SUPERVISION OF FABRICATION OF PRECAST STEEL FIBRE REINFORCED CONCRETE (SFRC) SEGMENTAL LINING

George Varghees*
C@nspecs Pte Ltd., Singapore

ABSTRACT

Precast reinforced concrete (RC) segments have been widely used to construct tunnels for mass rapid transit lines in Singapore. However, the reinforcement bar cages are labour intensive to fabricate and install in moulds. Then the cages must be adjusted in moulds to achieve minimum cover at critical locations such as bolt sockets and cover to external face. Supervision has to be tight to achieve good quality segments.

However, with the use of steel fibre reinforced concrete (SFRC), steel reinforcement bars have been eliminated. Steel fibres are added during the batching of concrete. Concrete is then poured in moulds and compacted. Compaction is done by using external vibrators mounted on moulds. For downtown line stage 3 contract 933, SFRC segments were used as tunnel lining. C@nspecs Pte Ltd supervised the production of SFRC segments in the factory.

This paper outlines the quality control tests done on the fresh and hardened concrete.

Keywords: *Precast Reinforced Concrete; Steel Fibre Reinforced Concrete (SFRC).*

1. INTRODUCTION

In densely built cities of today, the mass rapid transit is the best mode of urban transportation. Generally the transit lines are built underground to avoid congestion on surface. Tunnel boring machines (TBM) are used to bore the tunnels. Generally precast reinforced concrete tunnel segments are used as lining and they form the permanent tunnel to carry the railway line. Steel reinforcement bar cages are labour intensive to fabricate, install and supervise.

As the tunnels are built for a life span of 120 years, it is important that the reinforcement bars remain protected by providing the minimum cover of 40mm from the external surface. In the long term, any water seepage or chloride attack will corrode the reinforcement bars thus affecting the design life span of tunnel. SFRC eliminates the necessity of providing steel reinforcement bars and helps to provide a durable tunnel.

2. SFRC MIX DESIGN AND BATCHING

Coarse aggregate, fine aggregate and steel fibre, cement and silica fume are mixed dry for about 90 seconds. Polypropylene (PP) fibres are then added and mixed for 5 seconds. Water and admixture are added and mixed for another 15 seconds. Final mixing is done for another 10 seconds before discharging to the delivery bucket.

Concrete strength is specified as 60 N/mm^2. Mix design is done by precaster and confirmed by trial mix. Contract 933 PS-20.2.1 specifies that steel fibre reinforcement shall be deformed steel fibre produced by cold drawn wire. Steel fibres shall be for structural use in concrete (Group 1) complying with EN 14889-1 with aspect ratio 50 to 80. Minimum length of steel fibres shall be 50mm and tensile strength shall be

* Corresponding Author: E-mail - gv@conspecspl.com.sg

1000 MPa. Steel fibres shall be uniformly distributed in concrete and shall not tend to form fibre balls during batching and mixing. Steel fibre dosage was 40 kg/cubic metre.

Polypropylene (PP) fibres are added to the concrete mix to make it fire resistant. Contract 933 PS-20.2.2 specifies that polypropylene fibres shall be 100% virgin polypropylene monofilament fibre containing no reprocessed materials. The PP fibres shall comply with EN 14889-2 (Class 1a). Nominal cross-section diameter of PP fibres shall be between 18 microns to 20 microns and nominal length between 6mm to 12mm. The melting point of PP fibres is 160^{o}C +-10%. Minimum PP fibre dosage is 1.0 kg/ cubic metre.

Coarse and fine aggregate used shall not be alkali reactive. Mortar bar tests are done to determine whether aggregate is alkali reactive. According to ASTM C1260, aggregate shall be with marginal reactivity, expansion <0.2%. Sieve analysis is done weekly to ensure grading.

Cement used is Portland cement. Pulverised Fuel Ash (PFA) is added to cement to make it low-heat. Silica fume is added to the mix to make it denser. Portland cement, PFA and silica fume together form the binder. Total binder content is 370 kg/m^3 to 400 kg/m^3. Approved super plasticizer is added in the design mix to improve workability. Water cement ratio is generally 0.35.

3. STEEL FIBRE REINFORCED CONCRETE PROPERTIES

Contract 933 PS-20.4 specifies the characteristic compressive cube strength as 60 N/mm^2 and characteristic tensile splitting strength as 4.5N/mm^2. Characteristic limit of proportionality (LOP) value, $f_{R,1}$ and $f_{R,4}$ are 4.2 N/mm^2, 2.8N/mm^2 and 1.4N/mm^2 respectively.

4. CONFIRMATION OF MIX DESIGN BY TRIAL MIX

Cement Three batches of trial mix are conducted. Average cube compressive strength at 28 days shall be 70 N/mm^2. Three samples are tested for Rapid Chloride Permeability before production starts.

Contract 933 PS-20.7 gives the acceptance criteria for trial mix as follows:

Trial Mix and Acceptance	
Three steel fibre content tests on fresh concrete	EN 14721:2005
Three slump tests on fresh concrete	EN 12350-2:2000
Three density tests on fresh concrete	EN 12350-6:2000
Three air content tests on fresh concrete	EN 12350-7:2000
Twelve cubes for compressive strength testing, at 28 days	EN 12390-3:2002
Twelve cylinders for compressive strength testing, at 28 days	EN 12390-6:2000
Twelve prisms for compressive strength testing, at 28 days	EN 14651:2005

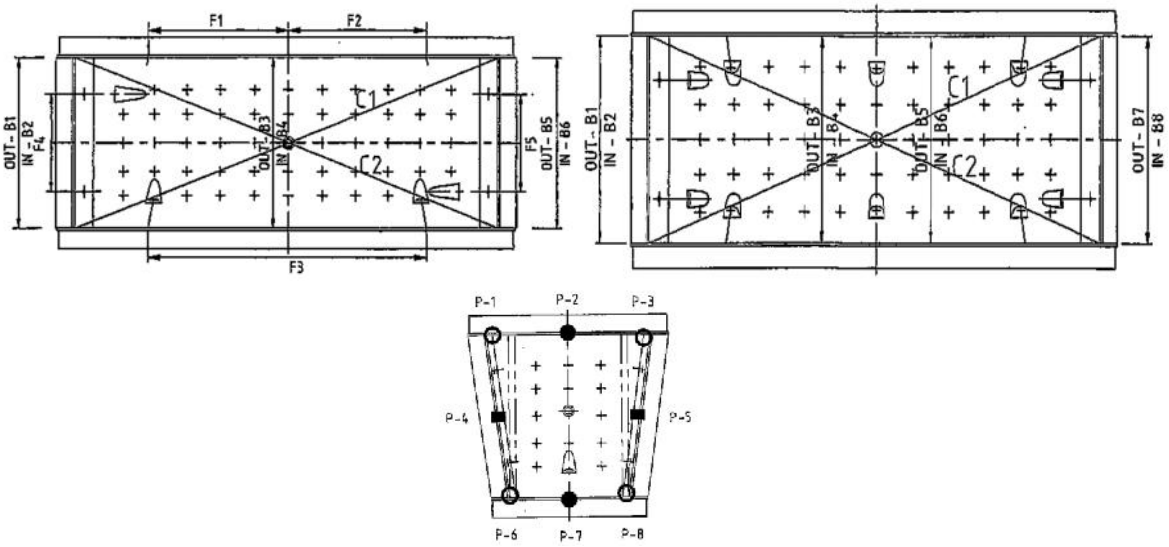
Contract 933 PS-20.7.3 gives the compliance criteria as follows:

The average steel fibre content > proposed steel fibre dosage minus 5%. Average slump value shall be within 20 mm or 25% of the designed slump value. Compressive strength of each cube tested > specified characteristic strength. Average compressive cube strength (from all 3 batches) > specified characteristic strength + 10 N/mm^2. Tensile splitting strength of each cylinder tested > specified characteristic strength. Average tensile splitting strength (from all 3 batches) > specified characteristic strength +1.5 N/mm^2.

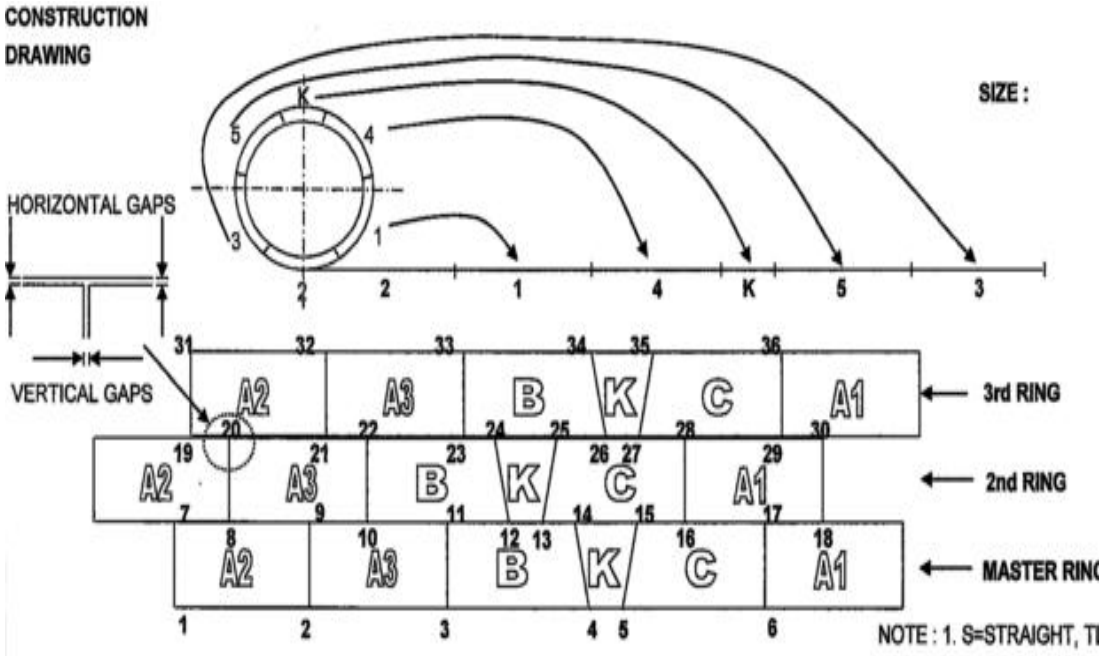
The limit of proportionality (LOP) value of each prism tested > specified characteristic value. Average limit of proportionality (LOP) value (from all 3 batches) > specified characteristic strength +1.8 N/mm^2. $F_{R,1}$ value of each prism tested > specified characteristic value. Average $f_{R,1}$ value (from all 3 batches) > specified characteristic strength +1.2 N/mm^2. $F_{R,4}$ value of each prism tested > specified characteristic value. Average $f_{R,4}$ value (from all 3 batches) > specified characteristic strength +0.6 N/mm^2

5. MOULDS USED

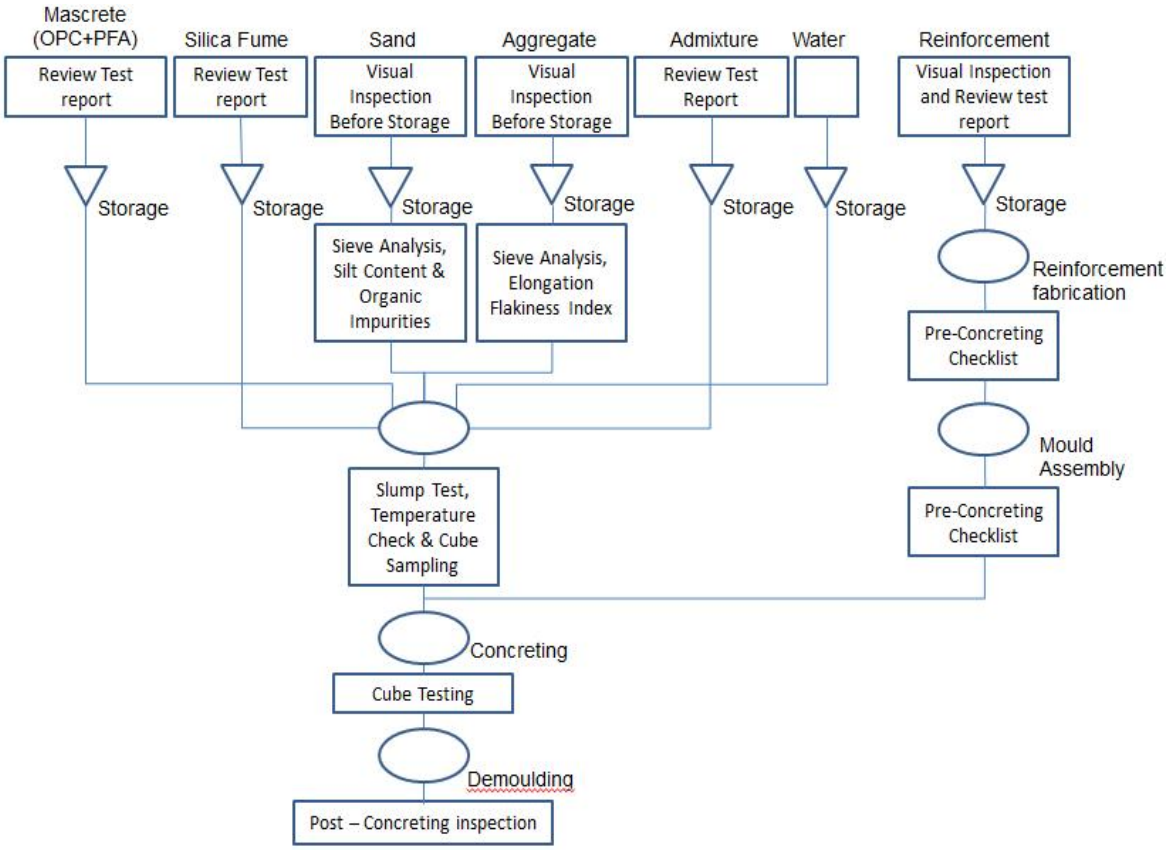
Mould dimension checks are done by independent Inspector before production and one cycle per every 100 casts.



Master ring / trial ring shall be assembled before production commences and checked for internal diameter, vertical and horizontal gaps etc.



The flow chart of production quality control is given below:



6. INSPECTION AND TEST PLAN

Activity / Particular	Standards / Frequency	Acceptance Criteria	Document Verified
Mascrete (OPC + PFA)	OPC – SS 26 PFA – BS 3892	Temperature < 75˚C	DO Mill Certificate
Silica fume	SS 26	-	DO Test Certificate
Sand (Sieve Analysis) Silt Content & Test for Organic Impurities	SS 31, SS 73	Max % by mass passing 75µm sieve – 3%	-
Check sand moisture before batching	-	Water for batching will be compensated to take into account the moisture content	-
Coarse aggregate Sieve analysis Flakiness & Elongation Index	SS 31, SS 73	% by mass passing 75µm sieve < 1 < 35%	Test report
Admixture	SS 320	-	Test report
Water	BS 3148	-	Test report
Calibrate concrete batching plant (in-house)	Monthly	Load Cells ± 3%	Calibration report
Calibrate concrete batching plant (external party)	Annually	± 3%	Calibration report
Calibrate concrete	Annually	± 3%	Calibration report

Activity / Particular	Standards / Frequency	Acceptance Criteria	Document Verified
cubes compression machine (external party)			
Maintenance of lifting equipments	3 months	Maintenance certificate to be current	Reports - catalogues
Check mould	Each mould before concreting	Check whether mould is clean, demoulding oil applied	Mould supplier specs, pre-concreting inspection form
Batching concrete	Mix design (daily)	Grade 60	Mix design verification from computer
Slump test	SS 78	For every batch of concrete	Slump test record
Concrete test cubes	M&W Specs Cl 11.8.3	For every batch	Cube compression test report
Cube tests	M&W Specs Daily	Demoulding – 10 N/mm^2 7 Days – Indicative 28 Days – 60 N/mm^2	Test Report
Pre-pour inspection	Before pouring concrete	Concrete Cover +5mm / – 0mm Check all cast-in-items are fixed	Inspection form
Demoulding	Each cast segment	Compressive Strength 10 N/mm^2	Cube test result
Curing	Each segment	Intrados sprayed with curing compound Extrados and sides (coating)	-
Inspect segment for defects / damage	Each segment	Check for non-conformance & damages	NCR
Wet Film Thickness	Wet film gauge 1 segment / day	200 microns	Post concreting check list
Dry Film Thickness	Elcometer paint inspection gauge 1 segment / day	Min 200 microns	Test Report
Pull-Out Adhesion Test	Elcometer adhesion tester (ASTM D 4541) Once a week for first month; subsequently 1:150 rings	Min 1.5 N/mm^2	Test Report
Rapid Chloride Permeability Test	ASTM C 1202 First 100 rings, 1:20 rings Subsequently1:150 rings	Average 700 coulombs or better < 1000 coulombs	Test report
Check dimensions of segment	As per specifications 1 :100 segments	Thickness +3/-1mm Width +/- 1mm	Segment dimension checklist
Check mould dimensions	Manufacturer specifications. Before project starts; subsequently every month	Specified tolerances by manufacturer	Mould dimension check report
Lifting Socket	Specifications 2 tests before production subsequently 1:2000 segments	FS of 3 against design pull-out force	Test report
Matching and interchangeability test	LTA Specs Every set of mould	LTA Specifications	Ring assembly & gap checklist
Storage of segment	Daily	Segments turned and stored with intrados face upwards	-
Delivery of Segments	Every load	28 days strength > 60 N/mm^2, no damages, ensure that segments are secured properly and stable	Delivery Order

7. SAMPLING AND TESTING OF SFRC DURING PRODUCTION

Contract 933 PS-20.8 specifies the following:

Fibre content testing shall be done on fresh concrete. One steel fibre content test is to be done per production day. Steel fibre content > proposed steel fibre dosage minus 20%. Tensile splitting strength tests are conducted on hardened concrete for 2 cylinders at 28 days for every 4 rings.

Average tensile splitting strength from any 4 consecutive tests shall be > characteristic tensile splitting strength + current margin. Tensile splitting strength from any individual test shall be > characteristic tensile splitting strength – current margin. Current margin = 1.64 x standard deviation

Flexural strength tests are done on hardened concrete for 2 prisms at 28 days for every 12 rings. Average LOP value from any 4 consecutive tests shall be > characteristic LOP value + current margin. LOP value from any individual test shall be> characteristic LOP value – current margin. Current margin = 1.64 x standard deviation

Average $f_{R,1}$ value from any 4 consecutive tests > characteristic $f_{R,1}$ value + current margin. $F_{R,1}$ value from any individual test > characteristic $f_{R,1}$ value – current margin. Current margin = 1.64 x standard deviation.

Average $f_{R,4}$ value from any 4 consecutive tests > characteristic $f_{R,4}$ value + current margin. $F_{R,4}$ value from any individual test > characteristic $f_{R,4}$ value – current margin. Current margin = 1.64 x standard deviation.

8. CURING OF SFRC AND POST-CONCRETE INSPECTION

All precast concrete segments shall be cured using moist curing, curing compounds or curing at elevated temperature. For steam curing, minimum and maximum temperature is 55°C and 67°C respectively inside the curing chamber. Curing period is from 6 to 7 hours before segments are de-moulded.

Post-concreting inspection is done by visual inspection to check for defects and surface finish. Common defects seen are cracks, honeycomb, concrete chipped off / spalled off etc. Segments with cracks or honeycomb are rejected whereas segments with chipped off edges are repaired according to the specification.

9. CONCLUSIONS

SFRC segments are a better alternative to reinforced concrete segments using conventional reinforcement bars. These segments help to reduce the labour employed in the factory and good quality control can be achieved in production. Production cycle can be shortened which will then increase the production capacity of the precast yard thus achieving higher productivity and savings in cost.