Quality Control of High-Strength Concrete in Metro Rail Construction: A Case Study of Mumbai Metro Line-5 (Thane-Bhiwandi Corridor)

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***Abstract*—Metro rail infrastructure relies on durable high-strength concrete whose quality must be controlled rigorously throughout construction. This paper presents a field-based study of the quality-control (QC) practices adopted for high-strength and blended concrete on Mumbai Metro Rail Line-5 (Thane-Bhiwandi-Kalyan), covering the elevated viaduct package (Afcons Infrastructure Ltd.) and the Mogharpada car-depot package (Rithwik Projects Pvt. Ltd.) under MMRDA. The Quality Management Plan, Inspection Test Plan and Request-for-Inspection workflow are reviewed, and the documented conformance of constituent materials and of four concrete grades (M15, M35 with 30% GGBS, M40 and M55 with micro-silica) is evaluated against the governing Indian Standards. All materials and mixes satisfied the specified limits; the 28-day trial-cube strengths (21.78, 49.96 and 55.36 N/mm2 for M15, M35 and M40) comfortably exceeded their target mean strengths. A real non-conformance (NCR-088) illustrates effective corrective-action management. The study concludes that a documented, IS-code-referenced QC chain is the principal driver of consistent concrete quality in metro construction.**

***Index Terms*—Quality control; high-strength concrete; metro rail; IS 10262 mix design; GGBS; micro-silica; inspection test plan; non-conformance.**

I. INTRODUCTION

Metro rail is the preferred mass-transit solution for large Indian cities, demanding concrete designed for a century of service under public-safety scrutiny. Modern metro substructures specify high-strength concrete (M45 and above), frequently blended with supplementary cementitious materials (SCMs) such as GGBS and micro-silica for strength and durability in marshy, chloride-bearing coastal ground. The performance of such concrete is sensitive to material variability, water-cementitious ratio and workmanship, making a rigorous, auditable quality-control system essential. This paper studies that QC chain on Mumbai Metro Line-5.

II. LITERATURE REVIEW

Basu et al. (2024) proposed a capacity-based approach to improve QC in HSC mix design [1]. Pakhale and Pal (2020) identified document control and quality assurance as principal challenges in Indian metro construction [2]. Mohamed (2018) showed that high SCM replacement maintains strength and improves durability when properly proportioned [3]. French et al. (1998) documented production-control measures for HSC in prestressed bridge girders [4]. Patel and Patel (2013) and Nirosha and Sashidhar (2024) confirmed the strength gains from silica-fume blending [7][8], while Khan (2025) and Gheewala et al. (2025) emphasised inspection and documentation as primary risk-mitigation measures in metro projects [6][9]. The literature is rich on the behaviour of HSC but comparatively sparse on the documented field QC chain that delivers such concrete on live metro projects - the gap addressed here.

III. PROJECT AND QA/QC FRAMEWORK

Mumbai Metro Line-5 connects Thane, Bhiwandi and Kalyan (MMRDA; General Consultant Systra-CEG-SMCIPL). The study uses records from the elevated viaduct (Afcons, Ch. 12000-24700 m) and the Mogharpada car depot (Rithwik). The Quality Management Plan (QP-1999-QC-01) defines the quality system; the Inspection Test Plan (Rev-4) specifies, for each material, the tests, the laboratory (in-house or third-party NABL), the IS reference and the frequency; and the Request-for-Inspection workflow provides closed-loop control through QC/Safety/Survey sign-off, consultant approval, and non-conformance management (Fig. 1).

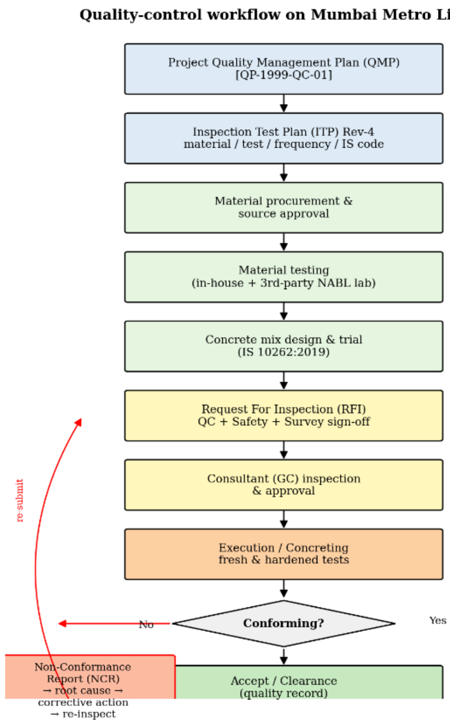

Fig. 1: Quality-control workflow on Mumbai Metro Line-5

IV. MATERIALS AND METHODOLOGY

Constituent materials were tested in the site laboratory and by NABL-accredited laboratories. Concrete was proportioned per IS 10262:2019 for severe exposure and verified by 150 mm trial cubes at 7 and 28 days per IS 516, assessed against IS 456:2000. Materials and their reference standards: OPC-53 (Ambuja, Ultratech; IS 269:2015), PSC (JSW; IS 455:2015), 10/20 mm coarse aggregate and crushed sand (IS 383:2016), micro-silica (Elkem 920D; IS 15388:2003), admixture (CAC Hyperfluid R250; IS 9103:1999), construction water (IS 456:2000) and HT strand (Tata 1860-P 15.2 mm LRPC; IS 14268:2022).

V. RESULTS AND DISCUSSION

All tested materials conformed to there IS specifications. Representative aggregate results: 20 mm crushing value 14.67%, impact 8.83%, flakiness 10.57%, water absorption 1.52% (all within IS 383); micro-silica SiO_2 89.77% (>= 85%); HT strand UTS 1927.8 MPa and breaking load 269.8 kN (>= 259). The four mix designs and their verification are summarized in Tables I and II.

Table I: Concrete mix proportions (kg/m3, SSD)

Constituent	M15	M35	M40	M55
Cement (OPC)	299	352	439	225
PSC	-	-	-	250
GGBS	0	150	0	-
Micro-silica	-	-	-	25
20 mm	608	536	566	612
10 mm	494	444	468	506
Crushed sand	881	784	827	816
Water	156	165	155	140
Admixture	2.99	5.02	4.83	~5.0
w/cm	0.52	0.33	0.35	0.28

Table II: Achieved strength versus target mean (N/mm2)

Grade	fck	Target mean	7-day avg	28-day avg	Remark
M15	15	20.78	13.66	21.78	Pass
M35	35	43.25	34.97	49.96	Pass
M40	40	48.25	38.94	55.36	Pass
M55	55	63.25	-	Design approved	Note

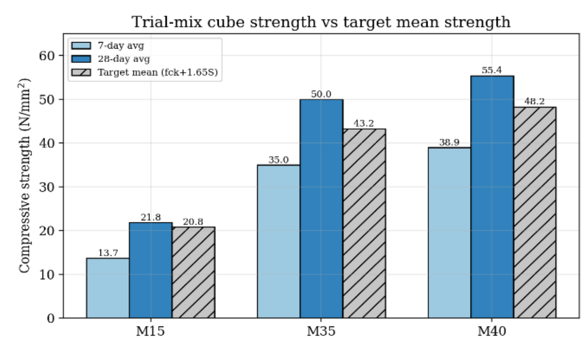

Fig. 2: Trial-cube strength versus target mean strength

Every grade exceeded its target mean strength with a comfortable margin, and 7-day strengths were 60-70% of 28-day values, consistent with normal strength development; all results satisfy IS 456:2000. The blended mixes achieved their strengths at low w/cm

(0.33 for M35 with 30% GGBS; 0.28 for M55 with micro-silica), confirming SCM effectiveness under disciplined QC. The non-conformance NCR-088 - damage to pile caps SP39/SP40 during UG-tank excavation at Anjurphata - was root-caused, repaired with micro-concrete per an approved methodology, and closed after re-inspection, demonstrating the closed-loop control in practice.

VI. CONCLUSIONS

The project operates a structured, document-driven quality system linking material approval, testing, mix design, inspection and non-conformance control. All constituent materials and all four mix designs conformed to the relevant Indian Standards, and the trial strengths exceeded their targets. A documented, IS-code-referenced QC chain is therefore the principal driver of consistent concrete quality in metro construction. Recording production-cube data for statistical process control and adding durability testing are recommended to further strengthen field QC.

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