GEOSPEC 1

# MODEL SPECIFICATION FOR PRESTRESSED GROUND ANCHORS

GEOTECHNICAL CONTROL OFFICE
Civil Engineering Services Department
Hong Kong

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**GEOTECHNICAL ENGINEERING OFFICE**
**Civil Engineering Department**
**Hong Kong**

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## FOREWORD

The first edition of this Model Specification was published in March 1984 and since then the technical standards specified have been widely used in both government and private projects involving prestressed ground anchors. In April 1988 a Working Group was set up to review the Model Specification, under the direction of a Steering Committee. The membership of the Working Group and Steering Committee are given on the opposite page. Consultants, contractors and government offices involved in anchor projects since publication of the first edition were asked to suggest improvements, and all the test and monitoring data passed to the GCO was put into a database. The amendments contained in this second edition are based on the replies received and an analysis of database records. In revising the specification for grease and plastics the Working Group was assisted by Dr T.T. Kam of the Government Laboratory, and, on the topic of cement grout, by Mr T. Carbray, Chief Geotechnical Engineer/Materials.

The technical standards incorporated in the second edition of the Model Specification have been adopted with due regard to existing local practice and after consideration of several relevant international and national codes. In particular, account has been taken of the requirements of the Fédération Internationale de la Précontrainte (FIP), the British Standard Code of Practice for Ground Anchorages, BS 8081 : 1989, and the Swiss and Austrian Codes.

A Prior Approval System which provides a framework for control of the standards of permanent prestressed ground anchors in Hong Kong is implemented in conjunction with the publication of this second edition. In future, permanent prestressed ground anchors will require the Prior Approval of the Director of Civil Engineering Services before they can be used for government and Housing Department projects. Prior Approval will also facilitate the use of ground anchors for private developments. Details of the Prior Approval System are given in Appendix B.

This Model Specification has been prepared in such a manner that the clauses contained herein should be used as model clauses for the preparation of a Particular Specification and should be modified or added to where necessary to suit the requirements of individual organisations.

In order to assist in the preparation of a Particular Specification, marginal notes in italics are provided against some of the clauses to amplify the intent of these clauses. Supplementary notes are given in Appendix A to cover design-related aspects and to provide advice specific to Hong Kong conditions.

Of great importance is the process of post-construction monitoring, which must continue throughout the life of an anchor system. It is also essential that those responsible for subsequent maintenance are consulted and their agreement obtained before ground anchors are adopted and that they are provided with complete 'as built' details. The requirement for long-term monitoring may be expensive and difficult to achieve, and for this reason ground anchors should only be used when other methods of providing the required support are not practicable.

Project engineers and designers are urged to make early use of this Model Specification to ensure that the installation and monitoring of prestressed ground anchors in Hong Kong will be to a satisfactory standard. Agents for prestressed ground anchors systems are invited to apply for Prior Approval to facilitate the use of their anchors in Hong Kong.

A.W. Malone
Principal Government Geotechnical Engineer
August 1989

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# 1. DEFINITIONS

## 1.1 DEFINITIONS OF TERMS

Acceptance Test. Load test carried out on a working anchor to check whether it is performing satisfactorily.

Aggressive conditions. Conditions where chemical, atmospheric, electrical, or microbiological attack of the anchor or any of its components may occur.

Anchor. See under Prestressed ground anchor.

Anchor class. Classification of an anchor based on its proposed usage.

Anchor head. That part of the anchor that transfers the tendon forces into the structure, object or ground mass which is to be supported by the anchor.

Anchor system. Proprietary anchor and all the procedures and requirements for installation, stressing and corrosion protection.

Anchorage zone. That part of the ground surrounding the anchor that is intended to provide the anchorage or restraint to the forces applied to the tendon.

Approved Anchor System. Anchor system approved for use by the Director of Civil Engineering Services.

Approved Anchor Type. Anchor within an Approved Anchor System approved for use under defined operating conditions by the Director of Civil Engineering Services.

Compression type anchor. Anchor, with an end plate or nut, whose tendon is unbonded.

Design free anchor length. Length of the anchor not intended to transmit load into the surrounding material.

Design working load. Load required to be applied by the anchor to the structure or the surface of a slope to ensure stability.

Draw-in. Reduction in extension of tendon on transfer of load from the jack to the anchor head.

Effective free length. Apparent length over which the tendon is assumed to extend elastically, as determined by stressing tests.

Extended Acceptance Test. Incremental load test that is less comprehensive than the Suitability Test.

Fixed anchor length. Design length over which the tension force is expected to be transmitted into the anchorage zone.

Lift-off test. Test to determine the residual load in the tendon.

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Lock-off load. Pre-determined load applied immediately prior to locking-off so as to provide the anticipated residual load in the tendon.

Nominated Anchor Contractor. Contractor accepted under the Prior Approval System for the installation of an Approved Anchor System.

Permanent anchor. Anchor whose service life is two years or more.

PFA. Pulverised fuel ash.

Prestressed ground anchor (hereinafter referred to as anchor). Tendon and its associated components that transmit load into soil or rock, the load carrying capacity of which can be checked by tensioning and which is proof-loaded prior to acceptance.

Prior Approval Documents. Documents which form the basis for Prior Approval by the Director of Civil Engineering Services of an Approved Anchor System and Approved Anchor Type(s).

Prior Approval System. System by which the Director of Civil Engineering Services grants Prior Approval to the use of proprietary prestressed ground anchor systems.

Residual load. Load remaining in the tendon at any time after locking-off, usually measured by a lift-off test.

Service life. Period over which an anchor is intended to remain effective in fulfilling its purpose.

Suitability Test. Comprehensive incremental load test carried out to check assumptions and parameters, to demonstrate the effectiveness of the installation procedure and to establish base criteria for Acceptance Tests.

Temporary anchor. Anchor whose service life is less than two years.

Tendon. High tensile steel bar, strand or wire acting as a tension member in an anchor.

Tension type anchor. An anchor whose tendon is bonded in the fixed anchor length.

## 1.2 DEFINITIONS OF SYMBOLS

### 1.2.1 Materials

$A_t$ = cross-sectional area of tendon ($mm^2$)

$E_t$ = modulus of elasticity of tendon (MPa)

$f_{pu}$ = characteristic strength of tendon (MPa)

### 1.2.2 Dimensions

$l_{ef}$ = effective free length (m)

[BLANK PAGE]

$l_{fr}$ = design free anchor length (m)

$l_v$ = fixed anchor length (m)

### 1.2.3 Forces

R = friction developed in effective free length (kN)

T = anchor load (kN)

$T_A$ = initial load selected for Suitability, Extended Acceptance or Acceptance Test (kN)

$T_D$ = specified design working load (kN)

$T_O$ = lock-off load (kN)

$T_p$ = test load for Suitability, Extended Acceptance or Acceptance Test (kN)

$T_R$ = residual load as measured at any time after locking-off (kN)

$T_{RC}$ = calculated residual load immediately after locking-off (kN)

$T_Z$ = nominal failure load of tendon (kN)

= $A_t f_{pu} \times 10^{-3}$

### 1.2.4 Deformations

$\Delta l$ = total extension of tendon relative to a datum (mm)

$\Delta l_e$ = elastic extension of tendon at each load stage (mm)

$$= \frac{l_{ef}(T - T_A)}{A_t E_t} \times 10^6$$

$\Delta l_k$ = travel of piston of stressing jack for each load stage (mm)

$\Delta l_{pl}$ = plastic or non-recoverable extension at each load stage (mm)

$\Delta l_r$ = calculated elastic extension of anchor under test load $T_p$ (mm)

For tension type anchors :

$$\Delta l_r = \frac{l_{fr}(T_p - T_A)}{A_t E_t} \times 10^6,$$

for compression type anchors:

$$\Delta l_r = \frac{(l_{fr} + l_v)(T_p - T_A)}{A_t E_t} \times 10^6.$$

$\Delta s$ = axial movement of anchor base plate relative to a datum (mm)

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### 1.2.5 Factors of Safety

$S = \frac{T_Z}{T_D}$ = load factor of safety for an anchor

= 1.6 for temporary anchors

= 2.0 for permanent anchors

$X = \frac{T_P}{T_D}$ = test load factor for a working anchor subject to Extended Acceptance or Acceptance Test

*NOTES*

*Clause 2.2 - The Engineer should note that details of the Prior Approval System are given in Appendix B. When anchors are covered by the Prior Approval System, the Engineer's decision shall not be in conflict with any requirement of the Prior Approval System.*

*Clause 2.3 - Further information regarding clarification of the contractual responsibility for supply and installation of anchors under the Prior Approval System is given in Section A.5 of Appendix A.*

*Parameters and information on which tenders must be based, viz. the working loads of the anchors, their anchor class, their design free lengths, the testing programme, the relative movement to be allowed for between the anchor pad and the anchorage body, ground investigation data including results of tests for ground aggressiveness (see Section A.9 of Appendix A), any special requirements for anchor construction and stressing (where applicable) and the general layout for the anchors should be given on the Drawings or other tender documents. If the Contractor is expected to design the anchor pad (Figure A1), then this should be stated on the Drawings, which should also include the allowable bearing pressure.*

*The Engineer, in preparing the Conditions of Tender, should require each tenderer to provide information with the tender to demonstrate the adequacy of the tender proposal (see Section A.21 of Appendix A).*

# 2. PREAMBLE

## 2.1 DRAWINGS

Ground anchors used in the Contract shall be in accordance with the requirements of this Specification and with the following drawings, which shall form part of the Contract :

*(STATE DRAWING NOS. & TITLES)*

## 2.2 GENERAL REQUIREMENTS

### 2.2.1 Permanent Anchors

The installation of permanent anchors, including drilling, water testing of drillholes, anchor installation, stressing and monitoring, shall be carried out in accordance with this Specification.

All permanent anchors shall have the Prior Approval of the Director of Civil Engineering Services. Only Approved Anchor Types of an Approved Anchor System shall be used. The details given in the Prior Approval Documents shall supersede requirements made in this Specification but must otherwise be applied in conjunction with its requirements.

The Contractor shall inform the Engineer in writing at least 28 days before installation commences of the name of the Approved Anchor System and the Approved Anchor Types he intends to use and the Nominated Anchor Contractor who will install the anchors.

The Contractor shall supply a copy of a full set of Prior Approval Documents to the Engineer on Site at least seven days prior to commencement of any work related to the anchors.

### 2.2.2 Temporary Anchors

The installation of temporary anchors, including drilling, water testing of drillholes, anchor installation, stressing and monitoring, shall be carried out in accordance with this Specification.

## 2.3 CONTRACTOR'S RESPONSIBILITIES

The Contractor shall be responsible for providing and installing the anchors and for determining :

(a) the number and type of bars, strands or wires,

(b) the drillhole diameter,

(c) the fixed anchor length,

(d) details of the grout to be used, and

(e) any other details necessary for the installation

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and performance of the anchors.

The Contractor shall test the performance of the anchors and shall replace any anchor that fails to meet the test conditions specified in Sections 6 and 7. After testing, the Contractor shall monitor the anchors up to the end of the Maintenance Period in accordance with the requirements of Clauses 4.6.2, 4.6.3 and 4.6.4.

*NOTES*

*Clause 3.3 - Less bleed should result when PFA is used as an admixture in the grout.*

# 3. MATERIALS

## 3.1 GENERAL REQUIREMENTS

The requirements listed in the following clauses shall apply, wherever relevant, to materials used in all anchors except when otherwise agreed by the Engineer. The handling, storage and use of materials shall comply with manufacturers' instructions.

An anchor shall not contain materials that are mutually incompatible with each other and the surrounding environment.

## 3.2 TENDONS

Prestressing tendons shall comply with the following:

(a) High tensile steel wire and wire strand to BS 5896 : 1980.

(b) Nineteen wire steel strand to BS 4757 : 1971.

(c) Hot rolled or hot rolled and processed high tensile alloy steel bars to BS 4486 : 1980.

Steel wire and wire strand shall be in coils of sufficiently large diameter to ensure that the steel wire and wire strand pay off straight.

Alloy steel bars shall be straight.

A certificate shall be submitted to the Engineer containing the following particulars on the prestressing tendons:

(a) The manufacturer's name and the date and place of manufacture,

(b) cast analysis,

(c) diameter, cross sectional area and unit mass,

(d) results of tests for mechanical properties, including the characteristic breaking load, characteristic 0.1% proof load, elongation at maximum load, relaxation and modulus of elasticity, and

(e) results of tests for ductility of prestressing wires.

## 3.3 CEMENT GROUT

Cements used for grouting anchors shall comply with BS 12 : 1978.

Grout shall consist of Ordinary Portland Cement and water. Sand and PFA shall not be used unless approved by the Engineer.

*NOTES*

*Clause 3.4 - Advice on the testing of grease, including initial acceptance tests and confirmatory tests on site and during monitoring, is given in Section A.12 of Appendix A.*

*Clause 3.5 - Advice on the testing of plastics, including initial acceptance tests and confirmatory tests on site, is given in Section A.13 of Appendix A.*

High alumina cement shall not be used.

Water shall be taken from the public supply of potable water and shall be at least to the quality specified in BS 3148 : 1980.

Admixtures shall comply with the requirements of BS 5075 : Part 1 : 1982 and BS 5075 : Part 3 : 1985 and shall only be used with the prior agreement of the Engineer.

The total sulphate ($SO_3$), chloride and nitrate contents of the grout shall not exceed 4%, 0.1% and 0.1% expressed as a percentage between the respective ion content and the cement content by mass in the grout. The total sulphate ($SO_3$) and chloride contents shall be determined by the method described in BS 1881 : Part 6 : 1971. The total nitrate content shall be determined by the method described in ASTM D 4327-84.

## 3.4 GREASES

The greases used shall be formulated and manufactured for the specific purpose of corrosion protection and to provide lubrication to prestressed high tensile steel tendons. Greases shall be water displacing, self-healing, thixotropic and shall be resistant to microbiological degradation. The properties of the grease shall be such that in the process of pumping voids are filled and intimate contact is established between the grease and all the steel surfaces of a strand or tendon.

Greases, including any used by the manufacturer of the tendons, shall comply with the requirements set down in Table 1.

The Contractor shall provide the following information :

(a) product identification details (including name of manufacturer, brand name, type and date of manufacture of product), and

(b) nature of the soap used (if any).

Any grease to be used in the Contract shall be accompanied by test certificates which show that it complies with the requirements set down in Table 1. Grease shall be used in accordance with the manufacturer's instructions.

Different types of grease shall not be allowed to come into contact with each other in any part of the anchor.

## 3.5 PLASTICS

Sheathing, ducting and other plastic components for tendon protection shall be made from high density thermoplastic material and the wall thickness shall be at least 1.0 mm.

The finished internal and external surfaces of the sheathing and ducting shall be smooth, clean and free from flaws, pin holes, bubbles, cracks and other defects. The material used shall be homogeneous, thermally stable and chemically inert and shall be resistant to chemical,

*NOTES*

*Clauses 3.5(f) and 3.6 - Joints in sheathing and ducting must be in accordance with an approved specification and detail provided by the Contractor and agreed by the Engineer. The Engineer's decision must not be in conflict with any requirement of the Prior Approval System.*

bacterial and fungal attack. Sheathing, ducting and other plastic protective components shall not contain any substances that will promote corrosion.

Plastic components shall be covered to prevent exposure to ultra-violet light from direct or indirect sunlight.

All plastics to be used in an anchor shall be accompanied by test certificates which show that the material complies with the requirements set down in Table 2. Plastics shall be used in accordance with the manufacturer's instructions.

All plastics used in an anchor shall be resistant to slip in the region of the fixed anchor length and shall be capable of withstanding the effect of load transfer.

The Contractor shall also provide the following information :

(a) product identification details (including name of manufacturer, brand name, type and date of manufacture of product),

(b) outer and inner diameter,

(c) wall thickness,

(d) amplitude and pitch, in mm, for corrugated sheathing or ducting,

(e) standard length in m, and

(f) jointing details.

## 3.6 METAL DUCTING

Metal ducting shall only be used with the agreement of the Engineer.

Metal ducting shall be suitably protected against corrosion, resistant to slip in the region of the fixed anchor length, and capable of withstanding the effect of load transfer.

The information specified in Clause 3.5(a) to (f) shall also be provided for metal ducting.

## 3.7 RUBBER RINGS

Rubber rings used in the corrosion protection system shall be manufactured from materials which comply with BS 2494 : 1986.

Product identification details (including name of manufacturer, brand name, type and date of manufacture of product), and evidence that the product complies with BS 2494 : 1986, shall be provided.

*NOTES*

*Clause 3.8 - It should be noted that the General Specification for Civil Engineering Works (1977) is being revised at the time of this Model Specification going to press. When the new edition of the General Specification for Civil Engineering Works is published, reference to the appropriate sections of the new edition should be substituted in this Clause.*

## 3.8 OTHER MATERIALS

All other materials used in anchors unless otherwise specified shall comply with the requirements of Section 26 of the General Specification for Civil Engineering Works (1977).

*NOTES*

*Clause 4.1 - Information on corrosion protection requirements for Prior Approval of permanent anchor systems is given in Section B.6 of Appendix B.*

*Clause 4.2 - Any Approved Anchor System should also be approved by the Engineer for use as a temporary anchor.*

*Clause 4.2.1 - Clause 8.1.1 and Appendix J.2 of BSI (1989) give guidance on the quality of pre-stressing steel and the maximum acceptable surface corrosion. Hong Kong conditions are sufficiently severe to promote stress corrosion failure at an area of apparently minor damage. It must be emphasised that steel which shows signs of pitting should be rejected.*

*Clause 4.2.4 - See note opposite Clause 3.8.*

# 4. SYSTEM REQUIREMENTS

## 4.1 CORROSION PROTECTION FOR PERMANENT ANCHORS

The corrosion protection system shall be in accordance with the Prior Approval Documents for the Approved Anchor System and Approved Anchor Types to be used.

## 4.2 CORROSION PROTECTION FOR TEMPORARY ANCHORS

### 4.2.1 General

The corrosion protection for temporary anchors shall comply with the requirements given in the following clauses.

All materials used shall be maintained clean and free of defects. In particular, all tendons shall be free of pitting. The corrosion protection system provided shall remain effective during installation and throughout the service life of the anchor.

### 4.2.2 Fixed Anchor Length

The tendon shall be contained within a grout-filled corrugated plastic sheath for tension type anchors and within a grease-filled steel cylinder for compression type anchors. The thickness of grout between the tendon and the sheath shall not be less than 10 mm as specified in Clause 4.3.3.

The sheathing shall be capable of withstanding the applied handling stresses, and the hydrostatic and grouting pressures and evidence of this acceptable to the Engineer shall be provided.

### 4.2.3 Design Free Anchor Length

Each bar or strand of the tendon shall be contained within a grease-filled plastic sheath sealed at the ends to prevent ingress of grout. The grease shall cover all exposed surfaces of the pre-stressing steel, and shall fill the voids between wires. Where the plastic sheath is to be deleted to permit the fitting of locking cones, wedges or nuts, the surrounding void shall be sealed and filled with grease. The corrosion protection shall not restrict the movement of the tendon under load.

### 4.2.4 Protection of Anchor Head

Corrosion protection measures of a standard equivalent to that provided for the free length of the anchor, and which shall remain effective throughout the service life of the anchor, shall apply to the anchor head, locking cones, wedges, nuts, exposed tendon above and below the head and other associated components. The protection shall include grease which complies with the requirements set down in Table 1. Exposed metal surfaces on the anchor head shall be protected in accordance with Section 19 of the General Specification for Civil Engineering Works (1977).

*NOTES*

*Clause 4.3.1 - Guidance notes on measures to avoid damage from compressive forces within the free length are given in Section A.14 of Appendix A.*

*Clause 4.4 - The Drawings must show which anchors are to be subjected to Suitability Tests. Guidance notes on the number of anchors to be tested are given in Table A3 (see Appendix A.15.4 of Appendix A).*

## 4.3 SYSTEM COMPONENTS

### 4.3.1 General

The anchor shall be designed to provide an ultimate load holding capacity of not less than $ST_D$. The anchor shall be designed and constructed so that compressive forces within the free length will not damage the corrosion protection.

### 4.3.2 Fixed Anchor Length

The fixed anchor length shall not be less than 3 m for all anchors subjected to Extended Acceptance and Acceptance Tests.

### 4.3.3 Spacers and Centralisers

Spacers shall be provided on multi-tendon anchors to ensure separation between the individual components, and to ensure individual tendons are positioned uniformly over the cross-section of the drillhole.

Centralisers shall be provided on the tendon at suitable intervals to meet the following requirements :

(a) Within the fixed anchor length, the tendon shall be positioned in the grout column so that a minimum grout cover to the tendon of 10 mm is maintained.

(b) Within the design free anchor length, there shall be a minimum clearance of 10 mm between the tendon and the sides of the drillhole or casing.

### 4.3.4 Anchor Head Components

The anchor head components which retain the force in the stressed tendon shall comply with the requirements of BS 4447 : 1973.

## 4.4 SUITABILITY TESTS

Suitability Tests shall be carried out on anchors designated on the Drawings in accordance with the procedures given in Sections 5 and 6. Alternative locations may subsequently be agreed by the Engineer.

The anchors for Suitability Testing shall be identical to working anchors designed and constructed for the specified design working loads, $T_D$, and load factors of safety, S. The test load for the Suitability Test shall be $T_p = 0.8T_Z$.

*NOTES*

*Clause 4.5 – The Drawings must show which anchors are to be subjected to Extended Acceptance Tests. Guidance notes on the number of anchors to be tested are given in Section A.15.5 and Table A4 of Appendix A.*

*Clause 4.6.1 – Guidance notes on monitoring when the arrangement of strands or bars at the head is asymmetrical are given in Section A.16 of Appendix A.*

*Clause 4.6.3 – Guidance notes on the measurement of residual load are given in Section A.17.5 of Appendix A.*

*Guidance notes on the interpretation of monitoring results are given in Section A.17.8 of Appendix A. It should be noted that variations in residual loads in the anchor during its service life will occur. A variation from the lock-off load to 90%* $T_D$ *has been stated for which the Engineer will be informed. For structures whose factors of safety are significantly affected by a 10% reduction in anchor loads, the designer should cater for this variation in his design.*

## 4.5 EXTENDED ACCEPTANCE AND ACCEPTANCE TESTS

As shown on the Drawings, each working anchor shall be subjected to either an Extended Acceptance or Acceptance Test in accordance with the procedures given in Sections 5 and 7.

The test loads shall be $T_P = XT_D$ but shall not exceed $0.8T_Z$,

where X = 1.5 for permanent anchors, and
X = 1.25 for temporary anchors.

## 4.6 MONITORING

### 4.6.1 Requirements for Monitoring

All anchors shall be installed so that the residual load in the tendon can be monitored. All monitoring operations shall be undertaken so that there is no overloading or damage to the anchor. The equipment shall be as specified in Clauses 5.6.3 and 5.6.4.

The Contractor shall monitor the anchors up to the end of the Maintenance Period in accordance with the programme and procedure given in Clauses 4.6.2 and 4.6.3.

### 4.6.2 Programme

The programme given in Table 3 shall be followed by the Contractor, except where otherwise required by the Engineer.

### 4.6.3 Procedure

The Contractor shall inspect the anchor pad, the protection cap, the anchor head and its corrosion protection, and shall report on their condition.

A 150 ml sample of the grease shall be recovered from the anchor head for subsequent submission to the Engineer for inspection.

Upon completion of the inspection, the residual load in the anchor shall be measured.

Finally, the corrosion protection and the anchor head protection shall be reinstated in accordance with the requirements of this Specification.

Should the variation in the residual load exceed ±10% of that measured immediately after locking-off, the Contractor shall immediately inform the Engineer and await his further instruction.

### 4.6.4 Monitoring Records

A monitoring record in a format similar to that of Figures 1 and 2 shall be submitted to the Engineer within 72 hours of completion of monitoring.

*NOTES*

*Clause 5.1 - The Engineer should advise the designer of any change in ground conditions that may require the relocation or realignment of the drillhole. Drillholes should be aligned and spaced to avoid their intersection or adverse interactive effects. Guidance is given in BSI (1989), Clauses 6.2.6, D.2.1 and D.3.5.3.*

*Clause 5.2 - The net water pressure for the test should only be reduced below one atmosphere if, in the opinion of the Engineer, a higher pressure is likely to damage the drillhole, for example by fracturing the ground where the fixed length is close to the ground surface. In such cases variations to the pressure, water loss and other details may be required to suit the particular condition and, appropriate adjustments or additional requirements should be included in Clause 5.2.*

*Where grout in the free length forms an essential part of the corrosion protection, water testing of the free length should also be carried out. The procedure for the fixed length test should be used as far as possible, but again, variations to the pressure water loss and other details may be required.*

*With reference to the fifth paragraph, it is usual to limit the grouting pressure to that exerted by the overburden. When the overburden pressure is exceeded, the Engineer should require the Contractor to measure the volume of grout injected at frequent intervals and to stop the operation if this exceeds anticipated losses. Excessive loss may result in damage to the anchorage zone, natural drainage paths, foundations and services.*

# 5. ANCHOR INSTALLATION

## 5.1 DRILLING

Drillholes for ground anchors shall be provided in accordance with the Drawings. The drillhole entry point shall be positioned within a tolerance of ± 75 mm. Deviation in alignment shall not exceed 1 in 20. Deviation from straight shall not exceed 20 mm in any 3 m length of drillhole.

The drilling method used shall be subject to the agreement of the Engineer.

In ground likely to collapse, the sides of the drillhole shall be supported by suitable lining tubes until supported by the anchor itself. Except where required by the Engineer, drillholes shall be flushed clean on completion of drilling and the opening protected or sealed to prevent the entry of foreign matter.

Drilling water shall comply with the requirements of Clause 3.3.

A drilling record in a format similar to that of Figure 3 shall be submitted to the Engineer in accordance with Clause 5.3.

## 5.2 WATER TESTING

The drillhole shall be subjected to a water test to determine the likelihood of grout loss around the fixed length. However the Engineer may agree to omit this test in exceptional ground conditions and/or where the Anchor System installation specification provides an alternative.

Subject to the agreement of the Engineer, the Contractor may pre-grout the fixed length prior to the water testing.

The test shall be carried out by the application of a net water pressure of one atmosphere (100 kPa), or a lower pressure agreed by the Engineer, at the proximal end of the fixed length which shall be maintained for a period of ten minutes. The water loss in this period shall not exceed 50 litres. The net water pressure shall be the difference between the applied test pressure and the existing water pressure in the drillhole.

The test may be undertaken using a drillhole packer to seal off the section under test. Alternatively, it may be carried out by using the net pressure defined above through filling the drillhole with water. The volume of water required to maintain a constant head shall then be measured and shall not exceed 50 litres over ten minutes.

Should the test fail, the fixed anchor length shall be grouted under a pressure not exceeding a pressure agreed by the Engineer. The drillhole shall then be flushed or drilled out, and the water test re-applied.

A full record of the water test in a format similar to that of Figure 3 shall be submitted to the Engineer in accordance with Clause 5.3.

*NOTES*

*Clause 5.3 – The Engineer should check the position, direction, length and diameter of the drillhole and that it is free from debris which could prevent the anchor from being properly 'homed' as a result of collapse or piping in the hole. An allowance of 0.3 to 0.7 m additional length is commonly added to the designed drillhole length to allow for debris that cannot be removed. Deterioration of the sides of the drillhole is to be avoided, and normally the anchor should be inserted as soon as possible after completion of the drilling.*

## 5.3 INSERTION OF ANCHOR

The Engineer shall be given assistance in his inspection of the drillhole and shall be provided with the records for drilling and water testing prior to the Contractor seeking his approval.

If the drillhole proves unacceptable the Contractor shall seek instruction from the Engineer as to whether the hole is to be grouted and redrilled, re-provided as a drainage hole or grouted and abandoned. Once the drillhole has been accepted, the Contractor shall proceed to insert the anchor.

The anchor shall be inserted within 24 hours of completion of the drilling except where otherwise agreed by the Engineer. The anchor shall be handled with care. During insertion, it shall be installed at a controlled rate to avoid damage to itself and the drillhole.

The anchor shall be positioned in accordance with the requirements of Clause 4.3.3 and shall be secured to prevent further movement.

## 5.4 CEMENT GROUTING

### 5.4.1 Water-cement ratio

The water-cement ratio of the anchor grout shall not exceed 0.45.

### 5.4.2 Bleeding, Free Expansion and Fluidity

The grout shall not be subject to bleeding in excess of 0.5% by volume three hours after mixing or 1% maximum when measured at 20$^{o}$C in a covered glass or metal cylinder of 100 mm internal diameter and with a grout depth of approximately 100 mm. In addition the water shall be re-absorbed within 24 hours.

Free expansion of the grout shall not exceed 10% at the ambient temperature.

Fluidity of the grout shall be tested in accordance with CRD-C 79-58. Except with the prior agreement of the Engineer, for grouts containing admixtures, the efflux time of the grout shall not be less than 15 seconds.

### 5.4.3 Strength

Grout cubes of 100 mm size shall be prepared and cured in accordance with BS 1881 : Part 3 : 1970, and the strength of grout cubes shall be tested in accordance with BS 1881 : Part 4 : 1970.

Grout cube strength at seven days shall be obtained for a set of three cubes and shall be at least 25 MPa.

*NOTES*

*Clause 5.4.6 - Delay in placing the grout may prove acceptable if a special approved retarding agent is added or the grout is cooled to delay its initial set.*

### 5.4.4 Sampling for Tests on Bleeding, Free Expansion, Fluidity and Strength

At least one sample of grout shall be obtained for each Suitability and Extended Acceptance Test anchor. In the case of Acceptance Test anchors, at least one sample shall be taken from each fresh grout batch used to grout the first five anchors. Thereafter, another sample shall be taken for every five additional anchors grouted with the same batch. The samples shall be taken not more than one hour after the grout has been mixed.

Each sample of grout taken shall be divided into three specimens. Each specimen shall be tested to determine the amount of bleeding, free expansion and fluidity.

A set of three grout cubes shall be prepared for cube strength determination in accordance with Clause 5.4.3 from each sample of grout taken.

### 5.4.5 Trial Grout Mixes

A trial grout mix shall be carried out in accordance with Clause 5.4.6 using the designed water-cement ratio and admixtures (if any) and the proposed grouting equipment to be used for the Contract.

One sample of the grout from the trial mix shall be divided into three specimens and each specimen shall be tested to show compliance with the bleeding, free expansion and fluidity requirements stated in Clause 5.4.2.

One sample of the grout from the trial mix shall be taken for determination of the grout cube strength to show compliance with the requirements in Clause 5.4.3.

One sample of the grout from the trial mix shall be divided into three specimens and each specimen shall be tested to show compliance with the total sulphate ($SO_3$), chloride and nitrate contents requirements stated in Clause 3.3.

Results of the trial grout mix tests showing the degree of compliance with the Specification shall be submitted to the Engineer at least two weeks before the commencement of grouting.

### 5.4.6 Grout Mixing

Batching of the dry materials shall be by weight. The amount of water used shall be measured by a calibrated flowmeter or a measuring tank.

The procedure to be followed for mixing the grout shall be that approximately two-thirds of the cement shall be added to the water, followed by the admixtures, if any, followed by the remaining third of cement.

The grout shall be mixed in a mechanical mixer capable of imparting a high shear action to the grout components so that a colloidal grout of uniform consistency is produced in a mixing time of less than five minutes.

*NOTES*

*Clause 5.4.8 - It is usual to limit the grouting pressure to that exerted by the overburden. When the overburden pressure is exceeded, the Engineer should require the Contractor to measure the volume of grout injected at frequent intervals and to stop the operation if this exceeds anticipated losses. Excessive loss may result in damage to the anchorage zone, natural drainage paths, foundations and services.*

*Clause 5.6.1 - Asymmetrical arrangements of strands or bars at the head should be avoided since this can give rise to some strands or bars being stressed to unacceptably high loads and renders residual load measurements more difficult. Further information on this point is given in Section A.16 of Appendix A.*

*The Engineer's approval should not be in conflict with any requirement of the Prior Approval System.*

The grout mixing process shall utilise a recirculating system where the grout is continuously discharged and recharged into the mixing unit during the mixing period.

After mixing, the grout shall be kept continuously agitated.

The grout shall be passed through a nominal 1.2 mm sieve prior to injection. The grout shall be used as soon as possible after mixing and in any case within 30 minutes of adding cement unless otherwise agreed by the Engineer.

### 5.4.7 Grout Injection Equipment

The pump used for grout injection shall be of the positive displacement type, i.e. it shall be actuated by a piston or screw. A flowmeter and a pressure gauge shall be provided. The Engineer's approval of the equipment shall be obtained prior to its use.

### 5.4.8 Grouting Procedure

The grouting operation shall be undertaken within 24 hours of the anchor being inserted except where otherwise agreed by the Engineer. The procedure adopted shall ensure that there are no air or water inclusions left in the grouted zone.

The grouting pressure adopted shall be the minimum consistent with undertaking the operation and shall avoid damage to surrounding buildings, land, structure, street and services.

Grouting shall proceed at a slow, steady rate and shall continue until injected grout of the same composition and consistency as that mixed has been emerging from the outlet for at least one minute.

### 5.4.9 Grouting Records

A record giving full details of the grouting operation for each anchor, in a format similar to that of Figure 4, shall be supplied to the Engineer prior to a request seeking his acceptance of the anchor.

## 5.5 FITTING ANCHOR HEAD

The anchor head and its associated components shall be fitted concentrically to the tendon within a tolerance of $\pm$ 5 mm and perpendicular to the tendon within a tolerance of $\pm 3^{o}$.

## 5.6 STRESSING

### 5.6.I General

The stressing operation shall be carried out under the direction of an experienced and competent supervisor approved by the Engineer.

*NOTES*

*Clause 5.6.3 - Wherever practical, the equipment should be such that the tendon may be stressed to its full test or working load in one operation. In some confined locations, the use of a smaller and lighter jack may prove necessary, resulting in the need for 'resets'. In these circumstances, mono-stressing may have application. Before agreeing to resets or mono-stressing, the Engineer must check the proposed procedure and verify that suitable results will be obtained. For further guidance, see Clause 10.6.3.4 of BSI (1989).*

*Clauses 5.6.3 and 5.6.4 - Additional information on measuring accuracy and calibration is given in Sections A.15.2 and A.15.3 respectively of Appendix A.*

The anchor shall not be stressed until the grout has attained a minimum cube strength of 25 MPa. The equipment shall be used in accordance with the manufacturer's operating instructions.

### 5.6.2 Safety

During stressing, the Contractor shall take all reasonable precautions to the satisfaction of the Engineer to protect against the consequence of sudden failure. In particular, people shall be excluded from the area of danger on the line of the anchor, and adequate warning signs and barriers shall be provided.

### 5.6.3 Equipment

Stressing equipment shall be of the type applicable to the Anchor System and shall be capable of tensioning the complete tendon to more than 80% of its characteristic strength in one operation, except where otherwise agreed by the Engineer. The jack wedges shall meet the requirements of BS 4447 : 1973.

The design of the jacking system shall be such as to allow the required measurements to be taken to the accuracy stated in Clause 6.2. In this regard, the system shall permit control of the jack extension (whether opening or closing) to an accuracy of ± 0.5 mm.

The pump unit shall be equipped with a site-regulated pressure overload relief valve to prevent tendon damage by overtensioning. All flexible connections between the pump and jack shall have a burst pressure of at least twice the maximum pump pressure rating.

### 5.6.4 Calibration

Calibration of all equipment shall be carried out in a laboratory approved by the Engineer.

The equipment calibration certificates shall comply with the following requirements :

(a) Stressing jacks.

The certificate shall have been issued within the preceding six months. It shall be accompanied by the related calibration curve and tabulated record of hydraulic pressure against jack load. The calibration shall be performed for the loading and unloading operations of the jack over its full working range.

(b) Load cells.

The certificate shall have been issued within the last 50 stressing operations for which the device was used or within the last 28 days, whichever is less, or as previously agreed by the Engineer

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after study of the manufacturer's operating instructions. Where complementary load cells are mounted in parallel and no significant variation between them is observed, these requirements may be extended to double those stated. If the cells are electrical, the calibration tests shall be conducted using the connecting cables that will be used on site.

(c) Pressure gauges used for stressing operations.

The certificate shall have been issued within the last 50 stressing operations for which the device was used or within the last 14 days, whichever is less, except when the gauge has sustained hydraulic or other shock, in which case it shall be replaced immediately by another gauge. Where complementary gauges are mounted in parallel and no significant variation between them is observed, these requirements may be extended to double those stated.

(d) Dial gauges.

The certificate shall have been issued within the preceding 12 months. The gauge shall be inspected prior to the start of each stressing operation and if found to be defective, it shall be replaced immediately by another gauge.

(e) Flowmeters and pressure gauges used during water testing or grouting.

The certificate shall have been issued within the last 100 operations for which the device was used or within the last 60 days, whichever is less, except when the gauge has sustained hydraulic or other shock, in which case it shall be replaced immediately by another gauge.

The above and all other measuring devices not listed shall be subject to the acceptance of the Engineer who may require evidence of compliance with the relevant British Standard or equivalent.

### 5.6.5 Maximum Load

The maximum load applied to the tendon shall not exceed 80% of $T_Z$.

### 5.6.6 Programme

The Contractor shall submit the sequence of stressing he intends to follow for the Engineer's approval, unless the sequence is specified in the Drawings.

The Contractor shall submit a stressing programme and shall obtain the

[BLANK PAGE]

agreement of the Engineer at least one day before any stressing is undertaken. The Contractor shall give the Engineer adequate notice of the commencement of each stressing operation.

The programme shall include information on :

(a) the anchor designation and the date it will be stressed,

(b) the lock-off load, $T_0$,

(c) the calculated extension, $\Delta l_r$, and

(d) details of the tests to be carried out.

*NOTES*

*Clause 6.1 - If modifications to anchor details approved under the Prior Approval System are necessary, approval from the Director of Civil Engineering Services must be obtained by the Contractor, through the Agent for the anchor system, before the modifications are presented to the Engineer for his acceptance.*

*Clause 6.2 - An explanation of the requirements of this clause is given in Section A.15.2 of Appendix A.*

# 6. SUITABILITY TESTS

## 6.1 GENERAL REQUIREMENTS

The Engineer shall evaluate the results of the Suitability Tests in accordance with Clause 6.5 below and shall inform the Contractor of his findings within three days of their receipt.

Modifications required as a result of Suitability Tests shall be approved by the Engineer before the Contractor commences the drilling for the working anchors. In no case shall drilling for the working anchors commence until the Engineer has accepted and approved the results of the Suitability Test. Anchors approved in the Suitability Test may be unloaded and, subject to their passing an Acceptance Test, they may be approved as working anchors.

## 6.2 MEASURING ACCURACY

Actual movements of the anchor head, $\Delta l$, and the base plate, $\Delta s$, relative to a datum approved by the Engineer shall be measured with instruments which have an accuracy of $\pm 2\%$ of $\Delta l_r$.

Forces in the tendon shall be measured with instruments which have an accuracy of $\pm 2\%$ of $T_p$.

In addition, for the measuring instrument used to determine the small change in load or deformation required by Clause 6.3(c), whichever is applicable, the difference in deviation from true of two successive peak extension ($\Delta l$) or force (T) readings in the load cycles, from $T_A$ to $T_p$ inclusive, shall not be greater than 0.5% of $\Delta l_r$ or $T_p$ respectively.

All instruments shall have graduations (or digital 'read-outs') that can and shall be read accurately to better than 2% of $\Delta l_r$ or $T_p$.

## 6.3 SUITABILITY TEST PROCEDURE

When required to carry out a Suitability Test (see also Clause 4.4), the Contractor shall adopt the following procedure, which is shown graphically in Figures 5 and 6.

(a) An initial load, $T_A$, shall be selected so that $0.1T_p \leqslant T_A \leqslant 0.2T_p$. The value of $T_p$ to be used shall be as specified in Clause 4.4. The range between $T_A$ and $T_p$ shall be divided into six to ten approximately equal steps of magnitude $\Delta T$.

(b) A datum shall be established to measure $\Delta l = \Delta l_e + \Delta l_{pl}$. The movement of this datum under the influence of anchor stressing shall not exceed 0.5% of the calculated anchor extension, $\Delta l_r$.

(c) A programme of cyclic loading and unloading shall then be carried out with the load being increased from $T_A$ in successive cycles by $\Delta T$, $2\Delta T$, $3\Delta T$,

*NOTES*

*Clause 6.3(c) - The value specified for Δt in Clause 6.3(c) should be arrived at as follows :*

| *Ground Conditions in Fixed Anchor Length* | *Symbol* | *Observation Time Interval Δt* |
|---|---|---|
| *More than 90% rock* | *UW-PW90/100* | *5 min.* |
| *50% to 90% rock* | *PW50/90* | *5 min. - 30 min.* |
| *less than 50% rock* | *PW30/50-RS* | *30 min. - 24 hrs* |

*Notes : (1) The descriptions of ground conditions and symbols are in accordance with the classification of rock mass weathering zones in Geoguide 3 (GCO, 1988).*

*(2) When there is less than 90% rock, the designer should decide the time Δt taking into account the likely time-dependent movements under steady load that can occur in the ground surrounding the fixed anchor length. When the soil portion is coarse-grained and free-draining, a value at the lower end of the range should be used. In fine-grained slow-draining soils, a value at the upper end of the range would be more appropriate.*

*Clause 6.3(d) - The residual load may be determined by a lift-off test or by use of a load cell. Directly comparable results will not be obtained unless identical procedures and equipment are used for all these measurements. Further advice on this is given in Section A.16 of Appendix A.*

*An explanation of the requirements of this clause is given in Section A.15.4 of Appendix A. Figure A3 illustrates the types of load versus extension graphs that can occur.*

etc., until the specified maximum load, $T_p$, is reached. After the specified load in each cycle is reached, measurements of the load decrease with the deformation held constant shall be taken for a time interval $n\Delta t$, where $\Delta t$ shall be :

INSERT VALUE(S)

and n shall initially be 1 but may subsequently be increased to 3 and then to 10 if the limiting values given in Table 4 are exceeded. Alternatively, measurements of the deformation increase with the load held constant can be taken for the same time intervals. After the above measurements have been taken for each cycle, the load shall be reduced to $T_A$ and the extension, $\Delta l$, recorded.

(d) After the cycle for the test load, $T_p$, has been carried out, a further cycle shall be undertaken in the manner shown in Figures 5 and 6. This shall be carried out as follows. Firstly, the tendon load shall be taken to $T_p$ and then reduced to $0.3T_p$ in four equal increments. Secondly, the load shall be increased in three equal increments to the lock-off load. For each of these load points, extension measurements shall be recorded. Finally, locking-off shall be carried out. During locking-off, the draw-in of the wedges or cones (if any are used in the anchor head) shall be measured, and the residual load determined by a method agreed by the Engineer. In addition, the zero friction line and the calculated residual load immediately after locking-off, $T_{RC}$, shall be determined according to Clause 6.5.1(e) and as shown in Figures 5 and 6.

## 6.4 TEST RECORDS

The measured loads and deformations at each cycle of the test shall be recorded and plotted as a load versus extension curve. The results shall be presented to the Engineer within seven days of completion of the test in formats similar to those of Figures 5, 6, 7 and 8.

## 6.5 ASSESSMENT OF SUITABILITY TEST

### 6.5.1 Test Conditions

The following test conditions shall be satisfied :

(a) Change of load or deformation.

The change of load or deformation shall not exceed

*NOTES*

*Clause 6.5.1(b) - The effect of friction in the free length is taken into account in setting the limits for the effective free length,* $l_{ef}$*. See Section A.15.4 of Appendix A.*

*Clause 6.5.1(e) - An explanation of the requirements of this clause is given in Section A.15.4 of Appendix A. Figure A3 illustrates the types of load versus extension graphs that can occur.*

the values given in Table 4, when assessed in accordance with the notes given below the table.

(b) Effective free length.

The effective free length, $l_{ef}$, as defined below, shall lie between the following limits up to the maximum test load, $T_p$ :

For tension type anchors :

$$0.9l_{fr} \leqslant l_{ef} \leqslant l_{fr} + 0.5l_v,$$

For compression type anchors :

$$0.9(l_{fr} + l_v) \leqslant l_{ef} \leqslant 1.1(l_{fr} + l_v),$$

where $l_{ef}$ shall be determined from the relationship :

$$l_{ef} = \frac{\Delta l_e(x) A_t E_t}{T(x) - T_A} \times 10^{-6},$$

where (x) refers to any point on the loading curve.

(c) Residual load.

The residual load measured in the immediate lift-off test shall not be less than $1.1T_D$.

(d) Draw-in of wedges.

The draw-in of the locking cones/wedges (if any are used in the anchor head) shall be within the limits given by the manufacturer of the anchor system.

(e) Zero friction line.

The last six points of the final cycle (see Clauses 6.3 (d)) shall be used to determine a zero friction line by the Least Squares Method.

### 6.5.2 Determination of Plastic Extension

The plastic extensions, $\Delta l_{pl}$, shown in Figure 7, shall be determined as shown in Figures 5 and 6. The Engineer's agreement shall be obtained for the values adopted or for appropriate modified values for use in Extended Acceptance Tests.

*NOTES*

*Clause 7.1 - The Drawings must show which working anchors are to be subjected to Extended Acceptance Tests. All other working anchors should be subjected to Acceptance Tests. See Section A.15.5 of Appendix A.*

*Notes on classes of anchors are given in Section A.8 of Appendix A.*

*Clause 7.3(c) - $\Delta t$ should be determined as described in the Note opposite Clause 6.3(c).*

# 7. EXTENDED ACCEPTANCE AND ACCEPTANCE TESTS

## 7.1 GENERAL REQUIREMENTS

All working anchors shall be subject to either Extended Acceptance or Acceptance Tests as shown on the Drawings.

The Engineer shall evaluate the results of the Extended Acceptance and Acceptance Tests in accordance with Clauses 7.5 and 7.8 below and shall inform the Contractor of his findings within seven days of their receipt.

Where the number of anchors to be installed is less than ten and they are all Class 1 anchors, the Extended Acceptance Tests shall be carried out prior to the commencement of drilling for the remaining anchors. In this case, the Engineer shall inform the Contractor of his findings within three days of receipt of the test results.

## 7.2 MEASURING ACCURACY

The provisions of Clause 6.2 shall apply to the measuring instruments to be used for Extended Acceptance and Acceptance Tests.

## 7.3 EXTENDED ACCEPTANCE TEST PROCEDURE

When required to carry out an Extended Acceptance Test (see Clause 4.5), the Contractor shall adopt the following procedure, which is shown graphically in Figures 9 and 10 :

(a) An initial load, $T_A$, shall be selected so that $0.1T_p \leqslant T_A \leqslant 0.2T_p$. The value of $T_p$ to be used shall be as specified in Clause 4.5. The range between $T_A$ and $T_p$ shall be divided into three approximately equal steps of magnitude $\Delta T$.

(b) A datum shall be established to measure $\Delta l = \Delta l_e + \Delta l_{pl}$. The movement of this datum under the influence of the anchor stressing shall not exceed 0.5% of the calculated anchor extension, $\Delta l_r$.

(c) A programme of three loading and unloading cycles shall then be carried out, with the load being increased from $T_A$ in successive cycles by $\Delta T$, $2\Delta T$, up to $T_p$. After the peak load in each cycle is reached, measurements of the load decrease with the deformation held constant shall be taken for a time interval $n\Delta t$, where $\Delta t$ shall be :

*INSERT VALUE(S)*

and n shall be 1 initially but may be increased subsequently to 3 and then to 10 if the limiting values given in Table 4 are exceeded.

*NOTES*

*Clause 7.3(d) and 7.3(e) - The residual load may be determined by a lift-off test or by using a load cell. Directly comparable results will not be obtained unless identical procedures and equipment are used for all these measurements. Further advice on this is given in Section A.16 of Appendix A.*

*Clause 7.5.1(b) - The effect of friction in the free length is taken into account in setting the limits for the effective free length, $l_{ef}$ (see Section A.15.4 of Appendix A).*

Alternatively, measurements of the deformation increase with the load held constant can be taken over the same time intervals.

After the above measurements have been taken for each cycle, the load shall be reduced to $T_A$ and the extension, $\Delta l$, shall be recorded.

(d) After the required measurements have been taken for the final test cycle, the load shall be increased to $T_O$. Locking-off shall be carried out and the residual load shall be measured immediately by a method agreed by the Engineer. The anchor may be completely unloaded prior to stressing to $T_O$ if desired by the Contractor.

(e) After 48 hours, the residual load shall be determined again.

(f) If the loss of residual load exceeds the limit given in Clause 7.5.1(d) below, it shall be determined again after a further period of 48 hours. If the limit given in Clause 7.5.1(d) for the second 48 hour period is exceeded, the residual load shall be determined again after a final 48 hour period. The three 48 hour periods shall be continuous.

## 7.4 TEST RECORDS

The measured loads and deformations for each cycle of the test shall be recorded and plotted as a load versus extension curve. The results shall be presented to the Engineer within seven days of completion of the test in formats similar to those of Figures 7, 9, 10 and 13.

## 7.5 ASSESSMENT OF EXTENDED ACCEPTANCE TEST

### 7.5.1 Test Conditions

If an anchor does not satisfy the following conditions, it shall not be accepted. However, at the discretion of the Engineer, the anchor may be accepted for use at a different working load, provided it is re-tested and satisfactorily complies with the following requirements :

(a) Change of load or deformation.

The change of load or deformation shall not exceed the values given in Table 4, when assessed in accordance with the notes given below the table.

(b) Effective free length.

The effective free length, $l_{ef}$, as defined below, shall lie between the following limits up to the maximum test load, $T_p$ :

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For tension type anchors :

$$0.9l_{fr} \leqslant l_{ef} \leqslant l_{fr} + 0.5l_v,$$

for compression type anchors :

$$0.9(l_{fr} + l_v) \leqslant l_{ef} \leqslant 1.1(l_{fr} + l_v),$$

where $l_{ef}$ shall be determined from the relationship :

$$l_{ef} = \frac{\Delta l_e(x) A_t E_t}{T(x) - T_A} \times 10^{-6},$$

where (x) refers to any point on the loading curve.

(c) Residual load.

The residual load measured immediately after locking-off shall not be less than $1.1T_D$ nor greater than $1.15T_D$.

(d) Loss of residual load.

The anchor shall be acceptable provided the loss of residual load in the 48 hour period immediately following locking-off (see Clause 7.3(e)) does not exceed 4% of the initial residual load (see Clause 7.3(d)). If the loss exceeds 4%, the test may be repeated for two further 48 hour periods (as described in Clause 7.3(f)), and the anchor shall be acceptable provided the total loss does not exceed 6% after the second 48 hour period or 7% after the third 48 hour period.

### 7.5.2 Determination of Plastic Extension

The plastic extensions $\Delta l_{pl}$ shown in Figure 7 shall be determined as shown in Figures 9 and 10 and shall conform with that obtained in an appropriate Suitability Test, if one has been performed.

Where the number of anchors to be installed is less than ten and they are all Class 1 anchors, the Engineer's agreement shall be obtained for the value adopted or for an appropriate modified value for use in Acceptance Tests.

## 7.6 ACCEPTANCE TEST PROCEDURE

When required to carry out an Acceptance Test (see Clause 4.5), the Contractor shall adopt the following procedure, which is shown graphically in Figures 11 and 12.

(a) An initial load, $T_A$, shall be selected so that $0.1T_p \leqslant T_A \leqslant 0.2T_p$. The value of $T_p$ to be used

*NOTES*

*Clause 7.6(c) - $\Delta t$ should be determined as described in the Note opposite Clause 6.3(c).*

*Clause 7.6(d) and (e) - The residual load may be determined by a lift-off test or by use of a load cell. Directly comparable results will not be obtained unless identical procedures and equipment are used for all these measurements. Further advice on this is given in Section A.16 of Appendix A.*

is specified in Clause 4.5.

(b) A datum shall be established to measure $\Delta l = \Delta l_e + \Delta l_{pl}$. The movement of this datum under the influence of the anchor stressing shall not exceed 0.5% of the calculated anchor extension $\Delta l_r$.

(c) The anchor shall be loaded up to the test load, $T_p$, and measurements of the load decrease with the deformation held constant shall be taken for a time interval $n\Delta t$, where $\Delta t$ shall be :

*INSERT VALUE(S)*

and n shall be 1 initially, but may be increased subsequently to 3 and then to 10 if the limiting values given in Table 4 are exceeded. Alternatively, measurements of the deformation increase, with the load held constant, can be taken over the same time intervals.

The load shall be reduced to $T_A$ and the extension, $\Delta l$, recorded.

(d) After the required measurements have been taken for the final test cycle, the load shall be increased to $T_0$. Locking-off shall be carried out and the residual load measured immediately by a method approved by the Engineer. The anchor may be completely unloaded prior to stressing to $T_0$ if desired by the Contractor.

(e) After 48 hours, the residual load shall again be determined.

(f) If the loss of residual load exceeds the limit given in Clause 7.8.1(d), it shall be determined again after a further period of 48 hours. If the limit given in Clause 7.8.1(d) for the second 48 hour period is exceeded, the residual load shall again be determined after a final 48 hour period. The three 48 hour periods shall be continuous.

## 7.7 TEST RECORDS

The measured loads and deformations shall be recorded and plotted as a load versus extension curve. The results shall be presented to the Engineer within seven days of completion of the test in formats similar to those of Figures 7, 11, 12 and 14.

*NOTES*

*Clause 7.8.1(b) - The effect of friction in the free length is taken into account in setting the limits for the effective free length, $l_{ef}$ (see Section A.15.4 of Appendix A).*

## 7.8 ASSESSMENT OF ACCEPTANCE TEST

### 7.8.1 Test Conditions

If an anchor does not satisfy the following conditions, it shall not be accepted. However, at the discretion of the Engineer, the anchor may be accepted for use at a different working load, provided it is re-tested and satisfactorily complies with the following requirements :

(a) Change of load or deformation.

The change of load or deformation shall not exceed the value given in Table 4, when assessed in accordance with the notes given below the table.

(b) Effective free length.

The effective free length $l_{ef}$ as defined below shall lie between the following limits up to the maximum test load, $T_p$ :

For tension type anchors :

$$0.9l_{fr} \leqslant l_{ef} \leqslant l_{fr} + 0.5l_v,$$

for compression type anchors :

$$0.9(l_{fr} + l_v) \leqslant l_{ef} \leqslant 1.1(l_{fr} + l_v),$$

where $l_{ef}$ shall be determined from the relationship :

$$l_{ef} = \frac{\Delta l_e A_t E_t}{T_p - T_A} \times 10^{-6}.$$

(c) Residual load.

The residual load measured immediately after locking-off shall not be less than $1.1T_D$ nor greater than $1.15T_D$.

(d) Loss of residual load.

The anchor shall be acceptable provided the loss of residual load in the 48 hour period immediately following lock-off (see Clause 7.6(e)) does not exceed 4% of the initial residual load (see Clause 7.6(d)). If the loss exceeds 4%, the test may be repeated for two further 48 hour periods (as described in Clause 7.6(f)), and the anchor shall be acceptable provided the total loss does not exceed 6% after the second 48 hour period or 7% after the third 48 hour period.

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### 7.8.2 Determination of Plastic Extension

The plastic extension $\Delta l_{pl}$ shown in Figure 7 shall be determined as shown in Figures 11 and 12 and shall conform with that obtained in an appropriate Suitability or Extended Acceptance Test.

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# 8. DESTRESSING

## 8.1 GENERAL REQUIREMENTS

Where instructed by the Engineer, anchors which are no longer required shall be destressed in strict accordance with the manufacturer's approved method or such other method as may be approved by the Engineer and in accordance with the safety requirements given in Clause 5.6.2.

All projections shall be removed and the void filled with grout in accordance with the requirements of Clause 5.4.

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TABLES

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Table 1 - Properties of Grease (Sheet 1 of 2)

| Property | Test Method | Acceptance Criterion |
|---|---|---|
| Base number | ASTM D 974-85 (modified)[2] | 0.5 min. |
| Water content | ASTM D 95-83 | 0.1% by mass max. |
| Chloride ion content | ASTM D 4327-84[3] | 5 ppm by mass max. |
| Nitrate ion content | ASTM D 4327-84[3] | 5 ppm by mass max. |
| Sulphide ion content | APHA : Part 427 : 1985[3] | 5 ppm by mass max. |
| Cone penetration (worked at 25 °C) | ASTM D 217-86 | 175-340 units (1 unit = 0.1 mm). |
| Corrosion prevention (48 hrs at 52°C & 100% relative humidity) | ASTM D 1743-73 (1981) | No corrosion is rated 1. Incipient corrosion (no more than 3 spots of visible size) is rated 2. Max. rating = 2. |
| Oil separation | ASTM D 1742-83 | 3% by mass max. |
| Evaporation loss | ASTM D 972-86 | 0.5% by mass max. |
| Flash point | ASTM D 93-85 | 150 °C min. |
| Drop point | ASTM D 566-76 (1982) | 60 °C min. |
| Oxidation stability : 100 hrs 400 hrs 1000 hrs | ASTM D 942-78 (1984) | Max. loss : 70 kPa 140 kPa 210 kPa |
| Effects of salt spray testing (1mm thick layer 500 hrs) | ASTM B 117-85 | No corrosion. |

Note : See notes on p75.

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Table 1 - Properties of Grease (Sheet 2 of 2)

Notes : (1) Manufacturer's certificates in respect of all the properties listed in the table shall be presented to show compliance with this Specification.

(2) Modified procedure for base number determination :

(a) Weigh accurately 1 to 1.5 g of sample into a 500 ml conical flask. Add 20 ml isopropanol and 5 ml toluene.

(b) Place a glass funnel on the top of the flask and heat the flask on a hot plate until the grease dissolves.

(c) Add about 100 ml of distilled and deionized water and pipette 10 ml of 1 N sulphuric acid to the flask. Heat the solution for 30 min. at temperature 80 - 90 °C.

(d) Add a few drops of phenolphthalein indicator solution and titrate with 1 N sodium hydroxide solution until the sample solution turns pink. Record the volume of the titre added.

(e) Calculate the base number of the grease sample using the following equation :

$$\text{Base number} = \frac{56.1\,(10 - V)}{m}\ \text{mg KOH/g}$$

where V = volume of 1 N sodium hydroxide solution used (ml)
m = mass of sample (g)

(f) Apply correction factors to the volumes of the acid and alkali if they are not exactly 1 N.

(g) Carry out a blank determination and correct the result accordingly.

(3) Procedure for extraction of water-soluble ions from grease for chloride, nitrate and sulphide ion contents determination :

(a) Weigh, accurate to 0.001 g, about 5 g of grease into a separating funnel, add 70 ml of xylene and shake the mixture until the grease is completely dissolved.

(b) Add 30 ml of distilled and deionized water to the funnel, shake for 10 min. and allow the organic and aqueous layers to separate. Run the bottom aqueous layer (and emulsion if present) to a second separating funnel.

(c) Repeat step (b) using separately 30 ml and 40 ml of distilled and deionized water for futher extraction.

(d) Add, to the second separating funnel containing the combined water extract, about 20 - 30 ml of xylene, gently swirl the mixture and again allow for complete separation of the 2 layers.

(e) To avoid inclusion of the organic solvent in the water extract, collect about 3/4 of the bottom aqueous layer, filter through a 0.2 µm filter paper and reserve the filtrate for determination of the contents of chloride, nitrate and sulphide.

(f) Carry out a blank determination, following the same procedure with the same amount of reagents.

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Table 2 - Properties of Plastics

| Property | Test Method | Unit | Acceptance Criterion | | |
|---|---|---|---|---|---|
| | | | PVC | PP | HDPE |
| Density | BS 2782 : Part 6 : 1980, Method 620 A | $kg/m^3$ | 1350-1400 | 900-910 | 950-940 |
| Tensile strength at yield at 23°C (Straining rate 50 mm/min.) | BS 2782 : Part 3 : 1976, Method 320 C | MPa | ⩾45 | ⩾30 | ⩾29 |
| Softening point (Vicat) | BS 2782 : Part 1 : 1976, Method 120 A | °C | ⩾75 | ⩾150 | ⩾110 |
| Hardness (Shore D) | BS 2782 : Part 3 : 1981, Method 365 B | - | ⩾65 | | |
| Brittleness temperature | ASTM D 746-79 | °C | ⩽5°C | | |
| Environmental stress cracking resistance | ASTM D 1693-70 (1980) | hrs | 200 (No cracking). | | |
| Fungal resistance | ASTM G 21-70 (1980) | - | Rating 1 or less[2]. | | |
| Bacteria resistance | ASTM G 22-76 (1980) procedure 'B' | - | No bacterial growth on surface of specimen. | | |
| Water absorption at 23±1°C | ASTM D 570-81 (Long term immersion) | % increase in weight | Max. 0.5 %. | | |
| Hydrostatic pressure resistance | BS 6437 : 1984 | - | No localised swelling, leaking or weeping. | | |

Notes :
(1) PVC = polyvinyl chloride ; PP = polypropylene ; HDPE = high density polyethylene.
(2) Observed traces of fungal growth shall not cover more than 10 % of the surface area.
(3) Manufacturer's certificates in respect of <u>all</u> the properties listed in the table shall be presented to show compliance with this Specification.

*NOTES*

*Table 3 – Guidance notes on the number of anchors to be monitored are given in Section A.17 and Table A5 of Appendix A.*

Table 3 - Frequency of Monitoring

| Anchor No. | Frequency of Monitoring |
|---|---|
| INSERT APPROPRIATE DATA FROM TABLE A5 | |
| Note : Time periods commence immediately after Acceptance and Extended Acceptance Test for the anchor concerned. | |

Table 4 - Limiting Values of Extension Increase and Load Loss

| Condition | Observation Period | Limiting Value within Observation Period | |
|---|---|---|---|
| | | Extension Increase (A) | Load Loss (B) |
| (a) | 0 ........ Δt | max. 2% of $\Delta l_r$ | max. 2% of $T_p$ |
| (b) | Δt ....... 3Δt | max. 1% of $\Delta l_r$ | max. 1% of $T_p$ |
| (c) | 3Δt ...... 10Δt | max. 1% of $\Delta l_r$ | max. 1% of $T_p$ |

Notes :
(1) (A) refers to test procedure where the load is kept constant during the observation period.
(2) (B) refers to test procedure where the deformation is kept constant during the observation period.
(3) If condition (a) is not satisfied, the observation period shall be increased to 3Δt and compliance with condition (b) tested. If condition (b) is not satisfied, the observation period shall be increased to 10Δt and compliance with condition (c) tested.

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FIGURES

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## RECORD OF ANCHOR INSPECTION

Contract ________ of ________

Anchor No. ________ Drawing No. ________

Site ____________________

Type ____________________

Type of Grease ____________________

Type of Ground ____________________

Grease Sample No. ____________________

**Before Removal of Protection Cap**

| Feature | Observation | Action |
|---|---|---|
| Adjacent ground | | |
| Structure | | |
| Pad | | |
| Cap | | |
| Seal | | |
| Fasteners | | |
| Anchor base plate | | |
| Other (specify) | | |

**After Removal of Protection Cap**

| Feature | Observation | Action |
|---|---|---|
| Inside of cap | | |
| Anchor movement | | |
| Internal seal | | |
| Fasteners | | |
| Grease | | |
| Tendon(s) | | |
| Locking-off components | | |
| Anchor base plate | | |
| Other (specify) | | |

Close-up colour photograph(s) of anchor head after removal of cap and grease

**Reinstatement of Protection Cap**

Brand of grease ____________________

Grease batch no. ____________________

**Remarks**

Supervised by ____________________

Approved by ____________________

Figure 1 - Proforma for Anchor Monitoring (Type 1)

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## RECORD OF RESIDUAL LOAD

Contract __________ of __________

Anchor No. ________________________

Type ____________________________

Test Load, $T_p$ = _______ kN ( ______ % U.T.S.)

Design Working Load, $T_D$ = ___________ kN

Lock-off Load, $T_0$ _________________ kN

Residual Load Immediately after Locking-off _____________ kN

| Time after Locking-off (hrs) | 48 | 96 | 144 |
| --- | --- | --- | --- |
| Residual Load (kN) | | | |

Site ___________________________

Limiting Lift-off Movement ___________ mm

Frequency of Monitoring _______________

_______________

### Residual Load Measurement - Clause 4.6.3

| Time after Locking-off | Date/Time | Gauge No. | Calibration Reference | Gauge Reading ( ) | | | Temp. (°C) | Lift-off Movement (mm) | | | Residual Load (kN) | Total Change in Prestress (% Immediate Residual Load) | Criteria | Condition Satisfied | Action/Remarks | Supervised by | Approved by |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | 1 | 2 | 3 | | 1 | 2 | 3 | | | | | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | Total change in prestress ≤ 10 % | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |
| | | | | | | | | | | | | | | Yes/No | | | |

Figure 2 - Proforma for Anchor Monitoring (Type 2)

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## RECORD OF DRILLING AND WATER TESTING

Contract __________ of __________

Site ____________________

Anchor No. ________________

Type ____________________

Design Free Anchor Length, $l_{fr}$ = __________ m

Fixed Anchor Length, $l_v$ = ____________ m

Total Length of Drillhole = ____________ m

Total Length of Casing = ____________ m

Inclination (To Horizontal) ________________ degrees

Orientation ________________ degrees

Diameter of Drillhole (Fixed Length) = ____________ mm

Level at Top of Drillhole ___________ mPD

### Drilling Operation - Clause 5.1

Method of Drilling/ Special Techniques ______________

Rig No. ____________________

Casing Type / ID ________________

Method of Flushing ______________

Logged by __________________

| Date/Time | Start/Finish Water Level (m) | Depth (m) | Flush Return | Description of Material Encountered | Remarks (Penetration Rate/m) |
|---|---|---|---|---|---|
| | | | | | |

### Water Testing - Clause 5.2

| Date/Time | | Depth to Standing Water Level before Test (metres) | Applied Pressure (kPa) | Test Section (m to m) | Water Loss (litres) | Criterion Satisfied | Tested by | Remarks |
|---|---|---|---|---|---|---|---|---|
| Start | Finish | | | | | | | |
| | | | | | | Yes/No | | |
| | | | | | | Yes/No | | |
| | | | | | | Yes/No | | |
| | | | | | | Yes/No | | |
| | | | | | | Yes/No | | |
| | | | | | | Yes/No | | |

### Pre-grouting Operation - Clause 5.2

| Date/Time | | Gauge Pressure (kPa) | Level of Pressure Gauge (mPD) | Section Grouted (m to m) | Grout Volume (litres) | W/C Ratio | Action Flush/Re-drill | Date/Time | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Start | Finish | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

### Approving Engineer's Comments

Supervised by ____________________

Approved by ____________________

Figure 3 - Proforma for Drilling and Water Testing

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RECORD OF ANCHOR GROUTING

**Contract** _ _ _ _ _ _ _ _ **of** _ _ _ _ _ _ _ _

Site _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Design Free Anchor Length, $l_{fr}$ = _ _ _ _ _ _ _ _ m

Date _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Anchor No. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Fixed Anchor Length, $l_v$ = _ _ _ _ _ _ _ _ _ _ _ _ m

Total Length of Casing _ _ _ _ _ _ _ _ _ _ _ _ _ m

Type _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Total Length of Drillhole = _ _ _ _ _ _ _ _ _ _ _ _ m

Estimated Volume of Grout to Fill Empty Hole _ _ _ _ _ _ _ _ _ _ _ _ litres

## Grout Mixing - Clause 5.4.6

Cement Type _ _ _ _ _ _ _ _ _ _ _

Additive Type(s) _ _ _ _ _ _ _ _ _ _ _

W/C Ratio _ _ _ _ _ _ _ _ _ _ _ _

Recommended Concentration _ _ _ _ _ _ _ _ _ _ _

| Mix No. | Weight of Cement (kg) | Volume of Water (litres) | Weight of Additive (g) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

## Grouting of Anchor - Clause 5.4.8

| Time | | Grout Used (litres) | Section Grouted (m to m) | Gauge Pressure (kPa) | Level of Pressure Gauge (mPD) |
|---|---|---|---|---|---|
| Start | Finish | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

## Sampling and Testing of Grout

| Test | Property | Sample No. | | | Criteria | Condition Satisfied |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| Fluidity - Clause 5.4.2 | Efflux time (seconds) | | | | ⩾ 15 s | Yes/No |
| Bleed - Clause 5.4.2 | % loss at 3 hours | | | | Loss ⩽ 0.5% | Yes/No |
| | % loss at 24 hours | | | | Loss ⩽ 1% | Yes/No |
| | Water re-absorbed within 24 hours | Yes/No | Yes/No | Yes/No | Yes | Yes/No |
| Strength - Clause 5.4.3 | 7 days 100mm cubes (MPa) | | | | 25 MPa | Yes/No |

| Remarks |
|---|
| |

Supervised by _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Approved by _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Figure 4 - Proforma for Anchor Grouting

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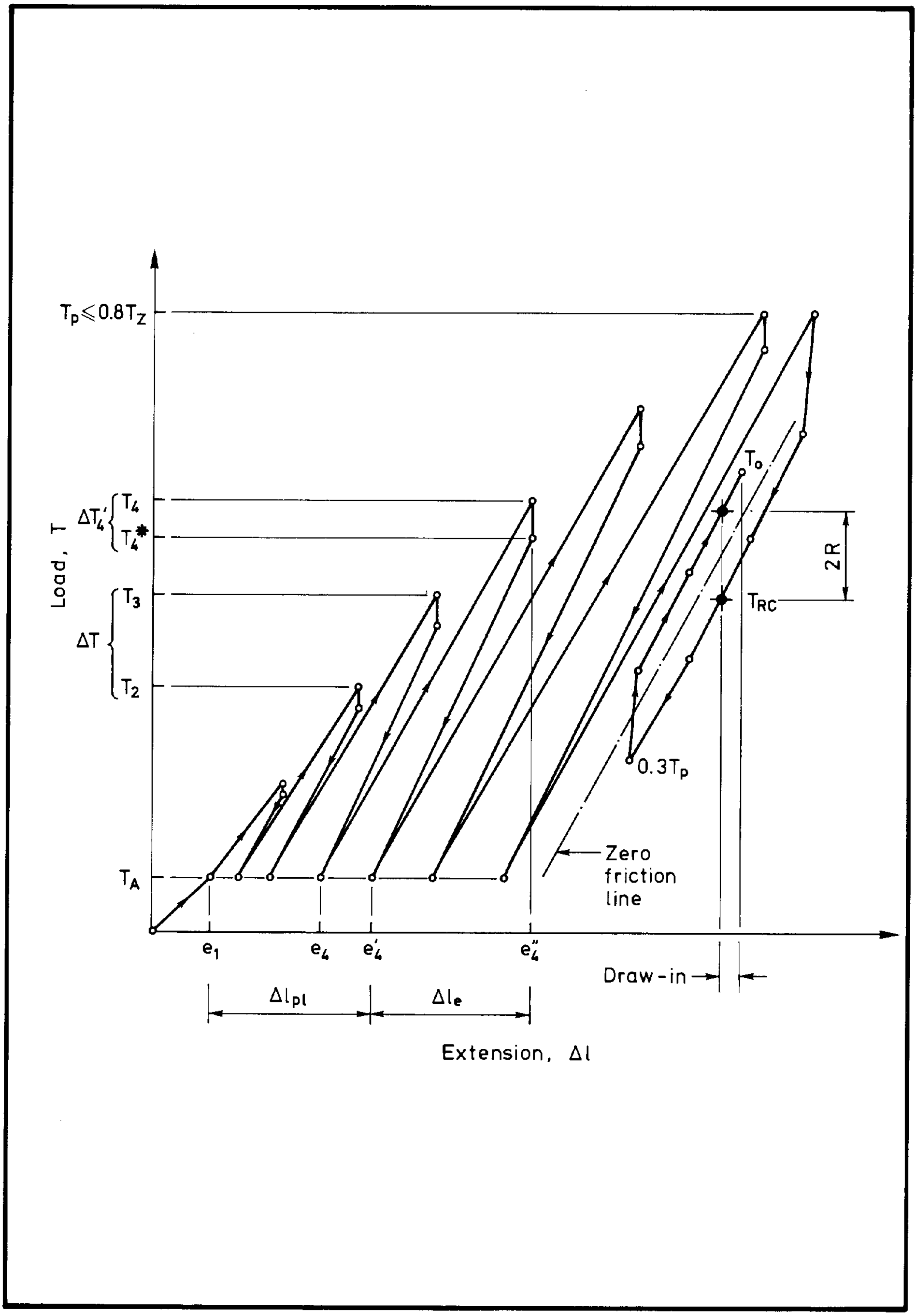


Figure 5 - Suitability Test (Constant Deformation)

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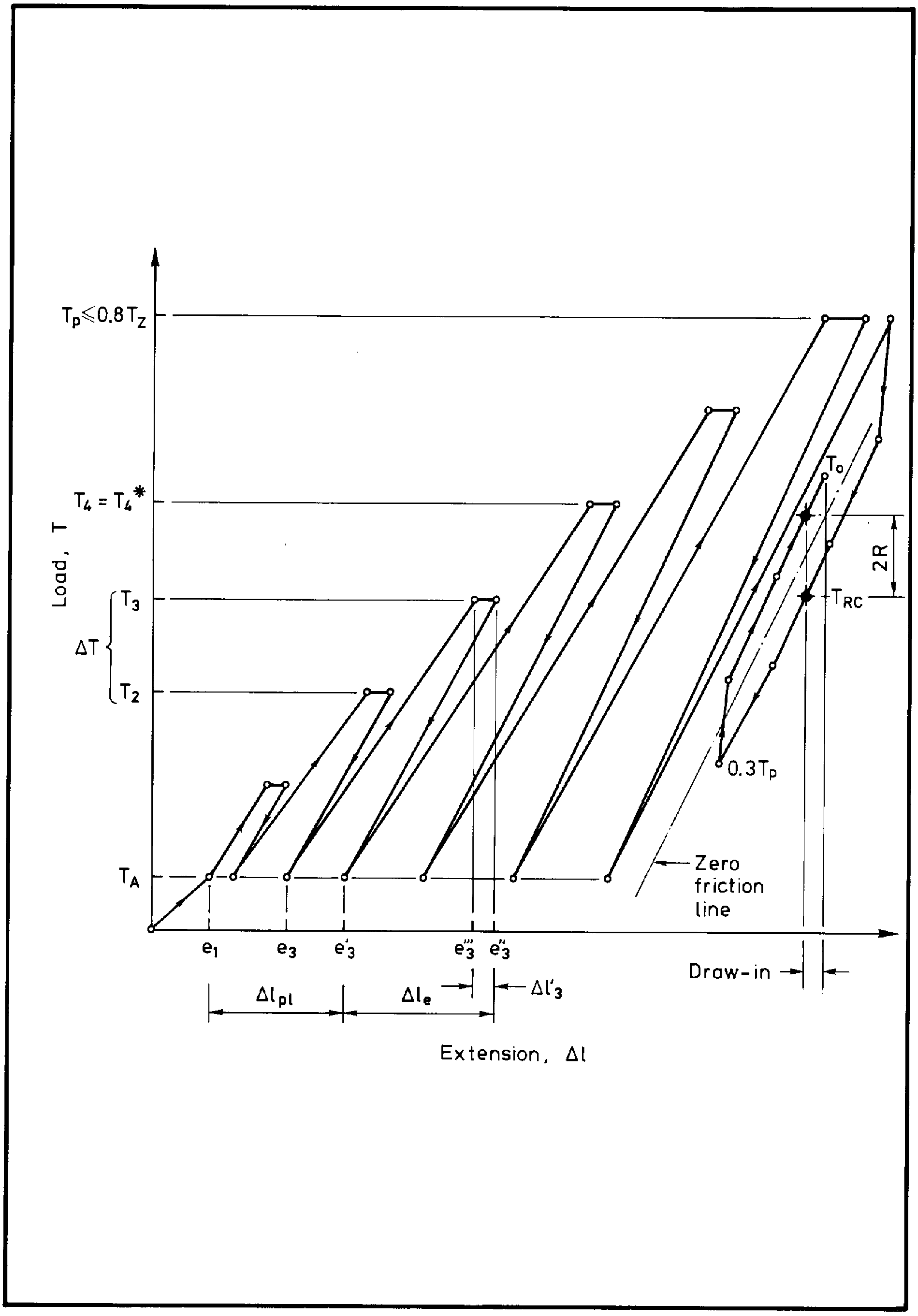


Figure 6 - Suitability Test (Constant Load)

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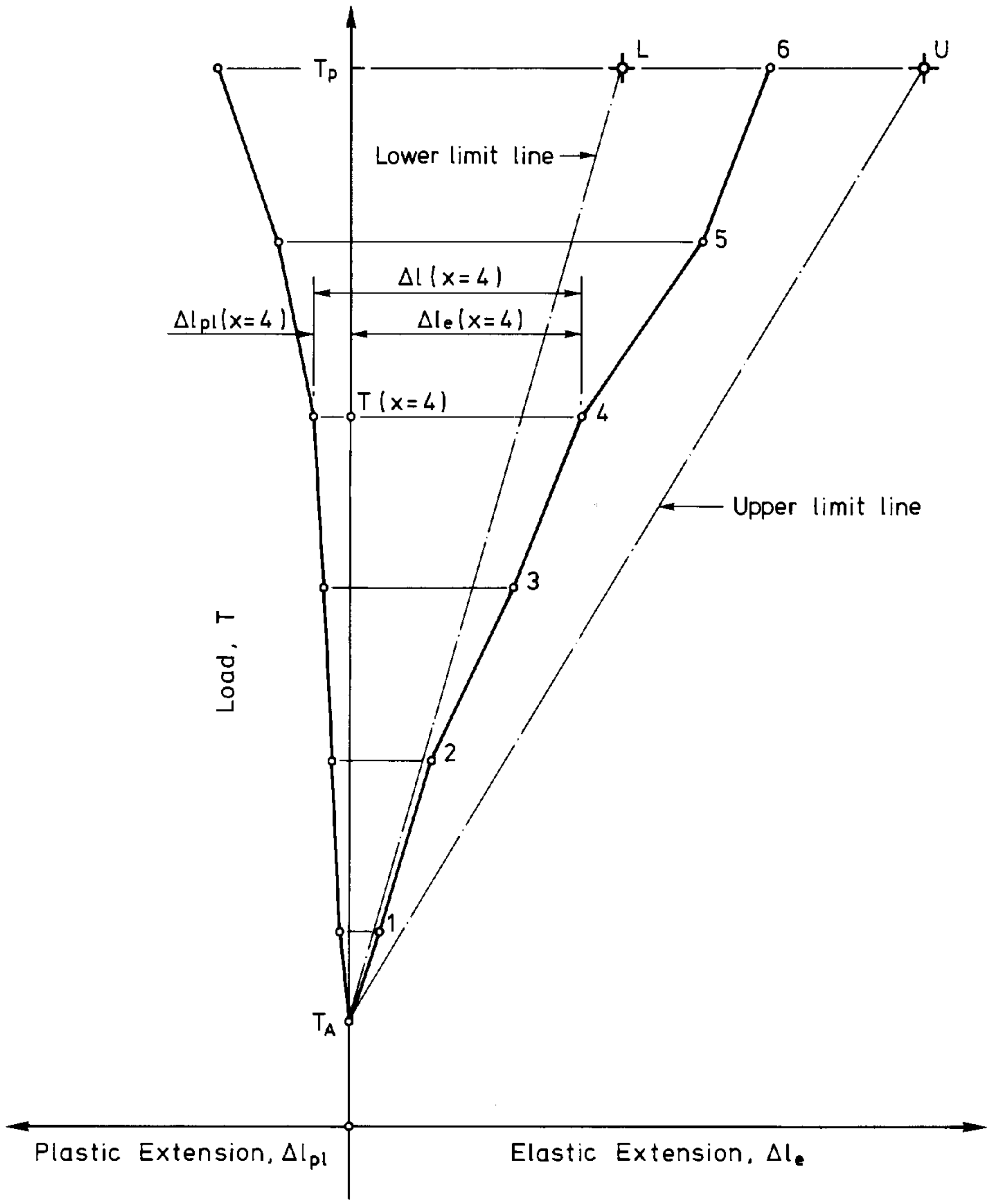


Note : Points 2 to 6 shall lie within the lines $T_A L$ and $T_A U$ where

L is given by $\Delta l_e = \dfrac{0.9 l_{fr}(T_p - T_A)}{A_t E_t} \times 10^6$

U is given by $\Delta l_e = \dfrac{(l_{fr} + 0.5 l_v)(T_p - T_A)}{A_t E_t} \times 10^6$

see Clause 6.5.1 (b).

For compression type anchors the terms $0.9 l_{fr}$ and $(l_{fr} + 0.5 l_v)$ shall be replaced by $0.9(l_{fr} + l_v)$ and $1.1(l_{fr} + l_v)$ respectively.

Figure 7 - Elastic and Plastic Extensions

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RECORD OF SUITABILITY TEST

Contract ________ of ________

Anchor No. ____________________

Type ____________________

Test Load, $T_p$ = ______ kN ( ______ % U.T.S.)

Design Working Load, $T_D$ = ____________ kN

Inclination ____________________

Diameter of Drillhole = ____________ mm (Fixed Length)

Design Free Anchor Length, $l_{fr}$ = ______________ m

Fixed Anchor Length, $l_v$ = ______________ m

Grip Length of Stressing Jack = ______________ m

Tendon Cross Sectional Area, $A_t$ = ____________ mm²

Modulus of Elasticity, $E_t$ = ____________ MPa

Type of Ground ____________________

Site ____________________

Date of Grouting ____________________

Date of Stressing ____________________

Weather ____________________

Temperature ____________________

| | 1st Loading Cycle | | | | 2nd Loading Cycle | | | 3rd Loading Cycle | | | 4th Loading Cycle | | | 5th Loading Cycle | | | 6th Loading Cycle | | | Refined Loading Cycle | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load step | $T_A$ | $T_1$ | $T_1^*$ | $T_A$ | $T_2$ | $T_2^*$ | $T_A$ | $T_3$ | $T_3^*$ | $T_A$ | $T_4$ | $T_4^*$ | $T_A$ | $T_5$ | $T_5^*$ | $T_A$ | $T_p$ | $T_p^*$ | $T_A$ | $T_p$ | | | | $0.3T_p$ | | | $T_o$ | | | |
| Load, T (kN) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Gauge reading | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Extension, Δl (mm) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Piston stroke, $\Delta l_K$ (mm) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Base plate movement, Δs(mm) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Draw-in Limit of Locking Cone/Wedge Specified by Manufacturer = ______ mm

Measured Draw-in = mm

↓ Deformation Increase (Load Constant) - Clause 6.5.1 (a)

| n Δt (min) | $T_1$ (kN) = / Calc. Extension, $\Delta l_r$ = | | | Condition Satisfied Yes/No | $T_2$ (kN) = / Calc. Extension, $\Delta l_r$ = | | | Condition Satisfied Yes/No | $T_3$ (kN) = / Calc. Extension, $\Delta l_r$ = | | | Condition Satisfied Yes/No | $T_4$ (kN) = / Calc. Extension, $\Delta l_r$ = | | | Condition Satisfied Yes/No | $T_5$ (kN) = / Calc. Extension, $\Delta l_r$ = | | | Condition Satisfied Yes/No | $T_p$ (kN) = / Calc. Extension, $\Delta l_r$ = | | | Condition Satisfied Yes/No |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\Delta l_1'$ | $\Delta l'_{Allow}$ | | | $\Delta l_2'$ | $\Delta l'_{Allow}$ | | | $\Delta l_3'$ | $\Delta l'_{Allow}$ | | | $\Delta l_4'$ | $\Delta l'_{Allow}$ | | | $\Delta l_5'$ | $\Delta l'_{Allow}$ | | | $\Delta l_6'$ | $\Delta l'_{Allow}$ | |
| 0 | | | | | | | | | | | | | | | | | | | | | | | | |
| (a) Δt = | | | | | | | | | | | | | | | | | | | | | | | | |
| (b) 3Δt = | | | | | | | | | | | | | | | | | | | | | | | | |
| (c) 10Δt = | | | | | | | | | | | | | | | | | | | | | | | | |
| | $T_1^*$ | $\Delta T_1'$ | $\Delta T'_{Allow}$ | | $T_2^*$ | $\Delta T_2'$ | $\Delta T'_{Allow}$ | | $T_3^*$ | $\Delta T_3'$ | $\Delta T'_{Allow}$ | | $T_4^*$ | $\Delta T_4'$ | $\Delta T'_{Allow}$ | | $T_5^*$ | $\Delta T_5'$ | $\Delta T'_{Allow}$ | | $T_p^*$ | $\Delta T_6'$ | $\Delta T'_{Allow}$ | |
| | | | | | | | | | | | | | | | | | | | | | | | | |

↑ Loss of Load (Deformation Constant) - Clause 6.5.1 (a)

| Conditions | Record | Criteria | Condition Satisfied Yes/No |
|---|---|---|---|
| Effective free length - Clause 6.5.1 (b) | $l_{ef} = \frac{\Delta l_e(x) A_t}{T(x) - T_A} E_t \times 10^{-6}$ ________ m | Tension type $0.9 l_{fr} \leq l_{ef} \leq l_{fr} + 0.5 l_v$ <br> Compression type $0.9(l_{fr} + l_v) \leq l_{ef} \leq 1.1(l_{fr} + l_v)$ | ____________ <br> ____________ |

| Remarks |
|---|
| |

Residual Load in Lift-off Tests - Clause 6.5.1 (c)

| Time after Locking-off | Date / Time | Gauge Reading ( ) 1 | 2 | 3 | Temp. (°C) | Lift-off Movement (mm) 1 | 2 | 3 | Residual Load (kN) | Criteria | Condition Satisfied | Record | Action/Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zero | | | | | | | | | $T_R$ _____ | $T_R \geq 1.1 T_D$ | Yes/No | $T_{RC}$ _____ kN | |

Supervised by ____________________

Approved by ____________________

Figure 8 - Proforma for Suitability Test

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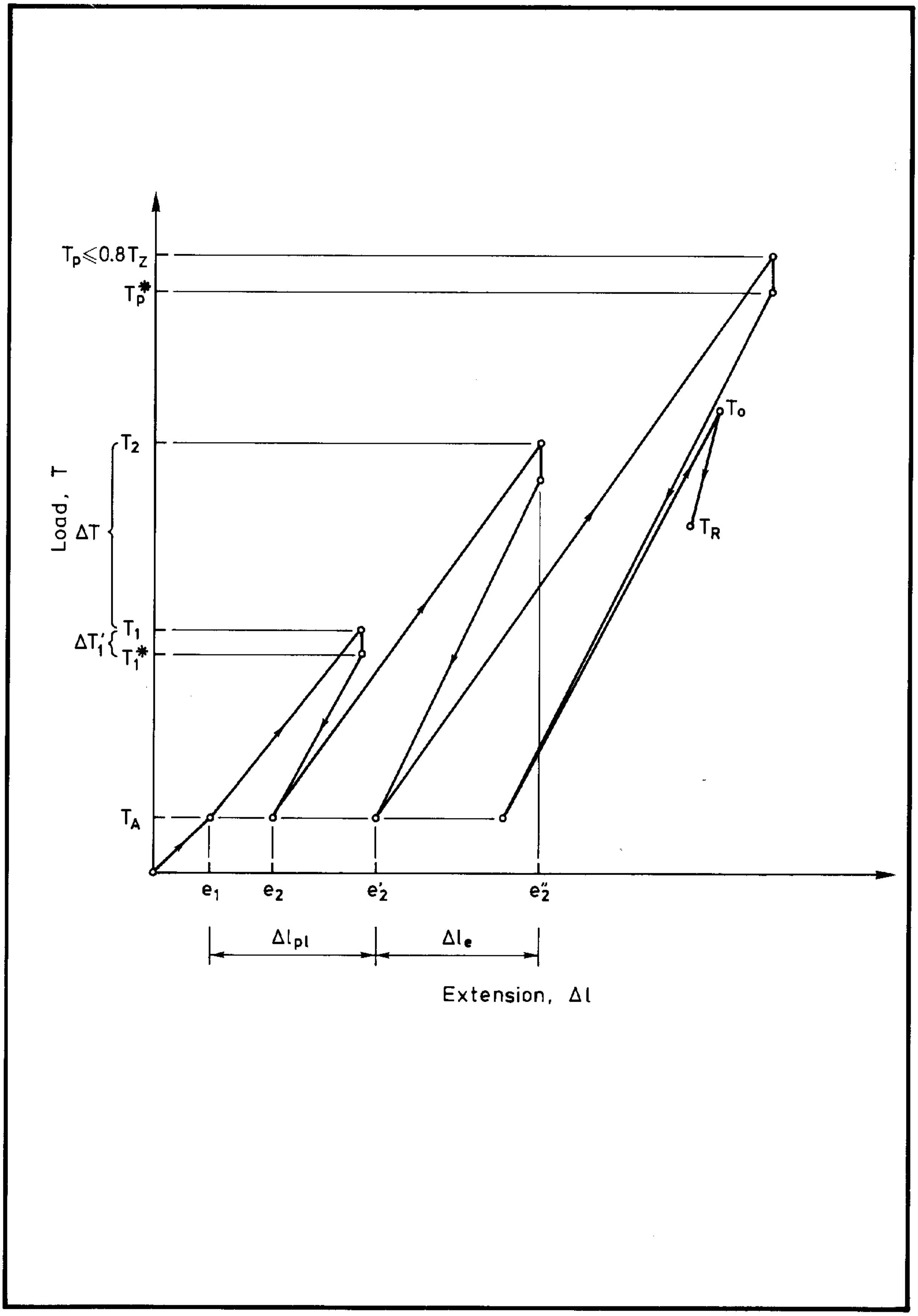


Figure 9 - Extended Acceptance Test (Constant Deformation)

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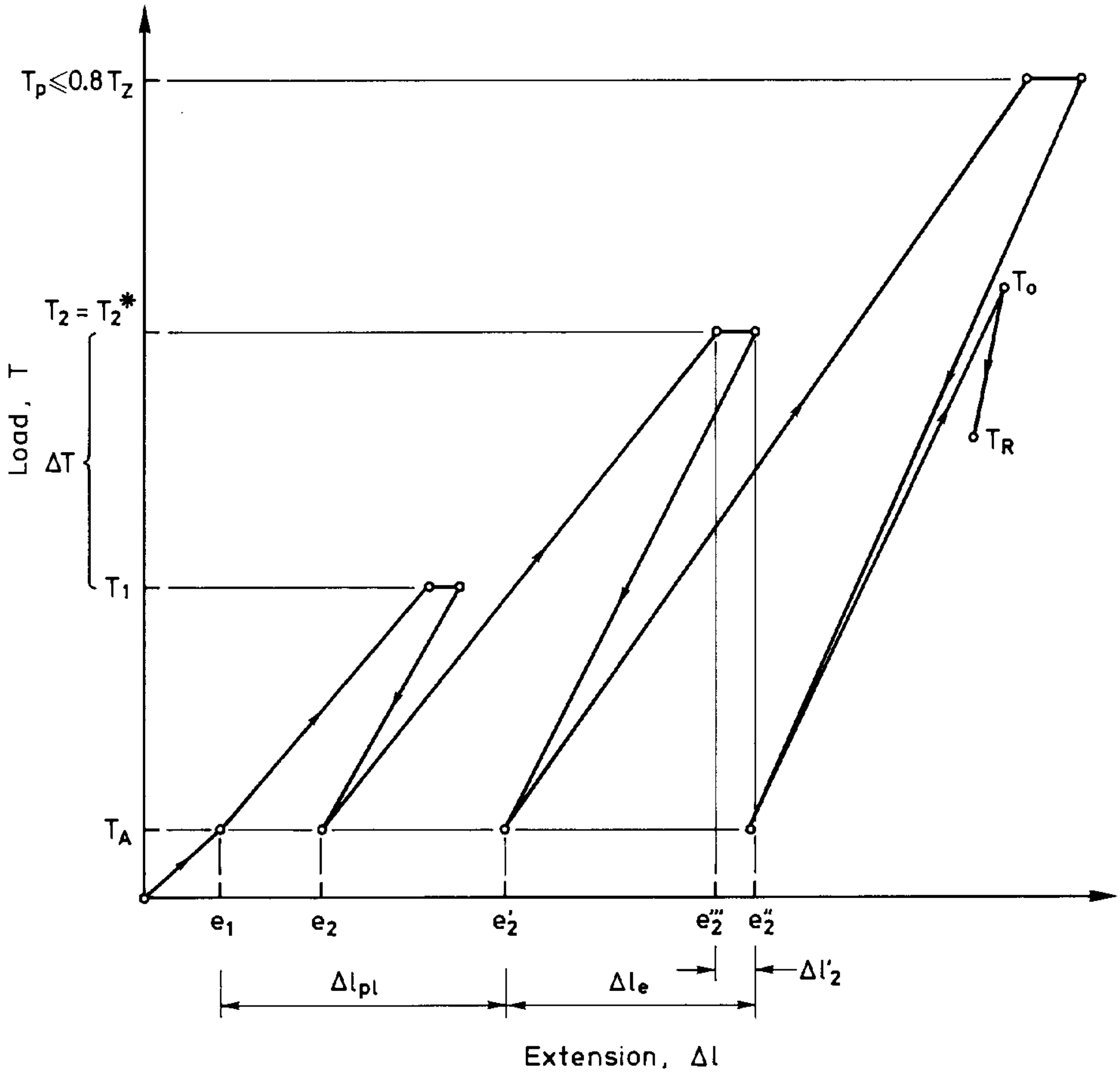


Figure 10 - Extended Acceptance Test (Constant Load)

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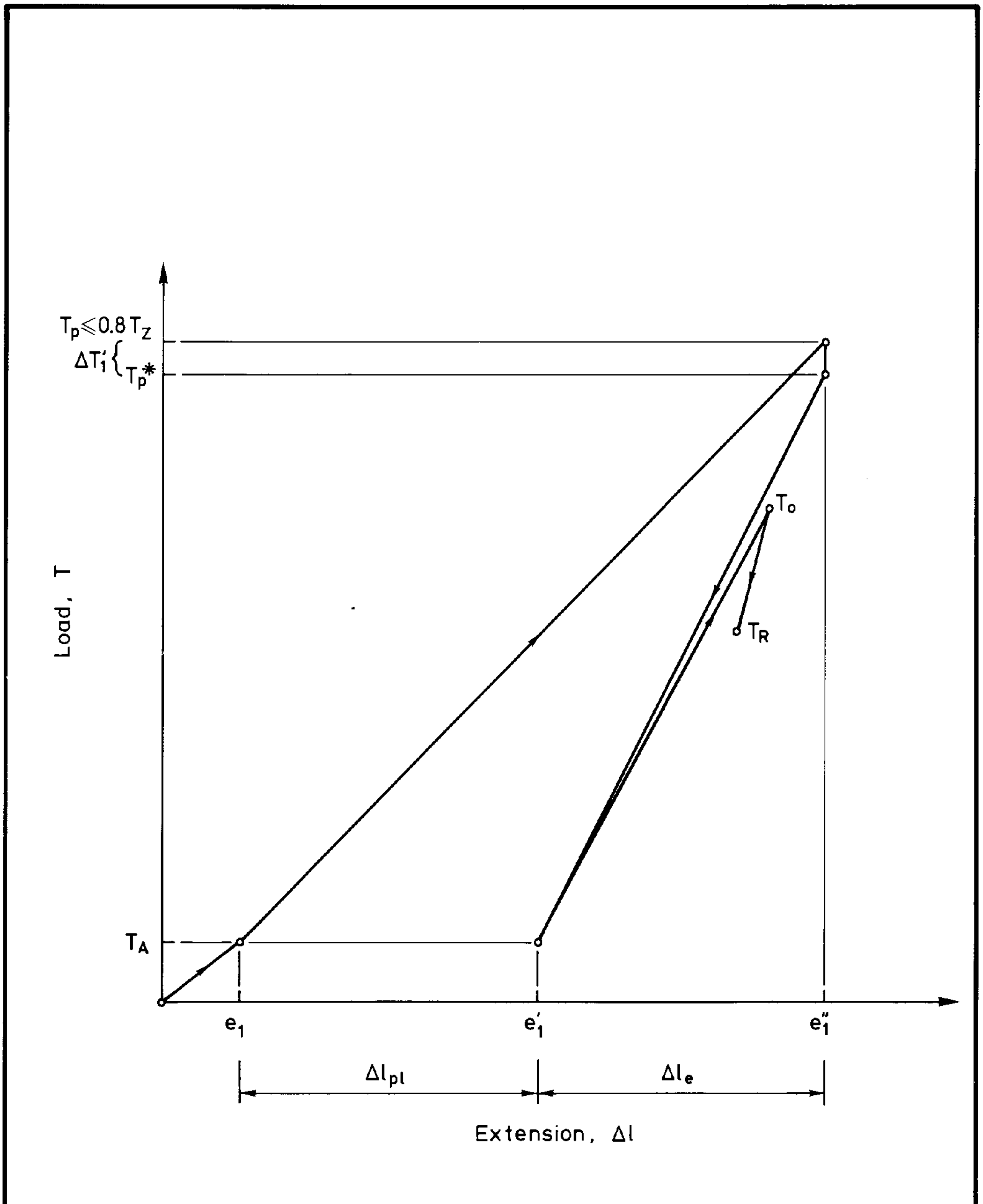


Figure 11 - Acceptance Test (Constant Deformation)

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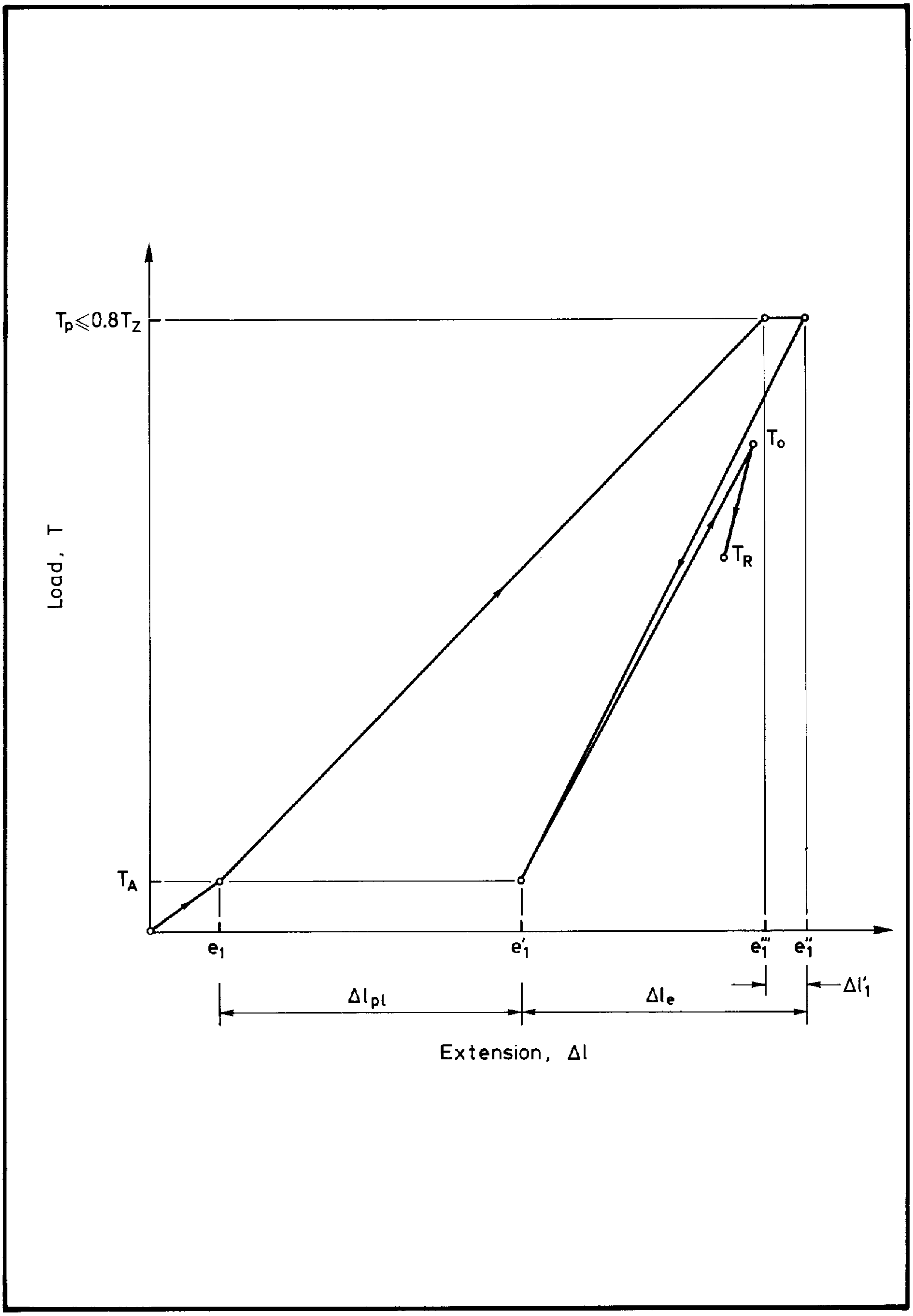


Figure 12 - Acceptance Test (Constant Load)

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## RECORD OF EXTENDED ACCEPTANCE TEST

**Contract** __________ **of** __________

Anchor No. ____________________

Type ____________________

Test Load, $T_p$ = ______ kN (______ % U.T.S.)

Design Working Load, $T_D$ = ____________ kN

Inclination ____________________

Diameter of Drillhole (Fixed Length) = ____________ mm

Design Free Anchor Length, $l_{fr}$ = ______________ m

Fixed Anchor Length, $l_v$ = ______________ m

Grip Length of Stressing Jack = ______________ m

Tendon Cross Sectional Area, $A_t$ = ____________ mm²

Modulus of Elasticity, $E_t$ = ____________ MPa

Type of Ground ____________________

Site ____________________

Date of Grouting ____________________

Date of Stressing ____________________

Weather ____________________

Temperature ____________________

| | 1st Loading Cycle | | | | 2nd Loading Cycle | | | 3rd Loading Cycle | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load step | $T_A$ | $T_1$ | $T_1$* | $T_A$ | $T_2$ | $T_2$* | $T_A$ | $T_p$ | $T_p$* | $T_A$ | | $T_o$ |
| Load, T (kN) | | | | | | | | | | | | |
| Gauge reading | | | | | | | | | | | | |
| Extension, Δl (mm) | | | | | | | | | | | | |
| Piston stroke, $\Delta l_K$ (mm) | | | | | | | | | | | | |
| Base plate movement, Δs (mm) | | | | | | | | | | | | |

↓ Deformation Increase (Load Constant) - Clause 7.5.1 (a)

| n Δt (min) | $T_1$ (kN) = | | | Condition Satisfied Yes/No | $T_2$ (kN) = | | | Condition Satisfied Yes/No | $T_p$ (kN) = | | | Condition Satisfied Yes/No |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Calc. Extension, $\Delta l_r$ = | | | | Calc. Extension, $\Delta l_r$ = | | | | Calc. Extension, $\Delta l_r$ = | | | |
| | | $\Delta l_1'$ | $\Delta l'_{Allow}$ | | | $\Delta l_2'$ | $\Delta l'_{Allow}$ | | | $\Delta l_3'$ | $\Delta l'_{Allow}$ | |
| 0 | | | | | | | | | | | | |
| (a) Δt = | | | | | | | | | | | | |
| (b) 3Δt = | | | | | | | | | | | | |
| (c) 10Δt = | | | | | | | | | | | | |
| | $T_1$* | $\Delta T_1'$ | $\Delta T'_{Allow}$ | | $T_2$* | $\Delta T_2'$ | $\Delta T'_{Allow}$ | | $T_p$* | $\Delta T_3'$ | $\Delta T'_{Allow}$ | |

↑ Loss of Load (Deformation Constant) - Clause 7.5.1 (a)

| Conditions | Record | Criteria | Condition Satisfied Yes/No |
|---|---|---|---|
| Effective free length - Clause 7.5.1(b) | $l_{ef} = \frac{\Delta l_e(x) A_t}{T(x) - T_A} E_t \times 10^{-6}$ = __________ m | Tension type: $0.9 l_{fr} \leq l_{ef} \leq l_{fr} + 0.5 l_v$<br>Compression type: $0.9(l_{fr} + l_v) \leq l_{ef} \leq 1.1(l_{fr} + l_v)$ | ________<br>________ |
| Plastic extensions - Clause 7.5.2 | 1st Loading Cycle $\Delta l_{pl}$ ________ mm<br>2nd Loading Cycle $\Delta l_{pl}$ ________ mm<br>3rd Loading Cycle $\Delta l_{pl}$ ________ mm | ________<br>________<br>________ | ________<br>________<br>________ |

Residual Load in Lift-off Tests - Clause 7.5.1(c) & (d)

| Time after Locking-off | Date / Time | Gauge Reading ( ) 1 | 2 | 3 | Temp. (°C) | Lift-off Movement (mm) 1 | 2 | 3 | Residual Load (kN) | Loss of Prestress (% Immediate Residual Load) | Criteria | Condition Satisfied | Action/Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zero | | | | | | | | | | | $1.1T_D \leq T_R \leq 1.15T_D$ | Yes/No | |
| 48 hours | | | | | | | | | | | Prestress Loss ≤ 4% | Yes/No | |
| 96 hours | | | | | | | | | | | Prestress Loss ≤ 6% | Yes/No | |
| 144 hours | | | | | | | | | | | Prestress Loss ≤ 7% | Yes/No | |

Remarks

Supervised by ____________________

Approved by ____________________

Figure 13 - Proforma for Extended Acceptance Test

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## RECORD OF ACCEPTANCE TEST

Contract ________ of ________

Anchor No. ____________________
Type ____________________
Test Load, $T_p$ ________ kN ( ______ % U.T.S.)
Design Working Load, $T_D$ = ____________ kN
Inclination ____________________
Diameter of Drillhole = ____________ mm
(Fixed Length)

Design Free Anchor Length, $l_{fr}$ = ____________ m
Fixed Anchor Length, $l_v$ = ____________ m
Grip Length of Stressing Jack = ____________ m
Tendon Gross Sectional Area, $A_t$ = ________ $mm^2$
Modulus of Elasticity, $E_t$ = ________ MPa
Type of Ground ____________________

Site ____________________
Date of Grouting ____________________
Date of Stressing ____________________
Weather ____________________
Temperature ____________________

| Load step | $T_A$ | $T_p$ | $T_p$* | $T_A$ | $T_o$ |
|---|---|---|---|---|---|
| Load, T (kN) | | | | | |
| Gauge reading | | | | | |
| Extension, Δl (mm) | | | | | |
| Piston stroke, $\Delta l_K$ (mm) | | | | | |
| Base plate movement, Δs (mm) | | | | | |

↓ Deformation Increase (Load Constant) - Clause 7.8.1 (a)

| n Δt (min) | $T_p$ (kN) = | | | Condition Satisfied Yes / No |
|---|---|---|---|---|
| | Calc. Extension, $\Delta l_r$ = mm | | | |
| | | $\Delta l_1'$ | $\Delta l'_{Allow}$ | |
| 0 | | | | |
| (a) Δt = | | | | |
| (b) 3 Δt = | | | | |
| (c) 10 Δt = | | | | |
| | $T_p$* | $\Delta T_1'$ | $\Delta T'_{Allow}$ | |
| | | | | |

↑ Loss of Load (Deformation Constant) - Clause 7.8.1 (a)

| Conditions | Record | Criteria | Condition Satisfied Yes / No |
|---|---|---|---|
| Effective free length - Clause 7.8.1(b) | $l_{ef} = \frac{\Delta l_e(x) A_t}{T(x) - T_A} E_t \times 10^{-6}$ = ________ m | Tension type: $0.9 l_{fr} \leq l_{ef} \leq l_{fr} + 0.5 l_v$<br>Compression type: $0.9(l_{fr} + l_v) \leq l_{ef} \leq 1.1(l_{fr} + l_v)$ | ________<br>________ |
| Plastic extension - Clause 7.8.2 | $\Delta l_{pl}$ ________ mm | ________ | ________ |

Residual Load in Lift-off Tests - Clause 7.8.1(c) & (d)

| Time after Locking-off | Date / Time | Gauge Reading ( ) 1 | 2 | 3 | Temp. (°C) | Lift-off Movement (mm) 1 | 2 | 3 | Residual Load (kN) | Loss of Prestress (% Immediate Residual Load) | Criteria | Condition Satisfied | Action/Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zero | | | | | | | | | | | $1.1T_D \leq T_R \leq 1.15T_D$ | Yes/No | |
| 48 hours | | | | | | | | | | | Prestress Loss ≤ 4% | Yes/No | |
| 96 hours | | | | | | | | | | | Prestress Loss ≤ 6% | Yes/No | |
| 144 hours | | | | | | | | | | | Prestress Loss ≤ 7% | Yes/No | |

Remarks

Supervised by ____________________

Approved by ____________________

Figure 14 - Proforma for Acceptance Test

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# APPENDICES

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# APPENDIX A

## NOTES ON DESIGN AND CONSTRUCTION

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## A.1 INTRODUCTION

The notes on design and construction given in this Appendix are intended to assist designers, contract engineers and others using this Model Specification, and should be read in conjunction with the notes given in Sections 1 to 8 opposite the specific clauses to which they refer. These notes supplement the recommendations of BSI (1989), and call attention to particular Hong Kong requirements.

## A.2 USE OF THIS MODEL SPECIFICATION

Tender documents specifying the use of prestressed ground anchors should make use in the Particular Specification of the appropriate specification clauses given in Sections 1 to 8 and should include, where appropriate, additional clauses, tables and drawings relevant to the works proposed.

## A.3 USE OF GROUND ANCHORS ON PROJECTS

Ground anchors can generally provide a ready structural means for inducing compressive forces into the ground. These compressive forces can be used to improve ground stability and/or to provide a restraint. However, forces external to the anchor imposed by loads or ground movements can subsequently alter the load in the anchor, even when the anchor has been properly installed and tested. The anchor's condition can deteriorate, particularly since its highly stressed tendon is susceptible to attack by corrosion from a number of sources. Permanent ground anchors are expensive to provide, monitor and maintain, and their overall cost should be carefully assessed before they are recommended for use. It is difficult to make effective arrangements for long-term monitoring, especially when they are used for a building development subject to multi-ownership. Viable permanent alternatives which do not require regular performance monitoring should always be preferred to ground anchors.

## A.4 RECORDS

Designers should note that data relevant to the design of ground anchors in Hong Kong, including site investigation records, are contained in the Geotechnical Information Unit of the Civil Engineering Library (see GCO, 1987) and may be inspected there.

## A.5 PRIOR APPROVAL SYSTEM

The Prior Approval System for Permanent Prestressed Ground Anchors (PASA) confers a level of acceptance on Approved Anchor Systems and on Approved Anchor Types within the Approved Anchor System. The object of the Prior Approval System is to ensure consistent and satisfactory standards in the provision of ground anchors and to save time for designers, contractors, suppliers, and approval authorities in avoiding repetitive checking of design of components and assembly details.

The Prior Approval Documents contain the approvals given in respect of the items listed in Section B.2.2 of Appendix B in the following sections :

(a) General Section. This section names the Agent and the Nominated Anchor Contractors. In addition, it covers all matters which are general to the Approved Anchor System, including component lists which give material and manufacturer, and procedures which cover such matters as supply, storage, handling, installation and monitoring.

(b) Particular Section. This includes a subsection for each Approved Anchor Type which comprises detailed drawings of the Approved Anchor Type showing the arrangement of its components, and citing operating parameters such as the allowable working load and permissible tolerance for compressive movement at the head.

Under the PASA, the Agent for an Approved Anchor System is held responsible for supply of the anchors and for ensuring that they are installed to a high standard. The Agent may undertake the installation or he may use a contractor (referred to as a Nominated Anchor Contractor). In some cases, the Agent may also be the "Contractor" referred to in the Model Specification (e.g. this ususally occurs where the anchors comprise all or most of the Works). In these cases, the responsibility under the contract for the supply, installation, testing, monitoring and other items listed in Clause 2.3 of the Model Specification is clear. However, in other cases, the main Contractor for the project may not be the Agent for the Approved Anchor System. In these cases, the contractual responsibility of the Agent should be clearly established. It is recommended that this be dealt with by including appropriate provisions in the Contract, for example, Special Conditions of Tender requiring the main Contractor to enter into a formal sub-contract with the Agent. For Hong Kong Government contracts, the necessary procedures for this are given in Section 5.9.10(3) and Appendix 2 of the Public Works Department Civil Engineering Manual, Volume II, Part 2, Amendment No. II - 1/89 (August).

A project designer, having decided that ground anchors will be used, needs to provide only the following information in relation to the anchors in any submission to the government approving or checking authority :

(a) a plan showing the location, inclination and length of the anchors required,

(b) the anchor class (see Section A.8), design working load and design free anchor length of each anchor,

(c) those anchors which are to be subjected to Suitability Tests and Extended Acceptance Tests,

(d) the compressive movement which must be allowed for between the anchor pad and the fixed length during stressing,

(e) details of the anchor pad provision, and

(f) arrangements made for long-term monitoring, including provision of access and the agreement of the relevant maintenance party that it is willing to undertake the required long-term monitoring and maintenance.

Provided the above information is included, submissions can be dealt with by the approving or checking authority without the particular anchor system to be used being named or details shown. Prior to construction, however, the approving or checking authority may require further details to be submitted for approval.

The PASA involves an initial thorough check and review of a manufactured proprietary anchor system and all the significant operations and provisions made for the satisfactory installation and monitoring of the performance of anchor types which form part of the anchor system. This check is undertaken by the Prior Approval Committee appointed by the Director of Civil Engineering Services. The approval granted under the PASA will be effective for one year provided satisfactory reports are received from works using the Approved Anchor System. Spot checks made by members of the Prior Approval Committee or reports received from Project Engineers may result in an immediate amendment in the approvals given, or in their entire withdrawal. In any case, all approvals will be reviewed for renewal, amendment or rejection on a fixed date each year.

The continued effectiveness of the PASA will depend on the above reporting system. Project Engineers are reminded that the system can only be operated effectively if Project Engineers adopt PASA requirements as a part of each ground anchor contract they let.

The PASA introduces a form of standardisation which should relieve the Engineer of a number of checks which he previously had to undertake. However, it should be remembered that under the Terms of Contract it does not relieve him of any of his usual responsibilities or requirements to fully supervise the works.

## A.6 REPLACEMENT OF PERMANENT ANCHORS

Provision should be made in the design of the structure for the replacement of any permanent anchor that fails. It would be necessary, therefore, to ensure that suitable access and working space can be provided for all anchors.

## A.7 EASEMENTS

The designer's attention is called to Public Works Department Technical Circular No. 7/80 "The Processing of Applications for Permission to Install Anchors in Crown Land", to Works Branch Technical Circular No. 2/89 "Prior Approval System for Permanent Prestressed Ground Anchors (PASA)", to Buildings Ordinance Office Practice Notes for Authorized Persons and Registered Structural Engineers No. 1978.50 "Prestressed Ground Anchors in Building Works" and No. 1981.77 "Mass Transit Railway Protection", and also to any appropriate General or Special Conditions in the lease or other land allocation documents.

## A.8 ANCHOR CLASS

This Model Specification groups anchors into one of six classes (Table A1) for the purpose of determining numbers of tests (Tables A3 and A4) and extent of monitoring required (Table A5).

The risk category is the determining factor in assigning the anchor class and depends upon the potential for both loss of life and economic loss in the event of anchor failure.

Typical examples are given in Table A2 and allowance should be made for planned development. Where the assessment of risk to life and economic risk are not the same, the category corresponding to the higher value should be taken.

## A.9 AGGRESSIVE CONDITIONS

While weathered rocks and soils derived from insitu rock weathering in Hong Kong are generally not aggressive, prestressed ground anchors are very susceptible to the effects of corrosion, and a designer intending to use anchors should therefore ensure that adequate investigations are made to determine whether or not aggressive conditions exist.

General advice on aggressive ground conditions in Hong Kong is given in GCO (1987), particularly in Chapter 13 and Table 12. Detailed information on ground aggressiveness towards ground anchors is given in BSI (1989) and FIP (1986).

It is recommended that, at any site for which permanent ground anchors are proposed, investigation of soil resistivity and redox potential, and the pH value, chloride ion and sulphate contents of the soil and groundwater should be carried out as a minimum. This range of tests should also be carried out where temporary anchors are proposed at marine sites or at sites where transported soils (including fill) are present. Further appropriate investigation and testing should be carried out if the conditions at the site are found to be more aggressive than those given in Table A6, and measures should be taken to ensure that adequate corrosion protection is provided.

At sites where waste materials have been dumped or where aggressive chemicals could have entered the ground as a result of past or current site usage, specific investigation and testing appropriate to the known site history should be carried out in addition to the above. Stray electric currents can prove aggressive and should not be overlooked at sites near electric railways, tramways or other possible sources of such currents (FIP, 1980).

Proprietary systems of permanent ground anchors acceptable under the PASA incorporate levels of corrosion protection which should be adequate for non-aggressive ground conditions as defined above and for fluctuating or transient groundwater conditions. This should be assumed unless stated to the contrary in the Prior Approval Documents. Special additional precautions, appropriate to the particular conditions at the site, must be taken where aggressive conditions exist. Where the effect of the aggressive conditions on permanent anchor components cannot be predicted with confidence, a more robust design solution, less susceptible to corrosion than ground anchors, should be adopted. For temporary anchors, measures appropriate to the degree and type of aggressiveness should be adopted.

For the above purposes, suitable special conditions should be included in the contract, where aggressive conditions exist, to inform tenderers of the nature of the aggressive conditions and to advise them that anchors supplied must be appropriate for such conditions.

In cases where there is a severe risk of corrosion, it may prove necessary to have a test anchor installed for exhumation and tests at a later date.

Advice on the testing of groundwater during long-term monitoring to detect any changes in the aggressiveness of the ground during the life of the anchors is given in Section A.17.6.

## A.10 ADVERSE EFFECTS

The stressing of ground anchors may cause deformation to existing structures, roads and buried services. It should be noted that test loads are higher than working loads. In addition, grouting, particularly pressure grouting, can seriously affect natural drainage, drains and services.

## A.11 DYNAMIC EFFECTS

Full consideration should be given to the effects of any transient loading which may influence the load carrying capacity of an anchor.

An anchor can be adversely affected by vibrations due to blasting, pile driving, and road or railway traffic. Current Hong Kong practice for building works generally limits peak particle velocity (i.e. the maximum velocity at a point in the ground mass due to a vibrating source) at structures to 25 mm/s for vibrations caused by blasting, and to 13 mm/s for those caused by any operation which can induce prolonged vibration (e.g. driving/withdrawal of piles). However, the Mines Division of the Labour Department should be consulted for limits for specific cases. More stringent requirements have been imposed for sensitive structures (e.g. service reservoirs, radar installations).

In order to avoid damage to anchors, the source of disturbance should be controlled so that the above limits are not exceeded. However, if this is not possible, anchors must be designed accordingly.

For road and railway traffic, the minimum distance between the fixed anchor length and the source of disturbance should be determined in accordance with the above requirements but, in the absence of suitable data, this should be set at 4 m.

## A.12 GREASES

Table 1 of the Model Specification has been formulated from a careful evaluation of the data on greases which have given satisfactory performance. The listed tests and the acceptance criteria have been included after full consideration of their practicability and relevance to corrosion protection.

A well-established manufacturer will have no difficulty in carrying out the specified tests. However, the Engineer may well wish to confirm the quality of the grease supplied. This may be achieved by returning a sample to the manufacturer and requesting his confirmation. This can prove time consuming, however, and the Engineer may prefer, depending on the extent of his concern, to carry out the tests listed in Table A7, which has been drawn up for this purpose. All these tests can be undertaken locally and quickly by various laboratories, and they provide a very good indication of whether the grease is or is not acceptable. Also, various laboratories (including the Public Works Central Laboratory) can, using infra-red spectroscopy, positively and quickly identify a 'signature' for a particular brand of grease against which samples of new supplies can be checked for identification.

Recommendations regarding the checking of grease during long-term monitoring are given in Section A.17.4.2.

## A.13 PLASTICS

The Model Specification requires confirmation from the manufacturer that the properties of plastics comply with Table 2, and major manufacturers should have no difficulty in complying with this requirement.

For confirmation of the quality of the plastic products supplied, it is recommended that a sample be returned to the manufacturer for identification. Major manufacturers have proved to be co-operative in carrying out such testing and, given prior warning, can respond quickly.

The tests listed in Table A8 can also assist in checking plastics, and they will give a fairly reliable indication of quality.

## A.14 COMPRESSION IN THE FREE LENGTH

Compressive forces can cause relative movements in the head and free length which can damage the corrosion protection system. Where possible, the anchor pad should be designed to spread the load to reduce movements and avoid damage. Where this is not possible, the anchor should incorporate measures which will allow movement to occur without damage. The measures should include separation of the free length grout from the anchor pad, and the provision of a bond breaker around the free length which extends an adequate distance below the pad.

The movements will depend on the design of the anchor pad and the compressibility of the ground, and the designer should carry out an analysis to determine their likely magnitude. Circumstances in which the movements would be unlikely to be large enough to require measures to be taken are when the whole length of the anchor is in rock, as in the case of holding-down anchors in foundations in rock, or where the fixed length is in rock and the anchor load is spread over a large area, as in the case of a monolithic retaining wall.

Under the PASA, permissible movements are specified for each Approved Anchor Type.

Contract documents must include the movement to be allowed for each anchor, so that an appropriate Approved Anchor Type can be supplied.

## A.15 TESTING

### A.15.1 General

Sections 6 and 7 of the Specification describe the procedures for the suitability and acceptance testing of anchors during a contract. Guidance for specifying these tests is given in Sections A.15.4 and A.15.5. Pre-contract testing of trial anchors is not covered in the Model Specification but is mentioned in Section A.15.6.

### A.15.2 Measuring Accuracy

The acceptance criteria given in Clauses 6.5, 7.5 and 7.8 of the Model Specification are intended to ensure that the initial residual load and likely future losses due to creep are within acceptable limits, and that a major proportion of the applied tendon load (more than 80%) is transferred and maintained at the location specified by the designer.

Errors in the measurement of the anchor load and extension lead to errors in the values of residual load, as well as in the calculated values of creep and effective free length. The tolerances specified in Clause 6.2 are designed to keep these errors within acceptable limits. In addition to these requirements, it is advised that hydraulic pressure gauges should have a reading dial of preferably not less than 200 mm in diameter. Each gauge should be capable of reading pressures in kPa or be accompanied by a chart from which the dial gauge reading can be converted into kPa. It is prudent to use gauges with a maximum operating capacity at least 30% in excess of the maximum load to be measured. It should be noted that readings obtained at low pressures are likely to be relatively less accurate than those obtained at high pressures.

The accuracy of instruments can be adversely affected by temperature variations. Instruments should be protected from direct sunlight by suitable covers or awnings.

Better accuracy can be obtained for the creep measurements required in Clauses 6.3(c), 7.3(c) and 7.6(c) by using the constant-load method rather than the constant-deformation method. The former method involves holding the pressure constant at a mark and measuring extensions with a dial gauge.

The application of the relative accuracy limits of 0.5% $\Delta l_r$ or $T_p$ within the overall tolerance of $\pm 2\%$ $\Delta l_r$ or $T_p$ is illustrated in Figure A2 for clarity and to allow the Engineer, if he so wishes, to check the calibration curves for the instruments used in the field. This figure is a diagrammatic representation that exaggerates the values of limit lines and the departures $d_1$ and $d_2$.

### A.15.3 Calibration

Requirements for calibration of instruments are given in Clause 5.6.4. These should be regarded as the minimum requirements to provide satisfactory accuracy for stressing and monitoring.

Equipment should be calibrated against standard measures (e.g. dead loads) which comply with the appropriate British Standard or equivalent. The equipment should, wherever possible, be calibrated as a set (i.e. pump, jack, pressure gauges and connecting cables and hoses), and maintained as a set throughout the contract period, or throughout a monitoring operation.

The set, wherever possible, should be calibrated at the commencement of stressing or monitoring operations.

### A.15.4 Suitability Tests

The designer should specify (see Clause 4.4 of the Model Specification) and show on the Drawings the number and location of the Suitability Tests, which should be in accordance with Table A3. The anchors selected for Suitability Tests should be representative of the full range of anchor types to be used (i.e. load capacities, lengths, inclinations and ground conditions likely to be encountered). However, since the Suitability Tests are to be undertaken before the working anchors are installed, their locations must also be selected to fit in with the construction sequence and programme for the project. The designer should therefore choose their location with great care and with adequate ground investigation.

If one or more of the acceptance criteria are not satisfied or if the results are borderline, it is most important to investigate the causes of non-compliance. For this purpose, the final cycle in Clause 6.3(d) has been introduced to enable the Engineer to make an informed decision. This cycle (Figures 5 and 6) provides information on :

(a) the amount of draw-in of the cones/wedges,

(b) the calculated residual load at the anchor head, $T_{RC}$, and at the top of the fixed anchor length,

(c) a value of the friction developed along the effective free length, and

(d) a load versus extension graph which may be compared with those shown in Figure A3.

The zero friction line gives the actual elastic extension of the tendon for the loads applied in the final cycle. The draw-in reduces the extension, as shown on Figures 5 and 6. The load in the tendon at the anchor head for this extension is $T_{RC}$ (the calculated immediate residual load). The immediate residual load acting on the fixed anchor length lies on the zero friction line at the same extension. The difference between these residual loads gives an estimate of loss due to friction.

Friction, R, may also be estimated, although with a lesser degree of confidence, using the plot given in Figure 7. This can be done by fitting a straight line between points 3 and above, using the Least Squares Method. The intercept between $T_A$ and this line on the load axis gives the estimated friction value.

The Model Specification takes friction, R, into account in setting a lower allowable limit for the effective free length. For this reason, R is not included in the formula for effective free length in Clauses 6.5.1(b), 7.5.1(b) and 7.8.1(b). In some circumstances, high friction can be reduced by performing a number of loading and unloading cycles.

### A.15.5 Extended Acceptance and Acceptance Tests

All working anchors are required to undergo an Acceptance Test, with the exception of a limited number which undergo an Extended Acceptance Test. For projects which contain less than ten Class 1 anchors, Extended Acceptance Tests may be carried out instead of Suitability Tests. The designer should specify (see Clauses 4.5 and 7.1 of the Model Specification) and show on the Drawings the number and locations of the Extended Acceptance Tests, which should be decided in accordance with Table A4. For cases with less than ten Class 1 anchors, the Extended Acceptance Tests must be undertaken first and the work programmed accordingly.

### A.15.6 Trial Anchor Tests

As recommended in BSI (1989) and other Standards, the ground or rock conditions at the site may be such as to require the installation, stressing and testing of special trial anchors before the project commences in order to determine design parameters for the working anchors. Such trials may also be necessary to check assembly and installation procedures and may include trial insertion and withdrawal to check whether those procedures will damage the corrosion protection. For trial anchors, the anchor types, the assembly installation and testing procedures, the measuring devices and the stressing programmes should all be fully specified by the designer, in a manner dependent upon the particular requirements. Trial anchors and trial anchor tests may include features and procedures which are not covered in the Model Specification.

## A.16 THE LIFT-OFF TEST

A lift-off test may be used to determine the residual load in the tendon. "Lift-off" occurs when an applied load in excess of the residual load causes a very small but perceptible movement of the stressing head, nut or other locking device away from the anchor base plate. Generally, this movement is small in comparison to the previous extension of the tendon, and the applied load at which it occurs can be taken as equal to the residual load. The test requires three or more cycles of loading and unloading to obtain a representative value for the residual load. The applied load and the lift-off movement must be recorded for each load application.

It must be emphasised that the test procedure should comply with the safety requirements given in the Model Specification and should follow the recommendations of the manufacturer of the system. However, it should also be appreciated that, if the operation is not properly controlled, the movement of the locking device may result in damage to the tendon. In some systems, the wedges move and re-grip the tendon; in others, they are subject to a load in excess of that previously applied, causing the wedges to grip deeper. A tendon with a short free length requires a relatively smaller movement to produce a significant increase in residual load and, in such cases, care must be taken to avoid over-stressing the anchor. In no case should the lift-off movement exceed the equivalent extension required to increase the tendon load by more than 1%.

The tendon can be tensioned with a stressing jack or a purpose-made hydraulic jack load cell, but the equipment should comply with the manufacturer's specification and should be maintained in a suitable condition at all times.

Lift-off is reached when there is an abrupt change in the extension and a change in the rate of increase of applied load. It is very desirable for a check to be carried out which will confirm that lift-off has been achieved. The arrangement of dial gauges shown in Figure A4 is recommended. This will allow such a check and will also clearly identify the residual load.

Experience with lift-off tests on multi-strand anchors where the anchor head is lifted, indicates that differential lifting of the head can occur. This may be the result of uneven loads in the strands or of their asymmetrical arrangement. Uneven loads can also result from differences in slippage of wedges or when strands have not been evenly tensioned initially. The differential loading in the strands prevents a straight lift-off of the head and gives rise to the movements shown in Figure A5.

The residual load can also be read directly through a compression load cell that is built into the anchor head during installation. Experience to date in Hong Kong indicates that the long-term reliability of load cells is poor, and therefore, provision should always be made for their replacement. The high costs associated with this provision and the maintenance of load cells should be taken into account in deciding whether to use load cells. It is also recommended, because of uncertainty of supply and other possible problems, that provision is always made for the lift-off test to be carried out as a back-up.

## A.17 LONG-TERM MONITORING AND MAINTENANCE

### A.17.1 General Considerations

Long-term monitoring of ground anchors is considered necessary for the following reasons :

(a) Compared with other civil engineering and structural elements, such as beams, columns, or piles, ground anchors are in many respects more akin to items of mechanical equipment, for which life-long checking and maintenance are normally carried out.

(b) Anchors are installed in the ground, which is a changeable and sometimes hostile environment, in which their integrity cannot be checked by direct visual inspection at each stage of construction, unlike a reinforced concrete beam.

(c) Creep of the installation can continue in certain situations, and this can seriously alter the loading.

(d) Without monitoring, failures of anchors can remain undetected until a major failure occurs. In some cases, this situation could arise after the failure of only a few anchors.

(e) Ground anchor failures have occurred in Hong Kong (Brian-Boys & Howells, 1984).

The extent and type of monitoring necessary varies from installation to installation, and is generally dependent on the risk category for which the anchors have been designed.

The monitoring is intended to check whether the anchor's condition and performance are satisfactory and are likely to remain so until the next monitoring. Monitoring can be undertaken using appropriate combinations of the following checks for the life of the installation :

(a) visual survey of the anchored structure or slope and the adjacent ground,

(b) visual survey of the exposed parts of individual anchors,

(c) inspection of the anchor head for selected anchors,

(d) measurement of residual load in selected anchors,

(e) measurement of level and composition of groundwater, and

(f) measurement of deformations of the anchored structure or slope.

Residual load checks will not detect the onset of corrosion in tendons, but it will reveal failure of the tendons, where this is not otherwise obvious, and it may also indicate failures of individual strands.

Careful maintenance of anchors is necessary throughout their service life. This includes routine maintenance, such as clearing plant growth from around the anchor head, and painting of the protective cap and other exposed metal surfaces, and also includes specific work, the need for which is indicated by the results of the monitoring, such as repairs to the anchor pad, replacement of rubber seals or grease and remedial measures (see Section A.17.8).

It should be appreciated that the costs of monitoring will be high, and the project designer should take this into account when undertaking feasibility studies for alternative methods of support. Also, in some locations, access to the anchors will be difficult. It is therefore advisable that the project designer should provide, as far as possible, safe access and working platforms under the installation contract to facilitate future monitoring and maintenance.

Section 4 of the Model Specification describes the procedures for monitoring which are to be carried out by the Contractor for the duration of the Contract and up to the end of the Maintenance Period. After this, the owner must make other arrangements for carrying out the monitoring and maintenance throughout the life of the installation.

### A.17.2 Extent and Frequency of Monitoring

Table A5 gives the minimum extent and frequency of monitoring considered necessary for the various anchor classes. The frequency of monitoring reduces with time, reflecting the increased confidence in the anchor's performance. The locations of the anchors to be monitored should be carefully chosen to give a true representation of the overall performance of each anchor group or part of the anchored structure. For example, the selection could be based on anchors representative of groups undertaking particular functions, anchors exhibiting unusual behaviour during installation and testing, anchors located in complex ground conditions, anchors placed in ground which may be aggressive or unusually long anchors.

Temporary anchors are often used in situations where their failure would have very serious consequences with regard to public safety. For example, they have been used to support deep basement excavations with occupied buildings or major roads located close to the edge. As well as being critical to the safety of the surrounding area, temporary anchors in such situations are vulnerable to damage by construction plant and can be subject to rapid changes in loading. Monitoring of temporary anchors should therefore always be carried out where they are used in situations where their failure can present an evident risk-to-life (i.e. other than in 'negligible' risk-to-life situations as defined in Table A2) or can result in a serious economic loss.

Where the potential failure of part of a group of anchors presents an extremely high risk to life or property, then the extent and frequency of the monitoring of that part should be adjusted accordingly; in these circumstances, a greater proportion of the anchors than given in Table A5 should be monitored. This should also be the case when anchor failures have occurred on a site.

A similar increase in monitoring may also be warranted where the structure or slope is highly susceptible to overall failure if the anchors fail, e.g. in a case where, without anchors, a retaining wall would have a factor of safety against overturning of less than unity and where, if one anchor fails, the remainder would undergo a large load increase.

### A.17.3 Visual Survey

A visual survey includes an inspection of all visible components of the Anchor System, the anchored slope or structure, the adjacent ground and the drainage facilities. It is one of the most effective ways of identifying areas of potential distress, and it must therefore be carried out in conjunction with the other forms of monitoring. The Engineer is responsible for undertaking visual surveys up to the end of the Maintenance Period.

Observations of distress (e.g. mass movement of the pad, cracking/ spalling of concrete, rust stains from the anchor head) should be described in detail and photographed. Instrumentation should be provided to record any future change in the defect where practicable. A competently maintained historical record will prove invaluable if a problem manifests itself suddenly.

It is important that a visual survey is undertaken by a person who is aware of the implications of the features being checked, and who is thus able to make a competent interpretation of the evidence available.

### A.17.4 Anchor Inspection

#### A.17.4.1 General Requirements

Inspections of selected anchors should be carried out in conjunction with the residual load measurements specified in Table A5. These inspections should include a comprehensive survey of the anchor pad and the immediately adjacent sections of the structure or slope, the protection cap and visible components of the anchor head after removal of the grease. Up to the end of the Maintenance Period, the Contractor will be responsible for this work.

Any defect should be carefully recorded, and an attempt should be made to identify its possible cause. Previous records should be checked to determine if the defect is new or whether there has been any change in its condition. If possible, defects should be photographed against a colour chart and scale rule, as appropriate.

The Engineer should instruct the Contractor to remedy all recorded defects before handing over the project to the client for subsequent maintenance.

A sample of grease should be recovered for possible testing. The amount of testing will depend on the nature and extent of any noticeable deterioration in the effectiveness of the grease. A list of tests recommended, in order of importance, is given in Table A7; the 150 ml specified in Clause 4.6.3 is sufficient to carry out the base number, water content and chemical tests. Upon completion of inspection, the corrosion protection must be restored using new grease.

#### A.17.4.2 Special Grease Checks

For the purpose of positively checking the long-term behaviour of the original grease, Table A5 specifies a series of special checks on previously undisturbed anchors, which should be carried out on a rotational basis. This requirement is in addition to the normal anchor inspections described above.

Samples of grease should be recovered for testing to verify continued compliance with the Model Specification. The tests given in Table A7 should be used for this purpose. Should there be any significant variation in properties of the grease, it should be replaced, and an attempt should be made to determine the cause of the deterioration. A full record of these special grease checks should be maintained.

### A.17.5 Residual Load Measurements

A programme of load measurements should be undertaken as specified in Table A5 to verify that the residual load remains acceptable. The residual load may change as a result of time-dependent effects (e.g. concrete creep, shrinkage, steel relaxation, slippage at rock/grout interface, rock and soil creep), changes in ambient temperature, groundwater level or monitoring techniques, corrosion of materials, wall/slope movement, poor alignment and strand pattern. The residual load can also be altered substantially by blasting, demolition, surcharging or earthworks affecting the ground in which the anchor is located.

The lift-off test and compression load cells are discussed in Section A.16.

Advice given in Sections A.15.2 and A.15.3 regarding measuring accuracy and calibration of equipment used for testing is also applicable to equipment used for monitoring.

### A.17.6 Groundwater Analysis

Sampling and testing of groundwater should be included in the monitoring programme on sites where investigations show that aggressive conditions exist, and they should be carried out on other sites if there is reason to suspect that aggressive conditions could have developed at any time during the life of the anchors. The method of sampling should ensure that samples are representative of the groundwater, and care must be taken to avoid contamination or dilution by other substances. Detailed recommendations in this respect are given in GCO (1987).

Background values of the constituents of the groundwater will be determined during initial investigation and the project designer should set concentration limits for acceptance and frequencies for subsequent monitoring.

### A.17.7 Deformation Survey

The overall performance of an anchored structure or slope can be monitored to provide an early warning of structural distress or to supplement the measurements of residual load. The techniques employed for detecting structural movements will vary from site to site and thus the specification for the work, including the frequency of monitoring, should be decided by the designer of the structure. Instrumentation for effective deformation measurements (viz. precise levelling and surveying, tiltmeters, extensometers, inclinometers, tell-tales, etc.) will generally prove expensive to provide.

### A.17.8 Assessment of Monitoring Results

If any variation in condition or behaviour is discovered during monitoring, an assessment should be made to determine the importance and effect of the variation. Previous records should be reviewed and consideration given to examining additional anchors.

The measured residual loads should be plotted against time for each anchor to establish whether there is a trend. The specified residual load measured immediately after locking-off includes a 10% allowance for time dependent losses during the service life of an anchor.

The residual load should stabilize close to the design load, $T_D$, but a variation from the immediate lock-off load to 90% $T_D$ can be expected. Where the load is outside this range, investigation and a careful diagnosis is required to ascertain the cause and to ensure that the anchor is performing properly. At this stage, the designer should be consulted. It will probably be necessary to increase the monitoring frequency and to monitor the overall structure/ground movement. This should continue until the load variation has stabilized at an acceptable level or appropriate remedial action has been decided upon, taken and proven effective.

In assessing the situation, consideration must be given to whether the changes in residual load reflect strains or changes in loading in the anchored structure or slope, or malfunctioning of the anchor itself. In either case, appropriate remedial measures must be taken to maintain the required factor of safety of the structure or slope. Where the residual load is increasing, action must be taken to ensure that it never exceeds the test load, $T_P$.

Options for remedial measures include the installation of additional anchors, a remedial stressing programme leading to restoration of the original load or acceptance at a lower load, or abandonment and replacement.

## A.18 RESTRESSING

Restressing of anchors by shimming beneath the anchor head is not recommended, because differential loads in the strands or bars may lead to overstressing of some of these. Unless re-stressing can be carried out by stressing the strands or bars individually, it should be avoided.

## A.19 DESTRESSING

The Engineer is advised to ensure that the sequence for destressing the anchors does not result in overstressing of adjacent anchors, slopes or structures.

## A.20 HANDOVER

The Engineer should, at handover, provide his client with a report giving the following information :

(a) site investigation and all test results,

(b) as-built drawings,

(c) the basis for anchor design including calculations of working loads, free lengths, fixed lengths, etc.,

(d) the specification for the materials which may need to be replaced,

(e) a summarised installation record, with dates, for each anchor,

(f) all anchor stressing records and test records, including those for trial anchors, Suitability Tests, Extended Acceptance and/or Acceptance Tests, unless there is a separate submission,

(g) a record of the monitoring results taken to date,

(h) the schedule and procedures for future monitoring and maintenance,

(i) guidelines on the interpretation of future monitoring results, and

(j) details of equipment and plant, including all calibrations.

**A.21 TENDER INFORMATION**

Specifiers should require the following information to be included with the tender, except where this is covered in a Prior Approval Document, in which case the reference number of the Document should be given :

(a) For each anchor, design calculations and full engineering drawings showing all the assembled parts of the system, including longitudinal and transverse sections and enlargements, showing details where appropriate. Details of connections should be shown in full. Details of the anchor pad or other form of anchor head support should be included where this is to be designed by the anchor supplier.

(b) The names and addresses of the sub-contractor (if any) who will be used for the anchor installation work.

(c) A component list, referenced on the Drawings, giving the component number, name, material, material standard, manufacturing process and surface coating or finish. Tenderers should confirm that documentary evidence will be provided which will show that the materials comply with the Model Specification.

(d) Details of the intended grout mix, including additives and admixtures and target minimum cube strength for seven days.

(e) A list of all equipment to be used for stressing, monitoring or destressing and the name of the laboratory which will undertake the calibration of the equipment.

(f) Details of procedures for material storage and transportation, drilling, water testing, anchor assembly and installation, stressing, testing, monitoring, destressing and maintenance. These should be given in summary form on the Drawings.

(g) Details of the features of each anchor and the conditions, including ground aggressiveness, for which its use is appropriate.

## A.22 RELEVANT NATIONAL STANDARDS

The following national standards have been referred to in the Specification Clauses and in Appendix A. The editions referred to are those considered to be applicable to the Model Specification, as at March 1989. Later editions, amendments, supplements and addenda that have been published are not necessarily applicable. However, it should be noted that the General Specification for Civil Engineering Works (1977) is being revised at the time of this publication going to press. When the new edition of the General Specification is published, reference should be made to that edition.

APHA : Part 427 : 1985 - Sulphide : Iodometric Method. Standard Methods for the Examination of Water and Wastewater. (Sixteenth edition). American Public Health Association.

ASTM B 117-85 - Standard Method of Salt Spray (Fog) Testing.

ASTM D 93-85 - Standard Test Methods for Flash Point by Pensky-Martens Closed Tester.

ASTM D 95-83 - Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation.

ASTM D 217-86 - Standard Test Methods for Cone Penetration of Lubricating Grease.

ASTM D 512-81 (1985) - Standard Test Methods for Chloride Ion in Water.

ASTM D 566-76 (1982) - Standard Test Method for Dropping Point of Lubricating Grease.

ASTM D 570-81 - Standard Test Method for Water Absorption of Plastics.

ASTM D 746-79 - Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact.

ASTM D 942-78 (1984) - Standard Test Method for Oxidation Stability of Lubricating Greases by the Oxygen Bomb Method.

ASTM D 972-86 - Standard Test Method for Evaporation Loss of Lubricating Greases and Oils.

ASTM D 974-85 - Standard Test Method for Neutralization Number by Color-Indicator Titration.

ASTM D 1693-70 (1980) - Standard Test Method for Environmental Stress Cracking of Ethylene Plastics.

ASTM D 1742-83 - Standard Test Method for Oil Separation from Lubricating Grease during Storage.

ASTM D 1743-73 (1981) - Standard Test Method for Corrosion Preventive Properties of Lubricating.

ASTM D 4327-84 - Standard Test Method for Anions in Water by Ion Chromatography.

ASTM D 4658-87 - Standard Test Method for Sulfide Ion in Water.

ASTM G 21-70 (1980) - Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi.

ASTM G 22-76 (1980) - Standard Practice for Determining Resistance of Plastics to Bacteria.

BS 12 : 1978 - Specification of Ordinary and Rapid-hardening Portland Cement. (Including amendment AMD 4259, 1983).

BS 1881 : Testing Concrete.

Part 3 : 1970 - Methods of Making and Curing Test Specimens. (Including amendments AMD 1948, 1976 and AMD 3062, 1979).

Part 4 : 1970 - Methods of Testing Concrete for Strength. (Including amendments AMD 782, 1971 and AMD 2167, 1976).

Part 6 : 1971 - Analysis of Hardened Concrete. (Including amendment AMD 763, 1971).

BS 2494 : 1986 - Elastomeric Joint Rings for Pipework and Pipelines.

BS 2782 : Methods of Testing Plastics.

Part 1 : 1976 - Method 120A.
Determination of the Vicat Softening Temperature of Thermoplastics.

Part 3 : 1976 - Method 320C.
Tensile Strength, Elongation and Elastic Modulus.

Part 3 : 1981 - Method 365B.
Determination of Indentation Hardness by Means of a Durometer (Shore Hardness).

Part 6 : 1980 - Method 620A.
Determination of Density of Solid Plastics Excluding Cellular Plastics (Immersion Method).

BS 3148 : 1980 - Methods of Test for Water for Making Concrete (Including Notes on the Suitability of Water).

BS 4447 : 1973 - The Performance of Prestressing Anchorages for Post-tensioned Construction.

BS 4486 : 1980 - Specification for Hot Rolled and Hot Rolled and Processed High Tensile Alloy Steel Bars for the Prestressing of Concrete.

BS 4757 : 1971 - Nineteen-wire Steel Strand for Prestressed Concrete.

BS 5075 : Concrete Admixtures.

Part 1 : 1982 - Specification for Accelerating Admixtures, Retarding Admixtures and Water-reducing Admixtures. (Including amendments AMD 4183, 1983 and AMD 4910, 1985).

BS 5075 : Concrete Admixtures.

Part 3 : 1985 - Specification for Superplasticizing Admixtures.

BS 5896 : 1980 - Specification for High Tensile Steel Wire Strand for the Prestressing of Concrete.

BS 6437 : 1984 - Polyethylene Pipes (Type 50) in Metric Diameters for General Purposes. (Including amendment AMD 5169, 1986).

CRD-C 79-58 - Flow Cone Method (US Corps of Engineers).

General Specification for Civil Engineering Works (1977), Hong Kong Government Printer.

## A.23 REFERENCES

Austrian Standards Institute (1976). Prestressed Anchors for Soil and Rock. Onorm B4455, Osterrreichisches Normungsinstitut, Vienna, 29 p.

Brian-Boys, K.C. & Howells, D.J. (1984). Prestressed ground anchor practice in Hong Kong. Proceedings of the International Conference on In Situ Soil and Rock Reinforcement, Paris, vol. 1, pp 231-236.

BSI (1989). British Standard Code of Practice for Ground Anchorages. British Standards Institution, BS8081, London, 180 p.

FIP (1980). Report on Prestressing Steel : 6. The Influence of Stray Electrical Currents on the Durability of Prestressed Concrete

Structures. Fédération Internationale de la Préconstrainte, Slough, United Kingdom, 32 p.

FIP (1982). Recommendations for the Design and Construction of Prestressed Concrete Ground Anchors. Fédération Internationale de la Précontrainte, Slough, United Kingdom, 31 p.

FIP (1986). State of the Art Report on Corrosion and Corrosion Protection of Prestressed Ground Anchorages. Fédération Internationale de la Précontrainte, London, 28 p.

GCO (1987). Guide to Site Investigation (Geoguide 2). Geotechnical Control Office, Hong Kong, 362 p.

GCO (1988). Guide to Rock and Soil Descriptions (Geoguide 3). Geotechnical Control Office, Hong Kong, 189 p.

Martak, L. (1979). The friction calculation in fixing the load of prestressed anchors with free tendon length. Proceedings of the Seventh European Conference on Soil Mechanics and Foundation Engineering, Brighton, vol. 1, pp 205-214.

Swiss Society of Engineers and Architects (1977). Ground Anchors. S.I.A. Standard 191, Zurich, 45 p.

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Table A1 - Categories of Anchor Classes

| Risk Category | Anchor Class | |
|---|---|---|
| | Temporary Anchor | Permanent Anchor |
| High | 3 | 6 |
| Low | 2 | 5 |
| Negligible | 1 | 4 |

Table A2 - Typical Examples for Determining Risk Category

| Risk Category | | Typical Examples |
|---|---|---|
| High | Risk-to-life | Failures affecting occupied buildings (e.g. residential, industrial, commercial, educational); buildings storing dangerous goods. |
| | Economic risk | Failures affecting rural or urban trunk roads or roads of strategic importance; essential services that could cause loss of that service for an extended period; buildings that could cause excessive structural damage. |
| Low | Risk-to-life | Failures affecting densely used open spaces and recreational facilities (e.g. sitting-out areas, playgrounds, car parks); roads with high traffic density; public waiting areas (e.g. railway platforms, bus stops, petrol stations). |
| | Economic risk | Failures affecting rural (A) or primary distributor roads that are not sole accesses; essential services that could cause loss of that service for a temporary period (e.g. power, water and gas mains). |
| Negligible | Risk-to-life | Failures affecting country parks; lightly used open-air recreation areas; roads with low traffic density; storage compounds (non-dangerous goods). |
| | Economic risk | Failures affecting country parks; open-air car parks; rural (B), feeder, district distributor and local distributor roads that are not sole accesses. |

Table A3 - Minimum Number of Suitability Test Anchors

| Class 1 | | Classes 2 & 4 | | Classes 3, 5 & 6 | |
|---|---|---|---|---|---|
| No. of Anchors | No. of Tests | No. of Anchors | No. of Tests | No. of Anchors | No. of Tests |
| 1-10 | 1 (3) | 1-10 | 1 | 1 | 1 |
| 11-50 | 1 | 11-50 | 2 | 2-10 | 2 |
| 51-250 | 2 | 51-233 | 3 | 11-175 | 3 |
| over 250 | 1 %* | over 233 | 1.5 %* | over 175 | 2 %* |

Notes :
(1) A minimum of one anchor shall be tested in each class.
(2) The number of tests resulting from the percentage figures marked (*) shall be rounded to the nearest whole number.
(3) As stated in Section A.15.5, in this case, an Extended Acceptance Test may be carried out instead of a Suitability Test.

Table A4 - Minimum Number of Extended Acceptance Tests

| Anchor Classes 1 & 2 | Anchor Classes 3, 4, 5 & 6 |
|---|---|
| 3 %, but at least 2 | 6 %, but at least 4 |

Table A5 - Guide to Extent and Frequency of Monitoring

| Anchor Class (See Table A1) | Frequency of Visual Survey | Monitoring of Individual Anchors | | |
|---|---|---|---|---|
| | | Number of Anchors for Monitoring to Nearest Whole Anchor Number[1] | Frequency of Anchor Inspection and Residual Load Measurements after Locking-off | Extent and Frequency of Special Grease Checks[2] |
| 1<br>4 | Monthly, up to the end of the Maintenance Period, then yearly thereafter | 7 % of first 50 anchors<br>3 % of additional anchors | 2 weeks, 1 month, 3 months, 6 months, 1 year, 18 months, 2 years, 5 years, then every 5 years thereafter | One anchor every 5 years |
| 2<br>5 | Fortnightly, up to the end of the Maintenance Period, then yearly thereafter | 10 % of first 50 anchors<br>7 % of second 50 anchors<br>5 % of additional anchors | 2 weeks, 1 month, 3 months, 6 months, 9 months, 1 year, 18 months, 2 years, then every 2 years thereafter | Two anchors 2 years, 5 years then every 5 years |
| 3<br>6 | Weekly, up to the end of the Maintenance Period, then every 6 months thereafter | 15 % of first 50 anchors<br>12 % of second 50 anchors<br>10 % of additional anchors | 2 weeks, 1 month, 3 months, 6 months, 9 months, 1 year, 18 months, 2 years, then every year thereafter | Three anchors 2 years, 5 years then every 5 years thereafter |

Notes:

(1) The same anchors are to be monitored each time. The number may have to be increased if necessary to provide a representative sample.

(2) Different anchors are to be selected each time for special grease checks so that original undisturbed grease can be sampled.

(3) Monitoring of piezometers is not included and should be specified separately.

(4) Circumstances requiring the frequency of monitoring to be increased are described in Section A.17.2.

Table A6 - Conditions under Which Detailed Investigation of Ground Aggressiveness Is Required

| Property | Value |
|---|---|
| Soil resistivity[1] | < 50 ohm m |
| Soil redox potential[1] corrected to pH = 7 | < 0.40 volts<br>< 0.43 volts for clay soils |
| pH of soil or groundwater | < 5 |
| Chloride ion content in soil[2] | > 0.2 g / litre |
| Total sulphate content in soil[3] | > 0.2 % by weight |
| Sulphate ion content in soil[2] | > 1.0 g / litre |
| Sulphate ion content in groundwater | > 0.3 g / litre |

Notes : (1) Based on insitu tests.
(2) Based on 2 : 1 water / soil extract.
(3) Concentration of sulphates expressed as $SO_3$.

Table A7 - Significance of the Various Tests Applicable to Grease

| Name of Test | New Grease Prior to Use[1] | Existing Grease During Anchor Monitoring |
|---|---|---|
| Identification by infra-red spectroscopy[2] | Essential | Not necessary |
| Base number | Essential | Essential |
| Water content | Essential | Essential |
| Chloride ion content | Essential | Essential |
| Nitrate ion content | Essential | Essential |
| Sulphide ion content | Essential | Essential |
| Cone penetration | Essential | Essential ★ |
| Corrosion prevention | Desirable * | Not necessary |
| Oil separation | Desirable * | Not necessary |
| Flash point | Desirable * | Not necessary |
| Drop point | Desirable * | Not necessary |

Legend :

★ The need for cone penetration test may be assessed by textural feeling of the grease.

* Desirable tests are listed in order of priority.

Notes : (1) These tests apply to grease delivered to the site and are for checking general compliance with the specification. Manufacturers' certificates showing compliance with all tests must be supplied, in accordance with Table 1 of this Model Specification. See also Section A.12.

(2) Use of Infra-red Spectroscopy

(a) Principle : Infra-red spectroscopy is an instrumental analyticol technique, in which a sample is irradiated with electromagnetic radiation in the infra-red region of the spectrum (wavenumber range 4000 $cm^{-1}$ to 600 $cm^{-1}$), and the wavenumbers (or alternatively the frequencies) at which absorption occurs are recorded to produce the somple's infra-red spectrum. Because the wavenumbers or frequencies of infra-red absorption peaks are very characteristic for various types of chemical bonds, the presence of a particular structural group in the molecular compounds can be identified. Taken over a range of wavenumbers or frequencies, the spectrum constitutes a 'signature' which qualitatively identifies a particular material.

(b) Technique for Grease Identification : The sample may be evenly smeared on a KBr disc, which is then inserted into the cell holder and scanned for its infra-red spectrum.

Table A8 - Recommended Quick Confirmatory Tests to Check the Quality of Plastic Components

| Name of Test | Test Method |
|---|---|
| Identification of plastics | Infra-red spectroscopy |
| Tensile strength at yield at 23°C (Strain rate = 50 mm/min.) | BS2782 : Part 3 : 1976, Method 320C |
| Water absorption at 23°C | ASTM D 570-81 (24hr immersion) |
| Density | BS2782 : Part 6 : 1980, Method 620A |

Notes :

(1) The selection of the above tests was made in consideration of the local availability of the testing facilities (in some cases, expertise and knowledge), the required testing time, and the general properties of the thermoplastics specified. They are therefore useful for obtaining quick confirmation that plastic components delivered to the site are in general compliance with the specification.

(2) For the infra-red spectroscopy technique for identification of thermoplastics with a sample thickness greater than 1mm, the samples may be hot pressed by high pressure to be converted to a thin film suitable for infra-red transmission. See note (2) on p145 which is also appliable to plastics.

(3) Infra-red spectroscopy when applied to theromoplastics identification will provide information on its generic type and not a 'signature' of a particular manufacturing process or 'brand'.

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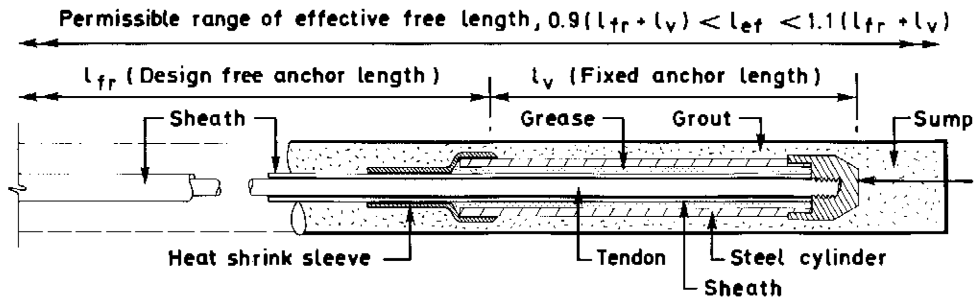
Notes :

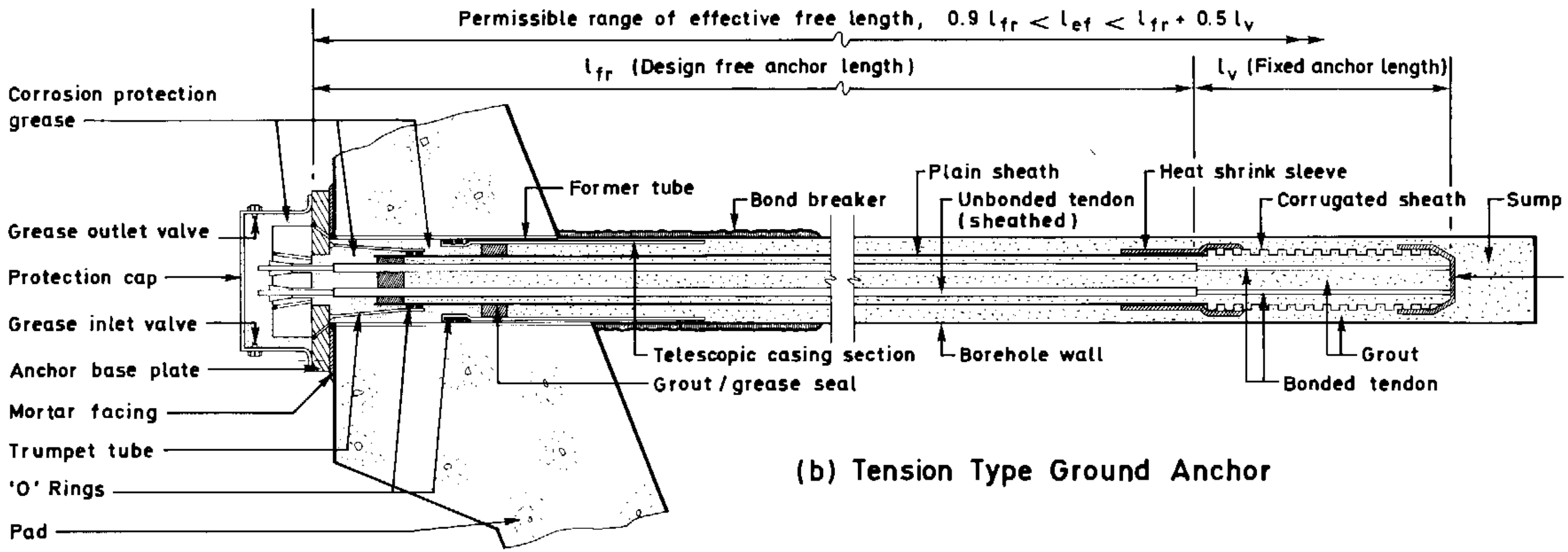
(1) This drawing shall not be used to represent a working system or form part of a specification.

(2) This diagram is included to clarify the components and terms for typical ground anchors that have been used in Hong Kong. Compliance with the details shown does not imply acceptability under the Prior Approval System.

(3) For additional details refer to a manufacturer's manual.

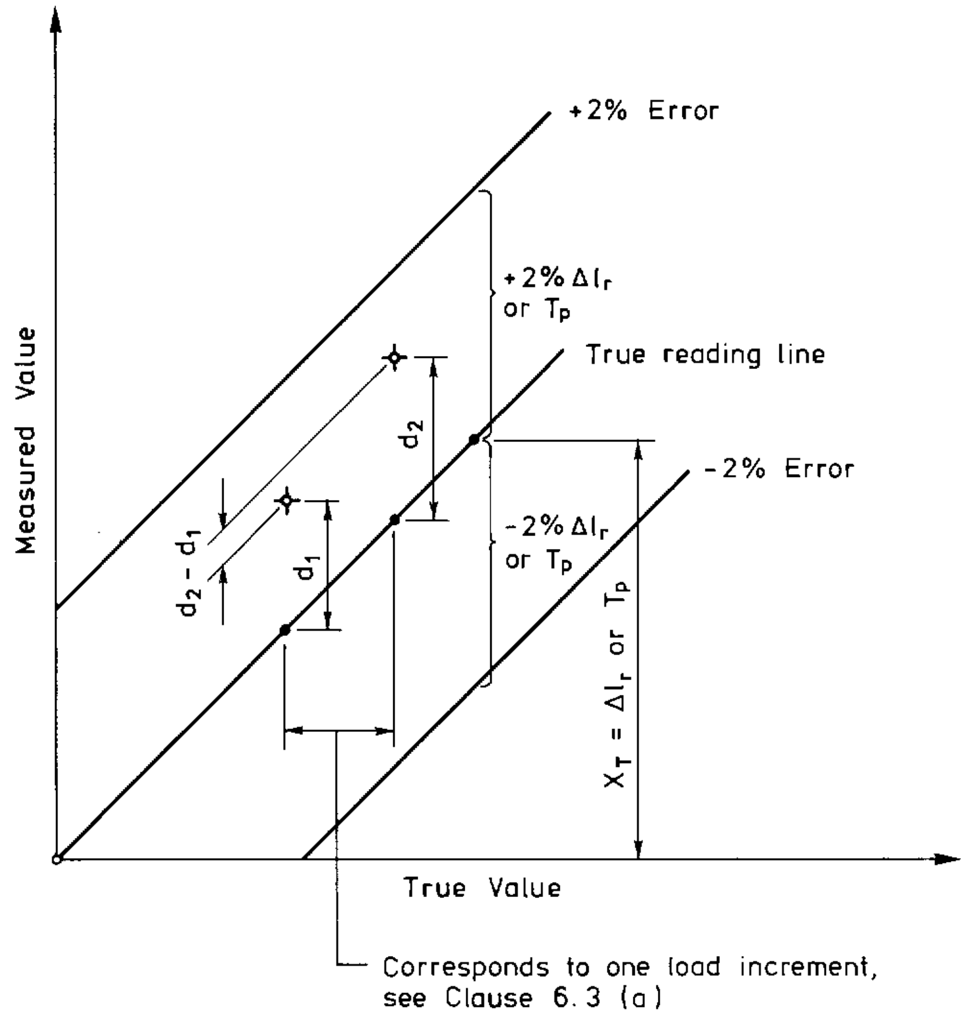



(a) Compression Type Ground Anchor




(b) Tension Type Ground Anchor

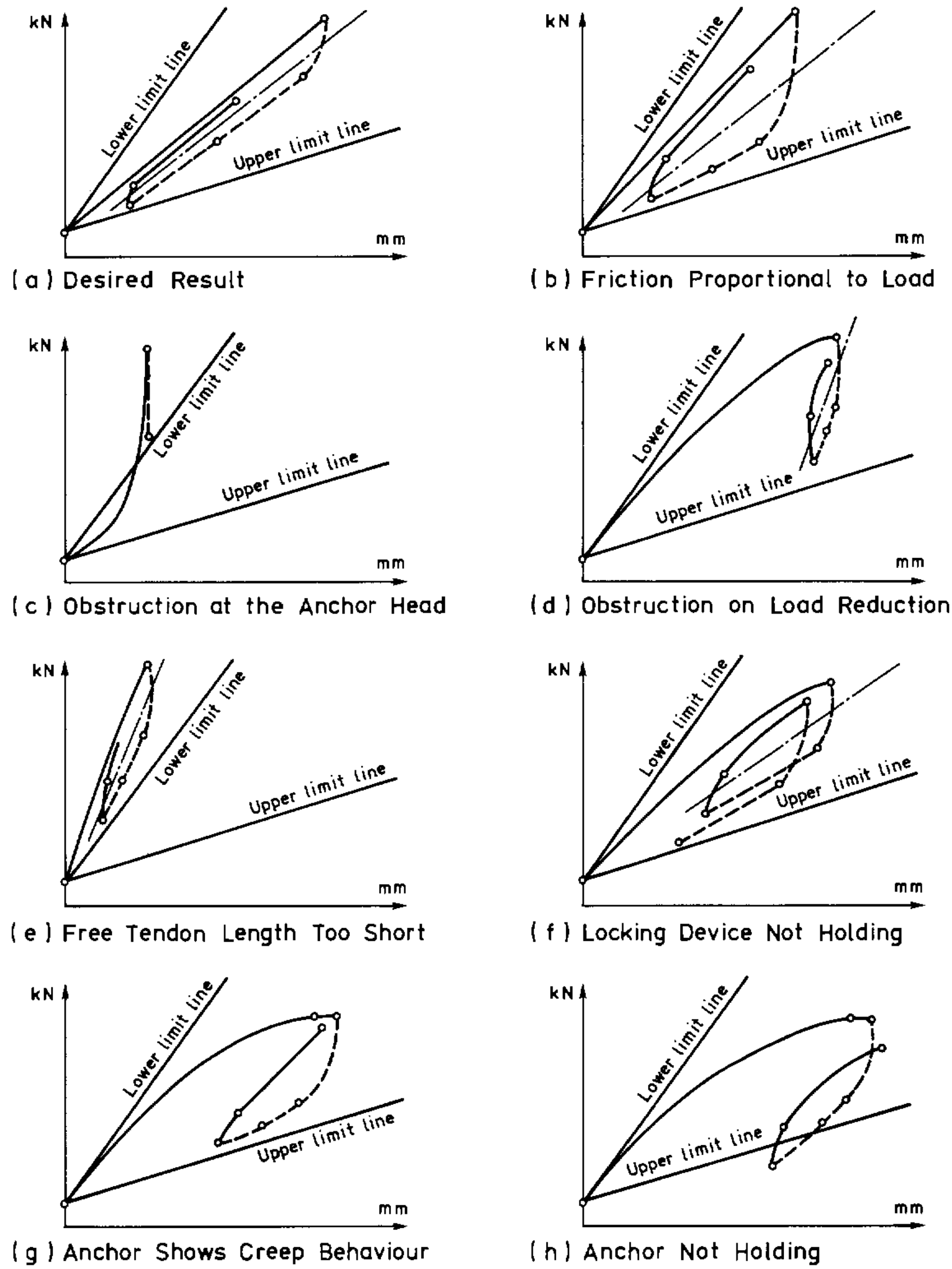
Figure A1 - Typical Ground Anchor Arrangements




Notes : (1) A load increment shall lie between 10% and 16% $T_p$, see Section A.15.2 for additional explanation.

(2) Relative accuracy is defined as $\frac{d_2 - d_1}{X_T} \times 100\%$.

Figure A2 - Diagrammatic Representation of the Specified Limits of Measuring Accuracy

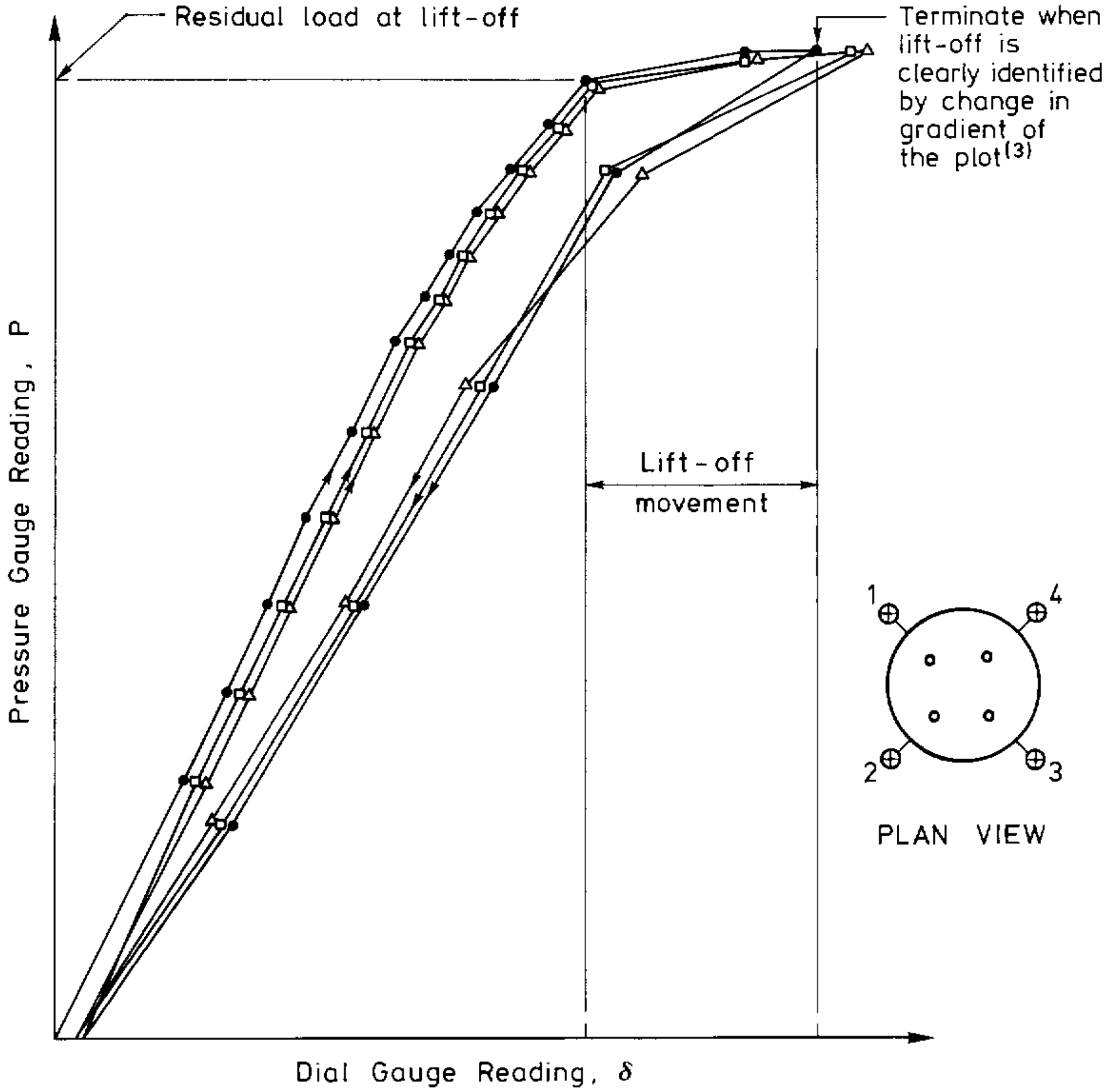



Legend :

——— Load is increasing  – – – – – Load is reducing  —·— Zero friction line

Note : Figure based on Martak (1979). See also Appendix A.15.4 (d).

Figure A3 - Typical Load : Extension Graphs




Legend :

- ●—● Loading cycle no. 1
- □—□ Loading cycle no. 2
- △—△ Loading cycle no. 3
- ⊗ Positions of dial gauges
- o Strands at anchor head

Notes :

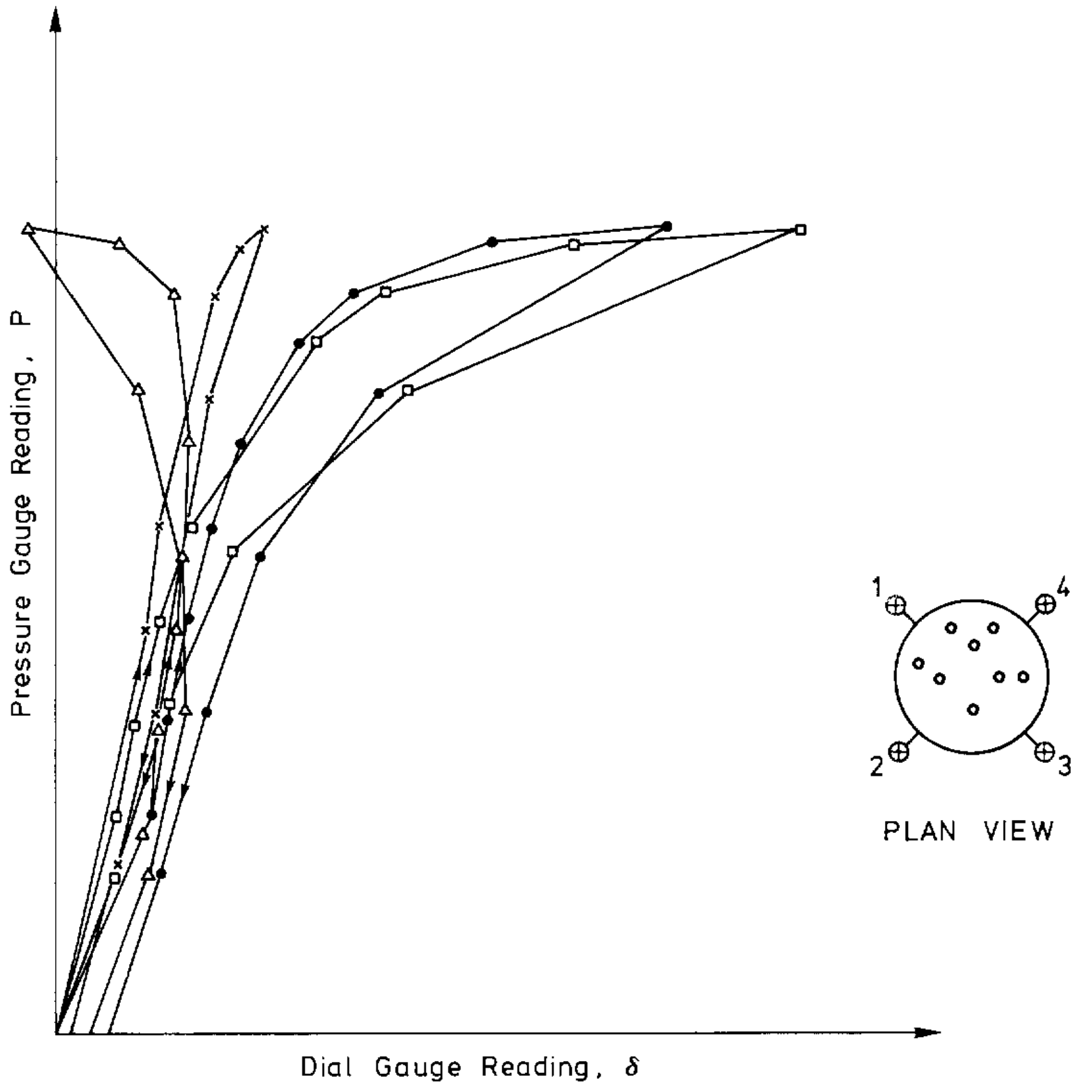
(1) Dial gauge reading, $\delta$ is the average of the four dial gauge readings.

(2) The residual load is depicted by a sudden change in the gradient of the plot of dial gauge versus pressure gauge readings.

(3) In no case should the lift-off movement exceed the equivalent extension required to increase the tendon load by more than 1% (see Section A.16).

(4) The above data are obtained from anchor monitoring by Housing Department.

Figure A4 - Typical Load : Average Anchor Head Movement Graph for Lift-off Test




Legend :

—△——△— Reading of dial gauge no. 1
—●——●— Reading of dial gauge no. 2
—□——□— Reading of dial gauge no. 3
—×——×— Reading of dial gauge no. 4
⊗ Positions of dial gauges
∘ Strands at anchor head

Note : The above data are obtoined from anchor monitoring by Housing Department.

Figure A5 - Typical Load : Anchor Head Movement Graph for Lift-off Test for Asymmetrical Tendon Arrangement

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# APPENDIX B

## PRIOR APPROVAL SYSTEM

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## B.1 INTRODUCTION

Permanent prestressed ground anchors require the Prior Approval of the Director of Civil Engineering Services (DCE) before they are used in Government projects. The Prior Approval System will also facilitate the approval of ground anchors for use in private projects. Under the Prior Approval System for Permanent Prestressed Ground Anchors (PASA), DCE issues a Letter of Prior Approval for an anchor system that meets the requirements of this Appendix. In connection with the PASA, a new category for permanent ground anchors has been introduced into the Hong Kong Government Lands and Works List of Approved Suppliers of Materials and Specialist Contractors for Public Works.

An anchor system shall be assessed by DCE on the basis of a submission made by the authorized Agent. The submission shall be in accordance with the details listed below, which may be amended or added to from time to time. Where such amendments or additions become necessary, the Agent will be notified, and he will be required to seek a new Prior Approval within one month, by submitting the details or information sought in the notification letter. All submissions and correspondence shall be in English, and technical data shall be in SI units.

## B.2 DETAILS OF SUBMISSIONS

### B.2.1 Preliminary Submission

A preliminary submission of an anchor system is required from the Hong Kong based fully authorized Agent of the Principal of the anchor system. This submission shall include :

(a) evidence of authorization from the Principal's Head Office,

(b) evidence that the anchor system has been successfully used, and details of major works undertaken,

(c) any relevant national certificates of approval, and

(d) the name(s) of the Anchor Contractor(s) authorized by the Agent to install the anchor system.

### B.2.2 Final Submission

If a preliminary submission is accepted, the applicant will be informed by letter, upon receipt of which a final submission can be made. The final submission shall contain the following items :

(a) Drawings.

Full engineering drawings, showing all the assembled parts of the system, including longitudinal and transverse sections and enlargements, showing details where appropriate.

All linework and writing on drawings shall be clear and legible. Drawings shall be to such a scale that the characteristics of the components are clearly apparent; normally, a scale of 1 : 5 or larger shall be used, with enlargements at full scale or larger. The maximum size of drawing sheet acceptable is A1 size.

(b) Specifications.

Component lists, referenced to the Drawings and giving the following details, in tabular form :

(i) component no.,
(ii) component name,
(iii) place of manufacture,
(iv) material,
(v) surface coating or finish,
(vi) dimensional tolerances,
(vii) material standard, and
(viii) relevant test certificates.

(c) Report.

A report describing the features of the anchor system and the conditions for which its use is appropriate. For instance, the effect of an axial compressive load on the corrosion protection system should be covered.

(d) Operating Manual.

An operating manual for the system, detailing the manufacturer's recommended procedures for storage, transportation, installation, stressing, testing, monitoring, destressing and special maintenance requirements.

(e) Information on Agent's Storage.

A statement, in general terms, from the Agent on his intended level of inventory and where it is to be stored, together with an undertaking that the stored items will be properly protected against damage or improper handling.

(f) Information on Anchor Contractor(s).

The name(s) and address(es) of the Anchor Contractor(s) authorized by the Agent to install the anchors, together with evidence demonstrating that they are adequately experienced in installing the anchor system.

If any of the above information is not included or is not properly presented, the applicant will be informed in writing of the shortcoming and will be given the opportunity to make a further application.

### B.2.3 Anchor System Inspection and Testing

An applicant shall be prepared, on request, to make available any components of the anchor system for inspection and/or testing.

At his absolute discretion, DCE may call for a full-scale demonstration of the anchor system as part of the assessment process. The applicant shall be prepared to arrange, at his own expense, a full-scale demonstration of an anchor, including installation, stressing, testing and exhumation for examination.

## B.3 REQUIREMENTS FOR APPROVAL

In considering applications for Prior Approval, DCE applies the following general requirements :

(a) The anchor system shall be internationally proven and accepted.

(b) There shall be an established Agent of the Principal in Hong Kong who shall be capable of ensuring adequate supplies of all components and spare parts and that the anchors are installed to a high standard, including the provision of advice in the event of unforeseen difficulties at any time during a contract.

(c) There shall be Anchor Contractors authorized by the Agent who shall be capable of installing the anchors and of satisfactorily carrying out the stressing and testing required.

(d) The anchor system shall comply with all relevant requirements of this Model Specification for Prestressed Ground Anchors.

(e) The corrosion protection of the anchor system shall comply with the corrosion protection guidelines given in Section B.6.

## B.4 APPROVAL

Should DCE approve the submission or part thereof, the applicant shall be notified by a Letter of Prior Approval, which will state any conditions relating to such Approval. This shall give general approval for the Approved Anchor System and specific approval for Approved Anchor Types within that Approved Anchor System to be used as permanent ground anchors. It shall also name the Anchor Contractor(s) authorized by the Agent and accepted under the terms of the Prior Approval System to install the system (Nominated Anchor Contractor(s)), and shall specify any limitations that are to be observed.

The Letter of Prior Approval and the submission to which it refers shall together constitute and be referred to as the Prior Approval Documents pertaining to the Approved Anchor System.

Any amendment to the Approved Anchor System or Approved Anchor Type shall require approval in accordance with the above procedure before it can be adopted. Only those items relevant to the proposed amendment need be submitted, together with a clear description of how the change will affect the Approved Anchor System. DCE shall be informed of such changes or any change in Agent or Nominated Anchor Contractor, within a period of one week of the change.

At any time after Prior Approval, DCE may call for further information or demonstrations of the Approved Anchor System to resolve problems which have become apparent.

At his absolute discretion, DCE may withdraw approval of an Approved Anchor System or Approved Anchor Type at any time.

All costs relating to the preparation of the submission and any demonstrations of the anchor system shall be the responsibility of the applicant.

## B.5 REVIEW

All Prior Approvals shall be subject to review by DCE at any time.

## B.6 CORROSION PROTECTION FOR PERMANENT GROUND ANCHORS

### B.6.1 Introduction

Corrosion protection systems for permanent ground anchors vary in both their construction and materials used. For this reason, detailed requirements for permanent anchors are deliberately not given in the Model Specification for Prestressed Ground Anchors. During the Prior Approval process, an anchor system is assessed on its own merits against broadly stated guidelines. These guidelines are given below, but will be developed and refined as experience dictates.

### B.6.2 Level of Protection

An important distinguishing factor between temporary and permanent anchors is that permanent anchors must incorporate a high level of corrosion protection. The first requirement of any anchor system submitted for Prior Approval, therefore, is that it should have adequate corrosion protection. This is usually judged in terms of the number and type of layers of corrosion protection (effective physical barriers to corrosion) provided, taking into consideration the ground conditions likely to be encountered.

The requirements for corrosion protection are different in the fixed length, the free length and in the anchor head. The protection usually consists of a combination of waterproof sheaths, grout (or an equivalent barrier) and grease. A grout layer is considered an acceptable barrier provided any cracking which occurs during stressing does not render it ineffective in preventing corrosion.

In the fixed length, a suitable sheath surrounding the tendon constitutes an acceptable corrosion barrier. An effective grout layer, as described above, is also acceptable as a corrosion barrier.

In the free length, the corrosion protection usually consists of a sheath surrounding the greased strand or bar and a layer of grout which encases the sheath. The purpose of the grease is to provide lubrication to reduce friction between the strand and the sheath, and it also forms part of the corrosion protection system, in that it prevents contact between the atmosphere and the tendon surface and creates the correct electrochemical environment. However, this grease is not considered to be one of the permanent physical barriers protecting the free length in a corrosion protection system, because it cannot be assumed with confidence that it will not dry out or leak in time. In some bar systems, a first layer of corrosion protection in the free length consists of a sheath with the gap between the sheath and the bar filled with grout. Another layer of protection is provided by a second sheath which surrounds the first layer and prevents any bond developing between the encapsulated bar and the outer sidewall layer of grout. In some systems, the gap between the two sheaths is filled with grease.

In the head, where any sheath on the strand or bar must be removed to allow locking-off by wedges or a nut, grease is acceptable as a corrosion protection layer, because it can be checked and replaced. The grease must be contained by separate means on each side of the anchor base plate, usually by a trumpet tube arrangement below the plate and by a protection cap above. These containers form a second outer protection layer. The provision of effective seals in these containers is of vital importance to prevent loss of grease or ingress of water, and they are therefore a part of the outer protection layer.

Some anchor systems provide increased levels of protection to those described above.

### B.6.3 General Requirements for Corrosion Protection Systems

The general requirements (not exhaustive) for a protection system are:

(a) It should consist of robust, mutually compatible components which will withstand (without damage) handling, transportation, storage, installation and, where appropriate, an aggressive environment.

(b) It should be such that the permanent and non-replaceable components are sufficiently durable not to degrade within the anchor's service life.

(c) It should be provided with a telescopic section and/or trumpet (as appropriate) which will sustain compressive stresses, without significant damage to the anchor or its corrosion protection.

(d) It should not restrict the movement of the free length of the tendon or prevent the anchor from being monitored.

(e) It should be designed to avoid the formation of voids which can lead to corrosion.

(f) It should be provided with a protective cap at the anchor head to prevent the ingress of fluids.