CONTENTS

25 STEEL FIBRE REINFORCED CONCRETE (SFRC) AND HYBRID SEGMENTAL LINING

25.1 General

25.1.1 This section outlines the design and construction requirements for fibre reinforced concrete and hybrid segmental lining. The specification for cast in-situ concrete linings or sprayed concrete linings are covered elsewhere in the Particular Specification.

25.1.2 The Contractor shall only use Steel Fibre Reinforced Concrete (SFRC) segments and Hybrid segments for tunnel lining. The hybrid segments shall be provided at locations where longitudinal reinforcement is required to strengthen the SFRC segmental lining.

25.1.3 The aspect ratio of segment shall not be more than 9.5.

25.2 Design Requirements for SFRC and Hybrid Segments

25.2.1 The design of SFRC and Hybrid segment shall comply with SS EN 1990, SS EN 1992, SS EN 1993, SS EN 1997, SS 674 and the Authority's requirements. It is the Contractor's responsibility to prove and present to the Engineer his compliance with the stated criteria.

25.2.2 Hybrid Segments

25.2.2.1 Hybrid segment is defined as segment lining containing steel fibre that meets the Authority's requirements and longitudinal reinforcement that the minimum bar area at each side of the segment complies with the $A_{s,min}$ in accordance with SS EN 1992-1-1.

25.2.2.2 Hybrid segment shall be designed as wall subjected predominantly to out-of-plane bending, in accordance with SS EN 1992-1-1. The transverse reinforcement shall be provided at a maximum spacing of 12 times the size of the smallest longitudinal bar.

25.2.2.3 Except for segment joint design, the contribution from SFRC material can only be considered in Serviceability Limit State (SLS) crack width design. The Contractor shall propose parameters of the SFRC crack width design for the Engineer's acceptance, based on relevant test results and the specification requirements, whichever is governing.

25.2.2.4 The calculated maximum SLS crack width for Hybrid segment shall not exceed 0.3mm. The Contractor shall take note that SS674 offers two approaches for crack width calculations, and that the more onerous result from the two equations shall be adopted.

25.2.3 SFRC Segments

25.2.3.1 When the area of longitudinal reinforcement at either side of segment cannot satisfy the $A_{s,min}$ in accordance with SS EN 1992-1-1, the segment shall be considered as SFRC segment.

25.2.3.2 The design compressive strength of SFRC segment, f_{cd} shall be computed based on the following equation:

$$f_{cd} = \alpha_{cc,f} f_{ck} / \gamma_f$$

where

$\alpha_{cc,f}$ coefficient accounting for long term effects and of unfavourable effects due to the way in which the load is applied

f_{ck} characteristic compressive cylinder strength of concrete at 28 days

γ_f partial factor for fibre concrete

25.2.3.3 The $\alpha_{cc,f}$ shall be computed based on the following equation:

$$\alpha_{cc,f} = 0.30 + 0.5\, f_{R3}/f_{R1} \quad \text{where} \quad 0.60 \le \alpha_{cc,f} \le 0.85$$

The $\alpha_{cc,f}$ shall be verified based on relevant f_{R3} and f_{R1} test results and the specification requirements and is subject to the Engineer's acceptance.

25.2.3.4 The contribution from SFRC material can only be considered in the following design parameters:

- tensile splitting strength in segment joint design;
- LOP in SLS crack check; and
- $\alpha_{cc,f}$ in segment joint design and ULS M-N Interaction Curve.

The Contractor shall propose parameters of the SFRC design for the Engineer's acceptance, based on the relevant test results and the specification requirements whichever is governing.

25.2.3.5 The SFRC tunnel lining shall remain uncracked in all load combinations. The maximum flexural tensile stress of SFRC lining under flexure shall be within the characteristic value of LOP of SFRC material.

25.2.4 Additional reinforcement bars at segment joint of SFRC and Hybrid segment shall be provided if the structural capacity is found to be insufficient at the segment joint. The design action at segment joint shall be resisted by both bar reinforcement and SFRC material in ULS and SLS load combinations.

25.2.5 For Hybrid segment and SFRC segment where reinforcement bars are provided at segment joints, epoxy coating is required at extrados, radial and circumferential joints of the segment.

25.3 Constituent Materials of Concrete

25.3.1 Aggregates

25.3.1.1 During the entire segment trial and production, the Contractor shall maintain constant supply and ensure a strict regime on the quality control including but not limited to dust coating of gravels, moisture content of gravels and sand, during material delivery and inspection at the time of acceptance of materials.

25.3.1.2 The Contractor shall install a minimum of 3 number of moisture probes in each of coarse and fine aggregate storage bins. The recorded moisture content of the coarse and fine aggregate in the respective batches shall be accounted in the total water content during the batching of concrete to ensure consistency of water/cement ratio as per the approved design mix.

25.3.1.3 The maximum aggregate size shall be 20mm for fibre reinforced concrete.

25.3.2 The Contractor shall propose an acceptance zone on the grading curve for the aggregates to be used for SFRC. This shall be established and accepted by the Engineer prior to any SFRC batching for trials or segment production. Grading tests shall be carried out at weekly intervals when SFRC is being batched for trials or segment production. Aggregates whose grading are found to fall outside the aforementioned acceptance zone shall be rejected.

25.3.3 Steel Fibres

25.3.3.1 Steel fibre reinforcement shall be deformed steel fibre produced by cold drawn wire. Steel fibres shall be for structural use in concrete (Group I) complying with EN 14889-1. The steel fibre product shall have a valid EC certificate and declaration of conformity issued by an appropriate certification body as per requirement in EN14889-1. The steel fibre product shall have the relevant CE marking and labeling.

25.3.3.2 Steel fibres shall have round cross-section and hooked ends.

25.3.3.3 The aspect ratio of the steel fibres shall be between 50 to 80.

25.3.3.4 The minimum length of the steel fibres is 50mm.

25.3.3.5 The minimum tensile strength of the steel fibres is 1300MPa.

25.3.3.6 The steel fibres used shall be uniformly distributed in the concrete and shall not tend to form fibre balls during batching and mixing.

25.3.3.7 The steel fibre type shall be selected on the basis of compliance with this Specification and on suitability and ease of use in the batching, mixing and concrete placement processes proposed, as demonstrated by trials.

25.3.3.8 The steel fibres shall be manufactured under a quality system certified to ISO 9001.

25.3.3.9 The steel fibre dosage shall not be less than 40 kg/m3.

25.3.4 Polypropylene Fibres

25.3.4.1 Polypropylene fibres shall be 100% virgin polypropylene monofilament fibre containing no reprocessed materials. Polypropylene fibres shall comply with EN 14889-2 (Class I a). The polypropylene fibre product shall have the relevant CE marking and labeling as stated in EN 14889-2.

25.3.4.2 Polypropylene fibres shall have a nominal cross-section diameter between 18microns to 20microns.

25.3.4.3 Polypropylene fibres shall have a nominal length between 6mm to 12mm.

25.3.4.4 Polypropylene fibres shall have a melting point of 160°C ± 10%.

25.3.4.5 The polypropylene fibres shall be selected on the basis of compliance with this Specification and on suitability and ease of use in the batching, mixing and concrete placement processes proposed, as demonstrated by trials.

25.3.4.6 The polypropylene fibres shall be manufactured under a quality system certified to ISO 9001.

25.3.4.7 Polypropylene fibres shall be supplied in water soluble bags. Each bag shall contain 1.0kg of polypropylene fibres.

25.3.4.8 The minimum polypropylene fibre dosage shall be 1.0kg/m^3.

25.4 Handling and Storage of Materials

25.4.1 Fibres shall be stored in dry-sealed containers until required for use. The surface of fibres should be kept dry and clean with no corrosion, grease, dirt, mill scale and deleterious materials that may reduce the bond between the fibres and the concrete.

25.5 Steel Fibre Reinforced Concrete Properties

25.5.1 The Contractor shall ensure sufficient dosage of steel fibres are provided to meet the following minimum requirements for SFRC and Hybrid concrete:

a) Characteristic compressive cylinder strength, tested to EN 12390-3, of 50N/mm^2;

b) Characteristic tensile splitting strength, tested to EN 12390-6, of 4.5 N/mm^2;

c) Characteristic limit of proportionality (LOP) value, tested to EN 14651, of 5.5 N/mm^2;

d) Characteristic fR,1 value, tested to EN 14651, of 5.2 N/mm^2; and

e) Characteristic fR,3 value, tested to EN 14651, of 3.1 N/mm^2.

25.5.2 Where the above minimum requirements on the steel fibre reinforced concrete properties are not met, the Contractor shall increase the characteristic compressive strength of the concrete and the tensile strength and/or dosage of steel fibres in the concrete to meet the above minimum requirements.

25.6 Concrete Mix and Additives

25.6.1 The design of mix shall consider the effects to workability with the addition of steel fibres and polypropylene fibres. In addition, design of mix shall ensure no segregation and no excessive bleeding.

25.6.2 The design of mix shall be tailored to achieve all the specified requirements on concrete strength properties, water penetration and workability.

25.7 Batching Concrete

25.7.1 Steel Fibre Dosing

25.7.1.1 Steel fibres shall be added during concrete batching at the batching plant. Steel fibres shall not be added into the mixer of ready-mix trucks.

25.7.1.2 Steel fibres shall be added to the batching plant mixer as per the steel fibre supplier's recommendation.

25.7.1.3 Steel fibres shall be added via a fully automatic fibre dosing machine. The fibre dosing machine shall have a weighing/control system which integrates with a mixing computer. The fibre dosing machine shall achieve a weighing accuracy of ±1.0%. The dosing capacity of the fibre dosing machine shall be compatible with the type of steel fibre, dosage of steel fibre and rate of concrete production. The fibre dosing machine shall be calibrated by an independent accredited agency at a frequency not longer than every six (6) months.

25.7.2 Polypropylene Fibre Dosing

25.7.2.1 Polypropylene fibres shall be added during concrete batching at the batching plant. Polypropylene fibres shall not be added into the mixer of ready-mix trucks.

25.7.2.2 Polypropylene fibres, in water soluble bags, shall be added to the batching plant mixer using an automated system.

25.7.3 Mixing Concrete

25.7.3.1 The Contractor shall demonstrate that the method and timing of the addition of steel fibres and polypropylene fibres achieves a uniform distribution of fibres throughout the mix.

25.8 Trial Mix and Acceptance

25.8.1 Trial Batches

25.8.1.1 The Contractor shall propose the mix design and carry out his laboratory trials. Following which he shall demonstrate the suitability of his mix design at the casting yard batching plant. Separate trial batches of concrete using accepted materials shall be carried out to achieve the requirements in the Particular Specification prior to full-scale production.

25.8.1.2 Each batch shall be of sufficient size to provide samples for testing specified in the Particular Specification.

25.8.1.3 During production the Engineer may require additional trial mixes and tests to be carried out before a change is made in the materials or in the proportions of the materials to be used.

25.8.2 Sampling and Testing on Trial Batch

25.8.2.1 The Contractor shall perform the following tests, as a minimum, on trial batches for steel fibre reinforced concrete. For each trial batch, the following number of test specimens shall be made from each batch:

a) Three (3) steel fibre content tests on fresh concrete, to EN 14721;

b) Three (3) slump tests on fresh concrete, to EN 12350-2;

c) Three (3) density tests on fresh concrete, to EN 12350-6;

d) Three (3) air content tests on fresh concrete, to EN 12350-7;

e) Twenty (20) cubes for compressive strength testing, at 28 days, to EN 12390-3;

f) Twenty (20) cylinders for tensile splitting strength testing, at 28 days, to EN 12390-6;

g) Twenty (20) test prisms for flexural strength testing, at 28 days, to EN 14651; and

h) Three (3) cubes for water penetration testing at 56 days, to EN 12390-8, where the maximum depth of water penetration for each individual sample shall not be more than 5mm.

25.8.2.2 The testing facility for flexural prism tests shall possess sufficient stiffness and shall be capable of testing the prism to capture residual flexural strengths to a minimum of crack width opening displacement of 2.5mm. The test shall be terminated at a CMOD value not less than 4mm as per EN 14651.

25.8.2.3 The Contractor shall utilize external vibrating device, with proven effectiveness, such as vibration table the like to the acceptance of the Engineer to compact the concrete test specimens. Internal vibrating device using manual compaction shall not be used, e.g. rod or poker vibrator.

25.8.2.4 The Contractor shall check failed specimens to ensure the random distribution and alignment of the steel fibres which shall be uniformly distributed. Should the fibre alignment and distribution be noticeably non-random or not uniformly distributed, the tests shall be repeated.

25.8.3 Compliance Criteria

25.8.3.1 The results of tests on the three consecutive trial batches cast separately shall comply with the following requirements:

a) The average slump values, from tests on all three (3) batches, shall be within 20mm or 25%, whichever is the greater, of the designed slump value;

b) The compressive strength of each cylinder tested shall exceed the specified characteristic strength. The average compressive cylinder strength, from tests on all three (3) batches, shall exceed the specified characteristic strength by at least 10N/mm^2;

c) The tensile splitting strength of each cylinder tested shall exceed the specified characteristic value. The average tensile splitting strength, from tests on all three (3) batches, shall exceed the specified characteristic value by at least 0.5N/mm^2;

d) The limit of proportionality (LOP) value of each prism tested shall exceed the specified characteristic value. The average limit of proportionality (LOP) value, from tests on all three (3) batches, shall exceed the specified characteristic value by at least 0.6N/mm^2;

e) The fR,1 value of each prism tested shall exceed the specified characteristic value. The average fR,1 value, from tests on all three (3) batches, shall exceed the specified characteristic value by at least 1.8N/mm^2; and

f) The fR,3 value of each prism tested shall exceed the specified characteristic value. The average fR,3 value, from tests on all three (3) batches, shall exceed the specified characteristic value by at least 1.5N/mm^2.

25.8.4 Non-compliance

25.8.4.1 If the result of any tests does not comply with the specified criteria, particulars of proposed changes to the materials, mix design or methods of production shall be submitted to the Engineer.

25.8.4.2 Further trial batches shall be made until the result of every test complies with the specified criteria.

25.8.5 Approved Concrete Mix

25.8.5.1 A concrete mix that complies with the specified criteria for trial mix shall become an approved concrete mix. The designed slump value used to produce an approved concrete mix shall become the approved slump value.

25.9 Sampling and Testing of SFRC during Production

25.9.1 Fibre Content Testing on Fresh Concrete

25.9.1.1 One (1) steel fibre content test, to EN 14721, shall be conducted per production day.

25.9.1.2 A compliance criterion is that the steel fibre content shall not be lower than the proposed steel fibre dosage.

25.9.1.3 A further compliance criterion is that steel fibre and polypropylene fibres shall be randomly aligned and uniformly distributed in the concrete test samples.

25.9.2 Tensile Splitting Strength Testing on Hardened Concrete

25.9.2.1 Two (2) cylinders for tensile splitting strength test, at 28 days, to EN 12390-6, shall be made for every four (4) tunnel lining rings that are cast. Sampling for tensile splitting strength testing shall be carried out together with the sampling for compressive cube strength testing described under **Clause 11.8** of Materials & Workmanship Specification for Civil & Structural Works.

25.9.2.2 Compliance criteria is that the average tensile splitting strength obtained from any four (4) consecutive tests exceeds the characteristic tensile splitting strength by a value equal to the current margin and the tensile splitting strength obtained from any individual test is not less than the characteristic tensile splitting strength less the current margin. Current margin is defined as a value equal to 1.64 times the standard deviation.

25.9.3 Flexural Strength Testing on Hardened Concrete

25.9.3.1 Two (2) prisms for flexural strength testing, at 28 days, to EN 14651, shall be made for every twelve (12) tunnel lining rings that are cast. Sampling for flexural strength testing shall be carried out together with the sampling for compressive cube strength testing.

25.9.3.2 Compliance criteria are described as follows:

a) The average limit of proportionality (LOP) value obtained from any four (4) consecutive tests exceeds the characteristic LOP value by a value equal to the current margin and the LOP value obtained from any individual test is not less than the characteristic LOP value. Current margin is defined as a value equal to 1.64 times the standard deviation;

b) The average $f_{R,1}$ value obtained from any four (4) consecutive tests exceeds the characteristic $f_{R,1}$ value by a value equal to the current margin and the $f_{R,1}$ value obtained from any individual test is not less than the characteristic $f_{R,1}$ value. Current margin is defined as a value equal to 1.64 times the standard deviation; and

c) The average $f_{R,3}$ value obtained from any four (4) consecutive tests exceeds the characteristic $f_{R,3}$ value by a value equal to the current margin and the $f_{R,3}$ value obtained from any individual test is not less than the characteristic $f_{R,3}$ value. Current margin is defined as a value equal to 1.64 times the standard deviation.

25.10 Production and Installation of SFRC Segmental Lining

25.10.1 General

25.10.1.1 The requirements under **Clause 16.2** of Materials & Workmanship Specification for Civil & Structural Works shall apply. The subsequent clauses are amplification clauses or additional clauses to the Materials & Workmanship Specification for Civil & Structural Works.

25.10.1.2 The Contractor shall note that BCA's Construction Productivity Awards on Value Added Productivity (VAP) gives recognition and incentives to progressive firms which strive towards higher productivity and encourage more builders to steer towards the productivity movement in the local construction sector. The Contractor is therefore encouraged to produce his SFRC segmental linings in the Republic of Singapore.

25.10.1.3 The Contractor shall ensure that the segment casting yard has a suitable quality assurance accreditation and that it operates a computerized record system that is to the acceptance of the Engineer. The casting yard shall have a dedicated batching plant to support the casting operations for the steel fibre segments.

25.10.1.4 The Contractor shall establish a laboratory within the segment casting yard to facilitate concrete testing. The laboratory shall be equipped with the appropriate testing apparatus to carry out all concrete testing required in the Particular Specification. Prior to conducting any concrete testing associated with the SFRC works, the laboratory shall obtain the necessary accreditation(s) from the Singapore Accreditation Council (SAC). The Contractor may submit alternative proposals to test the samples at an accredited commercial laboratory subject to the acceptance of the Engineer.

25.10.1.5 The Contractor shall note on the longer duration that may be required to finalise the SFRC mix design, trial mixes and his desired concrete workability. The Contractor shall commence his trial mixes not later than three (3) months after the award of Contract to achieve the compliance requirements as stated in **Clauses 25.8** and **25.9** of the Particular Specification prior to full scale segment production.

25.10.2 Concrete Placement

25.10.2.1 The segments shall be cast in factory-controlled conditions, with no exposure to weather conditions such as direct sunlight or rain.

25.10.2.2 Before placing concrete, moulds shall be inspected for cleanliness. Any build up of mould release oil shall be removed prior to placing the concrete. The concrete shall be placed directly into the moulds and as soon as possible after mixing. Compaction of the concrete shall be carried out in such a manner as to produce concrete, which is dense, homogeneous, and free from voids. All surfaces shall be sound and free from honeycombing, blowholes and projections.

25.10.2.3 The Contractor shall utilize external vibrating device or vibrating moulds to compact the concrete. Internal vibrating device using manual compaction shall not be used, e.g. poker vibrators. Vibration system shall be table vibration or external electric vibrators (minimum 3 nos.) mounted on the underside of the mould unit (inner surface). The Contractor shall carry out computerised FEM analysis for mould design to establish resonant vibration in consultation with the vibrator supplier. The Contractor shall conduct site testing to determine the most effective vibration time, including but not limited to achieve full compaction of concrete and minimise the generation of air pockets. There shall be a dedicated covers (flabs) to be provided for each individual mould. There shall be rubber gasket with replacements attached to the side of the mould cover to minimise grout loss.

25.10.2.4 The Contractor shall conduct site testing to determine the most effective vibration time, including but not limited to achieve full compaction of concrete and minimize the generation of air pockets.

25.10.3 Segment Casting Tolerances

25.10.3.1 The Contractor may propose alternative laser based methods and details of the proposed method of control shall be included in the Project Quality Plan.

25.10.4 Demoulding, Handling, Stacking and Transporting

25.10.4.1 Notwithstanding the requirements of the M&W Specification **Clause 16.2.5** 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 demoulding the segments.

25.10.4.2 The segments shall be stored on a prepared level base, stacked and positioned in a safe and stable manner.

25.10.4.3 Within the casting yard, vacuum lifting equipment shall be used when demoulding, handling and transporting segments. During the demoulding, the support and handling arrangements shall be designed to ensure that the flexural Limit of Proportionality (LOP) at the age of demoulding is not exceeded. The Contractor shall determine and submit the LOP at the age of demoulding of the approved mix design during trial mix stage to the Engineer. The Contractor shall engage a PE to carry out a design check, including but not limited to segment demoulding and handling, to ensure that the LOP at the age of demoulding is not exceeded and submit for the Engineer’s acceptance.

25.10.4.4 Spacers shall be used between stacked segments. The spacers shall not be cast into the segment and shall be easily detached and shall not stain the segments. The spacers shall be used to minimize bending stresses in the segment, by supporting the segments within 50mm of the quarter points. The maximum stacking stress shall not exceed the characteristic LOP calculated for the strength of concrete at the age of stacking. The Contractor shall determine and submit the LOP at the age of stacking of the approved mix design during trial mix stage to the Engineer. The Contractor shall engage a PE to carry out a design check, including but not limited to segment stacking, to ensure that the characteristic LOP calculated for the strength of concrete at the age of stacking is not exceeded and submit for the Engineer's acceptance.

25.10.4.5 The segments shall not be transported to Site or built into the Works until they have achieved the 28-day compressive cube characteristic strength. Segments shall be inspected for damage prior to transportation into the tunnel. Damaged segments shall be repaired in accordance with the accepted repair method subject to the acceptance of the Engineer before transporting into the tunnels. Segments that have been damaged more than the extent allowed for repair in the Materials & Workmanship Specification for Civil & Structural Works shall be discarded.

25.10.4.6 When transporting segments to tunnel works site or into the tunnel, the Contractor shall provide lifting equipment that minimizes handling stresses on the segments by either lifting segments at the quarter points or providing continuous lifting force over at least 50% of the segment length. Chains, wire ropes, etc. shall not be used to bear against segment surface while lifting. The Contractor shall submit his proposed handling method for the Engineer's acceptance.

25.10.5 Erection

25.10.5.0 The segmental lining shall be lifted and erected using vacuum lifting equipment within the TBM. The Contractor shall design the segmental lining taking full account of his proposed vacuum lifting equipment and develop all necessary details for the sockets. The Contractor's QP shall endorse the vacuum lifting proposals, and the Contractor shall submit for approval to the Engineer.

25.10.5.1 All segment joints faces shall be cleaned before bolting segments together. The segment erector shall be designed to compress the gaskets against adjacent segments prior to tightening of the bolts. All bolts shall be retightened prior to release of the shoving force and before the ring leaves the tail skin.

25.10.5.2 The Contractor shall submit his proposal to repair built segments that have been subsequently damaged to the Engineer for acceptance.

25.10.5.3 Immediately prior to the erection of a tunnel segment, the gasket shall be checked for cleanliness and position. Any non-conformance to the requirements of this Specification shall be remedied prior to building the segment.

25.10.5.4 Sufficient load shall be applied, as per gasket supplier's recommendation, to the segment to completely compress the gasket.

25.10.6 TBM Propulsion

25.10.6.1 Propulsion rams shall be fitted with proper shoes so that the ram reaction will be safely distributed against the tunnel linings and will not cause damage to the linings. The shoes shall be spaced such that any one shoe shall not span between two segments in all ring positions. This may be achieved by setting a multiple of the ram pitch angle to match to the pitch angle of the segmental lining radial (longitudinal) joints.

25.10.6.2 The SFRC segmental lining has been designed for TBM thrust jacks arrangement, ram shoe configuration and thrust loading as specified on the Authority's Drawings. The Contractor shall allow provision for sufficient reinforcement bars to suit his preferred TBM propulsion design. The cost of all works shall be deemed included in the Contract Price.

25.11 Fixtures and Coatings for SFRC Segmental Lining

25.11.1 Threaded Fasteners and Cast-in Fixings

25.11.1.1 The requirements for cast-in bolts and dowels shall follow the requirements of **Clause 18** of the Particular Specification.

25.11.1.2 The length of each bolt shall allow for washers and grommets and for all adjustments required in the alignment of tunnels.

25.11.1.3 The contractor shall conduct full scale pull-out test on the bolting 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 does not rupture. Before production, the testing frequency shall be one (1) test per two thousand (2000) cast-in bolt sockets. All pull-out tests shall achieve a proof load of 180kN. Tested lining segments shall not be incorporated into the Works.

25.11.2 Grout Holes

25.11.2.1 Grout hole shall be a proprietary cast-in system. The grout hole shall be made of high density polyethylene. Alternative proposals on the grout hole material may be submitted to the Engineer for acceptance.

25.11.2.2 Grout holes shall terminate short of the outer surface of the segment.

25.11.2.3 Each grout hole shall include a threaded socket cast into the segment and a threaded grout plug with a hydrophilic washer. The hydrophilic washer shall only be included if the hole is used by the Contractor for grouting. The internal diameter of the socket shall be not less than 50mm. The socket shall be arranged such that the grout plug in its final position does not protrude into the tunnel beyond the inner surface of the segment. The head of the plug shall incorporate a suitable means by which it can be tightened and removed, for example a square or hexagonal socket or head, but shall be of a design that cannot trap water when inserted below axis level. The design of the socket, plug, washer and any ancillary material such as grease or other coating to the threads shall be to the acceptance of the Engineer. The assembly shall have a design life of not less than 120 years.

25.11.2.4 Grout sockets and plugs shall be capable of withstanding the ground water pressure and any additional pressure caused by grouting without leakage. In any case, they shall be able to resist a liquid pressure of not less than 7 bar above atmospheric pressure without leakage.

25.11.2.5 Immediately after the lining is erected, each grout plug shall be fully screwed into place. When the grout plug is in place, no water or grout shall seep into the tunnel from around the outside of the socket, from between the grout plug and the socket or through the grout plug.

25.11.2.6 When a grout hole is used for secondary or tertiary grouting it shall be extended through to the exterior surface of the segment by drilling in a manner that does not cause damage to the concrete beyond the intended diameter of the hole. The diameter of the drilled hole and the means of drilling shall be to the acceptance of the Engineer.

25.11.2.7 Each grout hole shall include a non-return valve that allows the grout to flow from segment intrados to extrados, but not in the reverse direction.

25.11.2.8 Upon completion of the Contract, the Contractor shall leave each grout hole in a condition such that the grout plug can be removed without damage to it or to any part of the socket or the tunnel lining segments.

25.11.3 Waterproofing Coatings for Segments

25.11.3.1 The Contractor shall note on the provision of waterproofing coatings for hybrid segments is required.

25.11.4 Guiding Rod

25.11.4.1 The assessment on the bursting stress and bearing stress at radial joint of tunnel segment shall consider the change in radial joint geometry due to the recess of the guiding rod.

25.12 Contractor's Submissions

25.12.1 Details of Tunnel Lining

25.12.1.1 The Contractor shall submit the following to the Engineer for acceptance:

a) SFRC design parameters (including but not limited to fck, LOP, tensile splitting strength, fR1, fR3, $\alpha_{cc,f}$) which need to be verified by relevant test results;

b) Fully dimensioned shop drawings including details to suit vacuum lifting equipment;

c) Full details of segment fixtures including bolting systems, dowel systems, grout sockets and plugs, and gasket systems;

d) Full details of any products to be used for remedial work and the method of application; and

e) Procedure for handling, stacking, temporary protection, and transportation of segments from the time of demoulding to installation.

25.12.2 Details of Segment Manufacturer

25.12.2.1 The Contractor shall submit the following to the Engineer for acceptance:

a) Project experience demonstrating experience in production of precast concrete to the levels of quality required by this Specification;

b) Curriculum Vitae (CV) of proposed Plant Manager for segment manufacturer;

c) Quality Assurance (QA) / Quality Control (QC) plan for segment manufacture;

d) Experience of segment mould manufacturer, drawings and details of the moulds proposed for use, and details of working methods for their manufacture and use; and

e) Layout and details of the casting facilities, including curing and storage areas.

25.12.3 Details of Fibres

25.12.3.1 The Contractor shall submit the following to the Engineer for acceptance:

a) Details of proposed steel fibres and dosage rate;

b) Details of proposed polypropylene fibres and dosage rate; and

c) Method of dispensing fibres.