Long Term Performance of Rapid Strength Concrete (RSC) Slabs On California Highways

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Previous Caltrans Study of RSC Performance

- Caltrans conducted a study in 2008 titled “Evaluation of Rapid Strength Concrete Slab Repairs” that documented the short-term (3-year) performance of RSC. (Bhattacharya, Zola, and Rawool, 2008)

- Fifteen projects located in six Regions/Districts and 10 counties on major freeways containing 5,430 slabs that were surveyed and distress recorded.

- These projects averaged about 3 years in age at the time of the survey.

  ✓ “Only 1.4 percent of the slabs surveyed showed premature distress.”
3-Year Results (only 1.4% distressed) Are Impressive, But.....

• 3-Year short term performance RSC was very good, but what about longer term performance?

• The RSC repairs are currently around 13-years as of 2018 and under heavy truck traffic. How are they performing now?
Objective: Conduct a Follow-up Study

- **Conduct a follow-up study** that documents the long-term performance of Rapid Strength Concrete (RSC) in California for independent slab replacements. [RSC Age 2005 – 2018 = 13 years]
- **Identify distress types** that develop long term in RSC in the field so that they can be addressed in procedures, specifications and standard provisions.
- **Estimate the longevity** of the RSC.
- **Suggestions for improvements** based on performance results.
Available Data for Long-Term RSC Performance

• **Six RSC projects** were randomly selected by CALTRANS from the original 15 projects.

• The six projects (each with a total length of several miles) were from the same RSC study published in 2008 where the RSC manufacturer was known.

• **Total of 12 lanes** were surveyed (inner and outer).

• A total of **1,493 RSC slabs** located on six projects were surveyed using the latest 2018 Caltrans video monitoring films where all observable distresses were identified.
# Summary of RSC Projects 2018

(Note: Missing data being located)

<table>
<thead>
<tr>
<th>Route</th>
<th>District, County, ID</th>
<th>Post Mile</th>
<th>2016 2-Way AADTT</th>
<th>Design</th>
<th>Construction &amp; RSC Constr. Year</th>
<th>Age of RSC, years</th>
<th>Type RSC Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-10</td>
<td>8, San Bernardino 08-0A180</td>
<td>0–14.8</td>
<td>17,000</td>
<td>8-9 in JPCP 6-in LCB 4-in AB</td>
<td>1970s, 2005</td>
<td>13</td>
<td>CTS</td>
</tr>
<tr>
<td>I-10</td>
<td>8, San Bernardino 08-49370</td>
<td>14.8–20.0</td>
<td>20,000</td>
<td>8-9 in JPCP 6-in LCB 4-in AB</td>
<td>1970s, 2005</td>
<td>13</td>
<td>CTS</td>
</tr>
<tr>
<td>I-10</td>
<td>8, San Bernardino 08-4192U</td>
<td>24.5–39.1</td>
<td>17,000</td>
<td>8-9 in JPCP 4-in CTB 4-in AB</td>
<td>1970s, 2005</td>
<td>13</td>
<td>CTS</td>
</tr>
<tr>
<td>I-5</td>
<td>7, LA 07-45050</td>
<td>76-88.6</td>
<td>17,000</td>
<td>8-9 in JPCP 4-in CTB 3-in AB</td>
<td>1970s, 2005</td>
<td>13</td>
<td>4X4</td>
</tr>
<tr>
<td>US-50</td>
<td>3, Sacramento 03-0A840</td>
<td>0.8–4.8</td>
<td>8,500</td>
<td>8-9 in JPCP 6-in LCB 4-in AB</td>
<td>1972, 2005</td>
<td>13</td>
<td>CTS</td>
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<tr>
<td>SR-126</td>
<td>7, Ventura 07-24490</td>
<td>0–13</td>
<td>2,800</td>
<td>8-9 in JPCP 4-in CTB 4-in AB</td>
<td>1972, 2006</td>
<td>12</td>
<td>CTS</td>
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</table>
### Summary of 12 Lanes Surveyed 2018 (13-Years)

<table>
<thead>
<tr>
<th>Route</th>
<th>District</th>
<th>County</th>
<th>MP to MP</th>
<th>Material</th>
<th>Lane*</th>
<th>Truck Traffic**</th>
<th>Total Trucks***</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>0 - 14 EBL</td>
<td>CTS</td>
<td>1 Inner</td>
<td>17000</td>
<td>2,016,625</td>
</tr>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>14.5 - 20 WBL</td>
<td>CTS</td>
<td>4 Outer</td>
<td>20000</td>
<td>28,470,000</td>
</tr>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>15.5 - 19.9 WBL</td>
<td>CTS</td>
<td>3 Inner</td>
<td>20000</td>
<td>11,862,500</td>
</tr>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>15.5 - 20 EBL</td>
<td>CTS</td>
<td>3 Inner</td>
<td>20000</td>
<td>11,862,500</td>
</tr>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>24.5 - 30 EBL</td>
<td>CTS</td>
<td>3 Inner</td>
<td>24000</td>
<td>14,235,000</td>
</tr>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>24.5 - 30 EBL</td>
<td>CTS</td>
<td>4 Outer</td>
<td>24000</td>
<td>34,164,000</td>
</tr>
<tr>
<td>I-5</td>
<td>7</td>
<td>LA</td>
<td>76 - 88.6 NBL</td>
<td>4x4</td>
<td>1 Inner</td>
<td>17000</td>
<td>2,016,625</td>
</tr>
<tr>
<td>I-5</td>
<td>7</td>
<td>LA</td>
<td>76 - 88.6 NBL</td>
<td>4x4</td>
<td>2 Inner</td>
<td>17000</td>
<td>4,033,250</td>
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<tr>
<td>US-50</td>
<td>3</td>
<td>SAC</td>
<td>1.1 - 4.8 EBL</td>
<td>CTS</td>
<td>3 Outer</td>
<td>8500</td>
<td>10,083,125</td>
</tr>
<tr>
<td>US-50</td>
<td>3</td>
<td>SAC</td>
<td>0.84 - 2.9 EBL</td>
<td>CTS</td>
<td>1 Inner</td>
<td>8500</td>
<td>2,016,625</td>
</tr>
<tr>
<td>SR-126</td>
<td>7</td>
<td>VEN</td>
<td>0 - 13 EBL</td>
<td>CTS</td>
<td>1 Inner</td>
<td>2800</td>
<td>664,300</td>
</tr>
<tr>
<td>SR-126</td>
<td>7</td>
<td>VEN</td>
<td>0 - 4 EBL</td>
<td>CTS</td>
<td>2 Outer</td>
<td>2800</td>
<td>5,978,700</td>
</tr>
</tbody>
</table>

*1 Inner Lanes, 4 Outer Lane. **Two direction AADTT. ***Total Trucks over 13 year service life.
Field Data Collection 2008

• Two types of RSC included: CTS and 4x4 (Note: CTS supported this follow up survey)
  • CTS was used on five projects (864 slabs)
  • 4x4 was used on one large project (629 slabs)

• These slab replacements were completed in all lanes including the inner lane (with the lowest truck volume, designated Lane 1) across to the outer heavy truck lane (designated Lane 4 if there are 4 lanes in one direction).
Field Data Collection 2018

• **Distresses** that were identified in these slabs include the following:
  • Transverse cracking
  • Longitudinal cracking
  • Corner cracking
  • Joint spalling (spalling that occurred within the RSC slab, not in the surrounding concrete)

• In addition to the video surveys, **on-site visits were completed in July 2019** to help further verify their condition.
Section I-10, MP 24.5 to 39.1 EBL
(Pathways software used by Caltrans)
Photo of a Transverse Crack of a 18-19 ft RSC Slab with Skewed Joints
Caltrans RSC Specification 2005: Key Points

• **Description:** The replacement of short segments of single or multiple sequential slabs and possibly the underlying base in the same lane to match the existing concrete thickness. **Thickness of RSC slabs is the same as the existing JPCP (8-9 inches w/ random joint spacing).**

• **Removing Existing Pavement:** The existing concrete slab is removed and as needed the base course is replaced with a specified base material (typically lean concrete) and an RSC slab.

• **Base Replacement:** The replacement base is finished to the grade of the original base layer. If concrete, it is not textured but finished as a smooth surface.
Caltrans RSC Specification 2005: Key Points

• **Bond Breaker:** Placed between the existing base (typically cement treated base or lean concrete base) or new replacement base and the new RSC slab that consists of one of the following:
  • 1. White curing paper specified in ASTM C 171.
  • 2. White opaque polyethylene film specified in ASTM C 171, except the minimum thickness must be 6 mils.
  • 4. Curing compound No. 5. Apply in two separate applications.

• **Note that every effort is made to separate the two layers.** This has implications on future performance.
Caltrans RSC Specification 2005: Key Points

• Transverse & Longitudinal Joint Filler: A 1/4-inch thick commercial quality polyethylene flexible foam expansion joint filler is placed across the original transverse and longitudinal joint faces prior to placement of the RSC slab.
Caltrans RSC Specification 2005: Key Points

• **Dowels in Transverse Joints.** Most sections are believed to contain dowels anchored in the transverse joints.
  - There appeared to be no significant joint faulting or corner cracking on the projects surveyed, thus they most likely included dowels.
  - More recent standards indicate 4 dowels per wheel path in the truck lanes.
  - Dowels are typically spaced at 12-inches in the wheel paths with a diameter of 1.25-inches based on slab thickness of 9-inches or less.
Caltrans RSC Specification 2005: Key Points

• **Rapid Strength Concrete (RSC).** To reduce the disruption to traffic, Caltrans carries out overnight repairs, limiting lane closures to the hours between 11 pm and 5 am. Distressed concrete panels are removed and replaced with RSC during this limited time period.
  • Only cement mixes that meet the **early opening strength requirements within 2 to 4 hours after placement** are used.
  • **RSC is a concrete made with hydraulic cement** that develops opening age and 7-day specified modulus of rupture strengths.
  • RSC slabs must develop a **minimum modulus of rupture of 400 psi** before opening to traffic.
  • RSC slabs **minimum modulus of rupture of 600 psi at 7 days** after placement.
Description of RSC Slab Materials: CTS

• “CTS” is Rapid Set® cement, a belitic calcium sulfoaluminate (CSA) cement made by CTS Cement Mfg. Corp. (Provided support for this study)
  • Non-proprietary technology
  • Rapid strength gain; opening strength (400 psi flex) in 1.5 hours
  • Very low shrinkage
  • High sulfate resistance
  • ASR resistant
  • Can be used in volumetric mixer (mobile mix) or transit mixer (ready mix)”

Description of RSC Slab Materials: 4x4
(400 psi w/i 4 hrs)

• 4x4 is concrete system that uses portland cement, retarder, accelerator, and super-plasticizer
  • Patented technology; offered by multiple admixture suppliers
  • Rapid strength gain; opening strength (400 psi flex) in 4 hours “4x4”
  • Can be higher shrinkage if SRA isn’t used (Type-III cement)
  • Cannot be used in volumetric mixer (transit mix only)

Results from 2018 (13-Year) Survey

• **1,493 RSC replaced slabs were surveyed** using Caltrans video images from six projects collected in the year 2018. All of these projects were surveyed in 2008.
  • These RSC slabs were located in all traffic lanes from the inner most lane (#1) to the outer most lane (typically #4 the heaviest truck trafficked lane).

• **Distress types identified on the 2018 RSC slabs.**
  • Transverse mid-panel (fatigue) cracks
  • Longitudinal cracks
  • Corner cracks
  • Joint spalling (within the RSC replacement slab)
## Results From 2018 (13-Year) Survey

<table>
<thead>
<tr>
<th>Route</th>
<th>District</th>
<th>County</th>
<th>MP to MP+</th>
<th>RSC Material</th>
<th>Survey Lane*</th>
<th>AADTT 2016 Truck Traffic</th>
<th>Total Trucks In Lane</th>
<th>Total RSC Slabs</th>
<th>Trans Crk % Slabs</th>
<th>Long Crk % Slabs</th>
<th>Corner Crk % Slabs</th>
<th>Spall % Slabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>0 - 14 EBL</td>
<td>CTS</td>
<td>1 Inner</td>
<td>17000</td>
<td>2,016,625</td>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>14.5 - 20 WBL</td>
<td>CTS</td>
<td>4 Outer</td>
<td>20000</td>
<td>28,470,000</td>
<td>70</td>
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<td>0.0</td>
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<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>15.5 - 19.9 WBL</td>
<td>CTS</td>
<td>3 Inner</td>
<td>20000</td>
<td>11,862,500</td>
<td>183</td>
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<td>1.1</td>
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<td>SBD</td>
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<td>CTS</td>
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<td>SBD</td>
<td>24.5 - 30 EBL</td>
<td>CTS</td>
<td>3 Inner</td>
<td>24000</td>
<td>14,235,000</td>
<td>6</td>
<td>0.0</td>
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<tr>
<td>I-10</td>
<td>8</td>
<td>SBD</td>
<td>24.5 - 30 EBL</td>
<td>CTS</td>
<td>4 Outer</td>
<td>24000</td>
<td>34,164,000</td>
<td>45</td>
<td>4.4</td>
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<td>0.0</td>
<td>2.2</td>
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<td>I-5</td>
<td>7</td>
<td>LA</td>
<td>76 - 88.6 NBL</td>
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<td>1 Inner</td>
<td>17000</td>
<td>2,016,625</td>
<td>68</td>
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<tr>
<td>I-5</td>
<td>7</td>
<td>LA</td>
<td>76 - 88.6 NBL</td>
<td>4x4</td>
<td>2 Inner</td>
<td>17000</td>
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<td>0.0</td>
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<td>SAC</td>
<td>1.1 - 4.8 EBL</td>
<td>CTS</td>
<td>3 Outer</td>
<td>8500</td>
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<td>51</td>
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<td>2.0</td>
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<tr>
<td>US-50</td>
<td>3</td>
<td>SAC</td>
<td>0.84 - 2.9 EBL</td>
<td>CTS</td>
<td>1 Inner</td>
<td>8500</td>
<td>2,016,625</td>
<td>8</td>
<td>12.5</td>
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<td>0.0</td>
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<td>SR-126</td>
<td>7</td>
<td>VEN</td>
<td>0 - 13 EBL</td>
<td>CTS</td>
<td>1 Inner</td>
<td>2800</td>
<td>664,300</td>
<td>30</td>
<td>10.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>SR-126</td>
<td>7</td>
<td>VEN</td>
<td>0 - 4 EBL</td>
<td>CTS</td>
<td>2 Outer</td>
<td>2800</td>
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<td>223</td>
<td>45.7</td>
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<td>1.3</td>
<td>0.0</td>
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</table>

*Averages 8.8 0.3 0.3 0.8

*1 Inner Lanes, 4 Outer Lane.
Results from 2018 (13-Year) Survey

• The most prevalent distress type in the RSC slabs was transverse cracking. Based on past studies including observations in the field and finite element stress analysis, these cracks are nearly always caused by top down fatigue damage from heavy repeated truck loadings.
Illustration of Top Down Transverse Fatigue Cracking

Outside Lane

Shoulder

Direction of traffic

Critical location (top of slab)
Results from 2018 (13-Year) Survey

RSC Distress Types: 13 Years All Lanes

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>% RSC Slabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Cracks</td>
<td>9</td>
</tr>
<tr>
<td>Longitudinal Cracks</td>
<td>0.1</td>
</tr>
<tr>
<td>Corner Cracks</td>
<td>0.1</td>
</tr>
<tr>
<td>Joint Spalling</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Results from 2018 (13-Year) Survey

• The overall average percent slabs with transverse cracking increased from **0.8 to 8.8 percent slabs over 13-years** over all traffic lanes surveyed.

• The transverse cracked slabs occurred at a far higher rate in heavier truck outer lanes.
  • Outer truck lane percent cracked: 21 percent. (carried 20 million trucks)
  • Inner truck lane percent cracked: 3 percent. (carried 6 million trucks)
Typical Top Down Transverse Fatigue Crack
(Initiated at Outer Edge of Slab)
RSC Transverse (Fatigue) Cracking
(Over 13 years of Performance)

RSC Transverse Fatigue Cracks:
13 Years

- 6 Million Trucks (Inner Lane)
- 20 Million Trucks (Outer Lane)
Bond Breaker with LCB/CTB Increases Cracking

• All of the RSC slabs were placed on plastic sheeting or other bond breaker separating them from the CTB or LCB.

• Thus, they could not bond together and this created higher upward curling (from moisture gradient and hourly temperature gradients) and top of slab bending stresses (from truck loads and slab weight) potentially creating a more rapid transverse crack development.
Longitudinal Cracking, Joint Spalling, Corner Cracking

- Longitudinal cracking in the RSC slabs: **0.3 percent**.
  - Longitudinal cracking not identified in 2008.

- Transverse or longitudinal joint spalling in RSC slabs: **0.8 percent**.
  - Percent in 2008 was 0.44 (combined spalling and corner cracking).

- Corner cracking in RSC slabs: **0.3 percent**.
  - Percent in 2008 was 0.44 percent (combined spalling and corner cracking).
RSC Durability

• **RSC slabs exhibited no observable durability distress** (e.g., “D” cracking, freeze-thaw damage, shrinkage cracking, ASR) over the 13 years of service.
  • This finding of no durability issues is important in that the general impression is that RSC materials often develop durability problems over time.

• **Reports of RSC durability problems on two projects** were reviewed that exhibited quality issues. So clearly, construction quality is of utmost importance!
  • Construction at night makes this even more of a challenge but the overall data show this has been accomplished a large majority of the time in CA.
RSC Materials 4x4 & CTS

• The two RSC slab concrete materials CTS and 4x4 could not be directly compared as they existed on different projects in different climates with widely varying truck traffic volumes.

• However, the following table was prepared to show their performance in the “inner” lanes.
### 4x4 & CTS RSC Inner Lane Slabs Distress Over 13 Years
(4x4 = 629 slabs; CTS = 864 slabs)

<table>
<thead>
<tr>
<th>RSC Material</th>
<th>Inner Lane Trucks</th>
<th>Inner Lane Fatigue Transverse Cracks</th>
<th>Inner Lane Long. Cracks</th>
<th>Inner Lane Corner Cracks</th>
<th>Inner Lane Spalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x4 (1 Project, 629 slabs)</td>
<td>3.0 million</td>
<td>0.10%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>1.05%</td>
</tr>
<tr>
<td>CTS (5 Project, 864 slabs)</td>
<td>7.1 million</td>
<td>3.00%</td>
<td>0.07%</td>
<td>0.00%</td>
<td>0.50%</td>
</tr>
</tbody>
</table>

Both RSC materials provided excellent performance over 13-14 years for these projects.
On Site Review of RSC Slabs

• Conducted on-site visual review of five RSC projects July 2019
  • I-10, District 8, PM 0 to 14.8, San Bernardino (CTS RSC)
  • I-10, District 8, PM 14.8 to 20, San Bernardino (CTS RSC)
  • I-10, District 8, PM 24.5 to 39, San Bernardino (CTS RSC)
  • I-5, District 7, PM 76 to 88, “Grape Vine” Elevation 4,000 ft, (4x4 RSC)
  • SR 126, District 7, PM 0 to 13, Ventura, (CTS RSC)

• RSC slabs observed showed no durability cracking or other signs of durability problems, both in the videos and visually on-ground.

• RSC slabs after 14 years showed sound concrete and should survive well into the future.
Highway I-5 NB (PM 76-88)
NW of Los Angles showing original Inner #1 Lane (left) and Adjacent #2 Lane with Several RSC Slabs placed in 2005.
Highway I-5 NB (PM 76-88)
NW of Los Angeles showing original Inner #1 Lane (left) and Adjacent #2 Lane with Several RSC Slabs placed in 2005.
Highway I-5 NB (PM 76-88)

NW of Los Angeles showing a Transverse Joint between 14-year old RSC slab on left and original JPCP concrete that is spalled (placed about 1972) on right.
Highway I-10 EB (PM 15-30)
Near San Bernardino showing two 14-year old RSC slabs outer Lane #4.
Highway I-10 EB (PM 15-30)
Near San Bernardino showing 14-year old diamond ground transverse jointed RSC Slab in Lane #4 (outer lane). Good RSC durability as shown here was found at all sites.
Highway I-10 EB (PM 15-30)
Near San Bernardino showing another 14-year old RSC slab in Lane #4 (outer lane).
Highway I-10 EB (PM 15-30)

Near San Bernardino showing on the left side a 14-year old RSC slab surface in Lane #4 (outer lane) and on the right an original (1970s) JPCP slab (transverse top down fatigue crack).
Highway SR-126 EB (PM 0-13)
Near Ventura, 13-year old RSC replaced slabs in outer lane #2 (right) placed in 2006 with significant transverse fatigue cracks.
Highway SR-126 EB (PM 0-13)
Near Ventura showing an RSC slab placed in 2006 that has developed one top down transverse fatigue crack from heavy truck traffic & thin RSC slab (8-in)
Survivability of RSC Slabs

• Given the results from this survey, what is the expected life (or survivability) of the RSC slabs?

• Inner Traffic Lanes Survival
  ✓ Eight of the total 12 traffic lanes were considered “inner” lanes with lower truck traffic (6 million per 13-years). The average percent transverse fatigue cracking for these inner lane RSC slabs was 3.0% (0 to 12.5%).
  ✓ Six of these inner lanes had < 1% of any kind of distress but two lanes had 10 and 12.5% transverse fatigue cracking.
  ✓ Thus, the inner (lower truck) lanes can be expected to exhibit significantly more than 20 years of service.
Survivability of RSC Slabs

• **Outer Traffic Lanes Survival**
  • Four of the total 12 traffic lanes were considered “outer” lanes with higher truck traffic (mean = 21 million trucks 13-years).
  • Mean percent transverse cracking RSC slabs in outer lanes was 20% (3 to 46%).
  • At 13-years the only distress of significance is transverse fatigue cracking. All other distresses affected less than 4 percent RSC slabs in the outer lanes.

✓ *Thus, the survival longevity of the independent RSC slabs outer lane constructed to the same thickness as the old existing 8-9 inch JPCP, will be driven heavily by transverse fatigue cracking (e.g., 13+ years).*

✓ *If a thicker RSC slab can be placed, the fatigue damage issue can be eliminated (e.g. 20+ years).*