KERAJAAN MALAYSIA
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STANDARD SPECIFICATION FOR ROAD WORKS

Section 20 : Ground Improvement

SECTION 20 – GROUND IMPROVEMENT

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20.1 DESCRIPTION

This work shall consist of numerous ground improvement techniques and the use of geotechnical instrumentation taking into account general requirements, method of installation and relevant testing to be implemented during construction.

20.2 REMOVAL AND REPLACEMENT

20.2.1 General

This Section shall be read together with JKR Standard Specification for Roadworks, Section 2: Earthworks. The work involves removal of unsuitable material and/or soft soil layer and replaced with suitable material as shown in the Drawing. Unsuitable material and suitable material are as defined in JKR Standard Specification for Roadworks, Section 2: Earthworks.

20.2.2 Determination of Depth of Removal

The depth of removal shall be as shown in the Drawing or as determined by trial pits or JKR/Mackintosh Probe test as approved by the S.O. The trial pits or probe test shall be carried out at locations as indicated in the Drawing or as instructed by the S.O.

The apparatus used shall be the standard JKR probe or Mackintosh probe. Procedure of works and details of the JKR probe and Mackintosh probe are as per JKR Standard Specification for Roadworks, Section 17: Site Investigation.

20.2.3 Materials for Replacement

Where geotextile is specified, it shall be laid as shown in the Drawing before commencement of filling works. The specification of geotextile shall be in accordance with Sub-Section 20.4.

Unless otherwise indicated in the Drawing, suitable materials for fill and method of compaction shall conform to JKR Standard Specification for Roadworks, Section 2: Earthworks.

For replacement of excavated material under standing water, the fill material shall be granular material conforming to JKR Standard Specification for Roadworks, Section 2: Earthworks.

20.3 SURCHARGE

20.3.1 General

The execution of surcharging works shall be in accordance with this Specification and details as shown in the Drawing.

The scope of works shall cover the following:-

a) Spread, level and compact surcharging material in accordance with JKR Standard Specification for Roadworks, Section 2: Earthworks and details as shown in the Drawing.
b) Install geotechnical instrumentation to monitor and validate the performance of the works.
c) Removal and disposal of excess material on completion of specified surcharge period or as shown in the Drawing or when directed by the S.O.
d) Removal and disposal of excess material of the embankment to the line, level and grade in accordance to details as shown in the Drawing to complete the works.

The Contractor shall be responsible for the provision of surcharge material and the removal and disposal of excess material on completion of the specified surcharge period or when directed by the S.O.

20.3.2 Materials

Materials for use in surcharging shall be suitable material conforming to JKR Standard Specification for Roadworks, Section 2: Earthworks.

The filling material shall be laid in layer and compacted as per JKR Standard Specification for Roadworks, Section 2: Earthworks.

20.3.3 Surcharge Load and Surcharge Period

The surcharge load shall be applied throughout the surcharge period. The surcharge period specified in the Drawing is subjected to validation from field monitoring results, which may be shortened or lengthened at the discretion of the S.O. based on interpretation of field monitoring results.

20.3.4 Stability of Embankment

The height of the embankment including the surcharge shall at no time exceed the specified height in the Drawing. The placement of the surcharge materials shall be in uniform layers and care shall be given to ensure stability of the embankment. The contractor shall check at all times the rate of placement and adjust accordingly in order to avoid instability.

Stockpiling of excess earth, machineries or any other materials shall not be permitted on the embankment.

Where counterweight berm is designed to enhance the stability of the embankment including the surcharge, the counterweight berm shall be constructed first prior to placement of surcharge material.

The width, height and slope gradient of the counterweight berms shall be constructed in accordance to details shown in the Drawing. Any remedial works arising from non-compliance of the requirements of this section which leads to embankment failure shall be borne by the Contractor at his own cost and time.

20.3.5 Drainage Blanket

The drainage blanket layer shall consist of clean sand with less than 10% of fine content passing the 75 μm sieve having grading within the respective limits specified in JKR Standard Specification for Roadworks, Section 2: Earthworks, Table 2.1.

The drainage material for depositing in water shall be deposited without the associated use of a compaction plant.

The drainage blanket shall be built up evenly in horizontal layers, each not more than 300mm thick up to the design thickness as specified in the Drawing. Filling shall commence from the lowest level, and each layer shall cover the full area of the intended total fill area at that level before deposition of the subsequent layer commences.

The drainage system shall be regularly maintained throughout the surcharge period to ensure smooth dissipation of water. The outlets of water at the brinks of drainage blanket shall be cleared of any obstruction at all times by way of regular maintenance.

20.3.6 Instrumentation

Surcharge monitoring shall be carried out to monitor stability, settlement, deflection and pore water pressure of the embankment due to Surcharging. The types and numbers of instruments and frequency of monitoring shall be in accordance to the Drawing or as specified by the S.O. Specification for Instrumentation shall be in accordance with Sub-Section 20.10.

The monitoring results shall be submitted to the S.O. according to the agreed frequency and shall form part of the surcharge control measures. Evaluation and amendments to the surcharging design may be carried out from time to time by the S.O. based on interpretations of the monitoring results.

The Contractor shall be responsible for and shall follow the instructions of the manufacturer in the installation, calibration and testing of all measuring instruments and equipment's.

20.3.7 Removal of Surcharge Materials

Removal of surcharge materials shall only be carried out as instructed by the S.O. upon completion of the specified surcharge period and validated with field monitoring results.

There shall be no unauthorized removal of surcharge materials before the completion of the specified surcharge period and any remedial works arising from such unauthorized removal of surcharge shall be borne by the Contractor at his own cost and time.

20.3.8 Use of Surcharging In Conjunction With Other Ground Improvement Methods

When surcharging is used in conjunction with other ground improvement methods such as prefabricated vertical drains, the works shall conform to the requirements of the associated ground improvement works.

20.4 GEOSYNTHETICS

20.4.1 General

Unless otherwise specified elsewhere in the specification or on the Drawing, geosynthetics used in ground treatment shall conform to requirements as specified herein.

Geosynthetics used shall be manufactured by manufacturer that is ISO 9001 certified.

Geosynthetics shall be durable and resistant to naturally occurring chemical, fungi and bacteria when in contact with soils or materials to be treated. In addition, geosynthetics used shall be resistant against rotting, mildew, insects, salts, alkali, solvent and other constituents of the ground water.

The contractor shall be responsible for the true and proper setting-out of the areas to which the geosynthetics are to be placed and provide all necessary resources and equipment related to supply and laying of geosynthetics to the correct level and dimension as shown in the Drawing or as instructed by the S.O.

20.4.2 Packaging, Transportation and Storage

Geosynthetics shall be wrapped in heavy paper or similar heavy-duty protection covering for transportation and storage. If no covered area is available, geosynthetics shall be stored on raised platform and covered with a waterproof canvas. Geosynthetics shall be protected from sunlight, moisture, mud, dirt, dust, debris and other detrimental substances during transportation and storage.

Each roll of geosynthetics delivered to site shall be clearly labelled with the following:-

i) Product brand name
ii) Product type
iii) Product grade
iv) Date of manufacture or submission of mill certificate
v) Roll width and length
vi) Batch serial number

The Contractor is solely responsible for the good condition of the geosynthetics stored at the worksite and in the event of damages or deterioration of the geosynthetics due to improper storage, the Contractor shall be liable to replace the affected materials at his own cost when directed by the S.O.

All materials which are damaged during transportation, handling or storage and do not meet the minimum requirements of the specification shall be rejected by the S.O. and shall be immediately taken off the site. No payment of any kind shall be made on the rejected product.

20.4.3 Quality Control and Testing

20.4.3.1 Submission of Material Test Report (MTR)

The contractor shall obtain the S.O.'s approval prior to supplying the geosynthetics to the site. Prior to the procurement of materials, the Contractor shall provide a sample and Material Test Report (MTR) not older than two (2) years from the ISO/IEC 17025 accredited laboratory with the scope of accreditation referring to geosynthetics, showing full compliance of the proposed geosynthetics to all the specified property values corresponding to their respective test methods for the approval of the S.O. The ISO/IEC 17025 accredited laboratory shall be an internationally recognized accredited laboratory or higher learning institutions research laboratory.

The Contractor shall also submit technical data and samples to verify the physical, mechanical and hydraulic properties of the geosynthetics to be used for S.O.'s approval.

All tests shall be carried out in accordance with the Codes of Practices and Test Standards provided within this Specification. All cost associated with the tests and preparation of the report shall be borne solely by the Contractor.

20.4.3.2 Routine Sample Testing

Routine sample testing shall be carried out at a factory or at an accreditated laboratory witnessed by the S.O.'s representative. The Contractor shall submit test report after each routine test showing compliance of the Specification.

Prior to installation and at the discretion of the S.O., sampling shall be carried out as specified in Table 20.1 and Table 20.2. Control tests shall be carried out for each batch of geosynthetics in accordance with the provisions of Table 20.1 and Table 20.2.

The individual specimen for testing shall not be less than two (2) meters in length for non-woven geotextile and one (1) meter in length for high strength woven geotextile and geogrid, times the full width of the geosynthetics. Samples submitted for tests shall indicate the linear meters of the geosynthetics and manufacturer's identifications represented by the sample.

Table 20.1: Sampling Frequency and Testing Requirements for Geotextile

Area of Geotextile (m^2)	Number of Rolls to be Sampled Representing the Area of Geotextile	Testing by the Contractor	
		Non-Woven Geotextile	High Strength Woven Geotextile
Initial 10,000 or part thereof	1	Tensile strength, Elongation, CBR puncture, Permeability, Effective Opening Size (O_{90}) or Apparent Opening Size (O_{95})	Tensile strength, Elongation
Each subsequent 100,000 or part thereof	1		

Table 20.2: Sampling Frequency and Testing Requirements For Geogrid

Area of Geogrid (m^2)	Number of Rolls to be Sampled Representing the Area of Geogrid	Testing by the Contractor
		Geogrid
Initial 10,000 or part thereof	1	Tensile strength, Elongation
Each subsequent 100,000 or part thereof	1	

Should any individual sample selected at random fail to meet the Specification, then the entire roll represented by the sample shall be rejected and two additional samples shall be taken at random from two other rolls representing the same batch. If either of these two additional samples fails to comply with the Specification, then the entire batch of geotextile represented by the samples shall be rejected.

20.4.4 Geotextile

20.4.4.1 General

Geotextile shall be made of new synthetic polymeric fabric that are stable or stabilized against ultra violet (UV) radiation such that three months exposure to sunlight shall not reduce its specified strength to less than 70%.

20.4.4.2 Installation

Prior to laying of geotextile, site clearance shall be carried out in accordance with the Specification and Drawing or as directed by the S.O. All voids shall be filled with suitable material including the area cleared of large stones and exposed tree root systems or other such like protrusions. Geotextile fabric shall be installed to the shape and requirements as specified herein and in the Drawing.

Geotextile shall be placed just in advance of placement of the specified overlying fill material. Geotextiles laid shall be covered by the fill as soon as possible within seven (7) days of being placed. The counting of this foresaid seven (7) days shall commence immediately upon the geotextile being exposed from its protective wrapping. Installation proposals and trials as deemed required shall be carried out for approval by the S.O. prior to the acceptance of the placement method for the main works.

The geotextile shall be unrolled smoothly on the prepared ground. In general, high strength woven geotextile shall be placed transversely, across the direction of the road, or otherwise as approved by the S.O. The geotextile shall be laid flat on the underlying surface with no wrinkles or folds, and shall extend far enough over the edges of the embankment for a wrap-around as shown in the Drawing.

Adjacent geotextile rolls shall be overlapped or sewn in accordance with this Specification. Overlapping of geotextile without sewn connections shall only be allowed with the approval of the S.O. On curves and corners, geotextile may be folded or cut to conform to the direction as approved by the S.O. The seaming of geotextile is as described in Sub-section 20.4.4.3.

The specified overlying fill material properties and method of compaction on the geotextile fabric shall be in accordance with JKR Standard Specification for Roadworks, Section 2: Earthworks. Fill materials shall be deposited in layers in accordance with JKR Standard Specification for Roadworks, Section 2: Earthworks and shall be spread simultaneously with the dumping in a manner to prevent any localized distress or failure of the ground.

No traffic shall travel directly on the geotextile and there shall be no sudden stops, starts or turns on the fill materials by the construction equipment or other such actions which may cause damage to the geotextile.

In water logged or swampy areas, the geotextiles shall be sunk after jointing by ballasting with sufficient sandbags. To control the location of the mattress, buoys shall be fixed with ropes on the edges of the geotextile or using other method as approved by the S.O. The mattress shall be ballasted as soon as possible after positioning.

The contractor shall submit a detailed method statement on installation of the geotextile to the S.O. for approval prior to commencing installation works.

20.4.4.3 Jointing of Geotextile

In general, the joints are allowed for both machine direction (MD) and cross direction (CD) of the non-woven or woven geotextile used in separation and filtration application.

Jointing of reinforcement geosynthethics such as high strength woven geotextile, geogrid etc. is only allowed in the CD for reinforced soil structures (reinforced soil wall/soil slope and mechanically stabilized embankment).

a) Methods of Jointing

There are two common methods to joint the geotextile, which are by overlapping or seaming. The decision to use an overlap or seam shall be based on the following: -

i) the weakness of the foundation soil upon which the geotextile is directly placed with respect to the potential for mud waving during backfill operation;

ii) the material and labour costs of deploying individual geotextile panels with extra material required for the overlap versus the material and labour costs of seaming and installing large, fabricated panels; and

iii) the feasibility of deploying individual geotextile panels in poor access and/or adverse climatic conditions.

Table 20.3 provides a guide in determining overlap requirements for separation/stabilization applications based on sub grade strength. When the sub grade soils upon which the geotextile is directly placed provides shear strength less than CBR = 0.5, the adjacent geotextile panels shall be seamed.

Table 20.3: Guidelines for Geotextile Overlap Requirements as a Function of (Foundation Soil) Strength
(AASHTO M288-06)

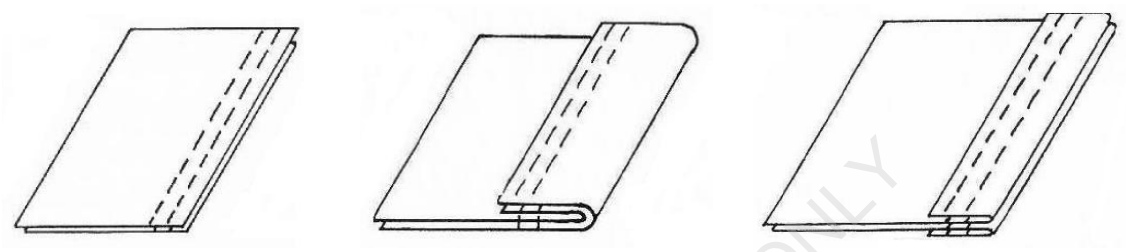
Soil CBR	Minimum Overlaps
>3	0.3 – 0.45 meters
1 – 3	0.6 – 1 meters
0.5 – 1	1 meter or seam
< 0.5	seam

b) Sewn Seams

The geotextile may be jointed using an approved handheld sewing machine by sewing a double thread ‘lock stitch’ with 'prayer' or ‘J’ or

'butterfly' seam (minimum lap of 50mm). Typically, polyester thread is used for seaming geotextiles. Minimum required density of stitches during sewing of the geotextile is 3 stitches per 25mm. The thread shall have a breaking load of not less than 200N.

The expected seam strength shall be more than 70% of the original strength of the non-woven geotextile. For high strength woven geotextiles, the expected seam strength shall be more than 30% of the original strength. Samples of such sewn seam assembly shall be tested in accordance with ISO 10321 or ASTM D4884 as requested by the S.O.



(i) Prayer Seam (ii) J Seam (iii) Butterfly Seam - with double thread 'lock stitch'

Figure 1: Types of Seam

20.4.4.4 <u>Non-Woven Geotextile</u>

Non-woven geotextile described in this specification shall be for separation and filtration application of the ground treatment.

Unless otherwise approved by the S.O., non-woven geotextile shall be needle punched fibres of polypropylene or polyester supplied by an approved manufacturer.

The physical, mechanical and hydraulic properties of non-woven geotextile shall meet the minimum requirements as given in Table 20.4. Minimum roll width shall be 4.0 meters.

In addition to requirements given in Sub-Section 20.4.3, the Contractor shall furnish test certificate from accredited laboratory that includes the following:-

a) Wide width tensile strength
b) Elongation
c) CBR Puncture Resistance
d) Permeability
e) Effective Opening Size, O_{90} or Apparent Opening Size, O_{95}

Table 20.4: Technical Properties of Non-Woven Geotextile

Item	Properties	Test Standard	Unit	Types of Non-Woven (NW) Geotextile			
				NW 9	NW 13	NW 19	NW 24
1.	Wide width tensile strength	ISO 10319 or ASTM D4595	kN/m	≥ 9	≥ 13	≥ 19	≥ 24
2.	Wide width elongation at break	ISO 10319 or ASTM D4595	%	≥ 35			
3.	CBR puncture resistance	ISO 12236 or ASTM D6241	N	≥ 1500	≥ 2100	≥ 2850	≥ 3850
4.	Cone drop	ISO 13433	mm	≤ 40	≤ 25	≤ 20	≤ 15
5.	Permeability at 50mm head	ISO 11058 or ASTM D4491	$l/m^2/s$	≥ 90	≥ 70	≥ 55	≥ 45
6.	Effective opening size, $O_{90,}$	ISO 12956	µm	≤ 120	≤ 100	≤90	≤90
	or						
	Apparent Opening Size, O_{95}	ASTM D4751	µm	≤270	≤240	≤ 190	≤180
7.	UV resistance	EN 12224	% retained after 430 hours	≥ 70			
		or					
		ASTM D4355	% retained after 500 hours				

20.4.4.5 High Strength Woven Geotextile

High strength woven geotextile described in this specification shall be for basal reinforcement application of the ground treatment.

Unless otherwise approved by the S.O, high strength woven geotextile shall comprise of woven yarns of high tenacity polyester filaments with properties that meet the requirements as given in Table 20.5. The edges of fabric shall be selvedged or otherwise finished in such a way to prevent the outer yarn from unraveling.

High strength woven geotextile shall be free of any flaws that may have an adverse effect on its physical and mechanical properties. Minimum roll width shall be 5.0 meters.

Table 20.5: Properties of Woven Geotextile

Item	Properties	Test Standard	Unit	Types of High Strength (HS) Woven Geotextile[4]					
				HS 100/50	HS 200/50	HS 300/50	HS 400/50	HS 600/50	HS 800/50
1.	Characteristics Short Term Strength – MD[1]	ISO 10319 or ASTM D4595	kN/m	≥ 100	≥ 200	≥ 300	≥ 400	≥600	≥ 800
2.	Characteristics Short Term Strength at 5% elongation – MD[1]	ISO 10319 or ASTM D4595	kN/m	≥45	≥ 90	≥135	≥180	≥270	≥360
3.	Characteristics Short Term Strength – CD[2]	ISO 10319 or ASTM D4595	kN/m	≥50					
4.	Elongation at Characteristics Short Term Strength - MD[1]	ISO 10319 or ASTM D4595	%	≤10					
7.	Long Term Design Strength at 120 years design life[3]	BS 8006	kN/m	≥ 55	≥110	≥170	≥ 220	≥ 355	≥ 475

[1] MD: Machine Direction
[2] CD: Cross Direction
[3] The long term design strength assessment should take into consideration of reduction factors for creep, installation damage, environmental effects and extrapolation of data
[4] For high strength woven geotextile with required strength more than 800 kN/m, special design and specification shall be discussed with the designer

20.4.5 Geogrid

20.4.5.1 General

Unless otherwise specified elsewhere in the Specification or in the Drawing, geogrid used as geotechnical reinforcement and in ground treatment shall conform to the requirements as specified herein.

Geogrid shall be made of high tenacity polyester with polymeric coating that meets the requirements as given Table 20.6. The geogrid shall be formed from cross-laid strips (geo-linear elements) bonded at the cross-over points. The geo-linear elements shall consist of continuous high tenacity polyester fibers with polymeric coating.

Bonding at the cross-over points shall be such that the properties as required by the Contract are not affected. The strength of the bond shall ensure the function of the geogrid is achieved.
The polyester fibres shall be:

(a) coated with polymeric material to completely prevent ingress of moisture;
(b) all free ends shall be sealed to completely prevent ingress of moisture

The weft (referring to CD) elements shall be the same quality material as the warp (referring to MD) elements.

Table 20.6: Technical Properties of Geogrid

Item	Properties	Test Standard	Unit	Types of Geogrid (GD)[4]						
				GD 40	GD 60	GD 80	GD 100	GD 130	GD 150	GD 200
1.	Characteristics Short Term Strength – MD[1]	ISO 10319 or ASTM D4595	kN/m	≥ 40	≥ 60	≥ 80	≥ 100	≥ 130	≥150	≥ 200
2.	Characteristics Short Term Strength at 5% elongation – MD[1]	ISO 10319 or ASTM D4595	kN/m	≥ 20	≥ 30	≥ 40	≥ 50	≥ 65	≥ 75	≥ 100
3.	Characteristics Short Term Strength – CD[2]	ISO 10319 or ASTM D4595	kN/m	≥ 30						
4.	Elongation at Characteristics Short Term Strength - MD[1]	ISO 10319 or ASTM D4595	%	≤ 10						
5.	Long Term Design Strength at 120 years design life[3]	BS 8006	kN/m	≥ 20	≥ 30	≥ 40	≥ 50	≥ 75	≥ 80	≥ 105

[1] MD: Machine Direction
[2] CD: Cross Direction
[3] The long term design strength assessment should take into consideration of reduction factors for creep, installation damage (clay, silt, sand or well graded gravel), environmental effects and extrapolation of data
[4] For geogrid with required strength more than 200 kN/m, special design and specification shall be discussed with the designer

20.4.5.2 Durability of Geogrid

Durability of the geogrid shall be such that a design life of 120 years is achieved. The geogrid shall not deteriorate from exposure to sunlight and due to chemical action or biodegradation when buried in wet soil.

Information relating to the durability of the geogrid shall be submitted as required by the S.O. for his approval.

20.4.5.3 Method of Installation

Installation of geogrid shall be carried out by qualified and experienced workers under the supervision of a competent person. The geogrid shall be installed in compliance to Manufacturer's instructions utilizing approved plants/equipment.

The fill to the lines and levels shall be well-graded granular, dry cohesive soils or other engineered fill as shown in the Drawing.

All works related to earthworks shall be referred to JKR Standard Specification for Roadworks, Section 2: Earthworks.

a) Installation of Geogrid for Reinforced Slope

At each level of geogrid reinforcement, backfill shall be roughly levelled before placing the geogrid. Compaction shall be carried out to the requirements of the Specifications. During backfill placement, trucks and heavy vehicles shall be kept back at least one (1) meter from the face of the Geogrid Reinforced Slope.

The deposition, spreading, levelling and compaction of the fill shall be carried out generally in a direction parallel to the facing and shall be executed in stages to alternate with the placing and fixing of the reinforcing elements and the facing. The geogrid shall be laid whereby machine direction (MD) is in a direction perpendicular to the face of reinforced wall or slope. The overlapping width of adjacent panels of geogrid shall be minimum 150mm.

Care shall be taken to ensure that the reinforcing elements and facing are not damaged or displaced during deposition, spreading, levelling and compaction of the fill. The program of filling shall be arranged so that no machines or vehicles run on the reinforcing elements.

The fill within one (1) meter of the face of the Geogrid Reinforced Slope shall be compacted using one of the following:-

i) Vibro tamper
ii) Vibrating plate compacter having a mass not exceeding 1000kg
iii) Vibrating roller having a mass per metre width of not more than 1300kg and a total mass of not more than 1000kg

The rear of the Geogrid Reinforcing Slope shall be adequately supported either by temporary shoring or by phasing the work to ensure the contemporaneous deposition of the retained fill material.

b) Protection of Completed Geogrid Reinforced Slopes from Erosion

The Contractor, as specified in the Drawing or where instructed by the S.O., shall carry out adequate erosion protection measures such as vegetation, etc.

c) Drainage

The Contractor, as specified in the Drawing or where instructed by the S.O., shall carry out adequate water discharge method such as horizontal drain, cascade drain, etc to ensure the drainage of impounding water on the slope and the surface runoff.

20.5 PREFABRICATED VERTICAL DRAINS (PVD)

20.5.1 General

This specification covers the technical requirements for the supply and installation of Prefabricated Vertical Drains (PVD) as described herein. All materials used shall meet the requirements of this specification and all works shall be executed in accordance with the details shown in the Drawing and the procedures described herein.

The Contractor shall provide all necessary resources including materials, skilled workers, and plant/equipment to execute and complete the works related to supply and installation of PVD as shown in the Drawing.

All materials and workmanship shall be in accordance with the appropriate British Standards current at the time of tender, including those listed in this Specification, except where the requirements of British Standards conflict with this Specification, the latter shall take precedence unless otherwise approved by the S.O.

The Contractor shall be responsible for the true and proper setting-out of the areas to which the PVD is to be placed and for the correctness of the lines, widths and levels.
The Contractor, where so directed by the S.O., shall be required to work to other contractors' Drawing whenever Drawing for temporary works not included in the Contract are related to details of the Works.

20.5.2 Soil Investigation Report

A soil investigation report shall be made available at the S.O.'s office for the Contractor's information. The report is intended solely as a preliminary guide and neither the completeness nor the accuracy of the information provided is guaranteed. No responsibility is assumed by the S.O. for any opinion or conclusion given in the report. The Contractor shall study the given report and make his own interpretation of the information provided and to make due allowance for the effect of site conditions on his construction operations.

20.5.2.1 Pre-Treatment Soil Investigation

Cone Penetration Test (CPT) may be carried out if necessary to verify the thickness of sub-soil to be treated using PVD. The CPT results shall be submitted to the S.O. for design verification purpose prior to the commencement of work.

20.5.3 Transportation and Storage

The PVD materials shall be labelled or tagged for sample identification and other quality control purposes. Each pallet shall be identified by the manufacturer's name, lot number, individual roll number, roll length, date of manufacture or mill certificate, manufacturer and product identification of the jacket and core.

During transportation and storage, the PVD shall be wrapped in heavy paper, burlap or similar heavy-duty protection covering. The PVD shall be protected from sunlight, mud, dirt, dust, debris and other detrimental substances during transport and on-site storage.

The Contractor shall ensure that the PVD is in good condition and properly stored in a covered area at the worksite. If no covered area is available, the PVD may be stored on raised platform and covered with a waterproof canvas. In the event of damage or deterioration of the PVD due to improper storage, the Contractor shall be liable to replace the affected materials at his own cost.

20.5.4 Materials

20.5.4.1 Prefabricated Vertical Drains (PVD)

General Requirements

Prefabricated Vertical Drains (PVD) shall be from an approved manufacturer and consist of a polymer core enclosed within an external non-woven filter jacket, and shall comply with the requirements as indicated in Table 20.7. The PVD shall be produced by factory with ISO 9001 certification. The manufacturing process as well as the relevant tests required shall be accredited. The filter jacket shall be capable of resisting all bending, puncturing and tensioning subjected during installation and design life of the drain.

The core shall be made of continuous plastic material fabricated to facilitate drainage along the axis of the vertical drain.

The prefabricated vertical drain shall be resistant against rotting, mildew, bacterial action, insect, salts, acids, alkalis, solvent and other constituents in ground water.

Table 20.7: Properties of Prefabricated Vertical Drain

Item	Properties		Test Standard	Unit	Types of PVD	
					Type A[1]	Type B[2]
	Material	**Core Filter**			Continuous plastic drain core wrapped in non-woven geotextile material	
1.	Dimension of drain	Width		mm	100 ± 3	
		Thickness		mm	4 to 5	
2.	Coefficient of permeability of drain filter		ASTM D 4491	m/s	≥ 1×10^{-4}	
3.	Discharge Capacity at Pressure, P=240kPa and Hydraulic Gradient, i=1		ASTM D 4716	m^3/s	≥ 25×10^{-6}	≥ 100×10^{-6}
4.	Apparent Opening Size, O_{95}		ASTM D 4751	μm	≤ 90	≤ 90
5.	Tensile strength of entire drain		ASTM D 4595	N	≥ 2500	≥ 2800
6.	Tensile strength of filter		ASTM D 4595	N/m	≥ 3000	≥ 6000
7.	Tensile elongation of entire drain at 1000N		ASTM D 4595	%	≤10	≤ 10

[1] PVD Type A: For common application where soft soil depth is generally <25m and less compressible soil [Vertical strain (Settlement) < 15%]

[2] PVD Type B: For more critical application such as when soft soil depth is generally ≥25m, highly compressible soil like peat or gyttja [Vertical strain (Settlement) ≥ 15%], PVD associated with vacum preloading method or other special considerations based on engineering judgement of the designer.

Quality Control and Testing

Submission of Material Test Report (MTR)

This section shall be in accordance with Sub-Section 20.4.3.1.

Routine Sample Testing

This section shall be in accordance with Sub-Section 20.4.3.2.

Prior to installation and at the discretion of the S.O., individual test sample shall be cut off from at least one roll selected at random to represent each batch or the first 100,000 metres, whichever is lesser. Individual sample shall be not less than 15 meters in length. Samples submitted for tests shall indicate the linear meters of drain and manufacturer's identifications represented by the sample.

20.5.4.2 Geotextile

This section shall be in accordance with Sub-Section 20.4.

20.5.4.3 Drainage Blanket

This section shall be in accordance with Sub-Section 20.3.5.

20.5.5 Installation

Proper method statement for installation shall be prepared and submitted to the S.O. for approval before commencement of works. The method statement shall include the use of all necessary resources such as materials, manpower, machineries and equipments. Also to include is the sequence of works with diagrammatical illustrations where necessary, workmanship requirements as well as the construction quality controls.

20.5.5.1 Procedure

The equipment used for the installation of the PVD shall have adequate capacity to install the PVD to the required depth at one go without the need for any withdrawal and re-insertion. The Contractor shall be responsible to ensure that the working platform is stable and safe without risk to workers and nearby buildings or structures.

20.5.5.2 Geotextile

The installation of geotextile section shall be carried out in accordance with Sub-Section 20.4.

20.5.5.3 Drainage Blanket

This section shall be in accordance with Sub-Section 20.3.5.

20.5.5.4 Prefabricated Vertical Drain (PVD)

Equipment

PVD shall be installed with approved equipment of a type which will cause minimum disturbance to the sub-soil during the installation and maintain the mandrel in a vertical position.

PVD shall be inserted into the soil using a mandrel or sleeve. The mandrel or sleeve shall protect the drain material from tears, cuts and abrasion during installation and shall be retracted after each drain is installed.

The size and shape of the mandrel or sleeve shall be as close as possible to the size and shape of the drains to minimize disturbance to the soil.

The length of the mandrel shall be not less than the maximum length of the drain. The mandrel shall be capable of making a clean puncture through any geotextile if necessary.

The mandrel or sleeve shall be provided with an anchor plate or similar arrangement at the bottom to prevent the soil from entering the bottom of the mandrel during the installation of the drain and to anchor the drain tip at the required depth at the time of mandrel withdrawal.

The installation equipment of PVD shall come with a data log that shows the details of each PVD installed which includes, among others, the tag number and depth depending on what is required by the S.O. The data log shall be converted into a file that is accessible and readable to the S.O.

Method Statement

Fourteen (14) working days before commencement of PVD installation, the Contractor shall submit full details of the materials, equipment, sequence and method proposed for PVD installation to the S.O. for review and approval. Approval by the S.O. on the installation sequence and methods shall not relieve the Contractor of his responsibility to install drains in accordance with the Drawing and specifications.

Approval by the S.O. of the method or equipment used to install the drains shall not constitute, necessarily, acceptance of the method for the remainder of the project. If, at any time, the S.O. considers that the method of installation does not produce satisfactory quality and productivity as expected, the Contractor shall alter his method and/or equipment as necessary to comply with these specifications.

Setting Out

The intended positions of PVD shall be marked, numbered and pegged by the Contractor using a baseline and benchmark indicated by the S.O. The Contractor shall take all reasonable precautions to preserve the pegs and is responsible for any necessary re-pegging.

Depth and Positioning

PVD shall be installed from the working surface to the depth shown in the Drawing, or to such depth as directed by the S.O.

The Contractor shall furnish to the S.O. on the next working day a summary of the PVD installed that day. The summary shall include the PVD type, location and length of PVD installed at each location.

Verticality

Equipment for PVD installation shall be plumbed prior to installation of each PVD and shall not deviate from the vertical more than 1 in 50 during installation of any PVD.

Tolerances

The position of installed PVD shall not vary by more than 150mm from the position indicated in the Drawing.

PVD installed which deviate more than 150mm from design plan position or are damaged or improperly installed shall be rejected and abandoned in place and replaced accordingly.

Installation

PVD shall be installed using a continuous push using static weight or vibration. Installation technique using driving is not permitted.

The installation shall be performed, without any damage to the PVD during advancement or retraction of the mandrel. In no case will alternate raising or lowering of the mandrel during advancement be permitted. Raising of the mandrel will only be permitted after completion of an installation.

The completed PVD shall be cut off neatly 150mm above the working grade, or as otherwise specified in the contract Drawing.

Instrumentation Damage

The Contractor shall observe precautions necessary for protection of any field instrumentation devices.

The Contractor shall replace, at his own expense, any instrumentation or equipment that has been damaged or become unreliable as a result of his operations prior to continuing with PVD installation or other construction activities.

Pre-Augering

The Contractor shall be responsible for penetrating overlying fill material as necessary to satisfactorily install the PVD. Satisfactory installation may require clearing obstructions defined as any man-made or natural object or strata that prevents the proper insertion of the mandrel and installation of the PVD.

Where obstructions are encountered below the working surface which cannot be penetrated by the installation equipment, the Contractor shall complete the drain from the elevation of the working surface to the obstruction and notify the S.O. prior to installing any more PVD.

At the direction of the S.O. and under his review, the Contractor shall attempt to install a new PVD within 600mm horizontally from the obstructed PVD. A maximum of two attempts shall be made as directed by the S.O. If the PVD still cannot be installed to the design tip elevation, the PVD location shall be abandoned and the installation equipment shall be moved to the next location, or other action shall be taken as directed by the S.O.

The Contractor may use augering, spudding, or other approved methods to loosen the soil and any obstructive material prior to the installation of PVD. The obstruction clearance procedure is subjected to the approval of the S.O.; however, such approval shall not relieve the Contractor of his responsibility to clear obstructions in accordance with the specification.

If augering is the selected method, the augers shall have a minimum outside diameter equal to the largest horizontal dimension of the mandrel, shoe or anchor, whichever is greater.

Splicing

Splicing of PVD material shall be done by stapling in a workmanlike manner and so as to ensure structural and hydraulic continuity of the drain. At the splice, the minimum overlap shall be 150mm and the lower portion of the jacket shall be external to the upper portion.

A maximum of 1 splice per PVD installed will be permitted.

20.5.5.5 Surcharge

This section shall be in accordance with Sub-Section 20.3.

20.5.6 As-Built Records

The Contractor shall submit to the S.O., the daily installation record verified by the S.O.'s representative, specialist contractor and main contractor on the next working day. The Contractor shall submit as-built PVD treatment area plan certified by a Licensed Surveyor within fourteen (14) working days of completion of the last PVD.

The as-built Drawing and records shall include the as-built position and depth of each PVD point noting any deviation outside specified tolerances.

20.6 STONE COLUMNS

20.6.1 General

The work shall consist of the supply of equipment, labour and materials for the execution of stone column works for ground improvement. The stone column described in this Specification shall be carried out by deep vibratory compaction incorporating stone columns formed with imported granular backfill complying with the requirements of the latest version of BS EN 14731.

This section shall be in accordance with Sub-Section 20.5.1.

20.6.2 Soil Investigation Report

This section shall be in accordance with Sub-Section 20.5.2.

20.6.2.1 Pre-Treatment Soil Investigation

This section shall be in accordance with Sub-Section 20.5.2.1.

20.6.3 Method Statement for Construction Operations

Two (2) weeks before the commencement of the works, the Contractor shall submit to the S.O., a detailed method statement for the works. The method statement shall contain the following:-

a. A detailed construction sequence;
b. Shop Drawing showing details of all special requirements for the construction activities;
c. Design calculation of key temporary works endorsed by a P.E.;
d. Materials, plant and labour requirement at each construction stage;
e. Rate of production output based on resources allocated;
f. Environmental Management Plan in related with the works;
g. Other information relevant to the works.

If requested by the S.O., the Contractor shall submit additional information pertaining to the method of construction.

The Contractor shall not change the methods which have been approved by the S.O. Approval by the S.O. of the Contractor's proposed methods of construction shall not in any way relieve the Contractor of any of his duty or responsibility under the contract.

20.6.4 Unexpected Ground Conditions

The Contractor shall report immediately to the S.O. any circumstances which, in the Contractor's opinion, indicate ground conditions that may differ from those expected by him from interpretation of the soil investigation report. The Contractor's report shall be in the form of written notice of which shall be given to the S.O. at the earliest possible time after encountering such conditions and obstructions. The report shall be accompanied by all information available to the Contractor which will materially assist the S.O. in verifying the conditions reported.

20.6.5 Adjacent Structures

The Contractor shall pay very careful attention to the construction constraints imposed by adjacent structures. The Contractor shall exercise extra care and implement adequate monitoring measures when carrying out the works so as not to disturb or damage the existing adjacent properties and foundations. The Contractor shall provide a proposal for monitoring adjacent properties for any detrimental effects arising out in execution of the works, so that appropriate and timely preventive action can be taken to minimise damage. The Contractor's proposal and monitoring program shall be certified by his Professional Engineer and approved by S.O.

The Contractor shall also carry out a condition survey of adjacent properties to establish the condition of the existing structures and facilities prior to commencement of work. Condition Survey shall be conducted by competent personnel and the result of the survey shall be submitted to the S.O. for record.

The Contractor shall be responsible for and shall bear the cost of such works and any claims of damage to adjacent structure and facilities arising from his execution of the works.

20.6.6 Existing Services

Prior to commencement of works, services in the ground and overhead shall be identified and clearly marked. The Contractor shall give all required notices to the appropriate utility authorities before commencement of works. The Contractor shall also locate existing services by piloting, protect existing services, rectify any damage or interference to them and provide temporary support while repairs are being carried out if so required.

20.6.7 Workmanship

The Contractor shall satisfy the S.O. regarding the suitability, efficiency and adequacy of the equipment to be employed. The Contractor shall state the type and number of rigs he intends to use.

On completion of each area of stone column, the Contractor shall grade debris and surplus material arising from the stone column to leave a reasonable firm and level working surface. On completion of the stone columns to the satisfaction of the S.O., the Contractor shall remove from the site all plant and unwanted material.

Installation of the stone columns shall be carried out by experienced Specialist Contractor approved by the S.O.

The Specialist Contractor shall employ personnel experienced in the construction of stone columns for this part of the Works.

For both dry and wet methods, the depth vibrator shall be sufficiently powerful to ensure:

a) The depth indicated in the Drawing may be reached; and
b) Adequate compaction of the stones can be achieved

For the avoidance of doubt, any equipment other than a depth vibrator as specified in the latest version of BS EN 14731, is non-complying and precluded.

20.6.8 Setting Out

Setting out shall be carried out by the Contractor from grid lines provided and maintained by the Contractor. Immediately before installation, the column position shall be marked with suitable identifiable pins, pegs or markers with minimum length of 300mm. The pins, pegs or markers shall be driven to the ground level and the location marked with contrasting material.

20.6.9 Materials

Material used for forming stone columns shall consist of hard and durable stone so as to remain stable during column construction and the working life of stone columns. The material may be natural or crushed stones or recycled material based on availability at site, and shall conform to the following requirements:-

a) The Aggregate Crushing Value (ACV) shall be not more than 30% (tested in accordance with latest MS 30 or equivalent);

b) The Flakiness Index shall be not more than 30% (tested in accordance with latest MS 30 or equivalent);

c) The average loss of weight in the sodium sulphate soundness test (5 cycles), shall not be more than 10% (tested in accordance with AASHTO Test Method T104 or equivalent);

d) The gradation shall comply with Table 20.8 as appropriate.

The above tests shall be carried out on every source of material supplied to site.

Material shall be used with a grading appropriate for compaction to form a dense column fully interlocking with the surrounding ground. Material shall be compatible with the vibro plant used and flow freely within bottom and through feed delivery system without arching, which may block these systems.

Material with particle size falling in the range of 20-40mm size (dry method) and 50-75mm size (wet method), its appropriate grading limit are as per Table 20.8. Quarry dust and other fine stone chippings shall be limited to not more than 5%. The material shall also be free of unsuitable material.

Prior to commencement of the works, the Specialist Contractor shall submit samples of the stone backfill from proposed source of supply to the S.O. for his approval.

Throughout the period of the works, when directed by the S.O., the Specialist Contractor shall be required to validate that the output from the approved sources of stone consistently conforms to the requirement of the Specifications and any conditions stipulated during the initial approval.

Table 20.8: Typical Gradings Used with the Different Processes

Process	Grading in mm
Dry top-feed process	40 to 75
Wet process	25 to 75
Dry bottom-feed process	8 to 50

20.6.10 Stone Column Construction

The construction method may either be the wet or dry process. Generally, the wet process is suited for sites underlain by very soft to firm soils and a high ground water table. For dry process, it is suitable for soils with undrained shear strength of about 40-60kPa with relatively low ground water table. If the dry process is used it shall be demonstrated on site that the hole made by the machine will remain open to enable the stone to

be placed cleanly to the bottom of the hole to form a continuous column to the surface.

Working platforms shall be designed, prepared and maintained by the Contractor in a manner suitable for the safe movement and working of the vibro plant. Material used to provide working platforms shall be granular, suitable for the ground conditions on which it is placed and shall not prevent poker penetration. Minimum thickness of the working platforms shall be at least 1000mm to ensure that stone compaction is effectively carried out to the ground surface.

Site working levels for the stone column shall be maintained throughout the duration of the Works. Where near surface obstructions occur, they shall be broken out prior to the commencement of the vibro works and the resulting voids shall be filled with granular material that can be penetrated and compacted by the vibrating poker.

The stone column shall be formed to the working surface without inclusion of clay or other unsuitable material preventing intergranular contact between stone particles.

When the dry top-feed process is being used, the vibrator may be removed completely from the hole to allow access for the stone. Where the dry bottom-feed process is used, the depth vibrator shall not be removed from the ground during column construction. When the wet process is being used, the vibrator shall be kept in the hole at all times in order to maintain stability of the sides and to ensure that the stone shall reach the required depth via the annular space around the vibrator.

The Contractor shall provide a supply of water if the wet process is selected. The Contractor shall indicate the rate of water supply required and be responsible for checking that this is available. The Contractor shall be responsible for supplying any extra storage tanks and pumping as required.

Any unnecessary excavation on the stone column construction shall be avoided. Where this is not possible, excavation of the constructed stone columns shall be carried out with prior approval from the S.O. and under his strict supervision to minimize the disturbance on the constructed stone columns. Compaction by rolling or tamping rammer shall be carried out before foundation construction.

The Contractor shall be responsible for disposal of effluent from the works and complying with the Environmental Law and Regulations. The Contractor shall provide countermeasures as required by the Environmental Management Plan (EMP) and maintain silt traps required. On completion of the stone column the Contractor shall remove all such equipment and backfill any pits.

In ground conditions where pre-boring is deemed necessary, it shall be carried out by a method and to a sequence agreed by the S.O. Pre-boring shall be carried out immediately before, or as near as practicable, to stone column construction to mitigate any safety issues associated with open excavations and prevent unnecessary deterioration of the underlying ground, for example due to water ingress**.**

20.6.10.1 Verticality

The maximum permitted deviation of the stone column from the vertical is 1 in 20.

20.6.10.2 Depth and Spacing

The depth and spacing of the stone columns shall be as shown in the Drawing and neither the depth nor spacing shall be varied without the prior agreement of the S.O. Any variations in depth of stone columns due to site conditions not anticipated in the design shall be reported immediately to the S.O. who shall advise on any action to be taken.

20.6.10.3 Tolerances

All stone columns shall be located to within 150mm of the plan positions shown on the stone column layout Drawing.

20.6.11 Construction Records

The Contractor shall keep records each of the stone column carried out as required by the S.O. and shall submit two signed copies of these records to the S.O. not later than the next working day after the stone column is completed. The duly signed records shall form part of the records for the works. Any unexpected conditions shall be noted in the records.

The Contractor shall ensure that the equipment to be used shall be instrumented with sensors and the data processed by a micro-processing unit to enable continuous monitoring and data capture of the following parameters during the construction of each stone column: -

a) The depth of vibrator and vibrator movements (depth of penetration); and

b) Power consumption (compaction effort)

Data captured shall be continuously displayed on an LCD unit and graphical output (plots of depths versus time and power consumption) shall be generated by an automated computerised recording device throughout the process of the stone column installation. This shall be done for each point and records shall be submitted to the S.O. by the next working day.

The records of each completed stone column shall contain but not limited to the following information where applicable:-

a) Identification number and location of stone column point
b) Date and time
c) Method of treatment
d) Equipment and personnel in-charge
e) Depth of penetration
f) Time required to reach maximum depth and withdrawal
g) Vibrator power consumption during penetration and compaction
h) Material consumption

Any observed ground heave or settlement during construction shall also be recorded and reported to the S.O.

20.6.12 Preliminary Stone Columns

Prior to commencement of actual stone column works, the Contractor shall carry out preliminary stone column as shown in the Drawing to establish the installation criteria for the subsequent stone column and for confirming the adequacy of the design, dimensions and working load through load test. The Contractor shall give at least three (3) days' notice of the commencement of construction of any preliminary stone column.

20.6.13 Testing Of Stone Column Works

To verify the design assumptions and working load, the Contractor shall carry out load test on stone column as shown in the Drawing or as instructed by S.O. The testing procedures shall be submitted two (2) weeks before the commencement of load test for S.O.'s approval. Loading of a stone column shall not commence until seven (7) days have elapsed after completion of its installation.

Load testing for stone column can be carried out using plate test or zone test as shown in the Drawing or as instructed by the S.O.

Plate test: A plate test is a loading test carried out using a plate on treated ground essentially used as a control of workmanship. It can be a single column plate load test or a group of four columns plate load test.

Zone test: A zone test is a loading test carried out over a large treated area, intended to test stone columns' performance over a wider and deeper zone than in the plate bearing test. A zone test is usually carried out by placing earth fill to simulate widespread loads, and the fill height will be determined to meet the required test pressures.

During the progress of a test, the testing equipment and all records of the test shall be available for inspection by the S.O.

20.6.13.1 Load Test Procedures

The plate load test shall be carried out in accordance with the latest version of MS 2038.

20.6.13.2 Submission of Results

Full test data and results shall be jointly signed in duplicate by the S.O.'s representative witnessing the test and the Contractor's authorized personnel immediately upon completion of the test. A copy of the records shall be kept by the S.O.

Within seven (7) days of the completion of the test, a complete test report inclusive of all necessary analysis shall be submitted to the S.O. This shall be as specified below for a plate bearing test or a zone test as appropriate.

Plate tests

The Contractor shall provide information about the tested ground in accordance with the following schedule where applicable: -

a. general
- contract identification
- date of test

b. test area details
- identification of area relative to site layout drawing
- brief description of position in structure
- ground level at test position
- excavated test level

c. treatment details
- date and time of treatment
- unexpected circumstances or difficulties

d. stone columns
- identification numbers of stone columns
- diameter and depth of stone columns exposed
- spacing of adjacent columns
- depth
- stone consumption

e. test procedure
- approximate weight of kentledge
- date and times of load application

f. test results
- load and settlement with time reported in tabular form, and in graphical form, load and settlement being plotted against time, and load against settlement.

Zone tests

The Contractor shall provide information about the tested ground in accordance with the following schedule where applicable: -

a. general
- contract identification
- date of tests

b. test area details
- identification of area relative to site layout drawing
- size and position of area
- ground level at test position
- excavated test level

c. treatment details
- date and time of treatment
- unexpected circumstances or difficulties
- identification number of stone columns
- depth of treatment
- stone consumption

d. test details
- plan showing position and extent of zone test fill in reference to the stone columns and instrumentation layout
- method of load-measurement, if any (e.g. pressure cells, or earth fill field density tests)
- Fill height measurements versus time (e.g. rod settlement gauges)
- dates and times of fill application, duration of instrumentation
- other instrumentation measurements over time (e.g. inclinometers, settlement markers).

e. test results

- load and settlement with time reported in tabular form, and in graphical form, load and settlement being plotted against time, and load against settlement

20.6.13.3 Completion of a Test

Upon completion of a test, all temporary structures used in the testing (concrete slab or ground anchor etc.) shall be dismantled and removed from site. The ground shall be made good to the original commencing surface level.

20.6.14 As-Built Records

The Contractor shall submit an as-built stone column location plan certified by a Licensed Surveyor to the S.O. within fourteen (14) working days after the completion of the works. Partial as-built plan may be submitted throughout construction of the works for verification by the S.O.

The as-built Drawing shall include the following information:

i. The stone column identification number and corresponding as-built depth of each point;
ii. Spatial coordinates of reference points delineating the treatment and where stone columns positions were deviated on site due to obstructions or other reasons with the knowledge of the S.O., the new position coordinates shall be included.

20.7 DEEP SOIL MIXING

20.7.1 General

The work shall consist of the supply of equipment, labour and materials for the execution of deep soil mixing (DSM) works. Deep soil mixing method shall comply to the latest version of BS EN 14679.

This section shall also be in accordance with Sub-Section 20.5.1.

20.7.2 Soil Investigation Report

This section shall be in accordance with Sub-Section 20.5.2.

20.7.2.1 Pre-Treatment Soil Investigations

This section shall be in accordance with Sub-Section 20.5.2.1.

The Contractor shall carry out chemical tests to determine the types of chemicals present in the soil for effective deep soil mixing. The Contractor shall provide Material Safety Data Sheet (MSDS) produced by the Manufacturer for the handling and storage of chemicals used. The use of chemicals shall be in accordance with JKR Standard Specification for Roadworks, Section 18: Soil Stabilisation.

20.7.3 Method Statement for Construction Operations

This section shall be in accordance with Sub-Section 20.6.3.

The method statement shall also include precautions against heave and settlement.

20.7.4 Unexpected Ground Conditions

This section shall be in accordance with Sub-Section 20.6.4.

20.7.5 Adjacent Structures

This section shall be in accordance with Sub-Section 20.6.5.

20.7.6 Existing Services

This section shall be in accordance with Sub-Section 20.6.6.

20.7.7 Specialist Contractors and Personnel

DSM works shall be carried out by experienced Specialist Contractor approved by the S.O. The Specialist Contractor shall have the following experience and personnel:-

a) Personnel experienced in the design, supervision and construction of DSM columns.

20.7.8 Setting Out

This section shall be in accordance with Sub-Section 20.6.8.

20.7.9 Material

20.7.9.1 Binder

Cementitious binders to be used shall be an approved variant of Portland Cement, complying to JKR Standard Specification for Roadworks, Section 9: Concrete or as per the latest version of BS EN 197-1. The cement shall be adequately protected from moisture and contamination in storage at the job site. Reclaimed cement containing lumps or deleterious matter shall not be used. Other binders shall only be acceptable if the project requirements can be met with their use. Laboratory tests shall be required to verify the suitability and dosage of the other binder variants.

If other chemicals are proposed, the material shall be in accordance with JKR Standard Specification for Roadworks, Section 18: Soil Stabilisation.

20.7.9.2 Water

Freshwater, free of an excessive amount of deleterious substances which can adversely affect the properties of the binder shall be used. It is the responsibility of the Contractor that the grout resulting from the water shall always meet the requirements of this specification.

20.7.9.3 Grout Suspension

Grout suspension shall be prepared on site using binder(s) as described in Sub-Section 20.7.9.1 and other additives, wherever required, in water. The grout shall be pumpable and workable with the DSM injection equipment.

20.7.9.4 Additives

Additives may be used to enhance the workability or final properties of the treated soil. Conventional additives include bentonite, fly ash, lime, sodium silicate, a set retarder, alkali activator, etc. Additives may be added to the water or the grout. Notwithstanding this, the use of additives is subjected to the approval of the S.O.

The Contractor shall provide Material Safety Data Sheet (MSDS) produced by the Manufacturer on the use of chemical additives to ensure the safety of the material used. The Contractor shall be made liable for any discrepancies that occur during the application of chemical additives in the absence of MSDS.

20.7.9.5 Soil Mixing Material

Soil-mixing material, resulting from the in-site mixing of soil with grout suspension (mainly for a wet method of mixing), should have a compressive strength as specified in the Drawing. The factor of safety concerning the maximum characteristic stress acting on a single column shall be not less than 2.0.

20.7.9.6 Steel Reinforcement

Steel reinforcement, if specified in the drawing shall comply with JKR Standard Specification for Roadworks, Section 9: Concrete, relevant specifications and Malaysian Standards.

20.7.10 DSM Column Installation

20.7.10.1 General

The Contractor shall satisfy the S.O. regarding the suitability, efficiency and adequacy of the equipment to be employed based on soil conditions and the requirements defined herein and in the design. The equipment chosen for the installation of works shall be in full compliance with the provision of the latest version of BS EN 14679.

20.7.10.2 Drilling Equipment

a) DSM equipment shall be capable of rotating down to the required depth or stiff layer through the weak soil and withdrawing the mixing

tool by simultaneous rotation and mixing of the binder with in-situ soil.

b) DSM machine shall have a single or multiple shaft(s) with cutting/mixing blades at the lower end.

c) DSM machine shall be able to operate at different rotation and withdrawal rates within the required range as in the design to complete the work and produce the required cement columns, and as required by the latest version of BS EN 14679.

d) The cutting/mixing blades shall have the minimum diameter as per design. The size of the mixing tool shall define the column diameter.

e) The mixing tools shall consist of minimum one nozzle for the binder delivery but shall be demonstrated that it is adequately sized to meet the binder dosage as required by design.

f) Real-time measuring and recording devices shall be provided throughout the mixing operation, to capture data e.g. column number, time, depth, pressure, feed rates, rotation speed, injection rate, injection volume, binder consumption, etc.

20.7.10.3 <u>Binder Delivery Station</u>

a) Dry Method

In the dry method, the deep soil mixing process shall be carried out by mixing the binder in powder form. The medium of transportation of binder is typically compressed air unless otherwise approved by the S.O. Binder storage tank(s)/ silo(s) is generally on-board with the DSM machine or on a separate self-propelled chassis connected to the DSM machine.

b) Wet Method

In the wet method, the deep soil mixing process shall be carried out by mixing the binder in slurry form. The medium of transportation of binder usually is water unless otherwise approved. The binder is generally prepared at the separate mixing and holding tanks and pumping station shall be required to deliver the binder to the DSM machine. The mixing and pumping station shall be able to produce enough volume of slurry required and enable continuous supply and controlled delivery of slurry.

20.7.10.4 <u>Working Platform Preparation</u>

Working platforms shall be designed, prepared and maintained by the Contractor in a manner suitable for the safe movement and working of the deep soil mixing equipment. The material used to provide working platforms shall be suitable for the ground conditions on which it is placed and shall not be detrimental to the drilling operation. Site working levels for the treatment shall be provided and maintained by the Contractor throughout the deep soil mixing works.

20.7.10.5 Soil Mixing Work

Unless otherwise specified, pressure feed of the binder shall be terminated approximately 0.5m to 1.0m below the working platform. Satisfactory quality shall not be relied on in the design over a depth of 1.0m below the working level, i.e. within the working platform material. If the deep soil mixing operation is interrupted for any reason, re-mixing or repositioning may be required upon confirmation from the S.O. on site.

The mixing tool rotation speed shall be adjusted to accommodate a constant rate of mixing as given in the design. The penetration/withdrawal rate of the mixing tool shall be maintained such that the proper amount of binder is added and the proper amount of mixing time is allowed as per design. Both the rotation speed for mixing tool and penetration/withdrawal rate can be adjusted according to drilling difficulty, upon confirmation from the S.O. on site.

The injection rate per vertical meter of column shall be predefined by the Contractor. The injection rate shall be adjusted accordingly, if necessary, with the working parameters in the paragraph above herein, throughout the work to achieve the requirement for the DSM columns. The injection rate of the binder shall be measurable and monitored with the appropriate device as proposed by the Contractor.

After completion, the DSM columns shall be left undisturbed for at least 14 days. The area of DSM columns shall not be driven over with heavy equipment.

20.7.10.6 Obstruction

In the event of obstructions preventing the drilling and installation of DSM columns, the S.O. shall be informed immediately. Remedial options subject to approval from the S.O. shall include: -

i) Reposition the column by offset at a short distance from the original position.
ii) Additional DSM column(s) around the obstruction, if necessary.
iii) Excavate, remove the obstruction, backfill and compact to the requirements of JKR Standard Specification for Roadworks, Section 2: Earthworks and reinstall the DSM column.

20.7.10.7 Verticality

The maximum permitted inclination of the DSM columns is 1 in 75.

20.7.10.8 Length, diameter and spacing

The length, diameter and spacing of the DSM columns shown in the Drawing shall be adjusted to suit site conditions when deemed necessary as instructed by the S.O.

20.7.10.9 Tolerances

The maximum permitted deviation of the centre of the DSM column from the centre point shown on the setting out drawing shall be 150 mm in any direction.

20.7.11 Construction Records

On the same day, a daily record shall be submitted to the S.O. summarizing the points completed and depths of DSM column installed. Two (2) copies of signed records for each soil mixing element shall be submitted to the S.O. on the next working day.

The record shall include the following information, but not limited to: -

i) Column ID or reference number;
ii) Depth of installation;
iii) Column top and toe level;
iv) Binder type and composition, injection rate and total injection volume;
v) Time for mixing during penetration and withdrawal;
vi) Rotation of mixing tool versus depth and blade rotations numbers;
vii) Weather report;
viii) Any other information as may be required by the S.O.

20.7.12 Preliminary DSM Column(s)

Before commencement of the DSM works, the Contractor shall carry out field trial as shown in the Drawing. A total number of minimum four (4) numbers of preliminary columns shall be constructed to verify the deep soil mixing methodology, suitability of the mixing tool and the design parameters. The quality of DSM columns shall conform to the design requirements and shall be verified using the appropriate testing method, e.g. by the mean of the load test. Loading on the DSM column shall not commence until fourteen (14) days have elapsed after completion of its installation.

Where excavation is possible, assessment of the geometric and mechanical characteristics of the DSM column should be made by visual inspection. Coring can be made on the completed columns. Unconfined Compressive Strength Testing (UCS) on samples recovered by coring or excavation can be made to verify the soil-mixing material compressive strength as specified in the design. UCS testing shall be carried out on three samples from at least one (1) of the trial columns. The sampling and

testing frequency may be varied based on project requirements or at the instruction of the S.O.

20.7.13 Quality Control and Quality Assurance

20.7.13.1 Quality Control

Before the commencement of all works, procedures for verification, control and acceptance shall be established in the method statement with reference to the drawing and specification.

Blade rotation number of soil mixing shall be used as a guide to verify the consistency of mixing and forming homogenous columns. Minimum blade rotation number in cohesionless soils shall be at least 300, whereas for cohesive soils it shall not be less than 400. For peaty and organic soils the blade rotation number shall be at least 600. These requirements shall be followed unless otherwise stated in the project requirement or instructed by the S.O.

The construction process shall be controlled and monitored automatically, with the aid of a computerised system. The following construction parameters and information shall be monitored continuously during execution:-

Table 20.9: Construction Parameters to be monitored during DSM Installation

Dry Method	Wet Method
• Air tank pressure • Time vs depth (penetration and retrieval rate) • Rotation speed (revs/min during penetration and retrieval) • The quantity of binder per meter of depth during penetration and retrieval	• Slurry pressure; air pressure (if any) • Time vs depth (penetration and retrieval rate) • Rotation speed (revs/min during penetration and retrieval) • The quantity of slurry per meter of depth during penetration and retrieval

20.7.13.2 Sampling

The sampling of DSM improved ground shall be done by conventional vertical coring. Double tube sampling shall also be acceptable provided the Contractor can demonstrate that good sample recovery can be obtained. Wet grab sampling shall also be permitted, and samples shall be prepared from wet grabs at the instruction of the S.O. The S.O. shall also instruct at what depth the sampling needs to be taken. Sampling shall ensure that the recovery ratio is at least 80% or otherwise instructed by the S.O.

At least 1% of the installed columns shall be sampled by coring, double tube or wet grabbing, unless otherwise stated in the drawing. Minimum three (3) samples from each sampled column shall be tested for UCS. The sampling and testing frequency may be varied based on project requirements or at the instruction of the S.O.

20.7.13.3 Unconfined Compression Test

Where necessary, the improvement from the treatment shall be tested by Unconfined Compression Test (UCT) of samples. The Unconfined Compressive Strength (UCS) of samples shall meet the requirements of the design, where the characteristic strength of samples shall be more than the project requirements.

UCS testing shall be done on cylindrical or cube samples having a minimum dimension of 50 mm diameter. Corrections to readings and reporting of values shall be per the latest version of BS EN 12504-1.

Where required the S.O. may specify additional tests to determine other engineering properties of the improved ground.

20.7.13.4 Load Test Procedures

This section shall be in accordance with Sub-Section 20.6.14.

20.7.13.5 Submission of Test Results

This section shall be in accordance with Sub-Section 20.6.14.2.

20.7.14 As-built Drawing

The Contractor shall submit an as-built DSM columns location plan certified by a Licensed Surveyor to the S.O. within fourteen (14) working days after the completion of the works. Partial as-built plan may be submitted throughout construction of the works for verification by the S.O.

The as-built Drawing shall include the following information:

i. The DSM column identification number and corresponding as-built depth of each point;
ii. Spatial coordinates of reference points delineating the treatment; and where DSM columns positions were deviated on site due to obstructions or other reasons with the knowledge of the S.O., the new position coordinates shall be included.

20.8 DYNAMIC COMPACTION

20.8.1 General

The works shall consist of supply of plant, equipment and specialist personnel for the execution of dynamic compaction (DC) works for ground improvement.

This section shall also be in accordance with Sub-Section 20.5.1.

20.8.2 Specialist Contractor

DC works shall be carried out by experienced Specialist Contractor approved by the S.O. The Specialist Contractor shall have the following experience and the personnel:-

a) The Specialist Contractor shall employ competent and experienced geotechnical engineer(s) capable of analyzing existing soil data, obtaining and interpreting additional data as required, performing field testing prior to, during and after DC works.

20.8.3 Soil Investigation Report

This section shall be in accordance with Sub-Section 20.5.2.

20.8.4 Method Statement for Construction Operations

This section shall be in accordance with Sub-Section 20.6.3.

20.8.5 Unexpected ground conditions

This section shall be in accordance with Sub-Section 20.6.4.

20.8.6 Adjacent structures

This section shall be in accordance with Sub-Section 20.6.5.

At locations where acceptable peak particle velocity or acceleration are likely to be exceeded, cut off trenches or other protective measures shall be taken. Contractor shall demonstrate to the satisfaction of the S.O., by trials, that his proposal will reduce the maximum peak particle velocity or acceleration to acceptable values.

20.8.7 Existing Services

This section shall be in accordance with Sub-Section 20.6.6.

20.8.8 Workmanship

Contractor shall satisfy the S.O. on the suitability and efficiency of the equipment to be employed.

The dynamic compaction (DC) works shall be performed by a qualified Contractor. The DC works shall be carried out up to the designed depth/compaction energy required to ensure the design criteria are achievable.

20.8.9 Setting out

Contractor shall perform setting out from the temporary bench mark (TBM) provided and shall be maintained by the Contractor. The approximate limits of work shall be shown in the DC shop Drawing and the exact limit shall be determined by the Contractor upon completion of the pre-treatment testing. DC points shall be marked with suitable and identifiable markers.

20.8.10 Working platform

The working platform shall be prepared and maintained by the Contractor and shall be suitable for safe movement and operation of the DC plant and equipment. The working platform shall be made of granular material and at least 1000 mm above the ground water level.

20.8.11 Spacing

The spacing of the DC point shall be shown in the construction drawing. This shall be confirmed by field calibration or field trial conducted as

approved by S.O.

20.8.12 DC field trial area

The Contractor shall perform at least one (1) DC field calibration or trial area prior to commencement of the full production DC works. Minimum trial area shall be 20 m x 20 m. The objective of the field trial is to determine the optimum compaction energy to be applied to the DC point and to confirm the technical data obtained is as per design.

20.8.13 Site Records

The Contractor shall keep and submit to the S.O. the following records:-

a) Number of blows for each DC point for each phase of DC works
b) DC pounder free fall height for each blow for each phase of DC works
c) Ground level before and after DC works
d) Any other record as required by the S.O.

20.8.14 Testing

20.8.14.1 Pre-Treatment Testing

The Contractor shall undertake soil testing prior to commencement of DC works to provide data for the purpose of refining the preliminary design in compliance with the acceptance criteria as specified. The field testing shall include the following:-

i) Pressuremeter Tests (PMT) shall be performed at every meter vertical interval and at changes in strata in accordance with the method outlined in ASTM D4719 or the latest version of BS EN ISO 22476-4.
ii) Cone Penetration Tests (CPT) shall be performed in accordance with ASTM D5778 or the latest version of BS EN ISO 22476-1.

The Contractor shall determine the total number of locations of pre-engineering tests necessary to analyse the soil conditions and to delineate the areas requiring DC works. Pre-engineering testing shall include the following as a minimum:-

i) A minimum of one PMT for every 2000 m² of area marked for improvement in the Drawing
ii) A minimum of one CPT for every 2000 m² of area marked for improvement in the Drawing

The Contractor shall determine locations of any additional testing that may be required if conflicting test results are indicated by two adjacent tests or to delineate areas for ground improvement.

20.8.14.2 Final Acceptance Testing

The Contractor shall verify the ground improvements works for compliance with the acceptance criteria by in-situ tests of the improved soils and by analysis of the test results. The final testing shall be conducted at a minimum of one week after completion of the ground improvement works.

The final tests shall generally be at the locations of the pre-engineering test locations and shall include the following field tests:-

i) Pressuremeter Tests (PMT) shall be performed at every meter vertical interval and at changes in strata in accordance with the method outlined in ASTM D4719 or the latest version of BS EN ISO 22476-4

ii) Cone Penetration Tests (CPT) shall be performed in accordance with ASTM D5778 or the latest version of BS EN ISO 22476-1

Final testing shall include the following as a minimum:-

i) A minimum of one PMT for every 2000 m² of area marked for improvement in the Drawing

ii) A minimum of one CPT for every 2000 m² of area marked for improvement in the Drawing

Areas in which the specified criteria are not met shall be reworked by the Contractor until the specified requirements are met. The S.O., at his discretion, may check the Contractor's test results by conducting additional and independent testing.

If necessary, correlation between the Cone Penetration Test (CPT) results with Pressuremeter Test (PMT) results can be conducted to obtain the limit pressure and pressuremeter modulus required for the engineering calculations.

20.8.15 Documents submission

The Contractor shall submit to S.O. documents regarding the DC works as follows:

i) Pre-treatment testing proposal – this document is a plan and schedule for pre-treatment testing and shall be submitted at least

seven (7) days before the pre-treatment testing is scheduled to begin.

ii) Pre-treatment testing report – this document shall be submitted not later than fourteen (14) days after completion of pre-treatment testing.

iii) Interim progress report – this document states the DC works operations, including pre-treatment testing, final acceptance testing, elevation measurements, quantities completed during month, cumulative quantities to date and a forecast of remaining work.

iv) Final technical report – this document shall be submitted at the completion of the DC works. The report shall contain graphical presentation of all parameters used by the Contractor to accomplish the acceptance criteria including all pre-treatment testing and final testing results together with as built Drawing. The report shall be submitted in five copies duly endorsed by a Professional Engineer.

20.9 PILED EMBANKMENT

20.9.1 General

The works shall consist of all labour, materials, tools, transportation, instrumentation, etc. necessary to construct piled embankment in accordance to the Drawing and JKR Standard Specification for Roadworks, Section 10: Piling Works.

The works shall cover the following: -

i. Mobilization and demobilization of all labour, plants, piling and drilling equipment on site.
ii. Supply, handling, pitching and installation of piles to the pile lengths as specified in the Drawing.
iii. Lengthening of piles by jointing to detail.
iv. Strip pile to cut-off level and check pile eccentricity.
v. Construct reinforced concrete slab as per the details in the Drawing.
vi. Carry out pile testing in accordance to JKR Standard Specification for Roadworks, Section 10: Piling Works on working piles as specified.

20.10 GEOTECHNICAL INSTRUMENTATION

20.10.1 General

Instrumentation shall be installed to measure horizontal and vertical displacement of the subsoil or structures supported by the subsoil and water pressures within the Works and shall remain operational both during and after the construction period specified in the Contract.

The Contractor shall be responsible for and shall follow the instruction 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 S.O. The Contractor shall inform the S.O. at least 2 days prior to undertaking installation of the equipment. The Contractor shall make due allowances in his construction programme for any delays which may arise on account of the installation of the instruments.

20.10.1.1 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 which project through and above the fill, special precautions shall be taken to provide protection from vehicles and plant including substantial and readily visible barriers at a radius of 750mm around each instrument. Heavy compaction equipment shall not approach within 1.0m of projecting instruments. Damaged instruments shall be replaced or repaired by the Contractor at his own expense within seven (7) days.

20.10.1.2 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 stabilization is complete.

All readout units shall be calibrated at least once a year and the calibration certificates submitted to the S.O.

20.10.1.3 Personnel

The Contractor shall submit names and curricular vitae of personnel (including instrumentation engineer and instrumentation technician) responsible for instrumentation and monitoring works. A programme of their attendance shall also be provided for the approval of the S.O. Deviation from the approved programme of attendance or the requirements given in this clause shall only be permitted with the approval of the S.O.

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. He shall be on site for the remaining monitoring on a basis to be agreed with the S.O.

All instrumentation and monitoring works shall be carried out by an experienced instrumentation technician. Instrument data obtained shall be verified by an instrumentation engineer.

20.10.1.4 Boreholes for Instruments

Boreholes for instruments may be drilled by any method provided that it results in a clean and stable hole of the required diameter to the correct depth. The method of forming boreholes, including the procedure for advancing casing, shall be submitted to the S.O. for approval before commencement of the works.

Boreholes shall be cased to their full depth unless strata are sufficiently competent for the hole to stay open under dry conditions. If boreholes are drilled using water as a flushing medium, clean water shall be used. Drilling mud or polymer additives shall only be used with the approval of the S.O. 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 the casing shall not be allowed and flushing of drilling water outside the annulus of the casing shall be minimized.

20.10.1.5 Grouting Of Boreholes

For all instruments placed in boreholes, grouting is required in parts of the borehole or the entire 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 that it imitates as closely as possible the strength or consistency of the natural soils present. Unless otherwise stated in the Drawing, the Contractor shall propose the suitable bentonite: cement mixture to S.O.'s approval. Grout shall be pumped into boreholes using a tremie pipe.

20.10.1.6 Labelling And Marking of Instruments

All instruments shall be labelled with their reference numbers at the location where readings or measurements are taken. The labelling shall be permanent using a method or material agreed by the S.O.

20.10.1.7 Survey Equipment and Survey Reference Station

The Contractor shall be responsible for establishing survey reference station at locations selected by the S.O. to monitor settlement markers, settlement plates, displacement markers and other instruments deemed necessary.

All survey equipment used in conjunction with the monitoring of instrumentation, including measuring tapes, levels and total stations shall be maintained and calibrated as required by the manufacturers and good surveying practice.

The survey reference station provides a reference for levelling or horizontal measurement to other points. The location of the survey reference station, shall be agreed by the S.O. The coordinates and elevation of the survey reference station shall be surveyed in and submitted to the S.O.

The survey reference station shall be established on undisturbed ground clear of the embankment. The survey reference station shall be located on stable ground not affected by the Works, preferably away from the construction activities. The survey reference station is to be located on structures free of settlement and lateral movement or as agreed by the S.O.

The survey reference station may comprise of a steel rod of 20mm diameter, which shall be driven vertically into the undisturbed ground for a minimum distance of 1.0m and shall project approximately 75mm above ground surface. The rod shall be surrounded by not less than 0.03 m^3 of concrete at surface level, and the top of the rod shall be carefully centre punched.

The survey reference station shall be checked at intervals to be established by the S.O. to ensure that it is stable during the course of the monitoring works.

20.10.1.8 <u>Deep Levelling Datum</u>

A deep datum is required to provide a reference for measurement of ground levels in areas of soft ground.

The Contractor shall propose the location and depth of the deep levelling datum for the approval of the S.O.

The datum itself shall be fixed into hard ground with SPT value more than 50 or rock and isolated from soft and compressible overlying strata. If the SPT value of more than 50 is not achievable at great depths, the Contractor and the S.O shall mutually agree on the termination depth.

A deep levelling datum shall consist of a 25mm galvanized iron (GI) pipe fixed into hard ground with cement grout. The datum pipe shall be isolated from the overlying soft ground by a 75mm GI pipe embedded 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 0.03m^3 of concrete. The details of the deep levelling datum including its protective measures are as shown in the Drawing. The concrete shall be scored with the reference number of the datum.

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

20.10.1.9 Instrumentation Equipment References

Details of equipment shall be submitted to the S.O. for approval. If the S.O. considers it necessary, demonstrations shall be arranged by the Contractor. Any supplier of geotechnical instrumentation shall demonstrate that the manufacturer operates an adequate system of product quality assurance.

20.10.2 Displacement Marker / Settlement Marker

Displacement marker / settlement marker is required to monitor the horizontal and vertical movement of the ground or embankment surface. The Contractor shall be responsible for establishing settlement markers at locations as shown in the Drawing or as determined by the S.O.

The marker shall comprise of a steel rod of minimum 20mm diameter which shall be driven vertically into the embankment or undisturbed ground for a minimum depth of 1.0m and shall project approximately 75mm above the ground surface. The rod shall be surrounded by not less than 0.03cu.m. of concrete at ground level, and the top shall be domed and centre punched. The details of the installation are shown in the Drawing. The concrete shall be scored with the reference number of the marker.

For the settlement marker, the level of the top of the rod shall be measured using standard precise levelling techniques, referencing and closing back to the survey reference station with instrument to a minimum of ±1mm accuracy.

For the displacement marker, the lateral movement shall be measured using a total station or other survey techniques agreed by the S.O.

20.10.3 Building Settlement Marker

Vertical deformation of adjacent structures shall be determined by means of precision devices to an accuracy of ± 1.0mm. The Contractor shall install building settlement markers at locations as specified by the S.O.

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
b) Fixed to the building lining 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 ± 1.0mm
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) Designed such that the studs are safe from any hazards and to human life

20.10.4 Rod Settlement Gauge

Rod settlement gauge is required to measure settlement beneath the embankment. The Contractor shall provide and install rod settlement gauge at locations and levels as shown in the Drawing or as specified by the S.O.

The details of the rod settlement gauge shall be as shown in the Drawing and the Contractor shall be responsible for the installation of all the gauges as work proceeds. The base plate and first length of the rod shall be placed as early as possible during earthworks, preferably before any significant filling has been placed. Extension lengths shall be installed when the level of compacted embankment is 250mm below the top of the preceding lengths.

Should a rod settlement gauge be damaged, or should the Contractor fail to extend the gauge when required, the Contractor shall stop all filling activities in the vicinity of the gauge until the necessary remedial works have been carried out. The Contractor shall be liable for any delay in his programme, or any additional works that need to be done as the result of such damage.

Should any rod settlement gauge be damaged in such a way as to make it useless for its purpose and unable for S.O. to assess the settlement, the Contractor shall engage a third-party specialist at his own cost to assess the settlement for measurement purposes and shall be agreeable and approved by S.O. as the final decision.

Rod settlement plates shall be monitored by standard precise levelling techniques, referencing and closing back to the survey reference station with instrument to a minimum of ±1mm accuracy. Levels shall be taken at the top of rod itself and the fill adjacent to the gauge on each occasion. When rods are extended, levels shall be measured immediately before and immediately after adding the extension.

20.10.5 Inclinometer

Inclinometer provides a method of measuring a continuous profile of horizontal deflection both at the surface of and within a mass of soil. The Contractor shall install inclinometer at locations and depths as specified by the S.O. The details of the inclinometer shall be as shown in the Drawing.

Inclinometer access tube shall consist of broached PVC tubing with four keyways set at right angles to each other and with couplings and end caps where necessary. The S.O. may instruct the Contractor to obtain spiral metric measurements of the keyways in the inclinometer tubing after installation. After that, assembly joints and rivets shall be wrapped in sealing tape. The tube shall be coated with thick grease over its upper part when it passes through compressible subsoils.

The assembled tube shall be lowered into borehole backfilled with a suitable bentonite: cement grout mix. Alternatively, the tube may be placed in an open borehole and grout placed afterwards. In granular material, the backfill may be sand or pea gravel. The keyways shall be orientated such that movements are measured parallel to and at right angles to the embankment axis.

Angular movements shall be measured by an inclinometer probe (torpedo) which shall be a biaxial type and the system shall be capable of measuring lateral deformation to an accuracy of ± 6mm over a depth of 25m.

The inclinometer data logger unit shall display the readings from the inclinometer torpedo on an alphanumeric display. 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 anyone set of readings
(d) Backlit LCD display

The readings shall be read at every 0.5m and stored in the data logger.

The level of the top of the access tube shall be measured by standard

precise levelling techniques as and when necessary.

20.10.6 Horizontal Inclinometer

The horizontal inclinometer provides a method of measuring vertical displacement beneath an embankment. Readings are taken at regular intervals across the entire width of the embankment. The Contractor shall install the horizontal inclinometer across the full width of the embankment at locations and with details as shown in the Drawing.

The horizontal inclinometer shall be installed before earthworks commence as shown in the Drawing and shall consist of 70mm or 85mm inclinometer casing installed in a trench. The trench shall be filled with sand or the excavated material provided it is suitable fill and stone free, and approval is given by the S.O. Each end of the inclinometer casing shall have an end cap and shall have an eye for retention of the instrument draw cord. Each end of the inclinometer casing shall also pass freely through a plastic protective cover set into a concrete pad. The concrete pads shall have minimum dimensions of 1.5m x 1.5m x 0.3m. They shall be located beyond the influence of the area causing settlement. At each concrete pad, a survey pin shall be cast into the concrete.

Sufficient inclinometer casing shall be installed to accommodate large relative movement of the ground.

The horizontal inclinometer readout unit shall have a resolution of ±0.02mm or better and a sensor accuracy of ±0.1mm or better.

Immediately before taking a set of readings, levels shall be taken of the two survey pins set into the concrete pads.

20.10.7 Hydrostatic Profile Gauge

The hydrostatic profile gauge provides a method of measuring vertical displacement beneath an embankment. Readings are taken at regular intervals across the full width of the embankment and provide a continuous profile of settlement. The Contractor shall install hydrostatic profile gauges at locations and with details as shown in the Drawing.

The hydrostatic profile gauge shall be installed before earthworks commences as shown in the Drawing and shall consist of semi-rigid or high-density polyethylene (HDPE) profile tube with minimum outer diameter of 50mm installed in a trench. The trench shall be filled with sand or the excavated material, provided it is suitable fill and stone-free, and approval is given by the S.O. Each end of the access tube shall pass freely through a protective cover fabricated in plastic complete with solid PVC taper-threaded plug. The plug shall have an eye for retention of the

instrument drawcord.

Each protective cover shall be set into a concrete pad. If the expected settlement is large such that the protective cover may not be long enough to accommodate the relative movement of the access tube, then the protective cover shall be extended using a suitable piece of plastic pipe. The concrete pads shall have minimum dimensions of 1.5m x 1.5m x 0.3m at both ends of the HDPE tube. The concrete pads shall be located beyond the influence of the located area causing settlement. A survey pin shall be cast into each of the concrete pad. Both ends of the access tube shall be covered with a suitable end cap at all times.

The readout device system shall be capable of measuring elevation with reference to the survey pin to an accuracy of ±1.0mm. Immediately before taking a set of readings with the hydrostatic profile gauge, levels shall be measured of the two survey pins set into the concrete pads.

20.10.8 Magnetic Extensometer

Magnetic extensometer provides a method of measuring settlement at a point or a series of points below the ground surface. The Contractor shall install magnetic extensometer at locations and as specified by the S.O. The details of the magnetic extensometer shall be as shown in the Drawing.

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 with minimum 33mm outer diameter and 24mm inner diameter. External coupling shall be used to connect the access tube and this compression/extension coupling shall allow axial movement of access tubes to minimize distortion due to vertical strain. A rigid PVC endcap shall be fixed to the lower end of the series of tubes.

A datum ring magnet shall be fixed approximately 1m above the lower end of the tube. Spider magnets shall be used within the subsoil and plate magnets within the fill.

The tubes and spider magnets shall be assembled prior to installation in such a way that the magnets remain in the correct position in relation to the tube.

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. Once in position the spider magnets shall be released.

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.

Magnetic extensometer 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, once with the probe moving upwards from the base. Immediately before or after taking a series of readings, the level of the top of the access tube shall be measured by standard levelling techniques.

20.10.9 Combined Magnetic Extensometer and Inclinometer

Combined magnetic extensometer and inclinometer 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 magnetic extensometer and inclinometer at locations, and with depths and details as shown in the Drawing or as specified by the S.O.

The specification for magnetic extensometer shall be referred to Sub-section 20.10.8 and the specification for inclinometer shall be referred to Sub-section 20.10.5 of this specification.

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.

20.10.10 Standpipe

Standpipe provides a method of monitoring the water table or ground water level. The Contractor shall install standpipe at locations and with depths and details as shown in the Drawing or as specified by the S.O.

The standpipe shall be slotted UPVC tubing of nominal size 50mm diameter. The perforated part shall be wrapped with filter fabric as indicated in the Drawing.

The UPVC tubing shall be installed in not less than 3m lengths, except for one shorter length as required to suit the total standpipe dimensions. The concrete upper end of the tube shall be set in concrete.

The standpipe shall be placed in a 100mm diameter borehole backfilled with a graded filter sand (600 to 1200microns) 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.

Depth to water in the standpipe shall be measured using a dipmeter.

20.10.11 Piezometer

20.10.11.1 Standpipe Piezometer

Standpipe piezometer give a measurement of piezometric level 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 depth and details as shown in the Drawing or as directed by the S.O.

Standpipe piezometer shall be installed in boreholes at locations as shown in the Drawing or as instructed by the S.O. The piezometer tip shall consist of a porous ceramic, plastic element or other suitable element not less than 150 mm long with minimum diameter of 25mm and shall be protected at each end by plasticised polyvinylchloride (UPVC) fittings. The filter element shall have a pore diameter of not more than 60 microns and a permeability of not higher than 3×10^{-4} m/s. The tubes shall be jointed together and to the porous element with threaded coupling or other approved coupling, tape and glue in such a manner that the joints remain leak proof under the anticipated head of water.

The standpipe piezometer shall be installed in a borehole of minimum 76mm diameter. The sand filter surrounding the porous element shall be clean and fall wholly between the limits of grading 600 and 1200 microns. The contractor shall ensure that no sand adheres to the soil in the sides of the borehole. Where there is water in the borehole the contractor shall allow sufficient time for all sand to settle. The final level 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.

Seals consisting of bentonite pellets shall be placed above, and if necessary, below a sand filter. 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 in the drawing. Before taking initial readings the contractor shall carry out simple falling head test by raising the water level 1.5m above the static level, using an extension pipe if necessary

The depth to water in the standpipe piezometer shall be measured using a dip meter.

20.10.11.2 Pneumatic Piezometer

Pneumatic piezometer is used to measure pore water pressures at specific depths within a soil profile. They can be used in a wide variety of

soil types. The Contractor shall install pneumatic piezometers at locations, and with depths and details as shown in the Drawing or as directed by the S.O.

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

The piezometers shall be connected to twin tubing with suitable brass couplings. Joints in the tubing other than at the piezometer tip or at the terminal point shall not be permitted. The tubing shall be connected either to suitable quick release couplings or a terminal point which shall be protected at all times. Where tubing is laid in trenches the backfill shall either be sand or excavated material, provided it is suitable fill and stone-free. The tubing shall be laid with sufficient slack to take up any lateral movements that are expected to occur due to settlement of embankments or structures.

Before installation and taking initial readings, the Contractor shall conduct a pressure test on the pneumatic piezometer tip in a container of water after connection to the tubing to check for leaks or poor connections. The ceramic element shall be workable 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.

20.10.11.3 Vibrating Wire Piezometer (VWP)

The Vibrating Wire Piezometer (VWP) is used to measure water pressure at specific depths in variety of soil types. The Contractor shall install VWP at location, and with depths and details as shown in the Drawing or as directed by the S.O. Prior to the installation of the VWP, the Contractor shall submit all required technical specifications, including a calibration certificate for S.O.'s approval.

VWP is used to monitor pore water pressures in soils. The VWP converts water pressure signal via components of VWP, include a porous tip containing a pressure-sensitive diaphragm; a pre-tensioned steel wire; and an electro-magnetic coil, one end of which is connected to the diaphragm, and the other to the body of the piezometer.

The VWP tip shall be of high air entry ceramic type with an average pore diameter of 50 micron using a stainless-steel body. The piezometer system shall have a pressure range with an accuracy of 0.1% of full scale.

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.

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 connecting the signal cable to the readout unit and the data shall be stored in the readout unit.

20.10.11.4 Installation of Piezometer (All Types)

The piezometer shall be installed in a borehole of not less than 76mm diameter. The drilling medium shall be water and extra care and attention shall be given during boring to ensure that the borehole is as vertical as possible to the required depth. Steel casing shall be used to prevent the collapse of the borehole. The borehole shall be flushed clean with water prior to installation.

Before installation the piezometer element shall be immersed in de-aired water for at least 24 hours to saturate the element. De-aired water shall be prepared by boiling, and subsequently allowing the water to cool before use.

The piezometer tip shall be installed in a borehole backfilled with graded sand filter to the depth indicated. The sand filter surrounding the porous element shall be clean and fall wholly between the limits of grading 600 and 1200 microns. The Contractor shall ensure that no sand adheres to the soil in the sides of the borehole. The Contractor shall allow sufficient time for all sand to settle. The final level of the top of the 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.

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, and the top part with a concrete plug. The bentonite:cement grout mix shall be designed to mimic the surrounding soil or as shown in the Drawing. A protective cover shall be set into the concrete with caps and air vents as indicated in the Drawing.

20.10.12 Commissioning And Base Readings

After installation, the functioning of each instrument shall be demonstrated to the S.O. 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. The three sets of readings shall be taken immediately after installation of the instruments. If there are significant differences or anomalies, further readings shall be taken. Once three sets of comparable readings have been taken, these shall be averaged to form the base readings.

In cases where instruments are installed during earthworks, 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 S.O.

20.10.13 Readings

The measured values shall be recorded on a record sheet. For readings that are recorded on data loggers, a record sheet shall be required giving references to the data stored. The format of plotted results shall be submitted to the S.O. for approval. Details of information and values to be stored on each record sheet in addition to the general information required but not limited to the following:-

Table 20.10: Data Required for Each Instrument

Instrument	Data Required
Displacement marker	- distance from fixed point (m) (details to be given) including base reading - change in distance from fixed point relative to base readings (mm)
Settlement marker	- reduced level of top of rod (mRL) including base reading - change in reduced level of top of rod relative to base readings and previous reading (mm)
Building Settlement Marker	- reduced level of stud (mRL) including base reading - change in reduced level of stud relative to base readings and previous reading (mm)
Survey reference station	- chainage, offset, coordinates (in WGS 84) and reduced level of top of rod (m)
Deep levelling datum	- reduced level of datum (mRL)
Rod settlement	- reduced level of top of rod (mRL) including base reading

gauge	- original ground level at gauge location (mRL) - reduced level of ground adjacent to gauge (mRL) - record of fill placed (m) - total thickness of fill (m) - record of extensions (m) - settlement of plate relative to base readings and previous reading (mm)
Hydrostatic profile gauge	- reduced levels of survey pins (mRL) - original ground level every 10.0m along line of gauge (mRL) - level of fill every 10.0m along line of gauge (mRL) - thickness of fill along the line of the - gauge (m) - distance from end of access tube to point used as reference for longitudinal measurement (m) - listing of elevation of access tube relative to survey pin at 1.0m intervals (mRL) - graph of settlement of access tube relative to base readings and thickness of fill against distance along the tube - maximum settlement relative to base readings and previous reading and its location (mm)
Horizontal Inclinometer	- reduced levels of survey pins (mRL) - original ground level every 10.0m along line of gauge (mRL) - level of fill every 10.0m along line of gauge (mRL) - thickness of fill along line of gauge (m) - distance from end of access tube to point used as reference for longitudinal measurement (m) - listing of elevation of access tube relative to survey pin at 0.5m intervals (mRL) - graph of settlement of access tube relative to base readings and thickness of fill against distance along the tube - maximum settlement relative to base readings and previous reading and its location (mm)
Magnetic extensometer	- reduced level of top of access tube (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) - graph and listing of horizontal movement of access tube relative to base readings against depth
Combined magnetic extensometer and inclinometer	- reduced level of top of access tube (mRL) including base reading - 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) - graph and listing of horizontal movement of access tube relative to base readings against depth depth to water from top of tube (m)
Standpipe piezometers	- depth to water from top of tube (mRL) including base reading - reduced level of top of tube (mRL) - reduced level of ground adjacent to standpipe (mRL) - water head (mRL) - change in water head relative to base readings (m)
Pneumatic piezometers	- water pressure reading (m water) including base reading - reduced level of piezometer tip as installed (mRL) - water head (mRL) - change in water head relative to base readings (m)
Vibrating wire piezometer	- water pressure reading (m water) including base reading - reduced level of piezometer tip as installed (mRL) - water head (mRL) - change in water head relative to base readings (m)

The Contractor shall submit to the S.O. the specified number of copies of each record sheet with necessary raw data within one (1) working day of taking the readings.

If any anomalous readings are detected and verified to be correct, the S.O. shall be informed immediately.

20.10.13.1 Frequency Of Readings

Each instrument shall be read immediately before and after each change in loading (i.e. each layer of embankment or structural fill, etc.) unless otherwise shown in the Drawing or as directed by the S.O. Any instruments found to be faulty shall be promptly brought to the S.O.'s attention so that remedial measures can be implemented.

20.10.13.2 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 values or trends, then further readings shall be taken immediately and the S.O. shall be informed. If the anomalous values persist, then the S.O. shall be informed and an investigation shall be carried out to find the reason(s) for the anomalous readings.

20.10.14 Report

20.10.14.1 General Information on All Records

All records of instrumentation including installation, readings or monthly

summaries, shall contain the following information: -

- Project name
- Contract name and number
- Instrument reference number and type
- Dates and times of installation and completion,
- Summary of reading
- Chainage and offset / coordinates in WGS 84
- Personnel names, roles and responsibilities
- Relevant comments or remarks

20.10.14.2 Installation Records And Reports

The Contractor shall prepare an installation record sheet for each instrument to be installed and submit to the S.O. for approval at least two weeks before installation commences.

20.10.14.3 Monthly Monitoring Reports

A sample of the format of the report shall be submitted to the S.O. including all graphical presentations for approval at least one month before submission of the first monthly report unless otherwise specified by the S.O. Each monthly report shall include :-

- a description/scope of monitoring works
- information on reading anomalies or corrections, if any, and factors which may influence measured data
- observations or remarks
- a drawing showing installed locations of instrumentation
- data tabulations or plots of instrument readings include but not limited to the following :- .

Table 20.11: Data Required for Each Instrument

Instrument	Data Required Plots and Summaries Required
Displacement marker	- deflection vs. time indicating direction of movement (tabulation and plot)
Settlement marker	- settlement vs. time (tabulation and plot)
Building settlement marker	- settlement vs. time (tabulation and plot)

Survey reference station	- chainage, offset coordinates and reduced level (tabulation)
Deep levelling datum	- reduced level (tabulation)
Rod settlement gauge	- thickness of fill and settlement of plate vs. time (tabulation and plot)
Hydrostatic profile gauge	- latest graph of settlement of access tube relative to base readings and fill thickness against distance along the tube - maximum gauge settlement and corresponding fill thickness vs. time (tabulation and plot)
Horizontal inclinometer	- latest graph of settlement of access tube relative to base readings and fill thickness against distance along the tube maximum gauge settlement and corresponding fill thickness vs. time (tabulation and plot)
Magnetic extensometer	- settlement of each magnet vs. time (tabulation and plot) - settlement of each magnet vs. depth for latest set of readings (plot)
Inclinometer	- latest graph of horizontal movement of access tube relative to base readings against depth - Maximum horizontal movement relative to base readings vs. time (tabulation and plot)
Combined Magnetic Extensometer Inclinometer	- as per magnetic extensometer and inclinometer described above
Standpipe piezometer /Pneumatic piezometer/ Vibrating wire piezometer	- water head vs. time (tabulation and plot) - excess water head vs. time (tabulation and plot) - all instruments in a profile plotted on the same graph

The Contractor shall submit four sets of report to the S.O. (hardcopy and softcopy) within seven (7) days after the end of each calendar month of monitoring.