The Combined Influence of Paste Volume and Volumetric Water-to-Powder Ratio on Robustness of Fresh Self-Compacting Concrete

Farid Van Der Vurst¹, Steffen Grünewald², Dimitri Feys³ and Geert De Schutter⁴

¹Ph.D. student, Ghent University
²Postdoctoral researcher, Ghent University and Delft University of Technology
³Assistant Professor Materials Engineering, Missouri University of Science and Technology
⁴Full Professor Concrete Technology, Ghent University

Abstract: In order to avoid durability problems caused by an inadequate consolidation of concrete, self-compacting concrete (SCC) has been developed. The mix design of SCC aims at balancing a minimum flowability allowing air bubbles to escape and a maximum flowability in order to avoid segregation. Because of the higher demands on mix design and additional requirements related to casting, SCC mixtures are in general more sensitive to small variations in its mix composition compared to conventional vibrated concrete. Besides improving the robustness of SCC with admixtures like Viscosity-Modifying Agents (VMAs), it is also important to find out why certain mixtures are more robust than others. This paper investigates the influence of the paste volume and the water-to-powder ratio (volumetric) on the robustness of fresh SCC mixtures. Nine SCC mixtures with a paste volume of 350, 375, and 400 l/m³ and a volumetric water-to-powder ratio of 0.75, 0.90, and 1.05 were subjected to a variation of ±8 l/m³ water. The robustness of the produced mixtures was quantified measuring the slump flow, V-funnel time, L-box ratio, and sieve stability.

Keywords: Robustness, Self-Compacting Concrete, Rheology, Paste Volume, Water-to-Powder ratio

1. Introduction

1.1. Self-compacting concrete

After investigating many durability problems of post-war Japanese concrete structures, Okamura and his team found that a majority of problems originated in a poor consolidation of concrete during the casting process. As a solution to avoid similar problems, a new type of concrete was developed for which external vibration was no longer needed to assure a good compaction: self-compacting concrete (SCC) [1, 2]. In order to combine sufficient fluidity – allowing air-bubbles to escape and complete formwork filling – and sufficient stability to avoid segregation, the high fluidity concrete contains higher powder content compared to conventional vibrated concrete, superplasticizer(s), and sometimes a viscosity-modifying admixture (VMA). However, because the target range for sufficient fluidity, sufficient segregation resistance, and to avoid an excessive stickiness is much smaller than the optimum range of conventional vibrated concrete, self-compacting mixtures are generally more sensitive to small variations in the mix proportions, materials properties, and casting circumstances.

To counter this larger sensitivity to small variations, also referred to as reduced robustness, a more severe quality control and better trained workers are needed. The use of SCC is nowadays still limited to cases where all conditions are well-controlled and situations in which an external compaction would cause great difficulties. To facilitate the use of SCC in general and especially for applications with specific requirements for fresh concrete, it is necessary to investigate the origin of the robustness of concrete.

1.2. The origin of the robustness

Although many parameters such as material characteristics [3-11], temperature [12-14], and shear history [15-18] affect the fresh behaviour of self-compacting concrete, most robustness studies focus on the influence of small changes in the material proportions [11, 19-42]. Of all changes in material proportions, inaccuracies in the water amount are responsible for the largest variations of the fresh behaviour of SCC [43, 44]. Therefore, many studies on the robustness of fresh SCC focus on the influence of small variations of the water content (± 5 to 10 l/m³). According to these publications, the sensitivity to small variations of the water content decreases as:
- A surplus of fine aggregates is included in the aggregates grading curve, preventing the coarse aggregates from becoming dominant [19-21, 45].
- The powder content increases [20, 21, 23].
- Part of the cement is substituted by silica fume or fly ash [22, 24].
- A VMA is added to the mixture [20, 28-39, 46].
- Certain types of superplasticizers are used [25-27].
- Opposing conclusions are drawn about the influence of the water-to-cement and water-to-powder ratio [19, 38].

The mechanisms and combination of influences of the powder content, the water-to-powder ratio, mineral additions and admixtures on the robustness are still unknown. Some authors indicate the importance of the paste volume, the paste density, and the paste viscosity [20, 21, 23], while others focus on the excess water in the concrete mix design [38] or make a link between the thixotropy and robustness [47, 48]. This paper attempts to determine the causes behind the influence of paste volume and volumetric water-to-powder ratio on the robustness of SCC.

2. Experimental work

2.1. Materials and mixing sequence

All mixtures are made with the same raw materials: Rhine sand 0/5, river gravel 2/8 and 8/16 (with a density of respectively 2630 kg/m³, 2670 kg/m³, and 2660 kg/m³), Portland cement CEM I 52.5 N (with a density of 3126 kg/m³ and a Blaine fineness of 370 m²/kg), limestone filler (with a density of 2685 kg/m³ and a specific surface area of 424 m²/kg, based on the particle size distribution), and a PCE superplasticiser with a solid content of 35%. The grading curve of the aggregates is illustrated in Figure 1 and the chemical composition of the cement as determined by an XRF analysis is given in Table 1. After premixing the cement, filler, and dry aggregates for one minute in a planetary pan mixer, water was added to the mixer and mixing continued for another minute. Finally, the superplasticizer was added and the concrete was mixed for two more minutes.

<table>
<thead>
<tr>
<th>Table 1. Chemical composition of the cement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>CaO</td>
</tr>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>Al₂O₃</td>
</tr>
<tr>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>K₂O</td>
</tr>
<tr>
<td>Na₂O</td>
</tr>
<tr>
<td>CO₂</td>
</tr>
<tr>
<td>SO₃</td>
</tr>
<tr>
<td>Cl⁻</td>
</tr>
<tr>
<td>L.O.I.</td>
</tr>
<tr>
<td>Insoluble rest</td>
</tr>
<tr>
<td>Cement [%]</td>
</tr>
<tr>
<td>62.30</td>
</tr>
<tr>
<td>18.77</td>
</tr>
<tr>
<td>6.00</td>
</tr>
<tr>
<td>4.06</td>
</tr>
<tr>
<td>1.07</td>
</tr>
<tr>
<td>0.58</td>
</tr>
<tr>
<td>0.51</td>
</tr>
<tr>
<td>0.60</td>
</tr>
<tr>
<td>3.35</td>
</tr>
<tr>
<td>0.067</td>
</tr>
<tr>
<td>1.82</td>
</tr>
<tr>
<td>0.41</td>
</tr>
</tbody>
</table>

2.2. Mixture compositions

The robustness of nine SCC mixtures was determined by measuring the slump flow, V-funnel time, L-box ratio, sieve stability, air content and density of the mixtures subjected to a variation of ±8 l/m³ water. The mixtures, given in Table 2, have different paste volumes (350, 375, and 400 l/m³) and volumetric water-to-powder ratios (0.75, 0.90, and 1.05), keeping the water-to-cement ratio constant. These paste volumes and volumetric water-to-powder ratio's correspond with the 20%, 50%, and 80% fractals of a database summarizing the properties of SCC mixes used in more than 175 papers [49, 1336].
50]. The superplasticizer dosage was always determined such that the Sieve Stability Index (S.S.I., tested according to EN 12350-11) of the reference mixture is between 8 and 12%.

### Table 2: Mix proportions of reference SCC mixes

<table>
<thead>
<tr>
<th>Paste volume / water-to-powder ratio (by volume) [l/m³] / [-]</th>
<th>Sand 0/5 [kg/m³]</th>
<th>Gravel 2/8 [kg/m³]</th>
<th>Gravel 8/16 [kg/m³]</th>
<th>Cement 152 N [kg/m³]</th>
<th>Limestone filler [kg/m³]</th>
<th>Water [kg/m³]</th>
<th>SP dosage [l/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 / 0.75</td>
<td>800</td>
<td>279</td>
<td>459</td>
<td>312</td>
<td>346</td>
<td>171</td>
<td>3.31</td>
</tr>
<tr>
<td>400 / 0.90</td>
<td>800</td>
<td>279</td>
<td>459</td>
<td>344</td>
<td>269</td>
<td>189</td>
<td>2.50</td>
</tr>
<tr>
<td>400 / 1.05</td>
<td>800</td>
<td>279</td>
<td>459</td>
<td>373</td>
<td>204</td>
<td>205</td>
<td>1.95</td>
</tr>
<tr>
<td>375 / 0.75</td>
<td>835</td>
<td>291</td>
<td>476</td>
<td>292</td>
<td>324</td>
<td>161</td>
<td>3.95</td>
</tr>
<tr>
<td>375 / 0.90</td>
<td>835</td>
<td>291</td>
<td>476</td>
<td>323</td>
<td>252</td>
<td>178</td>
<td>2.80</td>
</tr>
<tr>
<td>375 / 1.05</td>
<td>835</td>
<td>291</td>
<td>476</td>
<td>349</td>
<td>191</td>
<td>192</td>
<td>2.00</td>
</tr>
<tr>
<td>350 / 0.75</td>
<td>869</td>
<td>303</td>
<td>498</td>
<td>273</td>
<td>302</td>
<td>150</td>
<td>5.31</td>
</tr>
<tr>
<td>350 / 0.90</td>
<td>869</td>
<td>303</td>
<td>498</td>
<td>301</td>
<td>236</td>
<td>166</td>
<td>3.63</td>
</tr>
<tr>
<td>350 / 1.05</td>
<td>869</td>
<td>303</td>
<td>498</td>
<td>326</td>
<td>178</td>
<td>179</td>
<td>2.38</td>
</tr>
</tbody>
</table>

### Table 3: Fresh state properties of nine reference SCC mixes

<table>
<thead>
<tr>
<th>Paste volume / water-to-powder ratio [l/m³] / [-]</th>
<th>Slump flow [mm]</th>
<th>V-funnel time [s]</th>
<th>L-box ratio [-]</th>
<th>S.S.I. [%]</th>
<th>Density [kg/m³]</th>
<th>Air content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 / 0.75</td>
<td>673</td>
<td>13.7</td>
<td>0.82</td>
<td>9.4</td>
<td>2475</td>
<td>2.5</td>
</tr>
<tr>
<td>400 / 0.90</td>
<td>680</td>
<td>6.3</td>
<td>0.85</td>
<td>12.2</td>
<td>2369</td>
<td>1.6</td>
</tr>
<tr>
<td>400 / 1.05</td>
<td>688</td>
<td>3.5</td>
<td>0.83</td>
<td>12.0</td>
<td>2369</td>
<td>1.2</td>
</tr>
<tr>
<td>375 / 0.75</td>
<td>705</td>
<td>17.6</td>
<td>0.86</td>
<td>11.2</td>
<td>2394</td>
<td>1.9</td>
</tr>
<tr>
<td>375 / 0.90</td>
<td>680</td>
<td>8.0</td>
<td>0.91</td>
<td>10.1</td>
<td>2375</td>
<td>1.8</td>
</tr>
<tr>
<td>375 / 1.05</td>
<td>680</td>
<td>4.0</td>
<td>0.86</td>
<td>12.3</td>
<td>2372</td>
<td>1.4</td>
</tr>
<tr>
<td>350 / 0.75</td>
<td>865</td>
<td>15.9</td>
<td>1.00</td>
<td>10.5</td>
<td>2406</td>
<td>0.9</td>
</tr>
<tr>
<td>350 / 0.90</td>
<td>750</td>
<td>10.5</td>
<td>0.98</td>
<td>9.4</td>
<td>2375</td>
<td>1.5</td>
</tr>
<tr>
<td>350 / 1.05</td>
<td>675</td>
<td>5.3</td>
<td>0.80</td>
<td>8.0</td>
<td>2369</td>
<td>1.5</td>
</tr>
</tbody>
</table>

### Table 4: The robustness of nine SCC mixes

<table>
<thead>
<tr>
<th>Slump flow [mm]</th>
<th>400 / 0.75</th>
<th>400 / 0.90</th>
<th>400 / 1.05</th>
<th>375 / 0.75</th>
<th>375 / 0.90</th>
<th>375 / 1.05</th>
<th>350 / 0.75</th>
<th>350 / 0.90</th>
<th>350 / 1.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔSF</td>
<td>260</td>
<td>163</td>
<td>210</td>
<td>155</td>
<td>138</td>
<td>133</td>
<td>90</td>
<td>130</td>
<td>148</td>
</tr>
<tr>
<td>ΔSF / 16 l/m³</td>
<td>16.3</td>
<td>10.2</td>
<td>13.1</td>
<td>9.7</td>
<td>8.6</td>
<td>8.3</td>
<td>5.6</td>
<td>8.1</td>
<td>9.2</td>
</tr>
<tr>
<td>ΔSF / SFref</td>
<td>0.39</td>
<td>0.24</td>
<td>0.31</td>
<td>0.22</td>
<td>0.20</td>
<td>0.19</td>
<td>0.10</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td>V-funnel time [s]</td>
<td>13.7</td>
<td>6.3</td>
<td>3.5</td>
<td>17.6</td>
<td>8.0</td>
<td>4.0</td>
<td>15.9</td>
<td>10.5</td>
<td>5.3</td>
</tr>
<tr>
<td>ΔVF</td>
<td>11.4</td>
<td>3.8</td>
<td>3.8</td>
<td>18.4</td>
<td>5.4</td>
<td>2.2</td>
<td>21.8</td>
<td>5.4</td>
<td>2.8</td>
</tr>
<tr>
<td>ΔVF / 16 l/m³</td>
<td>0.71</td>
<td>0.24</td>
<td>0.24</td>
<td>1.15</td>
<td>0.34</td>
<td>0.14</td>
<td>1.36</td>
<td>0.34</td>
<td>0.18</td>
</tr>
<tr>
<td>ΔVF / Vref</td>
<td>0.83</td>
<td>0.60</td>
<td>1.07</td>
<td>1.04</td>
<td>0.68</td>
<td>0.56</td>
<td>1.37</td>
<td>0.51</td>
<td>0.53</td>
</tr>
<tr>
<td>L-box ratio [-]</td>
<td>0.82</td>
<td>0.85</td>
<td>0.83</td>
<td>0.96</td>
<td>0.91</td>
<td>0.86</td>
<td>1.00</td>
<td>0.98</td>
<td>0.8</td>
</tr>
<tr>
<td>ΔLB</td>
<td>0.78</td>
<td>0.19</td>
<td>0.35</td>
<td>0.06</td>
<td>0.27</td>
<td>0.15</td>
<td>0.02</td>
<td>0.02</td>
<td>0.19</td>
</tr>
<tr>
<td>ΔLB / LBref</td>
<td>0.049</td>
<td>0.012</td>
<td>0.022</td>
<td>0.004</td>
<td>0.017</td>
<td>0.009</td>
<td>0.001</td>
<td>0.002</td>
<td>0.012</td>
</tr>
<tr>
<td>S.S.I. [%]</td>
<td>9.4</td>
<td>12.2</td>
<td>12.0</td>
<td>11.2</td>
<td>10.1</td>
<td>12.3</td>
<td>10.5</td>
<td>9.4</td>
<td>8.0</td>
</tr>
<tr>
<td>ΔS.SI. / 16 l/m³</td>
<td>10.7</td>
<td>8.1</td>
<td>12.9</td>
<td>13.8</td>
<td>8.0</td>
<td>8.4</td>
<td>9.1</td>
<td>4.5</td>
<td>5.0</td>
</tr>
<tr>
<td>1337</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1. Variations of the slump flow

Because the superplasticizer dosage was always adjusted in order to have a S.S.I. of 10%±2%, the slump flow of the nine mixtures is not related to their paste volume or water-to-powder ratio (Table 3). However, as shown in Table 4 and Figure 2, the sensitivity of the slump flow to changes in the water content depends on the paste volume: the robustness of the flow decreases as the paste volume increases. Table 4 shows that the water-to-powder ratio of the mixtures has no clear influence on the robustness of the slump flow.
3.2. Variations of the V-funnel time

When the paste volume increases, the V-funnel time of the mixtures decreases slightly (about 3 sec difference between 350 and 400 l/m² for the same water-to-powder ratio); the sensitivity of the V-funnel time to variations in the water content also seems to be independent of the paste volume of the mixture. Mixtures with a higher water-to-powder ratio have a significant lower V-funnel time than mixtures with a lower water-to-powder ratio (see Tables 3 and 4). Especially, mixtures with a water-to-powder ratio of 0.75 are very sensitive to a decrease in the water content, making them very sticky and not easy to process. The robustness determined by changes in the V-funnel time therefore increases when the water-to-powder ratio increases (Figure 3).

3.3. Variations of the L-box ratio

Table 4 reveals no clear influence of the test responses on the L-box ratio results. The results are also difficult to interpret because of the poor flowability of the mixtures with 8 l/m² less water, a paste volume of 400 l/m² and volumetric water-to-powder ratios of 0.75 and 1.00, which have a slump flow of respectively 525 and 515 mm.

3.4. Variations of the sieve stability

As shown in Table 4 and Figure 4, an increase in the paste volume increases the sensitivity of the S.S.I. to variations in the water content. The paste volume has a larger effect than changes in the water-to-powder ratio.
4. Discussion of influence parameters

Mixtures were designed to show a specific level of sieve stability, regardless of the fluidity of the mixture. As static segregation must be avoided in all cases, the S.S.I. was chosen as "reference mix design parameter". The conclusions of this study may therefore deviate from other results in literature.

4.1. Workability tests for the robustness

Variations induced by changes in the water content affect the filling ability, the passing ability, and the segregation resistance and may result in a rejected mixture. Because a lack of robustness of an SCC mixture is most often not caused by the three key characteristics of SCC at the same time, it is not evident to grasp the variations of the slump flow, V-funnel time, L-box ratio, and sieve stability index into one global 'robustness value'. A better approach is to judge robustness of each mixture based on its most critical parameter: a poor flowability or a too viscous and sticky mixture when the mixture contains 8 l/m³ less water; or a severe segregation of the coarse aggregates or extreme bleeding occurring when 8 l/m³ water in excess is added to the mixture.

Figure 5: The robustness of all mixtures illustrated in a workability box

4.2. Influence of the paste volume

When the paste volume increases, the robustness to variations in the water content of the slump flow and S.S.I. decreases while the sensitivity of the V-funnel time is constant (Table 4 and Figure 3 to 5). As shown in Figure 5, the SCC mixtures with a higher paste volume (full lines) have a lower slump
flow to achieve similar stability and are thus more sensitive to a poor flowability when the water dosage is decreased by 8 l/m² or have a more than proportional increase in S.S.I. when 8 l/m² water is added to the mixture.

4.3. Influence of the volumetric water-to-powder ratio

The robustness determined by changes in the V-funnel time increases when the water-to-powder ratio increases (Table 4, Figure 3, and Figure 5, lines with circles). Because the superplasticizer dosage added to the mixtures decreases with a higher water-to-powder ratio to achieve similar stability, the resulting effect on the sensitivity of the slump flow and S.S.I. is rather limited. Mixtures with a higher water-to-powder ratio have a lower plastic viscosity, making them more dependent on the yield stress to assure a stable mix design. Therefore, the robustness of these mixtures should be assured by increasing the aggregates volume and thus reducing the paste volume. When the water-to-powder ratio of a mixture is rather low, the plastic viscosity might become too high when reducing water by 8 l/m² and the robustness should be guaranteed by a larger paste volume. The paste volume, however, should also not be too high, since this increases the sensitivity of the slump flow of the mixture.

5. Recommendations

Every application of SCC imposes specific demands towards the mix design of the concrete [24]. In order to combine specific workability demands with a sufficient robustness, the following is recommended regarding the paste volume and water-to-powder volume combination while assuming the stability of the mixture, summarized in Table 5.

Table 5: The recommended paste volume and water-to-powder ratio depended on the application

<table>
<thead>
<tr>
<th>Application</th>
<th>Recommended paste volume</th>
<th>Recommended volumetric water-to-powder ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large horizontal elements (floors and plates)</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Long horizontal elements (reinforced beams)</td>
<td>Low</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Long vertical elements (walls)</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Slender vertical elements (columns)</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

5.1. Large horizontal elements (floors and plates)

To facilitate the casting of large horizontal elements, SCC mixtures with high volumetric water-to-powder ratios should be used. Because the stability of such a mixture is provided by its high yield stress, the robustness can be improved by decreasing the paste volume of the mixture.

5.2. Long horizontal elements (reinforced beams)

A slow, but far flowing SCC mixture with a low paste volume and low water-to-paste ratio should be applied. In such a mixture, the stability is achieved by the high plastic viscosity. With a sufficiently high but not too high volumetric water-to-powder ratio, the needed robustness concerning changes in the water content is achieved.

5.3. Long vertical elements (walls)

In order to flow slowly and without segregation in between the reinforcement of long vertical elements, mixtures should have a low yield stress and a high plastic viscosity for its segregation resistance. The high plastic viscosity can be achieved with a low volumetric water-to-powder ratio. A maximum robustness is achieved by a higher paste volume, which should not be too high preventing the yield stress from becoming dominant and thus increasing the sensitivity to an too low flowability.
5.4. **Slender vertical elements (columns)**

In columns and slender walls, the mixture should have a high plastic viscosity and without specific demands towards the yield stress. Because the stability to segregation can be provided by a combination of an intermediate plastic viscosity and yield stress, the mixture needs a low volumetric water-to-powder ratio to obtain the required plastic viscosity and a relatively high paste volume.

6. **Conclusions**

An experimental program including nine SCC mix compositions with different paste volumes and volumetric water-to-powder ratio's demonstrates that the robustness of SCC should be tested with several workability parameters in order to determine the most critical parameter of the mixture for a specific application. Because the L-box ratio does not always provide clear trends, the analysis in this experimental program is based on the slump flow, V-funnel, and sieve stability measurements. For all mixtures, the superplasticizer dosage was adjusted to achieve a specific stability level (S.S.I. = 10±2%).

The robustness of the slump flow increases when the paste volume decreases, because mixtures with a lower paste volume depend mainly on their larger aggregate volume in order to obtain sufficient segregation resistance. The paste volume only has a minor influence on the V-funnel time and its sensitivity. A lower volumetric water-to-powder ratio increases the V-funnel time and increases the risk for the mixture of becoming too viscous when a small decrease of the water content occurs. The limited influence of the water-to-powder ratio on variations of the slump flow is probably caused by the lower superplasticizer dosage of the mixtures with a higher water-to-powder ratio.

7. **Acknowledgements**

The authors would like to thank the Science Foundation Flanders (FWO) for their financial support, and Tom Stulemeijer and Nathan Lampens for their assistance during the experimental work.

8. **References**


27th Biennial National Conference of the Concrete Institute of Australia in conjunction with the 69th RILEM Week

concrete
30 August – 2 September
Melbourne, Australia

construction innovations: RESEARCH INTO PRACTICE
Chair’s Preface

The proceedings contain 171 papers across 14 themes. All the papers included in the proceedings have been selected on the basis of least two peer reviews which were provided by independent reviewers (referees), who were experts in the subject field of the paper. We are grateful to the independent reviewers for their time and effort in reviewing the papers and providing reviews in a timely manner.

Professor Jay Sanjayan
Swinburne University of Technology
Conference Chair
Table of Contents

Keynote Presentations

Ultra High Performance Ductile Concrete: The Delivery from Research into Practice
Stephen Foster and Yen Lei Voo

Low Carbon Emission Geopolymer Concrete: from Research into Practice
Jannie S.J. van Deventer and John L. Provis

Creep and Shrinkage of Concrete – from Theoretical Background and
Experimental Characteristics to Practical Prediction Models
Harald S. Müller Raphael Breiner and Vladislav Kvitsel

Construction Methods

Concrete Hinges at Legacy Way
Peter Boesch, Chin Cheah and Peter Miller

Challenges, Opportunities and Design Impacts for Different Construction Methods on Curtis Island LNG Jetties
Jesper Jensen and Peter Kastrup

A Bond-Slip Modelling Approach for the Transfer Length of Pre-tensioned Concrete
Rik Steensels, Lucie Vandewalle and Hervé Degée

Design for Construction Cockburn Gateway Stage 3 Case Study
Bassam Matty

An Innovative Solution for Temporary Movement Joints in Concrete Floors
Lance Rogers

Officer South Sewage Pumping Station – A Diaphragm Walling Case Study
Marc Perl and Jaya Weerasinghe

Expansion and Mechanical Properties of Reactive Concrete incorporating Fused
Thamer Kubat, Ahmad Shayan and Riadh Al-Mahaidi

Construction 3D Printing
Laurie Edwards, Camille Holt, Louise Keyte, and Redmond Lloyd

The Application of Scattering-filing Stone Concrete on Highway Pavement
Weiguo Shen, Xing Cheng, Liu Cao, Xinning Li, Chaochao Li and Guiming Wang

Preparation and Application of 3D Printing Materials in Construction
Xiqiang Lin, Tao Zhang, Liang Huo, Guoyou Li, Nan Zhang, Baohua Wang
Repair and Retrofitting

The restoration and repairs of the Sir William Goodman Bridge designed by Sir John Monash, Adelaide
John Woodside and Leo Nolcos

Condition Assessment and Structural Repair Solutions for the Renovation of the Sheraton Hotel at Doha, Qatar
Satyajit Datar and Sajeev Kumar Krishnan

Adelaide Railway Station Façade Conservation Works Structural Engineering Aspects
David Kennedy

A Variety of Remediation, Maintenance and Serviceability in its 15 Year Life
Peter Kastrup and Andrew Turnbull

Design of FRP retrofitted concrete structures using AS5100 Part 8
Binh Pham

Investigation of Corrosion, Repair Assessment and Quality Assurance of a Basement subject to Saline Water Ingress
Jonathon Dyson, Marton Maroszzecky and Frank Papworth

Experimental Study on Anchorage Behaviour of the CFRP Grid in Mortar
Bo Wang, Kimitaka Uji, Junlei Zhang, Atsushi Ueno, Kentaro Ohno and Tran Vu

Influence of Fiber Net Reinforced Mortar Repair Coating on the Crack Opening Resistance of Concrete
Yoshinori Kitsutaka and Yukihiro Oyama

Performance of Fire-damaged Concrete Members Strengthened with NSM Laminates Embedded in Epoxy Adhesive
Awad Jadooe, Riadh Al-Mahaidi and Kamiran Abdouka

Behavior of Squat Columns Strengthened with Fiber Reinforced Concrete Jacket
Reza Hassanli and Minoru Kunieda

Failure Mode and Risk Analysis

A Review of Limit State Design Principles and Practice
Douglas Jenkins

Fasteners to Concrete: Failures and Solutions
D. J. Heath, E. F. Gad and J. Lee

AEFAC Anchor Installer Certification Program
Jessey Lee, David Heath and Emad Gad

Guide to Seismic Design & Detailing of Reinforced Concrete Buildings in Australia
Scott Munter, John Woodside and Peter McBean
Structures Research and Applications

Assessment of the Performance of a 24 Year Old Coating Applied to Concrete Bridge Piers Since Construction in a Saline Tidal Environment
Fred Andrews-Phaedonos, Ahmad Shayan and Aimin Xu

Behaviour of Concrete Filled Steel Stub Columns During and After Fire Exposure
Zhong Tao, Xing-Qiang Wang, Tian-Yi Song and Lin-Hai Han

Dynamic Performance Criteria for Suspended Courts at the National Tennis Centre
Mark Sheldon and Benjamin Delaney

Flexural Response of GFRP-Reinforced Geopolymer Concrete Beams
Ginghis B. Maranan, Allan C. Manalo, Warna Karunasena, Brahim Benmokrane and Priyan Mendis

An Experimental Study on the Long-Term Behaviour of Simply-Supported and Continuous Reinforced Concrete Slabs
Md Mahfuzur Rahman, Gianluca Ranzi, Daniel Dias-da-Costa, Arnaud Castel and Raymond Ian Gilbert

Influence of environmental temperature and moisture conditions on the fatigue resistance of concrete
Yasuhiro Koda, Shohei Minakawa and Ichiro Iwaki

An Approach for the Quantification of Ductility and Robustness of Reinforced Concrete Beams and Slabs
R. Ian Gilbert, Stephen Foster and Ankit Agarwal

Experimental study of the mechanical behavior of shear-critical prestressed and reinforced concrete beams
Kristof De Wilder, Guido De Roeck and Lucie Vandewalle

Development of a New Design Expression for the In-Plane Shear Capacity of the Partially Grouted Concrete Masonry Walls.
Thangarajah Janaraj and Manicka Dhanasekar

Transient Heat Transfer Analysis of Reinforced Concrete Members Using a Discrete Crack Approach
D. Dias-da-Costa, L. Godinho and G. Ranzi

In-Plane Behavior of Unbonded Post-Tensioned Concrete Walls
Reza Hassanli

Concrete Slab and Footing Systems for Large Industrial Buildings. A Critical Overview of Current Design Methods for Reactive Clay Sites
Anthony J Davis and Brian Ims
Fibres FRP Research and Applications

Creep of Cracked Polymer Fiber Reinforced Concrete
Rutger Vrijdaghs, Lucie Vandewalle and Marco di Prisco 373

Using FRP as Reinforcement in Precast Concrete Panels for Soil-Concrete Bridges
Sameh Salib 382

Torsional Strengthening of Concrete Members Using Near-Surface Mounted CFRP Composites
G. Al-Bayati, R. Al-Mahaidi and Robin Kalfat 390

Flexural Testing of Concrete Filled Fibre Reinforced Polymer Tubes (CFFT) with and without Internal Fibre Reinforced Polymer (FRP) Reinforcement
Qasim S. Khan, Josiah S. Strong, M. Neaz Sheikh and M.N.S. Hadi 400

Durability Study of Textile Fibre Reinforcement
Natalie Williams Portal, Nelson Silva, Katarina Malaga, Urs Mueller, Peter Billberg 408

Mechanical Properties and Post-crack Behaviours of Recycled PP Fibre Reinforced Concrete
Shi Yin, Rabin Tuladhar, Tony Collister, Mark Combe and Nagaratnam Sivakugan 414

A Novel Ultra High Performance Fibre Reinforced Concrete Spandrel Cladding Panel
Raafat El-Hacha, David Pesta, Gamal Ghoneim and Don Zakariasen 422

Upgrading the Dundas Point Boardwalk, Applecross with the use of GFRP Bar Reinforced Concrete Columns and Footings
Joel Brown 433

A Design Methodology for Fibre Reinforced Concrete Slabs-on-grade
Ravindra Gettu and Sunitha K Nayar 443

FRP Anchors for FRP-Strengthened Concrete Structures: Numerical Modelling
Scott T. Smith, Jia-Qi Yang and Zhen-yu Wang 453

Joint Free Restrained Slabs – SFRC combined with mesh
Alan Ross 459

Concrete Materials and Performance

Neutron Pair Distribution Function Analysis of Synthetic Calcium-Silicate-Hydrate
Claire E. White 471

Using Conventional Materials as Concrete Confinement
Hua Zhao and Muhammad N.S. Hadi 476

Behaviour of Crumb Rubber Concrete Columns under Seismic Loading
Osama Youssf, Mohamed A. ElGawady, Julie E. Mills, Xing Ma and Tom Benn 482

Sulfate Resistance Testing in Germany - Critical Review
Johannes Haufe, Anya Vollpracht and Wolfgang Brameshuber 492
Linking New Australian Alkali Silica Reactivity Tests to World-Wide Performance
Paul Rocker, James Mohammadi, Yute Sirivivathanon and Warren South

Mechanical Properties of Mortar with Oil Contaminated Sand
Rajab M. Abousnina, Allan Manalo and Weena Lokuge

Investigation into the Structural Properties of an Innovative Modified Concrete
Negin Sharifi and Bijan Samali

Twisted Steel Micro-Reinforcement: Proactive Micro-Composite Concrete Reinforcement
Luke Pinkerton, Kevin Fuller and Jeff Novak

Design of UHPFRC Mixtures to be used in Structures Subjected to Impact Loads
Michael F. Petrou, Konstantinos G. Trezos and Anna L. Mina

Effect Rubberised Aggregates from Tyres on the Engineering Performance of M. Sonebi, R. Summerville and S. Taylor

The Effectiveness of Mineral Admixtures and Low Water to Cement Ratio in Concrete for Immobilizing Cesium, Sodium and Iodide from Radioactive Waste
Irfan Prasetia and Kazuyuki Torii

Challenges contemporizing Australian Standards: Supplementary Cementitious Craig Heldrich

Effects of Chemical Admixtures and Aggregate Particles on Spatial Distribution of Cement Particles and Capillary Pores in Mortars
Takuma Nakagawa and Shin-ichi Igarashi

The Effect of Type of Fly Ash on Mechanical Properties of Geopolymer Concrete
M.P.C.M.Gunasekara, David W.Law and Sujeeva Setunge

Towards a More Sustainable Australian Cement and Concrete Industry
James Mohammadi, Warren South and Des Chalmers

Steel, Concrete or Plastic? Support your Reinforcement!
Scott Munter and Mark Turner

Performance of Architectural Concrete: New Approach
Vyacheslav Falikman, Vyacheslav Deniskin and Alexander Vainer

Torsional Behaviour of Reinforced Concrete T-Beam Sections
Douglas Anabalon

Effect of Ultraviolet Radiation on the Physical and Mechanical Properties of Polymer Matrix
Wahid Ferdous, Allan Manalo, Thiru Aravinthan and Gerard Van Erp

Self-healing of Cementitious Composites via Coated Magnesium Oxide/Silica Fume Based Pellets
Rami Alghamri and Abir Al-Tabbaa

Impact of Pore Structure of Lightweight Aggregates on Internal Curing
Pietro Lura, Mateusz Wyrzykowski, Sadegh Ghourchian, Sakprayut Sinthupinyo and Clarence Tang
Reinforcing ordinary Portland Cement Mortar using Carbon Nanotubes
Shu Jian Chen, Xiang Yu Li, Tong Bo Sui and Wen Hui Duan

The Significance of the Alkali Aggregate Reactivity Provisions in the VicRoads Structural Concrete Specification Section 610
Fred Andrews-Phaedonos, Ahmad Shayan and Aimin Xu

Long-term Experiments of Composite Slabs Using Recycled Coarse Aggregate
Qinghe Wang, Gianluca Ranz, Yue Geng and Yuyin Wang

Implications of Alkali- Aggregate Reaction for three Concrete Bridges
Ahmad Shayan, Aimin Xu and Fred Andrews-Phaedonos

Effectiveness of Traditional and Alternative Supplementary Cementitious Materials in Mitigating Alkali-Silica Reactivity
Daniel Pospischil, Vute Sirivivatnanon, Uthayakumar Sivathasan and Kevin Cheney

The Use of Reaction Kinetics in Classifying Alkali Silica Reactivity Potential of Bob Bornstein, David Hocking, Johwelvic Bacolod and Vute Sirivivatnanon

Fresh and Early-Age Properties of Cement Pastes and Mortars Blended with Nickel Muhammad Ashiqur Rahman, Prabir Kumar Sarker and Faiz Ahmed Shalik

Thermo mechanical Behaviour of Epoxy Based Polymer Matrix
Wahid Ferdous, Allan Manalo, Thiru Aravinthan and Gerard Van Erp

Development of an Acid Resistant Concrete
Shamila Salek, Bijan Samali, Vute Sirivivatnanon and Georgius Adam

Effect of the Chemical Composition of Building Materials on Algal Biofouling
Philippe Grosseau, Estelle Dalod, Alexandre Govin, Christine Lors, René Guyonnet and Denis Damidot

Expansive Behavior of Mortars - Containing Surf Clam Shell Powder at Early Age
Akio Watanabe, Kazumi Hirokawa and Takashi Kondo

The use of Cementitious Coatings to Reinstate Low Nominal Cover on Reinforced Concrete Structures
Neil Wilds

Behavior of Concrete after Exposure to Elevated Temperatures
Yaman S. S. Al-Kamaki, Riadh Al-Mahaidi and Ian Bennett

A Discussion on Service Life Prediction of Fly Ash Concrete Structures based on DuraCrete Methodology
Zhuqing Yu and Guang Ye

Effect of Combined Fibres on Fire Resistance of Large Specimens
Youngsun Heo and Byungyeol Min

Mechanical Properties of Fibre Reinforced High Volume Fly Ash Concretes
Yashar Shafaei, Faiz Shalik, Prabir Sarker and Salim Barhuiya
Admixtures and Polymers

Improving the Rheology of High Strength, very low W/C Ratio Concrete. 799
Gary Boon and Tony Thomas

The Effects of Superabsorbent Polymers on the Water Vapour Sorption Properties of Cementitious Materials 805

Benefits of Water-Resisting Admixtures to Watertight Concrete 814
Mohammadreza Hassani, Kirk Vessalas, Daksh Baweja and Zoe Schmidt

The Effect on Expansion of Wrapping Concrete Prisms with Cloth Saturated with Alkali Hydroxide 822
Yasutaka Sagawa, Kazuo Yamada, Shoichi Ogawa, Yuichiro Kawabata and Masahiro Osako

Innovations in Admixtures for Piling Concrete 832
Bruno D'Souza and Hairul Sarwono

Properties of Ultra-lightweight Concrete based on Protein and Surfactant foaming Agent 837
Patrick Hartwich, Thomas Adams, Ali Shams, Anya Vollpracht and Wolfgang Brameshuber

Effect of Guar Gum Derivatives on Fresh State Properties of Portland Cement-Based Mortars 848
Alexandre Covin, Marie-Claude Bartholin, Barbara Biasotti, Max Giudici, Valentina Langella and Philippe Grosseau

The Effect of Superplasticisers and Viscosity Modifiers on the Rheological Properties of Super Workable Concrete 858
Greg Langton and Gary Boon

Durability and Serviceability

Concrete Durability Performance Testing – The Approach Adopted in a Concrete Institute of Australia Recommended Practice 864
W. Green and F. Papworth

A Discussion on the Autogenous Shrinkage Interpretation from the Experimental Shrinkage Measurement Based on the Australian Testing Procedure AS1012.13 875
William A. Thomas, James Mohammadi and Warren South

Performance Test for Hydrophobic Impregnations for Protection against Chloride Ingress in Concrete 884
Nelson Silva, Elisabeth Helsing, Katarina Malaga, Eva Rodum, Minna Torkkel and Arvid Hejl

Durability of Concrete Caissons Made in Floating Docks 894
Jose Vera-Agullo, Francisco Manuel Castro-Visos, Francisco Javier Larraz-Bordanaba, Claudio Troncone-Cusati, Juan Pedro Asencio-Varela, Nelson Silva, Urs Mueller and Katarina Malaga
Prescriptive versus Performance-based Design Approaches for Concrete Durability
Hans Beushausen, Mark Alexander, Manuel Wieland and Stefan Linsel

Durability Performance of Crystalline-Modified Concrete Exposed to Severe Environments
Farhad Nabavi

ISO 16204 and the Correct Solution to Fick
Norwood Harrison

K-value for Carbonation of Concretes with Supplementary Cementitious Materials
Christina Nobis and Anya Vollpracht

Feasibility of Digital Image Correlation Technique to Determine Mechanical Properties of Corroded Steel Rebars
Ranjitha Rajagopal, Sameer Sharma, Radhakrishna G. Pillai and Sankara J.

Determination of Chloride Diffusion Coefficient of Concrete: Comparison of Bulk Diffusion and Electrical Field Method
Aimin Xu and Ahmad Shayan

Frost Test and the Significant Influence of Small Amounts of Ions Dissolved in Surface Water
Max J. Setzer

Durability Planning – a Formalised Approach in Concrete Institute of Australia Recommended Practice
Rodney Paull and Frank Papworth

Time-dependent Stiffness of Concrete Members under Cyclic Loading
Angus Murray, Raymond Ian Gilbert and Arnaud Castel

Role of Ettringite in Expansion and Cracking Potential in Steam Cured Precast Concrete Elements
Johnson Mak, Paul Thomas, Kirk Vessalas and Daksh Baweja

Improved Sustainability by Design for Concrete Durability
R. Doug Hooton

Exp-Ref: A Simple, Realistic and Robust Method to Assess Service Life of Reinforced Concrete Structures
Roberto Torrent

Durability Assessment of Concrete Immersed Tube Tunnel in Hong Kong-Zhuhai-Macau Sea Link Project
Kefei Li, Quanwang Li, Pianpian Wang and Zhihong Fan
Geopolymers and Non-traditional Binder Concrete

Effect of MgO Incorporation on the Structure of Synthetic Alkali-activated Calcium Aluminosilicate Binders
Brant Walkley, Racket San Nicolas, Susan A. Bernal, John L. Provis and Jannie van Deventer

Use of Geopolymer Concrete in Column Applications
Weena Lokuge, Jay Sanjayan and Sujeeva Setunge

Influence of Matrix Related Parameters on Strain Hardening Behavior of Engineered Geopolymer Composite (EGC)
Behzad Nematollahi, Jay Sanjayan and Faiz Uddin Ahmed Shaikh

EFC Geopolymer Concrete Aircraft Pavements at Brisbane West Wellcamp Airport
Tom Glasby, John Day, Russell Genrich and James Aldred

On Fly Ash Based Geopolymer Concrete and its Behaviour at Elevated Temperature
Tian Sing Ng, Stephen J. Foster and Samantha Milojevic

Development of Sugarcane Bagasse Ash Blended Geopolymer for use in Concrete
Deepika S, Madhuri G, Bahurudeen A and Manu Santhanan

Behaviour of Granulated Lead Smelter Slag-Based Geopolymer Concrete
M. Albitar, M.S. Mohamed Ali, P. Visintin and M. Drechsler

Influence of Binder on Alkali Reactivity of Aggregates in Geopolymer Concrete
Chandani Tennakoon, Ahmad Shayan and Jay G. Sanjayan

Rheological Properties of Sodium Carbonate Alkali-Activated Fly Ash/Slag pastes with Different Superplasticisers
Ahmed Abdalqader and Abir Al-Tabbaa

Direct Electric Curing of Alkali-Activated Concretes. Preliminary Study
Maxim Kovtun, Julia Shekhovtsova and Elsabe Kearsley

Investigation on Engineering Properties of Powder-activated Geopolymer Concrete
Kamal Neupane, Daksh Baweja, Rijun Shrestha, Des Chalmers and Paul Kidd

Alkali-Activated Foamed Concrete
Elsabe Kearsley and Maxim Kovtun

Alternative Concrete Materials from Industrial Waste
Valle Chozas, Ignacio del Val, José Vera and Íñigo Larraza

Progress Towards a Handbook for Geopolymer Concrete
Marita Allan Berndt, Jay Sanjayan, Stephen Foster, Arnaud Castel, Pathmanathan Rajeev and Craig Heidrich

Development of Low Shrinkage Water Repelling Foamed Concrete
Kai Tai Wan, Honggang Zhu, Binmeng Chen and Chuanlin Hu

A Resistivity-Based Approach to Indicate Chloride Permeability of Geopolymer
Amin Noushini and Arnaud Castel

Chloride induced Corrosion of reinforcing bars in Geopolymer concrete
M. Babaee and A. Castel

Specifying Fly Ash for Use in Geopolymer: A Conception of Reactivity Index
Hao Wang, Zuhua Zhang, John L. Provis and Jin Zou
Structural Monitoring and Assessment

Evaluation of the Level of Damage of Concretes Affected by Expansive Reactions at Meso and Microstructural Scale. Relationship between Alkali-aggregate Reaction and Internal Sulfate Attack
Esperanza Menéndez, Ricardo García Rovés and Nicanor Prendes

The Impacts of Temperature and Salinity Variance on Service Life Modeling as a Result of Climate Change.
Andrew Hunting, Sujeeva Setunge and David Law

In situ and Laboratory Testing of Different Repair Materials.
Luković, M., Gellweiler, W. A., Sierra Beltran, M. G., Blom, C. B. M., Savija, B., Zanten, van, D. C., Schlangen, E., Ye, G. and Taffijn, E.

Acid-soluble and Water-soluble Chloride – Testing Proficiency and Specification
Warren South, Tony Thomas and Vute Sirivivathanon

Integrated Fracture-based Model for the Analysis of Cracked Reinforced Concrete Beams
Tahreer M. Fayyad and Janet M. Lees

Predicting Fire Induced Spalling in Concrete Structural Elements
James M. de Burgh, Stephen J. Foster and Hamid R. Valipour

In-situ Concrete Strength Assessment based on Ultrasonic (UPV), Rebound, Cores and the SONREB Method
Frank Papworth, David Corbett, Reuben Barnes, Joseph Wyche and Jonathon Dyson

Full Scale Concentric Punching Shear Testing of Two-way Floor with Bonded Post-tensioning and Studrails
Fariborz Moeinaddini, Kamiran Abdouka and Andrew Barraclough

Experimental Study on Carbon Fiber Reinforced Concrete for Strain Measurement of RC Portal Frame
Fang-Yao Yeh, Kuo-Chun Chang and Wen-Cheng Liao

Early-age Concrete and Cracking

Temperature Monitoring of Concrete Elements for In-situ Strength Measurement and Prevention of Damage from Heat of Hydration
Reuben Barnes, Frank Papworth, William Ward and Jim O'Daniel

The Role of Dilation in Shrinkage Cracking of Concrete
Suhaila Mattar and R. S. Al-Rawi

High-absorptive Normal-weight Aggregates used as Internal Curing Agent
Pericles A. Savva and Michael F. Petrou

Tensile Properties of Early-Age Concrete
Duy NGUYEN and Vinh T.N. DAO

Experimental Study of Creep and Shrinkage in Early-age Concrete
Inamullah Khan, Angus Murray, Arnaud Castel and Raymond Ian Gilbert
Self-Compacting Concrete

The Combined Influence of Paste Volume and Volumetric Water-to-Powder Ratio on Robustness of Fresh Self-Compacting Concrete 1335
Farid Van Der Vurst, Steffen Grünewald, Dimitri Feys and Geert De Schutter

Instantaneous and Time-Dependent Behaviour of Reinforced Self-Compacting Concrete Slabs 1345
Farhad Aslani, Shami Nejadi and Bijan Samali

Foam Concrete-aerogel Composite for Thermal Insulation in Lightweight Sandwich Facade Elements 1355
Nelson Silva, Urs Mueller, Katarina Malaga, Per Hallingberg and Christer Cederqvist

Fib-C6

Prefabricating in Unusual Environments 1364
Marco Menegotto and Luciano Marcaccioli

Paddington Rail Station 1374
George Jones

PCI Design Awards Program 1382
Jason Krohn, Daniel Roman and Karia Vazquez

Sustainability of Structures with Precast Elements 1391
D. Fernández-Ordóñez, B. González-Rodrigo, J. Ramírez and R. Valdivielso

Major Projects Case Studies

Christchurch Art Gallery Foundation Strengthening and Building Re-Level 1400
James O'Grady, William Lindsay and Russell Deller

Design of Berthing Dolphins on Curtis Island LNG Jetties 1408
Jesper Jensen, Peter Kastrup and Matt Hodder

Lady Cilento Children's Hospital 1418
Ken Gallie and Darryl Feodoroff

Documentation of Bridge Deck Construction Using Industrially Produced Internally Cured, High Performance Concrete 1430
Timothy J. Barrett Albert E. Miller and W. Jason Weiss