that the level of performance is satisfying.

Comment 2: as soon as the ground anchor lifetime exceeds 2 years, this ground anchor shall have a protection qualified as « permanent », even if this lifetime remains significantly lower than the one of the supported structure.

Comment 3: the aggressivity of soils is evaluated under standard NF EN 14490, and the aggressivity of atmospheres to which the anchor head is exposed is evaluated under standard NF EN ISO 12944-2 (a few extracts of the latter are provided in annex E).

The level of protection of the whole ground anchor is chosen as the most unfavourable one stemming from the following tables:

Note: in areas with hot and humid climate (for instance Martinique, Guadeloupe, Reunion, Polynesia) or specific sites with hot water discharges, and for lack of experience about the site corrosiveness or of specific studies, it is advised to select the P level in the case of prestressed ground anchors and/or in prestressing steel.

Aggressivity of soils			Lifetime	
Soil characteristics	**Class**	**Index**	**≤ 2 years**	**>2 years**
Highly corrosive	I	≥ 13	P	P
Corrosive	II	9 to 12	P	P
Moderately corrosive	III	5 to 8	T	P
Lowly corrosive	IV	1 to 4	T	P

Table 6.1: level of protection in function of soils (see tables E.4 and E.5 of annex E)

Aggressivity of atmospheres		Lifetime	
Classification	**Category**	**≤ 2 years**	**>2 years**
Very high corrosiveness	C5 I and M	P	P
High corrosiveness	C4	P	P
Moderate corrosiveness	C3	T	P
Low & very low corrosiveness	C1 and 2	T	P

Table 6.2: level of protection in function of atmospheres (see table E.6 of annex E)

6.2 *TYPE T GROUND ANCHORS*

6.2.1 TYPES OF USABLE PROTECTION

A protective barrier shall suppress or prevent corrosion for a duration of at least two years.

Note: all precautions are assumed as being taken to prevent any damage to this single barrier during the execution process.

Figures 6.1 and 6.2 display examples of solutions that comply with the requirements of standard NF EN 1537 (clause 6.3.2.1).

This barrier is chosen in function of the part of the anchor and support systems, as follows:

<table>
<tr><th></th><th>Free length</th><th>Fixed length</th><th>Coupler</th><th>Anchor head</th><th>Bearing system</th></tr>
<tr><td>Plastic sheath and tube</td><td>possible</td><td>NU</td><td>possible</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Heat-shrinkable sleeve and sheath</td><td>possible</td><td>Forbidden</td><td>possible</td></tr>
<tr><td>Metallic sheath and tube</td><td>possible</td><td>NU</td><td>possible</td></tr>
<tr><td>Wax and grease</td><td>possible</td><td>Forbidden</td><td>possible</td><td>possible</td><td>NU</td></tr>
<tr><td>Metallic lining [a]</td><td colspan="3" rowspan="3">Forbidden</td><td>possible</td><td>possible</td></tr>
<tr><td>Paint</td><td>possible</td><td>possible</td></tr>
<tr><td>Sacrificial thickness</td><td>Forbidden</td><td>Possible [b]</td></tr>
<tr><td>Coating solely by the bonding grout</td><td>possible</td><td>Usité
voir paragraphe 6.2.2</td><td>possible</td><td>NU</td><td>NU</td></tr>
<tr><td>Grout coating in a sleeve</td><td>NU</td><td>NU</td><td>NU</td><td>possible</td><td>NU</td></tr>
<tr><td>Concrete sealing</td><td colspan="3" rowspan="2">NA</td><td>NU</td><td>NU</td></tr>
<tr><td>Protection cap</td><td>In use
See paragraph 6.2.4</td><td>NA</td></tr>
<tr><td colspan="6">NA: does not exist and/or is impossible
NU: no use</td></tr>
<tr><td colspan="6">[a] galvanisation or metallisation
[b] see paragraph 6.4.3</td></tr>
</table>

Table 6.3: protection products and devices for type T prestressed ground anchors

If the ground anchor is only a passive one, the table of choices is the following:

<table>
<tr><th></th><th>Free length</th><th>Bonded length</th><th>Coupler</th><th>Anchor head</th><th>Bearing system</th></tr>
<tr><td>Plastic sheath and tube</td><td>possible</td><td>NU</td><td>NU</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Heat-shrinkable sleeve and sheath</td><td>possible</td><td>NU</td><td>NU</td></tr>
<tr><td>Metallic sheath and tube</td><td>possible</td><td>NU</td><td>NU</td></tr>
<tr><td>Wax and grease</td><td>Possible</td><td>Forbidden</td><td>NU</td><td>possible</td><td>NU</td></tr>
<tr><td>Metallic lining a</td><td colspan="3" rowspan="2">Forbidden</td><td>possible</td><td>possible</td></tr>
<tr><td>Paint</td><td>possible</td><td>possible</td></tr>
<tr><td>Sacrificial thickness</td><td>Possible [b,c]</td><td>Possible [b,c]</td><td>Possible [b,c]</td><td>Possible [b,c]</td><td>Possible [c]</td></tr>
<tr><td>Coating solely by the bonding grout</td><td>possible</td><td>In use
See paragraph 6.2.2</td><td>possible</td><td>NU</td><td>NU</td></tr>
<tr><td>Grout coating in a sleeve</td><td>NU</td><td>NU</td><td>NU</td><td>possible</td><td>NU</td></tr>
<tr><td>Concrete sealing</td><td colspan="3" rowspan="2">NA</td><td>NU</td><td>NU</td></tr>
<tr><td>Protection cap</td><td>possible</td><td>NA</td></tr>
<tr><td colspan="6">NA: does not exist and/or is impossible
NU: no use</td></tr>
<tr><td colspan="6">[a] galvanisation or metallisation
[b] only for steels with an elastic limit lower than, or equal to, 500 MPa (forbidden beyond this value), unless otherwise provided in an ATE or ETE
[c] see paragraph 6.4.3</td></tr>
</table>

Table 6.4: protection products and devices for type T passive ground anchors

If other types of protection are proposed, they shall comply with the requirements of standard NF EN 1537 (paragraph 6.1.1).

6.2.2 PROTECTION OF THE FIXED LENGTH

The distance between the tendon and the borehole wall shall not be lower than 10 mm at any point of the borehole.

The experience acquired regarding the weak opening of cracks impacting the bond, combined to the high pH prevailing in the immediate proximity of the tendon, allow assuming that a protection solely ensured by the bonding grout is sufficient under standard NF EN 1537, provided that the following execution provisions are satisfied:

- installation of the ground anchor tendon, equipped with centralizers, in a borehole filled beforehand (see paragraph 7.4.2) with cement grout over the bond height, so that the coating continuity is guaranteed, and
- bond injection under a pressure not lower than 1 MPa.

A quality control and a verification of the injected volumes during the injection of the protection shall be carried out.

Picture 6.2: Note the sheath of the free part of these ground anchors being assembled on-site (© Sefi Intrafor)

6.2.3 PROTECTION OF THE FREE PART

The protection system should possess low friction properties, and allow the free motion of the tendon within the borehole.

This may be obtained with one of the following systems:

a. A plastic sheath enveloping each tendon, sealed at its end against water entries;
b. A plastic sheath enveloping each tendon, fully filled with an anticorrosion protective product;
c. A plastic or steel sheath or tube shared by all tendons, sealed at its end against water entries;
d. A plastic or steel sheath or tube shared by all tendons, fully filled with an anticorrosion protective product.

b and c are appropriate in conditions of aggressive soils.

Picture 6.3: Anchor head with a type T protection (©Freyssinet)

Picture 6.4: trumpet tube (© Alexis Piron-EDF)

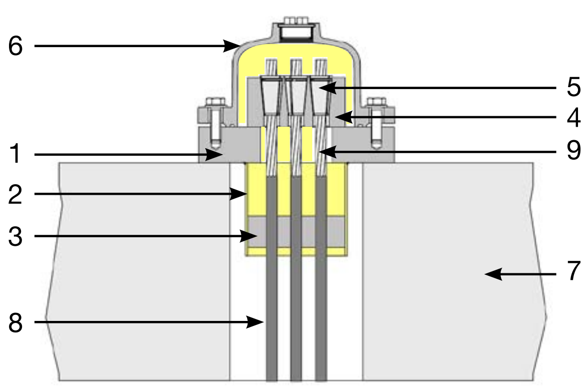


Figure 6.1: example of a type T protection for a strand ground anchor (example of a cast-in-place support)

Labels:

1. Bearing plate
2. Trumpet tube (seal-welded under the plate, filled with anti-corrosion product)
3. Optional barrier
4. Anchoring block (smooth or restressable)
5. Wedge
6. Protection cap (filled with anti-corrosion product and fixed on the bearing plate)
7. Support
8. Sheath of the free length
9. Bare strand

6.2.4 PROTECTION OF THE CONNECTION BETWEEN THE FREE PART AND THE ANCHOR HEAD

This interface is relative to the ground anchor part that corresponds to the thickness of the support system.

The purpose of the protection of the internal part of the anchor head is to overlap the protection of the free length in order to protect the short length of tendon located under the bearing device and going through the latter.

This protection is commonly obtained with a trumpet tube, which connection to the bearing plate remains sealed under the loads of the latter, with a 30 cm overlap of the free length protection, or with a mechanism that allows guaranteeing the protection of the tendon over its bare part.

Note 1: figures 6.1 and 6.2 display examples of a specific mechanism, where the trumpet tube is shorter than 30 cm

Note 2: the protection of the support system against corrosion does not fall within the scope of the present document.

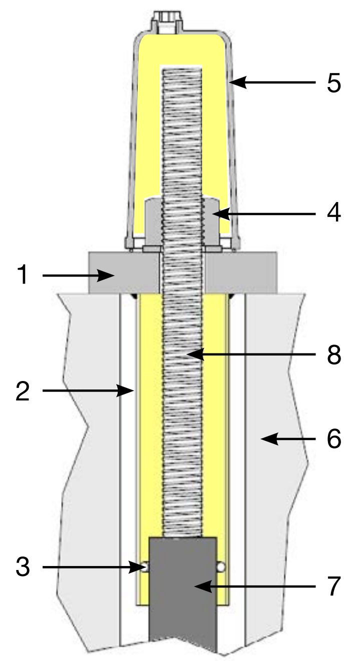


Figure 6.2: example of a type T protection for a bar ground anchor (example of a cast-in-place support)

Labels:

1. Bearing plate
2. Trumpet tube (seal-welded under the plate, filled with anti-corrosion product)
3. Optional barrier
4. Nut
5. Protection cap (filled with anti-corrosion product and fixed on the bearing plate)
6. Support
7. Sheath of the free length
8. Bare bar

6.2.5 PROTECTION OF THE ANCHOR HEAD

When the anchor head can be accessed for verifications, you should equip it with a waterproof cap (without any additional protection).
The following protections are also acceptable:

- a non-fluid anti-corrosion coating;
- combining an anti-corrosion product with a strip soaked with an anti-corrosion product.

Sealing is an alternative protection system that may be used in a few specific cases.

Note: sealing is incompatible with subsequent operations (lock-off test, change of measuring cells, re-stressing, etc.)

In the cases where the anchor head can no longer be accessed, the anchor head should be equipped with a metallic or plastic cap filled with an anti-corrosion product (see figures 6.1 and 6.2).

Note: as a reminder, for atmospheres of C4, C5 I or M corrosiveness, all temporary ground anchors are processed as being type P ground anchors (see table 6.2).

Proper waterproofing and a mechanical coupling shall be planned for between the cap and the bearing plate.

Picture 6.5: filling a trumpet tube with anti-corrosion product (wax)

6.3 *ADDITIONAL ELEMENTS FOR THE TYPE P PROTECTION*

The provisions outlined below are added, if needed, to the requirements stated for the type T in the previous paragraph.

6.3.1 TYPES OF USABLE PROTECTION

You should select two protection barriers against corrosion, to be chosen in the following tables: 6.5 or 6.6.

Comment: standard NF EN 1537 opens up the possibility of a single barrier, provided its integrity is proven for each ground anchor by an in-situ test (6.3.3.2). In the current state of knowledge regarding these tests, this solution has not been selected.

Figures 6.3 and 6.4 display examples of solutions that comply with the requirement of standard NF EN 1537 (see clause 6.3.3.1).

<table>
<tr><th></th><th>Free length</th><th>Bonded length</th><th>Coupler</th><th>Anchor head</th><th>Bearing system</th></tr>
<tr><td>Plastic sheath and tube</td><td>Possible</td><td>possible</td><td>possible</td><td colspan="2" rowspan="3">NA</td></tr>
<tr><td>Heat-shrinkable sleeve and sheath</td><td>Possible</td><td>Forbidden</td><td>possible</td></tr>
<tr><td>Metallic sheath and tube</td><td>Possible</td><td>possible</td><td>possible</td></tr>
<tr><td>Wax and grease</td><td>Possible</td><td>Forbidden</td><td>possible</td><td>possible</td><td>NU</td></tr>
<tr><td>Metallic lining a</td><td colspan="3" rowspan="3">Forbidden</td><td>possible</td><td>possible</td></tr>
<tr><td>Paint</td><td>possible</td><td>possible</td></tr>
<tr><td>Sacrificial thickness</td><td>Forbidden</td><td>Possible [b]</td></tr>
<tr><td>Coating solely by the bonding grout</td><td>Forbidden</td><td>Forbidden</td><td>Forbidden</td><td>NU</td><td>NU</td></tr>
<tr><td>Grout coating in a sleeve</td><td>possible</td><td>Mandatory</td><td>Mandatory</td><td>possible</td><td>NU</td></tr>
<tr><td>Concrete sealing</td><td colspan="3" rowspan="2">NA</td><td>possible</td><td>possible</td></tr>
<tr><td>Protection cap</td><td>possible</td><td>NA</td></tr>
<tr><td colspan="6">NA: does not exist and/or is impossible
NU: no use</td></tr>
<tr><td colspan="6">[a] galvanisation or metallisation
[b] see paragraph 6.4.3</td></tr>
</table>

Table 6.5: protection products and devices for type P prestressed ground anchors

If the ground anchor is only a passive one, the table of choices is the following:

	Free length	Bonded length	Coupler	Anchor head	Bearing system
Plastic sheath and tube	Possible	possible	possible	NA	
Heat-shrinkable sleeve and sheath	Possible	Forbidden	possible		
Metallic sheath and tube	Possible	possible	possible		
Wax and grease	Possible	Forbidden	possible	possible	NU
Metallic lining [a]	Forbidden			possible	possible
Paint				possible	possible
Sacrificial thickness	Forbidden [b]	Forbidden [b]	Forbidden [b]	Forbidden [b]	Possible [c]
Coating solely by the bonding grout	Forbidden	Forbidden	Forbidden	NU	NU
Grout coating in a sleeve	possible	Mandatory	Mandatory	possible	NU
Concrete sealing	NA			Forbidden [b]	possible
Protection cap				possible	NA
NA: does not exist and/or is impossible NU: no use					
[a] galvanisation or metallisation [b] allowed solely if the tension only occurs under accidental or seismic loadings [c] see paragraph 6.4.3					

Table 6.6: protection products and devices for type P passive ground anchors

If other types of protection are proposed, they shall comply with the requirements of standard NF EN 1537 (6.1.1).

6.3.2 PROTECTION OF THE FIXED LENGTH

The tendon shall be enclosed inside a tight ribbed sheath (see paragraph 4.3.1.3). A 5 mm coating shall be achieved by using a centralizer.

Note: besides its protective role, this sheath guarantees the transmission of forces between the tendon and the bond.

Cement grouts, when compliant with the requirements of EN 447, factory-injected or with a similar process within controlled conditions, are allowed at the condition that the two permanent anti-corrosion barriers guarantee a coating that is not lower than 5 mm between the tendon and the outer barrier.

The continuity of protection between the free part and the bonded part shall be fully guaranteed.

Note: the role of this protection is to counter any communication between the surrounding ground and the tendon through the bonding grout, due to fine cracks in the bond resulting from stressing.

Sleeves or valves possibly equipping the sheath for the purpose of executing the injection shall be conceived so that they restore the continuity of protection in its function of anti-corrosion barrier.

For ground anchors of the tube à manchettes type, the thickness of the metallic tube or of the corrugated plastic tube should not be lower than 3 mm, with a minimum tendon coating of 20 mm, obtained with a grout injected under a minimum pressure of 500 kPa.

6.3.3 PROTECTION OF THE FREE PART

The protection system, which shall allow the free motion of the tendon within the borehole, may be obtained with one of the following systems:

- A plastic sheath enclosing each element of the tendon, fully filled with a fluid anti-corrosion product, plus one of the provisions a, b, c or d below;
- A plastic sheath enclosing each element of the tendon, fully filled with a cement grout, plus one of the provisions a or b below;
- A plastic sheath shared by several elements of the tendon, fully filled with a cement grout, plus the provision b below.

a. A shared plastic tube or sheath, filled with a fluid anti-corrosion product;
b. A shared sheath or tube, sealed at their ends against water entries;
c. A shared plastic tube or sheath, filled with a cement grout;
d. A shared steel tube, filled with a dense cement grout.

To enable the free motion of the tendon during stressing, the sheaths, whether they are individual or shared, are not bonded to the tendon, or have a lubricated contact surface.

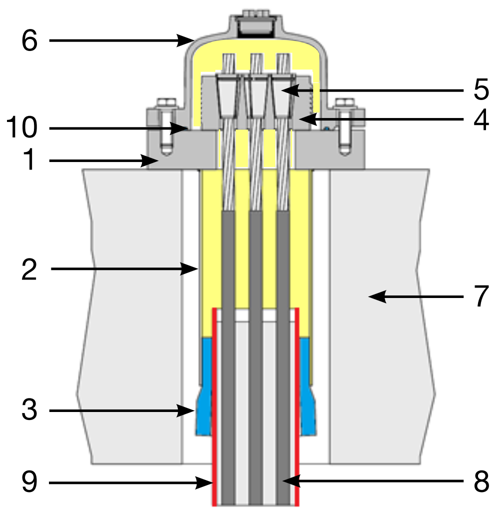
When a sheath is used, a smooth one is preferable.

6.3.4 PROTECTION OF THE CONNECTION BETWEEN THE FREE PART AND THE ANCHOR HEAD

There is no type P protection where the trumpet tube is shorter than 30cm.

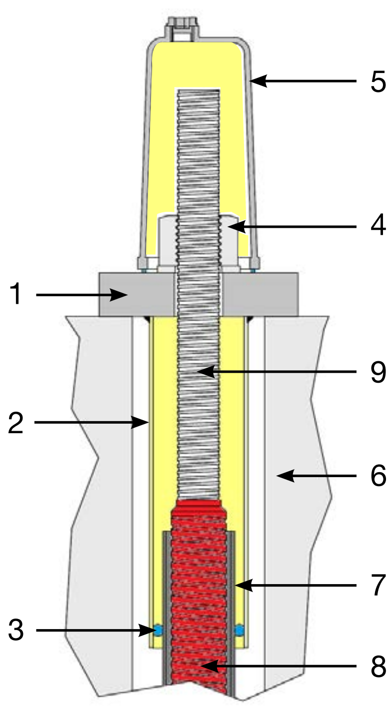
A sealing continuity should be maintained between the trumpet tube and the sealing sheath of the free part.

Note: the examples of figures 6.3 and 6.4 display a seal solution that ensures this sealing continuity.



Label:
1. Bearing plate
2. Trumpet tube (seal-welded under the plate, filled with anti-corrosion product)
3. Trumpet tube seal (tight)
4. Anchoring block (smooth or re-tensionable)
5. Wedge
6. Protection cap (filled with anti-corrosion product, fixed on the bearing plate)
7. Support
8. Free length sheath
9. Protective sheath of the tendon
10. Cap seal

Figure 6.3: example of a type P protection for a strand anchor (example of a cast-in-place support)



Label:
1. Bearing plate
2. Trumpet tube (seal-welded under the plate, filled with anti-corrosion product)
3. Trumpet tube seal (tight)
4. Nut
5. Protection cap (filled with anti-corrosion product, fixed on the bearing plate)
6. Support
7. Free length sheath
8. Protective sheath of the tendon
9. Bare bar

Figure 6.4: example of a type P protection for a bar anchor (example of a cast-in-place support)

6.3.5 PROTECTION OF THE ANCHOR HEAD

In all cases (whether the anchoring block may be accessed or not), the cap is mandatory (see figures 6.3 and 6.4).

The following should be done:
- the prior application of a protection;
- the anchor head equipped with a metallic cap (see note), or with a plastic one filled with an anti-corrosion product.

Note: the cap itself is justified in regard to corrosion.

If the cap contains a measuring cell, there should be an appropriate planning for the passing of the cable and for a cable-gland (to maintain tightness).

Picture 6.6: Anchor head with a type P protection (© Freyssinet)

Picture 6.7: Preparation of petroleum wax (anti-corrosion product) (© Alexis Piron-EDF)

6.4 CASE OF GROUND ANCHORS MADE OF COMMON STEELS

6.4.1 GENERAL POINTS

What is meant here by « common steels » are construction steels, steels for quenching and tempering (with an elastic limit lower than, or equal to, 500 MPa) and the reinforcing steels for reinforced concrete (see paragraph 5.1).

When intending to prestress ground anchors executed with such steels, protections of type T and P shall be used (see above).

For passive ground anchors:
- either the protections of types T or P are used,
- or the provisions defined below in regard to corrosion are applied.

Note 1: a protection of type T or P is here understood as being used for the whole anchor system.

Note 2: the anti-corrosion protection of the support system does not fall within the scope of the present document.

6.4.2 FIXED PART OF A PASSIVE GROUND ANCHOR

The experience acquired regarding the weak opening of cracks impacting the bond, combined to the high pH prevailing in the immediate proximity of the tendon, allow considering a protection solely ensured by the bonding grout as being sufficient under standard NF EN 1537, provided that the following execution provisions be satisfied:
- installation of the anchor tendon, equipped with preferably non-metallic centralizers, into a borehole filled beforehand (see paragraph 7.4.2) with a cement grout over the bond height, so that it guarantees the coating continuity, and
- injection of the bond under a pressure not lower than 1 MPa

A quality control and a verification of the injected volumes during the injection of the protection shall be carried out.

6.4.3 FREE PART OF THE PASSIVE GROUND ANCHOR

A reduction of the tendon cross-section should be taken into account, and calculated over the ground anchor lifetime.

Note: even though it is a misnomer, the cross-section reduction or the sacrificial thickness are sometimes considered as being « anti-corrosion protection measures »

This reduction may be determined from the following table, which provides the thickness loss (in mm) to be selected, by adopting the most unfavourable hypothesis between the class of soils and the category of atmospheres (see paragraph 6.1.2):

Aggressivity	Soils	Atmosphere	2 years	5 years	25 years	50 years	75 years	100 years
Very high	I	C5I and C5M	0.5	0.5	2.0	3.25	4.5	5.75
High	II	C4	0.2	0.2	1.0	1.75	2.5	3.25
Moderate	III	C3	0,.0	0.15	0.75	1.5	2.25	3.0
Low	IV	C1 and C2	0,.0	0.0	0.3	0.6	0.9	1.2

Table 6.7 : thickness loss (in mm) in function of aggressivity

In zones with a hot and humid climate (for instance, Martinique, Guadeloupe, French Guiana, Mayotte…) or specific zones with hot water discharges, and for a lack of an experience feedback about the site corrosiveness or of a specific study, the values indicated in this table should be doubled.

The thickness loss is also applied to couplers, when they exist.

In the absence of a justification of the configuration in regard to thickness losses, any coupler connection in the free part shall be tight, or made tight by adding a heat-shrinkable sleeve (or another similar element).

Note: the thickness loss is also applied to the thread itself, in the absence of tightness.

A lack of anti-corrosion protection for the free length does not exempt from ensuring the free motion of the tendon in the free part.

6.4.4 PROTECTION OF THE CONNECTION BETWEEN THE FREE PART AND THE ANCHOR HEAD

Two solutions are allowed: one consists in protecting this part (as for prestressed ground anchors, see paragraph 6.2.4), and the other one in taking into account the corrosion effect (see note).

Note: thickness losses similar to the ones on the free part may be taken into consideration (see paragraph 6.4.3)

Comment: you should adopt the same solution (protection or thickness loss) for this connection and for the head.

6.4.5 PROTECTION OF THE ANCHOR HEAD

When the anchor head is not embedded into a tight mechanism (reinforced concrete waling, or sealing) and without a protection such as the ones described for prestressed ground anchors, thickness losses similar to the ones on the free part shall be taken into account for the justification.

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7 EXECUTION

7 EXECUTION

All execution stages of ground anchors (see paragraph 5.2.1) shall be analysed within the framework of the Plan Particulier Sécurité et Protection de la Santé (Special health and safety protection plan*), or equivalent.

When the execution sequence of the operations is not achieved within a sufficiently short delay, an analysis shall be carried out, and can lead to additional provisions (for instance, carrying out a suitability test).

Note: assessing the delay is done in function of the soil nature, of which step fell behind schedule and of the provisions that were possibly applied to complete the execution (for instance, a re-drilling).

7.1 BOREHOLE

7.1.1 DRILLING METHOD

The drilling method shall be chosen in function of the ground conditions on the concerned site, with a view of minimising the negative effects caused by remoulded soils.
The purpose is to maintain optimum ground conditions, to guarantee anchoring performance, i.e.:

- avoiding a collapse of the borehole walls during the drilling execution and the tendon installation (if required, tubing will be used);
- restrict the decompression of surrounding grounds in non-cohesive soils;
- restrict the level variations of water tables;
- restrict the remoulding or alteration of the borehole walls in cohesive soils and loose rocks.

If the drilling method is modified during the execution process, it may be necessary to resume design. It is mandatory if this affects the bond.

7.1.2 DRILLING FLUID

The drilling fluid and the possible additives shall not have any adverse effects on the tendon, on the anti-corrosion protection, on the grout or on the borehole walls, in particular in the part of the fixed length.

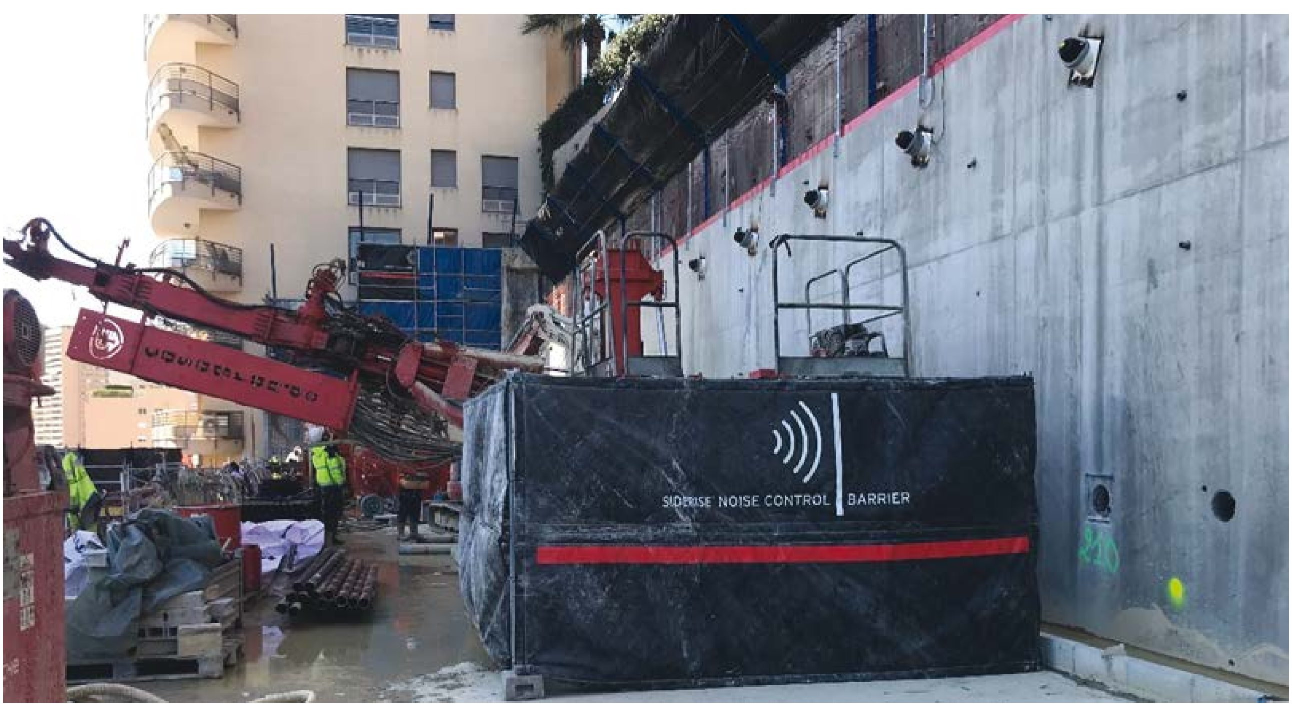
Comment: the environmental impact shall also be taken into consideration.

Note: the ratio between the entry section of the drilling fluid and the annular exit section of the fluid, and the particle size and unit weight of the borehole excavated materials, will condition the efficiency of the drilling system.

The choice of the drilling fluid may not be dissociated from the choice of the drilling tool.

Some fluids require precautions for given soils, e.g.:

- sands can loosen density, or be eroded when using compressed air;
- water-based drilling in cohesive soils can deposit a film on the walls, which will reduce the bond capacity of the ground anchor.



Picture 7.1: example of a mechanism used to reduce noise pollution during drilling (© Freyssinet)

Picture 7.2: drilling rig on a dam (©Cédric Helsy- Soletanche Bachy)

Picture 7.3: retromounted drilling rig (© Spie Fondations)

Picture 7.4: drilling rig installed on a barge (© Sefi Intrafor)

Picture 7.5: drilling rig in action (© Cédric Helsy- Soletanche Bachy)

7.1.3 ARTESIAN AQUIFERS AND WATER PRESSURE

You should take specific precautions when boreholes have to cross artesian aquifers or pressure flow areas.

The techniques allowing neutralising water pressure, preventing any resurgence and avoiding a borehole collapse or any erosion during drilling shall be defined beforehand and executed as such, including the installation procedures of the tendon into the borehole and of the execution of the bond with grout.

Note 1: clays, marls and marly rocks may swell or be damaged when subject to water flows over unnecessarily long periods of time.

Note 2: using compressed air may cause erosion in the borehole walls, through the action of unfavourable hydraulic gradients in the ground surrounding the borehole.

When meeting a high water table, it may be required to apply preventive measures, such as:

- using a dense drilling fluid;
- using specific drilling devices, such as water-locks, packers or extension tubes;
- lowering the water table level, after having assessed the risk of overall soil settlement and its consequences on adjacent grounds;
- uplifting the work platform;
- a prior ground injection.

Comment: it may prove pertinent to adapt the test programme to take these specific execution conditions into account.

7.1.4 NATURE OF SOILS

Drilling operations are carried out with a view of enabling the immediate detection of any notable variation of soil parameters, in relation to the hypotheses selected for ground anchor design.

An indicative log of the soils being crossed should be established, by using simple and practical identification data (for instance, soil class, colour of the return fluid or fluid loss) that can be easily recognised by the operator.

Note: in some soils, it is possible to introduce a geo-referenced video camera into the borehole to determine the nature of soils, discontinuities, etc.

Any significant discrepancy shall be immediately reported to the designer.

7.1.5 BOREHOLE DIAMETER

The borehole diameter shall be planned for to allow the specified coating thickness of the tendon to be applied over the whole anchor fixed length.

When the delay before implementing the ground anchor is long, the borehole may be reworked or widened.

Note: an increase of up to 20 % in soils does not require resuming the design process.

You should not increase the borehole diameter in rocks without a specific analysis.

7.1.6 BOREHOLE LENGTH

A borehole over-depth in regard to the specified length should be planned for when drilling cuttings may not be extracted from the borehole bottom.

Picture 7.6: borehole under water-lock (© Sefi Intrafor)

Picture 7.7: borehole with extension tubes (© Spie Fondations)

7.2 INSTALLATION OF THE TENDON OR OF ITS PROTECTIVE SHEATH

This article does not address processes where the tendon is constituted of the drilling tube or of drilling rods left in place.

The tendon, or its protective sheath, shall be installed directly into the sleeve grout.

Note: when the drilling fluid is unlikely to affect the bond quality (for instance, air-based or tubed drilling), the tendon, or its protective sheath, may be introduced before the sleeve grout.

All precautions shall be taken so that the various elements of the ground anchor remain undamaged during their installation (tendon, free part sheath, anti-corrosion protection barrier).

For ground anchors having tendons made of several bars connected to each other by couplers, the connections between the bars should not be a weak point. In particular, each bar shall be screwed over a length equivalent to half a coupler.

It is required that the tendon remains straight, particularly over the height of its free part.

Note: for vertical ground anchors, cables may be suspended, for instance.

Picture 7.8: manual installation of a ground anchor (© Sefi Intrafor)

Picture 7.10a: (right) unwinder to facilitate the ground anchor installation and (left) conditioning gantry and winder (© Freyssinet)

Picture 7.10b: ground anchor being unwinded into the borehole (© Freyssinet)

Picture 7.9: installation via helicopter (©Cédric Helsy- Soletanche Bachy)

7.3 *BONDING OF THE ANCHOR TO THE GROUND*

7.3.1 PRINCIPLE

Usually, the ground anchor bond is based on combining a borehole filling with a sleeve grout, with an injection under pressure over the fixed length.

Note 1: in some cases (e.g., in rocks), the injection under pressure is not systematically carried out.

Note 2: in the specific case of highly open soils, such as some slope screes, it is sometimes impossible to efficiently carry out such a filling. A pre-injection over the fixed length of the soil enclosing the borehole can be carried out, or alternatively, a system that allows containing the bonding product around the tendon may be adopted to guarantee the bonding.

These operations are described in the paragraphs below.

7.3.2 FILLING

The drilling fluid shall be substituted to the sleeve grout before introducing the tendon. The tendon shall be introduced immediately after implementing the sleeve grout.

In some cases (dry drilling, self-drilling ground anchor, etc.), the introduction of the tendon may be carried out before setting up the sleeve grout.

In all cases, the sleeve grout shall be introduced at borehole bottom, either via the drilling rods or through a tube with that purpose.

The recommended value of Water/Cement for the sleeve grout is 0.5 or less.
In the case where sleeve grout is replaced with mortar, the simple compression resistance of this mortar shall be at least equal to the one of a cement grout with a weight ratio W/C≤0.5. The company shall justify that this mortar is compatible with the chosen execution methodology.

7.3.3 INJECTION

7.3.3.1 GENERAL POINTS

Injection grouts are produced using cement, with or without admixtures.

The recommended W/C value for an injection grout is 0.5 or less. The injection method has a direct effect on the bond resistance.

Note: as a reminder, the injection may not be systematic (in rocks, for instance).

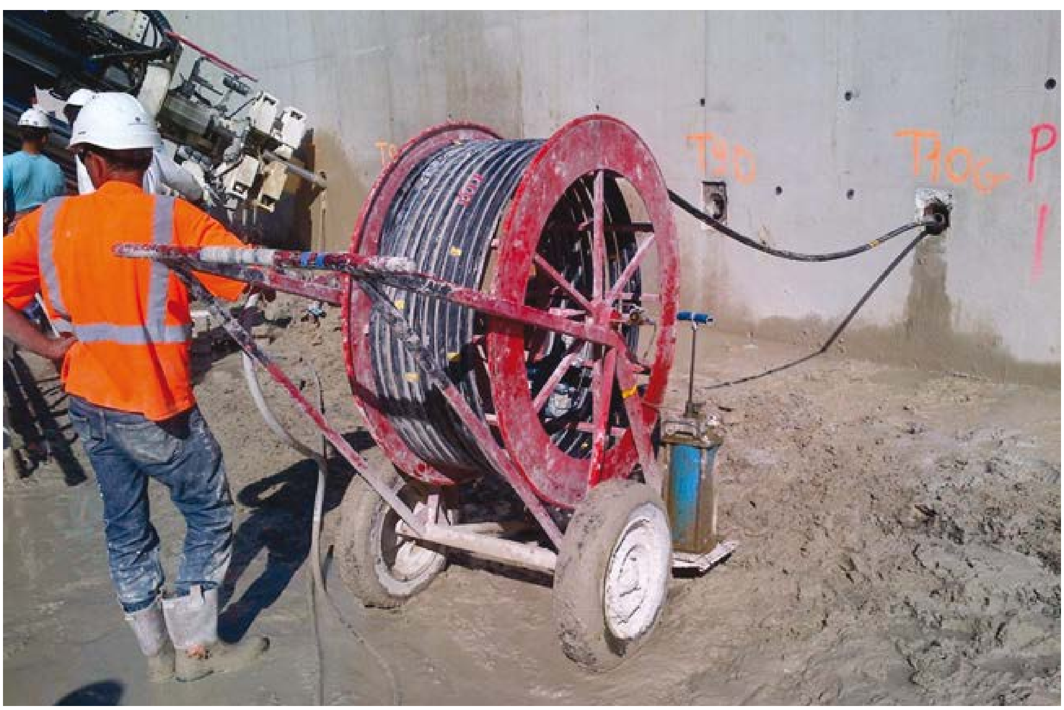
The execution mode of ground anchor bonds shall be the same than for failure test anchors.

The execution mode of bonds shall be stated in the work procedure handed to the Project Manager by the company.

Note: the two following paragraphs describe the commonly used injection modes.

Picture 7.11: grout manufacturing unit (© Sefi Intrafor)

Picture 7.12: set-up of the packer (© Spie Fondations)



Picture 7.13: IRS-type injection (©Freyssinet)

7.3.3.2 OVERALL AND ONE-PHASE INJECTION

The IGU (overall and one-phase injection*) is carried out:

- at a pressure lower than half the ground PLM limit pressure, without being lower than 1 MPa (see note);
- after the sleeve grout hardening and claquage (see figure 7.1);
- through orifices (manchettes of a recess tube, valves of a tube-tendon, recess tubes open at the base, etc.) of a number of at least 2 per metre over the fixed length;
- with a (simple) packer, or equivalent device, positioned at the upper part of the injection tube.

Note: an excess grout consumption that does not reach the indicated pressure may lead to split the operation into several stages, spaced apart over time.

Labels:
1. simple packer
2. sleeve tube
3. sleeve grout
4. manchettes
5. fixed part

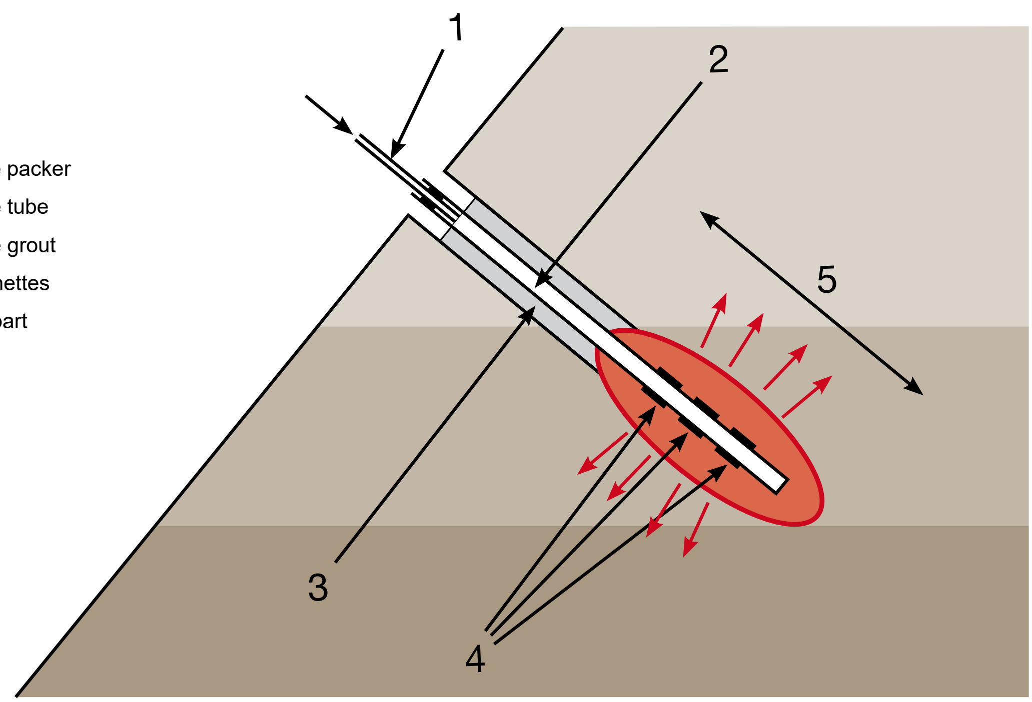


Figure 7.1: principle diagram of an IGU injection

7.3.3.3 SELECTIVE AND REPETITIVE INJECTION

The IRS (selective and repetitive injection*) is carried out:

- at a pressure higher than, or equal to, the ground PLM limit pressure, without exceeding 4 MPa;
- after the sleeve grout hardening and claquage;
- from a tube à manchettes or similar device (for instance, a tube-tendon with valves), with 2 to 3 manchettes per metre over the fixed length (see figure 7.2);
- with a double packer (or equivalent apparatus), by successive passes and repeated steps.

Note: an excess grout consumption that does not reach the indicated pressure may lead to split the operation into several stages, spaced apart over time.

Labels:

1. double packer
2. tube à manchettes
3. sleeve grout
4. manchettes
5. fixed part

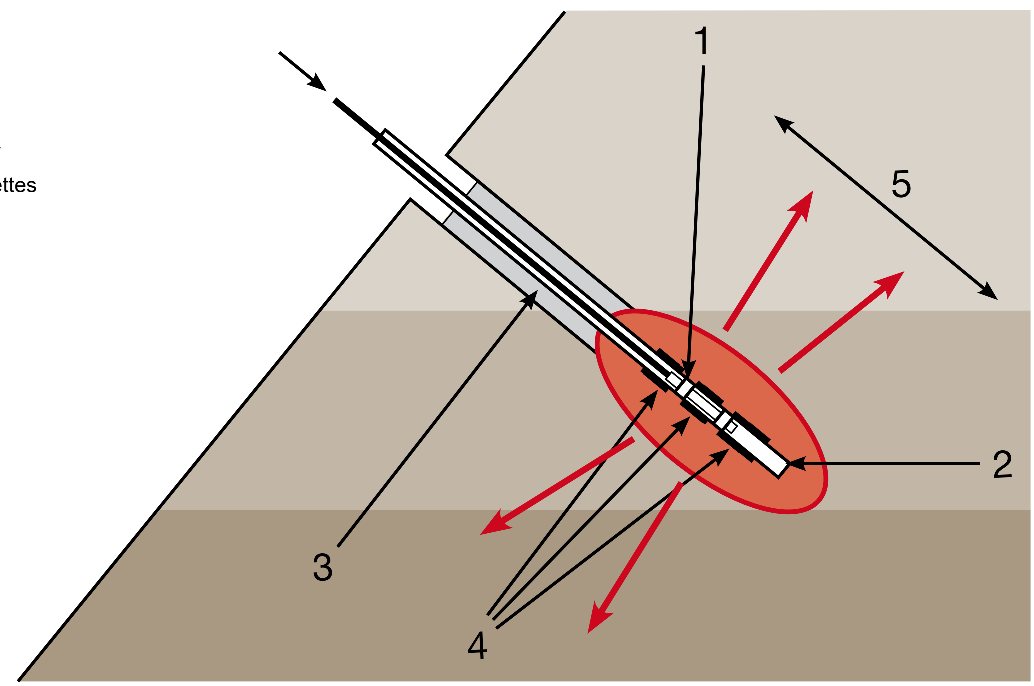


Figure 7.2: principle diagram of an IRS injection

7.4 GROUND ANCHOR IMPLEMENTATION

WARNING

Because it implies stressing the tendon, implementation is a dangerous operation.

At the very least, the following safety requirements shall be satisfied:
- forbidding access to the ground anchor proximity to anyone not concerned by the operation,
- entrusting the operation to skilled and trained personnel,
- using equipment in good condition,
- verifying that the anchor heads do not show any apparent defect.

7.4.1 INTRODUCTION

The ground anchor implementation aims at:
- subjecting the bond to a proof load (acceptance test) in order to validate its correct resistance, whether the ground anchor is prestressed or not,
- stressing the ground anchor at the desired prestressing load,
- ensuring the ground anchor sustainability by implementing the anti-corrosion protection of the anchor head.

The various implementation steps are:
- collecting the preliminary information (see paragraph 7.4.2) and issues to be anticipated (including the choice of equipment) (see paragraph 7.4.3),
- defining the procedure (see paragraph 7.4.4) and the operation preparation (see paragraph 7.4.5),
- carrying out the acceptance test (see paragraph 7.4.6) which leads to the acceptance (see paragraph 7.4.7),
- locking off the ground anchor (see paragraph 7.4.8) and implementing the anti-corrosion protection (see paragraph 7.4.10), which concludes implementation.

Picture 7.14: ground anchor stressing (© Sefi Intrafor)

7.4.2 PRELIMINARY INFORMATION

Prior to implementation, it is mandatory to obtain the following information:

- ground anchor lifetime: is it a temporary or permanent one (see section 5)? Does it have a type T or P protection (see section 6)?
- tendon characteristics (on the basis of material certificates, see paragraph 4.1),
    - steel grade (Yield load, ultimate load, modulus of elasticity),
    - number of strands, or type of tendon,
    - diameter and/or cross-section,
- bond length of the tendon L_S ,
- free length of the tendon L_L ,
- extra length L_e ,
- ground anchor inclination (angle within the vertical plane), and orientation, or azimuth (angle within the horizontal plane),
- bonding date, i.e., the injection end date,
- service load F_k ,
- tension after lock-off P_0 ,
- ground anchor identification,
- ground anchor location,
- stressing schedule (if needed),
- soil parameters:
    - soil nature,
    - plasticity index of the soil (Ip) for cohesive soils.

Comment: other information may prove useful, such as: soil aggressivity, specificities of the structure hosting the ground anchor, characteristics of the workstation (available space, access, structure resistance, etc.), presence of a control device, etc.

7.4.3 ISSUES TO BE ANTICIPATED

Annex I details the provisions required to carry out ground anchor tests in general, and, subsequently, stressing.

The provisions utilised during stressing cannot allow assessing the tension truly applied to the ground anchor tendon, nor its true elongation. One is therefore limited to measure a « global » tension, and to measure displacements which ipso facto result from several phenomenons.

7.4.3.1 GLOBAL TENSION AND TRUE TENSION

What is called « global tension » is the product of the effective cross-section of the jack by the filling fluid pressure, after a correction is made by calibrating the jack and pressure gauge.
The true tension in the tendon usually differs from the global tension, due to friction occurring in the anchor head and over the free length, which effect is labelled as « losses » (see paragraph 5.2.2.2).

7.4.3.2 MEASURE OF THE ELONGATION

The extent to which the tendon lengthens during stressing shall be assessed from the relative displacement of two markers (see annex I):

- one fixed to the tendon, with the second being a fixed point,
- or by default, the first one fixed to the mobile part of the jack, and the second one bound to the structure to be anchored.

Picture 7.15: Measuring elongation with a comparator (© Alexis Piron-EDF)

Comment 1: The displacement thus measured integrates various phenomenons, of different natures, and in particular:

- the set-up and adjustment of slacks and looseness (which only makes sense with a stressing process),
- the possible displacement of the bond,
- the possible displacement of the measuring marker (settlement of the anchorage part, deformation of the anchored structure under the effect of the applied forces, etc.).

Applying a tension of first reading $P_a(t_0)$, equal to about 10% of the proof load, may minimise the impact of such phenomenons on the measure.

Comment 2: It is not desirable to carry out measures in reference to a marker set on the mobile part of the jack. In the case of a measure of displacements with a fixed marker, it remains however pertinent to measure the displacements of the mobile part of the jack in order to obtain the ones of the structures to be anchored.

7.4.3.3 SHOWING THE RESULTS

The whole set of results obtained during stressing is represented with a diagram (see figure 7.4) by plotting:

- in the y-axis the global tension, as defined above (see paragraph 7.5.3.1), with the y-axis being graduated in pressure (read with a pressure gauge, in MPa) or in global tension (in kN),
- in the x-axis the displacement of the marker set on the tendon (see paragraph 7.4.3.2 – case with a fixed marker), or by default the discrepancy between the displacement of the marker set on the anchored structure and the one set on the mobile part of the jack (case without a fixed marker).

Comment: since the initial stage of the stressing operations corresponds to the installation of the ground anchor and its stressing equipment (partial or total adjustment of slacks and looseness), the diagram origin cannot be represented.

It is mandatory that the stressing diagram is plotted directly, without any correction of any nature, from the stressing and pressure values that were read.

7.4.4 PROCEDURE

7.4.4.1 SCHEDULING OF THE ACCEPTANCE TEST AND IMPLEMENTATION

The contents are detailed in paragraphs 7.4.4.2 et seq. The following main stages (represented on figure 7.3) can be identified:

a. installation (partial or total adjustment of slacks and looseness),
b. load build-up (see paragraphs 7.4.4.2 to 7.4.4.6 and 7.4.6.2),
c. proof load (see paragraphs 7.4.4.2, 7.4.4.6 and 7.4.6.3): end of the acceptance test,
d. cyclic loading, which may not concern all ground anchors (see note and paragraph 7.4.4.7),
e. lock-off (see paragraphs 7.4.4.8 and 7.4.8).

Note: cycles are required on the first 3 ground anchors of each series.

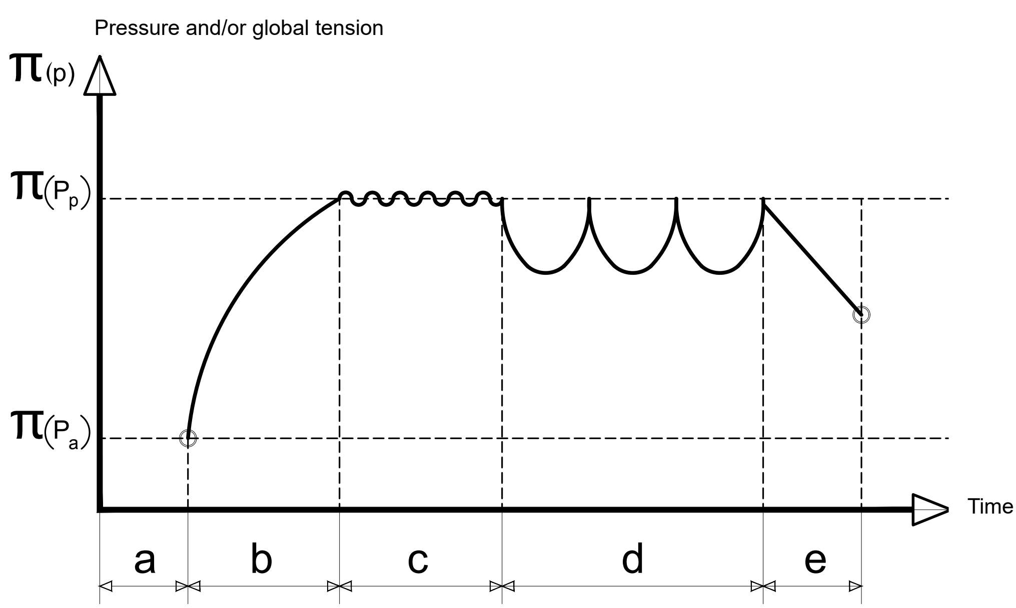


Figure 7.3: scheduling of an acceptance test and implementation of a ground anchor

Picture 7.16: Installation of the stressing jack on a strand ground anchor
(© Freyssinet)

7.4.4.2 LIMITATION OF THE PROOF LOAD

The proof load P_p is selected as being the lowest of the following:

- value obtained from the service load F_k (see paragraph 7.4.4.2.1),
- limit value relative to the tendon (see paragraph 7.4.4.2.2),
- possibly, a value relative to the structure (see paragraph 7.4.4.2.3 and annex I.4).

7.4.4.2.1 VALUE OBTAINED FROM THE SERVICE LOAD

In a general case, the proof load is equal to $\gamma_{a;rec;ELS}$ multiplied by service load:

$$P_p = \gamma_{a;rec;ELS} . F_k$$

For a temporary ground anchor: $\gamma_{a;rec;ELS} = 1{,}15$
For a permanent ground anchor: $\gamma_{a;rec;ELS} = 1{,}25$

In the specific case of a temporary ground anchor where P_b is greater than 1.15 . F_k (see note 1), one of the three following solutions below shall be chosen:

- a different equipment is selected, allowing a reduction of P_b (using a jack with a hydraulic seating device to reduce the anchor slipage at the utmost);
- a verification is carried out, allowing to ensure that $P_b < 0{,}8 . R_d$ (see notes 2 and 3);
- design is resumed with lower values of F_k and/or P_i (see note 4).

Note 1 : this case may occur, e.g., when P_i is close to F_k, or when the tendon has a low tension or a very short free length.

Note 2 : this option should be particularly taken into consideration when failure tests have demonstrated the existence of a margin in relation to theoretical design.

Note 3: 0.8 is the rounded value of 1.15 . 2/3 (this result being equivalent to the one of TA 95).

Note 4: this compels resuming a full structure design.

Specifically for permanent ground anchors, systematically testing all ground anchors with values greater than 1.25 . F_k does not provide any additional safety level, and may be detrimental to all bonds. This is the reason why it is formally unadvised to subject ground anchors to a proof load greater than 1.25 . F_k

7.4.4.2.2 VALUE TIED TO THE TENDON

In any case and for all types of ground anchors, the proof load P_p shall not be greater than the limit conventional resistance of steel R_{max} (see 5.3.2.6 and annex I.3).

Comment: usually, this limit relative to the tendon is covered by the design stages of the ground anchor.

7.4.4.2.3 VALUE TIED TO THE STRUCTURE

It is reminded that the structure has to be designed so that deformations and forces induced within it by the proof load values remain acceptable (see annex I.4).

However, there are certain cases, described below, where adaptations may be required. These cases correspond to:

- a limitation due to loading and/or
- a limitation due to the structure stiffness.

It would then be possible that the ground anchor may not be tested with the recommended values.

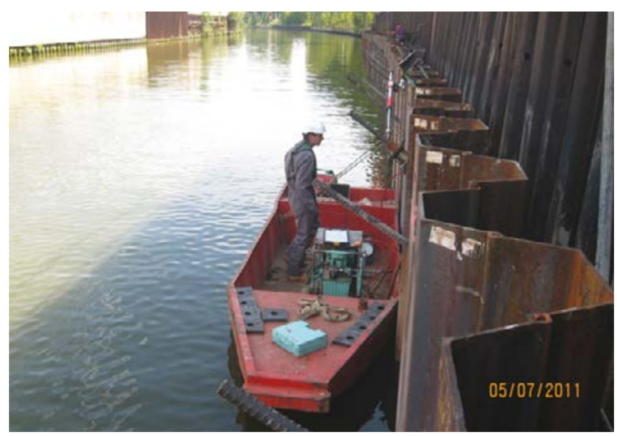
In these cases of limitation, if the chosen solution is to test the ground anchors at a value lower than $\gamma_{a;rec;ELS} . F_k$, i.e., than the usual proof load, it is required to:

- having carried out failure tests in a number greater than the one indicated in paragraph 8.3.1 (see comment), and/or
- resorting to an additional instrumentation, with control devices (see comment) that allow guaranteeing the proper functioning of ground anchors not tested at P_p.

Comment: the number of additional tests and equipment shall be specified in advance.

<u>Deformation of the structure under the loads due to ground anchor stressing</u>
In the case where applying the proof load originating from the usual provisions to ground anchors may produce forces within the structure that would be incompatible with its performance, a lower proof load should be selected and/or the number of ground anchors should be revised (a greater number of ground anchors of lesser capacities).

This case may be met, e.g., for sheet piles walls.



Picture 7.17: Example of ground anchor stressing on a sheet piles wall

<u>Case where ground anchor stressing may impact the structure integrity and/or internal stability.</u>
This case is limited to the reinforcing of existing structures, e.g., a masonry structure.

In the case of the proof load originating from the usual provisions to ground anchors may produce strengths within the structure that would be incompatible with its resistance, a lower proof load should be selected and/or the number of ground anchors should be revised (a greater number of ground anchors of lesser capacities).

7.4.4.3 DETERMINING THE STRESSING PRESSURES

The specifications of this chapter are founded on the observation that loads are usually assessed from pressure values obtained from the jack used for stressing, and not by a direct measure.

Note: the necessary adaptations should be carried out in the case where a direct measuring of loads is carried out.

Prior to any stressing, the following should be selected:

- the pressure corresponding to the first reading, subsequently called $\Pi(P_a)$,
- the pressures of the intermediate steps between $\Pi(P_a)$ and the proof pressure $\Pi(P_p)$,
- the value $\Pi(P)$, determined by taking into account the losses calculated a priori from the parameters of the jack and pressure gauges being used.

Comment: The pressure read on the pressure gauge, $\Pi(P)$, is the value resulting from the correction by the calibration of the jack (force/pressure relation) and of the pressure gauge.
If ψ is the value of the calculated or estimated friction corresponding to a given pressure $\Pi(P)$ being read on the pressure gauge, this pressure for a jack with a cross-section S is obtained from the following relation:

$$\Pi(P) = (P+\psi)/S$$

Note: ψ usually depends on the pressure applied to the jack, but may in some rarer cases be constant.

The goal is to reach true tensions (see paragraph 7.4.3.1) in the tendon at the bonding level (P_p or a fraction of P_p such as the tension of first reading P_a).

In general, for a same category of ground anchors bonded into a soil of identical parameters, determining the true friction (in the jack, the anchor head and the free length) is carried out on the first ground anchors of the series (see note).

Note: A flat value of 6% of losses is considered for the first three ground anchor of a same category during their stressing, unless there is a pertinent experience feedback.

The value of global tension (i.e., the value that corresponds to the true proof load P_p) is consequently corrected (see note and comment 1) for the following ground anchors, without however exceeding the limits recalled in paragraph 7.4.4.2 (comment 2).

Note: the losses considered to calculate pressures ($\Pi(P_p)$) are the average losses determined on the first three ground anchors (see paragraph 7.4.4.7).

Comment 1: if the losses determined on the first three ground anchors are significantly different from each other (a discrepancy of losses of more than 2%), losses should be measured on the next three ground anchors. If the discrepancies persist, it may prove required to determine losses for each ground anchor and to take them into account when calculating the lock-off and proof pressures of each ground anchor.

Comment 2: to verify that the applied load does not exceed the tendon limit resistance R_{max} (see paragraph 5.3.2.6), the tension applied on the tendon will be assessed as follows:

$$P+\psi-\psi_{vér}$$

This verification is mandatory if losses are high.

$\Pi(P_a)$ and intermediate pressures $\Pi(P)$ are subsequently re-adjusted by reference to $\Pi(P_p)$.

7.4.4.4 PROOF STAGE

The pressure for the proof stage is set to:

$$\Pi(P_p) = (P_p + \psi)/S$$

The displacement of the marker fixed to the tendon is measured over the duration of the proof stage, and then plotted on the stressing diagram (segment $M_pM'_p$ on figure 7.7).

7.4.4.5 FIRST READING

The pressure $\Pi(P_a)$ corresponding to the first reading is conventionally set at a value close to a tenth of the proof pressure, without corresponding to a force lower than 50 kN:

$$\Pi(P_a) = \mathrm{MAX}\{\Pi(50\ \mathrm{kN})\ ;\ \Pi(P_p)/10\}$$

Comment: examples of values to be considered for $\Pi(P_a)$ are mentioned in the comments of paragraph 7.4.4.6 below. The pressure $\Pi(P_a)$ shall be chosen cleverly. It shall not be too low (so that most of the slacks and looseness may be adjusted) nor too high (so that enough intermediate values may be produced).

7.4.4.6 DETERMINING INTERMEDIATE READINGS

There shall be at least four intermediate readings between $\Pi(P_a)$ and $\Pi(P_p)$ (see figure 7.4 below). They are distributed around the values of the following table:

	Starting point	Intermediate points				Proof stage
		1	2	3	4	
Tension value	P_a	30% P_p	50% P_p	70% P_p	90% P_p	P_p
Duration of observation	0	Time required for the measures				≥ 15 min

Table 7.1: parameters of the acceptance test stages

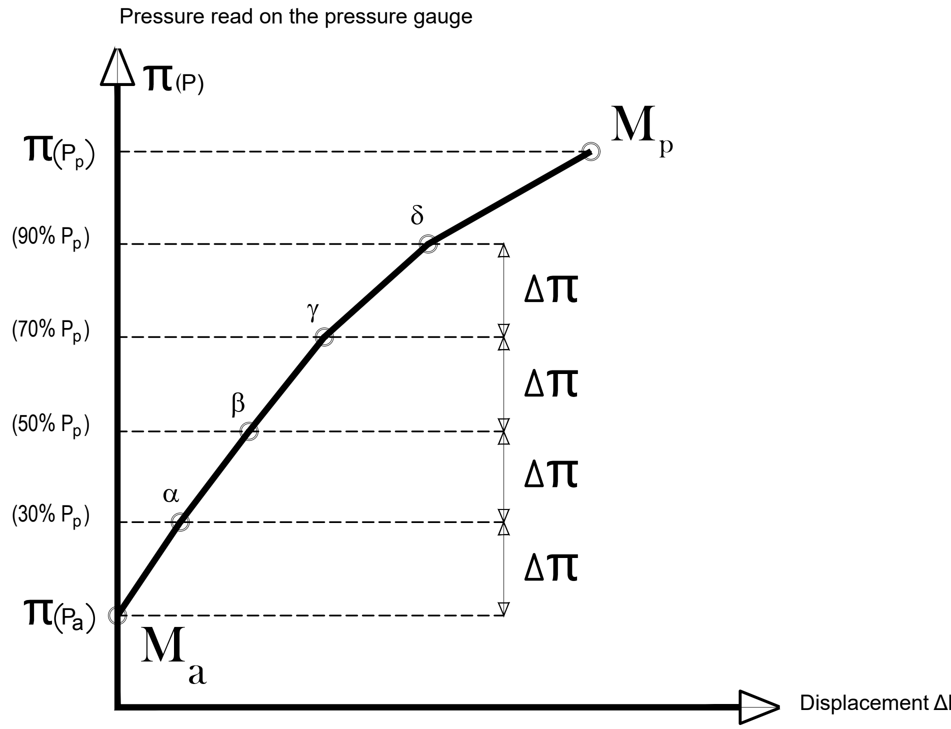


Figure 7.4: theoretical stages of an acceptance test

Comment: to facilitate readings and minimise delivery errors, the pressure $\Pi(P_a)$ and the intermediate pressures should, whenever practicable, correspond to the main graduations of the pressure gauge.

To assist in the process of companies, the table below indicates, in function of the chosen proof pressure $\Pi(P_p)$, the values of $\Pi(P_a)$ and of the intermediate pressures.

7.4.4.7 VERIFYING LOSSES DURING STRESSING

A verification of losses is mandatory on the first 3 ground anchors of a series.

It is achieved by carrying out a loading cycle after the proof stage (see figure 7.5).

Proof pressure $\Pi(P_p)$	First reading pressure $\Pi(P_a)$	Intermediate pressures $\Pi(P)$
17	2	5 ; 8 ; 11 ; 14
27	3	9 ; 14 ; 19 ; 24
54	6	17 ; 28 ; 39 ; 50

Table 7.2: examples of intermediate pressures (in MPa) for an acceptance test

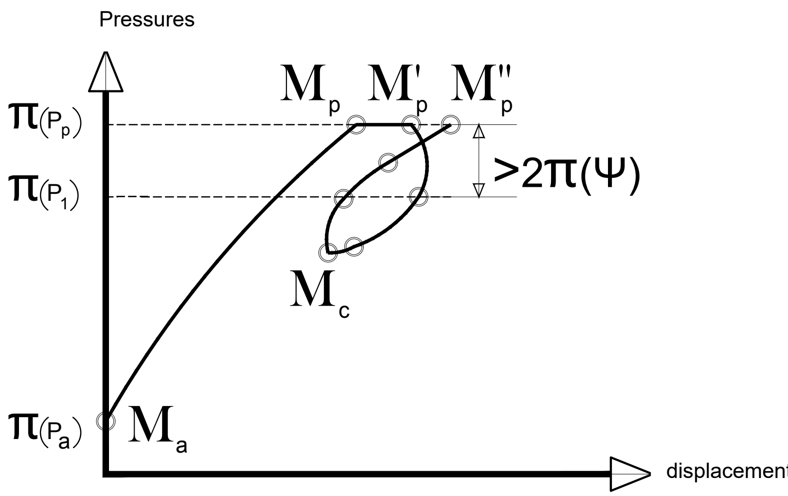


Figure 7.5: loading cycle after the proof stage of an acceptance test

The minimum provisions described below for the ground anchor acceptance test may be supplemented by specific provisions that may possibly allow:

- verifying the position of the point M_p,
- verifying the value of the losses taken into account within calculations.

Then, one or several cycles of unloading-loading in tension are carried out.

The first unloading point of the cycle is chosen so the discrepancy between Π (P_p) and Π (P_1) is at least equal to 2 Π (ψ). Usually, a point at 90% of Π (P_p) is appropriate. In some cases, a value lower than 90% may prove necessary.

The next points of the cycle are:
80% Π (P_p) - 70% Π (P_p) - 80% Π (P_p) - 90% Π (P_p) – Π (P_p).

Note: it is possible to select additional points.

An alternative to this full cycle is allowed, and consists in having a sufficient number of points during the unloading (over at least 2 $\Pi(\psi)$) below the value corresponding to the lock-off load P_b, with a loading toward lock-off (without necessarily reaching Π (P_p)).

Note: this method is less accurate for researching the true value of ψ.

If the cycle is achieved with a sufficient accuracy, an intermediate point X' may also be determined (see figure 7.6) in the middle of XM'_p, which represents the true tension under the pressure Π (P_p), with the segment $X'M'_p$ being equal to the true value of friction at the anchor head level, and above it.

This cycle may be carried out on each of the ground anchors in order to systematically verify losses and to detect possible defects during stressing.

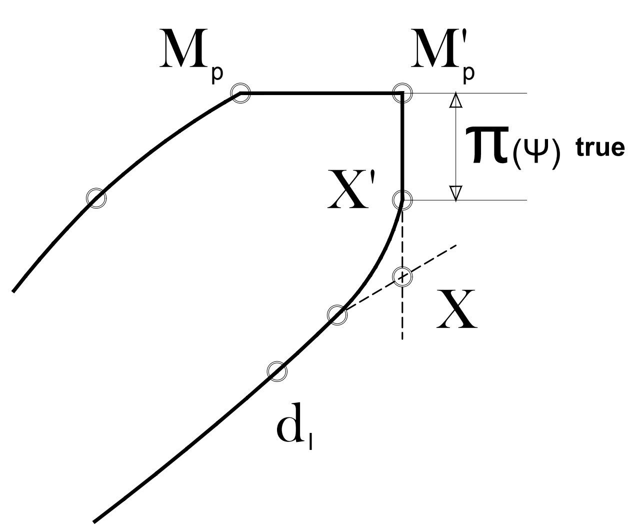


Figure 7.6: detail of the loading cycle

7.4.4.8 LOCK-OFF STAGE

The tension of lock-off start P_b is equal to the initial design tension P_i, plus the losses due to the ground anchor lock-off (see paragraph 5.2.2.3).

These losses are determined from the anchor entries (values r, usually expressed in mm) provided by the manufacturer of the stressing equipment. They shall be translated into loads by considering the free length L_L of the ground anchor. They will be labelled as ψ_t.
Stressing losses should be taken into account (see paragraph 5.2.2.2), corresponding to the value of P_b, written ψ_b, as stated below.

Lock-off during destressing
If ground anchor lock-off occurs during tendon destressing (for instance after the proof stage was carried out), the losses during stressing shall be deduced from the theoretical pressure. The pressure is then expressed by:

$$\Pi(P_b) = (P_i + \psi_t - \psi_b)/S$$

Lock-off during stressing
If ground anchor lock-off occurs during tendon stressing (for instance after a cycle was carried out), the losses during stressing shall be added to the theoretical pressure. The pressure is then expressed by:

$$\Pi(P_b) = (P_i + \psi_t + \psi_b)/S$$

7.4.4.9 PARTICULAR CASES

7.4.4.9.1 MULTI-STEP STRESSING

A specific scheduling, for instance due to the behaviour of the structure or of the retaining wall, can initially require a partial stressing of the ground anchor, with a final stressing afterwards.

For the case of cable anchors, the marks of the wedges in their final position should not « re-bite » the mark of the first stage (see figure 8.13). For this matter, one may consider modifying the partial tension (with the approval of the design office), or adapting a temporary clamping system, etc.

Provided the structure allows it, applying the proof load during the partial stressing will be favoured.

7.4.4.9.2 GROUND ANCHORS WITH GREAT FREE LENGTHS

In the case of great free lengths, it may prove impossible to find a jack having a stroke compatible with the tendon elongation and the foreseen displacements of the structure (see annex I.5.2).

An intermediate anchor lock-off shall then be planned for, with a stroke resumption of the jack that avoids the « re-biting » of wedge marks in the case of cable anchors (see figure 8.13).

7.4.4.9.3 LOW PRESTRESSING VALUE

The prestressing load should be sufficient (20% of the tendon elastic limit being a minimum value) to maintain the anchor head on the bearing plate.

In the opposite case, it is required to anticipate a mechanical system to maintain the anchor head (lock-nut for bars, wedge keeper plate for cables, etc.).

7.4.5 OPERATION PREPARATION

7.4.5.1 STRESSING SHEET

The stressing sheet shall be prepared by integrating all the parameters defined in the procedure:

- ground anchor characteristics (tendon, geometry),
- dates of bonding,
- date of stressing,
- pressures/displacement charts,
- plotting of the two lines corresponding to the increase in length (L_L+L_e) and to the increase in length (L_L+L_e+L_s/2), called elongation zone,
- tensions P_i, F_k,
- calculated pressures (intermediate points, proof, lock-off),
- operator's name.

7.4.5.2 VERIFYING THE SUPPORT SURFACE

The support surface may be of different types and include several elements: bearing plate, shim, load-transfer block, waling, etc.

One should verify that the whole system enables the proper installation of the anchor system, notably in relation to aligning and centring issues.

Comment: for instance, one shall verify that there is no risk of tendon shear, notably due to the support sliding or to parasitic friction.

If needed, the verification shall take into account the installation of a control device.

7.4.5.2 INSTALLATION

During the installation of the bearing plate, attention should be paid to the overlapping between the sheath(s) of the free length and the trumpet tube, so that the continuity of the anti-corrosion protection of type P or T is ensured (see section 6).

7.4.6 ACCEPTANCE TEST

7.4.6.1 GENERAL PROVISIONS

This operation shall be carried out by specialised and experienced personnel, under the monitoring of a qualified supervisor, coming preferably from a company specialised in the field of ground anchors, or from a manufacturer of stressing equipment.

Note: it is reminded that it is mandatory that the stressing diagram be directly plotted from the measured values, without any correction of any nature and without interpretation.

Besides, it is emphasised that the greatest care shall be taken to avoid any injury accident that could be caused by a possible premature failure of the ground anchor.

SOLETANCHE BACHY

CHANTIER BLANC MESNIL - LA MOREE

Date de mise en tension 18/03/2009

Tirant N° T06

Numéro 3883

Opérateur : ....

Pour tirants N° : 0

Tension d'essai..........: 68 Tonnes

Tension de service.....: 54 Tonnes

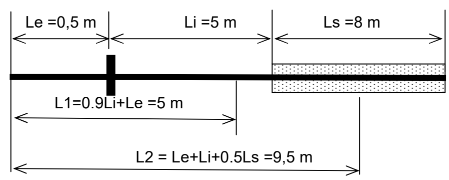
Tension initiale..........: 50 Tonnes

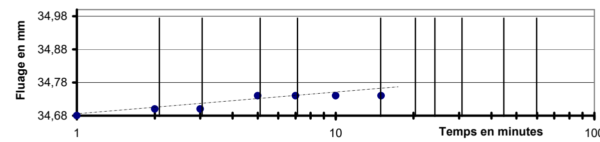
Armature
4 T15,7

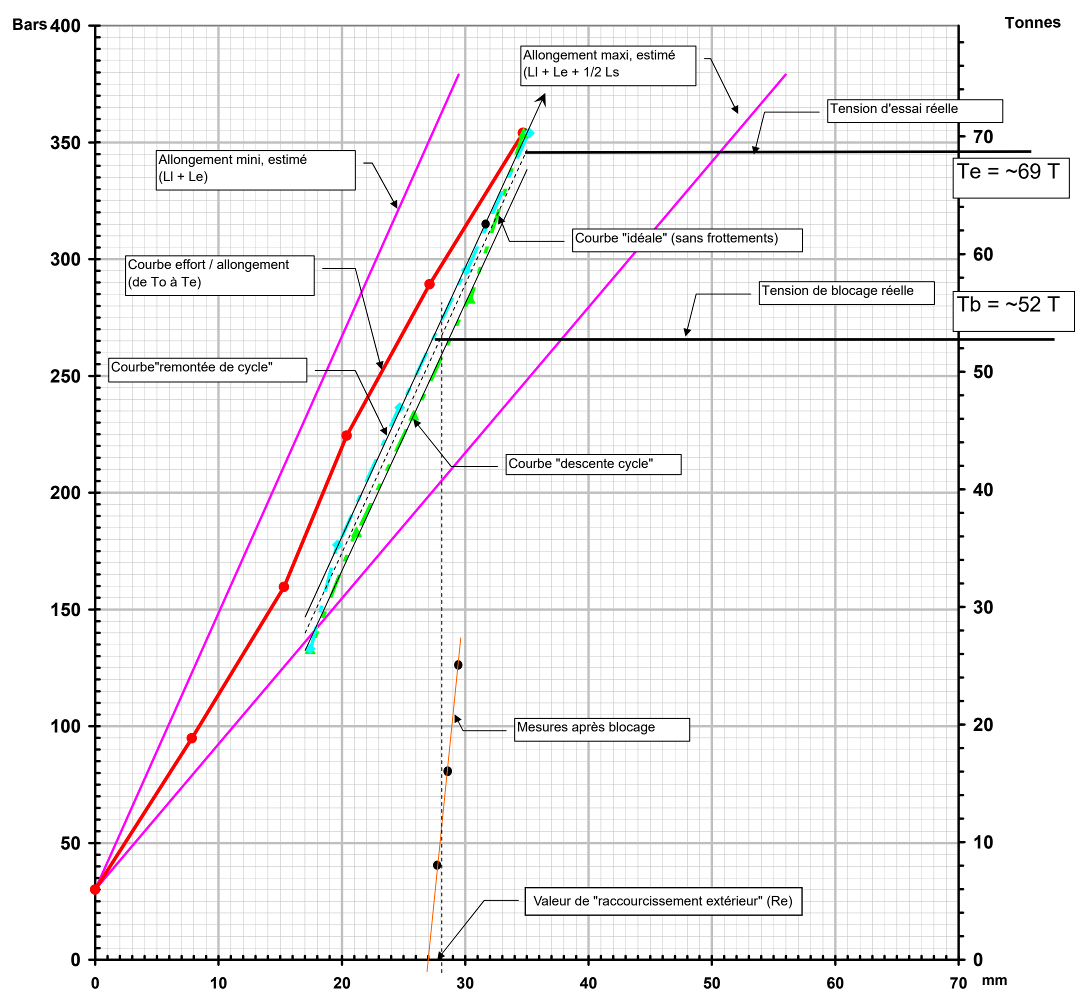
Vérin type : TENSA M4 **Section:** 194,78 cm² **Fluage maximum:** d(15' - 3') = 1,5 mm **Blocage**

						1'	3'	15'														
Pression	30	95	160	224	289	354	354	354	283	233	183	133	178	236	295	354	0	mors	30	315	125	80	40
Lecture	0,00	7,84	15,31	20,40	27,12	34,68	34,70	34,74	30,39	25,83	21,18	17,43	19,64	24,68	30,08	35,20		en		154,00	150,00	148,00	146,00
Allongement	0,00	7,84	15,31	20,40	27,12	34,68	34,70	34,74	30,39	25,83	21,18	17,43	19,64	24,68	30,08	35,20		place		0,00	-4,00	-6,00	-8,00

Temps	1	2	3	5	7	10	15	20	25	30	45	60
Fluage	34,68	34,70	34,70	34,74	34,74	34,74	34,74					







Tension (t) = 0,1986 x Pression (b) **Re = 2,1 mm** **Bloc filté :** OUI NON **Cale ;** OUI NON **N°** .... **Charge** ....

22/01/2010

Picture 7.18: example of a stressing sheet (© Soletanche Bachy)

7.4.6.2 PRESSURE BUILD-UP PROCESS

The process of pressure build-up is carried out without any measure, up to the value $\Pi(P_a)$. After measuring the relative position of markers for this pressure $\Pi(P_a)$, the pressure increase is carried out steadily up to $\Pi(P_p)$, with intermediate measure points of displacements for the pressure values set in paragraph 7.4.4.6. For each of these measure points, α, β, etc. (see figure 7.4.), the stopping duration is strictly limited to the time required to measure the displacement. Once the pressure $\Pi(P_p)$, is reached, the proof stage starts.

A cycle is recommended at the end of the proof stage, at the pressure $\Pi(P_p)$, with the unloading being carried out at least up to 70% of $\Pi(P_p)$ (see paragraph 7.4.4.7).

Comment: should the company wish it, and in addition to the minimum process described above, it may carry out loading-unloading cycles of limited amplitudes.

The first of these cycles may conveniently be carried out prior to reaching the pressure $\Pi(P_p)$.
However, the cycles between $\Pi(P_a)$ and $\Pi(P_p)$ should be avoided in cases where soils are likely to creep, because any subsequent interpretation will be difficult to achieve.

7.4.6.3 PROOF STAGE

Ground anchor acceptance consists in maintaining the anchor under a constant tension, equal to the proof load P_p, during the time span defined in paragraph 7.4.7.3, as well as in measuring the displacement of the marker fixed to the tendon during this test (case of a fixed marker).

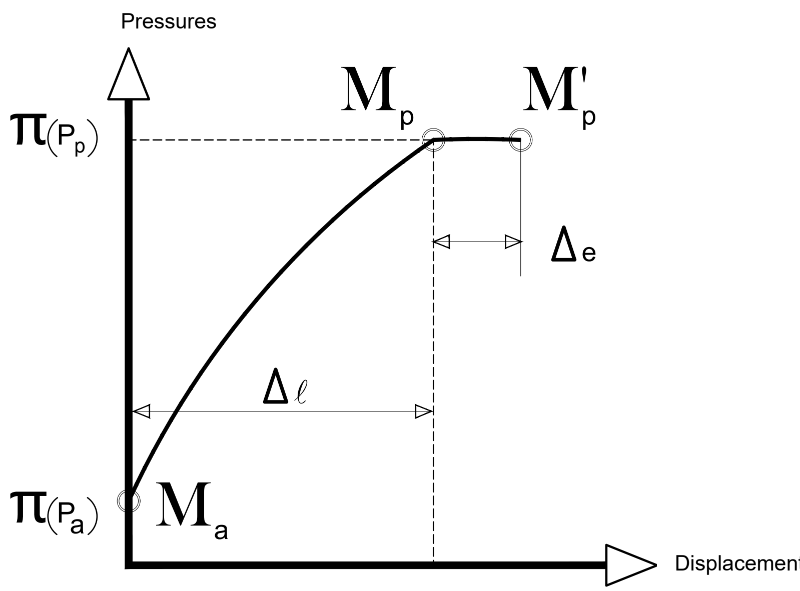


Figure 7.7: stressing diagram of an acceptance test

Given the usual provisions, it is impossible to maintain a strictly constant tension. Practically, the pressure gauge or the sensor is observed during the whole duration of the test, and the pressure is increased:

- before it lowers of more than 2 %,
- and in such a way it NEVER exceeds the pressure $\Pi(P_p)$ of more than 1 % (see figure 7.8 below).

The test origin is the time t_0, at which the pressure $\Pi(P_p)$ is reached (see figure 7.9 below).

This increase is carried out in less than a minute.

For the 15 minutes stages, displacement measures are carried out at the times t_0 + 1, 2, 3, 4, 5, 7, 10, 15 minutes.

When the stage is raised to 30 minutes (i.e., for soils likely to creep), the displacement measures are carried out at the times t_0 + 1, 2, 3, 4, 5, 7, 10, 15, 20, 25, 30 minutes.

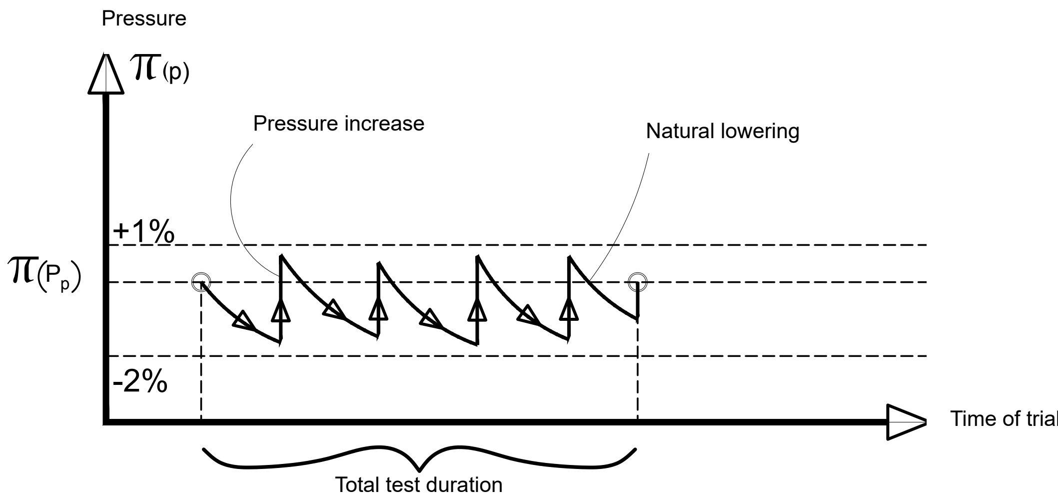


Figure 7.8: detail of how the proof load is maintained during an acceptance test

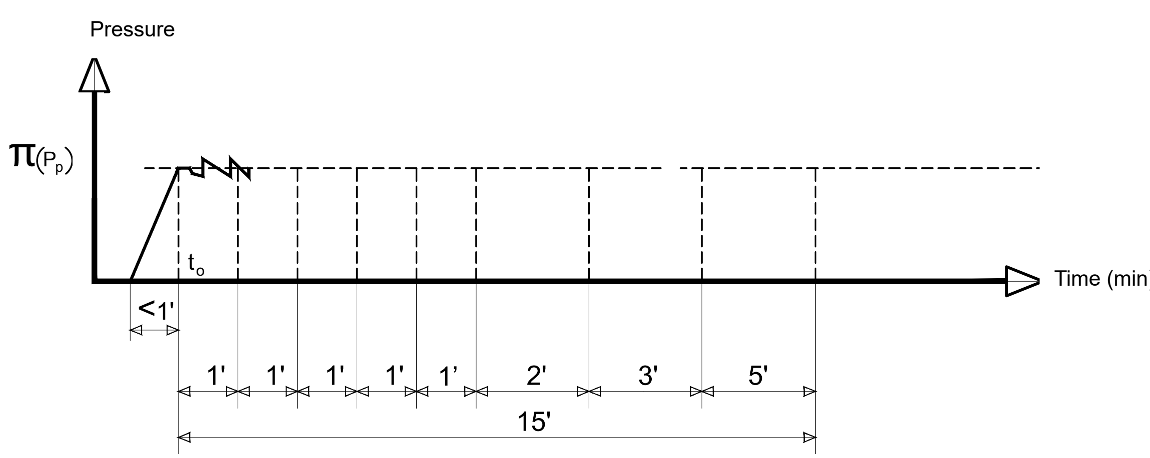


Figure 7.9: measuring intervals during the proof stage of an acceptance test

7.4.7 ACCEPTANCE

7.4.7.1 ACCEPTANCE CRITERIA - PRINCIPLES

For a ground anchor to be accepted, one shall verify that the plotting of the pressure/displacement curve during the pressure increase and that bond displacement during the test are satisfactory.

Note: as a reminder, anchor head displacement results from several phenomenons: the elastic elongation of the tendon and the possible measured bond displacement.

One may also benefit from calculating the equivalent free length of the ground anchor, but this calculation cannot constitute an acceptance criterion.

Comment 1: the bond displacement is assumed as being the one of the marker fixed to the tendon, possibly decreased of the elongation due to steel creep, which is all the more significant than the load it is subject to and the free length of the ground anchor are great.

Comment 2: these displacement measures should always and systematically be carried out in order to detect ground anchors having an abnormal behaviour. Such anomalies may stem from:

- a soil heterogeneity, but also from
- a faulty execution of the ground anchor.

7.4.7.2 CRITERION RELATIVE TO THE PRESSURE-DISPLACEMENT CURVE

The displacement value should be measured at each intermediate point located within the elongation zone determined by the two lines corresponding to the increase in length (L_L+L_e) and to the increase in length $L_L+L_e+L_s/2$.
At the proof load value, the displacement shall be located within this zone.

Note: under low pressures, an elongation lower than the theoretical value may be witnessed but this does not translate any anomaly.

7.4.7.3 CRITERIA RELATIVE TO THE PROOF STAGE

7.4.7.3.1 GENERAL CASE

The acceptance criterion is deemed as satisfied if the value of α is lower than 1.5.

It is usually required to have a 30 minutes stage (see note). The values of t_a and t_b used to assess α are respectively 5 and 30 min.

Note: standard NF EN ISO 22477-5 considers 15 minutes stages, but this stage duration is rarely sufficient for soils that are likely to creep.

If this criterion is not satisfied over 30 minutes, the stage is resumed to 60 minutes. In that case, α is re-calculated, but with t_a and t_b at respectively 30 and 60 min (with the criterion still being $\alpha \leq 1.5$).

7.4.7.3.2 IF THE ACCEPTANCE CRITERION IS NOT SATISFIED

If the acceptance criterion is not satisfied, and/or if α may not be determined, the ground anchor is deemed as being invalid for its use.

What may then be decided is:

- to carry out additional loading cycles that will allow assessing how it evolves over time (at least twenty cycles, with extreme loads ranging between around 90 % and 120 % of the service load, excluding friction),
- to use it at a lower tension value,
- to stress it, and follow up its evolution (it can be equipped, for instance, with a tension control device),
- to reinforce it,
- to re-execute it.

IMPORTANT NOTE: the solutions above are valid for a ground anchor exhibiting an accidental weakness. If the first ground anchors being tested systematically fail the acceptance criteria above, an appropriate decision shall be taken at job site level.

7.4.7.3.3 CASE OF SOILS UNLIKELY TO CREEP

The displacement criterion is more immediately usable in job site conditions over a short stage. Experience shows that (besides creeping soils) this displacement criterion between 3 and 15 minutes is not less safe than the α criterion on stages of 30 minutes and more.

Note: paragraph 5.1.1 qualifies the soils that are likely to creep.

If Δs_{3-15} represents the displacement of the marker between the times t_0 + 3 minutes and t_0 + 15 minutes, the test is deemed as being satisfying if:

$$\Delta s_{3-15} < 1.5 \text{ mm.}$$

Note 1 : measuring conditions and/or the existence of poorly known soils lead to propose a displacement value limited to 1.5 mm, but in most of the cases, the measured value does not exceed 1 mm.

If this condition is not met, the stage is extended to 60 min and α is calculated between times t_a = t_0+15 min and t_b = t_0+60 min

- for a permanent ground anchor, the acceptance criterion is $\alpha < 1.5$
- for a temporary ground anchor, the acceptance criterion is $\alpha < 2.5$

Comment: the criterion α is highly sensitive to the time interval it integrates. One should be cautious when comparing gross values. For instance, this value of 1.5 mentioned above does not have the same meaning than the same value from paragraph 7.4.7.3.1.

Paragraph 7.4.7.3.2 will be used if this criterion is not satisfied.

7.4.8 GROUND ANCHOR LOCK-OFF

7.4.8.1 GENERAL POINTS

Depending on the stressing system being used (lock-off type), ground anchor lock-off may be carried out either in the continuity of the proof stage with a partial destressing (hydraulic seating device), or with a full destressing to install the anchoring block wedges (mechanical or hydraulic seating device).

This schedule may be supplemented by the implementation of the anti-corrosion protection for the anchor head (see section 6), by the installation of control devices (see paragraph 8.6), etc.

In practice, the process of ground anchor lock-off usually causes tension losses by clamping, which leads to make a distinction between two lock-off load values:

- P_b tension at lock-off start,
- P_0 true tension at lock-off end.

The tension value at lock-off start P_b is defined in paragraph 7.4.4.8.

The real tension at lock-off end P_0 shall be as close as possible (+/-5%) to the calculated initial tension P_i.

Note: in the case of retaining walls, the prestressing value P_i is usually chosen at 80% of the reaction required to balance the earth pressure on the wall.

Comment: only the tension at lock-off start P_b can be directly measured.
The real tension at lock-off end P_0 can only be verified from the stressing diagram.
Lock-off losses (see paragraph 5.2.2.3) are, for a given process, sensibly constant and well-known.
The real tension at lock-off end P_0 is therefore known with a correct approximation, on the basis of the tension at lock-off start.

7.4.8.2 SCHEDULING

The tendon lock-off and the jack release are, if the equipment allows it, part of a continuous process. Otherwise, the procedure should be adapted:

- by using of an over-tension chair,
- by dissociating the test and lock-off stages (for cable anchors, wedges are implemented only during the lock-off stage).

In the most common cases, after the proof stage, the anchor destressing, made by releasing the jack pressure, is carried out until the lock-off pressure $\Pi(P_b)$ is reached. The calculation of the pressure $\Pi(P_b)$ is different if the lock-off has to be carried out after the ground anchor is fully released, i.e., during the pressure build-up. Instructions should be properly followed (see paragraph 7.4.4.8).

Tendon lock-off per se is then carried out.

The residual displacement of the marker fixed to the tendon is then measured at the point B corresponding to the pressure $\Pi(P_b)$ (see figure 7.10).

Picture 7.19a: Wedges being positioned (© Soletanche Bachy)

Picture 7.19b: Installation of the anchoring block and wedges prior to stressing (© Soletanche Bachy)

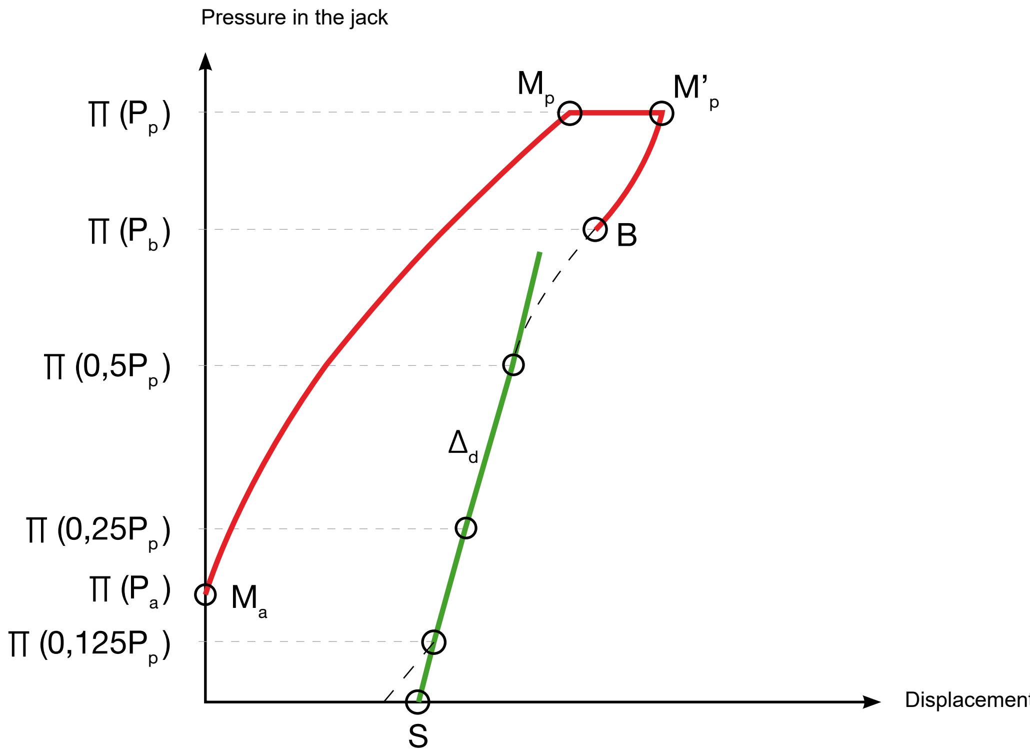


Figure 7.10: detail of the lock-off stage on a stressing diagram

The jack release is then operated. The marker fixed to the tendon displaces, because of the elastic shortening of the L_e part of the tendon, located between the bearing plate and the jack jaws. During release, the displacement of this marker is measured at three points, corresponding for instance to 0.5 P_p ; 0.25 P_p and 0.125 P_p.

Comment: the first measure point is chosen at a value sufficiently far from P_p so it is free of friction.

These 3 points allow plotting the line Δ_d and its intersection with the displacement axis.

7.4.8.4 DETERMINING TENSION AT LOCK-OFF END

A simple geometric construction allows determining the tension at lock-off end P_0 from the stressing diagram (see figure 7.11).

1. At the vertical of the point M'_p and below it, a point X' is plotted so that:

$$M'_pX' = \Psi_p = \Pi(\psi_p)/S \qquad \text{(see note 1)}$$

2. Through this point X', the line X'Y' is plotted, with a slope:

$$E/(L_e + L_L) \qquad \text{(voir note 2)}$$

3. On the displacement axis, the point S' is plotted at the right of the point S so that:

$$SS' = (L_e \,.\, F_k) / (E \,.\, A_s) \qquad \text{(voir note 3)}$$

4. Through this point S', a line S'S'' is plotted, parallel to the pressure axis

5. The intersection of the lines X'Y' and S'S'' gives a point R having an ordinate equal to the operating pressure in the jack (friction deduced) $\Pi(P_0)$

Note 1 : ψ_p represents the friction (see paragraph 5.2.2.2) corresponding to P_p.

Note 2 : if the marker used for displacement measures is chosen on the ground anchor between the structure and the jack jaws, the outer length L_e is counted between the bearing plate and the marker. Otherwise, the outer length L_e is counted between the bearing plate and the jack jaws (case of figure 7.12).

Note 3: SS' represents the theoretical elongation, under a planned tension F_k of a ground anchor element with a length L_e, having a tendon with a cross-section A_s and an apparent elasticity modulus E.

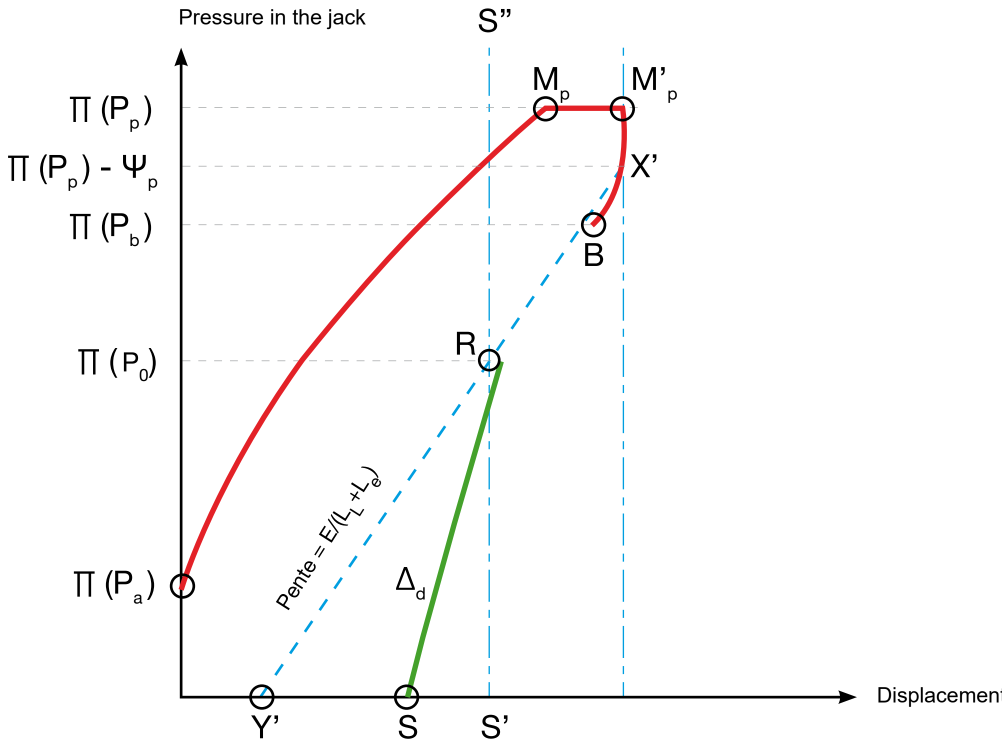


Figure 7.11 : graphical determination of P_0

The tension at lock-off end P_0 is therefore equal to:

$$P_0 = S \cdot \Pi(P_0)$$

Comment 1: even though the line S'S'' is determined with a correct accuracy, this is not the case of the line X'Y' because the length M'_p X' is evaluated, and the true slope may slightly differ from $E / (L_L + L_e)$.

Thus, determining tension at lock-off end P_0 is not a process that may be considered as being highly accurate, and a tolerance of +/- 5 % is allowed on the value found, compared to the planned project value.

Comment 2: the cycle method (see paragraph 7.4.4.7), which leads to a more accurate determination of the line X'Y', allows obtaining with greater accuracy a value of tension at lock-off end P_0.

7.4.9 INTERPRETATION AND REPORT

7.4.9.1 REPORT CONTENT

The stressing report shall contain the following data (see note):

- the log chart of displacement values,
- the plotting of the measure points recorded during the pressure build-up on a pressure/displacement diagram (see paragraph 7.4.3.3),
- the plotting of the measure points recorded during the proof load on a semi-logarithmic scale,
- the value α (slope of the creep curve) measured during the proof load (see paragraph 7.4.9.3 below),
- the determination of the equivalent free length (see paragraph 7.4.9.2.1 below).

Note: furthermore, the report includes the usual data, such as project name, ground anchor identification, stressing date, operator's name, etc.

Besides, it may also include:

- the determination of friction losses,
- the plotting of the cycle(s) of loading/unloading,
- the determination of the real tension after lock-off (P_0).

7.4.9.2 EQUIVALENT FREE LENGTH

7.4.9.2.1 DETERMINATION OF THE EQUIVALENT FREE LENGTH

What is called equivalent free length L_{eq} is the length of a tendon constituted similarly to the ground anchor, selectively anchored at both ends, and which would gain the same total elongation under a same tension P_p.

It is conventionally given by the formula below:

$$L_{eq} = E \cdot A_s \cdot \Delta\lambda_{ap} / (P_p - P_a)$$

Note 1 : $\Delta\lambda_{ap}$ corresponds to the elongation between $\Pi(P_p)$ and $\Pi(P_a)$.

Note 2 : P_a and P_p may be respectively deduced from $\Pi(P_a)$ and $\Pi(P_p)$ by the relation given in paragraph 7.4.4.3.

Comment 1: when the measures are carried out in relation to a marker fixed to the anchored structure, it is required, if this structure is deformable, to correct the elongation value $\Delta\lambda_{ap}$ to take into account the inner movement of the structure.

Comment 2: the apparent elasticity modulus E of the tendon may differ from the one of the steel that constitutes it (see paragraph 4.1.2.1).

7.4.9.2.2 FICTITIOUS POINT

The length L_{eq} counted from the point at which the tendon is fixed on the jack (fig. 7.12) – or from the marker fixed to the tendon if it is located between the bearing plate and the jack jaws -, defines an experimental position of the fictitious anchorage point P_f, which may be compared to the position of the fixed length/free length interface, and to the bond position.

The point P_f is usually located between the free length/fixed length interface and the middle of the bond length.

Comment: this calculation, which may prove lengthy, may be replaced by plotting beforehand two tension linear diagrams (see figure 7.13) corresponding to the two chosen criteria (L_L + L_e on the first part, L_L + L_e + $L_s/2$ on the second part). What is only verified is if the point M_p is located within the sector thus defined.

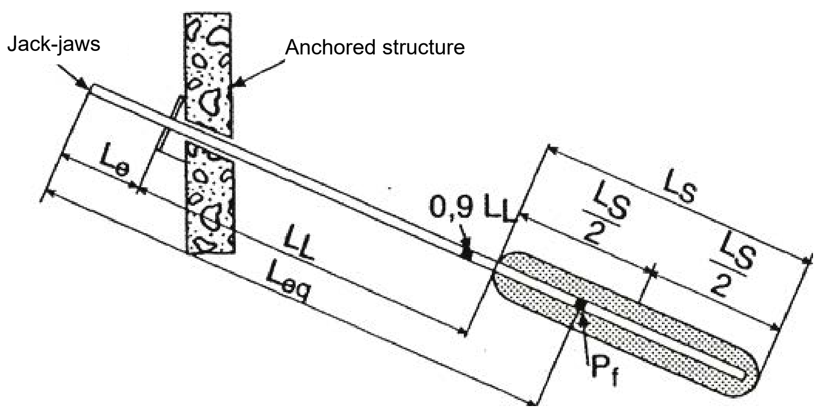


Figure 7.12: illustration of a fictitious point

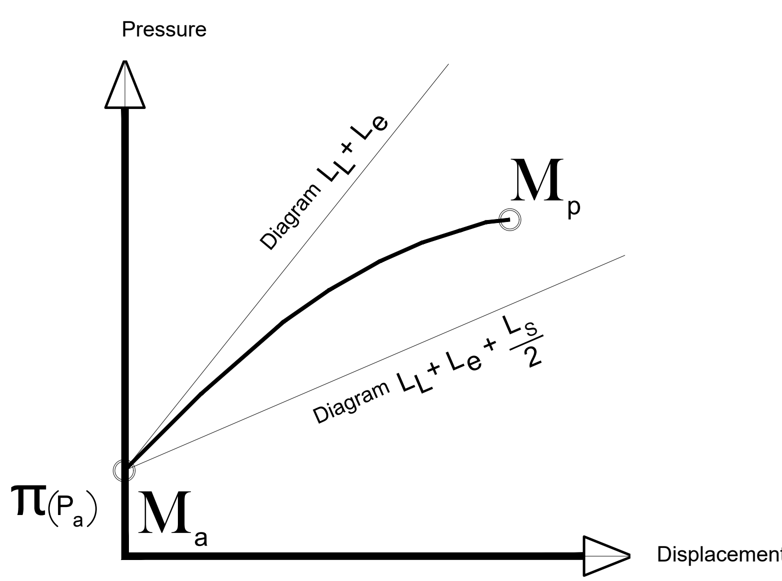


Figure 7.13: graphical representation of the fictitious point Pf

However, in some cases, the point P_f may be located outside the zone that was defined above:

- it is notably the case when soils are likely to creep and for which, due to the bond creep, the position of the fictitious anchorage point, as resulting from the displacement measure, does not have any physical meaning,
- this may also occur if there has been laitance penetration in the free length: what results from this is a hindrance when installing the protection afterwards. For these reasons P_f may admittedly be ahead of the plug, at the condition that it remains at a maximum distance of a tenth of the theoretical free length from it:
    - for ground anchors that require no protection,
    - for other ground anchors, provided that it is possible to justify a proper installation of the protection;
- lastly, if P_f is located beyond the middle of the bond, the reason of such an anomaly should be researched.

7.4.9.3 CREEP REPRESENTATION

α is calculated from the following formula:

$$\alpha = (\delta_b - \delta_a) / (\log(t_b) - \log(t_a)) = (\delta_b - \delta_a) / \log(t_b/t_a)$$

δ_a ground anchor displacement at time t_a
δ_b ground anchor displacement at time t_b
t_a start of the corresponding time interval (see table 7.3)
t_b end of the corresponding time interval (see table 7.3)

For the acceptance test, the measuring intervals are summarised in table 7.3 :

	15 min stage	30 min stage	Extended stage
t_a	3’	5’	15’ (non-creeping soils) otherwise 30'
t_b	15’	30’	60'

Table 7.3: values of t_a and t_b for the acceptance test

The measured displacements are plotted in function of time on a semi-logarithmic scale.

The curve shall not show any significant concavity.

7.4.9.4 CASE OF STRESSING WITH CYCLES

If a cycle is carried out, all the points used to calculate tension losses due to friction should be displayed on a graph. Please refer to 7.4.4.7.

The value of friction losses thus determined shall be recorded.

7.4.9.5 PRESTRESSING VERIFICATION

The prestressing value P_i should be close to the tension P_0 decreased of the probable deferred losses (see paragraph 5.2.2.4).

7.4.10 GROUND ANCHOR PROTECTION

This operation has a particular significance because it conditions ground anchor sustainability and shall be handled with the greatest care.
For that matter, please consult section 6 and refer to the instructions and blueprints of the manufacturer.

7.5 GROUND ANCHOR DESTRESSING

When it is stipulated on the specific documents of the contract, temporary anchors are extracted, whether partially or fully.
When there is no opposite stipulation, ground anchors are left in place.

Temporary ground anchors shall be mandatorily destressed. This destressing may only be carried out when the forces thus released are balanced by a substitution apparatus.

Note: this substitution apparatus is usually a partial or full contribution of the structure.

Comment: the case of ground anchors with a lifetime greater than 2 years and lower than the structure’s lifetime shall be specified.
All precautions regarding personnel safety shall be taken during the destressing or the extraction.

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8 TESTS, CONTROL AND MONITORING

8.1 GENERAL POINTS RELATIVE TO TESTS

8.2 PROVISIONS SHARED BY ALL FAILURE TESTS

8.3 INVESTIGATION TESTS

8.4 CONFORMITY TESTS

8.5 SUITABILITY TESTS

8.6 MONITORING

8 TESTS, CONTROL AND MONITORING

WARNING

Because they imply stressing, and no matter of which type they are, tests are dangerous operations.

At the very least, the following requirements shall be met:

- Forbidding the access to the test zone to anyone not concerned by tests,
- Entrusting the operation with skilled and trained personnel,
- Using sound equipment,
- Checking that the anchor heads do not show any apparent defect.

8.1 GENERAL POINTS RELATIVE TO TESTS

8.1.1 COMPARISON OF TESTS IN TERMS OF OBJECTIVES

8.1.1.1 FAILURE TESTS

The objectives of failure tests are to:

- verify that the ground anchor may be subjected to a set tension R_d and $R_{cr;d}$
- reach a bond failure by pull-out, provided the tendon limit conventional resistance R_{max} (see paragraph 5.3.2.6 and annex I) does not prevent this.

Ground anchors subjected to a failure test may not, under any circumstances, be re-used afterwards as structure ground anchors.

Depending on the construction progress of the structure, failure tests are called:

- either « investigation tests » when they are carried out on ground anchors installed on test pads designed and built prior to the start of job site works. Such tests are notably used to design and calculate structures (see note).
- or « conformity tests » (also called sometimes « design control ») when they are carried out at the very start of job site works on ground anchors, whether they are integrated or not to the structure (but not be used afterwards as ground anchors for the structure).

Note: investigation tests may be carried out within the framework of the contract dedicated to the construction of the structure, or of a specific contract, but in any case with a technology and procedure similar to the ones of the final ground anchors that will equip the structure.

8.1.1.2 SUITABILITY TESTS

(Execution) suitability tests are undertaken to statistically verify the common execution quality of the ground anchors equipping the structure.

Note: the « suitability tests » mentioned in paragraph 8.6.1 of EN 1997-1 are not execution controls, but design controls. In other words, they are conformity tests.

These tests do not allow quantifying the value of the safety coefficient specific to the ground anchor being tested.

Since they are carried out on structure ground anchors, the proof loads to which ground anchors are subject for the tests are limited to values supposed as incapable of initiating bond failure.

8.1.1.3 ACCEPTANCE TESTS

Acceptance tests represent a usual control procedure to which all the ground anchors of the structure are subject prior to their implementation. Carrying out acceptance tests precedes the lock-off operation.

Note: acceptance tests are one of the steps of ground anchor implementation, and as such they are described in paragraph 7.4.6.

These tests do not allow quantifying the value of the safety coefficient specific to the ground anchor being tested.

8.1.2 TESTING OPPORTUNITY. ROLE OF THE VARIOUS ACTORS

8.1.2.1 GENERAL FRAMEWORK

The following paragraphs can be applied to both temporary and permanent ground anchors.

At the exception of the cases addressed in paragraphs 8.1.2.2 and 8.1.2.3 (below), on a same project, but at various stages of its execution, three types of tests are carried out:

- failure tests (investigation tests or conformity tests),
- (execution) suitability tests,
- acceptance tests.

Failure test anchors are commonly used as suitability ground anchors.

8.1.2.2 INVESTIGATION FAILURE TEST

Investigation tests are mandatory for ground anchors bonded into cohesive soils that are likely to creep (see paragraph 5.1.1).

Comment: investigation tests are always mandatory in such soils, firstly because the knowledge of the bond behaviour in these materials remains limited, and secondly because these soils are highly sensitive to soil remoulding and bursting during drilling and injection. Consequently, forecasting is haphazard.

Beyond the cohesive soils addressed in the previous paragraph, investigation tests may also be required in the following cases:

1. The Developer intends (see note):

- to grasp the issues tied to the execution of drilling and bonding in a poorly known or difficult geological medium: slope scree, faulted or open materials, loess, ground with buried obstacles, etc.,

- to set, within the framework of large-scale projects, the optimal injection parameters for a required anchor resistance: dosing, amount of grout, pressures, number of passes,
- to assess the expertise of a company entrusted with executing the ground anchors.

2. A company proposes a ground anchor with a new technology, or one considered as being new (this is the case of systems used abroad, but not in France). The investigation test to which this new ground anchor will be subject to will then consist in not only testing how the bond holds in the soil, but also verifying the reliability of its overall design and the quality of its protection against corrosion.

3. Provided it is allowed by the contract, a company proposes a design specific for a site, for which the company considers that the general purpose charts translate poorly the supposed reality.

Note: if the Developer considers the possibility of exempting the company from such tests, the related terms and provisions are specified into the Contract (see below).

When a possibility of exemption is anticipated in the Contract, the document specifies in which conditions the Project Manager may exempt the company from investigation tests (company references, feedback of the proposed system in similar soils and conditions of use, personnel qualification, etc.).

In this case, it is the company, under its own responsibility, that request to benefit from it. The Project Manager makes the final decision.

Comment: the company, when exempted from investigation tests, is obliged to carry out conformity failure tests, as defined in paragraph 8.1.2.3.

Unless there is an opposite provision set out by the Contract, the material execution of investigation tests, the collection and interpretation of results are borne by the company. The company forwards its conclusions to the Project Manager and to the geotechnical engineer in charge of the G2 (geotechnical design) and/or the G4 (geotechnical supervision).

Note: if investigation tests are part of the contract, the geotechnical engineer in charge of supervision (G4) will give his/her opinion to the Project Manager, and the latter will give his/her approval prior any ground anchor execution.

8.1.2.3 CONFORMITY FAILURE TEST

Conformity tests are mandatory in the following cases:
- the company entrusted with the execution of ground anchors is not the one that carried out the investigation tests;
- the company that carried out the investigation tests has changed its execution method;
- no investigation tests were carried out.

Conformity testing may be not carried out in the case of temporary ground anchors executed in well-known soils that are unlikely to creep (see paragraph 5.1.1), provided the company:
- proposes a quality insurance accepted by the Project Manager,
- has itself carried out at least two failure tests (investigation tests or conformity tests) close to the job site, in soils having the same geological structure and compactness, using equivalent execution methods with similar tension forces (see note).

Note: such tests will satisfy the acceptance criteria (see paragraph 8.3.5.3 and/or 8.4.6) and will be approved by the Project Manager.

In counterpart, the company:
- either executes, at the start of job site works, two additional suitability tests,
- or installs a sensor instrumentation that allows determining the effective tension in the ground anchors being examined.

The material execution of conformity tests, the collection and interpretation of results are borne by the company; which forwards its conclusions to the Project Manager. Accepting these conclusions is mandatory prior to any work execution.

8.1.2.4 (EXECUTION) SUITABILITY TEST

Suitability testing is mandatory.

Note: as a reminder, these are not failure tests.

Comment: such obligation is justified by the need of statistically monitoring the common execution quality of the bond of the structure ground anchors. Besides, it is all the more required when incidents or issues occurred during the execution of some ground anchors, undermining the conclusions drawn from failure tests.

Suitability tests are used as acceptance tests.

The material execution of suitability tests, the collection and interpretation of results are borne by the company, which forwards its conclusions to the geotechnical engineer in charge of the G4 (geotechnical supervision), for a later approval by the Project Manager.

8.1.2.5 ACCEPTANCE TEST

Any ground anchor not being subject to a suitability test shall undergo an acceptance test.

8.2 PROVISIONS SHARED BY ALL FAILURE TESTS

8.2.1 GROUND ANCHOR CATEGORIES

Every time ground anchor failure tests are planned or decided, the minimum number of test anchors shall be determined in function of the rules and considerations mentioned below:
- Depending on their contribution to structure stability, ground anchors are classified into several categories. As many test anchors should be planned for as there are different categories of ground anchors (see comment 1);
- Within a same category of ground anchors, not all anchors may be executed into the same soil. In this case, one should

plan for, in each category, as many test series than there are different soil types requiring failure tests (see comments 2 and 3);

- It is impossible to make a valid interpretation of results from a test carried out on a single ground anchor;
- A test may only be deemed as being representative if the number of test anchors grows with the scope of the structure, therefore with the number of ground anchors planned in the project.

Comment 1: this means that all ground anchors having the same function in regard to structure stability belong to the same category. For instance, within the same structure, permanent vertical ground anchors ensuring the stability of the slab do not belong to the same category than inclined ground anchors, maintaining the vertical retaining wall (see figure 8.1).

Comment 2: this situation may occur for ground anchors laid out as several superposed layers (see figure 8.2).

Comment 3: the presence of a water table in the ground where the ground anchors have to be executed may possibly lead to create two sub-categories of ground anchors:

- ground anchors having their heads located above the static level of the water table,
- ground anchors having their heads located below the static level of the water table.

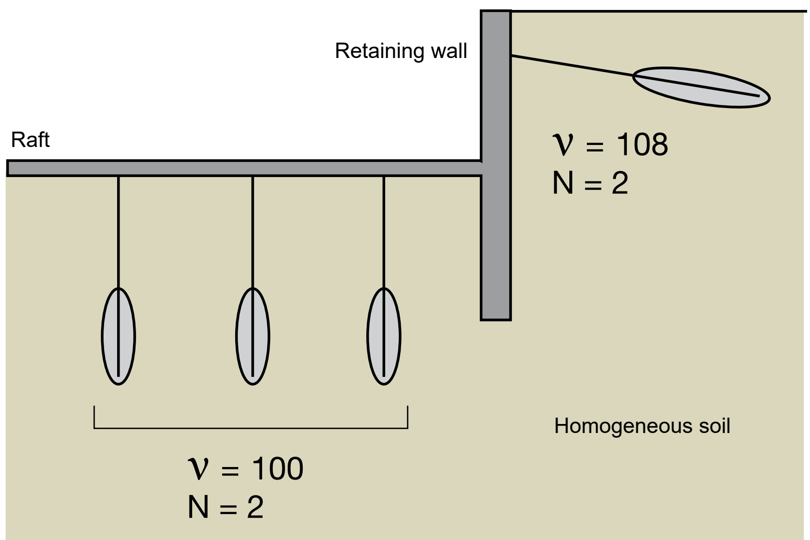


Figure 8.1: example of a homogeneous slab

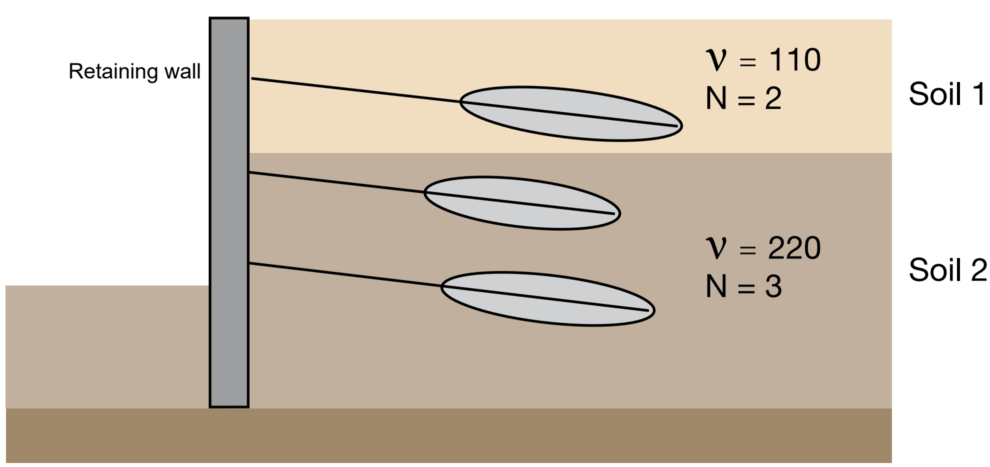


Figure 8.2: example of a bi-layered soil

8.2.2 EXECUTION OF FAILURE TEST ANCHORS, AND OF THE POSSIBLE SUPPORT STRUCTURE

8.2.2.1 EXECUTION PARAMETERS OF TEST ANCHORS

Except for the steel cross-section, which may be overabundant depending on the cases addressed in paragraph 8.2.2.2 below, failure test anchors shall conform to the ones that will be executed on the structure.

This prerequisite of conformity will notably concern:

- the drilling method,
- the length and level of the bonded part,
- the manufacturing, installation and grouting techniques of the ground anchor.

Comment: two factors can greatly influence bond resistance:

- the drilling method (in particular in cohesive soils): it is therefore essential to use a drilling method for test anchors identical to the one of the ground anchors equipping the structure;
- the injection procedure (including the maximum pressure): the procedure applied during testing shall be as close as possible to the one used subsequently on the whole site.

In the case where the anchor bond is executed in rocks, it should be additionally observed, for these anchors, the same drilling diameter than the one planned for the future works.

Note: the increase of the steel cross-section considered in paragraph 8.2.2.2 is therefore limited.

In the case of bonding in soft soils, which are always more or less compressible ones, the drilling diameter of test anchors may, if required, be 20% greater at most than the one considered for ground anchors that will equip the structure.

Note: a moderate increase in diameter has only little effect on test results, since the diameter of the injection bulb depends on the soil compressibility and on the maximum injection pressure.

Except for cases where bond is carried out in rocks, boreholes used for a prior ground investigation may not be re-used as such for the purpose of hosting test anchors.

Comment: in the case of rocks, the possibility of re-using an investigation borehole shall be analysed in function of the rock (in regard, amongst other things, to a natural fracturing causing instability in the borehole, or to an alteration of the exposed borehole walls), and of the delay between the investigations and the bonding of the test anchor.

8.2.2.2 CHOOSING THE STR RESISTANCE OF GROUND ANCHORS

Determining the maximum resistance of a failure test anchor is achieved:

- either in function of a service load known a priori (by investigation testing, or with charts), and for which a safety coefficient will be verified,
- or in function of the maximum GEO resistance (ie bonding resistance) that can be possibly obtained for the soil under consideration and for the given type of ground anchor.

In the case where it is intended to validate a design (for instance, the one stemming from the charts of annex H), the test is based on a design value of the pull-out resistance, assumed as being lower than the true value of pull-out.

In the second case, bond failure will be researched.

If R_k is the value stemming from the calculation model, in function of the ground and type of ground anchor, the value of P_p is selected as being at least equal to 1,5 R_k.

For lack of specification you should calculate the tendon cross-section so that the proof load P_p remains lower than R_{max}.

Comment: in order to install the tendon, this may imply executing a larger borehole diameter, which is not always feasible (see paragraph 8.2.2.1).

8.2.2.2 SUPPORT STRUCTURE

The provisions of annex I (see paragraph I.4) are applicable.

Since the final support structure (wall, slab, anchorage block, etc.) is usually not yet built (see note), or is not enough resistant at the date of the execution of ground anchor tests, temporary support blocks that can resist the loads induced by the test with minimum deformations should be designed and built.

Note: it is usually the case when carrying out investigation tests.

During testing, deformations shall be measured with the required accuracy, using a fixed marker outside the blocks.

Comment: in the case where a block rotation is detected, it should be verified if this influences the interpretation of results.

Measuring the block displacement proves required for tests of long duration carried out by clamping the head and removing the jack. It allows attributing the observed tension losses either to the support displacement or to the bond creep.

Picture 8.1a: concrete reaction block for a failure test (© SMG)

Picture 8.1b: steel reaction mass for a failure test
(© Spie Fondations)

8.2.3 EQUIPMENT AND DEVICES FOR THE EXECUTION OF FAILURE TESTS

For this, one will peruse annex I, which summarises the expected parameters of the equipment used for all tests.

Even though it is not mandatory at all, in some cases, measuring forces along the bond can significantly enhance all the conclusions drawn from failure tests. Given the attractiveness of such measures, it is recommended, whenever possible (large-scaler project, ground anchor with a new technology, cohesive soils), to equip ground anchors subject to failure tests with measuring devices.

Installing the measuring devices, carrying out the tests and interpreting the results shall be achieved by a specialised company (company, laboratory, engineering office, etc.).

Picture 8.2: example of a failure test system (© Spie Fondations)

Picture 8.3: example of a suitability test system (© SMG)

8.2.4 PROCEDURE

The procedure to carry out failure tests consists in measuring the anchor head displacements during loading stages with increasing values, then with decreasing values (see annex J).

Failure tests shall be carried out by qualified personnel and under the management of an experienced technician. The interpretation of test results shall be done as and when they are carried out.

Note: acquiring data and plotting the test diagram may be automated processes.

As a reminder, the greatest precautions shall be taken in order to avoid accidents, notably the ones consecutive to a possible premature rupture of the anchor tendon.

Comment: the choice of the steel cross-section is made so that bond failure occurs, in principle, before reaching the value R_{max}, which is below the steel conventional limit (see paragraph 8.2.2.2).

8.3 INVESTIGATION TESTS

The provisions below supplement paragraph 8.2.

8.3.1 NUMBER OF INVESTIGATION TEST ANCHORS

Investigation testing is carried out on at least two identical ground anchors, belonging to the same category (see paragraph 8.2.1), following the procedure defined in paragraph 8.3.5.

Determining the minimum number is a process that goes through the following steps:

- the total number of ground anchors planned for the structure is distributed into categories (see comment 1 of paragraph 8.2.1),
- in each category, the ground anchors are classified into sub-categories, depending on the nature of the soil into which they are bonded.

Given the criteria set above, the minimum number N of test anchors to be planned for in function of the number ν of ground anchors belonging to each sub-category is indicated in table 8.1 below:

ν	N
1 to 200	2
201 to 500	3
501 to 1000	4
1001 to 2000	5
2001 to 4000	6

Table 8.1: number of investigation test anchors

8.3.2 EXECUTION DATE OF THE INVESTIGATION TEST

It is mandatory that executing test anchors is planned for with a sufficiently long delay before executing the structure ground anchors.

This delay is imposed by:

- the time required to execute the test anchors,
- the time for the bond, and possibly for the support structure, to harden,
- the time allocated for the tests per se,
- the time required to collect and interpret results,
- the eventual adaptation of the project design, integrating the results of the investigation tests.

Executing the structure ground anchors shall not, under any circumstances, be initiated before the tests were interpreted, and before the execution project is approved.

Note: the sequence of the operations mentioned above requires a timespan of several weeks.

8.3.3 LOCATION OF INVESTIGATION TEST ANCHORS

Test anchors shall be established on the site, with a view of being as representative as possible to the category (and possibly, to the sub-category) to which they belong.
In particular, it is important that the layer where bond of test anchors will be set corresponds to the one of the future ground anchors, and that their inclination is sensibly identical.

Comment: this recommendation is particularly important in the case of layered soils, or when bonding is set in soils having a poor resistance.

It is often difficult to execute investigation test anchors strictly identical to the structure ground anchors. The procedure that contains the description and incidence of these discrepancies shall be validated by the Project Manager.

Note: if the representativeness of investigation tests is not deemed as being satisfying, it may be required to review the organisation and programme of conformity and execution suitability tests.

8.3.4 EXECUTION OF INVESTIGATION TEST ANCHORS

Since the objective of investigation testing is to assess the bond characteristic resistances, bond failure will be researched. An oversized tendon should be available (in regard to GEO – ie bonding - resistance), within the limits specified in paragraph 8.2.2.2.

8.3.5 PROCEDURE AND INTERPRETATION OF RESULTS

8.3.5.1 LOADING STAGES

The value of stages is defined in relation to the proof load P_p.

For the first ground anchor, the value of P_p is equal to the characteristic tension R_{max} of the tendon used during the test.

For the second ground anchor, the value of P_p is equal to the limit tension $R_{ELU;m}$ measured on the first anchor, or, if it was not observed, to R_{max}.

The proof load of the next ground anchors is established in function of the results of the first tests, usually as the $(R_{ELU;m})_{min}$ of the previous tests (under the condition that the previous tests are « homogeneous » ones, see paragraph 8.3.5.3).

8.3.5.2 STAGES OF INVESTIGATION TEST ANCHORS

The procedure and result interpretation of the test on the first ground anchor are carried out in compliance with the indications of the standard (see annex J).

Comment: annex J details in particular the graphical method that allows determining the critical creep load from the slope of the representative curves of creep.
The case displayed in figure J.3 of annex J is one where interpretation is convenient.

This graph may however show anomalies (an example is provided on figure 8.3). The reason of this anomaly should then be researched, which may lead to executing an additional test anchor.

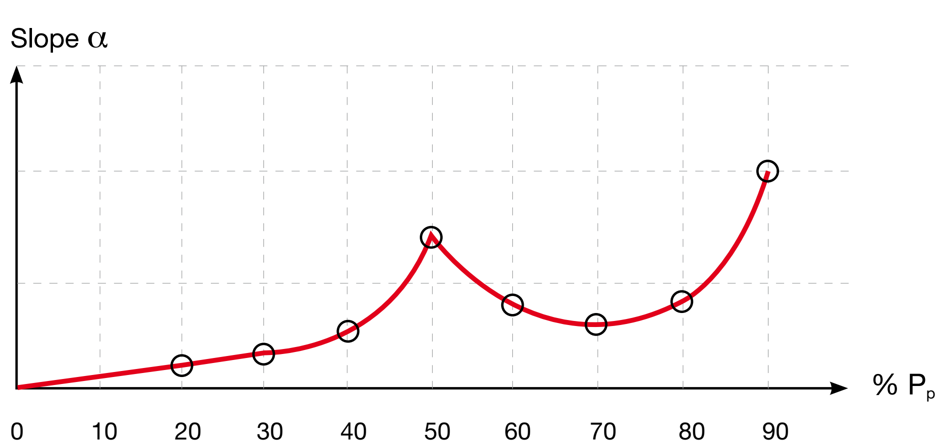


Figure 8.3: example of a test showing an anomaly

8.3.5.3 INTERPRETING INVESTIGATION TESTS

When the results between all the various ground anchors are homogeneous (see note and comment), assessing the characteristic resistance is achieved using the indications of paragraphs 5.3.3.3 and 5.4.2.

Note: results are considered as being homogeneous if the discrepancy between the mean measure value and the minimum and maximum extreme values remains lower than 10%:

$$(R_{ELU;m})_{min} \geq 0{,}9 \; . \; (R_{ELU;m})_{moy}$$
$$\text{et } (R_{ELU;m})_{max} \leq 1{,}1 \; . \; (R_{ELU;m})_{moy}$$

and

$$(R_{ELS;m})_{min} \geq 0{,}9 \; . \; (R_{ELS;m})_{moy}$$
$$\text{et } (R_{ELS;m})max \leq 1{,}1 \; . \; (R_{ELS;m})_{moy}$$

Comment: if needed, the reasons why the slopes of the creep curve are significantly steeper on the next ground anchors than on the first one should be analysed. One and/or the other of the discrepancies between the mean measured value and the maximum and minimum extreme values may happen to be greater than 10%, which may reveal an anomaly (see note).

Note: the anomaly may originate from, e.g., a different soil, a faulty or different ground anchor execution, etc.

The analysis that shall be achieved may lead to executing additional test anchors (see notes 1 and 2).

Note 1: the option of a third ground anchor is particularly pertinent when only 2 investigation test anchors are available.

Note 2: the testing process of these additional ground anchors may possibly differ from the one set in the standard (see annex J).

8.4 CONFORMITY TESTS

The provisions below supplement paragraph 8.2.

8.4.1 GENERAL POINTS

Conformity tests shall be carried out as work starts on test anchors executed within the same conditions than the ones planned in the execution technical sheet for the structure ground anchors (drilling method and diameter, free length, bond length, tendon, injection method, etc.).

Whenever possible, and even though the test was first designed to validate a design based on investigation tests or pre-design deduced from charts, the test shall be carried out until bond failure occurs.

Note 1: it is reminded that ground anchors used for conformity tests may not, under any circumstances, be re-used.

Note 2: it is possible to increase the tendon cross-section, provided it does not undermine the other parameters (in particular, the borehole diameter).

8.4.2 NUMBER OF CONFORMITY TEST ANCHORS

Structure ground anchors are classified into various categories (see paragraph 8.2.1) depending on their function and on the nature of the soil in which they are bonded.

For each ground anchor category, the minimum number of conformity test anchors to be planned is two.

8.4.3 EXECUTION DATE OF TESTS

Conformity testing is undertaken after the support structure has reached a sufficient resistance, and the cement has sufficiently hardened.

8.4.4 SUPPORT STRUCTURE

When the structure to be anchored is used as a support structure for the execution of tests, one shall ensure that the structure:

- is designed so that it will not undergo any disorder when the maximum test tensions are applied,
- integrates excess free recesses with the purpose of hosting these tests.

8.4.5 PROCEDURE

Above all, conformity testing is conceived to validate a design based on investigation tests, or on a pre-design deduced from charts (see paragraph 5.3.3.3), and for a proof load $P_p \geq R_k$.

Whenever possible, the test shall be carried out until bond failure occurs.

Note: hence, usually $R_k \leq P_p < 1{,}5 \; . \; R_k$

Comment: this means that the maximum tendon cross-section to be selected is the one compatible with the clauses of paragraph 8.2.2, regardless of the value of P_p (under the condition that $R_{max} > P_p$).

Note: it is reminded that ground anchors used for conformity tests may not, under any circumstances, be re-used.

8.4.6 INTERPRETATION OF RESULTS

As a reminder, the procedure is the one of the failure test described in annex J. In particular, each stage includes measuring the displacements Δ_s and assessing α between the times t_0 + 5 minutes and t_0 + 60 minutes.

P_m is the tension value of the proof stage for which Δ_s does not exceed the lowest of the two values $10^{-4} L_L$ and 1 mm (see figure 8.4).

Comment: Δ_s = 1 mm is sensibly equal to α = 1.0

Note : $P_m = P_p$ may occur when displacements are very small.

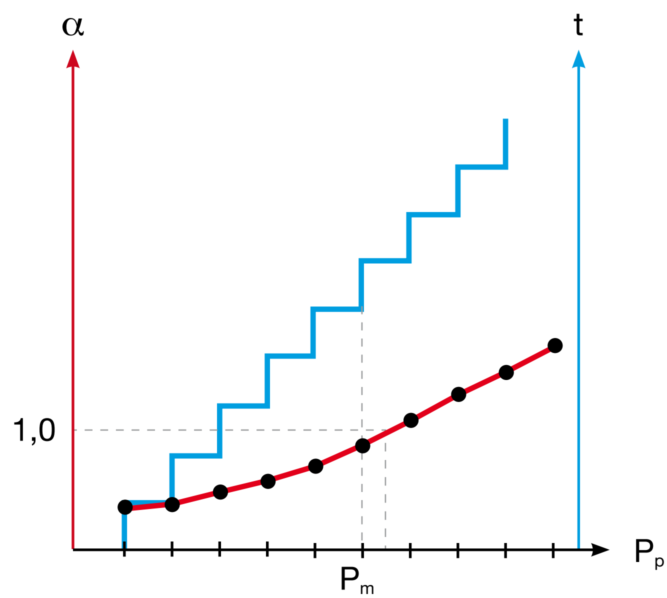


Figure 8.4: determining Pm

The interpretation is adjusted depending on whether the test has allowed identifying an abrupt change in slope on the curve of a in function of the load (corresponding to P'_c on figure J.3), or not.

1st case: P_c is not identified during conformity testing

The design hypotheses from the execution sheet are validated.

Note: usually, the execution sheet is produced during the G3 stage (execution study) after exploiting the geotechnical models of the G2 stage (design).

The critical creep resistance $R_{cr;d}$ is the lowest value between the value $R_{cr;d}$ from the initial execution sheet and the value of P_m.

2nd case: P_c is identified during conformity testing

The design hypotheses from the execution sheet may not be validated.

The critical creep resistance $R_{cr;d}$ is the lowest of the three following values:

- the value $R_{cr;d}$ from the execution sheet
- the tension P_m
- and 0.9 . P_c

If critical creep resistance after testing is lower than the value of the initial execution sheet.

If critical creep resistance after testing is lower than the value from the initial execution sheet, one should either multiply the ground anchors, or lengthen them to take over the service load.

This last solution may imply carrying out additional tests.

Comment: if several conformity tests are available for ground anchors of a same category, the analysis shall first focus on comparing the results between these tests, and on the reasons why different conclusions could possibly be drawn.

8.5 SUITABILITY TESTS

8.5.1 NUMBER OF SUITABILITY TEST ANCHORS

A test anchor to control execution is executed for each series of forty ground anchors, with a minimum of three test anchors per site.

Note: site means fieldworks completed with a unity of time and space. Operations entailing zones separated by several hundreds of meters, or operations comprising stages being months apart, are not considered as being sites.

8.5.2 EQUIPMENTS AND DEVICES FOR SUITABILITY TESTS

One will peruse annex I, which summarises all the expected characteristics of the equipment used by all tests.

Picture 8.4: suitability test (© Soletanche Bachy)

8.5.3 PROCEDURE OF SUITABILITY TESTS

The suitability testing procedure consists in measuring anchor head displacements during increasing loading stages, then decreasing ones (see annex J).

Note: if he/she deems it as being useful, the person in charge of executing the test may extend the duration of the final stage, under the condition that it is first approved by the Project Manager.

The value of proof load is: $P_p = \gamma_{a;rec;ELS} \cdot F_k$

Note: as a reminder:

for a temporary ground anchor, $\gamma_{a;rec;ELS} = 1.15$

for a permanent ground anchor, $\gamma_{a;rec;ELS} = 1.25$

8.5.4 ACCEPTANCE CRITERION OF GROUND ANCHORS SUBJECTED TO A SUITABILITY TEST

Under the proof load P_p of a suitability test, the value of α measured between the times t_0 + 5 min and t_0 + 60 min shall not exceed:

- 1.2 for temporary ground anchors,
- 1.0 for permanent ground anchors.

If this condition is not met, the ground anchor is deemed as being invalid for its use (see paragraph 7.4.9.3).

8.6 *MONITORING*

What is meant by « monitoring » is the implementation of periodic controls that consist in checking the state of the ground anchor.

Note: for instance, the state of tension within the ground anchor, the apparition of corrosion stains on the head or a water leakage at the head level (which constitute a warning about the ground anchor sustainability).

Comment: monitoring shall be decided during the project design phase, because it may prove difficult, or even impossible, to implement it afterwards.

8.6.1 GROUND ANCHOR INSTRUMENTATION TO CONTROL TENSION

8.6.1.1 PURPOSE OF THE INSTRUMENTATION

The purpose of instrumenting ground anchors is not to reach an accurate measure of tension, but rather to follow-up how it evolves over time, with a view of detecting any abnormal behaviour (tension loss, tension increase, etc.) before damages may impact the structure.

Comment 1: monitoring does not aim at clearing a doubt about the process, but at validating, with statistical measures, that tensions within the ground anchors are in line with the design, and at following how they evolve over time.

Comment 2: the next section (section 9) will provide Developers with recommendations relative to interpreting measures and to drawing consequences regarding controls.

Picture 8.5: instrumented anchor head (© Freyssinet)

Picture 8.6: instrumented anchor head with radio signal (at the forefront) (© Freyssinet)

The Contract (particular technical specifications and conditions*) shall specify if an instrumentation is required in the case of passive ground anchors.

8.6.1.2 OPPORTUNITY TO PROCEED TO A TENSION CONTROL

The tension of ground anchors having a lifetime greater than 2 years shall be periodically controlled during the whole lifetime of the ground anchor.

For temporary ground anchors having a lifetime lower than, or equal to, 2 years, the Contract shall specify if a periodic tension control is required, given the specificities of the structure, and shall set out the terms of such a control.

8.6.1.3 RESPONSIBILITY OF TENSION CONTROL

The first tension control of ground anchors, achieved in the continuity of the ground anchor acceptance test, is borne by the contract holder.

Unless otherwise specified in the Contract, subsequent tension controls of ground anchors will be borne by the Developer, or by the owner of the structure (see paragraph 9.7).

8.6.1.4 TENSION CONTROL SYSTEM

8.6.1.4.1 DEFINITION

A certain number of ground anchors of the anchored structure have to be equipped with a device that allows a regular control of tension.

The head of a ground anchor equipped with a tension control device shall also be compatible with a direct measure of tension by lock-off test during the whole ground anchor lifetime.

Comment 1: measuring tension by lock-off test notably allows verifying that the control device does not reveal any malfunction or deviation.

Comment 2: ideally, all ground anchors (whether they are instrumented or not) should be suitable for lift off ; cost overruns are particularly low for bar ground anchors.

Some specific designs of anchoring blocks allow replacing faulty control devices. The Contract specifies if using this technology is a requirement.

Note: this issue does not exist when using nuts (of bar ground anchors).

8.6.1.4.2 REFERENCE GROUND ANCHORS

Each ground anchor equipped with a control device shall be associated to at least 2 reference ground anchors, which also have heads allowing a direct measure of tension by lift off.

Note: the reference ground anchors belong to the same category (see paragraph 8.2.1) than the ground anchor equipped with a control device, and are located at its immediate proximity.

Direct tension control by lift off of the ground anchor equipped with a control device and of the reference ground anchors allows producing additional elements for the analysis and decisions relative to the behaviour of the anchored structure, with a view of defining the possible measures that should be taken to restore a normal situation.

Ground anchors equipped with a control device, as well as reference ground anchors, are selected in function of their accessibility, which takes into account the reading of control devices and the carrying out of lock-off tests during the whole lifetime of a ground anchor.

8.6.1.4.3 LAYOUT AND NUMBER OF CONTROL DEVICES

In each category (see paragraph 8.2.1), the minimum number N_A of ground anchors to be controlled, i.e., the minimum number of ground anchors that have to be equipped with control devices, is given by table 8.2 below.

ν	N_A	ν	N_A
1 to 10	1	93 to 110	9
11 to 20	2	111 to 130	10
21 to 30	3	131 to 150	11
31 to 40	4	151 to 170	12
41 to 50	5	171 to 190	13
51 to 64	6	191 to 210	14
65 to 78	7	211 to 230	15
79 to 92	8	231 to 250	16
Beyond 250 ground anchors, an additional control device shall be planned for each series of 20 anchors			

Table 8.2: number of control devices in function of the number ν of ground anchors in each category

The choice and distribution of ground anchors equipped with control devices shall take into account the criticality of the ground anchors and of the load and length ranges.

The Contract may specify an increase of the number of ground anchors equipped with a control device (N_A) in function of the critical features of the anchored structure.

Note: for highly sensitive structures, equipping all ground anchors with a control device may be recommended.

8.6.1.4.4 CRITERIA FOR CHOOSING CONTROL DEVICES

Control devices (see note 1) shall be reliable, simple, sturdy and adapted to the maximum tension exerted by the ground anchor (see note 2).

Note 1: there are different types of control devices: electric or hydraulic cells, equipped with vibrating wires, with stress gauges, using magnetostriction properties, etc.

Note 2: the maximum load is often the proof load of the acceptance (and suitability) test.

They shall produce an assessment of tension with accuracy equal at most to 10 % in regard to the force deduced from the jack pressure (after correction of friction), which is taken as reference.

Replacing control devices is most often complex and costly: one should be cautious when choosing control devices if the structure has a long lifetime.

Note: some control devices cannot be replaced.

Comment: choosing the number and type of control devices shall take into account the fact that such devices of permanent control inevitably end up with a failure rate.

The Contract may plan for an additional apparatus, with the purpose of automating the control and warning system.

Comment: gathering in the same point the automated readings of the various control devices leads to greater initial costs, but also allows decreasing the difficulty, duration and cost of all subsequent periodic visits.

8.6.1.4.5 IMPLEMENTATION OF CONTROL DEVICES

The anchor head, the bearing plate and the control device shall be conceived as a whole, by notably respecting the following recommendations:

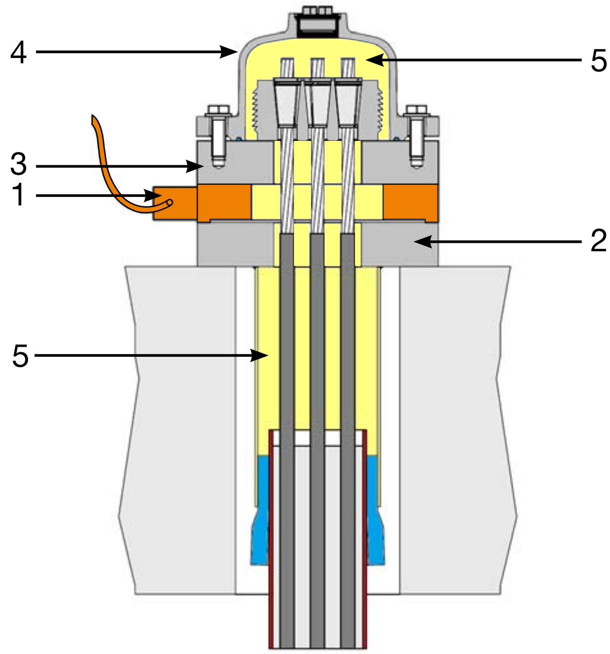
- at the design stage, a sufficient space should be planned for to install the control device and provide access to the anchor head equipped with the device, which encumbrance may sometimes be greater than the one of a non-equipped head,
- ensuring that the support surfaces in contact with the control device are fully plane, and perpendicular to the ground anchor,
- depending on the sensitivity of the site and of the structure, planning for a protection of the electrical equipment against lightning or submersion,

- planning for a protection of the control device against corrosion (if the device is not installed under the cap that ensures the protection of the anchor block)
- ensuring that the electrical wiring has proper routes, waterproofing and protection,
- ensuring that a periodic calibration is feasible (see paragraph 8.6.1.4.7), and, if needed, that the control device may be replaced over time.

Picture 8.7: anchor head with a cap equipped with a control device
(© François Morel-EDF)

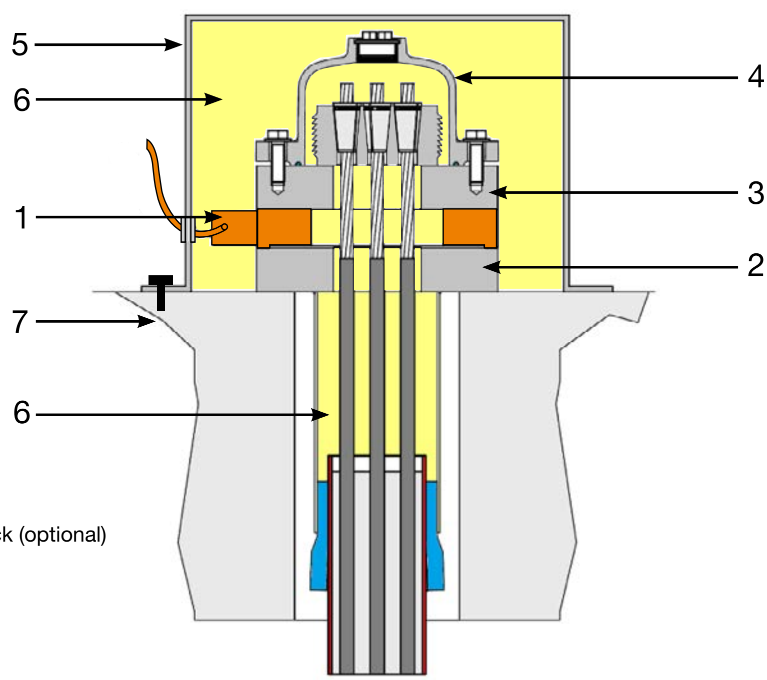
Picture 8.8: Anchor head instrumented with a type P protection
(© Soletanche Bachy)

Picture 8.9: Adjustable anchor head with a removable load cell (© Alexis Piron-EDF)



Labels:
1: Control device
2: Bearing plate
3: Distribution plate
4: Protection cap of the anchoring block
5: Anticorrosion wax (or equivalent)

Figure 8.5: example of assembly of a control device on an open air anchor head



Labels:
1: Control device
2: Bearing plate
3: Distribution plate
4: Protection cap of the anchoring block (optional)
5: Cap enclosing the cell
6: Anticorrosion wax (or equivalent)
7: Fastening apparatus

Figure 8.6: example of assembly of a control device on a confined anchor head

8.6.1.4.6 ACCEPTANCE OF THE CONTROL DEVICE

When the control device is being installed, an acceptance test should be carried out on it to ensure its conformity and proper functioning. This test shall notably include the following steps:

- checking that the control device is supplemented by its calibration certificate,
- carrying out a first measure on site, prior to installing it, in order to verify that the zero position of the sensor is correct,
- carrying out a second level of verification by comparing the force applied by the jack to the reading on the control device. This operation may be achieved during the stages of a suitability test or when carrying out measure points during the ground anchor stressing stage.

If a discrepancy greater than 10% between the reading on the control device and the jack pressure is observed on one of the last three stages or measure points, the origin of the discrepancy shall be researched (positioning error of the control device, malfunction, etc.). If the control device is deemed as being faulty, it shall be replaced.

After ground anchor lock-off and jack release, a final measure from the control device is carried out, and recorded on the stressing sheet. This value is compared to the true tension value after lock-off, deduced for the stressing curve.

Note: the force deduced from the jack pressure (after correction of friction) is taken as a reference.

8.6.1.4.7 METROLOGICAL VERIFICATION OF THE CONTROL DEVICE

The purpose of the metrological verification of the control device is to ascertain its proper functioning, notably the absence of deviation over time.

The frequency of the metrological verification is specified in the maintenance file of structures (or equivalent document).

Note: an abnormal variation (or an absence of variation, if a variation was expected) of the measures carried out with the control device may also impose this verification.

The metrological verification of the control device consists in carrying out lift off (see paragraph 8.6.2), and in comparing the value deduced from the lift off curve, assumed as being the reference, to the indication logged from the control device. If the difference between this discrepancy e2 and the one e1 observed during stressing is greater than 10% ((e2-e1)/e1>10%), the observed deviation may justify replacing the control device.

8.6.2 TENSION CONTROL BY LOCK-OFF TEST

WARNING

Because it implies stressing the tendon, lift off is a dangerous operation.

At the very least, the following recommendations shall be respected:

- prohibiting the zone to people not concerned by the operation,
- entrusting the operation with trained and qualified personnel,
- using sound equipment,
- verifying that the anchor heads do not show any apparent defect.

8.6.2.1 OBJECTIVES OF THE CONTROL BY LIFT OFF

Lock-off test may either be part of the periodic follow-up of the anchored structure, specified in the maintenance file of structures (or equivalent document), or be triggered by an abnormal evolution of forces observed by the control devices in the ground anchors, and/or by a behaviour anomaly from the anchored structure.

Lock-off test is also used to verify the proper functioning of the control devices, when ground anchors are equipped with them (see paragraph 8.6.1.4.7).

The analysis of the measures produced by lift off may trigger a tension adjustment (see paragraph 8.6.4.2).

In some cases, lift off may be supplemented by a proof stage.

8.6.2.2 PREPARATION OF THE LIFT OFF OPERATION

Preparing the lift off operation includes collecting data regarding anchor history (its execution, its stressing, the evolution of its tension over time, prior controls and lock-off tests, the anomalies that were possibly observed, the corrective actions that were undertaken, etc.).

For a ground anchor to be lifted off, it shall imperatively be equipped with a restressable anchor head, which is an issue to be taken into consideration as early as the design stage.

Prior to carrying out lift off, the protection cap shall be removed and the anchor head has to be unobstructed and cleaned. A visual inspection of the anchor head shall be done after cleaning.

Note: in some cases, for instance when there is apparent corrosion or presence of water, visual observations may lead to more thorough measures and investigations before allowing lift off.

The remarks made during this inspection are recorded on the lift off log sheet, with supporting pictures if needed.

If the observations made demonstrate that the lock-off test cannot be achieved, precautionary measures shall be taken (usually, and at the very least, initiating an enhanced structure monitoring). The enquiry shall be extended to the whole structure, and corrective provisions may prove required.

Ground anchor lock-off test shall be carried out without delay after the anti-corrosion protection of the anchor head is removed.

8.6.2.3 SPECIFIC LIFT OFF EQUIPMENT

The capacity of the system used to carry out lift off (jack and bearing chair) shall be at least equal to the one used for stressing (see paragraph 7.4).

Unlike with ground anchor stressing, where the jack is directly plugged on the tendon, lift off usually demands a specific design of the connecting system between the anchoring block and the jack (barrel, support stiffness, etc.).

Labels:
1: Tension nut
2: Jack
3: Bearing chair
4: Tension barrel
5: Tension rod
6: Threaded anchoring block
7: Bearing plate
8: Cable ground anchor
(anti-corrosion protection is not represented)

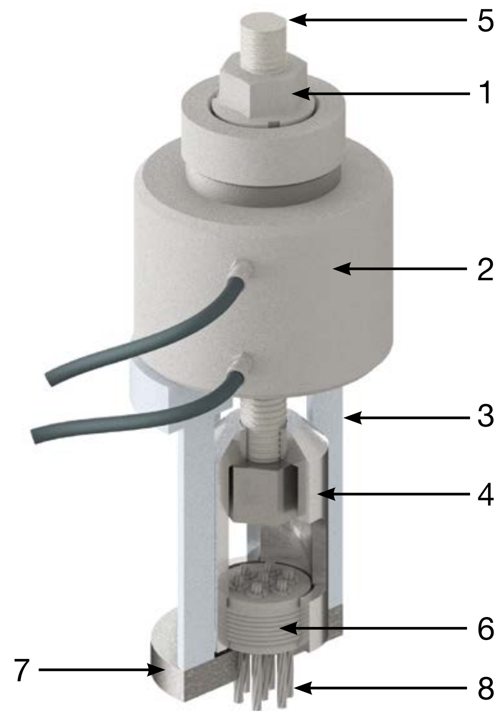


Figure 8.9: example of a lift off system for the head of a cable anchor (threaded anchoring block)

Labels:
1: Jack
2: Threaded anchoring block
3: Bearing chair
4: Bearing plate
5: Cable ground anchor
(anti-corrosion protection is not represented)

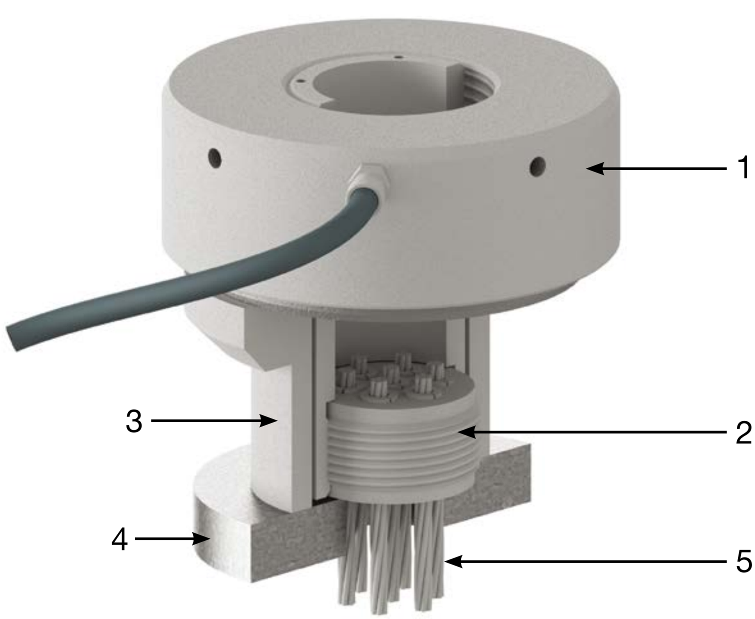


Figure 8.10: example of a compact lift off system for the head of a cable anchor (threaded anchoring block)

Label:
1: Tension nut
2: Jack
3: Bearing chair
4: Coupler
5: Tension rod
6: Anchoring nut
7: Distribution plate
8: Tendon (anti-corrosion protection is not represented)

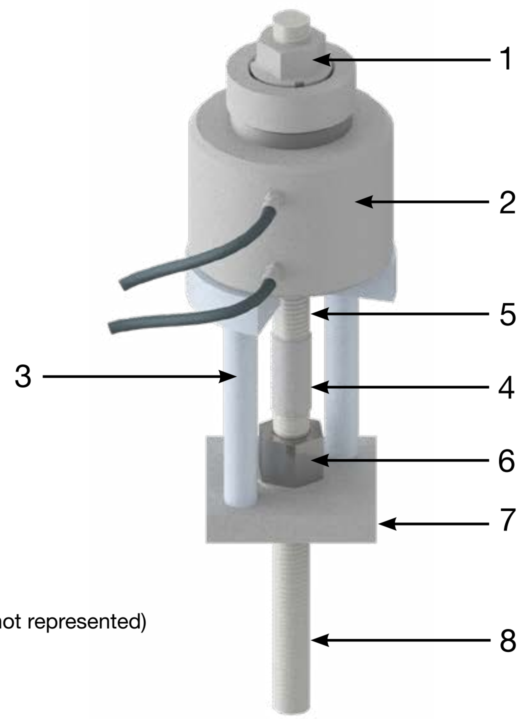


Figure 8.11: example of a lift off system for the head of a bar anchor

8.6.2.4 LIFT OFF PROCEDURE

Lift off is a difficult operation that shall be tasked to a company possessing the required qualifications (see paragraph 9.4) and, whenever possible, this should be the company that executed the ground anchors.

The key issues of lock-off test (real-time plotting of the curve, choosing intervals and deciding whether to stop or resume loading) are complex ones, and shall only be handled by an experienced operator.

During lift off, the tension value in the ground anchor is determined by the detachment of the anchor head.

Comment: this detachment is not always easy to spot. It is usually more accurate to assess it through a monitoring of deformations, by carefully exceeding the true tension in the ground anchor.

The lock-off test is calibrated on the basis of the supposed tension in the ground anchor, which shall be assessed beforehand from the following data:

- tension displayed on the control device (for instrumented ground anchors),
- serviceability tension,
- proof load (during stressing),
- ground anchor histories after they were implemented.

When these data are incomplete, or even non-existent, safety precautions shall be enhanced (for instance by offsetting the instruments of measures) and the programme may not be completed.

These data are also used to set the maximum force not to be exceeded during lift off.

Comment: this value depends on the lift off objectives (see paragraph 8.6.2.1).

The maximum force applied during lift off shall not exceed the proof load of the anchor acceptance test.

You should produce enough measure points so the operation may be deemed as being representative.
Determining these measure points is based on the following considerations:

- 6 tension increments are regularly distributed up to the supposed tension in the concerned ground anchor (see note 1);
- when a break in the curve slope is noted (and/or if the detachment of the anchoring block is visually observed), the following measuring intervals are reduced so at least 4 points are produced, with the final one being the maximum tension (see note 2);
- when the maximum jack pressure is reached, it is required to carry out closer increments at the start of the decrease (for instance, one every 0.5 MPa) ;
- then, ground anchor destressing starts by carrying out the very same increments than during the tension build-up (before detachment), unless there has been less than 3 increments (in which case at least 3 measure points should be carried out during the decrease);
- if no slope break is observed (or no detachment of the anchor head) before reaching maximum pressure, one should question the value of maximum tension and/or the lift off objectives.

Note 1: the first increment may be impacted by the installation at the start and by the catch-up of looseness.

Note 2: the 4 additional points may not be researched, especially when the ground anchor history is poorly known.

Comment: when works are automated, the build-up may be achieved, e.g., with a rate of 2 kN/s and of 5 to 10 kN/s during decrease.

If anchor head detachment occurs prematurely, and consequently prevents the proper exploitation of the stressing curve plotting because of a lack of points, lock-off test shall resume with a reduction of intervals.

The anti-corrosion protection of the anchor head shall be restored without any delay after the test is completed.

Picture 8.10: lock-off test of a ground anchor with an instrumented head (© Freyssinet)

8.6.2.5 PLOTTING AND INTERPRETING THE LIFT OFF CURVE

The lift off curve shall be plotted in real time.

The measure points recorded during build-up and decrease allow plotting the lift off curve, an example of which is displayed in dashed dots on the idealised graph below (see figure 8.12).

Whenever possible, the lift off curve should be plotted on a copy of the original stressing sheet, in order to better analyse the behaviour of the ground anchor to be lifted off.

The lock-off test shall allow clearly identifying the linear parts of the curve, before and after the anchor head lifts off.

In each of both linear zones, the median lines are plotted, which correspond to the true forces in the ground anchor. This plotting is carried out by considering the perpendicular to the curves of build-up and decrease (see the example of figure 8.12).

The intersection of these two curves (point A) characterises the effective tension in the ground anchor. On the graph, the pressure corresponding to this point is labelled as Π1. This pressure should be converted into a force by multiplying it with the cross-section of the lift off jack. The friction indicated on the jack calibration certificate shall not be taken into account because it is cancelled by the stressing/destressing cycle.

Comment: other interpretation methods are possible, such as, e.g., the one of 7.4.8.4. The choice of method is usually decided in function of the lift off objectives.

8.6.2.6 LOCK-OFF TEST FACTUAL REPORT

A factual report relative to lock-off test shall be written by the company that completed this operation, and then handed to the Developer.

This report notably includes:

- the location of the concerned ground anchors and their technical characteristics,
- gross data and the curves plotted in real time,
- if needed, the characteristics of the control devices equipping these ground anchors,
- the procedure used to execute lift off, compliant to the execution (including the possible adaptations made on site),
- the technical characteristics of the lift off jack used, and its unexpired calibration certificate,
- the technical characteristics of the other equipment used to carry out lock-off test,
- the date of intervention for each ground anchor, and its duration,
- the observations made, and pictures taken, when disengaging the anchor head,

- the lift off curves, plotted whenever possible on the original stressing curves, and their analysis,
- the effective tensions obtained after lift off,
- recordings carried out on the control devices, and if needed, the comparison with the data obtained from the jack and the afferent analysis,
- the description of the lock-off test and the observations made (incidents, non-conformities, etc.),
- the detail of the methods implemented to restore the anti-corrosion protection of the anchor head.

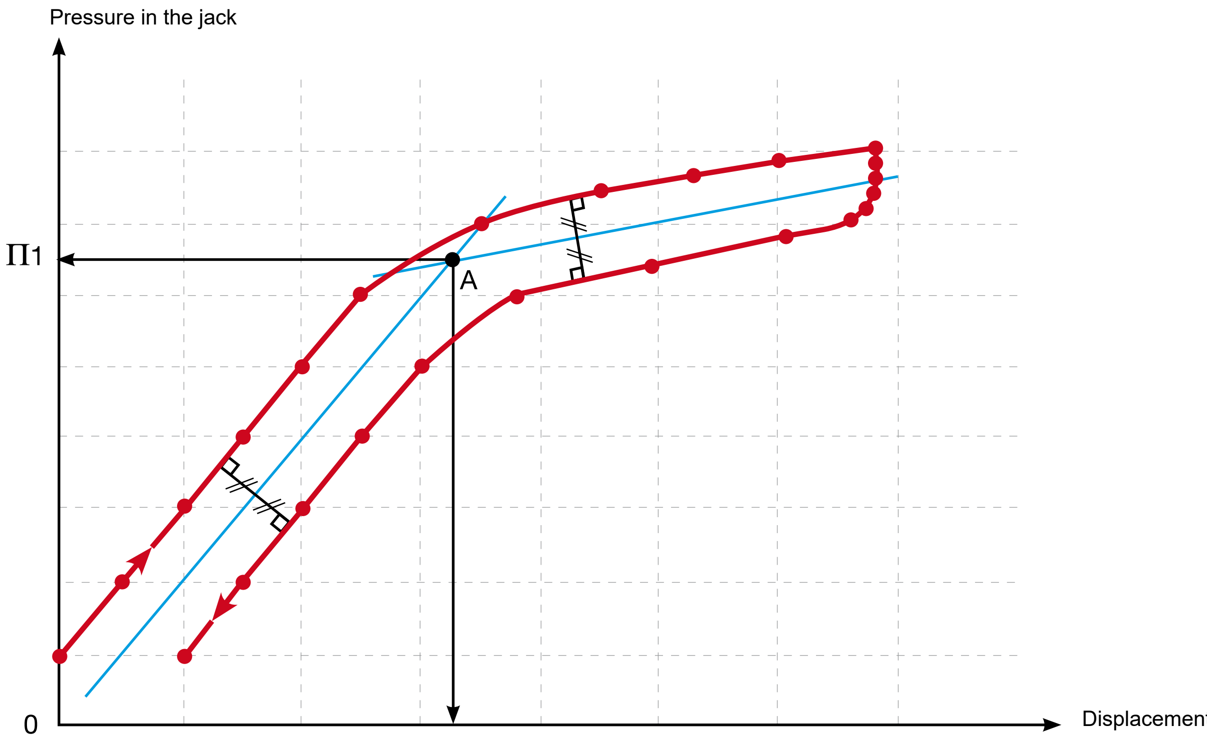


Figure 8.12: example of a lift off curve

8.6.2.7 CONTROL BY LOCK-OFF TEST WHEN THE ANCHOR HEAD WAS NOT DESIGNED FOR THAT PURPOSE

The present paragraph concerns ground anchors unequipped with monitoring systems (instrumentation, apparatus to take over forces), i.e., not designed to be lifted off at the date of implementation.

If stretching the tendon (bar or strands) is the selected solution, the coupler (see paragraph 4.1.4) or the connecting apparatus shall satisfy the requirements expected for anchor systems (see annex D).

In the case of cable ground anchors, a sufficient tendon over-length may allow taking over the tension on the strands, so that lift off can be achieved. Since this solution may damage the anchor system, it is unadvised and should only be used as a solution of last resort.

In the event this solution has to be implemented the following instructions should be respected at the very least:

- in no case should wedges be replaced above the initial location (see figure 8.13),
- the jack has to transmit forces to the bearing plate equipping the anchor head, through a bearing chair that allows the free motion of the anchor block,
- it shall be verified that the bearing plate can take over the applied load,
- a simultaneous take-over by all strands shall be favoured.

Note: it is reminded that the connection of the chair on the bearing plate is designed so efforts are transmitted without any harmful sliding.

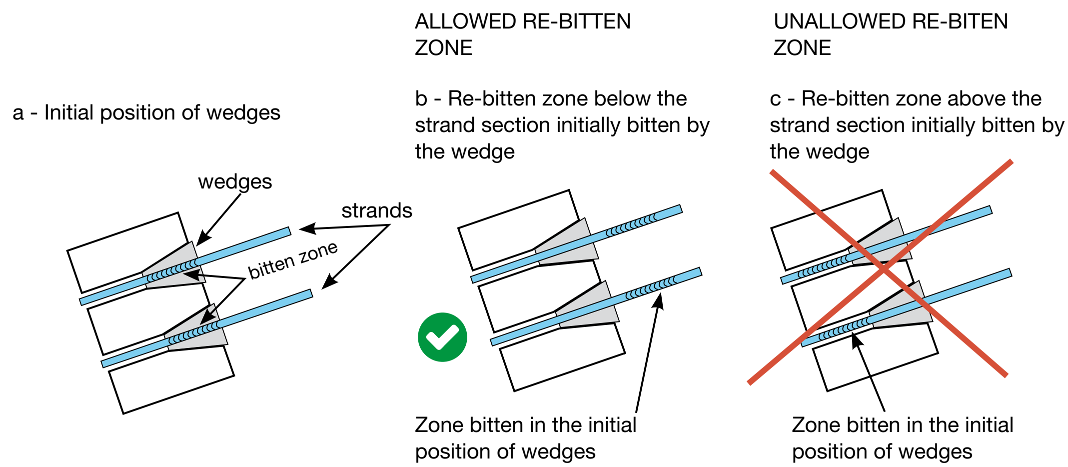


Figure 8.13: acceptable key position after a re-stressing operation causing wedge displacement

8.6.3 OTHER CONTROLS

8.6.3.1 OTHER CONTROLS OF TENSION

Non-destructive tests (END as French acronym) may be proposed to control ground anchor tension. Interpreting these tests requires a prior and appropriate calibration during ground anchor implementation, or during lock-off test.

As of today, these non-destructive tests may be of interest to reveal an anomaly, but may not replace lock-off test to determine tension with a sufficient accuracy in the ground anchor.

8.6.3.2 CONTROL OF THE GROUND ANCHOR SUSTAINABILITY

A visual inspection is almost always feasible, but remains limited to the anchor head. This visual inspection notably includes:

- examining the state of its apparent parts (cap, bearing plate) and of their anti-corrosion protections,
- searching any watertightness defect on the cap,
- examining the state of the anchoring block (or nut) when disassembling the cap, and after cleaning it (removing the anti-corrosion protection: grease, wax),
- whenever possible (access via the anchoring block), verifying that the trumpet tube is properly filled with the anti-corrosion product,
- whenever appropriate, examining the state of preservation of the control device,
- whenever appropriate, verifying the integrity of the protection system against power surges of the electrical control devices.

It is difficult to detect a possible alteration of the tendon over the anchor length. Only the verification of tendon integrity is currently achievable by non-destructive testing, notably for bars, using ultrasound and/or electromagnetic methods.

Note: What is meant by “sustainability” here is the state of preservation of tendons, notably in regard to corrosion, and to “integrity”, i.e., tendon breakage (or a situation that may lead to tendon breakage).

8.6.3.3 INSPECTION REPORT

After any intervention is completed, a detailed report shall be written by the company undertaking the inspection.

This report shall notably include the date of intervention, the location of the concerned ground anchor, the synthesis of observations made, pictures, methods implemented to restore the anti-corrosion protection and the recommendations stated.

The parameters that may lead to an evolution of tension should be logged:

- external temperature,
- head temperature (measuring devices),
- if pertinent, piezometric levels.

The inspection report may recommend carrying out additional controls.

8.6.4 EXPLOITING MONITORING DATA

8.6.4.1 ANALYSIS OF LOCK-OFF TEST RESULTS

A lock-off test campaign shall be supplemented with a more general analysis, based notably on:

- an analysis of the lock-off test factual report of ground anchors,
- the inspection report(s),
- the recording(s) from control devices,
- an analysis of the structure behaviour that integrates the lifetime history of the structure,
- any other available pertinent data (visual inspection of the structure and other structures at proximity, data produced by other instrumentation devices, logging and analysis of possible damages, etc.).

Besides being compared to the tension displayed by the control device (if the concerned ground anchor is equipped with such a device), the effective tension remaining in the ground anchor, as assessed by the lock-off test, is also compared to:

- F_k if the lock-off test occurs during the serviceability stage of the structure,

- P_0 if the lock-off test occurs shortly after the concerned ground anchor is tensioned (for instance, when there is a suspicion of undesired tension variations).

If the effective tension differs from the tension initially set during structure design, one may take advantage of the lift off operation to adjust tension (see paragraph 8.6.4.2).

8.6.4.2 ADJUSTMENT OF GROUND ANCHOR TENSION

WARNING

Because it implies stressing the tendon, adjusting tension is a dangerous operation.

At the very least, the following instructions shall be respected:
- prohibiting access to the work zone to people not concerned by the operation,
- entrusting the operation with skilled and experienced personnel,
- using sound equipment,
- checking that ground anchors heads do not show any apparent defect.

8.6.4.2.1 GENERAL PRINCIPLES

In all cases, adjusting tension is a difficult operation that shall only be undertaken knowledgeably, with all the required precautions. A company possessing the appropriate qualifications and experience shall be missioned for this (see paragraph 9.4). Whenever possible, this company should be the one that executed the ground anchors.

Besides, adjusting ground anchor tension requires a full structure study and an analysis of its behaviour (see note).

Note: in particular, comparing tension during implementation with tension a year later may produce a « fair » assessment of this behaviour.

After adjusting ground anchor tension, the monitoring programme of the structure shall be reviewed, and the frequency of controls shall possibly be adapted, at least in the early days.

Adjusting ground anchor tension is usually less difficult:
- with bars than with strands,
- when it is planned for during the structure design stage (bar over-lengths, « restressable » anchor heads for strands, etc.).

It is unadvised to proceed to a destressing of strand anchors having an anchor head that was not designed for that purpose (heads allowing adjusting tension).

8.6.4.2.2 PRACTICAL METHOD

After lift off, if the tension in the ground anchor needs adjusting (higher or lower), the theoretical value of which the anchor head has to be displaced, Δl, may be graphically determined from the curve of true tension applied to the ground anchor (see below):

1. Π2 is calculated, which is the pressure corresponding to the force being researched (tension adjustment). The required force is divided by the cross-section of the lift off jack, disregarding the friction indicated on the calibration certificate of the jack.
2. The point B is plotted, which corresponds to Π2 (force being researched), on the median line.
3. The discrepancy between the projections of points A and B on the x-axis produces the value Δl being researched. This value is usually rounded to the nearest millimetre.

Adjusting tension is carried out either by interposing or removing load-transfer blocks, or by modifying the position of the nut or threaded ring equipping the anchor head. This operation is carried out during an additional stressing stage, by applying to the jack a pressure higher than $\Pi(P_i)$ in order to sufficiently detach the anchoring block.

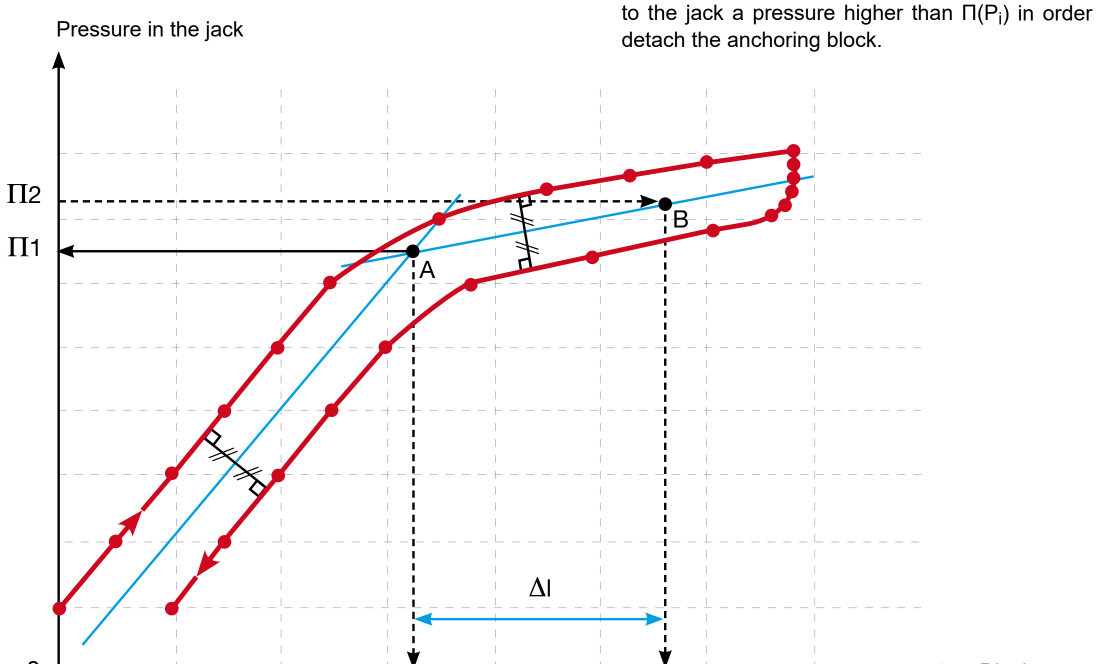


Figure 8.14: determining Δl for re-stressing

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9 RECOMMENDATIONS FOR DEVELOPERS

9.1 PREAMBLE

9.2 GEOTECHNICAL INVESTIGATIONS AND STUDIES

9.3 SPECIFICITY OF GROUND ANCHORS

9.4 CHOICE OF CONTRACTORS

9.5 PROTECTION OF GROUND ANCHORS

9.6 TESTS

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9.8 INSTALLATION AUTHORISATIONS AND FEES

9.9 PARTICULAR PROVISIONS RELATIVE TO ANCHORED STRUCTURES

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9 RECOMMENDATIONS FOR DEVELOPERS

9.1 PREAMBLE

Ground anchors, whether temporary or permanent, have the purpose of stabilising civil engineering structures or buildings of various functions (see annex A), and are frequently used, in both the fields of construction and public works, because of the benefits gained from this technique.

The attention of Developers and their advisors should be drawn on some specificities characterising ground anchors, their execution, control and monitoring.

9.2 GEOTECHNICAL INVESTIGATIONS AND STUDIES

Within the framework of a project entailing ground anchors, appropriate hydrogeological, geological and geotechnical investigations and studies shall be carried out beforehand, in compliance with standard NF P 94-500.

The attention of Developers is drawn on the fact that ground anchors often fall outside the investigative scope allocated to building the structure. The Developers shall consequently acquire data for the zones where ground anchors will effectively be executed.

Developers should notably collect data relative to the aggressivity of soils, waters and the environment of the site where the ground anchors will be located (see annex E).

9.3 SPECIFICITY OF GROUND ANCHORS

Technology plays a fundamental role in the field of ground anchors.

Developers shall notably pay attention to:

- the method used to execute the borehole in which the tendon will be installed,
- the borehole diameter, in regard to the ground anchor diameter,
- the manufacturing method of the ground anchor,
- the type of anti-corrosion protection,
- the bond method of the ground anchor,
- ground anchor monitoring, and more generally, monitoring of the anchored structure,
- the possibility of achieving a future adjustment of tension.

9.4 CHOICE OF CONTRACTORS

Developers shall pay a particular attention to the qualifications of the various contractors and personnel hired to build the structure anchored by ground anchors:

- Project Managers having an experience of special geotechnical projects;
- geotechnical engineers entrusted with the missions G2 to G4 of standard NF P 94 500, in particular;
- companies specialised in the field of ground anchors, which are currently in a relatively limited number (see note);
- manufacturers and suppliers of tension control devices;
- contractors specialised in the fields of tests and controls, and in the monitoring of structures

Note: e.g., these companies hold a Carte Professionnelle de Travaux Publics (professional certificate of Public Works*) issued by the FNTP (National Federation of Public Works*) bearing the professional identification 254-ancrages (254-anchors*), or a qualification certificate Qualibat 1252 or 1253.

Managing the operation may prove difficult when using a chain of sub-contractors.

9.5 PROTECTION OF GROUND ANCHORS

During its lifetime, and because the ground anchor is a structure that is mainly buried, protecting tendons against corrosion is essential.

The anti-corrosion protection of the elements constituting the ground anchor depends on the type of project, on its lifetime and on the aggressivity of the environment. The Developer will find useful information pertaining to this in section 6.

The anti-corrosion protection shall notably be fully guaranteed at the connection between the anchor head and the end of the free length. At this point, the tendon is particularly exposed to corrosion (in particular, see the paragraphs relative to the anchor head, in section 6).

The Developer shall take all required precautions to avoid any damage to anchor heads during the whole lifetime of the structure.

If it proves required to temporarily remove the anti-corrosion protection of the anchor heads (for instance, when carrying out an inspection), or if this protection becomes damaged, its integrity shall be restored without any delay.

9.6 TESTS

Despite the thoroughness with which the geotechnical investigation is achieved, some uncertainties may remain and affect the knowledge about the soils in which the ground anchors are installed.

To these uncertainties, others may be added, related to the very technology of ground anchors (see paragraph 9.3 above). Developers should therefore carry out the tension tests described in the present document.

We remind you in particular how investigations tests are useful for designing, when available as soon as possible

Applying the pre-design methods (see note) described in annex H does by no means exempt the company from carrying out the tension tests described in the present document.

Note: notably, pre-design methods are very useful to promptly assess the soundness of a succinct pre-project.

9.7 MONITORING

9.7.1 GENERAL GUIDELINES

For ground anchors with a lifetime greater than 2 years, Developers shall carry out an inspection and a systematic tension control on a certain number of ground anchors equipping the structure. For that purpose, Developers and Project Managers shall take care of the later accessibility of the ground anchors selected for this aim (see paragraph 8.6).

In the case of a large number of ground anchors, it may be pertinent to automate the recording, storing and processing of data.

The procedure of periodic control, as for any other required pertinent data relative to forces and instructions of these ground anchors, shall be notified by the Developer or Project Manager to the operator and/or be mentioned in the co-ownership regulations (or equivalent document).

Note: this recommendation is also valid when ownership or operating rights change.

Comment: procedures include, e.g., the nature of controls (visual inspection, tension control, lock-off tests, etc.) or their duration and frequency (see paragraph 9.7.2).

To enable a better follow-up of the structure, it is strongly advised to Developers to equip all final ground anchors (see note) with anchor heads that allow lift off and/or adjusting tension afterwards.

Note: such a measure may also be useful for non permanent ground anchors.

9.7.2 DURATION AND FREQUENCY OF PERIODIC TENSION CONTROLS

At first, control is usually a quarterly one, with the final quarterly control being carried out a year after the last stressing of the ground anchors equipping the structure. Beyond this point, control becomes annual and extends over the whole lifetime of the structure (see paragraph 8.6.1.2), at a fixed date during the year.

When seasonal variations may influence the behaviour of the structure, an increased frequency of control may be decided by the Developer.

Comment: the attention of Developers is drawn on the required completion of these controls over the period extending between the last control carried out by the company and the acceptance date of structures. The Contract may specify which entity is entrusted with the duty of carrying out these controls.

9.7.3 CASE OF AN ABNORMAL BEHAVIOUR

When periodic controls reveal a potentially abnormal behaviour of the ground anchors or of the anchored structure, a geotechnical engineer (see note), or a specialised Project Manager should be contacted.

Note: if the structure is still in the process of being built, those are usually the geotechnical engineers who carried out the G3 and G4 missions (standard NF P 94 500).

Comment: for guidance, the following may be deemed as constituting an abnormal behaviour:
- an absolute tension variation of 20% for a given ground anchor,
- a frequent variation, or a total absence of variation, of a control device,
- a significant variation (more than 2%), toward the same direction, of several devices.

Other measures, other types of controls (such as lock-off tests) and/or additional provisions may then be recommended

9.8 INSTALLATION AUTHORISATIONS AND FEES

In the more general case, ground anchors in the periphery of the structure to be built are located under abutting properties or under public land.

Developers are liable for acquiring, prior to executing ground anchors, the required authorisations from the owners of the concerned lands, and to pay for the incurred fees.

Comment: this issue of lands in the vicinity should be addressed as soon as possible (preferably before issuing the Contract, or, otherwise, one may undergo additional technical constraints or a poorly provisioned financial burden.

9.9 PARTICULAR PROVISIONS RELATIVE TO ANCHORED STRUCTURES

For exceptional structures, or structures likely to be subsequently modified, or structures within an environment likely to change, the Developer may require a design founded on criteria of safety.

This type of design consists, for instance in the case of an accidental ground anchor breakage, in temporarily distributing the corresponding reaction as temporary over-tensions on a sufficient number of adjacent ground anchors. Executing one, or several, additional ground anchor(s) shall then be taken into consideration, within the shortest delay, to terminate these over-tensions.

In such cases, where one or several additional ground anchors should be executed, the Developer shall plan for a certain number of spaces in the body of the anchored structure (see comment) in which new ground anchors may be installed.

The selected spaces have to be accessible to allow, firstly the set-up of a drilling rig, and secondly the implementation, without any excessive difficulties, of the execution operations for the new ground anchor(s).

Comment: these spaces are also useful to mitigate a ground anchor failure during a first stressing.

Anchored structures shall be capable of resisting both the temporary loads caused by load transfers due to the accidental failure of a ground anchor, and the loads resulting from the execution of additional ground anchor(s).

Comment 1: it is not necessarily required to proceed in advance to the reinforcement of anchored structures. What is sufficient is that it was planned for during the design stage of the structure, and that it can be subsequently executed without any excessive difficulties.

Comment 2: in the event of an accidental tendon breakage, anchor heads may be brutally ejected from their bearing elements. As a result, they may cause injuries to people, or damages in the vicinity. Unless the immediate environment cannot be accessed by people, or specific precautions were taken about the vicinity, Developers should secure anchor heads to the other elements or use systems that can efficiently prevent any accidental head projection (with, e.g., a protection plate or a chain).

9.10 CONTRACT DOCUMENTS

The results of the geotechnical study (see paragraph 9.2) shall be fully stated in the written documents of the undertaking contract, so companies specialised in the field of ground anchor execution, when formulating their technical proposal, may be thoroughly informed of the parameters of the various geological levels (specific weight, friction angle, plasticity index, aggressivity of soils, level of the water table, etc.).

Comment: geological and geotechnical investigations should preferably be carried out on the volume of ground concerned by ground anchors (see paragraph 9.8).

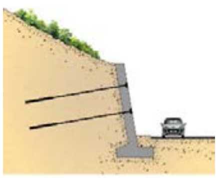
The Developer shall pay great attention to the drafting of the written documents of the Contract, which specify the expected role of the ground anchors, their lifetime, the tests and controls to which they will be subject, and the type of anti-corrosion protection they will require.
The documents that companies shall contractually provide to Developers are, at the very least, the following:

- a technical note that defines:
    - the qualification and function of the employed personnel,
    - the main characteristics of the ground anchors to be executed (type, resistance and/or service tension, spacing, lengths, etc.) and of their associated equipment, including authorisations if needed.
    - the type and implementation procedure of the chosen anti-corrosion protection,
    - the execution procedure (drilling, manufacturing, installation, bonding, stressing) and the technical characteristics of the equipment and products being used, including the calibration certificate of the jacks,
    - the achievement of tests, including summarising tables and the interpretation resulting from them,
    - the make and model of the control device being used, its characteristics, its installation conditions, and the calibration certificate of each control device,
    - the measures taken to guarantee safety on the site.
- the plan that provide details of the structure of the proposed ground anchor, and an overview plan of all ground anchors to be installed on the anchored structure.

Comment: when drafting written documents, a distinction should be made between what matters and what does not. Operation costs are directly bound to the scope of obligations imposed to companies. When they are not needed, such costs should be avoided so they do not burden the project. The present document was drafted to satisfy this requirement: only few additional elements are required to use it in an operational manner.

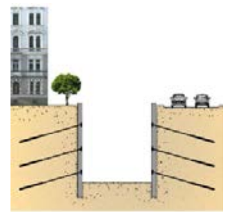
ANNEX A - EXAMPLES OF GROUND ANCHOR USES

Retaining walls



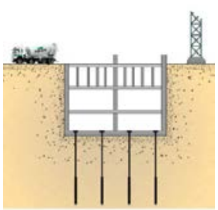
The ground anchor is the essential element that transmits forces from a retaining wall to the ground, thus guaranteeing the overall stability.

Excavations



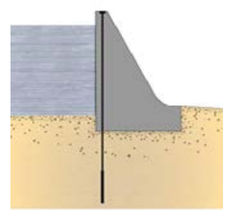
The use of ground anchors allows executing very large excavations, without overspace. Wall displacements during the various project stages are brought over control through the prestressing force applied to the ground anchor.

Uplift forces



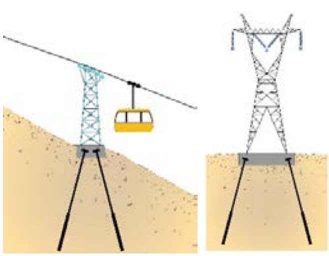
Executing vertical ground anchors, to take over uplift forces due to a hydrostatic thrust, allows stabilising a structure by blocking motions.

Dams



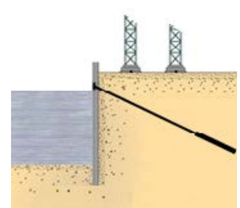
Dam stability may be enhanced by ground anchors installed in the substratum. Besides increasing tilt resistance, the applied prestressing allows improving dam waterproofing.

Pylon anchorage



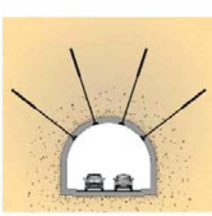
Anchoring pylons with prestressed ground anchors limits, or cancels (notably in rocky grounds), the effects from fatigue on the anchor itself.

Quay walls



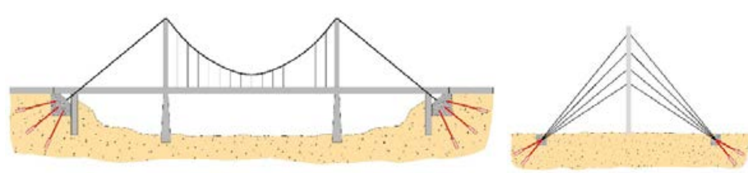
Taking over wall stability of existing quays is usually ensured by using prestressed ground anchors, in order to limit how tension varies with the variations of water levels.

Underground



When it is required to block vault motions, ground anchors are a sustainable solution.

Cable anchorage



Anchoring a cable anchorage mass to the ground (cable-stays, support cables) with prestressed ground anchors allows limiting, or cancelling (in rocky grounds), motions, and therefore the effects from fatigue.

ANNEX B - COMPARISON BETWEEN TESTS IN FUNCTION OF THE FRAMES OF REFERENCE

Table B.1 below indicates in bold the terms recommended by the Working Group

	failure testing on test anchors (1)		testing on structure anchors (2)	
TA 95 and present guide	**Investigation test**	**Conformity test**	**Suitability test**	**Acceptance test (3)**
NF EN 1537	Investigation test		Suitability test	Acceptance test
NF EN 1997-1 : 2005	Investigation test		Suitability test	Acceptance test
NF EN 1997-1/A1 : 2014	Investigation test	Suitability test (4)		Acceptance test
NF EN 1997-1-NA : 2018	**Investigation test**	**Conformity test**	**Suitability test**	**Acceptance test**
NF P 94-282	Investigation test		Suitability test	(5)
NF P 94-153	Failure test		Suitability test	(5)
NF EN ISO 22477-5	Failure test		Suitability test	Acceptance test

Tableau B.1 : comparaison des essais selon certains référentiels

1. The present guide adopts the term « test anchor » (see paragraph 3.1.1.7).
2. The present guide adopts the term « structure ground anchor » (see paragraph 3.1.1.6).
3. For ground anchors, an acceptance test is systematic, and one should not consider carrying out a statistical acceptance test (which may exist for other geotechnical structures).
4. Clause 8.5.2 (1) P introduces the « suitability test » which aims at measuring the ultimate limit state resistance of a ground anchor. This constitutes in fact a design control, i.e., it is a conformity test.
5. Undescribed concept.

ANNEX C - EVOLUTION OF NOTATIONS BETWEEN TA 95, NF EN 1997-1/A1, NF P 94 282 AND NF EN 1997-1/NA

C.1 COMPARISON OF NOTATIONS

Table C.1 below compares the notations used in the current and previous editions.

Only the definitions used in the present guide are being compared. The recommended notations are indicated in the grey cells.

NOTATIONS				Definitions (3)	see paragraph
EN 1997-1/A1	NF P 94 282	TA 95 (1)	**NF EN 1997-1/NA (2)**		
$\gamma_{a;ULS}$	γ_a		$\gamma_{a;ELU}$	Partial factor of ultimate limit state resistance for bonds in transient or permanent design situations	
$\gamma_{a;SLS}$	$\gamma_{a;c}$		$\gamma_{a;ELS}$	Partial factor of serviceability limit state resistance for temporary or permanent bonds	
$\gamma_{a;acc;SLS}$			$\gamma_{a;réc;ELS}$	Partial factor for the (acceptance) test of the bond in regard to serviceability limit state	
(4)	γ_{Rd}		$\gamma_{Rd;GEO}$	Partial factor of model relative to the justification method (tests vs design from charts, e.g.)	
nd	γ_{Rd}		$\gamma_{Rd;STR}$	Partial factor of model on the type of steel of structural elements of the ground anchor	
γ_{serv}			γ_{serv}	Partial factor for the effect of actions for ultimate limit states in permanent and transient design situations	
ξ_{ULS}			ξ_{ELU}	Correlation factor to be applied within the framework of a verification by test methods	
$E_{ULS;d}$	P_d	nd	E_d	Design value of the effect of actions at the ultimate limit state to which the bond has to resist	C.2
$F_{serv;d}$	nd	nd	F_d	Weighed design value of service tension F_k	C2 et C.3
$F_{serv;k}$	$P_{d;serv}$	T_s	F_k	Characteristic value of serviceability tension of the ground anchor, including the effect of the lock-off load	C.3
P_0		T_r	P_0	Lock-off load: residual load present in the anchor head immediately after the stressing operation	
P_b		T_b	P_b	Initial tension increased of all losses existing in the ground anchor before the material operation of lock-off	

(4)		T_i	P_i (4)	Initial tension, minimum value defined by design that has to exist in the ground anchor to guarantee structure stability during the future construction stages	
P_p		T_e	P_p	Proof load, maximum test load to which an anchor is subjected during a given load test	
$R_{SLS;d}$	$R_{ac;d}$		$R_{cr;d}$	Design serviceability limit state resistance value of the bond	C.2
$R_{SLS;k}$	$R_{ac;k}$	nd	$R_{cr;k}$	Characteristic serviceability limit state resistance value of the bond	C.2
$R_{ULS;d}$	$R_{a;d}$	nd	R_d	Design ultimate limit state resistance value of the bond	C.2
$R_{SLS;m}$	$R_{ac;m}$	T_c	$R_{ELS;m}$	Measured value of the bond critical creep resistance	
$(R_{SLS;m})_{min}$	$(R_{ac;m})_{min}$		$(R_{ELS;m})_{min}$	Minimum value of $R_{SLS\,;m}$ during several tests for each distinct soil condition	
$R_{ULS;m}$	$R_{a;m}$	T_u	$R_{ELU;m}$	Measured value of the bond pull-out resistance	
$(R_{ULS\,;m})_{min}$	$(R_{a\,;m})_{min}$		$(R_{ELU\,;m})_{min}$	Minimum value of $R_{ULS\,;m}$ during several tests for each distinct soil condition	
$R_{ULS;k}$	$R_{a;k}$	nd	R_k	Characteristic ultimate limit state resistance value of the bond	C.2
nd	$R_{t;serv;d}$	T_p	R_{max}	Limit conventional resistance of the tendon	
$R_{t;d}$	$R_{t;d}$		$R_{t;d}$	Design ultimate limit state resistance of the structural elements of a ground anchor	

1. The concepts covered by the TA95 are addressed relatively differently in the Eurocodes (for instance, the first one relies on SLS while the second one favours the ULS). The proposed corresponding items may only be approximate and require, if needed, a more thorough analysis.
2. Standard NF EN 1997-1/NA (national annex of the Eurocode) was revised in 2018, and you should adopt its notations.
3. These are not literal translations (« imposed » by the standardisation body) but more « French » transcripts, deemed as being equivalent.
4. This concept exists, but is not formalised by a notation in the standard.

Table C1: comparison of notations

C.2 COMMENTS ON THE REMOVAL OF SLS OR ULS INDEXES

For anchors, the design values of actions, or of the effects of actions, are solely associated to ULS verifications. It is therefore not pertinent to mention the type of limit state being verified (ULS or SLS).

Similarly, for characteristic values, the term F_k is necessarily associated to a SLS. It is therefore not pertinent to mention the limit state to which this term refers. The term $F_{serv,d}$ is *ipso facto* equal to F_d.

For resistance, the SLS or ULS mention is not in use in France because the verifications of these limit states is achieved by considering two different concepts: for the ULS, it is the limit resistance, written R (R_k when it is the characteristic value that is relevant, or R_d when it is the design value), while for the SLS it is the creep resistance or creep load, written R_{cr} ($R_{cr;k}$ when it is the characteristic value that is relevant, or $R_{cr;d}$ when it is the design value).

The limit resistance R corresponds to an equilibrium failure or to an excessive displacement of the ground anchor.

In the first case, it may be assessed by considering the asymptote of the load/displacement or uplift/displacement curves.

The creep resistance R_{cr} corresponds to an absence of displacements deferred over time when the load applied on the ground anchor is lower than R_{cr}. It corresponds to an increase in the rate of displacements accumulated for each loading stage being constantly maintained.

C.3 SERVICE TENSION OF THE GROUND ANCHOR, INCLUDING THE EFFECT FROM THE LOCK-OFF LOAD

This concept was introduced for educational purposes for countries in which ground anchor practice is different, or in the framework of an approach 1, which is not in use in France.

In the continuity of the calculation methods from the recommendations of TA 95 and from standard NF P 94-282, the formula 8.2 of clause 8.5.1(1)P of standard NF EN 1997-1/A1 is simplified in France under the form:

$$E_{ELU;d} = F_{ELU;d} = F_{serv;d}$$

ANNEX D - ANCHOR SYSTEM TEST

D.1 PREAMBLE

This annex transcribes extracts from the EAD 160004-00-0301 document, which are both pertinent and adapted for ground anchors.

If ground anchors are not subjected to cyclic loadings, the fatigue tests described below are not mandatory.

D.2 STATIC LOADING TEST IN TENSION

D.2.1 TEST SPECIMEN

The system to be tested shall be assembled correspondingly to the considered application, by using all the components required to anchor the tendon.

These components are selected randomly.

The geometric configuration of the tendons in the test specimen shall be identical to the one specified by the supplier. Tendon data to be produced are the following:

- The main mechanical and geometrical tendon properties, including the actual ultimate strength;
- The total cross-section of tendons;
- The surface characteristics of tendons.

Relevant geometrical and mechanical properties of the anchor components shall also be determined.

The free length of the tendons in the system to be tested shall not be lower than 3.0 m, except for bars, for which the minimum length is 1.0 m.

If more than one grade of tensile elements of the same type is to be used with the same type of anchor, the tests shall be performed using the grade with the highest characteristic tensile strength, and/or load.

D.2.2 TEST PROCEDURE

The trial body is mounted on a bench or on a test rig, respecting, for compound tendons, the geometric configuration specified by the supplier.

The tendon is stressed at one of its end, using a representative jack, comparable to the one used on site and specified within the supplier's guide, by steps corresponding to 20 %, 40 %, 60 % and 80 % of the characteristic tensile strength of tendons.

The pressure in the jack is gradually and steadily increased, at a rate of around 100 MPa per minute.

When forces in the jack reach 80% of the characteristic strength, the anchor is locked on the test rig and is maintained at a constant 80 % for one hour.

Then, using the test rig, the load is gradually increased up to failure, with a maximum increase of the relative elongation of 0.002 per minute.

The uncertainty of the values measured with the measuring equipment shall lie within + or – 1%. Loads shall be maintained within a maximum tolerance of + or – 2%. The load measured in the jack shall be adjusted to take into account the estimated losses by friction in the anchors, so it ensures that the specified load was correctly applied to the anchor head used for measures.

D.2.3 MEASURES AND OBSERVATIONS

The measures and observations to be carried out and logged are the following:

- Checking that components comply with the supplier's specifications (materials, machining, geometry, hardness, etc.);
- Relative displacement Δs in function of load and time of the tendons in regard to anchorage, on at least two elements;
- Relative displacement Δr in function of load and time between the individual components of the anchor, on at least two components, such as wedges for compound tendons;
- Full load-deformation diagram, recorded continuously over the whole duration of the test;
- Elongation ε_{Tu} of the prestressing tendons on the free length, at the maximum measured force F_{Tu} ;
- Maximum measured force F_{Tu} ;
- Failure location and mode;
- Examination of the elements after disassembly, photographic documentation, comments, including the residual deformations of the anchor head.

D.2.4 ACCEPTANCE CRITERIA

The number of anchors or couplers to be tested to qualify a model is 2. To qualify a full range, the number is 2 on a small model, 1 on a medium model, and 2 on the larger models.

The acceptance criteria are:

- The maximum measured force shall not be lower than 95% of the actual ultimate strength, or lower than 95% of the characteristic failure resistance of the tendon.
- The total tendon elongation on the free length at the maximum measured force shall be at least of 2%.
- Failure shall occur by tendon breakage. The failure of the test specimen shall not be caused by a failure of one of the elements of the anchor head or of the couplers (small longitudinal cracks on the jaws are not considered as being a failure of the anchor head).
- The residual deformations of the elements of the anchor system after testing shall confirm the reliability of the anchor system. Any residual deformation shall be logged.
- At a force of 80% of the tendon characteristic strength, the relative motions between the elements of the anchor head, and between the tendon and the elements of the anchor head, have to stabilise within the first 30 minutes.

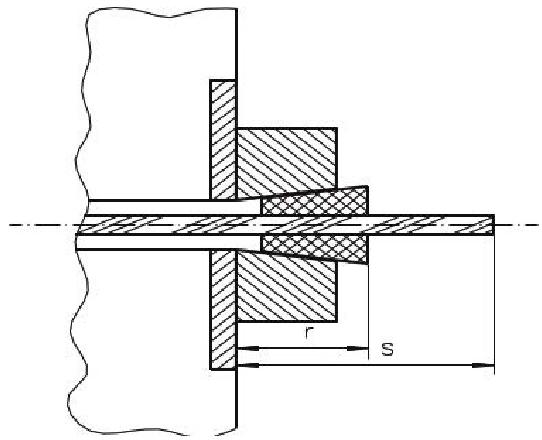


Figure D1: detail at the level of an anchor head, before lock-off
(example of an anchorage with wedges)

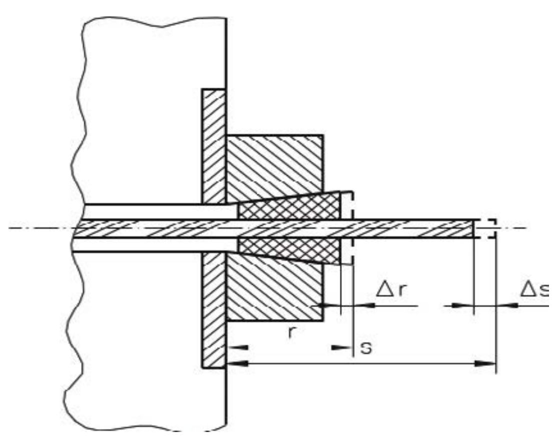


Figure D2: Displacements during a test, after lock-off (displayed
here for an anchorage with wedges)

D.3 FATIGUE TEST

D.3.1 TEST SPECIMEN

The test specimen corresponds to the one described for the static loading test.

On at least one tendon end, the anchorage and all the elements that deviate the tendon into the anchorage, and at the entrance of the duct, shall be identical to the ones specified into the supplier's guide, without their geometry or material or machining be modified. The elements that deviate the tendons shall be kept at a set distance from the anchorage, in order to duplicate the actual deviation and the relative movements in regard to tendons.

If both ends of the system possess the anchorage characteristics specified above, the test will count to two tests.

If, for the same anchorage type, several tendon grades of the same type may be used, testing shall be carried out on the highest grade.

For compound tendons, and whenever possible, the system shall be tested with the total number of tendons that can be hosted by the anchorage. However, the number of tendons to be tested in the tendon-anchor system may be reduced as follows: for a system of n tendons, the reduced number of tendons n' assembled for the test shall comply with:

- if $n \leq 12 : n' \geq n/2$
- if $n \geq 12 : n' \geq 6 + (n - 12)/3$

Tendons with the most severe angular deviation in regard to the cable axis shall be included in the test.

D.3.2 TEST PROCEDURE

The test shall be carried out in a tension test rig, at a constant loading rate not exceeding 10 Hz, with a constant maximum load corresponding to 65 % of the characteristic strength of prestressing tendons.

The range of load variation $\Delta F = \max F - \min F$, corresponding to a range of stress variation of 80 MPa, shall be maintained constant over the whole duration of the test consisting of 2 million cycles. On its free length, the tendon shall remain without duct or filling materials.

The test specimen shall be tested so secondary oscillations are precluded. When assembling the specimen and fitting it in the test rig, specific precautions shall be taken to ensure that the load is evenly distributed on all tendons.

D.3.3 MEASURES AND OBSERVATIONS

The measures and observations to be carried out and logged are the following:

- Checking that components comply with the supplier's specifications (materials, machining, geometry, hardness, etc.);
- Relative displacement between the tendons and the individual elements of the anchor head, as well as between the anchor head elements, in function of the load and of the number of load cycles, on at least two prestressing tendons.
- Examination of the elements of the anchor head and of the prestressing tendons after testing, in order to observe the possible damages and deformations due to fatigue.
- Logging of failure locations, and of the number of tendons ruptured by fatigue, in function of the number of load cycles (for compound tendons),
- Examination of the elements after dismantling, photographic documentation, comments.

D.3.4 ACCEPTANCE CRITERIA

The number of anchor systems to be tested is 2 to qualify a model.

To qualify a full range, the number is 1 for smaller models, 1 for medium models and 2 for the largest model.
The acceptance criteria are:

- no failure by fatigue of the elements of the anchor system shall occur;
- for compound tendons, no more than 5% of the tendon cross-section shall be lost during the fatigue test consisting of 2 million cycles with amplitude of 80 MPa at a maximum force of 65% of the characteristic limit strength of the tendon.

ANNEX E - TAKING INTO ACCOUNT THE ENVIRONMENT AGGRESSIVITY

E.1 CHOICE OF CEMENTS, GROUTS AND MORTARS

The environment aggressivity is evaluated under the indications of standard NF EN 206/CN. Tables E.1 and E.2 below are excerpts from the standard.

Class labelling	Environment description	Informative examples, illustrating the choice of exposure classes
1 / No risk of corrosion or attack		
X0	For non-reinforced concrete, or concrete without embedded metallic parts: all exposures except abrasion, chemical attack or by frost/thaw. For reinforced concrete, or concrete with embedded metallic parts: very dry.	Concrete inside buildings where the moisture content of ambient air is very low.
2 / Corrosion by carbonatation		
When reinforced concrete, or concrete having embedded metallic parts, is exposed to air and humidity, exposure classes shall be defined as follows:		
XC1	Permanently dry or humid	Concrete inside buildings where the moisture content of ambient air is low; concrete permanently submerged in water
XC2	Humid, rarely dry	Concrete surfaces subject to a long-term contact with water; large number of foundations
XC3	Moderate humidity	Concrete inside buildings where the moisture content of ambient air is moderate or high; outside concrete, but sheltered from rain
XC4	Alternation of humidity and drying	Surfaces subject to contact with water, but not belonging to the XC2 exposure class
3 Corrosion by chlorides other than seawater chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Humid, rarely dry	Pools; concrete exposed to industrial waters containing chlorides
XD3	Alternation of humidity and drying	Bridge elements exposed to projections containing chlorides; roadways; slabs of vehicle parking lots
4 / Corrosion by seawater chlorides		
When reinforced concrete, or concrete having embedded metallic parts, is subject to a contact with seawater chlorides or to the action of air containing sea salt, the exposure classes shall be defined as follows:		
XS1	Exposed to air containing sea salt, but not in direct contact with seawater	Coastal structures, or close to a coast
XS2	Permanently submerged	Elements of marine structures
XS3	Intertidal zone, zone subject to projections or to sea spray	Elements of marine structures
5 / Attack by frost-thaw, with or without a de-icing agent		
When concrete is subject to a significant attack due to frost-thaw cycles while being wet, the exposure classes shall be defined as follows:		
XF1	Moderate water saturation without de-icing agent	Vertical concrete surfaces exposed to rain and frost
XF2	Moderate water saturation with de-icing agent	Vertical concrete surfaces of road structures exposed to frost and to airborne de-icing agents
XF3	High water saturation without de-icing agent	Horizontal concrete surfaces exposed to rain and frost
XF4	High water saturation with de-icing agent or seawater	Roads and bridge decks exposed to de-icing agents; concrete surfaces directly exposed to frost and to projections of de-icing agents; areas of marine structures subject to projections and exposed to frost
6 / Chemical attack		
When concrete is subject to a chemical attack from the natural soils and underground waters, the exposure classes shall be defined as follows:		
XA1	Environment with low chemical aggressivity	Concrete exposed to natural soils and underground waters, under Table E2 below
XA2	Environment with moderate chemical aggressivity	Concrete exposed to natural soils and underground waters, under Table E2 below
XA3	Environment with high chemical aggressivity	Concrete exposed to natural soils and underground waters, under Table E2 below

Table E1: exposure classes

Chemical characteristic	Reference test method	XA1	XA2	XA3
Surface and underground waters				
SO^{2-}_4 in mg/l	EN 196-2	> 200 and < 600	> 600 and < 3000	> 3000 and < 6000
pH	ISO 4316	< 6,5 and > 5,5	< 5,5 and > 4,5	< 4,5 and > 4,0
Aggressive CO_2 in mg/l	prEN 13577:1999	> 15 and < 40	> 40 and < 100	> 100 up to saturation
NH_4^+, in mg/l	ISO 7150-1 or 7150-2	> 15 and < 30	> 30 and < 160	> 60 and < 100
Mg^{2+}, in mg/l	ISO 7980	> 300 and < 1000	> 1000 and < 3000	> 3000 up to saturation
Soil				
SO^{2-}_4 in mg/kg[a)] total	EN 196-2[b)]	> 2000 and < 3000[C)]	< 3000[C)] and < 12000	> 12000 and < 24000
Acidity in ml/kg	DIN 4030-2	> 200 Baumann Gully	Not encountered in practice	

a. Clayey soils with permeability lower than 10^{-5} m/s may be classified into a lower class.
b. The test method recommends extracting SO^{-2}_4 with hydrochloric acid. Alternatively, it is possible to proceed to this extraction with water if this is common practice on the site where the concrete is used.
c. The limit shall be brought back to 3,000 mg/kg, in the case of an accumulation of sulphate ions in concrete, due to the alternation of dry and humid periods, or due to capillary rise.

Table E2: limit values for the exposure classes corresponding to chemical attacks from natural soils and underground waters

The choice of cement is then made according to the indications of FD P 18-011, recalled in the table below:

Environment	Exposure class	Cement choice
Environment containing sulphates (solutions), with the exclusion of seawater	XA1	No specific recommendations
	XA2	(below 1,500 mg/l) • SR cements compliant with standard NF EN 197-1 and with the additional requirements stated in 6.3 • Cements compliant with standard NF P 15-317 (PM) or NF P 15-319 (ES)
		(below 1,500 mg/l) • SR cements compliant with standard NF EN 197-1 and with the additional requirements stated in 6.3 • Cements compliant with standard NF P 15-319 (ES)
	XA3	• SR cements, compliant with standard NF EN 197-1 and with the additional requirements stated in 6.3 • Cements compliant with standard NF P 15-319 (ES)
Environment containing sulphates (soils)	XA1	No specific recommendations
	XA2	• SR cements compliant with standard NF EN 197-1 and with the additional requirements stated in 6.3 • Cements compliant with standard NF P 15-317 (PM) or NF P 15-319 (ES)
	XA3	• SR cements compliant with standard NF EN 197-1 and with the additional requirements stated in 6.3 • Cements compliant with standard NF P 15-319 (ES)
Acid environment and pure waters	XA1	• CEM II/B-S, CEM II/B-V, CEM II/B-P, CEM II/B-Q, CEM II/B-M (S-V), CEM III compliant with standard NF EN 197-1 • SR cements compliant with standard NF EN 197-1 • Cements compliant with standard NF P 15-317 (PM) or NF P 15-319 (ES) • CEM IV/A and B compliant with standard NF EN 197-1
	XA2	• CEM II/B-S, CEM II/B-V, CEM II/B-P, CEM II/B-Q, CEM II/B-M (S-V), CEM III compliant with standard NF EN 197-1, SR cements compliant with standard NF EN 197-1 and with the additional requirements stated in 6.3 • CEM V compliant with standard NF P 15-319 (ES) • CEM IV B compliant with standard NF EN 197-1 • Cements compliant with standard NF P 15-319 (ES)
	XA3	• CEM III/A, B and C, CEM V/A and B compliant with standard NF P 15-319 CEM IV/B compliant with standard NF EN 197-1

Note: SSC sulphated cements compliant with standard NF EN 15743+A1, and calcium aluminate cements compliant with standard NF EN 14647, may be used in all environment classes.

Table E3: choice of cement in function of the environment

E.2 CORROSION OF STEELS

E.2.1 BURIED PARTS

Soil aggressivity is evaluated according to the classification given in table E4 below:

Soil parameters	Class	Index ΣA
Highly corrosive	I	13 or more
Corrosive	II	9 to 12
Moderately corrosive	III	5 to 8
Lowly corrosive	IV	4 or less

Table E.4: classification of soil aggressivity on steels

The index is calculated according to the indications of table E.5 below:

Criteria	Parameters	Weight A of the criterion
Soil nature [1]	**Texture** • heavy, plastic, sticky, impermeable • clayey-sandy • light, permeable, sandy, cohesionless soils **Peats and marshes** **Industrial wastes** • Slag, ashes, coal • Construction waste (plaster, bricks) • **Liquid pollutions** • Industrial or sewage waters • Waters affected by de-icing salts	 2 1 0 8 8 4 6 8
Resistivity (Ω cm)	$\rho < 1000$ $1000 < \rho < 2000$ $2000 < \rho < 5000$ $5000 < \rho$	5 3 2 0
Humidity	Body of brackish water (variable or permanent) Body of freshwater (variable or permanent) Above water tables – wet soils (water content < 20%) Above water tables – dry soils (water content < 20%)	8 4 2 0
pH	< 4 4 à 5 5 à 6 > 6	4 3 2 0
	Global index	Sum of the weights above ΣA

[1] The weighing value of the “soil nature” criterion could be the maximum value applicable to this soil, from the sub-classes "texture", "peats", "industrial wastes", and "liquids". The maximum weight of each criterion is lower than, or equal to, 8.

Table E.5: index of soil aggressivity on steels

E.2.2 PARTS IN OPEN AIR

The aggressivity of atmospheres is evaluated according to the classification given in table E.6 below, extracted from standard NF EN ISO 12944-2:

Category of corrosiveness	**Weight loss per surface unit/thickness loss** (first year of exposure)				**Examples of typical environments in a temperate climate** (for informative purposes)	
	Low alloy steel		**Zinc**		**Exterior**	**Interior**
	Weight loss g/m²	Thickness loss µm	Weight loss g/m²	Thickness loss µm		
C1 Very low	≤ 10	≤ 1,3	≤ 0,7	≤ 0,1	-	Heated buildings with clean atmospheres, such as offices, stores, schools, hotels
C2 Low	> 10 to 200	> 1,3 to 25	> 0,7 to 5	> 0,1 to 0,7	Atmospheres with a low level of pollution. Rural areas particularly	Non-heated buildings where condensation may occur, such as warehouses or sport halls
C3 Moderate	> 200 to 400	> 25 to 50	> 5 to 15	> 0,7 to 2,1	Urban and industrial atmospheres, moderate pollution due to sulphur dioxide. Coastal areas with low salinity	Manufacturing plant with high humidity and a relative air pollution, such as food industries, breweries, industrial laundries, dairy industries
C4 High	> 400 to 650	> 50 to 80	> 15 to 30	> 2,1 to 4,2	Industrial areas and coastal areas with moderate salinity	Chemical plants, pools, coastal shipyards
C5-I Very high (industrial)	> 650 to 1500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Industrial areas with high humidity and aggressive atmospheres	Buildings or areas with a permanent condensation and a high pollution
C5-M très elevée (marine)	> 650 to 1500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Marine and coastal areas with high salinity	Buildings or areas with a permanent condensation and a high pollution

Note:
1. The loss values used for the categories of corrosiveness are identical to the ones indicated in ISO 9223.
2. In the coastal areas of hot and humid regions, the losses of weight or thickness may exceed the limits from the C5-M category. Particular precautions shall therefore be taken when choosing paint systems to protect steel structures in such areas.

Table E.6: corrosiveness categories of atmospheres on steel

ANNEX F - PROCEDURE TO JUSTIFY THE STABILITY OF THE ANCHORAGE SOIL MASS

F.1 PREAMBLE

This annex transcribes annex G of standard NF P 94-282.

Note: some clauses, relative to anchors not in the scope, were simplified for ease of reading.

Through successive iterations, it leads to assessing the minimum free length to be set for the ground anchor.

F.2 GENERAL PRINCIPLE

To verify the stability of the anchorage soil mass of a retaining wall (see figure F.1), the stability of the part of the ground mass located above the wall bottom and delineated by the vertical plane OB passing against the rear side of the wall and through the vertical plane CD that meets the assumed application point (A) of the end result of anchorage forces (see notes 1 and 2) shall be demonstrated, and for all pertinent cases of loads and combinations thereof, one should:

- establish the minimum destabilising load (tension) P_{dst} in an anchor row, by researching the most unfavourable sliding surface going through A and ending in any point M of the OB plane (see note 3), then,
- verify that the following inequality is satisfied: $P_d \leq P_{dst;d}$

Comment: P_d is the design load value (tension) applied to the ground anchor per linear meter of wall. In the text body, it should be similar to F_d.
$P_{dst;d}$ is the design value of the destabilising load (see notes 4 to 6 and paragraph F.3).

Note 1: conventionally, the analysed failure surfaces stem from the particular points A_i associated to each anchor row, usually defined at the « fictitious anchorage point » of a bond-type anchor (see 7.5.9.2.2).

Note 2: in common practice, the adopted « fictitious anchorage point » (i.e., the point of application of the end result of anchorage forces) is the middle of the bond.

Note 3: the verification is usually carried out (see paragraph F.3.1 (2)) for a volume of ground going through a point M corresponding to the point of null shear force of the wall under the excavation level (base of the « active » part of the wall).

Note 4: within the vertical plane OB, the action of the front part of the soil mass is represented by the wall reaction on the soil mass, equal and opposed to the distribution or total stress applied by the soil mass on the wall. It may itself be broken down into:

- the distribution of effective stress on the vertical facing OB, which end result is P'_e
- the distribution of water pressures on the vertical facing OB, which end result is U_e.

Note 5: the tension P_i (see comment) applied on the anchor is to be taken into account as indicated below, either at the level of the fictitious anchorage point, or, in the case addressed in F.3.2 (3) between the fictitious anchorage point and the anchor head.

Note 6: the action from the soil mass beyond the vertical C_iA_i is assumed as being characterised by the result of active pressure forces on the segment C_iA_i, which may itself be broken down into:

- the result P'_a of the effective stress from active pressure on this segment,
- the result U_a of water pressure on this segment.

Comment: Pi (notation stemming from standard NF P 94-282) has, within this annex, a definition that differs from the one used in the text body.

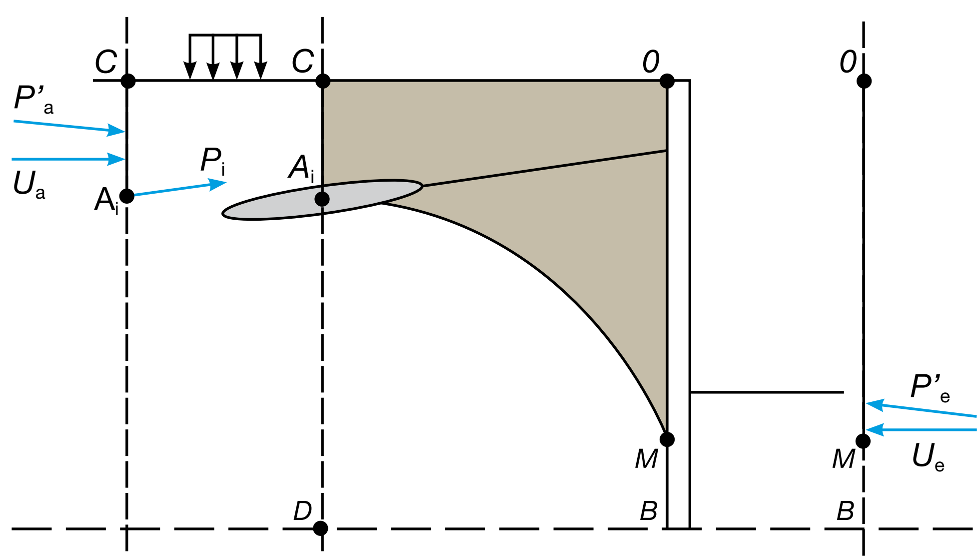


Figure F.1 Definition of the ground zone where stability is analysed (example of a retaining structure with a single anchor row)

F.3 DETERMINATION OF THE DESTABILISING FORCE

F.3.1 WALL WITH A SINGLE ANCHOR ROW

(1) To establish the minimum load (tension) P_{dst} in an anchor row capable of destabilising a block [C_iA_iMO], the calculations values of the following (Figure F.2) are to be considered (see notes 1 et 2):

- the weight of the ground mass $W_{g;d}$;
- the end result of external forces acting on the mass $F_{e;d}$;
- the reaction from the wall on the vertical segment OM, broken down into:
    - the force $P'_{e;d}$ opposed to the result of effective pressures from the mass on this length of wall,
    - the force $U_{e;d}$ opposed to the result of water pressures on this length of wall;
- the reaction of the rear mass on the vertical segment CiAi, broken down into:
    - the force $P'_{a;d}$ equal to the result of effective active pressures from the mass on this segment,
    - the force $U_{a;d}$ equal to the result of water pressure on this segment;
- the reaction due to ground and water on the considered failure surface A_iM, broken down into:
    - the resistance $R_{f;d}$ due to friction on this failure surface,
    - the resistance $R_{c;d}$ due to cohesion on this failure surface;
- the result $R_{u;d}$ of water pressures on this failure surface;
- the tensions $P_{i;d}$ representing the action of ground anchors.

Note 1: the active pressure acting on the rear vertical plane of the soil mass is due to ground and to possible surcharges.

Note 2: when piezometric conditions at the rear of the wall are considered as being hydrostatic (water pressure defined by a single horizontal piezometric surface), the result of the forces W_g, U_e, U_a and R_u is equal to the submerged weight of the soil mass [C_iA_iMO]. The equilibrium may therefore be studied by only considering the total unit weight for the parts outside the water body, and the submerged unit weight for the parts under the water body, by disregarding the forces U_e, U_a and R_u.

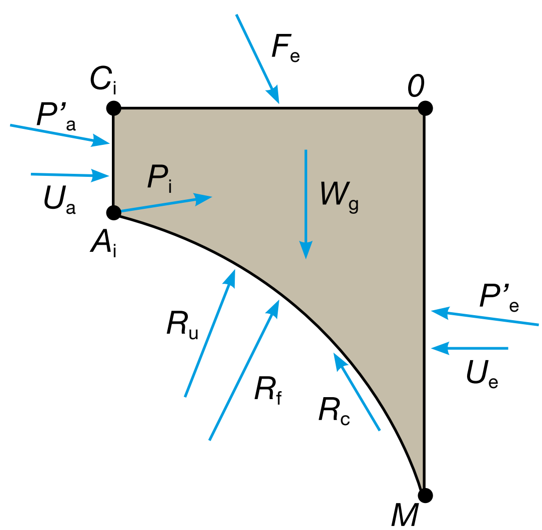


Figure F.2: forces to take into consideration when verifying the equilibrium of a soil mass (general case)

(2) To establish the minimum load (tension) P_{dst} in an anchor row capable of destabilising a soil mass [C_iA_iMO],one should research the most unfavourable sliding surface leading to the point M of the plane OB corresponding to the point of null shear force of the wall (see note 1).

Note 1: the partial factors indicated in Annex A of standard NF P 94-282 correspond to this usual procedure. It is allowed to examine other positions of the point (see note 2).

Note 2: when the obtained minimum destabilising load is lower than the one obtained by considering the point of null shear force, one should ponder if the configuration would not be one outside the domain of structures for which the usual procedure (M at the point of null shear force) is assumed as being validated. By default, (i.e., for common project conditions) one should consider for the value of destabilising load the one corresponding to the point of null shear force.

(3) To establish the sliding surface leading to the point M of the plane OB of line segments, circular arcs, or successive logarithmic spiral-shaped arcs, may be taken into consideration (see notes 1 to 5 below).

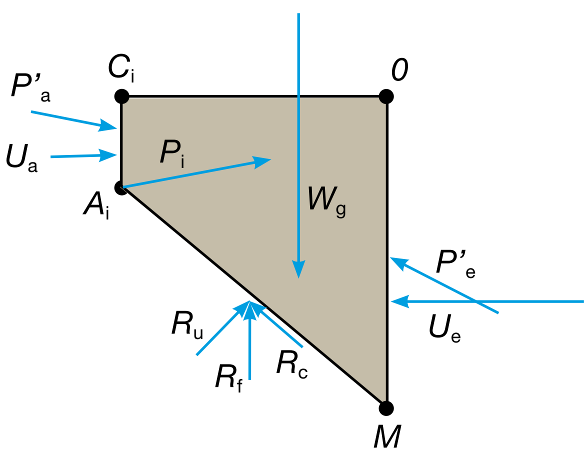
Note 1: it is common practice to consider plane failure surfaces.

Note 2: when only line segments are being considered, the minimum destabilising load $P_{dst;d}$ directly results from the force polygon applied to each soil mass (Figure F.3). Additional hypotheses should be advanced when the segment AiM crosses one or several layer limit(s). The commonly adopted hypothesis consists in breaking down the soil mass into several sub-masses, with vertical boundaries going through these intersecting points, and in assuming that the reactions between these soil masses are horizontal ones. This hypothesis is related to the one adopted within Bishop's method applied to circular failure surfaces.

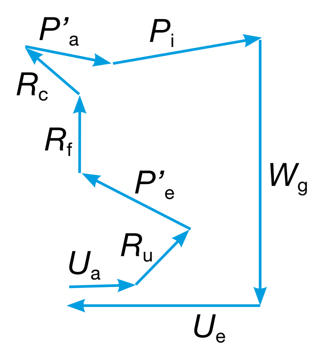
Note 3: when circular arcs are being considered, the equilibrium may be solved by a calculation with the slice method, using an acknowledged method.

Note 4: the kinematic exterior approach, developed within the framework of the theory of failure calculation, may also be applied to the equilibrium of soil masses [C_iA_iMO], associated to the choice of logarithmic spiral-shaped arcs for the failure lines A_iM. Each failure line is then constituted of successive logarithmic spiral-shaped arcs having the same poles and defined by the friction angle of each of the layers met along A_iM.

Note 5: failure calculation establishes that logarithmic spiral-shaped arcs with a downward concavity usually produce minimum destabilising loads that are lower than the ones obtained by considering line segments or circular arcs. According to the theory of failure calculation, and since it is a kinematic exterior approach, the numerical values of the destabilising loads obtained with this approach are, with certainty, higher than the loads causing soil mass failure.



a) Forces acting on the block



b) Funicular force polygon

Figure F.3 Graphical solving of the soil mass equilibrium in the common case where the lower boundary of the soil mass is assumed as being a line segment

(4) The equilibrium of the soil mass, under the actions applied to it, defines the minimum destabilising load (tension) P_{dst} of an anchor row i.

Note : $P_{dst;d}$ corresponds, for a given case of load and combination of loads, to the minimum destabilising load, which is a value that may not be exceeded without causing a wall reaction greater than the one taken into account.

(5) When determining the minimum destabilising load (tension) P_{dst} of an anchor row:

- The actions (weight of the ground mass, loads on or in the ground, water levels) to be considered are the ones adopted to determine the wall reaction (see notes 1 and 2);
- The design value $P'_{e;d}$ of the wall reaction representing the action from the ground on the segment OM to be considered is the one corresponding to the state of pressures against this wall, in the calculation situation being examined.

Note 1 : as a reminder, the verification is to be carried out following the approach of calculation 2 by using the sets of partial factors A 1 and M 1 defined in Annex A of standard NF P 94-282, articles A.2.1, A.2.2 respectively for the actions and soil properties, and the sets of partial factors R2 defined in Annex A of standard NF P 94-282, article A.2.6 for soil resistances.

Note 2: the ratio between the minimum destabilising load (tension) in the ground anchor and the maximum load (tension) applied to a ground anchor is in a rough order of magnitude of 1.5 (~1.1 x 1.35).

F.3.2 WALL WITH SEVERAL ANCHOR ROWS

(1) In the case of a wall with several anchor rows, the entirety of the anchoring forces shall be considered by following one of the two procedures (2) and (3) below.

Note: in the case where one uses calculation software that cannot take into account forces other than the internal forces of the soil mass under study, one should consider a sufficient number of mechanisms, or adapt the geometry of the considered soil mass, to integrate the anchoring forces at proximity that may exert unfavourable actions (see clause (3)).

(2) When the research of the most unfavourable mechanism is carried out by considering one soil mass for each anchor row with the traditional methods (plane failure surface going through the fictitious anchorage point and the point of null shear forces), the equilibrium of each of the soil masses being studied is to be verified:

- By taking into account the anchoring forces applied in the part of the ground mass located inside the considered mass ;
- By taking into account, or not, the anchoring forces applied outside the considered soil mass, depending on their situation in relation to the soil mass, in accordance with the current methods, recalled on Figure F.4

(3) When failure calculation is applied, and a systematic scanning of the failure mechanisms is carried out, it is allowed not to take into account the forces outside each examined soil mass, as indicated on Figure F.5.

Note: in some particular configurations (anchors at proximity of each other), it may however be required to examine a soil mass delineated by a failure surface leading to a point Ai not located at the centre of the anchor row under examination, but slightly lower on the same vertical plane, so the row under the one being examined will be considered in the equilibrium of forces.

(4) In the case of several anchor rows, several situations may have to be examined, and in this case the minimum destabilising loads obtained in each situation are to be compared (with the comparison only being made on the sums of loads) to the maximum loads obtained in each of the rows for the same situation.

Labels:

Solid line = ground anchor taken into account

Dashed line = ground anchor not taken into account

1: active pressure zone

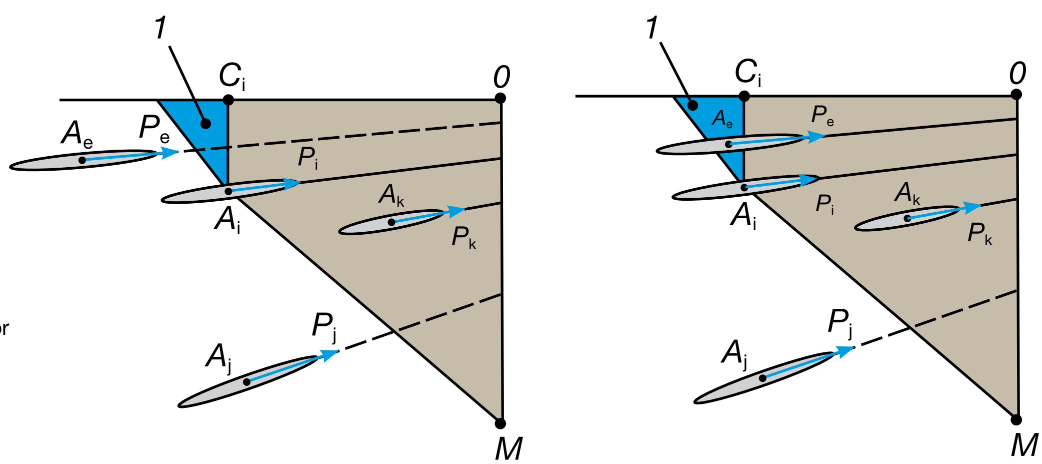


Figure F.4: conditions for taking into account ground anchors in the equilibrium of a soil mass, under current methods

Labels:

Solid line = ground anchor taken into account

Dashed line = ground anchor not taken into account

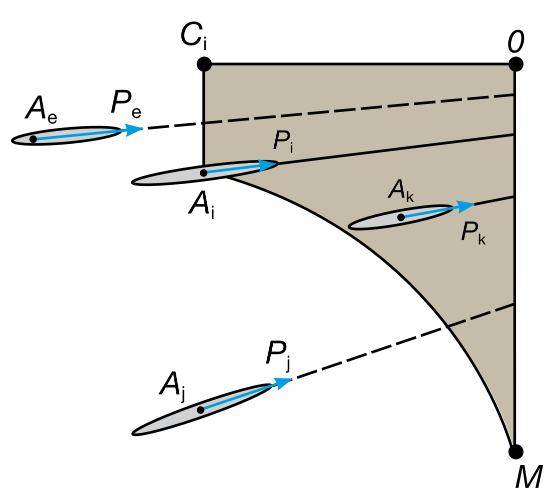


Figure F.5: conditions for taking into account ground anchors in a soil mass equilibrium, within an analysis by systematic scanning of the failure mechanisms

ANNEX G - OVERALL STABILITY VERIFICATION OF VERTICAL GROUND ANCHORS FOR RAFTS

G.1 PREAMBLE

This annex transcribes annex 2 of the recommendations of TA 95. The only change was aligning the notations with the more recent texts.

G.2 METHOD

G.2.1 PRINCIPLE

The principle consists in studying the vertical uplift stability of a ground mass constituted of ground volumes associated to each of the ground anchors being simultaneously loaded in tension.

G.2.2 PRACTICAL METHOD

Around each ground anchor, a unitary volume of effective weight W is plotted, equal to the limit tension of the ground anchor:

$$W = R_d$$

It will be assumed that there is no resistance reduction if the volumes associated to two adjacent ground anchors do not intersect, and that there is a reduction in the opposite case.

Comment: this notion of « associated volume » may not however be used bi-univocally, in the current state of knowledge, to assess the pull-out resistance of a ground anchor.

G.3 ASSOCIATED UNITARY VOLUME

The expression « cone of influence » is frequently used for this associated unitary volume.
Only the case of vertical ground anchors will be addressed below.

G.3.1 ACTUAL SHAPE

The volume actually associated to a ground anchor has undoubtedly a roughly cylindrical shape, ending in the bonding zone with a conical volume, with its top located at the low end of the bond (see figure G.1 a).

In soils which behaviour is mainly governed by internal friction, the volume displayed above is substituted with a conical volume of half-angle β at the top (see Figure G.1 b).

And, when these soils are overlain by a purely frictional soil, but having a high resistance contrast with the soil below, the associated volume in such formations is reduced to a cylinder built on the cone base (see figure G.1 c).

In soils which behaviour are mainly governed by cohesion, the volume displayed in G.1 is substituted with a cylindrical volume connected to the bond base at a depth of half the fixed length ($r = L_s / 2$) with a conical volume of half-angle of 45° at the top (see figure G.2).

Comment: the influence volume is a calculation method, and does not materially correspond to the ground volume being displaced when a ground anchor pulls out.

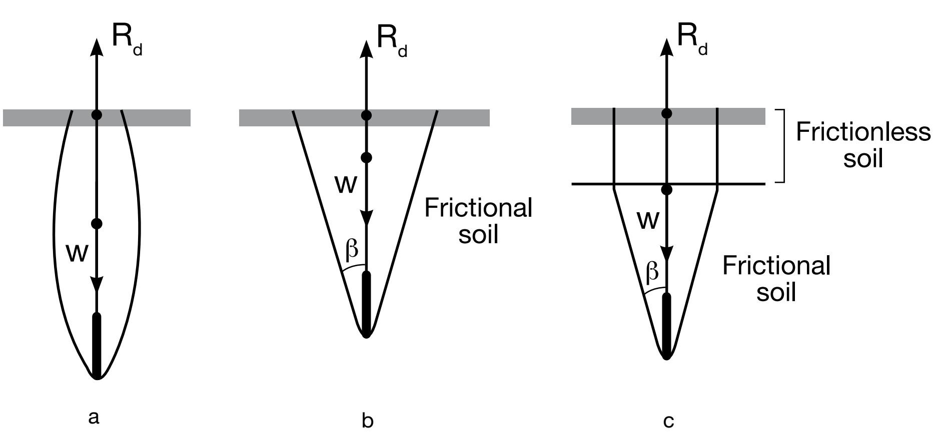


Figure G.1: associated unitary volume (frictional soil)

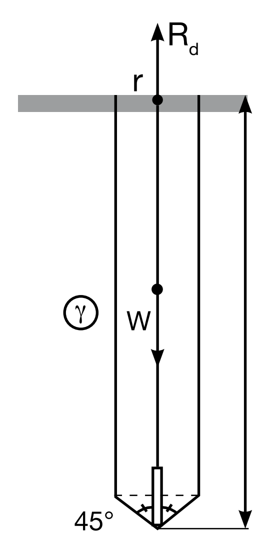


Figure G.2: associated unitary volume (cohesive soil)

G.3.2 PRACTICAL VOLUME, IN A HOMOGENEOUS SOIL WITH A PREVAILING INTERNAL FRICTION

This is a cone of revolution, the axis of which being the ground anchor, of total height L and half-angle at the top defined in the article G.3.6 below (see figure G.3).

Its base radius r:

$$r = L \,.\, tg\, \beta$$

is determined so the volume V of the ground mass thus obtained has an effective weight W equal to:

$$W = \pi\, r^2 \,.\, \gamma \,.\, L/3$$

This may also be written, according to G.2.1:

$$r = \{ 3 \,.\, R_d / (\pi \,.\, \gamma.\, L) \}^{1/2}$$

i.e., by assimilating 3 to π, which is justified by the lack of accuracy of the hypotheses

$$W = r^2 \,.\, \gamma \,.\, L$$
$$r = \{ R_d / (\gamma \,.\, L) \}^{1/2}$$

Comment 1: the same simplification will be carried out in articles G.3.3 and G.3.4 below.

Comment 2: The specific weight «γ» of the soils associated to the ground anchor will be, in function of the location of the water table possibly prevailing in these soils, either the natural unit weight of these soils, or the bulk density taking buoyancy into account.

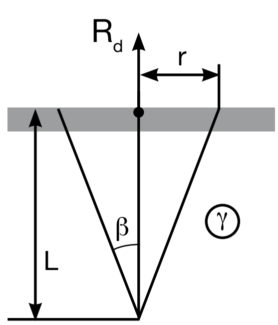


Figure G.3: unitary associated volume
(frictional homogeneous soils)

G.3.3 PRACTICAL VOLUME IN A LAYERED SOIL WITH PREVAILING INTERNAL FRICTION

z_1 and z_2 are layers with respective densities γ_1 and γ_2 (see figure G.4), ζ is in this case the ratio of z_2 to the length L:

$$z_2 = \zeta \,.\, L$$

The value of r can be deduced:

$$r = \{ (R_d / L) / (\gamma_1 + (\gamma_2 - \gamma_1) \,.\, \zeta^3) \}^{1/2}$$

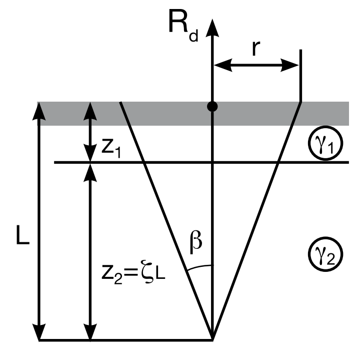


Figure G.4: associated unitary volume
(frictional layered soil)

G.3.4 PRACTICAL VOLUME, IN A SOIL WITH PREVAILING INTERNAL FRICTION SURCHARGED BY A FRICTIONLESS SOIL

L_r is the length of the ground anchor into the resistant soil (see figure G.5). A cone will then be considered, of length L_r overlain by a cylinder in the frictionless soil layer of specific weight γ_0 and thickness z_0. What is found is:

$$W = (\pi \,.\, r^2 / 3) \,.\, (\gamma \,.\, L_r + 3 \,.\, \gamma_0 \,.\, z_0)$$

or

$$R_d = r^2 \,.\, (\gamma \,.\, L_r + 3 \,.\, \gamma_0 \,.\, z_0)$$

This allows obtaining the value of r:

$$r = \{ R_d / (\gamma \,.\, L_r + 3 \,.\, \gamma_0 \,.\, z_0) \}^{1/2}$$

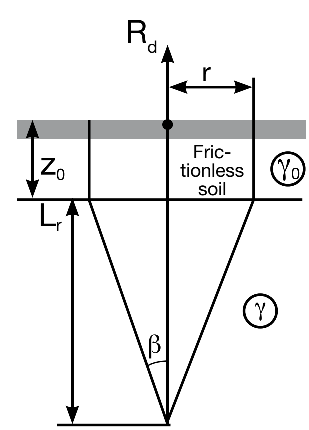


Figure G.5: associated unitary volume
(frictional soil overlain by a frictionless soil)

G.3.5 G.3.5 PRACTICAL VOLUME IN A SOIL WITH A PREVAILING INTERNAL FRICTION AND UNIFORMY SURCHARGED

The formulas of article G.3.4, are applied, replacing $z_0 \cdot \gamma_0$ with s, which is the unitary value of the uniform surcharge (see figure G.3).

The latter shall only be taken into account if there is no accidental risk of it vanishing.

G.3.6 LIMIT VALUE OF THE HALF-ANGLE β AT THE TOP

It shall be verified that the opening of the cone of influence remains equal to 2/3 of the effective internal friction angle of the soil.

G.3.7 PRACTICAL VOLUME IN A HOMOGENEOUS SOIL WITH A PREVAILING COHESION

This a cylinder of revolution, ended at its lower base by a cone having a half-angle of 45° at its top, with the latter being located at the lower end of the anchor bond (see figure G.2).

The radius « r » of the cylinder and of the base of the connecting cone is given by the equation:

$$R_d = \gamma \,.\, \pi \,.\, r^2 \,.\, (L - 2\,r/3)$$

where γ and L have the same meaning than in G.3.2.
Once this volume is geometrically determined, and when the ground anchor is fully executed in a homogeneous cohesive soil, one shall verify that the shear stress caused by R_d on the lateral surface of the cylinder is lower than 2/3 C_u.

G.3.8 PRACTICAL VOLUME IN A SOIL WITH A PREVAILING COHESION, OVERLAIN BY SOILS OF DIFFERENT NATURES

The cylindrical practical volume, as displayed on G.3, will be extended with the same diameter through the overlying soils taken into account, which will be considered with their specific apparent unit weights, if pertinent.
In that case, and as in G.3.7, one shall verify that the shear caused by R_d on the cylindrical surface of the considered volume remains lower than 2/3 of the limit shear resistance of the various soil layers in contact with the cylinder.

G.3.9 PRACTICAL VOLUME IN A SOIL WITH A PREVAILING COHESION AND UNIFORMLY SURCHARGED

The surcharge, of unitary value « s », will be taken into account on the cross-section of the cylinder leading to the surface, and added to the apparent weight of the practical volume, as displayed in G.3.

The latter shall only be taken into account if there is no accidental risk of it vanishing.

$$R_d = \gamma \,.\, \pi \,.\, r^2 \,.\, (L - 2\,r/3) + s \,.\, \pi \,.\, r^2$$

As in G.3.7, one shall verify that the shear stress caused by R_d on the lateral surface of the cylinder remains lower than 2/3 C_u.

G.4 REDUCTION OF THE VOLUME OF INFLUENCE

G.4.1 PRINCIPLE

Knowing r, one may:

- either lay out ground anchors so that intersections are avoided,
- or assess the reduction to apply on R_d.

G.4.2 REDUCTION OF R_d IN THE CASE OF ADJACENT CONICAL VOLUMES

This reduction, equal to the weight ΔW of the area delineated by the shared chord (see figure G.6), i.e.:

$$R'_d = R_d \,.\, (W - \Delta W) / W$$

or, in a homogeneous soil,

$$R'_d = R_d \,.\, (V - \Delta V) / V$$

Given the accuracy of the hypotheses, the second formula may be used for all types of soils.

G.4.3 PRACTICAL FORMULA IN THE CASE OF CONICAL VOLUMES

It is expressed by: $R'_d = \psi' \,.\, R_d$

ψ' is given by the curve of figure G.7 in function of the ratio a/r of the spacing of two successive ground anchors to the radius r of the cone of influence.

The practical formula may also be used:

- if $0 < a < 1.25\,r$ $\psi' = 0.5 + 0.4 \,.\, a/r$
- if $a \geq 1.25\,r$ $\psi' = 1$

IMPORTANT REMARKS

One should obviously verify that the serviceability tension of ground anchors is compatible with the assessments of R_d or R'_d previously made.

The above assessment of volume reduction is theoretically only applicable in the case of a linear set of equidistant ground anchors with identical strengths.

In the case of ground anchors executed on a regular grid with a mesh a x b, ψ'_a will be calculated in the « a » direction, and ψ'_b in the « b » direction, although one should take into account that the cones associated to the edge anchors will only be intersected on three sides.

In the case of soils where cohesion prevails (cylindrical associated volumes), one will proceed similarly, although taking into account:

- the shear resistance on the perimetral envelop surface of the group of ground anchors under consideration, which is limited to 2/3 of the undrained cohesion,
- of the long-term soil parameters, which may lead to a modification of the shape of the ground volumes associated to the ground anchors (prevailing ψ', for instance).

G.4.4 CASE OF ASSOCIATED CYLINDRICAL VOLUMES

One will proceed in a similar manner in the case of cylindrical associated volumes.

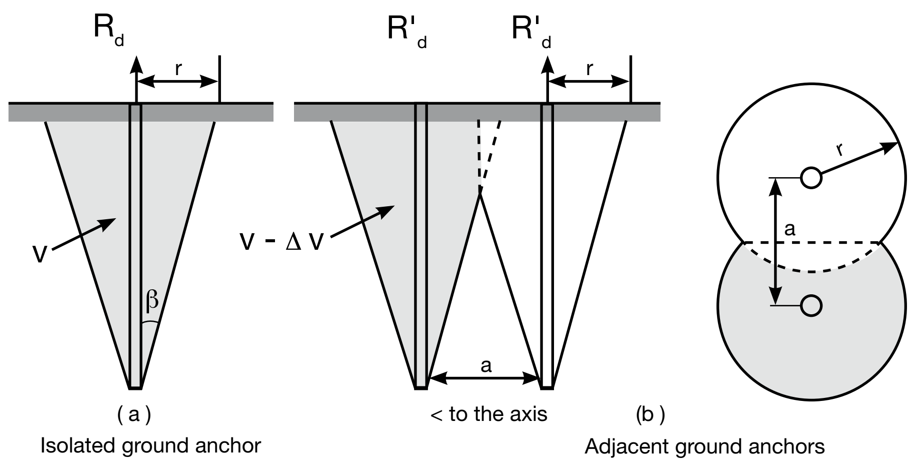


Figure G.6: reduction of the volume of influence (case of the cone)

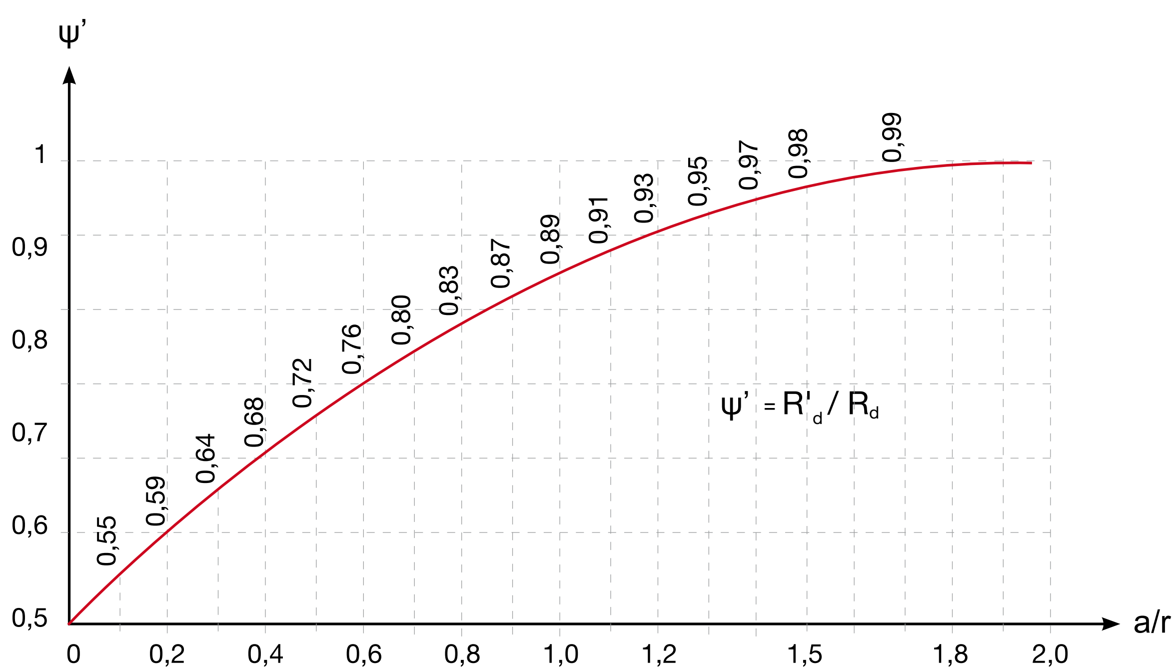


Figure G.6: reduction of the volume of influence (case of the cone)

ANNEX H - PRE-DESIGN WITH CHARTS

H.1 PREAMBLE

As a reminder, the only valid method for the justification during the execution stage (G3, under standard NF P 94 500) is carrying out failure tests.

Insofar as the charts of the present annex are used for a design study (stage G2 of standard NF P 94 500), failure tests may not be investigation tests, but conformity ones.

Comment: this annex recalls the pre-design charts of TA 95, founded on pull-out tests achieved before 1985. It would be extremely interesting to collect data from other tests carried out since that date, in order to re-process this database with the objective of updating the charts. Such contributions may be sent to the technical commission of CFMS.

H.2 CONDITIONS OF USE OF THE CHARTS

The charts result from the exploitation of a database (LCPC newsletter n°140 of Nov-Dec 1985), which prerequisites are the execution conditions below:

- using adapted equipment (tube à manchettes, packers, injection pumps, etc.) that was subject to controls leading to drafting reports;
- a follow-up of the various drilling and injection parameters, with continuous logs;
- the proper functioning of the various devices, and the continuous logging of the drilling parameters, which are essential to satisfy the requirements specified in table H.1, notably in terms of injection pressure.

Note: an ill-adapted functioning of the various devices requires justifications, which, when unachieved, may lead to question the ground anchor pre-design.

Comment: in regard to the period when the mentioned documents were drafted, the standards governing the SPT and CPT investigations (see note) have evolved. This has led to re-calibrating the x-axes, but the database was not enhanced, and this database of tests was not reinterpreted either.

Note: SPT calibration was only achieved for sands and gravels, since Eurocode 7 (NF EN 1997-2 § 4.6) only mentions SPT for cohesionless granular soils.

Charts are only provided for ground anchors called IGU and IRS, under the following definitions:

- In all cases, the borehole is equipped with reinforcements and with an injection system, i.e., a tube à manchettes executed in a sleeve grout. If the tendon is a metallic tube, this tube may be equipped with sleeves and be used as an injection system.
- After the sleeve grout hardens and claquages:
  - either the injection is carried out in a global and unitary manner (IGU), with an injection pressure equal to half the limit pressure of the ground, but at least equal to 1 MPa.
  - or, the injection of the bonding grout or mortar is carried out with a single or double packer, sleeve by sleeve, at an injection pressure greater than, or equal to, the limit pressure of the ground, but without exceeding 4 MPa. The injection is repetitive and selective (IRS).
- Under standard NF EN 1537, both types are obtained with a repetitive injection (see note 1) through a tube à manchettes of post-injection tubes:
  - IGU with a single pass and/or several steps and a single stage,
  - IRS with several steps and several stages (see note 2).

Note 1: the injection steps under repeated pressure are only counted after the grout, which was installed beforehand, hardens (sleeve grout).

Note 2: under the condition that the minimum pressure set in the contract during the injection under pressure is obtained, the IRS may be validated after a single injection step under pressure.

Note 3: the charts are NOT SUITABLE for ground anchors that are not injected under pressure.

H.3 EXPLOITING CHARTS

Once the type of injection and the nature of the bonding soil(s) are chosen, the limit lateral friction q_s is read on the chart.

Charts should always be used with caution in soils with a PLM limit pressure lower than 0.5MPa.

For a bond length L_s and a borehole diameter Ø, what is found is:

$$R_s = \pi \, Ø \, \alpha_s \, q_s \, L_s$$

Note: in the case of a multi-layered soil:

$$R_s = \pi \, Ø \int_0^{L_s} \alpha_s q_s(l) \, dl$$

A factor of model γ_{Rd} is selected, at least equal to 1.4 for the characteristic value:

$$R_k = R_s / \gamma_{Rd}$$

As a reminder: $R_d = R_k / \gamma_{a\,;ELU}$ with $\gamma_{a\,;ELU} = 1,10$

And for the SLS : $R_{cr\,;d} = R_d / \gamma_{serv}$

Comment: since $\gamma_{serv} = 1,35$
(see 5.3.2.1, NF EN 1997-1/A1 8.5.1 (1) and NF EN 1997-1/NA note 1 of 8.5.1 (1)), the following is re-obtained:

$$\gamma_{serv} \cdot \gamma_{Rd} \cdot \gamma_{aELU} = 1,35*1,4*1,1 \approx 2$$

the « historical » value of the safety coefficient F_t of the TA.

[3] That historical definition is different from the one which is in 7.3.3.2 and is used since TA85.

H.4 CHARTS BY SOIL TYPE

The classification of soils stems from table B.2.1 of standard NF P 94-262.

Soils	Coefficient α_s		Indicative conditions of application
	IRS (1)	IGU (1)	Usual grout quantity (2) to be injected V_i (3)
Gravels	1,8	1,3 to 1,4	1,5 V_s
Sandy gravels	1,6 to 1,8	1,2 to 1,4	1,5 V_s
Gravelly sands	1,5 to 1,6	1,2 to 1,3	1,5 V_s
Coarse sands	1,4 to 1,5	1,1 to 1,2	1,5 V_s
Medium sands			1,5 V_s
Fine sands			1,5 V_s
Silty sands			1,5 to 2 V_s for IRS -1,5 V_s for IGU
Silts	1,4 to 1,6	1,1 to 1,2	2 V_s for IRS -1,5 V_s for IGU
Clays	1,8 to 2,0	1,2	2,5 to 3 V_s for IRS -1,5 to 2 V_s for IGU
Marls	1,8	1,1 to 1,2	1,5 to 2 V_s for a compact layer
Marly-limestones			2 to 6 V_s or more for a fractured layer
Weathered of fragmented chalk			1,1 to 1,5 V_s if the layer is finely fractured
Weathered of fragmented rock	1,2	1,1	2 V_s or more if the layer is fractured

(1) Under the definitions stated above
(2) Grout dosage corresponds to a W/C ranging between 0.4 and 0.6
(3) V_s is the volume of the bonding bulb associated to α_s Ø, where Ø is the borehole diameter; V_i is the volume of sleeve grout plus the volume of post-injection grout.

Table H.1: parameters of injected volume and injection pressure associated to the charts

Sand and gravel

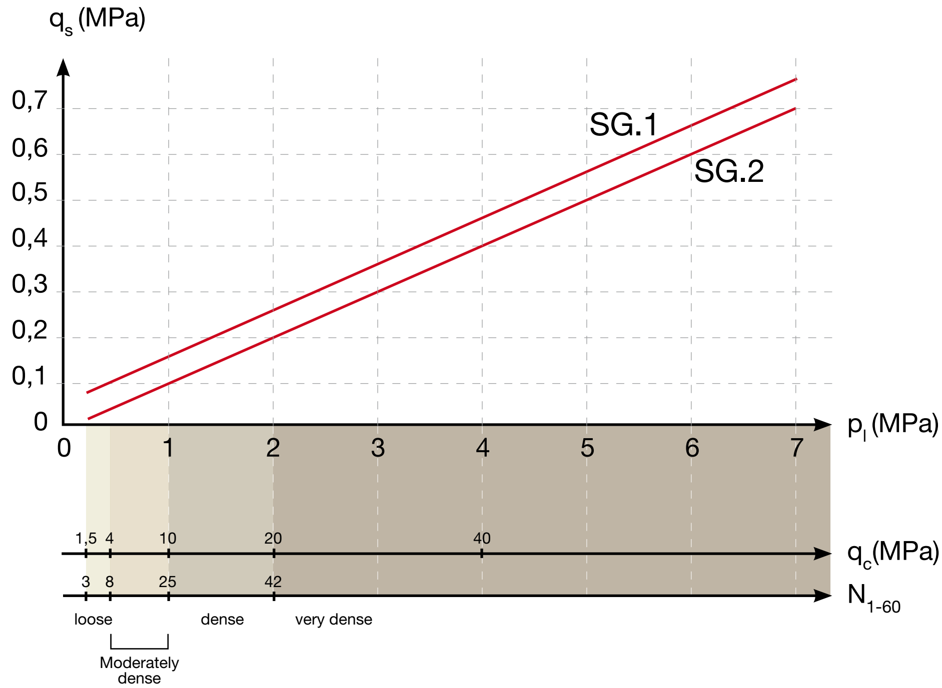


Figure H.1: pre-design chart for ground anchors bonded into sands and gravels

Labels:
SG1: chart for IRS ground anchors
SG2: chart for IGU ground anchors

Clay and silt

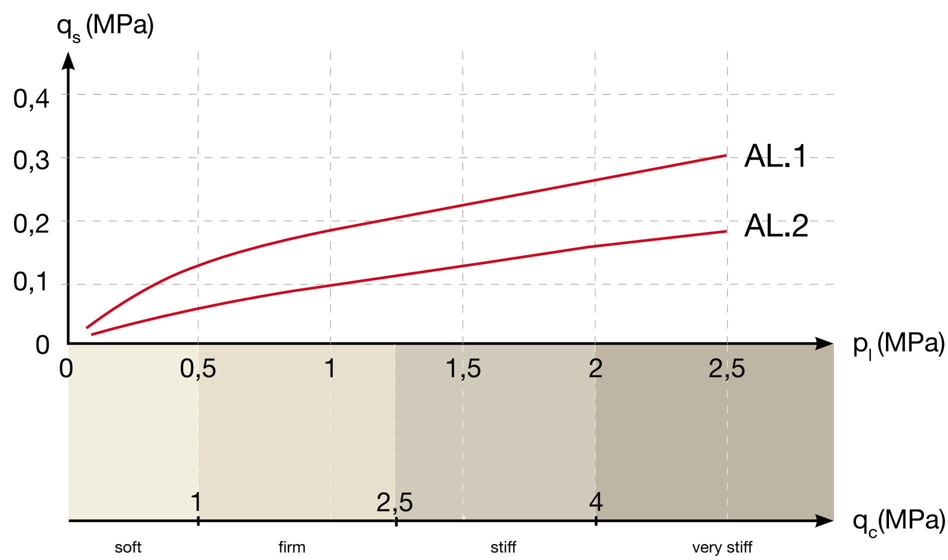


Figure H.2: pre-design chart for ground anchors bonded into clays and silts

Labels:
AL1: chart for IRS ground anchors
AL2: chart for IGU ground anchors

Chalk, marl and marly-limestone

Note: the marl classification is restricted here to soils having a $CaCO_3$ content higher than 30%.

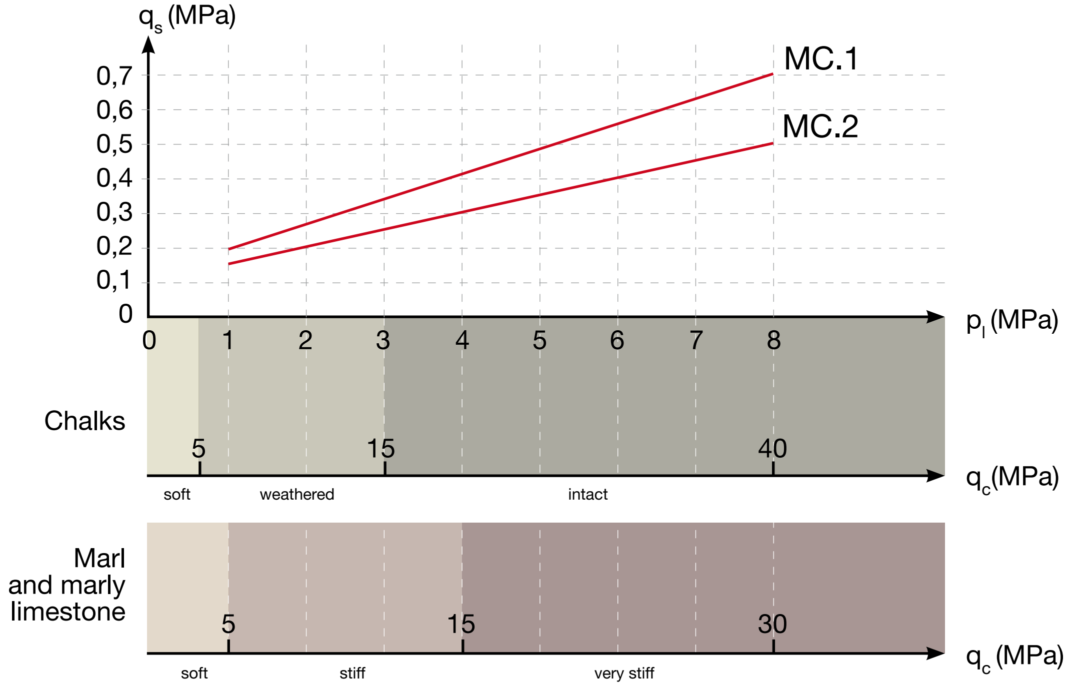


Figure H.3 : pre-design chart for ground anchors bonded into chalks, marls and marly limestones

Labels:
MC1: chart for IRS ground anchors
MC2: chart for IGU ground anchors

Weathered and fragmented rocks

For the general case of rocks, attention should be drawn on the fact that the STR grout resistance may prevail over the unitary axial friction when the chart leads to a high value of the latter.

Note: it is common practice to take this structural resistance into consideration when friction exceeds 800 kPa.

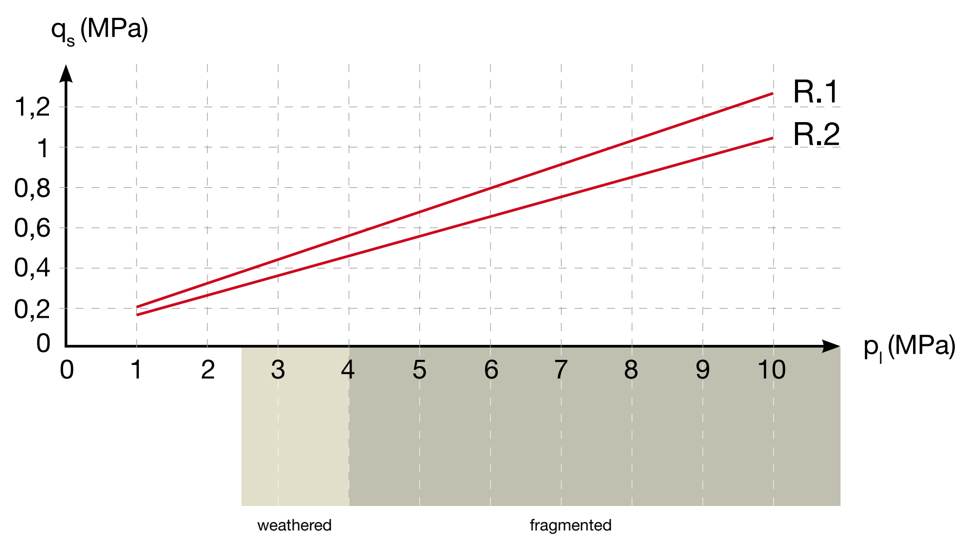


Figure H.4: pre-design chart for ground anchors bonded into weathered and fragmented rocks

Labels:
R1: chart for IRS ground anchors
R2: chart for IGU ground anchors

ANNEX I - CONDITIONS FOR STRESSING AND LOADING TESTS

I.1 PREAMBLE

Tests exclusively aim at reaching a ground resistance and at measuring deformations under this value, through ground anchor stressing. However, this objective may only be fulfilled if the following parameters are taken into account:

- the bond resistance is sufficient;
- the tendon strength is higher than the maximum intended tension to be applied P_p;
- the strength of the support structure is greater than the intended tension to be applied P_p (note);
- the equipment and devices are compatible with the objectives, and consistent with the last 2 parameters.

Note: usually, it will be requested that the support structure can only be barely deformable.

Comment: implementation of a ground anchor includes a step consisting in an acceptance test, and therefore is also concerned by the provisions below.

Using some delicate measuring devices on site may require building and using shelters.

I.2 BOND RESISTANCE

Loading the ground anchor may only happen when the bond has reached a sufficient resistance.

Note: a sufficient bond resistance is usually reached after 7 days.

Comment: a shorter time may be possible, but it is then recommended to justify a simple compression resistance of the grout of at least 20 MPa.

I.3 TENDON RESISTANCE

For all types of ground anchors, the proof load P_p shall under no circumstances be greater than the limit conventional resistance R_{max} (see paragraph 5.3.2.6).

Within the framework of failure tests, one may be driven to select a steel cross-section for the test anchor larger than the one chosen for the structure ground anchor.

I.4 SUPPORT STRUCTURE RESISTANCE

The expression « support structure » covers the following set of elements:

- the bearing plate (and the chair), which transmits forces from the ground anchor to:
- the waling, or distribution plate, which transmits forces toward:
- one (or several) support block(s) on the ground.

Picture I.1: Support structure for a loading test (© Soletanche Bachy)

This structure may be: dedicated to the test (which is the most frequent case for investigation tests), final (general case of acceptance tests), or intermediate, as a temporary reinforcement.

The structure shall be designed so that deformations and forces induced in it (see note 1) by the proof load values P_p (see note 2) remain acceptable.

Note 1: the resistance and deformation of the support ground are part of the parameters of the support structure.

Note 2: for lack of other specifications, the load induced by the test, taken into account for the justification of the support mass, is based on the resistance R_{max} (see paragraph I.3 above).

It shall be designed so that it does not undergo detrimental deformations caused by the forces applied to it.

Comment: a system that would be too deformable could not only cause a tension loss in the tendon, but also lead to disorders in the structure.

Besides, it would increase the risk of malfunction of the devices used to control tension over time (see paragraph 8.6).

One shall also ensure that there is a proper mechanical contact between the plate and the structure, and verify that the quality and/or recesses of the concrete below the bearing plate is/are sufficient in regard to the induced stress.

Comment: in the case of ground anchors that would not be perpendicular to the anchored structure, one should take into account the induced shear force (e.g. vertical component of the ground anchor load, in the case of a vertical retaining structure), by installing, for instance:

- a device against gliding under the bearing chair,
- a support mitigating the inclination (concrete pad, embedded recess, etc.).

Picture I.2: Recess in a shotcrete wall (© Soletanche Bachy)

I.5 EQUIPMENT AND DEVICES

I.5.1 GENERAL POINTS

Stressing control implies to know the tendon elongation, as well as the corresponding tension. For tension, jack pressure is measured using pressure gauges. For elongation, comparators are used, or any other device with a sufficient accuracy (see paragraph I.5.4).

Note: solely using the tension control device is uncommon.

Because of the specificities of the stressing process and of its subsequent interpretation, it is of particular importance that all equipment and devices are fully functioning, responsive and accurate.

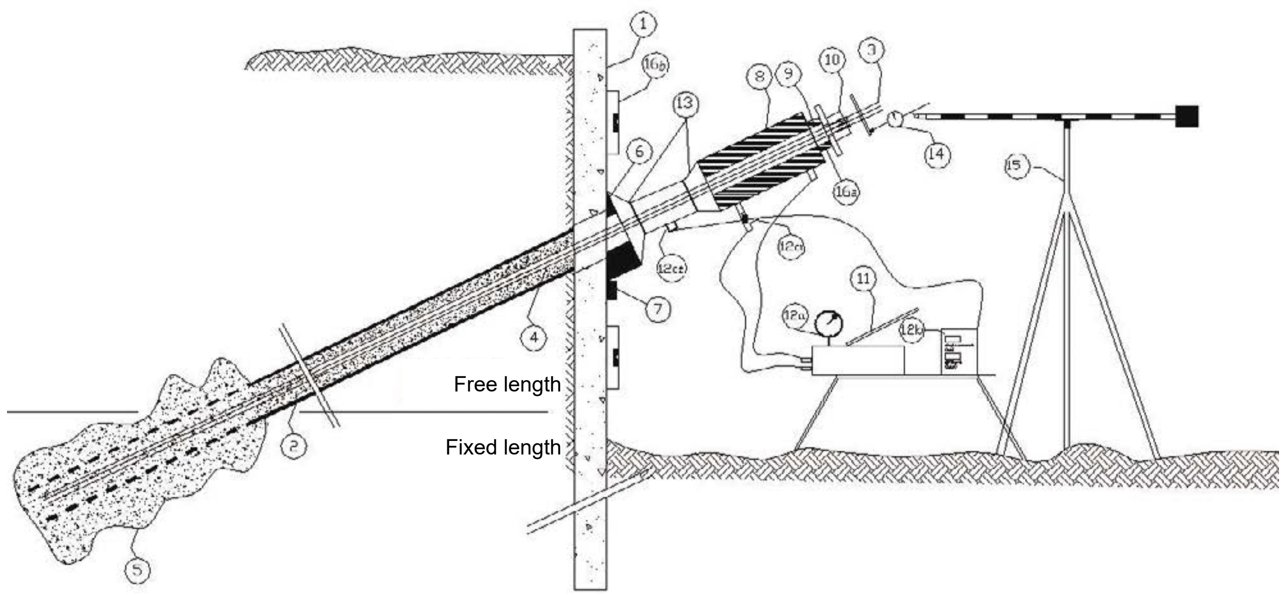


Figure I.1: execution principle of a static load test for a ground anchor

Labels :

1. support structure (in this instance, block or final wall)
2. borehole
3. external length L_e
4. free length L_L
5. fixed length L_s
6. angle recovery apparatus
7. anti-gliding stop (for load-transfer block)
8. hydraulic jack
9. jack piston
10. auxiliary lock-off device of the jack
11. pump or hydraulic unit
12. force measuring system
    - a. calibrated pressure gauge
    - b. measure box
    - c1. pressure sensor
    - c2. tension control device
13. distribution wedge
14. displacement measure system
15. fixed marker (tripod or, here, davit arm)
16. support measure
    - a. settlement
    - b. rotation

I.5.2 STRESSING EQUIPMENT

The stressing equipment includes a hydraulic jack powered by an electrical or manual pump.

Comment 1: the stressing system shall allow respecting the time allocated for the loadings between the various stages. 1 minute is the recommended value to move from one stage to another.

Comment 2: in order to guarantee that the applied loads remain constant over time, it is required that the jack and hydraulic system are fully functioning and do not show any leaks.

The device used to adjust the flow rate from the pump powering the jack shall be sufficiently fine to keep the accuracy within the expected boundaries.

Comment: tension forces should be maintained constant over the whole duration of each stage, with a measure discrepancy lower than 0.2% of the read value.

Depending on the selected prestressing system, the annular jack has a mechanical or hydraulic lock-off.

Note: hydraulic lock-off allows lower anchor entries than the mechanical one. In some particular cases, its use may prove required (very short free lengths, low lock-off load, etc.)

Whenever possible, the jack stroke shall remain compatible with the expected tendon elongation and the deformations of the support structure.

Picture I.3: Hydraulic pump to power the stressing jack (© Freyssinet)

Picture I.4: example of a stressing jack (© Freyssinet)

Comment 1: one should remain operational on a deformation range equal to at least 1,2 fois Δl_{es} (see note).

Comment 2: when a single jack cannot produce a sufficient stroke, several jacks may be used in series.

Note: $\Delta l_{es} = \Delta l_g + (L_L + L_S + L_e) \times R_{max} / A_s \times E$
where Δl_g is conventionally set at 0.01 m and E is the steel modulus

The jack shall have a capacity suitable for the maximum load that will be applied to the ground anchor. It shall be sufficient, but not excessive.

Note: 1.2 times P_p is a common value.

It is important to accurately know the active cross-section of the jack, as well as the losses by friction in the latter. These values shall be provided by the manufacturer, and recorded in a calibration or setting certificate not older than one year.

In the exceptional case where the jack used has losses by friction that are not proportional to tension, the stressing equipment shall be selected in a range of equipment where losses by friction do not exceed 10% of the maximum load applied to the ground anchor.

Comment: for instance, a 2,000 kN jack that, after being associated to the anchor elements, would have a constant friction of 80 kN for forces ranging from 100 to 2,000 kN, could only be used for a stressing of at least 800 kN.

I.5.3 LOAD MEASURING DEVICE

Loads should be measured with a jack having a pressure gauge providing the required accuracy, or with a tension control device suitable for the planned maximum tension.

Note: the tension control device being less frequently used, only the case of a jack with a pressure sensor is detailed below.

Measuring pressure is carried out either with a dial gauge or with a digital sensor.

The device used to measure pressures shall be chosen so that the maximum value of its scale should be equal to, at most, one and a half time the maximum planned pressure, taking into account the cross-section of the jack and its losses by friction.

Comment: only in the case where such a gauge or sensor is not marketed, is it allowed to use a device with a range of values corresponding to twice the maximum planned pressure.

The pressure gauges and sensors shall be calibrated, have the supporting calibration certificate, and be maintained in perfect condition. Their indications shall enable a comparison to the ones of a second pressure gauge, permanently kept on the site. To do so, the pressurisation ducts shall feature a connection allowing to swiftly mount in parallel this pressure gauge or sensor.

The corrected reading discrepancy of calibration (see note) between both devices for the maximum planned pressure shall not exceed 3 %. Ideally, you should permanently equip the pump with both devices.

Note: as a reminder, the calibration is here the discrepancy between the measure displayed by the measurement standard and the pressure gauge being verified.

If the corrected indications of the calibration (see note above) of both devices differ of more than 3 %, a diagnosis shall be made, and the faulty gauge or sensor shall be promptly replaced.

Pressure gauges are verified every 6 months with a standard pressure gauge, which is itself systematically subject to a yearly verification by an official body.

Measuring tension shall be made with accuracy lower than the higher of the two following values: 1% of the measured value and 10 kN.

Picture I.5: Apparatus to measure displacements (© Spie Fondations)

I.5.4 DEVICES TO MEASURE ELONGATION

Measuring elongation is made with a comparator, to measure the displacement at anchor head relative to a strictly fixed point, with accuracy lower than, or equal to, 1/100 mm.

Comment 1: if digital displacement sensors are used, they also shall have accuracy lower than, or equal to, 1/100 mm.

Comment 2: you should measure the elongation of the ground anchor from an apparatus connected to the tendon, or being directly set on the tendon (case of a bar or tube) at the rear of the jack.

Note: in the case of an acceptance test, one may settle for accuracy in an order of magnitude of 1/10 of millimetre.

The measuring equipment has preferably a sufficiently long stroke, so it will not have to be re-aligned, and is connected to the fixed point mentioned below.

Comment: a stroke of 1.2 times Δl_{es} is a usual value.

The comparator shall have been controlled one year at most before the date of measures.

The fixed point (for instance, a tripod supporting a rigid steel profile) shall be installed outside the zone influenced by the forces applied to the ground anchor, and remain insensitive to any self-deformation.

Comment: any heavy vehicle traffic, or any other activity capable of disturbing the measures (for instance, sheet pile driving) is prohibited at the immediate proximity of this fixed point.

Using a fixed point is mandatory because measuring displacement in relation to the structure does not produce satisfying results, and does not allow determining the absolute elongation of ground anchors following the deformations of the structure and of the bearing plate of the anchor head. Only at loading end, when all elements are in their final positions, may it allow assessing the relative elongation.

Note 1: when the set-up of such a fixed point is not feasible (within a context of marine works, for instance), one should also measure the displacements of the anchored structure in relation to a fixed point, to obtain, by difference, the ground anchor elongation.

Note 2: when the stressing of the first ground anchors has made possible to check that the structure possesses a sufficient rigidity (retaining structure with a thick diaphragm wall, for instance), the elongation may be determined by measuring the jack stroke.

Note 3: in particular, the equivalent free length (see paragraph 7.4.9.2) shall be assessed by using a fixed point.

I.5.5 CONTINUOUS LOGGING OF DEFORMATIONS AND LOADS

You should continuously log the displacements in function of the hydraulic pressures measured from the jack (or of the loads), and each of these values in function of time.

Note: these logs enable to detect transient anomalies and/or behaviours hidden by one-off measures. However, they do not exempt from carrying out one-off measures, which are usually far more accurate.

I.5.5 MEASURING TIME AND TEMPERATURE

Time measures are recorded with accuracy of one second.

Temperature logs are recorded with accuracy lower than or equal to, 1°C.

ANNEX J - PROCEDURE FOR AN ANCHOR STATIC LOADING TEST

J.1 PREAMBLE

The procedure described here complies with standard NF EN ISO 22477-5.

J.2 GENERAL PRINCIPLES

Following a programme defined in function of time, the test consists in applying a static tension force at the free end of the tendon, and in measuring the resulting displacement (see figure J.1).

The loading programme consists in applying a tension force P_p at the end of the ground anchor located outside the ground, with increments equal to ΔP.

Each loading stage is maintained constant during a set duration Δt. The time to go from one stage to another is lower than 1 minute.

Ground anchor destressing is also achieved by stages.

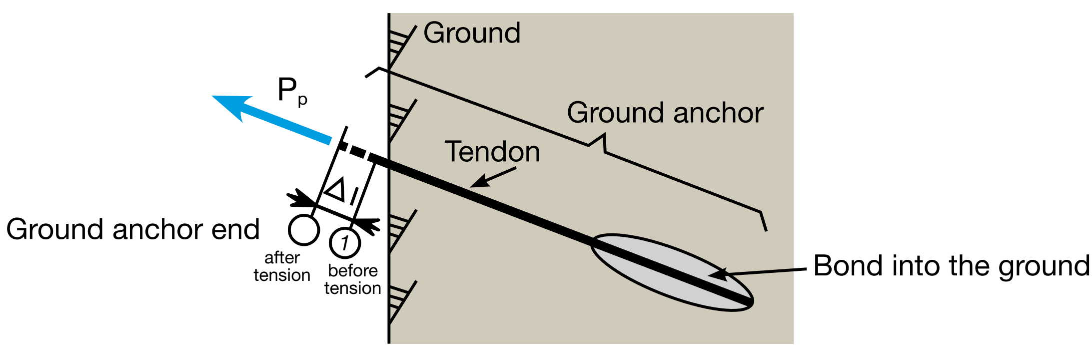


Table J.1: loading programme of a failure test

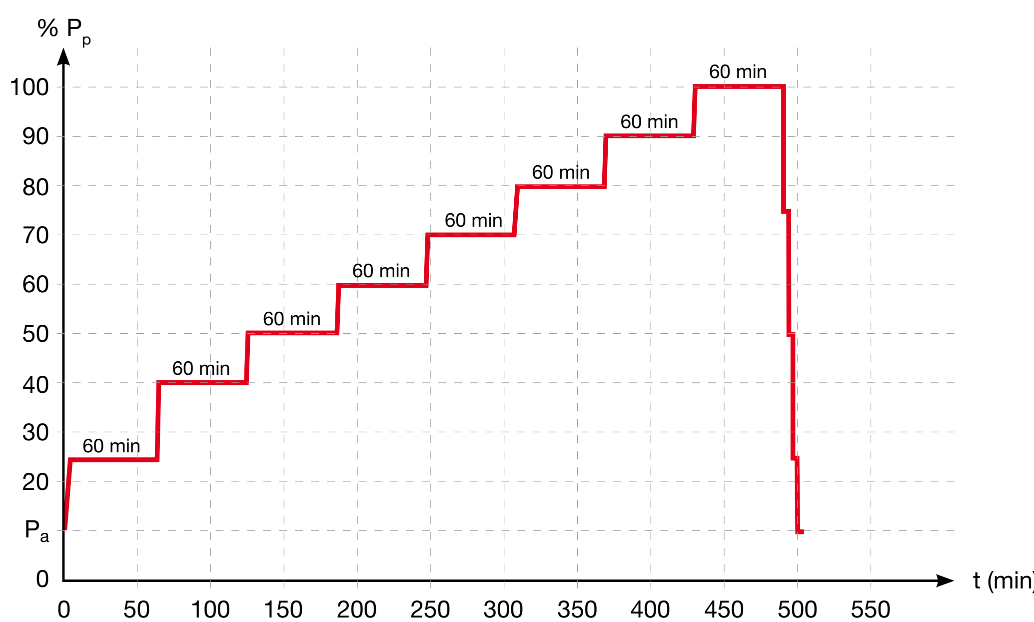


Figure J.2: loading programme of a ground anchor (example of a failure test)

The measures of force and displacement of the anchor end are numerically produced at minimum at the times t = 1, 2, 3, 4, 5, 7, 10, 15, 20, 25, 30, 45 and 60 minutes after the start of each stage.

Note: it is often pertinent to make additional measures at 40 and 50 minutes.

Creep rate α is measured at each stage between the times t_a = 5 min and t_b = stage end.

Note: the times t_a and t_b are counted from the time t_0, at which the stage load is stabilised.

Comment: as a reminder, α is the representative slope of the anchor head displacement for the test stage in function of the time logarithm. It is calculated from the following formula:

$$\alpha = (\delta_b-\delta_a) / (\log(t_b)-\log(t_a)) = (\delta_b-\delta_a) / \log (t_b/t_a)$$

δ_a anchor head displacement at time t_a
δ_b anchor head displacement at time t_b
t_a start of the corresponding time interval
t_b end of the corresponding time interval

J.3 PULL-OUT TEST SYSTEM AND EQUIPMENT

See annex I.

J.4 ORGANISING A FAILURE TEST

J.4.1 DATA COLLECTION

The loading programme is displayed on figure J.1.

The increments of the loading stages are given in table J.1 below:

Stages	Ref. (1)	1	2	3	4	5	6	7	8
Tension	P_a	$0{,}25.P_p$	$0{,}40.P_p$	$0{,}50.P_p$	$0{,}60.P_p$	$0{,}70.P_p$	$0{,}80.P_p$	$0{,}90.P_p$	P_p
Duration (min)	0	60 (2)	60 (2)	60	60	60	60	60	60

(1) The tension P_a, which corresponds to the first reading, is conventionally set at a value close to a tenth of the proof load, without however corresponding to a tension lower than 50 kN.

(2) Decreasing the first stages to 30 minutes may only be taken into consideration if the tendon head displacement is lower than, or equal to, 0.03 mm between 15 and 30 min, which corresponds to α being equal to 0.1 mm.

Table J.1: loading programme of a failure test

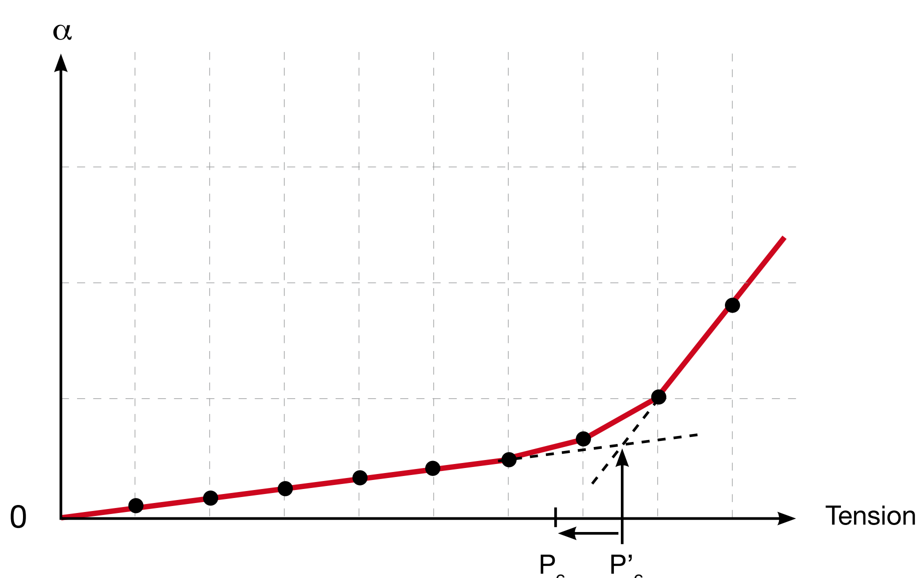


Figure J.3: curve of slopes α in function of tension

Comment 1: when bond failure is not observed during the test duration, you should resume testing beyond P_p, with, for instance, increment stages of 10% x P_p under the condition that tension remains lower than, or equal to, R_{max}.

Comment 2: the test may stop before the last stage if:

- The value of Δl_{es} (as defined in I.5.2) is reached or,
- The slope α exceeds the value of α_3 (last note of AN2 in standard NF EN 1997-1/NA)

Note 1: α_3 is the limit value of α according to method 3 of NF EN ISO 22477-5; as a reminder, α_3 = 5 mm for a failure test.

Note 2: experience shows that the 2nd criterion is practically never reached.

J.4.2 PRESENTATION OF RESULTS

Failure test data shall be graphically presented with the following curves:

- Curve « anchor head displacement in function of applied load »
- Curves « anchor head displacement in function of time » for each stage (see note)
- Curve« slope α in function of tension » (see figure J.3)

Note: these curves are usually regrouped on a single graph.

J.4.3 EXPLOITATION OF RESULTS

Usually, the first part of the curve « slope in function of tension » is sensibly linear, and then exhibits an upwards concavity (see figure J.3).

Comment: if neither of these conditions are met, the reason of this anomaly should be determined, and the test anchor possibly rejected.

Measured value of the anchor ULS resistance $R_{ELU,m}$.

If Δl_{es} or α_3 are reached during a stage, $R_{ELU;m}$ will be selected as the tension value of that stage.

In the opposite case, $R_{ELU;m}$ is the value of the highest stage (see note).

Note: this is usually P_p but it may be R_{max} (see comment 1 of J.4.1).

Measured value of the critical creep resistance $R_{ELS;m}$.

If there are at least 3 points aligned on the line passing through the origin, the critical creep resistance $R_{ELS;m}$ is defined as being the end of the linear range detected on the curve.

If all points are on a line passing though the origin, $R_{ELS\,;m}$ will be selected as the maximum value reached during the test.

In the other cases, the linear parts of the start and end of the curve meeting on the point of x-axis P'_c will be extended. Conventionally, what is selected is $R_{ELS;m} = P_c = 0{,}9\ P'_c$ (configuration displayed in figure J.3).

J.5 ORGANISING A SUITABILITY TEST

J.5.1 DATA COLLECTION

The loading programme is displayed on figure J.4 below:

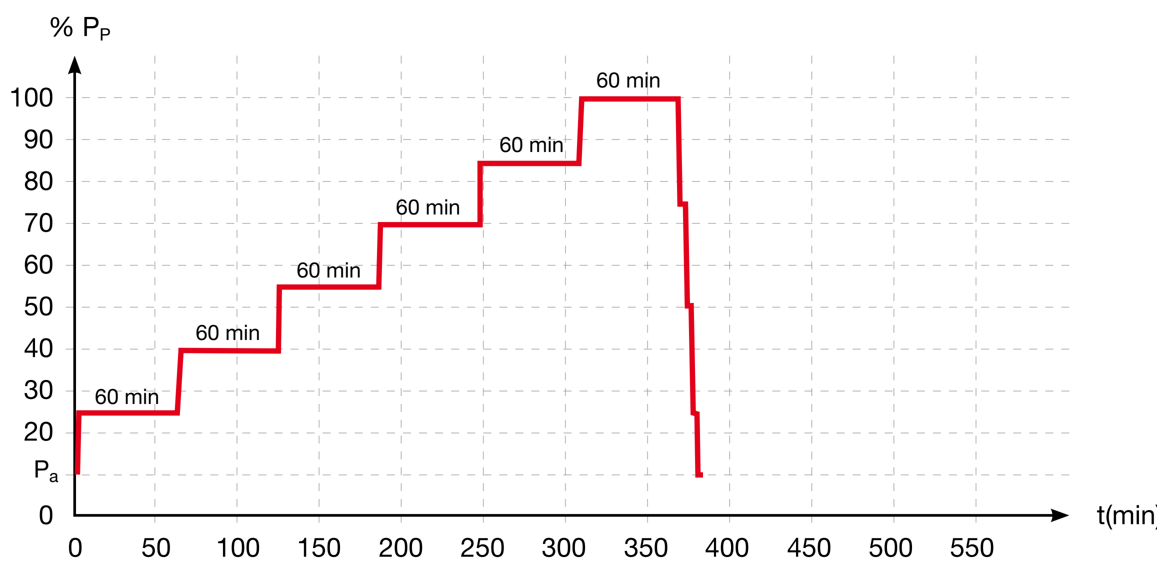


Figure J.4: loading programme of a suitability test

The increments for the loading stages are given in table J.2 below.

Stages	Ref. (1)	1	2	3	4	5	6
Tension	P_a	$0,25.P_p$	$0,40.P_p$	$0,55.P_p$	$0,70.P_p$	$0,85.P_p$	P_p
Duration (min)	0	60 (2)	60 (2)	60	60	60	60

(1) The tension P_a c, which corresponds to the first reading, is conventionally set at a value close to a tenth of the proof load. It aims at minimising the motions of the test system during the initial tension.

(2) Decreasing the first stages to 30 minutes may only be taken into consideration if the tendon head displacement is lower than or equal to 0.03 mm between 15 and 30 min, which corresponds to α being equal to 0.1 mm.

Tableau J.2 : programme de chargement d'un essai de contrôle

J.5.2 PRESENTATION OF RESULTS

Suitability test data shall be graphically presented by the following curves:

- Curve « anchor head displacement in function of time » for each stage (see note)
- Curve « slope α in function of tension », whenever possible.

Note: these curves are usually regrouped on a single graph.

ANNEX K - GROUND ANCHORS HAVING A FREE LENGTH NOT MATERIALISED BY A PHYSICAL BOUNDARY

K.1 PREAMBLE

Executing ground anchors having a free length not materialised by a physical boundary is not recommended.
It is only allowed for passive ground anchors.

Note: fastening with a torque wrench is not considered as prestressing.

However, it is mandatory to have a free length materialisation of at least 1 m at the head.

The provisions of the text body not corrected by the present annex remain applicable.

K.2 GEO JUSTIFICATION

Design founded on failure tests remains mandatory, and the tests shall satisfy one or the other of the following procedures:

- either the test anchors are equipped with physical barriers (unlike structure anchors) to allow the proper characterisation of the bond, and tests are carried out in accordance with standard NF EN 22477-5 (see annex J),
- or the test anchors are not equipped with such an apparatus, and tests are carried out as for piles under standard NF P 94 150-2 (pending standard NF EN 22477-2), following a programme that allows identifying the contribution of the free part not materialised in the lateral friction.

In the first case, the method described in the text body (see paragraphs 5.3.3.3 and 5.4.2) is applied to assess the bond characteristic resistance.

In the second case, the bond characteristic resistance is assessed from the statistical analysis methods of standard NF EN 1997-1 (paragraph 7.5.2), which standard NF P 94 262 (paragraph 9.2.2) has specified:

$$R_{t\,;k} = \text{Min}\,\{\,(R_c)_{moyen} / \xi_1\ ;\ (R_c)_{min} / \xi_2\}$$

Comment: notations are the ones of the mentioned standards. The definitions are recalled below, with, when pertinent, their correspondence with the present guide:

- $R_{t\,;k}$ is the bond characteristic resistance and corresponds to R_k or $R_{cr\,;k}$, depending on if it is the ultimate or serviceability limit state being addressed;
- R_c is the value of bond resistance measured during the test and corresponds to $R_{ELU\,;m}$ or à $R_{ELS\,;m}$, depending on if it is the ultimate or serviceability limit state being addressed;
- $(R_c)_{mean}$ is the arithmetic mean of all R_c ;
- $(R_c)_{min}$ is the minimum value of all R_c ;
- ξ_1 and ξ_2 are the correlation factors respectively applied to the mean and minimum values.

The factor ξ_i depends on the surface S of the geotechnical investigations (see note), on the number of tests N on the considered surface, and on the correlation ξ_i' function of N (see table K.1):

$$\xi_i = 1 + [\xi_i'(N)-1]\ .\ (S / S_{réf})^{1/2}$$

Note: if L is the longer length of the structure (including anchors area) and l the smaller length,

$$S = \text{MAX}(625\ m^2\ ;\ L\,.\,l\ ;\ L^2/2)$$

with S_{ref} corresponding to a reference surface, selected as equal to 2,500 m².

N	2	3	4	≥ 5
ξ_1'	1.30	1.20	1.10	1.00
ξ_2'	1.20	1.05	1.00	1.00

Table K.1: values of the factors ξ_i' (under NF P 94 262)

K.3 STIFFNESS ASSESSMENT

To apply 5.4.1, attention is drawn on the difficulty of assessing free length: it may be sound to proceed to a « range » calculation.

Note: when tests are carried out on test anchors identical to the structure anchors, it makes sense to use the stiffnesses measured during the tests.

K.4 CASE OF RETAINING ANCHORS

For the overall stability (paragraph 5.3.1 and annex F), one should take into account the fact that any friction in the non-materialised free part displaces the fictitious anchorage point toward the anchor head. Several stability verifications may be required, with variations of this anchorage point.

K.5 SUITABILITY AND ACCEPTANCE TESTS

A cycle should be carried out during the pressure build-up, by proceeding as follows: the pressure build-up is achieved per the stages defined for a ground anchor with a free length (see paragraph 7.4.6 for the acceptance test and annex J.5 for the suitability test).

When the deformation measured during a stage reaches the value expected for a materialised free length the load is brought back down to the first stage before re-increasing (while maintaining stages) up to the proof load.
If the proof load is obtained and this value is not reached, the design adequacy will have to be verified, in particular in relation to the stiffness taken into account (see paragraph K.3) or in regard to the overall stability (see paragraph K.4)

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