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## **18 TUNNELLING**

### **18.1 General**

- 18.1.1 The General Specification together with the Materials and Workmanship Specification for Civil & Structural Works provide minimum requirements for the design and fabrication of the TBM and for the execution of the tunnelling works. The Particular Specification Clauses given in this document provide additional requirements and should be read in conjunction with the Materials & Workmanship Specification for Civil & Structural Specification and the General Specification. In the event that any such Clauses contradict or are inconsistent with Clauses in **Clause 18** of the Particular Specification, the Clauses in **Clause 18** of the Particular Specification shall prevail.
- 18.1.2 Reference shall be made to **Clause 7** of the Particular Specification for details on coordination and interfaces with Interfacing Contractors, System-wide Contractors (SWC) and other parties.
- 18.1.3 Reference shall be made to **Clause 12** of the Particular Specification for details on underground obstructions and relocation, method statements with safe work procedures, close proximity and modification works to existing buildings or structures.
- 18.1.4 The Contractor shall fully acquaint himself with the anticipated geological details, conditions, and potential obstructions. The geology along the tunnel alignment is predominantly Bukit Timah Granite Formation. More detailed information is provided in the Factual Geotechnical and Geological Interpretative Baseline Report (GIBR).
- 18.1.5 The Contractor shall consider the expected nature of the geological conditions to be encountered in the bored tunnelling works, the effect of the compressible strata on settlement, particularly at strata interfaces, and the need to minimise settlement and maintain the structural integrity of all structures and buildings along the tunnel route when determining suitable tunnelling methods and operating parameters. All details of the chosen methods, along with their substantiation, shall be submitted to the Engineer for acceptance. The Contractor shall place his order for the TBM only upon the written acceptance of the proposed TBM design and tunnelling method.
- 18.1.6 The method statements submitted with the Tender shall not be regarded as satisfying this Clause and the Contractor shall make separate submissions for the written acceptance referred to above after award of the Contract.

- 18.1.7 The Contractor shall evaluate and verify anticipated obstructions, including but not limited to structures, utilities, drains, deep foundation elements, with and without as-built foundation records, and carry out the necessary site underground investigations and propose underpinning, diversion, removal to ensure no underground obstructions to the Works including TBMs drives. Costs of all such associated works are deemed included in the Contract Price.
- 18.1.8 The Contractor shall review the available geotechnical information provided in the Factual Geotechnical Report together with the geological profile given in the GIBR and carry out additional boreholes along the tunnel route to suit his tunnelling works. The Contractor shall carry out the additional boreholes, to satisfy the BCA and other authorities' requirements. The Contractor shall satisfy himself that sufficient information is available for the design and construction of tunnelling and its associated works. The spacing between additional and existing boreholes shall not be more than 30m. If any site constraints are encountered, the Contractor shall propose borehole locations to the acceptance of the Engineer. At locations where there is a drastic change in ground condition along the tunnel alignment, the Contractor shall carry out additional boreholes at closer spacing not more than 10m to determine the extent and actual ground condition.
- 18.1.9 The Contractor shall provide a passenger hoist (Lift) for the Launch Shaft. The Passenger hoist shall also be designed to accommodate a minimum of ten (10) persons together with one stretcher of 1.8m in length.
- 18.1.10 The Contractor shall note the tunnel alignment runs in areas with limited geological information and zones where limited access from the ground surface is allowed. The Contractor shall take this into consideration when designing the TBM to allow soil investigation from the TBM, such as but not limited to probing with facilities to retrieve core samples and geophysical survey, and to allow grouting through the TBM cutterhead in order to identify geological conditions, obstructions and mitigate potential hazards for tunnelling.

- 18.1.11 The Contractor shall refer to Clause 18.1.12 on the sampling and testing from the additional boreholes in order to assess soil properties relevant to tunnelling operation, to identify potential risks such as clogging, abrasivity, high permeability soil and to plan and optimize the soil conditioning strategy to the acceptance of the Engineer. The Contractor shall note the requirements in **Clause 15** of the Particular Specification on the preparation of the soil investigation report. All costs associated with additional Site Investigation are deemed included in the Contract Price.
- 18.1.12 The Contractor shall review the Factual Geotechnical report provided by the Authority and propose additional boreholes to ensure sufficient sampling and testing representative of the various ground condition is available at tunnel horizon.
- For each of the additional boreholes carried out, the Contractor shall carryout permeability test and collect minimum of three samples at (centre, crown and invert levels of the tunnel) to determine the following parameters:
1. Plasticity (Atterberg Limits) and Moisture Content
  2. Bulk Density and Dry Density
  3. Particle Size distribution (PSD)
  4. Quartz content, grain shape angularity of pebbles to be described
  5. Abrasivity test (Tests shall be carried out at 200m intervals and if the ground condition varies, additional tests will be required. The location of tests shall subject to the Engineer's acceptance.)
- The Contractor shall produce a test report for all additional boreholes before commencement of tunnelling works. The report shall also include PSD plots within tunnel horizon The cost of all works stated above shall be deemed included in the Contract Price
- 18.1.13 The Contractor shall note that the commencement of the TBM main drive with full backup duly installed and commissioned fully inside the bored tunnel is defined as the completion of tunnel initial drive.

- 18.1.14 The Contractor shall ensure that the security measures and design of the tunnels incorporate all the necessary security requirements in accordance with the Security Protection Plan (SPP) / Final Security Protection Plan (FSPP) and other security requirements imposed by the Authority.
- 18.1.15 The Contractor shall liaise with the, QP(S), AC and AC(Geo) and eAC provide the access, information and documentation required to allow them to carry out their duties in relation to the tunnelling.

## **18.2 Bored Tunnels Works**

- 18.2.1 The Contractor shall use one (1) TBM for the bored tunnelling works. It is envisaged that Earth Pressure Balance (EPB) type TBMs will be used.
- 18.2.2 It is envisaged that the Contractor shall launch the TBM from the launching shaft towards CR205 station.
- 18.2.3 The ground improvement for TBM dock in at CR205 interface is under the scope of CR206 contractor. The Contractor has to co-ordinate with the relevant parties to ensure the necessary works are completed before the TBM reaches the CR205 interface. The Contractor shall refer to **Clause 7** of the Particular Specification for the details of the interface requirements with CR206 and CR205 contractors.
- 18.2.4 No provision has been made for the retrieval of the TBM at the CR205 interface. The Contractor shall dismantle the TBM underground and retrieve it back to CR206 via the completed tunnels. The shield skins shall be left underground at the interface with station of CR205 and fully grouted by the Contractor to stabilize the ground. Cast in-situ or segmental permanent lining shall be constructed from the last segmental lining ring built within the shield skins to the interface with the CR205 headwall to form the permanent tunnels. The Contractor shall hack and subsequently prepare the interface wall such that the surface is suitable for the installation of hydrophilic strip and ensure water tightness has been achieved.

- 18.2.5      The Contractor shall design and provide ground improvement works or propose alternative methods to suit his construction methodology, for the TBMs' launching and docking to control water and ground ingress into the shaft/tunnel. The Contractor shall refer to the Authority's Drawings for the minimum sizes and requirements of the ground improvement works for TBMs' launching and docking. The abovementioned ground improvement works or alternatives shall be designed by contractor's QP(GEO) and submitted to the engineer for acceptance.
  
- 18.2.6      Permanent lining shall be constructed by the Contractor from the last segmental lining ring built within the shield skins to CR205 station headwall to form the permanent tunnels. The Contractor shall comply with the interface Key Dates in **Appendix B** of the Particular Specification. The Contractor shall follow to the interface details and scope as shown in the Authority's Drawings.
  
- 18.2.7      All costs associated with the works at the interface with the completion of the tunnelling and connection to the CR205 station are deemed included in the Contract Price irrespective of the construction method used at the interface.
  
- 18.2.8      The Contractor shall assess the tunnel alignment in detail and submit the impact assessment report including mitigating measures for tunnels undercrossing any buildings/structures piles within six (6) months of contract award. In the event the tunnel alignment affects the foundation, the Contractor shall closely coordinate with relevant authorities and propose mitigation measures to the acceptance of the Engineer.
  
- 18.2.9      The Contractor shall note that any bakau piles or tanalised timber piles that conflict with the tunnel alignment shall be treated as known obstructions and shall make provisions in his tunnelling programme accordingly. All necessary investigations, ground improvement, obstruction removal, utility diversions, and reinstatement/A&A works shall be deemed included in the Contract Price.
  
- 18.2.10     The Contractor shall take measures to ensure the impact of the bored tunnelling works on any structures within the tunnel influence zone is within allowable limits. Mitigation measures shall be put in place to ensure these limits are not breached.

- 18.2.11 The bored tunnel may under-cross existing roads, old railway corridor and run along existing road reserve corridors. The Contractor shall investigate road structures and undertake all necessary measures to ensure the tunnelling works beneath these roads do not affect the stability / safety of these road operations. Engagement and coordination with relevant authorities shall be carried out to ensure that mitigation works are in place, should road diversion or temporary road closure be required. The Contractor shall take responsibility to ensure both road operation and tunnelling works are not compromised. Details of construction method, protection measures and real-time monitoring shall be submitted to the Engineer for acceptance.
- 18.2.12 Volume Loss Limits:
- The Contractor shall ensure that his tunnelling operations are within the limits of the LTA Civil Design Criteria (CDC) notwithstanding the requirement for tighter limits as identified by the Contractor's impact assessment report.
- 18.2.13 Any information including the foundation types and depth shown in the Authority's Drawings are indicative only.
- 18.2.14 If required, Contractor shall carry out the strengthening work, diversion of road, temporary traffic management, removal of the piles prior to the tunnelling work and reinstatement of the affected structures.
- 18.2.15 The Contractor shall design, construct, maintain and subsequently remove the full noise enclosures with roof, including provisions for mechanical and electrical services, for the whole of the launch shaft and gantry crane working area, to shield the noise generated from the tunnelling works. The full noise enclosure shall be installed before the start of the initial drive of the TBM, and to be designed for multiple dismantling and reassembling of the TBM for the subsequent tunnel drive. The Contractor shall refer to **Appendix A** of the General Specification for full noise enclosure requirements for the launch shaft. The full acoustic enclosure shall be completed prior the commencement of the first EPB TBM's initial drive.

**18.2.16 Storage of Segments on Site**

- 18.2.16.1 The Contractor shall stockpile tunnel segment rings prior to the commencement of his tunnelling works. He shall propose to stockpile minimally at Site, two (2) months-worth of complete tunnel segment rings ("Minimum Number") based on his main drive tunneling programme, subject to the acceptance of the Engineer. In the event that the Site area is insufficient for the storage of the above quantities of tunnel segment rings, the Contractor shall propose location of other storage site/premises within Singapore for Engineer's approval. The Temporary Occupation License (TOL) and all associated cost of the storage areas shall be deemed included in the Contract Price.
- 18.2.16.2 The **Option Module A** specified in the Appendix to the Form of Tender shall apply for stockpiles stored at storage areas. The Contractor shall also comply with the requirements specified in the following Clauses.
- 18.2.16.3 The Contractor shall ensure that the Minimum Number of complete tunnel segment rings at the storage areas and requirements are met, before he can include this item in his one-time claim.
- 18.2.16.4 The Minimum Number of stockpile tunnel segment rings shall be maintained throughout the tunnelling works and only to be utilized for the last section of the tunnel. The Contractor shall seek the approval of the Engineer in the event he requires to draw down from the stockpile.
- 18.2.16.5 The Contractor shall propose and implement a tamper proof and non-removable tagging system to track the movement of segments from production to installation, subject to the Engineer's approval. The Contractor shall be responsible to provide, maintain and/or replace the scanner and associated equipment and software at his own expense.
- 18.2.16.6 Pavement for storage areas shall be designed by a Professional Engineer (PE), registered under the Singapore's Professional Engineer Board (PEB) to ensure safe storage of tunnel segment rings.
- 18.2.16.7 The Contractor shall at his own expense arrange for the Engineer and his appointed representatives to carry out inspection and audit for:
- (a) the storage areas and/or other premises; and
  - (b) the tunnel segment rings stored.



- 18.2.16.8 The Contractor shall optimise the land use and secure the land provision to implement the storage, subject to the relevant authorities' approval. The location of storage is subjected to the Engineer's acceptance. Where the stockpile (or part thereof) proposed is not at the Site, the Contractor shall minimise the number of storage sites/premises for the stockpile.
- 18.2.16.9 The Contractor shall ensure sufficient protection and security for the tunnel segment rings stockpile to prevent damage and loss.
- 18.2.16.10 Damage occurring to tunnel segment rings at any stage prior to erection shall be repaired promptly in accordance with the guidelines provided in **Appendix 16.1** of Materials & Workmanship Specification for Civil & Structural Works. Tunnel segment rings to which damage has occurred and which cannot be repaired shall be rejected, indelibly marked on the inner (concave) face and permanently removed from the storage areas. The amount of such tunnel segment rings shall be deducted from the interim payment in accordance with the **Option Module A** specified in the Appendix to the Form of Tender.
- 18.2.16.11 The Contractor shall submit the proposed team including but not limiting to, lifting supervisor and safety personnel. The Contractor shall appoint a supervisor who will inspect and ensure that the tunnel segments are properly secured prior to leaving the storage site/premises for delivery to Site.

### **18.3 Tunnelling Design**

- 18.3.1 The Contractor shall complete the tunnel segment design, developing the Authority's notional design to suit the rail alignment. The segment design shall be submitted to the Engineer and any other relevant authority for approval.
- 18.3.2 The Contractor shall engage qualified person Design (QPD) to calculate TBM face pressure and other key tunnelling parameters to meet the most onerous of the volume losses indicated in this Particular Specification and as determined by the Contractor for the safe completion of the tunnelling works, or as may be required by the Authority, AC, QP(S), BCA or any other relevant authority.

- 18.3.3 The Contractor shall identify risk and propose mitigation measures to control excavation and ground movement within the required limits. Measures proposed are to include grouting and additional monitoring where deemed necessary and are subject to the acceptance of the Engineer. At the areas where limited access from the ground surface is allowed, the grouting shall be carried out from the TBM. All measures are deemed to be included in the Contract Price.
- 18.3.4 The Contractor shall ensure that his design proposals take into account of construction loads including special crane loads required for installation of gantry cranes and TBM lowering/extraction and similar.
- 18.3.5 The Contractor shall ensure that all temporary works are endorsed by his QPs and is responsible for securing all necessary approvals for temporary works.
- 18.3.6 The Contractor shall be responsible for design and construction of proposed methods ground improvement works, assessment of the impact of the proposed methods on adjacent ground, structures, and utilities, and demonstrate that there is no adverse impact, to the Engineer, AC, AC(Geo), QP(S), and any other relevant authority.
- 18.3.7 Ground improvement of any kind, and other methods of minimising groundwater drawdown (including recharge wells) are considered a part of the Contractor's method of tunnelling. Any pore water pressure relief shall be limited to no more than one (1) meter below the existing piezometric levels. The Contractor shall ensure at all times that this specified drawdown limit is not breached, and where his design indicates a likelihood that the limit will be breached, the Contractor shall undertake ground improvement and/or installation of recharge wells to facilitate his construction works.
- 18.3.8 The Contractor shall submit drawings of the tunnel ring arrangement plan and section drawing to the Engineer a minimum of three (3) months before commencement of tunnelling works to the Engineer for acceptance. The drawings shall include rings numbering, chainage, topographical information, borehole information, anticipated geology and critical interfaces along the alignment.
- 18.4 Instrumentation & Monitoring**
- 18.4.1 The Contractor shall note that his QP shall be responsible for the instrumentation design and review levels for tunnelling works as per **Clause 14** of the Particular Specification.

**18.5 Approvals**

- 18.5.1 The Contractor is solely responsible for securing all necessary approvals to complete the tunnelling works.
- 18.5.2 The Contractor and his QP(D) shall present the design concepts for TBM face pressure and other key parameters for acceptance by the Engineer before proceeding with the design. Together with his Professional Engineers, the Contractor shall make all necessary submissions and be responsible for obtaining all necessary approvals including but not limited to submissions covering bored tunnelling works soil profile, tunnelling KPI, ground improvement, cutter head intervention, instrumentation and monitoring, impact assessment, and protective measures, etc.
- 18.5.3 The Contractor shall provide all documents to the QP(S) to demonstrate that he has obtained all necessary approvals for the tunnelling works from all relevant agencies.
- 18.5.4 The Contractor shall engage the PE and PE(Geo) to prepare Geotechnical Building Works (GBW) submission and obtain BCA's and all other relevant authorities/agencies approval. Cost of all works shall be deemed included in the Contract Price. The submission shall include but not be limited to:
- (a) TBM face pressure calculation, tunnelling Key Performance Indicators (KPIs) and report;
  - (b) Building and structure impact assessment including protective measures if necessary;
  - (c) Tunnel related ground instrumentation and monitoring review levels; and
  - (d) GBW drawings shall contain:
    - (i) Tunnel layout plan;
    - (ii) Tunnel vertical alignment in the Contractor's soil profile;
    - (iii) Buildings in proximity to tunnel;
    - (iv) Sectional details;

- (v) Locations, procedures, and instrumentation & monitoring proposals for planned TBM cutter head intervention or stoppages including adjustments to TBM compressed air pressure;
- (vi) Design and procedure for unplanned cutter head interventions; where the geotechnical conditions vary, the Contractor shall provide suitable procedures for each geotechnical condition;
- (vii) Ground improvement details;
- (viii) Table of engineering parameters by chainage covering depth of tunnel, construction volume loss & trough width, maximum surface settlement, TBM face pressure (target, minimum, and maximum), hydrostatics pressure, tail void pressure, and total vertical overburden stress for respective tunnels;

## **18.6 Engineering Control of Tunnelling**

- 18.6.1 The Contractor shall refer to **Appendix O1** of the General Specifications for the requirement on Engineering Control of Tunnelling.
- 18.6.2 A non-conformance report shall be raised by the Contractor for any ring which is found to be out of tolerance after erection and grouting. Any ring or part of a ring which does not satisfy these tolerances shall, if the Engineer so directs, be rebuilt by the Contractor.
- 18.6.3 The Contractor shall adopt a construction volume loss which is in line with or more stringent than the design volume loss as shown on the Authority's Drawings and **Clause 18** of the Particular Specification for the acceptance of the Authority's AC, QP(S), the Engineer and the approval of BCA.
- 18.6.4 In addition to **Appendix O1** of the General Specification, the Contractor shall provide the following KPI endorsed by the QP(Geo):
  - (a) Possible or safe stop locations for unplanned cutterhead intervention (CHI); and
  - (b) Compressed air pressure step down procedure of CHI.

- 18.6.5 A daily review meeting shall be held on Site. The meeting shall be attended by the Tunnel Manager, Senior Tunnel Engineer, Geotechnical Engineer and QP(S) representative with the Engineer as a minimum. The Plan for Tunnel Advance (PFTA) will be used in the Daily Review Meetings as a baseline to assess actual tunnel performance against that predicted and ensure that geotechnical and tunnel data are synchronized to effect optimal and safe tunnelling. The PFTA shall be updated as tunnelling progresses and information becomes available. The PFTA shall form the basis of the Tunnel Completion Report.

**18.7 Tunnel Boring Machines (TBMs)**

- 18.7.1 The Contractor shall refer to **Appendix P1** and **P2** of the General Specifications for the requirement on Tunnel Boring Machines.
- 18.7.2 Details in the General Specification are the minimum requirements for the design and fabrication of the TBM. Notwithstanding these requirements, it is the Contractor's responsibility to design and procure the tunnelling equipment that is best suited for the conditions to meet the schedule, along with the requisite performance and safety requirements.
- 18.7.3 The Contractor is not permitted to use any other type of machine or supplier other than those proposed in his Tender, unless accepted by the Engineer.
- 18.7.4 The Contractor shall investigate and determine the abrasivity of the ground along the tunnel alignment and submit a report to the Engineer demonstrating that this has been taken into consideration in the TBM design. The Contractor shall plan and allow for the cost of maintenance and/ or replacement of tunnelling equipment components throughout the course of works.
- 18.7.5 Fabrication of the TBM shall only commence following the Engineer's acceptance of the TBM design and tunnelling methods. The Contractor shall also include in his submission a schematic of the TBM assembly sequence, QA/QC plan, initial drive mode configuration including the safety features which should not be inferior to the main drive mode, and retrieving, dismantling sequence.

- 18.7.6 The Contractor shall coordinate and ensure that his Professional Engineer (PE) is engaged at the design stage to review the TBM design. The Contractor shall liaise with the TBM Supplier and ensure that the TBM is designed to suit the envisaged site conditions. All lifting points shall be endorsed by the Contractor PE prior to usage on-site.
- 18.7.7 Each of the Contractor's proposed TBM shall have a thrust output of not less than 46,000kN, or as required to achieve the contract requirements, whichever is higher. This force shall be provided from a series of hydraulic cylinders in a double thrust jack configuration located around the shield circumference.
- 18.7.8 The cutterhead shall be driven by variable speed electric drive system with an installed minimum power of 1,200kW.
- 18.8 Supply and Support of Tunnel Boring Machine**
- 18.8.1 In addition to the requirements of the General Specification **Appendix P2** and **O2**, each belt conveyor shall be provided with at least two (2) belt weighting device (for cross-checking) as part of an automatic monitoring system for the material discharge per ring of advance.
- 18.8.2 The Contractor shall ensure that thermal insulation is provided for the chilled water pipes when there is a possibility of condensation within TBM and backup.
- 18.8.3 The Contractor shall ensure that drift eliminators are provided for the cooling towers serving the TBMs.
- 18.8.4 Electricity supply for the TBM shall be 6.6kV or 11kV. The use of 22kV distribution is not permitted in the tunnels/launching shafts. All TBM's transformer proposed shall be of Silicon oil type with Air Natural (KNAN) configuration. Secondary winding of all transformers shall have a solidly earthed star-point.
- 18.8.5 Dry type transformers are not allowed in tunnels/launch shafts.
- 18.8.6 The segment erector shall be of vacuum type. It shall permit the safe handling and placement of the tunnel lining within the specified performance rates and provide adequate facility for the insertion and tightening of the segment bolts. When the erector is in operation, the TBM Excavation mode shall be automatically on standby as a safety requirement.

- 18.8.7 Segment retainer system shall be provided to hold the second last assembled segmental ring in position at the tail skin prior to next advance.
- 18.8.8 A probe drilling and ground treatment system shall be provided with the capability to drill and grout ahead of and around the TBM via use of the horizontal and inclined ground consolidation tubes. The drilling and grouting forward shall be done via the shield, bulkhead and cutterhead. This shall be done in accordance with LTA's specifications. The Contractor shall design the TBM such that it maximises the free working space in and around the TBM for the purpose of probe drilling and ground treatment. Probe drilling and grouting system shall be suitable for all types of geology as stated in the GIBR.
- 18.8.9 The Contractor shall ensure that all probing and grouting equipment, inclusive of drive unit, manipulator, extension rods and drill bits, as a minimum, are stored and available within the Backup for immediate deployment.
- 18.8.10 The probe drilling and ground treatment unit shall have independent power source. Drill diameter shall be 60 mm and the probe unit shall permit both drilling and coring for a "B" size core. The drilling equipment shall be capable of drilling a distance of 20 meters in the geological conditions foreseen.
- 18.8.11 The probe drilling and ground treatment unit shall allow drilling and grouting to be carried out ahead of the TBM face to cover a full 360 degrees annulus at a distance of 20 meters ahead. Each grout port shall be fitted with a valve, and shall be designed so that a blow-out preventer 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. The design shall be submitted to the Engineer for acceptance. 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 blowout preventers.

- 18.8.12 The Contractor shall design a suitable hydraulic manipulator for the probe drill and ground treatment unit. This shall be permanently located within the front zone of the Backup such that the equipment is always available for set up within 2 hours. A high degree of wear is to be expected for the material transport system. All components designed to transport the excavated material shall be manufactured to provide an abrasion resistant surface to minimise replacement and /or maintenance.
- 18.8.13 The design and capacity of the rolling stock muck skip arrangement shall consider the EPB TBM's maximum advance speed (mm/min), muck density, excavation diameter of tunnel, etc. The contractor shall operate with minimum 16m<sup>3</sup> capacity muck skips as a part of the rolling stock logistics.
- 18.8.14 Locomotives shall be provided with CCTV cameras mounted at both sides of the rolling stock and a monitor shall be placed inside locomotive operator's cabin to assist the operator's visibility.
- 18.8.15 The Contractor shall demonstrate the dimensions/volume of the skip is capable to meet the required tunnelling rates.
- 18.8.16 For the purposes of minimising spillage, each muck skips shall be marked with a line, 150mm below the top surface of the skip. The Contractor is to ensure that the skips are filled below this line, for accurate accounting in terms of volume as well to maintain the quality and safety standards within the tunnel.

## **18.9 Tunnel Construction Staff and Personnel**

- 18.9.1 The Contractor is to ensure that key staff proposed at tender, or suitable alternate staff (with the same level of qualification, experience, and capability as those originally proposed) expressly accepted by the Engineer in writing, are available on Site as required from the programmed start of TBM design until structural completion of all the tunnel drives. Each of the key staff shall have a designated deputy capable of covering the duties during agreed absences from site.



- 18.9.2 As a minimum requirement, the Contractor shall ensure that the Tunnel Manager and the Tunnel E&M Manager are available during TBM design, manufacturing and full time on site from three (3) months after Contract award until structural completion of all tunnel drives. Alternatives will not be acceptable unless to the acceptance of the Engineer. Each of the key staff shall have a designated deputy capable of covering the duties during agreed absences from site. Amount to be deducted for each period of absence from Site, except where the agreed deputy is covering the duties on the Site:
- (a) TBM Tunnel Manager \$40,000 per month; and
  - (b) TBM E&M Manager \$40,000 per month.
- 18.9.3 The absence for parts of a month for personnel mentioned in **Clause 18.10.2**, shall be assessed pro rata.
- 18.9.4 The Building and Construction Authority, Ministry of Manpower or the Qualified Persons may deem the absence of any of the key staff as unacceptable and immediately stop work at their sole discretion. In this case the Contractor is required to satisfy the relevant authority such that the work may be resumed. This is in addition to compliance with any requirements by the Engineer. All delays, stoppages, loss, and expense arising from the absence of any of the key staff shall be the Contractor's responsibility.
- 18.9.5 The Contractor shall deploy one tunnel team for each concurrent tunnel drive. Where the Contractor undertakes multiple drives concurrently, they shall ensure they provide one team per drive to ensure that the tunnelling works can be carried out on a 24-hour basis.
- 18.10 TBM Operation, Management and Control**
- 18.10.1 The Contractor shall upload TBM operating parameters to the Authority's designated server in accordance to **Clauses 7 and 14** of the Particular Specification.

- 18.10.2 Prior to tunnelling works, the Contractor shall carry out trials, with samples obtained along the tunnel alignment to propose additives or polymers for soil conditioning in order to demonstrate its effectiveness for the anticipated ground conditions. The Contractor shall ensure only non-toxic and biodegradable soil conditioning additives and polymers are used during tunnelling. The research, trials and relevant tests are to be carried out at the Contractor's cost. A report providing details of all tests and results along with a strategy for TBM soil conditioning shall be provided to the Engineer. The TBM shall be designed and equipped to condition the soil in accordance with the proposed strategy.
- 18.10.3 The Contractor shall minimise loss of service and wastewater in the tunnels by maintaining shut off valves in all lines within 30m of the TBM backup. All fluids purged during service pipe extension shall be contained and disposed of in the correct manner. Any leaks from service lines are to be arrested immediately. The Contractor shall refer to **Clause 13** of the Particular Specification for the wastewater management on site. The Contractor is to propose and maintain methods to keep the tunnel clean and dust free whilst minimising the use of water for cleaning and dust containment.
- 18.11 Cutter Head Interventions**
- 18.11.1 The Contractor shall undertake suitable site investigation at each identified location and the Contractor is to carry out all necessary measures including but not limited to ground treatment, to ensure the intervention can be carried out for extended periods without the requirement of additional support while minimizing the effect on groundwater pressures.
- 18.11.2 In addition to the requirements of **Appendix O1** of the General Specification, the Contractor's geotechnical engineer or engineering geologist shall inspect, during each TBM cutter head intervention and inspection, the geological conditions at the tunnel face. A report on each TBM cutter head intervention and inspection summarising the condition of the machine and the geology, shall be submitted to the Engineer and QP(S) within one (1) working day of the start of the intervention.
- 18.11.3 The Contractor shall study the historical data of mining in similar ground conditions and shall submit the proposed locations of planned cutter head interventions for the acceptance of the Engineer.

- 18.11.4 The Contractor shall allow for adequate cutterhead interventions in his construction requirements and programme for cutting tools check and replacement based on his TBM design for the baseline activity specified in the GIBR. All costs shall be borne by the Contractor and deemed to be included in the Contract Price.
- 18.11.5 Prior to crossing beneath any sensitive structures, the Contractor shall carry out joint inspection with QP(S)/SRE(T) or Qualified Site Supervisors (QSS) for the condition of cutter head tools in consultation with the TBM manufacturer to ensure safe tunnelling under these structures. The Contractor shall submit plan for cutterhead intervention for cutter tools check and replacement for Engineer's acceptance to be undertaken before entering the influence zone of the sensitive structure.
- 18.12 Tunnel Lining**
- 18.12.1 In addition to **Chapter 16** of Materials & Workmanship Specification for Civil & Structural works, the Contractor shall make reference to this Clause and **Clause 25** of the Particular Specification for the requirements on the segmental precast lining.
- 18.12.2 The Authority has made effort to standardize the segmental mould design as shown in the Authority's Drawings for the possible sharing of segments amongst the various civil contracts. The Contractor shall work with the Engineer's team upon award of contract to develop standard segment details not limiting to position of segment identification stamp and shear cones, the details of dowel system, the composite gasket, etc. prior to the confirmation of segmental mould design and casting of segments.
- 18.12.3 The foam strip to be provided along radial joints of segments to prevent grout from by-passing the shield tail skin seal. The foam strip shall be compressible, and no load shall be exerted by the foam strip on the segments when they displace underground loading.
- 18.12.4 The bolting system for connecting the segmental lining across radial joints shall be a proprietary spear bolt connection system. The bolting system comprises a bolt and an accompanying cast-in bolt socket. The bolt shall be a minimum M24 steel bolt Grade 8.8 or to an equivalent as approved by the Engineer.

- 18.12.5      The connections between precast concrete segmental rings across the circumferential joints shall be a proprietary dowel connection system. The design tensile capacity of each dowel across the circumferential joints shall be a minimum of 80kN, or such higher capacity as may be required to maintain the gaskets on the circumferential joints fully compressed on release of the TBM thrust jacks.
  
- 18.12.6      The Contractor shall submit and propose at least 2 brands of dowels for the Engineer's review. The Contractor shall indicate which is the preferred brand. All proposed dowels shall be designed to allow for built segments to be removed without damaging the adjacent rings/segments. In the event the chosen brand of dowels is to be replaced/substituted, the Contractor shall provide details of the modification required on the segmental lining moulds and the time required to complete the modification.
  
- 18.12.7      The design shear capacity of each dowel across the circumferential joints shall be a minimum of 160kN, or such higher capacity required for the application of torque equivalent to the maximum torque capacity of the Tunnel Boring Machine.
  
- 18.12.8      The Contractor shall conduct full scale pull-out test on the bolting and dowel system on sample lining segment to demonstrate that the cast-in bolt socket does not pull out from the lining segment and that the bolt or dowel does not rupture. Before production, a minimum of two (2) trial tests shall be carried out. During production, the testing frequency shall be one (1) test per two thousand (2000) cast-in bolt sockets and one (1) test per two thousand (2000) cast-in dowel sockets. All pull-out tests shall achieve a proof load of 180kN for bolting system and a proof load of 80kN for dowel system. Tested lining segments shall not be incorporated in the Works.
  
- 18.12.9      Dowel holes shall be designed such that different brand of dowels are interchangeable with minimum modifications and capable for segment removal subject to the Engineer's approval.
  
- 18.12.10     The tunnel segmental lining shall be designed for TBM thrust jacks arrangement, ram shoe configuration, thrust loading and secondary grouting pressure as required by the Contractor's design.
  
- 18.12.11     Notwithstanding the requirements of the **Chapter 16.2.5** of the Materials & Workmanship Specification for Civil & Structural Works on Steam Curing the referenced "specific strength" is to be taken as 70% of the design strength for the purpose of completing steam curing and de-moulding the segments.

- 18.12.12 To eliminate the risk of the build-up of stagnant water in tunnel segments, all non-free draining sockets or recesses shall be designed as mechanically sealed or with an end cap from the point of casting or immediately post-demoulding. Sealing is to remain in place until ring building commences.
- 18.12.13 **Bored Tunnel Lining Tolerances**
- 18.12.13.1 After grouting, the ring of segments of tunnel lining shall conform to the following tolerances:
- (a) The center of the ring of segments shall not depart from its design position by more than 42.5mm,
  - (b) Every internal diameter shall not be different from the design diameter by more than 25mm,
  - (c) The internal profile of the lining shall not depart from its design position by more than 55 mm (combining item a) and b) above);
  - (d) The square and plumb (pitch and yaw) of the lining shall not differ by more than 20mm from the design value measured over the internal diameter horizontally and vertically or by more than 20mm from the attitude of the shield,
  - (e) The leading edge of the lining shall not be out-of-plane by more than 6mm. The Contractor shall propose a system that can check for out-of plane,
  - (f) The absolute roll of the lining shall be no greater than  $\pm 40$ mm measured from a horizontal diameter. The roll of each ring in relation to the previous ring shall be no greater than can be accommodated within the limitations of bolt hole clearances; and
  - (g) Lips and steps between segments at radial and circumferential joints shall not exceed 5mm and these 5 mm will be deemed to be included in item c).
- 18.12.13.2 A non-conformance report shall be raised by the Contractor for any ring which is found to be out of tolerance after erection and grouting. Any ring or part of a ring which does not satisfy these tolerances shall, if the Engineer so directs, be rebuilt by the Contractor.

**18.13 Segment Casting Yard**

18.13.1 The segment moulds including all associated parts, to be used for producing tunnel segments, shall be new.

18.13.2 The Contractor shall submit the following information relating to the tunnel segment within six (6) months of the Contract award for the Engineer's review and acceptance:

- (a) Details of precast factory/yard, including but not limited to:
  - (i) The precaster's track record in precasting works of similar scale,
  - (ii) Carousel system supplier's track record in precasting tunnel segments of similar nature and scale of this project,
  - (iii) Batching plant supplier's track record,
  - (iv) Fibre dosing facility's track record,
  - (v) Curriculum Vitae (CV) of proposed team, including Production Manager, QA/QC Manager, engineers, laboratory technician for precast manufacturer,
  - (vi) Quality Assurance (QA) / Quality Control (QC) plan for precast manufacture,
  - (vii) Experience of segment mould manufacturer, drawings and details of the moulds proposed for use, and details of working methods for their manufacture and use.
- (b) Location(s) and utilisation plan of precast factory/yard,
- (c) Layout and details of the precast tunnel segment production facilities, including reinforcement & accessories assembly, casting, demoulding, curing and storage areas,
- (d) Production flowchart, including inspection and testing hold points,
- (e) Inspection & testing plan; and
- (f) Production schedule (in graphical or tabular form).

- 18.13.3 The Engineer intends to have inspection staff and/or QP(S) staff based at the casting yard during the segment production. The Contractor shall provide an office at the casting yard for the exclusive use of the Engineer's inspection staff (or other authorised persons) as described below to be included in his Contract Price:
- (a) Floor area no less than 18m<sup>2</sup>;
  - (b) Uninterrupted mains electricity supply;
  - (c) At least two (2) direct dial telephone lines and fax facilities and an e-mail connection;
  - (d) Air conditioning and lighting;
  - (e) Drinking water;
  - (f) Office furniture comprising three (3) desks (1200 x 700 mm), four (4) chairs, six (6) lockable filing cabinets (with key), six (6) open shelf units;
  - (g) One (1) PC with fast processor chip, at least 8GB DDR4 Ram, dedicated graphics card with at least Intel® Iris® Xe Graphics, at least 21-inch LCD monitor, keyboard and mouse, at least 1 TB HDD internal storage, installed with acceptable licensed operating system and licensed office productivity tools software. PC must come with broadband internet connection and printing facility must be made available;
  - (h) Lockable door (three (3) keys); and
  - (i) Be cleaned daily and maintained as necessary by the Contractor.
- 18.13.4 The Contractor's casting yard shall supply the non-exclusive usage of a photocopying and printing facility, including all necessary materials, for use by the inspection staff.
- 18.13.5 The Contractor shall submit method statement to the Engineer for acceptance. The method statement shall include the following:
- (a) Method of securing the segments to prevent any segment from falling off the trucks during the delivery;
  - (b) PE endorsed details of the proposed proprietary anchor points or designed anchor points located inside the side boards of the truck for securing the segments;

- (c) PE endorsed Calculations indicating that the load of the segments is within the registered capacity of the truck;
- (d) Calculations indicating the segments are secured with sufficient straps with at least a factor of safety of two (2);
- (e) Checklist for inspecting that the segments are properly secured which shall be attached to the Delivery Note;
- (f) Standard Operating Procedure (SOP) which includes the delivery route for the trucks, contact details of key staff and action to be undertaken when there is an incident of falling segments; and
- (g) Details of the supervision/escort arrangement of the segments from the fabrication yard to site, including the estimated time for the entire operation.

- 18.13.6 The Contractor shall appoint a supervisor who will inspect and ensure that the segments are properly secured prior to leaving the manufacturing facility. The supervisor shall endorse on the checklist and attach this checklist to the Delivery Note. The Contractor shall issue the SOP to all drivers who shall keep this SOP in his truck.
- 18.13.7 Within one month of completion of precast segmental lining production works, the Contractor shall ensure that one complete set of left and right segment moulds be stored and maintained at the Contractor's own storage yard in Singapore until completion of Basic Structure Completion – Tunnels indicated in **Appendix B** of Particular Specification.
- 18.13.8 The Contractor shall propose frequency of maintenance and inspection of these segment moulds subject to the acceptance of the Engineer.



**18.14 NOT USED****18.15 Tunnel Drainage**

The Contractor shall seek approval from relevant enforcement authorities (such as PUB and NEA) prior to the discharge of trade effluent generated from the construction and the tunnelling works into sewer, watercourse, Clementi stream or controlled watercourse. The Contractor shall treat and monitor the trade effluent to meet the respective allowable discharge limits before it is discharged into any sewer, watercourse, Clementi stream or controlled watercourse as approved by the relevant authorities. The Contractor shall note that Earth Control Measures (ECM) are meant for the containment and treatment of silty rainwater runoff only, and , not meant for the treatment of process water, such as oil, grease, cement, and bentonite from tunnelling activities. Such process water should be handled and treated separately to comply with regulatory requirements.

**18.16 Method Statements**

18.16.1 The Contractor shall comply with the requirements of **Appendix O1** of the General Specification.

18.16.2 In addition to the requirements of the General Specification and **Clause 12** of the Particular Specification the Contractor shall provide the method statement for achieving the required volume loss under sensitive structures.