# SPECIFICATION FOR INSTRUMENTATION AND MONITORING OF RETAINING STRUCTURES AND EXCAVATION

## 1.0 GENERAL

Instrumentation shall be installed to measure wall and soil movements, water table, anchor load and vibration. Instrumentation is part of the permanent works and shall remain in good condition and operational both during and after the construction contract, unless as agreed by the Engineer.

The Contractor shall be responsible for and shall follow the instructions of the manufacturer and the requirements of this specification in the installation, calibration and testing of all measuring instruments and equipment, which shall be carried out under the direct supervision of the Engineer unless agreed otherwise. The Contractor shall inform the Engineer at least 2 days prior to undertaking installation of the equipment. The Contractor shall make due allowances in his construction programme for delay which may arise on account of the installation of the instruments and of their maintenance.

The Contractor shall satisfy himself that the drillhole locations for the instrumentation are free from existing services prior to commencement of drilling. In order to avoid any utilities and services, the required drillhole positions may be adjusted on the site to the approval of the Engineer. For any damage and any claims arising from such damage, Contractor shall make every effort to make good the damage or have the damage made good as quickly as possible.

## 2.0 PROTECTION AND MAINTENANCE OF INSTRUMENTS

The Contractor shall take all necessary precautions to protect the instruments and maintain the instruments in good working order after commissioning. For all instruments that project through and above the ground, special precautions must be taken to provide protection from vehicles and plant including substantial and readily visible barriers at a distance of 750mm around each instrument. Heavy compaction equipment shall not approach within 1.5m of projecting instruments. Damaged instruments shall be replaced or repaired by the Contractor at his own expense within three days unless otherwise agreed by the Engineer.

## 3.0 STABILISING ELECTRONIC READOUT DEVICES

All electronic readout devices and transducers shall be shaded from direct sunlight during use. Probes which are used inside access tubes shall be placed inside the tube and allowed to come to a stable temperature for at least 10 minutes before use. Zero or starting values shall only be taken once temperature stabilisation is complete.

## 4.0 PERSONNEL

Personnel involved in the installation and monitoring of instrumentation shall consist of the following:-

**Instrumentation Engineer**
- at least 3 years experience of instrumentation using the equipment to be installed.

**Senior Instrumentation Technician**

- at least 2 years experience of instrumentation using the equipment to be installed.

**Junior Instrumentation Technician**
- fully trained in the installation and monitoring of the equipment to be installed.

The instrumentation engineer shall be responsible for the overall planning, implementation and monitoring of the instruments. He shall be on site throughout installation, commissioning and initial monitoring. His time on site shall be spent 100% on instrumentation. He shall be involved in the remaining monitoring on a basis to be agreed with the Engineer which shall include at least 20% attendance on site.

The Senior instrumentation technician shall be on site throughout installation, commissioning and all monitoring. He shall be assisted by sufficient junior technicians to meet the required programme of installation and monitoring, and shall ensure that all instrumentation works and monitoring is either carried out by or supervised by a suitably experienced technician.

The Contractor shall submit names and curricular vitae of personnel to carry out the instrumentation and monitoring and a programme of their attendance for the approval of the Engineer. Deviation from the approved programme of attendance or the requirements given in this Clause shall only be permitted with the approval of the Engineer.

## 5.0 BOREHOLES FOR INSTRUMENTS

Boreholes for instruments may be drilled by approved method provided that it results in a clean and stable hole of the required diameter to the correct depth. Boreholes shall be cased to their full depth unless strata are sufficiently competent for the hole to stay open under dry conditions. Boreholes shall be drilled using clean water. Drilling mud or polymer additives shall only be used with the approval of the Engineer. In the case of installation of piezometers, drilling mud or polymer additives shall not be permitted.

During drilling care shall be taken to ensure that minimum material is lost from outside the casing. Surging of casing shall not be allowed, and flushing of drilling water up the outside of the casing shall be minimised.

The method of forming boreholes, including the procedure for advancing casing, shall be submitted to the Engineer for approval before commencement of the works.

## 6.0 GROUTING OF BOREHOLES

For all instruments placed in boreholes, grouting is required of part or all of the borehole during installation. The grout shall be a bentonite : cement mixture with sufficient water to achieve a pumpable mix. The proportions of the mix shall be such as to imitate as closely as possible the strength or consistency of the natural soils present. The Contractor shall conduct trials on different mixes of bentonite : cement (from 4:1 to 8:1) to ascertain the relationship with strength. Specimens shall be cured and stored, then tested in undrained triaxial compression after 1 day, 2 days, 7 days, 14 days, 1 month and 3 months. 3 specimens shall be tested on each occasion, and the sources of bentonite and cement shall be the same as used for eventual installation. On the basis of these trials, the Engineer shall decide on the bentonite : cement proportions to be used, which may be varied depending on the application. Grout shall be poured or pumped into boreholes using a tremie pipe.

For inclinometer installed in the wall, the annulus between inclinometer access tube and wall shall be filled up with neat grout of grade 35.

## 7.0 LABELLING AND MARKING OF INSTRUMENTS

All instruments shall be labelled with their reference number at the location where readings or

measurements are taken. The labelling shall be permanent using a method or material to be agreed with the Engineer.

## 8.0 SURVEY EQUIPMENT

All surveying equipment used in conjunction with the monitoring of instrumentation, including measuring tapes, precise levels and theodolites shall be maintained and calibrated as required by the manufacturers. Certificates of calibration for all equipment shall be submitted to the Engineer and approved by the Engineer prior to carry out the field work.

## 9.0 TEMPORARY BENCHMARK AND DEEP LEVELLING DATUM

The temporary benchmarks (TMB) shall be installed at the nearby structure which is on end bearing piles and remote from the excavation area. At least 4 numbers of TMBs surrounding the site shall be established prior to work at site. The levels for all TBMs shall be checked/survey every three months or sooner as directed by the engineer. If no nearby structures on piles, a deep datum is required to provide a reference for measurement of ground levels. The datum itself is fixed into deeper firm ground and isolated from soft and compressible overlying strata. The Contractor shall be responsible for establishing a deep datum at locations, and with depths and details as specified by the Engineer.

A deep datum shall consist of a minimum diameter 25mm galvanised steel pipe fixed into firm ground with cement grout. The datum pipe shall be isolated from the overlying soft ground by a 75mm galvanised steel pipe bedded into the top of the cement grout. The Upper part of the 75mm pipe shall be surrounded by a square concrete plinth of not less than 0.06 cu.m. of concrete. The details of the equipment are shown on the drawing. The concrete shall be scored with the reference number of the datum.

The level value of a deep datum shall be established by standard levelling techniques from agreed bench marks in the vicinity. Levelling shall be closed back to the temporary bench marks to check the accuracy. The level shall be measured three times soon after installation of the datum, and shall be checked at intervals to be established by the Engineer.

## 10.0 INSTALLATION AND MONITORING

### 10.1 Settlement Markers

Details of settlement markers shall be as shown in the drawings. The contractor shall install settlement markers in locations indicated in the drawing or as directed by the Engineer.

Levels of the top of the rods of settlement markers shall be measured using precise levelling unless otherwise directed by the Engineer. The datum used shall preferably require only one set up of the level, and levelling shall be closed back to the datum.

### 10.2 Displacement Markers

Details of displacement markers are similar to settlement markers. For displacement markers, horizontal location of the top of the rod shall be measured by taping from a suitably located survey station or control point. If direct taping is not possible then other surveying techniques shall be used as agreed with the Engineer.

For survey stations, level and plan location of the top of the rod shall be established using agreed survey control. The measured values shall be checked using the agreed control at intervals to be agreed with the Engineer.

## 10.3 Inclinometers

The Contractor shall install inclinometer at locations, and with depths and details as specified by the Engineer. The inclinometer access tube shall be installed inside the wall (diaphragm wall, bored pile, secant pile etc.) unless otherwise directed by the Engineer. The toe of the inclinometer access tube shall be at least 1.5m below the toe of the wall. The Contractor shall make sure the construction of the wall do not cause damage to the inclinometer access tube and vice versa. If the inclinometer access tube is damaged, a new tube shall be installed to the satisfaction of the Engineer.

Inclinometer access tube shall consist of broached PVC tubing with four keyways set at right angles to each other and shall be supplied in 3.0m lengths with 0.3m long couplings and end caps. The spiral twisting of the keyways shall not exceed 0.75 degrees per metre length of the tubing. The grooves in each section of tube shall be accurately aligned using the alignment tool supplied before fixing the joint. Where necessary, the Engineer may instruct the Contractor to obtain spiral metric measurements of the keyways in the inclinometer tubing after installation. Each joint shall be completed using eight equally spaced pop revets supplied. After assembly joints and rivets shall be coated in sealing mastic and wrapped in sealing 'silver duct' tape. All joints must be watertight. The inclinometer access tube shall be assembled as it is inserted into the reinforcement cage using the couplings and pop revets supplied. The keyways shall be orientated such that movements are measured parallel to and right angles to the excavation face.

The bottom section of tube shall be fitted with a protective cap reveted in a similar manner to the tube joints. The cap fitting and all joints shall be made watertight using 'silver duct' tape or other means approved by the Engineer.

When the inclinometer access tube has been installed to the specified base elevation it shall be tested and proved to the Engineer that the sensor probe will run freely the full length of the tube. If any obstruction is found, the tube shall be removed and made good by the Contractor. When the tube has been found satisfactory, it shall be completely filled with clean water.

The annulus between the inclinometer access tube and the hole drilled in the wall shall be grouted. The grout shall have a minimum compressive strength measured on 100mm cubes of 20 $N/mm^2$ at 3 days and 35 $N/mm^2$ at 28 days. The grout shall be placed by pumping through a hose or pipe inserted to the full depth of the borehole and withdrawn as the annulus is filled. Initial grouting shall be completed in one operation and shall not cease until all water and diluted grout has been expelled from the top of the borehole. Immediately upon completion of grouting, the inside of the casing shall be flushed by passing a hose with clean running water to the full depth of the casing to remove any grout which may have entered.

For inclinometers installed in the ground behind the wall, the annulus between the inclinometer access tube and the borehole in the ground shall be grouted following Section 6.0 of this specification.

One or two days after initial grouting the level of grout in the borehole shall be checked and topped up to ground level if necessary. When the grout has set, a concrete pad shall be cast around the top of the casing. A removable protective cap with locking facility shall be fitted to the top of the casing and additional permanent protection shall be installed by the Contractor as required by this Specification. Equipment necessary for taking measurements from the inclinometer casing comprising sensor probe, cable, cable reel, data logger and indicator will be the responsibility of the Contractor.

Angular movements shall be measured by an inclinometer torpedo which shall be a biaxial type with a gauge length of 500mm, and the system shall be capable of measuring lateral deformation to an accuracy of ±10mm over a depth of 30m. The casing of the inclinometer probe shall be constructed of stainless steel and the probe shall be fully waterproof and corrosion proof. The inclinometer probe shall be supplied with a rigid carrying case fully lined with shockproof padding. The cable supplied for use with the inclinometer shall be a polyurethane sheathed cable with a minimum length of 50m, incorporating a central kelvar

straining wire. The cable shall be graduated in intervals of 500mm and shall be supplied complete with a portable cable reel.

The inclinometer data logger unit shall display the readings from the inclinometer torpedo on an alphanumeric display. The readout unit shall be powered by a re-chargeable battery with a minimum life of 12 hours continuous use between charges. A suitable automatic battery charger shall be supplied with the readout unit. The readout unit shall incorporate an RS232C port and a solid state data storage unit with the capacity to store at least 30000 readings directly from the inclinometer probe together with time and date of reading. The following facilities are also required within the readout unit:

a. Scan stored data.
b. Display of face errors as readings are being obtained.
c. Display of mean deviation and cumulative deviation of any one set of readings.
d. Graphical display of displacement profile between any two sets of readings.
e. Backlit LCD display.

A calibration frame shall be supplied to enable the inclinometer calibration to be checked at vertical and 10 degrees either side of vertical.

Immediately before or after taking a series of readings, the level and position of the top of the access tube shall be measured by standard levelling techniques. Before passing the torpedo down the access tube, a dummy torpedo should be lowered to the base of the tube and pulled up to check for obstructions or constrictions. The inclinometer torpedo shall then be lowered to the base of the access tube and raised taking readings every 0.5m until the torpedo reaches the top. The readings shall be read by and stored in the data logger. The procedure shall be repeated on the opposite face following the manufacturer's method and sign convention.

## 10.4 Load Cell

The Contractor shall install load cell at ground anchor head to monitor anchor load variation during excavation and blasting. The locations of load cell will be determined at site by the Engineer.

Vibrating wire load cell or any other approved type shall be hollow centrally with inner diameter not less than 100mm. The load range shall be at least 2.5 times the working load of the ground anchor. The load cell must be waterproofed for field use and material of the members shall be corrosion free or made from aluminium alloy.

The Contractor shall installed the load cell before prestressed and lock the ground anchor. The load cell shall be placed centrally to reduce errors that result from load misalignment and off-centre loading. Initial cell readout must be taken immediately after the installation complete.

The Contractor shall take all necessary protection to prevent damages to the cell throughout his contract period. If the cell is damaged, he shall immediately replace it at his own cost.

A copy of original certificate of calibration must be submitted to Engineer prior to the installation. The certificate is considered expired if the calibration was carried out more that 6 months ago.

The Engineer will reject any cell if the accuracy of the cell exceeds the allowable range.

## 10.5 Magnetic Extensometer

Magnetic extensometers provide a method of measuring settlement or heave at a point or a series of points below the ground surface. The Contractor shall install magnetic extensometers at locations and with depths and details as specified by the Engineer.

The magnetic extensometer shall consist of an access tube and a series of magnetic targets which are free to slide down the tube, together with a datum magnet which is fixed to the tube near its base. The access tube shall be a rigid PVC tube 33.5mm o.d. and 24.5mm i.d. with

threaded ends which provide both an internal and external flush coupling. A rigid PVC endcap shall be fixed to the lower end of the series of tubes. Compression/extension tubes shall be provided where required by the Engineer. All joints shall be sealed with a suitable PVC solvent cement.

The compression/extension tubes shall allow axial movement of access tubes to minimize distortion due to vertical strain. The tubes shall have treaded ends to provide an internally and externally flush coupled joint. The smaller diameter end tubes are fitted with 'O' rings or equivalent, and are free to slide within the larger diameter central cylinder. The minimum allowable compression and extension length shall not be smaller than 0.6m and 1.0m respectively.

A datum ring magnet shall be fixed approximately 2m above the lower end of the tube. Spider magnets shall be used within the subsoil, and plate magnets within fill where magnets can be placed during construction.

The tubes and magnets shall be assembled prior to installation in such a way that the magnets remain in the correct position in relation to the tube. The tube shall be coated with a thick grease over its upper part where it passes through compressible subsoils. It shall then be lowered together with all magnets and necessary accessories fixed in position into a 100mm diameter borehole backfilled with a suitable bentonite : cement grout mix of equivalent strength of the surrounding soil. Once in position the spider magnets shall be released.

Where the access tube passes through upper stiff crusts or fill material, it shall be sleeved by a larger diameter tube so that it can pass freely through these materials as settlement takes place. Where the access tube passes through fill which is being placed, the access tube and outer sleeve shall be extended as filling progresses. The top of the access tube, and the larger diameter sleeve where present, shall be protected with a suitable cover with facility for locking.

The readout device shall consist of a nickel plated brass probe containing a reed switch encapsulated in silicone rubber. The probe shall be connected via a nylon coated steel tape to a reel buzzer.

Magnetic extensometers shall be monitored by passing the probe down to the base of the access tube. The probe shall then be pulled upwards measuring the position of each magnet from the top of the tube. The position of each magnet shall be measured twice, once while moving upwards and once while moving downwards towards the magnet. Immediately before or after taking a series of readings, the level of the top of the access tube shall be measured by standard levelling technique.

## 10.6 Combined Inclinometers and Magnetic Extensometers

Combined inclinometers and magnetic extensometers provide a method of measuring both vertical settlement and horizontal displacement at a series of points below the ground surface.

The Contractor shall install combined inclinometers and magnetic extensometers at locations, and with depths and details as specified by the Engineer.

This specification should be read in conjunction with the specifications for inclinometers and magnetic extensometers; and only specifies requirements where they differ from the individual systems.

The access tube shall be telescopic inclinometer access tube, and magnetic targets shall be suitable for use with this tube .

The magnets shall be positioned in relation to sleeved joints such that they can move downwards without obstruction sufficiently to monitor the expected settlement. The borehole shall be 150mm diameter or size agreed by the Engineer.

## 10.7 Standpipes

Standpipes provide a method of monitoring the water table, or ground water level close to ground level. The Contractor shall install standpipes at locations and with depths and details specified by the Engineer.

Standpipes shall consist of a 25mm UPVC tube 2mm thick with an end cap and slotted over its lower around half of the tube circumference, and located every 50mm over the slotted part of the tube. The slotted part of the tube shall be wrapped in Terram 1000 filter fabric or equivalent.

The standpipe shall be placed in a 100mm diameter borehole backfilled with a graded filter sand (600 to 1200 microns) to the depth indicated. The top of the hole shall be sealed with bentonite pellets, and with a concrete plug. A protective cover shall be set into the concrete with caps and air vents.

Before taking initial readings the Contractor shall stabilise the standpipe by alternately baling and filling at least 10 times. The Contractor shall then carry out a simple falling head test and measuring the water level over a period of not less than 60 minutes.

Depth to water in the standpipe shall be measured using a dipmeter. The dipmeter shall be of the electric type, but simple metal probes attached to nylon cord may be used with the approval of the Engineer for shallow depths.

## 10.8 Standpipe Piezometers

Standpipe piezometers give a measurement of water pressure at a specific depth within a soil profile. They are generally used in soils of medium to high permeability. The Contractor shall install standpipe piezometer at locations, and with depths and details as specified by the Engineer.

Standpipe piezometers shall be installed as shown in the drawing. The piezometer tip shall consist of a porous ceramic or plastic element not less than 150mm long with a diameter not less than 30mm, and shall be protected at each end by unplasticised polyvinychoride (UPVC) fittings. The UPVC tubing shall be according to B.S. 3506 class 6 nominal size 3/4 inch, and shall be supplied and installed in not less than 3m lengths expecting for one shorter length as required to suit the total standpipe dimensions.

The filter element shall have a pore diameter of the order of 60 microns and a permeability of the order of 0.0003 m/s. The tubes shall be jointed together and to the porous element with threaded couplings, tape and glue in such a manner that the joints remain leakproof under the anticipated head of water. The tube should have at least 12mm internal diameter to allow air bubbles to rise freely.

The standpipe piezometer shall be installed in a 100mm diameter borehole. The sand filter surrounding the porous element shall be clean and fall between the limits of grading 600 and 1200 microns. The Contractor's arrangements shall ensure that no sand adheres to the soil in the sides of the unlined borehole. If there is water in the borehole the Contractor shall allow sufficient time for all the sand to settle. The final elevation of the top of this sand shall be recorded. The porous element shall be placed in the hole and the remaining sand filter shall then be added as described above. The final elevation of the top of the sand filter shall be measured by a flat-ended sounding rod. A sufficient number of soil samples shall be taken from the drillhole to accurately determine the subsurface profile and allow selection by the Engineer of appropriate tip levels for the piezometers.

Seals consisting of bentonite pellets shall be placed above, and if necessary, below a sand filter. The plug shall not be less than 1.0m thick. The remainder of the hole shall be filled with a bentonite : cement grout, and the top part with concrete with caps and air vents as indicated on the drawing.

Before taking initial readings the Contractor shall carry out a simple falling head test by raising the water level 1.5m above the static level, using an extension pipe if necessary, and measuring the water level over a 60 minutes period.

The depth to water in standpipe piezometers shall be measured using a dipmeter. The dipmeter shall be of the electric type, but simple metal probes attached to nylon cord may be used with the approval of the Engineer for shallow depths.

## 10.9 Pneumatic Piezometers

Pneumatic piezometers are used to measure water pressures at specific depths within variety of soil types. The Contractor shall install pneumatic piezometers at locations, and with depths and details as specified by the Engineer. Three methods of installation are described in this specification and the Engineer shall indicate which method is to be used.

Pneumatic piezometer tips shall be of high air entry ceramic type with an average pore diameter of 1 micron using marine brass or stainless steel bodies. The piezometer system shall be capable of measuring water pressures to an accuracy of ±0.2m head of water in the range 0 - 35m head of water.

The piezometers shall be connected to tubing comprising suitably coded twin 1.9mm i.d. and 3.2mm o.d. Type 11 nylon tubes and covered with a polythene sheath 1mm thick. Joints in the tubes other than at the piezometer tip or at the terminal panel shall not be permitted. The tubes from individual piezometers shall be colour-coded and marked every 3m. The tubing shall be connected either to suitable quick release couplings or a terminal panel which shall be housed in a lockable steel cabinet.

The arrangement of the equipment and the three methods of installation are shown in drawing.

**Installation in a sand pocket :**

The pneumatic piezometer shall be installed in a 100mm diameter borehole. The sand filter surrounding the porous element shall be clean and fall between the limits of grading 600 and 1200 microns. The Contractor's arrangements shall ensure that no sand adheres to the soil in the sides of the unlined borehole. Where there is water in the borehole the Contractor shall allow sufficient time for all the sand to settle. The final elevation of the top of this sand shall be recorded. The porous element shall be placed in the hole and remaining sand filter shall then be added as described above. The final elevation of the top of the sand filter shall be measured by a flat-ended sounding rod.

Seals consisting of bentonite pellets shall be placed above, and if necessary, below the sand filter. The remainder of the hole shall be filled with a bentonite: cement grout.

**Installation by pushing into the base of the borehole :**

The 100mm diameter borehole shall be terminated 0.3m above the required position of the piezometer tip. The piezometer tip with cable attached shall be pushed into the base of the borehole to the required depth using an arrangement of sufficiently stiff tubes. The borehole shall then be sealed with bentonite pellets and bentonite : cement grout. The piezometer tip should be properly deaired and applied with glycerine.

**Installation in the drainage blanket :**

For pneumatic piezometers installed in the bottom of the drainage blanket, an arrangement shall be used as shown in the drawing. The piezometer tip shall be placed in a container filled with graded sand between 600 and 1200 microns, and water. The water level shall be up to the top of the container which shall be open. The

container shall be placed at the base of the drainage blanket and sand shall also be placed immediately around and above the container.

The piezometer leads shall either be connected to quick release couplings set inside a suitable cover, or be taken to a terminal panel fixed inside a lockable steel cabinet. The cabinet shall be set on a concrete plinth typically 0.6x1.0x0.3m thick (plan dimensions may be adjusted to suit the cabinet size). Where cables are laid in trenches the backfill shall be sand. The cable shall be laid with sufficient slack to take up any lateral movements that are expected to occur due to settlement of embankments or structures.

The pneumatic readout unit shall be capable of storing 500 readings and shall incorporate an electronic pressure transducer, backlit digital display, RS232C interface and cable link, rechargeable battery providing at least 12 hours continuous are between charges, a rechargeable gas reservoir bottle, a reservoir pressure gauges, return +flow indicator, flow control valve and quick release self sealing leads for connection to the supply and return manifolds of the terminal panel. The readout unit shall be housed in a rigid weatherproof case with carrying handles and shall be capable of resolving readings to 1 kPa. An automatic charger for the readout unit battery shall be supplied suitable for 240V, 50HZ electricity supply. The Contractor shall make facilities available for recharging the gas reservoir with nitrogen.

Before installation and taking initial readings the Contractor shall pressure test the pneumatic piezometer tip in a container of water after connection to the tubing with a pressure of 500 kPa to check for leaks or poor connections. The ceramic element shall be deaired under vacuum and precautions shall be taken to ensure that it remains saturated during installation. During installation readings shall be taken when the piezometer tip is lowered down the borehole, when it is pushed in or placed in the sand pocket and at various times after installation to check the response of the piezometer and help find the static pressure value before the initial base readings are taken.

Readings shall be taken by and stored on the readout device. Care shall be taken to ensure that the flow and return leads are connected correctly.

## 10.10 Building Settlement Marker

Vertical deformation of adjacent structures shall be determined by means of precision devices to an accuracy of +/- 0.5mm. The Contractor shall install building settlement points at locations as specified by the Engineer.

The precise levels shall have robust tripods. Levelling studs are to be provided for the purpose of precise levelling. Levelling studs shall be:

a) Manufactured from stainless steel, grade 316 S13 to BS970: Part 1 or equivalent.
b) Fixed to the building linings in the same manner and standard.
c) Designed such that their use in conjunction with the appropriate precise instruments allow precision levelling to an accuracy of +/-0.5mm.
d) Designed such that the heads of the levelling studs on the walls can be easily levelled without the studs being vulnerable to damage.
e) When locating levelling rods and staffs onto levelling rods and staffs onto levelling studs, care shall be taken to ensure that the surface in contact is clean. Proper access shall be provided to the crown levelling studs for cleaning during surveying operations.

## 10.11 Tilt-meters

Tilt-meter shall be used to monitor changes in the inclination or rotation of structures and to provide an accurate history of movement and early warning of potential structural damage.

Tilt plates shall be mounted on the structure at locations specified by the Engineer. They must be either securely bonded using an approved rapid setting epoxy adhesive compound or screwed to

the surface of the structure. Extra care shall be taken to ensure proper alignment of the tilt plate to the required orientation.

The tilt-meter system shall include the required number of tilt plates, the portable tilt-meter and a readout unit. Tilt plates must be dimensionally stable and weather resistant. The portable tilt-meter shall be in metric unit system and housed in a rugged frame with precise machined surfaces to facilitate accurate positioning on the tilt plate which may be mounted horizontally or vertically as specified by the Engineer. The readout unit to be used must be suitable for the abovementioned tilt-meter unit and applications and shall be of a rugged, weather-proof design with easy to read display and rechargeable battery or equivalent. Sufficient length of jumper cable shall be provided for connecting the tilt-meter to the readout unit. The tilt-meter shall conform to:

| | |
|---|---|
| Range | +/- 30° from vertical |
| Resolution | 8 arc seconds |
| Temperature Coefficient | +/- (0.05% of reading + 5 arc seconds)/ °C |

Tilt reading shall be taken by positioning the tilt-meter on the tilt plate and connecting the tilt-meter to the readout unit. At least two readings shall be taken by rotating the tilt-meter at $180^0$ for each reading.

### 10.12 Accelerometers

For works involve vibration due to use of explosive or other means, accelerometers will be required. Details to be given in the Tender Document.

## 11.0 INSTRUMENTATION RECORDS

### 11.1 Commissioning and Base Readings

After installation, the functioning of each instrument shall be demonstrated to the Engineer, including the recording of measured values using the appropriate readout device. As part of the commissioning, three sets of readings shall be taken and compared. When instruments are installed before earthwork starts, then these three sets of readings shall also be taken before construction starts. If there are significant differences or anomalies, then further readings shall be taken. Once three sets of comparable readings have been taken, these shall be averaged to form the base readings, representing conditions before construction starts.

In cases where instruments are installed during construction, three sets of readings shall be taken in quick succession and the results compared. These results shall be used to provide base readings in a manner to be agreed with the Engineer.

### 11.2 General Information on All Records

All records of instrumentation, either installation, readings or monthly summaries, shall contain the following information :-

- Project name
- Contract name and number
- Instrument reference number and type
- Dates of installation, reading or summary
- Times of installation or reading
- Chainage and Offset (or coordinates if appropriate)
- Personnel responsible

- Relevant comments or remarks
- Reduced level

## 11.3 Installation Records

The Contractor shall prepare an installation record sheet for each instrument installed. The format of the sheet shall be prepared by the Contractor and submitted to the Engineer for approval at least one week before installation commences. The record sheet shall include the following information in additional to the general information required:

- Existing ground level at the time of installation
- Planned location in plan and elevation
- Planned orientation
- Planned lengths, widths, diameters, depths and volumes of backfill
- Plant and equipment used, including diameter and depth of any drill casing used
- Spaces for necessary measurements or readings required during installation to ensure that all previous steps have been followed correctly, including acceptance tests
- A simplified log of ground conditions (obtained during rotary wash boring)
- Type of backfill used
- As-built location in plan and elevation
- As-built orientation
- As-built lengths, widths, diameters, depths and volumes of backfill
- Weather conditions
- A space for notes, including problems encountered, delays, unusual features of the installation, and any events that may have a bearing on instrument behaviour
- A record of commissioning information, tests and readings
- Any colour coding used

The Contractor shall submit to the Engineer the specified number of copies of each installation report within one working day of completion on the installation, including taking of base readings.

## 11.4 Installation Reports

The Contractor shall submit an installation report once installation of all instruments is completed. Submission shall be within two weeks of completion including taking of all base readings. The report shall include :

- A text describing the scope of work, the site, the work carried out and the types of instrument installed
- All installation record sheets
- Plans and cross section drawings at a scale of 1:200 or other agreed scale showing the locations, elevations and details of all instruments
- Photographs of all the instruments used, illustrating installation and method of reading
- Values of all base readings taken together with any subsequent readings up to the time of submission

## 11.5 Readings

On each occasion that readings are taken from an instrument or set of instruments, the measured values shall be recorded on a record sheet. The format of the record sheet for each type of instrument shall be prepared by the Contractor and submitted to the Engineer for approval at least one week before readings commence. For readings that are recorded on data loggers, a record sheet shall be required giving references to the data stored. A computer system including interfaces, plotter, printer and software shall be available to make the data transfers, listings and plots required.

The format of plotted results shall be submitted to the Engineer for approval. Details of information and values to be stored on each record sheet in addition to the general information required are given below:

| Instrument | | Data required |
|---|---|---|
| Settlement marker | - | reduced level of top of rod (mRL) |
| | - | change in reduced level of top of rod relative to base readings and previous reading (mm) |
| Displacement | - | distance from fixed point (m) marker (details to be given) |
| | - | change in distance from fixed point relative to base readings (mm) |
| Survey station | - | offset, coordinates and reduced level of top of rod (m) |
| Deep datum | - | reduced level of datum (mRL) |
| | - | reduced level of toe (fixed point) (mRL) |
| Magnetic Extensometer | - | reduced level of top of access tube extensometers (mRL) |
| | - | reduced level of ground adjacent to access tube (mRL) |
| | - | distance of each magnet from top of tube (m) |
| | - | reduced level of each magnet (mRL) |
| | - | settlement of each magnet relative to base readings (mm) |
| Inclinometers | - | reduced level of top of access tube (mRL) |
| | - | reduced level of ground adjacent to access tube (mRL) |
| | - | horizontal movements of top of access tube by survey |
| | - | file name of data stored in data logger |
| | - | file name of data after transfer to floppy disk |
| | - | listing of deflection values and face errors every 0.5m |
| | - | graph and listing of horizontal movement of access tube relative to base readings against depth |
| | - | status of excavation and installation of support system including date and depth |
| Combined magnetic extensometer and inclinometer | - | as for magnetic extensometer and inclinometers |
| Load Cell | - | pressure ( psi ) |
| | - | load ( kN ) |
| Standpipes | - | depth of water from top of tube (m) |
| | - | reduced level of ground adjacent to standpipe (mRL) |
| | - | reduced level of top of tube (mRL) |
| | - | water head (mRL) |
| Standpipe piezometer | - | time and date |
| | - | reduced level of top of tube ( mRL ) |
| | - | reduced level of ground ( mRL ) |
| | - | depth of water from top of piezometer tube ( m ) |
| | - | water head ( mRL ) |
| | - | change of water head relative to base readings (m) |
| | - | water pressure readings (m water) |
| | - | daily weather chart |
| Pneumatic piezometer | - | file name of data stored in data logger |
| | - | file name of data after transfer to floppy disk |
| | - | reduced level of piezometer tip as installed (mRL) |

| | | |
|---|---|---|
| | - | estimated or measured settlement of piezometer tip (m) |
| | - | water head (mRL) |
| | - | change of water head relative to base readings (m) |
| Building Settlement marker | - | reduced level of centroid of point or stud (mRL) |
| | - | change in reduced level of centroid of point or stud relative to base readings and previous reading (mm) |
| Tilt-meter | - | time and date |
| | - | differential in pegs |
| | - | change in tilt with respect to initial reading |
| Accelerometer | - | file name of data stored in data logger |
| | - | file name of data after transfer to floppy disk |
| | - | positions of the accelerometer (coordinates and plan) |

The Contractor shall submit to the Engineer the specified number of copies of each record sheet with necessary listings and graphs within one working day of taking the readings unless otherwise directed by the Engineer.

## 11.6 Frequency of Measurement

Each instrument shall be read immediately before and after each stage of excavation or every week or at interval as agreed by the Engineer. During major excavation that required more than 1 day, monitoring shall be carried out daily or every alternate day for all instruments in the affected areas and the program shall be agreed by the Engineer. Any instruments found to be faulty shall be promptly brought to the Engineer's attention so that remedial measures can be carried out.

The Contractor shall monitor water levels in standpipe piezometers once daily for the first seven days after installation. Thereafter water levels shall be monitored at seven day intervals or as directed by the Engineer. During periods of continued rainfall, the water levels shall be monitored once daily for a duration as directed by the Engineer.

## 11.7 Anomalous Readings

Whenever sets of data are measured, they shall be compared to previous sets of data. If anomalous readings are present which differ from the expected value or trend, then further readings shall be taken immediately and the Engineer shall be informed. If the anomalous values persist, then the Engineer shall be informed and an investigation shall be carried out to find the reasons for the anomalous readings.

## 11.8 Monitoring Report

The Contractor shall submit a monitoring report every fortnightly. A proposal for the format of the report shall be submitted to the Engineer including all graphical presentations for approval at least one month before submission of the first report. Each fortnightly report shall include:

- a description of monitoring works which have been in operation during the preceding month
- information on reading anomalies or corrections, and factors which may influence measured data
- observations or remarks

- plan showing installed locations of instruments (taken from installation report)

- data tabulations or plots of instrument readings as given below. The Contractor shall have available suitable software for generating the required plots and tabulations. Zero time to be used in all plots and tabulations shall be agreed with the Engineer. The time axis shall be days from 'day zero', and an indication of date or months shall be included on the axis. The plots and tabulations presented each month shall be an update of the previous plots and tabulations, giving a complete record starting from the time of installation.

| Instrument | | Plots and Summaries required |
|---|---|---|
| Settlement marker | - | settlement vs time ( tabulation and plot ) |
| | - | settlement profile with distance from wall (tabulation and plot) |
| Displacement marker | - | displacement vs time indicating direction of movement (tabulation and plot) |
| | - | displacement profile with distance from wall (tabulation and plot) |
| Survey station | - | coordinates and reduced level (tabulation) |
| Deep datum | - | reduced level (tabulation) |
| Magnetic extensometer | - | settlement of each magnet vs time (tabulation and plot) |
| | - | settlement of each magnet vs depth for 4 latest sets of readings (tabulation and plot) |
| | - | settlement profile with distance from wall (tabulation and plot) |
| Inclinometer | - | latest graph and 3 other earlier graphs of horizontal movement of access tube relative to base readings against depth |
| | - | maximum horizontal movement relative to base readings vs time (tabulation and plot ) |
| | - | Important activity (e.g. depth of anchors installed, depth of excavation) should be plotted in the graph. |
| Combined magnetic extensometer and inclinometer | - | as for magnetic extensometers and inclinometers |
| Load cell | - | load vs time |
| | - | construction stage against time |
| Standpipes | - | water head (mRL) vs time (tabulation and plot) |
| | - | water level profile with distance from wall (tabulation and plot) |
| | - | changes of water head (tabulation and plot) |
| | - | Important activity like excavation or ground water pumping should be highlighted in the graph. |
| Standpipe piezometer | - | water head (mRL) vs time (tabulation and plot ) |
| | - | water level profile with distance from wall (tabulation and plot) |

| | | |
|---|---|---|
| | - | changes of water head (tabulation and plot) |
| | - | water head with depth for latest 4 sets of readings (tabulation and plot) |
| | - | Important activity like excavation or ground water pumping should be highlighted in the graph. |
| Pneumatic piezometer | - | water head (mRL) vs time (tabulation and plot) |
| | - | excess water head vs time |
| | - | water head vs depth for latest 4 sets of readings (tabulation and plot) |
| | - | water profile with distance from wall (tabulation and plot) |
| | - | Important activity like excavation or ground water pumping should be highlighted in the graph. |
| Building Settlement marker | - | building settlement vs. time (tabulation and plot) |
| | - | building settlement vs. monitoring stations (plot) |
| Tilt-meter | - | change in tilt (seconds) vs. time (tabulation and plot) |

All plots where time is the horizontal axis shall have the same scale for the time axis. Where fill thickness, settlement and excess water head are all available at the same location, the plots shall be combined on the same sheet where possible. Final layouts, scales and details shall be agreed with the Engineer at the time of submitting the format.

The Contractor shall submit the required number of copies of the monthly monitoring report to the Engineer within 7 working days of the end of the month being reported. If there are anomalies or sudden significant changes in the results, the Engineer should be informed within 1 day after monitoring.

**11.9 Presentation of Reading in Graphic Format**

The Contractor will have to submit to the Engineer for comment on the graphic presentation of the monitored readings. The presentation will have to be agreed by the Engineer prior to the field work. Hand plotted graphs are not acceptable.

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