A SIMPLE TOOL FOR SELF COMPACTING CONCRETE MIX DESIGN

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ABSTRACT
SCC can be made from any of the constituents that are generally used for structural concrete. In the mix design of SCC, the relative proportions of key components are generally considered by volume rather than by mass. On the basis of these proportions, a simple tool has been designed for self compacting concrete (SCC) mix design. In this paper, this tool has been evaluated with a SCC mix having 28% of coarse aggregate content, 35% replacement of cement with class F fly ash, 0.36 water/cementitious ratio (by weight) and 388 litre/m³ of paste volume. Crushed granite stones of size 20mm and 10mm are used with a blending 60:40 by percentage weight of total coarse aggregate. Detailed steps used in this tool are discussed in this study. This tool can also be used for self compacting mortar (SCM) design. It is practically seen that this simple tool is very much useful for the mix design of SCC with or without blended cement and with or without coarse aggregate blending.

KEYWORDS: Self compacting concrete, mix design, simple tool, self compacting mortar.

I. INTRODUCTION
According to ACI 237R-07, self compacting concrete (SCC) is highly flowable, non segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation [1]. Professor Okamura in Japan proposed a concept for a design of concrete independent of the need for compaction in 1986. Ozawa and Maekawa produced the first prototype of SCC at the university of Tokyo in 1988 [14] and [15]. The general purpose mix design method was first developed by Okamura and Ozawa [12].

Recommendations on the design and applications of SCC in construction have been developed by many professional societies like American Concrete Institute (ACI), American Society for Testing and Materials (ASTM), European Federation of National Trade Associations (EFNARC 2002) etc. Although SCC has passed from research stage to field applications, there are no systematic standards or specifications to be followed in its mixture proportioning [9].

In reviewing literature on the methods for proportioning SCC, numerous methods exist, most of which give only general guidelines and ranges of quantities of materials to be used in SCC proportioning. The emphasis of these methods is on the fresh properties of SCC [8]. From the review of previous research on SCC, it was found that the EFNARC method for proportioning SCC have been used extensively.

SCC with low yield stress will be achieved by adding superplasticiser (SP), water, paste or some additives (fly ash or GGBS) [11]. Viscosity is controlled by changing water content, paste content or adding some additives (fly ash) or viscosity modifying agent (VMA) [10] and [11].

As SCC requires high cement content that leads to increase in cost and temperature rise during hydration, additives or mineral admixtures such as fly ash, limestone powder or slag can generally be used as partial replacement of cement to reduce the cost and heat of hydration [13].
1.1 Selection of Mix Proportions
In designing the SCC mix, it is most useful to consider the relative proportions of the key components by volume rather than by mass [7]. The following key proportions for the mixes listed below [12], [7], [10] and [6]:

1. Air content (by volume)
2. Coarse aggregate content (by volume)
3. Paste content (by volume)
4. Binder (cementitious) content (by weight)
5. Replacement of mineral admixture by percentage binder weight
6. Water/binder ratio (by weight)
7. Volume of fine aggregate/volume of mortar
8. SP dosage by percentage cementitious (binder) weight
9. VMA dosage by percentage cementitious (binder) weight

1.2. Research Significance
A simple and user friendly tool has been developed for SCC mix design (“JGJ_SCCMixDesign.xls”) on the basis of key proportions of the constituents of SCC with or without blended cement and with or without coarse aggregate blending.

1.3. Outline of This Paper
This paper includes the selection of mix proportions for SCC from the relevant literature, the experimental program, material properties, design of SCC mix design tool, calculation of key proportions for a given SCC scenario, evaluation of SCC mix design and conclusions.

II. EXPERIMENTAL STUDY

2.1. Experimental Program
Our objective was to develop a simple tool for SCC mix design with the available materials. In this study, this tool has been used to design a SCC mix having 28% of coarse aggregate content and 388 litre/m$^3$ of paste volume, 35% replacement of cement with class F fly ash and 0.36 water/binder ratio (by weight). Crushed granite stones of size 20mm and 10mm are used with the blending 60:40 by percentage weight of total coarse aggregate.

2.2. Material Properties
This section will present the chemical and physical properties of the ingredients. Bureau of Indian Standards (IS) and American Society for Testing and Materials (ASTM) procedures were followed for determining the properties of the ingredients in this investigation.

2.2.1. Cement
Ordinary Portland Cement 53 grade was used corresponding to IS-12269(1987) [5]. The specific gravity of cement is 3.15.

2.2.2. Chemical Admixtures
Sika Viscocrete 10R is used as high range water reducer (HRWR) SP and Sika Stabilizer 4R is used as VMA. Percentage of dry material in SP and VMA is 40%.

2.2.3. Additive or Mineral Admixture
Class F fly ash produced from Rayalaseema Thermal Power Plant (RTPP), Muddanur, A.P is used as an additive according to ASTM C 618 [2]. As per IS-456(2000) [3], cement is replaced by 35% of fly ash by weight of cementitious material. The specific gravity of fly ash is 2.12.

2.2.4. Coarse Aggregate
Crushed granite stones of size 20mm and 10mm are used as coarse aggregate. As per IS: 2386 (Part III)-1963 [4], the bulk specific gravity in oven dry condition and water absorption of the coarse aggregate are 2.6 and 0.3% respectively. The dry-rodded unit weight (DRUW) of the coarse aggregate with the coarse aggregate blending 60:40 (20mm and 10mm) as per IS: 2386 (Part III)-1963 [4] is 1646 kg/m$^3$.

2.2.5. Fine Aggregate
Natural river sand is used as fine aggregate. As per IS: 2386 (Part III)-1963 [4], the bulk specific gravity in oven dry condition and water absorption of the sand are 2.6 and 1% respectively.

2.2.6. Water
Ordinary tap water is used.

III. **DESIGN OF SELF COMPACTING CONCRETE MIX DESIGN TOOL**

### 3.1. Material Properties for SCC Mix Design Tool

The following material properties for the SCC mix design tool are to be determined as shown in Table 1.

1. Specific gravity of cement, fly ash, coarse aggregate and fine aggregate.
2. Percentage of water absorption of coarse and fine aggregates.
3. Percentage of moisture content in coarse and fine aggregates.
4. Dry-rod ded unit weight (DRUW) of coarse aggregate for the particular coarse aggregate blending.
5. Percentage of dry material in SP and VMA.

<table>
<thead>
<tr>
<th>Material Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Cement</td>
</tr>
<tr>
<td>Additive – Fly Ash</td>
</tr>
<tr>
<td>Coarse aggregate (CA1 20mm)</td>
</tr>
<tr>
<td>Coarse aggregate (CA2 10mm)</td>
</tr>
<tr>
<td>Fine aggregate (Sand)</td>
</tr>
</tbody>
</table>

### 3.2. Detailed Steps for SCC Mix Design Tool

The detailed steps for mix design are described as follows:

1. Assume air content by percentage of concrete volume.
2. Input the coarse aggregate blending by percentage weight of total coarse aggregate.
3. Input the percentage of coarse aggregate in DRUW to calculate the coarse aggregate volume in the concrete volume.
4. Adjust the percentage of fine aggregate volume in mortar volume.
5. Obtain the required paste volume.
6. Adopt suitable water/binder ratio by weight.
7. Input the percentage replacement of fly ash by weight of cementitious material.
8. Input the dosage of SP and VMA (if required) by percentage weight of binder.
9. Adjust the binder (cementitious material) content by weight to obtain the required paste.

The coarse aggregate optimization is shown in Table 2. The input parameters section is shown in Table 3.

<table>
<thead>
<tr>
<th>Coarse aggregate optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>CA1 20mm</td>
</tr>
<tr>
<td>CA2 10mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Rodded Unit Weight(kg/cum)</td>
</tr>
<tr>
<td>% of CA in DRUW</td>
</tr>
<tr>
<td>% of Sand in Mortar</td>
</tr>
<tr>
<td>% of Fly ash</td>
</tr>
<tr>
<td>Wt. Water/Binder</td>
</tr>
<tr>
<td>Binder (kg/cum)</td>
</tr>
<tr>
<td>SP (% wt.of binder)</td>
</tr>
</tbody>
</table>
3.3. Output Constituent Materials for SCC

After giving all the necessary data, the tool automatically calculates and shows the required output. Concrete mix proportions by volume and total aggregate by weight are shown in Table 4.

**Table 4. Concrete Mix Proportions by Volume**

<table>
<thead>
<tr>
<th>Material</th>
<th>Coarse aggregate (kg/cum)</th>
<th>% of CA in concrete volume</th>
<th>Concrete Mix proportions by volume (lit/cum)</th>
<th>Sand (kg/cum)</th>
<th>Total aggregates (kg/cum)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>729.178</td>
<td>28.04530769</td>
<td>CA</td>
<td>280.4531</td>
<td>1591.626942</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mortar</td>
<td>719.5469</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sand</td>
<td>331.7111</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Paste</td>
<td>387.8357915</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>862.448942</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1591.626942</td>
<td></td>
</tr>
</tbody>
</table>

Paste composition is shown in Table 5. Constituent materials for SCC are shown in Table 6. Constituent materials for SCM are shown in Table 7. This tool also displays the constituent materials for the required volume of SCC or SCM as shown in Table 6 and Table 7. Aggregate proportions by volume and by weight are shown in Table 8.

**Table 5. Paste Composition**

<table>
<thead>
<tr>
<th>Paste composition</th>
<th>Vol. Water/Powder</th>
<th>0.969191695</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kg/cum</td>
<td>lit/cum</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>321.75</td>
<td>0.2574</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>173.25</td>
<td>0.1386</td>
</tr>
<tr>
<td>Water</td>
<td>178.2</td>
<td>0.027621</td>
</tr>
<tr>
<td>SP</td>
<td>4.455</td>
<td>0.003564</td>
</tr>
<tr>
<td>VMA</td>
<td>0.99</td>
<td>0.006138</td>
</tr>
<tr>
<td>Paste</td>
<td>387.5096</td>
<td></td>
</tr>
</tbody>
</table>

**Table 6. Constituent Materials for SCC**

<table>
<thead>
<tr>
<th>Material (kg/cum)</th>
<th>Initial</th>
<th>Adjusted</th>
<th>Required (cum)</th>
<th>g/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>321.75</td>
<td>321.75</td>
<td>1.99485</td>
<td>1994.85</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>173.25</td>
<td>173.25</td>
<td>1.07415</td>
<td>1074.15</td>
</tr>
<tr>
<td>Water</td>
<td>178.2</td>
<td>185.745</td>
<td>1.151619</td>
<td>1151.619</td>
</tr>
<tr>
<td>CA1 20mm</td>
<td>437.5068</td>
<td>437.5068</td>
<td>2.71254216</td>
<td>2712.542</td>
</tr>
<tr>
<td>CA2 10mm</td>
<td>291.6712</td>
<td>291.6712</td>
<td>1.80836144</td>
<td>1808.361</td>
</tr>
<tr>
<td>Sand</td>
<td>862.4489</td>
<td>862.4489</td>
<td>5.34718344</td>
<td>5347.183</td>
</tr>
<tr>
<td>SP (lit)</td>
<td>4.455</td>
<td>4.455</td>
<td>0.027621</td>
<td>27.621</td>
</tr>
<tr>
<td>VMA (lit)</td>
<td>0.99</td>
<td>0.99</td>
<td>0.006138</td>
<td>6.138</td>
</tr>
<tr>
<td>Unit Weight</td>
<td>2270.272</td>
<td>Total (kg)</td>
<td>14.12246519</td>
<td>14122.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Litres</td>
<td>6.12075648</td>
<td></td>
</tr>
</tbody>
</table>

**Table 7. Constituent Materials for SCM**

<table>
<thead>
<tr>
<th>Material (kg/cum)</th>
<th>Initial</th>
<th>Adjusted</th>
<th>Required (cum)</th>
<th>g/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>321.75</td>
<td>321.75</td>
<td>0.2574</td>
<td>257.4</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>173.25</td>
<td>173.25</td>
<td>0.1386</td>
<td>138.6</td>
</tr>
<tr>
<td>Water</td>
<td>178.2</td>
<td>183.5575</td>
<td>0.146845992</td>
<td>146.846</td>
</tr>
<tr>
<td>Sand</td>
<td>862.4489</td>
<td>862.4489</td>
<td>0.689959154</td>
<td>689.9592</td>
</tr>
<tr>
<td>SP (lit)</td>
<td>4.455</td>
<td>4.455</td>
<td>0.003564</td>
<td>3.564</td>
</tr>
</tbody>
</table>
IV. Calculation of Key Proportions

The detailed steps for calculation of key proportions are presented below with an example. The interface of SCC mix design tool for the mix 28.60:40 is shown in Figure 1.

SCC Mix Scenario: A SCC mix with 28% coarse aggregate content of concrete volume with a paste volume of 388 litre/m³ have been designed for water/binder ratio 0.36 (by weight). Cement has been replaced with 35% of Class F fly ash by percentage weight of cementitious material. Coarse aggregate of sizes 20mm and 10mm with coarse aggregate blending 60:40 by percentage weight of total aggregate are used in this mix. SP and VMA are used. All the material properties and input parameters are shown in Table 1 and Table 3. Air content assumed as 2% of concrete volume.

4.1. Calculation of Coarse Aggregate Content in Concrete Volume

Coarse aggregate blending : 60:40
Specific gravity of 20mm & 10mm : 2.6
DRUW of coarse aggregate : 1646 kg/m³
% of Coarse aggregate in DRUW : 44.3
Coarse aggregate weight : 1646*(44.3/100) = 729.18 kg/m³
Coarse aggregate volume : \[(729.18*(60/100))/2.6\] + \[(729.18*(60/100))/2.6\] =280.45 litre/m³ or 28.05%

4.2. Calculation of Mortar Volume

Mortar Volume : Concrete volume-coarse aggregate volume
: 1000-280.45 = 719.55 litre/m³

4.3. Calculation of Sand Volume

% of sand in Mortar volume : 46.1
Sand Volume : 719.55*(46.1/100) = 331.71 litre/m³

4.4. Calculation of Paste Volume

Paste Volume : Mortar volume-sand volume
: 719.55-331.71 = 387.84 litre/m³

4.5. Calculation of Paste Composition

Specific gravity of cement : 3.15
Specific gravity of fly ash : 2.12
Air content : 2% = 20 litre/m³
Water/binder ratio (by weight) : 0.36
% of fly ash by weight of binder : 35
% of SP by weight of binder : 0.9
% of VMA by weight of binder : 0.2
Binder : 495 kg/m³
Fly ash : 495*(35/100) = 173.25 kg/m³
Cement : 495-173.25 = 321.75 kg/m³
Water : 495*0.36 = 178.2 litre/m³
Volume of cement : 321.75/3.15 = 102.14 litre/m³
Volume of fly ash : 173.25/2.12 = 81.72 litre/m³
SP : 495*(0.9/100) = 4.46 litre/m³
VMA : 495*(0.2/100) = 0.99 litre/m³
Total Paste volume : Volume of (cement+fly ash+water+SP+VMA+Air)
102.14+81.72+178.2+4.46+0.99+20=387.51 litre/m³
In the tool, the binder has been adjusted to 495 kg/m³ in order to obtain the required paste volume of about 387.51 litre/m³ (say 388 litre/m³).

4.6. Calculation of Constituent Materials for Concrete

Specific gravity of sand : 2.6
% of absorption of 20mm : 0.3
% of absorption of 10mm : 0.3
% of absorption of sand : 1.0
% of moisture in 20mm : 0.0
% of moisture in 10mm : 0.0
% of moisture in sand : 0.0
% of dry material in SP : 40
% of dry material in VMA : 40
Cement : 321.75 kg/m³
Fly ash : 173.25 kg/m³
Initial water content : 178.2 litre/m³
Coarse aggregate : 729.18 kg/m³
20mm coarse aggregate (CA1) : 729.18*(60/100) = 437.51 kg/m³
10mm coarse aggregate (CA2) : 729.18*(40/100) = 291.67 kg/m³
Sand : 331.71*2.6 = 862.46 kg/m³

Adjusted water content = Initial water - [CA1*(% of moisture - % of absorption)/100]
- [CA2*(% of moisture - % of absorption)/100]
- [sand*(% of moisture - % of absorption)/100]
- [SP*(100-% of dry material in SP)/100]
- [VMA*(100-% of dry material in VMA)/100]
= 178.2 - [437.51*(0-0.3)/100]-[291.67*(0-0.3)/100]
- [862.46*(0-1)/100]-[4.46*(100-40)/100]-[0.99*(100-40)/100]
= 185.75 litre/m³

Adjusted 20mm coarse aggregate : CA1*[1+(% of moisture/100)]
437.51*[1+(0/100)] = 437.51 kg/m³

Adjusted 10mm coarse aggregate : CA2*[1+(% of moisture/100)]
291.67*[1+(0/100)] = 291.67 kg/m³

Adjusted sand : sand*[1+(% of moisture/100)]
862.46*[1+(0/100)] = 862.46 kg/m³

4.7. Calculation of Constituent Materials for Mortar

Coarse aggregate contribution should not be considered in the adjustment of water. The remaining constituents are already discussed in the section 4.6.
Initial water content : 178.2 litre/m³

Adjusted water content = Initial water - [sand*(% of moisture - % of absorption)/100]
- [SP*(100-% of dry material in SP)/100]
- [VMA*(100-% of dry material in VMA)/100]
= 178.2 - [862.46*(0-1)/100]-[4.46*(100-40)/100]-[0.99*(100-40)/100]
= 183.56 litre/m³

4.8. Mix Proportions

Mix types with percentage relative proportions and mix proportions of constituent materials are shown in Table 9 and Table 10.
Table 9. Percentage Relative Proportions of SCC Mix

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Coarse Aggregate Blending Percentage By Weight (20 mm and 10 mm)</th>
<th>Percentage of Coarse aggregate</th>
<th>Percentage of Mortar</th>
<th>Percentage of Sand in Mortar</th>
<th>Percentage of Paste By Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>28_60:40</td>
<td>60 40</td>
<td>28.05</td>
<td>71.95</td>
<td>46.1</td>
<td>38.8</td>
</tr>
</tbody>
</table>

*28_60:40: where 28 is the percentage of coarse aggregate volume in a concrete mix 60:40 is the coarse aggregate blending by percentage weight of 20mm and 10mm resp.

Table 10. Mix Proportions of Constituent Materials

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Binder kg/m³</th>
<th>Cement Kg/m³</th>
<th>Fly Ash Kg/m³</th>
<th>Water l/m³</th>
<th>20mm Kg/m³</th>
<th>10mm Kg/m³</th>
<th>Sand kg/m³</th>
<th>SP l/m³</th>
<th>VMA l/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>28_60:40</td>
<td>495</td>
<td>321.75</td>
<td>173.25</td>
<td>178.2</td>
<td>437.51</td>
<td>291.67</td>
<td>862.46</td>
<td>4.46</td>
<td>0.99</td>
</tr>
</tbody>
</table>

V. EVALUATION OF SCC MIX DESIGN

The SCC mix designed by the SCC mix design tool has been evaluated by conducting the SCC fresh properties tests on the 28_60:40 SCC mix.

5.1. SCC Fresh Properties

SCC fresh properties i.e., slump flow, T50cm at initial and at 60 minutes, V-Funnel time, V-Funnel time at 5 minutes (T5min) and L-Box ratio (h2/h1) are presented in the Table11 for the SCC mix 28_60:40.

Table 11. Fresh Properties of SCC

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Slump Flow (mm)</th>
<th>T50cm (sec)</th>
<th>V-Funnel Time (sec)</th>
<th>L-Box Ratio (h2/h1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>At 60 min</td>
<td>Initial</td>
<td>At 60 min</td>
</tr>
<tr>
<td>28_60:40</td>
<td>696</td>
<td>657</td>
<td>3.12</td>
<td>4.28</td>
</tr>
</tbody>
</table>

As it can be seen from the above results, the mix 28_60:40 has met the SCC acceptance criteria mentioned by EFNARC [7]. Hence, it is practically seen that SCC mix design tool is very much useful in designing any SCC mix. The only challenge in getting successful SCC mix is the adjusting the key proportions of the constituents.

VI. CONCLUSIONS

The following conclusions can be drawn on the basis of SCC mix design tool:

Self compacting concrete mix design tool is developed based on the key proportions of the constituents. This tool is very simple and user friendly for the self compacting concrete mix design.

This tool can be used for the SCC mix with or without blended cement and coarse aggregate with or without coarse aggregate blending. This tool can also be enhanced for multi blended cements with more additives.

This tool is also useful for Self compacting mortar design. It displays all necessary data for SCC mix design and also displays constituent materials for SCC or SCM for the required volume.
Figure 1. SCC Mix Design Tool Interface

REFERENCES

[1]. American Concrete Institute. “Self-Consolidating Concrete”, ACI 237R-07.
Authors

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