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Illinois Modified Standard Penetration Test Procedure

Prepared for
Illinois Department of Transportation

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Introduction

The Standard Penetration Test (SPT) (ASTM D1586-11 or AASHTO T 206-09) has been used to estimate strength parameters of soils for a long time. It has also been used to estimate undrained shear strength parameters for weak rocks when it is difficult to obtain high quality/undisturbed samples for laboratory testing. However, the full 18 inches (45 cm) of penetration required to measure an N-value (number of blows to drvie split- spoon sampler the last 12 inches), can be difficult or impossible to obtain in weak rocks. To limit overstressing and damage to a split-spoon sampler, the ASTM and AASHTO test standards permit the penetration of a sampler to be halted under the following conditions:

1. A total of 50 blows have been applied during any one of the three 6 inch (0.15 m) increments,
2. A total of 100 blows have been applied, and
3. There is no observed advance of the sampler during the application of 10 successive blows

SPT data recently obtained from twenty one (21) Illinois Department of Transportation (IDOT) bridge sites underlain by weak shales typically exhibits penetrations of the split-spoon sampler of only 6 to 12 inches (15 to 30 cm) after 100 blows of an automatic trip hammer weighing 140 lbf (63.5 kg) with a drop distance of 30 inches (76 cm). This is problematic because it limits the correlated material strength to conservative values for foundation design by having less than 18 inches of penetration. Using these lower bound strengths may lead to conservative and more costly foundation designs. To expand the range of strengths interpreted from SPT results in weak fine-grained rocks (e.g. shales), the SPT procedure was modified to record penetraton data in 10 blow increments and correlate it to undrained shear strength of weak fine-grained rocks. The resulting Modified SPT (MSPT) procedure is summarized below.

MSPT Applicability

The MSPT procedure is designed to be used in weak rocks and shales that exhibit unconfined compressive strength (UCS) between 10 and 100 ksf. The test provides a means for estimating undrained shear strength of such geomaterial as per the correlation developed by Stark et al. (2017). Geomaterial with a UCS between 10 and 100 ksf is also referred to as cohesive Intermediate Geologic Material (IGM) by O'Neill and Reese (1999).

When To Use The MSPT

The following two drilled shaft deisgn scenarios are envisioned for the MSPT: (1) site with prior subsurface investigation and (2) new site with no existing subsurface data. The following paragraphs describe how to use the MSPT for these two scenarios.

Prior Subsurface Investigation

If boring logs are available from a previous site investigation, determine the range of UCS from the boring logs and reported testing. If the UCS is between 10 and 100 ksf, use the MSPT for these materials and rock coring is not required if the foundation will be founded in these geomaterials. If the foundation will not be founded in these materials and the UCS exceeds 100 ksf in the other materials, rock coring of the founding materials is needed to measure the UCS for design purposes. If the foundation will not be founded in these materials and the UCS is less than 10 ksf in the other materials, traditional SPTs and soil testing of the founding materials is needed to measure the UCS for drilled shaft design purposes.

New Site with No Prior Subsurface Investigation

If investigating a new site where no previous testing or borings logs are available, a boring should be initially drilled with traditional SPTs being conducted at a reasonable depth interval, e.g., every 2.5 ft to 5 ft (0.75 to 1.5 m). Standard SPT sampling should be continued until a material with strengths typically in the range of 10 to 100 ksf, such as shale or other cohesive IGMs, are encountered, and/or the split-spoon sampler is unable to penetrate the full depth (18 inches) prior to termination. Under such conditions, the drilling crew should switch to rock coring using a double tube swivel type, split core barrel to decrease the exposure of the cored shale to the drilling fluid and maintain the strength and integrity of the shale for laboratory testing. The core barrel could have a diameter of 2.0 to 2.5 inches, e.g., NX or NQ-2 core barrel.

Shale cores should be examined to identify the geologic description of the encountered shales. Fissure Spacing, Rock Quality Designation (RQD), and Total Core Recovery (TCR) should be measured. If the extracted shale cores are highly fragmented/broken that will prevent obtaining intact specimens for laboratory UCS testing, MSPT should be conducted in a second borehole adjacent to the rock coring borehole to evaulte the UCS of that layer.

Where there are multiple borings to be drilled at a new project site, both rock coring and MSPT are recommended for the first boring to determine if the site materials are a candidate for the MSPT and to have a visual sample of the materials for contracting purposes. If the rock core or split-spoon sample exhibits an UCS between 10 and 100 ksf via visual inspection, e,.g., weak and/or highly fractured, or using a field Rimac device, proceed with MSPTs and further rock coring may not be needed at the other boring sites. MSPTs should be conducted at a reasonable depth interval, e.g., every 2.5 ft to 5 ft (0.75 to 1.5 m). At any MSPT borehole, if the measured pentration for the last 40 blows is less than 0.5 inches, the drilling crew should stop the MSPT testing and switch to rock coring because the UCS probably exceeds 100 ksf.

Modified Standard Penetration Test

The MSPT is based on a new defined parameter termed the Penetration Rate (N_{rate}) which utilizes penetration per 10 blows instead of blows per foot. The Penetration Rate is defined as the inverse of the slope of the secondary or linear portion of a penetration versus cumulative blow counts relationship for an individual SPT (see Figure 1). The results of MSPTs conducted for twenty one (21) Illinois Department of Transportation (IDOT) bridge sites underlain by weak rocks and shales show that N_{rate} generally approaches a constant value after 40 to 60 blows and it remains constant regardless of the achieved penetration (See Note 1). Therefore, the rate of penetration can provide a means of evaluating the strength of the material beyond the current

SPT procedure terminating criteria. The MSPT is stopped after 100 blows regardless of the depth of penetration.

<u>Note 1:</u>

This is likely due to the split-spoon sampler passing through the disturbed material at the bottom of the boring and reaching intact/undisturbed material below after 40 to 60 blows.

MSPT Procedure

The MSPT procedure is simple and similar in many respects to the SPT (ASTM D1586-11 or AASHTO T 206-09). The equipment used in the MSPT is the same as that used in SPT but the blow count and penetration data is collected differently. At each MSPT elevation or depth, the sampler penetration is measured at the end of ten (10) blows of a 140 lbf (63.5 kg) hammer falling 30 inches (76 cm) using a measuring device, such as a stick ruler. This measurement is repeated 10 times for a total of 100 blow and then the MSPT is stopped. MSPTs show a secondary/linear slope, which is often achieved after 40 to 60 blow counts for the weak fine-grained rocks tested herein with an unconfined compressive strength (UCS) of 10 to 100 ksf (0.48 to 4.8 MPa).

Figure 1 shows the penetration depth versus blow count relationship and the initial and secondary slopes of the blow count versus penetration relationship from a MSPT. The initial slope is associated with disturbed and loose material or cuttings at the bottom of the borehole and the tip of the split-spoon sampler of the MSPT. The initial slope is not representative of the UCS of the intact/undisturbed weak rock and thus is not used for the correlation between N_{rate} and UCS developed herein. The secondary slope is typically more linear and representative of the intact strength of the weak fine-grained rock. The procedure for obtaining the secondary slope and penetration rate is outlined below:

1. Drill to the desired depth of the MSPT, insert the MSPT split-spoon sampler (see Note 2) and necessary drill rod,

2. Considering the length of drill rod exposed above the casing, choose and mark a convenient point on the drill rod at which depth of penetration measurements will be taken using a measuring device, e.g., a stick ruler. This convenient point could be the bottom of the anvil or a drill rod joint.
3. Measure the initial distance of the drill rod segment between the top of the hollow stem auger or borehole casing and the point chosen in Step 2.
4. Apply 10 blows to the top of the drill rod using a 140 lbf hammer falling 30 inches, measure and record the new distance between the top of the hollow stem auger casing and the point chosen in Step 2. This can be accomplished by stopping the test or by using a stick ruler that is inserted into this length and read between the 10^{th} and 11th blows of this sequence.
5. Measure and record the new distance between the top of the hollow stem auger casing and the point chosen in Step 2 before the 11^{th} blow of this sequence,
6. Repeat Steps 2 through 5 to obtain the sampler penetration for the 20-, 30-, 40-, 50-, 60-, 70-, 80-, 90-, and 100-blow count increments.
7. Obtain the SPT hammer energy rating from the driller for analyzing the MSPT results.

Note 2:

The split-spoon sampler and the driving shoe shall be in a good to new condition and must be replaced if it is dented or distorted. The opening of the driving shoe should be confirmed with a #11 rebar to ensure the opening is circular and 1 3/8 inches (34.9 cm) in diameter and the driving shoe reasonably sharp.

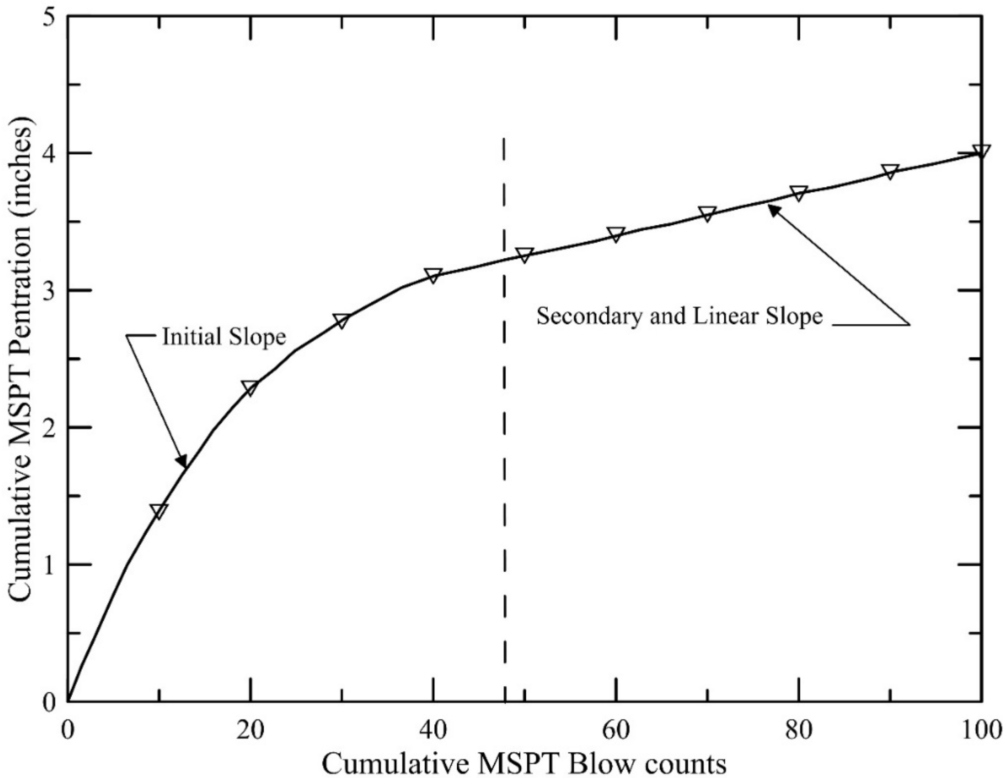

Figure 1. Typical MSPT cumulative penetration versus cumulative blow counts plot for Illinois weak shale

MSPT Analysis Procedure

The procedure for determining N_{rate} from the relationship of penetration depth versus MSPT blow counts is shown in Figure 1 and is outlined below:

1. Using the data obtained from a MSPT, plot the cumulative penetration versus cumulative blow count.
2. Determine the range of the linear portion of the resulting cumulative penetration versus cumulative MSPT blow count plot relationship.
3. Draw the best fit line through the linear portion of the cumulative penetration versus MSPT blow count plot.
4. Determine the slope of the best fit line, which is the Secondary Slope.

5. N_{rate} is the inverse of the Secondary Slope obtained in Step 3 and is defined as:

$$N_{\text{rate}} = \left(\frac{\Delta\text{Cumulative MSPT Blow count}}{\Delta\text{Cumulative Penetnration}}\right)$$

Irregular Cumulative Penetration Rates Analysus

Cumulative penetration versus cumulative blow count relationships may contain two or more linear portions (see Figure 2). Irregular plots indicate the sampler has entered a different stratigraphic layer or encountered a gravel or cobble particle. Thus, rock and/or soil material present in the split-spoon sampler from a MSPT should be carefully inspected to document any changes in material type or presence of a gravel or cobble particle, which will assist in understanding aberrant trends in the data when it is plotted. Irregular cumulative penetration versus cumulative blow count relationships can be conservatively interpreted by using the secondary slope that yields the lowest value of N_{rate} or by taking the average slope which yields an average N_{rate}.

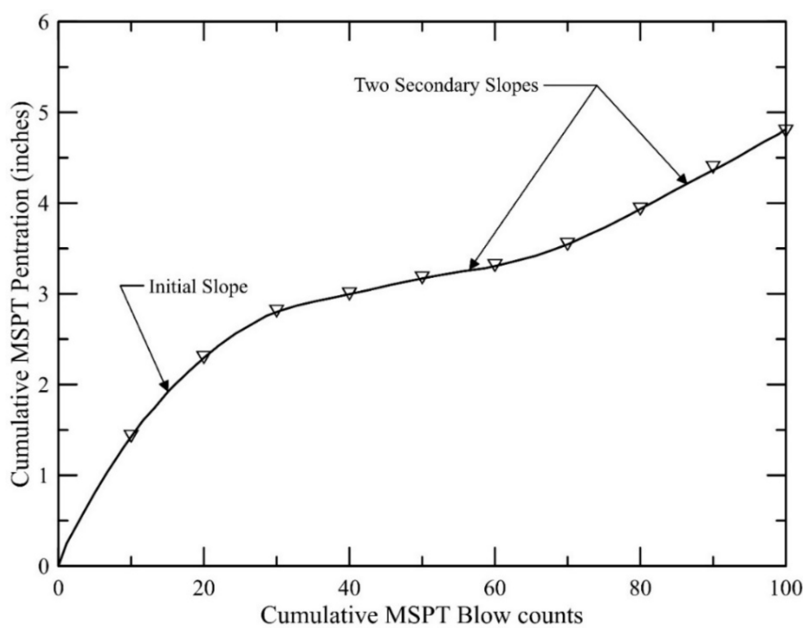

Figure 2. Irregular MSPT cumulative penetration versus cumulative penetration blow counts plot for Illinois weak shale

MSPT Penetration Rate Correction

As with blow counts obtained from traditional SPTs, the MSPT penetration rate should be corrected for the effect of hammer energy, borehole diameter, sampler liner, and drill rod length (see Table 1). If the MSPT blow counts and penetration rate are obtained using an automatic trip hammer, the results from this study indicate 75% to 95% of the theoretical maximum hammer energy is delivered to the drill rod. To minimize the MSPT blow counts corrections, an energy ratio of 90% shall be used because all of the drill rigs used during this study utilized an automatic trip hammer and imparted an average of 90% of the theoretical maximum hammer energy. Thus, MSPT N_{rate} values obtained using an automatic trip hammer, which is the most commonly used hammer by IDOT, do not require significant corrections in comparison to the previously suggested energy correction factor for soils, i.e., 60% of the theoretical maximum hammer energy. A normalized penetration rate, $(N_{rate})_{90}$, was developed herein and is defined as follows for hammers that deliver 90% of theoretical maximum energy:

$$(N_{rate})_{90} = \frac{N_{rate} \times E_M \times C_B \times C_S \times C_R}{0.9}$$

where:

$(N_{rate})_{90}$ = N_{rate} corrected for 90% of the theoretical energy and various field procedures

E_M = hammer efficiency

C_B = borehole diameter correction

C_S = sampler correction

C_R = rod length correction, and

N_{rate} = measured penetration rate

Table 1 shows the recommended borehole diameter, rod length, and sampler correction factors from Skempton (1986). If the hammer does not yield 90% of the theoretical maximum hammer energy, the measured hammer energy should be inserted for E_M in the equation above to normalize the measured N_{rate} to 90% of the theoretical maximum hammer energy. The sampler correction assumes that liners will be installed in the split-spoon sampler to be consistent with Skempton (1986) even though the practice now is to not use liners.

Table 1: N_{rate} Correction factors after Skempton (1986)

Effect	Variable	Term	Value
Borehole diameter	2.5 – 4.5 inches 6 inches 8 inches	C_B	1.00 1.05 1.15
Sampling Spoon	Smooth sampler (or with liners) Sampler without liners	C_S	1.0 1.2
Rod Length	30 – 100 ft 20 – 30 ft 13 – 20 ft 10 – 13 ft	C_R	1.0 0.95 0.85 0.75

MSPT Data Sheets

Drilling information and MSPT data obtained at each borehole shall be recorded in the field and include the following:

1. Date,
2. Name of the Drilling Crew,
3. Type and Make of the drill rig,
4. SPT Hammer Efficiency,
5. Project/Bridge Location,
6. Boring Number and location (station and coordinates),

7. Ground Surface Elevation,
8. Ground water surface Elevation,
9. MSPT elevations and depths,
10. Description of recovered weak rock or shale, and
11. Measured penetration depth every 10 blows to the nearest 0.1 inches (2.5 mm).

Table 2 shows an example of a sample data sheet that could be used to record the MSPT data in the field.

Table 2: Sample MSPT Data Sheet

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Modified SPT Log

Route: ______ Structure No.: ______ (Exist.) ______ (Prop.) Date: ______ Page: ______ of ______

Section: ______ Description: ______

County: ______ Logged by: ______ Sampler Tube Length: ______ in.

Boring No.: ______ Station: ______ Offset: ______ Latitude: ______ Longitude: ______

Drill Rig: ______ Hammer Type: ______ Hammer Efficiency (%): ______ Surface Elevation: ______

Borehole Diameter. (in.) ______ Split-barrel Sampler Description: ______

	Measured Rod Length (ft)	*Blows where exposed rod length is measured (blows)*											$N_{rate,90}$	q_u	Young's Modulus
		0	10	20	30	40	50	60	70	80	90	100	(bpf)	(ksf)	(ksi)
Test Elevation															

References

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