NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

Chemical Stabilization Subgrade/Base QA Field Manual

Materials and Tests Unit
GeoMaterials Laboratory

Chemical Stabilization
QA Subgrade/Base Field Testing

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North Carolina Department of Transportation
Geotechnical Engineering Unit – Geopavement Section
Materials and Tests Unit - GeoMaterials Laboratory

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Section 1 – Purpose

The purpose of this school is to explain the techniques and procedures for performing QA testing on chemical stabilization operations. The content in this manual contains information regarding chemical stabilization procedures, however, when performing QA testing or sampling, a technician must also be familiar with the *NCDOT Standard Specifications for Roads and Structures* (*Standard Specifications*) and any "Project Special Provisions" concerning chemical stabilization procedures and/or requirements. A thorough understanding of the stabilization procedures cannot be overemphasized since it is necessary in achieving the desired structural performance when the roadway is subjected to traffic loads. Any technician performing Chemical Stabilization QA testing (i.e. obtaining specimen for unconfined compression test or D.C.P.s) must have a valid Chemical Stabilization Subgrade/Base QA Field Certification

Section 2 – Importance of Proper Sampling and Testing

A sample is defined as a "portion, piece, or segment that is representative of a whole". It is therefore important that the procedure(s) used to obtain this small portion not compromise the requirement that it be a representation of the larger portion. This same concept also applies to density testing and chemical specimen obtained during the operation since each test represents a large portion of the roadway.

Section 3 – Types of Chemical Stabilization

Chemical stabilization is utilized to increase the strength or bearing capacity of soil and serve as a moisture barrier in preventing water from penetrating into the pavement structure. Though any area of an embankment could be chemically stabilized, subgrade (top 8 inches below the pavement structure) is generally the only area a stabilization chemical is used. Currently, the Department uses either lime or cement for stabilizing soil. Lime is generally used when the soil contains a high clay concentration and cement typically reacts well with sandy or silty soils.

Section 4 – Monitoring the Operation

In order to ensure proper chemical stabilization of a soil layer, the entire operation should be monitored for compliance with the following:

- Appropriate section(s) of the *Standard Specifications*
- Applicable Project Special Provisions
- Density testing procedures covered in the *Conventional Density Manual*
- Applicable testing procedures listed in ASTM or AASHTO manuals
- Procedures covered in the chemical stabilization training courses

Lime Operation

Once the primary mixing operation is complete, shape and lightly compact the treated area to allow for proper drainage and minimize evaporation. These steps must be taken prior to curing the stabilized area. Cure the stabilized layer for a period of 1 to 4 days while keeping the surface of the treated area moist to prevent drying and cracking. The surface must also be maintained with the proper crown and sealed during the primary cure period. The Engineer can determine the actual duration of cure time with four days being the maximum time period.

Begin final mixing and pulverizing immediately after the final cure period for the full depth of the stabilization. Pulverize and mix material until all clods are broken down to pass a ½ inch (12.7mm) sieve and at least 80 % pass the No. 4 (4.75 mm) sieve. Add water as required to raise the moisture content prior to compaction. Begin the compaction operation immediately after completing the mixing and pulverizing of the treated area. During the compaction operation, maintain the moisture content in the treated area between optimum and optimum plus 2 %. If necessary aerate and dry or add moisture to maintain the desired moisture content. Compact the full depth of the mixture to a density equal to at least **97 %** of that obtained by compacting a sample of the soil lime mixture in accordance with AASHTO T 99 as modified by the Department.

Perform sufficient blading of the treated area to eliminate irregularities and perform final rolling of the completed surface with a pneumatic-tired roller or if permitted a smooth steel wheel roller. Complete shaping, final mixing, compacting and finishing on the same day preliminary curing is completed. Perform work during daylight hours unless otherwise provided in the project special provisions or traffic control plans. If the above work is not completed as specified, rip up the entire section and add additional lime. The compacted thickness of a completed stabilized soil layer will be determined by measurements made in test holes located at random intervals not to exceed 500 feet (152.5 m). Avoid deviating from the measured stabilized thickness to that shown on the plans by more than plus 1 inch (25.4 mm) or minus ½ inch (12.7 mm). If an area is deficient in thickness by more than ½ inch (12.7 mm), remove and replace with lime treated soil having the minimum thickness. However, if the deficiency is not considered sufficient to seriously impair the required strength of the treated soil layer, the layer maybe left in place with a price reduction as determined by the Engineer.

Once the lime-treated area has been compacted, shaped, and finished, it must be protected for a 7-day curing period (final curing) in accordance with the provisions of Section 543 of the *Standard Specifications* and any applicable project special provisions. A completed section may be opened when necessary to lightweight local traffic, provided it has hardened sufficiently to prevent marring or distorting of the surface and provided curing is not impaired. Do not use construction equipment on the treated soil except as necessary to discharge material into a spreader, or as may be otherwise permitted for embankment construction. Maintain the lime-treated soil in an acceptable condition until final acceptance of the project. Perform repairs to lime-treated soil by replacing the full depth of the treated soil layer rather than adding a thin layer of lime stabilizing material to the existing layer.

<u>Cement Operation</u>

Immediately after the cement has been spread, mix with the loosened soil for the full depth of the treatment until a homogenous and uniform mixture is produced. Continue mixing the material until 100 % of the mixture passes a ½ inch (12.7 mm) sieve and a minimum of 80 % passes a No. 4 (4.75 mm) exclusive of any aggregate. Add additional water that is necessary to bring the moisture content to no more than 2 percentage points above or below the optimum moisture content. If the moisture content exceeds the specified range the contractor may, if approved by the Engineer, reduce the moisture content to within the specified range by re-mixing or blading. Avoid excessive concentrations of water as well as wet spots or streaks on or near the surface. After all mixing water has been applied; continue mixing until a uniform mixture is obtained at the required moisture content. Perform the operations of cement spreading, water application, and mixing so they result in a uniform soil, cement, and water mixture for the full depth and width of the area being treated. Re-mix any soil and cement mixture that has not been compacted and finished within 30 minutes.

Immediately begin the compaction operation after the mixing operation is completed. Verify that the moisture content of the mixture is within the desired range (2 percentage points above or below optimum moisture content). Compact the mixture to at least **97 %** of that obtained by a moisture-density test using AASHTO T 134 as modified by the Department. As initial compaction is nearing completion, shape the surface of the treated area to the required lines, grades, and cross-section. Maintain the moisture content of the surface material at not less than optimum during finishing operations. If necessary, lightly scarify the surface to remove any tire imprints or smooth surfaces left by equipment. Continue compaction until a uniform and adequate density is obtained. Perform the compaction and finishing in such a manner as to produce a dense surface free of compaction planes, cracks, ridges, or loose material. When rain causes excessive moisture, reconstruct the entire section.

The compacted thickness of a completed stabilized soil layer will be determined by measurements made in test holes located at random intervals not to exceed 500 feet (152.4 mm). Avoid deviating from the measured stabilized thickness to that shown on the plans by more than plus 1 inch (25.4 mm) or minus ½ inch (12.7 mm). If an area is deficient in thickness by more than ½ inch (12.7 mm), remove and replace the section having the minimum thickness. However, if the deficiency is not considered sufficient to seriously impair the required strength of the treated soil layer, the layer maybe left in place with a price reduction as determined by the Engineer. At the end of each day's construction, form a straight transverse construction joint by cutting back into the completed work to form a true vertical face. Build soil-cement for large wide areas in a series of parallel lanes of convenient length and width meeting the approval of the Engineer. Form straight longitudinal joint at the edge of each day's construction by cutting back into completed work to form a true vertical face free of loose or shattered material. Construct joints to provide a vertical joint having adequately mixed properly compacted material immediately adjacent to the joint. If necessary, cutting back into the previously constructed area during mixing operations may form a longitudinal joint adjacent to partially hardened soil-cement built the preceding day.

After the cement treated base has been finished as specified, cure it in accordance with Section 543 of the *Standard Specifications* and any applicable project special provisions. A completed section may be opened when necessary to lightweight local traffic, provided it has hardened sufficiently to prevent marring or distorting of the surface and provided curing is not impaired. Do not use construction equipment on the treated soil except as necessary to discharge material into a spreader, or as may be otherwise permitted for embankment construction. Maintain the soil-cement in an acceptable condition until final acceptance of the project. Perform repairs to soil-cement by replacing the full depth of the treated soil layer rather than adding a thin layer of cement stabilizing material to the existing layer.

Section 5 – QA Procedures for Chemical Stabilization

When designing a pavement structure, the strength of the soil immediately below the pavement plays a vital role in its overall performance. Inadequate performance of a treated subgrade can be caused by several factors including: improper sampling or laboratory testing during the design phase, inadequate chemical application, inadequate compaction, poor construction practices, and/or failure to protect treated area during the recommended curing period. Failures occurring in the subgrade can result in a failing pavement structure; therefore, during construction QA testing and sampling must be utilized to verify that the treated area will perform as designed.

<u>Density Acceptance</u>

Any technician performing density acceptance testing for chemical treated subgrade or base must have valid Conventional Density Testing Certification or a valid Nuclear Density Certification if testing with a nuclear gauge.

At the beginning of a chemical stabilization operation an inspector should obtain a randomly located soil sample after the primary mixing is completed, but before any additional water is added. The sample should consist of enough material to perform a 4 -point moisture density curve (refer to the *Conventional Density Testing Manual* for curve procedures). Immediately perform the moisture density curve and, if requested, provide the optimum moisture and maximum density information to the geologist or engineer monitoring the stabilization operation.   The inspector should utilize the information from the curve to aid in his/her judgement of optimum moisture when performing density acceptance tests. Once the contractor has completed and finished the chemically treated section and is ready for a density test, perform a long test (test #1) in the area where the bulk sample was taken for the moisture density curve.

Prior to the chemical operation beginning, a subgrade investigation should have been completed during construction when the contractor initially reached subgrade elevation. The investigation will include obtaining soil sample(s) which are taken to either a NCDOT laboratory or a NCDOT certified laboratory for design purposes and are used in determining the type and amount of chemical (lime or cement) needed to achieve the desired strength. A list of NCDOT certified "Geotechnical Laboratories" is provided on Materials and Tests - GeoMaterials (Soils) Laboratory website: https://connect.ncdot.gov/resources/Materials/Pages/SoilsLaboratory.aspx . During the design process the laboratory will utilize the material to perform moisture density curves and make chemical specimen to be tested for strength by performing an unconfined compression test. The information and data determined by the laboratory tests and subgrade investigation can be used to aid the inspector with the following:

- Approximate location of significant variations in soil type
- General knowledge of maximum density
- General knowledge of optimum moisture
- General knowledge of how the soil reacts with the chemical (i.e. strength)

The inspector should use information provided by the laboratory with the understanding that a construction project is dynamic and constantly experiencing changing conditions due to weather, construction processes, etc. As a result, the soil properties in the area to be treated may have changed significantly since it was initially sampled. An inspector must recognize if any significant changes have occurred since the area was initially sampled and perform additional moisture density curves to aid the chemical stabilization operation in the judgment of optimum moisture.

The initial long test and moisture density curve performed at the beginning of the operation will count towards the minimum requirement of 1 long test (Test #1) with moisture density curve for every 15 tests performed. For example, if a total of 75 density tests are required for cement stabilized subgrade, a minimum of 5 tests must be a long test (Test #1) with a moisture density curve for each test. The remaining 70 densities required for the stabilized subgrade can be short tests (Test #1a). Additional moisture density curve(s) (either with or without chemical added) can be performed to provide information to the contractor, engineer, or geologist. Be aware that when performing a moisture density curve on raw soil (no lime or cement additive), its optimum moisture and maximum dry density will change slightly once the chemical agent is incorporated into the soil. For example, when lime is added to soil the maximum dry density will decrease slightly and its optimum moisture will increase slightly. When cement is added to soil the maximum dry density will increase slightly and optimum moisture will decrease slightly. Refer to the latest edition of the *Conventional Density Manual* for density testing procedures. When testing chemically stabilized subgrade (lime or cement), one tanker load is defined as an operation and the frequency for density acceptance testing will be as follows:

- One test per operation (tanker load) for 4 operations or less per day
- One test per two operations for 5 to 8 operations per day
- One test per three operations for 9 or more operations per day

In order to ensure proper hydration and easier compaction of a chemically treated section, the moisture content must be monitored. Proper hydration of the mixture is critical for the treated subgrade to achieve the desired design strength, and maintaining a soil at or near optimum moisture aids in the compaction process since water acts as a lubricant. Adjustments in the amount of water added should be made when the moisture content falls outside the specified tolerances as determined by the data provided from the laboratory. Therefore, when performing a short test (Test #1a) a 300-gram moisture sample must be obtained to determine the in-place moisture content. The results of the moisture test can be recorded on M&T Form 504 with the results of the short test. Additional 300-gram moisture sample(s) can be taken any time during the chemical operation to monitor the moisture content and an experienced inspector, engineer or geologist can and should routinely monitor the moisture content by applying the practices discussed in the *Conventional Density Manual* for judging optimum moisture.

Density Acceptance Test Failures

When a density acceptance test fails to meet the minimum specified density requirement, the contractor may continue the compaction operation. However, the compaction operation must not exceed specified time constraints. If the contractor cannot achieve the minimum density requirement, the failing area can be reconstructed by “sweetening” with the addition of the appropriate chemical (lime or cement) added at a rate of 50 % of the original design rate. The “sweetening” process should be started within 24 hours of completing the first stabilization attempt and will be completed at no cost to the Department. When additional stabilization chemical is applied, it must be placed, mixed, compacted, and finished in accordance with the *Standard Specifications* and any applicable project special provisions. If the contractor fails to meet the minimum density requirement on the second attempt, the design engineer should re-evaluate the area to be stabilized and take the necessary corrective action including possible removal and replacement.

Performance Acceptance

In order to verify if the stabilized subgrade will perform as designed, stabilized soil samples must be obtained during construction for performing an unconfined compression test. The frequency for obtaining soil samples is one specimen every **440 feet (135 meters)** or fraction thereof unless otherwise specified. The soil sample is compacted in a “split” Proctor Mold in accordance to ASTM test D 698.

Equipment

The following equipment is necessary for obtaining a performance acceptance specimen:

Cooler (24 Quart)
Water
Bucket
Large Scoop
Small Scoop
Steel Straight Edge
Cup
Stiff-blade Spatula
50-lb Floor Weight
1/30 cu. ft. Split Mold with Base Plate and Collar
Rammer (5.5-lbs with 12-inch drop)
Soil Pan
No. 4 Sieve
Wire Brush

Procedures

The procedures used for making a specimen are similar to performing an AASHTO T 99 proctor mold as described in the *Conventional Density Testing Manual*. However, when making performance acceptance specimen, the chemically treated soil is compacted in a split mold at the same moisture content as it is being compacted during the compaction operation. Do not confuse this procedure with the density acceptance tests where the soil is compacted in the mold at optimum moisture. Specimen can be obtained once the contractor has mixed the chemical into the soil, completed any necessary adjustments to the moisture content, and is ready to begin compaction of the stabilized area. The following steps summarize the procedures for obtaining performance acceptance specimen:

1. Utilize random numbers to locate a sampling site.
2. Obtain sample after the contractor begins the compaction operation, but prior to any compaction equipment passing over the sampling site.
3. Use large scoop and fill bucket a third to one half full of material.
4. Place material in the soil pan.
5. Apply judgement factors discussed the *Conventional Density Manual* to judge if the material is above or below optimum moisture and record observations in a diary.
6. Immediately compact the treated soil in the 1/30 cu. ft. split mold at the same moisture content as it is being compacted on the subgrade.
   a. Place the 50-lb floor weight on a flat compacted surface.
   b. Spray lubricant in mold.
   c. Place the 1/30 cu. ft. split mold on 50-lb weight.
   d. Compact the first of three equal layers using 25 blows with the compaction rammer. Ensure rammer is applying the correct amount of energy by holding the

rammer vertical and allowing it to drop 12-inches. The rammer should also be routinely checked to verify it meets specification requirements.

   e. Use the stiff-blade spatula to scribe grooves after the first layer is compacted.
   f. Add soil and compact the second layer using 25 blows.
   g. Use the stiff-blade spatula to scribe groves after the second layer is compacted.
   h. Add soil and compact the third layer using 25 blows.
   i. Carefully remove the collar and verify scrape off is between ¼ to ½ an inch over the mold (If not discard and make another specimen).
   j. Use the steel straight-edge to carefully remove soil until it is smooth and even with the top of the mold (if necessary fill in voids with fine material).

7. Once the specimen is completed, inspect it to ensure the top and bottom are flat and scrape off is correct.
8. Carefully place the specimen in a cooler containing a small amount of water covering the bottom.
9. Do not allow the specimen to come in direct contact with the water.
10. Transport the specimen to a humidity room and place it in the room for a seven (7) days curing period (ASTM D 1633).
11. After curing remove specimen from the humidity room.
12. Carefully extract pill from the split mold.
13. Record condition of pill (i.e. is pill cracked or split, is the top or bottom surface irregular, is "scrape-off" correct, etc.).
14. Perform an unconfined compression test (following ASTM D 1633 procedures).
15. Record results and determine if specimen meets or exceeds the minimum requirements.

Unless otherwise specified, the minimum target value for the specimen should be:

- Lime 60 psi
- Cement 200 psi

When utilizing cement for chemical stabilization, the target value or strength <u>should</u> <u>not</u> <u>exceed</u> **600 psi**. Any treated area(s) exceeding this strength limit can result in the subgrade behaving similar to a concrete slab which often creates problems for flexible pavement structures.

If the unconfined compression test does not meet the minimum requirement, Dynamic Cone Penetrometer tests (DCP) can be performed to determine if the entire section fails to meet the minimum performance requirements (refer to Section 6 for DCP procedures). When using the DCP on cement treated section(s), the test must be conducted prior to significant curing or the test may become too difficult to complete.

In order to improve the performance of any remaining area(s) to be stabilized the design engineer can utilize the data from the DCP, preliminary subgrade investigation, and unconfined compression tests to make any necessary adjustments (i.e. increase application rate of chemical agent). The DCP test result(s) should meet or exceed a minimum value of:

- Lime 60 psi
- Cement 200 psi

When utilizing lime for chemical stabilization, a DCP may be performed in place of the unconfined compression test. The DCP should not be performed until the minimum curing time (7 days) has elapsed.

<u>Failure of Performance Acceptance Tests</u>

If a chemically treated area fails to meet the minimum performance requirements based on the unconfined compression test and/or DCP test(s), the design engineer should conduct an investigation to determine the cause(s). During the investigation the design engineer may determine corrective action including “sweetening” the treated section in question with additional stabilization chemical. When additional stabilization chemical is applied, it must be placed, mixed, compacted, and finished in accordance with the *Standard Specifications* and any applicable project special provisions. Additional density and performance acceptance tests must be performed to verify that the corrective action has achieved the desired performance. The design engineer should re-evaluate the data to determine if adjustments in the chemical application rate need to be made in order to achieve the desired results for any remaining areas to be stabilized. During re-evaluation if the design engineer determines that unsuitable soil exists in any area(s) to be chemically treated, he/she may request removal and replacement with a more suitable soil. If necessary consult with the Geopavement Section when dealing with performance failures for assistance in conducting an investigation and identifying possible methods for correcting the problem.

Section 6 – Dynamic Cone Penetrometer (DCP)

The DCP can be used to measure the strength of soil by dropping the 17.6 lb. (8 kg.) sliding hammer for 22.6 inches (575 mm) and measuring the downward vertical movement or penetration of the device. For example, an area with a weak soil will require fewer blows to penetrate a given distance.
Normally, the DCP will only be used on lime-treated subgrades. Soil Cement subgrade DCP investigations can be performed if little curing time has occurred on the subgrade in question.

Testing Equipment and Procedures

Equipment:
1. Cone Penetrometer Hammer, 2 connecting rods & tip (refer to Diagram 1).
2. Pencil & marking stake
3. Masking tape

Important Safety Note:
When using a DCP careful attention should be given to the handling and operation of the device since the hammer weighs over 17 pounds and can cause serious injuries.

Procedures:
1. Assemble parts with the use of the diagram. Make sure connections are tight and secured. Loose connections could result in equipment damage.
2. Place penetrometer gently on testing area with pointed end down.
3. Place marking stake approximately 4”- 6” along the side of the penetrometer. Write station, lane, and reference to grade point on the marking stake to differentiate from future readings.
4. Mark the stake once to show the starting point.
5. Lift the hammer carefully to the top of the small cylinder and release, making sure not to slam the hammer against the top when raising hammer.
6. Mark on the stake the amount of penetration after each drop.
7. Repeat steps 5 & 6 until instrument has penetrated approximately **12 inches** (30 centimeters).

Calculations

The CBR value is determined by the following formula:

$$\mathbf{CBR = 10\wedge^{[1.53 - (Log\ X) * 1.066]}}$$

X = penetration in centimeters

The CBR value can be converted to PSI by using the following formula:

$$\mathbf{psi = ((CBR/.070)\wedge.658)*1.171}$$

Dynamic Cone Penetrometer - Diagram

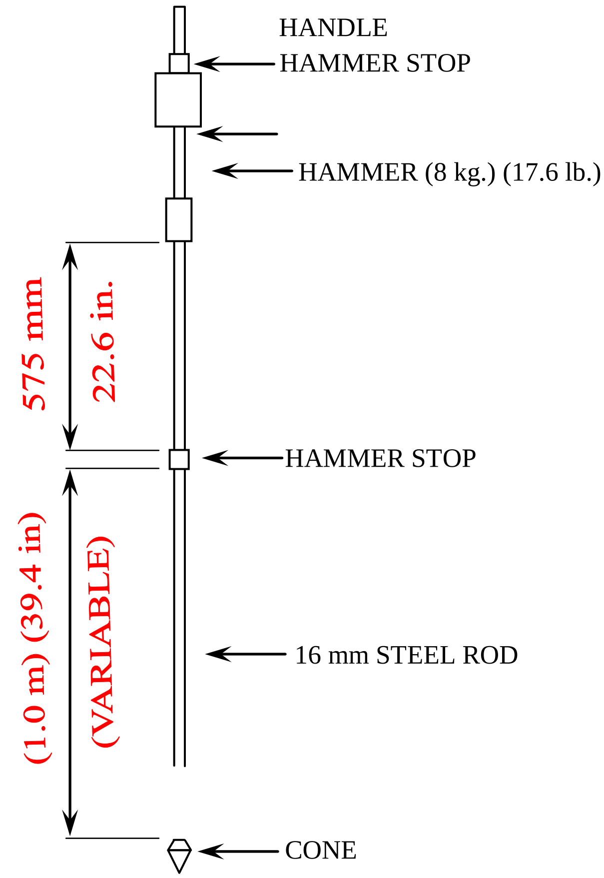


Diagram 1

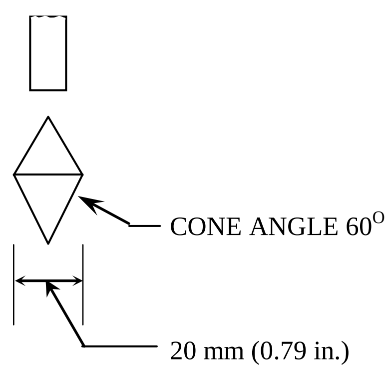
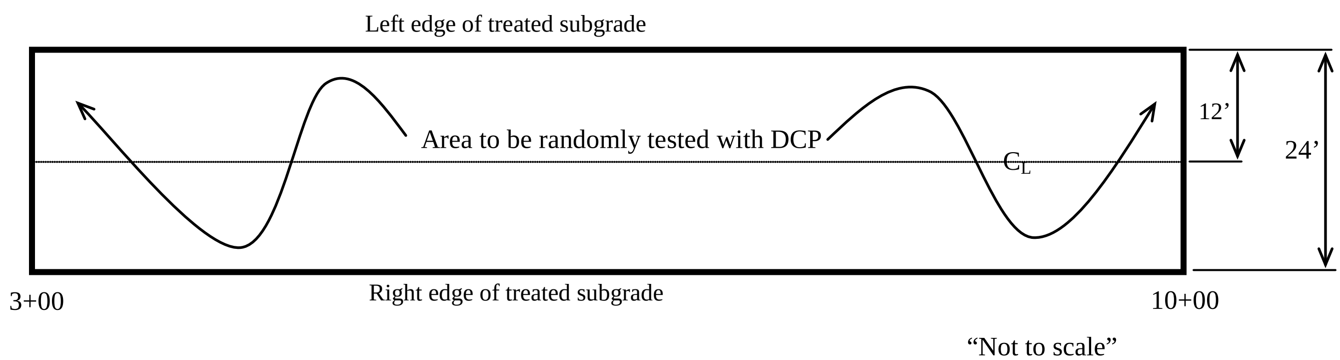


Diagram 2

Procedures for Random Location of DCP Test Sites

In random sampling, a table of random numbers is used to locate test sites randomly to avoid biased testing. Once a number has been used it is marked through and not used again. Random sampling is done in two dimensions by locating a station (length) and a pull distance from edge (width). Refer to the following example.

1. In the following example, the stabilized subgrade is 24 feet wide (two 12-foot lanes) and the area in question begins at station 3+00 and ends at station 10+00.



Plan View

Diagram 3

2. To determine the number of test locations take the length of the section in question and multiply by the number of 12-foot lanes. Then divide the results by 440 (round up to the next whole number).
   For the given example:

   Total Length: 10+00 – 3+00 = 700 ft
   Total number of 12 ft lanes = 2
   Therefore: 700 ft x 2 = 1400
   Then 1400 / 440 = 3.18 (round up to 4)
   Total number of locations = 4

3. Divide the section into the total number of locations to get the length between each location. Record the locations from the beginning station to the ending station to the nearest foot.
   For the given example the data recorded should be as follows:

700 / 4 = 175 foot sections

Beginning station - 3+00
4+75
6+50
8+25
Ending station - 10+00

NOTE: The greater than symbols point to the randomly located test site.

4. Determine the random sample multipliers by referring to the random sample number table (or by using calculator). The random numbers used in the example are 29, 41, 27, and 05. Place a decimal in front of these two digits (i.e. 0.29, etc).

5. Multiply each random sample multiplier by the length of the four equal sections determined in #3 above. The length is 175 feet.

Test section length:	175	175	175	175
Random number:	x 0.29	x 0.41	x 0.27	x 0.05
Distance:	51	72	47	9

6. Add the distance determined in #5 to the beginning stations of each section determined in #3 to locate the stations where the test will be performed.

Beginning station:	3+00	4+75	6+50	8+25
Distance:	+51	+72	+47	+09
Random test site:	3+51	5+47	6+97	8+34

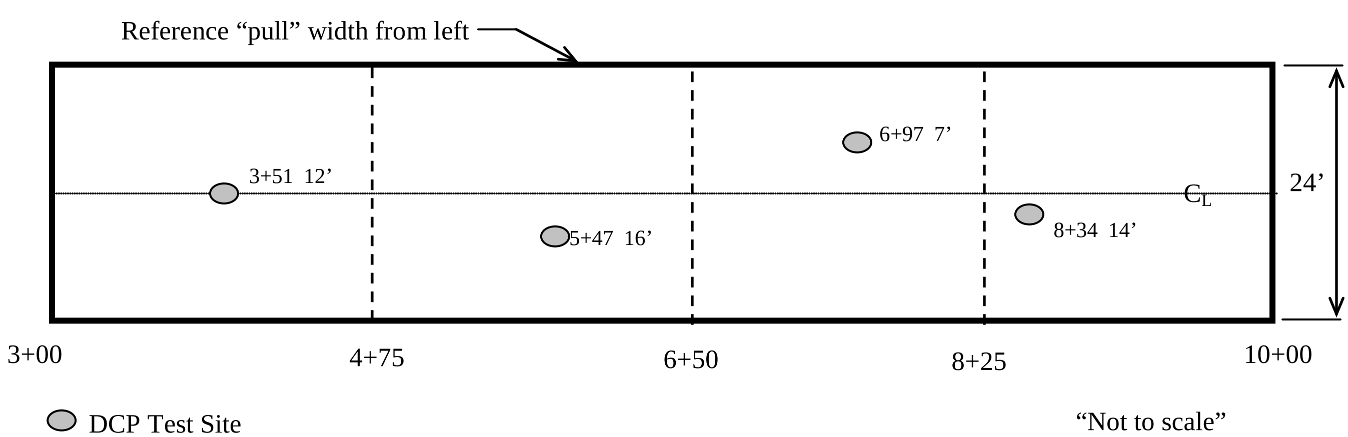
7. A second set of random sample multipliers is to be used in determining the distance from the edge of the section where the tests are to be located. Either the left or right edge can be chosen, however, once a reference edge is established it must be used throughout the entire chemical stabilization operation. Refer to random sample numbers 52, 67, 30, and 60. In this example the random numbers used are: 0.52, 0.67, 0.30, and 0.60.

8. Multiply each random sample multiplier determined in #7 by the width of the section and round to the nearest foot. Perform DCPs at least 1 foot from the edge of stabilized subgrade.

Width of section:	24	24	24	24
Random number:	x 0.52	x 0.67	x 0.30	x 0.60
Distance:	12	16	7	14

Station		Test Location	
Beginning station –	3+00		
		3+51	12’
	4+75		
		5+47	16’
	6+50		
		6+97	7’
	8+25		
		8+34	14’
Ending station -	10+00		

The diagram below shows the individual sites where DCP tests are performed. Refer to page 19 for DCP testing pattern at each site.

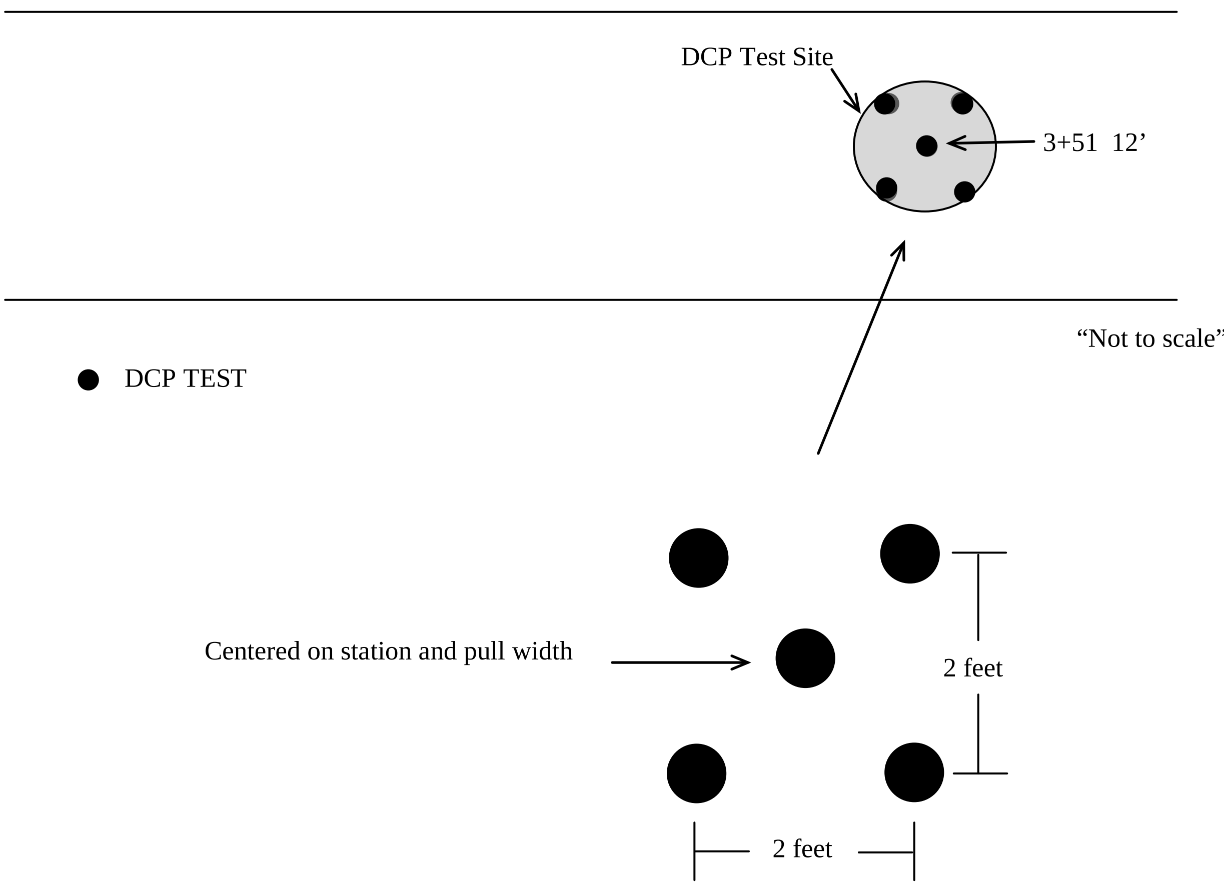


Plan View

Diagram 4

Dynamic Cone Penerometer - Testing Pattern

Diagram 5 shows the testing pattern of DCP's at each of the randomly located test sites and a plan view of the how the investigation should be performed. Five DCP's are to be performed as shown in the diagram and averaged to achieve a single CBR value at each station. The CBR value is then converted to PSI and the resulting PSI values will reveal the condition of the stabilized subgrade.



DCP PATTERN

Diagram 5

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