CONTROLLING THE CONSISTENCY OF SELF-COMPACTING CONCRETE

Imas Satyarno\(^1\), Slanet Widojo\(^2\), Antonius A Dharmawan\(^3\) and Jeffry O Baklara\(^4\)

ABSTRACT

Self-Compacting Concrete or SCC is defined as concrete that has an ability to compact by means of its own weight and without the need for vibrating compaction. This kind of concrete has been introduced since more than 10 years ago and was applied mostly for precast concrete. Currently, Self-Compacting Concrete is widely used for big projects including for underwater concrete. In the fresh condition SCC must have a very high consistence and has an ability to flow. This paper discusses the application of Sika Viscocrete-3 to control the consistence of SCC. In the experiment Sika Viscocrete-3 admixture and silica fume were used in the mix in addition to water, cement, and aggregate, to achieve the requirements for SCC. Two water-cement ratios of 0.40 and 0.43 were applied with variation of Sika Viscocrete-3 of 0.3% 0.6%, 0.8%, 1.0% and 1.3% of binder weight. Three methods of measuring concrete consistency were used they were slump test, flow table test, and U type test. From the test results it can be concluded that the Sika Viscocrete-3 should be at least 0.70% for water-cement ratio of 0.45 and 0.80% for water-cement ratio of 0.40 to achieve the requirement of SCC. It is also found that the application of Sika Viscocrete-3 increases significantly the SCC consistency and compressive strength. However, it is worth to note that as the concrete becomes SCC compaction process shall be omitted to avoid excessive bleeding that tends to reduce the compressive strength.

INTRODUCTION

In underwater concrete projects, it is required that the concrete has a very high consistence. This is because the concrete must flow readily into place and consolidate under its own weight as vibration might cause surrounding water to mix with the in-place concrete and wash out the cement (Malisch 1989). A lump of 150 mm to 230 mm is commonly used to satisfy the above requirements and can only be achieved by Self-Compacting Concrete.

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This type of concrete has been developed more than 10 years ago in Japan primarily to avoid the need of compacting machine even in the crowded reinforcement [Ouchi (2001)]. The SCC must fill the formwork completely without large bubbles, enclose the reinforcement, desaturate with the force of gravity and must not segregate [Proskuc (2003)]. According to EFNARC (2002) SCC has the following advantages:
1. faster construction,
2. reduction in site manpower,
3. better surface finishes,
4. easier placing,
5. improved durability,
6. greater freedom in design,
7. thinner concrete section,
8. reduced noise levels due to the absence of vibration,
9. safer working environment.

Recently SCC is used in big projects such as in the project of the longest Akashi-Kaikyo suspension bridge in Japan that was opened in 1998. In this project SCC was used in the two anchorages [Ouchi (2001)]. In the final analysis, the use of Self-Compacting Concrete shortened the anchorage construction period by 20% from 2.5 to 2 years.

Although SCC has been commonly used in overseas, this kind of concrete is still rarely used in Indonesia. This is especially because the required admixture is just recently introduced in Indonesia by Sika (2001), that is Sika ViscoCrete-5. Therefore it is necessary to carry out an experiment to study the application of this admixture in making Self-Compacting Concrete especially in controlling the concrete consistency.

THEORY

The consistency or workability of normal concrete is greatly determined by the amount of water used in the mix. The more the water used the more consistency or workability will be achieved, which can be indicated by the increase of slump (Neville (1975), Minnock and Young (1981)). To maintain the water-cement ratio, and hence the compressive strength, the amount of cement used to be increased as the amount of water is increased. To achieve a slump of 175 mm for example around 200 to 250 liters of water per cubic meter of concrete is required. If the water-cement ratio or w/c of 0.40 is used, which is common for under water concrete, the required cement is already around 500 to 625 kg. More water seems unreliable to be used to get a higher consistency. To increase concrete consistency beyond that level, Sika ViscoCrete-5 has been produced [Sika (2001)] for the use in Self-Compacting Concrete.

Sika ViscoCrete-5 is a third generation of superplasticizer which facilitates extreme water reduction, excellent flowability with at the same time gives optimal cohesion and highest self compacting behaviour. It acts by different mechanism, through surface adsorption and steric separation effect on the cement particles in parallel to the hydration process. This admixture is based on aqueous solution of modified
polyurea-cyanoate, where the appearance is turbid liquid. The density is 1.09 kg/l, and the pH value is 8.6. Sika Visocrete-5 does not contain chloride or other steel corrosion-promoting ingredients.

As mentioned above, Self-Compacting Concrete has a very high slump, which commonly more than 200 mm as shown in Figure 1. This makes the Slump Test not be reliably used for measuring the SCC consistency. Instead two other methods are recommended, they are Flow Table Test and U-Type Test.

Flow Table Test is commonly used for concrete with high consistency like SCC as shown in Figure 2. The apparatus consists of two sheets of wood 70 cm by 70 cm where the top sheet is covered with steel plate and is mounted so that it can be jolted by a drop of 4 cm [Neville and Brooks (1987)]. A mould in the shape of fracture of a can is placed at the center of the table and is filled with concrete. The mould is raised vertically after 30 seconds. The table is then jolted 15 times in 4 seconds. As a result the concrete spreads over the table, and the average diameter of the spread concrete is measured. The concrete can be said as highly flowable if the concrete spread shown in Figure 2 is more than 50 cm.

Figure 1: Very high slump of Self-Compacting Concrete.
The new test method proposed for evaluating Self-Compacting Concrete has been proposed by the Taisei group, that is the U-Type Test as shown in Figure 3 [Ouchi (2001)]. In this test the degree of compactibility can be indicated by the height of the concrete reached after it flows through an obstacle. The concrete is said as Self-Compacting concrete if the height h shown in Figure 3 is at least 240 mm [Ferraris, et al. (2000)].

For underwater concrete, Malisch (1986) suggests that minimum of 300 kg of cement per cubic meter concrete must be used in the mix. Up to 15% pozzoland to improve the flow characteristics is also recommended with the maximum water-cement ratio is 0.45. Fine aggregate content of 45% to 55% by volume of total aggregate must be adopted.

Figure 2: Flow Table Test

Figure 3: U-Type Test.
EXPERIMENTAL WORKS

The materials, apparatus and variations applied in the experiment are explained as follows. More detail explanation of the experiment can be found in Dharmawan (2002), Bakkara (2003), and Widodo (2003).

Materials

The materials used in the experiment are:

1. water,
2. Type I Portland Cement of Gresik,
3. well graded crushed aggregate from Purworejo, where the maximum diameter is 20 mm, the specific gravity is 2.60, and the water absorption is 2.14%.
4. fine aggregate from Progo river, where the specific gravity is 2.68, the water absorption is 2.32%, and the fineness modulus is 2.90,
5. Sika ViscoCrete-5 and Sikacrete-W (silica fume) as concrete admixtures.

Apparatus

The main apparatus used in this research are as follows:

1. a set of sieve shaker,
2. concrete mixer,
3. concrete cylinder mould,
4. mould for the slump test,
5. apparatus for Flow Table Test as shown in Figure 2,
6. apparatus for U-Type Test as shown in Figure 3,
7. Los Angeles machine,
8. Universal Testing Machine,
9. other supporting apparatus such as caliper, weighing, stopwatch and spoon.

Procedure

To see the effect of Sika ViscoCrete-5 in controlling the consistency of Self-Compacting Concrete, the variations of this admixture as the weight of binder were used as follows 0.3%, 0.6%, 0.8%, 1.0% and 1.3%. It is noted here that the maximum applied Sika ViscoCrete-5 already exceeds the maximum dosage recommended by the producer that is 0.80%. Three test methods to measure the concrete consistency or workability were applied, they were Slump Test, Flow Table Test and U-Type Test. The concrete was then poured into the moulds with two methods. In the first method the concrete was compacted during the pouring as shown in Figure 9, and in the second method the concrete was not compacted. The cylinders were then tested after 56 days to evaluate their compressive strength and the effect of compaction on the compressive strength.
Mix Design

The mix design was taken based on SNI 03-2834-1992 with two water-cement ratios. They were 0.40 for high performance underwater concrete and 0.45 for ordinary under water concrete. A modification of the mix was taken in the aggregate composition, where the portion of fine aggregate was taken 50% of the total aggregate to reduce the possibility of segregation as suggested by Malisch (1986). To further reduce the possibility of segregation silica fume was also added in the mix. The amount of silica fume was 10% of the applied cement weight. The composition of materials used with variation of Sika Visocrete-5 of 0.30%, 0.60%, 0.80%, 1.00% and 1.30% is shown in Table 1. The amount of water is reduced as the amount of admixture is increased to maintain the same water-cement ratio.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Water cement ratio = 0.40</th>
<th>Water cement ratio = 0.45</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variation of Visocrete-5</td>
<td>Variation of Visocrete-5</td>
</tr>
<tr>
<td></td>
<td>(percentage of binder's weight)</td>
<td>(percentage of binder's weight)</td>
</tr>
<tr>
<td>Viscocrete-5 (l)</td>
<td>1.4 2.8 3.8 4.7 6.1</td>
<td>1.3 2.5 3.4 4.2 5.4</td>
</tr>
<tr>
<td>Water (l)</td>
<td>203.5 202.0 201.0 200.0 198.5</td>
<td>203.5 202.5 201.5 200.5 199.5</td>
</tr>
<tr>
<td>Cement (kg)</td>
<td>462 462 462 462 462</td>
<td>413 410 410 410 410</td>
</tr>
<tr>
<td>Silica fume (kg)</td>
<td>51 51 51 51 51</td>
<td>46 46 46 46 46</td>
</tr>
<tr>
<td>Coarse aggregate (kg)</td>
<td>811 811 811 811 811</td>
<td>840 840 840 840 840</td>
</tr>
<tr>
<td>Fine aggregate (kg)</td>
<td>811 811 811 811 811</td>
<td>840 840 840 840 840</td>
</tr>
<tr>
<td>Total weight (kg)</td>
<td>2340 2340 2340 2340 2340</td>
<td>2340 2340 2340 2340 2340</td>
</tr>
</tbody>
</table>

Note: binder = cement + silica fume

EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental results and discussions explained in this paper are divided into two parts, they are consistency or workability and compressive strength.

Consistency or Workability

The results of consistency tests using the three methods are shown in Table 2 and Figures 4 to 6. From these table and figures it is clear that Sika Visocrete-5 significantly increases concrete's consistency. This result is in accordance to the Yamada (2000) test results that superplasticizer which is based on polycarboxylate has an ability to disperse cement particles and effectively increases the cement fluidity.
<table>
<thead>
<tr>
<th>Sika ViscoCrete-5 (%)</th>
<th>Average slump (cm)</th>
<th>Average Flowability (cm)</th>
<th>Average Self-Compactability (cm)</th>
<th>Water-cement ratio</th>
<th>Water-cement ratio</th>
<th>Water-cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.40</td>
<td>0.45</td>
<td>0.40</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>17.5</td>
<td>20</td>
<td>40</td>
<td>46</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>0.6</td>
<td>21.0</td>
<td>23</td>
<td>46.5</td>
<td>48</td>
<td>20</td>
<td>22</td>
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<tr>
<td>0.8</td>
<td>23.0</td>
<td>24.5</td>
<td>50</td>
<td>51.3</td>
<td>25</td>
<td>28</td>
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<tr>
<td>1.0</td>
<td>24.5</td>
<td>25</td>
<td>51</td>
<td>53</td>
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<td>29</td>
</tr>
<tr>
<td>1.3</td>
<td>25.5</td>
<td>26.5</td>
<td>54.5</td>
<td>57</td>
<td>30</td>
<td>32</td>
</tr>
</tbody>
</table>

The graphs of slump values shown in Figure 4 tend to asymptote at the value of 24 cm which correlate to the application of around 0.80% of Sika ViscoCrete-5. This means that the slump cannot distinctly indicate the level of consistency for the slump beyond this value. Therefore, the application of slump test is not recommended to measure the consistency of Self-Compacting Concrete as previously noted by Ouchi (2001).

![Figure 4: Effect of Sika ViscoCrete-5 on slump.](image-url)
The Flow Table Test and U-Type Test on the other hand can still distinctly measure the concrete consistency for the application of Sika ViscoCrete-5 more than 0.80%. From Figure 5, it is clear that concrete is very flowable for the application of Sika ViscoCrete-5 over 0.70% for water-cement ratio of 0.45 and 0.80% for water-cement ratio of 0.40. From Figure 6 it is apparent that to make a Self-Compacting Concrete the required amount of Sika ViscoCrete-5 is at least 0.65% for water-cement ratio of 0.45 and is at least 0.75% for water-cement ratio of 0.40.

Figure 5: Effect of Sika ViscoCrete-5 on flowability.
Figure 6: Effect of Sika ViscoCrete-5 on Self-Compacting Concrete.

Compressive Strength

The results of compressive tests at the age of 56 days are shown in Figure 7 for water-cement ratio of 0.40 and in Figure 8 for water-cement ratio of 0.45. From these figures, it is clear that the application of Sika ViscoCrete-5 has the following effects on the compressive strength of concrete.

1. The compacted concrete and the uncompacted concrete or Self-Compacting Concrete show different trends of compressive strength due to the application of Sika ViscoCrete-5. In this case the compaction was carried out using standard procedure with 16 mm steel bar as shown in Figure 9.

2. At lower content of Sika ViscoCrete-5, the compressive strength of compacted concrete is higher than the uncompacted one. On the contrary at higher contents of Sika ViscoCrete-5 the compressive strength of compacted concrete is lower than the uncompacted one. The different is more distinct in the case of water-cement ratio of 0.40.

3. For uncompacted concrete or Self-Compacted Concrete, the compressive strength is consistently increases as more Sika ViscoCrete-5 is used. In the case of 0.40 water-cement ratio, the compressive strength increases from 29 MPa for 0.30% of Sika ViscoCrete-5 to 44 MPa for 1.30% of Sika ViscoCrete-5 or increases 52%. In the case of 0.45 water-cement ratio, the compressive strength increases from 28 MPa for 0.30% of Sika ViscoCrete-5 to 45 MPa for 1.30% of Sika ViscoCrete-5 or increases 61%.
Figure 7: Effect of compaction in concrete with Sika ViscoCrete-5 for 0.40 water-cement ratio on compressive strength.

Figure 8: Effect of compaction in concrete with Sika ViscoCrete-5 for 0.4 water-cement ratio on compressive strength.
Figure 9: Compacting concrete with standard 16 mm steel bar.

Figure 10: Compressive test results that show weaker region in the upper part due to bleeding that happened during compaction.
The lower compressive strength of compacted concrete is caused by the fact that Sika ViscoCrete-5 tends to increase bleeding. As the concrete is compacted in the mould the water rises to the surface and make a higher water-cement ratio in the upper region than in the lower region [Dharmawan (2002) and Bakkara (2003)]. As the water-cement ratio in the upper region of cylinder is lower than the lower one, the upper region becomes weaker. This can be seen during the compressive test where the concrete crush occurred in the upper region as shown in Figure 10. Therefore compaction procedure should be avoided in the Self-Compacting Concrete, especially for the application of high content of Sika ViscoCrete-5.

CONCLUSIONS

From the experimental results and discussions mentioned above it can be concluded that the application of Sika ViscoCrete-5 to control the consistency of Self-Compacting Concrete with 0.40 and 0.45 water-cement ratios has the following conclusions.

1. The amount of Sika ViscoCrete-1 shall be taken at least 0.70% for water-cement ratio of 0.45 and 0.80% for water-cement ratio of 0.40 to satisfy the requirements of Flow Table Test and Slf-Compacting Test.

2. Although the application of 1.30% of Sika ViscoCrete-5 still shows a good result in term of consistency and compressive strength, the application of Sika ViscoCrete-5 above this value is not recommended by the Sika manufacturer.

3. The compressive strength of Self-Compacting Concrete increases as the increase of Sika ViscoCrete-5.

4. Compaction process should be avoided in the Self-Compacting Concrete as it can reduce the compressive strength due to bleeding that occurs due to the compaction itself.

RECOMMENDATION

Further study should be done to see the application of Self-Compacting Concrete on the concrete structures with reinforcement. The study can also be extended for underwater concrete structures.

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