CONCRETE MATERIAL AND CONSTRUCTION INNOVATIONS PROVIDE SUSTAINABILITY BENEFITS IN COLORADO AGENCY

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BACKGROUND

Shrewd modifications to concrete mixtures and resourceful construction practices led to cost savings of more than 50 percent, time savings of several weeks, and significant reductions in various environmental impacts. This was demonstrated on a concrete pavement reconstruction project on Peña Boulevard, a four-lane divided highway that connects the City of Denver (via I-70) to Denver International Airport (DIA).

WHAT WAS THE MOTIVATION?

Constructed in the early 1990s, the jointed plain concrete pavement (JPCP) on Peña Boulevard exhibited severe alkali-silica reactivity (ASR) distress that required increasing amounts of expensive repair. Given the on-going maintenance issues and the overall severity of distress, in 2011 authorities at DIA proposed a pavement reconstruction calling for an 11-inch (279-mm) doweled JPCP placed on a 12-inch (305-mm) Colorado Department of Transportation (CDOT) Class 6 aggregate base. However, because of concerns related to the overall reconstruction cost and the adverse impacts of a prolonged construction period, DIA was interested in pursuing an alternative approach that would reduce costs and minimize the overall duration of construction. The project was completed in 2014.

WHAT WAS DONE?

DIA worked with its contractor to develop a cheaper and quicker design alternative, one that featured the rubblization of the existing JPCP to serve as a foundation for the new pavement. This approach reduced removal and hauling costs and expedited the overall construction operations while providing a strong, stable foundation for the new pavement (see figure 1 [Cloud 2015]).

Figure 1. Rubblized surface prior to placement of the 2-inch CDOT Class 6 aggregate base.

In addition, the contractor incorporated innovations in the concrete paving mixture to reduce both economic and environmental costs while enhancing constructability. A mix design was developed featuring a modified Shilstone aggregate grading with two coarse aggregates, one intermediate aggregate, and a fine aggregate (Ungerman 2015). The benefits of such a gradation include reduced cement content, increased durability, and improved workability. Table 1 compares the mix proportioning of that optimized concrete (Mixture B) to a typical CDOT Class P concrete that meets CDOT's 2017 Standard Specifications for Road and Bridge Construction (Mixture A) and indicates a reduction of about 6 percent in cementitious materials.

The time savings was substantial. Rubblizing a 1-mile segment of pavement took only six days versus an estimated several weeks to remove a 1-mile segment of roadway, recondition the subgrade, and place the CDOT Class 6 aggregate base.

–Michael Cloud, DIA Project Engineer

WHAT COST BENEFITS WERE ACHIEVED?

For the size of this project (100,000 yd2 [83,600 m2]), the alternative approach of using rubblization provided a cost savings of roughly $0.5 million over the conventional remove and replace approach; this reduced the cost of concrete removal, Class 6 aggregate base, and geotextile from $0.95M to $0.45M, a 53 percent savings (Cloud 2015). The original, as-designed remove and replace option would not only incur greater costs due to demolition, removal, hauling, and material disposal, but would also be more susceptible to rain delays and would have required several more weeks of additional construction time. Furthermore, additional traffic impacts and user delays would have been incurred due to the extended construction period.

Table 1. Mixture proportions for a "typical" CDOT Class P mixture and the optimized mixture for the Peña Boulevard project.

Mixture Constituent	Mixture A: Typical CDOT Class P (CDOT 2017)	Mixture B: Optimized (Ungerman 2015)
ASTM C150 Cement	452 lb/yd^3	–
ASTM C595 Blended Cement[1]	–	422 lb/yd^3
ASTM C618 Class F Fly Ash	113 lb/yd^3	108 lb/yd^3
ASTM C33 Coarse Aggregate #4	–	440 lb/yd^3
ASTM C33 Coarse Aggregate #67	1675 lb/yd^3	1036 lb/yd^3
ASTM C33 Intermediate Aggregate #9	–	691 lb/yd^3
ASTM C33 Fine Aggregate	1370 lb/yd^3	973 lb/yd^3
Water	226 lb/yd^3	209 lb/yd^3
Air	6%	6%
w/cm	0.40	0.40

1 It is assumed that the ASTM C595 Type 1L has been inter-ground with 12 percent limestone.

WHAT ENVIRONMENTAL BENEFITS WERE ACHIEVED?

To assess the broader environmental impacts of the design and material choices, a life-cycle assessment (LCA) was performed independently several years after the pavement construction to evaluate the environmental impacts associated with design and materials choices associated with three different construction alternatives (presented in table 2). The LCA assumed a lane-mile as the functional unit and was performed using the SimaPro software. This analysis was not considered in the original design/construction alternative selection but was performed later to quantify the environmental impacts.

- Alternative 1A: The original, as-designed option featuring a typical CDOT Class P concrete mix (Concrete Mix A in table 1) and complete removal and replacement of the pavement structural section in which the existing concrete pavement is reprocessed off-site and brought back as aggregate base.
- Alternative 2B: The selected alternative featuring the use of an optimized concrete mixture (Concrete Mix B in table 1) and in situ rubblization of the existing concrete.
- Alternative 3A: A conceptual alternative that featured Concrete Mix A and the complete removal and landfill disposal of the existing pavement and the construction on new pavement using an aggregate base with virgin materials.

Figure 2 shows selected environmental impact results from the limited LCA, which included impacts from the demolition phase and any landfilling of the existing pavement as well as the material acquisition, transportation, and construction of the new pavement. Similar use and performance of all three options was assumed over the design life with each alternative exhibiting similar maintenance and end-of-life scenarios. Alternative 2B, which featured the innovative optimized concrete mixture with rubblization, exhibits the best environmental performance of the three alternatives for the selected impact categories. In real terms, the environmental saving incorporated in Alternative 2B resulted in a reduction of global warming potential of 220 tons (200 metric tons) of CO2-eq. (carbon dioxide equivalents) and 1,500 million BTU (1,600 GJ) of energy—equivalent to over 11,000 gal (41,600 L) of diesel per lane-mi (1.6 lane-km) of constructed pavement—compared to Alternative 3A. This is important as the City and County of Denver have a goal of an absolute reduction of greenhouse

Table 2. General description of the alternatives considered in the LCA.

Alternative	Existing Pavement	Base	New Pavement
1A. Remove & Replace	Remove existing pavement and 12 inches (305 mm) of lime-treated subgrade	Reapply broken up existing pavement, 4 inches (102 mm) of RCA, geotextile, 12 inches (305 mm) of RCA	11-inch (279-mm) JPCP (CDOT Class P mix)
2B. Rubblized	Rubblized and compacted	2-inch (51-mm) RCA (from other stockpiles)	11-inch (279-mm) JPCP (Optimized mix)
3A. Reconstruct	Remove existing pavement and 12 inches (305 mm) of lime-treated subgrade, recondition and compact 18 inch (457 mm) of subgrade	Geotextile, 12-inch (305-mm) virgin aggregate	11-inch (279-mm) JPCP (CDOT Class P mix)

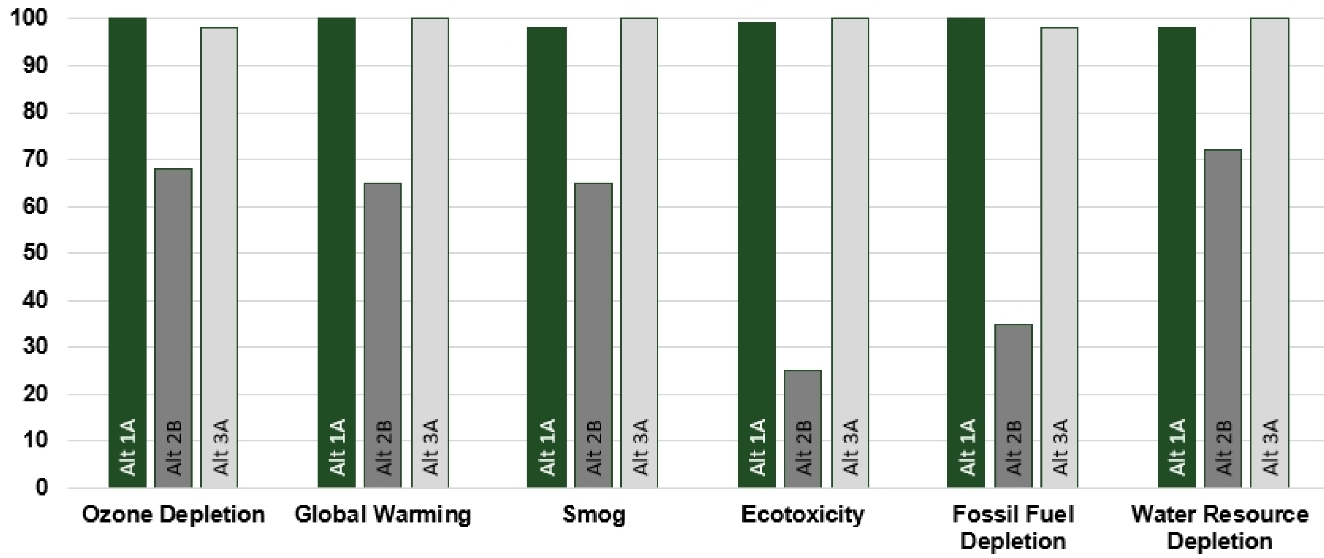

Figure 2. LCA results for pavement alternatives.

gas (GHG) emissions to 1990 levels by 2020 (Denver 2015) and the State of Colorado is committed to a 26 percent reduction in GHG emissions from 2005 levels by 2025 (Colorado 2018). These environmental benefits were achieved along with the significant time and cost savings that Alternative 2B also provided.

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

This project demonstrates that relatively small changes in design, materials, and construction can result in significant improvement in cost effectiveness, time savings, and environment impact. The following represent key outcomes of this project:

- The contractor and the agency collaborated to explore alternative designs and ultimately select an option that produced significant economic and constructability benefits.
- The use of rubblized JPCP as base in lieu of removal and replacement:
  - Resulted in direct economic savings of $0.5 million.
  - Reduced construction time that resulted in less impact to the traveling public along with a reduced risk of construction delays due to inclement weather.
  - Demonstrated superior environmental performance to the other alternatives in all impact categories (but it also included environmentally friendly mix design changes).
- The use of the modified concrete mix design featuring optimized aggregate grading, reduced total cementitious materials content, and an ASTM C595 Type IL portland-limestone cement:
  - Was economical, readily constructible, and had superior environmental performance in all environmental impact categories.
  - Saved 220 tons (200 metric tons) of CO2-eq. compared to the "business as usual" option with respect to global warming potential.

  - Positively contributed to the City and County of Denver as well as to the State of Colorado in making progress toward their stated climate action plan goals.

- Together, the mix design modifications and construction innovations used on this project provided cost savings of more than 50 percent, time savings of several weeks, and significant reductions in various environmental impacts. The project demonstrated that environmental benefits can be achieved while simultaneously reducing costs.
- Agency specifications providing flexibility allow the contractor to innovate and develop solutions that can provide both economic and environmental benefits.

REFERENCES

Cloud, M. 2015. *Inbound & Outbound Peña Boulevard Reconstruction. Presentation*. Denver International Airport, Denver, CO.

State of Colorado. 2018. *Colorado Climate Plan*. Accessed September 11, 2018.

City of Denver. 2015. *City and County of Denver Climate Action Plan*. Accessed September 11, 2018.

Ungerman, G. 2015. *Pena Boulevard – A Successful Project with True Sustainability and Cooperation Between the Owner and Contractor*. Presentation. Denver International Airport, Denver, CO.

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