CAIT-UTC-REG39

FDR Stabilizer Selection Using Simple Soil Tests

Final Report
September 2022

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16. Abstract
Most local agencies that use full-depth reclamation (FDR) choose the stabilizer to be used by selecting a vendor rather than performing test on the pavement materials. Most of the methods available for selecting the technique or additive to be used rely on a sieve test and the plastic index (PI). The PI is not sensitive at the low values found in materials like the glacial tills common across the northeast. However the Sand Equivalent (SE) is more sensitive in those materials and can be performed quickly. Five soils were tested to see if the SE with a sieve test could be used to discern if asphalt emulsion would be a good stabilizer additive for FDR. A proposed new matrix for which stabilizer technique or additive was proposed. Three sets of pavement materials (surface asphalt concrete and base gravels) were then tested to confirm the proposed stabilizer selection matrix. The results confirmed that the SE test may be a good alternative for local agencies trying to decide which stabilizer to use.

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Abstract

Most local agencies that use full-depth reclamation (FDR) choose the stabilizer to be used by selecting a vendor rather than performing test on the pavement materials. Most of the methods available for selecting the technique or additive to be used rely on a sieve test and the plastic index (PI). The PI is not sensitive at the low values found in materials like the glacial tills common across the northeast. However the Sand Equivalent (SE) is more sensitive in those materials and can be performed quickly. Five soils were tested to see if the SE with a sieve test could be used to discern if asphalt emulsion would be a good stabilizer additive for FDR. A proposed new matrix for which stabilizer technique or additive was proposed. Three sets of pavement materials (surface asphalt concrete and base gravels) were then tested to confirm the proposed stabilizer selection matrix. The results confirmed that the SE test may be a good alternative for local agencies trying to decide which stabilizer to use.

Narrative Description

Description of the Problem

Full Depth Reclamation (FDR) is a commonly used technique to improve the quality of the base for local roads and streets. Stabilization is done using mechanical, chemical, or bituminous methods. (*1*) One of the most important steps is choosing the correct stabilizer for the current road conditions. However, the choice of the material to be used is too often based upon discussions with a local vendor or other empirical methods. When we spoke with various local highway agencies about how they chose the stabilizer method, the almost universal response was that the choice was made by selecting a vendor to do the work, not by using field tests to determine the proper stabilizer for the site. This method is backwards from what should be done.

The concept of full depth reclamation is to blend the existing asphalt surface with the base and add stone, chemicals, bituminous materials, or a combination of each to make a new base for the road prior to an overlay. The goal at the end of the process is to have a base that meets the same standards for gravel quality that would be expected if new clean material was imported to make the base. For New York State that would be a fines content of less than 8 percent and low or non-plastic behavior as demonstrated with the plastic limit (PL) or sand equivalent (SE). (*2*)

Previous work with the New York State Department of Transportation showed that the base gravels even under state highways was usually above the recommended limit of 8 percent fines. (*3*) This makes the use of FDR even more valuable as it is less expensive than total reconstruction and utilizes existing materials efficiently. (*4*)

In the northeast United States, the common choices for stabilizer method include:

- Pulverization of the asphalt and base layers to lower the fines content
- Adding aggregate and pulverizing the asphalt and base layers
- Adding asphalt emulsion, foamed or not, to bind up the fines
- Adding salt, typically calcium chloride, to reduce the frost susceptibility
- Adding cement to cement the fine particles and increase strength.

Lime and fly ash are not regularly used in the northeast since few glacial soils have the recommended PI of more than 20. The problem for a small local agency is there is no single test or set of tests that can be used to determine which stabilizer to use. While the common soil tests of grain size analysis and plasticity are used, they have limitations for the low plastic materials found in most base gravels. (*5; 6*) While grain size and percentage are critical, the plasticity of most base gravels are very low and not an indicative method for which stabilizer will actually have the best chances of success.

The Air Force researched the idea of using simple tests to select the stabilizer. To this each, a series of figures was developed to illustrate the steps to determine the stabilizer to be used. The chart for base materials is shown in Figure 1. (*6*) The method showed promise, but upon review three fundamental issues are noted.

One, there was nothing about just adding stone or using the existing asphalt layer as a modifier.

Two, the number of base gravels above 25 percent is small. Three, the lower plasticity cutoff at 6 for bituminous (asphalt) stabilization is very low and the PI is not sensitive at that level.

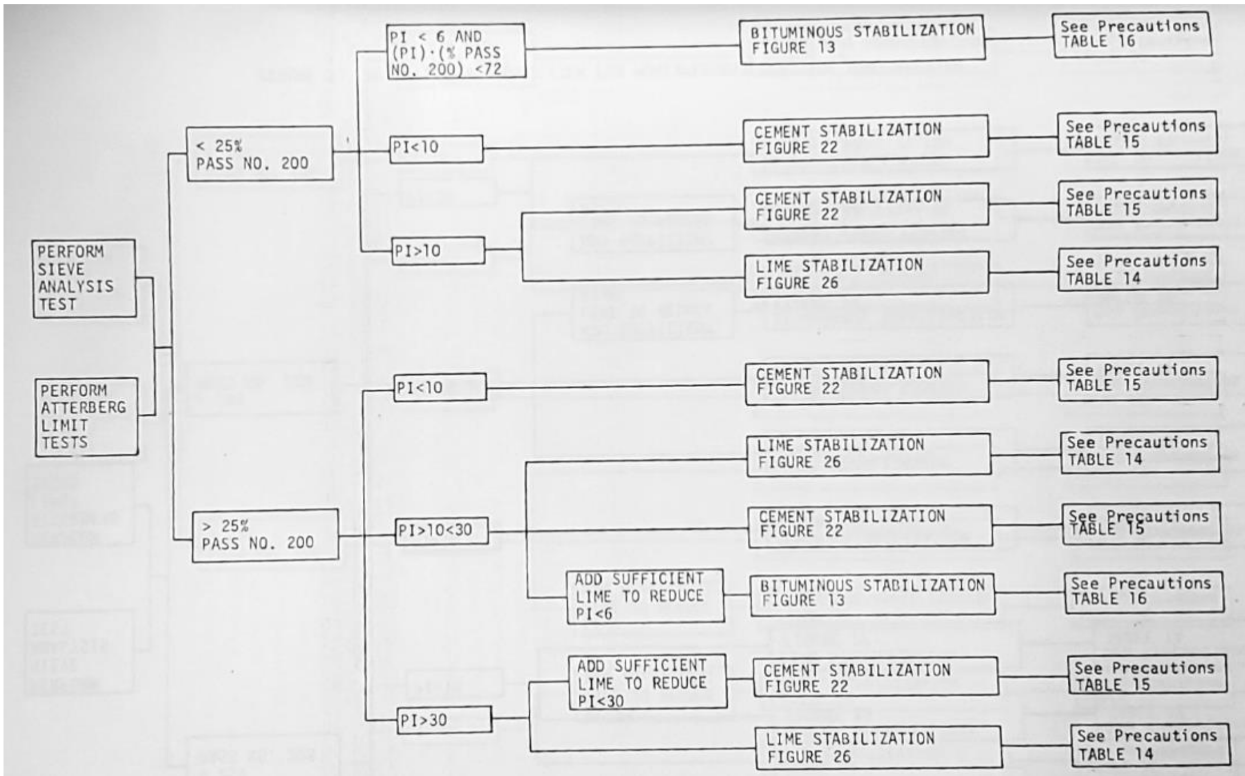

Figure 1. Selection of Stabilizer for Expedient Base Construction

Since the Air Force chart, others have developed updated values, but surprisingly, the 6 PI cutoff still exists even with the most current American Road and Transportation Builders Association (ARTBA) Basic Asphalt Recycling Manual. (*5*)

Finally, Guymon et al (*7*) showed that even a relatively small amount of fines could be frost susceptible if the SE tests was low. This is the basis of the SE requirements in the Cornell recommended gravel specifications. When developing the gravel standards for low-volume roads that are now part of the New York State Department of Transportation Standard Specifications (*8*), the Cornell University Local Roads Program also noted that the sand equivalent (SE) test was more sensitive to minor changes in the clay-like fraction of the fine particles.

There is no effective way for a local agency (or a state agency) to perform simple soil test for determine the proper stabilizer to use in FDR construction. The PI is not sensitive enough and may miss materials that are frost suspectable.

Goal of the Research

Cornell proposed to use the sand equivalent (SE) test with grain size analysis to provide a quick and economical method to allow the best stabilizer to be chosen. The method, if successful, would allow agencies the ability to do two very simple and inexpensive tests to choose the right stabilizer for full-depth reclamation (FDR).

FDR is less expensive than reconstruction and allows reuse of the existing base and surface materials in an efficient and economical way. However, using the wrong stabilizer can cause unanticipated problems and be more costly in the long run.

The initial plan was to perform the applicable tests for asphalt, calcium, and cement stabilization for all of the materials collected. Basic tests, including sieve analysis with a sand equivalent test, along with additional tests were performed on each material to determine the applicability of the possible stabilizing techniques. Once the initial testing was complete, the results were to be used to determine if the proper stabilizer can be selected using only a sieve analysis with a sand equivalent test.

Local agencies were contacted who had upcoming stabilization projects. From at least two different local agencies, samples were obtained. These soils were set aside and tested after the proposed new matrix was complete. This verification was to be a vital part of the research as there would be a very small number of samples of soils to be tested.

Development Process

A literature review was completed to determine if similar work has been done by others and to learn about the testing protocols used for the most common stabilizers in the FDR process. (*1; 5*) The authors also spoke with a few companies in the upsate New York area who do stabilization to see what methods they used to determine the type and amount of stabilizer. While more modern techniques such as the use of gyratory compactors are being used in some cases to test FDR mixes, the old Marshall stability test (*9*) is still commonly used and would meet the needs of this study. It is recommended that a future study look at new testing methods such as use of gyratory compacton to see if there are any differences.

The Cornell Local Roads Program recommends a fines content of less than 8 percent in a subbase gravel with 5 percent being preferred for base gravels. (*3; 10*) The amount of gravel sized particles is recommended to be 50-70 percent. This is illustrated by Figure 2 and Table 1 from the Cornell Local Roads Program workshop manual *Roadway and Roadside Drainage.* For stabilization, this is really an unwritten goal of stabilizing the soil.

Soils for typical base and subgrade conditions and were available for this project. The goals was to ensure a wide range of possible soil types near the each of the preferred range of gravel, sand, and fines for a base. For each of the soils, even if there were previous tests, a new set of sieve, Atterberg Limits, and Sand Equivalent tests were completed. These data were compiled and plotted on a similar triangular chart shown in Table 2 and Figure 3 respectively. The data were sorted by SE test value with high SE as a blue diamond and low SE as a red circle.

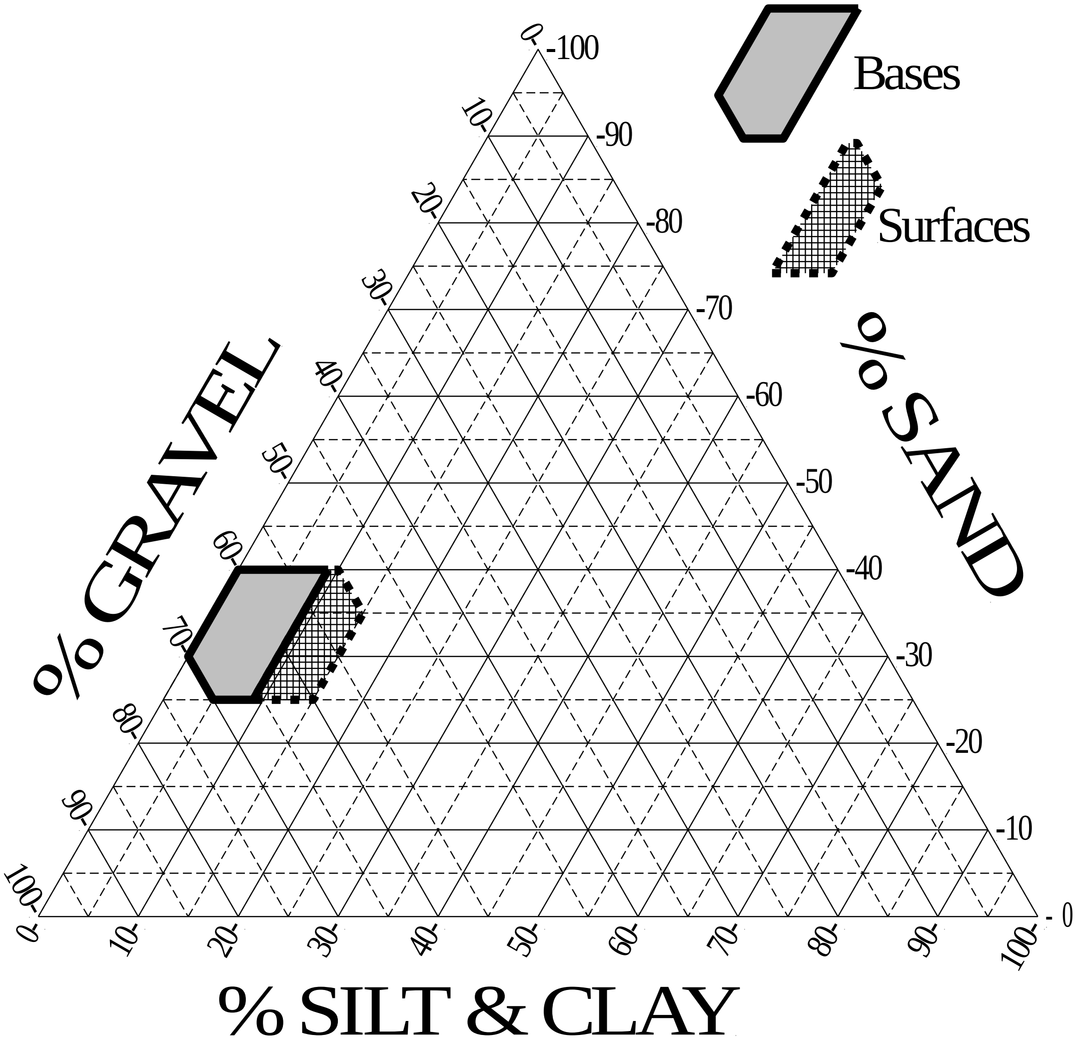

Figure 2. Triangular Classification Chart Showing recommended percentages or base and surface gravels (*10*)

Table 1. Gradations of Gravels for Roads

Soil type	Percentage of materials		Notes
	SURFACE	BASE	
Cobbles	0%	0%	No material larger than 3" should be used
Gravel	50 - 70%	50 - 70%	Same for both surfaces and bases
Sand	25 - 40%	25 - 40%	Same for both surfaces and bases
Fines	8 - 15%	0 - 8%	More fines needed in a surface gravel

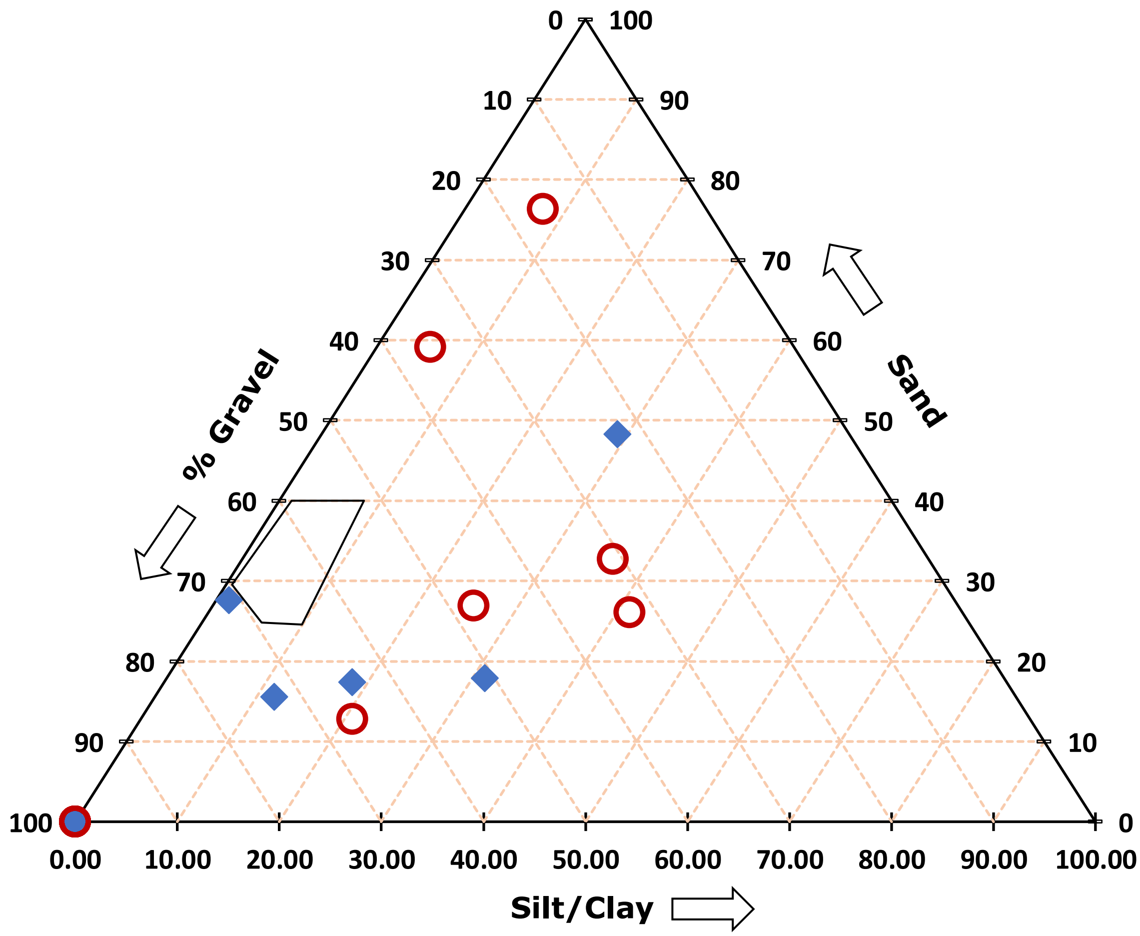

Figure 3. Soils Tested for Possible Inclusion in Stabilization Tests

Table 2. Base and Subgrade Soils Tested

Sieve Percentages			PI	SE	Location	Sample Depth/Name
Gravel	**Sand**	**Silt/Clay**				
16%	76%	8%	4%	4%	BC	#3
36%	59%	5%	1%	8%	NYS 197	6"-1'6"
33%	26%	41%	2%	11%	NYS 357	1-2' below AC
31%	33%	36%		13%	NYS 088 Wayne	1'-2' below asphalt #1
48%	27%	26%	5%	14%	Spencer	1'-2' below asphalt
66%	13%	21%	3%	18%	Orange County	2nd Ft under AC
64%	17%	18%		23%	Spencer	0'-1' base
51%	18%	31%		25%	NYS 088 Wayne	0'-1' below asphalt
73%	16%	12%		31%	NYS 233	0-12" below asphalt #2
23%	48%	29%	NP	33%	Westchester	Bag 2
71%	28%	1%	NP	41%	Jeff County	Rt.5 0.6'-1.6'

Some of the subgrade materials were way too far from the optimum zone (too much sand or fines) or had too high of a PI value to be useful in the study and they were removed. A total of five soils were selected to provide a test of the use of the sand equivalent as an alternative for plasticity in stabilizer selection. It may be worth reviewing these choices in light of the final stabilizer selection matrix.

Sand Equivalent

The sand equivalent provides a measure of the cleanliness of an aggregate and the relative proportion of detrimental clay-like particles in the aggregate. It is a very useful, if underutilized test that is more sensitive in the low plasticity range. The fines passing than the #40 sieve in a gravel mix are soaked and then shaken in a flocculting solution and the particles are allowed to settle out over 20 minutes. The upper portion of the cylinder of material becomes clear over time as shown in Figure 4. The ratio of the total height of the column which contains visble particles (clay reading) to the portion that will support a weight (sand reading) is the Sand Equivalent (SE). The value of the test is that it accounts for the volumetric quality of clays and accoutns for the clay like behavior of silts in a single test. A higher SE value is related to more sand and higer qulaity.

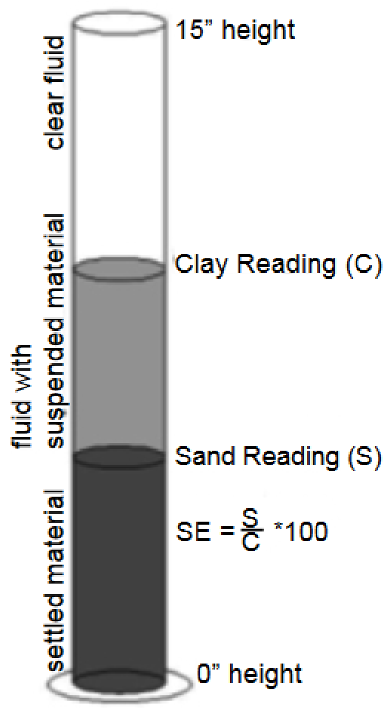

Figure 4. Sand Equivalent Test

Stabizer Methods

The most common stabilizer methods s were chosen and a matrix showing the possible stabilizers for various base fines contents was prepared Table 3 from the literature. The notes columns shows the recommended plasticity. The Basic Asphalt Recycling Manual (*5*) does list the SE test, but it is only as a supplement to the plasticity index (PI) and not as a definative test on its own. Lime, a common stabilizer, is not included in this research due to the lack of use and low PI values in New York State.

The orignal plan had been to test each stabilizing technique from the samples available. This was not done for three reasons. One, there was no real value in doing so for the pulverization, added aggregate or calcium chloride techniqes. In those cases, the results were already driven by the SE test and the fines percentages of the blended mix. Two, the literature was silent on the plasticity and SE test for cement. So when the budget and time became tight, the testing was limited to asphalt stabilization only. For future work, a series of tests for the cement stabilization is recommendaed to confirm the results.

Table 3. Stabilizers Associated with Various Base Fines Contents with Notes Related to Plasticity

Stabilizer	Fines Content	Notes
Aggregate or pulverization	0-10%	SE > 35 / PI < 2
Asphalt	10-18%	PI < 6 (SE>30)
Calcium Chloride	5-20%	SE > 30 Same fines when done!
Cement	12-20%	

For the five selected soils, an optimum moisture and maximum density was determined using a standard Proctor test. Using the protocols from the Basic Asphalt Recycling Manual, a range of added asphalt emulsion was tested with using a soaked (wet) Marshall stability test determine the optimum percentage of asphalt emulsion to be added to the soil. The optimum moisture for the combined added water and asphalt in the emulsion was set as a constant. The plasticity was non-plastic or less than 4 in every single soil tested. The asphalt emulsion selected was the one with the highest stability (load) if it was near the lowest flow (displacement of sample) reading. Even samples with low stability were selected to confirm they would not be good candidates relative to a wet versus dry test.

Samples were 4 inches in diameter and tested on their side in a Marshall stability rig with a load applied by a Universal testing machine. The movement of the head of the testing machine was 1-2 inches per minute as per the standard.

A dry Marshall stability test at the selected asphalt emulsion content was used to determine if the stabilized mix would be a good candidate for stabilization. Several methods have been recommended included setting a minimum level of stability for the dry and wet mixes, the ratio of stability (flow) between the wet and dry methods, and the maximum loading force when dry or wet. Each was problematic but made some intuitive sense. When speaking with the local asphalt companies, the percentage used was based on historical use, and not based upon direct laboratory testing.

As an alternative, an associated modulus was used to determine if the asphalt addition was successful or not. This value is the peak load divided by the area of asphalt slug at the midpoint divided by the strain over the diameter of the stabilized sample. The area is 4 inches (the diameter of the slug) times the thickness in inches. The strain is determined by dividing Marshal Flow number (in inches) by the diameter of the slug (4 inches). This is not a pure modulus measurement, but just allows a comparison between the wet and dry tests. The associated modulus, is shown in Equation 1. The wet and dry data are shown in Table 5.

$$Associated\ Modulus\ (psi) = \frac{Peak\ Load\ (lbs)/4\ (in)*Slug\ Thickness\ (in)}{Flow\ (in)/4\ (in)} \quad (1)$$

If the ratio between the associated modulus for the wet and the dry test was less than 0.25, then it was felt that the mix would not be stable in wet spring thaw conditions and should not be used. The higher the wet to dry ratio, the better the relative stabilization value.

The primary audience is local highway agencies, so a medium traffic level was assumed. Therefore, the final list of criteria for successful addition of asphalt emulsion checked the minimum peak force, the range of stability, and the ratio of the modulus between the wet and dry tests. These are shown in Table 4.

Table 4. Criteria For Asphalt Stabilization Used

Criteria	Minimum Value
Stability (peak force (wet))	250 (51,110 N)
Ratio of dry to wet associated modulus.	0.25

Table 5. Results of Wet and Dry Marshall Stability Tests for Base Stabilization

Sample	Location	Asphalt Emulsion	Fines	SE	Wet		Dry		Modulus Ratio (wet/dry)
					Peak Load	Associated Modulus	Peak Load	Associated Modulus	
		%	%		lbs	psi	lbs	psi	
A	Spencer 0-1	2.4%	19%	23	**319**	425	745	834	**0.51**
B	NYS 233	4.2%	26%	31	**948**	1,820	1,927	4,370	**0.42**
C	NYS 197	3.0%	5%	8	**430**	387	1,673	2,150	0.18
D	Jeff 0.6-1.6	3.6%	1.3%	41	79	124	528	873	0.14
E	Spence 1-2	4.8%	12%	14	**716**	1,020	1,839	3,770	**0.27**

Based upon the literature, sample E should have been a good candidate based upon fines content, sample A would be marginal due to excess fines, samples C and D would be poor candidates due to a lack of fines, and sample B should have been a poor candidate due to excess fines.

The results showed that A and B were good candidates, E was marginal, and C and D were poor candidates. Not having enough fines is a valid reason NOT to use asphalt stabilization which explains samples C and D. The other samples show that PI is not a good measure of whether a soil is a good candidate for soil stabilization. Even at 26 percent fines, sample B showed both excellent peak load wet and dry and high associated modulus. Sample A was also a good candidate even though the SE was less than the recommended value of 30. Sample E was marginal, just above the recommended value of modulus ratio of 0.25 between wet and dry conditions.

Proposed New Chart for Stabilizer Selection

A new chart of stabilizer selection was developed based on these results. It is still recommended that the PI test be performed to confirm the soil is non-plastic or at least very low, but the SE is the driving test. Table 6 shows the new proposed stabilizer use table.

Table 6. Proposed New Stabilizer Selection Associated with Base Fines Contents and Sand Equivalent

Blended Fines Content (Asphalt and base layers a total of 8 inches deep)	Stabilizer	Plasticity (base layer only)[1]
0-8%	Pulverization only	SE ≥ 35
0-12%	Aggregate [2]	SE ≥ 35
8-14%	Asphalt	SE ≥ 25
14-20%	Asphalt	SE ≥ 30 / PI = NP
5-20%	Calcium Chloride	SE ≥ 30 Same fines when done![3]
12-20%	Cement	

[1] Still check the PI, but reality is that the SE is the actual driver

[2] If the blend with the aggregate is less than 8%

[3] Useful for low-volume roads <1,000 vpd with <400 preferred. If above 1,000 vpd, fines needs to be less than 8%.

The percentage of fines for the blended layers of asphalt and base can be estimated by assuming the fines content of the blended asphalt layers is 0. The highway manager only has to account for the thickness of the asphalt and base layers. The final driver when there is overlap (such as in the use of added aggregate) is, of course, economics. The cost for each stabilizer that would meet the criteria should be checked and the lowest overall costs stabilizer should be selected.

It is understood that there may be other mitigating circumstances such as availability of materials or time of year that also may need to be included in the final decision.

Confirming the New Chart

There is not enough data in five test points to be able to make any statistical analysis of the new chart. The three samples from the two local counties were held aside to confirm the final proposed matrix. One sample came from Steuben County, NY and the other two from Lewis County, NY. Table 7 shows the result of the wet and dry stability tests for the two counties.

Based upon the fines and SE values, all three sites should be good candidates according to the new matrix. Most current research would say that neither Lewis site would be a good candidate due to either high fines content (Lewis A) or low SE (Lewis B). The same indirect Marshall Stability tests were performed on the three materials to determine if the updated matrix was valid. The surface asphalt was mixed into the base as the ratio of the exiting site assuming a total depth of 8 inches. For instance, if the existing asphalt layer as 4 inches thick, then 50 percent each of the base and the asphalt layer were blended together for testing.

Table 7. Results of Wet and Dry Marshall Stability Tests for Test Samples from Counties

Sample	Location	Asphalt Emulsion	Fines	SE	Wet		Dry		Modulus Ratio (wet/dry)
					Peak Load	Associated Modulus	Peak Load	Associated Modulus	
		%	%		lbs	psi	lbs	psi	
A	Steuben	3.0%	12%	43	486	5,180	995	10,430	0.50
B	Lewis A	4.1%	30%	63	410	4,360	780	8,820	0.49
C	Lewis B	3.0%	10%	25	457	5,290	579	8,230	0.64

Table 7 shows that all three samples of soils are good candidates for asphalt stabilization. The high fines content of sample B is offset by the very high SE value. Yes, there are fines, but they are mostly silts and can support weight as shown by the SE value of 63.

For asphalt stabilization, there needs to be some fines to allow the asphalt to bind and not act as a lubricant. There appears to be a relationship between the allowable percentage of fines and the SE value. This is included in the new proposed table for stabilizer selection (Table 6)

Conclusions

Overall, this is a relatively small project without enough replicates to make a statistical analysis with significance. However, the results do show that the Sand Equivalent (SE) can be utilized to determine if a particular form of full depth reclamation (FDR) is applicable. Specifically, the SE test when combined with the fines content can differentiate between soils that are good candidates for mechanical, bituminous, or salt-based frost improvement forms of FDR. If a material is not applicable for these then an agency just needs to do a cost comparison between cement stabilization or full depth reconstruction.

It also appears that a single cutoff for asphalt stabilization (currently 18% fines with an SE greater than 30 or a PI of less than 6) is not appropriate. Moreover, there is empirical evidence that a relationship between the SE and fines content may be appropriate for determining when to use asphalt stabilization. It may even be possible to use this relationship to make a first pass and the amount of asphalt to be added to the mix.

For future work there are additional activities which would be helpful.

- Select and test soils with high plasticity and correspondingly low SE values to confirm that SE is the correct tool for selection of bituminous stabilization. Or use the results to determine if there are PI and SE values where PI is the better measure.
- Perform a similar study for cement to see if SE could also be used to determine the limits of cement stabilization.
- Perform post-mortem analysis of the stabilization tests to determine the basic properties of the mix with regard to fines and SE value to confirm the stabilization did improve the base quality to the expected range of low fines and high SE. Does the asphalt stabilization bind the fines or just bind some of them?

Technology Transfer

A key component of this research that is not directly part of the project but is being done by the Cornell Local Roads Program is technology transfer. Below is a list of the items completed or being finalized to spread the word of this project.

Webinars

A webinar on gravel materials was held by the NYS LTAP Center - Cornell Local Roads Program on August 9 using the preliminary results of this study. Future webinars by the program will include these results. Over 50 attendees were registered for the session in August. These sessions will be worth one Professional Development Hour for continuing education credit in New York State.

Presentations

A one-hour presentation on the results of this study and FDR stabilization in general will be submitted for presentation at the winter 2023 New York State County Highway Superintendents Association Conference in Saratoga Springs, NY. Over 50 of the 57 county highway departments across New York State will be in attendance. The sessions will be worth one Professional Development Hour for continuing education credit in New York State.

Demonstration and Pilot Projects

The two agencies who provided the materials for this project will be notified of the results. The Cornell Local Roads Program will work with them as they perform road repairs in 2023 and confirm that the selection of the stabilization method matches the result of this work.

Tech Sheet

A multi-page technical sheet will be prepared and added to the NY LTAP Center’s *Deeper Digs* tech sheet series. It will outline the tests to be performed and provide guidance on using the results as part of a stabilization project. This tech sheet will include the matrix for proper stabilizer which is the primary output from the project. The matrix will allow local agencies to select the proper stabilizer to be used with FDR processes.

TRB paper

A referred paper will be submitted for the 2023 International LVR Conference to be held in Cedar Rapids, IA July 23-26, 2023.

Final Report

This final report meeting the requirements of the Region 2 UTC is submitted at the end of the project and outlines the project. It makes recommendations for improvements with future research. All the records from this project will be submitted to the UTC for future use by all researchers.

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