Experimental Investigation of the Form Filling Ability of Concrete in relation to Teeroff Beams

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Abstract

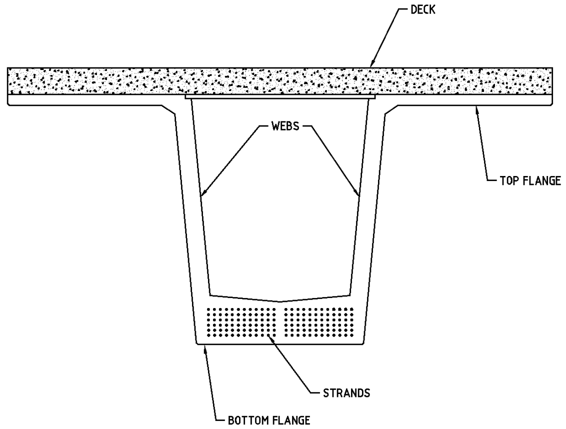
This project focuses on assessing the form-filling ability of concrete in Teeroff beams (TBs), particularly those with longer spans which require larger beam dimensions and additional bottom flange reinforcement. These modifications could potentially affect the concrete's ability to fill the formwork adequately. To address this, a full-scale L-shape mould (LSM) to represent the bottom flange and one web of a TB have been used. Main Roads WA's Approved Teeroff Mix (S65) and a Self-Compacting Concrete (SCC) mix used in industry will be tested in laboratory-controlled pours, with and without reinforcement in the LSMs. Transparent panels will allow observation of the top and side surfaces of the bottom flanges, while the coring of hardened specimens will provide material samples for further testing. The research aims to enhance confidence in the constructability of as designed TB cross-sections, thereby contributing to the reduction of project delays and additional costs due to unsatisfactory TBs. Experimental results on the fresh and hardened properties of concrete used for the test pours have been obtained following AS 1012.

1. Introduction

The Teeroff Beam (TB) is a form of precast beam used in the construction of bridges in Western Australia. It was derived from the Super-Tee Beam developed by VicRoads in the early 1990s. Super-Tee and Tee-Roff Beams have been used as an alternative to “I” and “U” beams of spans ranging from 20 m to 30 m. Both Super-Tee and Tee-Roff beams offer advantages over “I” and “U” beams in terms of structural efficiency, ease in manufacturing, and ease in construction, providing a permanent form for the in-situ concrete deck slab (Gray, 2003). The ends of these beams comprise of solid end blocks. These precast beams are delivered on-site, and an in-situ poured deck slab is added wherein the deck and the beam act compositely. For visualisation, see Figure 1.

For bridges that require longer spans, the cross-sectional dimensions of the TB are increased. The beam’s depth can exceed 2 m, and the bottom flange width may exceed 1.5 m. In addition, the prestressing needed on the bottom flange of TBs may require up to six layers of strands. The foregoing cross-section modifications raise the question of whether the concrete is still filling the form properly, especially with the congested reinforcement placement. As per best practices in the concrete industry (Cement Concrete & Aggregates Australia, 2020a), a suitable depth of concrete fall ensures homogeneity. Whilst the concrete needs to be suitably compacted, vibro-compaction should ideally not be used to make the concrete move and run through. Excessive vibration can cause segregation of the concrete mix which results in inadequate strength (Cement Concrete & Aggregates Australia, 2020b). It is expensive for the precast industry and the client to repair and/or replace unsatisfactory beams. MRWA Structures Engineering have specified geometric limits to impose a standard design for TBs (less than 1.8m deep) to increase confidence that the as-constructed TBs will have the required quality and avoid these costly problems.

Figure 1 Typical Teeroff Beam Section (Left) (Pre-Stressing Strands shown are



for illustration only, may differ from the actual TB Configuration), Finished Teeroff Beam (Right) (Delta Corporation Limited, 2018)

2. Methodology

The project will experimentally investigate the concrete flow through a local representation of a TB. All the experimental pours will use ready-mix concrete sourced from local concrete suppliers. Samples from the freshly mixed concrete will be extracted for compressive strength and air content tests, following AS 1012.8.1 and AS 1012.9. Compressive strength test will follow AS 1012.8.1 and AS 1012.9 while air content measurement of freshly mixed concrete will follow ASTM C231. In addition to the traditional slump/spread measurement as per AS 1012.3.1 and AS 1012.3.5, assessment of the viscosity of the concrete mixes (with aggregate sieved out) will also be undertaken using a rotational rheometer following ASTM C1874:2020. Clear panels in the LSM will enable the movement of the concrete mixture flowing through the bottom flange to be visually observed and recorded. The homogeneity of the hardened concrete specimens will be visually inspected after stripping the form panels from the LSM. A quantifiable relative measure of homogeneity is to be obtained through coring and subsequent material testing of the core samples. Cores will be used to measure density, absorption, and volume of permeable voids (VPV) following AS 1012.21.

2.1 Materials Description

The project will undertake experimental pours using a LSM with a nominal 1.60 m web depth. The concrete mixes used for the experimental pouring are a S65 concrete mix commonly used in Teeroff beams, and a SCC mix provided by Holcim Australia. The maximum aggregate size for both mixes is 14 mm, and both mixes have a water-to-cement ratio of 0.38. The S65 mix has a design slump of 200 mm, while the SCC has a 650 mm design slump flow. For every experimental pour, a 2-cubic-metre concrete truck discharges the concrete to the LSM. The materials for the framing and form panels of the LSMs are treated timber and plywood with phenolic film. All timber connections are fastened with galvanised wood screws. An oil-based form-release agent and phenolic film are used to ensure the reusability of framings and forms.

2.2 Experimental Process

To date, several pours of the LSM have been completed, as listed in Table 1. For all the pours no vibration was applied to the formwork, including those using the S65 mix. All the experimental pours were allowed to harden and subsequently subjected to coring for VPV and density testing. The (three) core samples from the hardened concrete were extracted 160 mm from the right edge of the specimen (see Figure 5). For concrete flow recording, a camera with 4K resolution at 60 frames per second was used. The actual experimental setup is shown in Figure 2. To measure the viscosity, yield stress, and temperature of the freshly mixed concrete, a Brookfield AMETEK DV3T rheometer with a V73HB vane-type spindle was used. Samples for the viscosity test were tested at 50 RPM vane-speed. Yield stress test samples were pre-sheared under 100 RPM for one minute, rested for one minute, and thereafter run at ~5 RPM (Brookfield, 2024).

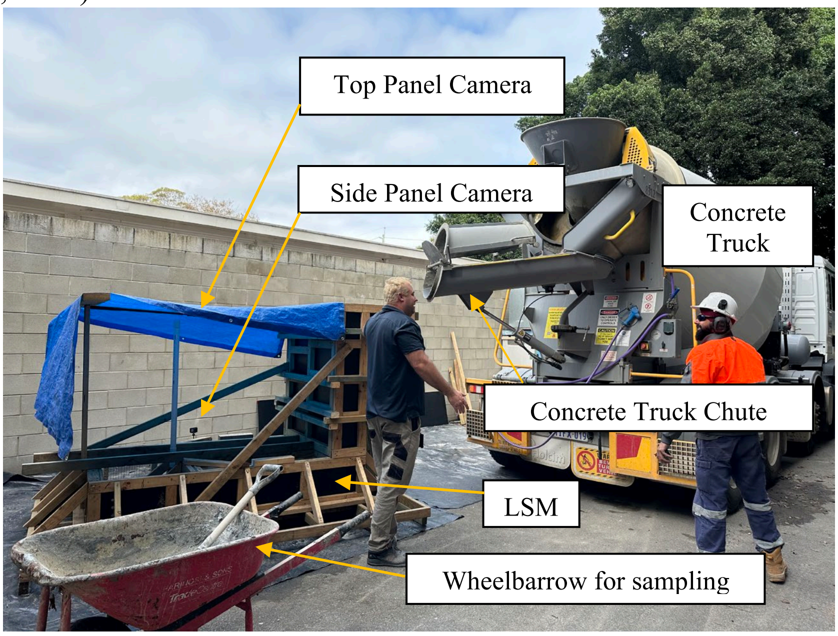


Figure 2 Actual experimental set-up of pouring

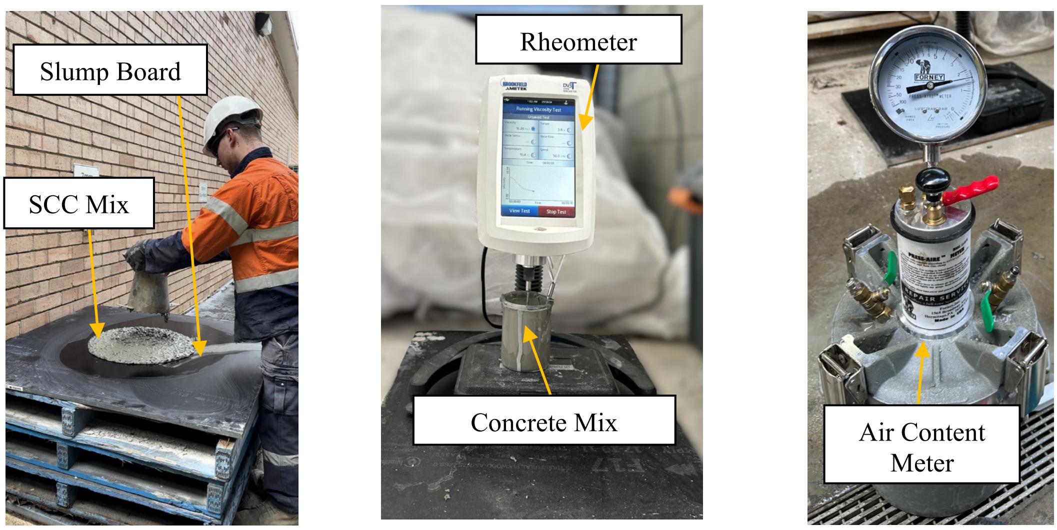


Figure 3 Slump flow measurement (left), rheometer testing (left), and air content test (right)

Before casting the LSMs, the slump was measured for the S65 mix and the slump flow with T500 time were measured for the SCC mix. These measurements were checked against the requirements in MRWA Specification 820 (Main Roads WA, 2023). After the slump/slump flow was approved for pouring, a sample of 250 mL was obtained for rheometer testing. Samples were tested for 120 seconds viscosity testing and then tested to obtain the yield stress. While doing the yield stress testing, another 9 litres sample was extracted from the concrete truck for measurement of the air content of the concrete mix. Two LSMs were poured during each concrete pour. The concrete mix was directly placed through the chute of the truck.

Experiment Mark (EM)	Flange Width (m)	With reinforcements?	Concrete mix	Sample mark
EM-1	1.50	No (NR)	S65[1] (H)	01-1500NR-HNV
	1.20	Yes	S65[1]	01-1200WR-HNV
EM-2	1.80	No	SCC (S)	01-1800NR-S
	1.20	Yes	SCC	01-1200WR-S
EM-3	1.50	Yes	S65[1]	01-1500WR-HNV
	1.20	No	S65[1]	01-1200NR-HNV
EM-4	1.80	Yes	SCC	01-1800WR-S
	1.20	No	SCC	01-1200NR-S
EM-5	1.50	Yes	SCC	01-1500WR-S
	1.50	No	SCC	01-1500NR-S

Table 1 Experimental pouring schedule

3. Preliminary Results and Discussion

The results obtained for the fresh properties of the concrete mixes used for the pouring are summarised in Table 2. For EM-1 to EM-4, the mix samples taken for rheometer testing were not sieved for the 14 mm aggregates. This was to confirm the practicality of the testing method and to avoid delays as the timing of the testing is crucial. For EM-5, the aggregates were sieved, and six samples were tested, three from the concrete used for the first LSM and three from the concrete used for the second LSM. For sample marks 01-1800WR-S, 01-1500WR-S, and 01-1500NR-S, the achieved web depth heights were 1.20 m, 1.30 m, and 1.20 m (c.f. 1.6m as-planned) due to difficulties encountered in relation to the LSM during pouring (such as leaking of concrete from formwork joints and excessive deformation of the top panel and supporting timbers).

EM	Type	Temp. (˚C)	Slump/Spread (mm)	T500 (s)	Air Content (%)	Viscosity (Pa-s)	Yield Stress (Pa)
EM-1	S65	21.5	190	-	-	51.36	-
EM-2	SCC	21.1	630	1.60	1.30	112.4	64.0
EM-3	S65	21.0	170	-	1.80	238.0	4152.0
EM-4	SCC	24.0	610	4.00	1.80	14.23	54.0
EM-5	SCC	24.0	550	5.00	1.20	8.41	46.0

Table 2 Fresh properties of concrete used in pouring

[1] MRWA-Approved High slump S65 (H) concrete mixture with No Vibration (NV).

EM	Type	Sample mark	Hardened Density (kg.m^{-3})	Mean Absorption (%)	VPV	MRWA VPV Limits
EM-1	S65	01-1500NR-HNV	2360	6.0	13.6	15.0
		01-1200WR-HNV	2360	6.1	13.8	15.0

Table 3 Hardened properties of concrete used in pouring

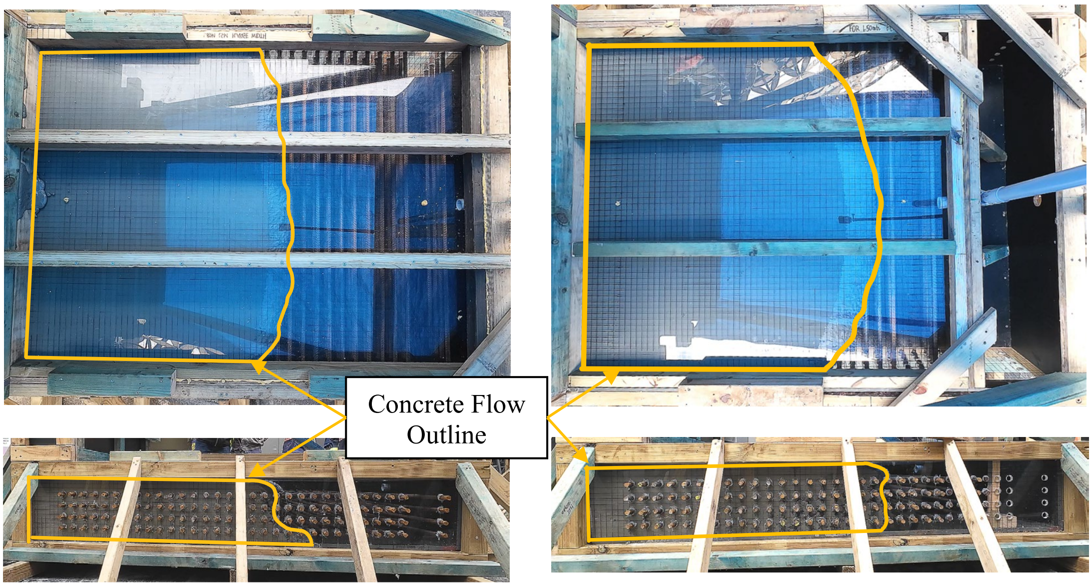


Figure 4 Concrete flow through LSM: Top View of 01-1800WR-S (SCC) (top left), Side View of 01-1800WR-S (SCC) (bottom left), Top View of 01-1200WR-HNV (S65) (top right), and Side View of 01-1200WR-HNV (S65) (bottom right)

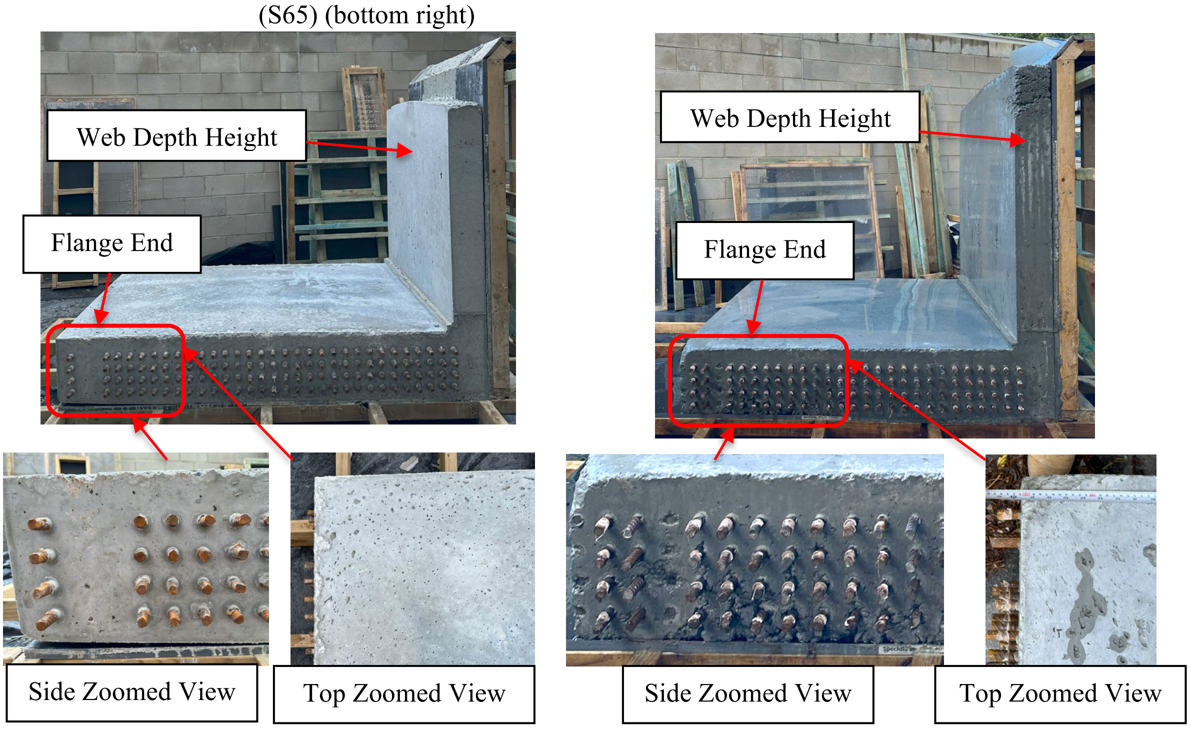


Figure 5 Demoulded samples with reinforcements: (Left) – 01-1800WR-S - LSM with 1.80m Flange Width poured using SCC, (Right) – 01-1200WR-HNV - LSM with 1.20m Flange Width poured using S65 mix.

4. Conclusions and Future Work

The S65 Teeroff Mix shows a lower viscosity value compared to the self-compacting mix supplied by Holcim. For a Bingham fluid such as concrete, the yield stress for SCC is less compared to the S65 mix. The SCC mix 'front' at the bottom of the bottom flange appears to progress first, prior to that of the concrete volume over the remainder of the flange thickness. However, it should be noted that no vibration was used for the S65 mix, which is the typical scenario. Future pours that would incorporate vibration would provide a more valid comparison. For the S65 mix, because of its high viscosity and yield stress, the 50 x 50 mm grid reinforcement appears to prevent the S65 mix from flowing liberally. It was observed that the S65 mix tends to build up in the chute discharge area of the bottom flange (near web). After building up and reaching the level of the top bar, it starts to flow laterally along the flange from the top level, spilling down to the gaps between the reinforcement while doing so. The top panel of the LSM for both concrete mixes tend to be subjected to an increasing pressure as the bottom flange fills up and the concrete height in the web increases. It was noticeable that the bottom flange of the LSM filled faster with the SCC mix compared to the S65 mix.

It was observed after demoulding that the bottom reinforcement of the bottom flange, near the opposite side of the chute discharge, was not properly filled with S65 mix, and discontinuity of edges was also observed. For the SCC mix, the bottom flange was properly filled, and fewer voids were observed on the side and top. It was observed that the VPV values of the EM-1 samples were within the MRWA Specification 820 VPV Limits, even though no compaction was carried out during the pouring. Future works for this project include testing with a web depth of 0.9 m to investigate the effect of drop height on the homogeneity of the poured LSM bottom flange. Additional pours using the S65 mix will also be done but with vibration of the formwork during pouring. Results from cored sample testing (actual compressive strength and VPV) will also help complete the study.

5. Acknowledgements

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