4 TUNNEL

4.1 PRIMARY SUPPORT SYSTEM OF TUNNELS

4.1.1 Description

1 All tunnels (including cross passages and subways) constructed by conventional means (i.e. not by TBM tunnelling, cut-and-cover or cover-and-cut method) shall be permanent lined with cast in-situ concrete ad secured with a primary support system during the excavation.

2 As primary support a combination of a sprayed concrete layer, lattice girders/steel sets, anchors/bolts, forepoling/spilling and pre-installed pipe roofing may be applied. Other systems proposed by the Contractor are subject the acceptance of the Engineer.

3 The design of the primary support system of the tunnels shall ensure:

(a) The safe construction of the tunnels primary support structure itself;

(b) The primary support shall arrest ground movement;

(c) The structural integrity and the serviceability performance of all the influenced buildings/structures, by confining their deformations within acceptable/permissible limits shall be ensured.

4.1.2 Design and Analysis Methodology

1 A structural analysis shall be performed for each tunnelling class with the following objectives:

(a) To verify that the primary support measures foreseen for this class are sufficient, safe and cause acceptable tunnel wall convergence and ground movements; and

(b) Calculations for the safety factor of the design for this tunnelling class. This shall be achieved by performing a supplementary analysis of a specific tunnelling class, using the geotechnical parameters of the immediately inferior class.

2 The structural analysis shall be performed in two-dimensions (i.e., assuming plane strain conditions). In special cases (e.g. in the design of tunnel intersections or under adverse geotechnical conditions), 3-D analyses shall be performed;

3 Two-dimensional analyses shall include the 3-D effects of the tunnel excavation face by one of the following methods:

(a) Internal pressure reduction method, i.e., by reducing the internal pressure of the excavated cross-section to a value compatible with the wall convergence, at the location where the primary lining is installed; or

(b) Modulus reduction method, i.e., by reducing the modulus of the excavated cross-section to a value compatible with the wall convergence, at the location where the primary lining is installed;

4 The Contractor shall investigate and assess, as necessary, any structures which are below and above the tunnel regarding possible adverse influences on the tunnel works below and address the results of such findings in his design;

5 Given that the presence and the nature of the ground water affect the design, the following factors shall be examined:

(a) The range of groundwater pressures during the construction phase, in short-term and mid-term conditions;

(b) The impact on any structures (i.e. impact on building foundations, subsidence etc.) due to the changed ground water level during the tunnel excavations;

(c) The impact of water on the geomaterials being excavated, such as looseness, disintegration and/or swelling etc;

(d) The design of the appropriate drainage system for the works, regarding short-term and mid-term inflows; and

(e) The local drainage characteristics of the surrounding geomaterials shall be taken into account for the determination of the most appropriate method for excavation and control of the ground water;

4.1.3 References

1 The following standards are approved and/ or referred to in this Section:

ASTM C227.....Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

ASTM C289.....Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)

ASTM C1260.....Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

BS 5000-3 .....Rotating electrical machines of particular types or for particular applications - Generators to be driven by reciprocating internal combustion engines. Requirements for resistance to vibration

BS 5304 .....Code of practice for safety of machinery; (BSI PD 5304 Guidance on safe use of machinery)

BS 6164 .....Health and safety in tunnelling in the construction industry. Code of practice

BS 6724 .....Electric cables. Thermosetting insulated, armoured cables of rated voltages of 600/1 000 V and 1 900/3 300 V for fixed installations, having low emission of smoke and corrosive gases when affected by fire. Specification

BS 7375 .....Distribution of electricity on construction and demolition sites. Code of practice

BS 7430 .....Code of practice for protective earthing of electrical installations

BS 7671 .....Requirements for Electrical Installations. IET Wiring Regulations

EN 197 .....Cement

EN 206 .....Concrete - Specification, performance, production and conformity

EN 287 .....Qualification test of welders - Fusion welding

EN 292 .....Safety of machinery - Basic concepts, general principles for design; (ISO 12100 Safety of machinery — General principles for design — Risk assessment and risk reduction)

EN 450 .....Fly ash for concrete

EN 480 .....Admixtures for concrete, mortar and grout - Test methods -

EN 620 .....Continuous handling equipment and systems - Safety requirements for fixed belt conveyors for bulk materials

EN 853 .....Rubber hoses and hose assemblies - Wire braid reinforced hydraulic type – Specification

EN 934 .....Admixtures for concrete, mortar and grout

EN 981 .....Safety of machinery - System of auditory and visual danger and information signals

EN 1008 .....Mixing water for concrete - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete

EN 1012 .....Compressors and vacuum pumps - Safety requirements

EN 1992 .....Eurocode 2: Design of concrete structures:

EN 1993 .....Eurocode 3: Design of steel structures:

EN 1997 .....Eurocode 7 - Geotechnical design:

EN 1997-1 .....Eurocode 7: Geotechnical design - Part 1: General rules

EN 12110 .....Tunnelling machines - Air locks - Safety requirements

EN 12336 .....Tunnelling machines - Shield machines, thrust boring machines, auger boring machines, lining erection equipment - Safety requirements; (EN 16191 Tunnelling machinery - Safety requirements)

EN 12620 .....Aggregates for concrete

EN 12390 .....Testing hardened concrete

EN 13263 .....Silica fume for concrete

EN 14889 .....Fibres for concrete

EN 15167 .....Ground granulated blast furnace slag for use in concrete, mortar and grout

EN 50402 .....Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or of oxygen - Requirements on the functional safety of gas detection systems

EN 60034-9 .....Rotating electrical machines - Part 9: Noise limits

EN 60079 .....Explosive atmospheres

EN 60204 .....Safety of machinery - Electrical equipment of machines

EN 60529 .....Degrees of protection provided by enclosures (IP Code)

EN 60898 .....Electrical accessories - Circuit breakers for overcurrent protection for household and similar installations.

EN 61310-1 .....Safety of machinery - Indication, marking and actuation - Part 1: Requirements for visual, acoustic and tactile signals

ISO 1436 .....Rubber hoses and hose assemblies — Wire-braid-reinforced hydraulic types for oil-based or water-based fluids — Specification

ISO 9000 .....Quality management systems — Fundamentals and vocabulary

ISO 9001 .....Quality management systems — Requirements

ISO 9606-1 .....Qualification testing of welders — Fusion welding — Part 1: Steels

ISO 15609 .....Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding

ISO 15609-1 .....Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding

ISO 15614-1 .....Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys

ISO 15614-12.....Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 12: Spot, seam and projection welding

ISO 17660.....Welding — Welding of reinforcing steel —

ISO/TR 11688-1.....Acoustics — Recommended practice for the design of low-noise machinery and equipment — Part 1: Planning

ISO/TR 11688-2.....Acoustics — Recommended practice for the design of low-noise machinery and equipment — Part 2: Introduction to the physics of low-noise design

ISO/IEC 17050-1.....Conformity assessment — Supplier's declaration of conformity — Part 1: General requirements

Health and Safety Executive HSE L96: A guide to the Work in Compressed Air Regulations

4.2 TUNNEL FINAL LINING

4.2.1 General

1 The tunnel final lining structures consist of either the following:

(a) Reinforced cast – in situ concrete; or

(b) Reinforced precast concrete segmental rings.

2 These shall be designed and constructed in a manner which ensures that any movements and deformations, which may result from the most unfavourable possible loading conditions, will not exceed (in any case) limits beyond which these structures lose their structural capacity and integrity, either during construction or during their prescribed design life of 120 years.

3 Tunnel final linings shall be designed in accordance with the provisions of the Design Specification, entitled “Design Loads”.

4 The primary support shells of the tunnels shall not be considered in the design of the tunnels final lining.

5 The design of tunnels final linings shall not allow for any long term relief and/or effect related to ground arching effects (i.e. full overburden pressure shall be taken into account in the design).

6 The distribution of the lateral ground pressures on to the tunnels final linings shall consider the construction method, the relative rigidity of the lining and the interaction of the lining with the ground. The tunnel final linings shall be designed to withstand the at-rest earth pressure (K_0 conditions).

(a) The design of the tunnels final linings shall consider the full hydrostatic groundwater pressures, with consideration of the maximum long – term levels of the existing groundwater tables (design groundwater level). The minimum short-term levels of the groundwater due to the dewatering activities within the tunnel influence zone shall be considered in the design.

7 Tunnel final linings shall be designed to resist grouting pressure.

8 The design of the tunnels final linings shall comply with the safety requirements of Eurocode EN1992 for concrete structures, EN 1993 for steel structures and EN1997-1 in terms of the applicable partial factors and design approaches.

9 Specifically, for fire safety, the design of the tunnels final linings shall comply with the fire safety requirements mentioned in the Design Specification, entitled: 'Fire Protection and Life Safety Requirements'.

10 Minimum Design Requirements

11 Concrete intended for use in the tunnels shall comply with the specifications of QCS and EN 206 (with the most conservative standard prevailing in the case of conflict) and for:

(a) Cast in-situ concrete structures the minimum design concrete class shall be C30/37 and the reinforcement shall consist of minimum category B500Band

(b) The tunnels' precast segmental lining, the minimum design concrete class shall be C40/50 and the reinforcement shall consist of minimum category B500B, or approved alternative reinforcement.

12 For the design of the reinforced precast concrete segmental rings, the following are essential:

(a) Segmental linings shall be designed not only for the ground and groundwater pressures, but also for all handling, transportation, stacking and erection forces with an allowance for impact. In addition segmental linings shall be designed to resist all forces which may be applied by the equipment used for this.

(b) The segmental lining design shall take into consideration the contact stresses at the joints and the bending caused by the loads eccentricity at the joints.

13 The layout of the structure and the interaction between the structural members shall be such as to ensure a robust and stable structure. Adequate jointing between precast elements or between precast members and cast in-situ structures shall be achieved using appropriate reinforcement and/or special ties in order to ensure their stability and waterproofing, even when subjected to accidental stresses (such as excessive impact, fire, etc.) and possible differential pressures of the supports.

4.2.2 Minimum Construction Requirements Applicable in the Design

1 Continuous end-to-end cracking of the concrete is not permitted. The Contractor shall document and justify minimum reinforcement requirements, subject to a SONO from the Engineer.

2 Depending on the soil and ground water aggressiveness, which will be identified after the appropriate sampling and testing, all necessary measures shall be taken, consistent with the overall design life of the Works and as reasonably determined by the Contractor, in order to ensure reduced permeability and increased resistance of the final lining. These measures shall be submitted to the Engineer for a SONO and include (indicatively but not limited to) special concrete mix (admixtures, special cement etc.), construction measures (larger concrete cover, additional surface reinforcement, curing etc.), special design (limitation of cracking etc.), coating of the exterior surface of the lining, by using special resistant materials, special reinforcement, special resistant waterproofing gaskets (for segmental lining) or waterstops (for cast in- situ lining).

3 The presence of a primary support lining shall not be taken into consideration for determining which surface is in contact with water or soil or with lean concrete.

4 In all areas of the Works, for which there is a provision for cross-passages and the connection of the TBM tunnel to shafts, recesses for E/M installations, etc., specific parts of the precast segments of the main tunnel shall be cut. Cuts shall be made in the main TBM tunnel with precision after installation of the TBM tunnel segments, using the undisturbed cutting method, and shall be made only at the intersection of the connecting tunnel with the main TBM tunnel and geometrically correspond to the outer perimeter of the connecting tunnel. The entire procedure shall be performed diligently so as not to cause any damage, displacement, loosening or disconnection of the precast segments of the main tunnel. All relevant designs shall follow and incorporate this method.

5 Tunnels shall be checked for uplift using:

(a) The dead loads;

(b) All permanent loads; and,

(c) The uplift groundwater pressures.

6 Regarding ground water levels, the Contractor's calculations shall be based on the worst-case scenario likely to occur within the design life of the Works, as this will be estimated on the basis of the appropriately evaluated hydrogeological data (including predictions about ground water fluctuations during the design life of the Works). Any possible effects from the presence of the structure on the groundwater flow shall be considered in the calculations.

7 Where necessary, a construction sequence adequately safeguarding against uplift during all stages of construction shall be indicated on appropriate drawings.

8 The tunnels' uplift safety factor shall be determined on the basis of paragraph 2.4.7.4 and 10.2 of EN1997-1.

4.2.3 Submissions

1 The design of tunnel final lining shall include, but not be limited to the design report, the calculations, any documents related to additional checking or annexes of the calculations, the construction drawings and any other supporting material needed for the better substantiation of the design.

2 The design report shall include at least the following items:

(a) Table with the basic design assumptions;

(b) Table with the geotechnical and geometrical characteristics of the soil stratigraphy, as well as sketches of the geotechnical cross-sections;

(c) A separate chapter in which the structural analysis models shall be clearly described and fully substantiated. This chapter shall contain a detailed description of the individual components of the various models, such as their geometry, their supporting and coupling conditions, the moment of inertia and elastoplastic properties of all members, as well as the properties of any springs or elements used for the simulation of the ground – tunnel interaction;

(d) A separate chapter presenting and justifying in detail all loads exerted onto the model and all loading combinations used in the design, in accordance to the provisions of the Design Specification, entitled: 'Design Loads';

(e) A separate chapter describing, justifying, evaluating and presenting in detail the results of the calculations and the dimensioning of all structural members. For this scope, and as a minimum requirement, the following shall be included:

(i) moments, shear and normal forces,

(ii) the deformed structural model including values of the calculated deformations

(iii) the calculated reinforcement for each structural element.

4.2.4 Safeguarding Tunnel Corridors

4.2.5 Metro Corridor planning stage:

1 The planning corridor width for the Metro Tunnels comprises:

(a) The outlined tunnel structure;

(b) The construction tolerance zone;

(c) The exclusion zone;

(d) The alignment adjustment zone; and

(e) The minimum distance between two adjacent tunnel tubes.

2 Definition of outlined tunnel structure:

(a) For the segmental tunnel lining an outer diameter of 7.5m has been assumed.

3 Definition construction tolerance zone:

(a) For the shield driven tunnels a construction tolerance of 0.5m will be taken into account. The construction tolerance zone is defined as a square with equal sides of 8.5m.

4 Definition of exclusion zones:

(a) For third parties no structures shall be closer than 5m horizontally, 6m from the top and 3 m from the bottom of the outlined construction tolerance zone. For planned structures intruding into this zone approvals from the Employer must be obtained.

5 Definition of alignment adjustment zones:

(a) The Employer is retaining the flexibility to move tunnels 3m horizontally and vertically 3m towards Ground Level. The zone underneath the tunnels is defined infinite to safeguard maximum flexibility.

6 The outline of the Metro Corridor is compulsory for all parties and will be added into the Urban Integration Plans. In certain locations the full tolerance may not be required. The Engineer will advise accordingly.

7 The parameters described above are depicted in Figures 4.4 and 4.5 below.

Figure 4.4
Limit of deviation for general Tunnel arrangement

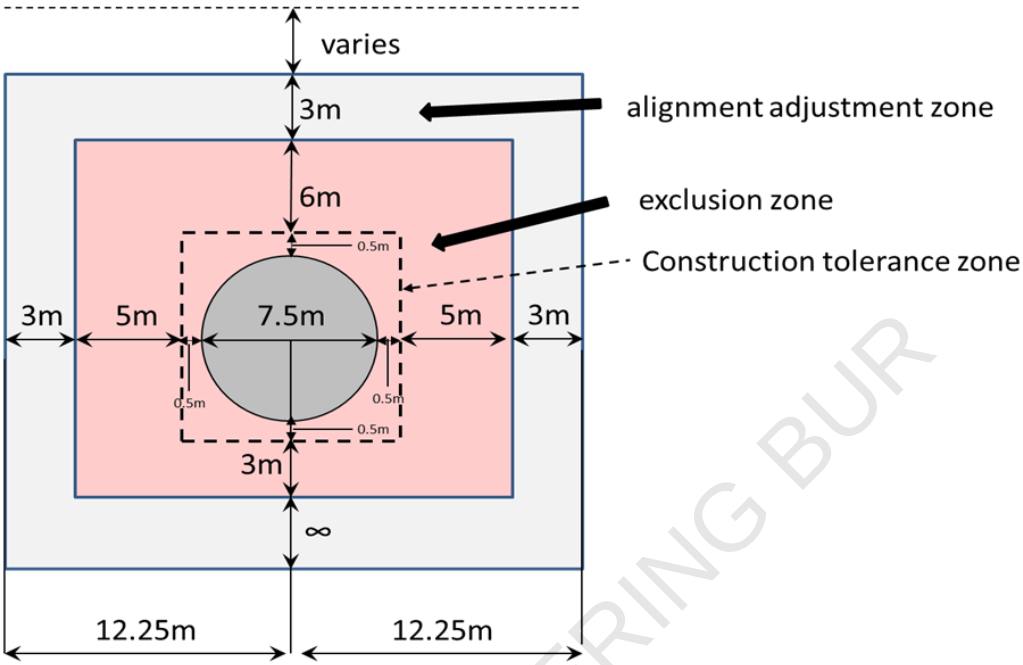
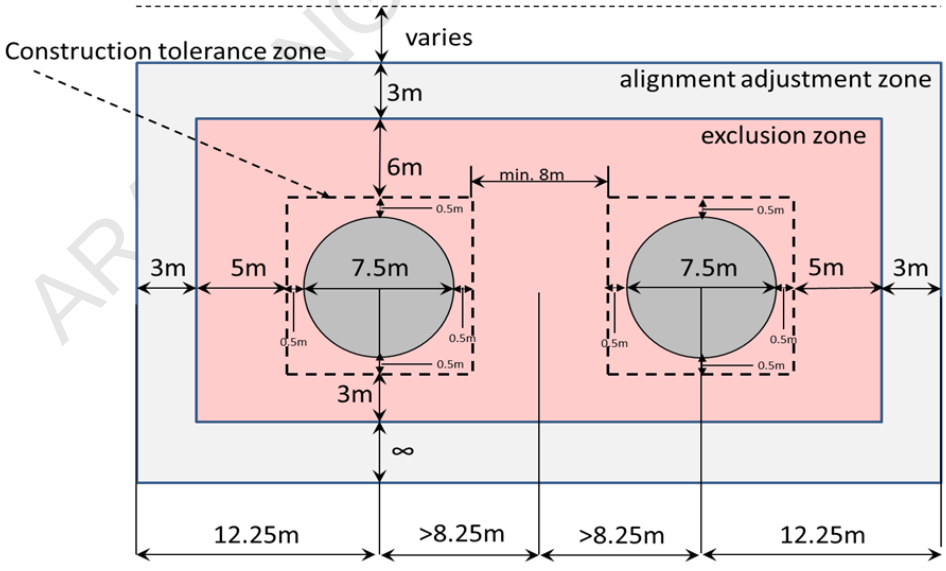


Figure 4.5
Limit of deviation for Twin Tunnel arrangement



4.3 TUNNEL EXCAVATIONS WITH TBM

4.3.1 General

1 The key issues for the Contractor to manage for the construction of tunnels using tunnelling equipment include:

(a) its availability/performance/reliability/serviceability;

(b) assembly, use, removal, with the required equipment;

(c) cutter disc wear;

(d) its stopping periods;

(e) the availability of the correctly certified technical human resources and the supply of all materials needed.

(f) TBM work shall be performed in line with international best practice and the conditions at the Site, which contains different geomaterials.

(g) TBM shall be supplied new and shall be state-of-the-art. The TBM shall be suitable for the ground conditions to be encountered and shall incorporate necessary soil conditioning. They shall be supplied in accordance with all applicable Regulations, and relevant Qatar Construction Specifications, British and European standards. The Contractor shall always use the latest published version of any regulation or standard that relates to health and safety.

4.3.2 Selection of TBM

1 The operation and control features of the TBM shall be designed to minimize sub-surface and ground settlement. Ground loss arising from the TBM boring and tunnel construction operations shall be limited to a maximum value of 1% of the excavated volume, with more stringent limits on maximum ground loss as specified in the Contract Documents. The TBM operating principles shall govern its use in order to meet these requirements.

2 The Contractor is solely responsible for the selection of the TBMs to be used for the tunnelling operations and shall be according to the Project specifications and requirements detailed herein. As a minimum, the following factors shall be taken into account for TBM selection:

(a) The geological, hydrogeological and geotechnical conditions in the zone of influence of the Works;

(b) The geometry of the tunnel section and its alignment;

(c) Manufacture and supply of the machines and their back-up equipment;

(d) Assembly and preliminary tests in the factory, including the grout and soil conditioning system. TBM manufacture shall allow for attendance of the Contractor maintenance and the Engineer during the final assembly and commissioning works;

(e) Technical assistance during assembly at the worksite;

(f) Commissioning and tests at the work site;

(g) Technical assistance during the dismantling operations;

(h) All applicable environmental regulations and licenses;

(i) The stability conditions of the tunnel face and the tunnel section;

(j) The requirements to limit ground and structures deformations below the acceptable levels, as described in the Technical Specification

(k) Any tests to confirm design assumptions;

(l) The time constraints regarding the tunnel construction;

(m) Applicability of supplementary supporting methods if necessary;

(n) Availability of spaces necessary for auxiliary facilities behind the machine and around the access tunnels;

(o) Direction control and measurement system;

(p) The supply and management of spares, consumables and wear parts;

(q) Design of the tunnel boring machine (TBM) and backup equipment and ongoing input during design and manufacture;

(r) Operation and maintenance manuals in English and Arabic, provided electronically together with 4 paper copies;

(s) Technical assistance from the Manufacturer during the tunnel start-up until the specified performance is demonstrated as being achieved, and as necessary thereafter to assist the Contractor in achieving the required performance throughout the tunnel drives as constructed drawings of the TBM, technical documentation and details of planned maintenance requirements prior to commencing TBM and/or Tunnelling Equipment operations including updated operational manuals;

(t) A detailed programme for the design and manufacture of the TBM's. The Contractor and the TBM Manufacturer shall attend regular meetings with the Engineer to monitor the design and manufacture of the TBM to the Contract schedule.

3 An excavation control system shall be installed necessary for tunnelling operations, orientation and operation of the TBM excavation, backfill grouting and operation of auxiliary facilities. The system will control accurate alignment, excavation control (belt weighers, laser scanner, flow meters and profilers) to ensure stability of the face of the tunnel and minimum disturbance of the surrounding ground and structures.

4 A TBM operational control and monitoring data acquisition system shall be provided. The system shall be compatible with the project-wide underground construction instrumentation and monitoring requirements. The monitoring system shall record and report the key information that will ensure the reliable and safe operation of the TBM. The monitoring system shall also record all necessary parameters to ensure ground movements are kept within the specified limits. The Contractor and Manufacturer shall submit a list of target programmed TBM control parameters to the Engineer for a SONO.

4.3.3 Inspections and tests

1 Prior to commencing any operation with the TBM the Contractor shall submit a programme for the supply, inspection, testing, transfer, assembly and operation of the TBM.

4.3.4 Tunnel Excavation with TBM

1 The bearing positions of the thrust rams shall be designed for the bearing capacity of the geomaterials and the tunnel lining, in order to avoid failures.

2 The thrust rams shall operate either individually or together in any possible combination.

3 Access must be given to all working or maintenance areas of the TBM. Provision shall be made for emergency exits.

4 All necessary measures to prevent the risk of water ingress shall be taken before commencement of the Works.

5 Immediately upon any work stoppage, the stability of all TBM excavations and the safe condition of the tunnel (including regular inspections) shall be ensured.

6 All lighting used by the Contractor shall ensure uniformly distributed lighting in all working areas.

4.3.5 Operation of TBM

1 All information relevant to the control of the TBM operation shall be accessible to the Engineer in real time.

2 Operation and maintenance of the TBM, shall be according to the guidelines of the manufacturer and the operation and maintenance manuals, which shall always be up to date and available for inspection of the Engineer.

3 An air-conditioned control cabin shall be provided at the front end of the back-up system from which the TBM will be driven. This shall contain all the remote controls and visual displays as necessary for the safe operation of the TBM and its environment.

4 A separate above-ground monitoring facility shall be provided for each TBM that will duplicate all the remote controls and visual displays within the respective (sub-surface) Control Cabin.

5 The cutting tools shall regularly be inspected.

6 The TBM bearing shall be regularly inspected. The bearing shall be removable rearward from the front bulkhead with the minimum of disturbance to the other components, in the event of the need for replacement. A replacement main bearing should be available within 12 weeks should the replacement be required.

7 The cutter head shall be a substantial structure, which provides the necessary mechanical support to the tunnel face. It shall incorporate the necessary abrasion protection features to enable the shield to be able to complete excavation of the tunnels through all the expected geological conditions.

8 The cutter head structure and bearing with its support system shall be rated to absorb the maximum forces envisaged in operation. This shall include normal operation and ultimate load condition where full power may need to be used in the event the TBM becomes stuck, resulting in maximum shove loading and maximum torque.

4.3.6 Tunnel Excavation Data Reports, Shift Reports

1 Detailed data for all TBM excavations shall be kept.

4.3.7 As-built Details

1 The Contractor shall keep records of as-built details of the tunnelling works, including ring erection and soil conditions encountered during boring.

4.3.8 Safety Regulations

1 The design and manufacture of the TBM and back-up systems shall comply with all applicable laws and regulations, relevant Codes of Practice relating to safety and relevant Qatar Construction Specifications, British and European standards including, but not limited to, those described below. The Contractor shall always use the latest published version of any regulation or standard that relates to health and safety.

(a) EN 12336: Tunnelling Machines – Safety Requirements.

(b) EN 12110: Tunnelling Machines – Air Locks-Safety Requirements.

(c) BS 6164: Code of practice for safety in tunnelling in the construction industry.

(d) The Work in compressed Air Regulations 1996.

(e) HSE L96 A Guide to the Working in Compressed Air regulations (1996).

(f) ISO 9000 and 9001 Quality management and quality assurance standards.

(g) EN 60079 Electrical apparatus for potentially explosive atmospheres.

(h) EN 50402: Electrical apparatus for the detection and measurement of combustible or toxic gases or vapours or of oxygen. Requirements on the functional safety of fixed gas detection systems.

(i) EN 981: Safety of machinery. System of auditory and visual danger and information signals.

(j) EN 60034-9 Rotating Electrical Machines – Noise Limits.

(k) ISO/IEC 17050 – 1: Conformity assessment. Suppliers declaration of conformity. General requirements.

(l) EN 981: Safety of machinery-System of Danger and Non Danger signals with sound and light.

(m) EN 61310-1: Safety of Machinery-Indicating, marking and actuating principles; part 1 Visual, audible and tactile signals.

(n) EN 1012: Compressors and vacuum pumps; Safety requirements.

(o) ISO/TR 11688; Parts 1 & 2: Recommended Practice for the design of low noise machinery and equipment.

(p) EN 620: Specification for mechanical and spliced joints in conveyor belting for use underground.

4.3.9 Fire Prevention

1 A fire hazard assessment which will identify and mitigate all potential fire sources shall be carried out by the Contractor jointly with the TBM Manufacturer and submitted to the Engineer for a SONO.

2 Subject to the conclusions of the hazard assessment, the TBM and back-up systems shall be provided with:

(a) The fire suppression system which shall be suitable to mitigate the risks identified in the hazard assessment.

(b) Emergency plunger buttons at suitable locations to activate a fire alarm.

(c) Hand held extinguishers provided with colour coded covers in suitable locations.

(d) A means of rapidly shutting off fresh air ventilation to the tunnel face, after the area has been evacuated.

(e) Operators and training manuals for use by the Contractor.

(f) Conveyor belting, rubber covered rollers and other similar parts to be manufactured in materials that reduce the fire risk, fire load, spread of flame and toxic fume risk.

(g) Hydraulic hoses shall comply with EN 853/ ISO 1436. The hose covers to be flame retardant and to conform to the requirements of MSHA. All hydraulic hoses shall be fitted with swaged end connections, re-usable fittings are not permitted.

(h) Gas monitoring for oxygen deficiency, CO_2, CO, H_2S, NO_2, SO_2 and CH_{1-4}.

(i) Smoke detection and rate of temperature rise.

(j) Water mist screen to be positioned at the rear of the back-up System.

(k) Low density foam generators to be sited at high fire risk areas with either automatic or manual operation in the event of fire.

(l) Spraying nozzles to be installed at the last sledge to create an anti-smoke curtain in case of fire in the tunnel.

(m) Essential services shall be protected so that they remain operable during all tunnelling operations for a period of 1 hour. The essential services are:

(i) Emergency power supplies

(ii) All fire suppression systems

(iii) TBM emergency lighting

(iv) Environmental monitoring systems

(v) All controls and tunnel communications

(vi) The security of the air supply and control systems to the man lock shall remain operable in all emergencies, particularly in the case of fire

(vii) Emergency evacuation chambers

4.3.10 Electrical Specification

1 All TBM electrical installations shall comply with all relevant regulations and with all relevant British, European and Qatar standards. The Contractor shall always use the latest published version of any regulation or standard that relates to health and safety.

2 The following list of relevant regulations and standards in non-exhaustive:

(a) BS 6164 Code of Practice tunnelling

(b) EN 12336: Tunnelling Machines Safety Requirements

(c) Electricity at Work Regulations 1989

(d) BS 7671: Requirements for Electrical Installations

(e) IEE Wiring Regulations 16th Edition

(f) BS 5304 and EN 292: Safety of Machinery

(g) BS 7430:. Earthing

(h) EN 60204: Safety of Machinery

(i) BS 7375: Distribution of Electricity on Construction sites

(j) EN 60529: Degrees of Protection of Enclosures

(k) BS 6724: armoured cables for low emissions

(l) BS 5000-3: Rotary Electrical Machines for Particular applications

(m) EN 60898: Moulded case and miniature circuit breakers

4.3.11 Environmental Conditions

1 Control and monitoring of environmental conditions to include but not limited to:

(a) Fire protection systems

(b) CCTV monitoring of work areas

(c) Electrical power

(d) Humidity

(e) Dust monitoring

(f) Inundation of the cutter head chamber

(g) Ventilation air supply (including failure)

(h) Gas detection system for oxygen deficiency, CO_2, CO, H_2S, NO_2, SO_2 and CH_4. The data acquisition unit shall include provision for the monitoring of tunnel gas alarms throughout the tunnel to provide early warning to the TBM operator of potential gas danger

4.4 TUNNEL EXCAVATION BY CONVENTIONAL MEANS

4.4.1 General

1 This Specification applies to all tunnel excavation Works using conventional mechanical means and the implementation of the tunnel's primary support. All tunnel excavation Works shall be in accordance with Contractor's design which has received a SONO.

4.4.2 Working Conditions

1 Safe and continuous access to all tunnels, as well as the required safety conditions shall be ensured throughout the execution of Works.

2 All lighting used by the Contractor shall ensure uniformly distributed lighting in all working areas.

3 Pumping, drainage and mud and water removal equipment shall be installed, operated and maintained, in order to ensure that all Permanent Works shall be constructed in dry conditions and shall be protected against water.

4.4.3 Working Interruptions

1 Upon any work stoppage the stability of all tunnel excavations and the safe condition of the tunnel (including regular inspections) shall be ensured.

4.4.4 Safety Measures and Systems

1 An emergency power supply shall be available on site to provide power for all electrical installations, which are considered essential for the safety of the tunnel and the working personnel.

2 An emergency evacuation procedure shall be prepared which is also approved by local authorities.

4.4.5 Work Execution

1 Pre-excavation Works

(a) Prior to the commencement of the tunnel excavation Works, all necessary measures shall be taken to locate, fill and seal any voids from all investigation boreholes that may be encountered during excavation.

(b) If required by the design and/or method statement, and prior to commencing any tunnel excavation works, ground improvement works shall be performed.

2 Monitoring

(a) Prior to the commencement and throughout the tunnel excavation Works, as well as after their completion, it shall be ensured that all monitoring instruments that have been installed are fully functional, regularly calibrated and monitored.

(b) The Engineer may instruct the stoppage of the works, when the instruments are not completely installed, or the Contract requirements are not fulfilled.

3 Geological mapping of the excavation surfaces

(a) Geological mapping of the excavation surfaces shall be performed upon completion of each heading/bench advance, except for where the immediate sealing of the excavation face using shotcrete is required.

(b) The geological mapping shall be performed concurrently with the excavation. The tunnel's faces shall be cleaned to the extent possible so as to enable collection of the necessary data for the complete geological mapping and the classification of the geomaterial at the tunnel face.

4 Probe drillings

(a) Investigation drillings through the tunnel face and/or through the ground surface for further investigation of ground and groundwater conditions and of possible weak zones, voids wells or any other disturbances shall be carried out.

(b) The number, location and orientation of probe drillings shall be designed in a manner to collect the maximum possible amount of data, depending on the type and the inclination of strata, the presence of water, the geometry and the tunnel alignment. All drilling logs shall be made available to the Engineer.

5 Emergency Conditions in the Tunnel

(a) When wells or other voids are encountered during excavation Works, the area shall immediately be protected against collapse, to ensure the safety of the Works and all persons.

(b) Any damage to the Works or the structures, including local failure of the primary support, shall be reinstated immediately.

6 Surveys

(a) The correct construction, orientation and shape of the tunnel, based on the design (such as, alignment data, structural tolerances, convergence tolerances) shall be verified. Measurements of excavated cross sections shall be performed.

(b) The minimum thickness of the primary support shall always be greater than or equal to the relevant thickness in the design.

7 Tunnel Excavation Shift Reports

(a) A Shift Report for all underground excavations shall be maintained. This report shall include sufficient data for the full recording of the cycle of Works. The report shall be available to the Engineer at all times.

4.5 PRECAST CONCRETE TUNNEL LINING SEGMENTS

4.5.1 General

1 This Specification concerns the supply of materials and equipment as well as execution of Work for the production and installation of precast concrete segments to be used as the lining of all TBM.

2 The segmental precast concrete lining shall consist of a number of precast segments to form rings.

3 Radial joints in adjacent rings shall be staggered so that there are no continuous joints. The circumferential joints between adjacent rings shall be continuous.

4 Tapered rings shall be used to negotiate horizontal and vertical curves and to correct for line and level.

5 All precast concrete lining segments shall have EPDM gaskets inserted into recesses provided in all four mating surfaces of the individual segments. The size and position of the gasket shall be sufficient to take account of all tolerances for the segments and gaskets. Where it is proposed to erect segmental lining without applying shield jacking forces to compress the gaskets it shall be demonstrated that the required watertightness of the segments joints shall still be achieved by adequately compressing the gaskets or by other acceptable means for the SONO from the Engineer.

4.5.2 Materials

1 Concrete

(a) The concrete shall be a minimum strength of class C40/50 as defined under EN 206.

2 Cement

(a) The cement shall comply with the requirements of EN 197.

3 GGBFS

(a) GGBFS intended for use for segments shall comply with EN 15167.

4 Fly Ash

(a) Fly Ash intended for use for both the segments shall comply with EN 450.

5 Microsilica

(a) Microsilica intended for use for segments shall comply with EN 13263.

6 Aggregates

(a) Fine aggregates shall be natural or crushed rock sand in compliance with EN 12620.

(b) Coarse aggregates shall not contain materials which may cause reduction of strength or durability of the concrete. Coarse aggregates shall be crushed aggregate from an approved natural source in compliance with EN 12620.

(c) The potential alkali aggregate reactivity has to be determined and evaluated either by the relevant ASTM standards ASTM C289 and ASTM C1260 and ASTM C227.

7 Water

(a) Water shall comply with the requirements of EN 1008. Additionally, to account for the high risk of chloride-induced reinforcement corrosion, the maximum allowable chloride content of the mixing water is 250 mg/l.

8 Admixtures

(a) Admixtures used in the concrete shall conform to EN 934, EN 480 and shall be mutually compatible. They shall be accompanied by full documentation from the manufacturer, which shall be submitted to the Engineer for a SONO. Use and dosage of admixtures shall be in accordance with the manufacturer's recommendations.

9 Steel

(a) If reinforcement steel for segmental lining is used, it shall be new. The reinforcement shall be of minimum B500B category or approved alternative reinforcement.

(b) If steel fibre reinforcement is used for segmental lining it shall comply with EN 14889 and have a minimum tensile strength of 1100 N/mm^2.

(c) Manufacturer's production certificates shall be supplied.

(d) Reinforcement bar welding shall be carried out by certified welders in accordance with Standard ISO 17660, ISO 15609-01, ISO 15614-1 and ISO 15614-12. The welding quality shall be certified through EN 287 or ISO 9606-1.

10 Fasteners, fixings and fittings screws and bits

(a) Specifications for all temporary and permanent fasteners and cast-in fixings shall be provided. All permanent inserts shall be stainless steel.

11 Segment identification

(a) The following information shall be cast in to the internal (concave) surface of all segments or shall be incorporated on a bar code fixed permanently to the inside face of the segment:

(i) QR – followed by the Contract Number

(ii) Date of production

(iii) Mould number

(iv) Ring type e.g. left hand taper or right hand taper

(v) Segment type

(vi) The Contractor shall number the concrete rings in sequential order between the stations, clearly stencilled in clear large durable black numbers on completion of each tunnelled drive.

12 Tests and Checks during Construction

(a) The concrete mixture shall be regularly checked for conformity with the laboratory concrete mix design. The total water-cement ratio shall be in the range prescribed in the laboratory concrete mix design.

(b) In addition, chloride penetration tests shall be performed according to NT Build 492. The tests reports shall be available to the Engineer at all times.

(c) The compressive strength test shall be performed in accordance to EN 12390 and all other tests with EN 206.

13 Tests on the Production Line

(a) Prior to the beginning of the full-scale production of lining rings, three trial rings shall be built and assembled to check that the required tolerances have been met.

(b) At least 1 in every 20 segments produced from each mould shall be checked for compliance with the casting tolerances. Checks shall continue throughout the production period and shall be performed on segments selected at random by the Engineer for the control of the production of segments to the required tolerances.

(c) All segments shall be systematically checked for surface defects and repaired if required.

(d) Dimensional control of segments shall be made on a daily basis to meet the tolerance ranges. The internal diameter of the completed ring, during tunnel lining construction, will be checked on Site.

14 Repair of Segments

(a) A special methodology for the repair of defective segments, addressing all types of repairs shall be provided. The repairs shall include all the methods related to the surface preparation, the work sequence, the appropriate repair materials (depending on the type of defect), the equipment to be used, and the checks to be carried out at each phase of repairing. This methodology shall be submitted to the Engineer for a SONO.

(b) With reference to the repair of segments, two cases of repair are distinguished. The first case relates to the repair of segments located either in the production plant, or the construction Site area before their final placement in the tunnel. The second case relates to segments that have already been incorporated in a ring within the tunnel. A methodology statement for each of these cases shall be prepared for a SONO from the Engineer.

(c) Categories of segment defects are defined as minor, medium and major, as shown in Table 4.1 below

Table 4.1 Tunnel Segment Defects

Category	"Minor"	"Medium"	"Major"
	Broken edge < 5mm Air holes < 8mm Crack width < 0.15mm Crack depth < 20mm **No need for repair**	Broken edge 5mm to 25mm Air holes 8mm to 14mm Crack width 0.15mm to 0.20mm Crack depth < 20mm Surface depression < 20mm **Can be repaired**	Broken edge> 25mm Air holes > 14mm Crack width > 0.20mm Crack depth > 20mm Surface depression > 20mm **Shall be rejected**

(i) Minor defects can be accepted without repair.

(ii) Medium defects can be repaired only after the detailed method statement has been given a SONO from the Engineer. Precast concrete segmental linings shall be of waterproofing class 1

(iii) Where a major defect occurs prior to the final placement of the relevant segment in the tunnel it shall be rejected.

(iv) All defects in the segment which will be in contact with the gasket shall be repaired

15 Tolerances of Segmentally Lined Tunnels

(a) Tunnels supported with segmental concrete lining, as part of the Permanent Works, shall conform to each of the following tolerances by reference to the axis:

(i) Segment width: +/- 0.5mm;

(ii) Segment thickness: +/- 3.0mm;

(iii) Segment arc length: +/- 0.6mm;

(iv) Inner radius of a single segment: +/- 1.5mm;

(v) Deviation of the 'AS BUILT' diameter of the inner face of the segments: 1.0mm and from a perfect circle: 5.0 mm;

(vi) Width of segment grooves: +0.2 mm – 0 mm;

(vii) Depth of segment grooves: +0.2 mm – 0mm;

(viii) Axis of segment grooves: +/-1.0 mm;

(ix) Longitudinal joint evenness: +/- 0.5 mm;

(x) Ring joint evenness: +/- 0.5 mm;

(xi) Unevenness of joints causing stress on the section: not permitted;

(xii) Outer diameter of the constructed ring: +/- 10 mm;

(xiii) Inner diameter of the constructed ring: +/- 10 mm;

(xiv) Outer perimeter of the constructed ring: +/- 30 mm;

(xv) Torsional angle in the longitudinal joint: + 0.04°; and

(xvi) Angle of longitudinal joint conicity: + 0.01°.

4.6 GROUTING FOR SEGMENTAL LINING, CONTACT GROUTING AND FILLING OF VOIDS

4.6.1 General

1 This specification concerns the provision of labour, materials, installations and equipment for filling all voids, including karst voids.

2 This specification applies to tunnels excavated either by TBM or by conventional methods.

3 All voids between the excavation profile and outer limit of the theoretical temporary lining (in sprayed concrete lining (SCL) tunnels) or the segmental lining (in tunnel boring machine (TBM) tunnels) shall be filled with cement grout.

4 Any other voids encountered ahead of the tunnel excavation face shall be filled with cement grout, if their presence prevents or otherwise obstructs the advancement of the excavation face.

5 Grouting for filling karstic voids may require primary and secondary grouting. Primary grouting is the initial grouting which is applied immediately after a unit of lining has been built. Where primary grouting does not completely fill all voids, secondary grouting shall be carried out.

6 Grout shall remain effective for the design life of the tunnel. The grout shall not degrade, shrink or lose strength to an extent that the tunnel would be damaged or become unserviceable as a result.

END OF PART