5 IN-SITU TESTING, INSTRUMENTATION AND MONITORING

5.1 GENERAL

5.1.1 Scope

1 Testing of soils in place, and provision of instrumentation and monitoring of groundwater and subsurface gases.

2 Related Sections and Parts are as follows:

This Section

Part 1............... General
Part 2............... Boreholes
Part 3............... Pits and Trenches.

5.1.2 References

1 The following standards and other documents are referred to in this Part:

ASTM D420................Site Characterization for Engineering, Design, and Construction Purposes

ASTM D2488..............Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)

ASTM D4428/D4428M Standard Test Methods for Crosshole Seismic Testing

ASTM D5092/D5092M Standard Practice for Design and Installation of Groundwater Monitoring Wells

ASTM D5777..............Standard Guide for Using the Seismic Refraction Method for Subsurface Investigation

ASTM D6432..............Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation

ASTM D7128..............Standard Guide for Using the Seismic-Reflection Method for Shallow Subsurface Investigation

ASTM D7400/D7400M Standard Test Methods for Downhole Seismic Testing

BS 1377 ....Methods of test for soils for civil engineering purposes

BS 5930 ....Code of practice for ground investigations

BS 7022 ....Guide for geophysical logging of boreholes for hydrogeological purposes

EN 1997-2 ....Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing

CIRIA guide C562 .....Geophysics in engineering investigations

The Geological Society Engineering Group Working Party Report on Engineering Geophysics, *Quarterly Journal of Engineering Geology*, 21, pp. 207-271, 1988.

Clarke B.G. and Smith A., A model specification for radial displacement measuring pressuremeters, Ground Engineering, Volume 25, No. 2, March, 1992.

5.2 TESTING, INSTRUMENTATION AND MONITORING GENERALLY

5.2.1 Testing

1 The following information shall be submitted for each test record to be included in the daily report, preliminary log and factual report:

(a) Date of test.

(b) Project name, exploratory hole number and location.

(c) Depth and location of test or depths covered by test.

(d) Information on water levels in exploratory hole during testing.

(e) Original ground level at test site.

(f) Soil type and description as identified from the sample.

2 All results shall be reported in SI units.

3 Where load, displacement or other measuring equipment is used which necessitates regular calibration, then this shall be carried out in accordance with the relevant standard (the preferred method) or the manufacturer's instructions, by a calibration service approved by Qatar General Organization for Standardization (Qatar Standards- QS). Evidence of calibrations and copies of calibration charts shall be supplied to the Engineer prior to commencing work and when otherwise requested.

5.2.2 Instrumentation and Monitoring

1 The top of each standpipe, gas monitoring standpipe and piezometer tube shall be protected by a cover. The type of protective cover shall be approved by the Engineer.

2 When instructed by the Engineer, the Contractor shall install a protective fence around the top of a standpipe or piezometer. The fence shall be constructed of corrosion treated angle iron, galvanised wire, and corrosion resistant wire mesh fencing suitable for use in the climate of Qatar or a fence as a agreed upon with the Engineer.

3 Daily readings of depths to water in groundwater monitoring standpipes and piezometers shall be made by the Contractor, with an instrument approved by the Engineer.

4 Where the presence of gas is suspected or when directed by the Engineer, gas measurements, using an approved in-situ meter, shall be made by the Contractor during construction of exploratory holes and in gas monitoring standpipes. The depth to water and barometric pressure shall be measured immediately after each gas measurement.

5 Unless otherwise designated, piezometers, and standpipes protection shall not be removed from the site.

6 Other instrumentation and monitoring shall be carried out as designated.

5.3 TESTS

5.3.1 Tests in accordance with BS 1377 or EN 1997

1 The following in-situ tests shall be carried out and reported in accordance with BS 1377 or EN 1997:

(a) in-situ density by

(i) Small pouring cylinder method.

(ii) Large pouring cylinder method.

(iii) Water replacement method.

(iv) Core cutter method.

(v) Nuclear method.

(b) Static cone penetration test (CPT) and Piezocone (CPTu), capacity to suit scheduled depths unless otherwise designated

(c) Dynamic probing (DPH or DPSH).

(d) Standard penetration test (SPT).

(e) Plate loading test (see Notes below).

(f) Shallow pad maintained load test.

(g) California bearing ratio (CBR).

(h) Vane shear strength (VST).

(i) Apparent resistivity of soil.

(j) Redox potential.

(k) Pressurementer or Self-boring Pressuremeter (PMT)

(l) Pocket Penetrometer.

(m) Flat dilatometer (DMT)

NOTES: Plate Load Test Limitations

(i) It should be emphasized that the results of the plate bearing test apply only to the ground which is significantly stressed by the plate, this is typically a depth of about two times the diameter or width of the plate. The depth of ground stressed by a structural foundation will, in general be much greater than that stressed by the loading test if the foundation are wider than the width of the test plate.

(ii) Plate load tests are particularly suitable for coarse granular materials which cannot be tested by normal laboratory means or by penetration test. The main pitfall in predicting settlement from these tests is that the zone of stressed soil beneath the plate is much smaller than that unaffected by deeper strata whose load bearing and settlement characteristics may critically affect the behavior of the foundation.

2 The general applicability of the test method depends in part on the geo-material types encountered during the site investigation and the precision with which engineering calculations are to be made. A summary of the commonly available tests and the obtained soil parameters is shown by Tables 5.1 and 5.2.

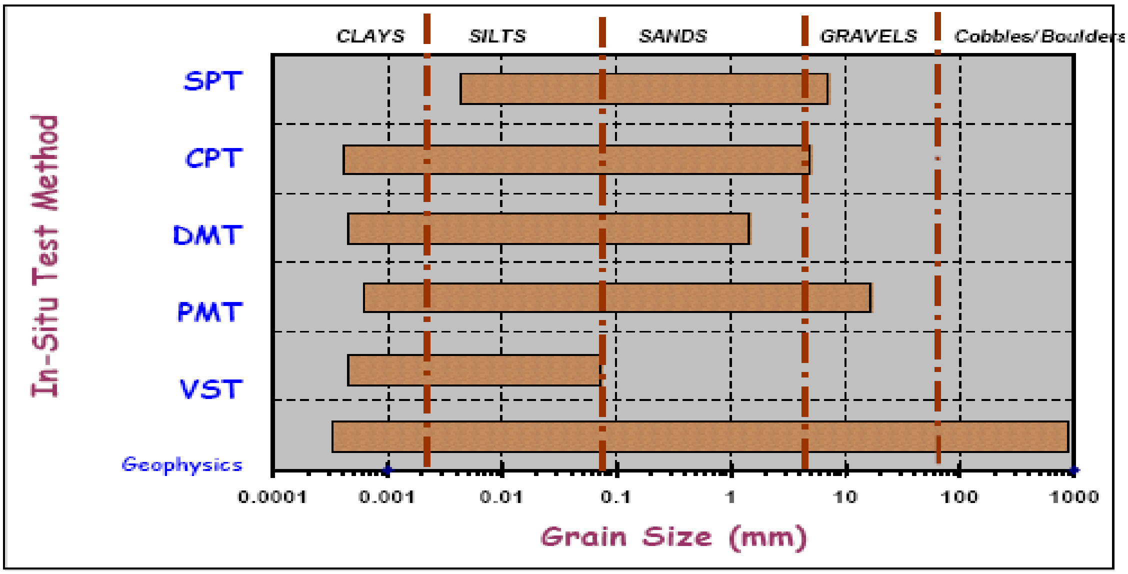
Table 5.1

Parameters available from available in situ tests according to ground conditions

Test type	Parameters required							
	K_0	φ'	c_u	σ_c	E'/G	E_u	G_{MAX}	k
SPT		G	C	R	G	C	G	
CPT		G	C		G			
Marchetti dilatometer	G,C				G			
Borehole pressuremeter			C		G,R	C		
Plate loading test			C		G,R	C		
Field vane			C				G,C,R	
Self-boring pressuremeter	G,C	G	C		G,C			
Falling/rising head test								G
Constant head test								C
Packer test								R

G = granular, C = cohesive, R = rock.

Table 5.2
Relevance of in-situ test to different soil types



5.3.2 Tests in accordance with BS 5930

1 The following in-situ tests shall be carried out where applicable and reported in accordance with BS 5930:

(a) Constant head permeability test.

(b) Variable head permeability test.

(c) Packer permeability test.

5.3.3 Geophysical Methods of Investigation

1 Geophysical testing shall be carried out as designated. The Contractor shall submit to the Engineer a full description of equipment and procedure for each geophysical method required.

2 The Engineer should assess the risk(s) related to the project at hand (based on the structure importance, size, economical loss, and number of occupants, in addition to the geologic hazards) and define the method(s) to be used and survey size allowing the various risks identification and their possible mitigation.

3 A useful guideline detailing common surface geophysical methods and their recommended use is given in Table 5.4 (given at the end of this Part 05).

4 The equipment and procedure, and information to be submitted for the following geophysical methods of investigation, shall be as described in BS 5930, BS 7022, ASTM and the Geological Society Engineering Group Working Party Report on Engineering Geophysics:

5 SURFACE GEOPHYSICAL METHODS

(a) electrical resistivity methods (ERT-2D &3D)

(b) seismic refraction (ASTM D5777) and reflection method (ASTM D7128)

(c) magnetic method

(d) gravity method

(e) electromagnetic method

(i) Ground conductivity.

(ii) Transient electromagnetic.

(iii) Ground Penetration Radar (GPR) ASTM D6432.

(f) Borehole geophysical logging.

(g) Cross-hole seismic method.

(h) Multi -Channel Analysis of Surface Waves (MASW)

(i) Refraction Microtremor (ReMi)

6 BOREHOLES SEISMIC METHODS

(a) Standard Cross Hole Seismic Test (ASTM D4428/D4428M)

(b) Down Hole Seismic Test (ASTM D7400/D7400M)

(c) PS Suspension Log:

(d) Full Wave Form Sonic Logging:

(e) Seismic Cone Penetration Testing (SCPT) –

(f) Cross Hole Seismic Tomography

(g) Single Hole Seismic Tomography

(h) Three Arm Caliper.

(i) Fluid (Temperature/Conductivity) Log.

(j) Electric Log.

(k) Verticality Logging.

(l) Gamma –Gamma Logging.

7 The following table (Table 5.3) summarizes the Common Surface Geophysical Methods and Their Recommended Use.

Table 5.3:
Common Surface Geophysical Methods and Their Recommended Use

Application	METHOD							
	MASW	SR	SRT	SRF	ReMi	ERT	MG	GPR
Cavity Mapping	x		x	x		x	x	x
Geology Mapping (faults, fractures)				x	x		x	
Stratigraphy	x	x	x	x	x	x		x
Rockhead Determination	x	x	x	x	x			
Groundwater Detection						x		x
Contamination Mapping						x		
Locating Buried Features (archeology, utilities, landfills)								x
Measuring Pavement Thickness								x
Locating Rebar in Concrete								x
Rock Quality Determination	x	x	x	x	x			

Recommended Method
Less Recommended Method
Least Recommended Method

8 In case that surface geophysical Survey is required the following guidelines can be followed:-

(a) For Master planning design the Geotechnical survey may be taken in a large scale of grids.

(b) For Infrastructure design (road, drainage, supplies, IT, power, HV), the geophysical survey can follow the project grid in addition to selective boreholes to calibrate/verify the survey. In addition, it could be necessary to narrow the grid at potential identified risk areas combined with probing of anomalies.

(c) For Plot design (Buildings, facilities) the Geophysical survey at grid of 3 to 10m can be done in addition to probe Boreholes at the location of Anomalies.

(d) The geophysical survey shall be conducted to a specified depth of significance, in accordance with the project specifications and the relevant codes (BS 5930 & CIRIA guide C562 “Geophysics in Engineering Investigations”).

(e) The geophysical survey shall cover all foundation/pile areas and extend in all orthogonal directions beyond the line of the outermost foundation/pile. Reference should be made to the foundation / piling drawing for the areas concerned

(f) The survey configuration shall be designed to identify voids and /or cavities (open and/or infilled) in any orthogonal direction. The vertical depth of the study shall be to the lower level below the foundation and stressed area. Where piles are designed as end bearing the survey shall extend at least 5m below the toe levels (if possible).

9 A report documenting the survey procedures and results shall be submitted. The report shall include detailed discussions of verification, survey procedures, quality control checks and any other pertinent information.

10 The report shall mainly consist of, but not limited to, the following sections:

(a) Presentation of:

(i) Site description

(ii) Site geology

(iii) Objectives of the survey

(iv) Detailed description of the methodology of the survey, equipment used for data acquisition and method

(v) Plan showing the location of geophysical survey lines.

(b) Data acquisition containing:

(i) Scope of work

(ii) Topographic surveying showing the as built of geophysical survey lines or points.

(iii) Data collection describing survey design parameters, field acquisition parameters, data collection instrumentation, field procedures and field quality control measures

(c) Data processing and presentation containing

(i) Data validation

(ii) Data processing

(iii) Evaluation of the results

(iv) Presentation of geophysical results as 2D or 3D models.

(d) Discussion of results containing:

(i) Subsurface strata classification within the site

(ii) Correlation between survey results and suspected cavities/voids (open and/or unfilled) at site, if any.

(iii) Suspected ground anomalies related to cavity / void features (open and/or infilled) shall be annotated and referenced with a unique identifier.

(iv) Classify the resulting anomalies as low, medium and high risk. The classified anomalies shall be marked clearly on the vertical and horizontal cross sections and tabulated in the report text.

(v) Propose location of geotechnical boreholes with special emphasis on verification boreholes in locations of suspected voids/cavities/anomalies.

11 All geophysical survey reports shall be submitted to the Engineer and project owner in the form of factual and interpretative reports in both softcopy and hardcopy formats. The geophysical survey data shall be submitted and in the original document format and in excel as applicable.

5.3.4 Special In-Situ Testing

1 Special in-situ testing shall be carried out as designated.

2 The Contractor shall allow for the excavation of boreholes, trenches or trial pits necessary for the execution of inspection tests.

3 Inspection tests shall be decided as directed by the Engineer. These tests shall include but not limited to those in Table 5.4.

Table 5.4:
Quality Assurance Tests for Completed Work

Recommended Test per Layer	
Shallow Fill (trench or test pit)	Deep Fill (boreholes)
In-situ CBR	Field density
Plate load Test	Layer Thickness
Field density	DCP Test
Layer Thickness	SPT
DCP Test	Pressure meter
	Large Scale Loading

5.3.5 Hand Penetrometer and Hand Vane for Shear Strength

1 Hand penetrometer and hand vane tests shall be carried out where required to give a preliminary estimate of undrained shear strength of the soil tested.

2 Hand (or pocket) penetrometer equipment shall be of an approved proprietary make with stainless steel tip of end area 31 mm^2 with an engraved penetration line 6 mm from the tip. The scale shall be suitably graduated. The procedure for the test shall be in accordance with the manufacturer's instructions. Both unconfined compressive strength and estimated shear strength shall be reported for the soil tested.

3 Hand vane equipment shall be of an approved proprietary make with stainless steel vanes having a length of 19 mm or 33 mm and a length-to-diameter ratio of 2:1. The scale shall be suitably graduated. The procedure for test shall be in accordance with BS 5930 and the manufacturer's instructions. Peak shear strength and residual shear strength shall be recorded.

4 The reported shear strengths for the hand penetrometer and hand vane shall be the average of 3 tests in close proximity. Tests giving inconsistent results shall be reported and comments on the relevance of the tests noted.

5.3.6 Self-boring Pressuremeter

1 The equipment shall be of the Cambridge type (soft ground) self-boring pressuremeter (SBP) unless otherwise designated. The instruments, calibration, operator, installation, testing procedure, on-site data processing and analysis, information to be submitted, report data processing and analysis and information to be submitted in the report shall be as described by Clarke and Smith (1992) and as designated.

NOTE: Table 33 of BS5930:2015 provides a guideline of the applicability and usefulness of various in-situ tests.

5.4 INSTRUMENTATION AND MONITORING

5.4.1 Groundwater

1 When groundwater is encountered in exploratory holes, the depth from ground level of the point of entry shall be recorded together with depth of any casing. Exploratory hole operations shall be stopped and the depth from ground level to water level recorded with an approved instrument at 5 minutes intervals for a period of 20 minutes. If at the end of the period of 20 minutes the water level is still rising, this shall be recorded together with the depth to water below ground level, unless otherwise instructed by the Engineer, and the exploratory hole shall then be continued. If casing is used and this forms a seal against the entry of groundwater, the Contractor shall record the depth of casing at which no further entry or only insignificant infiltration of water occurred.

2 Water levels shall be recorded as required by the Contract and at the beginning and end of each shift. On each occasion when groundwater levels are recorded, the depth of the exploratory hole, the depth of any casing and the time shall also be recorded.

3 Where artesian conditions are encountered, the Contractor shall immediately inform the Engineer and agree a method for dealing with the conditions.

5.4.2 Installation of Standpipes and Piezometers

1 Standpipes for monitoring groundwater levels and changes in groundwater levels shall be installed in exploratory holes, as instructed by the Engineer. They shall be to the designated form and detail, and appropriate dimensions and depths shall be recorded at the time of installation.

2 Standpipe piezometers for monitoring groundwater levels in exploratory holes shall be installed as instructed by the Engineer. They shall be to the designated form and detail, and appropriate dimensions. The installation details of the standpipe piezometers shall be recorded.

3 The Contractor shall install piezometers of the hydraulic, electrical or pneumatic type described in BS 5930 or as designated by the Engineer.

5.4.3 Installation of Gas Monitoring Standpipes

1 Standpipes for monitoring gas concentration in exploratory holes shall be installed as instructed by the Engineer. Warning signs or other safety measures required by the General Civil Defence Department of the Government shall be complied with. Standpipes shall be of the designated form and detail. All dimensions and depths shall he recorded at the time of installation.

5.4.4 General Geotechnical Instrumentation

1 Geotechnical instrumentation and monitoring, refers to in-situ installed devices that will enable, through monitoring, the understanding of the ground and groundwater behaviour/conditions, allowing an optimized design, quality control, and risk management in relation with geotechnical constraints (excavation slopes, foundations, shoring systems, dewatering…etc.).

2 Reasons for Instrumentation

(a) Instruments are used to characterize the initial site conditions. Common parameters of interest in a site investigation are pore-water pressure, permeability of the soil and slope stability among others.

(b) Instruments are used to verify the design assumptions and to check that performance is as predicted.

(c) Instruments are used to monitor the effect of construction. Instrument data can help the engineer to determine how fast construction can proceed without the risk of failure.

(d) Instruments can be used to confirm the quality of the work.

(e) Instruments can provide early warning for impending failures, allowing time for safe evacuation of the area and time to implement the remedial action.

3 Choosing Instrumentation

(a) Each project presents a unique set of critical parameters. The designer must identify those parameters and then select instruments to measure them. The behavior of a soil or rock mass typically involves not one, but many parameters. In some cases, it may be sufficient to monitor only one parameter, but when the problem is more complex, it is useful to measure a number of parameters and to look for correlation between the measurements.

(b) Ground conditions sometimes affect the choice of instrument. For example, a standpipe piezometer is a reliable indicator of pore-water pressure in soil with high permeability, but is much less reliable in soil with low permeability. Temperature and humidity also affect instrument choice. In tropical heat and humidity, simple mechanical devices may be more reliable than electrical instruments.

(c) An automatic data acquisition system is required when there is a need of real time monitoring or the sensors are located at a remote site or in a location that prevents easy access.

(d) Groundwater Monitoring Wells and Standpipe Piezometers shall be installed as per ASTM D5092/D5092M or the latest version of ASTM relevant specs. The construction method should protect the different groundwater layers (i.e. groundwater on top and below the less permeable layer of MIDRA SHALE) so it can give accurate readings of the groundwater levels and prevents mixing groundwater of different layers.

(e) The following table summarizes the applications and corresponding instruments to be used. This is only a guideline and not mandatory.

No.	***Measurement***	***Application***	***Instruments***
1.	Water level and Pore Water Pressure	• Determine safe rates of fill. • Predict slope stability. • Design and build for lateral earth pressures. • Design and build for uplift pressures. • Monitor the effectiveness of drainage schemes.	• Piezometer
2.	Lateral Deformation	• Evaluate the stability of slopes and embankments • Determine the need and timing for corrective measures. • Verify the performance and safety of structures such as retaining walls and embankments	• Inclinometer
3.	Settlement and Displacement	• Verify that soil consolidation is proceeding as predicted. • Predict and adjust the final grade of an embankment. • Verify the performance of engineered foundation • Determine the need and timing for corrective measures.	• Extensometer • Settlement Plates • Surveying
4.	Crack Movement	• To provide early warning of performance problems	• Crack meter

5.	Tilting of structures	• Evaluate stability of structures. • Determine the need and timing for corrective measures. • Verify the performance and safety of structures.	• Tilt meter
6.	Pressure	• Verification of the distribution, magnitude, and directions of total stresses in an embankment or in the clay core of a dam. • Confirm that tailings material is densifying at design rate. • Estimate overburden pressure acting on foundation.	• Pressure cell
7.	Load	• Verify the performance of tiebacks, rock bolts, and other anchor systems • Verify the load value with the pressure gauge.	• Load cell
8.	Strain	• Verify the structural members of buildings and bridges during and after construction. • Determine the strain in tunnel linings and supports. • Determine the areas of concentrated stress in pipes. • Verify the load distribution along the pile shaft.	• Strain Gauge

Reference: “Geotechnical Instrumentation for Monitoring Field Performance”, by John Dunnicliff.

NOTE: Long term monitoring instrumentation should be done on project basis and cannot be mandatory for all projects.

END OF PART