Incorporating Chemical Stabilization of the Subgrade in Pavement Design and Construction Practices

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Project Background

As a result of an economic study conducted in 2007 [Geiger, Ricciardi, and Rawlings, 2007], the Ohio Department of Transportation’s (ODOT’s) Office of Geotechnical Engineering (OGE) recommends global chemical stabilization be incorporated into the design of all major pavement projects. It is anticipated global stabilization will save up to 50% over spot stabilization while providing a superior foundation for paving; the savings in part results from reduction in delays and costs associated with change orders due to wet subgrade conditions. The OGE recommendation to globally stabilize all Interstate and other divided highways with four or more lanes more than 1 mile in project length was implemented by ODOT under Geotechnical Bulletin (GB) 1.

Chemical stabilization of the subgrade generally increases the modulus of the soil and improves the uniformity of the soil throughout the length of a project, and if designed and constructed properly, should enhance the long-term performance of the pavement structure. It is anticipated this increase in the modulus of the subgrade may allow for a thinner asphalt pavement to be designed.

Chou et al [2004] recommended a procedure for incorporating the stabilized subgrade into the pavement thickness design process. Chou’s method incorporates a combined modulus which represents both the unstabilized subgrade and the stabilized subgrade. Chou’s report includes DCP data gathered from seven sites as listed in Table 1 of that report [Chou, 2004, p. D-8 and D-9]. However, “some sections that were planned to be stabilized were found to have been non-performed.” [Chou, 2004, p. 8] Specifically, only four of the sites listed actually had the stabilization performed, the others having only some ad hoc subgrade modification. Of these sites with stabilization performed, three had lime stabilization, except one site, State Route 2 in Erie County, had three stabilization types: lime, cement, lime and cement together, plus no stabilization on a control section. However, the majority of ODOT stabilization projects use cement stabilization. ODOT’s Office of Pavement Engineering (OPE) has not implemented the design procedure in Chou’s report because there was not sufficient validation of durability using
in-service pavements. Furthermore, as the OPE works towards a mechanistic/empirical approach, a modulus value for each layer of subgrade, the chemically stabilized layer and the underlying untreated layer, will be needed for design. It is crucial for OPE to obtain validation of durability.

**Study Objectives**

This study aims to provide ODOT with a basis for incorporating subgrade chemical stabilization into pavement design practice. The specific objectives of this project include:

- Evaluate the longevity and durability of chemically stabilized subgrade soils using the DCP, FWD, and coring/sampling.
- Examine the uniformity of the properties of chemically stabilized subgrade soils along the pavement projects, in particular the modulus or stiffness as determined by DCP and FWD data.
- Use finite element modeling (e.g. with ABAQUS software) of the entire pavement structure from surface to underlying unstabilized subgrade to determine the level and nature of stresses and strains on unstabilized subgrade under the stabilized subgrade layer.
- Determine how the design of a flexible pavement should be modified when the subgrade is chemically stabilized. Recommend a procedure to incorporate stabilized subgrade modulus and thickness into the ODOT’s current pavement design procedure [AASHTO, 1993] and the Mechanistic-Empirical Pavement Design Guide (MEPDG).
- Compare and contrast the aforementioned recommended procedure to the procedure recommended by Chou et al [2004].
- Review the mix design properties of chemically stabilized subgrade soils currently used by ODOT, in particular thickness and strength of the chemically stabilized soil layer. Conduct an analysis to determine what thickness and minimum strength of chemically stabilized layer is necessary for construction and pavement design purposes.

**Description of Work**

Twenty pavement sites were selected across the state of Ohio for the field study, representing various roads that had subgrade stabilization. Twelve used cement stabilization (ranging from 4.3% to 7.3% cement) and eight had lime stabilization (ranging from 4.7% to 7.4% lime). Also, five of the pavements were rigid (concrete) and the remaining fifteen were flexible (asphalt). Each site was visited by a research team, who made measurements at about ten points along the pavement. The field study at each site included portable seismic properties analyzer (PSPA) measurements of the pavement surface modulus, falling weight deflectometer (FWD) measurements of deflection in response to a known impact from a dropped weight, cores that were drilled to measure the pavement thickness, and dynamic cone penetrometer readings that provided data used to determine the resilient modulus of the aggregate base, stabilized subgrade, and unstabilized subgrade. In addition, original test data collected at the time of construction were consulted. The resilient modulus of the soil at each site was computed using four approaches: an ODOT procedure based on soil classification, a procedure used by Chou et al. [2004], a method using the DCP data following Wu and Sargand [2007] and B.K. Roy [2007], and back calculation from the FWD data per the 1993 AASHTO Pavement Design Guide [AASHTO, 1993]. The AASHTO Pavement Design Guide is based on computing a structural number with coefficients computed for each layer to determine the strength of the material. The modulus and layer coefficients were computed for the stabilized subgrade and the aggregate base using the FWD data and the AASHTO [1993] procedure, and using the DCP data and the AASHTO [1993] procedure and the B.K. Roy [2007] procedure. The resilient modulus of the stabilized subgrade was also computed as a ratio to the unstabilized subgrade modulus, and the resilient modulus of the base computed as a ratio to that of the stabilized subgrade.

In all cases, the stabilized subgrade showed an increased resilient modulus; the least improvement was a factor of 1.7 for lime and 2.7 for cement stabilized, while the average improvement was a factor of 8 for lime and 14.5 for cement. The base layers of the pavements were about 1.8-9.0 times as stiff as the stabilized subgrades, with the average being 3.9 for lime and 4.7 for cement stabilized subgrades. Design examples suggesting how to design a pavement incorporating a stabilized subgrade following the AASHTO 1993 manual are given, along with finite
element models and a validation of the back calculation from the FWD data.

Research Findings & Conclusions
Chemical stabilization has been successfully used to treat subgrade soils by permanently changing their physical and chemical properties. By reducing plasticity and increasing stiffness and load bearing capacity, the subgrade may be used as a construction platform and will have enhanced long term structural stability. Theoretical and experimental work was performed to investigate the effect of stabilization on pavement design and construction practices. The initial objective was to look at the impact of stabilized subgrade on pavement design. Analysis of the early data indicated the stabilized subgrade also has a positive impact on the aggregate base material. Accordingly, a decision was made to examine the unstabilized subgrade, stabilized subgrade, and aggregate base as a system and look at the interaction of the layers.

Based on the findings of this project, the following conclusions can be drawn:

1. As borne out by FWD and DCP measurements, both cement stabilization and lime stabilization resulted in significant long term increases in the modulus of the stabilized subgrade relative to the unstabilized subgrade,
2. Current construction procedures will effectively chemically stabilize approximately 85% of the design thickness for cement, and 80% for lime, based on the design thicknesses included in this study of 9 in (23 cm) (1 section), 12 in (30 cm) (10 sections) and 14 in (36 cm) (2 sections), and 16 in (41 cm) (7 sections).
3. Weak stabilized material was encountered at a few holes on many projects indicating a need for improved quality control/quality assurance.
4. The finite element study of compressive stress on the subgrade during construction indicates there is little benefit, in terms of construction load repetitions, for thicknesses greater than 12 in (30 cm) for lime stabilized soil and 8 in (20 cm) for cement stabilized soil.
5. ODOT's current requirement that all chemically stabilized soil achieve unconfined compressive strength of 100 psi (689 kPa) in 8 days is consistent with practices to assure durability in other states and should be continued.
6. The compressive vertical strain at the top of the subgrade layer decreases with increasing the stabilized layer thickness; however it does not decrease significantly after a stabilized layer thickness of 18 in (46 cm) for cement stabilized soils and 22 in (56 cm) for lime stabilized soils.
7. The modulus of the aggregate base is increased because it is confined by the stabilized soil underneath and the pavement on top. The base modulus is enhanced regardless of the thickness of the stabilized subgrade layer evaluated in this study (9 in (23 cm) to 16 in (41 cm)).
8. The significant increase in the modulus of the base and stabilized subgrade may justify decreasing the thickness of flexible pavement layer. However, there are other factors to be considered in the final pavement design, such as temperature gradients or endurance limit of the asphalt fatigue layer.

Recommendations for application of stabilized subgrade are as follows:

1. The stabilized subgrade should be considered in the thickness design procedure by assigning a layer coefficient when using the 1993 AASHTO Guide for Design of Pavement Structures. It is recommended the designer select a layer coefficient using the cumulative frequency chart in Figure 18 of the report with an appropriate level of confidence for the pavement structure being designed.
2. When using a mechanistic/empirical pavement analysis procedure, it is recommended the stabilized subgrade modulus be estimated by applying a multiplier to the natural subgrade modulus. For implementation, the multiplier values obtained from analysis of DCP data, 4.7 for cement stabilized subgrade and 3.9 for lime stabilized subgrade, are recommended.
3. The enhancement of the stiffness of the aggregate base due to confinement should be considered in the thickness design procedure by assigning a higher layer coefficient when using the 1993 AASHTO Guide for Design of Pavement Structures. It is recommended the designer select a layer coefficient using the
cumulative frequency chart in Figure 19 of the report and with an appropriate level of confidence for the pavement structure being designed.

4. When using a mechanistic/empirical pavement analysis procedure, it is recommended the granular base modulus be estimated by applying a multiplier to the stabilized subgrade modulus. For implementation, the multiplier values obtained from analysis of DCP data, 1.2 for cement stabilized subgrade and 1.5 for lime stabilized subgrade, are recommended.

5. To avoid localized weak stabilized subgrade, a stiffness based quality control/assurance procedure, such as the one recommended by Sargand, Wu, and Figueroa [2005, 2006], for the stabilized subgrade should be implemented.

6. A minimum stabilized subgrade design thickness of 16 in (41 cm) is recommended for lime treated soil and a minimum stabilized thickness of 12 in (30 cm) is recommended for cement treated soil to ensure the in-situ thickness is achieved to endure construction traffic. This will ensure sufficient thickness to attain the full benefit while allowing for variability seen in actual applications at field sites.

References


