INFRASTRUCTURE RESEARCH

MEMORANDUM

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FROM: INFRASTRUCTURE RESEARCH
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DATE: March 13, 2024

SUBJECT: Evaluation of Selected Pavement Specifications and Responses to Questions Relevant to Design and Construction of Cement-Treated Soil and Aggregate Layers in El Paso County, Colorado

Project Background and Objectives

The first phase of this project involved extensive field testing to enable a formal comparison of pavements comprising cement-treated soil (CTS) with pavements comprising untreated base course (UTBC) in El Paso County, Colorado. Some of the conclusions of that phase of work included the following:

- A high degree of variability exists in the bearing capacities of the native subgrade soils, with California bearing ratios (CBRs) ranging from 3 to 122.
- For pavements comprising CTS and pavements comprising UTBC, a high degree of variability exists in both layer thicknesses and structural properties, with hot-mix asphalt (HMA) thicknesses ranging from 3.75 to 8.17 in., base layer thicknesses ranging from 4.0 to 15.0 in., and base layer CBR values ranging from 22 to 351.
- For pavements comprising CTS and pavements comprising UTBC, significant differences were observed between design and measured HMA and base layer thicknesses, with differences between measured and design HMA thicknesses ranging from -0.25 to +3.00 in. and differences between measured and design base layer thicknesses ranging from -4.0 to +9.0 in.

While the cause of high variability within the listed pavement properties was not explicitly investigated for the tested sites, the opportunity to potentially revise relevant specifications was recognized as a means for reducing variability in future construction (Guthrie and Rogers 2010). To that end, pavement and materials specifications in Appendices D and J of the *Engineering Criteria Manual* (El Paso County 2016) were reviewed in the second phase of the project, with proposed improvements given. In addition, answers to specific questions about pavement design and construction from El Paso County personnel were developed. Finally, motivations for using cement treatment and best construction practices were also outlined for consideration by El Paso County personnel.

Review of Specifications

Following a review of Appendices D and J in the specifications, the following comments and questions, which are provided by page number and/or section, were developed:

Appendix D

Page 293, Section D.2.1: Testing of soil for water-soluble sulfates is appropriate not only for construction of portland cement concrete, but also for determining the suitability of soils for treatment with calcium-based stabilizers such as cement, lime, and kiln dust. For treatment of soil, in particular, the soluble sulfate concentration should be below 3000 ppm to avoid needing to use special construction practices, such as mellowing (Harris et al. 2006).

Page 296, Section D.3.5: Should the text indicate that the working stress should not be greater than 75 percent?

Page 297: Estimating a resilient modulus value by multiplying the CBR by 1500 is appropriate only for CBR values up to a maximum of about 20 (Huang 2004).

Page 297, Section C: Beyond just the subgrade, each subsurface layer must be evaluated for adequate protection in the 1993 American Association of State Highway and Transportation Officials (AASHTO) flexible pavement design method (Huang 2004).

Page 298, Table D-3: Compared to values that represent best practices for design and construction, the structural layer coefficient and required 7-day unconfined compressive strength (UCS) values are too high. Specification of high 7-day UCS values commonly leads to high amounts of shrinkage cracking, which can reflect into an overlying asphalt layer. In cold regions, 7-day UCS values ranging from 450 to 500 psi and layer coefficients (a_2) ranging from 0.16 to 0.20, correlated to 7-day UCS, should be used following the 1993 AASHTO flexible pavement design method; at this level of treatment, resistance to both freeze-thaw and wet-dry cycling damage is typically achieved (Wilson et al. 2015).

Page 298, Table D-3: The term “stabilized” with respect to “cement-stabilized subgrade” is not technically correct because testing to ensure permanency of the material properties derived from cement application is not specified; instead, “treated” would be more correct.

Page 298, Table D-3: The point in time when a plasticity index (PI) less than 6 should be achieved is not given here but is given later in the specifications. Clarifying that a PI less than 6 should be achieved by a certain amount of time after treatment (24 hours, for example) would be appropriate.

Page 298, Table D-3, Note 3: “Micro fracturing,” which is also called microcracking, applies to any cementitiously treated base layer that may exhibit shrinkage cracking of sufficient width to propagate into the overlying asphalt layer. The microcracking process should be terminated when a target percent reduction in the stiffness of the layer has been achieved. The target percent reduction depends on the device used to monitor the microcracking process (Guthrie and Hope 2011).

Page 298, Table D-3, Note 4: Why should crushed concrete not be used as a temporary driving surface?

Page 298, Section F: Why is D_2 constrained to be less than or equal to the product of 2.5 and D_1? Especially in cold regions, use of thick, non-frost-susceptible base layers is often appropriate.

Page 298, Section G: This text implies that UTBC is, by definition, a permeable material. However, in many other locations, UTBC is typically considered to be a dense-graded material with relatively low porosity and low permeability.

Page 298, Section G: While permanently draining water, or reducing the moisture content, of swelling soils is theoretically desirable, preserving the soil at the lower moisture content can be difficult, if not impossible, given the numerous sources of potential water ingress in pavements. For this reason, some agencies deliberately allow the pavement subgrade to remain wet, thereby minimizing the cyclic swelling and shrinking caused by cyclic wetting and drying, respectively. In this case, a lower resilient modulus that reflects the higher moisture content should be utilized in the pavement design process.

Page 299, Section D.4.2: Pavement base layers are desirable to minimize the occurrence of pumping, faulting, and frost heave and to provide a stable construction platform during construction of a concrete surface layer, for example.

Page 299, Section B: Reference to “3.4” for the modulus of elasticity of concrete is given without units. It should be 3.4 million psi.

Page 299, Section D: Standard deviations of 0.35 and 0.45 for concrete (rigid) and asphalt (flexible) pavements, respectively, are appropriate for use in designing new pavements. Higher values, such as 0.49 for asphalt pavements, are appropriate for use in designing rehabilitated pavements (Huang 2004).

Page 305, Section A: A Type II cement or a cement with an equivalent or higher resistance to sulfate attack should be allowed. Especially given that many cement producers are increasingly transitioning to Type IL cement, not all of which is produced using a clinker that meets the requirements for a Type II or Type IV cement, an increasing reliance on direct testing of sulfate resistance is recommended.

Page 306, Section H: A curing time should be given. Typically, a 28-day curing period is used to define the design strength.

Page 307, Section D.5.7: The range in 7-day UCS values is too high, and specification of a minimum cement content, which also appears to be too high, would be unwarranted if a minimum 7-day UCS is given.

Page 308, Sections D.5.8 and D.5.9: Why are the minimum required 7-day UCS values given for materials treated with cement, fly ash, lime, and kiln dust different from each other? Are they all being used as pavement base layers? Also, for what reason(s) is the specific value for minimum thickness given?

Page 308, Section D.5.9: The minimum acceptable lime content should be determined through Eades and Grim testing if stabilization, rather than modification, is the desired outcome (Guthrie et al. 2011). The objective of modification is to provide a temporary improvement in material properties to aid in construction, while the objective of stabilization is to provide a permanent improvement in material properties that can influence the pavement design.

Page 309, Section D.6: As previously noted, soluble sulfate testing should be performed to determine the suitability of soils for treatment with calcium-based stabilizers such as cement, lime, and kiln dust.

Appendix J

Page 522, Table J-1: This table is missing soil tests for 7-day UCS and soluble sulfates, at minimum.

Page 522, Section J.3: A compaction lift thickness should be given.

Page 524, Section J.4.2: A minimum of two, rather than one, 7-day strength and lime content determinations per project, should be considered. A single determination may not be representative of the project.

Page 525, Section J.4.3: In section J.3.1, a minimum of one test within 12 in. of a manhole is required, but section J.4.3 indicates a minimum of 20 percent of the tests within 12 in. of a manhole. Why are these requirements different? The latter requirement is repeated again on pages 526 and 528.

Page 525, Section J.4.4.C: Six samples is likely too high for every 500 tons of material placed, and a 28-day UCS test should not be required unless a 28-day UCS was specified in the design process.

Page 525, Section J.4.4.C: Where is a UCS test indicated? Where are curing and capping procedures given? Where are reporting requirements, such as load, dry density, and water content at the time of testing, given? Are procedures available for incorporating reclaimed asphalt pavement (RAP) in tested samples?

Page 527, Section J.4.6.E: This section specifically indicates fly ash. Should other pozzolans also be mentioned?

Page 528, Section J.4.8.B: Use of phenolphthalein, which turns pink for pH values higher than about 8.0 to 9.5, is possible in the field but may not provide a clear indication of the depth of treatment. This approach inherently assumes that the native soil has a pH lower than 8.0 to 9.5 and that the treated soil has a pH within this range or higher, which may not apply to every project. Furthermore, the trenching process required to expose a vertical face of the treated soil may inadvertently contaminate the underlying soil, blurring the pink boundary. Instead of phenolphthalein, a dynamic cone penetrometer could be used within the first one to two days, depending on the stiffness of the treated layer, to more reliably estimate the depth of treatment.

Page 528, Section J.4.8.C: Over what time period must the treated layer develop sufficient compressive strength to meet the design compressive strength?

Page 528, Section J.4.8.C: A time period of 1.5 hours is too long in many cases, depending on the treatment type and concentration and the environmental conditions. A time period closer to 0.5 hours is recommended. Higher air temperatures, lower relative humidity values, and higher wind speeds require shorter time periods (Guthrie et al. 2009).

Page 528, Section J.4.8.C: Specimens that are compacted in the field should be extruded from their molds and sealed in the field for curing.

Page 529, Table J-3: One moisture/density test for every 2 ft of elevation may be inadequate for trenches, which often settle over time.

Page 529, Table J-3: Has the "T" patch been used in El Paso County? In this approach, a trench through a pavement structure is backfilled to the same elevation as the bottom of the asphalt, and the asphalt is then cut back 1 to 2 ft on both sides of the trench so that the material just under the original edge of the asphalt can be properly compacted. Given the improved compaction and the extension of the new asphalt patch beyond the edges of the trench, the probability of settlement of the patch is lower (Guthrie et al. 2015b).

Page 530-531: UCS testing is not mentioned.

Page 530-531: Estimates of dry density obtained from nuclear density gauge testing can be artificially low in soils or aggregates containing RAP or cementitious products because hydrogen in benzene rings and in calcium-silicate-hydrates is incorrectly counted by the gauge as water, causing an artificially high water content.

Answers to Questions from El Paso County Personnel

The following answers are responsive to specific questions received from El Paso County personnel with respect to the design and construction of asphalt pavements:

Question 1: "Is there a way to account for or quantify the impacts of drainage to CTS roads vs UTBC roads. My understanding is that one of the benefits of an UTBC, as part of more typical pavement cross section (HMA, UTBC, native sub-base) is permeation of water, especially in roads with cracks (which we have a lot of). A low-strength cementitious base would not be as permeable. Is that a variable to quantify or account for when considering applicability of CTS in-lieu of UTBC?"

Answer: The effects of cement treatment on permeability depend on the properties of the material being treated and the amount of cement being used (Bhattacharja and Bhatty 2003, Guthrie et al. 2007, Guthrie et al. 2012). For a cohesionless soil, treatment with increasing amounts of cement would be expected to cause decreasing permeability to the extent that cementitious products form within the voids between the soil particles. However, for a cohesive soil, treatment with increasing amounts of cement would be expected to first cause increasing permeability and then decreasing permeability. The increasing permeability would occur as the thickness of the diffuse double water layer surrounding the clay particles decreases, promoting a flocculated edge-to-face orientation with higher porosity than the original dispersed orientation. With increasing amounts of cement, the permeability would subsequently decrease as cementitious products form within the voids between the clay particles.

When subsurface pavement drainage is needed, an open-graded aggregate is commonly used to provide high permeability, and, in the absence of a well-drained subgrade soil, water that passes through the aggregate layer is daylighted into an open ditch or actively removed using longitudinal edge drains and outlet pipes. However, when stability is needed, a dense-graded aggregate is commonly used to provide higher bearing capacity, which usually corresponds to lower permeability. Therefore, depending on the particle-size distribution, either a UTBC layer or a CTS layer may exhibit a higher permeability.

A key consideration in predicting performance relates to the moisture sensitivity of CTS and UTBC layers. While a UTBC layer may experience significant changes in stiffness with changes in moisture, a properly designed CTS layer may exhibit only minor changes in stiffness with changes in moisture. Given the many sources of water ingress into pavement structures, the ability to retain stiffness in the presence of moisture would be expected to be an advantage of CTS over UTBC; CTS layers can and should be designed to perform well in the presence of moisture. Indeed, one of the benefits of cement stabilization is that it can be used to create a durable, moisture- and frost-resistant base layer.

<u>Question 2:</u> "How do road cuts impact the effectiveness (and thus applicability) of CTS? We have significant instances of utility cuts, even in new roads. How do cuts, even with deliberate repairs, effect the structural integrity of a CTS cross section?"

Answer: In general, road cuts through CTS or UTBC layers lead to accelerated deterioration caused by increased pavement roughness, at minimum (Guthrie et al. 2015b). Patching of these layers should be performed using materials with engineering properties similar to those of the original materials to restore lateral continuity, to the degree possible, within the pavement structure. Data suggesting that pavements comprising CTS are more or less susceptible to damage from road cuts than pavements comprising UTBC were not identified in the literature. El Paso County personnel may consider implementation of "no-cut" policies for new roads and/or cut fees in certain cases to offset the reduction in expected pavement service life (Guthrie et al. 2015b).

Question 3: “Need to know what material properties would be triggers for the applicability of CTS (e.g. Plasticity Index, sulfates, percent organics, expansive soils, etc.). Same question for applicability/triggers for other types of chemical treatments like lime.”

Answer: Cement treatment is viable for most soil types and will in many cases be preferable to lime and fly ash, even for soils with relatively high PI values (Bhattacharja and Bhatty 2003). For treatment of soil with calcium-based stabilizers such as cement, lime, and kiln dust, the soluble sulfate concentration should be below 3000 ppm to avoid needing to use special construction practices, such as mellowing (Harris et al. 2006). Particular consideration should be given to soils with an organic content greater than 2 percent or a pH of less than 5.3; soils that meet these criteria are not necessarily unsuitable for cement treatment but may not develop satisfactory strengths (Robbins and Mueller 1960).

Lime treatment is typically considered for soils with PI values higher than 10, and appropriate lime concentrations to achieve stabilization are determined using the Eades and Grim test, as previously indicated.

Question 4: “Is it possible (probably outside the SOW for this study) to do a side-by-side simulation of CTS vs UTBC? What about a PCI curve generation to account for extended years of service?”

Answer: Yes, a study that involves a side-by-side comparison of CTS and UTBC and includes deterioration modeling would definitely be possible. Such a study would be a valuable addition to the current project, would potentially provide an opportunity to demonstrate the benefits of specific improvements to the relevant pavement and materials specifications, and would allow instrumentation of CTS and UTBC layers to monitor moisture content through the seasons, for example. Infrastructure Research personnel have extensive experience with such experimentation and would be very interested in participating.

Question 5: “This is more of a comment than a question: The last paragraph of Memo it states “Given these observations… CTS and UTBC are both viable options for roadway construction in El Paso County”. I wonder if it is not more accurate to say that statistically there is no structural benefit to CTS vs UTBC. I only say this because this memo focuses primarily on the structural performance of the pavement types (unless my questions above are included in the analysis). The conclusion may be the same, namely that both may be options under certain conditions, but the path to get to that conclusion, in my opinion is very specific.”

Answer: Pavement performance is often evaluated in terms of distress, skid resistance, smoothness, and structural capacity (Huang 2004). While skid resistance is usually related to material properties of the surface layer, inadequate structural capacity commonly precedes the onset of distress and roadway roughness and is therefore of primary concern. The data collected in the first phase of this project did not indicate statistically significant differences between pavements comprising CTS and pavements comprising UTBC with respect to either distress or structural capacity. Extended monitoring of selected pavement segments studied in the first phase of this project would provide additional information about the durability of CTS and UTBC layers in El Paso County.

Question 6: “How does CTS affect full depth reclamation? We are using FDR more and more, so how does the applicability and effectiveness of CTS work when FDR is a consistent part of our long term preservation/maintenance efforts?”

Answer: Full-depth reclamation (FDR), with or without cement stabilization, is commonly used for reconstructing asphalt pavements within the United States and in numerous other countries and can be applied to pavements comprising either CTS or UTBC in many cases. The use of FDR may be limited in cases where the existing asphalt layer is too thick or too thin, the asphalt layer exhibits too much fatigue cracking, excessive amounts of crack seal are present, the maximum aggregate size is too large for efficient processing with a reclaimer, the particle-size distribution of the resulting blend of RAP and base material is unsuitable to meet the design requirements, the existing base material is too stiff to be pulverized by the reclaimer, or too many buried utilities exist within the intended depth of reclamation, for example. With respect to construction of stabilized base layers, use of too much stabilizer (such as cement, lime, fly ash, or cement kiln dust) can lead to difficulty with pulverization (Guthrie et al. 2015a); regardless of the type of base layer that is present, project-level investigations should be performed on pavement segments for which FDR is being considered to ensure that this method will be appropriate.

Summary

As a summary of key points related to the second phase of this project, the following motivations for using cement treatment and best construction practices are provided for consideration by El Paso County personnel:

Motivations for Using Cement Treatment

- Cement is widely considered as the most versatile stabilization agent.
- When properly designed, a cement-treated layer has increased strength and durability.
- Cement treatment can be used to eliminate or reduce soft spots in the subgrade soil.
- A cement-treated layer would be expected to more widely distribute traffic loads onto the underlying subgrade soil, thus reducing compressive stresses in the soil that might otherwise lead to structural rutting of the pavement.
- A cement-treated layer would be expected to reduce fatigue cracking of the overlying asphalt layer.
- A cement-treated layer would be expected to be more resistant to damage from both freeze-thaw cycling and sustained freezing.
- A cement-treated layer can maintain a comparatively high minimum stiffness despite seasonal changes in temperature and water content.
- A cement-treated layer can be designed to have low permeability to minimize the movement of water through the layer.
- A cement-treated layer allows for the design of thinner pavement sections.
- Cement treatment can facilitate the use of existing materials, where applicable, requiring little or no material hauling, and therefore saves energy by reducing mining and hauls.

Best Construction Practices for Cement Treatment

- In urban environments, cement slurry, rather than cement powder, can be applied to totally eliminate fugitive cement dust (Guthrie et al. 2020).
- Methods should be utilized for ensuring that the slurry or powder is distributed as uniformly as possible.
- During the blending phase, the reclaimer should be driven slowly to ensure adequate mixing of cement and soil; the mixing drum should engage the material for 3 to 5 seconds.
- The moisture content of the treated material should be closely monitored during construction, and water trucks should be readily available to supply additional moisture if needed.
- Compaction should be completed before substantial hydration of cementitious materials occurs; otherwise, breaking of early-forming cementitious bonds during densification will lead to lower strengths (Guthrie et al. 2009).
- The cement-treated layer should ideally be moist-cured until the asphalt surface course is placed or for 7 days, whichever comes first.
- Microcracking of a cement-treated layer should be performed if an asphalt surface course will be placed.
- UCS testing of field-mixed Proctor samples is recommended to verify that target strengths are achieved.
- Stiffness testing is recommended to guide the microcracking process and to open the cement-treated layer to early trafficking.

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