CASE STUDIES USING SELF-COMPACTING CONCRETE

- PREFABRICATED ELEMENTS
- TUNNEL LINING
- BUILDING FRAME AND SLABS
- REPAIR OF GIRDERS
PREFABRICATION: Urban elements with exposed aggregate finish

Street/Park bench
Model: Banc-U 140/Silla-U
Modular, Simply supported
Product of Escofet (Spain)

Characteristics:
weight: 815/408 kg
minimum thickness: 53 mm
minimum angle: 55°
Preliminary trials in the laboratory

- **Fresh Concrete**
  - Slump flow = 65 cm, \( T_{50} = 6 \) sec.
  - V-Funnel flow time = 11 sec.
  - Blocking ratio = 0.83

- **Hardened Concrete**
  - Compressive strength at 24 hours = 40 MPa
  - Uniform distribution of the gravel
Prototype of bench: *Casting*

The mould is placed in the inverted position (with the base on top and horizontal).

The concrete is poured directly from the bucket. The consolidation is by self weight.
Prototype of bench: *Demolding*

The element is demoulded after 24 hours.

The bench is lifted out of the mould and turned over.
Evaluation of surface texture

Surface finish of the bench

A range of high quality surface textures can be obtained.
Requirements of exposed-aggregate finish

- **Aesthetic requirements**
  - Uniform aggregate spacing on surface
  - Colour contrast when aggregates are exposed

- **Components**
  - Cement type CEM I 52.5R
  - White marble powder
  - Polycarboxylate-based superplasticizer
  - Crushed black granite aggregates
    - (0-2.5 mm, 2.5-6 mm & 6-15 mm)
Concrete mix design

**Composition in kg/m³**

<table>
<thead>
<tr>
<th></th>
<th>cement</th>
<th>water</th>
<th>marble powder</th>
<th>superplasticizer</th>
<th>sand</th>
<th>gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/m³</td>
<td>406</td>
<td>177</td>
<td>243</td>
<td>8.5</td>
<td>675</td>
<td>825</td>
</tr>
</tbody>
</table>

Slump flow, $D_F = 670$ mm

Slump flow time, $T_{50} = 5$ sec

V-Funnel time, $T_v = 18$ sec
FILLING THE MOULD

Vibrated concrete

Time: 10 min
Workers: 4

Time: 3.5 min
Workers: 2
FINISHED PRODUCT
Merits of SCC in Prefabrication

- Reduction in fabrication time and labour
- Much less noise during fabrication
- No harm due to vibration for the workers
- Less wear-and-tear of moulds
- Lower mould weight (i.e., lower cost)
Challenges that Remain in Prefabrication

- Air bubbles on top surface of mould may not be removed. New vegetable oil based demoulding agents seem to help reduce the surface voids.

- Needs to be tried in India
Guidelines for the Fabrication of SCC
Prefabrication

- Air bubbles on the (top) surfaces of moulded elements can be reduced by using appropriate demoulding agents, and applying slight vibration.
- Vents should be provided for the release of air to ensure sharp corners and edges.
- Bottom-up pumping is often the best in closed moulds.
- Effects of heat curing should be checked for each mix.
HIGH-STRENGTH SCC

Site overview: Martorell, Spain

REPAIR OF COLLAPSED TUNNEL LINING
Tunnel Characteristics

Details

- Length: 3,046 m
- Ø excavation: 12.9-15.5 m
- Internal diameter: 12-14 m
- SCC thickness: 0.46-0.76 m
- Strength class: 80 MPa
- Circumferential reinforcement 8Ø32mm/m
- Volume of SCC: 124,000 m³
- Steel density: 10,000 kg/m³

HIGH-STRENGTH SCC IN TUNNEL LININGS
HIGH-STRENGTH SCC IN TUNNEL LININGS

On-site arrangement

Tunnel section

Mixer, pump and formwork
HIGH-STRENGTH SCC IN TUNNEL LININGS

Reinforcement

- 8 bars of Ø32mm per meter
- 30mm bar spacing at splice zone
- Minimum cover 35 mm
# HIGH-STRENGTH SCC IN TUNNEL LININGS

Mix design and fresh properties

<table>
<thead>
<tr>
<th>Components (kg/m³)</th>
<th>Mix L1</th>
<th>Mix L2</th>
<th>Mix L3</th>
<th>Mix L4</th>
<th>Mix L5</th>
<th>Mix L6</th>
<th>Mix L7</th>
<th>Mix S1</th>
<th>Mix S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement I 52,5 SR</td>
<td>498</td>
<td>500</td>
<td>498</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>492</td>
<td>500</td>
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<tr>
<td>Limestone filler</td>
<td>124</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>93</td>
<td>-</td>
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<tr>
<td>Silica fume</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>49</td>
<td>50</td>
</tr>
<tr>
<td>Fly ash</td>
<td>-</td>
<td>-</td>
<td>124</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>182</td>
<td>186</td>
<td>182</td>
<td>202</td>
<td>197</td>
<td>193</td>
<td>193</td>
<td>188</td>
<td>165</td>
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<tr>
<td>Crushed limestone sand (0-2 mm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>426</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>Natural siliceous sand (0-2 mm)</td>
<td>337</td>
<td>352</td>
<td>337</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>373</td>
<td>-</td>
</tr>
<tr>
<td>Crushed limestone sand (0-5 mm)</td>
<td>505</td>
<td>528</td>
<td>505</td>
<td>638</td>
<td>1067</td>
<td>576</td>
<td>576</td>
<td>508</td>
<td>576</td>
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<tr>
<td>Natural siliceous sand (0-5 mm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>411</td>
<td>411</td>
<td>-</td>
<td>411</td>
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<tr>
<td>Crushed granite gravel (6-12 mm)</td>
<td>688</td>
<td>720</td>
<td>688</td>
<td>573</td>
<td>575</td>
<td>658</td>
<td>658</td>
<td>684</td>
<td>658</td>
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<tr>
<td>Superplasticizer (polycarboxylate)</td>
<td>15.7</td>
<td>13.2</td>
<td>14.5</td>
<td>11.8</td>
<td>10.5</td>
<td>11.8</td>
<td>11.8</td>
<td>12.7</td>
<td>11.0</td>
</tr>
<tr>
<td>VMA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.8</td>
<td>2.5</td>
<td>2.0</td>
<td>2.0</td>
<td>-</td>
<td>2.0</td>
</tr>
<tr>
<td>SRA (glycol-based)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.0</td>
<td>-</td>
<td>-</td>
</tr>
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<table>
<thead>
<tr>
<th>Test results</th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump flow spread, Dₙ (mm)</td>
<td>630</td>
<td>630</td>
<td>610</td>
<td>640</td>
<td>610</td>
<td>590</td>
<td>590</td>
<td>710</td>
<td>610</td>
</tr>
<tr>
<td>Slump flow time, T₅₀ (s)</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>V-funnel time, Tᵥ (s)</td>
<td>23</td>
<td>9</td>
<td>16</td>
<td>11</td>
<td>12</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>J-ring difference, ΔD (mm)</td>
<td>50</td>
<td>45</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>
Compressive strength tests of cylinders: $f_{ck} \geq 12.5$ MPa at 24 hours and $80$ MPa at 28 days.

Splitting tensile strength: $f_t \geq 8$ MPa at 28 days.

Autogeneous shrinkage on sealed specimens at 20ºC (68ºF); $\leq 300$ microstrains at 3 months.

\textit{Water curing for at least 7 days was prescribed.}
HIGH-STRENGTH SCC IN TUNNEL LININGS

Autogeneous Shrinkage

Strain (microstrain)

Age (days)
Merits of SCC

- High strength can be achieved
- Congested reinforcement makes SCC essential
- Increases construction speed (with respect to vibrated concrete)
- Labour requirement is low
Challenges that Remain

- Need to decrease testing time and QC labour. (Complete testing of fresh concrete takes at least 20 minutes and requires at least 3 people)
- Early-age shrinkage could be high. (Curing is essential but could be difficult in applications like tunnels; shrinkage reducers may be required)
- Unavailability of fillers, and the difficulty in storing and batching fillers in existing readymix plants could pose problems.
CONCRETING OF RESIDENTIAL BUILDING

- Building in Chennai
- More than 220 cubic metres of M40 SCC was placed in a total of 34 “nights” (of concreting).
- M40 SCC cost varied from Rs. 4000-5300/m³ (over the period of March 2006 – Aug. 2007).
- SCC found to be about 20% more expensive than conventional concrete of same strength.
- Additional cost of concrete over conventional M30 concrete was about 6% of total construction cost.
**Typical concrete mix design**

<table>
<thead>
<tr>
<th>Component</th>
<th>kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (53 grade OPC)</td>
<td>390</td>
</tr>
<tr>
<td>Metakaolin</td>
<td>20</td>
</tr>
<tr>
<td>Fly ash</td>
<td>150</td>
</tr>
<tr>
<td>Water</td>
<td>180</td>
</tr>
<tr>
<td>Sand</td>
<td>860</td>
</tr>
<tr>
<td>Gravel</td>
<td>780</td>
</tr>
<tr>
<td>Polycarboxylate-based superplasticizer</td>
<td>6</td>
</tr>
<tr>
<td>Viscosity modifying agent</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Slump flow varied from 500-600 mm
Piles, Frames and Slabs of Building
Merits of SCC

• Dependence on worker skill and responsibility is reduced (especially when casting is done at night).

• Concreting duration is reduced (less disturbance).

• Labour requirement is lower.

• Piles can be expected to be more compact, especially when water is present in the bore holes.

• Slab finish is excellent (no need to plaster ceilings).
Challenges that Remain

• Loss of self-compactability due to long transportation times (need to redose admixtures).

• Plastic shrinkage could be high, resulting in cracking especially in slabs (need to limit flow to optimum, and not overdose retarder).

• Formwork should be rigid and strong enough to resist pressure of fresh SCC.

• Not easy to partially cast beams or slabs.

• Robustness needs to be ensured since components and humidity of aggregates could vary considerably over project span.
REPAIR OF REINFORCED CONCRETE GIRDERS

- Lecture theatre in Chennai

- Concrete at the bottom of girders were found to be poorly compacted leading to corrosion of rebars

- Bad concrete was removed and cover replaced with SCC
## Typical mix design

<table>
<thead>
<tr>
<th>Component</th>
<th>kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (53 grade OPC)</td>
<td>515</td>
</tr>
<tr>
<td>Fly ash</td>
<td>220</td>
</tr>
<tr>
<td>Water</td>
<td>257</td>
</tr>
<tr>
<td>Sand</td>
<td>653</td>
</tr>
<tr>
<td>Gravel (max. 6 mm)</td>
<td>653</td>
</tr>
<tr>
<td>Polycarboxylate-based</td>
<td>7</td>
</tr>
<tr>
<td>superplasticizer</td>
<td>1.5</td>
</tr>
<tr>
<td>Viscosity modifying agent</td>
<td></td>
</tr>
</tbody>
</table>

Slump flow is about 650 mm
STEPS IN THE REPAIR PROCESS

• Chipping and removal of the plastering and weathering courses
STEPS IN THE REPAIR PROCESS

• Cutting and removal of the slab between the girders
STEPS IN THE REPAIR PROCESS

- Removal of the poorly compacted cover (shear cracking in the first two girders led to the “discovery” that there was no middle reinforcement and there were insufficient stirrups). Supports were provided for the concrete above the bars to avoid further cracking.
STEPS IN THE REPAIR PROCESS

• Placing of self compacting concrete cover
STEPS IN THE REPAIR PROCESS

- Construction of steel frames on the concrete girders
- Covering with corrugated light steel roofing
STEPS IN THE REPAIR PROCESS

• Wrapping of girders with FRP for shear strengthening and for increasing the ductility.
Merits of SCC

• Ensures filling of cover space.

• Dependence on worker skill is low.

• Finish is good.

• Less expensive than commercial microconcrete since it can be “tailor-made” for the application.
Challenges that Remain

- Confidence needs to be built up through more applications.
- Robustness needs to be ensured.
- Fly ash is difficult to procure when only small quantities are needed.
Guidelines for the Fabrication of SCC Mixing

- Forced-action mixer is recommended (but gravity-type tilted-axis mixers have also been used).
- Moisture content of aggregates should be measured and accounted for.
- Any change in the characteristics of the components that can affect the rheology should be controlled.
- High concrete temperatures should be avoided (by using ice or liquid nitrogen cooling if required).
- At very low temperatures, hot water may have to be used in the mix, and the moulds heated.
Guidelines for the Fabrication of SCC

In situ construction

• Maximum transportation time should be specified.

• When mixing is continued in truck, it should not be filled to more than 80% of nominal capacity.

• Truck drum should be rotated at low speed (1-4 rpm) during transportation, and at high speed for 3 minutes before discharging.

• Truck drivers and other personnel should be trained and informed.

• When pumped, the pumping length should not exceed 300 m, and the slopes should be between 1/10 and 1/30.
**Guidelines for the Fabrication of SCC**

*In situ construction*

- Free fall height of concrete should be limited to 3-5 m.
- Maximum pumping velocity per outlet should be 10-20 m³/hr.
- Rigidity and water-tightness of the molds and joints should be guaranteed. To avoid excessive pressure on formwork, vertical casting speed should be limited to about 2 m/hr.
- Air should be allowed to escape from the formwork during filling.
- Spacing between reinforcement bars and cover should be controlled to avoid unexpected restrictions in concrete flow.
Guidelines for the Fabrication of SCC

In situ construction

• Cold joints should be avoided. If there is a delay of more than 30 minutes between pours, the surface should be tamped or vibrated before placing the next layer.

• Water curing is needed during 3-7 days to avoid plastic shrinkage cracking. Later, the surface can be covered with a plastic sheet or curing membrane.
The Future of SCC Technology

• Could lead to Higher Performance in a Cost-Effective, Energy-Efficient and Worker-Friendly Manner.

More Sustainable, “Greener” Technology.

Challenges Need to be Addressed through University-Industry Cooperation.