# PARTICULAR SPECIFICATION

# APPENDIX BK

# STEEL FIBRE REINFORCED CONCRETE FOR IN-SITU CASTING

## 1 General

1.1 This Appendix states the requirements for the design and construction of cast in-situ Steel Fibre Reinforced Concrete (SFRC) structures. The specifications for SFRC for segmental tunnel lining construction is covered elsewhere in the Particular Specification.

1.2 The SFRC shall be adopted to the whole area and section thickness of the proposed structural element.

## 2 Design Requirements and Considerations for SFRC

2.1 The SFRC design shall comply with SS EN 1992, SS 674:2021 and the Authority's requirements. It is the Contractor's responsibilities to prove and present to the Engineer his compliance with the stated criteria.

2.2 The SFRC shall only be adopted as hybrid system for cast in-situ structures. The contribution from SFRC can only be considered for SLS crackwidth design. The ULS and remaining SLS design shall be based on reinforced concrete design with no contribution from the steel fibre.

2.3 The crackwidth calculations shall be based on SS 674:2021 Equation (7.6) and Equation (7.7), and the more onerous result from the two equations shall be adopted.

2.4 Contractor is to verify the fibre orientation factor, $\eta_f$ value through the mock-up. The $\eta_f$ value for design shall be based on mock-up or 0.5, whichever smaller.

2.5 Contractor is to verify the characteristic fR,1 value through the flexural strength testing, at 28 days, in accordance with EN 14651. The fR,1 value for design shall be based on test results or 5.0 $N/mm^2$, whichever smaller.

2.6 The minimum characteristic compressive cylinder strength tested to EN 12390-3 shall be 35 $N/mm^2$.

## 3 SFRC Concrete Mix and Additives

3.1 The SFRC design mix shall be tailored to achieve all the specified requirements on concrete strength properties, water penetration, workability and in compliance with the M&W Specifications.

3.2 The SFRC design mix shall take into consideration the effects from the addition of steel fibre on workability. The designed slump value shall achieve minimum slump class of S4 based on test to EN 12350-2.

## 4 SFRC Trial Mix and Acceptance

4.1 Trial Batches

4.1.1 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 batching plant. Separate trial batches of concrete using accepted materials shall be carried out to achieve the requirements stated in **Clause 4.3.1** prior to the mock-up test and full-scale production.

4.1.2 The trial mix shall be produced in the same method as the actual SFRC mix to be used on site.

4.1.3 Each batch shall be of sufficient size to provide samples for testing specified in **Clause 4.2**.

4.1.4 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.

4.2 Sampling and Testing on Trial Batch

4.2.1 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:

(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) test beams for flexural strength testing, at 28 days, to EN 14651; and

(g) 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.

4.2.2 The testing facility for flexural beam tests shall possess sufficient stiffness and shall be capable of testing test beams 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 4 mm as per EN 14651.

4.2.3 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.

4.3 Compliance Criteria

4.3.1 The results of tests on the three (3) consecutive trial batches cast separately shall comply with the following requirements:

(a) The steel fibre content shall be $\geq 0.90$ of the proposed steel fibre dosage and the average fibre content of the 3 batches shall be $\geq 0.95$ of the proposed steel fibre dosage

(b) 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;

(c) 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$^2$; and

(d) 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$^2$.

4.4 Non-compliance

4.4.1 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.

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

4.5 Approved Concrete Mix

4.5.1 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.

## 5 Site Mock-up

5.1 Contractor shall propose at least one mock-up to each proposed SFRC element, to the Engineer's acceptance. The mock-up is to be carried out after Approved Concrete Mix is obtained.

5.2 The proposed mock-up structure shall be representative of the intended SFRC element in terms of size, reinforcement detailing and all other relevant features deemed necessary by the Engineer. The proposed mock-up structure to represent long and/or wide elements, eg. slab or wall shall be at least 3m x 3m x element thickness. The construction method is to be the same as the actual SFRC element on site, especially the casting direction and methodology including delayed cast due to concrete delivery. The vibrating device to be adopted on site for the actual SFRC element shall be used for the mock-up.

5.3 In the event that the Engineer is not satisfied with the production quality of the mock-up structure, further mock-up structure shall be erected until a satisfactory standard is achieved.

5.4 The types and location of tests on the mock-up shall be determined and agreed with the Engineer. The test method shall be in accordance with European Standard and agreed with the Engineer. The mock-up shall as a minimum, be assessed for compressive strength, density, steel fibre content, fibre orientation factor and fR,1 value.

5.5 Contractor is to verify the fibre orientation factor, $\eta_f$ value through the mock-up. The $\eta_f$ value for design shall be based on mock-up or 0.5, whichever smaller.

5.6 Contractor shall maintain the mock-up structure until the Engineer directs for its removal.

5.7 The casting of the actual permanent SFRC element on site shall only commence upon the Engineer's acceptance to the mock-up.

## 6 Sampling and Testing of SFRC on the Construction Site

6.1 Fibre Content Testing on Fresh Concrete

6.1.1 Three (3) steel fibre content test, to EN 14721, shall be conducted per 100m$^3$ or per pour (whichever is more frequent).

6.1.2 The fibre content of every fresh sample shall be $\geq 0.90$ of the proposed steel fibre dosage. Average fibre content of 3 fresh samples from a load shall be $\geq 0.95$ of the specified steel fibre dosage.

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

6.2 Flexural Strength Testing on Hardened Concrete

6.2.1 Two (2) prisms for flexural strength testing, at 28 days, to EN 14651, shall be made per 100m$^3$ or per pour (whichever is more frequent). Sampling for flexural 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.

6.2.2 Compliance criteria is that the average fR,1 value obtained from any four (4) consecutive tests exceeds the characteristic fR,1 value by a value equal to the current margin, and the fR,1 value obtained from any individual test is not less than the design characteristic fR,1 value. Current margin is defined as a value equal to 1.64 times the standard deviation.

## 7 Constituent Materials of SFRC Concrete

7.1 Aggregates

7.1.1 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. 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.

7.1.2 The maximum aggregate size shall be 20mm.

7.1.3 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 during construction. Grading tests shall be carried out at weekly intervals when SFRC is being batched for trials or during construction. Aggregates whose grading are found to fall outside the aforementioned acceptance zone shall be rejected.

7.2 Steel Fibres

7.2.1 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.

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

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

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

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

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

7.2.7 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.

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

7.2.9 The steel fibre dosage shall not be less than 20 kg/$m^3$.

7.2.10 The steel fibre 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.

## 8 Batching of SFRC Concrete

8.1 Steel Fibre Dosing

8.1.1 Steel fibres shall be added during concrete batching at the batching plant based on the steel fibre supplier's recommendation. Steel fibres shall not be added into the mixer of ready-mix trucks.

8.1.2 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, subject to the Engineer's acceptance.

## 9 Casting of SFRC on the Construction Site

9.1 The requirements under Clause 11 of Materials & Workmanship Specification for Civil & Structural Works shall apply. The clauses in this Appendix are amplification or additional clauses to the Materials & Workmanship Specification for Civil & Structural Works.

9.2 The Contractor shall engage an accredited laboratory with necessary accreditation(s) from the Singapore Accreditation Council (SAC-SINGLAS). The laboratory shall be equipped with the appropriate testing apparatus to carry out all concrete testing required.

9.3 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.

9.4 The Contractor shall not cast SFRC against soil. The Contractor shall only cast SFRC against formwork or lean concrete.

## 10 Contractor's Submissions

10.1 The Contractor shall submit the following documents for Engineer's acceptance, including but not limited to :

(a) Design parameters for SFRC;

(b) Details of proposed SFRC mix;

(c) Details of proposed steel fibres and dosage rate;

(d) Method statement for dispensing, dosing and mixing steel fibres;

(e) Method statement and testing plan for proposed mock-up;

(f) Method statement for SFRC delivery to site;

(g) Method statement for SFRC casting;

(h) Quality Assurance /Quality Control plan for in-situ casting;

(i) Laboratory results from tests on trial mixes;

(j) Laboratory results from tests on samples collected at the construction site; and

(k) All other relevant method statement and test results.