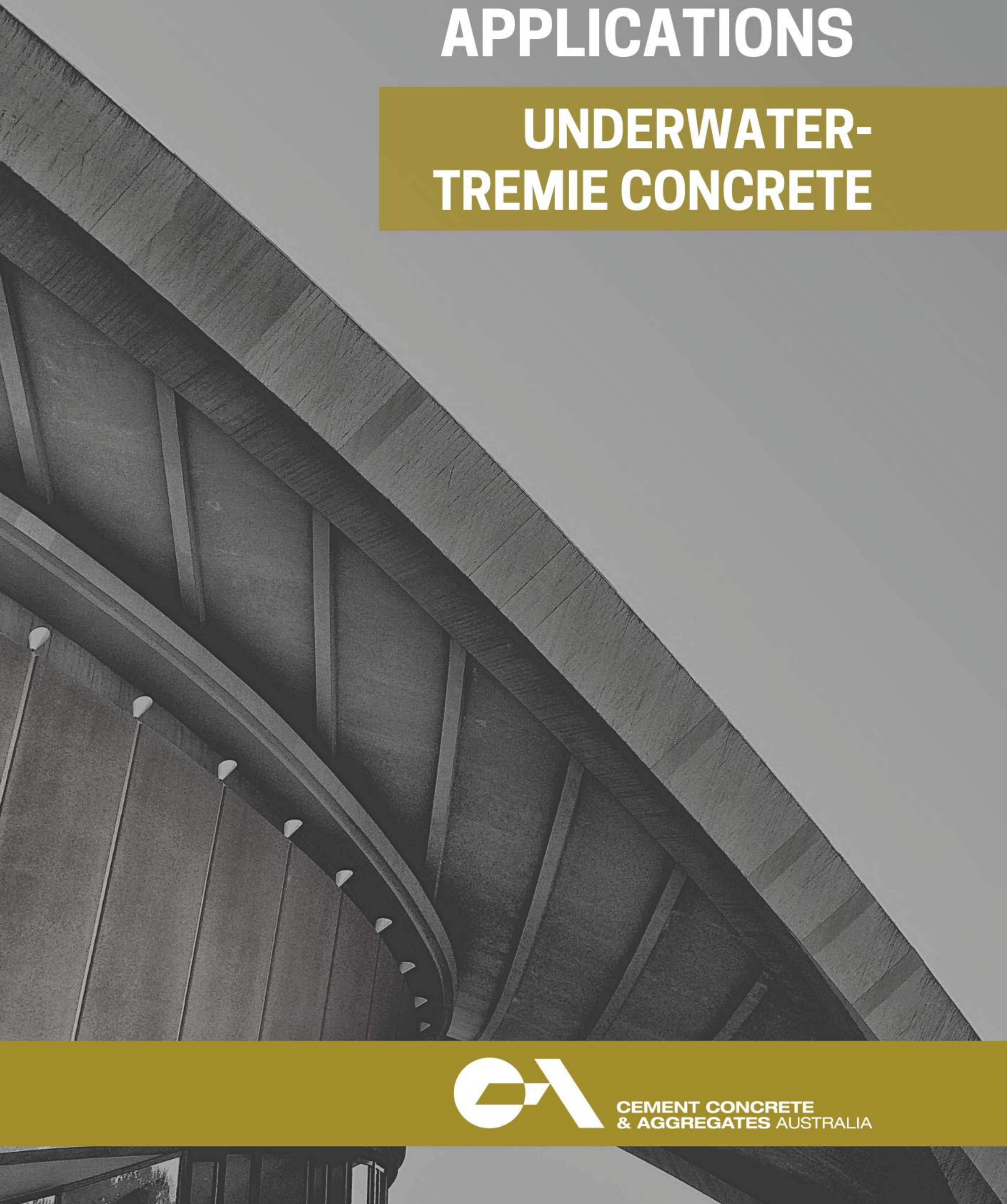
PART VI.
SPECIAL CONCRETE APPLICATIONS

UNDERWATER-TREMIE CONCRETE



CEMENT CONCRETE & AGGREGATES AUSTRALIA

CONTENTS

1. OUTLINE

Tremie concrete is used for placement of structural members under deep excavations such as bored-pile foundations, retaining contiguous/secant pile walls, diaphragm and cut-off walls (CIA Recommended Practice Z17 [4]). Depending on construction techniques, Tremie concrete can be placed under either dry or wet conditions. A tremie pipe is normally employed to place this type of concrete.

The Tremie pipe is a smooth straight steel pipe with a diameter that is usually from 150 mm to 300 mm (between 8 times and 16 times the maximum aggregate size of the concrete mix), and long enough to reach the bottom of a deep bored pile. It has a hopper, or a chute attached on top so the filling of the concrete can be maintained. The hopper capacity should be equal to the volume of pipe being employed (see **Figure 21.1**). The Tremie pipe facilitates concrete placement at deep locations.

In dry construction, concrete is sensitive to segregation due to the great height of falling and possible contact with reinforcement or surrounds. In wet construction (i.e. placing concrete underwater or under a drilling support fluid), major difficulties are from the washout of fines from the mix. The key ability of the mix is for it to flow under its own weight.

The operation of a tremie setup is generally from either a working platform (set up over water) or it can be suspended from a crane. In most cases the tremie hopper is filled from a concrete pump or crane and kibble (with chute fitted). Where a large caisson or deep foundation requires multiple filling points then it is likely that more than one tremie will be used in suitable locations to ensure that the concrete will fill the structure uniformly from the base.

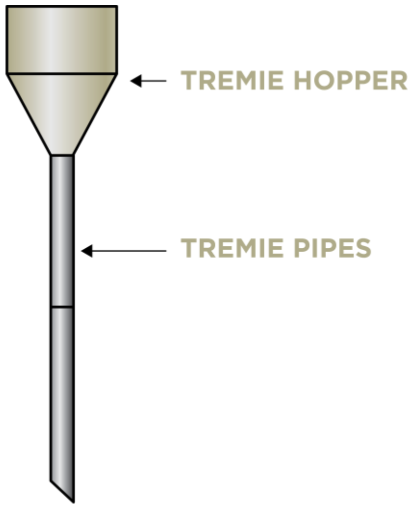


Figure 21.1 – Tremie Pipe and Hopper Setup

When a tremie concrete pour starts it is usual to 'plug' the pipe at the base of the hopper with a 'pig'. The 'pig' is normally made of a spherical foam rubber ball with diameter greater than the diameter of the tremie pipe. The purpose of this is to separate the first concrete placed from the water to avoid washout of the concrete. The 'pig' descends down the tremie pipe and eventually comes out at the bottom of the pipe and floats up to the water surface. This allows the concrete to flow out onto the floor of the structure and to surround the tremie pipe with minimal washout and segregation of the concrete.

The bottom of the tremie pipe must be maintained in the concrete at all times and as the quantity of concrete placed rises, the ideal position of the tremie pipe end is approximately 1.5 m below the rising concrete/water interface surface. To maintain this height the tremie will need to be carefully lifted during the placement with shortening of the pipe by removal of pipe segments below the hopper as required.

The tremie concrete must be placed at a rate that avoids setting of the concrete in the tremie pipe or above the tremie pipe in the structure. This is usually achieved using retarding or slump retaining admixtures in the concrete mix.

2. PROPERTIES OF TREMIE CONCRETE

2.1 GENERAL

Similar to super-workable concrete, Tremie concrete requires good flow characteristics (e.g. filling ability, flowing ability and passing ability) and stability (i.e. water retention, fines washout resistance and segregation resistance). **Table 21.1** is adapted from CIA Recommended Practice Z17 to illustrate mix design properties of tremie concrete compared to other types of concrete.

Table 21.1 – Properties of Tremie and Other Concretes

Qualitative Parameters	Normal Concrete	(Wet) Tremie Concrete	Super-Workable Concrete
Binder Volume	Low	Medium	Medium
Coarse Aggregate Volume	High	Medium	Medium/Low
Paste Volume	Low	Medium	Medium/High
Paste Viscosity	Low	Medium	Medium/Low
Concrete Viscosity	High (flow by vibration)	Medium/Low	Medium/Low
Concrete Yield Stress	High	Medium/Low	Low

When placing concrete underwater, it is usual to add more cement to the mix than would normally be required for the specified strength so as to improve mix workability and reduce the risk of washout. Some specifications nominate as much as 10% more cementitious material.

Discharge at the end of the Tremie pipe requires the concrete to flow to fill the forms or voids, and in most situations, it is impossible to see if that is happening under water.

Because of the lack of visibility, it is suggested that horizontal flow of highly flow-able concrete in wet construction be limited to a radius of flow of 3 m. For dry construction, free fall height (i.e. distance between the exit point of the Tremie pipe and the top of rising concrete surface) is suggested to be limited to 3 m – with the horizontal flow limited to 1.5 m – to avoid possible segregation (CIA Recommended Practice Z17).

For underwater applications, tremie concrete needs to be placed at slumps greater than 175 mm. In some conditions where high flowing concrete properties are required the target slump may need to be increased to around 250 mm with a slump flow between 400 mm and 550 mm [7].

Table 21.1 demonstrates that Tremie Concrete Rheology is positioned between that of Normal Concrete and Super-workable Concrete (refer to Section 22 of this Guide).

The key characteristics of tremie concrete are:

- Workability (an ability to self-compact under gravity);
- Workability retention (maintain its workability for the period of placement);
- Stability (resistance to segregation, bleeding and filtration).

Not surprisingly, some of these requirements are shared with those of super-workable concrete.

3. TESTING OF TREMIE CONCRETE

3.1 GENERAL

Tremie concrete can be tested for hardened properties in much the same way as standard concrete (refer to Part VIII, Section 26 of this Guide). The key differences in test methods relate primarily to its plastic properties.

3.2 PLASTIC PROPERTIES

Tremie concrete requires testing for plastic properties that may differ from the test methods used for normal concrete. The key properties that help describe the rheology of a tremie concrete mix are:

- Consistency;
- Viscosity;
- Resistance to segregation;
- Workability retention;
- Bleeding;
- Filtration;
- Heat of hydration.

Testing for these properties is discussed in the following sub-sections.

Consistency

The common test method used is the slump test carried out to AS 1012.3.1 [3]. The traditional tremie concrete target slump specification has been between 180 mm and 240 mm. As the specified slump starts to rise above 220 mm it is found that specifying the slump does not provide a sufficiently accurate measure of rheology and so the slump flow tested in accordance with AS 1012.3.5 becomes a more relevant measure.

Viscosity

EFFC/DFI Task Group [7] suggests a test for assessing the viscosity of a tremie concrete based on the slump flow test. This is similar to the T_{500} test used for Super-workable concrete but is suitable where the specified slump flow is between 400 mm and 500 mm. The test referred to as the 'slump flow velocity' and is assessed by determining the time from lifting the slump flow cone until the flow ceases. If the average final flow diameter was exactly 500 mm then this time measurement would be the T_{500} value for that test. In the case of the 'slump flow velocity' (SFV), the value is calculated from the final flow diameter in mm (D_{final}), and the time to reach that diameter (t) in seconds, using this formula:

$$SFV = (D_{final} - 200) / t \qquad \text{.....}\textbf{Eq.21.1}$$

In the case where D_{final} = 500 mm, the SFV = 300/T_{500}. So, if T_{500} equals 6 seconds then the SFV equals 50 mm/sec.

The SFV is only relevant where a slump flow is specified between 400 mm and 550 mm.

Resistance to Segregation

Plastic concrete in deep foundations relies on its shear yield strength to prevent segregation once placed. The relatively high density of coarse aggregate compared to the concrete mix mortar fraction can lead to segregation of the mortar from the coarse aggregate. This static form of segregation is exacerbated by significant retardation of the concrete.

A suitable method for assessing this form of segregation is provided in ASTM C1610 *'Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique'.* The method used in this test is to form a column of the plastic concrete to be assessed, leave it to stand for a defined period of time (e.g. 15 minutes to 2 hours depending on the retardation of the mix) and then assess the coarse aggregate content of the concrete in the top 25% of the column concrete volume compared with the coarse aggregate content in the bottom 25% of the column concrete. The coarse aggregate is removed by washing the concrete over a 4.75 mm sieve and retaining the coarse aggregate fraction.

The difference in mass of SSD coarse aggregate from the bottom section compared to the top section is expressed as a percentage of the total mass of coarse aggregate from both sections. Typically, the maximum allowable static segregation is 15%.

Workability Retention

Workability retention is best assessed using a sample of concrete that is prevented from losing moisture during the test period. The slump test or slump flow test (as specified) is carried out at regular intervals (30-minute intervals until complete) until significant slump loss is detected. A significant slump low loss would be a reduction in slump flow of 50 mm.

With some types of slump retention admixtures, the slump flow may increase slowly after mixing before slowly reducing after a period. If this is detected, then the test interval may need to be shortened to capture the range of slump flow results over time as flow that is too high may promote segregation of the mix.

Bleeding

Bleeding of concrete is common to all types of concrete but is a greater issue in deep pile construction. Bleeding is a form of segregation where the mix water separates from the binder. Under the significant pressure gradients that exist in the concrete mixture as a result of differential density between binder and aggregates and water, water is driven up to the surface of the concrete. In some deep piles and foundations this shows up as 'bleed channels' that may follow up the outside of the pile or along reinforcement. This channelling can lead to washout of binder and some fines in the local area and so can be detrimental to the concrete structure's durability.

To reduce the tendency for bleeding it is often necessary to amend the grading of the mix binder and other fines with the possible addition of ultra-fine materials to reduce total bleeding and bleeding rate. A common specification for 'bleeding' is to limit the maximum bleed rate.

The test method for bleeding is AS 1012.6 *'Methods of testing concrete, Part 6: Determination of bleeding of concrete'* [9].

Filtration

The property of 'filtration' in the concrete mix may be related to bleeding in deep foundations and piles. The effect of bleeding under pressure can also drive water out of the concrete and into the surrounding ground. The impact of this is a rapid loss of concrete workability.

CIA Z17 [4] and EFFC/DFI Task Group [7] suggest the use of the Bauer Filtration test for assessing this property of the tremie concrete, as well as setting maximum loss of water through the filter under a pressure of 5 bar (approximately 500 kPa).

Heat of Hydration

One property of tremie concrete that may be of concern is the potential for the heat developed during hydration of the binder to lead to unacceptable temperature rise. The conditions where this may be of concern are:

- When the structure (pile or deep foundation) has minimum dimensions of 600 mm or more;
- The binder combination selected has not been designed to reduce the temperature rise in the concrete;
- The maximum estimated concrete temperature exceeds 75ºC.

In these cases, the mix design, mix delivery temperature and possibly the structure's reinforcement may require review to ensure durability of the structure. The mix binder constituents may need to include higher proportions of supplementary cementitious materials such as fly ash and/or ground granulated blast furnace slag. The initial temperature of the concrete can also be lowered to reduce the maximum temperature of concrete after placement (refer to Section 18 of this Guide in relation to *Hot weather concreting* and temperature control).

Assessing the potential temperature rise in a concrete mix is best assessed using a 1 m × 1 m × 1 m form-ply box filled with the proposed concrete mix and a thermocouple setup to monitor temperature rise (refer to CIRIA C660 [10] section 7.2.1).

3.3 HARDENED PROPERTIES

The standard tested properties for hardened concrete also largely apply to tremie concrete, namely:

- Compressive strength;
- Tensile strength;
- Drying Shrinkage;
- Modulus of elasticity;
- Creep.

For a given compressive strength and plastic density of tremie concrete the relationships between compressive strength and tensile strength, modulus of elasticity and creep are expected to be the same as for normal concrete (refer to AS 3600 [1]).

Drying shrinkage of tremie concrete is dependent on mix design and due to slightly lower coarse aggregate contents may be slightly higher than that in some normal concrete mixes, but still conforming to AS 1379 [2].

4. MIX DESIGN AND SPECIFICATION OF TREMIE CONCRETE

4.1 GENERAL

In Part III of this Guide the mix design of normal concrete is discussed. The basic steps of mix design outlined in Part III of this Guide are the same for tremie concrete as for normal concrete – with the necessary corrections for reduced coarse aggregate content, slump, minimum binder content and binder combination.

4.2 MIX DESIGN

The total cementitious content of a tremie concrete mix should be greater than 400 kg/m^3 with a maximum particle size of coarse aggregate of 20 mm – where the minimum spacing between reinforcement bars in the structure are 80 mm or greater. If spacing between reinforcement is less than 80 mm then the maximum aggregate size should be no more than 25% of the minimum spacing. The inclusion of SCM's in the mix (e.g. Ground slag or fine grade fly ash) can assist with reducing the temperature rise in the concrete as well as with improved flow-ability and cohesiveness of the concrete.

Anti-wash out admixtures can be of great advantage with the placement of tremie concrete underwater. These admixtures stabilise the water in the concrete and reduce bleed as well as helping to reduce any loss of fines during placement and setting.

The water content of tremie concrete will depend on the admixture combination being used but would be expected to be between 170 litre/m^3 and 200 litre/m^3 for the purposes of developing a preliminary mix design with 20 mm maximum sized aggregate.

When choosing a mix design method, it is recommended to use the 'British Road Note 4' method as set out in Part III of this Guide. Referencing Figure III.3 of this Guide, it is recommended that for tremie concrete with 20 mm maximum sized aggregate the combined aggregate grading curve 3 is used for binder contents as high as 600 kg/m^3, and the combined aggregate grading curve 4 for binder contents as low as 400 kg/m^3. If the binder content exceeds 600 kg/m^3 then the mix may need a careful review in terms of the impact on temperature rise in the hardening concrete.

The admixture selection will depend on the specified properties of the tremie concrete mix. For example, if the concrete must retain its consistency for two hours after placement then it is likely that a slump retaining admixture will need to be used in conjunction with a high range water reducer or medium range water reducer (depending on the target slump or slump flow). If there are concerns that the mix may be washed out when placed under water, then an anti-washout admixture may also be required.

The preliminary design air content of a tremie concrete mix should be between 2.0% and 4.0% as a guide, though the actual mix value will be dependent on the admixture and material selection.

It is essential that a proposed tremie concrete is trial mixed in the laboratory and on-site to ensure that its plastic and hardened properties are suitable as well as conforming to the specified properties.

4.3 SPECIFICATION

Specification of tremie concrete is largely aimed at achieving the necessary plastic properties as well as hardened state properties. The tremie concrete should be able to fill the forms with no compaction applied and without significant segregation, washout or bleeding.

Typical specified plastic properties will include:

- Slump or slump flow target (and acceptable range);
- Slump flow velocity;
- Workability retention;
- Static segregation;
- Bleeding;
- Bauer filtration;
- Maximum concrete temperature rise.

Generally, a selection of these tests may be specified as well as a testing frequency. The EFFC/DFI Task Group [7] document does provide some useful guidelines on specifications for these tests and has influenced the typical values provided in **Table 21.2**.

Table 21.2 – Typical Tremie Concrete Plastic Property Test Specified Values and Allowable Variation

Test Method	Target Range	Max.	Min.
Slump (mm)	180 - 220	S+40	S-40
Slump flow (mm)	400 - 800	SF+50	SF-50
Slump flow velocity (mm/sec)	10 - 50	SFV+5	SFV-5
Workability Retention (mm)	Specified	N/A	S-40 S-50
Static Segregation (%)	$\leq$15	SS+2	N/A
Bleeding Rate (mL/min)	$\leq$0.1	BR+0.02	N/A
Bauer Filtration (mL)	$\leq$23	BF+3	N/A
Maximum Temp. Rise (^{o}C)	Specified T	T+3	N/A

The hardened concrete specified properties will be as for Normal Class concrete and as detailed in AS 1379 [2].

5 REFERENCES

1) AS 3600 – *Concrete structures*
2) AS 1379 – *Specification and supply of concrete*
3) AS 1012.3.1 – *Determination of properties of concrete – Slump test*
4) CIA Z17 Recommended Practice, *'Tremie Concrete for Deep Foundations'*, Concrete Institute of Australia
5) AS 2758.1 – *Aggregates and rock for engineering purposes – Concrete aggregate*
6) AS 1012.3.5 – *Determination of the properties related to consistency of concrete – Slump flow, T_{500}, J-ring test*
7) EFFC/DFI Task Group, *'Guide to tremie concrete for deep foundations'*, European Federation of Foundation Contractors & Deep Foundation Institute
8) ASTM C1610 – *Standard Test Method for Static* Segregation *of Self-Consolidating Concrete Using Column Technique*
9) AS 1012.6 – *Methods of testing concrete, Part 6:* Determination of *bleeding of concrete*
10) CIRIA-C660, *'Early age thermal crack control in concrete'*, P.B. Bamforth

CCAA OFFICES

NATIONAL OFFICE (NSW)
Level 10
163 -175 O'Riordan Street
Mascot NSW 2020

POSTAL ADDRESS
PO Box 124
Mascot NSW 1460
Telephone: (02) 9667 8300

QUEENSLAND
Level 14, 300 Ann Street,
Brisbane QLD 4000
Telephone: (07) 3227 5200

VICTORIA
Suite 910/1 Queens Road
Melbourne VIC 3004
Telephone: (03) 9825 0200

WESTERN AUSTRALIA
45 Ventnor Avenue
West Perth WA 6005
Telephone: (08) 9389 4452

SOUTH AUSTRALIA
Level 30, Westpac House
91 King William Street
Adelaide SA 5000
Telephone: (02) 9667 8300

TASMANIA
PO Box 1441
Lindisfarne TAS 7015
Telephone: (03) 6491 2529

ONLINE DETAILS
www.ccaa.com.au
Email: info@ccaa.com.au