Long-Term Performance and Rehabilitation Strategy of Portland Cement Concrete Pavement on US-290 in Houston, Texas

Moon Won

ABSTRACT

The 27-mi (43.5 km) portion of US-290 between Loop 610 and Badtke Road consists of portland cement concrete (PCC) pavement built at various times with different pavement structures (10-inch-thick and 13-inch-thick (250 mm and 330 mm) slabs) and two pavement types (continuously reinforced concrete pavement (CRCP) and jointed reinforced concrete pavement (JRPC)). As of 2012, the age of the pavements varies from 7 to 52 years.

Over the years, the traffic on US-290 has increased steadily, and the highway capacity has been exceeded in some parts of the section, resulting in traffic delays and high user costs. The Houston District of the Texas Department of Transportation is planning to increase the highway capacity of this section. Detailed evaluations were made to develop optimum short-term and long-term strategies.

All of the sections are in good structural condition with no punchouts, regardless of pavement age and slab thickness. However, major functional distresses exist in the 10-inch (250 mm) sections, all built with siliceous river gravel as the coarse aggregate. The primary distress type present is severe spalling. Yet, from a structural standpoint, all four sections outperformed design traffic by 3 to 10 times. All of the 13-inch (330 mm) CRCP sections used crushed limestone as the coarse aggregate, and spalling distress is almost nonexistent. Based on the performance of CRCP built with crushed limestone coarse aggregate with a stabilized base and tied concrete shoulder, it is believed that the 13-inch (330 mm) CRCP sections will provide excellent long-term performance with minimal maintenance required.

The recommended short-term strategy is to place a 4-inch (100 mm) bonded concrete overlay on the 10-inch (250 mm) CRCP sections built prior to 1985, and an 8-inch (200 mm) unbonded concrete overlay with a 2-inch (50 mm) asphalt interlayer on the 10-inch JRCP built in 1973 through 1977. Recommended long-term strategies include removal and replacement of all the current 10-inch (250 mm) PCC pavements with 13-inch (330 mm) CRCP and widening the existing 13-inch CRCP.

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INTRODUCTION

For the last few decades, the population and business activities along the US-290 corridor in Houston, Texas, have increased steadily, resulting in traffic delays and high user costs. As of 2011, the average daily traffic on US-290 near Loop 610 exceeded 200,000 vehicles. The roadway system was not designed to handle today’s high traffic levels. To alleviate traffic delays, the Houston District of the Texas Department of Transportation (TxDOT) is planning to expand the highway capacity of the roadway, which includes widening or removing/replacing the existing pavement system. The limits of the project are from Loop 610 to Badtke Road, approximately 27 mi (43.5 km). The existing pavement type is portland cement concrete (PCC) pavement, mostly continuously reinforced concrete pavement (CRCP) with a short section of jointed reinforced concrete pavement (JRCP). Currently, the estimated cost of the project is more than $4 billion. There are eight pavement sections within the project limits, built at various times with different slab thicknesses. The oldest one was built in 1960 with 10-inch (250 mm) CRCP, and the newest one in 2005 with 13-inch (330 mm) CRCP. The oldest section is more than 50 years old, with more than 115 million cumulative equivalent single-axle loads (ESAL) in one direction. To develop an optimized plan to increase the highway capacity of the roadway, detailed evaluations were conducted to estimate the remaining lives of each section. The structural capacity and remaining life of each pavement section were evaluated by field testing using various methods, including rolling dynamic deflectometer (RDD), falling-weight deflectometer (FWD), and coring. Traffic information was obtained from TxDOT’s Pavement Management Information System (PMIS). In addition, the PCC pavement was visually evaluated for its functional condition. Based on the detailed evaluations, an optimized plan, both short-term and long-term, was developed to preserve the condition of the pavement and increase the highway capacity of the roadway.

Description of US-290 Section

The US-290 section under this evaluation extends from Loop 610 to Badtke Road, from the northwest side of the City of Houston toward northwest. The length is approximately 27 centerline miles (43.5 km), between reference marker 711 (Badtke Road) and 738 (Loop 610). Table 1 below provides information on the various sections. It shows that the age of the pavement varies from 7 to 52 years, and the slab thicknesses are 10 (250 mm) and 13 inches (330 mm). The base structure consists of a 1-inch (25 mm) asphalt base on top of a 6-inch (150 mm) cement-stabilized base.
Table 1. Various Pavement Sections in US-290

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Length (mi)</th>
<th>Pavement Type</th>
<th>Construction Year</th>
<th>Slab Thickness (in.)</th>
<th>FWD Deflection (mil)</th>
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</thead>
<tbody>
<tr>
<td>Badtke Rd</td>
<td>Mueschke Rd</td>
<td>7.0</td>
<td>CRCP</td>
<td>2005</td>
<td>13</td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Mueschke Rd</td>
<td>Telge Rd</td>
<td>4.9</td>
<td>CRCP</td>
<td>1994</td>
<td>13</td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Telge Rd</td>
<td>Eldridge Rd</td>
<td>3.1</td>
<td>CRCP</td>
<td>1985</td>
<td>10</td>
<td>2.4</td>
</tr>
<tr>
<td>Eldridge Rd</td>
<td>FM 529</td>
<td>2.6</td>
<td>CRCP</td>
<td>1989</td>
<td>13</td>
<td>1.7</td>
</tr>
<tr>
<td>FM 529</td>
<td>W Little York Rd</td>
<td>1.9</td>
<td>CRCP</td>
<td>1986</td>
<td>13</td>
<td>1.6</td>
</tr>
<tr>
<td>W Little York Rd</td>
<td>43rd St</td>
<td>4.9</td>
<td>CRCP</td>
<td>1980</td>
<td>10</td>
<td>2.6</td>
</tr>
<tr>
<td>43rd Street</td>
<td>Dacoma St</td>
<td>2.4</td>
<td>JRCR</td>
<td>1973–77</td>
<td>10</td>
<td>Not evaluated</td>
</tr>
<tr>
<td>Dacoma St</td>
<td>Loop 610</td>
<td>0.6</td>
<td>CRCP</td>
<td>1960</td>
<td>10</td>
<td>Not evaluated</td>
</tr>
</tbody>
</table>

1 mi = 1.61 km; 1 in. = 25.4 mm

Overall Condition of US-290 Section

Visual observations of the pavement sections revealed that most of the sections were in good functional condition, with few surface defects, except for the sections between Loop 610 and W. Little York Road. The primary distress type in the sections between Loop 610 and W. Little York Road was severe spalling. No punchouts were observed. All the spalling distresses were repaired with various methods. One method was to use epoxy-based material to fill the spalling, as shown in figure 1. Another method was full-depth repair as shown in figure 2. Spalling in the Houston District has been a serious distress in CRCP, requiring periodic repairs and resulting in low ride scores. Over the years, TxDOT sponsored a number of research studies to address the spalling issue in the Houston area (1, 2, 3). The research findings indicated that the use of a specific coarse aggregate type with a high coefficient of thermal expansion (CTE) was responsible for the severe spalling problems. Based on the research findings, the Houston District requires a maximum allowed CTE coarse aggregates must meet for use in CRCP. Since the Houston District implemented this requirement, spalling problems have practically disappeared.

Another distress type was lane separation at longitudinal construction joints, as shown in figure 3. This distress is confined to the JRCP section. In the past, the use of bent tie bars was common at TxDOT. Investigation of lane separations indicated that some bent tie bars were not straightened or some of them were broken. Currently, the use of bent bars is not a common practice in TxDOT. Only multi-piece or single-piece tie bars are allowed. Figure 4 illustrates surface slot-stitching to keep the lanes from further separation. Figure 5 shows the surface slot stitching operation. This operation is time consuming, especially if vertical drilling hits tie bars or longitudinal steel. There has been only partial effectiveness with this method, with degrading ride quality.

Figure 3 and figure 4 show that, even though there is lane separation at longitudinal construction joints, the overall condition of the JRCP is excellent after more than 30 years of service.
Figure 1. Repair of spalling with epoxy material.

Figure 2. Repair of spalling with full-depth repair.

Figure 3. Lane separation at longitudinal construction joint.

Figure 4. Repair of lane separation with surface slot stitching.
Structural Capacity Evaluations

The structural capacity of the pavement in four sections was evaluated by FWD and RDD, as shown in table 1. Overall, the deflections are small. Under the TxDOT research project for rigid pavements database, FWD testing was conducted statewide on 27 CRCP test sections. Each test section is 1,000 ft (305 m) long. Figure 6 shows the deflections at 9,000 lb (4,082 kg) loading for CRCP with various slab thicknesses obtained from the database project (4). Each point represents an average of 21 deflections, measured at 50-ft (15 m) intervals in each section. The graph shows that deflections decrease as slab thickness increases. The age of the
CRCP test sections in the rigid pavement database varies substantially. Also, in Texas, two types of base are used: 4-inch (100 mm) asphalt-stabilized base and 1-inch (25 mm) asphalt base on top of a 6-inch (150 mm) cement-stabilized base. Figure 6 shows that the age and base type do not have substantial effects on deflections. The back-calculated modulus of subgrade reaction value with Westergaard’s interior condition from the statewide testing conducted in the rigid pavement database was about 300 lbf/in²/in (81 kPa/mm).

Deflections measured in each section were comparable to the statewide average values, indicating that the structural condition is satisfactory except for the section between Telge Road and Eldridge Road, which was built in 1985. This section is 10-inch (250 mm) CRCP on a 1-inch (25 mm) asphalt base and a 6-inch (150 mm) cement-stabilized base. There were no punchouts, and very little spalling was observed, even though the coarse aggregate was the same type that typically caused severe spalling problems in the Houston District. As discussed below, coring indicated multiple delaminations, and there is a strong potential for severe spalling problems in the future in this section. In the Houston District, the time between concrete placement and severe spalling occurrence varies substantially. In some projects, spalling occurred within 2 to 3 years, while in other projects, it took more than 15 years before severe spalling occurred.

RDD testing was conducted only in the sections from Telge Road to 4,000-ft (1,219 m) east of FM 529. RDD testing was not conducted for all the sections because the RDD speed was limited to 1 mi/h (1.6 km/h) and scheduling conflicts prevented testing in the whole project. Figure 7 and figure 8 illustrate the deflections by RDD in the eastbound outside lane.

Figure 7. RDD deflections from Telge Road to Eldridge Road.

Figure 8. RDD deflections from Eldridge Road to FM 529.
Overall, the deflections in the 10-inch (250 mm) CRCP built in 1985 are larger than those of the 13-inch (330 mm) CRCP built in 1989. Also, a larger variability is observed in the 10-inch CRCP than in the 13-inch CRCP. Larger deflections normally represent surface delaminated areas. As discussed below, delaminations were observed in a concrete core obtained in the 10-inch CRCP section.

**Slab Delaminations and Transverse Crack Evaluations**

Concrete cores were taken from sections between Telge Road and Eldridge Road (10-inch CRCP). All of the 13-inch (330 mm) sections were built with crushed limestone as coarse aggregates, and based on the performance of CRCP in Texas, these sections will provide good long-term performance without major maintenance needs, and there was no need for investigations for slab delaminations.

Figure 9 shows the locations of three cores in the section between Telge Road and Eldridge Road. It shows that transverse cracks are tight and no spalling is observed after 25 years of service. Three cores were taken, and figure 10 shows a core taken in location B in figure 9. The transverse crack stopped about 3 inches (75 mm) from the surface. In CRCP, it is observed that most of the transverse cracks do not go through the slab depth; rather, they stop a few inches from the surface, which explains the high level of load transfer efficiency (LTE) at the transverse cracks and the excellent performance of CRCP in Texas.

In figure 9, it is observed that crack widths at three core locations are different; the crack width at location C is the largest, and those at A and B are negligible (figure 10). Figure 11 shows a core taken at location C. Even though the crack width is large at the surface of the slab (left side of the picture), the crack width at the mid-depth of the core is quite small. LTE at this crack would be near 100 percent because aggregate interlock near the mid-depth of the slab appears to be intact. In TxDOT’s rigid pavement research project, extensive field testing has been conducted to evaluate LTE values in Texas. The findings from 7 years of testing on 324 transverse cracks twice a year indicate that LTE values are greater than 95 percent at almost all the transverse cracks evaluated, regardless of crack spacing, slab thickness, and the season of testing (winter vs. summer) (4). In figure 11, a horizontal crack is observed at the mid-depth of the slab. This crack could be a result of torque exerted on the concrete by coring operations. To ascertain that the horizontal crack is not the result of a coring operation, the inside of the core hole was evaluated. Figure 12 shows that horizontal cracks exist in the concrete slab, indicating that the horizontal crack is not the result of a coring operation. In general, horizontal cracking in CRCP is observed in pavement sections where concrete with a high CTE is used. The high curling stress resulting from a high CTE of concrete appears to induce horizontal cracking, which leads to partial-depth distresses.
Figure 9 shows a wide transverse crack in the section between Telge Road and Eldridge Road. A core was taken at 2.5 ft (0.8 m) away from the longitudinal construction joint (lane marking line), which is under the wheel path. Figure 14 shows the core taken from location E in figure 13. Three horizontal cracks are observed at 2.5, 4.5, and 5.0 inches (65, 115, and 125 mm) from the surface. Even though the surface of the pavement looks normal except for a large crack width, multiple delaminations shown in figure 14 will result in severe spalling. It is not known how
long it will take before these delaminations develop into spalling, but, based on the severity of the shallow delaminations, it should not be long before severe spalling takes place. The large RDD deflections shown in figure 7 are believed to be due to shallow delaminations. There are a number of locations with shallow delaminations in this section. It is interesting to note that there were no punchouts in this section after more than 25 years of service, even though the design life of this pavement, when it was built, was only 20 years.

A side of the pavement was cut to add shoulders in a CRCP section between W. Little York Road and 43rd Street, with a 10-inch (250 mm) slab thickness built in 1980, which provided a good opportunity to observe the condition of base and transverse cracks. Figure 15 shows a wide transverse crack. In the CRCP research community, it has been postulated that a wide transverse crack as shown in figure 15 is detrimental to CRCP performance due to reduced LTE. Figure 16 shows the closeup view of the side at the transverse crack in figure 15. The crack is confined in the top 2 to 3 inches (50 to 75 mm), below which the crack disappeared. This is consistent with the transverse crack characteristics shown in figure 10. It should be noted that transverse cracks develop to alleviate temperature and moisture variations (environmental loading) near the concrete surface. Once a crack occurs and environmental stresses are relieved, the crack does not propagate, especially when reinforcement is present, as in CRCP. LTE testing was not conducted at this crack location. However, LTE would be near 100 percent, since the crack stopped at 2 to 3 inches from the surface. This indicates that, even though severe spalling is the major distress on this section, the structural capacity was not compromised.
Remaining Life Analysis

As stated earlier, it was decided that all of the 13-inch (330 mm) CRCP sections would remain in place and additional lanes would be added to increase the highway capacity. The decision was based on the performance of excellent CRCP sections in Texas built with crushed limestone coarse aggregate. The same decision was not made for the 10-inch (250 mm) CRCP sections, primarily because of the age of the pavement, slab thickness, and the coarse aggregate type used. Siliceous river gravel was used for all of the 10-inch sections. Efforts were made to assess the remaining life of the 10-inch pavement sections.

To assess the remaining life of the 10-inch (250 mm) sections, cumulative traffic from the opening of the sections was estimated using traffic information in the PMIS. The PMIS provides average daily traffic (ADT) and percentage of trucks for each year from 1993 to 2010. It does not provide traffic information prior to 1993. The yearly ESAL burden was estimated as follows:

1. Use 1.2 for equivalent axle-load factor for trucks, and 0.7 for lane distribution factor.
2. Determine daily ESAL by ADT*percent truck*1.2.
3. Determine yearly ESAL by daily ESAL*365*0.7.

In this evaluation, the contributions of cars to the pavement damage are ignored. The ESAL values from the construction of the sections prior to 1993 were estimated by extrapolation with the regression equation. Figure 17 shows the annual ESAL variations from 1993 to 2010 for the section between Telge Road and Eldridge Road, along with the regression equation. The cumulative traffic for each section was estimated by summing up all the annual ESALs from the opening of the section to 2011.
In the remaining life analysis, the design traffic was estimated with the current input values for rigid pavement design that would result in the slab thickness used (10 inches (250 mm)), which is 11.5 million ESALs. When the pavement designs were developed for the 10-inch sections, higher values for reliability and concrete strength were used. As a result, 11.5 million ESALs is a slightly over-estimated value, which would result in less conservative values for the remaining life analysis. Table 2 summarizes the results of the analysis. The ratio in the 5th column was obtained by the ratio of the 4th column (cumulative traffic to 2011) to the 3rd column (design traffic). The remaining life (percent) is defined as 100 times (1 – ratio).

Table 2. Remaining Life Analysis

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Design Traffic [million ESAL]</th>
<th>Cumulative Traffic to 2011 [million ESAL]</th>
<th>Ratio</th>
<th>Remaining Life [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telge Rd</td>
<td>Eldridge Rd</td>
<td>11.5</td>
<td>35.7</td>
<td>3.1</td>
<td>-210</td>
</tr>
<tr>
<td>W Little York Rd</td>
<td>43rd Street</td>
<td>11.5</td>
<td>75.7</td>
<td>6.6</td>
<td>-560</td>
</tr>
<tr>
<td>43rd St</td>
<td>Dacoma St</td>
<td>11.5</td>
<td>94.3</td>
<td>8.3</td>
<td>-730</td>
</tr>
<tr>
<td>Dacoma St</td>
<td>Loop 610</td>
<td>11.5</td>
<td>115.7</td>
<td>10.1</td>
<td>-910</td>
</tr>
</tbody>
</table>

The results in table 2 indicate that the remaining life for each section is negative, which does not make practical sense. On the other hand, at least from a theoretical standpoint, it indicates that the cumulative traffic for all the sections far exceeded the design traffic that was supposed to have caused the terminal condition of the pavement. It is interesting to note that the section between Dacoma Street and Loop 610 served more than 10 times the design traffic. The remaining life analysis shows that the sections performed quite well, far exceeding the design traffic.
life. What is not known is how much more traffic these sections can accommodate before major rehabilitation becomes necessary.

**Short-Term Strategy**

The funding level required to increase the highway capacity of the US-290 section is estimated at over $4 billion. At this point, the funding is not available and the functional condition of some of the sections needs to be improved. Recommendations were made to improve the functional condition of the section between Loop 610 and W. Little York Road. Based on the excellent performance of the 4-inch (100 mm) bonded concrete overlay (BCO) in Texas, 4-inch BCO was recommended for all 10-inch (250 mm) CRCP sections between Loop 610 and W. Little York Road (5). For the JRCP section, an 8-inch (200 mm) unbonded concrete overlay (UBCO) with a 2-inch (50 mm) hot-mix asphalt separation layer was recommended. BCO or UBCO is used to increase the structural capacity of PCC pavement. In this case, the 10-inch PCC pavement sections have adequate structural capacity, and thin asphalt overlays might be sufficient to provide a short-term solution to address functional distresses. However, the performance of asphalt overlays in Texas varies substantially, with an average life of about 6 to 7 years. Considering the high traffic on US-290, BCO and UBCO will provide long-term performance with practically no maintenance needed and thus were recommended. A do-nothing option was recommended for the 10-inch CRCP section between Telge Road and Eldridge Road. Severe spalling problems are anticipated in the future, and will be repaired as they occur.

**Long-Term Strategy**

Based on the structural capacity evaluations and remaining life analysis, the following long-term strategy was recommended to increase the highway capacity of US-290 as funding becomes available:

1. All of the 13-inch (330 mm) CRCP sections will remain in place, and more lanes will be added to the existing pavement. The widening sections will be 13-inch CRCP. New lanes will be tied to the existing CRCP by tie bars.

2. Even though the future BCO and UBCO on the 10-inch (250 mm) CRCP and JRCP sections may provide good long-term performance, they may not be able to provide more than 50 years of the performance needed for this section. It was recommended that the sections between Loop 610 and W. Little York Road and between Telge Road and Eldridge Road be removed and replaced with 13-inch (330 mm) CRCP.

**CONCLUSIONS**

The portion of US-290 between Loop 610 and Badtke Road is 27 mi (43.5 km) long and consists of PCC pavement built at various times with different pavement structures (10-inch (250 mm) and 13-inch (330 mm) thick slabs) and two pavement types (CRCP and JRCP). As of 2012, the age of the pavement varies from 7 to 52 years. Due to the increased traffic on US-290, the Houston District of the TxDOT is planning to increase the highway capacity of the section, and detailed evaluations were made to develop optimum short-term and long-term strategies.
All the sections are in good structural condition with no punchouts, regardless pavement age and slab thickness. However, major functional distresses exist in the 10-inch (250 mm) sections, all built with siliceous river gravel as the coarse aggregate. The primary distress type present is severe spalling. Yet, from a structural standpoint, all four sections with a 10-inch slab thickness outperformed design traffic by 3 to 10 times. The excellent structural performance can be attributed to 1) the use of stabilized, nonerodible base and 2) the use of tied concrete shoulder. Based on the performance of CRCP built with crushed limestone coarse aggregate with a stabilized base and tied concrete shoulder in Texas, it is believed that the 13-inch (330 mm) CRCP sections will provide excellent long-term performance with minimal maintenance required.

Since the funding needed for the long-term rehabilitation and widening is not available at this point, the Houston District of TxDOT is developing a short-term strategy to improve functional performance of the existing pavement sections and to enhance their structural capacity. Bonded and unbonded concrete overlays were recommended for 10-inch-thick (250 mm) sections between Loop 610 and W. Little York Road.

The findings from the evaluations indicate that rigid pavement design methodologies used for the existing sections were quite conservative. Also, the overall pavement structural system—PCC pavement slab with durable base system and tied concrete shoulder—worked well. The distresses observed in the sections were not due to structural deficiency; rather, due to the use of coarse aggregate type prone to spalling. Based on the findings, a long-term strategy was developed that places more emphasis on material selection and quality construction rather than just on a proper slab thickness determination.

ACKNOWLEDGMENT

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REFERENCES


