

FOUNDATION TESTING

**Working Group 07
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FOUNDATION TESTING

Working Group 22.07 (Foundations)

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CIGRE
STUDY COMMITTEE 22
WORKING GROUP 07
FOUNDATION TESTING

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CIGRE SC22 WG07

FOUNDATION TESTING

PREFACE

In 1989, Working Group 07 "Foundations" of CIGRE SC22 decided to form a task force to establish general ideas and guidelines for the testing of overhead line tower foundations. The task force consisted of:

N. R. Cuer	UK
P. Dallèves	CH
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One year later, Technical Committee 11 of IEC voted to carry out similar activities and founded a special working group, WG10. TC11 intended to use the study performed by CIGRE as a basis for the proposed IEC recommendations. In order to co-ordinate these projects, joint meetings of WG07 of CIGRE SC22 and WG10 of IEC TC11 were held during 1991 and 1992.

During the preparation of this report, WG07 comprised the following members:

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FOUNDATION TESTING

I. INTRODUCTION

1.1 General

The techniques outlined in this guide apply to foundation testing for overhead transmission line towers and pole structures. They are also applicable to telecommunication towers. The following modes of applied loadings are considered:

- (a) axial (vertical), either in uplift or compression;
- (b) lateral (horizontal) shear, including those which give rise to high overturning moments;
- (c) combined axial and lateral loads.

Only static monocytle or multicytle loadings are considered in this guide. In this context a cycle is defined as a complete loading stage from an unloaded state, through a series of load increments and back to an unloaded state.

Dynamic tests, multicytle high frequency loading with rapid applications of the load cycle and the special tests required in areas of seismic activity to ensure stability against liquefaction and flow slide conditions on piled or drilled shaft foundations are excluded from this guide.

These criteria relate to lattice towers with typical individual footings, i.e. concrete pyramid or pad and chimney foundations, steel grillages, drilled shaft or auger or caisson foundations, piles and grouted anchors and pole structures, H-framed structures or narrow based lattice towers with typical monofoundations, i.e. concrete blocks, drilled shaft or auger or caisson foundations and piles.

In this report, foundation testing is defined as the load carrying capacity of the total foundation as an interaction between the foundation itself and the surrounding soil and/or rock. The mechanical strength of the structural components is not within the scope of this report. However, in the case of grouted anchors, failure of structural components may predominate.

During testing of foundations, axial loads are normally applied as uplift forces. However, the criteria given are also valid for compression loading.

1. INTRODUCTION (continued)

1.2 Categories of Tests

With respect to the purpose of the test, the level of investigation and the method of execution, the following categories of foundation tests are defined.

1.2.1 Research Tests

Research tests are undertaken on foundations which are specifically installed in order to evaluate one or more of the following aspects:

- (a) the development of new or the refinement of presently available design parameters or methodologies by comparison with actual behaviour (load carrying and displacement);
- (b) the determination of constituent parts of the foundation resistance;
- (c) the evaluation of in-situ and laboratory tests;
- (d) the development of construction/installation techniques;
- (e) the evaluation of inspection and quality assurance procedures.

Research tests are normally executed up to failure without any limitations on the displacements. The level of instrumentation and investigation required is high and has to be designed according to the purpose of the test.

Because of the specialist nature of these tests, no recommendations are given with regard to test procedure or test evaluation. However, the recommendations relating to data collection and recording should wherever possible be adhered to.

1.2.2 Design Tests

Design tests are undertaken on specially installed foundations either:

- (a) for the verification of design parameters or methodologies;
- (b) to establish geotechnical design parameters and a design methodology for a specific application;
- (c) for the verification of construction procedures.

When tests are undertaken to verify contract design parameters, the test foundation should be identical to those proposed for the contract, subject to the criteria given in clause 3.1.

In the case of large diameter drilled shaft, auger, caisson or piled foundations (e.g. diameters in excess of 1.0m), it is often impractical to undertake design tests on a full size foundation. Design tests on smaller diameter test foundations may be considered subject to the following conditions [1]:

1. INTRODUCTION (continued)

- i) The ratio of the test foundation diameter to production foundation diameter is not less than 0.5.
- ii) The test foundation is installed using exactly the same techniques and materials as the production foundation.
- iii) Where necessary, the test foundation is instrumented in such a manner that the base and shaft resistances can be derived separately.

Tests are normally undertaken to a specific percentage (normally not less than 100%) of the design load or to the damage limit. Limitations of displacement should be considered where applicable. The level of instrumentation and investigation is adjusted to suit the purpose of the test. For the establishment of geotechnical design parameters, it may be necessary to take the test to failure.

Note: In this context, the design load means the ultimate load or factored working load or the load derived with respect to a specific return period of a climatic event. The damage limit is an arbitrary value selected on the load-displacement curve.

1.2.3 Routine/Proof Tests

Routine/proof tests are undertaken on as-built production foundations either to ensure that the foundation is correctly installed or that there are no major variations in the assumed geotechnical design parameters. Additional routine tests are carried out on foundations installed in heterogeneous soil conditions where a wide variation in the foundation resistance could be expected.

Tests are normally undertaken to a specific percentage (less than 100%) of the design load. Limitations of the displacement must be considered. The level of instrumentation and investigation is low but must be reliable. The foundation should be fully serviceable after testing.

Note: the specific percentage of the design load should relate either to the unfactored working load or the load derived with respect to a lesser return period of the climatic event.

1.3 Number of Tests

The number of tests undertaken will be dependent upon the following factors.

- (a) Type of test, i.e. design or routine/proof.
- (b) Significant variations in geotechnical parameters along the transmission line route.
- (c) Specific contract or national standard/code of practice requirements.
- (d) Proposed method of analytical review of the test results.

1. INTRODUCTION (continued)

Wherever possible, statistical techniques should be used to evaluate the test results, especially if the characteristic strength of the foundation is required, e.g. IEC 826 [2]. By such means, the results from two identical foundation tests in similar soil conditions under the same test loading regime can be analysed, particularly if the student's 't' method developed by Gosset [3] is adopted as the probability distribution. For a comparison between the student's 't' and normal probability distribution, see Appendix D.

The number of routine tests performed is normally related to either a fixed percentage, e.g. 5% of the total number of that type of foundation installed, or alternatively as a specific number per route kilometre of transmission line with a minimum requirement, unless they are specifically undertaken for geotechnical reasons.

1.4 Data Collection

To ensure that the data derived from the foundation test can be readily assimilated, it is of paramount importance that the tests are carried out in a systematic manner and all information is accurately recorded, especially the as-built dimensions of the foundations.

1.5 Agreement

The following points, where appropriate, should be agreed by all parties to the test prior to commencement of the overall test programme:

- (a) variations from the techniques given in these testing procedures;
- (b) method of conducting the ground investigations;
- (c) extent of contract foundation installation details to be recorded when subject to routine/proof tests;
- (d) any modifications or strengthening required to the stub steelwork or reinforcement for connection to the test apparatus for a design test on a production foundation;
- (e) acceptance criteria.

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1. INTRODUCTION (continued)

1.6 Safety

The design, erection and dismantling of the foundation test system and the application of load shall be undertaken in accordance with any statutory or regulatory requirements, especially if it is proposed to use mobile cranes to apply the test load to the foundations.

In the course of carrying out a test, should any unforeseen occurrences take place, further loading should not be applied until a proper engineering assessment of the condition has been made and steps have been taken to rectify any fault. Readings of gauges should however be continued where possible and when it is safe to do so.

All equipment used should be clearly marked with their safe working load capacity.

Where hydraulic jacks are used, the maximum test load expressed as a reading on the pressure gauge shall be clearly displayed and all operatives made aware of the limit.

2. GROUND DATA FOR TEST FOUNDATION SITES

2.1 General

Procedures for the actual ground investigation are outside the scope of these recommendations and reference should be made to an acceptable national standard, e.g:

BS 5930 [4]
ASTM D1452 [5]
DIN 4022 [6]
DIN VDE 0210 [7]

Details of the contractual requirements for a ground investigation are given in ICE Specification for Ground Investigation [8]. However, it has been assumed that an initial ground investigation will have been undertaken prior to the selection of a research test site and should, if possible, have been undertaken prior to the selection of a design test site.

2.2 Extent of Exploration

The scope and extent of the ground investigations will be dependent upon the purpose of the test and hence the test category. Geotechnical design parameters can be determined from in-situ tests, laboratory tests or be based on approximate values derived from empirical correlations. In certain conditions, a pre-construction ground investigation could be dispensed with, either where the geotechnical design parameters are based on the data derived at the time of installation of the test foundation, i.e. rock anchors, or where routine/proof tests are used to check installation criteria.

For research tests, an extensive ground investigation must be performed. The investigation should include in-situ and laboratory tests conducted on undisturbed samples, if possible. The exact details of the investigation will depend on the purpose and scope of the research programme.

For design tests, and where possible for routine/proof tests, the minimum level of ground investigation should be a visual-tactile examination of the soil, either from a trial pit or during the excavation of the foundation, using an appropriate national standard, e.g. ASTM D2488 [9].

If possible, the following additional tests should be undertaken:

- (a) Non-cohesive soils: auger boring with split-barrel standard penetration sampler for the recovery of disturbed samples, in conjunction with standard penetration tests (SPTs). If disturbed samples are taken directly from auger borings, these should be recovered from the base of the borehole.

Alternatively, cone penetration tests (CPTs) or pressure meter tests (PMTs) could be used in the absence of a large gravel content. If CPTs are used with continuous readings, the number of samples could be reduced.

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2. GROUND DATA FOR TEST FOUNDATION SITES (continued)

- (b) Cohesive soils: as for non-cohesive soils except that the use of SPTs in clay soils should be treated with caution. Alternatively, vane shear tests (VSTs) could be used in fairly uniform, fully saturated soils.
- (c) Rock: for weak rock, core drilling in conjunction with SPTs; for medium or hard rock, core drilling and visual examination of the recovered core. Alternatively, PMTs could be used.

If it is proposed to use alternative ground investigation techniques for production foundations compared to the test site (i.e. dynamic cone penetrometer), these alternative techniques should be calibrated at the test site.

2.3 Ground Investigation Criteria

- (a) Ground investigation should be undertaken as near as possible to the test foundation so that the investigation is representative of the soil at the test site and takes account of the theoretical failure surface of the foundation.
- (b) Time lapse between the ground investigation and foundation test should be kept to the minimum if there is a noticeable effect on the geotechnical properties due to rainfall or seasonal variations in the groundwater level.
- (c) Depth of investigation for uplift, lateral or combined uplift/lateral tests should not be less than 1m below the base of the test foundation.
- (d) Depth of investigation for compressive tests should be either:
 - (i) the foundation depth plus 1.5 x the maximum base width dimension for concrete pad and chimney or steel grillage foundations; or
 - (ii) 3m or 5 shaft diameters (whichever is the greater) below the foundation depth for drilled shaft, auger, caisson or piled foundations; or
 - (iii) at least 2m into rock or a hard dense stratum ($N_{SPT} > 50$) if this occurs before the recommended depth.
- (e) SPTs should be undertaken at the top of each stratum and then at 1m intervals in soil or weak rock.
- (f) PMTs should be undertaken in each stratum or as required.
- (g) CPTs should be taken continuously over depth of investigation.
- (h) VSTs should be undertaken at top of each stratum and then at 1m intervals.

2. GROUND DATA FOR TEST FOUNDATION SITES (continued)

- (j) Soil/rock description should be based on disturbed samples taken in each stratum and thereafter at 1m intervals. Soil/rock description should be in accordance with an acceptable national standard.
- (k) Highest ground water level and variation in water level.

2.4 Soil Classification and Strength

- (a) Soil classification and strength may be based upon a visual-tactile examination of disturbed soil samples.
- (b) Soil strength may be based upon empirical correlations from in-situ tests, i.e. SPTs, CPTs, VSTs and PMTs.
- (c) Soil classification may be based upon laboratory tests on disturbed samples, i.e:

Non-Cohesive

Particle size distribution
Moisture content
Relative density

Cohesive

Moisture content
Atterberg limit

- (d) Soil strength may be based upon laboratory tests on undisturbed samples. If samples with a degree of disturbance are used for strength tests, the results of such tests should be treated with caution.

Non-Cohesive

Direct shear box (immediate)
Bulk density

Cohesive

Unconfined compressive strength
Laboratory vane shear
Triaxial compression (undrained)
Bulk density

Laboratory tests should be undertaken in accordance with acceptable national standards, e.g. BS 1377 [10], ASTM D2487 [11].

For routine/proof tests, soil classification and empirical correlation of strength as in (a) and (b) above would be acceptable.

2. GROUND DATA FOR TEST FOUNDATION SITES (continued)

2.5 Exploration in Rock

For exploration in rock where there are no universally accepted rock classifications that correlate with the engineering properties of the rock mass, the following data should, where possible, be included in the results of the investigation:

- (a) Rock type and hardness - rock type description should be based on accepted national standard terminology.
- (b) Results of SPTs.
- (c) Extent and character of weathering.
- (d) Extent and distribution of solution channels in soluble rocks.
- (e) Discontinuities, i.e. bedding planes, faults and joints.
- (f) Cleavage.
- (g) Rock quality designation (RQD).

Points (c) to (f) would normally be based upon visual inspection and reference should be made to the appropriate national standard for standardisation of terminology.

RQD is defined as the modified core recovery percentage in which all pieces of sound core over 100mm are counted as recovered.

2.6 Ground Investigation Results

The results of the ground investigation and any subsequent laboratory testing should be recorded as shown in Appendix B, Table B1, together with a sketch plan of the site showing all pertinent physical and geological features. (See also clause 6.6.)

2.7 Geotechnical Design Parameters

The geotechnical parameters used in the design of the test foundation, together with the method of calculating these values (either from laboratory tests or empirical correlations), should be stated in the test report. (See also clause 6.6.)

2. GROUND DATA FOR TEST FOUNDATION SITES (continued)

2.8 Ground and Environmental Conditions During Foundation Installation

During the installation of any test foundation, the following information should be recorded wherever practical as a further correlation with the ground investigation (see also clause 6.6):

- (a) Visual-tactile description of soil/rock strata and corresponding soil/rock classification.
- (b) Ground water level.
- (c) Any local soil/rock phenomenon during construction, i.e. side instability, bottom heave, water ingress, weathering, discontinuities.
- (d) Dimensions of as-built foundations - see clause 3.2 and Appendix B, Tables B2 to B6.
- (e) Meteorological data.

If the foundations are backfilled, the geotechnical properties, including moisture content, of the backfill should be established by using field density tests and/or SPIs or a hand-held penetrometer. Details of the method of backfilling, e.g. depth of layers, compaction equipment used and number of passes, should be recorded.

3. FOUNDATION INSTALLATION

3.1 General

The test foundation should be installed strictly in accordance with the design requirements as far as dimensions and materials are concerned. It may however be necessary to modify either the stub or the reinforcing to provide an adequate and safe connection to the test apparatus. This connection should have a minimum ultimate design capacity of 1.5 times the maximum test load for design tests. However, any such modification shall not intrinsically alter the basic design characteristics of the foundation, e.g. the lateral stiffness of long slender piles.

Where for ease of testing under axial uplift or compression loading, the foundation is installed vertically as opposed to its true leg slope (hip slope, see Figure 1), this variation should be limited to foundations with a true leg slope of less than 1:5. Otherwise, all foundations should be tested with the foundation installed at the correct leg or guy slope.

Due cognisance should always be taken of any variation between the resultant design load vector to the vertical axis of the production foundation and of the resultant test load vector to the vertical axis of the test foundation.

The techniques used for the installation of the test foundations should, where possible, be as close as possible to those techniques it is intended to use on production foundations.

Where the cut-off level of the production foundation is normally below ground level, e.g. a pile set into a pile cap, but the test foundation is extended to ground level for ease of testing, the following measures should be taken:

- (a) either an allowance should be made in the test load for the soil interaction over the extended portion; or
- (b) the extended portion should be sleeved or otherwise protected to substantially reduce the soil foundation interaction.

Note: the above measures are only suitable when axial loads are applied.

3.2 Installation Records

All relevant details of foundation size, construction and installation details should be recorded in the format given in Appendix B, Tables B2 to B6. Although it is of paramount importance that as-installed foundation dimensions are accurately recorded, if necessary with an appropriate sketch, agreement on the details required for contract foundations for routine/proof tests should be made between all parties at the commencement of the contract. (See also clause 6.6.)

Where necessary, details of concrete additives or problems/delays in installation, especially concreting, together with all pertinent meteorological data which could affect the test results, should be recorded in the remark sections of the tables.

3. FOUNDATION INSTALLATION (continued)

3.3 Minimum Allowed Times Between Installation and Testing

The test foundation should not normally be tested until the following typical times have elapsed after installation, thereby ensuring adequate concrete or grout strength or to permit reasonable reduction or increase in the strength related properties of the ground.

The typical times are:

	<u>Days</u>
Steel grillages (after backfilling)	1
Concrete parts of a foundation	14 (*)
Grouted anchors (after grouting)	7 (*)
Driven piles in non-cohesive soils (after driving)	7
Driven piles in cohesive soils (after driving)	21 (+)
Drilled shafts or drilled piles in cohesive soils (after concreting)	14 (+)

(*) For routine/proof tests and for design tests if high strength concrete is used, a shorter elapse of time may be allowed, provided the concrete/grout strength test results have obtained a value twice that of the concrete stresses imposed during the test. For non-reinforced concrete a longer elapse time, e.g. 28 days, may be required.

(+) For foundations in cohesive soils, the time lapse between installation and testing is dependent upon the pore water dissipation, the load capacity of the foundation generally increasing with time after installation. Both the magnitude of the strength gain and the rate of gain will depend on the soil and foundation type and the method of installation. Ideally, where time-dependent load behaviour is expected, the delay between installation and testing should be approximately equivalent to the time lapse of the production foundation. Delays of greater than 28 days are uncommon [12].

If there is any doubt on the method of placing concrete in drilled shaft or piled foundations, a non-destructive integrity test, e.g. sonic-echo testing, should be undertaken prior to any test load application.

4. TEST EQUIPMENT

4.1 General

Although the exact arrangement of the test equipment will depend both on the test category and the mode of the applied loading (i.e. vertical or lateral), the constituent items of test equipment and their required degree of accuracy will remain unchanged.

This section of the guide is correspondingly divided into recommendations related to individual items of test equipment whilst the following section describes preferred test arrangements.

4.2 Calibration

All measuring equipment should have a valid calibration certificate before the commencement of any test.

4.3 Load Application and Measurement

4.3.1 Hydraulic Jack & Pressure Gauge

Hydraulic jacks should have a minimum stroke for design tests of either 100mm or 10% of the drilled shaft/pile shaft diameter and 50mm for a proof/routine test. This is applicable for both uplift/compression and lateral tests.

The jack capacity should not be less than 25% but preferably 50% in excess of the maximum expected test load for design tests and not less than 10% but preferably 25% for routine/proof tests.

Calibration of the jack and the associated pressure gauge should be undertaken as a single unit, to an accuracy of not less than 5% of the applied load. The jack should be calibrated over its complete range of piston travel for increasing and decreasing loads [13].

All equipment to be operated under hydraulic pressure (i.e. jack, pump, hoses and couplings) should be capable of withstanding without leaking a minimum pressure of 1.5 times the maximum expected pressure in the test [14]. Care should be taken when using motorised pumps since there is not inherent warning of the onset of the foundation failure.

4.3.2 Test Loading Beam/Frame

If test loading beams or frames are used in the application of the test load, they should possess an adequate structural stiffness and a minimum ultimate design capacity equivalent to 1.5 times the maximum expected test load. These recommendations also apply to pole structures used in the application of high overturning moments to drilled shaft foundations.

4. TEST EQUIPMENT (continued)

4.3.3 Electrical Resistance Dynamometers

Electrical resistance dynamometers should have a capacity not less than 25% but preferably 50% in excess of the maximum anticipated test load. Adequate precautions shall be taken to ensure that there is no major variation in their accuracy due to moisture, lead wire lengths, connections and temperature changes.

Calibration of the dynamometers should be undertaken to an accuracy within 5% of the applied load. Alternatively, mechanical or hydraulic dynamometers may be used, with a similar degree of accuracy.

4.4 Displacement Measurement

4.4.1 Reference Beam

The reference beam for measuring foundation displacement should comply with the following requirements:

- (a) The beam should be sufficiently stiff to support the instrumentation without excessive deflection. If more than one beam is used, they should be cross-connected to provide additional rigidity.
- (b) The minimum distance between the reference beam supports and the vertical centre line of the test foundation should not be less than the values quoted in clause 5.5. In addition, the reference beam support should be a minimum of 1.0m from the nearest edge of any reaction system supports (see Figure 3) [15].
- (c) The depth of the reference beam supports should not be less than 0.5m, dependent on the soil or rock type. However, in compressible soils, e.g. soft clays, the support should be sleeved such that the support is not in contact with the compressible soil.
- (d) To minimise temperature effects, the use of either a wooden reference beam or steel reference beam supported on rollers at one end is recommended. In the latter case, the free end should be effectively restrained against lateral and vertical movement.

4.4.2 Primary Foundation Displacement

Primary foundation displacement, either vertically or laterally, should be measured using either mechanical dial gauges or linear variable differential transformers (LVDT) or potential displacement transducers (PDT) and should comply with the following requirements.

4. TEST EQUIPMENT (continued)

(a) Mechanical dial gauges

- (i) Minimum resolution 0.1mm but preferably 0.01mm.
- (ii) Minimum range of travel 50mm but preferably 150mm.
- (iii) Dial gauge either rigidly attached to reference beam or on lugs attached to the test foundation with the plunger bearing on a smooth surface.
- (iv) The dial gauge should preferably be clamped in such a manner that the plunger expands as the load is applied.
- (v) The smooth bearing surface for the plunger should be either fixed to the test foundation or form part of the reference beam.

(b) LVDT/PDT

- (i) LVDT's and PDT's should be calibrated prior to use, with the calibration within the linear range of the device and within the range of measurement proposed.
- (ii) Resolution, travel and connection details as for the mechanical dial gauges.

4.4.3 Secondary Foundation Displacement

All primary foundation displacement measurements should be checked/controlled using the secondary measuring system described below:

- (a) Optical or electronic level with a fixed benchmark and a scale rigidly attached either to the foundation or foundation steelwork.
- (b) Minimum resolution 0.5mm.
- (c) Minimum distance of level and benchmark from centre line of test foundation or reaction system 10m.

4.4.4 Foundation Inclination (Rotation)

The inclination of the top of the foundation can be measured indirectly by:

- (a) The difference in readings between two vertical dial gauges/LVDT's in line with the horizontal test load; or
- (b) A horizontal dial gauge/LVDT bearing against a vertical rigid steel extension member attached to or embedded in the test foundation. The steel extension member should be aligned with the load application and project vertically 600mm above the top of the foundation. The dial gauge is attached to a reference beam in the normal manner [16]. Dial gauges or LVDT's should be in accordance with the requirements of Clause 4.4.2.

4. TEST EQUIPMENT (continued)

Alternatively, the inclination of the foundation can be measured directly using inclinometers. These should have an accuracy of +/- 0.1 degrees.

4.4.5 Soil Displacement

Ground surface vertical displacement should be measured as detailed below:

- (a) Ground surface displacement should be monitored by the movement of either timber stakes or steel reinforcing rods driven into the ground with a suitable scale securely attached. To facilitate ease of reading, all scales should be set to the same level. The displacements should then be read using an optical level or theodolite as detailed in clause 4.4.3.
- (b) If details of the subsurface displacement are required, the method described in ERA Report 5054 [17] may be adopted.

4.4.6 Subsurface Foundation Displacement

If details of the subsurface foundation displacement are required for pyramid, pad and chimney or grillage or concrete block foundations, one of the following methods may be adopted.

- (a) A loose cone-shaped tip is fitted to the end of a 20mm diameter steel pipe. The pipe is then driven into the ground as carefully as possible to make sure it is in contact with the underlying foundation. A 10mm diameter steel rod is then installed inside the steel tube and the outer tube withdrawn sufficiently to ensure it does not interfere with any foundation displacement, with a suitable scale attached to the steel rod.
- (b) A 10mm diameter steel rod is vertically embedded into a corner of the pad or pyramid, projecting above the ground line, with a suitable scale attached. Although the type of backfill material will dictate whether or not the rod is sleeved, care should always be taken during backfilling.

The displacement should be read using an optical level or theodolite as detailed in clause 4.4.3.

For measurement of the displacement of the lower grouted section of soil anchors, a small diameter rod could be cast into the grout and sleeved through the upper part of the anchor. A suitable scale should be attached to the rod and displacement read using an optical level, as detailed in clause 4.4.3.

5. TEST ARRANGEMENTS

5.1 General

The actual arrangement of the test equipment is dependent upon both the type of test (whether design or proof/routine) and the mode of the applied load. Although preferred test arrangements are described below, alternative methods may be used provided they are structurally safe, apply the load in the correct direction and any reaction system used does not have a significant effect on the results of the test.

5.2 Design Test - Uplift

Axial uplift loads for design tests, both monocyclus and multicyclus, may be applied using any of the arrangements detailed below. For convenience, tests on grouted anchors are normally undertaken using a jack and test loading beam system. Tests on guy anchors are normally undertaken using a winch and A-frame arrangement.

For all design tests a minimum of three primary displacement measuring devices should be used, mounted equidistant from the test foundation vertical axis and from each other. If however only single grouted anchors or helical screw guy anchors are tested, a single primary measuring device would be acceptable. In this case, it would be preferable to use an optical measuring device and not a dial gauge to ensure that any errors in the displacement measurement due to misalignment between the test foundation axis and the applied load are minimised.

Secondary displacement measuring devices should always be used.

If practical, a second back-up load measuring device should be used as a cross check and replacement in case of malfunction of the primary device.

5.2.1 Hydraulic Jack - Test Loading Beam

A hydraulic jack is used in conjunction with test loading beam and reaction system (see Figure 3) with the jack coaxial with the test foundation testing axis. The jack is normally mounted on the top flange of the test beam. The test load is applied using either a centre-hole jack in conjunction with a high strength reinforcing rod grouted into the test foundation, or by a special load transfer framework bolted to the test foundation stub.

5.2.2 Hydraulic Jack - Fulcrum Beam

For this arrangement, the beam is centralised over the test foundation with one end of the test loading beam connected via a hinge arrangement to a reaction pad footing. The hydraulic jack is inserted under the test loading beam at the other end (see Figure 4). The load is applied to the test foundation by a connecting framework attached to the centre of the beam. The axis of the hydraulic jack should be parallel to that of the test foundation. The advantage of this method is that inclined foundations or foundations with raked stubs may be tested without modification.

5. TEST ARRANGEMENTS (continued)

5.2.3 Mobile Crane

A mobile crane with hydraulic transmission is used in conjunction with a dynamometer. The dynamometer should be inserted between the crane hook and the test foundation. The main difficulty with this type of arrangement is ensuring that the load application is coaxial with the foundation testing axis. Provided this can be achieved (within plus/minus 2 degrees), the test arrangement is quick and relatively easy to set up. Due to possible misalignment or relative moment between the test foundation axis and the applied load, an optical system of displacement measurement should be used.

5.2.4 A-Frame Tensioner System

For the testing of guy anchors, a convenient test arrangement is the use of an A-frame in conjunction with a tensioning device via single or multi lead wire rope rigging (see Figure 5). The rigging is supported by a pulley block suspended from the apex of the A-frame. The tensioner may either be a powered mobile winch or a hand tensioner (e.g. Tirfor) depending on the required test load or rigging arrangement.

The actual position of the A-frame and displaced position of the pulley block must be accurately calculated prior to the test to ensure the load application is coaxial with the test axis of the foundation. An electrical resistance dynamometer should be inserted between the test foundation and the winch bond. Due to possible misalignment or relative moment between the test foundation axis and the applied load, an optical system of displacement measurement should be used.

To ensure stability of the A-frame fore and aft guys should be fitted and suitably anchored. The tensioning device and rigging should have a minimum ultimate strength capacity of 1.5 times the maximum expected test load.

5.3 Routine/Proof Test - Uplift

Routine/Proof uplift tests should be undertaken using test arrangements similar to those detailed in clause 5.2. In most cases the use of an optical level to measure the production foundation displacement would be acceptable.

5.4 Design Tests - Compression

Axial compressive design tests are normally undertaken using a hydraulic jack and test loading beam arrangement. The test loading beam is usually anchored to either reaction piles or a grouted anchor system.

Primary and secondary foundation displacement measurement and minimum reaction distances are identical to those given in clause 5.2.

5. TEST ARRANGEMENTS (continued)

Note: it is not normal practice to undertake compressive routine/proof tests on foundations since uplift tests are usually critical. If checks on bearing capacity are required, it would be preferable to carry out plate bearing tests in accordance with an appropriate national standard or code of practice. (See clause 2.1.)

5.5 Minimum Distance between Test Foundation and Reaction Systems

5.5.1 Uplift and Compression Tests

The minimum distance between the vertical centre line of the test foundation and the nearest edge of the supports of any reaction system (e.g. test loading beam or A-frame for vertical load applications) should not be less than the values quoted below.

- (a) Pad and chimney or grillage or concrete block or short drilled shaft foundations:

$$L = 0.5e + 0.35a$$

- (b) Long drilled shaft, piled or rock anchor foundations:

$$L = 1.5e \text{ or } 1.0, \text{ whichever is greater}$$

where L = distance between centre line of test foundation and edge of reaction supports (in metres)

e = equivalent width/diameter of foundation (in metres)

a = depth of foundation (in metres)

See Figures 2 and 3.

Note: in this context, the definition of 'short' and 'long' depends on the relative stiffness of the drilled shaft/soil combination and should be determined using acceptable soil mechanics principles.

5.5.2 Lateral Tests

For lateral tests, the minimum distance between the vertical centre line of the test foundation and the nearest edge of the supports of any reaction system is dependent upon the method of load application. Reference should be made to the text for individual test arrangements.

5.5.3 Combined Tests

For combined uplift and lateral tests, the minimum distances should be based upon the requirements of clauses 5.5.1 and 5.5.2 according to the method of load application.

For further information regarding minimum distances, reference should be made to EPRI EL5915 [18].

5. TEST ARRANGEMENTS (continued)

5.6 Design Tests - Lateral

Lateral uni-directional loads for design tests, both monocycle and multicycle, may be applied using any of the arrangements detailed in clauses 5.6.1 to 5.6.4. For convenience these may be grouped into four distinct load application arrangements:

- (a) Where the lateral test load is applied as a compressive force to the foundations using a hydraulic jack in conjunction with a reaction arrangement (reference clauses 5.6.1 and 5.6.2).
- (b) Where the lateral test load is applied as a tensile force to the foundation using a tensioner system (reference clause 5.6.3).
- (c) Where two identical foundations are installed and either a compressive force is applied by a hydraulic jack or a tensile force is applied by a tensioner system between them.
- (d) Where the lateral test load is small but a high overturning moment is required for tests on mono-pole foundations, e.g. drilled shafts. In this instance the lateral load is normally applied via a pole-tensioner system (reference clause 5.6.4).

All bearing plates, struts or blocks used to transfer the test load, reaction arrangements, wire ropes, winches, etc., should have a minimum ultimate design capacity equivalent to 1.5 times the maximum test load and, where appropriate, an adequate structural stiffness.

The lateral test load, except for the pole-tensioner system, should be applied horizontally and aligned with the central vertical axis of the foundation to minimise eccentric loading and to avoid a vertical load component.

Where necessary, foundations should either be cast with a square face or test load transfer steelwork incorporated to prevent localised damage or failure of the test foundation.

For lateral load tests it is normally only necessary to use one primary displacement measuring device, aligned with the lateral load. For convenience the reference beam should be installed on the opposite side of the foundation to the load application.

Inclination (rotation) of the top of the foundation may be measured using the procedure outlined in clause 4.4.4.

Secondary displacement measuring devices should always be used.

Measurement of the foundation vertical movement is optional and if required may be limited to a secondary displacement measurement.

If practicable, a second back-up load measuring device should be used as a cross check and replacement in case of malfunctions of the primary device.

5. TEST ARRANGEMENTS (continued)

5.6.1 Hydraulic Jack - Soil/Rock Reaction

Where soil/rock or site conditions are suitable, the lateral test load may be applied using a hydraulic jack reacted against the sides of the excavation (see Figure 6). Steel bearing plates should be inserted between the hydraulic jack and test foundation. The jack should be equipped with spherical bearings to minimise local eccentricities. If it is necessary to extend the distance between the hydraulic jack and the reaction system, this should be undertaken by the use of struts or blocks.

A timber or steel reaction framework should be used on the face of the excavation as necessary. There is no restriction on the separation between the test foundation and reaction system [16].

5.6.2 Hydraulic Jack - Reaction Platform

For lateral test load application above ground level a convenient method is the use of a hydraulic jack in conjunction with a reaction platform (see Figure 7). The reaction platform should comprise a base of timber, steel or concrete loaded with sufficient deadweight, e.g. precast concrete blocks, to provide the necessary resistance. The jack should be equipped with spherical bearings to minimise local eccentricities.

Suitable bearing plates on the test foundation and reaction platform should be provided as necessary. If it is necessary to extend the distance between the hydraulic jack and the reaction system, this should be undertaken by the use of struts or blocks. Although there is no restriction on the separation between the test foundation and reaction system [16], it is preferable to allow a minimum distance of 2m or $(3e)m$, whichever is greater, where 'e' is the equivalent foundation diameter.

5.6.3 Tensioner - Reaction System

An alternative method to that described in 5.6.2 is the application of the lateral test load as a tensile force using a tensioning device in conjunction with a suitable reaction system via single or multi-lead wire rope rigging (see Figure 8). The tensioning device may either be a powered mobile winch or a hand tensioner (e.g. 'Tirfor') depending on the required test load or rigging arrangement. An electrical resistance dynamometer should be fitted between the rigging and test foundation.

The reaction system may either be a reaction platform or ground anchors. A minimum clear distance of 6m or $(20e)m$ (whichever is greater) should be maintained between the test foundation and reaction system, where 'e' is the equivalent foundation diameter [16]. See figure 2.

5. TEST ARRANGEMENTS (continued)

5.6.4 Twin Foundations

Where twin foundations are installed, the relevant parts of clauses 5.6.1 and 5.6.2 should be used if the load is applied as a compressive force and clause 5.6.3 if the load is applied as a tensile force.

5.6.5 Pole Structure - Tensioner System

For tests on mono-pole structure foundations where the lateral load is relatively small but the applied overturning moment (OTM) is high, the usual test method is a pole structure-tensioner arrangement (see Figure 9).

The pole structure should be attached to the test foundation via embedded holding-down bolts or stub pole section. Suitable rigging attachment points should be provided on the pole to ensure the correct overturning moment is applied without an excessive vertical load component.

The tensioning device may either be a powered mobile winch or a hand tensioner (e.g. Tirfor) depending on the required test load or rigging arrangement, i.e. single or multi-lead system. An electrical resistance dynamometer should be fitted between the rigging and the pole.

The reaction system may be a reaction platform, ground anchors or the deadweight of the winch if a crawler tractor is used. A minimum clear distance of 6m or $(20e)m$ (whichever is greater) should be maintained between the test foundation and reaction system, where 'e' is the equivalent foundation diameter. See figure 2.

5.7 Routine/Proof Tests - Lateral

Routine/proof lateral tests should be undertaken using test arrangements similar to those detailed in clause 5.6. Due care should be taken of the load attachment to the production foundation to ensure no permanent damage or distortion is caused. In most cases the use of an optical level to measure the production foundation displacement would be acceptable.

5.8 Design Tests - Combined (Uplift and Lateral)

Combined vertical (uplift) and lateral load design tests, both monocytle and multicytle, may be undertaken using either of the arrangements detailed in clauses 5.8.1 and 5.8.2. The main difficulty in undertaking combined loading tests is ensuring the method used to apply the vertical test load does not restrain the foundation from moving laterally under the action of the lateral test load, unless a resultant load is applied.

All test loading beams or frames and associated equipment should possess an adequate structural stiffness and a minimum ultimate design capacity equivalent to 1.5 times the maximum test load (see also clause 5.6).

5. TEST ARRANGEMENTS (continued)

For measurement of the test foundation displacement, the requirements of both the vertical and lateral design tests should be combined, i.e. a minimum of three vertical and one horizontal primary displacement measuring devices in conjunction with their secondary measuring devices (see also clauses 5.2 and 5.6).

If practicable, a second back-up load measuring device should be used as a cross check and replacement in case of malfunction of the primary device.

5.8.1 Combined Mobile Crane and Tensioner - Reaction System

This arrangement is a combination of those described in clauses 5.2.3 and 5.6.3 whereby the uplift and lateral test loads are applied as separate load components. Between the electrical dynamometer (fitted in crane lead) and the test foundation, a universal acting device should be incorporated to minimise restraint against lateral displacement of the test foundation.

5.8.2 Combined Load Application

In this method the vertical and lateral test load are combined as a single resultant test load applied to the foundation. The actual test arrangement will depend on the angle of the resultant load to the vertical. Due cognisance should always be taken of any variation between the resultant design load vector to the vertical axis of the production foundation and of the resultant test load vector to the vertical axis of the test foundation.

For resultant angles less than 10 degrees to the vertical, the hydraulic jack test loading beam or fulcrum beam arrangements described in clauses 5.2.1 and 5.2.2 respectively may be used. In the former case it will be necessary to use either purpose-made test loading beam supports to cant the test loading beam to the correct resultant angle or wedges to cant the hydraulic jack to the correct resultant angle.

For any resultant angles, a steel tripod arrangement with the load applied by a hydraulic jack connected to the apex of the tripod via wire rope rigging systems may be used (see Figure 10). Variations on this arrangement could be made whereby the load is applied by a mobile winch with suitable ground anchors, connected to the test foundation via a pulley block suspended from an attachment plate at the apex of the tripod. In this case it would be necessary to calculate the resultant angle of the pulley block and adjust the position of the tripod accordingly.

Alternatively, the A-frame tensioner system described in clause 5.2.4 may be used.

In all test arrangements it will be necessary to provide special test foundation stub or load transfer steelwork, set at the angle of the resultant test load. Special provision may be required to accommodate any settlement of the test rigging under load.

5. TEST ARRANGEMENTS (continued)

5.9 Routine/Proof Tests - Combined (Uplift and Lateral)

Although it is feasible to test production foundations under combined routine/proof uplift and lateral test loads using any of the arrangements given in clause 5.8, careful consideration must be given to the strength of the load transfer steelwork, particularly if local load eccentricities are to be avoided with the consequential risk of localised damage to the production foundation. In addition, the possibility of settlement of the test rig should be considered.

6. TEST PROCEDURES

6.1 General

This section of the guide has been subdivided to take into account the category of test, mode of load application and whether the tests are monocytle or multicytle.

Prior to any testing, the foundation capacity and if possible the related displacement should if necessary be recalculated using the actual geotechnical parameters and as-installed foundation dimensions.

Values of admissible displacements associated with the applied design or proof load, as well as any applicable load factors, should be agreed between all parties at the design stage. If applicable, national standards and regulations may also have to be considered.

6.2 Data Recording

All measuring instruments should be protected when necessary to reduce environmental effects that could lead to distortion of the readings.

Displacement measurements should be taken at the beginning and end of all load increments, including the residual displacement on completion of the test.

During the execution of the test, the load versus displacement graph should be drawn, thereby giving an indicative guide to the foundation performance. For design tests, the load-time and displacement-time graphs should, if possible, also be plotted.

For routine/proof tests, the load-displacement graph should be drawn during the execution of the tests, thereby giving an indication of any unforeseen behaviour of foundation and the possibility of stopping the test prior to damage occurring.

If tests are standardised, it is recommended that a weather-proof pre-printed test data sheet is used.

6.3 Monocytle Tests

Monocytle tests should be undertaken if information is required on the behaviour of a foundation in response to a gradually increasing load, with particular reference to the largest load which can be resisted.

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6. TEST PROCEDURES (continued)

6.4 Design and Routine/Proof Tests - Monocycle Loading

Design and routine/proof tests for axial (uplift or compression), lateral or combined axial and lateral for monocycle loading may be undertaken using the typical range of values given in Table 6.4. These values are applicable to both tangent (suspension) and tension (angle/terminal) towers and pole structures.

Prior to commencement of the test, an initial application of 10% of the maximum test load should be applied to check the testing system reliability.

TABLE 6.4

<u>Test Class</u>	<u>Maximum Load</u>	<u>Load Increments %</u>	<u>Minimum Maintained Time/Increment (d)</u>
Design	Design (a)	25, 40, 50, 60, 70, 80, 90, 100, 0 (b)	10 mins.
Proof/Routine	Proof (c)	50, 75, 90, 100, 0	3 mins.

Notes:

- (a) The maximum test load applied to the foundation due to either the ultimate load or factored working load or the load derived with respect to a specific return period of a climatic event.
- (b) Loadings may be continued until failure occurs, provided satisfactory provision has been made for the sudden failure of an individual component. The maximum test load may be defined as an agreed percentage over the design load. Once the design load has been reached this should be held for 30 minutes prior to the recommencement of loading in 10% increments to the maximum test load, with only 3 minute time intervals between successive increments.
- (c) Maximum test load should be agreed between all parties prior to the commencement of the test and should be based on a specific percentage of the design load, which may be the unfactored working load or a reduced return period of the climatic event.
- (d) If continued movement (creep) is apparent at the end of either the 10 or 3 minute loading increment, an extension to the time increment should be considered.
- (e) If vertical and lateral loads are applied as separate components, the vertical component increment should be applied first.

6. TEST PROCEDURES (continued)

For multi-drilled shaft or piled or anchor foundations where only individual drilled shafts, piles or anchors are tested it may be necessary to adjust the design load under test to take account of the mass of the cap or any other part of the production foundation not installed as part of the test foundation.

6.5 Multicycle Tests

Multicycle tests should be undertaken where there is either:

- (a) a possibility of a noticeable reduction in the foundation resistance under cyclic loading compared to the monocyte value; or
- (b) where repeated, relatively low magnitude loadings could give rise to permanent foundation displacements after each cycle, resulting in an accumulation of foundation displacements such that structural damage would occur to any associated tower or structure if it were constructed on the foundations.

Multicycle tests should also be employed if the ground conditions are such that repeated or vibratory loadings could cause soil failure, i.e. liquefaction in some saturated silts and silty sands.

Although there is extremely limited information available, the main factors which appear to influence the behaviour of a foundation to cyclic loading, axial, lateral or combined, axial and lateral are detailed below and should where necessary be taken into consideration when planning multicycle loading tests [19], [20], [21].

- (c) Magnitude of the cyclic load as a percentage of the monocyte capacity.
- (d) Number of cycles.
- (e) Loading direction.
- (f) Soil characteristics and drainage profile.
- (g) Induced displacement as a percentage of the monocyte displacement.
- (h) Foundation type.

It should however be recognised that the actual multicycle loading is unlikely to be equal to the maximum monocyte design load and, below a critical threshold value of the peak-to-peak cyclic loading foundation displacement, there is no reduction in the monocyte foundation capacity for a large number of cyclic load applications.

6. TEST PROCEDURES (continued)

Table 6.5(A) gives a multicycle design test loading regime that has been successfully employed to establish at what load permanent set or foundation displacement remains when the load is relaxed (i.e. the foundation passes from a theoretical elastic state).

This testing regime is applicable for both tangent (suspension) and tension (angle/terminal) towers and pole structures and all modes of loading, i.e. axial, lateral or combined axial and lateral.

Prior to the commencement of the test, an initial application of 10% of the maximum test load should be applied to check the testing system's reliability.

TABLE 6.5(A)

<u>Test Class</u>	<u>Maximum Load</u>	<u>Load Increments % (b)</u>	<u>Minimum Maintained Time/Increment</u>
Design	Monocycle Design (a)	0, 12.5, 25, 0, 25, 37.5, 0, 37.5, 50, 0, 50, 62.5, 0, 62.5, 75, 0, 75, 87.5, 0, 87.5, 100, 0	5 mins. (c)

Notes:

- (a) See clause 6.4 for definition of maximum load.
- (b) Loadings may continue until failure occurs, provided satisfactory provision has been made for the sudden failure of an individual component. The maximum test load may be defined as an agreed percentage over the design load. Once the design load has been reached, this should be held for 15 minutes prior to the recommencement of loading in 12.5% increments to the maximum test load. If vertical and lateral loads are applied as separate components, the vertical component increment should be applied first.
- (c) The minimum maintained time increment is usually governed by the time it takes to read the various instruments.

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6. TEST PROCEDURES (continued)

An alternative multicycle loading system which has been used in contract design testing is given in Table 6.5(B). In this case, the loading cycle is between one or more specific values and zero in order to prove that with a specified value there is no permanent set, or at least no increasing permanent set, with an increasing number of cycles [*].

The load incremental values specified for the multicycle test should be based on a specific percentage of the design load, which may be the working load or a reduced period of the climatic event.

TABLE 6.5(B)

<u>Test Class</u>	<u>Maximum Load</u>	<u>Load Increments %</u>	<u>Minimum Maintained Time/Increment</u>
Design	Monocycle Design (a)	(i) 0, 17, 33, 0	(b) 5 mins. (d)
		17, 33, 0	(c)
		(ii) 17, 33, 50, 67, 0	(b)
		33, 50, 67, 0	(c)
		(iii) 33, 50, 67, 85, 100, 0	

Notes:

- (a) See clause 6.4 for definition of maximum load.
- (b) If no permanent set, continue to next higher cycle loading regime.
- (c) If permanent set is no greater than that at the end of the previous cycle, apply the next higher load regime. If the set is greater, continue using the same load cycle.
- (d) The minimum maintained time increment is usually governed by the time it takes to read the various instruments.

[*] A foundation can show a permanent set after an initial application of load but this set may not increase, no matter how many times the load is applied and relaxed. Alternatively, repeated applications can increase the magnitude of the permanent displacement set.

6. TEST PROCEDURES (continued)

6.6 Test Report

On completion of the test, the following information should be accurately recorded in the test report:

Section 1 - General

- (a) Category of test, i.e. design or proof/routine, including the overall reason for the test, e.g. verification of contract design parameters.
- (b) Type of foundation, e.g. concrete pyramid and chimney.
- (c) Mode of loading, i.e. axial, lateral or combined axial and lateral.
- (d) Loading cycles, i.e. mono or multi.

Section 2 - Geotechnical Data

- (e) General map of test location, clearly identifying principal geological features, boreholes and test foundation location.
- (f) Ground profile, including details of surface and underground drainage (if significant) and geotechnical discontinuities.
- (g) Ground investigation date (table B1).
- (h) Geotechnical design parameters - see clause 2.7.
- (j) Ground and environmental conditions during foundation installation - see clause 2.8.

Section 3 - Design Data

- (k) Design capacity of foundation and anticipated displacement, modified if necessary to take account of as-constructed dimensions and test site geotechnical parameters.

Section 4 - Construction Details

- (l) Details of foundation design and as-built dimensions - see tables B2 to B6.
- (m) Plan and elevation of test foundation.

6. TEST PROCEDURES (continued)

Section 5 - Test Arrangement

- (n) Plan and elevation of reaction system, fixed reference points (horizontal and vertical) for displacement measurement and details of connection of test foundation to load application system. The plan should give the unique reference number for each displacement measuring point, as well as for each load application point.
- (p) Load-displacement data sheet (tables B7 or B8).
- (q) Environmental record during test.
- (r) Load-displacement, load time and displacement time graphs as appropriate (see clause 6.2).
- (s) Calibration certificates of test equipment (see clause 4.2).

7. TEST EVALUATION

7.1 General

To assist in the evaluation of test results, detailed below are various methods which have been found to be satisfactory, although other methods may be used.

7.2 Ultimate Uplift/Compressive Capacity - Monocycle Loading

The following methods, which are outlined in greater detail in Appendix C, may be used to derive the ultimate uplift/compressive capacity from the results of design tests taken to failure [18]. (Note that the following is equally applicable to uplift and compressive tests).

- (a) If the load-displacement curve shows a distinctive turning point between elastic and plastic range, the ultimate capacity of the foundation may be evaluated using the 'tangent-intersection' method (see Figure C1) or 'log-log' method (see Figure C2).
- (b) If the load-displacement curve does not permit definite conclusions to be drawn as to the ultimate capacity of the foundation, the ultimate capacity may be defined as a given percentage of the failure or test load, e.g. 80% (see Figure C3) or 90% (see Figure C4).
- (c) For deep foundations, e.g. friction piles, the 'Hyperbolic' method (see Figure C5) may be used to determine the ultimate capacity.
- (d) For foundations where the displacement becomes the ruling factor, eg foundations in cohesive soils, or where foundations undergo large displacements before failure (e.g. steel grillage or pad and chimney foundations without an undercut subface or cast against formwork), the 'slope-tangent' method (see Figure C6) may be used to determine the ultimate capacity.

7.3 Ultimate Lateral Capacity

There are no general methods available for defining the ultimate lateral capacity of a foundation. Normally these are related to a specific movement or rotation of the foundation, e.g. 2 degrees of rotation for drilled shaft foundations for mono-pole structures.

7.4 Multicycle Loading

Due to the complexity of the inter-relationship between the different factors which need to be taken into consideration when planning the tests, there are consequentially no guidelines on test evaluation. However, any criteria produced should be agreed between all parties prior to the commencement of the tests.

8. ACCEPTANCE CRITERIA

8.1 Design Tests: Optimisation of the Foundation Design

The specified static design load or displacement should be compared with the ultimate capacity or measured displacement as derived from the design test.

If this comparison shows under capacity of the test foundation or a displacement larger than compatible with the structure, the designer should re-evaluate either the geotechnical parameters used in the calculations, or the design method itself (or both) in order to reach a satisfactory correlation of the calculation to the measured values.

Eventually, after consultation between the parties concerned, the foundation may have to be redesigned and undergo a new test.

8.2 Validation of a Production Foundation

The results of a design test on a 'production' foundation will be deemed satisfactory if the following conditions are fulfilled:

- (a) The specified design load has been validated by the test or the extrapolation of the load-displacement curve gives reasonable assurance that the design load will be achieved.
- (b) The associated displacement remains within specified limits which are compatible with the function of the structure.

Should the test exhibit results which cannot be correlated to the results of previous design tests (i.e. under capacity or excessive displacement) and assuming that the observed discrepancy is not attributable to either modified dimensions of the foundation or to different ground conditions, then performance of additional tests or redesign of the foundation may be required. If redesigned foundations are proposed, these should be tested prior to acceptance.

8.3 Routine/Proof Tests

The routine/proof tests should where possible be evaluated in conjunction with previously performed design tests.

In the case where the observed displacement exceeds the value agreed between the parties concerned or if the extrapolation of the test results (wherever possible) raises doubts as to the capacity of the foundation, the following measures should be taken:

- (a) Additional tests on at least two adjacent foundations (in the case of four-legged towers) in order to validate the results of the first test.
- (b) Provision of adequate reinforcement measures of the individual foundation or, if the results of these additional tests confirm the previous one, of all the appropriate tower foundations.

APPENDIX A

FIGURES

MAXIMUM LEG SLOPE (HIP SLOPE)

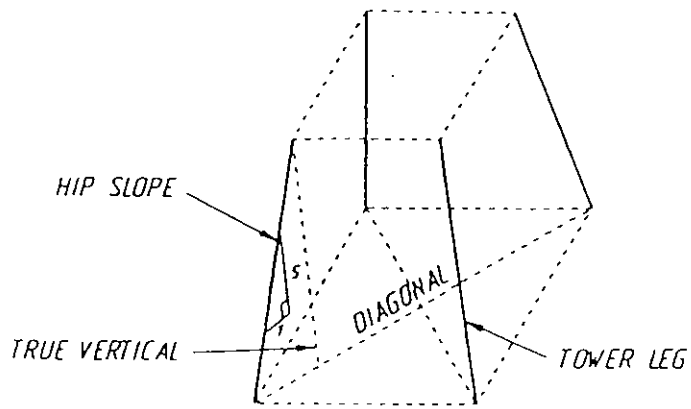
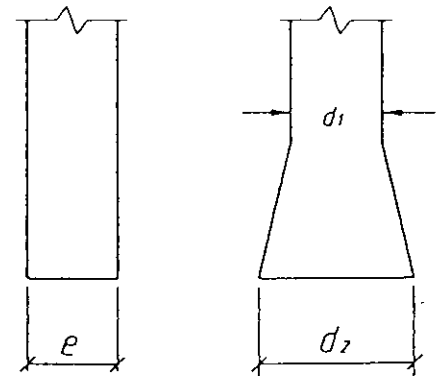
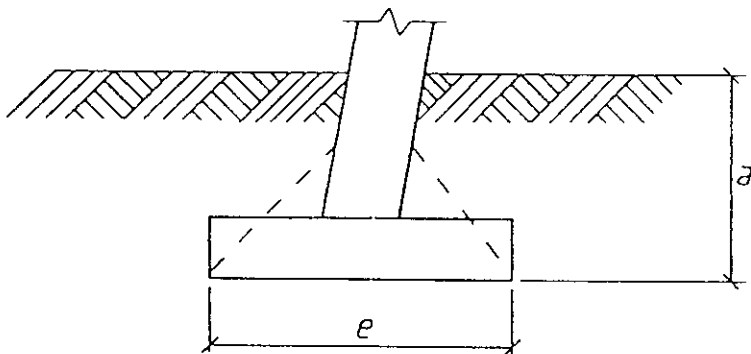


Figure : 1

EQUIVALENT FOUNDATION WIDTH OR DIAMETER

PYRAMID/PAD AND CHIMNEY FOUNDATIONS AND GRILLAGES:

DRILLED SHAFT, AUGER OR CASSON FOUNDATIONS



NOTE : MAXIMUM DIMENSION FOR RECTANGULAR
BASE TO BE USED

$$e = \frac{d_1 + d_2}{2}$$

PILES:

GRouted

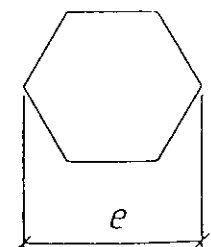
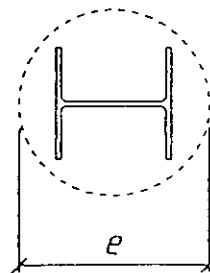
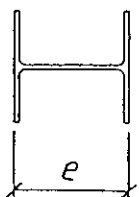
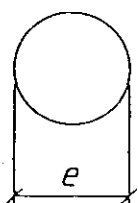
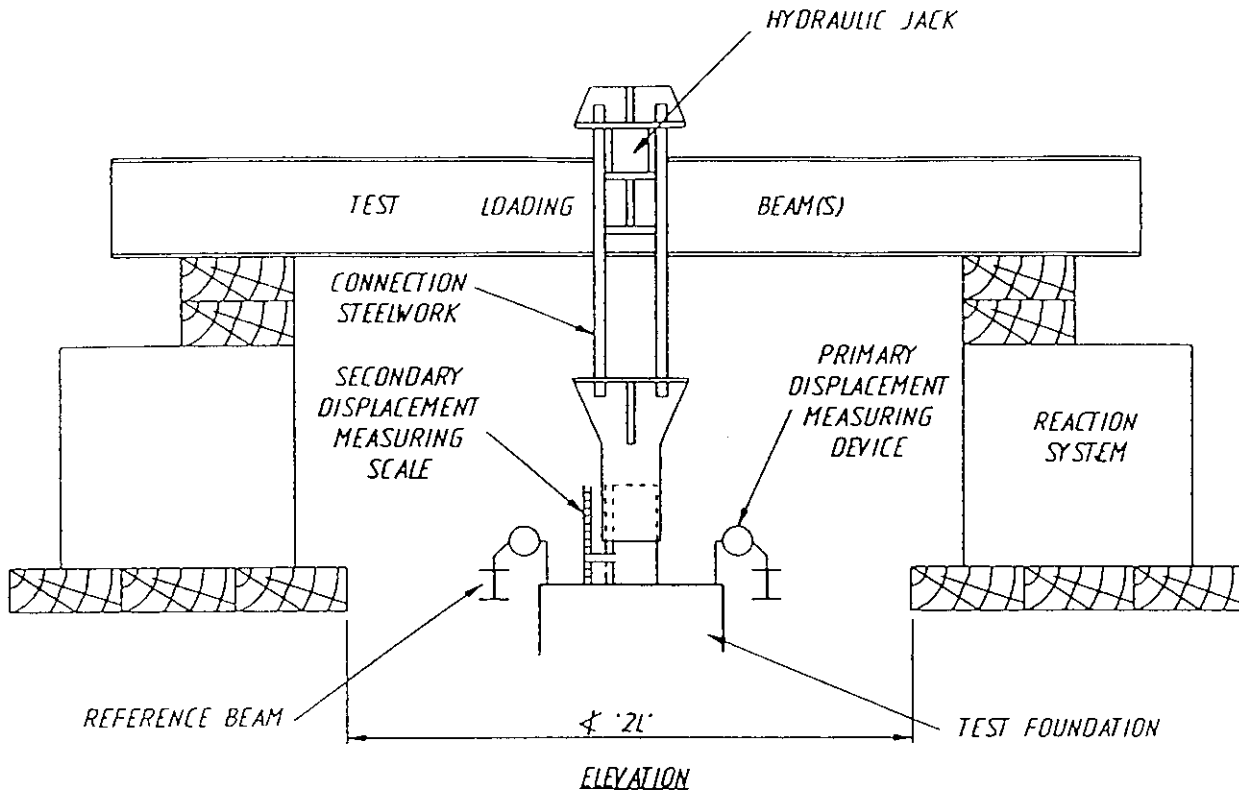
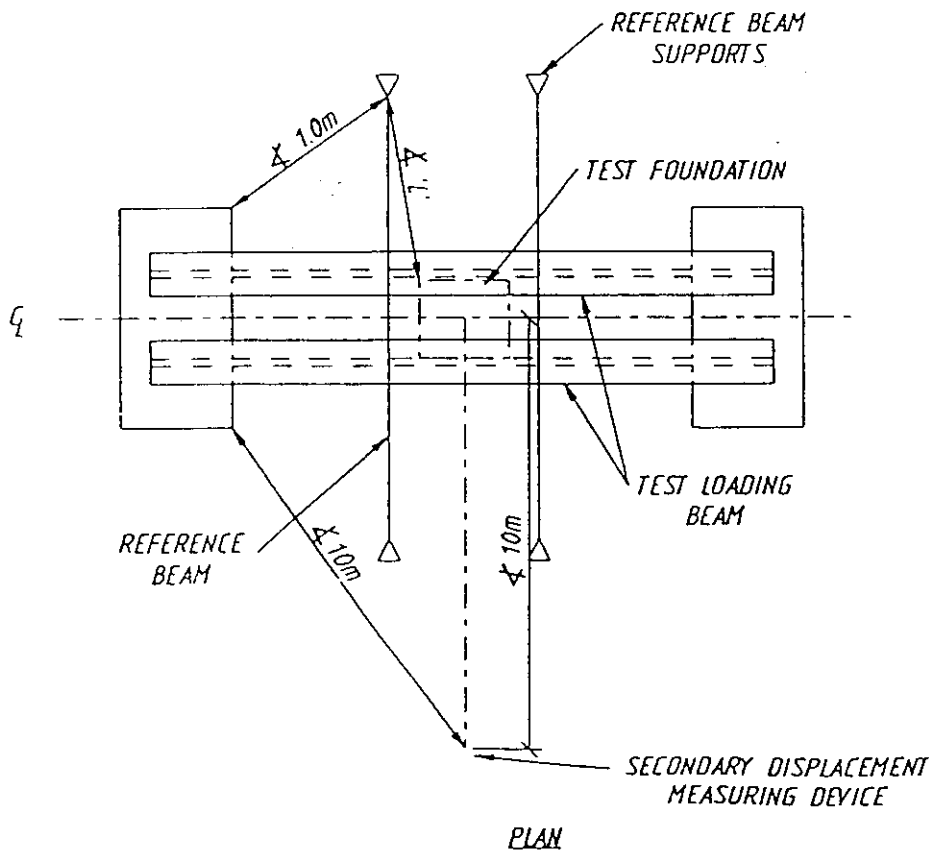


Figure : 2

GENERAL ARRANGEMENT OF TYPICAL
UPLIFT LOAD TEST



HYDRAULIC JACK - TEST LOADING BEAM
(REF CLAUSE 5.2.1)

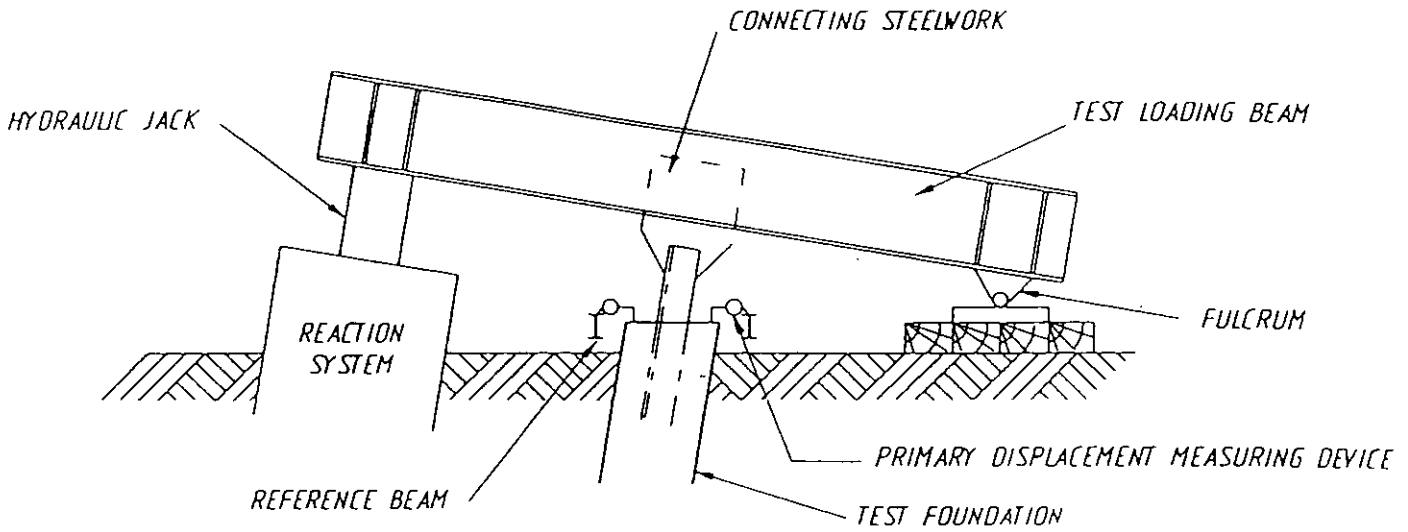


FOR DETAILS OF INDIVIDUAL
ITEMS OF EQUIPMENT SEE
CLAUSES :-

- HYDRAULIC JACK & PRESSURE GAUGE- 4.3.1
- TEST LOADING BEAM - 4.3.2
- REFERENCE BEAM - 4.4.1
- PRIMARY FOUNDATION DISPLACEMENT - 4.4.2
- SECONDARY FOUNDATION DISPLACEMENT - 4.4.3
- REACTION DISTANCE 'L' - 5.5

Figure : 3

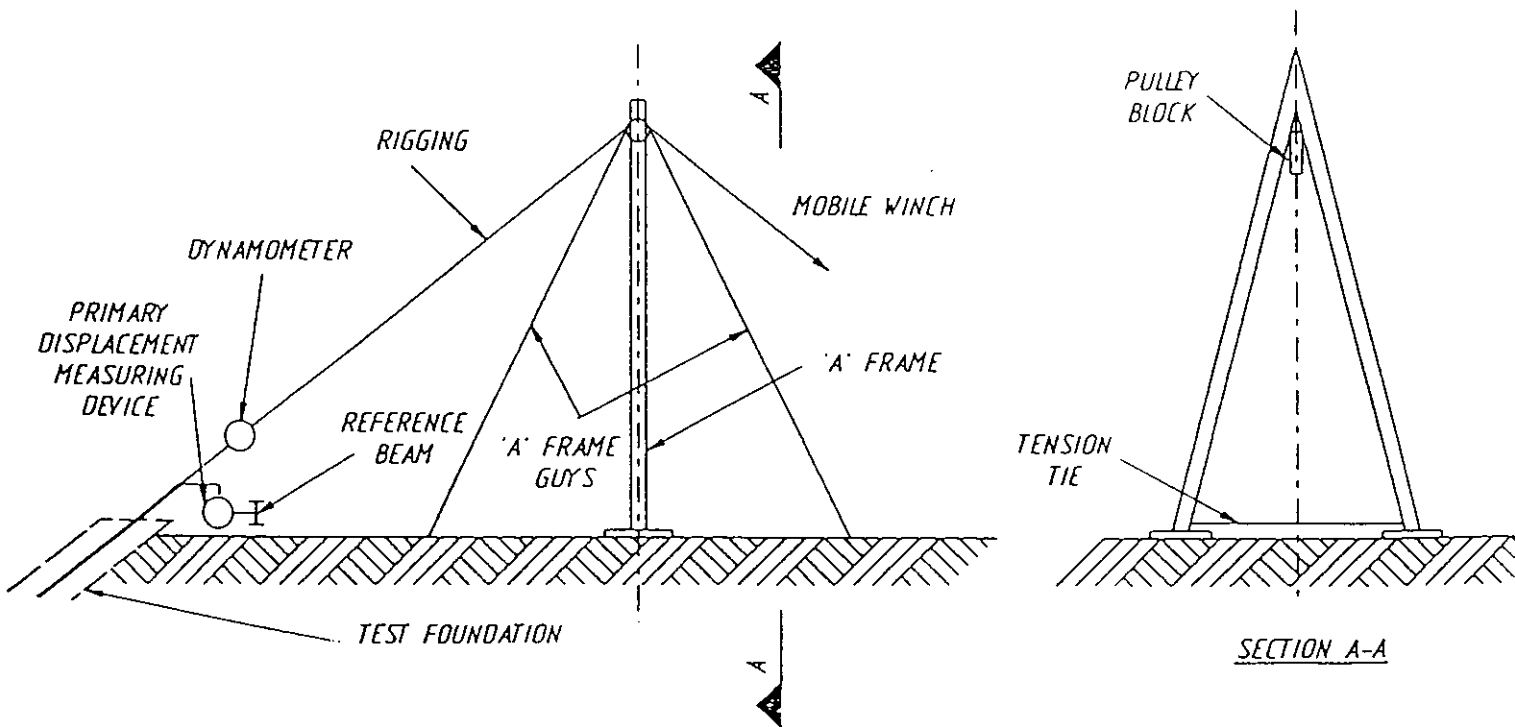
UPLIFT TEST ARRANGEMENTS



HYDRAULIC JACK - FULCRUM BEAM

(REF CLAUSE 5.2.2)

Figure : 4

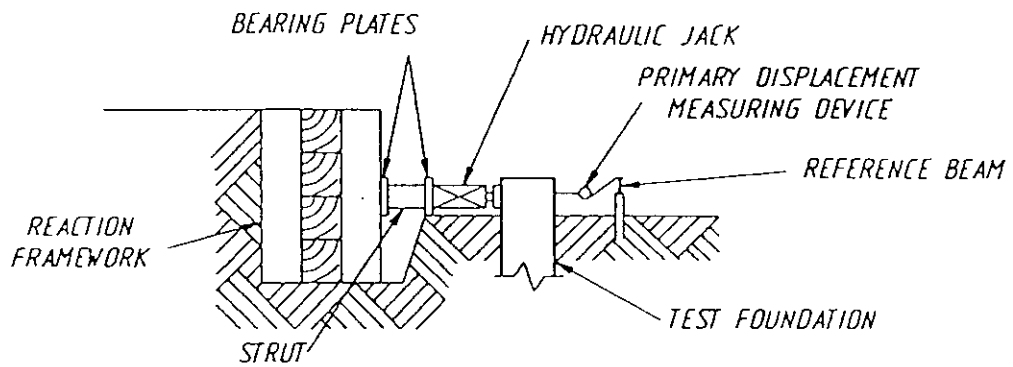


'A' FRAME - TENSIONER SYSTEM

(REF CLAUSE 5.2.4)

Figure : 5

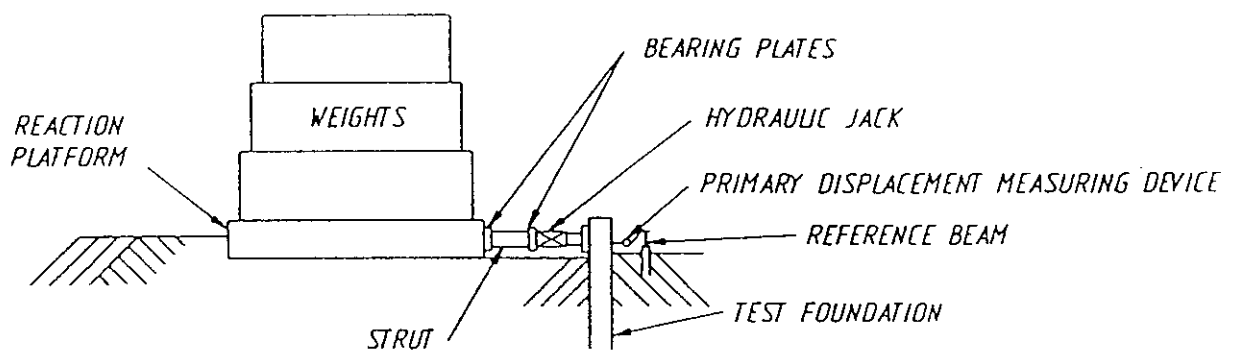
LATERAL TEST ARRANGEMENTS



HYDRAULIC JACK - SOIL/ROCK REACTION

(Ref Clause 5.6.1)

Figure : 6

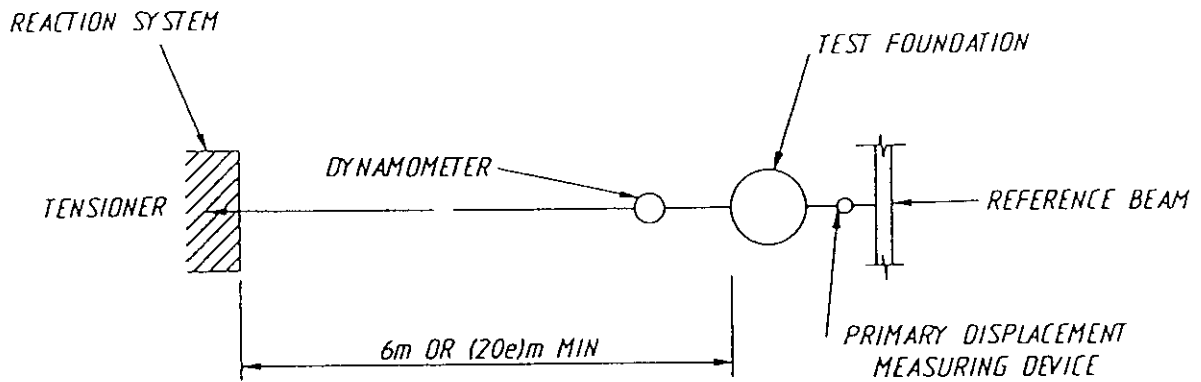


HYDRAULIC JACK-REACTION PLATFORM

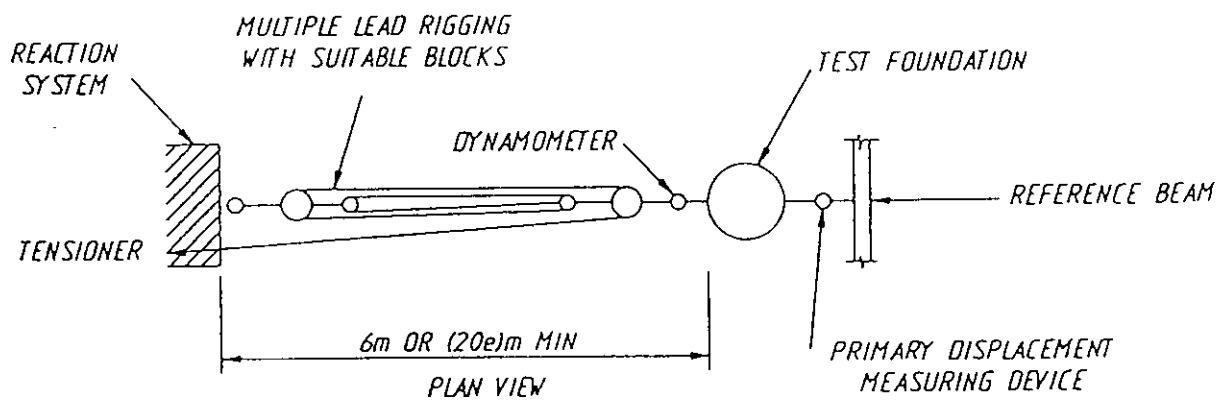
(REF CLAUSE 5.6.2)

Figure : 7

SINGLE LEAD RIGGING SYSTEM



MULTI LEAD RIGGING SYSTEM

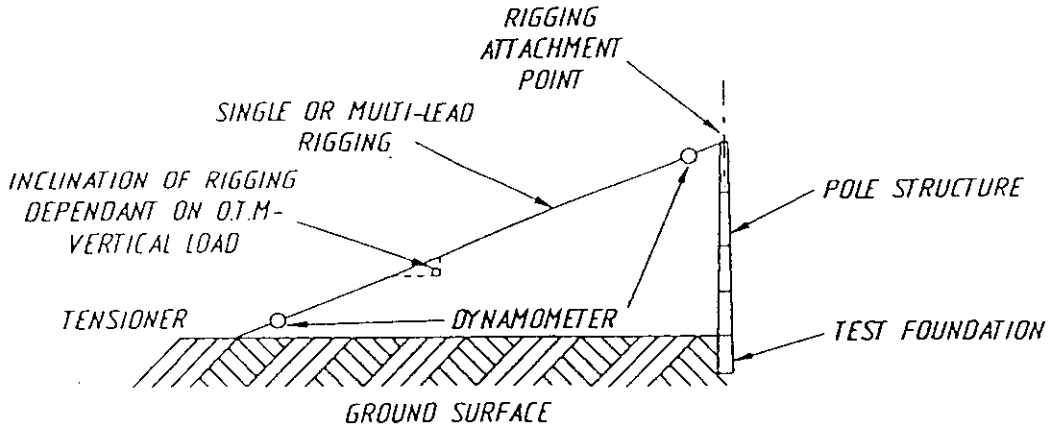


TENSIONER - REACTION SYSTEM
(REF CLAUSE 5.6.3)

Figure : 8

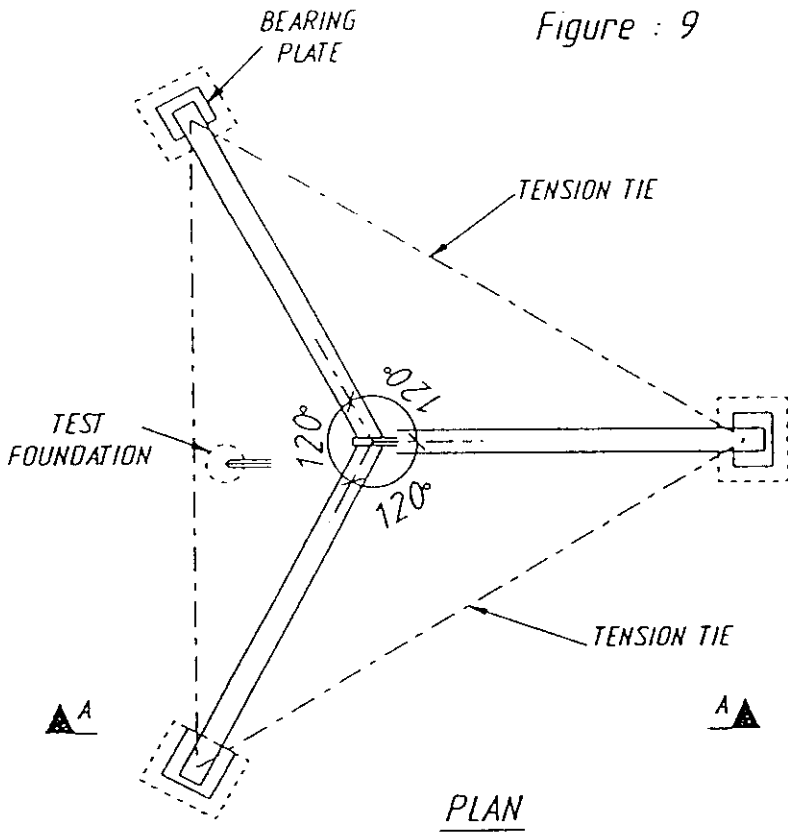
NOTE
SEE FIGURE 2 FOR EQUIVALENT
FOUNDATION DIMENSION 'e'.

LATERAL TEST ARRANGEMENT
(OVERTURNING MOMENT)

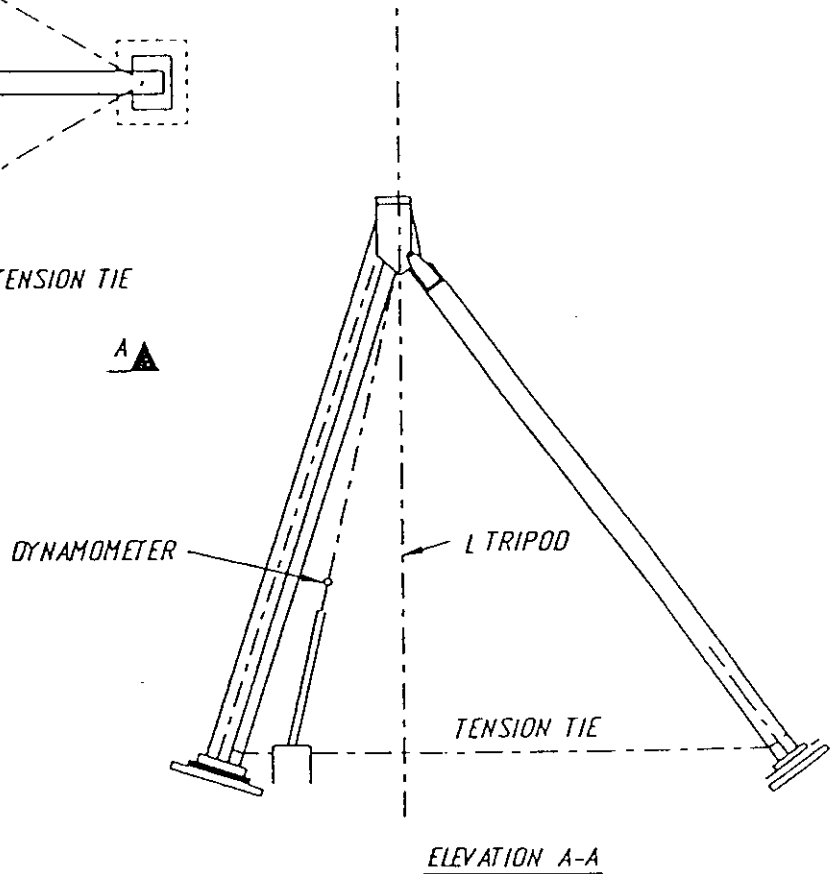


POLE STRUCTURE - TENSIONER SYSTEM
(CLAUSE 5.6.5)

Figure : 9



COMBINED TEST ARRANGEMENT



TRIPOD TENSIONER SYSTEM
(REF CLAUSE 5.8.2)

Figure : 10

APPENDIX B

TABLES FOR RECORDING TEST RESULTS

TABLE B-1
GROUND INVESTIGATION DATA

Test Site Reference:

Date of Investigation:

Boring No:

Ground Water Elevation(m):

GROUND SURFACE ELEVATION (m)

Depth (m)	Soil/Rock Description and Stratification incl. groundwater level	In-Situ							Laboratory									
		LEGEND SAMPLE	SPT blows/300mm	CPT (2) MN/m ²	VST N/m ²	Deformation Modulus kN/m ²	PMT		Moisture Content %	Liquid limit LL %	Plasticity Index P.I. %	Bulk Density Mg/m ³	Vane Shear kN/m	Unconfined Compression kN/m ²	Direct Shear		Triaxial -undrained	
							Creep Pressure kN/m ²	Limit Pressure kN/m ²							φ degrees	c kN/m ²	φ degrees	c kN/m ²

NOTES (1) Relevant national standard to be quoted

(2) Cone resistance and local skin friction where a friction jacket is used to be recorded

If continuous reading electrical cone penetrometer is used, graph results are to be included in test report

TABLE B2

CONCRETE PYRAMID/PAD AND CHIMNEY OR STEEL GRILLAGE FOUNDATIONS

		<u>Design</u>	<u>As-built</u>
Depth of foundation	m		
Length of foundation base	m		
Width of foundation base	m		
Rake to vertical x:1000			
Undercut: YES/NO			
Undercut dimensions (if yes):	m		
Thickness	m		
Length	m		
Width	m		
Excavation dimensions:			
Total depth	m		
Length	m		
Width	m		
Volume of concrete	cu.m		
Concrete strength (day cube/cylinder)	N/sq.mm		
Type of backfill			
Method of compacting backfill			
Date of excavation			
Date of concreting			
Time required to place concrete	(hrs)		
Date of backfilling			
In addition to the above for steel grillage foundations:			
Net base area	sq.m		
Gross base area	sq.m		
Mass of steelwork	Kg		
Meteorological conditions including Max-Min temperature during initial 24 hrs after concreting.			
Remarks:			

TABLE B3

DRILLED SHAFT, AUGER OR CAISSON FOUNDATIONS

	<u>Design</u>	<u>As-Built</u>
Shaft diameter	m	
Total embedded length	m	
Underream diameter	m	
Underream height	m	
Rake to vertical x:1000		
Capped: YES/NO		
Cap dimensions (if YES)		
Thickness	m	
Length	m	
Width	m	
Volume of concrete shaft	cu.m	
Volume of concrete, cap	cu.m	
Concrete strength	N/sq.mm	
(days cube/cylinder)		
Bored:		
- with temporary casing		
- with permanent casing		
- drilled under muds:		
- bentonite		
- others		
Meteorological conditions including		
Max-Min temperature during initial		
24 hrs after concreting both shaft and cap		
Date and time excavation completed: date time		
Date and time concreting commenced: date time		
Date and time concreting completed: date time		
Remarks:		

TABLE B4

<u>PILES</u>	<u>Design</u>	<u>As-Built</u>
Shaft diameter (circular pile)	m	
Lateral surface per metre of length (non-circular pile)	sq.m	
Total embedded length	m	
Underream diameter	m	
Underream height	m	
Rake to vertical x:1000		
No. of piles		
Capped: YES/NO		
Cap dimensions (if yes)		
Thickness	m	
Length	m	
Width	m	
Volume of concrete, pile	cu.m	
Volume of concrete, cap	cu.m	
Concrete strength (days cube/cylinder)	N/sq.mm	
Type of construction:		
* Driven:		
- steel		
- concrete		
- wood		
* Bored:		
- with temporary casing		
- with permanent casing		
- drilled under muds:		
- bentonite		
- others		
- height of casing		
* Others:		
Date and time excavation completed: date time }		
Date and time concreting commenced: date time } shaft and cap		
Date and time concreting completed: date time }		
For driven piles details of driving resistance, i.e. final set (number of blows to achieve a specific degree of penetration e.g. 25mm), any re-driving, use of preboring or jetting should be recorded.		
Meteorological conditions including		
Max-Min temperature during initial		
24 hours after concreting shaft and cap		
Remarks:		

TABLE 85

GROUTED ANCHORS

		<u>Design</u>	<u>As-Built</u>
Anchor hole diameter	m		
Total embedded length	m		
Bonded length	m		
Anchor bar diameter	mm		
Rake to vertical x: 1000			
No. of grouted anchors			
Anchor bar type & quality (yield stress)	N/sq.mm		
Capped: YES/NO			
Cap dimensions (if yes)			
Thickness	m		
Length	m		
Width	m		
Volume of concrete	cu.m		
Concrete strength (days cube/cylinder)	N/sq.mm		
Grout mix (including additives)			
Method of grouting under pressure - YES/NO if yes, pressure	kN/sq.mm		
Grout strength (days cube/cylinder)	N/sq.mm		
Date of drilling			
Date of grouting			
Date of pre-stressing			
Pre-stress applied - initial	kN		
- final	kN		
The drilling method and pressure at each injection stage if multistage injection procedures are used should be recorded.			
Meteorological conditions including Max-Min temperature during initial 24 hours after concreting anchor and cap			
Remarks:			

TABLE B6

GUY ANCHORS, INCLUDING HELICAL SCREW ANCHORS
(EXCLUDING GROUTED ANCHORS)

	<u>Design</u>	<u>As-Built</u>
Depth of foundation	m	
Length of foundation base	m	
Width of foundation base	m	
Rake to vertical x:1000		
Undercut: YES/NO		
Undercut dimensions (if yes)		
Thickness	m	
Length	m	
Width	m	
Excavation dimensions:		
Total depth	m	
Length	m	
Width	m	
Volume of concrete	cu.m	
Concrete strength (days cube/cylinder)	N/sq.mm	
Anchor rod type & quality (yield stress)	N/sq.mm	
Type of backfill		
Method of compacting backfill		
Date of excavation		
Date of concreting (if cast-in-situ)		
Time required to place concrete		
Date of backfilling		
Helical Screw Anchors:		
Total installed depth	m	
Pitch and diameter of helices	m x mm	
Number of helices		
Installation torque	kN.m	
Meteorological conditions including Max-Min temperature during initial 24 hours after concreting		
Remarks: If prefabricated anchor blocks used details of excavation, including slot for anchor rod to be clearly indicated.		

*TABLE B8
(PROOF TESTS)*

Project *Sheet* of
Location *Temp.*
Date *Weather*
Eng/Techn. *Foundation Type*
Remarks *Drawing Ref.*
Test Found No.

<i>Clock time</i>	<i>Elaps time (mins)</i>	<i>Reqd. load (kN)</i>	<i>Hyd. jack pressure (1)</i>		<i>Dynamometer</i>		<i>Actual Load (kN)</i>	<i>Foundation Displacement (mm)</i>		<i>Remarks</i>	
					<i>K=</i>			<i>Optical Level</i>			
					<i>Gauge Load (1)</i>				<i>reading</i>		
					<i>Reqd</i>	<i>Actual</i>			<i>Reqd</i>		<i>Actual</i>

NOTES:

- (1) Units to be stated, and both required & actual readings to be given.
- (2) Σ Change is the difference between current foundation displacement and the initial (zero load) displacement reading.

APPENDIX C

GUIDANCE NOTES FOR
GRAPHICAL DETERMINATION OF ULTIMATE UPLIFT CAPACITY

C.1 Tangent Intersection - Figure C1

The ultimate uplift capacity is defined as the load related to the intersection of two tangents to the load-displacement curve, one representing the elastic range and the other the plastic range.

C.2 Log-Log - Figure C2

The load-displacement data is re-plotted using a logarithmic scale and the two straight line portions of the graph are drawn. The ultimate uplift capacity is defined as the load related to the intersection of the straight line portions of the graph.

C.3 80% Criterion - Figure C3

The load-displacement data is plotted using transformed axis, with the y-axis equivalent to the square root of the displacement divided by the load, i.e: $\frac{\sqrt{\text{displacement}}}{\text{load}}$

and the x-axis as the displacement. The uplift capacity is determined from the y-intercept and the slope of the graph.

C.4 90% Criterion - Figure C4

The uplift capacity is defined as the load that gives twice the displacement as obtained for 90% of that load. Note that this is a trial and error method since it is necessary to assume an initial ultimate capacity, determine 90% of that capacity and check that the displacement at the ultimate capacity is twice that at 90% of that capacity.

C.5 Hyperbolic Model - Figure C5

The load-displacement data is plotted using transformed axis, with the y-axis equivalent to displacement divided by the load and the x-axis as the displacement. The ultimate uplift capacity is determined from the inverse slope of the graph.

C.6 Slope Tangent - Figure C6

The ultimate uplift capacity is determined from the intersection of a line drawn parallel to the initial linear portion of the load-displacement curve at a distance equivalent to 4mm displacement.

Note:

For compressive tests, the word compression shall be substituted for uplift in the above text.

Appendix C

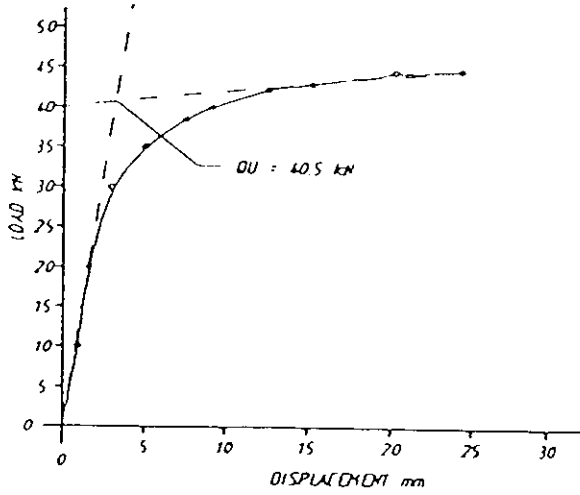


FIG. C.1. TANGENT INTERSECTION

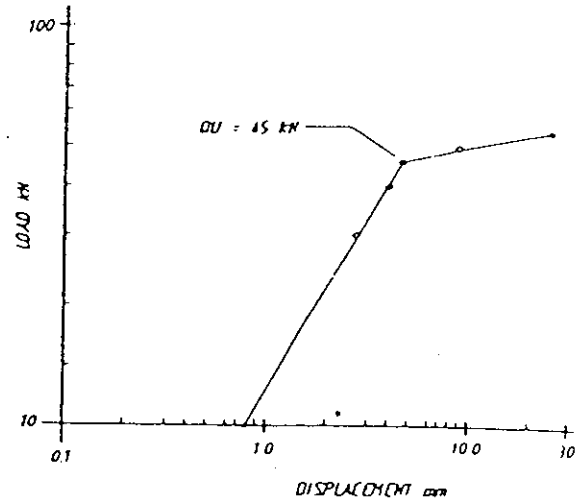


FIG. C.2. LOG-LOG

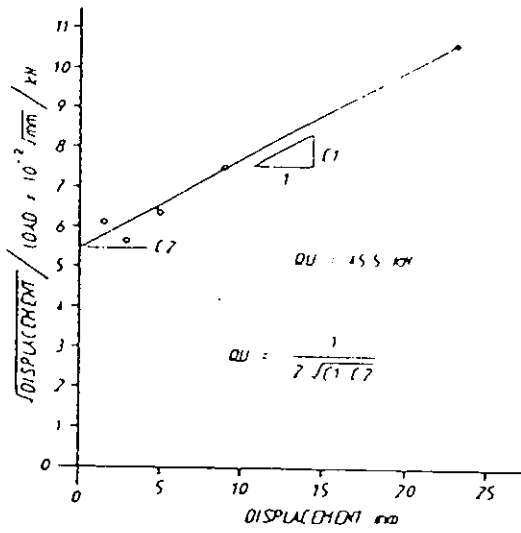


FIG. C.3. 80% CRITERION

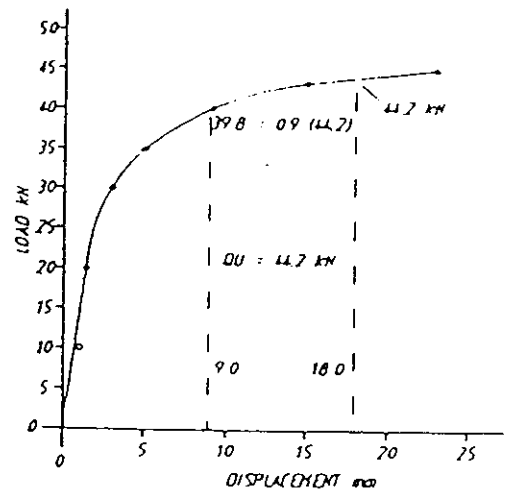


FIG. C.4. 90% CRITERION

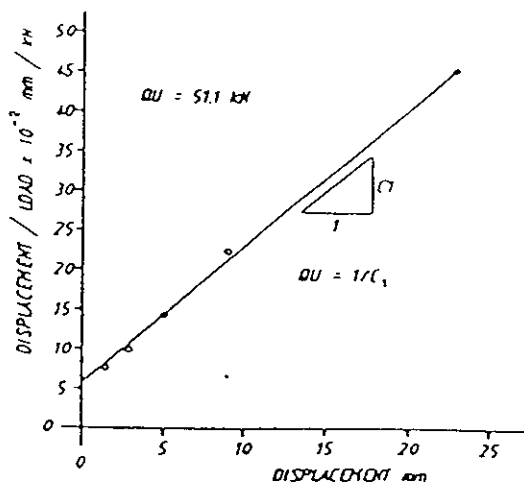


FIG. C.5. HYPERBOLIC MODEL

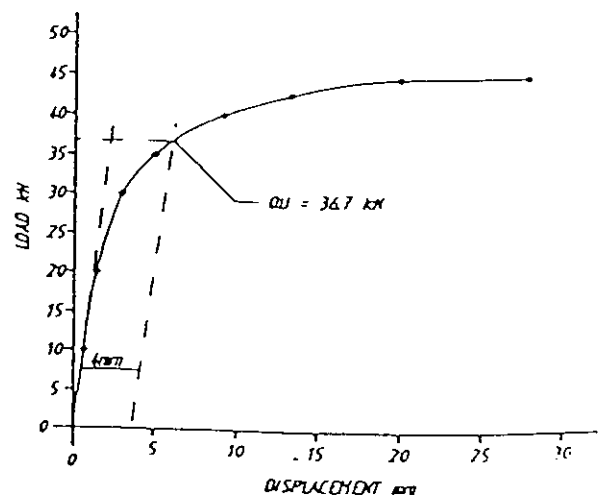


FIG. C.6. SLOPE TANGENT

APPENDIX D

COMPARISON OF NORMAL AND STUDENT'S 't' DISTRIBUTION

The assumption of normally distributed results is generally considered sufficiently accurate when it is based on a reasonably large data base but can lead to erroneous results when the data base is small. The difficulty can be overcome by the use of a method developed by Gosset who used the pseudonym "student". With this method, a family of bell-shaped curves are available, the form of which depend upon the number of observations. As the number of observations increases, the student's 't' distribution approaches the normal distribution shape.

The following table shows a comparison of normal and student's 't' X value for 90% and 95% certainties (10% and 5% exclusion limits respectively). Note that whereas the X value of the normal distribution is a constant for a given percent certainty, the X value for the student's 't' distribution decreases with the sample size, approaching the normal distribution X value.

<u>Size of Sample 'n'</u>	<u>Student's 't' distribution</u>		<u>Normal distribution</u>	
	<u>90%</u>	<u>95%</u>	<u>90%</u>	<u>95%</u>
2	3.08	6.31	1.28	1.64
5	1.53	2.13	1.28	1.64
10	1.38	1.83	1.28	1.64
15	1.34	1.76	1.28	1.64
20	1.33	1.73	1.28	1.64

Reference: Spiegel, M. R. (1972) "Theory and Problems of Statistics in SI Units", Schaum's Outline Series, McGraw-Hill Book Company (UK) Ltd., London.

APPENDIX E

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