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Sustainable Pavements: CRCP Across Texas

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Sustainable Pavements: CRCP Across Texas

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Introduction

The Texas Department of Transportation (TxDOT) is responsible for the management and maintenance of an extensive network of highways encompassing thousands of lane miles across the state, including 18,283 lane miles of continuously reinforced concrete pavements (CRCPs) as of 2024. This MAP brief delves into the successful deployment of CRCP (Figure 1) throughout Texas, highlighting the design principles and construction practices used to build these pavements and the substantial benefits they offer in terms of durability and sustainability. CRCPs are renowned for their exceptional performance in handling heavy traffic loads and resisting severe weather conditions, making them an economically viable solution for Texas' diverse and demanding transportation needs.

Design Principles

CRCP is characterized by the presence of continuous longitudinal steel reinforcement throughout the entire pavement section. The longitudinal steel keeps the transverse cracks caused by environmental and traffic loading tight, thereby maintaining a high level of load transfer across the cracks and resulting in reduced wheel load stress and fatigue damage in the concrete. The arrangement of this reinforcement system is purposefully designed to uphold the structural integrity of the pavement against a range of factors, including shrinkage, temperature fluctuations, and the stresses induced by traffic and environmental loading. CRCPs are engineered to offer 30 years of service life, with most surpassing their design life and requiring little to no repair.

Edward Goebel, Lubbock District, TxDOT, used with permission

Figure 1. State highway improvement project on US 62 in Lubbock County, Texas, featuring 10-inch CRCP (2016)

Per TxDOT policy, the minimum thickness for single mat CRCP is 7 inches, while the maximum thickness is 13 inches, with ½ inch increments. Additionally, all reinforcing steel and tie bars should consist of Grade 60 deformed bars. The longitudinal steel bars are placed at the mid-depth of the concrete slab for CRCPs under 10.5 inches thick or at 5 inches from the surface for CRCPs between 10.5 inches and 13 inches thick. For CRCPs thicker than 13 inches, two-layer reinforcement is required. Figure 2 illustrates a typical reinforcing steel arrangement for CRCP using a transverse bar assembly (TBA).

The thickness of the concrete layer is determined based on factors such as traffic loading, base type, subgrade stiffness, and environmental conditions. TxDOT's current design procedure for CRCP makes use of a mechanistic-empirical design procedure to determine slab thickness based on design life, traffic loading, subgrade treatment, and base layer criteria. The reinforced concrete layer is usually placed over either a 4-inch hot-mix asphalt (HMA) base or a 6-inch cement-treated base (CTB) with a 1½-inch HMA layer (bond breaker). Experts familiar with the use of CRCP in Texas advise the use of the latter to ensure sufficient structural support. One or more subbase layers may also be used, with the last layer consisting of treated or untreated subgrade. The subgrade treatment is selected based on the plasticity index (PI) of the in situ soil. For soils with a PI of less than 35, cement alone can provide adequate strength to the subgrade layer. For soils with a PI of 35 or greater, it is recommended that the subgrade be treated with a combination of lime and cement. To determine the best soil and base treatment, the reader is encouraged to review TxDOT's *Treatment Guidelines for Soils and Base in Pavement Structures Guide* (TxDOT 2019).

For more detailed insights into TxDOT's rigid pavement design procedure, refer to Chapter 8 of the TxDOT *Pavement Manual* (TxDOT 2021). Additionally, *Integrated Materials and Construction Practices (IMCP) for Concrete Pavements: A Manual of Practice* (Taylor et al. 2019) offers a broad spectrum of relevant topics, with Chapter 3, Basics of Concrete Pavement Design, providing foundational information on various design methodologies.

Construction Methods

Like all products, quality construction is essential to obtaining a CRCP that will meet or exceed expectations, even under traffic levels far greater than the assumptions used for design. Figure 3 illustrates the construction of a CRCP on Farm-to-Market Road (FM) 1938 in Westlake, Texas, captured on March 16, 2011. The image shows specialized machinery laying concrete over a prepared base that features an array of interconnected reinforcing steel. A skilled contractor will know how to provide a stable working platform as well as subbase and base layers that meet stiffness and non-erodibility requirements. Accurate grade control is essential not only to avoid waste and excess material use but also, more importantly, to ensure that the overall concrete thickness and reinforcing steel location are within specified tolerances. Proper crack control requires the steel mat to be located as described in the previous section. An overly thick pavement with steel reinforcement lower than specified may exhibit poor crack control, which could result in spalling and the need for partial-depth repairs over time.

While CRCP is more easily constructed on long, unobstructed stretches of roadway like those found on controlled access highways, thousands of miles of CRCP are placed in urban environments. Figure 4 depicts a 10-inch CRCP located on FM 865 between Almeda-Genoa Road in Harris County and FM 518 in Brazoria County, Texas (a non-freeway facility). The need to accommodate manhole covers and drainage inlets and especially the need to keep driveways accessible are some of the more challenging construction aspects in an urban environment, especially when a high level of pavement smoothness is a priority.

Nancy Beltran, Cement Council of Texas, used with permission

Figure 2. Typical reinforcing steel arrangement for CRCP

Pangil Choi, Maintenance Division, TxDOT, used with permission

Figure 3. CRCP under construction on FM 1938 in Westlake, Texas

Jamal Elahi, Galveston Area Office, TxDOT, used with permission

Figure 4. Non-freeway facility featuring 10-inch CRCP

Perhaps the greatest challenge in constricted spaces is the need to deliver the concrete to the slipform paver, because this generally requires a haul lane in addition to the new pavement. However, an experienced contractor can often find solutions to staging and access challenges, so providing the freedom to innovate can improve the likelihood of a successful final pavement.

The jointing techniques used for CRCP are mostly similar to those used for JPCP, including the need for proper timing and depth of saw cuts for longitudinal contraction joints. A major difference between the two pavement types is the absence of regular transverse contraction joints in CRCP. Since most in-service CRCP distresses occur at transverse construction joints and repair joints, the construction and inspection activities undertaken at the beginning and end of each day of paving should be given special attention. The focus on these activities emphasizes the importance of good construction practices during evening headers and morning concrete pouring, particularly in terms of compaction and curing. Similarly, terminal expansion joints require skill and attention in both design and construction.

For a more comprehensive understanding of CRCP construction, it is strongly recommended to refer to Chapter 9 of the TxDOT *Pavement Manual* (TxDOT 2021) and Chapter 8 of the IMCP manual (Taylor et al. 2019), both of which provide extensive details on rigid pavement construction techniques. Additionally, reviewing these manuals in their entirety can greatly enhance knowledge on the subject of CRCP construction methods.

Durability and Cost Benefits

CRCP offers several durability and cost benefits for infrastructure projects requiring good long-term performance. Since 1985, CRCPs in Texas have been designed to deliver service lives of 30 years; however, these pavements have consistently surpassed this expectation. In a service life analysis of CRCP projects within Texas, the TxDOT Maintenance Division found that as of 2023, CRCPs in Texas have averaged approximately 39.5 years of service before requiring rehabilitation, with many still maintaining their structural integrity (Choi 2024).

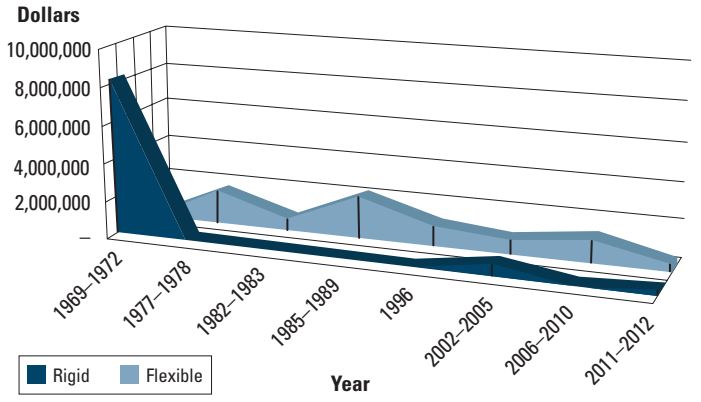
With fewer repairs and interventions needed compared to other pavement types, the ongoing maintenance costs of CRCP are substantially reduced. While CRCPs may involve higher initial costs compared to traditional pavement alternatives, the low maintenance requirements translate to cost savings over the pavement's service life. By conducting life-cycle cost analyses (LCCA), transportation agencies and project stakeholders can assess the total cost of ownership over the pavement's entire lifespan. LCCA considers not only construction costs but also maintenance, rehabilitation, and future replacement expenses.

In 2013, the TxDOT Construction Division and the Wichita Falls District conducted an LCCA of CRCP (rigid) versus HMA (flexible) pavements on US 287/US 81 in Montague County, Texas (Shawn and Hazlett 2013). The results indicated that while the initial construction cost for CRCP was higher, the long-term maintenance costs were significantly lower than those for HMA (Figure 5). The study concluded that the life-cycle cost per square yard was $42.65 for CRCP and $45.57 for HMA.

Since then, the initial cost difference between concrete and asphalt has become more competitive, potentially leading to greater savings. Currently, the Cement Council of Texas is seeking to collaborate with the Wichita Falls District to conduct an updated LCCA of CRCP versus HMA pavements in Montague County, Texas.

Sustainability

Over the last several years, the focus on sustainability within the concrete and cement industry has increased dramatically, and the industry has set a goal of reaching carbon neutrality throughout the construction value chain by 2050. With respect to concrete pavements, two broad-based strategies can be used to lower a concrete pavement's life-cycle CO_2 emissions. The first strategy is to improve pavement and concrete mix designs so that the pavement lasts longer and has lower embodied CO_2 both at initial construction and over its service life due to reduced maintenance and rehabilitation (M&R) needs.



Adapted from Shawn and Hazlett 2013

Figure 5. Life-cycle cost of CRCP (rigid) versus HMA (flexible) pavements on US 287/US81 in Montague County, Texas

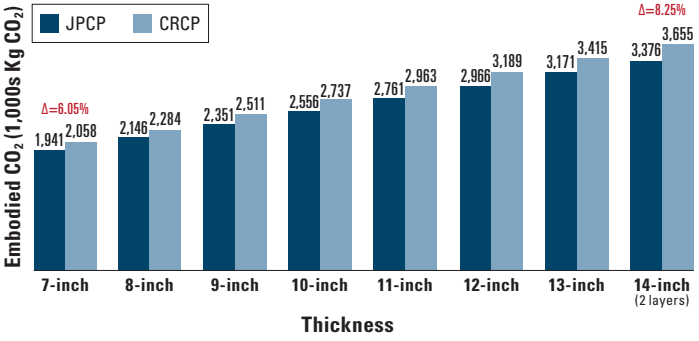
The second strategy is to lower the use phase impacts of the pavement, which accounts for the CO_2 emitted as the pavement is used by the public. These impacts include carbonation, lighting and albedo, and the fuel use of the vehicles driving on the pavement. While much of the current emphasis is on reducing a pavement's initial embodied CO_2 emissions, use phase emissions often dominate the materials, construction, and M&R phases, especially on high-volume truck corridors where CRCPs are most often used.

In terms of embodied CO_2, many designers and engineers assume that CRCPs have significantly higher embodied CO_2 compared to JPCPs with dowels due to the greater amount of steel used in CRCPs. However, an analysis performed by the authors shows that the difference in initial CO_2 emissions between comparable JPCPs and CRCPs is only between 6% and 8.25% depending on pavement thickness (as illustrated in Figure 6). While this difference may not seem significant, the true savings emerge during the use phase, where CRCPs outperform all other pavement systems due to their extended long-term performance and reduced pavement-vehicle interaction (PVI).

PVI is the excess rolling resistance resulting from the interaction between a vehicle and a pavement. Greater PVI increases the fuel consumption required to move the vehicle and thus causes additional CO_2 emissions. While PVI is a function of three components of the pavement system—roughness, stiffness, and texture—most of the emphasis in the United States has been on roughness and deflection. As a vehicle moves over a pavement, any roughness or irregularity in the surface will "bounce" the vehicle, which engages the vehicle's suspension system and decreases the vehicle's fuel efficiency. The rougher the pavement, the greater the loss of fuel efficiency and the greater the CO_2 emissions associated with using the pavement. Therefore, it is important to build smooth pavements that can maintain their smoothness throughout their lives. Similarly, when a vehicle drives on a pavement, the pavement deflects, and the vehicle must continuously drive uphill to overcome the deflection. Stiffer pavements, such as concrete pavements, deflect less under the weight of heavy vehicles, which lowers the excess PVI fuel consumption attributable to PVI (Akbarian et al. 2012, Louhghalam et al. 2016, Mack et al. 2018, Xu et al. 2019).

The best performing pavements exhibit both smoothness and stiffness, and CRCP is both inherently the stiffest type of pavement system and the system that tends to remain the smoothest the longest. These characteristics are evident in the extensive International Roughness Index (IRI) data that TxDOT has collected on CRCPs dating back to 1996, which are categorized by age in Figure 7. (Note that the CRCP age range from 0 to 9 years includes widening and other jobs. Thus, the actual increase in CRCP lane miles over the past 10 years is 4,711 lane miles.) These data demonstrate that CRCP maintains low and consistent IRI values over time, even as sections age beyond 30 years, which means that CRCP will have lower PVI-related environmental impacts compared to other pavement types whose IRI values deteriorate faster. These impacts can be further minimized, especially on high-volume roadways, through techniques such as diamond grinding, which enhances the smoothness of concrete pavements both during initial construction and throughout their service lives.

The other big savings in CO_2 emissions come from CRCPs' reduced need for maintenance and rehabilitation activities. Most asphalt pavements require rehabilitation approximately every 10 and 15 years, and most JPCP pavements need their first rehabilitation sometime between 25 and 35 years.



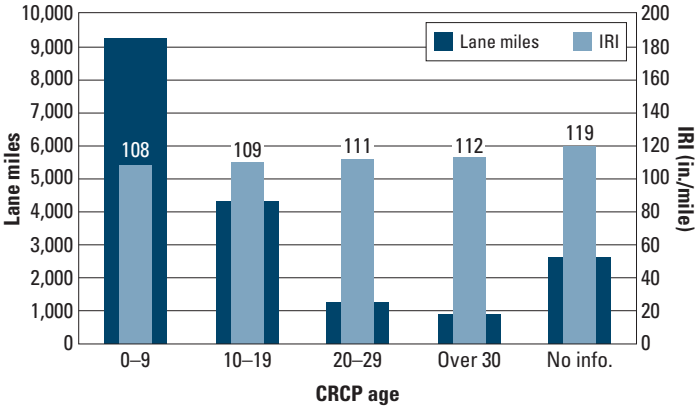
All pavements are 1 mile in length with four lanes (two 12-foot lanes in each direction).

All designs feature a 1-inch asphalt interlayer over a 6-inch cement-treated base over a 6-inch aggregate subbase and have full-depth concrete shoulders.

Embodied CO_2/global warming potential (GWP) values are based on average Industry-Wide Environmental Product Declaration (IW-EPD) values for cement, concrete, and steel; Embodied Carbon in Construction Calculator (EC3) median values for asphalt; European Union (EU) Ecoinvent values for aggregate; or representative company EPD values for lime, geogrids, and geofabrics.

Adapted from James Mack, Cemex, used with permission

Figure 6. Estimated embodied CO_2 (materials only) for JPCPs (with dowels) and CRCPs with various thicknesses



CP Tech Center; data provided by Maintenance Division, TxDOT

Figure 7. CRCP age versus lane miles and IRI values (1996–present)

CRCPs, however, have demonstrated an ability to last for nearly 40 years before requiring their first rehabilitation, with many lasting much longer than that. Parts of I-610 in Houston, Texas, for example, are approaching 65 years of service life without having undergone rehabilitation. With the need for fewer rehabilitation activities and work zones, congestion is automatically reduced, leading to decreased idling times, minimized stop-and-go traffic, and faster travel times, all of which collectively increase vehicles' fuel efficiency and, in turn, contribute to lower CO_2 emissions.

Achieving Long-Lasting CRCPs

Many of the challenges encountered with conventional concrete pavements also apply to CRCPs. These challenges include accounting for climate variability, mitigating the effects of expansive soils, and achieving proper construction quality.

Accounting for climate variations and their potential impact on pavement lifespan is crucial, as temperature fluctuations and extreme weather events can accelerate deterioration.

In the state of Texas, as well as in other parts of the country, a variety of soil types, including expansive soils, necessitate the implementation of appropriate treatments to effectively mitigate the potential challenges these soils present for CRCPs. Expansive soils in particular are a challenge because they have the tendency to undergo significant volume changes in response to variations in moisture content, which can lead to soil movement and subsequent pavement distress. One effective approach to minimize the detrimental effects of expansive soils on pavement performance involves implementing soil stabilization techniques. Soil stabilization with cement or a combination of lime and cement is often recommended as an effective solution to help mitigate the detrimental effects of moisture-induced volume changes by reducing the swell potential of soils and increasing their strength and stiffness. Testing is strongly recommended to ensure the selection of the most suitable stabilizer and its appropriate dosage. Additionally, proper subgrade preparation and drainage measures can help manage moisture levels within the soil, thereby mitigating the risk of expansive soil-induced damage to CRCPs.

Achieving proper construction quality is crucial for the long-term performance of CRCPs. Challenges such as achieving adequate compaction of the supporting layers, proper placement of reinforcement, and minimization of construction-related defects require attention to detail and effective quality control measures. By implementing rigorous quality control protocols, construction teams can ensure the long-term performance and durability of CRCPs, thereby maximizing their lifespan and minimizing maintenance requirements.

Ultimately, addressing these challenges to the long-term performance of CRCPs requires collaboration among engineers, designers, contractors, and transportation agencies to develop effective design, construction, maintenance, and rehabilitation practices tailored to Texas' specific conditions and requirements.

Conclusion

CRCPs play a vital role in enhancing infrastructure sustainability and minimizing maintenance costs in Texas. Their inherent durability and low maintenance requirements make them a preferred choice for highway pavements, especially in regions with heavy traffic and variable weather conditions. Given adherence to design principles that emphasize proper reinforcement placement, crack control, and adequate pavement thickness, CRCPs can withstand the rigors of climate change and heavy traffic loads while offering a lifespan of nearly 40 years with minimal to no repairs.

Additionally, CRCPs provide significant cost benefits over their life cycle due to their decreased maintenance needs and prolonged service life. This is supported by a TxDOT analysis (Choi 2024) indicating that CRCPs in Texas have an average service life of 39.5 years before the first rehabilitation and suggesting that CRCPs have the potential to last even longer.

Moreover, CRCPs contribute to sustainability efforts by minimizing carbon emissions during the use phase and reducing congestion through the need for fewer maintenance activities, ultimately benefiting the environment and road users alike.

To mitigate challenges such as climate variability and expansive soils, implementing effective soil stabilization techniques and rigorous quality control measures can ensure the successful performance of CRCP pavements in Texas. Through collaboration and innovation, CRCP technology will continue to evolve, offering sustainable and cost-effective solutions for Texas' transportation infrastructure needs.

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