So what is CSA concrete?
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Calcium SulphoAluminate Concrete
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$\text{C}_4\text{A}_3\text{S}$ reacts with gypsum, $\text{CS}$ to form ettringite.
So what is CSA concrete? Calcium SulphoAluminate Concrete

$C_4A_3S$ reacts with gypsum, $CS$ to form ettringite

- Main components (wt%):
  - $C_4A_3S$: 30%
  - $C_2S$: 45%
  - $CS$: 15%
  - $C_4AF$: 2%
  - Other: 8%
Key hydration reaction in CSA cement

Calcium Sulfo Aluminate + Calcium Sulfate + Lime + Water → Ettringite Crystals

\[ C_4A_3S + 8CaSO_4 + 6CaO + 96H_2O \rightarrow 3C_3A \cdot 3CaSO_4 \cdot 32H_2O \]
Key hydration reaction in CSA cement

\[ C_4A_3\overline{S} + 8CaSO_4 + 6CaO + 96H_2O \rightarrow 3C_3A \cdot 3CaSO_4 \cdot 32H_2O \]

- Calcium Sulfo Aluminate
- Calcium Sulfate
- Lime
- Water

Ettringite Crystals

Very Early Strength
Stable sulfate
All water used
Key hydration reaction in CSA cement

\[ C_4A_3\bar{S} + 8CaSO_4 + 6CaO + 96H_2O \rightarrow 3C_3A \cdot 3CaSO_4 \cdot 32H_2O \]

- **Calcium Sulfo Aluminate** + **Calcium Sulfate** + **Lime** + **Water** → **Ettringite Crystals**

- **Very Early Strength**
- **Stable sulfate**
- **All water used**

No subsequent reaction with sulfates
Key hydration reaction in CSA cement

\[ C_4A_3S + 8CaSO_4 + 6CaO + 96H_2O \rightarrow 3C_3A \cdot 3CaSO_4 \cdot 32H_2O \]

- **Very Early Strength**
- **Stable sulfate**
- **All water used**
- **No subsequent reaction with sulfates**
- **Low Shrinkage**
Advantages of CSA Cements

Most $\text{H}_2\text{O}$ is used in hydration product:
- No or low shrinkage

High 1.5 hour strength
- $f_c$ up to 3,000 psi, $f_r$ up to 350 psi

High sulfate resistance (no $\text{C}_3\text{A}$)

Low permeability (<500 coulombs ASTM C 1202)
- Low chloride diffusion

High durability
SHRP-C-362

- Very Early Strength (2000 psi @ 6 hours)
- High Early Strength (5000 psi @ 24 hours)
- Very High Strength (10,000 psi @ 28 days)
Early Age Strength Gain for CSA with changes in Temperature

Time (hrs)

Compressive Strength (MPa)

Compressive Strength (psi)

40 Degrees
60 degrees
70 degrees
90 degrees
110 degrees

Varied Temperature Curing.
Environmental Chamber Curing.
## Typical California CSA Mix Proportions

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount for 1 m³ (1 yd³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium Sulfoaluminate (CSA) Cement</td>
<td>390 kg (658 lb)</td>
</tr>
<tr>
<td>#57, Coarse Aggregate</td>
<td>989 kg (1667 lb)</td>
</tr>
<tr>
<td>River Sand, Fine Aggregate</td>
<td>867 kg (1462 lb)</td>
</tr>
<tr>
<td>Water</td>
<td>156 L (262 lb)</td>
</tr>
<tr>
<td>HRWR (polycarboxylate)</td>
<td>2.5 L (66 oz)</td>
</tr>
</tbody>
</table>

Note: Water amount assumes aggregate is at SSD condition.
Cement
Aggregate Bins
Admixture Tanks
Aggregate Bins & Admixture Tanks

Mixing & Delivery Auger

Batching Chamber
Batching Chamber
Cement
Aggregates
Hydraulics

Batching Chamber
Cement
Aggregates
Hydraulics
160% increase
Strength is Essential, but otherwise not Important
- Hardy Cross
Panel Replacement in California

Typical Panel

3.7m x 4.6m x 225 mm
12’ x 15’ x 9”
Panel Replacement in California

Typical Panel
3.7m x 4.6m x 225 mm
12’ x 15’ x 9”

1994 – 2008 (15 years)
Approx. 65,000 panels replaced using CSA concrete.
Panel Replacement in California

Equivalent to:

Approx. 200 lane miles

267,600 cu meters of CSA

or 350,000 cu. Yards of CSA
Production Rates with CSA

Average Volume per 8 hour lane closure:
134 m³ (175 yd³)

equivalent to 35 panels

Approx. one every 14 minutes
Production Rates with CSA

Highest Batch plant Volume in 10 hours:
776 m$^3$ (1015 yd$^3$)

equivalent to 203 panels
Production Rates with CSA

Highest Batch plant Volume in 10 hours:
776 m³ (1015 yd³)
equivalent to 203 panels

Highest Mobile Mixer Volume in 6 hours:
381 m³ (498 yd³)
equivalent to 100 panels
2007 Cost

Average Cost of a CSA panel replacement

$2,716 per panel
Cast Panel System

- Transporting 2 panels per flat bed to the job site
- Crane & crane operator to unload panels
- Base sand that has been laser screed and compacted prior to receiving panel
- Tying panels together & grouting tie cable pockets
- Waiting for grout to obtain strength
- Limited production capacity
- Geometric conditions
### Panel Replacement Costs – from Muench etal. (7)

<table>
<thead>
<tr>
<th>Panel Replacements</th>
<th>Rapid?</th>
<th>Cost ($)</th>
<th>Lane-mi</th>
<th>Panels Replaced</th>
<th>Rounded Cost/Panel ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tacoma, WA (2006)</td>
<td>Yes</td>
<td>735,000</td>
<td>10.4</td>
<td>29</td>
<td>25,300</td>
</tr>
<tr>
<td>Federal Way, WA (2006)</td>
<td>Yes</td>
<td>1,000,000</td>
<td>11.4</td>
<td>54</td>
<td>18,500</td>
</tr>
<tr>
<td>Bellingham, WA (2003)</td>
<td>No</td>
<td>660,000</td>
<td>13.2</td>
<td>265</td>
<td>2,500</td>
</tr>
<tr>
<td>Vancouver, WA (2006)</td>
<td>No</td>
<td>1,600,000</td>
<td>16.5</td>
<td>233</td>
<td>7,000</td>
</tr>
<tr>
<td>Spokane, WA (2007)</td>
<td>No</td>
<td>300,000</td>
<td>11.1</td>
<td>36</td>
<td>8,000</td>
</tr>
</tbody>
</table>

1 mi = 1.61 Km

a. Costs are approximate because of difficulties in separating panel replacement work from other work on single contracts, differences in costs between geographic locations, and differences in complexity and urgency of work.

b. The contractor lost a substantial amount of money on the Bellingham job. Therefore, the rounded cost per panel, while reasonably accurate for this job, is probably too low to use for future estimating.

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<tr>
<td>Tacoma, WA (2006)</td>
<td>Yes</td>
<td>735,000</td>
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<td>0.79</td>
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<tr>
<td>Federal Way, WA (2006)</td>
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<td>1.35</td>
</tr>
<tr>
<td>Bellingham, WA (2003)b</td>
<td>No</td>
<td>660,000</td>
<td>13.2</td>
<td>265</td>
<td>5.70</td>
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<tr>
<td>Vancouver, WA (2006)</td>
<td>No</td>
<td>1,600,000</td>
<td>16.5</td>
<td>233</td>
<td>4.01</td>
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<tr>
<td>Spokane, WA (2007)</td>
<td>No</td>
<td>300,000</td>
<td>11.1</td>
<td>36</td>
<td>0.92</td>
</tr>
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## 2007 Caltrans contracts.

<table>
<thead>
<tr>
<th>Contract #</th>
<th>Location</th>
<th>Material</th>
<th># Panels</th>
<th>Cost / Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>03-0C7704</td>
<td>03-PLA-80-R66.3/68.5</td>
<td>Rapid Setting Concrete</td>
<td>272</td>
<td>$2,295.00</td>
</tr>
<tr>
<td>01-457704</td>
<td>01-MEN-101-R31.6/R33.7</td>
<td>Rapid Setting Concrete</td>
<td>133</td>
<td>$2,715.75</td>
</tr>
<tr>
<td>05-491904</td>
<td>05-SLO-1-L16.7/18.1</td>
<td>Rapid Setting Concrete</td>
<td>209</td>
<td>$3,155.63</td>
</tr>
<tr>
<td>06-0G6204</td>
<td>06-KER-5-62.0/82.5</td>
<td>Rapid Setting Concrete</td>
<td>198</td>
<td>$2,640.00</td>
</tr>
<tr>
<td>04-269604</td>
<td>04-CC-24-R0.1/R8.3</td>
<td>Rapid Setting Concrete</td>
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<td>$2,731.05</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>1805</strong></td>
<td></td>
<td></td>
<td><strong>$2,703.39</strong></td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>444</strong></td>
<td></td>
<td></td>
<td><strong>$2,789.37</strong></td>
</tr>
</tbody>
</table>

Average Cost per Panel

<table>
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<th>Location</th>
<th>Material</th>
<th># Panels</th>
<th>Cost / Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-0F5004</td>
<td>06-KER-14-R17.9/T22.0</td>
<td>Asphaltic Concrete</td>
<td>128</td>
<td>$3,387.75</td>
</tr>
<tr>
<td>04-447204</td>
<td>04=ALA-92-6.8/8.2</td>
<td>Asphaltic Concrete</td>
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<td>04-4A6104</td>
<td>04-SOL-80-22.0/30.6</td>
<td>Asphaltic Concrete</td>
<td>282</td>
<td>$2,443.22</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>444</strong></td>
<td></td>
<td></td>
<td><strong>$2,789.37</strong></td>
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</tbody>
</table>

Average Cost per Panel
American Society of Civil Engineers (ASCE)

“2009 Report Card for America’s Infrastructure”

Roads = D-
33% in poor or mediocre condition
Questions?