GENERAL SPECIFICATION

APPENDIX P1

TUNNEL MACHINES

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GENERAL SPECIFICATION

APPENDIX P1

TUNNEL MACHINES

1. SCOPE

1.1. This section together with the Material and Workmanship Specification and Particular Specification provide minimum requirements for the design and fabrication of the Tunnel Boring Machine (TBM).

1.2. For all references (code of practice, standards and regulation) made in this Appendix, the latest editions of the referenced documents (including any amendments and/or replacements) apply.

1.3. The Contractor shall comply with, but such compliance is not limited to the following Singapore and International Standards;

a. Workplace Safety and Health Act,

b. Workplace Safety and Health (Construction) Regulations and in particular all aspects applicable to tunnelling works,

c. BS 6164: Code of Practice for Health and Safety in Tunnelling in the Construction Industry,

d. BS EN 16191: Tunnelling Machinery - Safety Requirements,

e. BS EN 12110: Tunnelling Machines – Air Locks – Safety requirements,

f. BS EN 1889-2: Machines for underground mines, Mobile machines working Underground, Safety, Rail locomotives,

g. CP88: Code of Practice for temporary electrical installations - Construction and building sites,

h. British Tunnelling Society Compressed Air Working Group: A Guide To the Work In Compressed Air Regulations, and

i. BS EN 60204 Safety of Machinery - Electrical Equipment of Machines.

2. DEFINITIONS

2.1. “TBM” (Tunnel Boring Machine) is a machine equipped with excavating machinery that is integral with the shield and which excavates the full tunnel profile.

TBM is a type of pressure balanced machine equipped with a separate chamber behind the cutter head where a mixture of earth and water (Earth Pressure Balance Machine – EPB TBM), slurry (Slurry TBM) or a similar medium is pressurised in the excavation chamber to balance the earth and hydrostatic pressure to be encountered.

2.2. “Shield” is a part of the TBM consisting of protective metal that is forced forward through the ground and which protects those working within it.

2.3. Tunnel lining can either be constructed using segments (Segmental Lining) or monolithic method (Monolithic Lining). Segmental Lining consists of a number of precast segments bolted or dowelled together, and are installed using a segment erector. Monolithic Lining exists as a singular piece and does not have any joints. Segmental linings will be erected in the tail of the shield within the “tail skin” and the shield will be forced forward by jacking from the last completed segments.

2.4. "Earth Pressure Balance Machine" (EPB TBM) is a TBM where the excavation chamber relies on excavated earth to support the ground. It is equipped with a screw conveyor, belt conveyor and belt weigher.

2.5. "Slurry TBM" (Slurry TBM) is a TBM which provides face support by pressurizing stabilising fluid (slurry counter pressure) inside the excavation chamber. Adjustment of slurry counter pressure at the face is dependent on the hydraulic circuit (supply of bentonite slurry, mucking of slurry and excavated materials).

2.6. "Hydro-Shield TBM" (Hydro-Shield TBM) is a type of Slurry TBM in which the slurry counter pressure inside the excavation chamber is compensated by a linked chamber (air-cushion chamber) partially filled with compressed air and pressurized slurry.

2.7. "Large Diameter TBM" (Large TBM) refers to any TBM exceeding the cutting diameter of 10m. Large Diameter TBM used for the construction of Single Bored Tunnel is defined as SBT.

2.8. "Rectangular Tunnel Boring Machine" (RTBM) refers to a TBM with a rectangular excavation profile. It may or may not be equipped with an earth pressure balancing capability.

"PB RTBM" (Pressure Balance RTBM) is a type of RTBM equipped with a separate chamber behind the cutter head where earth, slurry or a similar medium is pressurised in the excavation chamber to balance the earth and hydrostatic pressure to be encountered.

"Open-Faced Rectangular Tunnel Boring Machine" (Open-Faced RTBM) is a type of RTBM equipped with excavating machinery (road header, boom excavator, bucket excavator) which is independent or semi-independent from the shield and which will allow access to the face without entry through a separate chamber. Alternatively, excavation may be executed by manual tools.

2.9. "Open-Faced Tunnel Boring Machine" (Open-Faced TBM) is a shield equipped with excavating machinery (road header, boom excavator, bucket excavator) which is independent or semi-independent from the shield and which will allow access to the face without entry through a separate chamber. Alternatively, excavation may be executed by manual tools.

2.10. "TBM back-up" refers to the ancillary and other equipment associated with the TBM required for all of the necessary supporting services related to the machine operation and tunneling process, and which is towed behind the TBM as it advances.

2.11. "Slurry Treatment Plant" (STP) is a setup on-site to remove the excavated materials conveyed in the slurry so that the slurry can be recycled and reused for the continuous excavation/ mining by the TBM. The system separates and recovers the excavated materials from the slurry that was used as a transportation medium.

2.12. "Slurry Transportation System" (STS) refers to the pipeline system linking the TBM and STP with controlled valves, manual valves, pumps installed along feed and discharge pipelines enabling the circulation of pressurized slurry to the excavation face during tunnelling, transportation of excavated materials by slurry and maintenance.

3. SELECTION OF TBM

3.1. The Contractor shall submit with his tender, details of the intended TBM type and, preferred TBM manufacturers and factory of manufacture. The Contractor shall propose at least one but not more than two preferred TBM manufacturer for the Authority's consideration. These details shall include a narrative on his selection criteria with regard to soil and rock types along the tunnel drives and their characteristics, control of ground movement / settlement, ground water pressures, expected advance rates and any other considerations.

3.2. The Contractor shall demonstrate that his chosen TBM manufacturer has the required experience and track record to design and fabricate

the required TBM(s) to the Contractor's programme. The Contractor shall also demonstrate that the proposed TBM type can be used effectively in the soil strata encountered, is mechanically viable (repairable) without compromising safety or efficiency and that spare parts or components are readily available within 24 hours should there be a need to replace parts of the TBM during the works, including provision of skilled personnel to effect any such repairs.

3.3. The Contractor shall detail all ancillary components, for example; Compressed Air regulation and control, grouting, polymer injection, foam generation etc. in his submission. All main and ancillary components required for the operation and maintenance of the TBM shall be considered part of the TBM for purposes of guarantees, warranties and the requirements of these specifications and are to be provided and installed, by or through the chosen TBM manufacturer only.

3.4. The Contractor shall fully acquaint himself with the anticipated geological conditions. The TBM shall be capable of overcoming all conditions without difficulties while maintaining the required advance rates and operating parameters.

3.5. The Contractor's proposed TBM(s) must be able to control ground movements, including both settlement and heave, under all foreseeable circumstances, in all the types of anticipated geology and also mixed face conditions and thus negate any risk to buildings and other structures and utilities in the vicinity of the tunnel alignment. In his submission, the Contractor shall provide evidence of two projects where their proposed type of TBM has been used in similar ground conditions to those likely to be encountered on this project, detailing the advance rates achieved and settlements or settlement-related incidents recorded.

3.6. The Contractor shall carry out the works using the same type of TBM submitted at Tender stage and shall not be permitted to use any type of machine or manufacturer other than those proposed in his Tender.

3.7. The Contractor shall submit details to ensure that the TBM as manufactured, operated and maintained achieves the outputs specified within the Baseline Programme and the measures applied to ensure compliance by the TBM manufacturer. These details are submitted to the Engineer for acceptance prior to awarding the subcontract to the TBM manufacturer.

4. DESIGN AND MANUFACTURE

4.1. The detailed TBM design and specification shall be submitted to the Engineer for acceptance prior to fabrication. The Contractor shall also

include in his submission a schematic of the TBM assembly sequence, initial drive mode configuration and dismantling sequence.

4.2. The Contractor's TBM manufacturer shall make a presentation to the Engineer on the design and layout of the proposed TBM prior to fabrication.

4.3. The circular TBM shall be provided with anti-roll device, details of which shall be accepted by the Engineer, prior to the commencement of tunnelling works. The anti-roll device shall be able to resist rolling tendency of the TBM due to the cutting torque. Roll inclinometers shall be installed to provide an audible warning and automatic cut out system to the TBM at two pre-set levels. Such devices shall monitor roll in both directions.

4.4. The TBM shall be equipped with an acceptable device by which the quantity (volume/weight) of material excavated can be monitored and recorded automatically in real time. The device shall be located where it is least affected by vibration, roll and tunnel curvature. The device shall be configured so as to record all material removed from the cutter chamber. The measured quantity (volume/weight) shall be displayed in the control cabin and in the Engineer's office. An audible and visual alarm shall be incorporated in the control cabin and shall activate if the measured volume exceeds a pre-determined quantity related to machine advance.

4.5. The TBM shall be equipped with an air-conditioned control cabin. The monitoring and control instrumentation shall be grouped in suitable panels within the control cabin. The air-conditioned control cabin shall be located within the TBM, the TBM back-up or on the surface wherever applicable.

4.6. TBM and TBM back-ups shall be new on arrival to site with all the necessary documentation to substantiate this.

4.7. All TBM(s) shall be designed to maintain pressure on the excavated ground at all times. The TBM shall be able to at least balance the total overburden pressure (including hydrostatic pressure) and shall be capable of varying the face pressure as the overburden pressure changes. The face pressure sensors shall be designed such that they can be replaced from the rear of the bulkhead without reducing the face pressure. All sensors shall be calibrated in accordance with the manufacturer's recommendations. The Contractor shall submit a method statement detailing the calibration and replacement of face pressure sensors to ensure that the face pressure is accurately monitored throughout the tunnel drive. All bulkhead pressure readings shall be displayed in real time and in 10-second averages.

4.8. The final design details, drawings and specification of the TBMs shall be submitted within three months of the award of Contract to the Engineer for acceptance.

4.9. The TBM shall be shop manufactured in units of convenient size, suitable for field erection and dismantling under the specific site conditions of the Contract. The Contractor shall make every effort to minimise the site erection by delivering and assembling the TBM in component parts as large as possible. All of the main components and any single item weighing in excess of 10 Tonnes shall have their weight in metric tonnes marked on them in clear visible lettering prior to shipping. All components shall be designed with the lifting lugs at suitable locations to facilitate safe lifting. The Contractor shall engage PE to design all lifting lugs including but not limited to TBM shield, manlocks, screw conveyor etc. in accordance to the prevailing codes. Non-Destructive test on lifting lugs shall be carried out prior to lowering into the shaft. Non-generic lifting appliances such as spreader beams which are required for assembly and dismantling of the TBM shall also be provided, complete with PE-endorsed calculations and shop drawings, and test certificates demonstrating the safe capacity for use.

4.10. Prior to fabrication, a detailed programme for the design and fabrication of each TBM, indicating procurement and supply of key components and materials, stages of fabrication and testing shall be submitted. A monthly report stating the progress of the design and fabrication with respect to the above programme and outlining any notable issues or occurrences shall be submitted to the Engineer. Progress photographs shall accompany the report demonstrating procurement of materials and fabrication.

4.11. Prior to the delivery of TBM to site, the Contractor shall supply 1 (one) hardcopy in colour print and (six) softcopy (DVD) of the TBM operating manual, in English to the Engineer.

4.12. The Contractor’s TBM manufacturer shall review in detail and shall provide a written declaration confirming that he has reviewed the key components of the tunnelling system and that the TBM and support systems will be compatible and able to achieve the peak performance (which is at least twice the average rate) and schedule requirements of the tunnelling works based on the anticipated ground, or as agreed with the Engineer.

4.13. The detailed TBM design, drawings and specification shall be submitted to the Engineer for acceptance prior to fabrication. The Contractor shall also include in his submission a schematic of the TBM assembly sequence, initial drive mode configuration including the safety features but not limited to ventilation, firefighting system and walkway which shall not be inferior to the main drive mode, and dismantling sequence.

4.14. Prior to fabrication, the Contractor shall submit the following to the Engineer:

a. A detailed program for the design and fabrication of each TBM, indicating procurement and supply of key components and materials, stages of fabrication and testing;

b. Drawings showing sections of the design to illustrate the locations and orientations of plant, equipment and access ways;

c. During fabrication the Contractor shall submit the following to the Engineer;

d. A monthly report stating the progress of the design and fabrication with respect to the above program and outlining any notable issues or occurrences is to be regularly submitted; and

e. Progress photographs shall accompany the report demonstrating procurement of materials and fabrication.

4.15. Shop Drawings shall be provided to scale and at a scale showing sufficient detail to clearly demonstrate that all requirements of this Specification are met. There shall be sufficient vertical and horizontal longitudinal sections at tunnel axis and cross sections to clearly identify the different components of the TBMs, including trailing gear. The drawings shall include, as a minimum, the following information where applicable:

a. The name of the TBM manufacturer and the model numbers of all TBMs;

b. Cutter head, cutter head openings, cutter head tools, size and arrangement of tools. Submit designed cutter head power and torque;

c. Soil conditioning system;

d. Screw conveyor arrangement (including sealing system);

e. Thrust and steering systems. Submit proposed total operational and accidental thrust, jacking cylinders' arrangement, interface drawing showing plan and sections of ram shoes configuration, eccentricity between ram shoe and segment centerlines, ring building tolerance, etc.;

f. Alignment control, guidance system and data acquisition system (including sample display screens);

g. Articulation (including sealing system);

h. Bearings and bearing seals;

i. Drive system and main gear;

j. Tail seals and grease injection system (including sealing system);

k. Probe hole drilling system;

l. Tunnel lining grouting systems;

m. Compressed air system; including manlocks and control equipment;

n. Gas monitoring system;

o. Fire suppression system;

p. Schematic electrical system;

q. Ventilation system on TBM;

r. Segment handling system, including segment erector, method of gripping segments and the interface of TBMs with the segmental lining system elements;

s. Bentonite, foam and polymer injection systems;

t. Operator console and controls;

u. High Tension cable and water reels;

v. Segment lifting device;

w. Muck extraction and removal system;

x. Segment dismantling capability after ring erection;

y. Automatic face pressure; and

z. Backup trailer.

4.16. The TBM design shall permit removal of the structure of the machine including the cutterhead from within the shield, which may be left in place at the completion of the tunnel drive.

4.17. The Contractor shall not modify the TBM or any of its systems including interlocks without prior consultation and concurrence with the TBM manufacturer. The modification proposal including thorough risk assessment shall be submitted for the Engineer's acceptance.

4.18. The design of the TBM cutterhead shall:

a. prevent the cutterhead from moving at any point during maintenance or personnel entry into the excavation chamber;

b. provide an interlock to allow remote inching operation of the cutter head;

c. fit rotational drives with fail safe brakes; and

d. provide an interlock with the cutter head movement when the main bearing oil flow is no longer within specification.

4.19. For TBM with Segmental Lining, the design of the TBM shall:

a. control the propulsion cylinders from the main control cabin during the excavation cycle and from remote stations during the ring building cycle with an interlock provided to prevent duplicate operation of the shove propulsion cylinders; and

b. provide an erector equipped with fail-safe load-holding functions and alarm system.

5. FACTORY ACCEPTANCE TEST

5.1. The Contractor shall supply all necessary information to the Engineer to enable him to observe the commissioning inspection of the machine at the manufacturer’s factory, to ensure that the design and manufacture are in accordance with the specification.

5.2. Before the TBM is delivered to the tunnelling site, it shall be completely assembled together with TBM back-up to confirm the system is in full operational capability in the TBM manufacturer's workshop with all equipment installed so as to verify that it is in working order. The Engineer reserves the right to inspect the assembled TBM in the workshop prior to delivery. Sample segments shall be available to demonstrate the segment erection procedure. The TBM manufacturer and the Contractor shall provide a joint declaration to demonstrate the TBM and its necessary equipment installed are in working order in accordance with the Specifications and applicable regulations. The Contractor shall provide this declaration in his request for payment for TBM delivery.

5.3. The tail shield with tail seal brushes shall be assembled without internal bracing together with main shield during Factory Acceptance Test. Any out-of-tolerance pertaining to tail skin clearance shall be rectified within the factory before dispatching to the site. The design of tail shield shall have a tolerance of +10mm and -0mm in external diameter.

5.4. A dimensional survey is to be carried out by a qualified Surveyor for both intrados & extrados of the tail shield in the factory and on site without internal bracing.

5.5. The Contractor and the TBM manufacturer shall permit representatives of the Engineer to visit the TBM workshop at any time. The Contractor will be given one week notice of such visits and shall ensure that suitable English-speaking technical staff from either the Contractor or his TBM manufacturer is available to accompany the visitors around the premises.

5.6. The TBM shall come with manufacturer's supplied hand/foot holds and platform for working in the tunnel. These shall be fitted for inspection during the factory acceptance test. Anchorage points in the cutterhead for fall arrest protection shall be provided.

5.7. The Contractor shall supply all necessary information to the Engineer to enable him to observe the commissioning inspection of the machine at the manufacturer’s factory, to ensure that the design and manufacture is in accordance with the Specification.

6. TRANSPORT AND ERECTION OF THE TBM

6.1. When delivered to site the TBM shall be erected in the launch chamber or start shaft to the required grade and line, and to maximum tolerances of +10 mm, and -0mm in external diameter. Tail skin deformation shall not affect the minimum clearance for ring building as per design.

6.2. The Contractor shall ensure the structural clearance of minimum 30mm from extrados of segmental lining to the closest part of the tail shield at all the times and the Contractor shall submit relevant documents including survey reports duly endorsed by a qualified Surveyor as and when requested by the Engineer. This 30mm clearance should not be intruded during manufacturing.

6.3. The Contractor shall supply packing shipment lists in sufficient detail to allow the Engineer to verify the arrival of all critical machine components including spares. This information shall be provided 1 week prior to a TBM shipment to Singapore.

6.4. Services and utilities on site and on the TBM are to be colour coded to prevent accidental cross contamination and to warn where lines

contain high pressure or chemicals. The Contractor / TBM manufacturer shall follow the colour coding as shown below:

a. Industrial /Cooling water – Blue

b. Industrial Air – Grey

c. Breathing Air – White

d. Fire Fighting – Red

e. Dewatering – Black

f. Foam Injection – Violet

g. Grout and Bentonite – Brown

h. Hydraulic oil and Grease – Orange

i. Tail Sealer – Yellow

j. Other services - *Contractor to propose for the Engineer's acceptance

6.5. The Contractor shall submit the method statement prepared and agreed by TBM Manufacturer for safe erection, assembly and dismantling of the TBM.

6.6. The Contractor shall provide new umbilical for TBM during launching and umbilical cords at initial drive shall be laid on frames with rollers or hoists. If hoses are being reused, they shall be flushed and pressure tested prior to use. For used cables, continuity checks and megger test shall be conducted prior to use.

6.7. In the event of winches being used for delivering loads, it shall come with a spooler to ensure wires are neatly coiled. The winch design shall consider a safety factor of 2 for the heaviest load to be hauled.

7. SITE ACCEPTANCE TEST

7.1. Upon the completion of TBM assembly at launch shaft, the Contractor shall conduct site acceptance test (SAT) on the full functional testing of TBM to the satisfaction of the Engineer. The inspection checklist shall be provided by TBM manufacturer and submitted to the Engineer for acceptance prior to the site acceptance test.

7.2. The site acceptance test shall include the survey check of TBM shield roundness and any deviation from the approved design should be kept within the tolerance specified by the TBM manufacturer.

If the TBM shield roundness survey result is not within tolerance, the Contractor and TBM manufacturer shall submit a rectification proposal to the Engineer for acceptance and rectify the TBM shield deformation to the Engineer's satisfaction.

7.3. Prior to the launching of the TBM, the TBM manufacturer and the Contractor shall provide a joint declaration of full functional testing and conformity with the Specifications and associated codes and regulations.

7.4. If any deficiencies are evident in the TBMs or tunnelling system that have resulted in the required performance criteria or tunnelling schedule not being achieved then the Contractor and the TBM manufacturer shall take immediate action as deemed necessary, including modifications to the TBMs and/or tunnelling system, in order to improve the TBM performance in line with the agreed criteria and tunnelling schedule. All such actions/modifications to the TBMs/Tunnelling system shall be agreed with the Engineer prior to implementation. The Contractor shall not be entitled to claim any additional payments and/or extension of time for taking such measures or actions except where such deficiencies are not due to the Contractor’s default.

7.5. Prior to the initial drive and main drive, document review and site audit on compressed air plant installation on surface, tunnels and TBMs shall be carried out by the Engineer's appointed auditors to verify compliance to the Engineer's acceptance. The close out period to address site audit findings is set at a maximum of fourteen (14) days from date of audit.

8. SHIELDS AND BULKHEADS

8.1. The shield of any TBM supplied by the Contractor shall be a heavy duty fabricated structure which shall be manufactured to comply with EN 10025-2:2004 Grade S355JR / S355J0 or direct equivalent as a minimum standard and shall be built to a tolerance that ensures the tunnel linings can be built within the specified construction tolerances. It shall also be strong enough to avoid distortion under operational loads during driving and suitable for building the tunnel linings. The design shall take into account, amongst other things, the type, density, gradation, strength and abrasivity of the soil. The Contractor shall submit the relevant documents and test reports by a SINGLAS-accredited laboratory to the Engineer to substantiate that the Grade S355JR / S355J0 or direct equivalent grade steel has been used for fabrication of the shield.

8.2. The TBM shield shall be designed to support the full ground and groundwater loads without internal bracings during the dismantling of internal components up to the completion of the cast in-situ permanent lining. The Contractor shall provide structural calculations, carry out monitoring on the shield deformation during this period and submit the limits of deformation for the Engineer's acceptance.

8.3. The TBM shall be fitted with a pressure bulkhead capable of withstanding the total overburden pressure (including hydrostatic pressure) plus an adequate safety margin throughout the life cycle of the TBM with sufficient wear protection to the acceptance of the Engineer.

8.4. The bulkhead shall have an air purge port situated no more than 0.50m from the crown of the shield. This air purge port will be used to release possible pressurised air bubble at the top of the chamber. This port shall be able to be opened manually and automatically from the TBM operator panel.

8.5. The design of the structures of the shield body and other important members shall be supported by Finite Element (FE) method calculations. The TBM(s) structure shall be designed in accordance with the non-exhaustive requirements described below:

The shield (including tail skin) shall be designed to withstand all loads and forces occurring from the overburden and all loads and forces arising from transport, erection, launch, dismantling, prolonged stoppage and operating the TBM, both in normal mode and in modes required to correct misalignment. The Contractor shall provide the design of the shield for the Engineer's review and include details regarding plate thickness, weld requirements, material grade and the results of necessary calculations.

9. CUTTERHEAD AND DRIVE

9.1. The TBM cutterhead and spoil discharge system shall be designed to excavate through all anticipated ground conditions. Considerations shall be given to

a. Mixed face conditions;

b. Blockages;

c. High water ingress;

d. Abrasivity; and

e. Any other conditions that may affect the programme.

9.2. For TBMs excavating in rock or boulders, a system for reducing the size of the cutterhead openings such as slit control brackets or any other equivalent means shall be provided to prevent boulders entering the excavation chamber and causing blockage to the spoil discharge and conveyance system.

9.3. The cutterhead shall be capable of clockwise and anticlockwise rotation and shall only be able to excavate the ground whilst the hydraulic rams are being actuated. The design shall ensure that the cutterhead can be retracted back from the unexcavated ground to minimise the risk of the cutterhead jamming and to facilitate maintenance. A rapid response torque limiting device shall be installed which shall act to prevent damage to the drive transmission should a cutter head lockup occur. The cutter head shall be fitted with a low speed interlocked inching device capable of rotating the cutter head under fine control to obtain accurate positioning for the purpose of face inspection, cutter tool maintenance or probing.

9.4. The TBM cutterhead shall be designed such that tunnelling through GFRC ERSS, ERSS soft eyes, dome eye, and ground treatment zones is achievable.

9.5. The TBM shall be designed for safe entry and working in the cutterhead chamber. There shall be provisions against ingress of soil and water during cutterhead inspection and maintenance.

9.6. Overcutting shall be achieved by at least two programmable copy cutters (for soil only, one used as a spare) which shall be provided with a means to control and monitor their stroke and the circumferential location. The stroke for copy cutter shall be at least of 100mm more than the external cutting radius of TBM.

9.7. Recessed into the forward face of the pressure bulkhead shall be an adequate quantity of service penetrations for electricity, water, high pressure air, dewatering or any other facility that may be required and can be manually operated by maintenance personnel in front of the pressure bulkhead. The recesses shall have a cover to ensure the ingress of tunnel spoil does not occur. All services shall be suitably designed for use during compressed air works, without loss of pressure.

9.8. The TBM Cutters shall be mounted such that access for repair and replacement can be carried out from within the cutter head (‘back loaded’) in safe working conditions and without personnel accessing the excavation face.

9.9. The cutter head structure and bearing with its support system shall be capable to absorb the maximum forces envisaged in operation. These forces shall be included within the finite element analysis of the shield body structures. The Contractor shall provide the design of the cutter

head for the acceptance of the Engineer and include calculations to justify the plate thickness, weld sizes with input and output data demonstrating the adequacy of the structure under all loading conditions in graphical and numerical form.

Main Bearing and Grease

9.10. The main bearing shall be designed to transmit the cutter head torque and thrust forces.

9.11. The design for the main bearing lifetime under all operating loads shall be in accordance with ISO 281 L10. Calculations and load data shall be submitted to the Engineer prior to the purchase of the main bearing.

9.12. The Contractor shall submit the proposed bearing manufacturer to the Engineer for acceptance. The design life of the main bearing at the time that the TBM arrives at the Worksite shall not be less than 10,000 hours with a sealing system providing protection for the same period. The main bearing and sealing systems shall be tested and certified by the original manufacturer and verified for the minimum remaining design life of 10,000 hours.

9.13. The lubrication circuit for the bearing raceways and gear drives shall be provided with a facility for monitoring lubricant contamination.

9.14. The TBM shall provide condition monitoring of the main bearing, the sealing system and main drive gearboxes including oil flow, oil pressure, oil temperature including filter analysis and the measurement of metal parts per million on a regular basis to allow monitoring of the bearing, sealing system and main drive gearboxes to detect contamination and wear.

9.15. The Contractor shall submit a programme for manufacture, delivery and installation of TBM main bearings.

9.16. Sampling points shall be provided for all lubricants.

9.17. The TBM shall be configured to allow for the replacement of the main bearing, excavating tools and seals from behind the cutter head.

10. CUTTER TOOLS

10.1. Prior to the commencement of tunnelling the Contractor shall submit to the Engineer for acceptance his Method Statement for the maintenance and refurbishment of all cutter tools. Where disc cutters are provided, the Method Statement is to detail as a minimum workshop requirement, cutter disc refurbishment procedure, cutter disc hub wear limitations, limiting number of refurbishments for cutter disc

hubs, cutter types for varying ground, cutter tolerance for replacement/reuse. The Method Statement is to be endorsed by the TBM manufacturer /cutter supplier. All refurbished cutting tools shall have quality control check approved and witnessed by the cutter supplier.

10.2. The Contractor shall take note that all the cutter tools and their components shall be brand new for first dressing.

10.3. Where disc cutters are provided, the tip of all disc cutters at its limiting wear criteria shall offset ahead of the main cutter head structure by an optimum distance that allows the excavated material to move freely away from the face without becoming trapped between the face and the surrounding cutter head structure.

10.4. If the cutter head is fitted with a combination of rolling disc cutters and point/chisel attack bits (picks), in order to prevent the picks engaging the rock first, and becoming damaged or dislodged, they shall be recessed from the nominal profile of the disc cutters at a distance that allows for the penetration and wear of the disk cutters. The picks shall be fixed by secure fixings that will prevent dislodgement.

10.5. For tunnelling in Granite rock of weathering grade I-III, extra heavy duty grade cutters (utilizing disc cutters Rockwell Rc 55 or better) shall be used. Redundancy for the outer gauge is to be provided i.e. minimum 2 discs cutting on the same outer most cutting path are to be provided.

10.6. Chip insert bits shall not be used in Granite rock of weathering grade I-III.

10.7. A high degree of cutter head wear is to be expected on the plane surface of the cutter head, as well as the throat or openings of the buckets/scoops These surfaces shall be extensively prepared with abrasion resisting material/s, which shall have hardness greater than that of the free silica within the granite matrix. In mechanical terms the hardness shall be equal or greater than that provided by good quality disc cutters (Rockwell Rc 55 minimum).

10.8. The high degree of cutter wear would also result in frequent changing of cutting tools. The TBM shall be designed to facilitate the swift changing of cutting tools. The cutter head discs and/or picks and associated saddles/support blocks shall enable the respective cutter types to be removed or installed from behind the face of the cutterhead and shall be interchangeable. Saddles shall be fitted with replaceable abrasion-resistant shrouds to prevent rock chips travelling past the cutter opening.

10.9. In his submission the Contractor shall submit the allowable wear limit of the cutting tools and state how he will minimize this down time and

highlight any features he will incorporate on his TBM to facilitate this, detailing typical expected change times for gauge, face and double cutters. The Contractor's TBM manufacturer shall carry out a demonstration of the changing of the cutting tools at his factory premises.

10.10. The Contractor should simulate how the cutting tools will be changed in the tunnel by transferring the cutting tools to the material-lock and through into the cutterhead chamber. Cutters from the centre, middle and periphery of the cutterhead should be removed and exchanged with that transported in. The removed cutters are to be transported out.

10.11. This demonstration shall include the working platforms and access footholds /handholds that will be provided. Sufficient, non-slip footsteps and safety harness attaching points adjacent to all cutter locations shall be provided to insure cutter change personnel are adequately protected. Either a mechanical device to support the mass of any cutter assembly greater than 30 kg, or attachment points for personnel to connect hand operated lifting devices are to be provided.

10.12. The Contractor's TBM manufacturer shall not use any equipment that is not part of the tunnelling machine. A full report (written in English) including photographs shall be submitted to the Engineer within one month of the demonstration.

10.13. A wear detection system shall be incorporated into cutting tools, muck collecting buckets and the main cutter head structure which shall indicate when the wear has reached unacceptable levels. This system shall utilise either high pressure oil or suitably robust electrical sensors or an equivalent system and have sufficient locations around the cutterhead to provide adequate indication of wear and the need for specific remedial intervention for repair. A minimum of 6 (six) wear detectors shall be provided with at least one on the gauge cutter. Provision to measure overcut diameter of excavation shall be provided with an alarm provision if the overcut drops below a predetermined level.

10.14. The cutterhead shall have a series of paddles or structural arms protruding from the rear face of the cutterhead and from the front face of the shield bulkhead that are designed and located to prevent excavated material plugging within the excavation chamber. The mixing arms/paddles shall be rigid heavy structures designed to withstand any impact loading and shaped to improve flow through the excavated material. The arms/paddles shall be heavily protected from abrasion with suitable hard faced welding materials.

11. TAIL SHIELDS AND GROUTING SYSTEMS

11.1. The tailskin shall be fitted with a minimum of three rows of tail brush seals to prevent the ingress of water and/or grout between the tailskin and tunnel lining. The tail seal assembly shall be capable of withstanding the full overburden pressure (including hydrostatic pressure) and exclude the ingress of any grout being injected. In addition, a tail seal shall be incorporated on the outer surface at the rear of the tailskin to limit grout migration along the shield towards the face.

11.2. The lower section of the tail shield shall be fitted with non-slip surface and subject to the acceptance of the Engineer.

11.3. The tail must include a continuous pumping system for tail seal grease through pipes integral with the tail skin and evenly spaced around the circumference.

11.4. Any tail brush seals shall be replaceable and a minimum of two brush tail seals shall be replaceable from within the shield without exposing the ground during the drive.

11.5. The Contractor shall include in his TBM design submission, calculations to show that the TBM will be able to negotiate the horizontal and vertical tunnel alignment with sufficient clearance between the TBM tail skin and the extrados of the tunnel lining rings to allow the TBM to turn through all curves on the alignment without causing damage to the tunnel lining rings.

11.6. The TBM shall be designed to enable the void behind the segments to be grouted continuously and completely from the shield as it is propelled forward. The grout ports shall be incorporated within the tailskin rather than mounted externally on it.

11.7. The TBM shall be provided with two component liquid type backfill grout system. There shall be at least one active grout port and one spare grout port in each quadrant of the tailskin circumference, preferably located at or close to the tunnel shoulder and knee levels. Individual grout ports shall have independent grout lines leading up to the grout pump at the grout reservoir. All the grout pipes shall be fully enclosed within the tail skin to ensure no encroachment into tail skin clearance. The TBM shall have the facility and the capacity to inject grout simultaneously through at least four grout ports and through at least one grout port in each quadrant. The Contractor’s TBM manufacturer shall propose an operation procedure for the active and spare grout ports to be interchangeable and demonstrate this at his factory premises.

11.8. The TBM design shall enable the grout pipes to any individual port to be cleaned or replaced from within the shield in the event of a blockage without impairing the performance or preventing the use of any other grout port. At least one grout port in each quadrant of the shield shall be operational and available for grouting at all times during shield advancement. The TBM design shall enable automatic grout port flushing with return water back to the TBM. The grout tank at TBM back-up shall have at least double the theoretical grout requirement for each ring of tunnel advance to enable the filling of any overbreak as it occurs.

11.9. Grout pressure and flow rates shall be maintained at all times whilst the shield is advancing with varying speeds. The shield shall incorporate automatic systems for monitoring and controlling the volume and pressure of the grout being delivered to the tail void. The pressure and volume of the grout injected shall be measured near the injection point and data-logged.

12. SOIL CONDITIONINGS AND AUXILLIARY GROUND SUPPORT

12.1. The TBM shall be equipped with the facility to generate soil conditioning agents and deliver to the face during excavation.

12.2. The TBM shall be designed for and equipped with a supplemental ground stabilisation system. The TBM shall allow forward drilling through the shield, bulkhead and cutterhead for the purpose of probing ground conditions to carry out ground treatment to the surrounding ground. The TBM is to be provided with drilling equipment which shall be capable of being mounted in the machine. Each TBM shall be designed so that grouting can be carried out ahead of the TBM face for a full 360 degrees' annulus. Each grout port shall be fitted with a valve, and shall be designed so that a blowout preventer (BOP) can be fitted to control the loss of ground and groundwater during drilling. The proposed system shall comprise regularly spaced grout sleeve pipes built into the shield skin for grouting the ground ahead of the tunnel axis. The location and number of ports shall be adequate to facilitate full coverage of the ground in front of the cutterhead and fully around the shield for ground stabilization in all ground conditions. This shall be demonstrated by the Contractor in his TBM design to the acceptance of the Engineer. The drilling ports shall be readily accessible and be fitted with suitable non-return valves and located such that there is space for the use of blow out preventers. The Contractor shall also make provision in the design of the TBM to allow construction of a grout block in front of and around TBM cutterhead to enable cutterhead intervention in the event of an unforeseen event/obstruction in an area where access from surface is not achievable. The drilling equipment shall come complete with probing and grouting accessories. The Contractor shall propose and engage a competent drilling and grouting operator to deal with geology encountered in front of the TBM.

12.3. There shall be a sufficient number of injection ports in the cutterhead to inject additives for the purpose of conditioning the ground for effective excavation and soil discharge and/or to reduce face friction or wear on the cutterhead and cutting tools. Each port shall have its own individual feed line through the rotary coupler, with provisions made for clearing or replacing any blocked lines and/or ports from inside the TBM.

12.4. The TBM shall be equipped with an Automatic Face Control (AFC) system that is capable of automatically pumping bentonite slurry into the cutter head pressure chamber to compensate for deficiencies in the face support. The Contractor shall be responsible in maintaining a minimum pressure in the chamber whenever pressure at the tunnel face drops below the agreed minimum target face pressure. As a minimum the AFC shall comprise the following elements:

a. A tank located on the TBM trailing gantries that is filled with a support medium such as bentonite slurry or liquid polymer. The tank shall have a minimum storage volume of 6m3;

b. The tank shall feed a regulator vessel that is pressurised by compressed air or equivalent method to the desired face support pressure;

c. The chamber shall be provided with pressure cell that determine the pressure in the chamber at a minimum of three (3) different levels; and

d. The regulator vessel shall be connected to the crown of the chamber via an automatic valve. The valve shall be linked to the pressure cells and shall automatically open the line between the regulator vessel and the chamber as soon as the critical minimum pressure at any level is detected by the sensors.

13. THRUST AND STEERING SYSTEM

13.1. The TBM shall be equipped with shove rams of sufficient capacity to move it through all materials encountered at full hydrostatic pressure at a rate commensurate with the progress rate required by the programme, to the lines and grades shown. The rams shall be capable of simultaneous and individual actuation, controllable individual pressure and variable extension.

13.2. Rams shall be fitted with shoes of approved material so that the reaction of the rams will be safely distributed against the tunnel linings and does not cause damage to the linings and gaskets. Specifically, the ram shoes shall be designed so that the compressive loads are properly distributed onto the tunnel linings without affecting the gaskets, such as by providing recesses throughout into the jacking shoes to

avoid touching the gaskets during lining erection and properly distribution of compressive loads against the tunnel linings.

13.3. The ram shoes shall be designed such that they do not overlap joints in the segmental lining. Ram shoes located in the top half of the Shield shall be fitted with safety chains to prevent them from falling and injuring personnel.

13.4. Rams shall be provided with positive "pressure lock" facility to ensure that the face pressure is maintained during operation.

13.5. The TBM shall be articulated to allow for steering along the alignment. Articulation joints shall be provided with a sealing arrangement capable of withstanding the full overburden pressure (including hydrostatic pressure). Seals shall be protected from damage caused by material ingress during the activation of the shield articulation. Articulation rams shall be fitted with a mechanism to resist torque resistance.

13.6. At each articulation joint there shall be a sufficient number of lubrication injection points to the external portion of the shield structure. A non-return valve shall be connected to each injection point to arrest the flow of material from outside the shield.

13.7. The design of the TBM shall:

a) provide the facility to advance the TBM under the maximum face pressures expected in closed mode with maximum expected ground pressures acting on the shield including all steering and drag forces;

b) provide a propulsion system that advances the TBM by pushing off the leading edge of tunnel segmental lining;

c) provide propulsion cylinder shoes and pads that distribute the thrust without causing damage or distortion to the segmental tunnel lining;

d) fit propulsion cylinders with shoes so that the reaction of the cylinders will be safely distributed against the segmental lining without causing damage;

e) fit propulsion cylinders shoe guide bars to correct for any rotation of the shoes;

f) Propulsion cylinders are to be designed so that there is no eccentricity on segments during thrust process;

g) fit safety flanges to ram shoes in case of failure of erector system, and provide propulsion cylinders that operate individually or collectively in any combination; and

h) limit the load from one propulsion cylinder or combination thereof to avoid damage to the lining.

14. ERECTOR AND SEGMENT HANDLING

14.1. The TBM shall be equipped with a tunnel lining erector system capable of placing each lining segment safely into its final position along the periphery of the ring being erected. The erector and the tail skin/seal configuration shall be capable of removing damaged segments from an assembled ring within the first 500mm of the next TBM advance.

14.2. The tunnel lining erector shall be provided with all of the necessary safety systems for handling of the segments and shall have precise control with six degrees of freedom.

14.3. The rotation of the tunnel lining erector shall be provided by a minimum of two hydraulic motor gearbox units fitted with "fail-safe" braking device. The power of each drive unit shall be adequate to provide ring erection in the event of a failure of the other.

14.4. A "fail-safe" device shall be installed to prevent "overrun" of the erector rotation and this shall be arranged in a way that the erector can only operate at very slow speed in the vicinity of "overrun".

14.5. The erector shall be designed to enable the lowering of the segment from top dead centre to bottom dead centre location for safety, in the event of main power failure, whilst ring erection is in progress.

14.6. The controls for the shield rams and tunnel lining erector shall be arranged so that the operator has a clear unobstructed view of all of the plant that he is operating at all times.

14.7. The TBM shall be designed to allow the erection, installation of tunnel segmental lining and dismantling of the last built ring to replace at least two rows of tail seal brushes.

14.8. All hand held electrical equipment, such as the pendant controls for the segment erector and segment handlers shall be in watertight enclosures (IP65) and the control circuit it protected by a Ground Fault Interrupter Circuit.

15. MANLOCK AND COMPRESSED AIR

15.1. Compressed air work, air locks and all other installations shall comply, inter alia, with the requirements of Workplace Safety and Health Act (Chapter 354a), Workplace Safety and Health (Construction) Regulations, BS 6164 (Code of Practice for Safety in Tunnelling) and British Tunnelling Society Compressed Air Working Group: A Guide To the Work In Compressed Air Regulations. All components necessary for the underground operation of the Compressed Air System shall be factory fitted and comply with BS EN 12110 (Tunnelling machines – Air Locks Safety Requirement). For all the reference, the latest edition of the referenced document (including any amendments or replacement) applies.

15.2. All TBM(s) shall incorporate a minimum of one manlock comprising two compartments each with a capacity of 3 persons and minimum 2 metre clear space to accommodate a stretcher and two attendants for emergency rescue operations. Doors shall be capable of being opened without manipulation of the stretcher and patient. All air lock doors shall be made of steel. The use of cast iron or sliding air lock doors will not be permitted. The door for cutterhead chamber entry shall open into the manlock chamber direction. The man locks and all paraphernalia required for safe operation shall come factory fitted and comply with the latest version of BS EN 12110.

15.3. The TBM shall be provided with an independent material lock for transportation of all maintenance tools and cutters etc. into the pressure chamber. The material lock shall be dimensioned such that it provides adequate facility to pass items such as roller disc cutters, tools, rotary coupling elements etc. into the pressure chamber under compressed air.

15.4. The TBM shall be supplied with a factory-fitted chiller unit connected to the Compressed Air line to regulate temperature and humidity inside the working and evacuation chamber to comply with prevailing regulations.

15.5. All the pressure gauges fitted on man lock and material lock shall be in bar scale with pressure scale 0.5bar and diameter of pressure gauge shall be not less than 6-inch diameter. Gauges used for controlling the decompression of people to be calibrated every six (6) months. All pressure gauges & Barograph shall have a valid calibration cert issued by a SINGLAS-accredited laboratory.

15.6. The TBM shall be supplied with in-built humidity, temperature and oxygen monitoring devices in entry lock and manlock. In-built air, carbon and oil pre-filters shall also be provided outside the manlock and before the mass control valve to cleanse and purify compressed

air and to supply good breathing air to cutterhead and manlock on top of pre-filter system installed on surface.

16. VISUALISATION AND DATA MANAGEMENT

16.1. The TBM shall be fitted with a data logger which shall be linked by the Contractor to a colour monitor display in the Satellite and Engineer's office. Each TBM shall have its own dedicated colour monitor. The data logger shall display and record information in real time and shall have the facility to store all accumulated data from the tunnel drive and to read and display past data. As a minimum the data logger shall record and report the following information:

a. Start and finish time of the excavation stroke;

b. Stroke number, chainage and guidance system’s prediction of the next ten strokes after each build;

c. Numbers of thrust cylinders, location and pressures used during the stroke;

d. Extensometer readings of thrust cylinders at the start and end of the stroke;

e. Articulation cylinder position at the start and the end of the excavation stroke (articulation angle);

f. Clearance between tail skin and extrados of the tunnel segment at the end of each segment erection;

g. Amount of TBM roll at start and end of the excavation stroke;

h. Cutting direction, speed, pressure/torque of cutterhead;

i. Shield position and attitude for each ring;

j. All earth pressure sensor readings throughout the excavation stroke for cutter chamber and screw;

k. Volume and pressure of grout injected per stroke. Pressure shall be measured at the point of injection. Pressure and volume shall be monitored and recorded to an accuracy of not less than two decimal places;

l. Volume, pressure, rate of addition, type and location of soil conditioning added per ring and the cumulative amount per shift with the concentration value. The operation and control of the soil conditioning shall be from within the control cabin;

m. Pressure and quantity of tail grease consumed per ring;

n. Speed and torque of screw conveyor;

o. Rate of advance of TBM and stroke average rate of advance;

p. Use of copy cutter, amount and location;

q. Gas detector sensor readings and alarm activation system;

r. Main bearing axial force;

s. Main bearing lubrication temperature monitored at exit point if re-circulatory oil, or thermocouple against bearing if grease lubricated;

t. Volume and mass of material on the belt or in the slurry line;

u. Start and finish time of the ring erector operation;

v. Use of copy cutter, amount and location; and

w. Volume and pressure of lubricant injected around TBM shield. Pressure shall be measured at the point of injection.

16.2. Data loggers shall be connected to computer(s) which shall be appropriately configured so that the signals are processed and displayed on monitor(s) and/or printer(s) in colour. The Contractor shall provide computer(s), monitor(s) and printer(s) and all necessary peripherals and consumables necessary for the displays and printouts. The display monitor(s) with computer(s) and printer(s) shall be sited in the Engineer's office. All data loggers and ancillary equipment shall be fully operational at all times and shall be maintained by the Contractor.

16.3. Pressure and consumption of tail seal and lubrication grease for critical components shall be recorded on a per ring basis. These shall be displayed on the TBM monitoring screen.

17. SUPPORT SERVICES

17.1. The Contractor's Support Services shall be compatible with the design of the TBMs (Contractor to obtain the endorsement of TBM manufacturer), its intended spoil handling system and the ring erecting system to ensure that work can be carried out efficiently and safely.

17.2. The Contractor shall ensure that the Support Services to the TBM are capable of maintaining the required Tunnel production rate to enable the programme key dates to be achieved.

17.3. The Contractor shall have suitable safe systems by which spoil can be removed from the tunnels and rings and other construction materials can be delivered to the TBM.

17.4. The above systems shall be compatible with the design of TBM, its intended spoil handling system and the ring erecting system to ensure that work can be carried out efficiently and safely.

17.5. The Contractor shall provide a chiller unit of sufficient capacity at TBM back-up to ensure a cool working environment with maximum wet bulb temperature of 28 degree Celsius in working areas (ring building area, manlock entry location, TBM back-up) and maintain it in good condition at all times. This includes the supply of cool air as well as the cooling of the heat generated by TBM operation. The Contractor shall indicate the power dissipated as heat from the TBM and TBM back-up for the purpose of tunnel ventilation calculations.

17.6. Services in the tunnels shall be properly designed and installed to the appropriate standard, where relevant and shall be suited to the tunnel environment. Such services shall include, but not be limited to;

a. Pump lines,

b. Ventilation,

c. Lighting,

d. Firemain,

e. Water Supply,

f. Grout and accelerator lines, and

g. Electrical supply, including transformers.

17.7. Support services at the portal or commencement shaft shall be chosen to enable the efficient working of all tunnelling operations, to achieve the programme and to ensure a safe working environment for all persons. Such services shall include, but not be limited to, the spoil handling system, material delivery system and access / egress of personnel.

18. SPARE PARTS

18.1. The Contractor shall provide for each TBM, spare parts that are considered critical and long-lead items.

18.2. The Contractor shall maintain an inventory, recommended by the TBM and backup systems manufacturers, to ensure continued availability of the TBM and all essential systems. The Contractor shall submit this inventory list to the Engineer for acceptance and shall state where the items are stored (local/overseas) and the duration required to bring the items to site.

18.3. The Contractor shall store on site replacement parts and maintenance materials which shall include (where relevant) but not be limited to:

a. One complete set of discs, picks and cutters sufficient for one TBM;

b. Non-standard hydraulic rams, hydraulic hoses and components;

c. Spoil removal system belts, rollers, bearings and bolts;

d. One full set of tailseal brushes sufficient for one TBM; and

e. One full set of earth/fluid pressure sensors sufficient for one TBM.

18.4. Spare part components for the TBM shall be readily available.

19. OPERATION AND MAINTENANCE OF THE TBM

19.1. The TBM operation panel shall allow monitoring and where appropriate enable control of the following:

a. Forward thrust;

b. Ram pressure;

c. Alignment and altitude of the shield;

d. Cutterhead torque;

e. Main bearing grease and oil lubrication pressure flow and temperature;

f. Electrical load characteristic;

g. Face pressure;

h. Archimedean screw pressure;

i. Compressed air pressure in module;

j. Weight of spoil; and

k. Pressure and consumption of tail seal and lubrication grease per ring per component basis (for critical components).

19.2. The Contractor shall submit the following for acceptance by the Engineer at least 3 months prior to delivery of the TBM to jobsite:

i) a detailed operation and safety manual; and

ii) a detailed maintenance and safety manual.

This manual shall be prepared in English version and endorsed by the TBM manufacturer.

19.3. Both operation and maintenance safety manual shall highlight the safety features available in the system and the safe work procedures to mitigate all associated risks.

19.4. Under the maintenance manual, it shall include but not limited to the following maintenance regime:

~ compulsory replacement after certain working hours or at stage before main drive.

~ inspection and maintenance on daily, weekly, monthly, quarterly basis.

19.5. In particular, during a standstill of TBM for more than 24 hours, necessary checks and inspection prior to resuming tunnelling shall also be detailed in the operation and safety manual.

19.6. Record of training by TBM manufacturer for the Contractor's operational crews and dedicated maintenance crews shall be submitted prior to commencement of tunnelling.

19.7. The Contractor shall fully comply with the maintenance regime. Proper records of maintenance, refurbishment as well as inventory in workshop shall be available and fully accessible to the Engineer at all times.

19.8. The Contractor shall schedule maintenance of TBM such that it will not impact the progress of tunnelling.

19.9. An audit will be conducted at a maximum interval of every 3 months. All non-compliance shall be fully addressed within the stipulated time to the satisfactory of the Engineer.

19.10. A 1 hardcopy and 6 softcopies of the TBM manufacturer's operating and maintenance instructions written in English shall be provided to the Engineer within 14 days of completion of the TBM manufacturer's factory testing and commissioning.

19.11. The Contractor shall operate and maintain the TBM to the satisfaction of the Engineer and in accordance with the manufacturer's recommended operating and maintenance instructions.

19.12. The TBM operators and the Contractor's chief mechanic(s) shall be trained by the TBM manufacturer prior to the start up of the machine. Training is to be provided throughout the tunnelling process to allow for staff turnover.

19.13. Lubricants to critical components including the main bearing shall be analysed at regular intervals for the presence of metallic particles or ground contamination.

19.14. The Contractor shall not use any material in contact with hydraulic oil that will cause contamination.

20. DISMANTLING OF TBM

20.1. Provisions for disconnecting all services to the TBM shall be provided at the tunnel portal and at the tunnel face. All provisions shall be operated by authorised personnel only.

20.2. On completion of the drive, the TBM shall be dismantled and removed from the tunnel, unless otherwise stated.

20.3. If the TBM is required for another drive it shall be cleaned, refurbished and fully tested to the acceptance of the Engineer before the further drive begins.

20.4. If the shield is abandoned on completion of the tunnel drive a segmental or cast in-situ lining which complies fully with the requirements of the Specification shall be constructed within the shield skin after removal of all mechanical parts and sealing up all openings in the shield with steel plates of thickness similar to that of the shield to ensure water tightness.

21. SURVEY

21.1. The Contractor shall install in the TBM a real-time guidance system to the acceptance of the Engineer. Additional survey targets, devices, tell tales and survey marks shall be installed within the machine to facilitate a completely separate manual survey determination of the TBM position. The positioning and repeatable survey of these alternative survey target devices must be possible after TBM launch into the soil and full TBM back-up installation.

21.2. A TBM guidance system shall be a fully integrated system and shall comprise at least, measuring equipment, software, PC and display. The design tunnel alignment and Guidance system setup parameters entered into the system shall be password protected. The display shall be updated every few seconds and provide the operator with the necessary graphical and numerical information. The system must compute the precise machine position and offsets from the DTA. The following information shall be displayed:

a. Cumulative ring number from start of drive;

b. Chainage;

c. Pitch and roll;

d. Look up (plumb to DTA);

e. Lead (square to DTA);

f. Line and level at the TBM Cutter Head, Articulation and end of Tail Skin;

g. Prediction of shield position at cutter-head or other user determinable position ahead of current position; and

h. Horizontal and vertical articulation angle (where applicable).

The guidance system shall be capable of determining the 3D co-ordinated position of the TBM from the proven survey control in the tunnel to an accuracy of ±2mm. All guidance system parameters, input, output and reports shall be available in softcopy format (e.g. Excel or similar).

21.3. Prior to launching the TBM, the Contractor shall demonstrate to the satisfaction of the Engineer that the guidance system is fully functional and delivers accurate absolute and relative TBM position to DTA. In this respect, the Contractor shall demonstrate that the Auto Guidance

system output position equates to TBM commissioning survey position (obtained from single occasion external machine survey in the shaft) which equates to TBM position by manual survey of internal survey targets.

21.4. Prior to the commencement of tunnelling and then throughout the tunnel drive the Contractor shall establish and implement survey and alignment control procedures in compliance with Materials & Workmanship Specification Chapter 3, Survey and Setting Out.

21.5. During works planning, consideration shall be given for adequate shaft working space, working at height safety precautions and program time to facilitate the safe and accurate TBM Guidance system commissioning survey.

21.6. The design of the TBM and back-up shall take into consideration the installation position of Guidance system targets on the shield and the position of laser or total station survey device within the TBM back-up such that there is a continuous unobstructed line of sight between TBM mounted targets and survey measurement device during TBM excavation mode.

21.7. The TBM shall not advance without a fully operational guidance system.

22. SAFETY AND ENVIRONMENTAL

22.1. The TBM design shall make adequate provision for the safety of the workmen and the application of safe methods of tunnelling. This shall include provisions for ensuring that environmental conditions at the face comply with all relevant health and safety requirements and operatives can gain safe access to any part of the machine. The design shall also make provisions of a straight or direct escape route, as far as practicable, from the manlock to the tunnel walkway.

22.2. Provision shall be made throughout the length of the TBM and back-up equipment for the automatic detection and suppression of fires. This shall include the provision of a fully automatic fire curtain sited at the trailing end of the TBM back-up. The fire system shall be maintained in an efficient operating condition at all times. The fire system shall be designed for local humidity and temperature conditions in the tunnels and to handle the type of fire that may occur on the TBM.

22.3. During the tunnelling operation, the Contractor shall provide and maintain CCTV (closed circuit television) systems with panned cameras placed strategically within each tunnel drive at ring build area, last backup gantry, manlock area and any other location required by the Engineer. Each CCTV system shall be linked to colour monitors sited in the Engineer’s office and the cameras shall move in tandem with the shield.

22.4. The Contractor shall use synthetic hydrochloric fire resistant (type HFDU) fluids on all systems of the TBM and TBM back-up equipment so as to minimise the risk of an oil fire.

22.5. All materials used underground shall be non-combustible and low smoke emission type.

22.6. A physical barrier shall be located at the last TBM trailer to separate and protect the workers in the shield from moving railway equipment. The barrier shall be automatically closed whenever a train leaves the TBM backup. The barrier is only to be opened again once the returning train comes to a halt out-bye of the barrier and the banks-man has signalled the all clear. Clearly visible traffic signals are to be displayed to indicate if the gate is open or closed. The design of the physical barrier shall be capable of withstanding the impact of a runaway locomotive.

22.7. During segment assembly, ladders and platforms shall be provided to enable personnel to reach all pre-cast concrete segment bolt connection holes. Where possible all working platforms shall be fitted with safety handrails and toe boards. If it is necessary to reach more than 500mm horizontally beyond the edge of any platform, then connection points for safety harnesses shall be provided. Platforms shall be fitted with appropriate safety systems to prevent collision with the erector.

22.8. The segment erector and segment feeder (if any) shall be fitted with audible and visual alarms that activate prior to movement.

22.9. All moving machinery installed on the TBM shall be appropriately guarded. Guard design shall consider routine maintenance requirements. Audible/visual movement warning signals shall be installed together with an emergency stop system at locations to be agreed with the Engineer.

22.10. All TBMs shall be equipped with gas monitoring sensors, which shall be located at the screw conveyor discharge, TBM bulkhead zone and other appropriate areas along the TBM. All sensors shall be connected to an audible/visual alarm system located throughout the tunnel and at the surface. The alarm shall automatically activate at gas levels exceeding the permissible exposure levels as defined in the current Singapore Acts and Regulations.

22.11. The connection between the TBM shield and TBM back-up shall be automatically monitored. An alarm shall be connected to the TBM operator’s cabin and the data-logger system. The alarm shall activate an audible/visual alarm when the tow force exceeds designed tow force.

22.12. An automated traffic light system shall be incorporated at the end of TBM back-up to control the transportation system movements.

22.13. The Contractor shall provide an emergency generator at the TBM back-up which shall include, but is not limited to, power to support segment erector drive rotation, firefighting equipment, control system (monitoring in operator cabin), cable drum, lighting, secondary ventilation, manlock lighting, AFC and other emergency services in case of primary source power failure.

22.14. The Contractor shall submit a 3D model of the TBM in a format acceptable to the Engineer, including all the features, safety, space constraints, for better visualisation of TBM setup and accessibility. The 3D model shall form part of the process for the approval of TBM design by the Engineer.