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**October 2018**

**ROAD MAP TRACK 6**

**PROJECT TITLE**

**Portland-Limestone Cement after 10 Years in the Field**

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The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by the Federal Highway Administration.

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The October 2018 MAP Brief provides information relevant to Track 6 of the CP Road Map: Concrete Pavement Construction, Reconstruction, and Overlays.

This MAP Brief is available at [www.cproadmap.org/publications/MAPbriefOctober2018.pdf](http://www.cproadmap.org/publications/MAPbriefOctober2018.pdf).

**“Moving Advancements into Practice”**

**MAP Brief October 2018**

Best practices and promising technologies that can be used now to enhance concrete paving

**Portland-Limestone Cement after 10 Years in the Field**

**Introduction**

Portland-limestone cement (PLC) is an innovative cement that contains between 5% and 15% finely ground limestone. PLC is a relatively new cement in the United States—the first application for paving took place in Colorado in 2007.

This MAP Brief is intended to review experience with this product over the past 10 years regarding the following:

1. Acceptance of the product by specifying agencies
2. Growth in production
3. Performance in the field

To date, over 900 lane miles of highway paving has been completed with PLC in Colorado, Utah, and Oklahoma. The focus of this paper is the performance of these pavements in service.

The cement industry is a significant producer of CO<sub>2</sub>. For every ton of Portland cement produced approximately 1,800 pounds of CO<sub>2</sub> are released. Growing concerns over the environmental impacts of building materials has been one of the driving forces for the development of PLC. PLC cements containing up to 15% limestone can reduce carbon footprints up to 10% compared to ordinary portland cement (OPC).

Limestone, often considered an inert filler when added to portland cement, is not completely chemically inert and contributes to the development of the concrete's microstructure (FHWA 2011). Limestone is softer than clinker and has a finer particle size when interground, thus producing an improved particle size distribution. The fine limestone particles act as nucleation sites

increasing the hydration rate of the calcium silicates at early ages. Finally, limestone reacts with the aluminates phases to form carboaluminate phases. The extent of this reaction can increase with the fineness of the limestone and when PLCs are combined with fly ash or slag.

Specifically, the physical mechanisms include enhanced particle packing and paste density due to the enhanced overall cement particle size distribution and the “nucleation site” phenomenon—when small limestone particles are suspended in paste between clinker grains and become intermediate sites for calcium silicate hydrate crystal growth, which improves efficiency. The chemical mechanisms include limestone, which contributes calcium compounds to the solution for hydration interaction, and calcium carbonate, which reacts with aluminates compounds to produce durable mono- and hemi-carboaluminate hydrate crystals.

Previous research has shown that certain properties of the concrete could be negatively impacted with above 15% limestone addition.

Although somewhat new in the United States, some European countries have been using PLC since the 1960s. According to Cembureau (2012) PLC accounts for 25% of the cements produced in Europe. In 2005, the first commercial production of PLC in the United States was completed and sold under the A.S.T.M. C1157 performance-based specification for hydraulic cement.

**History of Performance**

PLC has been used by the ready mix and precast concrete industries. PLC has been used in thousands of cubic yards of concrete for commercial and residential projects.

Concrete blocks and retaining wall segments utilizing PLC have been in mass production for 12 years.

PLCs are produced by intergrinding high grade limestone with clinker and optimized to give equivalent performance to the OPC they are intended to replace. There are numerous papers detailing the performance of limestone cements in concrete (for example, Hooton et al. 2007, Thomas et al. 2010, and Tennis et al. 2011.). These papers show that, when properly optimized, PLC cements have produced equivalent performance to OPC. There is no significant impact on either the plastic or hardened concrete properties, and most users see no need to make adjustments to their mix designs for placing and curing practices. This means the same levels of fly ash or slag addition can be maintained without any significant adjustments in chemical admixtures—truly a win-win situation.

Durability testing for freeze/thaw resistance, sulfate resistance, shrinkage, and alkali silica reactivity have shown that the performance of PLC is equivalent to that of OPC.

## Acceptance by Specifying Agencies

From 2005 to 2012, PLC was produced and sold in accordance with ASTM C-1157 the Standard for Performance Hydraulic Cement. ASTM C-1157 is a completely performance-based standard and has no equivalent ASSHTO standard, which resulted in limited sales from 2005 to 2012. However, during this time, a great deal of research and pilot projects were carried out. This work added to the experience gained in actual projects in Colorado, Utah, and Oklahoma and “paved the way” for acceptance of PLC in the blended cement specifications of both AASHTO M240 and ASTM C-595 in 2012 under the designation of Type II.

Figure 1 shows PLC acceptance by state departments of transportation and the Federal Aviation Authority as of July, 2018.

Acceptance of PLC in AASHTO and ASTM led to more DOTs adopting PLC and a dramatic increase in production and sales volumes. Figure 2 shows PLC production growth between 2012 and 2016.

Some 30 plants have produced PLC—it is the most rapidly growing blended cement in the market. Table 1 shows a regional breakdown of PLC production.

## Field Performance

The real proof of any product is how it performs in service. Below are examples of paving projects in Colorado, Utah, and Oklahoma. These three states were selected

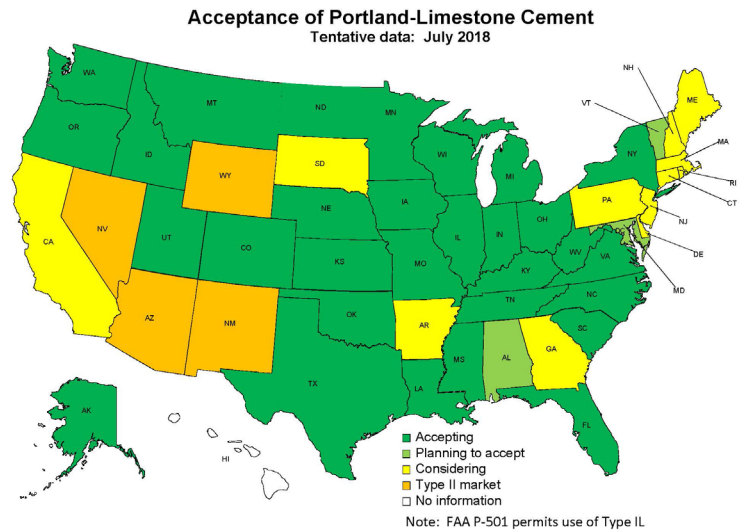


Figure 1. Acceptance of Portland limestone cements by state DOTs and the Federal Aviation Authority as of 2018 (Source: Tennis 2012)

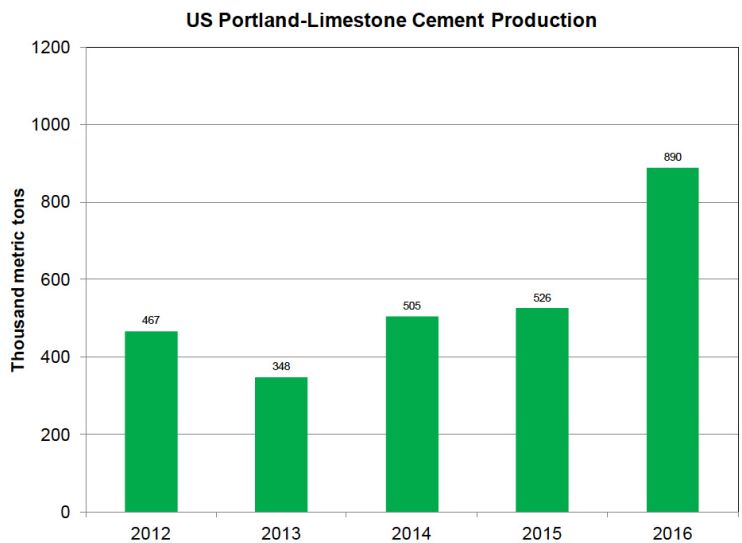


Figure 2. U.S. Portland limestone cement production, 2012–2016 (Source: Tennis 2012)

for the Map Brief because they were early adopters of PLC and thus have a longer history of pavements in service.

## Colorado

PLCs have been available in Colorado for over 10 years. PLCs have been used in the construction of over 800 lane miles of concrete pavement in Colorado and continue to be used daily in a variety of residential, commercial, and infrastructure projects. The use of PLCs has helped local and statewide efforts to meet engineering performance requirements and address environmental concerns by helping lower the environmental footprint of transportation infrastructure.

The City of Denver instituted a city-wide action plan “Greenprint Denver” to promote the importance of sustainable devel-

**Table 1. Regional distribution of plants producing Portland limestone cements. (Source: Tennis, Thomas, and Weiss, 2011.)**

Region	Number of plants
Northwest (ID, MT, OR, WA)	0
California/Nevada/Arizona	3
Rocky Mountain (CO, NM, UT, WY)	1
North Central (IA, MN, ND, NE, SD)	1
South Central (AR, KS, LA, MO, OK)	0
Texas	1
Southeast (AL, GA, KY, MS, NC, TN, SC, VA)	7
Great Lakes (IL, IN, MI, OH, WI)	3
Northeast (CT, DE, MA, ME, NY, PA, RI, WV, VA, VT)	3
Florida	3

**Note: At least one time between 2012 and 2016, eight plants did not identify their location.**

opment and ecologically friendly practices throughout the community. In 2007, the 40th Avenue project repurposed the former Stapleton Airport into a sustainable community. In support of increasing the sustainability of the newly constructed concrete pavement, the 40th Avenue and Havana construction projects used the ASTM C1157 Type GU PLC with 20% fly ash and recycled concrete aggregates from the demolished Stapleton Airport runways.

The mix was placed with a slipform paver by Castle Rock Construction during winter months. The mixture, which contained 10% limestone added to the cement, possessed excellent early strength gain with average compressive strength values of 1,930 (1 day), 3,790 (2 day), 5,220 (3 day), and 6,580 (7 day) psi. The seven-day flexural strength was 825 psi. The developer, owner, and contractor were all very satisfied with the performance and environmental benefits of the mixture and the local news media reported on the environmental benefits of the “green” concrete. The project was awarded the Sustainable Pavement Award by the Colorado/Wyoming Chapter of the American Concrete Paving Association in 2008.

In 2008, the Colorado Department of Transportation (CDOT) was the first DOT to allow the use of PLCs containing up to 10% limestone meeting ASTM C1157 and to allow blending with fly ash added at the concrete plant. Adopting PLCs helped CDOT to meet the state’s Climate Action Plan to lower the environmental impact of construction.

In their first project, CDOT used ASTM C1157 PLC on U.S. Highway 287 near Lamar, Colorado (see figures 3 and 4). Highway 287 is part of the Ports to Plains U.S. High-

way route that accommodates heavy truck traffic connecting commerce between Mexico and the United States. Castle Rock Construction was the contractor for this \$17.3 million-dollar construction project, which included seven miles of concrete paving and shoulder widening. The jointed plain concrete pavement used a CDOT Class P mixture (containing 10% limestone added to the cement) with ASTM C1157 PLC and 20% Class F fly ash. The PLC proved to be consistent and contributed to the quality performance incentive achievement per CDOT standards by achieving an average 28-day flexural strength of 695 psi (CDOT requirement is 650 psi). Hot weather concrete practices were followed as most of the paving was completed during summer months with temperatures of 100°F. Workers did not notice a difference between the widely used ASTM C150 Type I/II cement and the “new (at that time in 2008) and green” ASTM C1157 GU PLC. Eric Prieve, CDOT Concrete and Physical Properties Engineer, said “Using portland limestone cements for over 10 years allows Colorado to reduce greenhouse gas emissions in the construction of concrete pavements with no compromise in quality and long-term performance.”

Since this first project, Castle Rock Construction has used PLC concrete in most of its infrastructure work in Colorado, including Peña Boulevard, the four-lane highway that leads to the Denver International Airport. This sustainable green project was recognized with a Triad Award from Public Works magazine in 2015 for outstanding innovation and sustainability in using PLCs. Other notable projects include the 12 miles of new express lanes on U.S. Route 36 (National ACPA Award) and the current paving of 18 miles of six-lane Colorado State Highway 470.

Ralph Bell, CEO of Castle Rock Construction commented that they have partnered with cement manufactures on more than thirty projects over the past decade, and Portland limestone cement has been an integral part of their intense effort to improve the quality and rideability of more than 600 lane miles of concrete pavement in Colorado.



**Figure 3. Paving of U.S. Highway 287 using PLC. (Photo credit: Holcim (US) Inc., and Castle Rock Construction. Used with permission.)**





**Figure 4. Paving of U.S. Highway 287 using PLC. (Photo credit: Holcim (US) Inc., and Castle Rock Construction. Used with permission.)**



**Figure 5. SR 201 during paving. (Photo credit: Holcim (US) Inc., and Ralph L. Wadsworth Construction. Used with permission.)**

## Utah

The Holcim Devil's Slide plant, located near Morgan, Utah has manufactured PLC since 2006. Holcim rigorously tested limestone cements in laboratory and field applications to determine plastic properties and long-term durability before introducing their cement to the market. In each location where PLC has been produced, equivalent performance has been achieved. Limestone cements have been successfully utilized by concrete products manufacturers almost exclusively since 2006. Limestone cements have also been successfully used in many residential and commercial projects supplied by Ready Mix concrete producers.

The Utah Department of Transportation (UDOT) has long accepted cements meeting all ASTM specifications including C150, C595, and C1157. In 2009, the UDOT ran a trial of PLC in the Salt Lake Valley. Testing and evaluation was done under direction of Dr. Paul Tikalsky, who was then with the University of Utah (UU). The UU study found that pavements utilizing both PLC and OPC were comparable in both plastic and hardened properties. With this positive feedback, UDOT was comfortable moving ahead with other large-scale pavement projects incorporating limestone cements.

The first major paving project in Utah utilizing PLC was SR 201 in central Salt Lake Valley (see figures 5 and 6). SR 201 is a major east-west corridor linking downtown Salt Lake City with the western side of the Salt Lake Valley. In 2009, a section of this corridor was widened and reconstructed with concrete, and the eastbound lanes were constructed in August with ASTM C150 Type II/V cement and 25% Class F fly ash.

Two months later in October, the westbound lanes were constructed with PLC containing 10% interground limestone and 25% Class F fly ash. This provided UDOT and the contractor with an opportunity to compare concrete paving with both OPC and limestone cement. The westbound lanes



**Figure 6. SR 201 after paving. (Photo credit: Holcim (US) Inc., and Ralph L. Wadsworth Construction. Used with permission.)**

incorporated approximately 6,000 tons of PLC spanning three lanes for two miles. Doug Clements, who was the GM for Ralph L. Wadsworth Construction, the General Contractor on this project, noted, “The SR 201 project allowed us to compare our traditional cement concrete mixtures with limestone cement concrete mixtures in the same paving season. We did not see any major differences to mix performance in regard to maintaining air stability or finishing quality.”

In 2014, the I-80 reconstruction project from Silver Creek Junction to Wanship, Utah provided another project that would compare OPC and PLC in concrete pavements (see figure 7). I-80 is the major east-west corridor for truck commerce across Utah. This section of highway is located about 6,400 feet above sea level and is subject to drastic weather changes. The project section was 7.55 miles long and incorporated approximately 16,000 tons of limestone cement. With over 45% average daily truck traffic, the existing asphalt pavement was failing to withstand the loads and environmental conditions of this mountainous area. Re-

peated surface failures caused UDOT to repair this section of highway early and often.

In 2014, the eastbound lanes of I-80 were constructed with a traditional concrete paving mixture utilizing OPC and 25% Class F fly ash. The following paving season the westbound lanes were constructed with a concrete mixture utilizing PLC as the hydraulic binder. The two concrete mixtures performed similarly and met all concrete strength requirements for the project.

Concrete batching and placement crews did not see a noticeable difference between the two concrete mixtures. Cody Preston, Manager of Concrete Pavement at Geneva Rock said “We had seen equivalent performance in strength and workability with the limestone cement test mix during the first season, so we planned to use it on the westbound lanes. We were pleased that the limestone cement performed as good as or better than the OPC mixes in the field placements as well.”

UDOT has a formal pavement management system that reviews all pavements under UDOT jurisdiction annually. These reviews include evaluating the pavements with department engineers to catalog how well pavements are performing and what deficiencies can be found. UDOT has a standard protocol for scoring pavement sections during this evaluation process. Results from the most recent review of the two projects presented above were found to be comparable using this standard protocol. In both cases, the concrete roads are performing very well with both cements. The PLC sections, however, are performing slightly better than the OPC sections. Lonnie Marchant, UDOT Region 2 Materials Engineer stated, “As part of the UDOT pavement management system, all pavements are reviewed annually to evaluate pavement performance. As the department has reviewed the sections of SR 201 and I-80 utilizing both OPC and limestone cement, we have seen no difference in durability or pavement performance between the two cement types on these projects.”

The use of PLC in paving projects with UDOT has proven



**Figure 7. Paving eastbound I-80 lanes. (Photo credit: Holcim (US) Inc., and Geneva Rock Construction. Used with permission.)**

successful during construction and the life of the pavements. The use of limestone cements in paving applications is a sustainable and more environmentally friendly option for UDOT and any other municipality or developers that desire to build a durable and long-lasting pavement.

### Oklahoma

“YOU ARE NOW ENTERING AMERICA’S CORNER,” a sign reads as you travel on I-40 Westbound just outside Oklahoma City, which refers to the intersection of three of the most traveled superhighways in the United States, I-35, I-44, and I-40 (see figure 8). The sign symbolizes a major crossroads of trade and travel in the heart of Oklahoma City. Without the structural promise of these arterial roads, a majority of the country would be presented with a much longer, more indirect route to navigate throughout the Midwest and from coast to coast. The following case study focuses on the paved concrete stretch of I-40 in downtown Oklahoma City, otherwise known as the Crosstown Expressway.

In 2009, the Oklahoma Department of Transportation (ODOT) announced that construction of a new stretch of I-40 would begin later that year and be completed in 2012. The new route would be moved five blocks south of downtown and be designed with a ground level, paved concrete design. The number of lanes in each direction would be increased from three to five to accommodate the difference in traffic volume between the 1960s and the late 2000s (see figure 9 for photos of I-40 after paving).

Commuters and truck drivers expected a durable, safe means of travel that would outperform their previous crumbling roadway. A Type 1L (10) cement with 10% limestone was used. ODOT was confident in using this cement over OPC and awarded the mainline paving aspect of the project to Duit Construction, which bid the project with the use of Type 1L cement. John Privat, Quality Manager of Duit



**Figure 8. “America’s Corner” sign in Oklahoma. (Photo credit: Holcim (US) Inc. Used with permission.)**





Construction, weighed in with his thoughts about the product, “The cement’s performance in concrete is identical to Type I-II. We especially appreciate the positive aspect of sustainability. It’s a win-win for everyone involved.”

Duit Construction is a family-owned paving contractor based in Edmond, Oklahoma. The organization specializes in heavy highway paving and asphalt construction for the federal government, cities, counties, and airports across the southern Midwest. Duit has used PLC cement in multiple projects that demanded reliable concrete performance around Oklahoma. Mr. Privat continued to comment, “ODOT considered this a ‘showpiece project’ because of its proximity to downtown and its significance to the highway network.” He went on to explain how the concrete performed throughout construction on the Crosstown Expressway, “Our paving superintendent was very pleased with the finishing characteristics of our concrete compared to mix designs that use Type I-II cement.” When asked if he would support Type IL in the Oklahoma market again in the future, he enthusiastically replied, “Oh yeah!”

ODOT also had the chance to share their experience working with Duit Construction on this project. “The level of workability and ease of placement we saw with this product was more than sufficient,” remarked Matt Romero, Structural Materials Engineer with ODOT, when questioned about his experience using Type IL cement. He continued to discuss his stance on past projects that used Type IL, “We’ve heard nothing but positive feedback from the field. Over time, there have been no known issues on these paving projects.” Currently, Type IL cement is written in ODOT’s concrete paving specifications as a Special Provision. Mr. Romero expects this material to be written into their new specification book, which will be released in the near future.

## Summary

This MAP Brief shows examples of mainline paving with PLC in three different states. In all instances both the DOTs and the contractors were pleased with the performance of the product. The change to PLC was seamless, producing the same set times, the same early and late strengths, and maintaining the same amount of fly ash with no notable effect to chemical admixtures.

The performance of PLC paired with its reduced environmental impacts garners multiple advantages for all parties. A product that achieves equal performance compared to Type I-II with the added benefits of workability and finishability should be difficult to ignore. In today’s modern age of construction, the theme of sustainability should be embraced by producers and contractors.

PLC has proven itself in real life job applications. The future of any industry in the twenty-first century will need to focus

6 **Figure 9. Crosstown Expressway after paving. (Photo credit: Holcim (US) Inc., and Duit Construction. Used with permission.)**

on products and processes with lower environmental impacts. Products must not only have a lower carbon footprint but provide long-term durability. These projects demonstrate that pavements built using PLC have produced both excellent durability and improved sustainability.

After 10 years in service PLC demonstrates that it is truly a sustainable product and can provide the concrete paving industry with one way towards “Greener Roads of the Future.”

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