Subgrade Stability Manual

May 1, 2005

Illinois Department of Transportation

Bureau of Bridges and Structures

Illinois Department of Transportation

Departmental Policies

MAT-10
May 1, 2005

HIGHWAY SUBGRADE STABILITY MANUAL

1) POLICY

The Department shall publish and maintain a manual which provides guidelines for construction of highway subgrades.

2) PURPOSE

The purpose of this policy is to provide for the publication of a manual to serve as a guide and source of reference on the stability of subgrades for field personnel involved in the construction of highways.

3) GUIDELINES FOR IMPLEMENTATION

a) This manual is prepared with major emphasis on construction considerations. Design and long-term pavement performance are not considered in this manual.

b) Subgrade stability is defined as the strength and deformation properties of the subgrade soils that impact pavement construction activities.

c) This manual provides requirements for subgrade stability, as dictated by pavement construction activities. To be stable, the finished subgrade must have a minimum IBV of 6.0 if untreated, or 10.0 if treated, and a maximum rut depth of 0.5 inches under construction traffic.

d) Remedial options are described for unstable subgrade soils. These include: i) soil modification, ii) removal and replacement with rock, iii) aggregate over modified subgrade, iv) use of geosynthetic reinforcement, and v) moisture control.

4) RESPONSIBILITIES

a) The Bureau of Bridges and Structures (BBS) is responsible for the issuance and maintenance of this Policy.

b) The Division of Highways' Central Office and Regions/Districts are responsible for ensuring compliance with this Policy.

c) The Central Geotechnical Unit Chief at BBS should be contacted for questions regarding the application of these procedures.

5) ACCESSIBILITY

This manual may be accessed or downloaded from the Department's website.

CLOSING NOTICE

Supersedes: Department Policy MAT-10, Subgrade Stability Manual, May 1, 1982.

APPROVAL: [signature]
Victor A. Modeer, Jr.
Director of Highways

DATE: May 1, 2005 .

FORWARD

This manual is a revised version of the Subgrade Stability Manual (SSM) which was first published in March 1982. It has been revised to present the current state of practice at the Illinois Department of Transportation (IDOT), and to include any developments in test procedures or treatment methods that may have taken place over the past two decades. The main purpose of this manual is to serve as a guide and a source of reference information for field personnel involved in the construction of highways. It is aimed at presenting: 1) the tests used at IDOT to identify unstable subgrade soils, 2) the procedures for determining treatment thickness, and 3) treatment options commonly used by IDOT.

This manual is prepared on the basis of combined information from: 1) the 1982 SSM version, 2) subsequent reports and white papers submitted by the Project Team at the University of Illinois, Urbana-Champaign (UIUC), as part of the Illinois Cooperative Highway and Transportation Research Program, Project IHR-30, aimed at updating the 1982 SSM, 3) material provided by various IDOT Regions/Districts, representing IDOT current practice, and 4) discussions and review comments by the SSM Technical Review Panel (TRP) on the UIUC submittals.

The UIUC Project Team was represented by Dr. Marshall R. Thompson, Professor Emeritus and Project Supervisor; Dr. Erol Tutumluer, Associate Professor; and their graduate students G. Garcia and Jayhyun Kwon. The TRP at IDOT included: Doug Dirks (Bureau of Materials and Physical Research - BMPR), Edward Frank (District 1), Greg Heckel (District 6), Terry McCleary (District 3), Matt Mueller (Bureau of Safety Engineering), David Piper (Bureau of Safety Engineering), Tom Ripka (Bureau of Construction), Ray Seneca (District 4), and Riyad Wahab (BBS) - Author.

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1.0 Introduction

Subgrade is the top material below the pavement structure. This manual is directed to subgrade stability problems occurring during pavement construction. Its main objectives are to determine soil stability, treatment thickness, and treatment options. The manual is not for design purposes, since subgrade treatment used for construction expedience is not accounted for in IDOT's pavement design procedure. This manual is to serve as a quick guide, primarily for field personnel. More detailed discussions on each topic can be found in IDOT's Geotechnical Manual (1). Reference will be made to the UIUC White Papers (13, 14); and IDOT's 1982 SSM (15), Standard Specifications (16) or Test Procedures (17), as applicable.

2.0 The Subgrade Stability Problem

Subgrade stability is defined as the strength and deformation (rutting) properties of the finished subgrade soils that impact pavement construction activities. To be stable, the finished subgrade at the time of placing pavement layers must:

a) Have a minimum IBV of 6.0, if untreated, and 10.0 if treated.

b) Limit the maximum rut depth to 0.5 inch (12.5 mm) under all construction traffic, prior to pavement construction.

c) Provide good support for placement and compaction of pavement layers.

A subgrade that does not meet the above criteria is considered unstable, and must be treated prior to pavement construction. Examples of problem soils include those with high moisture and/or high silt content. High moisture content soils (2% to 3% above optimum, depending on the soil type) are unstable and cause excessive rutting. High silt content soils (65% to 80% silt, depending on the clay content) have three major problems. First, they exhibit excessive resilient (rebound) deflections (Figure 1) that make it difficult to achieve compaction of pavement layers, even though they may meet the requirements in a) and b) above. The resilient behavior of a silty "pumping" soil can be observed. When loading one spot an adjacent spot will rise. The subgrade rebounds (goes back to its original position) when the wheel load moves onto another spot. The second problem with silty soils is they are sensitive to moisture. Strength and density change rapidly with a slight change in moisture. Field observations show that sometimes when a silty soil "looks" dry and hard on the surface, repeated truck loads can draw moisture from high ground water into the surface and cause excessive rutting. The rise of water to the top may not occur immediately, depending on soil permeability, the load/tire pressure, and the number of truck passes. Repeated truck loads could also cause a reduction in soil strength due to remolding/disturbance. Figure 2 shows an extreme case in which the silty soil was overlain by approximately 4 ft (1.2 m) of material, but the silt particles were carried with the moisture to the top after a scraper drove over the area several times the day before. For this reason, quite often, silty soils satisfy density requirements in the upper material but do not meet the minimum stability requirements. The third major problem with silty soils is they are frost-susceptible, which negatively impacts long-term pavement performance.

Figure 1. Resilient (rebound) deflections of silty soils under wheel loads makes compaction of pavement layers difficult.

Figure 2. Repeated truck/equipment loads will draw moisture up to the surface of silty subgrade soils (pumping).

Therefore, while treatment of unstable subgrades is primarily performed to provide a temporary, stable platform under construction traffic, the treatment could indirectly influence the long-term pavement performance. However, it should be emphasized that subgrade treatment is performed to facilitate construction activities, and is not used in the pavement design to reduce pavement thickness.

Subgrade problems are typically identified during the soil investigation phase, in which a project specific geotechnical report is prepared. The report will often indicate the soil problem areas. Treatment limits (length, width and thickness) as well as the most feasible treatment option (best suited to the soil type and condition) are often recommended in the project geotechnical report. These recommendations are also included in the contract documents. However, treatment recommendations in the geotechnical report are considered approximate since they are based on soil data from individual soil borings which are commonly spaced at 100 ft to 500 ft (30 to 150 m). Soil information between the borings is based on interpretations by the geotechnical engineer. It is important that the field Inspector verifies the treatment (type, thickness and limits) recommended in the geotechnical report, using the procedures explained in this manual, before the contractor initiates remediation.

It is important to identify subgrade problems prior to pavement construction. If the problems are not identified, repeated loading from the paving operation damages the subgrade, the subgrade will have to be repaired. Subgrade repair requires additional time, during which concrete or hot mix asphalt delivered to the job site may have to be rejected. Also, if the hot mix asphalt pavement does not meet the density requirement due to a pumping soil, it may have to be removed and reconstructed at the contractor's expense, or an adjustment be made in the contract price.

3.0 Tests for Determining Subgrade Stability

For many years, IDOT has successfully used the dynamic cone penetrometer (DCP) and the static cone penetrometer (SCP) tests to determine subgrade stability in the field. The DCP and SCP test results have been correlated with the unsoake, insitu and laboratory, California Bearing Ratio (CBR) obtained immediately after compaction. IDOT has adopted the term Immediate Bearing Value (IBV) in lieu of the CBR, to differentiate it from the soaked CBR used for pavement design (See Glossary of Terms for the IBV definition).

3.1 The DCP Test

The DCP test is to be conducted according to Illinois Test Procedure 501, of IDOT's Manual of Test Procedures for Materials (17). The DCP (Figure 3) has been used extensively in many countries. It is a simple tool, rugged and economical, for evaluating insitu subgrade soil.

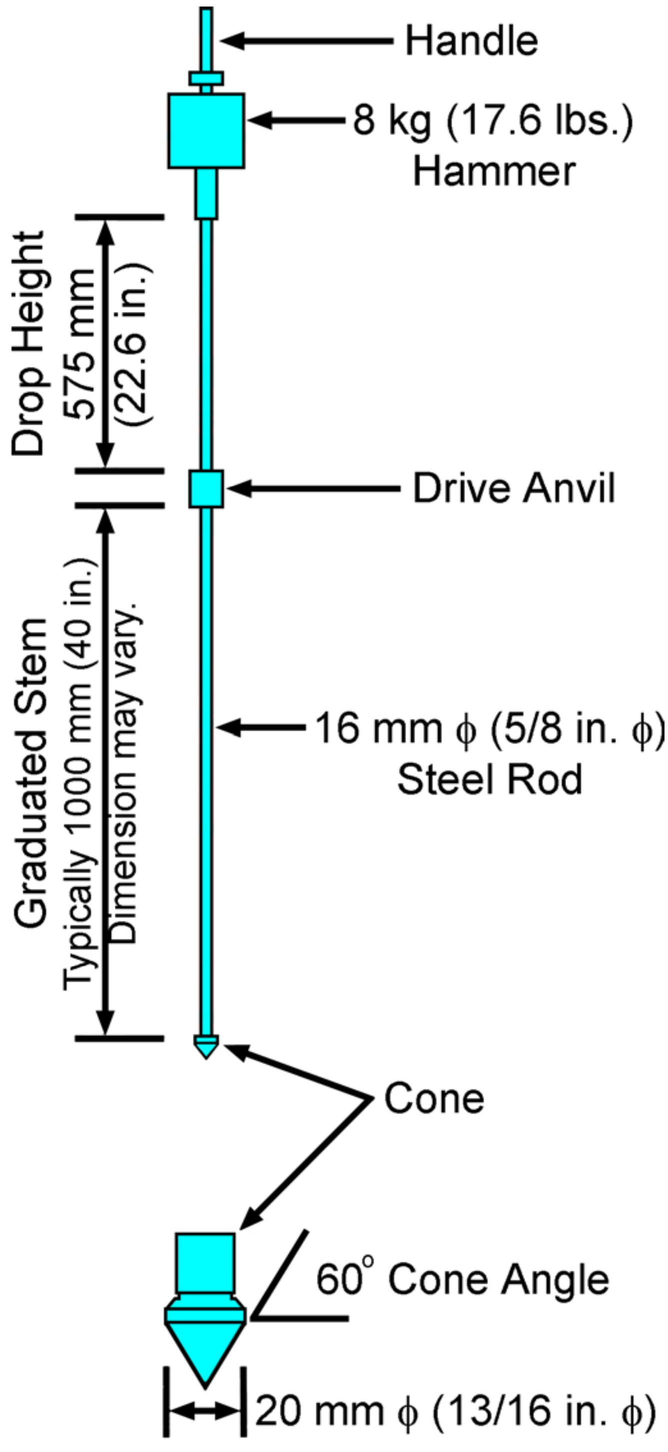


Figure 3. DCP apparatus.

The DCP (Figure 3) measures the penetration rate (PR), in terms of inches per blow (millimeters per blow), while the cone of the device is being driven into the subgrade. This is done by dropping the hammer on the drive anvil from the drop height specified. It is used to check the subgrade stability and thickness of subgrade treatment during construction.

The PR is a function of the in-situ shear strength of the material. The strength profile with depth gives an indication of the in-situ properties of the materials up to the depth of penetration, which is 40 in. (1000 mm), as needed. To convert the PR to IBV, use the following formula (8).

$$\mathbf{IBV = 10^{0.84 - 1.26 \times Log (PR)}} \qquad \textbf{Eq. 1}$$

where:
IBV = Immediate Bearing Value
PR = DCP penetration rate (in./blow)

A plot of IBV versus PR is shown in Figure A-1 in Appendix A. The unconfined compressive strength of the soil, Q_u, normally expressed in tons per square foot (tsf), has been correlated with the IBV as follows:

$$\mathbf{Q_u \text{ (tsf)} = 0.32 \times IBV} \qquad \textbf{Eq. 2}$$

The DCP is sometimes made with a dual mass, a 17.6 lb (8 kg) or a 10.1 lb (4.6 kg) weight. The dual mass DCP has the same cone and drop height as the single mass DCP, except it can be driven into the soil by dropping either the 17.6 lb (8 kg) or the 10.1 lb (4.6 kg) weight. The cone penetration caused by one blow of the larger weight is essentially twice that caused by the smaller weight (9). Based on this, if the dual mass DCP is used, the value of PR in Eq.1 will remain the same when using the 17.6 lb (8 kg) weight, but it should be multiplied by 2 when using the smaller weight. The larger weight helps penetrate high strength soils (IBV greater than 80).

3.2 The SCP Test

The SCP test is to be conducted according to Illinois Test Procedure 502, of the IDOT Manual of Test Procedures for Materials (17). The SCP (Figure 4) was developed by the US Army Corps of Engineers (9) for use in trafficability studies. It can be used to determine the subgrade stability. The SCP can also be used during the field investigation, for preliminary estimation of subgrade treatment. It is lighter, and less difficult to use than the DCP.

The SCP test is conducted by pushing the cone slowly into the soil by hand for field application. It may be machine mounted for laboratory use. The penetration is sustained at a constant rate, approximately 72 in./min. (1.8 m/min.). If the soil is soft enough to allow for hand pushing at this rate, the entire 18 in. (450 mm) long stem should be pushed in approximately 15 seconds. The cone index (CI) is obtained by dividing the penetrometer load by the projected base area of the cone. However, the CI is measured directly from a calibrated dial gauge. The units of the CI are psi, but they are not expressed in practice.

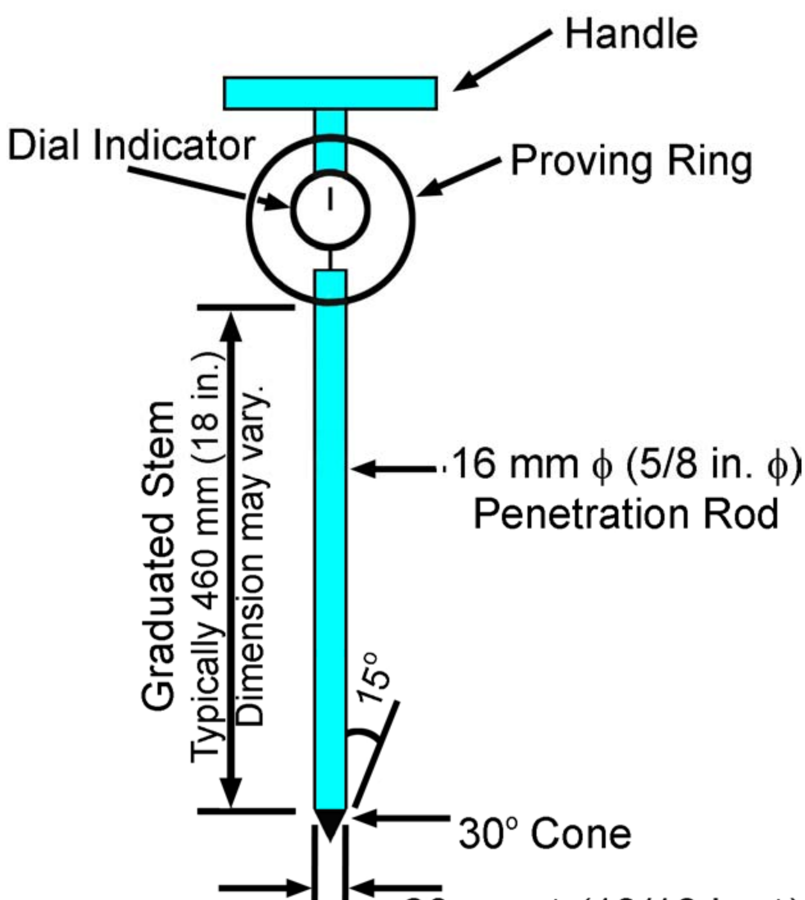


Figure 4. SCP Apparatus.

The CI is a function of the in-situ shear strength of the material. In most cases, the CI is determined for various depths of soil penetration. The proving ring should have a minimum capacity of 150 lb (667 N), which implies that the SCP is limited to a CI of 300. Therefore, in very stiff clays or in a modified soil, the SCP may not be a practical tool to be used for determining subgrade stability. The DCP would be an option in this case. Also, the stem length of the SCP is limited to a maximum of 18 in. (450 mm). The IBV can be obtained from the CI, using Eq. 3 below:

$$\mathbf{IBV = CI / 40} \qquad \textbf{Eq. 3}$$

The unconfined compressive strength, Q_u, can then be determined from Eq. 2.
For ease of applying Eqs. 1 to 3 in the field, Inspectors may prefer to use the relationships between PR, IBV, CI and Q_u, as shown in Figure A-2 (Appendix A). Field Inspectors may choose different tabulated data, depending on the depth intervals blows are counted.

3.3 Proof Rolling

Proof rolling is not a direct test for evaluating subgrade stability, as are the DCP and SCP, but is a highly recommended field procedure which should be used prior to running the DCP or SCP tests. Proof rolling involves driving a loaded truck, or heavy construction equipment, repeatedly over the subgrade (especially in cut areas) and observing the surface deflections and the development of rutting. It is intended to distress the soil to conditions anticipated during construction.

Due to construction schedules, proof rolling is not used by all IDOT Regions/Districts. Some Districts prepare a Special Provision for every job, requiring proof rolling of all driving lanes for the entire project. Other Districts find this time consuming, and prefer to proof roll only areas of potential problem, identified by the DCP, SCP, or observation.

Other Districts perform proof rolling during construction by observing the subgrade performance under haul trucks or construction equipment, prior to subgrade treatment. Thus, in this case, a Special Provision is not necessary. The District Geotechnical Engineer (DGE) should be contacted regarding the District practice.

Proof rolling is an economical method of identifying unstable/unsuitable soils during construction, when they can easily be dealt with prior to pavement construction. Proof rolling provides the following benefits:

a. It helps identify silty soils, as mentioned in Section 2.0. Repeated passes of truck loads cause moisture to move up from high ground water, soften or remold the moisture-sensitive silty soils and, consequently, cause excessive rutting.
b. It helps identify any misleading DCP or SCP data in silty soils. The IBV or CI values in these soils may be high but do not actually reflect the resilient (rebound or pumping) behavior exhibited by the silty soils after repeated truck loads. Running the DCP or SCP tests at the high deflection and rutted areas will provide more realistic information for determining the necessary thickness and type of subgrade treatment. Also, proof rolling helps delineate treatment areas in conjunction with the DCP or SCP testing, since proof rolling alone is not sufficient for determining the treatment thickness.
c. It helps identify any soft soils underlying a relatively thin, hard material (crust) on top. The DCP and SCP tests cannot be used to identify the full extent of the underlying soft soils, since these tests are conducted at select locations. If a soft soil exists below the crust, proof rolling will "soften" the crust and make it deform (rut) excessively, or crack and extrude the underlying softer soil.

Typically, proof rolling should be conducted as follows:

1. The Inspector should observe the earthwork at all times during construction to identify weak areas prior to proof rolling.

2. The subgrade is prepared according to the Standard Specifications, in which the subgrade shall meet the density requirement. District Special Provision may also have moisture or other requirements. The Inspector should consult the DGE regarding the district's practice. If conditions change after subgrade preparation, due to rain or construction traffic before determining the type and thickness of treatment, the subgrade should be reworked. Otherwise, proof rolling results may no longer represent the subgrade conditions.

3. The length of subgrade, prepared for proof rolling, should be 500 to 1000 ft (150 to 300 m) at a time. If the section is too large, the period between truck passes will be too long to "excite" the moisture sensitive silty soils, and may not exhibit excessive rutting.

4. The Contractor should provide a fully loaded, tandem-axle truck, or loaded truck/equipment similar to those anticipated during pavement construction. The number of truck passes in proof rolling is dictated by the field conditions. Sometimes, for example, in cut or at-grade sections with high moisture silty soils, one or two passes might be adequate to cause several inches of rutting, thereby indicating subgrade instability. However, in fill sections where density and moisture can be controlled for each lift, five to six passes may or may not be adequate to indicate stability, depending on whether or not the underlying material is a compacted lift or insitu soil. The number passes (if not specified in a District Special Provision) should be a minimum of three to four truck passes, or until the subgrade rutting exceeds 0.5 inch. This is particularly important in cut or at-grade sections with silty soils, having more than 75% silt.

5. During proof rolling, the Inspector should observe the subgrade performance at all times. The last truck pass is usually performed at walking speed so that the Inspector may follow to observe the rebound deflections, and rutting and/or pumping of the subgrade. Immediately after the last truck pass, the Inspector should test areas showing more than 1.25 in. (32 mm) of rutting and areas of high rebound deflections (pumping), with the DCP or SCP, to determine the required treatment thickness. The 1.25 in. (32 mm) rutting is based on field observations (15) when the IBV is 3, which is the minimum required value at the bottom of a 12 in. (300 mm) Improved Subgrade. However, Inspector should ensure that the finished subgrade does not exhibit more than 0.5 inch (12.5 mm) of rutting.

4.0 Determining Treatment Thickness

The primary purpose of determining the subgrade treatment thickness in the field is to verify the adequacy of the treatment thickness shown on the plans. Typically, the plans show a 12 in. (300 mm) “Improved Subgrade” as the minimum treatment thickness. If the thickness shown on the plans is not adequate, it should be adjusted in the field to the thickness determined by the procedure outlined in this section. If the treatment thickness as determined herein is less than that shown on the plans, the planned thickness should be used, or the DGE should be contacted to recommend reducing or eliminating the planned thickness. Treatment thickness should not be reduced or eliminated without the concurrence of the DGE.

Before determining the actual treatment thickness in the field during construction, the Inspector should review the soil conditions and treatment thickness recommended in the project geotechnical report or on the plans. In order to verify the planned treatment thickness, or change it as necessary, the Inspector should follow the procedure below:

1. Complete rough grading:

   Case 1 – Aggregate (Figure 5):

   Complete rough grading to an elevation equal to the bottom of the proposed aggregate layer.

   Case 2 – Modified Soil (Figure 5):

   Complete rough grading to an elevation equal to the top of the proposed modified subgrade.

2. Proof roll if specified in a District Special Provision, or make observations of subgrade during construction if the District does not have a Special Provision. Note that the equipment used for pavement construction might be different from those used during subgrade observation, prior to pavement construction.

3. Perform the DCP or SCP test at representative locations (preferably at rut locations, if any).

   Case 1 – Aggregate (Figure 5):

   Compute the IBV values (or measure the CI) for the following depth ranges:

   0 - 6 in. (0–150 mm)   6 -12 in. (150-300 mm)   12-18 in. (300-450 mm)

   Case 2 – Modified Soil (Figure 5):

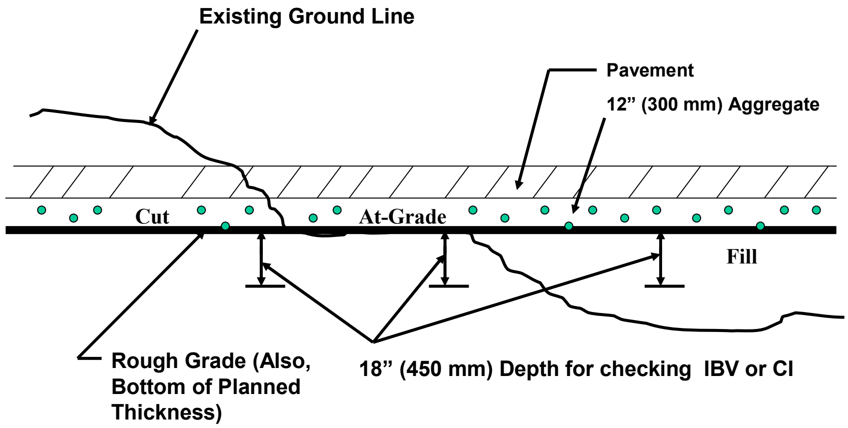
   Use only the DCP, drive it through the 12 in. (300 mm) modified soil*, and compute the IBV values for the following depth ranges:

   12-18 in. (300-450 mm)   18-24 in. (450-600 mm)   24-30 in. (600-750 mm)

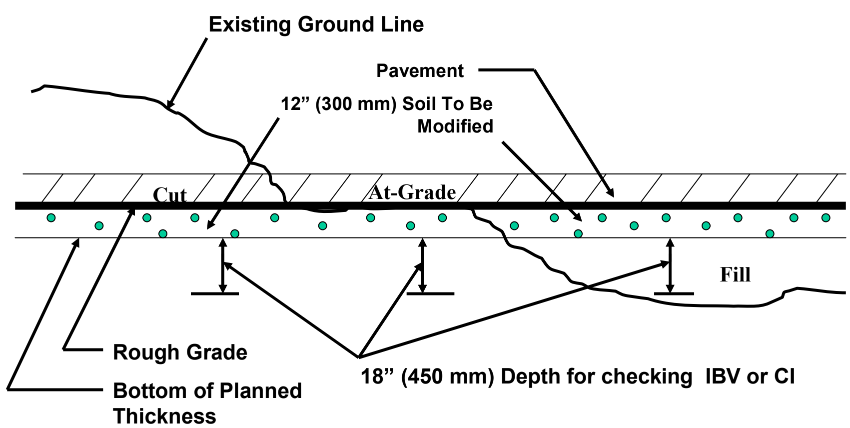
   * The modified soil does not need to be evaluated since it will be modified/treated.

4. Compute the available cover above each 6 in. (150 mm) increment determined in Step 3. At the top of the first increment, the available cover is the same as the planned treatment thickness, which is 12 in. (300 mm) in the typical cases shown in Figure 5. For the

subsequent 6 in. (150 mm) increments, the available cover will be the planned treatment thickness plus these depth increments (see the examples in Table 1).



Case 1. Improved Subgrade - Aggregate



Case 2. Improved Subgrade – Modified Soil

Figure 5. Checking the IBV or CI below typical 12 in. (300 mm) Improved Subgrade.

5. Use Figure A-2 (Appendix A) to determine the required treatment thickness (required cover) equivalent to the IBV or CI value at each 6 in. (150 mm) increment determined in Step 3.

6. Compare the cover required, as determined in Step 5, with the cover available (Step 4) at the top of each 6 in. (150 mm) depth increment. The top of the first increment is the bottom of the planned treatment thickness (rough grade elevation).

7. The additional required treatment thickness at each depth increment is the cover required minus the cover available. The recommended, additional treatment thickness is the largest difference among the three 6 in. (150 mm) depth increments. If the soil in the second depth increment is soft and it requires more than 18 in. (450 mm) treatment, as in Example 4 of Table 1, the top 6 in. (150 mm) soil will have to be removed/treated and should be included in the additional thickness, even though it is not soft .

8. The total recommended thickness is the required additional thickness (including any uppr material to be treated/removed) plus the planned thickness.

9. If the total recommended treatment thickness, determined in Step 8, is greater than 24 in. (600 mm), consult the DGE.

Table 1 shows examples of determining treatment thickness for various IBV values with depth, assuming the planned treatment thickness is a typical 12 in. (300 mm) “Improved Subgrade”. Typically, the treatment thickness should be uniform over a given area, and should correspond to the average treatment thickness over that area, unless there is a significant variation. If a significant variation in treatment thickness is observed, the Inspector should consult the DGE or select the most conservative treatment thickness. Also, the recommended additional thickness should be confirmed by proof rolling, if required by the District, or by observing the subgrade under haul trucks or construction equipment.

5.0 Common Treatment Options

Several options are available to provide a stable working platform to support construction operations. These options are summarized below, but more detailed discussions can be found in IDOT’s Geotechnical Manual.

Table 1. Examples of determining treatment thickness.

Depth Below Improved	Increment Bottom of Subgrade[1]	Available Cover on Top[2]	Example 1		Example 2		Example 3		Example 4	
Aggregate In. (mm)	Modified Soil In. (mm)	in. (mm)	Observed IBV[3]	Required Cover[4] in. (mm)	Observed IBV[3]	Required Cover[4] in. (mm)	Observed IBV[3]	Required Cover[4] in. (mm)	Observed IBV[3]	Required Cover[4] in. (mm)
0 - 6 (0 - 300)	12 - 18 (300 - 450)	12 (300)	3	12 (300)	2	16 (405)	1.5	18 (450)	5	0
6 - 12 (150 - 300)	18 - 24 (450 - 600)	18 (450)	2	16 (405)	5	10 (250)	4	11 (280)	1	23 (585)
12 – 18 (300 - 450)	24 - 30 (600 - 750)	24 (600)	1	23 (585)	1	23 (585)	7	8 (200)	1	23 (585)
Additional Required[5]	**Thickness in. (mm)**			**0**	**4**	**(100)**	**6**	**(150)**	**11**	**(280)**
Total Treatment in.	**Required Thickness (mm)**		**12**	**(300)**	**16**	**(405)**	**18**	**(450)**	**23**	**(585)**

(1) See Figure 5.
(2) Assuming a typical 12 in. (300 mm) Improved Subgrade.
(3) For the corresponding 6 in. (150 mm) increment.
(4) From Figure A-2, round up to the nearest inch, or follow District practice.
(5) Confirm by proof rolling and consult with the DGE.

5.1 Soil Modification

Soil modification is to be conducted according to the "Laboratory Evaluation/Design Procedure for Soil Modification with Various Materials", in IDOT's Geotechnical Manual. Soil modification involves the use of modifiers such as lime, fly ash, or cement, which are incorporated in the soil to enhance its strength. While it is important to use a modifier that does not cause any long term, detrimental effects on the pavement, such as swelling, soil modification is not aimed at improving the long term strength of the soil. The modified subgrade is required to have a minimum IBV of 10.0.

The following materials can be used as modifiers, with the limitations indicated for each modifier:

- **By-Product, Non-Hydrated Lime Kiln Dust (LKD).** It is the most commonly used modifier by IDOT. LKD, and lime in general, do not sufficiently modify silty soils with less than 15% clay. Clay is needed to react with lime and develop the required strength.

- **By-Product, Hydrated Lime.** It works the same way as the LKD but requires 24 hour waiting "mellowing" period after adding water and before compaction, since it is a coarser material than the LKD.

- **Lime Slurry** (with revised specification). It works the same way as LKD, but may require 24 hours of curing after compaction, to develop full strength, before supporting any construction traffic.

- **Class C Fly Ash**. It works with high silt soils, which do not react with lime, since fly ash has cementitious and pozzolanic characteristics that do not depend on a reaction with clay to develop the required strength. However, fly ash requires 24 hours of curing after compaction, and the amount of material needed is two to three times the amount usually required for modification with LKD (18).

- **Slag-Modified Portland Cement.** It works with all soil types, regardless of the clay content. It requires a slightly smaller amount than LKD to provide the same strength, but also requires 24 hours of curing after compaction.

- **Portland Cement.** It works the same way as the slag modified cement, but requires slightly more material than the LKD to provide the same strength.

- **Lime-Fly Ash Blend.** Other states (12) have successfully used a combination of lime and fly ash for soil modification. The lime-fly ash option provides a stable construction platform in silty soils (12). For high silt, low clay soils, a blend of lime-fly ash could be considered to allow the lime to react with the clay portion and the fly ash to provide strength. If this option is considered, a complete laboratory mix design and a field evaluation (test section) must be performed for the specific project, in order to determine the optimum conditions for the lime-fly ash blend.

The construction procedure is similar for any of the above listed modifiers. One important fact should be considered in any soil modification. Quite often, it is much easier to accomplish uniform mixing of a soil, with any of the modifiers list above, in the laboratory than in the field. Therefore, the DGE should be consulted regarding the constructability of a certain modifier in conjunction with the project soil type and field conditions. Also, the laboratory IBV is conducted on the compacted soil-modifier mixture while it is confined in a 4 in. (200 mm) mold, compared to the field IBV test conducted in a relatively unconfined condition. Therefore, the controlled laboratory mixing and confinement effects result in higher laboratory IBV than field values. A correlation is yet to be established between the laboratory and field IBV values, which are currently projected to be equal.

5.2 Removal and Replacement with Granular Material

This option is usually considered when the modification option is not feasible because of the soil gradation, to avoid dust from the modifier, or because of time and weather restrictions. IDOT Districts use various “granular materials” to replace the unsuitable soil. The type of granular material used by a District depends on what is locally available. Consult the DGE for the type and gradation requirements of granular materials commonly used by the District. However, Table 2 can also be used as a general guide for specifying the gradation.

The Table 2 gradations require a minimum 3 in. (75 mm) aggregate cap, meeting the material gradation of CA 6 or CA 10 in Section 1004 of the Standard Specifications.

The 3 in. (75 mm) cap is part of the total planned thickness. The aggregate and the capping material are compacted to the "Satisfaction of the Engineer".

Table 2. General aggregate gradation for subgrade replacement.

Undercut Thickness	Aggregate Gradation
Less than 12 in. (300 mm)	Gradations with a maximum size of 4 in. (100 mm)[a]
Greater than 12 in. (300 mm)	Primary Crusher Run[b]
Greater than 36 in. (900 mm)	Primary Crusher Run[b] or Shot Rock[c]

[a] Gradations with a maximum size of 2 in. (500 mm) or smaller shall have less than 6% passing the No. 200 sieve
[b] Some Districts require D quality, breaker-run crushed stone, with 6 in. (150 mm) top size and 15% to 40% passing the 2 in. (50 mm) sieve. Consult the DGE for specific requirements.
[c] Shot rock dimensions shall not exceed 18 in. (450 mm).

The aggregate type and quality are important factors for determining the required thickness. The aggregate layer must have a minimum IBV of 15, and it must not be "moisture sensitive", such as the dense-graded CA 6 gravel with fines on the high end of IDOT's acceptable limits (13). It should be noted that an aggregate Improved Subgrade needs some fines to hold it together. Moisture sensitive aggregate will experience strength loss with small moisture changes, thereby increasing rutting within the treatment layer. Recycled asphalt pavement (RAP) and or crushed concrete typically have low fines content (- #200 sieve) and low PI for the fines. Thus, these materials may display "low" moisture sensitivities. However, RAP may not perform well due to lack of fines to hold it together.

When the subgrade soil is soft or silty, the DGE may require a geosynthetic fabric (i.e., a geotextile) to prevent intermingling of the subgrade and aggregate layers.

The cost of granular materials is usually higher than the soil modification option. Also, the cost increases with the distance to the source of granular material. Due to cost or unavailability of granular materials, some Districts are considering the use of less than 12" (300 mm) removal and replacement. District 6 is conducting an Experimental Feature to evaluate the rutting behavior of several aggregate types under repeated truck loads. The study is aimed at evaluating IDOT's current procedure (Figure A-2) for aggregate thickness requirements, and determining the effects of compaction and aggregate type on the required cover thickness. Preliminary results indicate an 8 in. (200 mm) thick crushed aggregate layer, compacted to 95% of standard dry density

(AASHTO T 99) performed as well as 12 in. (300 mm) of the same material, compacted to the satisfaction of the Engineer. Also, the 8 in. (200 mm) crushed aggregate performed better than a 12 in. (300 mm) gravel.

5.3 Aggregate on Top of a Modified Subgrade

Constructing an aggregate layer over a modified soil layer is a viable option when the required treatment thickness is large, the strength of the modified soil is marginal, and aggregate or recycled materials (RAP or crushed concrete) are available and economical. The combined thickness of the aggregate and modified subgrade is obtained from Figure A-2, in the same manner as described in Section 4.0. However, the DGE should be consulted to determine the optimal thickness of each layer.

5.4 Use of Geosynthetics

Geosynthetics (i.e., geogrid and geotextiles) may be used for subgrade restraint and base reinforcement. Geotextiles also prevent intermingling of the subgrade and aggregate layers. Subgrade restraint may occur when a geosynthetic is placed at the subgrade/aggregate interface to increase the support of the construction equipment over a weak subgrade. Base reinforcement is considered for the purpose of long-term pavement performance, which is outside the scope of this manual. Only subgrade restraint will be discussed in this section. When used for subgrade restraint, geosynthetics are placed on top of the weak subgrade, beneath the aggregate layer. They provide tensile resistance and provide lateral restraint as wheel loads attempt to cause rutting in the subgrade (Figure 6).

In order for geosynthetics to develop full tensile resistance, it is very important to place them in a taut or stretched condition. If placed with wrinkles or in a loose condition on a weak subgrade, the wheel load will have to develop excessive rutting in the underlying soil before the geosynthetic develops enough tension to provide the required restraint. In general, high elastic modulus geosynthetics require less deformation, and hence less soil rutting, to develop the tensile resistance required for subgrade restraint. Thus, the elastic modulus could be used as an important factor for selecting products of similar cost.

Geogrids and geotextiles have alternately been used for subgrade restraint, but most applications have been based on manufacturers' specifications and claims, some of which are yet to be substantiated through laboratory and field data. Through the interlock between the grids-soil and grids-aggregate, geogrids are assumed to have higher friction and confining stresses than the smoother surface geotextiles. However, geogrids do not prevent intermingling of the subgrade and aggregate layers.

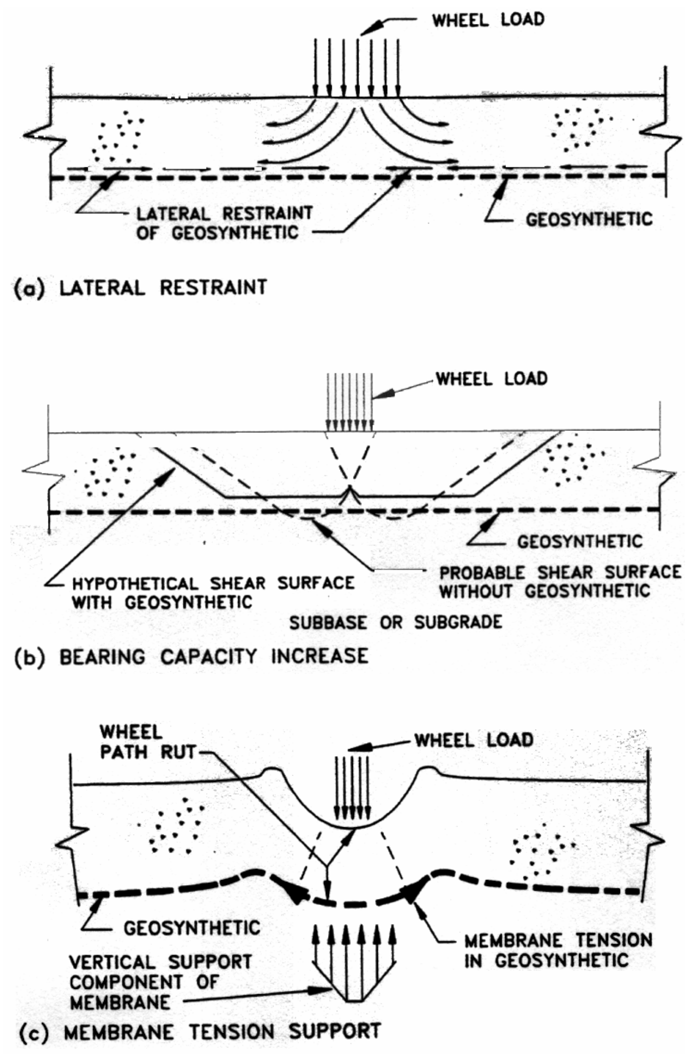


Figure 6. Reinforcement mechanisms for subgrade restraint (11).

Several software programs have been developed to determine the design aggregate thickness for subgrade restraint and base reinforcement with geosynthetics. Examples include Amoco's RACE (Roadways And Civil Engineering) for geotextiles, Tensar's SpectraPave2™ for geogrids, and CROW developed in the Netherlands for geosynthetics.

It has always been assumed that, as a rule of thumb, geosynthetics could reduce the aggregate cover, determined from Figure A-2 in Appendix A, by as much as 30%. The amount of thickness reduction depends on the type and strength characteristics of the geosynthetic, aggregate, and the subgrade soil.

Based on analyses (14) of geotextiles (woven and nonwoven) and geogrids, it is recommended that Table 3 be used as a guideline for preliminary aggregate thickness design when using geosynthetics for subgrade restraint. Table 3 indicates that the use of geosynthetics should only be considered when the subgrade IBV/CI is 3/120 or less, i.e., when the required aggregate cover exceeds 12 in. (300 mm) according to Figure A-2. The greatest benefits are achieved when the IBV/CI is 1.5/60 or less. It is important to note that the rut depth assumed in the geosynthetic analyses is 2 in. (50 mm), compared to the currently acceptable rut depth of 0.5 in. (12.5 mm) assumed in Figure A-2. For IBVs less than 1, or CIs less than 40, larger thickness reduction could be achieved, depending on the type of geosynthetic and the associated method of analysis recommended for the product. The Inspector should consult the DGE, when the IBV is less than 1, or the CI is less than 40.

Not all types and/or brands of geosynthetics have the same engineering properties. This makes the performance and, consequently, the specifications of geosynthetics product specific. For these reasons, IDOT currently does not have generic specifications that could be applied to all geosynthetic products to be used for subgrade restraint. Some soils require both a geotextile for separation, to prevent intermingling of the subgrade and the aggregate, and a geogrid for subgrade restraint. This combined geotextile-geogrid option has been used, but has proven to be cost prohibitive. The DGE should be consulted for designing or specifying a geosynthetic for subgrade restraint.

Due to a lack of documentation on field and lab performance data, it has been recommended (14) that Central Geotechnical Unit (CGU) verify the cost/benefits of using geosynthetics in new projects. When documenting any field problem or concern, the DGE should provide a copy of the cost/benefits to the CGU's Chief. This will help to establish a statewide performance database for geosynthetics used in subgrade restraint.

Table 3. Guideline for aggregate thickness reduction using geosynthetics (14).

IBV/CI	Aggregate Cover without Geosynthetics in. (mm)	Aggregate Cover with Geotextile in. (mm)	Aggregate Cover with Geogrid in. (mm)
1/40	22 (560)	16 (405)	15 (375)
1.5/60	18 (450)	12 (300)	12 (300)
2/80	16 (400)	12 (300)	10 (250)
3/120	12 (300)	12 (300)	9 (230)

5.5 Moisture Control

All fine-grained soils (fine sand, silt, and clay) are vulnerable to moisture. However, silty soils are extremely moisture sensitive and need special attention. Figure 7 shows the sharp drop in the IBV (33 to 4) of the silt when its moisture was increased by 2% over the optimum. However, the IBV for the clay (Figure 7) did not decrease as significantly as for the silt, when the clay moisture increased by 2% over optimum. In this example, both soils achieved over 97% of the maximum dry density (AASHTO T 99) when compacted at 2 % above optimum moisture, but they did not achieve a minimum IBV of 6.0 required for stability (according to Figure A-2). Field and laboratory data (15) indicate that the compaction moisture must be less than 110% of optimum to ensure an IBV of 6.0. Therefore, control of field moisture is essential to achieving compaction and stability.

To control the field moisture, the Standard Specifications require proper drainage of the area and air drying the top 8 in. (200 mm) of the subgrade. Drainage of the area will remove surface water, but will not significantly reduce the moisture content of fine-grained soils. Drying is accomplished through evaporation of soil moisture. Disking and tilling of the soil accelerates the drying process, by reducing the size of soil lumps, thereby increasing the surface area exposed to evaporation.

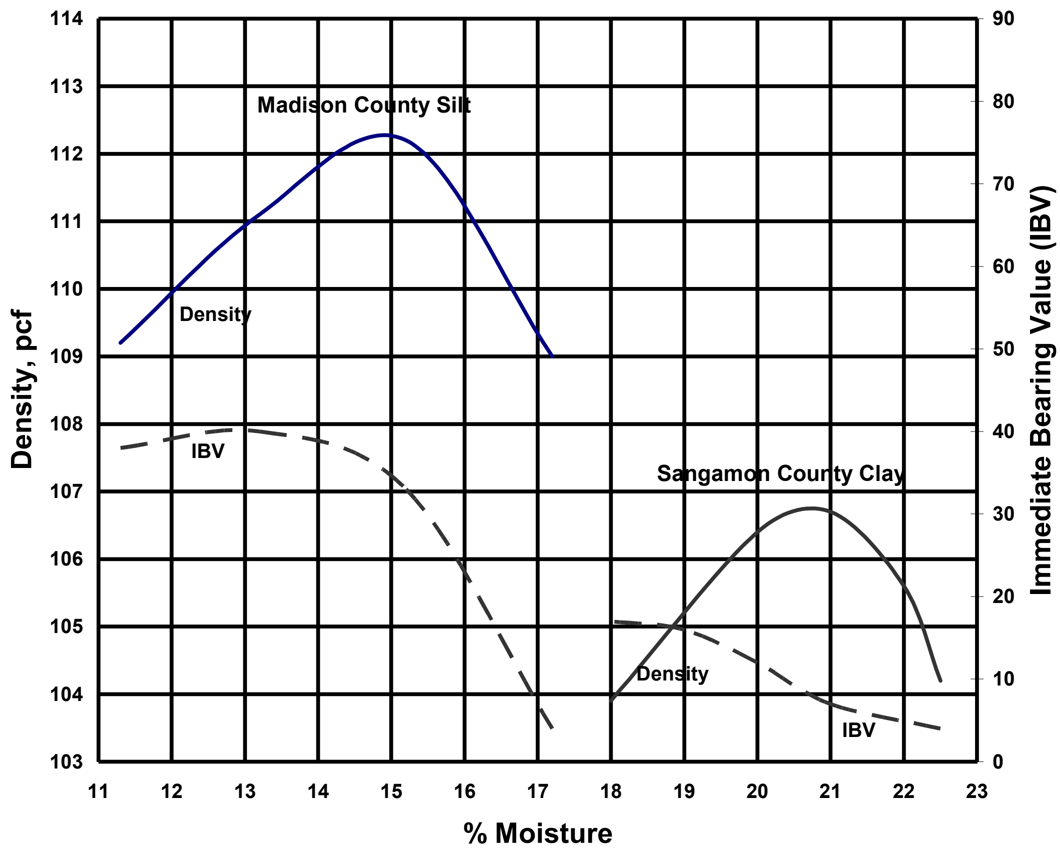


Figure 7. Effect of wet of optimum moisture on the IBV of silt, compared to clay.

The effectiveness of disking and tilling for drying the soil depends on the groundwater elevation, and weather conditions including air and soil temperatures, daily sunshine, humidity, rain, and wind velocity. If the groundwater is high, there may be a continual movement of moisture to the surface, which makes drying much slower. A dry crust may form at the surface but wet, soft soils may remain below. The weather conditions require careful planning/scheduling of the construction activities. If a project schedule requires construction over the winter, drying the soil could become a very slow and costly process, in which case a drying agent such as lime or fly ash (0.5% to 1.5%) may have to be used. Also, it may be possible to place the soil at the optimum moisture during the dry end of a construction season, say in June. However, if paving is planned towards the wet end of the season, say in October, it will be difficult to maintain the soil moisture at optimum, especially if the groundwater is high.

Freeze-thaw cycles over the winter could have a very detrimental effect on the subgrade stability. In these cases, the subgrade may have to be reworked, or removed and replaced with granular material, since the drying option might become slow and costly. The difficulty of maintaining the optimum moisture over the winter remains the same for modified subgrade. However, the Standard Specifications require that modified subgrade be graded to provide positive drainage and that the surface must be covered with plastic sheeting or bituminous material, to help maintain the optimum moisture. Based on the discussion above, it should be concluded that moisture control is not a permanent treatment.

ABBREVIATIONS AND GLOSSARY OF TERMS

BBS – Bureau of Bridges and Structures.
BDE – Bureau of Design and Environment.

BMPR – Bureau of Materials and Physical Research.

CGU – Central Geotechnical Unit of the BBS.

CI – Cone Index is a strength value determined by the SCP test. The CI value is equal to the penetrometer load (pounds) divided by the cone base area (in.) and has units (not expressed) of psi.

DCP – Dynamic Cone Penetrometer, refer to Figure 3.

DGE – District Geotechnical Engineer.

IBV – Immediate Bearing Value is a measure of soil strength, obtained by conducting the standard bearing ratio test, according to AASHTO T 193, on the molded soil sample immediately after compaction (without soaking).

Finished Subgrade – The top surface of a roadbed upon which the pavement and shoulders are constructed. See Article 101.47 of the Standard Specifications.

Improved Subgrade – Typically, a 12 in. (300 mm) thick layer of aggregate or modified soil, to provide a stable working platform under construction traffic.

IDOT – Illinois Department of Transportation

LKD – Lime Kiln Dust is by-product, non-hydrated lime.

PR – Penetration Rate for DCP test, in./Blow (mm/Blow)

Qu – Unconfined compressive strength.

Rough Grade – The top of a modified soil or the bottom of aggregate subgrade prior to any treatment.

SCP – Static Cone Penetrometer, refer to Figure 4.

SSM – Subgrade Stability Manual.

TRP – Technical Review Panel.

UIUC – University of Illinois, Urbana-Champaign.

Unsuitable
Subgrade – A subgrade having materials not meeting the requirements of IDOT's Geotechnical Manual (1).

Unstable
Subgrade – A subgrade having an IBV less than 6.0.

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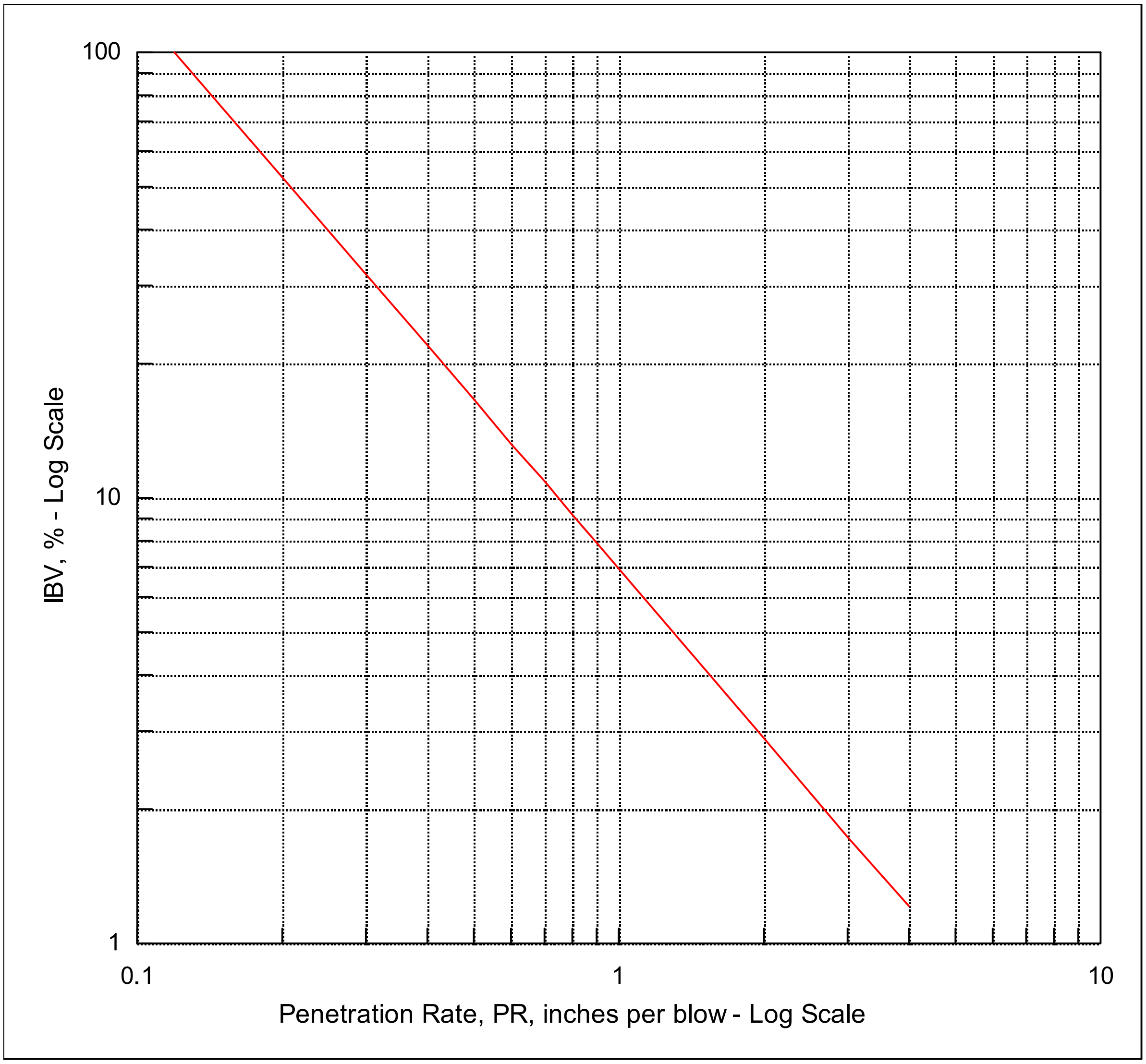
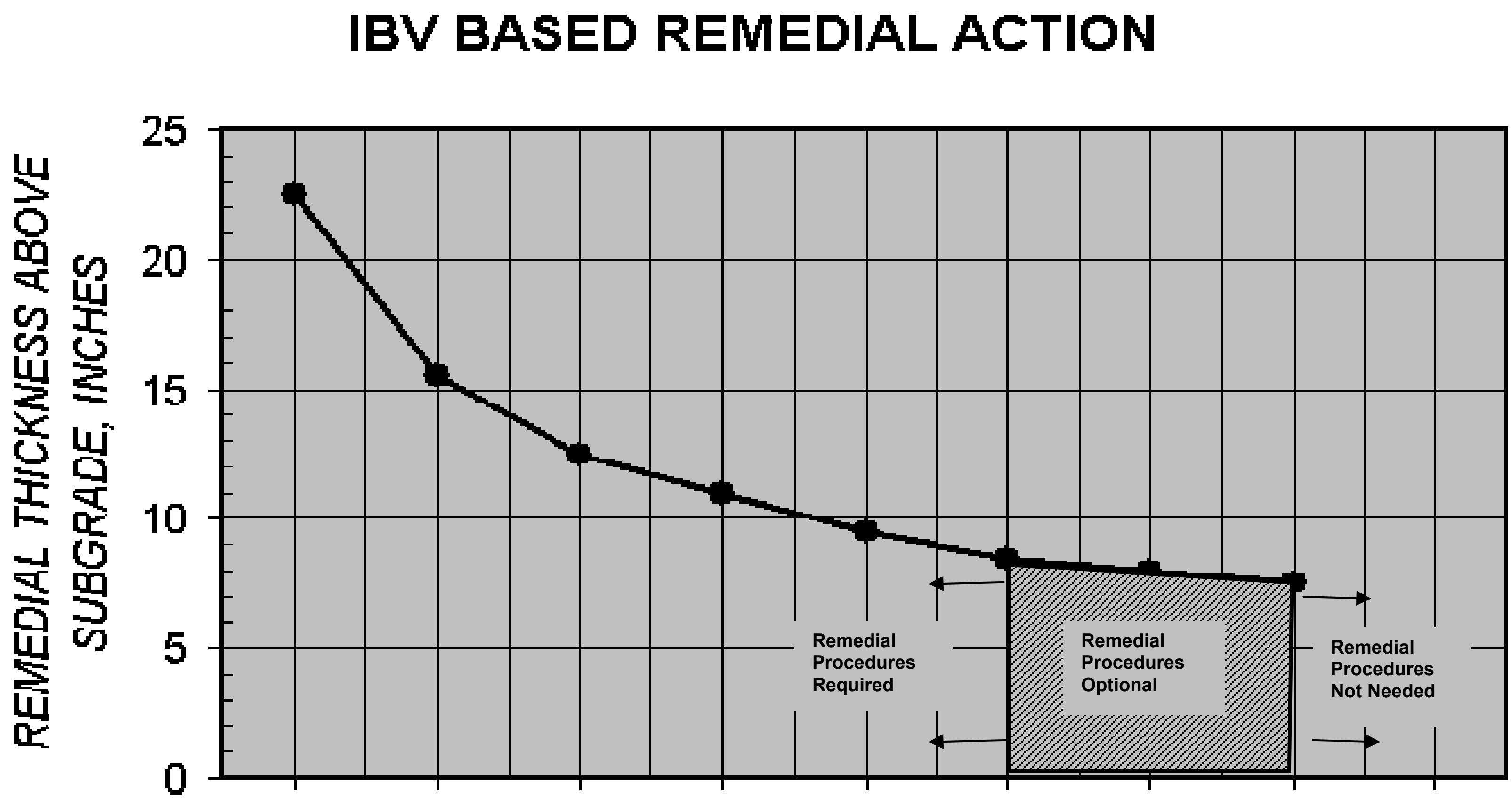
APPENDIX A



$$IBV = 10^{0.84 - 1.26 \times LOG [PR (inches/blow)]}$$

Figure A-1. The IBV versus the PR, from DCP test.



IBV	1	2	3	4	5	6	7	8	9
Cone Index(CI)	40	80	120	160	200	240	280	320	360
Shear Strength (psi)	2.25	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25
Qu (tsf)	0.32	0.64	1.00	1.28	1.60	1.94	2.24	2.56	2.88
Rate (in./Blow)	4.6	2.6	2.0	1.5	1.3	1.1	1.0	0.9	0.8
Rate (Blows/6")	1.3	2.3	3.0	4.0	4.6	5.5	6.0	6.7	7.5
Treatment Thickness	22.5	15.5	12.5	11	9.5	8.5	8	7.5	0

Figure A-2. Thickness design as a function of IBV, CI, Shear Strength, and Q_u for subgrade treatment (granular backfill or modified soil).