Cement Slurry Application Using a Ready-Mixed Concrete Truck: Best Practices for Urban Pavement Construction

W. Spencer Guthrie
Department of Civil and Environmental Engineering
Brigham Young University
Provo, Utah, USA
guthrie@byu.edu

Elizabeth D. S. Smith
Department of Civil and Environmental Engineering
Brigham Young University
Provo, Utah, USA
elizabethdssmith@gmail.com

Robert J. Stevens
Department of Civil and Environmental Engineering
Brigham Young University
Provo, Utah, USA
rjstev7@gmail.com

Tenli Waters Emery
Department of Civil and Environmental Engineering
Brigham Young University
Provo, Utah, USA
tenliwaters@gmail.com

***Abstract*—A relatively new and increasingly popular method of urban pavement construction involves the application of cement slurry as an additive to soil and/or aggregates to improve the engineering properties of these materials. The purpose of this research was to identify and document best practices related to cement slurry application with ready-mixed concrete trucks as utilized on urban pavement construction projects. The methodology for this research involved field visits to pavement construction sites in northern Utah where active cement slurry applications could be observed. The results of this work provide valuable guidance that is expected to accelerate training of both drivers and construction workers who are involved in cement slurry projects.**

***Keywords*—cement slurry, full-depth reclamation, pavement construction, portland cement, ready-mixed concrete truck, slurry spreader**

I. Introduction and Background

Portland cement has been used in pavement construction for many decades as an additive to soil and/or aggregates to improve the engineering properties of these materials [1]. The cement is spread onto the surface of the soil or aggregate to be treated and immediately mixed to a specified depth. The cement-treated layer is then compacted and cured, or maintained in a moist condition, for several days. Over time, the cement chemically reacts with water in the compacted layer to generate cementitious products that bind the individual soil or aggregate particles together [2]. When an appropriate amount of cement is added, this hydration process can lead to significant improvements in strength and durability. When the layer is able to withstand trafficking without marring [3], a concrete, asphalt, or chip seal surface is usually applied to complete construction of the new pavement structure [4, 5, 6].

Because cement has historically been applied in the form of a fine powder, the use of cement treatment has been limited to rural areas where fugitive cement dust is not a large concern [7]. However, with recent advancements in cement slurry application [4], which ensures the total absence of fugitive cement dust, cement can now be applied even in highly populated urban areas without concern. In many cases, pavement engineers are specifying cement slurry treatment in conjunction with full-depth reclamation (FDR), which is a process that involves pulverization and mixing of a failed asphalt surface course with a portion of the underlying base material to create a new, recycled base material [8]. Because existing materials are recycled in situ, minimal material is transported to or from the construction site, reducing costs, construction traffic, and environmental impacts. For these reasons, FDR with cement slurry treatment is becoming an increasingly popular method of urban pavement reconstruction.

Cement slurry can be easily mixed at a typical concrete batch plant and conveniently delivered to a pavement construction project in ready-mixed concrete trucks [4]. Dry concrete batching plants are preferred so that the cement can be blown into the truck slowly, after the majority of the water has been added, and thereby avoid cement clumping. The slurry is discharged from the truck through standard concrete chutes that can be fitted with a patented Slurry Spreader [9], which not only enhances the uniformity of the cement slurry application but also increases the speed at which the load of slurry can be discharged. Because most urban areas are in close proximity to at least one concrete batch plant, cement slurry treatment is a viable option for nearly all urban pavement construction projects.

Although the same batch plants and trucks that are used for concrete mixing and delivery can be used for cement slurry mixing and delivery, the method of discharging cement slurry is different from the method of discharging concrete. In particular, when discharging cement slurry, ready-mixed concrete truck drivers must unload the slurry while driving their trucks at a relatively constant speed over the layer of soil or aggregate that is being treated and simultaneously adjusting the position of the end of the chute, as needed, to apply cement slurry only in the desired treatment areas. With experience, most drivers can become very proficient at this process; however, the industry has requested a guidance document to describe best practices for cement slurry application in order to accelerate training of both drivers and construction workers who are involved in cement slurry projects.

The purpose of this research was therefore to identify and document best practices related to cement slurry application with ready-mixed concrete trucks as utilized on urban pavement construction projects. The following sections describe the research methodology, discuss the results of the work, and offer conclusions based on the findings, which are expected to be valuable to engineers, contractors, and material suppliers.

II. Research Methodology

The methodology for this research involved field visits to pavement construction sites in northern Utah where active cement slurry applications could be observed. Specifically, three sites in American Fork and Salt Lake City were visited during the years 2018 and 2019. Beyond careful observation of the cement slurry application processes employed at the sites, interviews with ready-mixed concrete truck drivers, owners, engineers, contractors, and laborers were arranged to gain information about their experience and perspectives related to best practices for cement slurry application.

Because cement slurry began to be applied with ready-mixed concrete trucks in Utah by at least 2009 [7], when the first Slurry Spreader prototype was developed, many of the truck drivers had prior experience with this process. A formal questionnaire survey of all truck drivers at one site in American Fork indicated that 59 percent of the drivers had experience spreading slurry, with or without an attached Slurry Spreader. Among these, 35 percent had experience specifically using the Slurry Spreader, although their experience was limited to just two prior projects, on average, as shown in Table **Error! Reference source not found.** The drivers who participated in the questionnaire survey had been driving ready-mixed concrete trucks for between 1 month and 50 years, as also shown in Table 1, with an average of almost 8 years. Thus, while some drivers had decades of driving experience, none of the drivers had significant experience spreading slurry, with or without a Slurry Spreader. For this reason, development of a guidance document to describe best practices for cement slurry application was needed.

TABLE I. Summary of Driver Survey Responses

Survey Topic	Experience Driving a Ready-Mixed Concrete Truck	Number of Experiences Spreading Slurry	Number of Experiences Using the Slurry Spreader
Minimum	1 month	1	1
Average	7.6 years	2	1.7
Maximum	50 years	6	4

III. Discussion

Several important aspects of cement slurry application using a ready-mixed concrete truck and a Slurry Spreader were identified in this work. These include safety, calculations, cement slurry spreading, and mixing and compaction, as described in the following sections.

A. Safety

As on all construction sites, safety is the highest priority. Subsurface utilities should be marked prior to any roadway excavation or FDR work, and those that are expected to be near the surface may need to be exposed so that the actual depth can be assessed in advance. When manholes, water valve covers, and other similar utilities cannot be lowered below the depth of cement slurry mixing, these should be prominently marked with bright paint. Overhead utilities, such as low-hanging electrical wires, should also be marked if they are likely to interfere with the construction operations.

Regarding the construction workers, in addition to standard personal protective equipment (such as hard hats, safety vests, and eye protection), gloves should be worn by those responsible for handling concrete chutes, the Slurry Spreader, or other items that may be in contact with cement slurry. Safety-toed rubber knee boots with adjustable top straps are recommended for those who will be working in the areas of active cement slurry application. Cement slurry that comes in contact with the skin should be rinsed off as soon as possible to prevent skin irritation. Unlike the requirements for some cement powder applications, personnel applying cement slurry are not required to wear respirators given the absence of fugitive cement dust.

The safety of local drivers and pedestrians must also be ensured. A traffic control plan should be prepared and implemented to prevent local drivers from entering the work zone and to minimize congestion in the area as much as possible. Beyond the flaggers who may be needed for traffic control, additional personnel may be assigned to direct pedestrians needing to walk along or cross through the construction corridor; special attention may be warranted along walking routes to and from schools, libraries, bus stops, and other similar destinations.

All individuals must be cautious around ready-mixed concrete trucks and other construction vehicles and equipment. They should also avoid standing under the concrete chute or Slurry Spreader and, if the Slurry Spreader must be moved manually, it should be picked up by two persons.

B. Calculations

Cement slurry is comprised of water, portland cement, and sometimes chemical admixtures such as hydration stabilizer and/or water reducer [8]. The use of hydration stabilizer extends the setting time of the cement, which can be especially desirable on projects constructed during hot weather and/or involving long transit distances. Water reducer, which is less commonly used, can reduce agglomeration of the cement particles and thereby facilitate a higher degree of cement hydration. The proportions of water and cement are selected to ensure adequate consistency of the slurry, which needs to be able to flow through the chute and Slurry Spreader but not flow into gutters or other low points when applied to the ground. A solids content of 70 percent, which corresponds to a water-cement ratio of 0.43, has been shown to work well for many projects in Utah [4]. If the slurry has a relatively low viscosity due to a high amount of water, creating furrows in the surface of the reclaimed material may be necessary to prevent the slurry from running out of the treatment area.

The amount of cement slurry to be applied to a given material is usually specified by the engineer in terms of a percentage of cement by weight of dry soil and/or aggregate, usually as needed to achieve a specified 7-day unconfined compressive strength (UCS) [10, 11]. For example, a specified cement concentration of 4 percent would require the application of 4 lb of cement to 100 lb of dry soil and/or aggregate. If the treatment depth was 8 in. and the target dry density of the soil and/or aggregate was 125 lb/ft^3, 3.3 lb of cement would need to be applied per 1 ft^2 of area. If the solids content of the cement slurry was 70 percent, 4.8 lb of cement slurry would need to be applied per 1 ft^2 of area.

To prevent spillage of the cement slurry during braking or acceleration in transit, a load of slurry is often limited to 60 to 80 percent of the normal capacity of the ready-mixed concrete truck [4]. Thus, a truck with a 10-yd^3 capacity may carry only 6 or 8 yd^3 of cement slurry at a time. Building on the previous example calculations, if 1 yd^3 of cement slurry weighed 3100 lb and a truck was carrying 6 yd^3 of slurry, the load should be spread over an area of 3875 ft^2. In the simplest approach, if the width of the work zone is constant along its length, a longitudinal distance over which the load of cement slurry should be spread can be easily computed. For example, if the width was 18 ft, the length would be 215 ft to achieve the previously stated coverage rate.

More complicated calculations are required when the width of the work zone is variable or when the treatment depth changes within the work zone. A change in treatment depth can occur when some material originally next to a concrete curb or around a manhole, for example, must be excavated and spread out on top of the adjacent material in order to be treated and mixed properly before being returned to its original location and compacted in place. Because the additional thickness of material to be treated increases the target cement application rate, the thickness must be measured, and a calculated amount of additional cement slurry must be applied in those areas.

After the area to be covered by the load in a truck has been determined, the perimeter of that area should be clearly marked with bright paint, as shown in Fig.1, to guide the cement slurry application process. Additional paint markings are recommended to delineate areas that may require additional cement slurry. Marking treatment areas too far in advance is not advised, as construction trafficking and the application of water for general dust control can disturb the markings.

Because compaction will occur soon after cement slurry application, the in situ moisture content of the soil and/or aggregate to be treated should not be excessive before slurry application. Because the slurry will increase the water content of the treated material, the in situ water content prior to cement slurry application should be appropriately lower than the optimum moisture content (OMC) specified for compaction of the treated material. For example, if the in situ moisture content was 6.3 percent by weight of dry soil or aggregate, the addition of cement slurry described in the previous calculations would increase the moisture content by 1.7 percent to a total of 8.0 percent by weight of dry soil or aggregate. If the OMC for the treated material was only 5.5 percent, the in situ materials would need to be scarified and aerated to reduce the in situ moisture content to a target of 3.8 percent prior to the application of cement slurry.

C. Cement Slurry Spreading

Depending on the number of available Slurry Spreaders and the travel time between the concrete batch plant and a project site, several ready-mixed concrete trucks may need to be scheduled for the cement slurry application process. For projects typical of those in Utah, a time interval of 20 to 30 minutes between trucks is recommended, depending on the complexity of the cement application process, when one Slurry Spreader is used.

When a truck arrives on site, the person responsible for guiding the process reviews the batch ticket provided by the driver. He or she specifically ensures that the cement slurry proportions are correct, verifies the number of cubic yards in the load, and checks the time at which the slurry was batched. While the inclusion of hydration stabilizer in the slurry can greatly extend the maximum allowable time between batching and unloading [8], evaporation of water from the load during this time can necessitate adding more water to the load to restore the desired consistency. For ambient temperatures around 90°F and relative humidity values less than 50 percent, adding approximately 1 gallon of water per cubic yard of cement slurry can correct a loss in slurry consistency associated with about 1 hour of elapsed time between batching and unloading. For higher temperatures and/or longer delay times, greater amounts of water may be required. The cement slurry should be discharged before the slurry temperature begins to substantially increase (when the outside surface of the mixing drum of the truck feels hot to the touch), indicating active cement hydration.

For applying the cement slurry with a Slurry Spreader, as shown in Fig. 2 for a front-discharge truck, one extension chute is usually added to the flop-down chute of the truck, and the Slurry Spreader is then attached to the end of the extension chute. The Slurry Spreader can be manually positioned onto the end of the extension chute by two persons, or the truck driver

Fig. 1. Marking the perimeter of a treatment area.

Fig. 2. Front-discharge truck with an attached Slurry Spreader.

may pick up the Slurry Spreader with careful maneuvering of the chute and truck. When the Slurry Spreader is appropriately attached and lifted so that the nozzles are approximately 1 ft above the grade, the truck driver moves to the beginning point for the first discharge pass and positions the Slurry Spreader in the right position, for example, as depicted in Fig. 3.

Following instructions from the person responsible for guiding the process, who should also provide a brief overview of the expected discharge plan, the truck driver then begins rotating the drum to discharge the slurry. A drum rotation speed of about 2.5 rpm is generally recommended to maintain a constant head of slurry in the Slurry Spreader without overfilling it. As the slurry begins to flow through the Slurry Spreader, the driver begins driving down the grade in a direction parallel to the centerline of the roadway and at a designated ground speed selected to achieve the target cement application rate, being directed through predetermined hand signals or radio communication by the person responsible for guiding the process. Although the target cement application rate can be verified by measuring the weight of cement slurry collected in a small pan or on a sheet of known area that is placed on the surface of the base material prior to slurry spreading, it can also be assessed using visual inspection; for reference, Fig. 4 displays cement slurry applications corresponding to cement concentrations of approximately 4, 6, and 8 percent by weight of dry aggregate.

When the end of the treatment area is reached, the driver stops the truck, quickly swings the Slurry Spreader to the left position, for example, and immediately continues to spread slurry in the other direction. When the other end of the treatment area is reached, the driver again stops the truck, quickly swings the Slurry Spreader to the center position (the final position in this example) and again continues to spread slurry.

If slurry remains in the truck after the treatment area is initially covered, additional overlapping passes may be made, with the objective of uniformly discharging the entire load of slurry within the indicated treatment area. If the slurry is discharged before the treatment area is covered, a road grader may be used to redistribute the slurry from areas of high

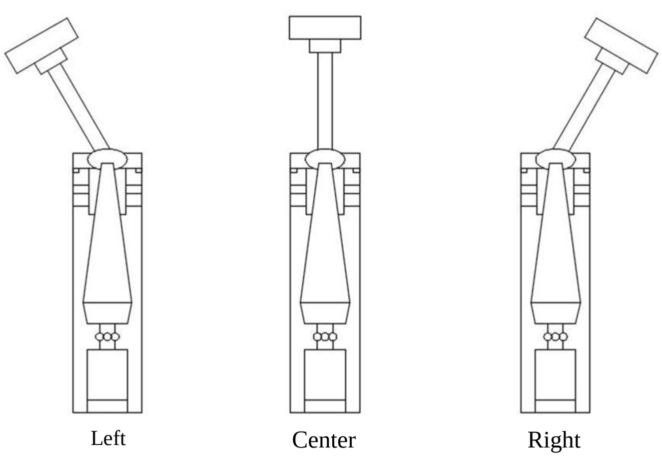
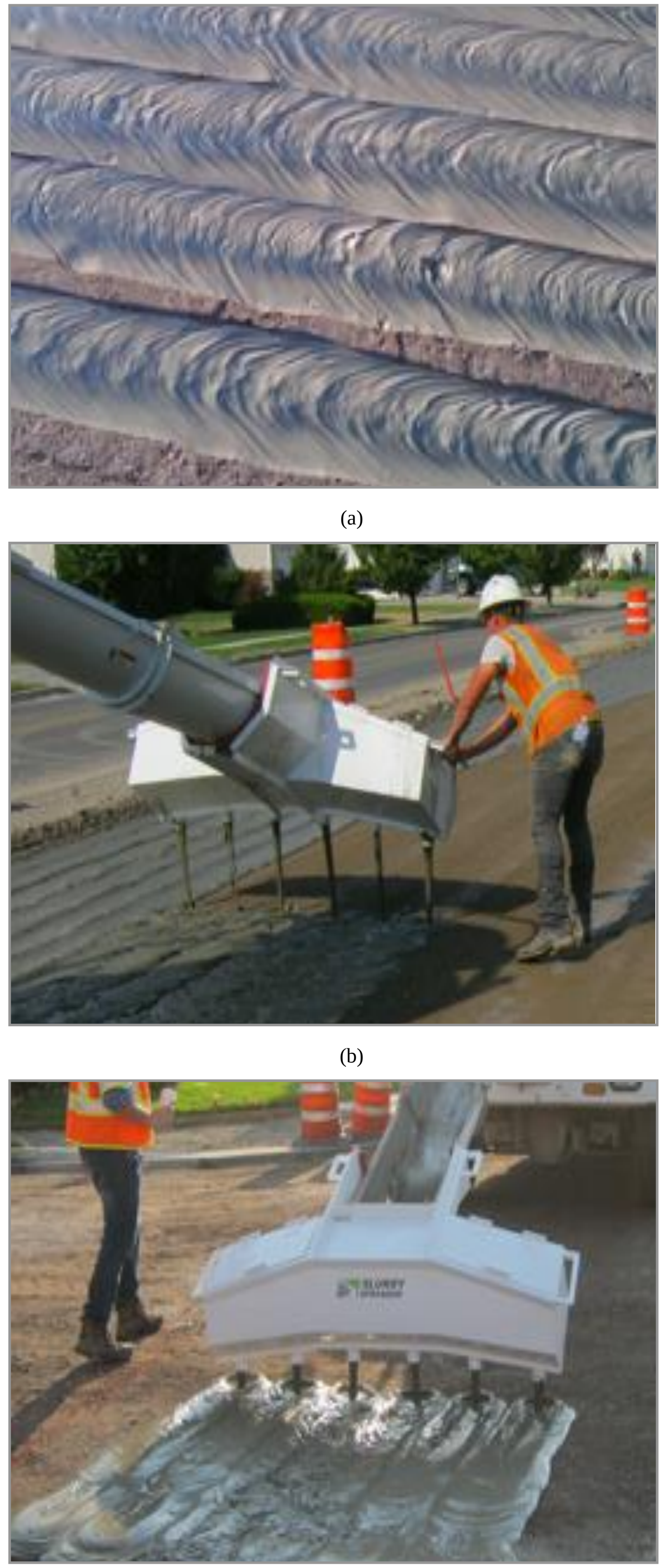


Fig. 3. Example positions of a Slurry Spreader attached to a ready-mixed concrete truck.



(a)

(b)

(c)

Fig. 4. Cement slurry at cement concentrations of a) 4 percent, b) 6 percent, and c) 8 percent.

concentration to areas of low concentration. Of these two options, the former is preferred, even though the truck driver is required in that case to drive through the slurry that was just placed. (In general, a discharge plan should be developed that minimizes the requirement for the driver to drive through the slurry, as monetary fines are often levied for tracking debris onto adjacent streets outside of the work zone. If a driver must drive through the slurry, he or she should carefully rinse the truck tires before leaving the site.)

During slurry spreading, the person responsible for guiding the process should carefully watch the flow of slurry through all nozzles of the Slurry Spreader and immediately stop the driver if one or more of the nozzles becomes clogged or partially clogged. A nozzle can be clogged by a chunk of concrete or other debris that remained inside the drum of the ready-mixed concrete truck after a previous project, for example, and then contaminated the slurry. In such a case, the nozzle can be easily cleared by opening the appropriate lid of the Slurry Spreader and inserting a wooden dowel, length of rebar, or similar object through the nozzle. The person may also need to occasionally press down on one side of the Slurry Spreader to hold it in a level position, especially on steep cross slopes, to ensure uniform flow from all nozzles. (If the person can no longer be seen by the truck driver, such as when the Slurry Spreader is in the center position of a rear-discharge truck, a third person should be assigned to assist with the cement slurry application process for safety purposes.) Finally, both the person(s) on the ground and the truck driver should watch for utilities, holes, vehicles, equipment, and other obstacles in the driving direction.

After a truck has been unloaded, the chute and Slurry Spreader should be rinsed with water (as well as the truck tires, if necessary), and the Slurry Spreader should be manually removed from the chute or carefully set down by the truck driver in a position where it can be used with the next truck. To maintain uniformity in moisture content down the grade, the driver should minimize the amount of water used for initial rinsing and complete more thorough cleaning at a proper wash-out location prepared for that purpose.

D. Mixing and Compaction

Reclamation to the prescribed depth should begin immediately after cement slurry application [12]. Where possible, successive treatment areas should be sequenced in advance to allow cement slurry application in the next area while reclamation occurs in the previous area, as illustrated in Fig. 5. In general, one pass of the reclaimer at a slow walking speed is sufficient for adequate mixing of the cement slurry into the underlying soil and/or aggregate. If longitudinal striations of cement slurry are visible on the surface of the mixed material, a second pass should be made in the affected area, and the reclaimer operator should then drive more slowly in other areas. (Driving too slowly is also not desirable, though, because the mixing process can cause larger aggregate particles to break down into smaller particles, which may reduce the strength of the treated material.)

The mixed material should be compacted to final density using a pad-foot and/or smooth drum roller as soon as possible after the mixing process is complete. In the absence of precipitation, frequent watering of the compacted layer, typically for 7 days, is required to ensure continued curing of the treated material, which is critical for the development of strength and durability [13]. During the curing process, microcracking of the cement-treated layer may be specified to prevent possible reflection cracking of the layer into an asphalt surface course [14].

Fig. 5. Simultaneous cement slurry application and reclamation operation in adjacent treatment areas.

For quality control and/or quality assurance purposes, field sampling of the treated material should occur after mixing and before compaction [15]. For 7-day UCS testing, which is the most common approach for assessing the quality of cement-treated soils and/or aggregates, the inspector should immediately compact cylindrical specimens having 4-in. diameter and 4.6-in. height, usually following standard or modified Proctor procedures. The specimens are often cured in airtight plastic bags that prevent evaporation of water from the specimen until UCS testing is performed. Other tests may also be performed either on site or in a laboratory as needed or required. Where possible, a qualified inspector should be present on site during all cement slurry application, reclamation, and compaction operations to ensure that appropriate procedures are followed.

IV. CONCLUSION

The purpose of this research was to identify and document best practices related to cement slurry application with ready-mixed concrete trucks as utilized on urban pavement construction projects. The methodology for this research involved field visits to pavement construction sites in northern Utah where active cement slurry applications could be observed and included interviews with ready-mixed concrete truck drivers, owners, engineers, contractors, and laborers. The results of this work provide valuable guidance about safety, calculations, cement slurry spreading, and mixing and compaction that is expected to accelerate training of both drivers and construction workers who are involved in cement slurry projects.

Acknowledgment

The authors acknowledge the cooperation of American Fork and Salt Lake City personnel, as well as the participation of Staker Parson personnel, in the completion of this research. The work was motivated by observations of industry leaders at the National Ready-Mixed Concrete Association.

References

[1] American Concrete Institute, “State-of-the-art report on soil cement,” ACI Materials Journal, vol. 87, no. 4, July/August 1990, pp. 395-417.

[2] Portland Cement Association, “Soil-cement information: cement-treated aggregate base,” publication SR221S, Portland Cement Association, Skokie, IL, 2006.

[3] W. S. Guthrie and G. B. Reese, “Assessing rutting susceptibility of cement-treated base material under early trafficking with heavy Clegg impact soil tester,” Transportation Research Record: Journal of the Transportation Research Board, no. 2059, Transportation Research Board of the National Academies, Washington, DC, 2008, pp. 72-79.

[4] D. A. Clem and W. S. Guthrie, “Cement slurry delivery system uses mixer truck for full-depth reclamation,” Concrete in Focus, Summer 2018, pp. 28-33.

[5] H. J. Miller, M. Amatrudo, M. A. Kestler, and W. S. Guthrie, “Mechanistic analysis of reconstructed roadways incorporating recycled base layers,” Transportation Research Board 90th Annual Meeting Compendium of Papers, Transportation Research Board of the National Academies, Washington, DC, January 2011.

[6] B. T. Wilson and W. S. Guthrie, “Strength and deformation characteristics of a cement-treated reclaimed pavement with a chip seal,” Transportation Research Record: Journal of the Transportation Research Board, no. 2212, Transportation Research Board of the National Academies, Washington, DC, 2011, pp. 100-109.

[7] C. A. Hope, B. T. Wilson, and W. S. Guthrie, “Comparison of dry powder and slurry application techniques for cement stabilization of aggregate base materials,” Transportation Research Board 90th Annual Meeting Compendium of Papers, Transportation Research Board of the National Academies, Washington, DC, January 2011.

[8] P. A. Dixon, W. S. Guthrie, and D. L. Eggett, “Factors affecting the strength of road base stabilized with cement slurry or dry cement in conjunction with full-depth reclamation,” Transportation Research Record: Journal of the Transportation Research Board, no. 2310, Transportation Research Board of the National Academies, Washington, DC, 2012, pp. 113-120.

[9] “Revolutionizing urban pavement reconstruction,” www.slurryspreader.com, accessed February 17, 2020.

[10] W. S. Guthrie, A. V. Brown, and D. L. Eggett, “Cement stabilization of aggregate base material blended with reclaimed asphalt pavement,” Transportation Research Record: Journal of the Transportation Research Board, no. 2026, Transportation Research Board of the National Academies, Washington, DC, 2007, pp. 47-53.

[11] B. Wilson, W. S. Guthrie, and D. L. Eggett, “Correlation of results from freeze-thaw and vacuum saturation testing of cement-treated base and subgrade materials,” Proceedings of the American Society of Civil Engineers Sixteenth International Conference on Cold Regions Engineering, CD-ROM, Salt Lake City, UT, July 2015.

[12] W. S. Guthrie, J. E. Michener, B. T. Wilson, and D. L. Eggett, “Effects of environmental factors on construction of soil-cement pavement layers,” Transportation Research Record: Journal of the Transportation Research Board, no. 2104, Transportation Research Board of the National Academies, Washington, DC, 2009, pp. 71-79.

[13] W. S. Guthrie, T. B. Young, B. J. Blankenagel, and D. A. Cooley, “Early-age strength assessment of cement-treated base material,” Transportation Research Record: Journal of the Transportation Research Board, no. 1936, Transportation Research Board of the National Academies, Washington, DC, 2005, pp. 12-19.

[14] W. S. Guthrie and C. A. Hope, Evaluation of portable devices for monitoring microcracking of cement-treated base layers, publication SN3045c, Portland Cement Association, Skokie, IL, 2011.

[15] W. S. Guthrie and M. A. Rogers, “Variability in construction of cement-treated base layers: material properties and contractor performance,” Transportation Research Record: Journal of the Transportation Research Board, no. 2186, Transportation Research Board of the National Academies, Washington, DC, 2010, pp. 78-89.