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Final Report VTRC 23-R7

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 23-R7	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Investigation of Number 10 Screenings for Subgrade Soil Improvement		5. Report Date: December 2022
		6. Performing Organization Code:
Author: M. Shabbir Hossain, Ph.D., P.E.		8. Performing Organization Report No.: VTRC 23-R7
9. Performing Organization and Address: Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903		10. Work Unit No. (TRAIS):
		11. Contract or Grant No.: 114311
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation, 1401 E. Broad Street, Richmond, VA 23219	Federal Highway Administration, 400 North 8th Street, Room 750, Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final Report, May 2019-October 2022
		14. Sponsoring Agency Code:

15. Supplementary Notes:
This is an SPR-B report.

16. Abstract:

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Three sources of screenings with two marginal soil types at various mixture rates were studied in the laboratory to determine an appropriate field application. The engineering improvements were determined using the California bearing ratio, density, plasticity reduction, and resilient modulus. At a mix rate of 50% by weight, increased density, reduced optimum moisture content, and reduced plasticity were observed. Some improvements for the clayey soil as measured by the soaked California bearing ratio were observed, but none for silty soil. Improvement in the resilient modulus, which is the subgrade support value for mechanistic pavement design, was not obvious and depended on the field moisture condition. No improvement in resilient modulus was observed at the field equilibrium moisture condition predicted by the *Mechanistic-Empirical Pavement Design Guide* using the Thornthwaite moisture index model, as amended subgrade seems to achieve equilibrium at or near 90% degrees of saturation.

17 Key Words: quarry byproduct, screenings, No. 10 screenings, subgrade improvement, soil amendment, and subgrade modification		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 31	22. Price:

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FINAL REPORT

INVESTIGATION OF NUMBER 10 SCREENINGS FOR SUBGRADE SOIL IMPROVEMENT

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

December 2022
VTRC 23-R7

DISCLAIMER

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FINAL REPORT

INVESTIGATION OF NUMBER 10 SCREENINGS FOR SUBGRADE SOIL IMPROVEMENT

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INTRODUCTION

Quarry byproducts (QBs) are the excess materials produced during quarrying operations; most could be used in the restoration of the quarry; however, there are significant amounts of QBs remaining that need to be managed. Stroup-Gardiner and Wattenberg-Komas (2013) identified three of these QBs:

1. screenings
2. settling pond fines
3. baghouse fines.

"Screenings" are defined as the fraction of crushed stone finer than the 4.75-mm (No. 4) sieve that accumulates after primary and secondary crushing to produce an aggregate with a specified gradation. The aggregate quarries in some parts of Virginia have an abundant supply of screenings, and useful disposal of such materials is becoming a challenge. A sustainable use of this byproduct would be beneficial to both the industry and user agencies. Such stone dust was studied at the Illinois Center for Transportation Research (Qamhia et al., 2018) in pavement structures for both bound and unbound applications as subbase material in an accelerated loading facility. The unbound applications in the Illinois study included mixing of this QB with recycled aggregate and filling up the voids of a large stone base for additional stability. Researchers in India (Agarwal, 2015; Lal et al., 2014; Pal et al., 2017; Satyanarayana et al., 2013) reported using stone dust to amend subgrade soil and observed substantial improvements in the properties of the soil such as the California bearing ratio (CBR) and permeability when the stone dust was mixed in different proportions; they also reported the use of lime along with the stone dust in some cases. Pedarla et al. (2015) showed significant structural benefit when sand (particle size 0.92 to 0.95 mm) was mixed with fat clay for a low volume roadway subgrade. No. 10 screenings may also provide a benefit similar to that of sandy soil mixing.

When poor subgrade materials are encountered in Virginia roadway projects, they are often dealt with in one of the following ways: (1) treat in place with cement and/or lime, (2) remove by undercut and replace, (3) improve by use of geosynthetics, or (4) manage by leaving the poor material in place and using thicker pavements. Another option could be the amendment of the subgrade by mixing with No. 10 screenings.

PURPOSE AND SCOPE

The purpose of this study was to measure the properties of subgrade soil when amended by mixing with No. 10 screenings and to determine if the improvement was sufficient to leave the unsuitable soil in place. Such improvement would eliminate the need for undercutting or other means of improvement as only in-place mixing with No. 10 screenings would be needed. The main properties considered for subgrade improvement were the CBR and the resilient modulus.

Two marginal/unsuitable soils mixed with three sources of screenings at various mixture rates were evaluated for engineering improvements as measured by the CBR, density, plasticity reduction, moisture sensitivity, and resilient modulus. The No. 10 screenings were unwashed QBs satisfying the criteria for AASHTO No. 10 coarse aggregate (usually 100% passing the 3/8-in sieve, 100% to 85% passing the No. 4 sieve, and 10% to 30% passing the No. 100 sieve); the additional criterion used in this study was a maximum allowable percent passing the No. 200 sieve of 20%.

METHODS

Overview

Three tasks were performed to achieve the study objectives:

1. Conduct a literature review to assess the state of the research and current findings for use of QBs, specifically No. 10 screenings, in a pavement structure with a focus on subgrade improvement, and conduct a survey of other state departments of transportation (DOTs) to inquire about their practices regarding aggregate screenings.

2. Conduct a laboratory study to measure the improvement and/or change in the engineering properties of subgrade soil when mixed with No. 10 screenings in different proportions.

3. Evaluate subgrade support by assessing the changes in engineering properties for subgrade support improvement considering location and environmental/climatic conditions in Virginia.

Literature Review and State DOT Survey

The VDOT Research Library was contacted to search the published literature related to the use of QBs, specifically No. 10 screenings. The search included several databases including TRID, WorldCat, RiP, State DOT Search Engine, Google Scholar, NTRL, Compendex, Knovel, NTIS, ScienceDirect, GeoRef, Dissertations and Theses Global, Web of Knowledge/Web of Science, and Materials Science and Engineering Collection.

In addition, a survey of other state DOTs was conducted to explore any use of No. 10 screenings in subgrade modification and unbound applications. A single-question survey as shown in Figure 1 was sent to state DOT representatives through the AASHTO Research Advisory Committee.

Use of screenings to amend/ improve poor subgrade condition

Q. Does your agency use aggregate screenings (a quarry byproduct, similar to AASHTO #10 gradation) in the base, subbase or subgrade:

[ ] Mixing with poor subgrade at certain percentage to improve the condition
[ ] Use as un-stabilized subbase or base
[ ] Use as stabilized subbase or base
[ ] Use as filler for an open graded base course
[ ] Mixing with poor subgrade along with stabilizing agent such as cement or lime

Figure 1. Survey Question to State DOTs for the Use of No. 10 Screenings

Laboratory Study

Three sources of No. 10 screenings based on gradation and geology and two poor subgrade soils, one silty and another clayey, were selected for the study. They were mixed at different proportions, 35% (or 33%) and 50%, to study the improvements in the engineering properties. Both individual soil/aggregate and their blends were tested for properties such as gradation, specific gravity, liquid limit, plastic limit, moisture-density relationship, CBR, and resilient modulus. Optimum moisture content (OMC) and maximum dry density (MDD) were determined using the standard Proctor test. The degree of saturation of the tested resilient modulus samples (cylindrical samples, 2.8 in by 5.6 in) were calculated using compacted sample moisture content, density, and specific gravity values. Engineering properties were measured in accordance with the following VDOT and AASHTO standards:

- AASHTO T 87: Standard Method of Test for Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test

- AASHTO T 88: Standard Method of Test for Particle Size Analysis of Soils

- AASHTO T 100: Standard Method of Test for Specific Gravity of Soils

- AASHTO T 89: Standard Method of Test for Determining the Liquid Limit of Soils

- AASHTO T 90: Standard Method of Test for Determining the Plastic Limit and Plasticity Index of Soils

- AASHTO T 99: Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5-kg [5.5-lb] Rammer and a 305-mm [12-in] Drop

- Virginia Test Method (VTM) 8: Conducting California Bearing Ratio Test, Soaked CBR Value—(Soils Lab) (VDOT, 2007). This standard is similar to AASHTO T 193, Standard Method of Test for the California Bearing Ratio, and provides comparable results. A cylindrical soil sample 6 in by 6 in is compacted in a mold at OMC and MDD.

- AASHTO T 307: Determining the Resilient Modulus of Soils and Aggregate Materials.

Although resilient modulus is stress dependent, a fixed stress condition was selected for the relative comparison. The resilient modulus values were calculated at a confining pressure of 2 psi and a cyclic deviator stress of 6 psi from the fitted parameters for the universal constitutive model based on the AASHTO T 307 test. All samples were compacted at MDD. Resilient modulus tests were conducted in accordance with AASHTO T 307 at two moisture contents: OMC and wet of OMC.

Material Selection and Characterization

The subgrade soils typically considered unsuitable or poor for pavement support were selected for amendment testing. Two subgrade soils, one from Lynchburg, Virginia, and the other from Fairfax, Virginia, were used for this study. The soil from Lynchburg was predominantly silt, and the soil from Fairfax was mostly clay; both are shown in Figure 2.

In addition, three No. 10 screenings were selected based on varying amounts of particles passing the No. 200 sieve and their respective performance as measured by the CBR. Figure 3 shows the No. 10 screenings selected for the study. All five materials were tested for soil index properties, Proctor and subgrade soil support (CBR and resilient modulus) values.

Figure 2. Subgrade Soils: (a) silt (borderline elastic) from Lynchburg; (b) fat clay from Fairfax. Sp. Gr. = specific gravity; LL= liquid limit; PL = plastic limit; PI = plasticity index; CBR = California bearing ratio.

Figure 3. No. 10 Screenings: a) screening 1; b) screening 2; c) screening 3. Sp. Gr. = specific gravity; CBR = California bearing ratio.

Blend Proportions and Properties

Subgrade soils were amended/modified by blending No. 10 screenings with virgin soil at different proportions. Two blends were investigated: 50% and 35% (33%). All proportions were on a weight basis, and the blending was performed in the laboratory by hand mixing in the dry condition. Blended materials were tested for soil index properties, Proctor and resilient modulus; a few were also tested for CBR. Samples were prepared at OMC and MDD for resilient modulus and CBR tests. Table 1 shows the blends considered for evaluation.

Table 1. Blends Considered for the Study

Blend Proportion	Blend ID	Soil	Screenings
50% (SILT)	S50-50SCR1	50% Silt	50% Screenings 1
	S50-50SCR2	50% Silt	50% Screenings 2
	S50-50SCR3	50% Silt	50% Screenings 3
35% (SILT)	S67-33SCR1	67% Silt	33% Screenings 1
	S65-35SCR2	65% Silt	35% Screenings 2
	S65-35SCR3	65% Silt	35% Screenings 3
50% (CLAY)	C50-50SCR1	50% Clay	50% Screenings 1
	C50-50SCR2	50% Clay	50% Screenings 2
	C50-50SCR3	50% Clay	50% Screenings 3
35% (CLAY)	C65-35SCR1	67% Clay	33% Screenings 1
	C65-35SCR2	65% Clay	35% Screenings 2
	C65-35SCR3	65% Clay	35% Screenings 3

Moisture Sensitivity

Soil support values are inherently sensitive to the presences of moisture. The widely used measure of soil support for pavement construction is the CBR, and it is measured after 96 hours of soaking to represent the worst case scenario. Resilient modulus values, a mechanistic measure of support, could also be measured at a higher moisture content than optimum. To assess this moisture sensitivity, resilient modulus values were measured at both OMC and at a high moisture, wet of optimum. Since the density of the sample also plays a significant role, the density for both tests (at OMC and high moisture) was kept at or close to MDD. The degree of saturation, which combines moisture and density, was used as the variable for the analysis. The degrees of saturation of the tested samples were calculated using the compacted sample moisture content, density, and specific gravity values. The wet of OMC was adjusted to achieve a degree of saturation above 90% for each sample. The samples prepared at OMC and MDD usually give a degree of saturation from 60% to 80%. A linear interpolation or extrapolation was used to estimate the resilient modulus at the desired degrees of saturation.

Subgrade Support Evaluation

The improvement of subgrade was envisioned to involve in-place mixing of No. 10 screenings at different proportions to improve the load carrying capacity as measured by the CBR or resilient modulus. These measures of subgrade support condition are usually very sensitive to the in-situ moisture condition. Some of the pavement design approaches consider a worst case scenario of a fully saturated condition, but in reality most pavement stays in an unsaturated condition for most of its design life, depending on the soil type and environmental condition.

The subgrade support value is often influenced by the moisture condition, especially for poor soils such as fat clay (CH) and elastic silts (MH). These soils are usually considered unsuitable because they exhibit a significant loss of support when saturated. Although they are constructed at OMC and compacted to MDD, most reach an equilibrium moisture condition within a few years of construction (Zapata et al., 2009). This equilibrium condition depends on the soil water characteristic curve (SWCC) and climatic condition. The SWCC is defined by the index properties of the respective soil. The climatic condition encompasses precipitation, evapotranspiration, moisture availability in the soil, and the proximity of the ground water table (GWT). The seasonal variation because of rain events usually cycles around this equilibrium condition and is small compared to the initial moisture adjustment. The backcalculated subgrade modulus from testing with a falling weight deflectometer after several years of construction would most likely represent this equilibrium condition.

The new *Mechanistic-Empirical Pavement Design Guide* (MEPDG) (ARA, 2004) exclusively uses resilient modulus in addition to other soil index properties to characterize the subgrade soil and other unbound (base and subbase) layers. An enhanced integrated climatic model in the MEPDG is used to account for the moisture changes of unbound layers during the design life of the pavement. In general, this model predicts an equilibrium moisture condition (in terms of degrees of saturation) for the unbound layer and adjusts the resilient modulus accordingly. This equilibrium condition usually occurs within the first few months to a few years of construction and has a more pronounced moisture effect than the usual seasonal variations. Therefore, the MEPDG design approach does not always consider the worst case scenario of complete saturation as in the soaked CBR; rather, it considers site-specific conditions to calculate the moisture equilibrium. Both the worst case scenario as depicted by the soaked CBR and the moisture equilibrium approach adopted by the MEPDG were considered for this study.

Matric suction at the equilibrium moisture condition (equilibrium matric suction) was determined using the enhanced integrated climatic model as described in the MEPDG for each blend of subgrade and No. 10 screenings. The equilibrium degree of saturation was predicted as a function of matric suction from SWCCs.

Matric suction dictates the equilibrium moisture condition according to the SWCC, which represents the water storage capacity in the pores of the soil structures with respect to the suction as a result of the unsaturated condition. There are several prediction models for SWCCs, and most of them are based on empirical correlation. The MEPDG used the sigmoidal model proposed by Fredlund and Xing (1994). A series of SWCCs are provided in the MEPDG with varying soil index properties, as presented in Figure 4. For plastic soil, the SWCCs vary with wPI, where w = % passing No. 200 sieve (in decimals) and PI = plasticity index. For non-plastic materials, SWCCs vary with the value of D_{60} (particle size in millimeters for which 60% of materials are finer).

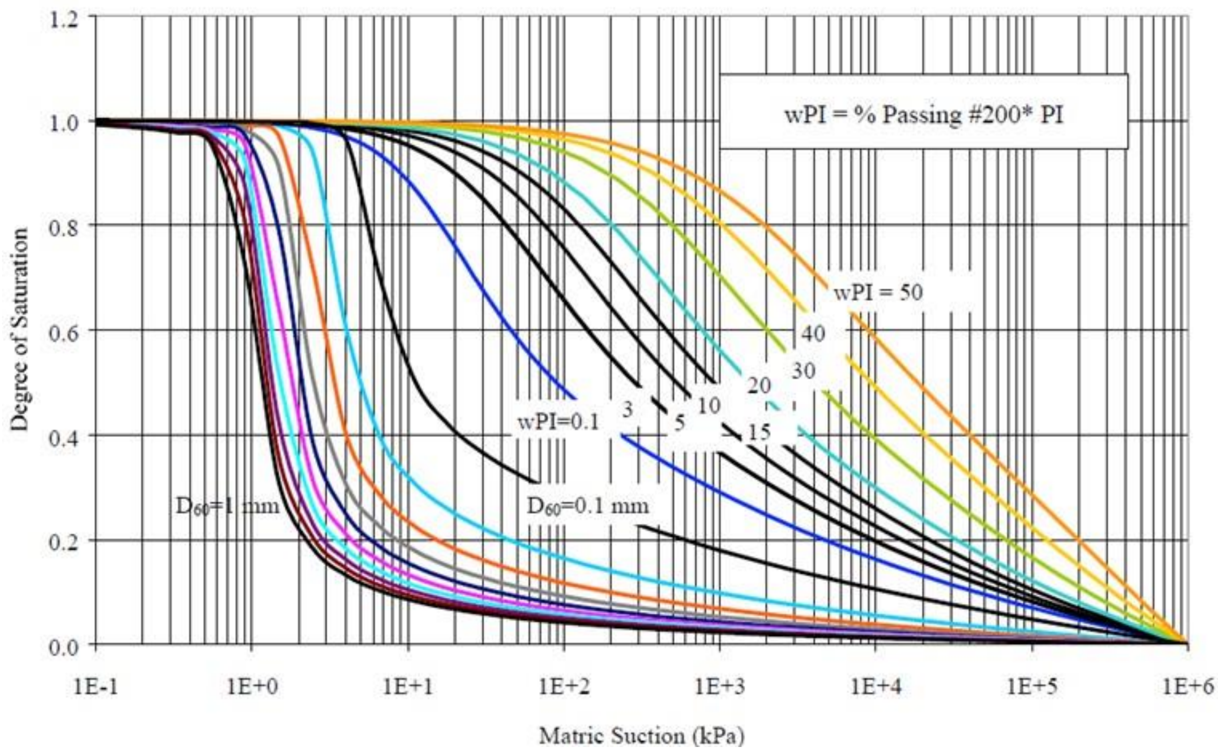

Figure 4. Predicted SWCCs (Soil Water Characteristic Curves) Based on D_{60} and wPI. D_{60} = particle size corresponding to 60% finer; wPI = product of % passing No. 200 sieve (in decimals) and plasticity index (PI). From ARA, Inc., ERES Consultants Division. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Final Report, NCHRP Project 1-37A. Appendix DD-2: Resilient Modulus as Function of Soil Moisture. Transportation Research Board of the National Academies, Washington, D.C., 2004, Figure 13, p. DD-2.34. Copyright, National Academy of Sciences. Reproduced with permission of the Transportation Research Board. (http://onlinepubs.trb.org/onlinepubs/archive/mepdg/guide.htm).

Prediction of Equilibrium Matric Suction

The equilibrium matric suction was predicted in accordance with the models presented in the MEPDG: the GWT model, and the Thornthwaite moisture index (TMI) model. The TMI model is used in the later versions (Versions 0.9 to 2.6) of the MEPDG (Darter et al., 2006), and the GWT model was used in the older version (ARA, 2004); both of them are discussed here. These models were used to predict matric suction and equilibrium moisture condition for both subgrade soils along with the respective 35% and 50% blends.

GWT Model

The older version of the MEPDG (ARA, 2004) used a very simple model to predict matric suction of soil as a function of only GWT depth from the point of interest in the subgrade in accordance with Equation 1:

Matric suction (kPa) = Depth of ground water table (m) × Water density (9.81 kg/m^3) [Eq. 1]

Matric suctions and equilibrium moisture conditions were determined for GWT depths of 1 m, 3 m, 5 m, and 10 m for both subgrade soils and their respective blends.

TMI Model

Subsequent research (Zapata et al., 2009) indicated that the simplified GWT model has a very high prediction error and there is a limited effect of the GWT when the depth is more than 3 ft. The authors suggested a new model, presented in Figure 5, incorporating the TMI and soil properties to predict matric suction, i.e., the TMI-P_{200}/wPI model for subgrade materials

where

TMI = Thornthwaite moisture index
P_{200} = % passing No. 200 sieve
w = % passing No. 200 sieve (in decimals)
PI = plasticity index.

From a field investigation (Zapata et al., 2009), this model accurately predicted the actual field condition and was later incorporated into Version 0.9 of the MEPDG (Darter et al., 2006). The TMI for Virginia varies from 20 to 40 according to the map presented by Thornthwaite (1948). Therefore, matric suction and respective equilibrium moisture conditions were determined for TMIs of 20 and 40. Again, both subgrade soils and their respective blends were considered for this model.

RESULTS AND DISCUSSION

Literature Review

In 2013, Stroup-Gardiner and Wattenberg-Komas provided a comprehensive review of practices regarding the use of recycled materials and byproducts in highway applications in an NCHRP Synthesis Report. One of the byproduct materials considered were QBs, with screenings being one of them. It was estimated that Virginia produced 5 million tons of QBs in 2000, which included screenings, settling pond fines, and baghouse fines.

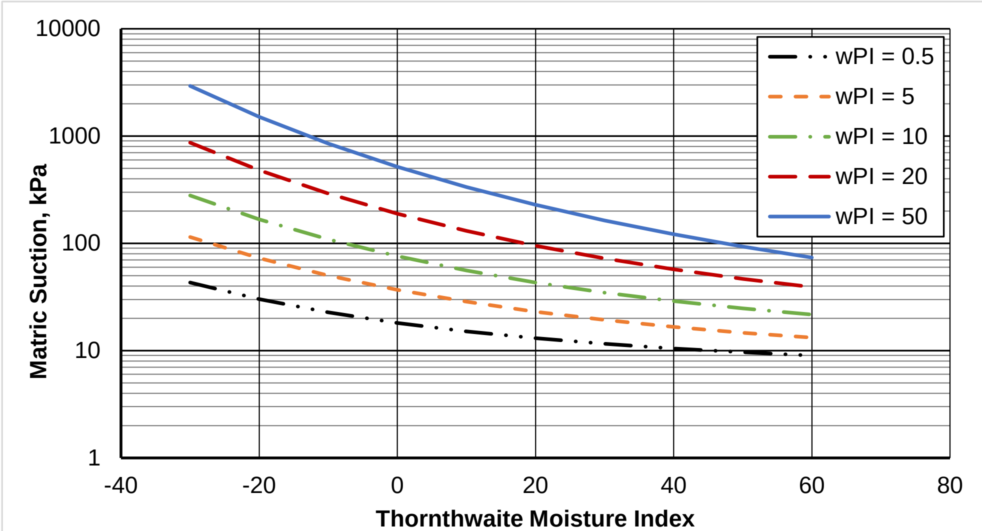

Figure 5. TMI model for Predicting Matric Suction for Subgrade Materials. Adapted from Zapata et al., 2009.

Many barriers to the use of these products were mentioned, including the lack of definition (product characterization), no best practice guide, inadequate knowledge of local availability, and source variability. Trucking costs for long haul and additional processing to remove some of the fines added a significant cost to these otherwise waste materials. The authors reported a survey of screening use by state DOTs, and the following seven uses were identified:

1. drainage material, 6 states
2. embankment, 5 states
3. flowable fill, 8 states
4. hot mix asphalt, 25 states
5. surface treatment, 11 states
6. portland cement concrete, 7 states
7. soil stabilization, 1 state.

Qamhia et al. (2018) explored the use of QBs in pavement base, subbase, and subgrade improvements. They considered both bound and unbound applications. Two unbound applications were (1) to use QBs to fill the voids in a large stone base/subbase to increase stability, and (2) to add QBs as fines up to 15% total in dense-graded base/subbase. These were constructed over a soft subgrade of CBR $\leq$ 1 as construction platform and low volume road applications. QBs were also used in stabilized applications with 3% cement or 10% fly ash as base or subbase and a base with 70% QBs and 30% coarse recycled asphalt pavement or recycled concrete aggregate. Stabilized sections were constructed over a subgrade with an unsoaked CBR of 6 for applications on low to medium volume roads. Sixteen full-scale sections were built at the Illinois Center for Transportation's (ICT) accelerated loading facility with a super single wheel load of 10,000 lb loaded for 135,000 passes. Fatigue and rutting were monitored during loading, and performance was evaluated using a falling weight deflectometer and a dynamic cone penetrometer. At the end of the loading experiment, forensic investigations were done by trenching. Field test sections were constructed on poor subgrade with a 21-in test layer capped by 3 in of conventional base aggregate. Two-lift construction of large stone aggregate with QB fines resulted in higher rutting than single-lift construction. All sections showed satisfactory results and improved rutting performance, indicating suitable applications for QBs. The cement-stabilized QBs with recycled asphalt pavement or recycled concrete aggregate performed the best.

Studies have been conducted in India to improve subgrade using QBs. Anjana and Johnson (2019) used quarry fines along with oxides of calcium and aluminum to improve poor quality clay subgrade. In this stabilized application, sizes of quarry fines were 100% passing the No. 40 sieve, and different combination of fines and oxides were used to stabilize the clay. The unconfined compressive strength was used as the measure for clay subgrade improvement. A combination of 40% quarry fines with 6% calcium oxide and 1% aluminum oxide achieved an unconfined compressive strength of 53 psi compared to 4 psi for clay soil only; this stabilized soil retained a strength of about 13 psi after seven cycles of wet and dry conditions. With the use of only 40% quarry fines a strength of 22 psi was achieved with no residual strength after seven cycles of wet and dry conditions. In another study, Kumar and Biradar (2014) showed an increase in CBR from 1.8 to 4.2 with 40% quarry dust in a clay soil. Agarwal (2015) investigated the use of stone dust to improve the soaked CBR of a clay soil. The soaked CBR of clay (USCS classification CL) and stone dust (USCS classification SP) by themselves were 1.95 and 11.5, respectively. When stone dust was mixed at 30% with clay, the soaked CBR was only 2.91. Although this was a minor or negligible improvement in CBR, density (MDD) increased and water need (OMC) decreased.

Mwumvaneza (2015) explored the use of QBs as a pavement layer in a sustainability study at the University of Illinois at Urbana-Champaign. QBs by themselves showed a strength too low to be used as an effective unbound pavement layer but when stabilized with cement and Class C fly ash, strength improved greatly, in the range of 10 to 30 times. Such a stabilized application provides a sustainable use of a waste material such as QBs and optimizes energy consumption.

Pedarla et al. (2015) studied the improvement of soft clay subgrade by mixing with clean sand. A fat clay (USCS classification CH) subgrade was modified by mixing industrial silica sand with particle sizes between 0.92 and 0.95 mm. As expected, the inclusion of sand particles made the soft clay a stronger and stiffer material. Unconfined compressive strength was improved from 25 psi to 40 psi for a 50% sand mixture in laboratory-prepared samples. Laboratory samples were also tested for resilient modulus; the average value increased from 7,252 psi to 17,405 psi for a 50% sand mixture. Sand was mixed at different proportions to investigate the appropriate proportions for a field application in a low volume road design. In the resilient modulus test, strain-softening behavior was observed for mixtures with up to 10% sand and strain-hardening behavior was observed for mixtures with 10% to 50% sand, behaving more like a granular material.

Puppala et al. (2012) presented a field demonstration of the use of limestone QB as base material in a Texas DOT roadway project. As the QB showed a low strength and modulus in the laboratory testing, it was stabilized with 2.3% cement to use as the base material in the field demonstration project. Stabilization increased the unconfined compressive strength from 17 psi to 209 psi, and it reduced the vertical swelling strain from 6% to 0%. The stabilized materials behaved more like a granular material in the resilient responses and were used to construct a base layer in a field project.

Rupnow et al. (2010) conducted a study to investigate the use of limestone screenings as a structural subbase layer on a low volume unpaved roadway in Iowa. Limestone screenings were stabilized using 30% cement kiln dust (CKD) and a combination 15% CKD and 15% fly ash. Although the 30% CKD section failed due to cycles of freezing and thawing, the 15% CKD +15% fly ash section showed good durability and performed well. There were two controlled sections of unstabilized screenings, and they also performed well on the low volume road.

In summary, the trend is to use QB as some sort of stabilized base or subbase layer. As mentioned previously, this study was limited to the unbound application of QB as a modifier to poor subgrade soil through an in-situ mixing operation.

State DOT Survey

A single-question survey was sent to representatives of all state DOTs through the AASHTO Research Advisory Committee ListServ. A total of 27 states responded to the question, with most states reporting that they do not use No. 10 screenings to amend poor subgrade by mixing. The following states responded to the survey: Alabama, California, Delaware, Georgia, Illinois, Indiana, Kentucky, Louisiana, Massachusetts, Maryland, Maine, Minnesota, Montana, Mississippi, Montana, Nebraska, Nevada, New York, Oklahoma, Rhode Island, Tennessee, Texas, Utah, Washington State, and Wyoming. Table 2 summarizes the responses.

Laboratory Study

Material Selection and Characterization

All materials were tested for soil index properties, which are summarized in Table 3. They were also characterized as subgrade; Table 4 presents these results along with the respective standard Proctor (moisture-density relationship) test results. The two commonly used properties of subgrade for pavement design are soaked CBR and resilient modulus. The soaked CBR test is performed after 96 hours of soaking and theoretically represents the worst case scenario. The resilient modulus test does not have a similar protocol; therefore, the results would be variable and very sensitive to the moisture condition; in this case, tests were conducted at OMC and MDD.

Although a subgrade is usually constructed at the OMC and MDD, it will not stay at the OMC, which makes predicting the actual subgrade support value during the design life of the pavement a challenge. According to the conventional design practice, both subgrade soils mentioned in Table 3 are considered unsuitable based on the poor soaked CBR values. An assessment based on the resilient modulus value would require an estimate of the field moisture condition, which is usually difficult to predict.

Table 2. Survey Responses From State DOTs for Use of No. 10 Screenings

State	Use of No. 10 Screenings[a]	Comments (Verbatim)
Alabama	No	
California	No	Use as un-stabilized and stabilized subbase or base, and as filler for an open graded base.
Delaware	No	Screenings are used in an undercut area that is wet as long as the material meets Borrow Type B specification (less than 10% passing the No. 200 sieve). A fabric is placed on the unstable subgrade then a 2-3' deep bridge lift of screenings is placed. Screenings are placed and compacted in one lift, water is used as needed to facilitate compaction.
Georgia	No	GADOT is currently working with aggregate producers to have a research project/test strips to include some quarry byproduct/screenings in the Graded Aggregate Base.
Illinois	No	IDOT does permit a certain percentage of minus #4 material up to 40%, in their "Aggregate Subgrade Improvement" Special Provision. This is used to create a working platform of which a base layer can be placed when the subgrade is in poor condition.
Indiana	No	INDOT stabilizes soils with cement / or lime in addition to excavation and replacement with granular material.
Iowa	No	The Iowa DOT does not have a similar type of material specified.
Kentucky	No	Use as both un-stabilized and stabilized subbase or base.
Louisiana	No	Louisiana DOT does not use limestone or any other aggregate screenings in base, subbase or subgrades. This is mostly in part due to the fact that Louisiana does not have any mining operations except for sand and natural river gravel.
Massachusetts	No	MassDOT does not have specific requirements that stipulate the use of such material nor specifically state that it can't be used as long as the final product met the specifications.
Maryland	No	MDOT does not use aggregate screenings (No. 10 dust) in any of the applications noted in the survey. AASHTO No. 10 material is used in asphalt mixtures.
Maine	No	MaineDOT allows use of any aggregate type/size (by itself or blended with other aggregates) as long as the resulting material meets DOT spec including gradation requirements. The only specific use for aggregate screenings besides use as a constituent of an asphalt mixture has been to apply them to a layer of Full-Depth Recycled base prior to stabilization with foamed asphalt as a means of increasing the total fines of the material to promote binding of the asphalt.
Michigan	No	It has been used unbound for subbase on the pavement projects and abutment backfill.
Minnesota	Yes	Typically, this material is allowed in all of the applications mentioned in the survey as long as the specifications are met, however DOT does not designate its use.
Missouri	No	It may be used as fill material, but typically not in a base rock.
Mississippi	No	The Mississippi DOT does not utilize aggregate screenings to improve subgrade soils.
Montana	No	Montana DOT does not use aggregate screenings for these applications.
Nebraska	No	We do not use quarry by products in our subgrade or base. We only have ledge rock quarries on the eastern side of the state and screenings end up in our asphalts.
Nevada	No	Nevada DOT does not have a specification to use No. 10 screenings. It may be used as a backfill material if the spec requirements are met.
New York	No	NYSDOT does not use aggregate screenings for any applications. It is possible that contractors may use such material for temporary haul roads or similar.
Oklahoma	No	Oklahoma DOT does not specifically use screenings as a matter of routine or procedure but use aggregates to improve soil conditions or as unstabilized base.
Rhode Island	Yes	Mixing with poor subgrade at certain percentage to improve the condition – Used by contractors to meet gradation in the specifications.
Tennessee	No	No, Tennessee does not use screening for this purpose.
Texas	No	TXDOT specs do not specifically call for the use of screenings as described.
Utah	No	UDOT does not specify the use of crusher fines for use in base, subbase or subgrades.
Washington	No	The Washington State DOT does not use aggregate screening gradations that are similar to AASHTO No. 10 in the base, subbase or subgrade.
Wyoming	No	Wyoming DOT does not utilize aggregate screenings to improve subgrade conditions.

[a] To amend poor subgrade by in-situ mixing.

Table 3. Index Properties of Soil and No. 10 Screenings

Material	Type/Mineralogy (Specific Gravity)	USCS/ AASHTO Classification	D_{60} (mm)	% Passing No. 200 Sieve	LL	PL	PI
Soil 1	Silt (2.989)	ML[a] (Silt with Sand); A-7-6 (17)	-	81.0	47	28	19
Soil 2	Clay (2.832)	CH (Fat Clay with Sand); A-7-6 (27)	-	84.5	53	22	31
Screenings 1	Arch Marble (2.762)	-	1.8	21	-	-	-
Screenings 2	Greenstone (3.055)	-	1.2	6.8	-	-	-
Screenings 3	Granite/Quartz Diorite/Granodiorite (2.682)	-	1.0	14.3	-	-	-

USCS = Unified soil classification system; D_{60} = particle size corresponding to 60% finer; LL = liquid limit; PL = plastic limit; PI = plasticity index; - = Not applicable.
[a] A borderline elastic silt (MH).

Table 4. California Bearing Ratio (CBR) and Resilient Modulus for Selected Soils and No. 10 Screenings

Material	Optimum Moisture Content (OMC) (%)	Maximum Dry Density (MDD) (pcf)	Resilient Modulus[a] (psi)	Soaked CBR (%)
Soil 1 (Silt)	23.2	10 3.2	10 ,942	2.4
Soil 2 (Clay)	18.9	10 6.3	14,168	2.0
Screenings 1	9.2	130.2	6,039	22.9
Screenings 2	11.0	133	5,241	29.1
Screenings 3	10 .1	126.4	5,161	52.5

[a] Resilient modulus at confining pressure = 2 psi, and cyclic deviator stress = 6 psi; sample was compacted at OMC and MDD.

Blend Proportions and Properties

Two blending schemes were used to amend the subgrade soils: 50% and 35%. In addition to the index properties, the blends were characterized for subgrade support values. The properties of the various soil-screenings blends are summarized in Table 5. When non-plastic No. 10 screenings were blended with poor subgrade soils, the following property changes were observed as compared to the virgin soils:

- Decrease in percent passing the No. 200 sieve (85% to 80% to around 50% to 60%).
- Decrease in liquid limit and plasticity index (silt soil, 19 to 12 to 15; clay soil, 31 to 12 to 18).
- Decease in OMC (silt soil, 23% to 14% to 17%; clay soil, 19% to 12% to 15%).
- Increase in MDD (silt soil, 103 pcf to 110 to 117 pcf; clay soil, 106 pcf to 115 to 127 pcf).

- Improvements in soaked CBR, with clay soil showing more improvement than silt soil. In clay, soaked CBR went from 2.0 to more than 10 in multiple blends, whereas silt had negligible improvement. CBR improved in only one blend (Screenings No. 2 with 50% blend), to 6.0 from 2.7. In many empirical pavement design approaches, a soaked CBR represents the worst case moisture scenario in the field.

- Decrease in resilient modulus at OMC for all blends.

As discussed previously, virgin soils would have performed better with regard to resilient modulus if they had stayed at the OMC and MDD conditions as constructed. Both of these soils are considered poor, and they may not stay at OMC in the field. Therefore, further investigation was performed to determine the effect of moisture on the resilient modulus values in the field.

Table 5. Index Properties and California Bearing Ratio (CBR) of Soils, Screenings, and Blends

ID	Blend	% Passing No. 200 Sieve	Liquid Limit (LL)	Plasticity Index (PI)	OMC (%)	MDD (pcf)	Resilient Modulus[a] (psi)	CBR[b] (%)
SCR 1	100% SCR 1	20	Non-plastic D_{60} = 1.8 mm		8.3	130.5	6,039	22.9
SCR 2	100% SCR 2	5	Non-plastic D_{60} = 1.2 mm		9.5	131.6	5,241	29.1
SCR 3	100% SCR 3	11	Non-plastic D_{60} = 1.0 mm		9.0	123.0	5,161	52.5
SILT (ML)	100% Soil 1	81.0	47	19	23.2	10 3.2	10 ,942	2.7
S50-50SCR1 (ML)	50% Soil 1 + 50% SCR 1	58	37	13	15.5	117.4	6,463	2.6
S50-50SCR2 (SC)	50% Soil 1 + 50% SCR 2	49	38	14	16	115.6	6,202	6.0
S50-50SCR3 (CL)	50% Soil 1 + 50% SCR 3	52	37	14	13.8	113.6	9,420	3.9
S67-33SCR1 (ML)	67% Soil 1 + 33% SCR 1	65	41	15	17.4	110 .1	7,546	3.5
S65-35SCR2 (ML)	65% Soil 1 + 35% SCR 2	59	47	19	18.6	10 8.5	11,028	NA
S65-35SCR3 (CL)	65% Soil 1 + 35% SCR 3	61	47	24	18.8	110	9,914	NA
CLAY (CH)	100% Soil 2	84.5	53	31	18.9	10 6.3	14,168	2.0
C50-50SCR1 (CL)	50% Soil 2 + 50% SCR 1	57	31	11	11.9	121.8	10 ,435	11.1
C50-50SCR2 (SC)	50% Soil 2 + 50% SCR 2	48	31	11	12	127.3	12,492	13.2
C50-50SCR3 (CL)	50% Soil 2 + 50% SCR 3	51	30	11	13	119.2	9,018	3.0
C65-35SCR1 (CL)	65% Soil 2 + 35% SCR 1	62	36	16	14.8	117.4	10 ,493	10
C65-35SCR2 (CL)	65% Soil 2 + 35% SCR 2	59	34	14	14.1	122.1	11,168	4.2
C65-35SCR3 (CL)	65% Soil 2 + 35% SCR 3	60	39	18	14.5	115.3	11,130	9.8

OMC = optimum moisture content; MDD = maximum dry density; SCR = screenings.
[a] Resilient modulus at confining pressure = 2 psi, and cyclic deviator stress = 6 psi; sample was compacted at OMC and MDD.
[b] Soaked CBR at OMC and MDD.

Moisture Sensitivity

Resilient modulus tests were also conducted at moisture contents higher than OMC to estimate the moisture sensitivity of soil-screenings blends. The degree of saturation for each sample was calculated from the measured specific gravity, density, and moisture content. The variations in resilient modulus with degree of saturation for silty and clayey soil and associated blends are shown in Figures 6 and 7, respectively. The measured resilient modulus values at OMC and wet of optimum moisture content are presented in Table 6.

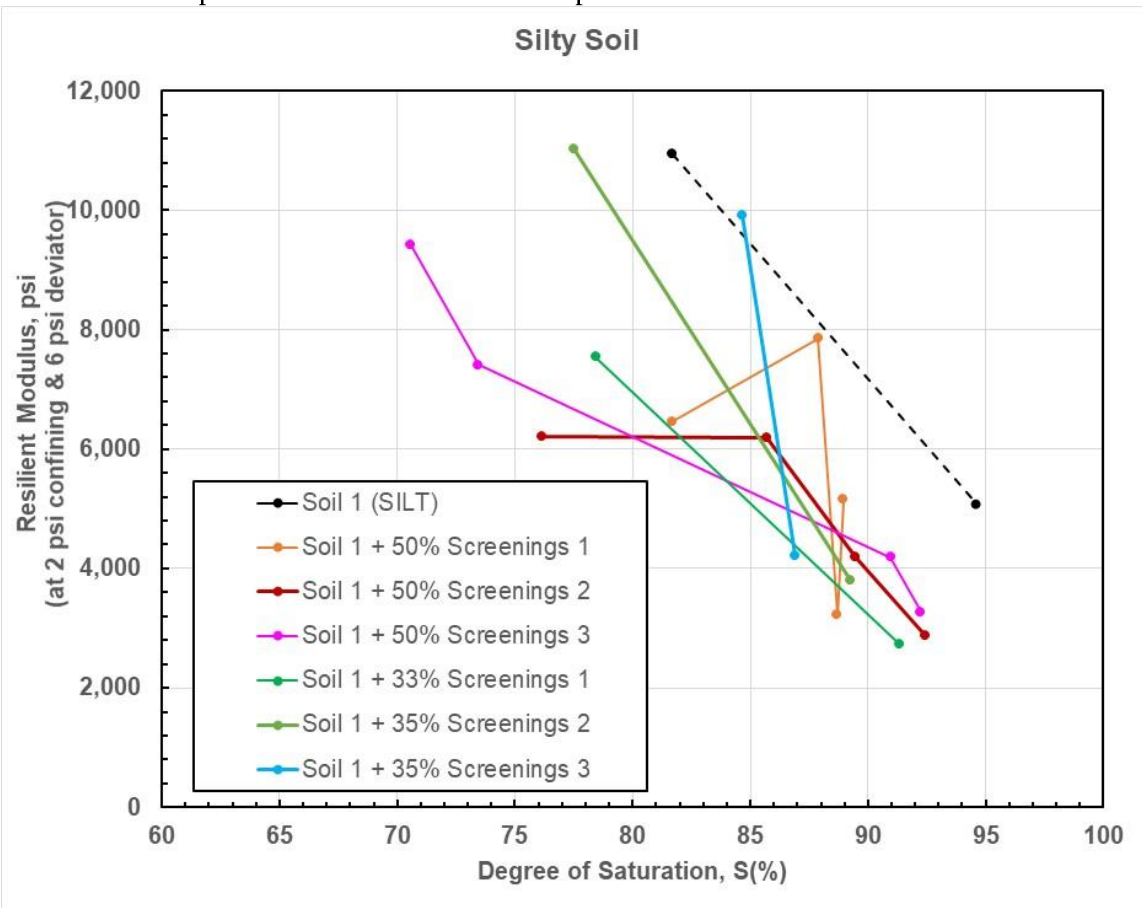

Figure 6. Variation of Resilient Modulus With Degree of Saturation for Silty Soil Modification. S = degree of saturation.

In general, there was a decrease in resilient modulus with an increase in degree of saturation, as evident in Figures 6 and 7 for silty and clayey soils, respectively. Although both moisture content and density influence the modulus value, the increase in moisture after construction will substantially reduce the resilient modulus and make the subgrade support poor/unstable. As the degree of saturation approaches 90%, all blends and virgin soils showed very low modulus, indicating poor subgrade condition. The challenge is to know the actual moisture content in the field during the design life of a pavement. The soaked CBR represents the worst case condition to design conservatively. Some models in the MEPDG predict the field moisture condition. Some of these were considered in this study, and their predicted results are discussed in the next section.

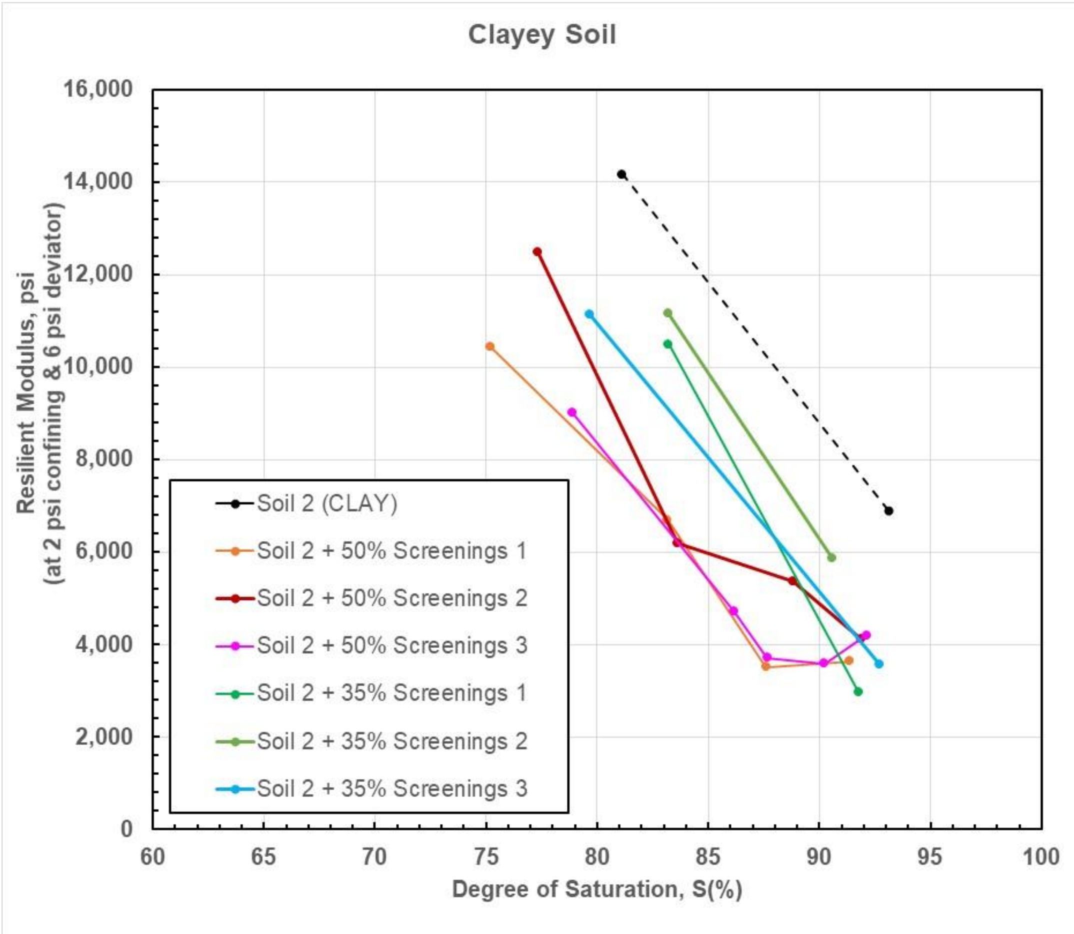

Figure 7. Variation of Resilient Modulus With Degree of Saturation for Clayey Soil Modification. S = degree of saturation.

Table 6. Measured Resilient Modulus Values at Different Degrees of Saturation

Soil Blend	At Optimum Moisture Content (OMC) Degree of Saturation (%)	At Optimum Moisture Content (OMC) Resilient Modulus[a] (psi)	At Wet of OMC Degree of Saturation (%)	At Wet of OMC Resilient Modulus[a] (psi)
SILT	81.7	10942	94.6	5086
S50-50SCR1	81.7	6463	88.7	3218
S50-50SCR2	76.1	6202	92.5	2879
S50-50SCR3	70.6	9420	92.2	3268
S67-33SCR1	78.4	7546	91.3	2733
S65-35SCR2	77.5	11028	89.3	3799
S65-35SCR3	84.7	9914	86.9	4220
CLAY	81.1	14168	93.1	6899
C50-50SCR1	75.2	10435	91.4	3640
C50-50SCR2	77.4	12492	91.9	4129
C50-50SCR3	78.9	9018	92.1	4204
C65-35SCR1	83.2	10493	91.8	2974
C65-35SCR2	83.2	11168	90.6	5873
C65-35SCR3	79.7	11130	92.7	3570

[a] All samples were compacted at 100% maximum dry density of standard Proctor; resilient modulus was calculated at 2 psi confining pressure and 6 psi cyclic deviator stress from the fitted universal constitutive model to the measured values.

Subgrade Support Evaluation

Field Equilibrium Moisture Condition

It is apparent from Table 5 that unsuitable soils would have performed satisfactorily if the subgrade condition could have been maintained at OMC, which is usually not practical in most field conditions. As mentioned previously, the climatic models in the MEPDG (ARA, 2004; Darter et al., 2006) were used to assess the subgrade moisture condition.

Although subgrade is compacted at OMC and MDD during construction, it reaches an equilibrium moisture condition, often something other than OMC, depending on the properties of the subgrade, local climate (evaporation and precipitation), and depth of the GWT. This change in moisture is usually significant compared to the seasonal changes attributable to individual rainfall events. Two models (GWT and TMI) were considered to predict the equilibrium moisture condition in the field, and their results are presented here.

GWT Model

The equilibrium moisture conditions in terms of degree of saturation for all blends were estimated using the information in Figure 4 and the GWT model outlined in the MEPDG (ARA, 2004), as explained previously. The respective degrees of saturation (in decimals) were estimated for GWT depths of 1 m, 3 m, 5 m, and 10 m and are presented in Table 7. As explained earlier, estimation of equilibrium moisture condition is a two-step process: (1) GWT depth dictates matric suction, and (2) the soil index properties, such as percent passing the No. 200 sieve and PI, are used to estimate the equilibrium degree of saturation from the matric suction using the SWCCs in Figure 4.

Table 7. Equilibrium Moisture Condition (Degree of Saturation) as Predicted by the GWT Model

Soil Blend	% Passing No. 200 Sieve, w (in decimals)	PI	wPI	Degree of Saturation at Equilibrium Condition ($S_{equilibrium}$ in decimals) Based on Matric Suction[a]			
				1 m GWT	3 m GWT	5 m GWT	10 m GWT
SILT	0.810	19	15.4	0.98	0.94	0.91	0.83
S50-50SCR1	0.576	13	7.5	0.97	0.88	0.82	0.70
S50-50SCR2	0.486	14	6.8	0.97	0.88	0.82	0.70
S50-50SCR3	0.518	14	7.3	0.97	0.88	0.82	0.70
S67-33SCR1	0.654	15	9.8	0.97	0.91	0.86	0.76
S65-35SCR2	0.588	19	11.2	0.97	0.92	0.87	0.77
S65-35SCR3	0.613	24	14.7	0.98	0.94	0.91	0.83
CLAY	0.845	31	26.2	0.99	0.97	0.96	0.92
C50-50SCR1	0.573	11	6.3	0.96	0.86	0.79	0.68
C50-50SCR2	0.480	11	5.3	0.96	0.85	0.78	0.67
C50-50SCR3	0.511	11	5.6	0.96	0.85	0.78	0.67
C65-35SCR1	0.623	16	10.0	0.97	0.91	0.86	0.76
C65-35SCR2	0.590	14	8.3	0.97	0.88	0.82	0.70
C65-35SCR3	0.602	18	10.8	0.97	0.92	0.87	0.77

GWT = ground water table; PI = plasticity index; wPI = product of % passing the No. 200 sieve (in decimals) and the PI.
[a] Matric suction (kPa) for a water table depth is estimated as (9.81 × GWT depth) in millimeters and is used in Figure 4 to estimate degree of saturation at equilibrium moisture condition.

The equilibrium moisture condition, as predicted by the GWT model (older version of the MEPDG) (ARA, 2004), in terms of degree of saturation was lower for the blends compared to the poor or marginal soils for a GWT depth of 3 to 5 m or higher. Differences in degrees of saturation are more pronounced in the clay blends than silt, compared to the virgin soil. Resilient modulus values were interpolated or extrapolated for the respective degree of saturation from Figures 6 and 7. Some of the interpolated values for different GWT depths are presented in Table 8. The difference in degree of saturation between virgin and blended soil was small for the 1 m and 3 m GWT depth. On the other hand, the 10 m GWT depth yielded some of the conditions similar to or even better than the OMC/MDD conditions.

Table 8. Resilient Modulus Values (Estimated) at Different Degrees of Saturation Corresponding to Different GWT Depths

Soil Blend	% Passing No. 200 Sieve, w (in decimals)	PI	Resilient Modulus at Equilibrium Moisture Condition Corresponding to GWT Depth[a]			
			1 m GWT	**3 m GWT**	**5 m GWT**	**10 m GWT**
SILT	0.810	19	3543	5359	6721	10352
S50-50SCR1	0.576	13	3524	5421	6686	9217
S50-50SCR2	0.486	14	2758	4471	5613	7898
S50-50SCR3	0.518	14	2347	4553	6024	8966
S67-33SCR1	0.654	15	616	2856	4722	8455
S65-35SCR2	0.588	19	N/A	2117	5195	11351
S65-35SCR3	0.613	24	N/A	N/A	N/A	N/A
CLAY	0.845	31	3329	4542	5149	7576
C50-50SCR1	0.573	11	760	5316	8505	13517
C50-50SCR2	0.480	11	1220	7277	11131	17188
C50-50SCR3	0.511	11	1417	5858	8684	13125
C65-35SCR1	0.623	16	N/A	3643	8046	16851
C65-35SCR2	0.590	14	1274	7721	12019	20616
C65-35SCR3	0.602	18	1067	3973	6879	12691

GWT = ground water table; PI = plasticity index; N/A = not available.
[a] Extrapolated resilient modulus values corresponding to respective degrees of saturation.

TMI Model

According to the TMI model, the equilibrium condition depends on the local weather condition as defined by the TMI, which is an indication of local evapotranspiration and precipitation. For Virginia, the TMI varies from 20 to 40 (Thornthwaite, 1948). For these TMI values, matric suctions and respective degrees of saturation were determined using Figure 5 and Figure 4, respectively. The equilibrium degrees of saturations are presented in Table 9. Similar to the previous model, resilient modulus values were extrapolated or interpolated from Figures 6 and 7 for the equilibrium moisture conditions, and the values are presented in Table 10.

Table 9. Equilibrium Moisture Condition as Predicted by the EICM

Soil Blend	% Passing No. 200 Sieve, w (decimals)	PI	wPI	Equilibrium Moisture Condition[a]			
				Matric Suction (KPa)		Degree of Saturation ($S_{equilibrium}$ in decimals)	
				TMI = 20	TMI = 40	TMI = 20	TMI = 40
SILT	0.810	19	15.4	60	35	0.89	0.93
S50-50SCR1	0.576	13	7.5	30	22	0.88	0.91
S50-50SCR2	0.486	14	6.8	30	20	0.88	0.92
S50-50SCR3	0.518	14	7.3	30	20	0.88	0.92
S67-33SCR1	0.654	15	9.8	37	27	0.88	0.91
S65-35SCR2	0.588	19	11.2	42	29	0.89	0.91
S65-35SCR3	0.613	24	14.7	60	35	0.89	0.93
CLAY	0.845	31	26.2	100	65	0.92	0.94
C50-50SCR1	0.573	11	6.3	25	20	0.88	0.91
C50-50SCR2	0.480	11	5.3	22	18	0.89	0.90
C50-50SCR3	0.511	11	5.6	22	18	0.89	0.90
C65-35SCR1	0.623	16	10.0	40	28	0.88	0.91
C65-35SCR2	0.590	14	8.3	31	23	0.88	0.92
C65-35SCR3	0.602	18	10.8	40	30	0.89	0.91

EICM = enhanced integrated climatic model; TMI = Thornthwaite moisture index; PI = plasticity index; wPI = product of % passing No. 200 sieve (in decimals) and the PI.
[a] Matric suction (kPa) based on the *TMI-P_{200}/wPI model* (Zapata et al., 2009) for Virginia and degree of saturation (S) determined using soil water characteristic curves (ARA, Inc., 2000).

Subgrade Modification

The main objective of this study was to determine the improvement in engineering properties of poor subgrade soil when modified by mixing with QB No. 10 screenings. There were some obvious improvements in the moisture-density relationship: OMC decreased and density increased; the relative comparison of the improvements is shown in Figure 8. Therefore, it is possible to use dry No. 10 screenings to reduce the in-situ moisture of a wet subgrade provided a proper mixing mechanism such as use of a full-depth reclaimer could be employed. The increase in density indicates an improved packing of particles, which may result in stronger material.

The subgrade support values used in the pavement design is the CBR or resilient modulus value. The use of the CBR is common in conventional design and usually represents the worst case scenario when soaked values are considered. On the other hand, resilient modulus has been used in more mechanistic-based design and the moisture sensitivity needed to be considered separately. Both of these approaches were investigated in this study.

Table 10. Resilient Modulus Values (Estimated) at Equilibrium Condition Based on TMI

Soil Blend	OMC and MDD		Equilibrium Condition w/ TMI 20 (Lower Limit in Virginia)		Equilibrium Condition w/ TMI 40 (Upper Limit in Virginia)	
	Degree of Saturation (%)	Resilient Modulus[a] (psi)	Degree of Saturation (%)	Resilient Modulus[b] (psi)	Degree of Saturation (%)	Resilient Modulus[b] (psi)
SILT	81.7	10942	89	7628	93	5812
S50-50SCR1	81.7	6463	88	5421	91	4788
S50-50SCR2	76.1	6202	88	4471	92	3709
S50-50SCR3	70.6	9420	88	4553	92	3572
S67-33SCR1	78.4	7546	88	3976	91	2855
S65-35SCR2	77.5	11028	89	3964	91	2733
S65-35SCR3	84.7	9914	89	N/A	93	N/A
CLAY	81.1	14168	92	7576	94	6362
C50-50SCR1	75.2	10435	88	4405	91	3038
C50-50SCR2	77.4	12492	89	5075	90	4524
C50-50SCR3	78.9	9018	89	4243	90	3839
C65-35SCR1	83.2	10493	88	6284	91	3643
C65-35SCR2	83.2	11168	88	7721	92	4856
C65-35SCR3	79.7	11130	89	5716	91	4556

TMI = Thornthwaite moisture index; OMC = optimum moisture content; MDD = maximum dry density; N/A = not available.
[a] All samples were compacted at 100% MDD of standard Proctor; resilient modulus was calculated at 2 psi confining pressure and 6 psi cyclic deviator stress.
[b] Extrapolated or interpolated (linear) values.

Soaked CBR values were measured on the soil samples and most of the blended materials when No. 10 screenings were mixed with the poor subgrade soils at different proportions. A relative comparison of the soaked CBRs for the blends and soils is shown in Figure 9. Some improvement was observed in CBR values, especially for clay soil with 50% No. 10 screenings, but the results were inconsistent. It is important to note that the CBR test itself is highly variable.

The resilient modulus, the subgrade property used for mechanistic pavement design, was also measured for the blends as well as the soils. As mentioned earlier, the soil-only resilient modulus values at OMC and MDD were higher than for their respective blends, as shown in Figure 10. It is obvious from the figure that virgin soils would perform better than any blends at OMC and MDD, the condition immediately after construction. But these conditions are not sustainable (maintained) for fine-grained soils, as the moisture level changes according to the local climate and soil conditions. Soon after construction, within a couple of years, in-situ subgrade moisture changes to an equilibrium condition. Although there are some predictive models available, there is no definitive way of predicting this condition.

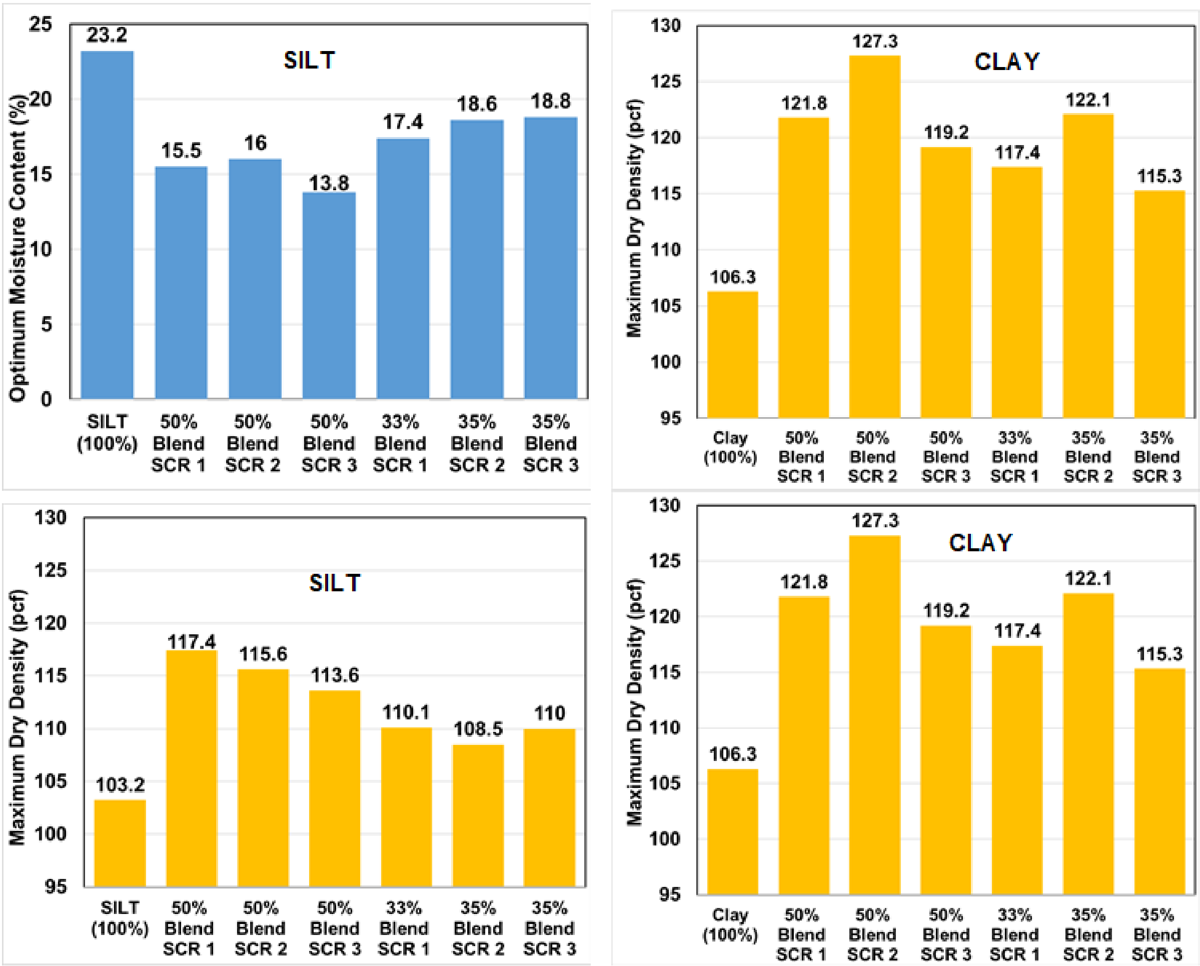

Figure 8. Effect of Blending on Moisture-Density Relationship. SCR = screenings.

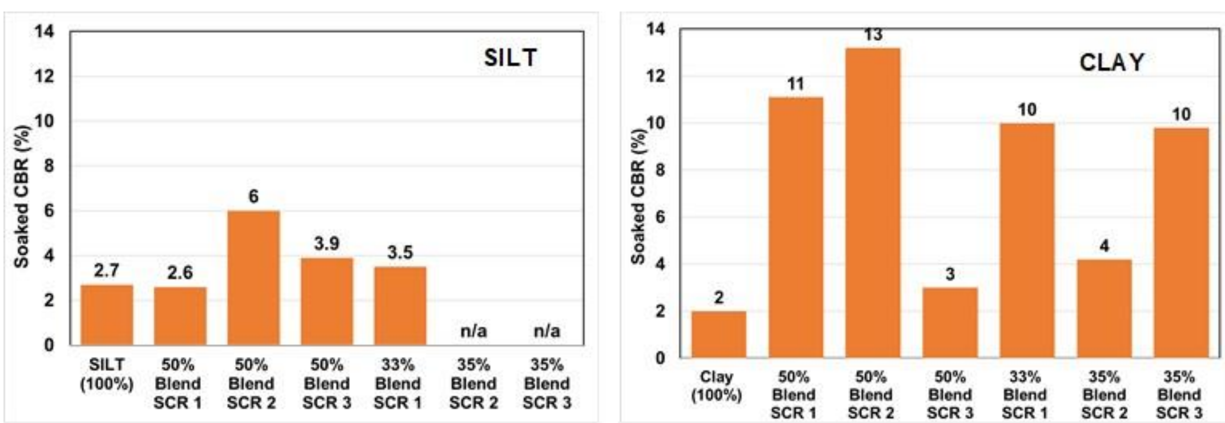

Figure 9. Relative Comparison of California Bearing Ratio (CBR) Improvement for Blended Soil. SCR = screenings.

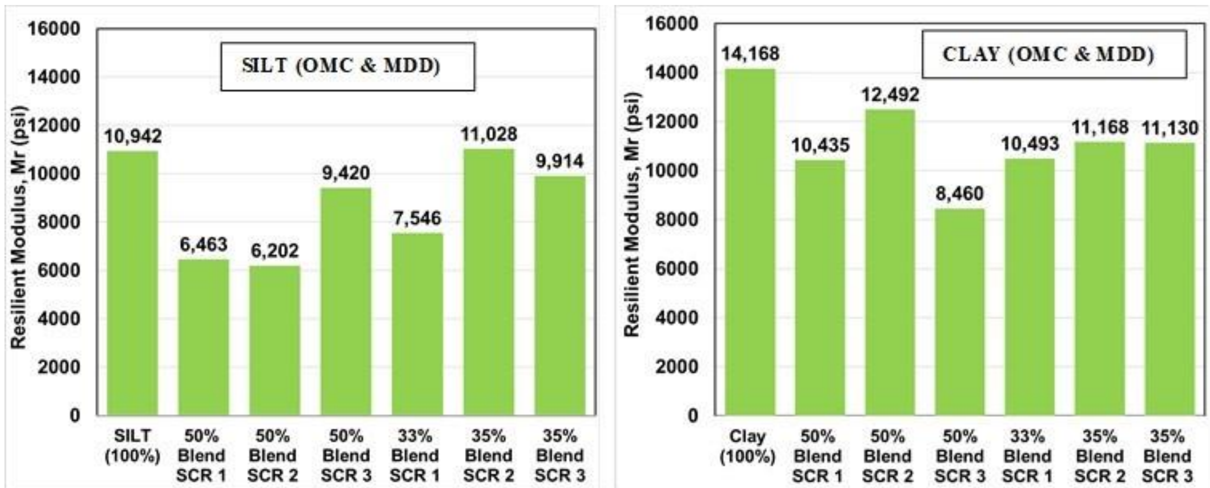

Figure 10. Comparison of Resilient Modulus for Blends at Optimum Moisture Content and Maximum Dry Density. SCR = screenings; OMC = optimum moisture content; MDD = maximum dry density.

As discussed previously, two of these models outlined in different versions of the MEPDG were explored to predict the equilibrium moisture condition. Resilient modulus was estimated for the respective equilibrium moisture condition. Estimated values are presented in Figures 11 and 12 for a GWT depth of 5 m (15 ft) and a TMI value of 40, respectively. Unfortunately, none of the blends showed any improvement over the soils-only case; the clay soil blends were better than silt soils, as also observed in CBR measurements.

The TMI model indicates the equilibrium moisture condition closer to 90%, and consequently none of the options/blends shows any improvement or acceptable subgrade support condition to justify modification. As mentioned earlier, the TMI model does not consider the effect of the GWT as long as it is deeper than 3 ft or so, which may be a limitation of this model. On the other hand, the GWT model does not consider the effects of local evapotranspiration and precipitation. The equilibrium moisture condition directly relates to the depth of the GWT and soil properties. There are some improvements with the clay soil blends when the GWT model is considered for predicting the equilibrium moisture condition whereas the TMI model does not show any improvement.

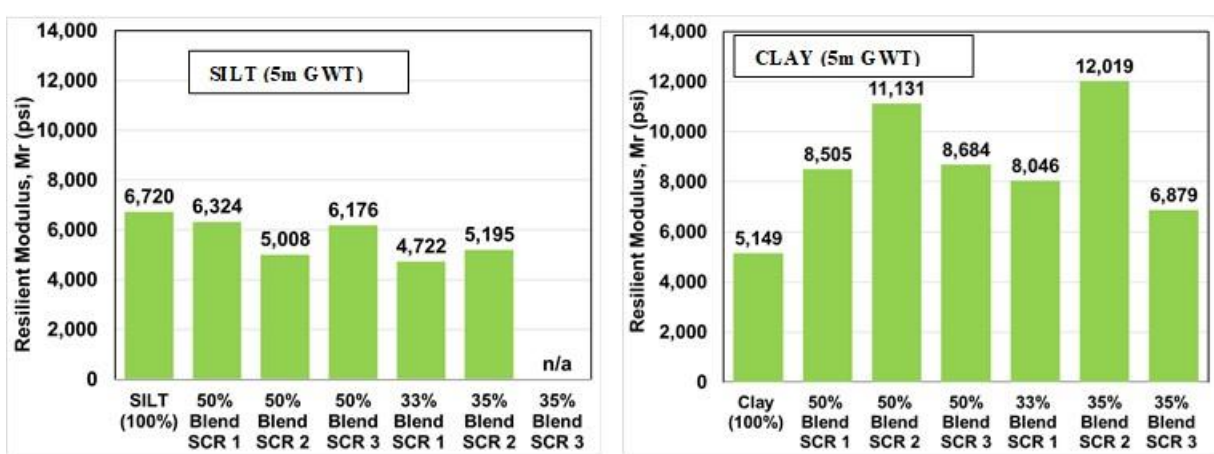

Figure 11. Estimated Resilient Modulus Values for 5 m Ground Water Table (GWT) Depth

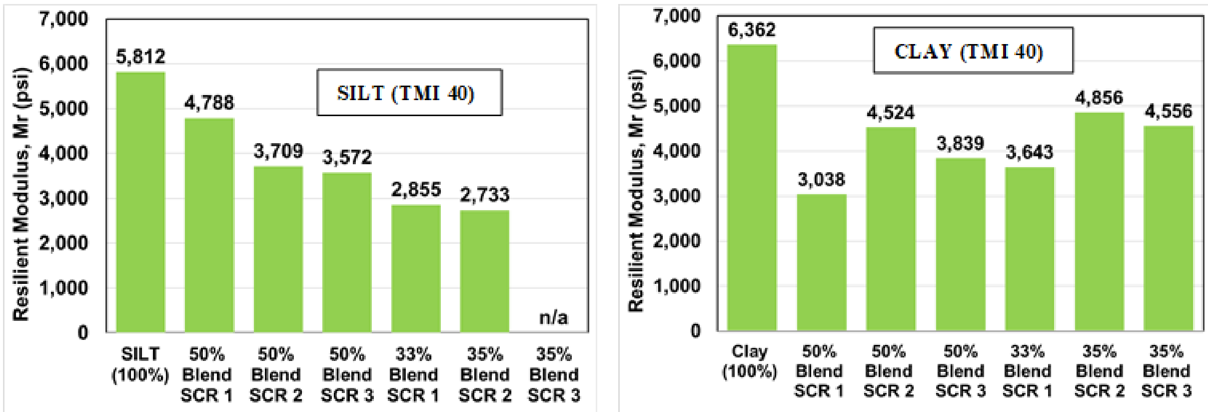

Figure 12. Estimated Resilient Modulus Values for TMI 40. TMI = Thornthwaite moisture index; SCR = screenings.

A few other points may need to be considered in an amendment process of poor subgrade using No. 10 screenings. Mixing screenings with the subgrade soils would require specialized equipment such as a full-depth reclaimer. The cost of screenings depends on their availability in the local market. Therefore, it will be advisable to investigate the cost on a project-by-project basis. In addition, an assessment of the improvement in CBR would be a better indication than the resilient modulus value since actual moisture prediction is difficult. In order to use the No. 10 screenings amendment technique, it will be necessary to predict/assess accurately the equilibrium moisture condition in the field if the mechanistic design approach is followed.

CONCLUSIONS

- *Subgrade amendment using No. 10 screenings did not show any quantifiable long-term benefit in the support condition as measured by the resilient modulus for pavement when the mechanistic pavement design approach is used. However, some improvement in the soaked CBR value was observed for clayey soil subgrade.*

- *In order for VDOT to use the No. 10 screenings as a subgrade amendment, it will be necessary to predict/assess accurately the post-construction changes in moisture (e.g. equilibrium moisture condition) if the mechanistic pavement design approach is followed, as resilient modulus is very sensitive to the moisture condition.*

- *When a fat clay and a marginal elastic silt were amended by mixing with No. 10 screenings at a rate of 35% to 50% by weight, the OMC for compaction decreased, the MDD of compacted soil increased, the plasticity decreased, and the clay soil showed some improvements in the subgrade support value as measured by the soaked CBR.*

- *Resilient modulus was measured lower for the screenings-amended soil compared to just the poor soil at OMC and MDD, which is usually the as-constructed condition. It is important to note that the subsequent moisture change and actual stress condition would dictate the field resilient modulus.*

- *When the field equilibrium moisture condition was predicted using the older version of the MEPDG* (ARA, 2004) *where only the influence of GWT depth was considered, the degree of saturation for modified soil was lower compared to only soil for a GWT depth of 3 to 5 m or higher, which resulted in a higher resilient modulus at the equilibrium moisture condition when the depth of the GWT was higher than 5 m for clayey soil, but silty soil did not show any improvement.*

- *When Version 0.9 of the MEPDG* (Darter et al., 2006) *was used to predict the equilibrium moisture condition in the field on the basis of the TMI model where climatic condition was considered, the degree of saturation was close to 90% or above for both types of soils; no improvement in their resilient modulus values were observed.*

- *The literature review and DOT survey indicated that No. 10 screenings could be used in a pavement structure as stabilized subbase.*

RECOMMENDATIONS

1. *VDOT's Materials Division should consider the use of No. 10 screenings to amend poor fine-grained (mostly clayey) subgrade for secondary roads only on a project-by-project basis, and the improvement should be assessed by the soaked CBR as measured in accordance with VTM-8.*

2. *VDOT's Materials Division, along with VTRC, should explore the use of No. 10 screenings as stabilized base or subbase as indicated in the literature.*

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, the current VDOT specification allows the use for No. 10 screenings in subgrade modification with improvements shown in the soaked CBR for roadways, and it seems consistent with the recommendation from this study. VDOT's Materials Division will review the language and make necessary changes, if any, based on the findings and recommendations of this study by June 2023.

5. Soft ground stabilization

No. 10 Screenings may be used as a replacement or stabilizing agent for soft or unsuitable soils in

> parking areas, under building pads or foundations, or under roadways. In the event soft or unsuitable soils are identified, No. 10 Screenings may replace or be mixed into the soil in a prescribed percentage to improve the bearing capacity of the soil. Replacement shall require confinement by surrounding ground. For mixing, the percentage of screenings to be used shall be determined by sampling the soft/unsuitable soil and mixing with varying percentages of No. 10 Screenings in the laboratory. Proctor samples and CBR samples of each mixture shall be prepared in accordance with VTM-1 and VTM-8, respectively. The mixture resulting in the desired minimum CBR will determine the minimum amount of No. 10 Screenings to be used. Field mixing of the No. 10 Screenings shall be accomplished by layering the appropriate amount of screenings on top of the soft/unsuitable soil followed by blending to a depth of 8 inches to achieve the blend percentage determined in the laboratory. Mixing shall be accomplished by means of a self-propelled or self-powered machine equipped with a mechanical rotor or other approved type of mixer that will thoroughly blend the No. 10 Screenings with the soil (VDOT, 2022).

With regard to Recommendation 2, VTRC and VDOT's Materials Division will develop a research needs statement to consider evaluating the use of No. 10 screenings as stabilized base or subbase and submit it to the VTRC Pavement Research Advisory Committee, Subcommittee C, for consideration.

Benefits

There is no apparent benefit of using No. 10 screenings to amend poor subgrade soil. Marginal improvements were observed for clayey soil, and none was observed for silty soil. The in-situ blending would require specialized equipment, which would be similar to other forms of chemical stabilization such as the use of lime or cement. The cost of No. 10 screenings is variable throughout Virginia, and the improvements with their use are not as obvious as with other stabilization techniques.

ACKNOWLEDGMENTS

The author thanks the members of the study's technical review panel for their contributions: Don French, Lynchburg District Materials Engineer, VDOT, Co-Champion; Tommy Schinkel, Richmond District Materials Engineer, VDOT, Co-Champion; William Bassett, Geotechnical Program Manager, VDOT Structure and Bridge Division; Wansoo Kim, Program Manager, Soils, Aggregates, and Buried Structures, VDOT Materials Division; and Kevin Vaughn, Representative, Virginia Transportation Construction Alliance. The author also acknowledges the help from VDOT's Lynchburg District for collecting and providing samples for the study and from VDOT's Materials Division Soils Lab for conducting tests for the study. The author also acknowledges VTRC technicians Matthew Bray, Ken Herrick, and Jason Oliver for their laboratory work; Rebecca M. Ernest, VDOT Research Library, for conducting a thorough literature search for this study; and Linda Evans, VTRC editor, for her support in reviewing and preparing the report.

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