CONCRETE PAVING MIXTURE WITH SLAG CEMENT AND RECYCLED AGGREGATE IN THE CITY OF SEATTLE

AUTHORS

Sarah Lopez, NCE

Nicole Dufalla, NCE

CONTRIBUTOR

Thomas Van Dam, Wiss, Janney, Elstner Associates, Inc.

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National Concrete Pavement Technology Center
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
cptechcenter.org

Peter Taylor, Director
515-294-3230 / ptaylor@iastate.edu

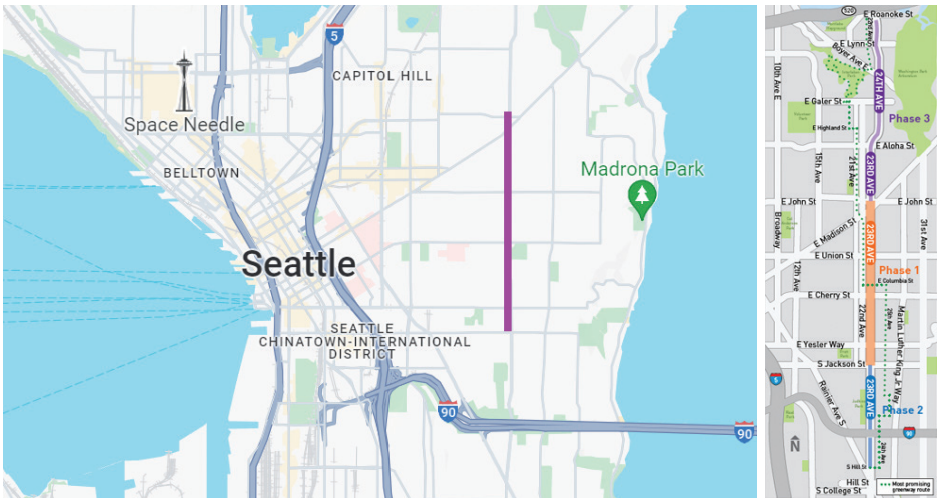
National Concrete Pavement Technology Center

Tech Center

IOWA STATE UNIVERSITY
Institute for Transportation

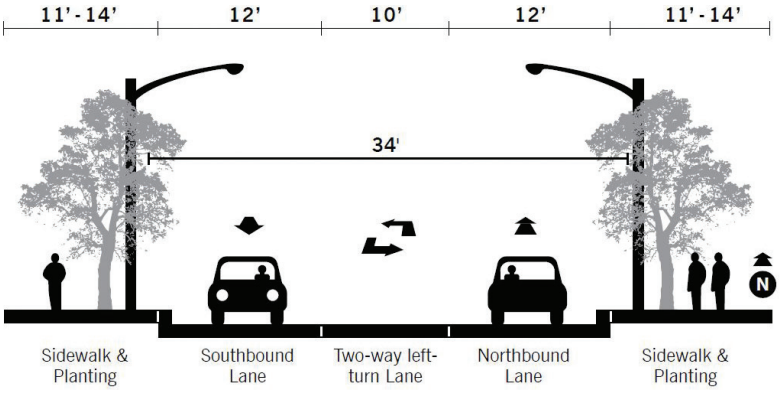
Introduction

Twenty-third Avenue in the city of Seattle, Washington, is an arterial street that receives upwards of 20,000 vehicles daily (Seattle Department of Transportation 2015). The city opted to reconstruct 23rd Avenue because of deteriorated road surface conditions and safety concerns associated with narrow lane widths. Phase 1 of the project (2015–2017) involved reconstruction of a segment, originally a four-lane roadway with two lanes of traffic in each direction, between East John Street and South Jackson Street, as shown in Figure 1. The updated configuration, shown in Figure 2, is a three-lane street, with one lane of traffic in each direction and a center turning lane (Seattle Department of Transportation 2015).



(left) © 2024 Google Earth; Data: SIO, NOAA, US Navy, NGA, GEBCO, INEGI, Landsat/Copernicus; (right) Seattle Department of Transportation n.d.-a

Figure 1. Project location in relation to the city of Seattle (left) and the specific section reconstructed in Phase 1 (right)



Seattle Department of Transportation n.d.-a

Figure 2. Updated configuration of 23rd Avenue

The following carbon reduction strategies were used in the concrete mixture for the Phase 1 project:

- ASTM C989 slag cement was used as a supplementary cementitious material (SCM) to replace a portion of the portland cement.
- This concrete mixture used ASTM C467 recycled concrete aggregate (RCA) for most of the coarse aggregate. (Note that while using RCA is a good strategy for environmental stewardship, it inconsistently reduces the embodied carbon in the concrete mixture. The true reduction in embodied carbon must be evaluated through a life-cycle assessment [LCA] in accordance with ISO standards on a case-by-case basis.)

Pavement Design, Materials, and Construction

Structural Design

The pavement section consisted of a 12 in. jointed plain concrete pavement (JPCP) placed on a 6 in. compacted City of Seattle Type 2 subbase.

Paving Materials

The concrete mixture utilized ASTM C467 RCA and contained 25% ASTM C989 slag cement by weight of total cementitious materials. The mixture had a total cementitious content of 611 lb/yd³ and was designed for a 28-day compressive strength of 4,000 psi. A second concrete mixture without slag cement was approved for the project but, according to available records, did not appear to be used. The second mixture is included here for comparison purposes. Both mixture proportions are listed in Table 1.

Construction

Figure 3 illustrates the construction sequence:

1. Coated dowel bars were placed using dowel baskets (Figure 3a).
2. The concrete was placed using a ready mix truck in fixed forms, and a roller screed was used for strike-off (Figure 3b and 3c).
3. The surface was hand finished (Figure 3d).

During construction, the slag cement mixture was observed to be workable and finished well. The results of laboratory tests on the concrete mixtures (Table 2) indicated that the laboratory mixtures exceeded the 28-day target strength of 4,000 psi at 7 days (for the mixture with slag cement) and at 3 days (for the mixture without slag cement). The slower initial strength gain of the mixture with slag cement was expected. However, it is important to note that both mixtures were over-cemented.

Table 2. Average compressive strengths during laboratory mixture design process

Testing Day	Average Compressive Strength, psi	
	Paving Mixture with Slag and Recycled Aggregate	Paving Mixture with Recycled Aggregate Only
1	2,566	3,322
3	3,696	4,564
7	4,890	5,556
14	5,534	6,252

Table 1. Mixture proportions of paving concrete

Mixture Constituent	Mixture Quantities, per Cubic Yard of Concrete	
	23rd Avenue Mixture with Slag Cement	23rd Avenue Mixture without Slag Cement
ASTM C150 Type I/II Portland Cement	458 lb	611 lb
ASTM C989 Slag Cement	153 lb	—
ASTM C33 Coarse Aggregate #8	107 lb	183 lb
ASTM C467 Recycled Aggregate	1,725 lb	1,646 lb
ASTM C33 Fine Aggregate	1,252 lb	1,272 lb
Water	240 lb	240 lb
Air	5%	5%
Water-to-Cementitious Materials (w/cm) Ratio	0.39	0.39
W.R. Grace Zyla 630 (Type A Water Reducer)	27.5 oz	27.5 oz
W.R. Grace Daravair 1000 (Air Entrainer)	4.28 oz	3.97 oz

Figure 3. Photos from 23rd Avenue construction

Carbon Reduction Analysis

For each of the concrete mixture designs submitted for this project, an environmental product declaration (EPD) from the supplier was available that included a calculated global warming potential (GWP) for the mixture based on the environmental impacts of its constituents. The GWP values of the concrete mixtures submitted for the project are presented in Table 3. The inclusion of slag cement reduced the GWP by approximately 43% compared to the concrete paving mixture without slag.

A local concrete mix design using only virgin aggregate was unavailable, making it difficult to estimate the impact that RCA has on GWP. Generally, utilizing RCA in concrete mixtures is considered a good strategy for environmental stewardship. Its impact on GWP is inconsistent, however, and must be evaluated on a case-by-case basis.

Table 3. Comparison of reported GWP for concrete mixtures

Mixture Description	Estimated GWP (kg CO_2-eq/m^3)
Paving mix with RCA and slag	205
Paving mix with RCA only	361

Pavement Performance and Maintenance History

The Seattle Department of Transportation quantifies the condition its pavements using the pavement condition index (PCI) described in ASTM D6433. The PCI synthesizes measurements of select pavement distresses and performance parameters into a single value, a quality metric ranging from 0 to 100, that indicates the overall road condition. The PCI metric corresponds to a pavement condition rating (PCR) as shown in Table 4 (from ASTM D6433).

Table 4. PCI road condition ratings utilized by the Seattle Department of Transportation

Pavement Condition Rating (PCR)	Pavement Condition Index (PCI)
Good	86–100
Satisfactory	71–85
Fair	56–70
Poor	41–55
Very Poor	26–40
Serious/Failed	0–25

Source: Seattle Department of Transportation n.d.-b, ASTM D6433

In 2022, the Seattle Department of Transportation reported an average PCI of 96.1 (good) on 23rd Avenue (Seattle Department of Transportation n.d.-c). The lowest rating of 85 (satisfactory) was on a single block of the street, with all other blocks in good condition per ASTM D6433 thresholds. A visual assessment by NCE in 2023 similarly found 23rd Avenue to be in good condition (Figure 4).

Lessons Learned

The concrete mixture used for the 23rd Avenue reconstruction project in Seattle, Washington, showcases a carbon reduction strategy in which slag cement was utilized as a 25% replacement for portland cement. The mixture also used RCA for most of the coarse aggregate. Another mixture approved for this project similarly used RCA but excluded slag cement. The lessons learned from this reduced-carbon concrete pavement section include the following:

- **The reduced-carbon concrete mixture exceeded the required strength.** The reduced-carbon concrete mixture (containing RCA and slag cement) exceeded the target 28-day compressive strength requirement within 7 days (likely by day 4) and exhibited a comparable but slightly lower 14-day strength compared to the concrete mixture without slag cement. The slower initial strength gain of the mixture with slag cement is known, as is its improved long-term strength and durability.
- **The pavement is exhibiting good performance.** The section of 23rd Avenue reconstructed in Phase 1 has performed well for over six years and is maintaining a good condition rating, with an average PCI of over 96 as of 2022. Only one block of the street received a satisfactory condition rating during the 2022 survey. A visual site assessment in 2023 indicated that the pavement remained in good condition.
- **The strategies explored reduced the estimated carbon emissions.** The inclusion of slag cement reduced the estimated embodied carbon emissions of the mixture by approximately 43%; GWP decreased from 361 kg CO_2-eq/m^3 for the mixture with RCA and no slag cement to 205 kg CO_2-eq/m^3 for the mixture with slag cement and RCA.
- **There is room for additional carbon reduction in the concrete mixture.** Both mixtures had a total cementitious content of 611 lb/yd^3 and met the 28-day compressive strength requirement in less than 7 days. This suggests that both concrete mixtures may be over-cemented. Further carbon reduction can likely be realized by reducing the total cementitious content of future mixtures through aggregate optimization.

NCE, used with permission

Figure 4. Surface condition of 23rd Avenue as of March 2023

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