Outlines

- Introduction
- Properties of fresh self-compacting concrete
- Mix design principles
- Testing self-compacting concrete
- Application
- References
**Introduction:** Definition

Self compacting concrete (SCC), also known as self consolidating concrete, is:
- a highly flowable,
- non-segregating concrete

that:
- can spread into place,
- fill the formwork and
- encapsulate the reinforcement without any mechanical compacting

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**Introduction:** Development of SCC

- Self-compacting concrete (SCC) developed by Professor Hajime Okamura of Kochi University of Technology, Japan, in 1986
- During his research, Okamura found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate compacting of the concrete in the casting operations.
- By developing concrete that self-compacting, he eliminated the main cause for the poor durability performance of their concrete.
- By 1988, the concept was developed and ready for the first real-scale tests.
**Introduction:**
Problems with Conventional Concrete

- Requirement of **skilled worker** for compaction in conventional concrete
- Difficult to use mechanical compaction for
  - Underwater concreting
  - Cast in-situ foundation
  - Structures with heavy reinforcement

**Introduction:**
Comparison between conventional concrete and SCC
**Introduction:** Mechanism for achieving Self compactability

- Reduction of water to binder ratio
- Limitation of coarse agg. content & max. size
- Addition of mineral admixture
- Usage of Super plasticizer & VMA*

High segregation resistance of mortar & concrete

High Deformability of mortar & concrete

Self compactability

*) Viscosity Modifying Agent (VMA)

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**Introduction:** Mechanism for achieving Self Compactability

**Limiting coarse aggregates**
- Deformability
- Segregation resistance
- Passing ability

**Adding super-plasticiser**
- Flowability
- Liquid limit
- Segregation resistance

**Reducing water-powder ratio**
- Segregation resistance
- Deformability

*Figure 2.6: Mechanisms of achieving self-compactability. ↑ increases, ↓ decreases*
Properties of fresh SCC

SCC must have the following characteristics in fresh state:

1. **Filling ability** (excellent deformability) - flows easily at suitable speed into formwork

2. **Passing ability** (ability to pass reinforcement without blocking) - passes through reinforcements without blocking

3. **High resistance to segregation** - the distribution of aggregate particles remains homogeneous in both vertical* and horizontal** directions

*) *Static segregation* due to gravity, vertical direction

**) *Dynamic segregation* due to flow, horizontal direction
Deformability (flow and filling ability)

- “Excess Paste Theory” explains the mechanism governing the workability of concrete.
- Enough paste to cover the surface area of the aggregates, and that the excess paste serves to minimize the friction among the aggregates and give better flow-ability.
- Without the paste layer, too much friction would be generated between the aggregates resulting in extremely limited workability.

![Image of aggregates and excess paste](image)

Passing ability

- The probability of blocking increases when the volume fraction of large aggregates increases.
- The size of aggregates, their shapes and their volume fraction influence the passing ability of SCC
- The potential of collision and contacts between particles increases as the distance between particles decreases; which therefore results in an increase in the internal stresses when concrete is deformed, particularly near obstacles causing blockage.
Segregation resistance

- Segregation resistance is largely controlled by viscosity
- ensuring a high viscosity can prevent a concrete mix from segregation and/or bleeding.
- Bleeding is a special case of segregation in which water moves upwards by capillary action and separates from the mix.
- Some bleeding is normal for concrete, but excessive bleeding can lead to a decrease in strength, high porosity, and poor durability particularly at the surface

Segregation resistance

- Two basic methods can ensure adequate stability:
  - The first approach uses a super-plasticiser (SP), low water/cement ratio, high powder content, mineral admixtures, and low aggregate content.
  - The second approach is based on incorporating a viscosity-modifying admixture (VMA), low or moderate powder content and super-plasticiser
SCC mix design principles

Mix design principles
- The flowability and viscosity of the paste is adjusted by proportioning the cement and additives water to powder ratio and then by adding super plasticizers and VMA.
- The paste is the vehicle for the transport of the aggregate, therefore the volume of the paste must be greater than the void volume in the aggregate.
- In order to control temperature rise and thermal shrinkage cracking as well as strength, the fine powder should be added to keep the cement content at an acceptable level. e.g. fly ash, mineral filler, silica fume etc.
**SCC mix design principles**

**SCC should have**

- Low coarse aggregate content
- Increased paste content
- Low water powder ratio
- Increased super plasticizer dosage
- Viscosity modifying agents

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**SCC mix design principles**

- **Limits on SCC material proportions**

<table>
<thead>
<tr>
<th></th>
<th>High fines</th>
<th>VMA</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cementations (kg/m³)</td>
<td>450 - 600</td>
<td>385-450</td>
<td>385-450</td>
</tr>
<tr>
<td>Water / Cementations material</td>
<td>0.28 - 0.45</td>
<td>0.28 - 0.45</td>
<td>0.28 - 0.45</td>
</tr>
<tr>
<td>Fine aggregate / Mortar (%)</td>
<td>35 - 45</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Fine aggregate / Total Aggregate (%)</td>
<td>50 - 58</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Coarse aggregate / Total mix (%)</td>
<td>28 - 48</td>
<td>45 - 48</td>
<td>28 - 48</td>
</tr>
</tbody>
</table>
SCC mix design principles

![Graph showing SCC mix design principles](image)

SCC mix design: **Penttala design method**

- It is based on statistical analysis of a large number of concrete tests in which the most important variables were derived by **linear regression** and, thereafter, the model was generated by non-linear regression so that the best correlation was achieved.

- It was noticed that in addition to water-cement ratio and the dosage of superplasticizer the properties of the sub-mm (# < 0.125 mm) dry ingredients (especially the gradation curve) had the largest effect on the properties of self-compacting concretes.
SCC mix design principles

Binders and fillers

granulometer data

SCC mix design: Penttala design method

Figure 2: Slump flow and $T_{90}$-values of the test concretes
In order to determine the gradation properties of binders and fillers, new variables were introduced: $F_{125}$, $V_{125}$, $H_{p125}$, $L_{p125}$ and $H_{v125}$

$L = \text{linearity}$

$H = \text{fineness}$

$p = \text{weight}$

$v = \text{volume}$

$F_{125} = \text{weight of all dry ingredients} \leq 0.125 \text{ mm}$

$V_{125} = \text{volume of all dry ingredients} \leq 0.125 \text{ mm}$

Figure 3: The fineness modulus $H$ and linearity term $L$ calculated by weight basis from the gradation curve of the dry ingredients below 0.125 mm sieve data of the self-compacting concrete. The gradation curve is obtained from granulometer data

### SCC mix design: Penttala design method

- Limit values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump flow [mm]</td>
<td>600</td>
<td>850</td>
</tr>
<tr>
<td>$T_{50}$ time [s]</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Amount of cement [kg/m$^3$]</td>
<td>200</td>
<td>420</td>
</tr>
<tr>
<td>Amount of fly ash [kg/m$^3$]</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Amount of limestone filler [kg/m$^3$]</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Amount of superplasticizer [kg/m$^3$]</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Amount of water [kg/m$^3$]</td>
<td>155</td>
<td>170</td>
</tr>
</tbody>
</table>
SCC mix design: Penttala design method

- non-air entrained SCC
- sulphate resistant cement
  - CEM I 42,5 SR
- presented in Equations 3 and 4.

\[ D = a + b \cdot \ln \left( \frac{W}{C} \right)^c \cdot \left( \frac{100 \cdot N_t}{C + L_t + K_f} \right)^d \cdot N_t^e \cdot H_{vl25}^f \cdot T_{50}^g \]  
\[ T_{50} = a + b \cdot \ln \left( \frac{W}{V_{125}} \right)^c \cdot \frac{F_{125}}{d \cdot D^e} \]

in which
- \( D \) is the spread diameter in slump flow test [mm],
- \( T_{50} \) is the time when spread is 500 mm [s],
- \( W/C \) is water cement ratio,
- \( N_t \) is superplasticizer dosage [kg/m³],
- \( L_t \) is fly ash content [kg/m³],
- \( K_f \) is the content of calcium carbonate filler [kg/m³],
- \( L_{p125} \) is the linearity term calculated on weight basis,
- \( a, b, c, d, e \) are coefficients, and
- \( Ln \) is natural logarithm.

Coefficients: slide 26
SCC mix design: Penttala design method

- air entrained SCC
- all three cements types
  - CEM IIA 42,5 R,
  - CEM IIA 52,5 R
  - CEM I 42,5 SR
- presented in Equations 5 and 6.

\[
D = a + b \times \ln \left( \frac{W}{C} \right)^c \times C^{d} \times H_{v125}^{e} \times T_{50}^{f}
\]  \tag{5}

\[
T_{50} = a + b \times \ln \left( \frac{W}{C} \right)^c \times \left( \frac{W}{V_{125}} \right)^d \times H_{p125}^{e} \times A^{f} \times D^{g}
\]  \tag{6}

in which \( H_{p125} \) is fineness modulus of the gradation curve calculated between 1-125 µm when the passing values are weight based, and \( A \) is the air content of concrete [%].

Coefficients: slide 26

SCC mix design: Penttala design method

Table 1: Coefficients of Equations 1-6

<table>
<thead>
<tr>
<th>Eq.</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>742,733</td>
<td>5,46097</td>
<td>66,5981</td>
<td>45,4153</td>
<td>-13,3588</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>251,099</td>
<td>2,95211</td>
<td>2,15606</td>
<td>2,97203</td>
<td>-11,7104</td>
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<tr>
<td>3</td>
<td>-1487,92</td>
<td>14,3373</td>
<td>-4,69812</td>
<td>15,4106</td>
<td>-17,1175</td>
<td>41,7838</td>
<td>-3,61218</td>
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<td>4</td>
<td>540,139</td>
<td>3,4259</td>
<td>-12,1626</td>
<td>-9,39379</td>
<td>-14,7728</td>
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<tr>
<td>5</td>
<td>2935,39</td>
<td>27,4467</td>
<td>-36,224</td>
<td>-28,8996</td>
<td>14,4494</td>
<td>-2,07793</td>
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<tr>
<td>6</td>
<td>303,128</td>
<td>8,01143</td>
<td>-3,17554</td>
<td>-6,24567</td>
<td>-2,97027</td>
<td>0,7047</td>
<td>-4,28655</td>
</tr>
</tbody>
</table>
SCC mix design: **Penttala design method**

**Solution of the equations:**
- Two unknown terms spread D and T50-time
- The solution has to be found by iteration
- Three interactive spread sheet Excel-programs have been derived for a convenient solving of the equations.
- The programs provide also an estimate for the one and 28 day compressive strength values which are also derived by statistical means.
- The program gives a suggestion for the change of cement and superplasticizer content for the next iteration round.

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Excel programs
Assessing the workability of SCC mix can be divided into three categories:

1. **Qualitative assessment**: it is a general description of concrete behaviour such as workability, flow-ability, stability, compactability, pump-ability... etc.

2. **Quantitative empirical assessment** to be used as a simple description of quantitative behaviour such as slump flow test, L-box test, J-Ring ... etc.

3. **Quantitative fundamental assessment**: it is a description related to rheological terms of concrete, e.g. plastic viscosity, fluidity and yield value.
Testing self-compacting concrete

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Property Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump-flow</td>
<td>Filling ability</td>
</tr>
<tr>
<td>(T_{50}) Slump-flow</td>
<td>Filling ability</td>
</tr>
<tr>
<td>J-Ring</td>
<td>Passing ability</td>
</tr>
<tr>
<td>V-funnel</td>
<td>Filling ability</td>
</tr>
<tr>
<td>V-funnel at (T_{5}) minutes</td>
<td>Segregation resistance</td>
</tr>
<tr>
<td>L-box</td>
<td>Passing ability</td>
</tr>
<tr>
<td>U-Box</td>
<td>Passing ability</td>
</tr>
<tr>
<td>Fill-box</td>
<td>Passing ability</td>
</tr>
<tr>
<td>GTM screen stability test</td>
<td>Segregation resistance</td>
</tr>
<tr>
<td>Orimet</td>
<td>Filling ability</td>
</tr>
</tbody>
</table>

Flow-ability using slump test

- evaluate the deformability of SCC in the absence of obstacles.
- two different aspects are measured:
  1. the filling ability by measuring the horizontal flow (spread) diameter \(SF\)
  2. the viscosity of mix by measuring the time needed for SCC to reach 500 mm flow \(t_{500}\).
- The segregation resistance in this test can be detected visually
Flow-ability using slump test

The difference between d1 and d2 should be less than 50 mm otherwise the test should be repeated.

spread diameter $SF$

$$SF = \frac{(d_1 + d_2)}{2}$$
Flow-ability using slump test

- **SF1 (550 - 650 mm)** → unreinforced or slightly reinforced concrete structures
- **SF2 (660 - 750 mm)** → normal applications (e.g. walls, columns)
- **SF3 (760 – 850 mm)** is typically produced with a small maximum size of aggregates (less than 16 mm) → for vertical applications in very heavy structures, structures with complex shapes, or for filling under formwork.

J-ring test - Passing ability tests

- J-ring is a test used in conjunction with a slump test to assess the passing ability of SCC through gaps in the obstacles, e.g. reinforcement.
- For this test, the slump test apparatus is used with an open steel rectangular section ring with 16 steel rods (ϕ16 mm) and 100 mm height
- The gap between the bars is 42 mm.
- Wider gaps can be used when fibres are introduced to the mix which should be 1-3 times the maximum length of fibres used.
J-ring test - Passing ability tests

Blocking step $P_J$

$$SF_J = \frac{(d_1 + d_2)}{2}$$

$$P_J = \frac{\Delta h_{x1} + \Delta h_{x2} + \Delta h_{y1} + \Delta h_{y2}}{4} - \Delta h_0$$

$\Delta h_0$: is the height measurement at the centre of flow

$\Delta h_{x1}$, $\Delta h_{x2}$, $\Delta h_{y1}$, $\Delta h_{y2}$ are the four measurement heights at positions just outside the J-ring.
J-ring test - Passing ability tests

Table 2.1. Passing ability criteria

<table>
<thead>
<tr>
<th>(SF-SFj)</th>
<th>Passing ability rate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25 mm</td>
<td>0</td>
<td>No visible blocking</td>
</tr>
<tr>
<td>25 mm - 50 mm</td>
<td>1</td>
<td>Minimal to noticeable blocking</td>
</tr>
<tr>
<td>&gt; 50 mm</td>
<td>2</td>
<td>Noticeable to extreme blocking</td>
</tr>
</tbody>
</table>

• The blocking step $P_j$ should be less than 10 mm

L-box test

• The L-box test is used to assess the filling and passing ability of SCC, or in other words the ability of concrete to pass through reinforced bars without blocking or segregation.

• After filling the vertical column of the L-box, the gate is lifted to allow SCC to flow into the horizontal part after passing through the rebar obstructions.

• Two measurements are taken, $(H_1, H_2)$ heights of concrete at the beginning and end of the horizontal section, respectively.

• The ratio $H_2/H_1$ represents the filling ability, and typically, this value should be $0.8\sim1$, while the passing ability can be detected visually by inspecting the area around the rebar.
L-box test

In L-box, 2 or 3 smooth steel bars with 12 mm diameter can be used to represent light or dense reinforcement with distance between them 59 and 41 mm, respectively.

The passing ability ratio $PL$

$$PL = \frac{H_2}{H_1}$$
**L-box test**

- $H_1$ is the mean depth of concrete in the vertical section of the box
- $H_2$ is the mean depth of concrete at the end of the horizontal section of the box.
- $t_{200}$ and $t_{400}$ are also recorded which represent the time of SCC to reach 200 mm and 400 mm from the gate

**Criteria of acceptance**

- No signs of segregation or bleeding.
- Passing ability ratio $P_L$ *should be between 0.8 and 1; a value more than 1 means an error.*
- There is no recommendation for $t_{200}$ and $t_{400}$ values, but larger values represent higher viscosity.

**V-funnel**

- The V-funnel flow time is the period a defined volume of SCC needs to pass a narrow opening
- Gives an indication of the filling ability of SCC provided that blocking and/or segregation do not take place
- The flow time of the V-funnel test is to some degree related to the plastic viscosity
- The V-funnel flow time $t_V$ is the period from releasing the gate until first light enters the opening, expressed to the nearest 0.1 second.

_V-funnel_  
(Alternative method to T50 for filling ability)
Interpretation of the V-funnel result:

- The V-funnel test measures the ease of flow of concrete.
- Shorter flow time indicates greater flow ability.
- For SCC a flow time of 10 seconds is considered appropriate.
- The inverted cone shape restricts the flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking.
- **After 5 minutes of settling**, segregation of concrete will show a less continuous flow with an increase in flow time.
Penetration test

- Alternative method for resistance to segregation
- The test aims at investigating the resistance of SCC to segregation by penetrating a cylinder with a given weight into the fresh SCC sample.
- If the SCC has poor resistance to segregation, the cylinder will penetrate deeper due to the less amount of aggregate in the upper layer of the sample.
- Therefore the penetration depth indicates whether the SCC is stable or not.

The inner diameter, height and thickness of the cylinder are 75 mm, 50 mm and 1 mm, respectively. The total weight of the penetration head is 54 g.
Penetration test

- The test can be combined with the L-box test.
- During the L-box test, the penetration cylinder is then adjusted to just touch the upper surface of concrete.
- After releasing the screw, the cylinder is allowed to penetrate freely into the concrete for 45 seconds.
- The final penetration depth can be recorded by reading the scale.
- It was found that a good segregation resistance of the tested SCC can be indicated by a penetration depth that was less than 7 mm.
**Orimet test**

- The Orimet flow time is the period a defined volume of SCC needs to pass a narrow opening (a tube narrowed by an orifice).
- The flow time of the Orimet test is to some degree related to the plastic viscosity.
- The Orimet flow time $t_O$ is the period from releasing the gate until first light enters the opening, expressed to the nearest 0.1 second.
- Acceptance criteria for SCC is 0 – 5 sec.

**U-Box test**

- The test is used to measure the filing ability of SCC
- Fill the vertical section of the apparatus
- Lift the sliding gate
- After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H1).
- Measure also the height in the other equipment (H2).
- Calculate H1-H2, the filling height.
- If the concrete flows as freely as water, it will be horizontal, so H1-H2=0.
- Therefore the nearest this test value, the ‘filling height’, is to zero, the better the flow and passing ability of the concrete.
Acceptance criteria for Self-compacting Concrete

<table>
<thead>
<tr>
<th>Method</th>
<th>Unit</th>
<th>Typical range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>slumpflow by Abrams cone</td>
<td>mm</td>
<td>650</td>
</tr>
<tr>
<td>$T_{50cm}$ Slumpflow</td>
<td>sec</td>
<td>2</td>
</tr>
<tr>
<td>J-ring</td>
<td>mm</td>
<td>0</td>
</tr>
<tr>
<td>V-funnel</td>
<td>sec</td>
<td>6</td>
</tr>
<tr>
<td>Time increase, V-funnel at $T_{5\text{minutes}}$</td>
<td>sec</td>
<td>0</td>
</tr>
<tr>
<td>L-box $(h_2/h_1)$</td>
<td></td>
<td>0,8</td>
</tr>
<tr>
<td>U-box $(h_2-h_1)$ mm</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Fill-box</td>
<td>%</td>
<td>90</td>
</tr>
<tr>
<td>GTM Screen stability test</td>
<td>%</td>
<td>0</td>
</tr>
<tr>
<td>Orimet</td>
<td>sec</td>
<td>0</td>
</tr>
</tbody>
</table>
SCC applications

**Burj Khalifa in Dubai (2010)**

- Over 828 meters high and 166 stories
- Self-compacting concrete is playing a greater role in high-rise construction to overcome the problem of congested reinforcement and ease of placement.

SCC applications

**Sodra Lanken - Sweden (1997)**

- Notably was one of the largest infrastructure projects that used SCC.
- 6 km long four-lane highway in Stockholm involved seven major junctions, and rock tunnels totalling over 16 km partly lined with concrete and over 225,000 cubic meters of concrete.
- Incorporating SCC was ideal to cope with the density of reinforcement required and the highly uneven rock surfaces.
SCC applications

George Wharf (2004), London Docklands

- SCC has been used to save time and manpower
- SCC was used in limited areas on two floors in lift shaft walls, upstand beams and columns and for stairs precast on site.

SCC applications

Dragon Bridge (2012), Alcalá De Guadaira, Seville, Spain

- 124 m long bridge, distributed in four spans, stands out due to its unique shape.
- The dragon’s body is made up of 4 meters high and 2 meters wide, of self-compacting reinforced concrete
References

1. The European Guidelines for Self-Compacting Concrete Specification, Production and Use

2. Measurement of properties of fresh self-compacting concrete
   http://www2.cege.ucl.ac.uk/research/concrete/Testing-SCC/Final%20project%20report.pdf

   http://www.researchgate.net/publication/272682135

   http://www.researchgate.net/file.PostFileLoader.html?id=549a98cdd685cc92758b4675&assetKey=AS%3A273657778114563%401442256506810