Rapid Strength Concrete for Transportation Structures and Pavements

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Challenging call for sustainability to the construction industry

✧ Volumes of consumption of natural materials for concrete;
✧ Duration of service life of structures and pavements;
✧ Necessity of limiting carbon dioxide footprint

✧ **Millions of tones of natural materials** are used annually for complete rebuilding of deteriorating concrete transportation infrastructure.
✧ **Inconvenience to public caused by long closures** of bridges, highways, city streets, etc. usually needed for repair and preservation work complicates efficient maintenance.
Change design & maintenance practices to enhance sustainability and reduce environmental impact...

- Extension of service life of structures and pavements;
- Design and implementation of repairable concrete structures and pavements; and
- Use of special rapid hardening concretes for preservation & rehabilitation of structures & pavements allowing for acceleration of construction and minimizing public inconvenience.

Rapid strength concrete has been successfully used for maintenance, repair and extension of services life of:
- Bridges
- Tunnels
- Airfields
- Highways
- City streets
Accelerate construction by enhancing strength gain of cast-in-place concrete...

- Hydraulic cements intended for enhancing early age strength gain;
- Non-chloride accelerators;
- Lower water-cementitious material ratio;
- Enhance development of early-age bond of cement paste to coarse aggregate
- Increase initial temperature of concrete
- Increase temperature of concrete during curing

Emergency rehabilitation of truck bypass tunnel damaged by fire between Interstate Highway-5 & Highway-14, Los Angeles County, CA, USA, November 2007. Rapid strength concrete was produced with Type III high-early Portland cement and contained a non-chloride accelerator.
Compressive strength $\geq 17$ MPa; Corresponding Flexural strength $\geq 2.8$ MPa

- One hour plus when rapid hardening cements are used
- Two hours plus when Type III Portland cement with accelerators is used

Pavement rehabilitation: Interstate Highway 10, (Pomona, CA, USA) started mid-1999, completed 2000
- $> 25,000$ yd$^3$ (19,000 m$^3$) RSC with calcium sulfoaluminate (CSA) cement;
- Performed night time, freeway closures limited to 10 hours to minimize impact on mobility;
- Satisfactory performance of the replacement pavement recorded for 10 years and counting.
Rapid hardening cements – no accelerators required

- Rapid setting & hardening of binder (ASTM C1600) → fast strength development of RSC.
- Workability is achieved by using *set controlling admixtures & high range water reducers.*

![Graph showing the development of compressive strength of concrete with Calcium Sulfoaluminate Cement](image-url)

**Development of Compressive Strength of Concrete with Calcium Sulfoaluminate Cement**

- Time, hours (logarithmic scale)
- Compressive strength, MPa

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RSC with Type III Portland cement – non-chloride accelerators must

- Approximately 46 to 59 mL accelerator per 1 kg of cement can yield compressive strength of 17 – 20 MPa or flexural strength of 2.8 MPa in 2 to 4 hours;
- Very low w/cm is essential;
- Hydration controlling admixtures and high range water reducers assist in providing needed workability.

RSC with
- Type III Portland cement
- Non-chloride accelerator
- Superplasticizer
- Hydration controlling admixture

was first used in 2000 for full-depth pavement replacement on State highway 405 in Culver City, CA, USA.

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### Transportation Structures – Typical Applications of RSC for Emergency and Planned Rehabilitation

<table>
<thead>
<tr>
<th>Application</th>
<th>Min Strength Requirement at the Time of Opening to Service, MPa</th>
<th>Min Curing Time after Completion of Finishing, hours</th>
<th>Materials &amp; Proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hydraulic Cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Admixtures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max w/cm</td>
</tr>
<tr>
<td>Bridge Decks</td>
<td>21 compressive</td>
<td>3</td>
<td>Rapid hardening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HRWR; SC; Latex</td>
</tr>
<tr>
<td>Approach Structures</td>
<td>8.5 compressive</td>
<td>1</td>
<td>Rapid hardening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HRWR; SC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Portland Type III</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HRWR; SC; Accelerator</td>
</tr>
</tbody>
</table>

**Abbreviations:**

- HRWR – high range water reducer
- SC – set controlling admixture

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# Pavements – Typical Applications of RSC for Emergency and Planned Rehabilitation

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<tr>
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<th>Min Curing Time after Completion of Finishing, hours</th>
<th>Materials &amp; Proportions</th>
<th>Hydrualic Cement</th>
<th>Admixtures</th>
<th>Max w/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean Concrete Base</td>
<td>5.0 (725 psi) compressive</td>
<td>1</td>
<td>Rapid hardening</td>
<td>HRWR; SC</td>
<td>~ 0.55-0.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Portland Type III</td>
<td>HRWR; SC; Accelerator</td>
<td>~ 0.32-0.34</td>
<td></td>
</tr>
<tr>
<td>Pavement Course</td>
<td>2.8 (400 psi) flexural</td>
<td>1</td>
<td>Rapid hardening</td>
<td>HRWR; SC</td>
<td>~ 0.40-0.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Portland Type III</td>
<td>HRWR; SC; Accelerator</td>
<td>~ 0.32-0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.8 (550 psi) flexural</td>
<td>1.5</td>
<td>Rapid hardening</td>
<td>HRWR; SC</td>
<td>~ 0.38-0.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Portland Type III</td>
<td>HRWR; SC; Accelerator</td>
<td>~ 0.32-0.34</td>
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**Abbreviations:**
- HRWR – high range water reducer
- SC – set controlling admixture

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**RSC must be proportioned for Constructability…**

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<tr>
<th>Property</th>
<th>Performance Notes</th>
<th>Proportioning Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump</td>
<td>4 to 8 inches</td>
<td>➢ HRWR</td>
</tr>
</tbody>
</table>
| Segregation resistance    | Good                               | ➢ Continuous aggregate grading  
➢ Moderate to moderately low w/cm  
➢ Controlled addition rate of HRWR  
➢ Optimized water content  
➢ High fineness of hydraulic cement |
| Retention of workability  | 15 to 40 min after discharge       | ➢ Set controlling admixture  
➢ Control of initial temperature of RSC                                               |
| Rate of bleeding           | Moderately low to low              | ➢ High fineness of hydraulic cements  
➢ Low to moderately low w/cm is achieved by using HRWR                                |
..must also account for **durability & exposure conditions**..

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<tr>
<th>Property</th>
<th>Performance Notes</th>
<th>Proportioning Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability</td>
<td>Lower than regular PCC</td>
<td>➢ w/cm=0.32-0.45 is most common</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Quicker hydration of cements and faster consumption of water, leaving less water for evaporation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Higher rate of hydration of CSA cement</td>
</tr>
<tr>
<td>Sulfate resistance</td>
<td>RSC can be specified for high sulfate resistance</td>
<td>➢ CSA cement is high sulfate resistant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Type III PC can be specified and produced for high sulfate resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ w/cm=0.32-0.45 is most common</td>
</tr>
<tr>
<td>Deleterious expansion due to the use of reactive aggregates</td>
<td>Can be mitigated</td>
<td>➢ Cements are available as low-alkali</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ CSA cement can be used with Class F fly ash for achieving the required strength within 2-4 hours</td>
</tr>
</tbody>
</table>

**Abbreviations:**
- PC – portland cement
- PCC – portland cement concrete
- CSA – calcium sulfoaluminate (cement)

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…all the while being reasonably resistant to volume changes.

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<tr>
<th>Property</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Shrinkage(*)</td>
<td>RSC with CSA cement <strong>lower than PCC</strong> (0.018 – 0.030% in 28 dry days after 7 days of moist curing).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RSC with Type III PC <strong>close to PCC</strong> (0.030 – 0.050% in 28 dry days after 7 days of moist curing).</td>
<td>✦ Cements finer than Type I/II/V PC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✦ Upon hydration, consume water faster than regular PCC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✦ CSA cement combines higher absolute amount of water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✦ Non-chloride accelerators (Type III PC RSC) effect shrinkage much less than chloride-based admixtures</td>
</tr>
</tbody>
</table>

Note: (*)Shrinkage data featured in the table represents RSC with siliceous aggregates available in Southern California, USA.
Limited bleeding + Fast setting → lower risk of plastic cracking...

• Limited bleeding → lower plastic settlement over reinforcement, dowel and tie bars

• Fast setting → lower potential for plastic shrinkage cracking compared to regular PCC with the same rate of bleeding.
...but higher potential of superficial temperature cracks...

- Rapid cooling of the top layer in cold periods causes contraction and retardation of tensile strength gain.

- Underlying warmer RSC develops strength quicker and restrains contraction of the near-surface material.

Superficial temperature cracks can be prevented. Minimum temperature of placement of RSC should be determined by constructing and evaluating mockups. Rapid cooling can be prevented by the use of appropriate thermal insulation.
“Over-working” of concrete while finishing is more harmful to RSC than regular concrete

Increase in water content of the near-surface layer of RSC may lead to formation of cracks due to:

✧ Increase in w/cm;
✧ Retardation and reduction of tensile strength; and
✧ Larger moisture-related volume changes restrained by underlying faster setting and hardening RSC.

✧ This mechanism is initiated either by segregation of RSC or by water application upon finishing and can be prevented by proper construction practices.

Application of water to the surface of flatwork during finishing must be controlled and limited to prevent the weakening of the near-top layer of paste.

Along with proper curing, this also enhances abrasion resistance of RSC pavements and bridge decks.

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Rehabilitation of airfield with RSC

Rapid strength concrete with CSA cements is most often produced using volumetric measuring and continuous mixing equipment. VMCM equipment allows for:

- Producing concrete at or near point of placement,
- Reducing time between mixing and placing,
- Producing concrete in exact required volumes,
- Reducing demand in set controlling admixtures, and
- Enhancing uniformity of workability and strength.
Rehabilitation of highway with RSC

RSC with Type III Portland cement is most often produced using transit mixers. High range water reducer and set controlling admixture are added at the batch plant. Accelerators are added in the field using calibrated dispensers with pump mounted on truck chassis. Such sequence of the addition of admixtures enhances uniformity of workability and strength.
Closing Remarks:

- Project experience validates the beneficial use of RSC for extending service life of concrete structures and pavements. RSC types featured in the presentation have been utilized on hundreds of projects for planned and emergency repair of bridges, tunnels, airfields, highways, and city streets.

- The best results are achieved when RSC is proportioned (designed) with consideration for constructability, durability, exposure, and site conditions.

- Constructability is, in large, determined by the following properties: (i) Workability (slump, time within which RSC retains the design consistency, and segregation resistance), (ii) Rate of strength gain in early age (determining time needed for achieving the minimum strength required for opening transportation structures and pavements to service), and (iii) Resistance to cracking in early age before stress relief measures can be executed (development of tensile strength and strains due to volume changes).
Closing Remarks:

- RSC can be specified for special exposure conditions, including among others resistance to sulfates, resistance to alternate freezing and thawing, and protection of reinforcing steel.

- Low to moderately low w/cm, and faster and higher than of regular concrete consumption of water due to hydration decrease permeability, which reduce ingress of moisture and solutions of corrosive ions and enhance durability. Certain RSC types are specifically efficient for repair of structures subject to intrusion of aggressive ions.

- Rapid development of tensile strength enhances cracking resistance of RSC.

- Control of the initial temperature of RSC and proper adjustments to dosage rates of chemical admixtures are convenient and reliable methods used by RSC suppliers for enhancing predictability and uniformity of workability and strength.
Closing Remarks:

- Method of production and delivery of concrete is recommended to be selected with consideration for the type of RSC, as provided in this presentation. Proper selection of the method of production and delivery enhances constructability and assures uniformity of strength gain.

- Use of rapid strength concrete is a viable solution for preservation and rehabilitation of aging infrastructure, which minimizes inconvenience to public caused by construction work.
QUESTIONS?