RTA Study on the Use of Self-Compacting Concrete

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Abstract Self-compacting concrete (also known as Super-workable concrete in Australia and Self-consolidating concrete in North America) is defined in EN 206 Part 9: Additional Rules for Selfcompacting Concrete (SCC) as concrete that is able to flow and compact under its own weight, completely fill the formwork with its reinforcement, ducts, box outs etc, whilst maintaining homogeneity. A study on self-compacting concrete was conducted by RTA Bridge Engineering for the possible use of SCC in certain reinforced and prestressed concrete bridge elements where mechanical compaction is hindered by OHS requirements and often times not practically feasible to assure a homogeneous concrete end product. Self-compacting concrete is considered as an improvement on the current applications of high or very high slump flowable concrete. This paper will discuss the conducted study that includes laboratory mix design trials, full scale field trials and the project verification trials. The study resulted in the preparation of draft clauses for the inclusion of SCC in the next major amendment of the RTA QA Specifications B80 – Concrete Work for Bridges (RTA B80).

Introduction

From time to time, new technology emerges to offer better alternatives and or provide practical solutions to limitations of existing practice and traditional methods. Self-compacting concrete (SCC) is one of the technologies that appear to live up to the better-alternative challenge faced by the construction industry today.

The availability of SCC has presented a viable option to the construction industry as limitations of conventionally vibrated concrete (CVC) are identified, including:

- The occupational, health and safety (OHS) issue of sending a worker down a deep confined space element to mechanically vibrate the poured concrete.

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- Reduced working hours for a construction site in a residential area due to noise restrictions by the local council and community concerns.
- The inability of conventional concrete to completely fill an intricate formwork resulting in honeycombs, and other structural and surface imperfections.
- The insufficient consolidation of concrete and encapsulation of reinforcement at congested areas where the spacing restricts the insertion of the minimum sized internal vibrator.

SCC also offers advantages over high or very high slump ‘flowable’ concrete, including [1], [2]:

- A higher certainty of passing ability, particularly on elements with congested reinforcements.
- Offers segregation resistance resulting in a more homogenous product.
- A better correlation between the sample and in-place properties of concrete.

Recognition of the challenge

The following major issues were identified in carrying out contract works in the RTA:

- Proposals by contractors to use SCC in some bridge elements where the project management team has little or no experience on the use of SCC.
- Inadequate provisions of existing specifications and standards to ensure adequate implementation of quality assurance.
- Defects experienced with current concrete used and methods of placement particularly for deep foundations and in rehabilitation works where space is highly constrained.

The above challenges were recognised and guided the identification of the elements in bridges and related structures that may be suitable for SCC application, namely:

- Permanently cased cast-in-place reinforced concrete piles, under RTA QA Specifications B58 [3].
- Bored cast-in-place reinforced concrete piles without permanent casing, under RTA QA Specifications B59 [4].
- Elements heavily congested with reinforcement where homogenous mechanical compaction is not assured.
- Elements where the access for internal vibrators is difficult.

Clause 9 of RTA QA Specifications B58 – Permanently Cased Cast-In-Place Reinforced Concrete Piles (RTA B58) [3] requires compaction of concrete using vibrators from the bottom to the top of the pile. This requirement implies OHS constraints and may not be practicable for small diameter deep foundations. Likewise, RTA B58 provision requires the concrete used must be in accordance with RTA B80 [5] and, for a tremie placement method, to be self-compacting. However, the current provision of RTA B80 Edition 5 Version 5 does not specify how the concrete mix is assessed to be self-compacting [5].

Although the use of the term 'self-consolidating concrete' or SCC has been used in recent years with reference to mixtures with ultra workability in conventional concrete applications, drilled shaft (or bored pile) concrete has always been intended as a self-consolidating mixture [6].

An improvement to the relevant RTA QA specifications was envisaged. The purposes of the study are:

- To address the OHS concerns of compacting concrete in small diameter deep foundations.
- To investigate how the principles of self-compacting concrete could be used to improve the concrete used for deep foundations, particularly by tremie placement.
- To enhance the knowledge within RTA Bridge Engineering and maintain the capacity of an informed client for this particular technology.
- To assess the relevant test methods used and standardised overseas for adoption within the RTA.
- To propose suitable amendments to relevant RTA QA specifications and the corresponding guide.
- To verify the use of SCC on a pilot project

Literature review

The RTA Bridge Engineering carried out a literature review on the state of the knowledge of SCC which was completed in June 2009 and published internally in the RTA.

The information gathered in the literature review, indicated that in most cases SCC fresh and hardened properties appear to be similar or better than CVC [1], [7], [8], [2], [9].

Where the SCC property appears to perform lower than CVC, the deviation was observed to be within the limits of existing concrete design codes [1], [2]. Hence, it is considered that the use of SCC requires no design code amendments.

Recent development of SCC mix design proportioning and the availability of third generation admixtures has enabled the customization of an SCC application to the desired performance of a project's fresh and hardened property specific criteria [1], [2].

SCC key fresh properties and standard methods of assessment

Various literature indicated that the fresh properties of SCC have the same characteristics as conventionally vibrated concrete (CVC), with emphasis on flow.

The key fresh flow properties of SCC are characterised to satisfy field requirements [1], [10], [2], [9], as follows:

- Filling ability – the ability of SCC to flow under its own weight (without vibration) into and fill completely all spaces within intricate formwork, containing obstacles, such as reinforcement.
- Passing ability – The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.
- Segregation resistance (Stability) – the ability of SCC to remain homogeneous in composition during transport, placement, and after placement without constituents separating from the mass.

In addition to the normal measurement of concrete fresh properties, a number of test methods are available to test particularly the key fresh properties of SCC. As verified in some studies, no single method could test all three key fresh properties of SCC [12], [22], [8].

The test methods available have been evaluated by a number of organisations including ICAR Project 108 (Aggregates in Self-Consolidating Concrete) [10] and the European Testing SCC Project (European Union Growth Contract No. G6RD-CT-2001-00580) [12].

Laboratory and field trials

To verify the fresh properties conformity with performance criteria established elsewhere, laboratory and full scale field trials were carried out to assess actual performance of a properly design SCC mix produced from local materials.

Scope of trial

The scope of the SCC laboratory and field trials include:

- Development of SCC mix design using local materials.
- Testing of the key SCC fresh properties in the laboratory using the identified test methods.
- Testing of the key SCC fresh properties on a full scale field trial simulation using the identified field acceptance test method.
- Check the capability to replicate the SCC design mix.
- Assessment of the repeatability of the identified test methods.
- Full scale production of SCC design mix from a concrete batching plant.
- Investigate actual performance of the SCC mix on a full scale field trial.

For the purpose of this trial, the performance criteria were specified as follows:

- Strength requirement, f'_c = 50 MPa at 28 days
- Shrinkage requirements for exposure classification B_1/B_2, per RTA B80 [5];
  - ♦ 500 micro strain for three weeks
  - ♦ 700 micro strain for eight weeks

- Slump flow target value, ***SF*** = 650 ± 80 mm (range of 570 to 730 mm)
- Time to flow 500 mm diameter, T_{500} = 2 – 5 seconds
- Visual stability index rating (VSI rating) of less than 2 (see ASTM C 1611 [13])
- J-Ring test value, ***JR*** = 0 – 10 mm
- J-Ring slump flow spread differential, ΔSF_J = 0 – 50 mm
- Sieve segregation resistance value, ***SR*** ≤ 18%

Trial 01

Two full scale test columns, made of Ø600mm x 6000mm long heavy duty spiral steel pipes, were set-up vertically on a concrete base at the Sheahan Bridge Duplication project site with the cooperation of Fulton Hogan Pty Ltd. SCC was supplied by CEMEX Canberra.

This trial was focused on the effects of placement method, namely:

- Pump placement with hose starting very close to bottom of column and then submerged by at least 300mm to poured concrete.
- Pump placement with end of hose at top of column, free fall of 6 meters.

Trial 02

The main focus of the second trial was to validate the capability to replicate the production of a properly design SCC mix and to assess the repeatability of the identified test methods of SCC fresh properties.

Two design mixes were developed for the trial. The final design mixes were reproduced in triplicate at the BORAL laboratory in Sydney and tested according to the identified procedures for key fresh properties of SCC.

The full scale field trial was set-up at the De Martin and Gasparini P/L yard in Homebush and comprised of two Ø400mm x 6000mm high columns. Maximum reinforcement area of 0.04Ag, per AS5100.5/10.7, was provided within 1000mm region from top and bottom ends of the column ie 8 – Ø28mm. Two reinforcing bars were bundled for each main bar location giving a clear spacing of main reinforcement to about 40mm. Circular fitments spaced at 75mm on centres were installed within the 1000mm region from ends of top and bottom of the trial columns. The reinforcement arrangement represented a typical heavily congested reinforced concrete pile element at a reinforcement splice.

Test methods adopted to test key fresh flow properties

The following test methods were used to assess the fresh properties of SCC:

Filling ability – The method adopted was ASTM C1611 [13] which measures the filling ability of the SCC mix through the measurement of slump flow spread, viscosity through time to flow at 500mm diameter, and a qualitative indication on stability by assigning a VSI rating.

Passing ability – The base method adopted was ASTM C 1621 [14]. The J-ring test for passing ability of SCC has a number of versions presented in various standards, publications, and papers of past international RILEM symposia. For the purpose of this trial, the authors compared ASTM C 1621 [14], ICAR 2008 [10] (PCI 2003 [15]), CIA Z40 – 2005 [7] and EN12350-12 [16].

Stability (Resistance to Segregation) – The method adopted was EN12350-11 [17]. This method was originally suggested by GTM Construction as a field acceptance test to assess the static stability of SCC mix. This method was found by others to correlate well with ASTM C 1610 [18], [10].

Hardened properties testing

Standard tests were used to assess compressive strength, density, modulus of elasticity and shrinkage. The samples were prepared without any compaction with the SCC mix poured from a container directly to the sampling mould or cylinder and excess mix struck off the top of mould.

A hardened visual stability index (HVSI) rating [1], [20], was assigned to cylinder and or cut in-situ samples.

Further assessment and testing of the in-situ properties of hardened trial columns were conducted as follows:

- Visual survey of test columns to assess surface finish after stripping of forms.
- A 1000mm long truncated wedge was cut from the top along the length of each of the trial columns to assess the hardened concrete aggregate distribution profile and was assigned a HVSI.
- Ø75 x 300mm cores were taken within 1000mm from top, 1000mm from bottom, and the middle section of the test columns to check for density and strength.
- Beam samples, 100 x 100 x 300mm, for sorptivity test procedure RTA T362 were taken from each test columns (Trial 02 only).
- Core samples, Ø95mm, were taken in close proximity to the respective beam samples location for sorptivity test procedure ASTM C 1585 [20] (Trial 02 only).

Trials mix design and plant production

The mix designs used for the trials were independently developed by the participating concrete suppliers.

Field trial 01 SCC mix design was developed by CEMEX Australia Pty Ltd - Canberra Materials Laboratory (CEMEX Canberra) [now Holcim Australia Pty Ltd]. The SCC mix which contained 14mm maximum nominal aggregate was produced from the CEMEX dry batching plant at the Sheahan Bridge duplication project site.

Laboratory and Field Trial 02 SCC two mix designs were developed by BORAL Resources (NSW) Pty Ltd – Sydney Materials Laboratory (BORAL Sydney). The two mix designs were produced from BORAL Concrete – Enfield Plant for the full scale field trial.

Results and discussion

The following were the results and some discussion of the trials.

Laboratory Trial: Trial 02

Table I below shows the key fresh properties test results of the laboratory part of Trial 02.

Table I. Trial 02 Key Fresh Properties – Laboratory Trial Mix

Method	Slump flow with T_{500} and VSI rating			J-Ring					*SR* value [6]	Yield
Mix No	*SF* spread, mm	T_{500}, sec	VSI rating [2]	SF_J spread, mm	ΔSF_J spread, mm	*JR* value [3]	ΔPA_J [4]	B_J [5]		
01-TM1199	660	2.3	1	590	70	33	16	22	10	0.999
01-TM1200	680	2.3	1	620	60	14	13	24	12	0.998
01-TM1201 [7]	760	2.0	2.0	780	- 20	5	4	7	19	0.986
02-TM1202	640	3.3	1	590	50	6	9	14	6	1.007
02-TM1203	650	4.1	1	620	30	16	11	16	5	1.006
02-TM1204	680	3.7	1	620	60	14	11	20	5	1.009

[2] VSI rating based on Daczko, J, Kurtz, M 2001 and Daczko, J 2002 [22] recommendation and sample photographs from the Interim Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete Institute Member Plants, PCI 2003 [15]

[3] J-ring value, ***JR***, is based on the formula $JR = 2 \times median(H_{in} - H_{out}) - median(H_{centre} - H_{in})$.

[4] J-ring passing ability difference, ΔPA_J, is based on the formula $\Delta PA_J = mean(H_{in} - H_{out})$ from CIA Z40-2005 [7].

[5] J-ring blocking step, ***BJ***, is based on the formula $BJ = mean(H_{out} - H_{centre})$ from EN12350-12 [16].

[6] Sieve segregation resistance value, ***SR***, per EN12350-11 [17].

[7] Higher initial dosage of HRWRA was suggested after the first two mixes yielded a residual slump of 20mm (as delivered on-site simulation). RTA QA Specifications B80 requires a minimum of 40mm slump prior to the addition of admixtures. Climate control in the laboratory was turned on as the outside temperature increased.

The criterion for filling ability, as measured by the slump flow spread, was satisfied by all mixes except for mix 01-TM1201. The resulting fresh properties of SCC Mix 01-TM1201 indicated the influence of ambient temperature for the same amount of high range water reducing admixture (HRWRA) dose.

The viscosity criterion was satisfied by all trial SCC mixes.

The VSI rating appears to give a consistent qualitative indication on segregation resistance. The Sieve segregation resistance test appears to be consistent with the VSI rating assigned to all the mixes.

The performance criterion for J-ring passing ability difference (CIA Z40-2005) and J-ring blocking step (EN12350-12) were taken as the same as the J-ring value (ICAR2008 and PCI2003).

The passing ability criterion, as measured by J-ring test for this trial, appears to give conflicting values. Observations on the sample parameters and accuracy of the formula to give a consistent value to measure the passing ability of the SCC mix were as follows:

- The **ICAR2008** and **PCI2003** J-ring value formula, $JR = 2 \times median(H_{in} - H_{out}) - median(H_{centre} - H_{in})$, appear to misrepresent the actual behaviour of the SCC sample. Further analysis of the formula suggest that as the height at the centre of the SCC patty inside the J-ring, H_{centre}, increases, the ***JR*** value could decrease. An increase in height at the centre of the J-ring indicates blocking and thus preventing the SCC from passing through the reinforcement thereby creating a lump in the middle. A low ***JR*** value could mislead the interpretation of the result seeming to satisfy the criteria when the actual performance suggest otherwise.
- The **CIA Z40-2005** J-ring passing ability difference formula, $\Delta PA_J = mean(H_{in} - H_{out})$ only considers the difference in height of the SCC patty along the J-ring perimeter. The height at the centre of the patty appear to be disregarded, hence, a lump of the SCC patty inside the J-ring may not influence the result of the calculation and could give a misleading result that will seem to satisfy the performance criteria.
- The **EN12350-12** J-ring blocking step formula $BJ = mean(H_{out} - H_{centre})$ measures the difference in height between the centre of the SCC patty inside the J-ring and just outside the J-ring from four locations. This simplified formula gave a consistent value and seem to correlate with the slump flow differential.
- The **ASTM C 1621** J-ring slump flow differential formula, $\Delta SF_J = SF - SF_J$, measures the difference in slump flow spread with and without the J-ring. The measured slump flow spread from ASTM C 1611 could be used as long as the test is done within six minutes. The accuracy of the resulting value however is influenced by the single operator standard deviation of the slump flow spread test which is ±27mm.

Considering the above observations for passing ability test by J-ring, it is proposed to use the two test procedures, ASTM C 1621 and EN12350-12, to get a comparative assessment. ASTM C 1621 could be harmonised with ASTM C 1611 when done within 6 minutes of each other. The criterion for blocking step is proposed to be adjusted to account for the gradient of the SCC patty from the perimeter of the J-ring to the centre of the patty inside the ring.

Table II gives the hardened properties of SCC final design mix for Trial 02.

The test results show that the strength requirement of 50 MPa was satisfied by all SCC trial mixes. The density show a low variance within the mix group indicating that the mixes are within the tolerance of repeatability.

The drying shrinkage of the SCC show marginally higher results than the performance criteria for an Exposure Classification B1/B2 for the three weeks and eight weeks period of 500μm and 700μm, respectively. However, the results are lower than the 800μm requirement for Exposure Classification C [5].

Table II. Trial 02 Hardened Properties – Laboratory Trial Mix

Property / **Mix No**	**Compressive strength**, MPa			**Density at 28d**, kg/m^3	**Drying shrinkage**, μm		**Modulus of Elasticity at 28d**, GPa
	7 days	**14 days**	**28 days**		**3 weeks**	**8 weeks**	
01-TM1199	53.0	59.0	71.0	2410	N/A	N/A	N/A
01-TM1200	55.5	60.0	73.5	2405	590	730	3.55
01-TM1201 [7]	55.0	59.0	70.5	2410	N/A	N/A	N/A
02-TM1202	48.0	55.5	69.5	2360	N/A	N/A	N/A
02-TM1203	48.0	59.5	71.0	2385	630	750	3.69
02-TM1204	47.5	57.0	70.5	2375	N/A	N/A	N/A

Field trials: Trial 01 and 02

For Field Trial 01, the same concrete mix supplied pro bono by CEMEX Australia was used for both test columns and was not adjusted prior to casting. The test columns for Trial 01 test columns were prepared and SCC placed with the cooperation of Fulton Hogan Pty Ltd, contractor for the Sheahan Bridge Duplication Project.

For Field Trial 02, the slump flow spread was initially checked and mix was adjusted by adding HRWR only, remixing for three minutes each time. Once the target slump flow spread was attained, the other SCC fresh properties were checked ie passing ability by J-ring test and L-box test, resistance to static segregation by sieve segregation test, and air content. Concrete was supplied by

Boral Concrete - Enfield. The test columns for Trial 02 were prepared and SCC placed by De Martin and Gasparini Pty Ltd at their yard in Homebush.

Table III shows the key fresh properties test results of the field Trials 01 and 02.

For Trial 01, sieve segregation test was not carried out as no proper equipment was available at the time of field trial. J-Ring test was not carried out as the L-box test indicated no blocking.

The results in Trial 01 indicated that although the SCC mix appeared to have satisfied the passing ability, the slump flow spread appeared to be too large with a VSI rating that indicated potential for severe segregation.

Table III. SCC Key Fresh Properties – Field Full Scale Trials

Method / **Mix No**	**Slump flow with T_{500} and VSI rating**			**J-Ring**					***L Box*** ***H_1/H_2*** [8]	***SR*** **value** [6]
	SF **spread**, mm	***T_{500}***, sec	**VSI rating** [2]	***SF_J*** **spread**, mm	**Δ*SF_J*** **spread**, mm	***JR*** **value** [3]	**ΔPA_J** [4]	**B_J** [5]		
Trial 01										
01	810	3.0	3	-	-	-	-	-	1.0	-
Trial 01										
01-T1	650	2.9	0.5	600	50	20	11	13	0.68	12
01-T2 [8]	610	2.6	0.5	600	10	18	10	12	0.68	14

[8] L-box test filling ratio ***H_1/H_2***.

[9] Placement of concrete was delayed for 15 minutes due to the malfunction of the concrete pump remote control

Both SCC field Trial 02 batching plant produced mixes satisfied the filling ability criteria by slump flow spread, viscosity criteria by T_{500}, and indicated good resistance to segregation with a good VSI rating.

The passing ability criteria appear to be marginally satisfied. The ICAR 2008 and PCI 2003 formula gave a ***JR*** value result that could be interpreted as not satisfying the criteria. The CIA Z40-2005 and EN12350-12 formulae gave results indicating marginal conformance. EN12350-12 appears to be consistent and correlate well with the slump flow differential. The L-box test appears to have a low ratio indicating marginal conformance.

The stability criteria appear to be satisfied with the sieve segregation results well within the performance criteria and the VSI rating appears to be consistent with the sieve segregation results for the field trial SCC mixes.

Slump patty of Field Trial 01 indicated a significant potential of segregation, see **Fig. 1**.

Field Trial 01: VSI rating of slump patty = 3 Field Trial 02: VSI rating of slump patty = 0.5

Fig. 1. Slump flow spread of field trial mixes and range of VSI rating.

The test results of cylinder samples prepared for the field trials are as shown in **Table IV**.

Table IV. SCC Hardened Properties – Cylinder Strengths of Field Full Scale Trials

Age, days	**Strength**, MPa			**Density**, kg/m^3			**Remarks**
	Trial 01	**Trial 02**		**Trial 01**	**Trial 02**		
		Mix 01	**Mix 02**		**Mix 01**	**Mix 02**	
1	21	-	-	2310	-	-	Sample not compacted.
6	41	-	-	2309	-	-	Sample not compacted.
7	52	43	39	2359	-	-	Sample not compacted.
28	72	56	61	2367	2225	2265	Sample not compacted.
28	63	-	-	2390	-	-	Sample conventionally prepared.

The results show that the mixes meet the specified strength. The sample that was conventionally prepared shows a higher concrete density but lower strength compared to the SCC samples prepared without compaction. This seems to verify the notion by others that a well designed SCC will have a slightly higher strength compared with conventional concrete because of an improved interfacial transition zone between the aggregate and hardened paste [2].

Table V shows the in-situ hardened properties of SCC cores of test columns for Field Trial 01 and 02.

The results indicated that for a free fall placement, the strength distribution is greater than that for tremie placement. Observation on the aggregate distribution profile from a longitudinal wedge cut also noted more entrapped air with the free fall placement method

Table V. SCC Hardened Properties – Core Strengths of Field Full Scale Trials

Location	**Strength**, Mpa				**Density**, kg/m^3			
	Field Trial 01[10]		**Field Trial 02**[11]		**Field Trial 01**[10]		**Field Trial 02**[11]	
	T	**F**	**T1**	**T2**	**T**	**F**	**T1**	**T2**
Within 1000mm from top	38	61	54.5	49.0	2244	2125	2325	2320
Within 1000mm from top	53	42	51.5	53.0	2136	2182	2380	2315
Within 1000mm from top	58	56	56.0	54.0	2190	2233	2355	2315
Within 1000mm from top	69	53	55.5	51.5	2259	2262	2390	2310
Within 1000mm from top	58	72	54.5	51.0	2346	2260	2335	2320
Average, top	***55***	***57***	***54***	***52***	***2234***	***2212***	***2357***	***2316***
Middle of column	72	51	53.0	51.5	2328	2395	2335	2320
Middle of column	71	56	54.5	51.5	2329	2329	2345	2305
Middle of column	-	-	56.0	51.5	-	-	2340	2310
Average. middle	***72***	***54***	***55***	***52***	***2328***	***2362***	***2340***	***2312***
Within 1000mm from base	-	-	51.0	51.0	-	-	2335	2320
Within 1000mm from base	-	-	48.5	50.5	-	-	2360	2315
Within 1000mm from base	64	74	49.5	55.5	2341	2323	2355	2325
Within 1000mm from base	69	73	52.0	56.5	2316	2321	2365	2315
Within 1000mm from base	78	76	51.0	54.5	2323	2313	2375	2330
Average, bottom	***70***	***74***	***51***	***53***	***2326***	***2318***	***2355***	***2319***
Average, total	***63***	***61***	***53***	***52***	***2281***	***2274***	***2353***	***2317***

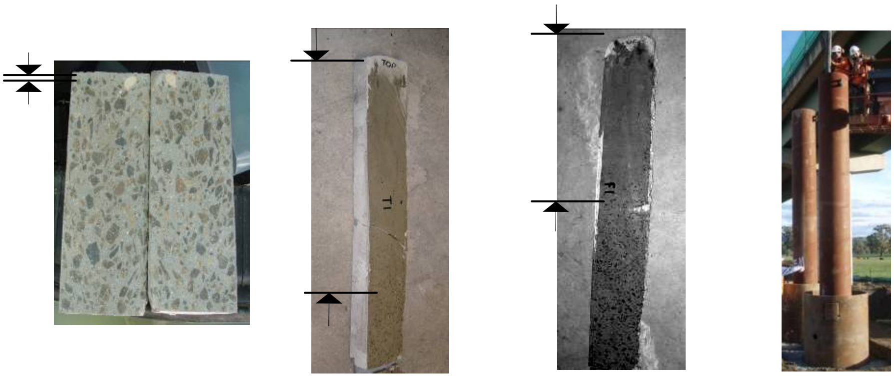
[2] Field Trial 01 assessments carried out at CEMEX laboratory in Canberra.
[2] Field Trial 02 assessments were done at BORAL laboratory in Sydney.

The segregated portion of the SCC generally indicated a lower strength and lower density. The properly designed SCC showed a narrow spread of strength and density.

The truncated wedge longitudinal strip cut from the test SCC columns for Field Trial 01 above show that the actual aggregate distribution profile of hardened SCC has significant segregation at the top 500mm to 750mm of the test columns. This was expected as the fresh properties showed a high potential for segregation.

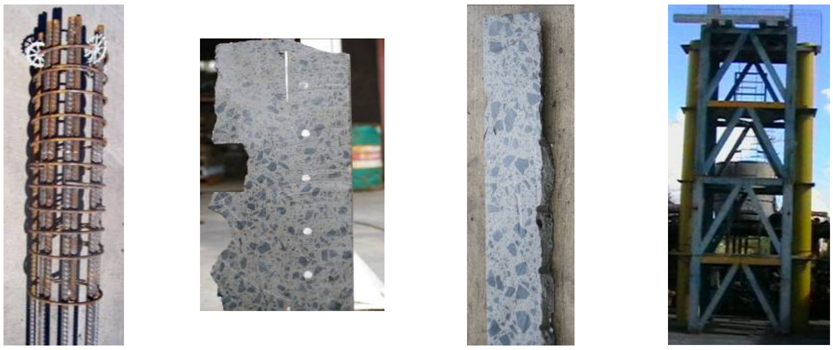
The truncated wedge longitudinal strip cut 1000mm from top of the test SCC columns for Field Trial 02 show that the actual aggregate distribution profiles of hardened SCC were relatively uniform.

Test set-up and wedge cut samples are shown in **Fig. 2** and **Fig. 3**.



(a) Profile of cylinder sample, (b) Profile of top portion of Test Columns **T_1** and **F_1**, HVSI rating = 3 (c) Set-up

Fig. 2. Field trial 01: Column concrete matrix profile and set-up.



(a) Test column reinforcement (b) Profile of top portion of Test Columns **T_1** and **T_2**, HVSI rating = 1 (c) Set-up

Fig. 3. Field trial 02: Column concrete matrix profile and set-up.

Despite the marginal test results of the passing ability tests for Field Trial 02, the actual performance indicated complete encapsulation of the congested reinforcement configuration. The holes within the spacers were observed to be properly filled with the SCC mix.

Proposed Amendments to RTA B80

The objectives of proposed amendments to RTA B80, in addition to the standard requirements of conventionally vibrated concrete, are to ensure that the key fresh properties performance criteria listed in the table below are satisfied during the mix design, production, transport, and placement of SCC.

The SCC key fresh flow properties performance criteria proposed for adoption in RTA B80 are shown in **Table VI**:

A guide on the use of SCC is also being prepared to provide as a handy reference to RTA personnel that may be involved in the design, construction and maintenance of elements in bridges and related structures using SCC.

Table VI. SCC Key Fresh Properties Proposed Testing Regime and Performance Criteria

SCC Key Property	During laboratory trials	Site acceptance test	Performance Criteria	Frequency
Filling ability	ASTM C1611 (Slump flow)	ASTM C1611 (Slump flow)	550 - 820mm or Target ± 50mm	Every batch
Passing ability	ASTM C1621 (J-ring)	Not normally required	≤ 50mm	Initial batch or as may be required.
	EN 12350- (J-ring)	Not normally required	≤ 15mm	
Stability	EN 12350- (Sieve test)	Not required	≤ 15 %	Laboratory only
	ASTM C1611: (VSI rating)	ASTM C1611: (VSI rating)	≤ 2	Every batch
	ASTM C1712 (Rapid test)	ASTM C1712 (Rapid test)	≤ 10 mm	Initial and every fourth batch
Viscosity	ASTM C1611 (T_{500})	ASTM C1611 (T_{500})	2 – 5 sec	Every batch

The test methods proposed for adoption in the RTA B80 were chosen as:

- Test methods for site acceptance utilize existing apparatus already familiar to current testers.
- Additional apparatus can be manufactured locally at an affordable price.
- The additional apparatus and tests do not require major change to site set-up.
- The tests, particularly for the initial batch, work in harmony with each other and are easy to perform.

Project Verification Trials

Project verification trials were conducted at the two Hume Highway alliance projects to assess the feasibility of using country based suppliers and verify the repeatability and reliability of the proposed standards, field and laboratory tests.

The trials were as follows:

- Hume Highway Tarcutta Alliance – Tarcutta Bypass Project
  - ♦ The SCC used for this project verification trial was supplied by the plant owned by Leighton Contractors.
  - ♦ SCC was used for the continuous flight auger (CFA) piles of the two bridges over Tarcutta Creek.
  - ♦ All CFA piles were integrity tested and all cylinder samples indicated good results.
  - ♦ SCC fresh properties were assessed using the identified test methods.

- Hume Highway Woomargama Alliance – Woomargama Bypass Project
  - ♦ The SCC used for this project verifications trial was mostly supplied by a local concrete supplier, BORAL Country NSW – Holbrook, which has a conventional concrete batching plant. The remaining SCC was supplied by the plant owned by Abi Group.
  - ♦ SCC was used for all the bored piles in the two bridges of the project.
  - ♦ The proposed site acceptance test regime detailed in Table VIII was used for all the production piles with parallel testing carried out by Coffey Information and Boral Concrete (Country) NSW – Holbrook. The parallel tests used different bases — steel and polycarbonate material — but gave results within the tolerance of ASTM C 1611.
  - ♦ The parallel tests also trialled the two acceptable orientations of the slump cone - normal and inverted - which did not significantly affect the results, verifying the test done by others elsewhere.
  - ♦ The rapid assessment of segregation resistance, ASTM C 1712 [23], was reported to correlate well with the VSI rating and sieve segregation test results.
  - ♦ Further, HHWA carried out a trial to assess the effect of placement methods in piles. An internal RTA report will be made of this trial.

The trials were assessed to be successful.

Conclusion

The literature and this study show that SCC offers some advantages that could be beneficial to some civil engineering structures cast on site. The study also shows:

- Self-compacting concrete could be produced by a country based local supplier.
- Further trials to test robustness of a properly design SCC mix would be beneficial to assess tolerance of the adopted SCC performance criteria.
- As with any other new technology, training of all personnel involved in the use of SCC is imperative, provided the training is not onerous.
- SCC can be a suitable material to be used on elements where access to internal or external compaction is difficult.
- Most conformance criteria and test methods already used overseas could be adopted.
- Conformance criteria for passing ability using J-ring as measured by blocking step may be adjusted to account for the gradient of the SCC patty from the perimeter of the J-ring to the centre of the SCC sample patty. Hence, the internationally recognised criteria of 10mm may be increased to 15mm.
- The combination of ASTM C 1621 and EN 12350-12 improves the assessment of fresh flow property, where considered critical.
- ASTM C 1611 appears to be sufficient for site acceptance test for every batch of concrete delivered. A quantitative verification on resistance to segregation using ASTM C 1712 is suggested at the initial delivery and every fourth load thereafter or where a retest is necessary ie VSI = 2.

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