U.S. Department of Transportation
Federal Highway Administration

SUSTAINABLE PAVEMENTS PROGRAM

ECONOMICAL CONCRETE WITH RECYCLED CONCRETE AGGREGATE PROVIDES SUSTAINABILITY BENEFITS IN TEXAS

FHWA-HIF-19-081

Reusing old concrete pavement as an aggregate source for new pavement construction can lead to significant cost savings, reductions in virgin material usage, and overall sustainability benefits. This was demonstrated on a concrete pavement reconstruction project on I-10, a ten-lane divided interstate located on the west side of Houston, Texas.

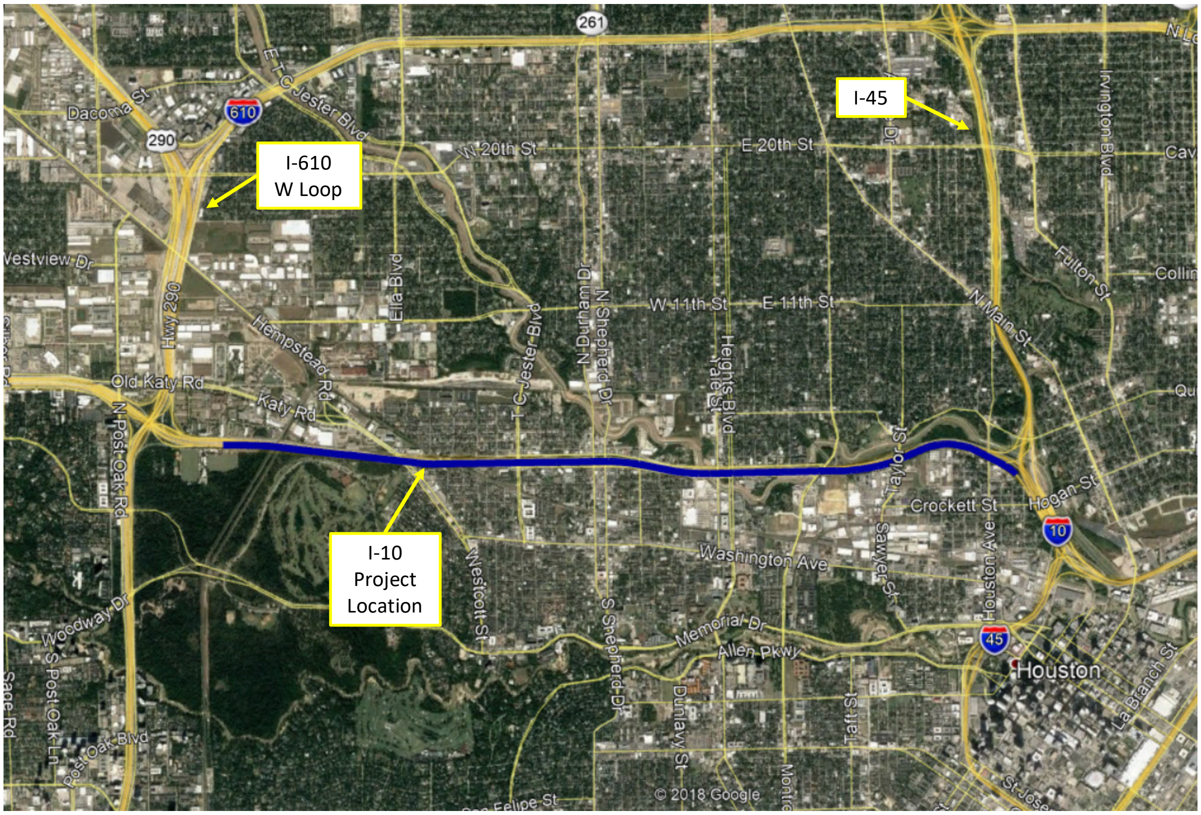
WHAT WAS THE MOTIVATION?

In the 1990s, the Texas Department of Transportation (TxDOT) struggled with a lack of suitable locally available aggregate sources and rising costs of virgin materials. At the same time, the Department had experienced a few performance issues with virgin aggregates in its continuously reinforced concrete pavement (CRCP) designs. Given the growing availability of concrete for recycling, TxDOT began exploring the use of recycled concrete aggregate (RCA) in infrastructure projects. However, one challenge in using RCA in CRCP was a limited understanding of the mix design requirements and the impact of RCA on long-term performance.

WHAT WAS DONE?

OVERVIEW

To gain a better understanding of RCA usage in CRCP, TxDOT looked to incorporate it in the 1995 reconstruction of a 5.8-mi segment of I-10 in the Houston metropolitan area (between the I-610 West Loop and I-45, see figure 1). The original CRCP was built in 1968 and exhibited significant distress after nearly 27 years of service and under very heavy traffic loadings (Won 2001). The contractor elected to use 100 percent RCA in the concrete for the new CRCP, primarily as a cost savings measure. The project was unique because it was one of the first in the nation using 100 percent RCA (both coarse and fine) and contained no virgin aggregate (TxDOT 1998). As part of this project, TxDOT performed a comprehensive study to address the concerns regarding impacts on fresh and hardened concrete properties as well as CRCP concrete performance (Won 2001).



© 2018 Google Earth; Data: SIO, NOAA, US Navy, NGA, GEBCO, INEGI, Landsat/Copernicus; Added text box overlays and line over project location.

Figure 1. I-10 project location.

This project included the following two typical pavement sections (Won 2001):

- **Typical Section 1 (approximately 3/4 of the project length):** A 14-inch CRCP on a 3-inch asphalt-stabilized base (ASB), all resting on 6-inches of lime-treated subgrade. This design also featured:
  - 14-inch tied concrete shoulder (CRCP).
  - Double mat longitudinal reinforcement: 2 layers of #5 bars at 7-inch spacings, with the top layer placed 6 inches below the slab surface and the bottom layer placed 4 inches above the slab bottom.
- **Typical Section 2 (approximately 1/4 of the project length):** An 11-inch CRCP overlay on a 1-inch ASB separation layer over the existing CRCP. This design also featured:
  - 11-inch tied concrete shoulder (CRCP).
  - Single mat longitudinal reinforcement: #6 bars at 7-inch spacings and placed at mid-depth of the slab.

No information on the specific mix design used for the project is available, other than the requirement for a 6-sack (564 lbs/yd^3) concrete mix. TxDOT also required that the RCA conform to the same specification requirements as virgin aggregates and performed testing of the material to evaluate its properties and characteristics. Table 1 presents properties of the RCA aggregate used on the project and compares them with typical values for conventional virgin materials (gravel or siliceous sand).

Table 1. RCA material properties (data source: Won 2001).

Material	Property	Test Method	RCA Test Result	Typical Value for Virgin Gravel or Siliceous Sand
Coarse Aggregate	Specific gravity	ASTM C127	2.45 - 2.48	~ 2.6
	Mortar content	-[1]	~ 30%	n/a
	Water absorption	ASTM C127	3.9 - 4.1%	< 2%
	Sodium soundness loss	ASTM C88	1 - 9%	1 - 2%
	Magnesium soundness loss	ASTM C88	1 - 4%	2 - 6%
	LA abrasion	ASTM C131	32 - 38%	mostly < 20%
	Thermal coefficient	-[1]	16 - 26 με/°C	-[1]
	Freeze-thaw loss	Tex-433C	11.5%	-[2] (lightweight agg. ~9%)
	Alkali-silica reactivity	ASTM C1260	0.023%	varies
Fine Aggregate	Specific gravity	ASTM C128	2.37	~ 2.6
	Water absorption	ASTM C128	7.9%	~ 1%
	Angularity	NAA Method	38.6%	34.5%

[1] Test method not listed/value not available.

CONSTRUCTION

At the start of the project, the contractor had difficulty producing a concrete mixture with consistent workability and strength. It was determined that the former was the result of inadequate moisture control of the RCA stockpile, and this was mitigated by installing a sprinkler system for the aggregate stockpiles. When proper workability was achieved, construction crews reported little difference in the finishing operations between the RCA paving mixtures and conventional paving mixtures (Won 2001).

The strength values fluctuated as the project progressed, requiring some adjustments to the mix proportioning. In addition, the construction crews noted inconsistent concrete and premature setting during placement, which was attributed to the presence of the high volume of recycled fines in the mixture. As a result, in 1999 TxDOT changed its specifications to limit the amount of RCA fines in concrete mixtures to a maximum of 20 percent (Won 2001). This is consistent with current practices that commonly limit the maximum amount of RCA fines to no more than 30 percent (Snyder 2016).

POST-CONSTRUCTION TESTING

To evaluate the in situ properties of the concrete containing the RCA, 15 cores were taken throughout the project shortly after construction; these test results are summarized in table 2 (Won 2001; Choi and Won 2009). In general, the strength values were noted to be lower than typical values for concrete with virgin aggregates, but the RCA concrete did meet the TxDOT specifications.

Table 2. In situ concrete properties (data sources: Won 2001; Choi and Won 2009).

In-situ Property	Method	Avg.	Range
Compressive strength, 28-day	-	4,615 lb/in^2	4,260 – 5,270 lb/in^2
Indirect tensile strength, 28-day	-	486 lb/in^2	415 – 535 lb/in^2
Modulus of elasticity	-	2.58 x 10^6 lb/in^2	-
Coefficient of thermal expansion	Tex-428-A	-	4.7 – 5.3 με/°F
Chloride content	Tex-617J	1436 ppm	-
Sulfate content	Tex-620J	0.04 lb/yd^3	-
Density	-	2.24	2.19 – 2.36
Water absorption	ASTM C642	10.86%	-
Permeability	ASTM C1202	466 Coulomb	366 – 628 Coulomb

Petrographic analyses of cores taken from the CRCP revealed good bond between the original siliceous river gravel aggregate and the old mortar, and between the old and new mortar. Additional testing performed on extracted cores revealed the following (Won 2001):

- The modulus of elasticity of RCA concrete is much lower than that of virgin aggregate concrete.
- The coefficient of thermal expansion for RCA concrete is similar to virgin aggregate concrete.
- The chloride content of RCA concrete is higher than virgin aggregate concrete while sulfate content is comparable.
- The density of RCA concrete is lower and water absorption is higher than those of concrete with virgin aggregates, yet RCA permeability was still classified as “very low” per ASTM C1202.

WHAT BENEFITS WERE ACHIEVED?

PERFORMANCE

Since its construction in the mid-1990s, the performance of this pavement has been very good. An average crack spacing of 7.2 ft was reported in 1999, along with crack widths in the range of 0.008 to 0.028 inches (Choi and Won 2009). These cracks were very tight although some variability in widths existed, even within a single crack.

One very positive performance observation was the absence of meandering cracks and crack spalling that has afflicted many CRCP in Texas that were constructed with siliceous river gravel (which was the coarse aggregate in the original, recycled concrete) (Choi and Won 2009). It is hypothesized that the low modulus of the RCA concrete and its strong bond between the RCA and new mortar are key factors in its favorable performance. Figure 2 depicts the condition of the project in 2013, while table 3 provides a summary of International Roughness Index (IRI) performance collected between 2011 and 2016. Over the 5-year period, IRI values remained in the range of 113 to 120 inches/mi, where the TxDOT threshold between “good” and “fair” ride is 119 inches/mi.

© 2013 TXDOT

Figure 2. Overview of I-10 condition in 2013.

This project established the baseline for using RCA and allowed TxDOT to develop statewide specifications for using RCA in concrete pavements. RCA continues to see significant usage in pavements as a cost savings measure, and the performance of these sections has been outstanding.

–Andy Naranjo, TxDOT

Table 3. CRCP performance, 2011–2016 (data source: TxDOT).

Year	No. of Spalls	No. of Punchouts	No. of PCC Patches[1]	Avg. IRI (in/mi)
2011	9	4	1	115
2012	1	3	3	119
2013	1	0	0	119
2014	3	4	5	113
2015	2	7	1	120
2016	8	5	1	116

1 No asphalt concrete patches were reported.

COSTS

Overall, the contractor was not only able to realize a significant cost savings on this project by using RCA from the demolition of the existing CRCP but also achieved a lower environmental impact from reduced virgin aggregate demand (mining, crushing, hauling), and minimizing or eliminating off-haul of demolished concrete. Moreover, with a CRCP overlay placed over portions of the project, the contractor achieved both cost savings (by eliminating demolition, hauling, and crushing costs of the existing CRCP) and reduced environmental impacts associated with those activities.

Table 4 provides an estimate of the virgin aggregate savings for this project, based on standard TxDOT mixture proportions. This estimate assumes 0.6 percent longitudinal steel, a cementitious content of 550 lb/yd^3, a *w/cm* ratio of 0.45, and a density of 140 lb/ft^3.

Table 4. Estimated virgin aggregate savings.

CRCP Thickness (in)	Area (yd^2)	Aggregate (tons)
11	93,274	42,250
14	287,048	165,500
Total Virgin Aggregate Savings		207,750

The use of RCA on this project resulted in cost savings of $2 per ton of aggregate when compared to the delivery of limestone, and $5 per ton of aggregate when considering disposal savings (Raine 2010). Overall, in very rough economic terms, this translates into cost savings of approximately $1.4M.

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

This project demonstrates that RCA can be used to replace virgin aggregate and achieve adequate levels of performance on high-volume roadway facilities. The CRCP on I-10 was constructed in 1995 with 100 percent RCA (both coarse and fine components) and is considered a success by TxDOT. The following presents some of the key outcomes and lessons learned from this project:

- In many past cases, sustainability benefits were achieved simply through cost saving measures applied by contractors and/or agencies. The contractor elected to use RCA purely for economic reasons but this decision also resulted in unquantified environmental benefits. An estimated savings of over 200,000 tons of virgin aggregate was calculated based on typical concrete proportions, roughly correlating to cost savings of about $1.4 million.
- Although not quantified, other sustainability benefits include reduced social impacts (fewer haul trucks), less emissions from not having to mine virgin aggregate, and less waste (demolished concrete) sent to a landfill.
- RCA moisture control, specifically for the RCA fines, was very important to achieving workable aggregate.
- Concrete made with RCA had lower modulus of elasticity, lower strength (compressive and indirect tensile), and higher water absorption

than comparable concrete with virgin aggregates, but these findings were expected. No significant differences were reported for permeability and coefficient of thermal expansion.

- After 10+ years of service (reported in 2009), the CRCP made with 100 percent RCA concrete had excellent performance. As of 2016, ride quality has remained good with an average IRI of 116 in/mi.
- The low modulus of the 100 percent RCA concrete and good bond between RCA and new mortar are likely key factors that contributed to good performance of this CRCP.
- A major outgrowth of the work done on this pilot project was TxDOT's development and implementation of a specification in 2004 for the use of RCA in concrete pavements as a cost saving measure. A major component of that specification was the restrictions of recycled fines to no more than 20 percent.

REFERENCES

Choi, S. and Won, M. 2009. "Performance of Continuously Reinforced Concrete Pavement Containing Recycled Concrete Aggregate." *Proceedings, GeoHunan International Conference: Challenges and Recent Advances in Pavement Technologies and Transportation Geotechnics*. Changsha Hunan, China. American Society of Civil Engineers, Reston, VA. pp 165 – 172.

Texas Department of Transportation (TxDOT). 1998. *Recycled Concrete Aggregate in Portland Cement Concrete Pavement*. Texas Department of Transportation, Austin, TX.

Raine, W. 2010. "Roadway Use of Reclaimed Materials." *Using Recycled Content Products in Roadways*. Technical Workshop. Houston-Galveston Area Council. Texas Department of Transportation, Austin, TX.

Snyder, M. B. 2016. *Introduction to Concrete Recycling*. Concrete Pavement Recycling Series, Tech Brief No. 1. National Concrete Pavement Technology Center, Iowa State University, Ames, IA.

Won, M. C. 2001. *Performance of Continuously Reinforced Concrete Pavement Containing Recycled Concrete Aggregate*. Report. FHWA/TX 01-1753-1. Texas Department of Transportation, Austin, TX.

ECONOMICAL CONCRETE WITH RECYCLED CONCRETE AGGREGATE PROVIDES SUSTAINABILITY BENEFITS IN TEXAS

CONTACT

Federal Highway Administration (FHWA)
Office of Preconstruction, Construction, and Pavements Heather Dylla
(Heather.Dylla@dot.gov)

RESEARCHER

This case study was developed by Thomas J. Van Dam and Jeff Stempihar, NCE, and Kurt Smith, Applied Pavement Technology, Inc., and was prepared under FHWA's Sustainable Pavements Program (DTFH61-15-D-00005). Applied Pavement Technology, Inc. of Urbana, Illinois served as the contractor to FHWA.

DISTRIBUTION

This document is being distributed according to a standard distribution. Direct distribution is being made to the Divisions and Resource Center.

AVAILABILITY

This document may be found at:
https://www.fhwa.dot.gov/pavement

KEY WORDS

concrete pavement, sustainability, blended cements, construction innovations, life-cycle assessment, cost savings

CREDITS

Unless otherwise noted, FHWA is the source for all images in this document.

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation (USDOT) in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

NON-BINDING CONTENTS

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies.

QUALITY ASSURANCE STATEMENT

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.