JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Development of Subgrade Stabilization and Slab Undersealing Solutions for PCC Pavements Restoration and Repairs

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SPR-4004 • Report Number: FHWA/IN/JTRP-2020/13 • DOI: 10.5703/1288284317128

RECOMMENDED CITATION

Behnood, A., & Olek, J. (2020). *Development of subgrade stabilization and slab undersealing solutions for PCC pavements restoration and repairs* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2020/13). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317128

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NOTICE

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-2020/13		

4. Title and Subtitle	5. Report Date
Development of Subgrade Stabilization and Slab Undersealing Solutions for PCC Pavements Restoration and Repairs	April 2020
	6. Performing Organization Code
7. Author(s) Ali Behnood, Jan Olek	**8. Performing Organization Report No.** FHWA/IN/JTRP-2020/13
9. Performing Organization Name and Address Joint Transportation Research Program (SPR) Hall for Discovery and Learning Research (DLR), Suite 204 207 S. Martin Jischke Drive West Lafayette, IN 47907	**10. Work Unit No.** **11. Contract or Grant No.** SPR-4004
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The loss of functionality and the development of distress in concrete pavements is often attributable to the poor subbase and subgrade conditions and/or loss of support due to the development of the voids underneath the slab. Subgrade soil stabilization can be used as an effective approach to restore the functionality of the subgrades in patching projects. This research had two main objectives: (1) identifying the best practices for soil stabilization of the existing subgrade during pavement patching operations and (2) identifying and developing new, modified grouting materials for slab stabilization and undersealing. Various stabilization scenarios were tested and showed improved performance of the subgrade layer. The use of geotextile along with aggregate course was found to significantly reduce the settlement. Non-removable flowable fill was also found to significantly reduce the subgrade settlement. Cement-treated aggregate and lean concrete provided the best performance, as they prevented formation of any noticeable settlement in the underlying subgrade.

17. Key Words	18. Distribution Statement
subgrade stabilization, concrete pavements, repairs, slab undersealing	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	50 including appendices	

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EXECUTIVE SUMMARY

Introduction

Subgrade condition plays a significant role in a pavement's long-term performance. The loss of functionality and the development of distress in concrete pavements is often attributed to poor subbase and subgrade conditions and/or loss of support due to the development of voids underneath concrete slabs. In the past, concrete pavements were often placed atop compacted but unmodified soil; however, subgrade strengths weaken significantly when wetted, thus causing reduced bearing capacity and loss of concrete slab support. Loss of slab support in turn leads to development of distresses in the pavements, which often necessitates the installation of patches to restore roadway functionality. In such cases, the pavement patching operations are typically preceded by the removal of some depth of soil and the return of an equivalent volume of compacted aggregate.

More recently, concrete pavements constructed in Indiana are placed on subbase layers consisting of 3 inches of open graded #8 aggregates over 6 inches of dense graded #53 aggregates. While this subbase provides a more stable support for the slabs, once it becomes saturated with water, its efficiency dramatically decreases. The pavement supported by saturated subbase will be more prone to settlement, and this will make it more susceptible to water intrusion.

This research was initiated to achieve two main objectives: (1) to identify the best practices for soil stabilization of existing subgrade during pavement patching operations and (2) to identify/develop new/modified grouting materials for slab stabilization/undersealing. The findings of this research will allow Indiana Department of Transportation (INDOT) to extend the service life of highways by improving the performance of subgrades during the concrete pavement patching operations.

Findings

1. In this research, two additives (i.e., Type I ordinary portland cement (OPC) and a liquid polymer) were evaluated for "in-situ" subgrade stabilization with the aim to restore (and to potentially improve) the functionality of the selected soils within the patch area. From the results of the unconfined compressive strength tests, the OPC was found to be an effective additive to restore the functionality of the soils. However, the moisture content of the soil also plays an important role. It was found that the addition of 6% OPC at a water content between $\pm 5\%$ of the optimum moisture content (OMC) can restore the functionality of the soil.
2. The results of various stabilization scenarios showed that all of them improved the performance of the subgrade layer. The only exception was the stabilization scenario with 3 inches of #8 aggregate and 6 inches of #53 aggregate (i.e., scenario #5), which did not produce any significant reduction in the observed settlement of the underlying subgrade layer compared to unmodified soil. The use of geotextile along with the aggregate course was found to significantly reduce the settlement. Non-removable flowable fill was also found to significantly reduce the subgrade settlement. Cement-treated aggregate and lean concrete provided the best performance as they prevented formation of any noticeable settlement in the underlying subgrade.
3. A wide range of cement-based grouts was evaluated to optimize their performance in terms of strength, setting time, fluidity, and bleeding. The following grouts were found to provide the best performance:
   - Grout mix prepared with Type I OPC; w/c = 0.5.
   - Grout mix prepared with Type I OPC and silica fume (SF); w/b = 0.5 and 5% of SF.
   - Grout mix prepared with Type I OPC and calcium chloride (CC); w/c = 0.6 and 5% of CC.

Implementation

The results of the experimental work performed during the current study suggests that the use of lean concrete with a low cement content (i.e., 130 lb/yd^3) and a high w/c of 1.5 constitutes a good subgrade layer in patching areas. The results suggest that the INDOT could benefit from the lean concrete and have reasonable expectations that lean concrete would perform well under traffic loads and environmental conditions and could possibly be less expensive compared to other methods.

This change can be accommodated by revising the standard specifications, along with applicable design guidelines and the pay items. With regard to slab undersealing, the results of the present study suggest that a grout mix made with Type I OPC and a w/c of 0.5 can provide satisfactory performance in terms of strength, setting time, fluidity, and bleeding. Similar performance, with slightly reduced strength and increased fluidity, can be obtained with a grout mix made with Type I OPC, 5% silica fume, and a w/b ratio of 0.5. The other potential grout mix with satisfactory performance is the one made with Type I OPC and a w/c of 0.6 while also containing 5% of calcium chloride. Since calcium chloride significantly reduces the setting time, this grout mix would be recommended for the projects with short closure times. Lower CC content (i.e., 3%) would be recommended for the projects where higher fluidity is important while higher CC content (i.e., 7%) would be recommended for the projects where quicker setting time is important.

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TABLE LIST

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1. INTRODUCTION AND PROBLEM STATEMENT

Subgrade plays a significant role in long-term pavement performance. The loss of functionality and the development of the distress in concrete pavements is often attributed to poor subbase and subgrade conditions and/or loss of support due to the development of voids underneath concrete slabs. In the past, concrete pavements were often placed atop compacted, but unmodified soil. However, subgrade strengths weaken significantly when wetted causing reduced bearing capacity and loss of concrete slab support. Loss of slab support in turn leads to development of distresses in the pavements often necessitating the installation of patches to restore roadway functionality. In such cases, the pavement patching operations are typically preceded by the removal of some depth of soil and the return an equivalent volume of compacted aggregate.

More recently, concrete pavements constructed in Indiana are placed on subbase layers consisting of 3 in. of open graded #8 aggregates over 6 in. of dense graded #53 aggregates. While this subbase provides a more stable support for the slabs, once it becomes saturated with water, its efficiency dramatically decreases. The pavement supported by saturated subbase will be more prone to settlement, and this will make it more susceptible to water intrusion.

Subgrade soil stabilization can be used as an effective approach to restore the functionality of subgrades (Behnood, 2018). In civil engineering, soil stabilization is a technique used to refine and to improve such engineering properties of soils as mechanical strength, permeability, compressibility, durability and plasticity (Behnood, 2018). While the properties of soil may be improved physically or mechanically, the term "stabilization" mainly refers to chemical improvements of soil properties by way of adding chemical admixtures (Behnood, 2018). Soil stabilization is widely used in many civil engineering applications such as sub-base and subgrade construction, rail and road construction, foundation construction and embankments, backfill for bridge abutments and retaining walls, etc.

A wide array of materials has been successfully used to stabilize the subgrade soils such as ordinary portland cement (OPC), lime, industrial by-products (e.g., fly ash, slag, etc.), polymers, chemical reagents, fibers, waste/recycled materials (e.g., shredded tires, crushed glass, etc.), asphalt emulsion, tar, bitumen and so on (Al-Mukhtar, 2012; Behnood, 2018; Lin et al., 2007; Prusinski & Bhattacharja, 1999; Sol-Sánchez et al., 2016). However, the use of these materials in small-scale patching projects, where schedule is tight, has not been investigated in the past. Soil stabilization with chemical admixtures is beneficial in many aspects (Behnood, 2018; Nicholson, 2015; Petry & Little, 2002) such as (1) enhancing shear and compressive strength; (2) improving durability and resistance to severe environmental conditions such as wetting-drying or freezing-thawing cycles, weathering, and erosion; (3) reducing permeability; (4) reducing swelling potential and volume instability, and controlling shrinkage; (5) reducing the plasticity index (PI); (6) reducing soil compressibility, deformation, and settlement; (7) improving resilient modulus; and (8) reducing clay/silt-sized particle.

1.1 Objectives

This research was initiated to achieve two main objectives: (1) to identify the best practices for soil stabilization of the existing subgrade during pavement patching operations and (2) to identify/develop new/modified grouting materials for slab stabilization/undersealing. The findings of this research will allow INDOT to extend the service life of highways by improving the performance of subgrades during the concrete pavement patching operations.

2. U.S. SURVEY RESPONSES

This chapter covers the current policies and approaches regarding the subgrade soil stabilization and slab undersealing such as the following:

1. Any established methodology for soil stabilization/slab undersealing.
2. What triggers subgrade stabilization.
3. What materials are suitable for subgrade soil stabilization/slab undersealing.
4. Whether the agency has standards, specifications or guidelines for subgrade soil stabilization/slab undersealing.
5. What equipment are suitable for subgrade soil stabilization/slab undersealing.
6. Other factors that apply to a successful subgrade soil stabilization/slab undersealing.

In order to collect the abovementioned information a survey was sent to the members of the AASHTO Subcommittee on Maintenance with copies to the members of the research advisory committee. A total of 26 states responded to the survey. It should be noted that two distinctive responses were received from the state of Indiana. A copy of this survey and the tabulated responses are provided, respectively, in Appendix A and Appendix B.

The first survey question asked if the respondents consider soil stabilization/slab undersealing as part of their standard specification for PCC pavement restorations and repairs. In response for subgrade soil stabilization, 7 out of 26 (26.9%) said it was and 19 (73.1%) said that it was not. In response for slab undersealing, 10 out of 26 (38.5%) said it was and 16 (61.5%) said it was not. The subgrade soil stabilization and slab undersealing are not part of PCC patching practices to most states, as respectively, illustrated in Figures 2.1 and 2.2.

There are a variety of approaches used to modify/restore the functionality of subgrade of the PCC pavements. In Utah, the concrete pavement is not directly placed on a subgrade or untreated base layer. All of the PCC pavement in Utah is placed either on a lean concrete base in the past or an HMA layer as the current

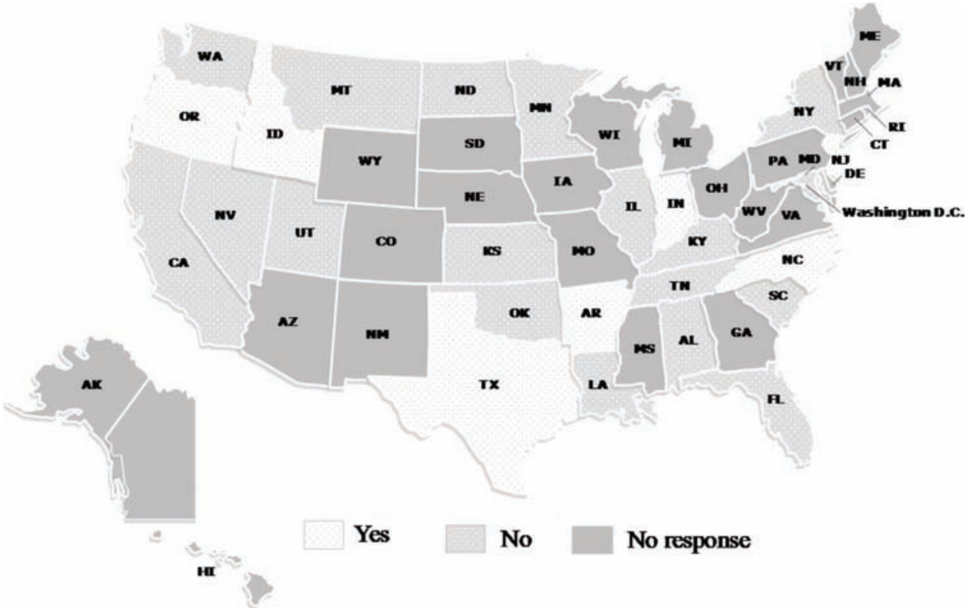

Figure 2.1 Is the option for subgrade stabilization part of your standard specification for PCC pavement restoration and repairs?

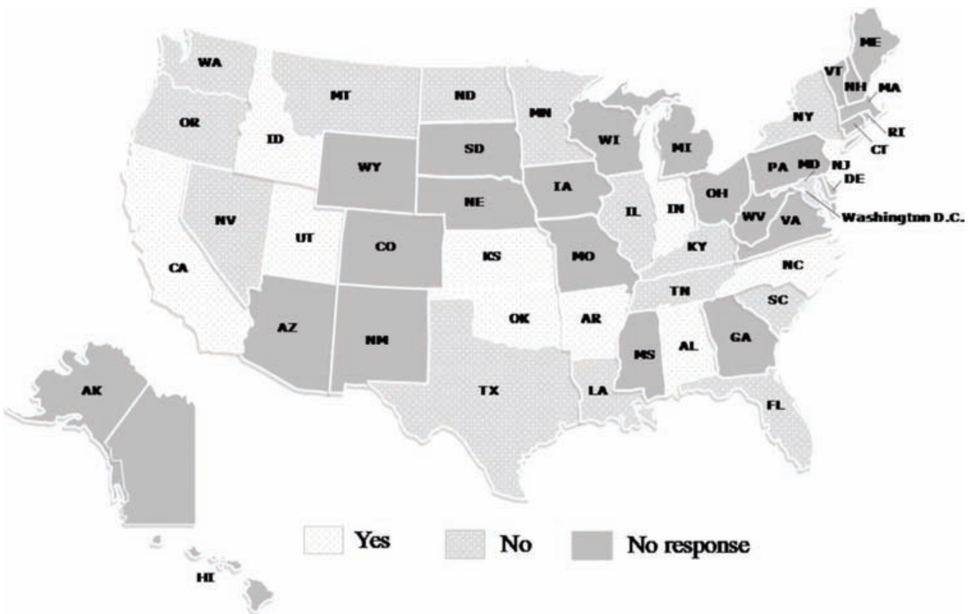

Figure 2.2 Is the option for subgrade undersealing part of your standard specification for PCC pavement restoration and repairs?

state practice (as of the date of survey, February 2017). In addition, Utah reported that slab undersealing and slab jacking is done to address voids and differential settlement in PCC pavement not as an established process in addressing subgrade or untreated base failure beneath the PCC pavement. New York reported that "fine grading of subbase is usually the only subgrade improvement done with concrete pavement projects." Removing the saturated subgrade and replacing it with aggregate material is the approach usually taken by the state of Kansas to restore the functionally of the subgrade. Stabilizing the subgrade soil in small patching practices is not specified in the state of Kansas.

States were asked if they have established methodology for determining areas of a pavement where subgrade stabilization/slab undersealing may be required as part of PCC pavement repair project; the responses to the soil stabilization and slab undersealing are, respectively, shown in Figures 2.3 and 2.4. Only a few states including Oregon, Kansas, Indiana, North Carolina, and New Jersey have established methodology for determining the areas where subgrade stabilization and or slab undersealing may be required as part of PCC pavement repair project. The state of Texas has established methodology only for determining the areas where slab undersealing is required.

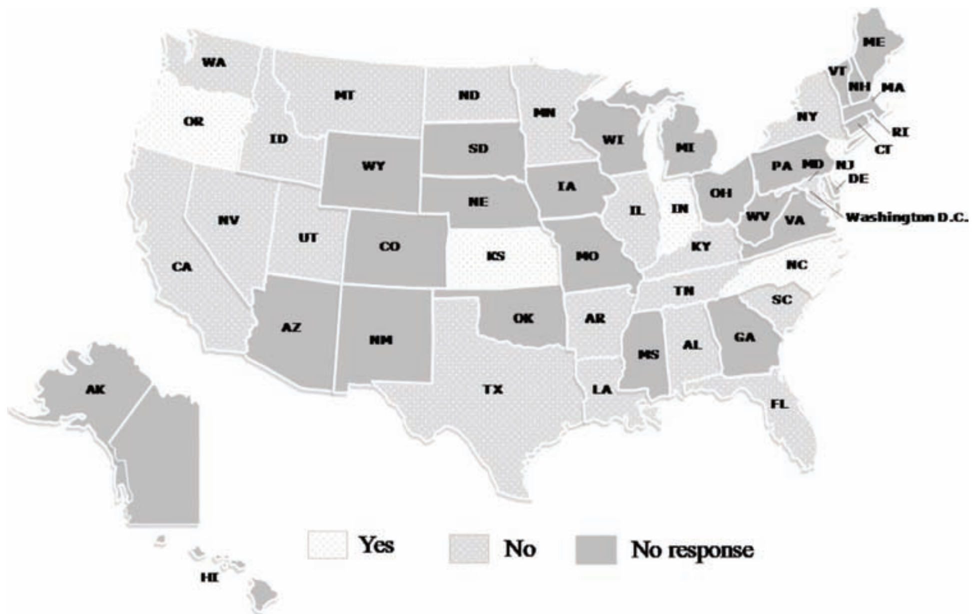

Figure 2.3 Do you have established methodology for determining areas of a pavement where subgrade stabilization may be required as part of PCC pavement repair project?

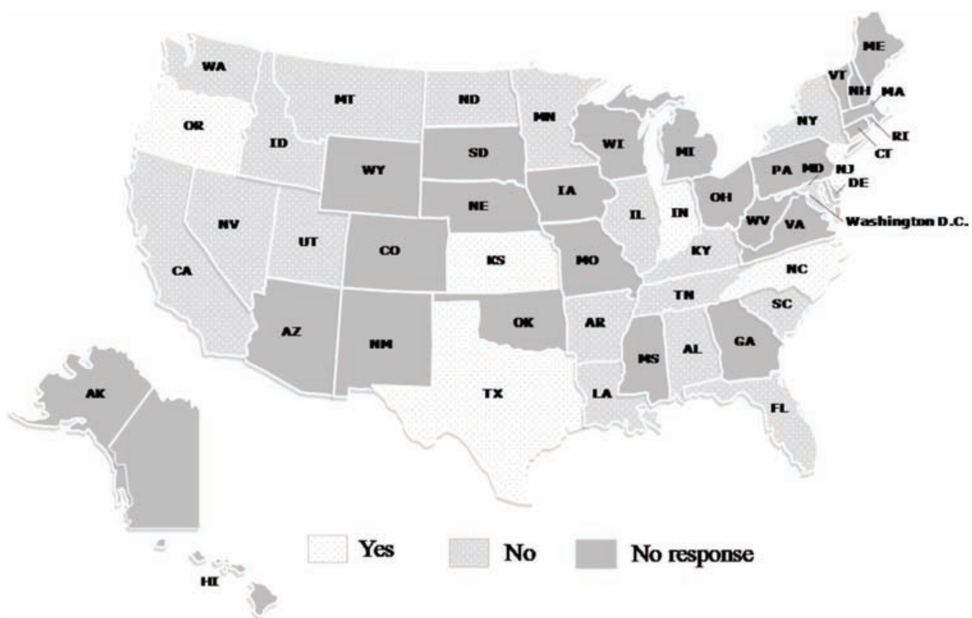

Figure 2.4 Do you have established methodology for determining areas of a pavement where slab undersealing may be required as part of PCC pavement repair project?

States were also asked what triggers the selection of subgrade stabilization or slab undersealing as part of PCC pavement restoration and repair project, the results of which are shown in Figures 2.5 and 2.6, respectively. Three of the main factors that trigger the selection of subgrade or slab undersealing in PCC patching practices are: (1) extent of damage, (2) visual inspection of the damage, and (3) poor ride quality. Sudden safety problems, possibility of having subgrade soil erosion, type/properties of the subgrade soil, and pavement closure time were among the other factors that were indicated by a few states as triggers for the selection of subgrade stabilization or slab undersealing in pavement patching practices.

In an attempt to get an idea of the scale of the state PCC patching programs combined with subgrade soil stabilization/slab undersealing, the survey asked what percentage of all PCC pavement restoration/repair projects involved soil stabilization and/or slab undersealing in the state. Figure 2.7 shows that only a few states consider subgrade soil stabilization for more than 30% of their PCC pavement repair. Only in Indiana

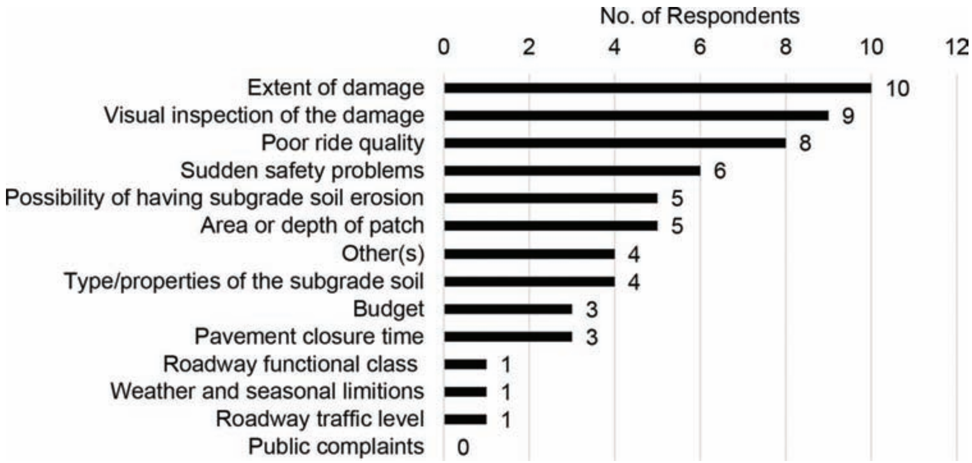

Figure 2.5 Is there a "trigger" parameter that governs the selection of subgrade stabilization as part of PCC pavement restoration and repair projects?

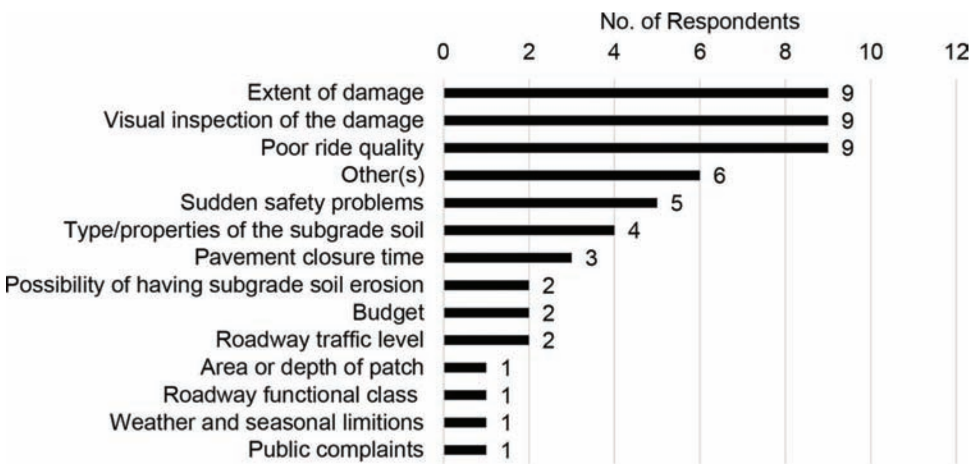

Figure 2.6 Is there a "trigger" parameter that governs the selection of SLAB undersealing as part of PCC pavement restoration and repair projects?

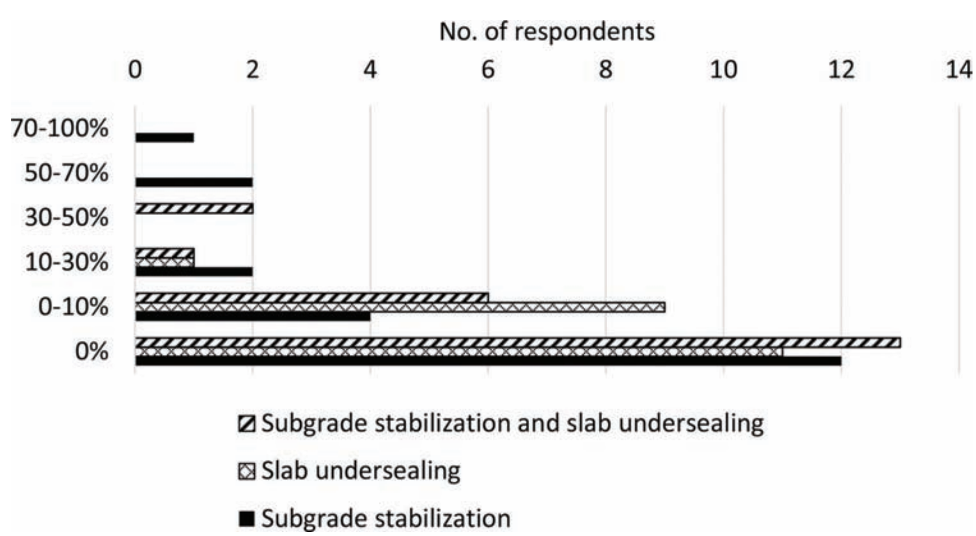

Figure 2.7 What percentage of all PCC pavement restoration/repair projects in your jurisdiction involve subgrade soil stabilization and/or slab undersealing?

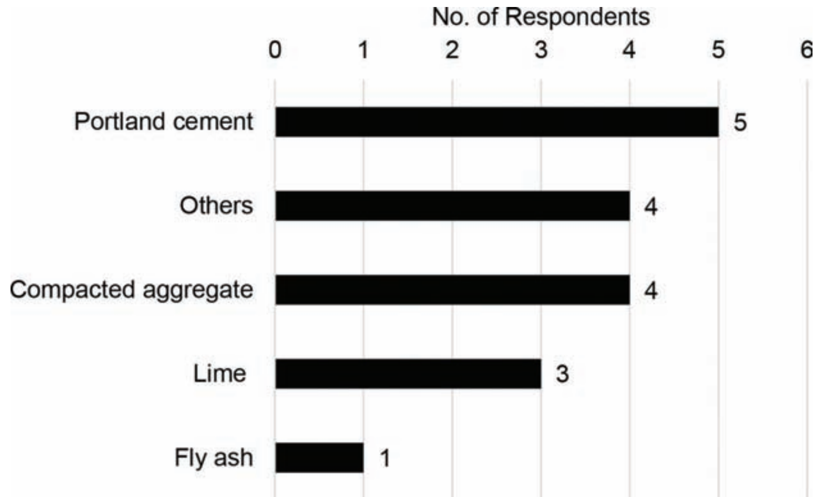

Figure 2.8 What materials are used for subgrade stabilization as part of PCC pavement restoration and repairs in your area?

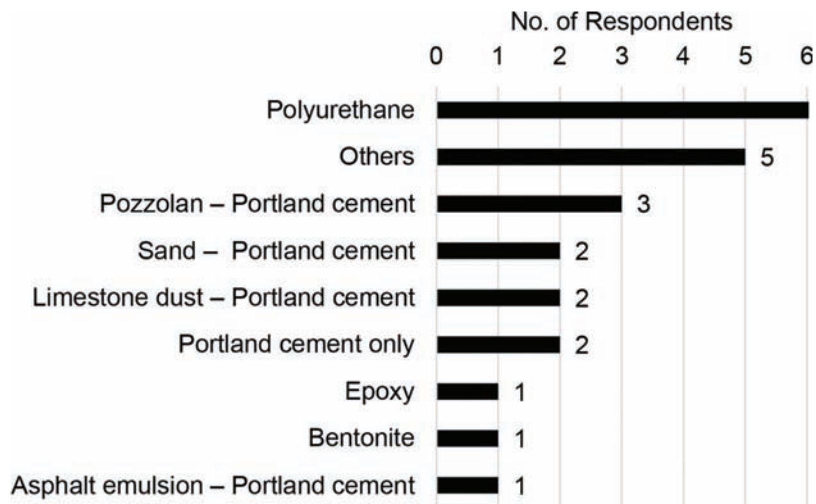

Figure 2.9 What materials are used for slab undersealing as part of PCC pavement restoration and repairs in your area?

about 70%–100% of the PCC pavement repair is done combined with soil stabilization. North Carolina and South Carolina reported that about 50%–70% of pavement patching practices include subgrade soil stabilization. Slab undersealing is usually done for less than 30% of PCC pavement repair practices.

The most common materials used by state DOTs for subgrade soil stabilization and slab undersealing as part of PCC pavement restorations and repairs are shown, respectively, in Figures 2.8 and 2.9.

Another question on the survey asked states if they have undertaken or sponsored any past (or ongoing) research in the area of soil stabilization/slab undersealing for PCC pavement restoration and repair. Out of 23 responses to this question, 21 agencies (91.3%) said no. While New Jersey reported that both soil stabilization and slab undersealing had been studied as part of PCC pavement restoration and repair in the state, Kentucky stated that only subgrade soil stabilization was in their research program.

States were also asked if there is a need for more research or information in the area of subgrade soil stabilization/slab undersealing; the results for the former and later parts of the question are shown, respectively, in Figures 2.10 and 2.11.

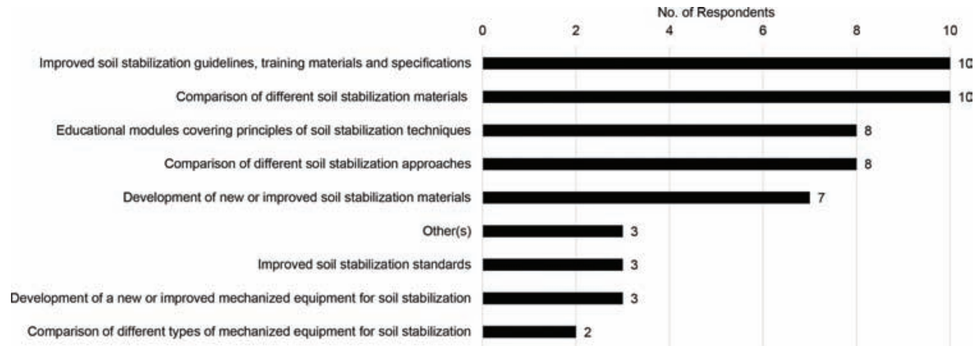

Figure 2.10 Is there a need for more research or information in the area of soil stabilization (Please select all that apply)?

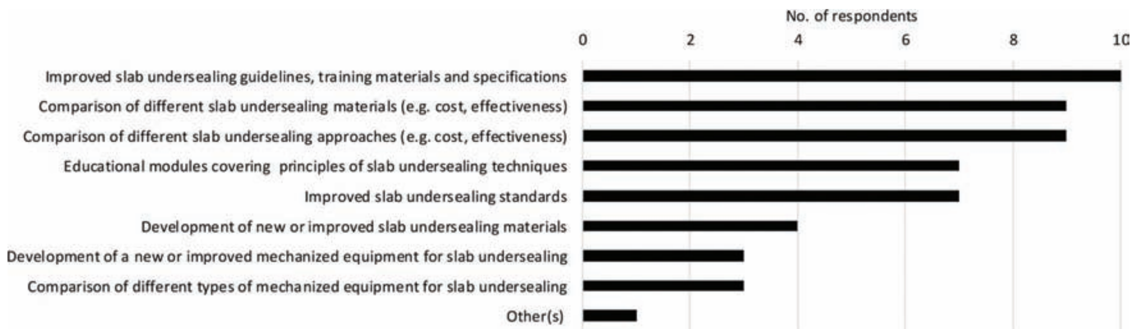

Figure 2.11 Is there a need for more research or information in the area of slab undersealing (Please select all that apply)?

3. CHEMICAL MODIFICATION

To investigate the effects of chemical modification on the strength properties of clayey soils, three types of clays were stabilized with the ASTM C150 (12) Type I OPC. There are three main reasons to select OPC as the potential calcium-based stabilizer: (1) chemical and physical properties of OPC are less variable than those of lime and fly ash (Behnood, 2018); (2) OPC tends to set sooner with higher strength-gain properties compared with calcium-based stabilizers (e.g., lime) (Behnood, 2018); and (3) OPC is the most commonly used additive for soil stabilization among state DOTs. A liquid polymer (LP), namely AGB-WT, was also used to assess the effects of a non-calcium-based stabilizer on the properties of soils in patching projects.

Various types of tests, such as Atterberg limits (including liquid limit (LL) and plastic limit (PL)), Proctor tests, and particle size analysis (PSA) tests were performed to characterize the soils. Atterberg limits tests were conducted following the ASTM D4318-10 specification. Proctor tests were carried out in accordance with the ASTM D698-12 to obtain the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) of the soils. A summary of the results of the tests used to characterize the soils are given in Table 3.1. Figure 3.1 shows the results of the PSA test conducted in accordance with the ASTM D422-63.

The soils used in the experiments were labeled as S_1, S_2, and S_3. According to the Unified Soil Classification System (USCS), S_1 and S_2 were classified as ML (lean silt) and S_3 was classified as CH (high plasticity clay). According to the American Association of State Highway and Transportation Officials (AASHTO), S_1, S_2, and S_3 were, respectively, classified as A4, A-7-6, and A-7-5. These types of soils are the common soils in the state of Indiana.

3.1 Experimental Program—Testing Protocol

A series of unconfined compressive strength (UCS) tests were performed on the soils modified with various amounts of OPC (a calcium-based stabilizer) to investigate its effects on the strength-gain of the treated soils. In this study, the amount of added water was also changed to investigate the effects of water content on the strength-gain properties of the stabilized soils. The use of various OPC contents and water contents will allow for evaluating a wide range of potential cement stabilization scenarios. The UCS tests were conducted after 4 hrs, 8 hrs, 1 day, 7 days, 14 days, and 28 days. Three replicate specimens were tested at the appropriate testing time for each of the modifier-soil-water combinations. All the prepared specimens were cured in an environmental chamber with a Relative Humidity (RH) of 50% and a curing temperature of 23°C.

TABLE 3.1
Summary of the tested soils indices

Soil ID	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (pcf)	AASHTO Classification	USCS Classification
S_1	27.1	25.0	2.1	17.3	94.8	A4	ML
S_2	43.5	27.1	16.4	22.1	100.4	A-7-6	ML
S_3	84.0	27.5	56.5	21.2	93.8	A-7-5	CH

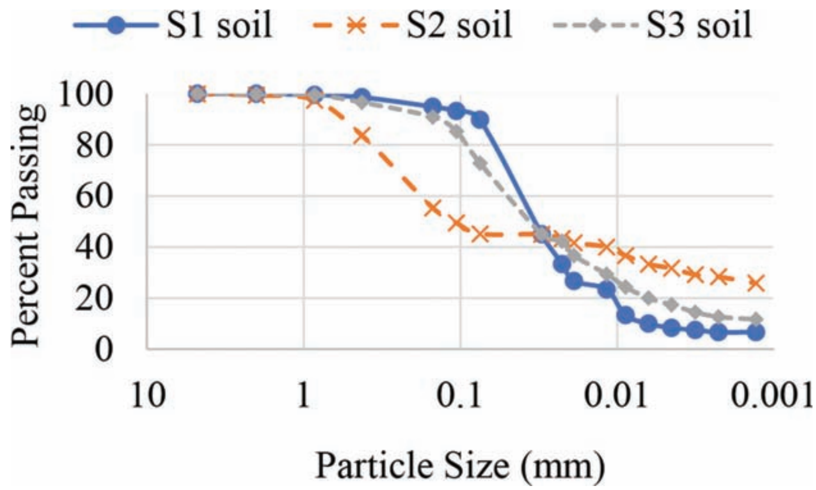

Figure 3.1 Granulometry test results of the tested soils.

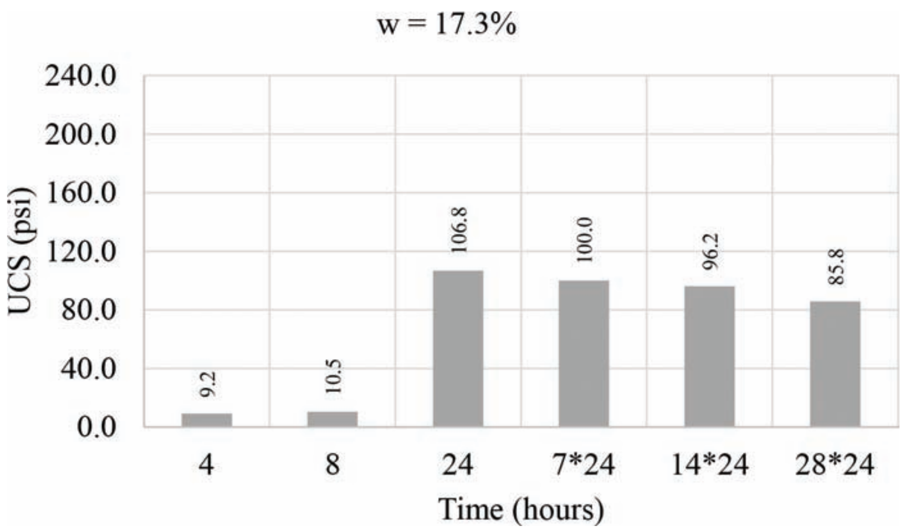

Figure 3.2 Strength development of S1 soil compacted at its OMC (17.3%)—without adding any stabilizer.

3.2 Results and Discussion

The strength development of S1 soil (without any treatment) as a function of time is shown in Figure 3.2. At early ages (i.e., 4 hrs and 8 hrs), the values of the UCS of S1 soil are very low. That soil reaches its maximum load-bearing capacity (i.e., 106.8 psi) after one day as it dries out. It can be seen that the UCS of S1 soil shows a decreasing trend after 24 hours. Some cracks due to the shrinkage of the samples, might remain in them, which can reduce the value of UCS. The effects of OPC on the UCS of S1 soil after the addition of 4%, 6%, 8%, and 10% OPC (by the weight of dry soil) are shown in Figure 3.3. In order to investigate the effects of water content, cemented soil samples were mixed with different water contents. As shown in Figure 3.3, increase in the amount of added cement always resulted in the increase in the early-strength of soils. The addition of OPC, as shown in Figure 3.3, increases the early strength of soils, irrespective of the

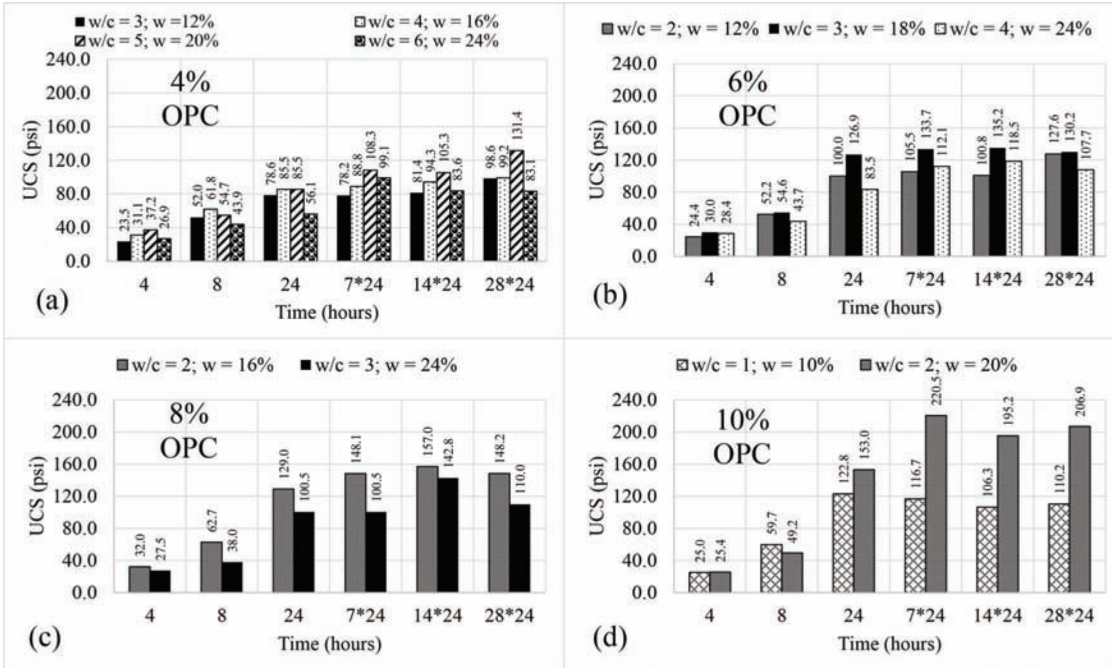

Figure 3.3 Strength development of S1 soil treated with (a) 4% OPC, (b) 6% OPC, (c) 8% OPC, and (d) 10% OPC.

OPC content and water content. The improved UCS at early ages is an advantageous, especially when working with tight schedules during patching operations. OPC plays two main roles in improving the early strength of soils (Behnood, 2018): first, it absorbs a fraction of the free water and partially dries the soil, and second, its hydration creates stronger products with higher density.

Comparing Figures 3.2 and 3.3a, it can be seen that, irrespective of the water content (w/c ratio), the values of 1-day UCS of S_1 soil treated with 4% OPC were always lower than the UCS values of the untreated soil (106.8 psi vs. ~56–85 psi). It could be due to the effects of water content used in the preparation of these samples. It should be noted that none of these water contents is the OMC of the untreated soil (16.3%). After one day of curing, treated soil with 4% cement and mixed with 20% water (about 3% above the OMC of the untreated soil) (Figure 3.3a) shows relatively comparable results with untreated soil. The increase in the UCS is because of the continuing hydration of the cement particles, which makes the system stronger at later ages. The other samples treated with 4% cement and mixed with 12%, 16%, or 24% of water show lower compressive strength values than the untreated soil mixed with 17.3% water (i.e., OMC). It should be noted that the addition of cement increases the OMC of the cemented soil (Behnood, 2018) since it requires some extra water for the hydration of the cement particles. Therefore, 20% water is likely the closest point to represent the OMC of the system. There are three main interesting observations regarding the stabilizing of S_1 soil with 4% cement: (1) irrespective of the water content, the addition of 4% cement improves the early strength of the stabilized soil, (2) compacting the soil at its OMC or at a moisture content close to the OMC is important with respect to obtaining a desirable UCS, and (3) the addition of 4% cement is not sufficient to compensate for the shortage/excess of water as compared to the OMC.

Figure 3.3b shows that the addition of 6% OPC can further improve the UCS of S_1 soil, especially at later ages. For example, irrespective of curing period, the UCS of S_1 soil treated with 6% cement and mixed with 12% water is higher than that of S_1 soil treated with 4% and mixed at the same water content. Similarly, the UCS of S_1 soil treated with 6% cement and mixed with 24% water is higher than that of S_1 soil treated with 4% and mixed at the same water content. Figures 3.3c and 3.3d show that although the UCS is a function of the amount of mixed water, further addition of OPC can potentially increase the UCS values. For example, it can be seen that the UCS of S_1 soil mixed with 8% OPC and 16% water is higher than that of S_1 soil mixed with 4% OPC and the same water content. Similar behavior can be seen when comparing the UCS value of S_1 soil mixed with 8% of OPC and 24% of water with that of mixed with 4% of OPC and the same water content. The highest UCS value is associated with the sample treated with 10% cement and mixed with 20% water. Therefore, stabilizing the soil with 10% cement and at its OMC can provide satisfactory strength properties of the soil. Overall, the results of the UCS tests show that the addition of 6% OPC to S_1 soil while keeping the water content in the range of OMC – 5% to OMC + 5% restores the functionality of the soil after 7 days.

The feasibility of the use of a commercially available LP was also investigated as a soil stabilization agent.

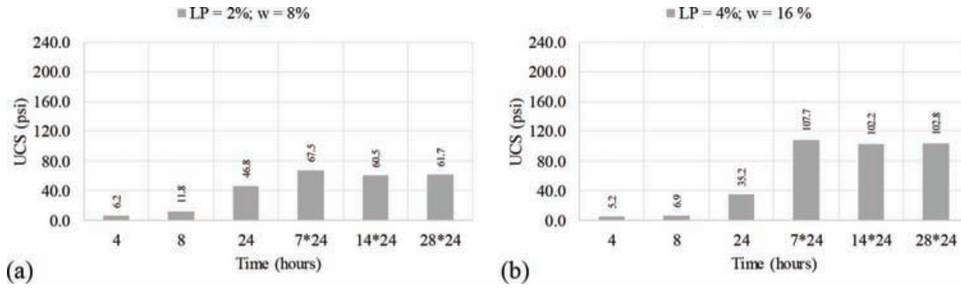

Figure 3.4 Strength development of S1 soil treated with (a) 2% liquid polymer and mixed with 8% water and (b) with 4% liquid polymer and mixed with 16% water.

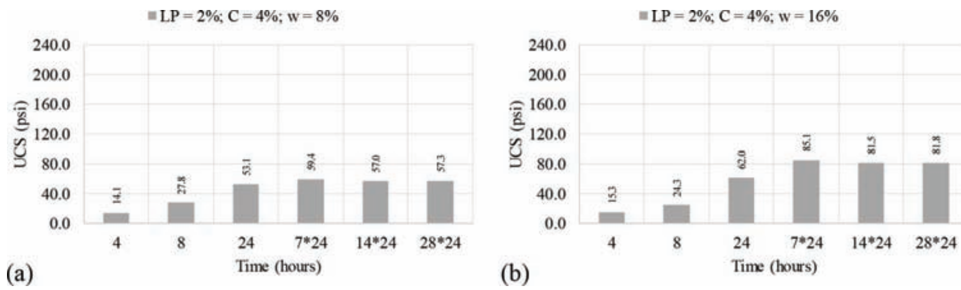

Figure 3.5 Strength development of S1 soil treated with 2% liquid polymer and 4% cement and (a) mixed with 8% water and (b) mixed with 16% water.

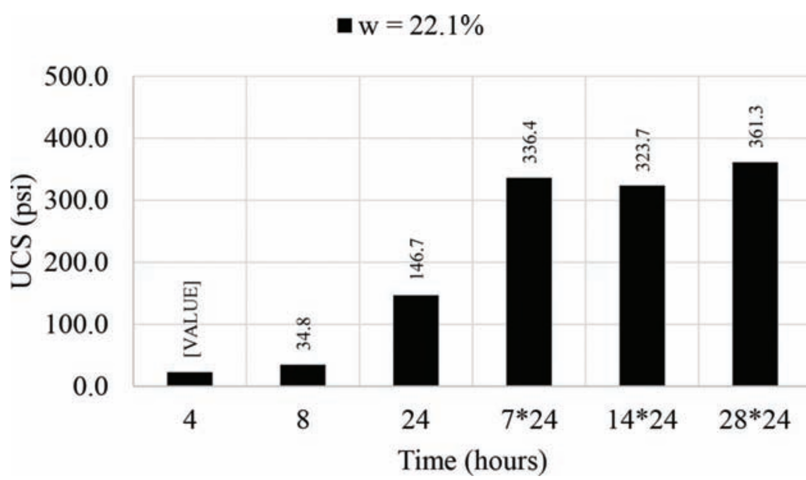

Figure 3.6 Strength development of untreated S2 soil compacted at its OMC (22.1%) as a function of time.

Figures 3.4a and 3.4b show that the UCS of S_1 soil treated with, respectively, 2% LP plus 8% water and 4% LP plus 16% water. The water contents of these systems were selected following the producer's recommendation. It is clearly evident that neither early strength nor the later strength is improved with the addition of LP. Therefore, LP is not an effective soil stabilization agent and it is not a good replacement for cement.

In an attempt to study the combined effects of cement and LP, two soil samples were prepared by the addition of 4% cement to the abovementioned LP-stabilized soil. That is, for the first sample, S_1 soil was mixed with 2% LP, 4% cement and 8% water while for the second sample, S_1 soil was mixed with 2% LP, 4% cement and 16% water. The results of UCS tests of these soils are illustrated in Figure 3.5. Interestingly, the addition of cement to the LP-modified soil did not improve the UCS of the soil and, surprisingly, it even caused a reduction in the values of UCS.

To further investigate the effects of OPC on the strength gain of soils, two other types of soils (i.e., S_2 and S_3) were stabilized with varying amounts of OPC and water. The UCS of S_2 soil compacted at its OMC (without adding any additive) and at different curing periods is illustrated in Figure 3.6. The value of the maximum UCS for this soil is about 361 psi. The slight fluctuation in the UCS values after at and after seven days could be due to the effects of shrinkage and micro cracks in the samples.

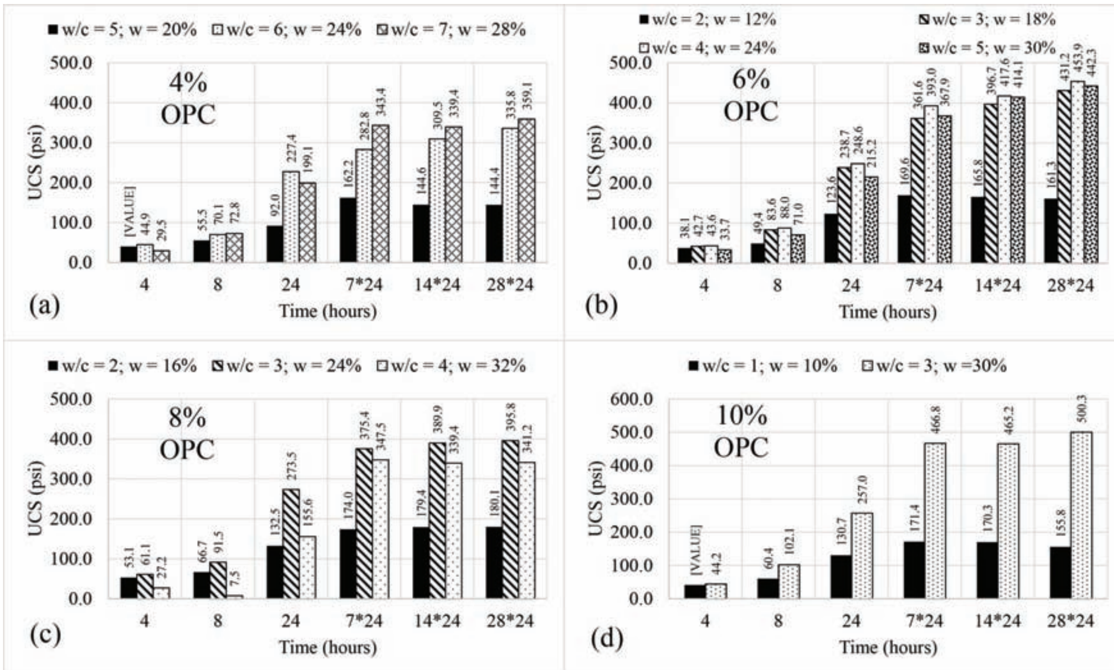

Figure 3.7 Strength development of S2 soil treated with (a) 4% OPC, (b) 6% OPC, (c) 8% OPC, and (d) 10% OPC.

Figure 3.7 shows that mixing S_2 soil with OPC can potentially increase the UCS of the soil. However, it is significantly dependent upon the water content added to the OPC-soil system. Figure 3.7a shows that the addition of 4% OPC to S_2 soil and mixing it with 24% water slightly increases the UCS. Figure 3.7b shows that by adding 2% more OPC (i.e., a total of 6% OPC) to the soil mixed with 18%, 24%, or 30% water, leads to even further increase in the UCS. However, S_2 soil mixed with 6% cement and 12% water does not restore the functionality of the soil. It should be noted that 12% water content is significantly lower than the OMC of S_2 soil (which was 21.2%, see Table 3.1). The addition of 8% OPC can further increase the UCS when the soil is mixed with an appropriate amount of water (Figure 3.7c). Further increase in the value of UCS can potentially be obtained by adding more cement to the soil (Figure 3.7d).

Figure 3.8 shows that S_3 soil compacted at its OMC (i.e., 21.2%) reaches its maximum UCS (~125 psi) after about one week. Thereafter, its strength remains relatively constant over time. The UCS tests results obtained for S_3 soil treated with OPC confirm the findings from the UCS tests obtained for S_1 and S_2 soils. In other words, OPC treatment can potentially increase the UCS of the soils (Figure 3.9). It should again be noted that OPC content and water content plays a significant role in the strength development of the treated soil. Figure 3.9a shows that, after one day (irrespective of the content of the mixing water), the addition of 4% OPC to S_3 soil did not increase the USC value to the level of that obtained for unmodified soil compacted at its OMC. However, after seven days, S_3 soil modified with 4% OPC and mixed with 20%, 24%, or 28% water slightly increased the UCS values. It can be seen that after 7 days, due to the hydration of cement particles, the UCS of S_3 soil treated with 4% OPC and mixed with 20%, 24%, and 28% increased, respectively, by about 22%, 13%, and 17% compared to the UCS of the unmodified soil after 7 days. Figure 3.9b shows that the addition of 6% OPC to S_3 soil, mixed with 18%, 24%, or 30% water, increased the UCS values at all testing ages. Similarly, the addition of further OPC increases the UCS as shown in Figures 3.9c and 3.9d. Overall, the results of UCS tests shows that the addition of 6% OPC to the soil while the water content is in the range of OMC -5% and OMC + 5% can restore the functionality of the soil to the level of the UCS of the untreated soil compacted at its OMC. This observation is in line with the findings from the behavior of S1 and S2 soils. In other words, by adding 6% of OPC to the soil samples tested in this study and using a water content in the range of OMC - 5% and OMC + 5%, satisfactory results can be obtained with regard to the strength gain of the soils.

3.3 Use of PL as a Replacement for OMC for Soil Modification

The results of the UCS tests conducted on the three types of clays indicated that the addition of 6% type I OPC while the water content is in the range of OMC – 5% and OMC + 5% can restore the functionality of the soil. However, determining the OMC of the soils is a time-taking process and requires patience. Therefore, an alternative method is required to find the value of the OMC when schedule is tight. The use of 1-point proctor test can save in time; however, this procedure is

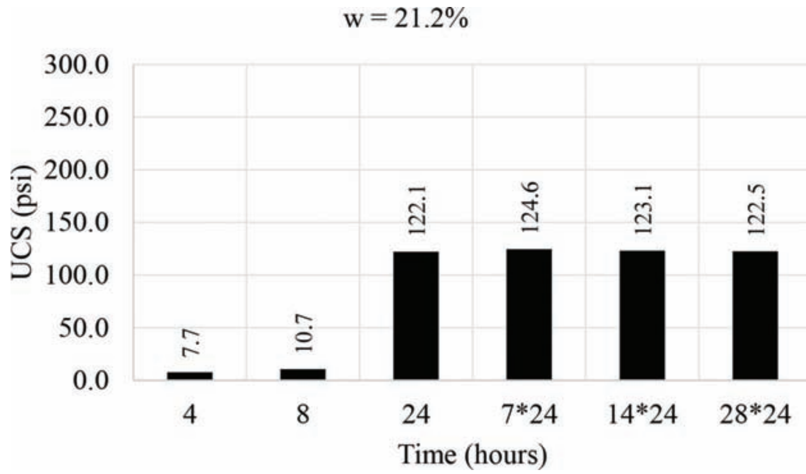

Figure 3.8 Strength development of untreated S3 soil compacted at its OMC (21.2%) as a function of time.

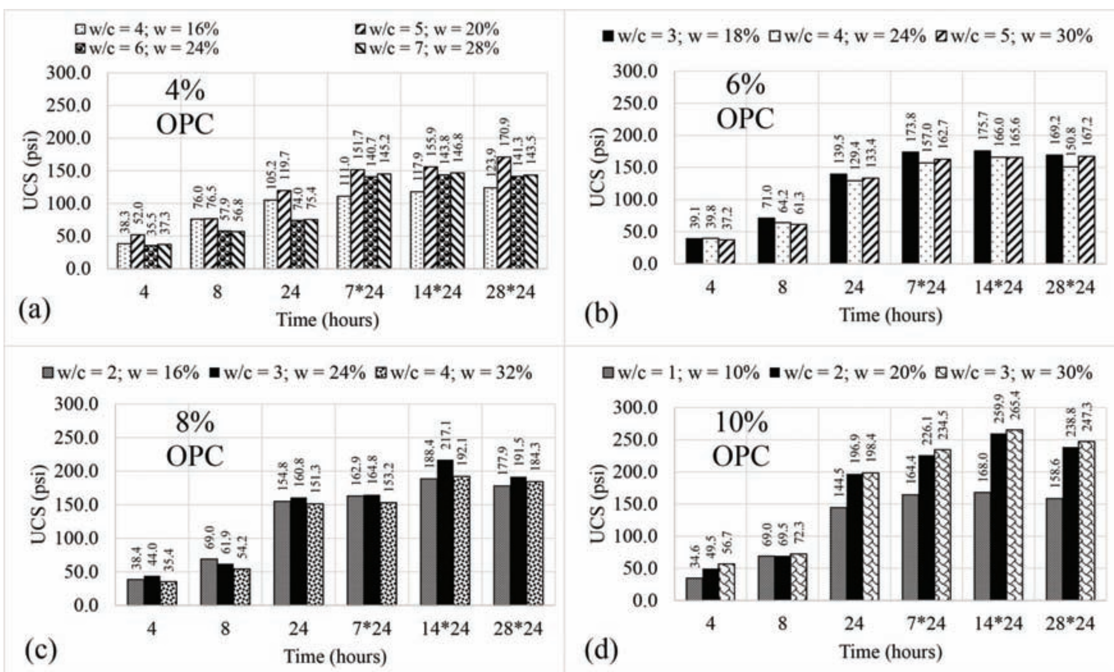

Figure 3.9 Strength development of S3 soil treated with (a) 4% OPC, (b) 6% OPC, (c) 8% OPC, and (d) 10% OPC.

also not so time effective. Previous research has shown that there is a good correlation between OMC and PL (Hossein Alavi et al., 2010). In this study, the use of this correlation is suggested for obtaining a moisture content in the vicinity of the OMC. Thus, developing a relationship between the OMC and PL would be very helpful to efficiently estimate the value of the OMC using the value of PL. For this purpose, the values of OMC and PL of a wide variety of soils were collected from published literature (Ali & Mohamed, 2018; An et al., 2018; Estabragh et al., 2018; Han et al., 2018; Harris, 1969; Lv et al., 2018; Nagaraj et al., 2015; Trivedi et al., 2013; Wei et al., 2018; Yan et al., 2018) to develop a model that presents the relationship between the OMC and the PL (Figure 3.10). The database collected in this study included 447 distinctive data records. Figure 3.11 shows the frequency of the differences between the predicted OMC and the actual OMC. For about 90% of the data records, the difference between these two values is in the range of OMC – 5% and OMC + 5%. Thus, with a high level of confidence, the value of the OMC can be calculated using the value of the PL. This approach provides a quick and reliable method to determine the OMC of the clayey soils where schedule is tight.

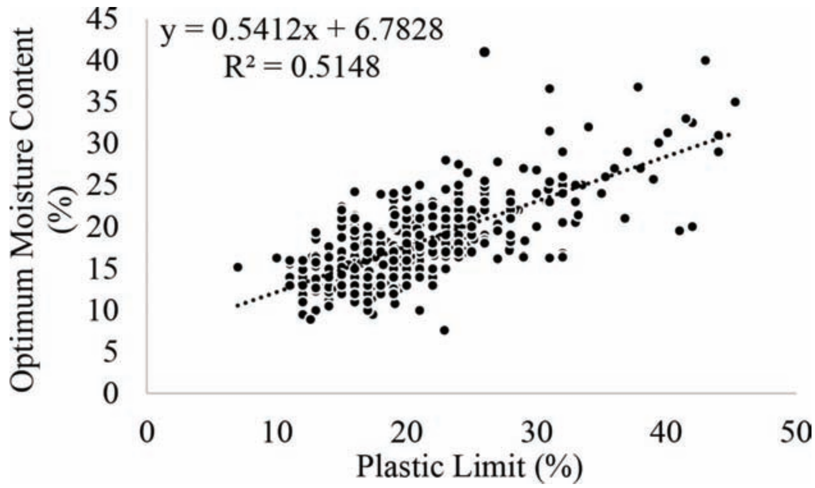

Figure 3.10 Relationship between the OMC and PL.

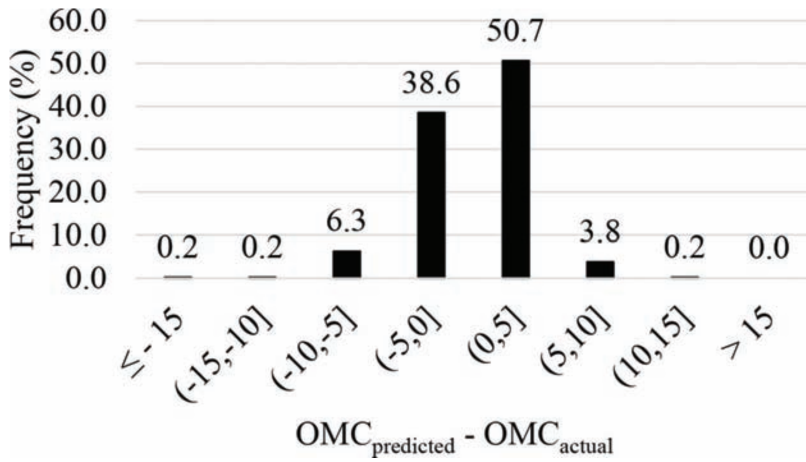

Figure 3.11 The frequency of the differences between the predicted OMC and the actual OMC.

4. SOIL STABILIZATION SCENARIOS

In this section, the experimental program, which were used to study the performance of various subgrade stabilization methods, will be discussed.

4.1 Test Box

This study was specifically planned to quantify the differences in performance of various subgrade stabilization scenarios in patching areas. For this purpose, as schematically shown in Figure 4.1, a test box with a footprint of 6 ft. (1.82 m) × 6 ft. (1.82 m) and a height of 4 ft. (1.22 m) was constructed using C 6 × 13 steel channels restrained by 1/4 × 2 × 2 steel angles. Each channel was bolted to the channel below and above it in the middle span of the channels to further restrain them. The joints between the channels were sealed using epoxy joint sealer to provide a confined environment and to prevent the moisture loss from the joints. A hydraulic actuator was used to apply cyclic loads to the pavement test sections through a loading plate sitting on the surface of the pavement. The loading plate was a steel plate with the dimensions of 12 in. × 12 in. × 2 in. To provide the confinement in the subgrade structure, a concrete slab with the footprint of 70 in. × 70 in. and the thickness of 6 in. was placed on the top of the subgrade test sections. A central hollow area within the confining concrete slab with the size of slightly bigger than 12 in. × 12 in. allowed the steel plate to pass through and transfer the load directly on the surface of the base layer. The cyclic loading (typically for a total of 400,000 cycles) in this study consisted of repeated cycles of a loading with a frequency of 0.77 Hz and a maximum load of 40 kN (9,000 lbf).

Similar test box has been used by other researchers to evaluate the performance of various types geotextiles and geogrids in the pavement layers (Abu-Farsakh et al., 2016; Perkins, 1999; Tingle & Jersey, 2005). Figures 4.2a and b show the actual test box used in this study. The actuator and concrete slab are shown in Figures 4.2c and d, respectively.

As shown in Figures 4.1 and 4.3, the test box was instrumented with five Linear Variable Differential

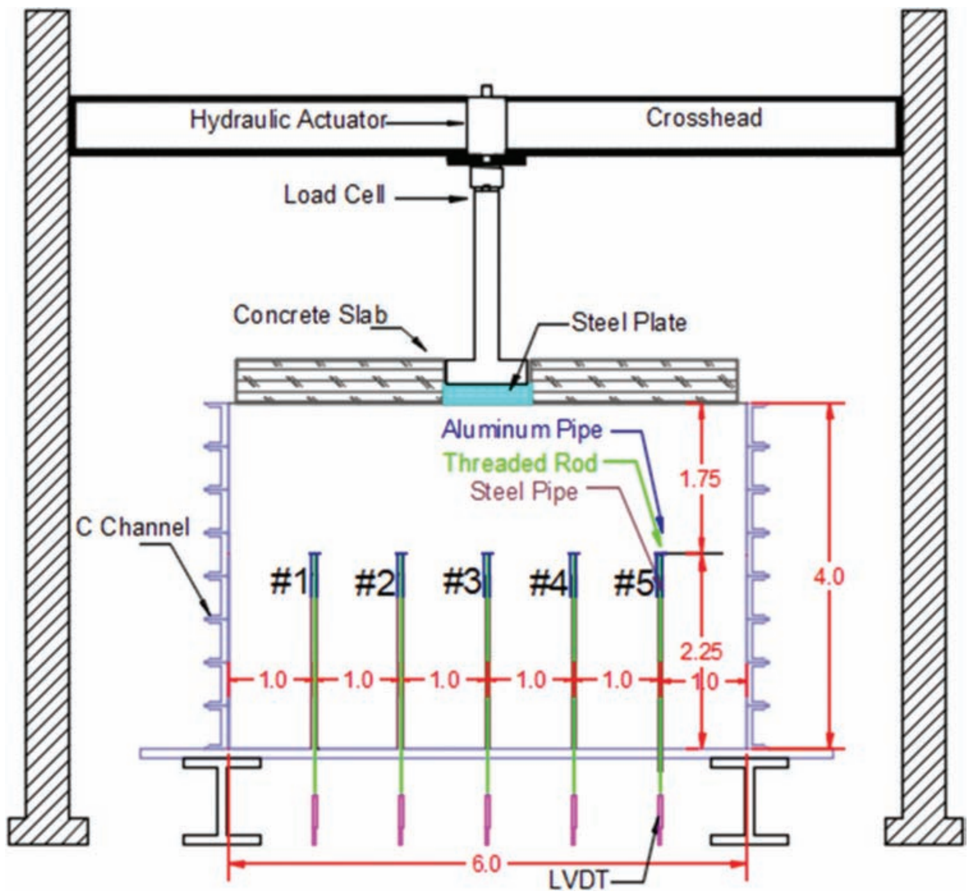

Figure 4.1 Schematic presentation of the test box used for the evaluation of subgrade stabilization techniques (all dimensions in ft.).

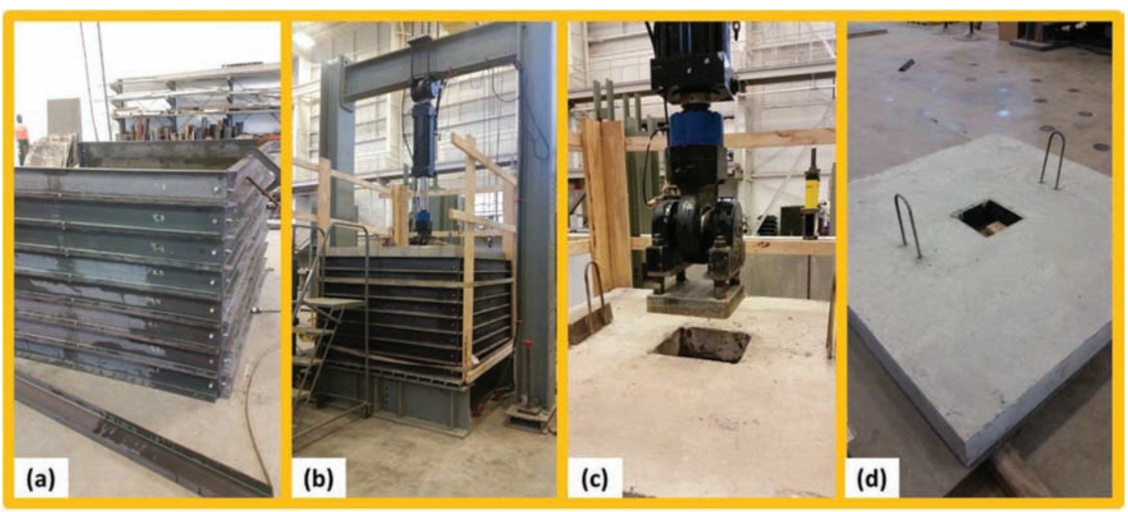

Figure 4.2 Test box used for the performance evaluation of various subgrade stabilization scenarios: (a) construction process, (b) front view, (c) actuator with attached steel plate, and (d) confining concrete slab.

Transformer (LVDT) sensors to allow for the measurement of the deformation of the subgrade soil due to the applied load. For the instrumentation of LVDTs, five steel pipes were used to hold the round aluminum caps with flat bottoms (Figure 4.3a). The diameters of these caps were slightly bigger than the dimeters of the steel pipes. This feature allowed the inverted aluminum caps to easily move around the steel pipes. The aluminum caps were attached to threaded rods (Figure 4.3b) which extended to the bottom of the box through the

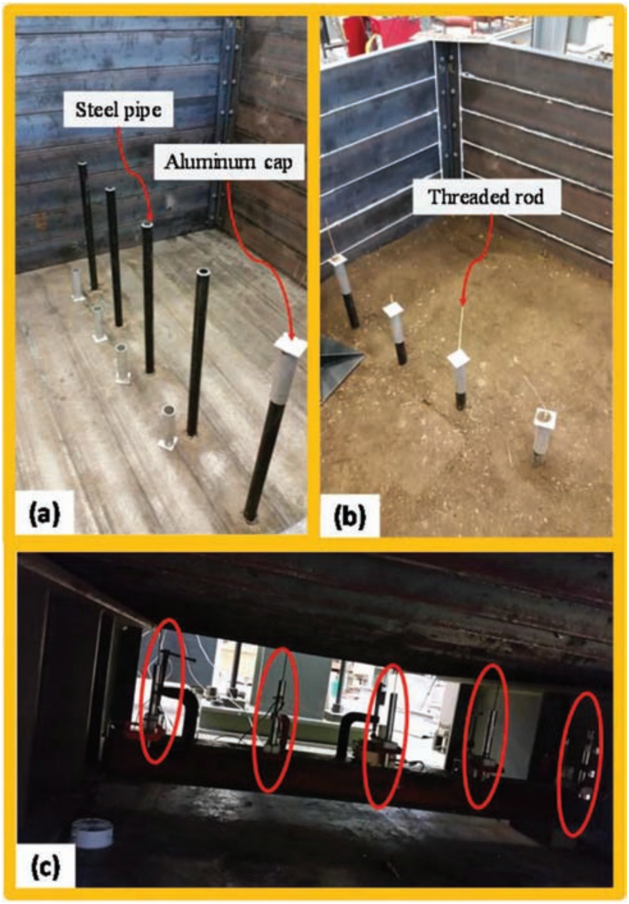

Figure 4.3 Customized LVDTs used for the measurements of subgrade deformations: (a) steel pipes and aluminum caps, (b) threaded rods screwed to the aluminum caps, and (c) LVDTs located underneath the box.

steel pipes and connected to the LVDTs (Figure 4.3c). This setup allowed for the measurement of the load-associated deformation of the subgrade at the height of 27 in. from the bottom of the box (depending on the particular slab scenario, the top part of the aluminum cap was located either flush with the top of the subgrade soil or 3–12 in. below).

This custom-built test box was used to investigate the effects of various types of soil stabilization solutions (scenarios) such as the use of ordinary portland cement, aggregate base course (ABC), geogrid (GG) and/or geotextile (GT) with ABC, geotextile with cement-stabilized soil, GT with in-situ compacted soil, flowable fill, and lean concrete.

4.2 Subgrade Soil Stabilizations Scenarios

In this study, the performance of fourteen different soil stabilization scenarios were evaluated and compared with each other using the testing setup as described in previous section. The differences between these scenarios include the types of materials used in the base layer and the thickness of the base layer. The total thickness of all test sections was 48 in. (equal to the height of the box). In the control (#1) scenario, the test section consisted of 48 in. of untreated but compacted soil simulating the unmodified subgrade layer. In other scenarios, the top portion of the unmodified subgrade layer was partially replaced by other materials (from now on, the replacement material will be called the base layer). Table 4.1 presents the details of stabilized subgrade sections in various stabilizing scenarios. These sections are schematically presented in Figure 4.4. For the scenarios involving geosynthetics, these materials

TABLE 4.1
Subgrade soil stabilization scenarios evaluated in this study

ID	Scenario[a]
1	48 in. of unmodified compacted soil-control
2	9 in. of cement-treated soil + 39 in. of unmodified compacted soil[b]
3	9 in. of cement-treated soil + 39 in. of unmodified compacted soil[c]
4	9 in. of cement-treated soil + GT + 39 in. of unmodified compacted soil[b]
5	3 in. of #8 aggregate + 6 in. of #53 aggregate + 39 in. of unmodified compacted soil
6	3 in. of #8 aggregate + 6 in. of #53 aggregate + GT + 39 in. of unmodified compacted soil
7	9 in. of #53 aggregate + GT + 39 in. of unmodified compacted soil
8	3 in. of #8 aggregate + 9 in. of #53 aggregate + GT + 36 in. of unmodified compacted soil
9	3 in. of #8 aggregate + 9 in. of #53 aggregate + GT + GG + 36 in. of unmodified compacted soil
10	3 in. of #8 aggregate + 9 in. of #53 aggregate + GG + 36 in. of unmodified compacted soil
11	3 in. of #8 aggregate + 18 in. of #53 aggregate + GT + 27 in. of unmodified compacted soil
12	9 in. of cement-treated # 53 aggregate + 39 in. of unmodified compacted soil[b]
13	9 in. of non-removable flowable fill + 39 in. of unmodified compacted soil[b]
14	9 in. of lean concrete + 39 in. of unmodified compacted soil–200 lb/yd[c] of cement[b]
15	9 in. of lean concrete + 39 in. of unmodified compacted soil–130 lb/yd[c] of cement[b]

[a]For the scenarios involving cement stabilization, 6% of cement at a moisture content of OMC + 3% was used.
[b]Test started after 4 hr of curing at room temperature.
[c]Test started after 24 hr of curing at room temperature.

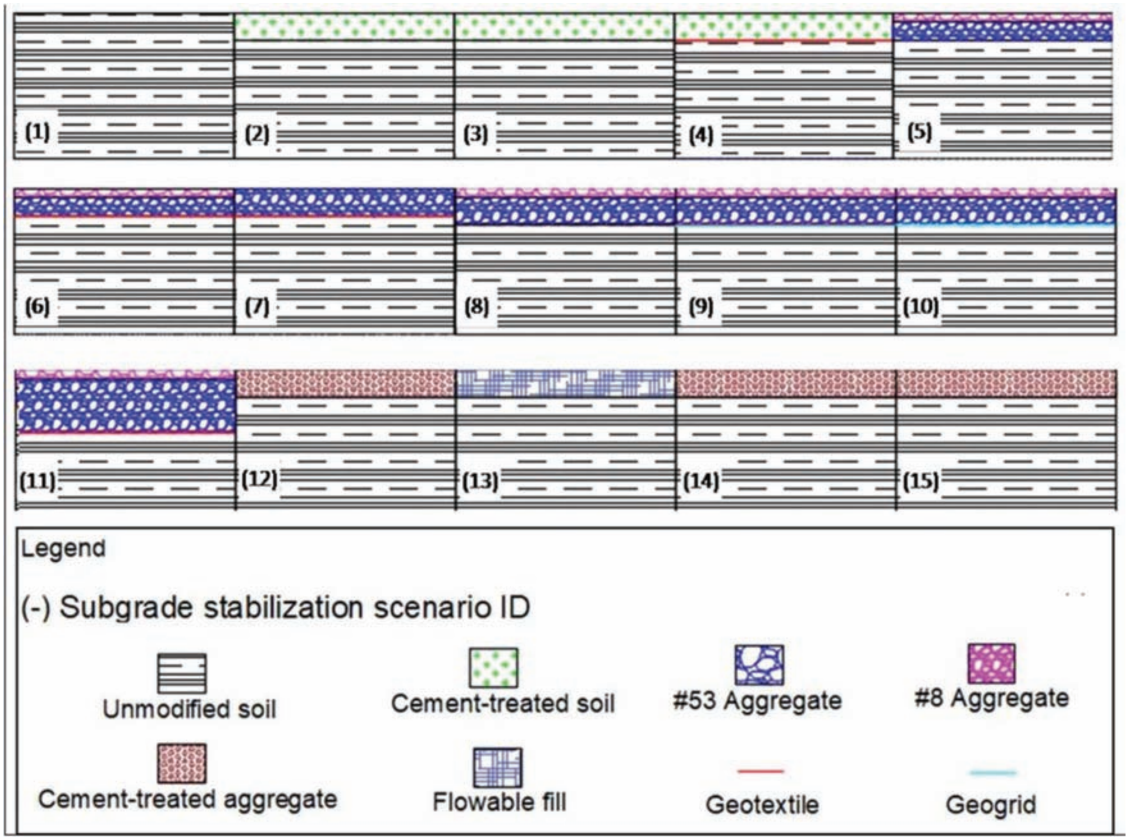

Figure 4.4 Schematic of the individual layers used in various subgrade stabilization scenario sections.

were placed at the interface between the unmodified subgrade layer and base layer.

4.3 Materials

4.3.1 Subgrade Soil

The subgrade soil consisted of a clay having a liquid limit of 35.9% and a plastic index of 17.7%. This soil is classified as A-6 according to the American Association of State Highway and Transportation Officials (AASHTO) or as CL (lean or low plasticity clay) according to the Unified Soil Classification System (USCS). The optimum moisture content of this clay was 15.8% and its maximum dry density was 104.9 pcf. During the construction, the target moisture content and dry density of subgrade were set as 18%–20% and 94 pcf, respectively, to simulate a weak subgrade soil. The UCS of the soil after one day of curing was obtained as 122.1 psi.

4.3.2 Coarse Aggregates

Following the specifications of the Indiana Department Transportation (INDOT) (2018), the two types of course aggregates were used in this study: #8 and #53 aggregates. The particle size distributions of these two aggregates are given in Figure 4.5.

4.3.3 Geosynthetics

Two types of geosynthetics were used in this study: a high-strength geotextile (GT) and a biaxial geogrid (GG). The physical and mechanical properties of the geosynthetics (as provided by the manufacturer) are presented in Table 4.2.

4.3.4 Cement-Treated Aggregate, Lean Concrete, and Flowable Fill

Several types of cement-based mixtures were also used in some of the evaluated sections. The mixture proportions of these mixtures are given in Table 4.3.

4.4 Construction Control

Zorn Light Weight Deflectometer (LWD) was used to measure the in-place properties of the subgrade soil. The measurement was repeated for at least five times for each scenario. The results of LWD tests are given in Table 4.4.

4.5 Results and Discussion

As previously mentioned, the customized LVDTs were installed at the depth of 21 in. from the top of the box to measure the load-associated responses of the

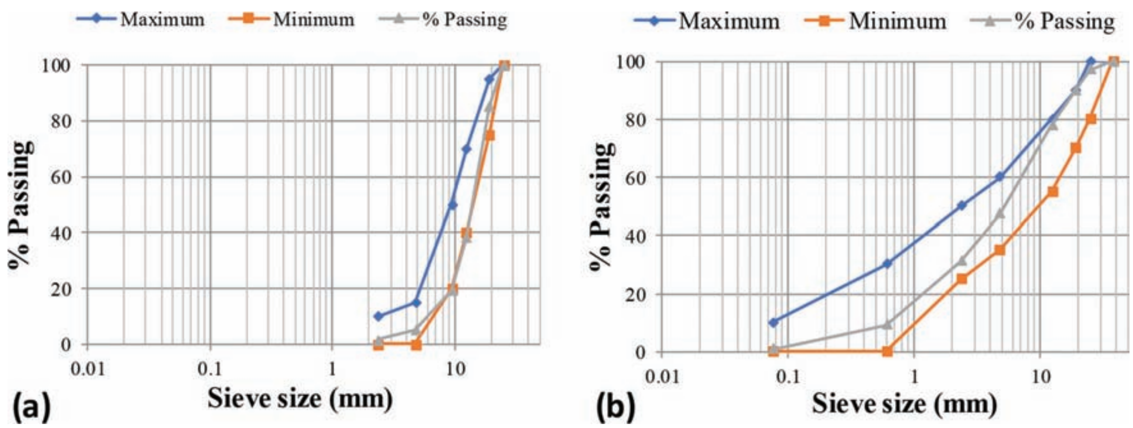

Figure 4.5 Particle size distribution of the coarse aggregates: (a) #8 aggregate and (b) #53 aggregate.

TABLE 4.2
Physical and mechanical properties of geosynthetics used in this study

		Tensile Strength (kN/m) @ 2% strain		Tensile Strength (kN/m) @ 5% strain		
Geosynthetic	**Polymer Type**	**MD[a]**	**CD[b]**	**MD[a]**	**CD[b]**	**Aperture Size (mm)**
GT	Polypropylene	7.0	15.8	21.0	55.2	0.425[c]
GG	Polypropylene	4.0	5.5	8.0	10.5	33 × 33

[a]Machine direction.
[b]Cross machine direction.
[c]Apparent opening size (AOS).

TABLE 4.3
Mixture proportion of cement-based mixtures

	Type of Mixture			
Mix Component	**Cement-Treated Aggregate**	**Flowable Fill**	**Lean Concrete I**	**Lean Concrete II**
Type I cement (lb/yd^3)	193	87	200	130
# 23 Sand (lb/yd^3)	–	4,079	1,592	1,744
#8 Aggregate (lb/yd^3)	–	–	1,887	1,931
# 53 Aggregate (lb/yd^3)	3,530	–	–	–
Water (lb/yd^3)	297	118	210	195
Air entraining agent	–	–	1.4 oz/cwt	1.4 oz/cwt
Reducer	–	–	3.00 oz/cwt	3.00 oz/cwt
1-day compressive strength (psi)	–	–	363.3	96.7
7-day compressive strength (psi)	–	–	1,195.0	436.7
28-day compressive strength (psi)	–	–	1,315.0	598.5

subgrade (i.e., settlement/deformation values). Figure 4.6 illustrates the development of deformations of the depth of 21 in. from the top of the test box (measured by all the LVDTs) over the testing period for the evaluated scenarios. To better compare the performance of various pavement sections, the deformations registered by the center (#3) LVDT are shown in Figure 4.7. Moreover, Figure 4.8 shows the deformations registered by all the LVDT (i.e., LVDT #3) after the completion of 400,000 cycles of loading. It should be noted that the negative values of deformation indicate downward movement of LVDT core.

Figure 4.7 shows that all the subgrade stabilization scenarios successfully reduced the deformation of the subgrade. This is quite evident from the highest value of deformation under the center LVDT for the scenario with unmodified soil when compared to the other scenarios. One interesting observation can be seen in the performance of the cement-treated soil scenarios (either after 4 hr of curing (scenario #2) or 24 hr of curing (scenario #3). For these scenarios, as shown in Figure 4.8, the center LVDT and the LVDTs located in 1 ft. from the center show less deformation compared to the base section constructed with unmodified soil. However,

TABLE 4.4
Results of LWD tests on constructed pavement sections

ID	LWD on Top of Subgrade Layer E (MPa)		LWD on Top of Base Layer E (MPa)
	Before Starting the Test	After Completing the Test	Before Starting the Test
1	—	**10.1**	**13.8**
2	9.3	–	14.2
3	9.8	10.5	16.5
4	8.9	–	17.3
5	9.1	–	15.6
6	8.5	–	15.6
7	8.7	9.3	14.5
8	8.7	10	16.9
9	10	11.2	14.7
10	11.2	–	17.2
11	10.7	11.3	17.3
12	9.4	9.5	–
13	9.5	10.2	–
14	9.5	9.7	–
15	9.6	–	–

Boldface indicates that the results represent the average of 3 tests.

the LVDTs located 1 ft. from the walls show more deformation in the cement-treated soil scenarios compared to the scenario with unmodified soil.

As shown in Figure 4.7, the pavement section stabilized with 3 in. of #8 aggregate and 6 in. of #53 aggregate (scenario #5), initially showed significant reduction in the settlement of the subgrade. Compared to the other subgrade stabilization scenarios, scenario #5 shows a faster strength loss due to the cyclic loading. At the completion of 400,000 cycles, the difference between the settlement in this scenario and the scenario with unmodified soil (scenario #1) is not considerable (Figure 4.8). However, the addition of GT to scenario #5 (i.e., stabilization scenario #6) significantly improves the performance of the subgrade layer. The use of GT under the aggregate layer can also help to separate the aggregates from soil. Comparable performance can be seen in the sections without drainage layer (i.e., scenario #7). An increase in the thickness of aggregate layer (scenarios #8 and #11) further improves the performance of subgrade layers. Although the use of GG in the subgrade stabilization (scenario #10) improves the performance of subgrade layer, it is not as effective as GT.

The comparison of the performance of scenario #4 (cement-treated soil + GT) with that of scenario #2 (cement-treated soil without GT) reveals that the use of geotextile can slightly reduce the settlement in the subgrade layer. The scenarios with cement-based mixtures, the scenarios with cement-treated aggregate (scenario #12) and lean concrete with 200 lb/yd^3 of cement (scenario #14) did not show any settlement in the subgrade layer even after the completion of 400,000 cycles. The scenario with flowable fill showed similar results with the aggregate-based layers with GT. The lean concrete scenario with 130 lb/yd^3 of cement (scenario #15) showed a slight settlement in the subgrade after the completion of 400,000 cycles.

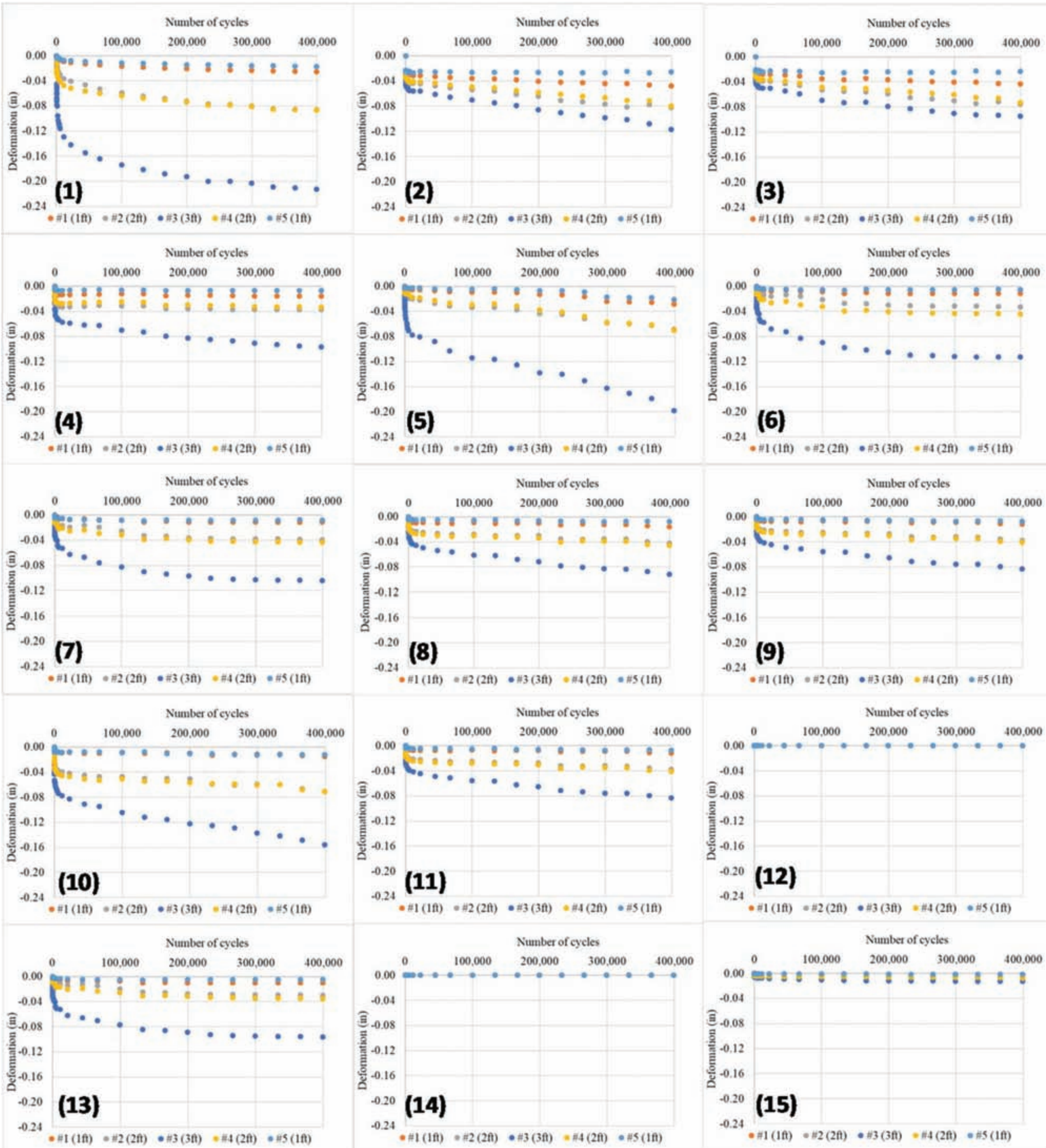

Figure 4.6 Deformations of the subgrade as a function number of load cycles as detected by all five (#1–#5) LVDTs (in the legends, numbers in the parentheses show the distance from the wall of the box).

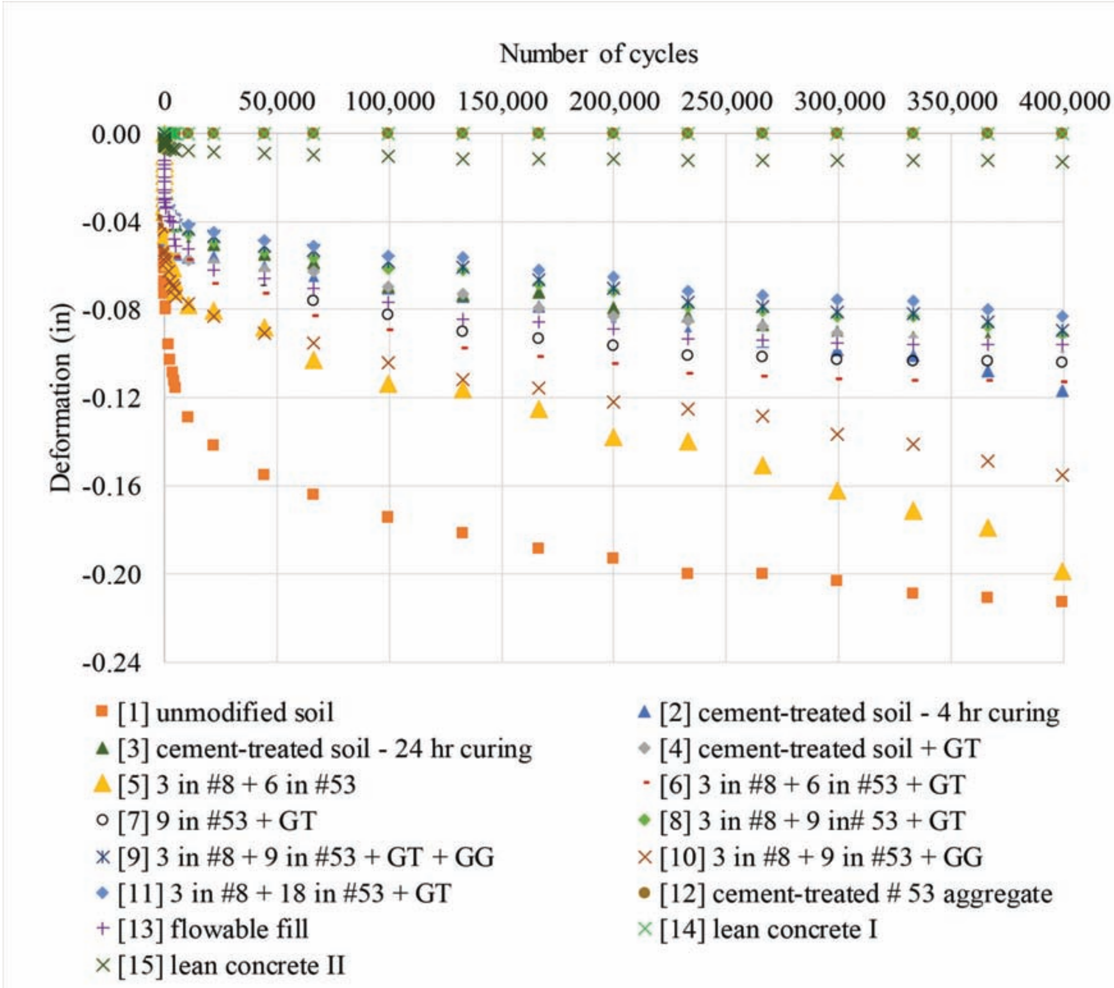

Figure 4.7 Deformations of the subgrade layers at the center of the test box (LVDT#3) as a function of the number of load cycles.

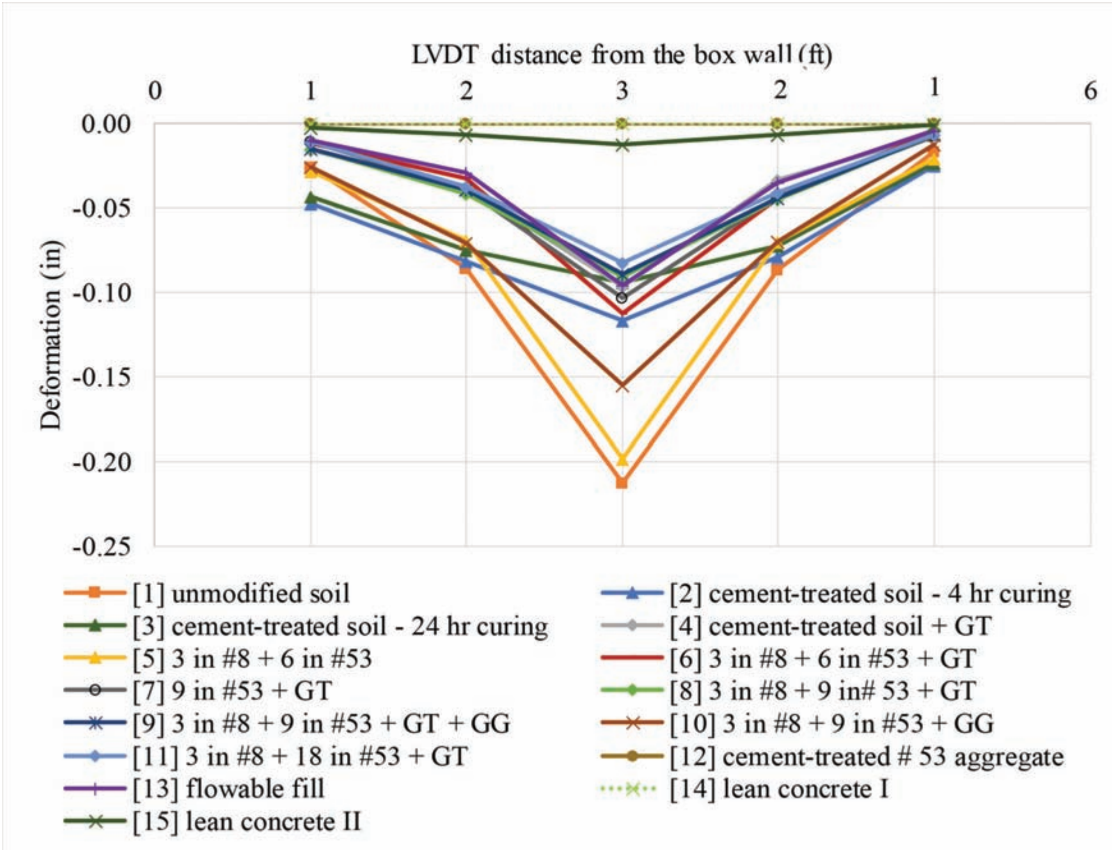

Figure 4.8 Deformations of the subgrade at various distances from the wall of the test box.

5. SLAB UNDERSEALING

Grouting is an efficient approach to strengthen and seal the ground in many civil engineering applications including subgrade layers in paving projects. Permeation grouting is one of the most common grouting methods, in which the grout is injected into the pores of the soils in order to increase the cohesion between the soil particles and enhance the strength properties. A wide array of chemical grouts and cement-based materials have been used in previous studies (Azadi et al., 2017; Kamalakannan et al., 2018; Zhang et al., 2019).

The main objectives of this phase of the study are optimization of the performance of grouts for slab undersealing projects and propose the grout mixtures with the best performance. Overall, the efficiency of a grout can be determined based on four different characteristics as follows:

1. Strength. It is one of the fundamental characteristics of the grout to withstand the traffic loads in pavements.
2. Setting time. The setting time defines the effective radius for transportation of the grout mixtures to be used within an acceptable range of viscosity. In slab undersealing projects, a rapid setting time is desirable, so that the grout would set quickly before opening the roadway to traffic.
3. Bleeding. Water can be squeezed out from the pores between cementitious particles into the ground. This phenomenon, which is known as bleeding, can reduce the pumpability and mobility of the grout.
4. Viscosity. Viscosity is the resistance of a material to flow. To evaluate the viscosity of a grout, the time that it takes for a certain amount of material to flow out from a funnel can be measured.

5.1 Experimental Program

In this study, a wide range of cementitious materials were used in preparation of the grout mixtures. The cementitious materials used included Type I portland cement (PC), Type III portland cement (PC), silica fume (SF), Class C fly ash (FA), and calcium chloride (CC). To optimize the performance of grout mixtures, four different properties were considered including 7-day compressive strength (ASTM C942-15), setting time (ASTM C191-13), fluidity (ASTM C939/C939M–16a), and bleeding (ASTM C940-16). With regard to compressive strength, a minimum value of 500 psi was used as a criterion to select the grouts with enough strength. The criteria used for bleeding and flow time were set as 2% and 8 s to 15 s.

5.2 Results and Discussion

The properties of the grouts prepared with Type I PC and various water to cement ratios (w/c) are given in Table 5.1. In some of the grouts, a high-range water reducer (HRWR) was used to evaluate its effects on the performance of the grouts (especially their fluidity). All the grouts prepared with Type I PC provided satisfactory compressive strength. The grouts having a w/c of 0.4 did not provide satisfactory fluidity. Moreover, although the grouts with w/c above 0.5 showed acceptable fluidity, the excessive bleeding prevents their use as an efficient grout. Only the grout having a w/c of 0.5 showed satisfactory results in terms of strength, setting time, bleeding, and fluidity. The addition of HRWR to this grout decreases the flow time. However, since HRWR increases the setting time, it would not be suggested to be used.

Table 5.2 shows the properties of the grouts containing Type I portland cement and Class C FA with varying water to binder ratios (w/b) and FA to PC ratios (FA/c). It can be seen that only two grouts (i.e., w/b of 0.4 and FA/c of 1.0 or 2.0) showed satisfactory setting time. However, these two grouts did not show acceptable fluidity. Therefore, the use of Class C FA would not be suggested for the projects that setting time is a concern.

The results of the performance tests on the grouts containing Type I PC and SF with varying amounts of SF (by the weight percent of total cementitious materials) and w/b are shown in Table 5.3. It can be seen the grout containing 5% SF and made with a w/b of 0.5 showed the satisfactory performance in all the conducted tests.

The results of the grouts containing Type I PC, Class C FA, and SF shows that these types of grouts, due to the delayed setting time, would not be recommended for the projects where rapid setting material is required (Table 5.4).

As shown in Table 5.5, all grouts containing Type I PC and CC showed satisfactory performance in all the

TABLE 5.1
Grout mixtures with Type I PC

w/c	HRWR (%)	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
1	0	8.87	24.70	610	1,688
0.75	0	9.62	9.18	425	3,215
0.6	0	9.93	2.35	366	3,890
0.5	0	14.87	1.82	317	4,360
0.5	0.5	11.36	0.00	500	3,302
0.4	0	260	0.37	251	5,083
0.4	0.25	Did not flow	0.00	–	–
0.4	0.5	43	0.00	388	4,640
0.4	1	81	0.00	398	4,847
0.4	2	Did not flow	0.00	–	–

TABLE 5.2
Grout mixtures with Type I PC and Class C FA

w/b	FA/c	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
0.5	3.0	10.05	0.25	905	332
0.5	2.0	10.41	0.10	615	1,285
0.5	1.0	11.39	0.00	609	2,103
0.5	0.5	11.43	0.00	407	3,062
0.4	1.0	22.43	0.00	367	3,712
0.4	2.0	20.25	0.00	370	2,648

TABLE 5.3
Grout mixtures with Type I cement and silica fume

w/b	SF (%)	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
0.75	10	9.37	13.9	398	2,790
0.6	10	10.63	3.61	323	3,240
0.6	5	9.90	2.61	305	3,667
0.5	15	23.56	1.25	277	4,551
0.5	10	18.69	1.25	270	4,591
0.5	5	12.82	0.9	264	4,650

performance tests conducted. The only exception was the mix containing 7% CC and having a w/c of 0.5, which did not show enough fluidity. The addition of CC to the grouts containing Type I PC significantly decreases the setting time. This could be beneficial for the projects where schedule is tight to quickly open the roadway to the traffic. Among the mixtures containing Type I PC and CC, the one having the w/c of 0.6 and 5% CC shows the optimized performance when considering the results obtained from all conducted performance tests.

Tables 5.6, 5.7 and 5.8 show the performance tests results of the mixtures containing Type III PC, Type III PC and Class C FA, and Type III PC and SF, respectively. With regard to the grouts containing only Type III PC (Table 5.6), only the mixture with a w/c of 1.0 provided satisfactory fluidity. The optimized performance of the grouts containing Type III PC

TABLE 5.4
Grout mixtures with Type I PC, FA, and SF

w/b	SF (%)	FA/c	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
0.5	5	2.0	9.68	0.00	854	732
0.5	5	1.0	9.77	0.00	605	1,257

TABLE 5.5
Grout mixtures with Type I PC and CC

w/c	CC (%)	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
0.6	3	9.86	0.00	182	4,235
0.6	5	10.62	0.00	151	3,280
0.6	7	11.87	0.00	111	2,925
0.5	3	12.71	0.00	164	4,010
0.5	5	14.32	0.00	108	3,220
0.5	7	Did not flow	0.00	93	2,880

TABLE 5.6
Grout mixtures with Type III PC

w/c	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
1.0	10.58	1.00	337	1,812
0.75	19.69	0.20	305	2,618
0.5	Did not flow	0.00	210	–

TABLE 5.7
Grout mixtures with Type III PC and Class C FA

w/b	FA/c	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
0.75	2.0	9.92	3.10	690	490
0.5	1.0	12.95	0.00	334	3,036
0.5	2.0	12.91	0.00	547	1,628
0.5	3.0	10.29	0.00	558	640

TABLE 5.8
Grout mixtures with Type III PC and SF

w/b	SF (%)	Flow (s)	Bleeding (%)	Setting Time (min)	Compressive Strength (psi)
0.6	5	19.33	0.00	272	3,854.7
0.6	10	18.53	0.00	241	3,805.7
0.6	15	16.40	0.00	230	3,293.0

and FA was obtained with the mixture having a w/b of 0.5 and FA/c of 1.0 (Table 5.7). As shown in Table 5.8, the combination of Type III PC and SF did not provide satisfactory fluidity.

6. OVERALL SUMMARY AND CONCLUSIONS

The loss of functionality and development of distresses in concrete pavements is often attributed to poor subbase and subgrade conditions and/or loss of the support due to development of voids underneath concrete slabs. Subgrade soil stabilization can be used as an effective approach to restore the functionality of subgrades in patching projects. This research was conducted to achieve two main goals: (a) to identify the best practices for soil stabilization of the existing subgrade during pavement patching operations and (b) to identify/develop new/modified grouting materials for slab stabilization/undersealing. The conclusions based on the results of this study are as follows:

1. In large-scale projects, subgrade stabilization is done to improve the geotechnical properties of the subgrade soils such as Atterberg limits, strength properties, hydraulic conductivity and so on. However, in small-scale soil stabilization projects, which are usually done in patching areas, the objective is mainly to restore the functionality of the subgrade soil, rather than improving it.
2. The survey of the state DOTs conducted as a part of this research provided useful information about the established methodologies for soil stabilization/slab undersealing, about common materials used for subgrade soil stabilization/slab undersealing, as well as various standards, specifications or guidelines for subgrade soil stabilization/slab undersealing, equipment for subgrade soil stabilization/slab undersealing, etc.

   In this research, two additives (i.e., OPC and a liquid polymer) were evaluated for "in-situ" subgrade stabilization with the aim to restore (and to potentially improve) the functionality of the selected soils within the patch area. From the results of the UCS tests, OPC was found to be an effective additive to restore the functionality of the soils. However, the moisture content of the soil also plays an important role. Specifically, it was found that the addition of about 6% OPC to soils with moisture contents within the range between - 5% OMC and + 5% OMC can adequately restore their functionality. It is therefore recommended, for these cases where the "in-situ" soil stabilization was selected as a way to restore the functionality of the subgrade, that ~9 in. of the original subgrade soil be removed and mixed with 6% of OPC at the proper moisture content which would be recommended to be determined using the plastic limit to achieve a moisture content within the range between - 5% OMC and + 5% OMC. Then, the "in-situ" modified soil can then be returned to its original place to provide a subgrade with restored functionality. It should be noted, however, that from the practical perspective, it may be easier to replace the removed soil with lean concrete or cement-treated aggregate.
3. The results of various stabilization scenarios showed that most of them improved the performance of subgrade layer. The only exception was the stabilization scenario (Al-Mukhtar et al., 2012) (3 in. of #8 aggregate and 6 in. of #53 aggregate), which did not produce any significant reduction in the observed settlement of the underlying subgrade layer compared to unmodified soil. The use of GT along with aggregate course was found to significantly reduce the settlement. Non-removable flowable fill was also found to significantly reduce the subgrade settlement. Cement-treated aggregate and lean concrete provided the best performance as they prevented formation of any noticeable settlement in the underlying subgrade layer. As a matter of general summary, it should also be pointed out that the scenario involving the use of lean concrete with a cement content of 130 lb/yd^3 (i.e., lean concrete II) is likely to provide the most efficient approach considering the logistics and cost of the project. This is because an increase in the number of components of any particular treatment scenario (e.g., use of multiple layers of aggregate combined with installation of the GT or GG) will, inevitably, not only increase the complexity of the installation but will also add to the cost of the project.
4. A wide range of cement-based grouts was evaluated to optimize their performance in terms of strength, setting time, fluidity, and bleeding. The following grouts were found to provide the best performance:
   - Grout mix prepared with Type I PC; w/c = 0.5
   - Grout mix prepared with Type I PC and SF; w/b = 0.5 and 5% of SF
   - Grout mix prepared with Type I PC and CC; w/c = 0.6 and 5% of CC

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APPENDICES

Appendix A. Screening Questionnaire

Appendix B. Surveys

APPENDIX A. SCREENING QUESTIONNAIRE

The Indiana Department of Transportation is conducting research on "Development of Subgrade Stabilization and Slab Undersealing Solutions for PCC Pavements Restoration" and on "Best Practices for Patching Composite Pavements". Since the topics are closely related, this questionnaire has been developed to gather information for both studies. The main focus of these projects is on small-scale repairs which will be referred to as patches not exceeding the area of a typical pavement slab (~ 15ft × 12 ft).

The loss of functionality and development of distress in concrete pavements is often attributable to poor sub-base and sub-grade conditions and/or loss of support due to the development of voids underneath the slab. In the past, concrete pavements were often placed atop compacted, but unmodified, soil. Once this subgrade becomes wet, it may experience volume and strength changes, which, over time, will reduce its load bearing capacity and thus its ability to effectively support the slab. This will lead to development of distress in the slab itself, often necessitating installation of patches to restore the functionality of the roadway. In such cases, the pavement patching operations are typically preceded by removal of some thickness of soil and return of a like thickness of compacted aggregate.

Similar problems can develop in composite (asphalt over concrete) pavements resulting in the need for patching. The difficulty in efficiently patching composite pavements can be exacerbated by challenges in determining the extent of the patch needed to get into sound concrete, since the concrete cannot be inspected visually. Matching the patch to the existing pavement can create logistical problems with having different materials and equipment available, allowing time for the concrete to cure before placing the asphalt, maintenance of traffic, maintenance of drainage, and more.

The complete removal of existing poor quality subgrade soil is expensive and not always effective as it is difficult to compact the replacement soil in the relatively small area of the patch. In addition, the support of the adjacent panels can also be negatively affected. Inverted T patches have been used in the past to support the adjacent pavement, but are typically not used in Indiana now because of performance problems and constructability issues; doweled concrete patches are used instead. As such, the alternatives for in situ stabilization of the existing soil or slab undersealing should be explored.

This survey is being sent to the members of the AASHTO Subcommittee on Maintenance with copies to the members of the Research Advisory Committee. If you feel someone else in your department is in a better position to answer, please feel free to forward this to them. The survey consists of 17 main questions and we estimate that completion of this questionnaire should not take more than 15-20 minutes. Your cooperation in completing this questionnaire will help to ensure the success of this effort. We respectfully request that this survey be completed and submitted by March 30, 2017.

General Information, Please provide your contact information.

First & Last Names	
Position/Title	
Agency	
Address	
City/Town	
State/Province	
Zip/Postal Code	
Country	
Email Address	

Q1. May we contact you for additional information?

- Yes
- No
- Please contact (name and phone or email) Instead,

Q2. Is the option for subgrade stabilization/slab undersealing part of your standard specification for PCC pavement restoration and repairs?

	Yes	No
Subgrade Stabilization		
Slab Undersealing		

If "YES" to Q2., provide short description or provide link to the appropriate document.

Q3. Do you have established methodology for determining areas of a pavement where subgrade stabilization/slab undersealing may be required as part of PCC pavement repair project ?

	Yes	No
Subgrade Stabilization		
Slab Undersealing		

If "YES" to Q3., provide short description or provide link to the appropriate document.

Q4. Is there a "trigger" parameter that governs the selection of **SUBGRADE STABILIZATION** as part of PCC pavement restoration and repair project? If yes, please click all answers that apply from list below.

- ☐ Visual inspection of the damage
- ☐ Roadway traffic level
- ☐ Pavement closure time
- ☐ Weather and seasonal limitations
- ☐ Area or depth of patch
- ☐ Extent of damage
- ☐ Public complaints
- ☐ Poor ride quality
- ☐ Sudden safety problems
- ☐ Possibility of having subgrade soil erosion
- ☐ Type/properties of the subgrade soil
- ☐ Roadway functional class (e.g., arterial road vs. highway or urban vs. non-urban, and so on)
- ☐ Budget
- ☐ Other(s) (please specify)

Q5. Is there a "trigger" parameter that governs the selection of subgrade **SLAB UNDERSEALING** as part of PCC pavement restoration and repairs? If yes, please click all the answers that apply from list below.

- ☐ Visual inspection of the damage
- ☐ Roadway traffic level
- ☐ Pavement closure time
- ☐ Weather and seasonal limitations
- ☐ Area or depth of patch
- ☐ Extent of damage
- ☐ Public complaints
- ☐ Poor ride quality
- ☐ Sudden safety problems
- ☐ Possibility of having subgrade soil erosion
- ☐ Type/properties of the subgrade soil
- ☐ Roadway functional class (e.g., arterial road vs. highway or urban vs. non-urban, and so on)
- ☐ Budget
- ☐ Other(s) (please specify)

Q6. What percentage of all PCC pavement restoration/repair projects in your jurisdiction involve subgrade soil stabilization and/or slab undersealing?

	0%	0-10%	10-30%	30-50%	50-70%	70-100%
Subgrade Stabilization	○	○	○	○	○	○
Slab Undersealing	○	○	○	○	○	○
Subgrade stabilization **and** Slab Undersealing	○	○	○	○	○	○

Q7. What materials are used for **SUBGRADE STABILIZATION** as part of PCC pavement restoration and repairs in your area? (Please select all that apply and indicate the percentage out of the total material used in the boxes provided (if applicable))

- ☐ Portland Cement
- ☐ Lime
- ☐ Fly Ash
- ☐ Other(s) (please specify)

Q8. What materials are used for **SLAB UNDERSEALING** as part of PCC pavement restoration and repairs in your area? (Please select all that apply)

- ☐ Portland Cement Only
- ☐ Limestone dust-portland cement
- ☐ Pozzolan-portland cement
- ☐ Asphalt emulsion-portland cement
- ☐ Sand-portland cement
- ☐ Polyurethane
- ☐ Bentonite
- ☐ Epoxy
- ☐ Other(s) (Please specify)

Q9. Do you use any type of mechanical equipment/machinery for soil stabilization/slab undersealing or for compaction when performing "small-area" PCC or composite pavement restoration and repair operations?

	Yes	Yes, but only for repairing by contracts	No
Subgrade Stabilization	○	○	○
Slab Undersealing	○	○	○
Compaction of replacement materials	○	○	○
Composite pavement patching	○	○	○

If "Yes" to Q9, please provide short description or provide link to the appropriate document.

Q10. Has your organization undertaken or sponsored any past (or ongoing) research in the area of soil stabilization/slab undersealing for PCC pavement restoration and repair or patching composite pavements?

- Soil stabilization
- Slab undersealing
- Both
- Patching composite pavements
- None
- Planning to initiate research

If "Yes" to Q10, please provide links to the documents summarizing the findings.

If "Yes" to Q10, what were the main areas of research? (Please select all that apply)

- Performance of soil stabilization/slab undersealing materials
- Development (adaptation) of mechanized equipment for "small-area" soil stabilization/slab undersealing operations
- Triggers for initiation of soil stabilization/slab undersealing operations
- Cost effectiveness of soil stabilization/slab undersealing or patching
- Methods to patch composite pavements
- Others (please specify)

Q11. Is there a need for more research or information in the **area of soil stabilization** (Please select all that apply):

- Comparison of different soil stabilization approaches (e.g. cost, effectiveness)
- Comparison of different soil stabilization materials (e.g. cost, effectiveness)
- Comparison of different types of mechanized equipment for soil stabilization
- Development of a new or improved mechanized equipment for soil stabilization
- Development of new or improved soil stabilization materials
- Improved soil stabilization standards
- Improved soil stabilization guidelines, training materials and specifications
- Educational modules covering principles of soil stabilization techniques
- Other(s) (please specify)

Q12. Is there a need for more research or information in the **area of slab undersealing** (Please select all that apply):

- ☐ Comparison of different slab undersealing approaches (e.g. cost, effectiveness)
- ☐ Comparison of different slab undersealing materials (e.g. cost, effectiveness)
- ☐ Comparison of different types of mechanized equipment for slab undersealing
- ☐ Development of a new or improved mechanized equipment for slab undersealing
- ☐ Development of new or improved slab undersealing materials
- ☐ Improved slab undersealing standards
- ☐ Improved slab undersealing guidelines, training materials and specifications
- ☐ Educational modules covering principles of slab undersealing techniques
- ☐ Other(s) (please specify)

Q13. Do you have any additional comments or suggestions?13

APPENDIX B. SURVEYS

Survey Respondents

Agency	Name	Title
AL	Scott W. George	State Materials and Tests Engineer
AR	Joe Sartini	State Maintenance Engineer
CA	Deepak Maskey	Senior Transportation Engineer
FL	Bouzid Choubane	State Pavement Materials Engineer
ID	Clint Hoops	Structural Materials Engineer
IL	Charles Wienrank	Pavement Design Engineer
IN	Chris Moore	Greenfield District Pavement Engineer
KS	Greg Schieber	Bureau Chief of Construction & Materials
KY	Wheeler Nevels	Transportation Engineer Branch Manager
LA	Jacques Deville	Pavement Preservation Program Manager
MD	Geoff Hall	Pavement & Geotechnical Division Chief
MN	Maria Masten	MnDOT Concrete Engineer
MT	Jody Bachini	MDT Maintenance Reviewer
NC	Scott Capps	State Maintenance and Equipment Engineer
ND	T.J Murphy	Transportation Engineer
NJ	Robert Blight	Supervising Engineer in Pavement Design & Technology Section
NV	Darin Tedford	Chief Materials Engineer
NY	Tom Kane	Professional Engineer 2
OK	Christopher Clarke	Geotechnical Branch Manager
OR	Karen Strauss	Pavement Design Engineer
SC	David Cook	State Maintenance Engineer
TN	Mark Woods	State Pavement Engineer
TX	Magdy Mikhail	Director Pavement Asset Management Section
UT	Scott Andrus	State Materials Engineer
WA	Jeff Uhlmeyer	State Pavement Engineer

Tabulated Survey Responses

Q2(a). Is the option for subgrade stabilization part of your standard specification for PCC pavement restoration and repairs?	
Yes	AR, ID, IN, NC, NJ, OR, TX
No	AL, CA, FL, IL, KS, KY, LA, MD, MN, MT, ND, NV, NY, OK, SC, TN, UT, WA
No Response	AK, AZ, CO, CT, DE, GA, HI, IA, MA, ME, MI, MO, MS, NE, NH, NM, OH, PA, RI, SD, VA, VT, WI, WV, WY

Q2(b). Is the option for slab undersealing part of your standard specification for PCC pavement restoration and repairs?	
Yes	AL, AR, CA, ID, IN, KS, NC, NJ, OK, UT
No	FL, IL, KY, LA, MD, MN, MT, ND, NV, NY, OR, SC, TN, TX, WA
No Response	AK, AZ, CO, CT, DE, GA, HI, IA, MA, ME, MI, MO, MS, NE, NH, NM, OH, PA, RI, SD, VA, VT, WI, WV, WY

If yes to Q1(a) and Q1(b), provide short description or provide link to the appropriate document.	
AR	Our standard specifications refer base and subbase repair items to other sections within our specifications.
ID	http://apps.itd.idaho.gov/apps/manuals/manualsonline.html
IN	We typically require FWD testing on all pavement projects that enable us to determine areas of high deflection under the pavement. This is indicative of voids under PCCP or composite pavements. These are locations we target for undersealing or PCCP patching.
NC	This item shall consist of raising, leveling, and undersealing concrete pavement slabs using a High Density Polyurethane Foam (HDPF) in accordance with these specifications at locations shown on the plans or as directed by the Engineer. This work shall include drilling injection holes, placing of HDPF material, densifying the underlying soil, and testing and surveying to control the pavement leveling operation.
NJ	We use high density polyurethane to stabilize, underseal and sometimes lift concrete slabs. Our specification is available upon request.

Q3 (a). Do you have established methodology for determining areas of a pavement where subgrade stabilization may be required as part of PCC pavement repair project?	
Yes	IN, KS, NC, NJ, OR
No	AL, AR, CA, FL, ID, IL, KY, LA, MD, MN, MT, ND, NV, NY, SC, TN, TX, UT, WA
No Response	AK, AZ, CO, CT, DE, GA, HI, IA, MA, ME, MI, MO, MS, NE, NH, NM, OH, OK, PA, RI, SD, VA, VT, WI, WV, WY

Q3(b). Do you have established methodology for determining areas of a pavement where subgrade stabilization may be required as part of PCC pavement repair project?	
Yes	IN, KS, NC, NJ, OR, TX
No	AL, AR, CA, FL, ID, IL, KY, LA, MD, MN, MT, ND, NV, NY, SC, TN, UT, WA
No Response	AK, AZ, CO, CT, DE, GA, HI, IA, MA, ME, MI, MO, MS, NE, NH, NM, OH, OK, PA, RI, SD, VA, VT, WI, WV, WY

If yes to Q3(a) and Q3(b), provide short description or provide link to the appropriate document.	
IN	We typically require FWD testing on all pavement projects that enable us to determine areas of high deflection under the pavement. This is indicative of voids under PCCP or composite pavements. These are locations we target for undersealing or PCCP patching (which involves removal of a depth of subgrade replaced by compacted aggregate).
KS	Both of these would be determined through a pavement investigation which would include Falling Weight Deflectometer testing, coring and dynamic cone penetrometer testing to determine if voids are present and what condition the subgrade is in.
NC	The contractor shall prepare concrete to be leveled by profiling existing pavement and determining where the pavement needs to be raised. Void filling shall be in areas as indicated and as directed by the engineer. A series of holes shall be drilled into the pavement 3 - 8 foot O.C. with exact location and spacing to be determined in the field.
NJ	We determine undersealing locations via FWD. Transverse joints exhibiting maximum deflections greater than 15 mils using 9,000 lb load drop require undersealing to stabilize and bring deflections below 10 mils.
OR	http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/docs/pavement/pavement_design_guide.pdf
TX	Ground coupled GPR is used to determine locations where voids exist beneath the pavement.

Q4. Is there a "trigger" parameter that governs the selection of subgrade stabilization as part of PCC pavement restoration and repair project?

Agency	Visual inspection of the damage	Roadway traffic level	Pavement closure time	Weather and seasonal limitations	Area or depth of patch	Extent of damage	Public complaints	Poor ride quality	Sudden safety problems	Possibility of having subgrade	Type/properties of the subgrade soil	Roadway functional class	Budget	Other(s)
AL														*
AR	*		*		*	*		*						
CA	*	*	*		*	*			*	*	*	*	*	
FL						*		*	*					
ID	*							*			*			
IL														
IN	*					*		*	*	*	*			
KS														*
KY														
LA														
MD														
MN			*		*	*				*			*	
MT	*			*	*	*		*		*			*	
NC	*					*		*	*					
ND														
NJ	*					*		*			*			
NV														
NY														
OK														
OR	*				*	*			*					
SC	*					*		*	*	*				
TN														
TX														
UT														*
WA														*

Other comments

1. AL: ALDOT usually does not perform subgrade stabilization on CPR projects.
2. KS: In small patch situations we do not specify subgrade stabilization, we would remove any saturated subgrade and replace with aggregate material.
3. NY: Fine grading of subbase is usually the only subgrade improvement done with concrete pavement repair projects.
4. UT: Utah does not place concrete paving directly on a subgrade or untreated base layer. All of our PCCP is placed on either a lean concrete base in the past or a HMA layer as our current practice.
5. WA: SDOT may have isolated areas requiring subgrade stabilization but for the most part stabilization is outside the norm. If subgrade conditions are marginal. WSDOT will not construct using PCC. If PCC has been used in the past and subgrade is a problem WSDOT will likely reconstruct with a HMA option.

Q5. Is there a "trigger" parameter that governs the selection of slab undersealing as part of PCC pavement restoration and repair project?														
Agency	Visual inspection of the damage	Roadway traffic level	Pavement closure time	Weather and seasonal limitations	Area or depth of patch	Extent of damage	Public complaints	Poor ride quality	Sudden safety problems	Possibility of having subgrade	Type/properties of the subgrade soil	Roadway functional class	Budget	Other(s)
AL	*					*		*						
AR	*		*			*		*						
CA	*	*	*	*	*	*		*	*	*		*	*	
FL														
ID	*					*		*			*			
IL														
IN	*					*		*	*	*	*			
KS						*					*			*
KY														
LA														
MD														
MN						*		*	*					
MT														
NC	*	*	*			*		*	*		*			
ND														
NJ														*
NV														*
NY														
OK														
OR	*													
SC														
TN														
TX	*					*		*						
UT														*
WA	*						*	*	*				*	*

Other comments

1. KS: Pavement investigation
2. NJ: If I define undersealing as stabilizing a transverse joint, then I've already described our FWD procedure in a previous answer.
3. OR: We are a CRCP state and while we have a spec, we haven't done this in several years and should be considered a very small part of your statistic.
4. UT: Utah does slab undersealing and slab jacking to address voids and differential settlement in our PCCP but not as an established process in addressing subgrade or untreated base failure beneath the PCCP.
5. WA: Slab undersealing is a very small part of WSDOT's pavement program.

Q6. What percentage of all PCC pavement restoration/repair projects in your jurisdiction involve subgrade soil stabilization and/or slab undersealing?			
Agency	Soil stabilization	Slab undersealing	Soil stabilization and slab undersealing
AL	0	0%–10%	0
AR	0%–10%	0%–10%	0
CA	0%–10%	0%–10%	0%–10%
FL			0%–10%
ID			30%–50%
IL	0	0	0
IN	70%–100%	10%–30%	10%–30%
KS	0	0%–10%	0
KY	0	0	0
LA	0	0	0
MD	0	0	0
MN	0%–10%	0%–10%	0%–10%
MT	10%–30%	0	0
NC	50%–70%	0%–10%	0%–10%
ND	0	0	0
NJ			30%–50%
NV	0	0	0
NY	0	0	0
OK			
OR	10%–30%	0	
SC	50%–70%	0%–10%	0%–10%
TN	0	0	0
TX	0	0%–10%	
UT	0	0	0
WA	0%–10%	0%–10%	0%–10%

Q7. What materials are used for subgrade stabilization as part of PCC pavement restoration and repairs in your area?

Agency	Portland cement	Lime	Fly ash	Others
AL				*
AR	*	*		
CA	*	*		
FL				*
ID	*			*
IL				
IN				*
KS				
KY				
LA				
MD				
MN				*
MT				*
NC	*	*	*	*
ND				
NJ				*
NV				
NY				
OK				
OR				*
SC	*			
TN				
TX				
UT				
WA				*

Other comments

1. AL: ALDOT does not perform subgrade stabilization on CPR projects.
2. FL: Chemical stabilization is not common. Subgrade stabilization relied mostly on mechanical stabilization using improved granular materials such as limerock.
3. KS: Compacted aggregate on most PCCP patches below the slab (95%).
4. MN: We would rework the base if we had larger repair areas—nothing usually done on traditional full depth patches other than putting in additional steel in concrete.
5. MT: 100% gravel—compaction.
6. NC: geotextile fabric 25%.
7. OR: Aggregate, 100%.
8. WA: WSDOT does not have much experience. Portland Cement was used where stabilization has been done.

Q8. What materials are used for slab undersealing as part of PCC pavement restoration and repairs in your area?

Agency	Portland cement only	Limestone dust – Portland cement	Pozzolan – Portland cement	Asphalt emulsion – Portland cement	Sand – Portland cement	Polyurethane	Bentonite	Epoxy	Others
AL		*	*		*				*
AR					*	*	*		
CA			*						
FL									*
ID	*					*			
IL									
IN				*					
KS			*			*			
KY									
LA									
MD									
MN									*
MT									
NC		*				*		*	
ND									
NJ						*			
NV									
NY									
OK									
OR									*
SC	*								
TN									
TX						*			
UT						*			*
WA						*			

Other comments

1. AL: Two component foam.
2. MN: Cement/Fly Ash/Agricultural Lime typical. We usually only do undersealing or mudjacking around bridge approach.
3. OR: We don't do this anymore.
4. UT: The marked polyurethane used in slab jacking.

Q9. Do you use any type of mechanical equipment/machinery for soil stabilization/slab undersealing or for compaction when performing "small-area" PCC or composite pavement restoration and repair operations?				
Agency	Soil stabilization	Slab undersealing	Compaction of replacement materials	Composite pavement patching
AL	No	No	No	No
AR				
CA	Yes	Yes	Yes	Yes
FL	No			
ID	No	No	No	No
IL	No	No	No	No
IN	Yes	Yes		
KS	No	Yes, but only for repairing by contracts	Yes, but only for repairing by contracts	Yes, but only for repairing by contracts
KY				
LA	No	No	No	No
MD	No	No	No	No
MN	No	No	No	No
MT	Yes, but only for repairing by contracts		Yes, but only for repairing by contracts	Yes, but only for repairing by contracts
NC	No	No	No	No
ND			Yes, but only for repairing by contracts	Yes, but only for repairing by contracts
NJ	Yes, but only for repairing by contracts	Yes, but only for repairing by contracts	Yes	Yes
NV	No	No	No	No
NY	No	No	No	No
OK				
OR	No	No	No	No
SC	Yes		Yes	
TN				
TX	No	No	No	No
UT	No	No	No	No
WA	No	No	No	No

If yes to Q9, provide short description or provide link to the appropriate document.	
CA	http://www.dot.ca.gov/hq/esc/oe/construction_contract_standards/std_specs/2015_StdSpecs/2015_StdSpecs.pdf See Section 41
IN	Drill for the holes, distributor with pumps to pump in the asphaltic material.
KS	http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burConsMain/specprov/2015/834.pdf
NJ	Hand grading and hand operated plate vibratory compactors are used for subbase/subgrade compaction. Sometimes high density polyurethane or cement slurry is injected after repair to ensure support of the precast concrete repair.
SC	Unsound material is excavated and CR-14 is added and mechanically compacted using vibratory compactors.

Q10. Has your organization undertaken or sponsored any past (or ongoing) research in the area of soil stabilization/slab undersealing for PCC pavement restoration and repair or patching composite pavements?	
Soil stabilization	KY
Slab Undersealing	
Both	NJ
Patching composite pavements	
None	AL, Ca, FL, ID, IN, KS, LA, MD, MN, MT, NC, ND, NV, NY, OR, SC, TN, TX, UT, WA
Planning to initiate research	
No response	AK, AR, AZ, CO, CT, DE, GA, HI, IA, MA, ME, MI, MO, MS, NE, NH, NM, OH, OK, PA, RI, SD, VA, VT, WI, WV, WY

If yes to Q9, provide short description or provide link to the appropriate document.	
IN	INDOT probably has conducted past research, particularly on soil stabilization, but I am unaware of the results
KY	Performance of soil stabilization/slab undersealing materials, Cost effectiveness of soil stabilization/slab undersealing or patching
NJ	Performance of soil stabilization/slab undersealing materials, Triggers for initiation of soil stabilization/slab undersealing operations, Cost effectiveness of soil stabilization/slab undersealing or patching

Q11. Is there a need for more research or information in the area of soil stabilization								
Agency	Comparison of different soil stabilization approaches	Comparison of different soil stabilization materials	Comparison of different types of mechanized equipment for soil stabilization	Development of a new or improved mechanized equipment for soil stabilization	Development of new or improved soil stabilization materials	Improved soil stabilization standards	Improved soil stabilization guidelines, training materials and specifications	Educational modules covering principles of soil stabilization techniques
AL	*	*					*	*
AR								
CA			*	*	*	*	*	
FL							*	*
ID	*				*		*	*
IL								
IN	*	*	*	*	*	*	*	*
KS								
KY					*			
LA				*				
MD								
MN	*	*						
MT	*	*			*	*	*	*
NC	*	*					*	*
ND							*	
NJ	*	*			*			
NV								
NY								

OK								
OR								
SC		*			*			
TN								
TX							*	*
UT					*		*	
WA	*	*						

Q12. Is there a need for more research or information in the area of soil stabilization

Agency	Comparison of different slab undersealing approaches	Comparison of different slab undersealing materials	Comparison of different types of mechanized equipment for slab undersealing	Development of a new or improved mechanized equipment for slab undersealing	Development of new or improved slab undersealing materials	Improved slab undersealing standards	Improved slab undersealing guidelines, training materials and specifications	Educational modules covering principles of slab undersealing techniques
AL							*	*
AR								
CA	*	*	*	*	*	*	*	*
FL							*	*
ID	*	*				*	*	*
IL								
IN	*	*	*	*	*	*	*	*
KS								
KY								
LA	*	*	*			*	*	
MD								
MN	*	*						
MT								
NC	*	*					*	*
ND							*	
NJ	*	*			*			
NV								
NY								
OK								
OR								
SC						*	*	
TN								
TX	*	*	*	*	*	*	*	*
UT				*		*		
WA	*	*						

Q13. Do you have any additional comments or suggestions?	
KS	KDOT does not utilize subgrade stabilization underneath patches. We specify that the subgrade is not to be damaged and if damaged then repair with aggregate material. If the subgrade is in need of repair, we specify an aggregate material as this is quicker and easier to get compaction in the short areas for patching.
MT	Montana has a total of 60 miles of concrete pavement and a over 20,000 miles of asphalt pavement. Therefore, concrete pavements are extremely low on the priority level in this state. The main focus and funding is towards asphalt pavements.
NY	NYSDOT uses products such as Uretek on a very limited basis. We do not use it as part of a typical concrete pavement restoration project.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

About This Report

An open access version of this publication is available online. See the URL in the citation below.

Behnood, A., & Olek, J. (2020). *Development of subgrade stabilization and slab undersealing solutions for PCC pavements restoration and repairs* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2020/13). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317128