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U.S. ARMY TEST AND EVALUATION COMMAND TEST OPERATIONS PROCEDURE

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SOFT SOIL MOBILITY

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1. SCOPE.

1.1 Purpose.

This Test Operations Procedure (TOP) describes methods used to measure, analyze, and report the severity/condition of test environments and perform tests of traction and floatation of wheeled and tracked vehicles operating in low soil strength conditions. Data required to support the North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM) are also presented and defined.

1.2 Background.

a. Throughout history terrain has limited military ground operations in warfare. The type, time, direction, and extent of such operations are dictated by the type and condition of existing terrain. The success of many planned operations have been jeopardized by unforeseen changes in soil conditions with vehicles becoming immobilized due to a loss of traction and/or floatation.

b. Road mobility is but one portion of the total mobility picture. Wheeled and tracked vehicles operating on roads constructed of hard, smooth surfaces are typically not confronted with mobility difficulties. Off-road operation, where soft soil conditions like mud, sand, swamps, wet clay, and rice paddies exist, constitutes the mobility challenge to which this procedure addresses.

c. Vehicle floatation and traction limits are a function of the soil's shear strength. Soil shear strength can vary widely over small areas and with depth in the ground profile, especially in very soft conditions making soil trafficability characterization challenging with a need for a large number of in-situ shear strength measurements. Trafficability predictions were conceived as a very inexact science with a confusing array of methods^{1**}.

1.3 Limitations.

a. The procedures outlined in this TOP apply to conventional designs of wheeled and tracked vehicles operating on test courses such as those described in TOP 01-1-011A². Additional natural and prepared test environments may be required to analyze unique vehicle designs and attributes, or to address specialized mobility test requirements.

b. Tests are typically conducted in the prevailing weather conditions with some exception. Tests should not be conducted in the rain or with frozen soil. Test areas are further prepared for specific environmental conditions to include soil strength profile and moisture. The use of specialized agricultural equipment and irrigation are needed based on the test requirements. VCI testing is currently required to be performed only on natural, unprepared lanes due to the difficulty in replicating natural soil conditions.

** Superscript numbers correspond to Appendix D, References.

c. Off-road mobility challenges created by brush, trees, and solid obstacles are not covered by this procedure, nor is the interrelationship of maneuverability and mobility discussed.

2. FACILITIES AND INSTRUMENTATION.

2.1 Calibration.

a. All measuring tools and instrumentation will be calibrated against a higher order standard at periodic intervals not to exceed twelve months. Records showing the calibration traceability to the National Institute of Standards and Technology (NIST) will be maintained for all measuring and test equipment.

b. All measuring and test equipment will be labeled with the following information:

- (1) Date of calibration.
- (2) Date of next scheduled calibration.
- (3) Name of the organization and technician who calibrated the equipment.

c. A written calibration report will be provided that includes as a minimum the following information for all measurement and test equipment:

- (1) Type of equipment, manufacturer, model number, etc.
- (2) Measurement range.
- (3) Accuracy.
- (4) Calibration interval.
- (5) Type of standard used to calibrate the equipment (calibration traceability of the standard must be evident).

2.2 Measurement Tools.

<u>Item</u>	<u>Requirement</u>
Steel tape	± 0.5 millimeter (mm) (0.02 inch (in.)) or better accuracy
Pi-tape (diameter measuring)	± 0.3 mm (0.01 in.) up to 3600 mm (142 in.)
Depth gauge	± 0.1 mm (0.004 in.) or better accuracy

<u>Item</u>	<u>Requirement</u>
Platform scales	^a Capable of weighing the tire or wheel to an accuracy of $\pm 0.5\%$ of the scale's range

^a To obtain measurements with good accuracy and resolution, measurement of the lightest tire or wheel should use at least 10% of the scale's range.

2.3 Instrumentation.

<u>Devices for Measuring</u>	<u>Maximum Error of Measurement</u>
Road speed (velocity)	± 0.2 kilometers per hour (km/hr) or ± 0.1 miles per hour (mph)
Wheel or sprocket speed	$\pm 0.5\%$ of full-scale range
Engine speed	$\pm 0.5\%$ of full-scale range
Drawbar force	$\pm 0.5\%$ of full-scale range
Wheel or sprocket output torque	$\pm 1\%$ of full-scale range
Wheel spindle force	$\pm 1\%$ of full-scale range
Steering effort	$\pm 1\%$ of full-scale range
Acceleration	$\pm 0.05g$
Pitch, roll, and yaw rate	± 0.1 degrees per second (deg/sec)
Temperature	± 2 °Celsius (°C) (4 °Fahrenheit (°F))
Pressure	$\pm 1\%$ of full-scale range
Vehicle sinkage (transit and rod)	± 25 mm (1 in.)
Vehicle sinkage (high density laser scanning survey systems)	± 2 mm (0.1 in.)
Cone index (cone penetrometer)	$\pm 5\%$ of reading
Percent soil moisture content	$\pm 0.5\%$ of reading
Relative humidity	$\pm 3\%$ (0 to 90%) and $\pm 4\%$ (90 to 100%)

<u>Devices for Measuring</u>	<u>Maximum Error of Measurement</u>
Barometric pressure	± 1.0 millimeter of mercury (mm Hg)
Wind speed	± 2 knots (kts), 3 km/hr, 1 meter per second (m/s), or $\pm 5\%$ of reading (whichever is higher)
Wind direction	± 7 degrees

NOTE: Values may be assumed to represent ± 2 standard deviations. Thus, the stated tolerances should not be exceeded in more than one measurement out of 20.

2.3.1 Cone Penetrometer.

a. The cone index (CI) is measured using a Corps of Engineers cone penetrometer, described in Field Manual (FM) 5-430-00-1³. The cone penetrometer is typically configured with a 30-degree cone having a 0.5 or 0.2 in² base area, an 18 or 36 inch steel shaft of 3/8-in. diameter, a proving ring, a dial indicator, and a handle. The amount of force required to manually push the cone slowly through a given soil is indicated on the dial inside the proving ring after being translated to the CI value, indicated over the 0-300 lb/in² for the 0.5 in² cone or 0-750 lb/in² for the 0.2 in² cone. The CI represents the shearing resistance of the soil in the plane perpendicular to the base of the cone. FM 5-430-00-1 covers the calibration and use of the cone penetrometer.

b. When used for remolding tests in remoldable sands or for CI measurements in higher strength soil conditions, the cone penetrometer is configured with the 0.2 in² cone.

c. Use of a digital cone penetrometer may also be used when a large number of measurements are needed. The digital penetrometer measures and records the force as a function of depth, as well as the global positioning system (GPS) coordinates for each measurement. Digital cone penetrometers have been found to be less accurate than manual read cone penetrometers. This issue stems from inaccuracies in the depth readings. Therefore, manual cone penetrometers are highly recommended over digital models, especially for VCI testing and any soil characterizations supporting Key Performance Parameter (KPP) or Key System Attribute (KSA) requirements.

2.3.2 Inertial Measurement System.

Vehicle reactions are measured using a 6-degree of freedom (6-DOF) inertial measurement system to record pitch (θ), roll (ϕ), and yaw (Ψ) rates, and longitudinal (x), lateral (y), and vertical (z) acceleration of the chassis. The transducer should be mounted as close as practical to the center of gravity of the test vehicle.

2.3.3 Control Area Network (CAN) Bus.

If the test vehicle is equipped with a CAN data bus, applicable data should be monitored and recorded, as described in TOP 01-2-506⁴. The data bus can provide key information for mobility tests, including gear ranges selected and attained, torque converter status, throttle position, relative power and torque values, traction control status, etc. The validity of the data bus information must be verified or the source of data documented.

2.3.4 Spinning Wheel Integrated Force Transducer (SWIFT).

The SWIFT^{***} transducers (commercially available) measure the three forces and three moments at the transducer center. The SWIFT measurement system transforms the measured rotating wheel loads to non-rotating axle loads in real time. Additional post processing geometric transformations are performed to determine the forces and moments at the tire contact patch. Force and moment data from the rotating transducer provide important performance measurements of tractive force and suspension loads. The high stiffness and natural frequency of the SWIFT, combined with the excellent resolution make it ideal for tire and wheel testing. Table 1 presents the performance characteristics of the U.S. Army Aberdeen Test Center (ATC) owned transducers.

TABLE 1. ATC WHEEL FORCE TRANSDUCERS

MAXIMUM CALIBRATED LOAD/RATINGS	SWIFT 40 (4 EACH)	SWIFT 50 (4 EACH)
Longitudinal force, F_x , kN (lb)	40 (8,992)	220 (49,458)
Lateral force, F_y , kN (lb)	30 (6,744)	100 (22,481)
Vertical force, F_z , kN (lb)	40 (8,992)	220 (49,458)
Overturning moment, M_x , kN-m (in-lb)	9 (79,657)	50 (442,537)
Rolling resistance moment, M_y , kN-m (in-lb)	13 (115,060)	50 (442,537)
Aligning moment, M_z , kN-m (in-lb)	9 (79,657)	50 (442,537)
Maximum usable speed, rpm	2,200	
Shock resistance, each axis	50 g	
Force nonlinearity, % of full scale	1	
Moment nonlinearity, % of full scale	1	

***The use of brand names does not constitute endorsement by the Army or any other agency of the Federal Government, nor does it imply that it is best suited for its intended application.

2.4 Facilities and Specialized Equipment.

2.4.1 Test Courses.

a. Physical descriptions of the off-road test areas at ATC are presented below. See paragraph 3.4 for information regarding the Unified Soil Classification System (USCS) classification.

<u>Name</u>	<u>Description</u>
Marsh	The marsh areas are along the creeks that feed the Chesapeake Bay. The area is subjected to tidal action and is flooded periodically by tidal and storm surges. The soil is mainly fine grained with some peat. The areas and their USCS classification are: Munson Test Area (MTA) marsh course - ML, Perryman Test Area (PTA) marsh area - ML, and Spesutie Narrows - MH. The PTA marsh area is located inland along a small creek fed by a wetland pond that periodically floods after heavy rains. The area has 22,300 m ² (240,000 ft ²) of heavy growth vegetation, but can be prepared without the root structure. The marsh areas are considered bottomless as far as vehicle mobility is concerned.
Sandy Loam Course	The MTA abrasive mud course (Hog Wallow) is a 73 x 290 meter (m) (240 x 950 feet (ft)) level area. An irrigation system supplies water to the area for additional moisture, when needed. The course is classified as SM by the USCS and is considered a remoldable sand material. The soil strength and remolding index are variable with moisture content. This course is maintained and can be tilled to a depth of 55 centimeters (cm) (22 in.) using a rotary spading machine.
Munson Sand Course	The Munson sand course provides a standard for analyzing tractive effort and drawbar pull of wheeled and tracked vehicles under controlled conditions. The sand is contained in a concrete bin that facilitates tilling and drainage, and prevents contamination from the surrounding soil. The 6 x 161 m (20 x 530 ft) straight portion of the course has sufficient length to produce stabilized data for a given condition. The 29 m (95 ft) circular bed at the end of the course is used for analyzing the ability of vehicles to steer in sand, for determining track-throwing tendencies, and the effect of sand accumulation in suspension systems. The course material is classified as SP by the USCS. This course is

maintained by a rotary spader and can be groomed and dried using an offset disc and cultipacker. The sand depth is 76 cm (30 in.).

Dig Sites

PTA has four dig site areas. The dig sites have permanent sediment and erosion controls. If unused the areas tend to grass over and are periodically reopened using an offset disc. After each test program the disturbed area is leveled until the next use. Dig site 1 has large trapezoidal shape and is 481 m (1580 ft) in length while the width changes from 61 m (240 ft) to 24 m (80 ft) at its narrowest point. The soil is classified as SC-SM by the USCS. Dig site 2 is a long relatively narrow area having a width of 27 to 37 m (90 to 120 ft) and a length of 640 m (2100 ft). The soil is classified by USCS as SM. Dig site 3 is an area that is 165 m (540 ft) long and 84 m (275 ft) wide. The soil is classified as CL by USCS. Dig site 4 has a length of 366 m (1200 ft) and a width of 30 m (100 ft) and is classified as CL-ML by USCS.

PTA Mud Bypass

The mud bypass course is a 6 x 213 m (20 x 700 ft) area with USCS SM soil. The course is maintained using an independent well-fed irrigation system and is tilled using rippers, offset discs, and a rotary spading machine as program requirements dictate.

Alternate Landing Zone

PTA has a grass field that is known as the Alternate Landing Zone. It is utilized for training by the Maryland National Guard as a confined area landing zone. The area dimensions are 38 x 206 m (125 x 675 ft) with soil that is classified as CL-ML by the USCS. The elevation change over its length is 1.6 m (5.2 ft.).

Prepared Dirt Slopes Churchville Test Area (CTA)

These slopes are used for controlled tests to analyze the tractive ability of vehicles. Four slopes: (1) 10 percent, 67 m (220 ft); (2) 15 percent, 76 m (250 ft); (3) 20 percent, 67 m (220 ft); and (4) 25 percent, 183 m (600 ft), are particularly useful for measuring mobility performance and for comparison tests of experimental and standard vehicles. The slopes are classified as SM by the USCS.

b. Physical descriptions of the off-road test areas at the U.S. Army Yuma Test Center (YTC) are presented below.

<u>Name</u>	<u>Description</u>
Sand Grades	The longitudinal sand grades are located in an alluvial plain that lies next to Highway 95. The course material is, soft, loose, dry, wind sorted beach sand that was imported from southern California. The sand slopes have nominal grades of 5-, 10-, 15-, 22-, and 28-percent, respectively, and are prepared prior to test for a uniform condition by disc harrowing. The testable portions of each grade is a different length: 5% grade is 61 m (200 ft), 10% grade is 30 m (100 ft), 15% grade is 55 m (180 ft), 22% grade is 37 m (120 ft) in length, and the 28% grade is 32 m (104 ft).
Sand Dynamometer Course	The sand dynamometer course is composed of primarily Gilman Family, Harqua Family, and Glenbar soils that are sandy silty loams with fine particles. These soils are easily moved by wind action and tend to build extensive low dunes. The sand dynamometer terrain is described as sandy upland. The course is built upon one of the larger dunes and has adequate space for multiple passes over untracked terrain between surface preparations. The uniformity of the course surface is maintained by disc harrowing. The course is used primarily to determine vehicle speeds and mobility in deep sand.

2.4.2 Specialized Tools/Equipment.

The specialized tools/equipment used to characterize the soil conditions and their applicable standards are presented below.

<u>Soil Measurement</u>	<u>Applicable Standard</u>
Soil sieves and sieve shaker	American Society for Testing and Materials (ASTM) E11 ⁵ and ASTM C136 ⁶
Soil trafficability test kit	FM 5-430-00-1
Soil moisture test kit (Speedy Moisture Kit)	ASTM D4944 ⁷
Soil moisture (Time Domain Reflectometry)	ASTM D6565 ⁸
Soil moisture test pans	ASTM D2216 ⁹
Casagrande Liquid Limit Device	ASTM D4318 ¹⁰

3. REQUIRED TEST CONDITIONS.

3.1 Vehicle Preparation.

a. Initial inspection of the test vehicles should be conducted as described in TOP 02-2-505¹¹, with emphasis given to the following:

- (1) Condition of engine.
- (2) Condition of power train.
- (3) Condition of suspension components.
- (4) Condition of tires or tracks.

NOTE: New tires or track are usually tested on the vehicles, but often worn tires and grousers are used to analyze the loss of performance due to wear. In all cases the exact condition of the components is documented.

(5) Record inspection data on a report form, appropriate to the vehicle (e.g., Department of the Army (DA) Form 2404).

(6) Perform oil analysis on critical component fluids as required.

(7) Perform necessary tests to optimize track tension or tire pressure of the test vehicle.

(8) Adjust the vehicle test weight to the specified combat or gross vehicle weight by the addition of on-vehicle equipment and additional weights, paying attention to axle weight and tire load limits.

(9) Determine and record weight distribution using TOP 02-2-801¹² as a guide.

(10) Take characteristic photographs of vehicle and record weights and dimensions of the vehicle using TOP 02-2-500¹³ as a guide.

(11) Ensure test driver is familiar with test vehicle operation to include driveline configuration setting specific for off-road operations.

b. Tire pressure should be set as specified in the Technical Manual (TM) or Detailed Test Plan (DTP). If the vehicle is equipped with a Central Tire Inflation System (CTIS), the appropriate off-road tire pressure settings should be used. If the vehicle is equipped with traction control technology, tests should be performed with and without the system operational, provided engagement of traction control is driver selectable.

3.2 Instrumentation.

a. The vehicle is instrumented to measure vehicle performance under a variety of operating and environmental conditions to include full-throttle (tractive effort and drawbar pull), part-throttle (resistance to motion, power loss, and crossing velocity), and maneuverability (bead unseating, track loss, and steering effort). High driveline loads are applied to the vehicle during soft soil mobility tests, so critical temperatures should be measured to avoid potential overheating during the test. The instrumentation commonly used consists of a mobile field dynamometer, an engine speed tachometer, a calibrated speed measuring device with a speed indicator for the driver, sprocket or wheel tachometers for all powered traction elements, and the appropriate pressure gages and thermocouples. Temperatures are generally sampled once per second, while the rotational speeds, drawbar force, and pressures are generally sampled at a minimum of ten times per second.

b. Moisture content should always be measured and recorded during soft soil testing. Three different procedures may be used. The primary method for determining soil moisture content is the laboratory method where the reduction of mass of the collected soil sample by oven drying determines the percentage of moisture present. This procedure is described in ASTM D2216. A second method is using the calcium-carbide-gas pressure method. This procedure is outlined in ASTM D4944. The third method is the use of time-domain reflectometry (TDR). This is an electromagnetic method that determines the moisture content in the soil. A probe is inserted into the soil and the instrumentation sends a pulsed waveform through the probe. The returned signal is influenced by the dielectric content of the soil. This procedure is outlined in ASTM D6565. The accuracy of the moisture content measurements are $\pm 0.5\%$ of the reading up to 20%. Data are reported to the nearest 1%. The calcium carbide gas pressure method is quicker and more convenient, however the laboratory method is more accurate and is considered the benchmark standard that the other methods attempt to match. Therefore, the reduction of mass method (ASTM D2216) is preferred, especially for VCI testing and for soil characterization supporting KPP or KSA test requirements.

c. Sinkage (or rut depth) is measured to characterize vehicle floatation. There is a distinction between sinkage and rut depth. Sinkage is a dynamic measurement of vertical movement of the wheel hub relative to the ground while driving, but may be difficult to measure in practice. Fine-grained soils often rebound slightly immediately after a wheel pass, and both fine-grained and coarse-grained soils often fill in a rut to some degree immediately after wheeled vehicle traffic. The remaining static depression is called a rut, and is much easier to measure. For practical purposes, measurement of rut depth is often used in lieu of sinkage.

d. A surveyors' transit and rod or a high-density laser scanning survey system may be used to measure the rut depth.

(1) When using the transit and rod, measurements should be taken along the travel path at predetermined intervals. At each location three measurements per tire or track path are measured. The measurements are taken inside and outside of each path in the undisturbed soil and another in the compressed area.

(2) Two high-density survey laser scanning tools have been used at ATC; a Leica model C10 and a Leica model HDS6000. The scanners are line of sight instruments that use a Light Detection and Ranging (LiDAR) laser to collect thousands of position measurement points very quickly. Three dimensional terrain profiles are created from the LiDAR data, which can then be used to estimate rut volume and surface deformation. The scanner is moved between successive measurements to completely cover the area of interest. The data from the different measurement locations are merged into a single three-dimensional survey of the test area. Rut depth measurement requires scanning before and after vehicle traffic.

(3) Since the scanner is line of sight tool, the area must be mowed as short as possible or graded. Grass and weeds are not easy to differentiate from rough terrain. Extraneous items must be manually removed from the surface data during data reduction. The scanner will not penetrate standing water and must be setup on stable ground. Mud or freezing/thawing ground may shift causing the scanner to stop functioning. Deep tire tracks or very rough terrain within the track area will require multiple scans to capture all the needed data. The accuracy for both scanners is ± 2 mm for surface modeling.

3.3 Test Controls.

- a. All safety Standard Operating Procedures (SOPs) are observed throughout test operations.
- b. Correct levels of vehicle lubricant, hydraulic fluid, coolant, etc., are maintained throughout the tests.
- c. Vehicles are operated until their normal operating temperatures are reached before initiating each test.
- d. Critical fluid temperatures must be monitored during the test. The high loads placed on the drive train could potentially result in overheating of fluids.
- e. Tests are conducted using a consistent test vehicle throttle response to capture the maximum traction limit the vehicle can develop in the particular soil condition as a function of slip with vehicle speeds and gear ranges controlled by varying the applied load with the dynamometer vehicle. The test should be conducted at as wide a speed range as possible within the limitations of the load application equipment. Full throttle operation may not produce the best performance. Traction testing should aim to characterize the performance from zero to 100 percent slip.
- f. Testing is usually confined to single-pass operation to assure test conditions are as controlled and reproducible as possible. Multiple-pass operations are required in various soil strength profiles to adequately determine the single pass performance with confidence. Controlled steady throttle responses are required for all tests. Full throttle operation may not produce the best performance.

g. For soil drawbar pull testing the drawbar connection between the test vehicle and dynamometer truck needs to be inspected under load for a level connection. Any difference between the height of the drawbar at the test item and dynamometer can result in force being measured at an angle and could introduce error.

h. The vehicle operator must be briefed about stopping without signals from the dynamometer crew. If the operator stops without the dynamometer crew being ready, considerable damage may be done to the equipment.

3.4 Soil Characterization Methods.

a. Soil samples of sufficient quantity will be collected to accurately characterize each test lane considered for testing. The physical properties of the soils will be characterized using a combination of field and laboratory techniques.

b. A basic field sieve analysis may be conducted to broadly grade the soil. The following definitions from TM 5-330¹⁴ apply:

(1) Fine-grained soil - A soil of which more than 50 percent of the grains, by weight, will pass a No. 200 sieve (smaller than 0.074 mm in diameter).

(2) Coarse-grained soil - A soil of which more than 50 percent of the grains, by weight, will be retained on a No. 200 sieve (smaller than 0.074 mm and larger in diameter).

(3) Highly-organic soil - A soil, such as peat, readily identified in the field by their distinctive color and odor, spongy feel, and frequently fibrous texture. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

NOTE: Highly-organic soils are not addressed in this TOP.

c. Additional sieve analysis will be conducted in the laboratory following the procedures described in ASTM C136, ASTM C117¹⁵ and ASTM D422¹⁶ as guides. A soil sample is passed through a stack of sieves (of decreasing screen size) and the weight percentages of soil passing through different sizes of sieves are measured and recorded using DD Form 1206 (Appendix C). Grain Size Distribution Graph - Aggregate Grading Chart, DD Form 1207 (Appendix C), is used to present the data graphically.

(1) The coefficient of uniformity, C_u is determined for each coarse-grained soil sample. C_u is defined as the ratio of the grain diameter corresponding to 60 percent passing (D_{60}) to the grain diameter corresponding to 10 percent passing (D_{10}) on the grain size distribution curve.

$$C_u = (D_{60})/(D_{10}) \quad \text{Equation 1}$$

(2) The coefficient of curvature for coarse-grained soil samples, C_c is computed using the values D_{10} , D_{30} , and D_{60} , as shown in the following equation.

$$C_c = (D_{30})^2 / (D_{60} \times D_{10}) \quad \text{Equation 2}$$

(3) A well-graded soil is defined as having good representation of all grain sizes from smallest to largest, with the smaller grains filling in between the larger grains. In the USCS, well-graded sands must have $C_u > 6$ and C_c from 1-3. Well graded gravels must have $C_u > 4$ and C_c from 1-3. Soils not meeting these criteria are considered poorly graded. Uniformly graded soils have particles primarily of the same size and/or range. A gap-graded soil will be represented by small and large particles with limited soil content in the intermediate sieve ranges.

(4) The grain size distribution curve is broken down into 3 distinct areas based on sieve size. The gravel range includes materials retained on the 3-inch through No. 4 sieves, with coarse gravel ranging from 3-inch to 0.75 inch. Fine gravel is from 0.75-inch to No. 4. Sands are defined as materials retained between the No. 4 and No. 200 sieves with three intermediate classifications; coarse, medium and fine. Coarse sand is defined as materials retained between the No. 4 and No. 10 sieves. Medium sand is defined as materials retained between No. 10 and No. 40 and fine sand is the materials retained between No. 40 and No. 200 sieves. The remainder of material smaller than the No. 200 sieve is classified as silt or clay, which can be further distinguished using the hydrometer analysis¹⁵. Silt particles are larger in size than clay particles.

d. Specific gravity, Atterberg limits, and the plasticity index (PI) will be determined for each sample in accordance with ASTM D4318. The Atterberg limits generally refer to the liquid limit (LL) and plastic limit (PL). The liquid and plastic limits are associated with the amount of moisture in the soil and determine the boundaries of the plastic and liquid states of fine-grained soils. The liquid limit is the lowest moisture content at which soil behaves like a liquid. This is tested using a Casagrande cup or liquid limit machine. The plastic limit is the lowest amount of moisture needed to roll the soil sample into a 1/8 in. diameter thread without having it crumble. The Plasticity Index (PI) is the numerical difference between LL and PL and defines the region where soil exhibits plastic properties. Soils with a high PI tend to be clay soils. The plastic state's shear strength will tend to decrease with the increase of moisture content.

e. Atterberg limit data are used to determine the soil's relative resistance to deformation, acceptable moisture contents, and to develop artificial moisture modification protocol to change compaction and remolding characteristics for the proposed test site if additional soil strength profiles are needed. Plasticity is the ability of a soil to deform without cracking or failing. Soils in which moisture films are relatively thick compared to particle size, like clay, remain plastic over a wider range of moisture content.

f. Once the sieve analysis, liquid limit, plastic limit, plasticity index data are obtained, the plasticity chart¹⁷ shown in Figure 1 and the USCS classification chart¹⁸ shown in Figure 2 are used to classify the soil.

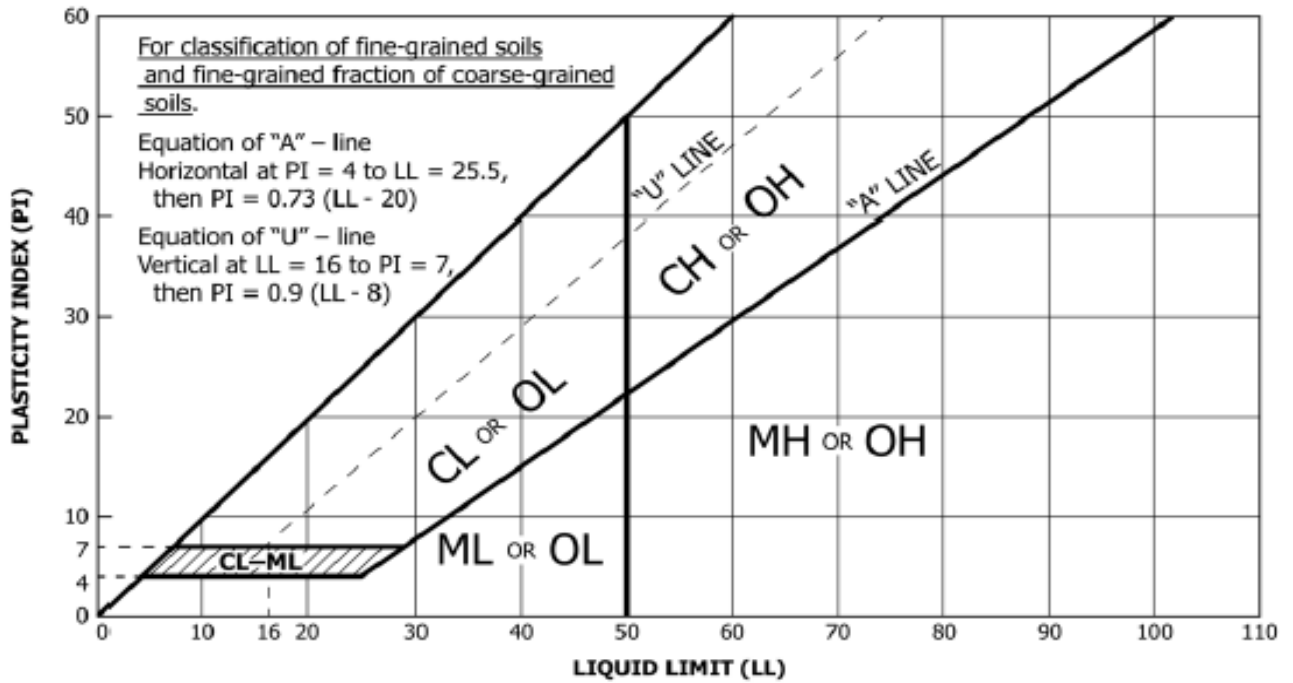


Figure 1. Plasticity chart.

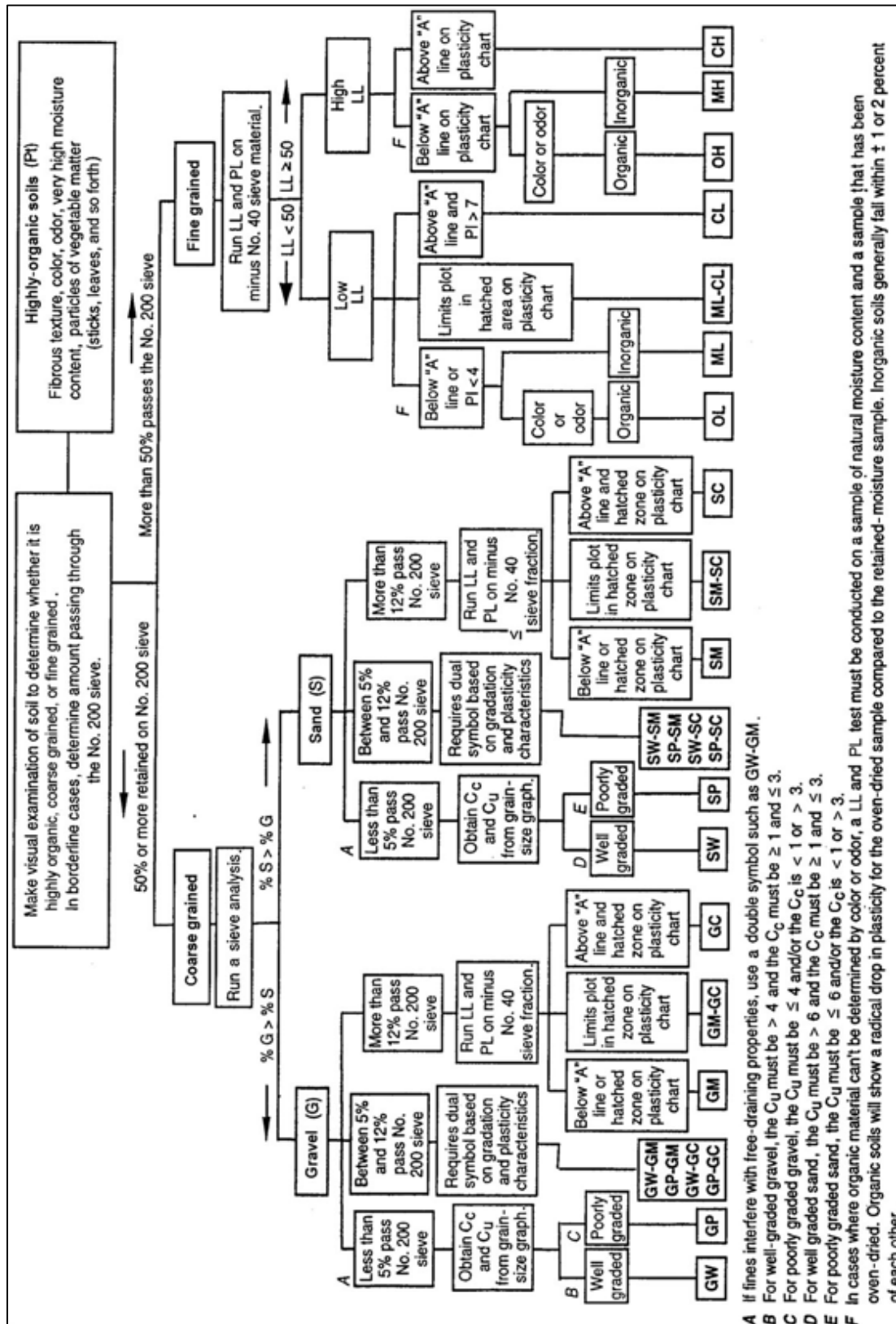


Figure 2. Unified Soil Classification System.

g. On-site field testing will include cone penetrometer readings and soil moisture content determination. A minimum of 10 measurements for each wheel track will be taken. If inconsistent soil strength profiles are encountered, additional measurements will be necessary. For soils types that have remoldable characteristics, a minimum of four remolding tests will be conducted in the same general locations as the cone index measurements. FM 5-430-00-1 will be used as a guide for soil sample collection and soil strength measurement techniques. Appendix C provides data sheets suitable for recording field measurements of soil conditions.

h. The remold index (RI) test for fine-grained soils and sands with fines, poorly drained will be conducted using TM 5-330 as a guide. Specific attention is required as the test procedures are different for the two soil types.

3.5 Soil Preparation Methods.

a. Tilling provides a largely repeatable soil condition that makes it attractive for some vehicle performance comparisons, but tilling is not required for all mobility/performance testing. Soil preparation requirements will vary based on the specific goals of the test.

b. The controlled soil bins are prepared for testing using a variety of methods depending on the initial condition, weather, soil type, and final testing conditions. Tillage breaks up the soil compaction and adds air into the soil allowing moisture to penetrate in a more consistent manner. ATC currently uses a rotary spading machine driven by an all-wheel drive farm tractor, (Figure 3). The rotary spader has a working width of 3.5 m (11.8 ft) and single pass depth of 55 cm (22 in.). The implement has a rotary shaft with 9 spade banks. Each spade bank has 4 spading shovels. The tilling depth is set by the tractor's hydraulic three-point hitch system and maintained with draft control. The draft control allows for consistent tillage depth over rough or uneven terrain. The tractor-spader combination has a Vehicle Cone Index (VCI) of 23 providing adequate mobility in low soil strength environments. For optimized soil mixing, the tractor is operated in first gear at 3.2 kph (2 mph). Coarse grain soil bins should be tilled to a depth of at least 30 cm (12 in.) below anticipated sinkage of the test vehicle.



Figure 3. Soil conditioning the MTA Abrasive Mud Course (Hog Wallow) facility.

c. Other soil conditioning devices utilized by ATC include a three-shank ripper attachment pulled by a crawler tractor. The crawler can rip to a depth of 64 cm (25 in.). A modified trailer mounted chisel plow provides a 46 cm (18 in.) tillage depth. Offset discs allow the equipment operator to smooth over soft soil areas after testing and to expose more subsurface soil to the air. The offset disc can till 20 to 30 cm (8 to 12 in.) deep.

d. For soft soil areas in low-lying areas, coastal flooding and tidal action prepare, smooth, and naturally maintain the soil conditions.

e. Fine grain soils should be kept in a suitable slippery condition or low shear strength by continued flooding to provide a condition where water remains visible on the surface. Once the area is saturated above the liquid limit the area is allowed to air dry back to a soil strength and moisture content required for testing. This procedure may take several days between test scenarios depending on the ambient environmental conditions. Periodic checks will be needed as the clay dries to find the condition required for testing.

4. TEST PROCEDURES.

4.1 Tractive Effort/Drawbar Pull on Hard Surface.

a. This test is conducted in accordance with TOP 02-2-604¹⁹ as a baseline for soft soil mobility testing. The test vehicle tows a mobile field dynamometer by means of an instrumented drawbar over a dry, clean, level, paved surface. Road speed is measured using a non-contact speed transducer attached to the test vehicle. Wheel or track-sprocket speeds are measured and recorded to compute the percentage of slip. Measurements are made at sufficient increments of road speed, including vehicle stall when possible, to delineate the following performance curves. Only the lowest gear ranges are tested as the data will be used as comparison data for the off-road mobility tests. The following data are typically required.

- (1) Sprocket output torque and power as a function of road speed (tracked vehicle).
- (2) Tractive effort and power as a function of road speed (wheeled vehicle).
- (3) Drawbar pull and drawbar power as a function of road speed.
- (4) Percent wheel or track slip as a function of drawbar pull.
- (5) Percent wheel or track slip as a function of road speed.

b. For wheeled vehicles, tractive effort can be measured directly using the SWIFT described in paragraph 2.3.4, or indirectly with strain gaged driveshafts or axle shafts. Sprocket output torque for tracked vehicles is measured using strain gages applied to sprocket output shafts or transmission to final drive propeller shafts, depending on the driveline configuration. If indirect measurements are selected, then the axle, wheel end, and/or final drive gear ratios are required as well as the appropriate component efficiencies to compute sprocket output torque and tractive effort. Strain gage applications are custom for each installation and require a physical calibration to determine the output voltage versus torque relationship, as installed. Calibration is best performed using a fabricated beam, where a measured force is applied tangentially to the end of a beam of known length to generate torque. The beam is attached to each instrumented shaft as shown in Figure 4 for a wheeled vehicle and Figure 5 for a tracked vehicle.



Figure 4. Torque calibration of a high mobility multipurpose wheeled vehicle (HMMWV) axle half shaft.

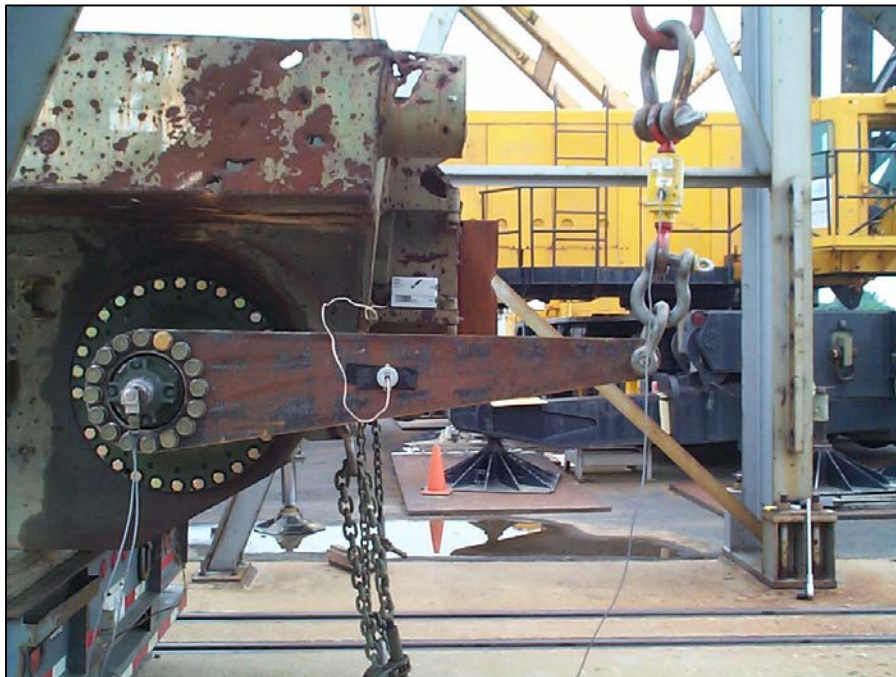


Figure 5. Torque calibration of an Abrams sprocket output shaft.

c. Refer to TOP 02-2-604 for the formulas needed to compute drawbar power, track or wheel slip. Refer to TOP 02-2-806²⁰ for the formulas needed to compute tractive effort and sprocket output power from measured sprocket speed and torque.

4.2 Drawbar Pull in Soft Soil.

a. Testing is conducted in a similar manner to the hard surface drawbar pull test (paragraph 4.1) except that the mobile field dynamometer or other suitable vehicle is towed over level, soft soil tilled to a specified depth or is used to retard motion on a mud surface. The soil condition is determined and drawbar force, sprocket or wheel speeds, engine speed, and ground speed are measured. The test vehicle is connected to the dynamometer truck using an instrumented drawbar or a suitable tow strap and loadcell. If possible, a test fixture or harness should be fabricated and installed on the test vehicle to direct the drawbar load vector through the vehicle center of gravity, rather than through the tow pintle to replicate weight transfer for slope performance predictions.

b. After removing any slack from the intra-vehicle connection, the test vehicle should accelerate slowly to a throttle condition that provides consistent performance. Throttle position that provides peak torque or a specific transmission condition may generate better performance than full throttle operation. The dynamometer vehicle should not begin to apply any resistive loading until a stabilized speed condition is reached based on the gear selected and the soil conditions. Multiple runs may be required to fully characterize the drawbar force as a function of true ground speed and slip. Sufficient data should be collected to capture the full range of slip for a given soil condition and vehicle configuration.

c. Field dynamometers are used to control the test vehicle speed and measure the resulting drawbar force. The force and speed relationship is related to the reserve power of the test vehicle. ATC often uses a modified M548 Ammunition Transporter as a soft soil dynamometer. The M548 with its' height adjustable drawbar and 50,000 lbf range loadcell can generate resistive loads up to 111 kN (25,000 lbf). Drawbar force up to 44 kN (10,000 lbf) is often controlled using a four-wheel-drive Kubota tractor equipped with an automatic transmission.

d. Local soil conditions may limit the coefficient of friction between the surface and the test vehicle. The friction limit may be reached before peak engine torque of the test vehicle is reached. Therefore, different test vehicle throttle settings may be required to test to the traction limits.

e. If the drawbar pull data are being used for gradeability simulation, the test vehicle payload should be adjusted to match the total vehicle and axle weights normal to the longitudinal grade of interest. For example, a 21,700 lb GVW truck would be tested at 20,784 lb GVW to simulate the proper axle loads on a 30-percent grade. The appropriate axle weights are dependent on wheelbase as well as grade. Alternatively, the tire pressures for wheeled vehicles should be adjusted to reflect common sidewall deflections between the level and slope conditions for better compatibility.

4.3 Crossing Velocity/Acceleration Test.

a. Crossing velocity tests are conducted to determine the sustained ground speed, power consumption, and vehicle sinkage observed when negotiating a low soil strength area. The test area is prepared by tilling and controlled moisture application to provide lanes of consistent soil strength profiles versus depth. Vehicles typically need lane lengths of 30 to 91 m (100 to 300 ft) to reach their maximum speed.

b. Vehicles are operated in the prepared lanes in two ways. Acceleration tests are conducted where the vehicle is operated at wide-open throttle, starting from rest until a maximum sustained ground speed is reached. Times to reach specific ground speeds and the maximum ground speed are measured, as well as the maximum vehicle speed. Wheel or track slip is computed using the measured ground speed and the driven wheel or sprocket speeds.

c. Tests are also conducted operating the test vehicle at sustained ground speeds using part throttle. The sustained ground speed is measured. Wheel or track slip is computed using the measured ground speed and the driven wheel or sprocket speeds. Torque measurements, gear ratios, driveline efficiencies, and sprocket or wheel speeds are used to compute the power required to negotiate each soil condition at the sustained speed. The soil resistance-to-motion is determined by comparing the observed soft soil performance to paved surface performance.

4.4 Steering Mobility.

a. The increasing and decreasing step slalom course outlined in Allied Vehicle Testing Publication (AVTP) 03-30 Steering and Maneuverability²¹ is used to analyze steering performance in low soil strength environments. Only the sections from 10 to 30 m spacing are used for soft soil mobility testing, as shown in Figure 6. The step slalom course should be run in both steer directions. Changes in steering wheel angle, steering effort, and vehicle pitch, roll, and yaw rates are measured as a function of slalom ground speed. Entrance, average, and exit ground speeds should be presented.

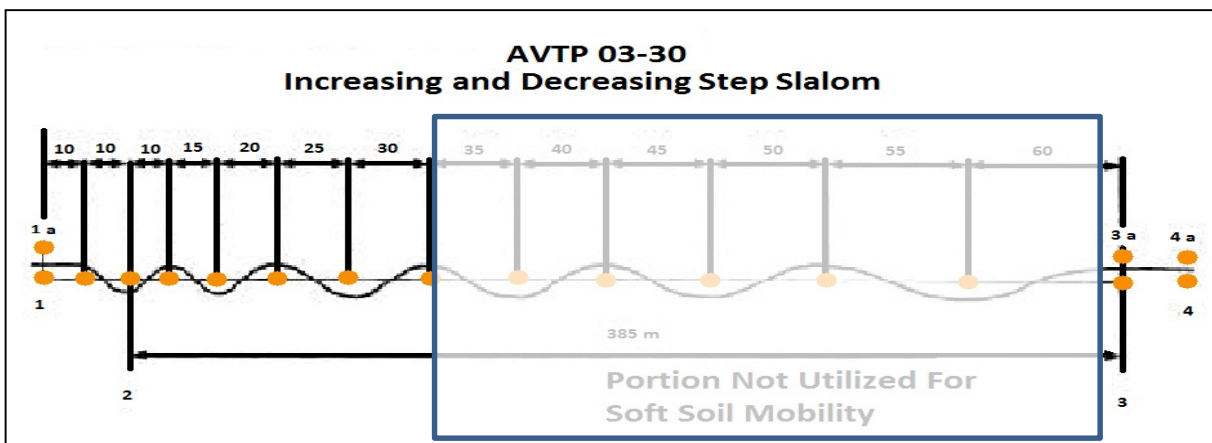


Figure 6. AVTP 03-30 step slalom course. Greyed out portion not utilized for soft soil mobility.

b. Lay out the course with consistent soil strength along its length and width. The test vehicle is accelerated to the target speed and the driver attempts to maintain that speed throughout the course. Each test starts from rest in the prepared soil lane. Allow sufficient space prior to the first gate (cone) for the vehicle to accelerate to the target speed. A test run is considered successful when the test vehicle is able to negotiate the course cleanly while maintaining the target speed. The test vehicle's target speed should be increased until the course cannot be negotiated.

4.5 Bead-slip.

Tire bead slip tests are conducted to determine the ability of tires to remain on their rims at reduced tire pressures under maximum wheel torque conditions. Straight-line test runs are conducted in off-road conditions (sand or sandy loam) and repeated on paved surfaces with the tire pressure decreased incrementally until bead slip occurs or the bead becomes unseated. Wheel loads are sustained and measured by applying drawbar loads with a mobile field dynamometer. The wheels and tires are marked in accordance with TOP 02-2-704A²², Section 3.1.3. Bead slip is observed by the relative movement between the tire and wheel.

4.6 Military Tire Bead Unseating.

a. Refer to paragraph A.4 of Society of Automotive Engineers (SAE) Recommended Practice J2014²³ for the detailed data requirements, test course conditions and dimensions, test procedure, and instrumentation. The purpose of this test is to determine tire/rim slip, air loss, or bead unseating when operated at the minimum recommended inflation pressure. The test course is a "figure-8" and requires the test vehicle wheelbase and full-lock turning diameter measured at the centerline of the front axle travel path to calculate the test course radius of curvature (R) and the interconnecting straight sections (A). Figure 7 shows the course layout. The test area for the bead unseating test is sand (preferred) or sandy-loam (SP or SM as determined by USCS). The depth of the material is at least 750 mm (30 in.), tilled to at least 200 mm (8 in.), and dried to a moisture content of less than 2.0% in the top 75 mm (3 in.). The cone index at the 75 mm (3 in.) depth should not exceed 100.

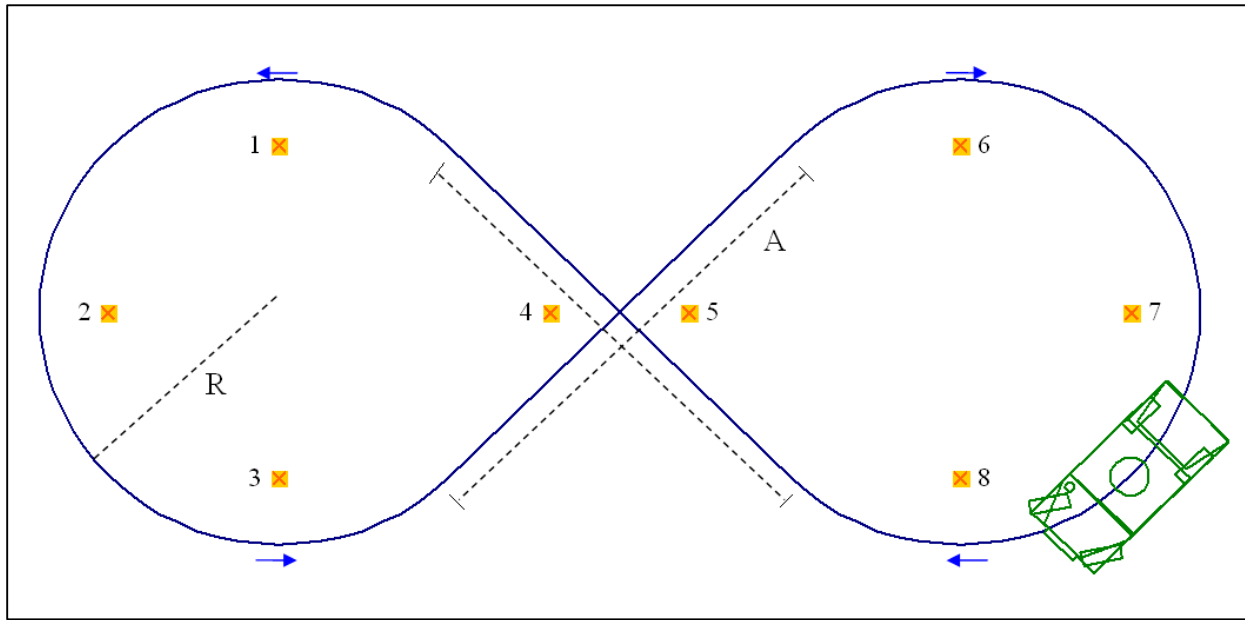


Figure 7. Test course dimension for bead unseating test.

b. The test vehicle is loaded so that each individual static test tire load is within $\pm 5\%$ of the maximum tire load for the intended vehicle (unless otherwise specified). The cone penetrometer will be used to measure soil strength of the test area berm before and after each test sequence.

4.7 Track Misguiding Test.

a. Tracked vehicles are operated in deep-tilled sand and sandy loam soils to analyze their ability to maintain positive engagement of the track to the drive sprockets and maintain clearances between roadwheels, support rollers, and vehicle hull. Excessive build-up of soil in the roadwheel path and sprockets will also be analyzed. Loss of body/hull to track clearance is a concern.

b. Track tension should be checked and adjusted after a track break-in and suspension warm-up is conducted. A typical warm-up should consist of 20 to 30 minutes of moderate speed operation on a level gravel road. Track tension should be verified upon completion of each series of steering maneuvers. If a track misguide occurs, the vehicle should be stopped immediately to prevent further suspension and track damage.

c. Testing starts with straight-line operations in the forward and reverse directions in the prepared soil. Specific attention should be given to areas where soil accumulates between the track, hull, sprockets and suspension elements. Still photographs and video coverage is the best method of documentation. Ground speed, sprocket speeds, and sprocket output torques may be measured for comparison between maneuvers and test environments.

d. Steering maneuvers are conducted using the general instructions for the steering mobility test (paragraph 4.4) and the tire bead unseating test (paragraph 4.6). Observations are made for indications of clearance problems or track misguiding.

4.8 Vehicle Cone Index, Single Pass (VCI₁).

a. VCI₁ is a vehicle performance metric used to quantify mobility on soft soils. Testing is conducted in accordance with U.S. Army Corps of Engineers, Geotechnical and Structures Laboratory Report ERDC/GSL SR-13-2²⁴. The observed VCI₁ value is a measure of the minimum soil strength necessary for a vehicle to consistently complete one pass over the soil.

b. Natural off-road lanes are located on soft-soil terrain that provides a range of soil strengths near the expected VCI₁ value. Single pass VCI can be estimated using vehicle characteristics and historical data. The estimation process is presented in paragraph 4.9. The standard technique used to measure VCI₁ is inference from zero- and multi-pass test results. Cone index, remold index, and moisture content measurements are conducted in the test lanes to characterize soil strength. The rated cone index (RCI) is computed for each test lane, and is defined as:

$$RCI = CI \text{ (Cone Index)} \times RI \text{ (Remold Index)} \quad \text{Equation 3}$$

c. Test lanes are a minimum of two to three vehicle lengths long, relatively straight and level, and of uniform soil consistency throughout the lane. The vehicle is operated in its lowest gear at a slow, steady speed (3-5 km/hr (2-3 mph)) in a straight line through the identified test lane. Steady throttle is applied throughout each test trial.

d. For a particular test lane, the vehicle will either become immobilized on the first pass or complete the pass successfully. If immobilization occurs in the forward direction, defined as a complete loss of forward movement, the vehicle will be placed in reverse and an attempt will be made to back out. If the vehicle does not move more than one vehicle length, the test event is considered a zero pass immobilization point. If the initial pass is successful, repeated passes are conducted in the forward and reverse directions in the same tracks until immobilization is encountered. The vehicle will traffic forward for the first pass and traffic in reverse for the second pass, and so on. The number of successful passes is recorded for each test lane.

e. For each test trial, the number of successful passes is plotted versus RCI. The complete set of data are then used to graphically infer the RCI soil strength associated with a single successful pass. The VCI₁ value is equated to the observed RCI value for the single pass.

4.9 Estimation of Vehicle Cone Index Using Mobility Index.

a. The ability of a vehicle to traverse areas of low soil strength is impacted by vehicle traction and the floatation. The mobility index (MI) was developed to address the overall vehicle trafficability. The MI is a dimensionless number obtained by applying specific vehicle characteristics and attributes known to influence traction using the following formula. Correlation of the MI to VCI has been established by rigorous field testing/experimentation. MI

is an excellent analytical tool to estimate vehicle mobility and to prepare the needed soil conditions for field testing. The MI relationship for wheeled vehicles is presented below.

$$MI_w = [(CPF*WF)/(TEF*GF) + WLF - CF](EF)(TF) \quad \text{Equation 4}$$

$$CPF = w/(0.5ndb)$$

$$TEF = (10+b)/100$$

$$WLF = w/2000$$

$$CF = h_c/10$$

$$GF = 1 + 0.05c_{GF}, \quad c_{GF} = 1 \text{ if tire chains are used or } 0 \text{ if not}$$

$$EF = 1 + 0.05c_{EF}, \quad c_{EF} = 1 \text{ if power-to-weight ratio } < 10 \text{ Hp/ton or } 0 \text{ if not}$$

$$TF = 1 + 0.05c_{TF} \quad c_{TF} = 1 \text{ if a manual transmission or } 0 \text{ if automatic}$$

$$WF = c_{WF1}(w/1000) + c_{WF2},$$

where:

$$w < 2,000 \text{ lb} \quad c_{WF1} = 0.553 \text{ and } c_{WF2} = 0$$

$$2,000 \leq w < 13,500 \text{ lb} \quad c_{WF1} = 0.033 \text{ and } c_{WF2} = 1.050$$

$$13,500 \leq w < 20,000 \text{ lb} \quad c_{WF1} = 0.142 \text{ and } c_{WF2} = -0.420$$

$$20,000 \leq w < 31,500 \text{ lb} \quad c_{WF1} = 0.278 \text{ and } c_{WF2} = -3.115$$

$$31,500 \leq w \quad c_{WF1} = 0.836 \text{ and } c_{WF2} = -20.686$$

b. The nomenclature and units of measure used in the wheeled MI calculation is presented in Table 2.

TABLE 2. MOBILITY INDEX NOMENCLATURE (WHEELED VEHICLE)

VARIABLE	DESCRIPTION
b	Average tire section width, inflated and unloaded, inches
CF	Clearance factor, dimensionless
CPF	Contact pressure factor, dimensionless
d	Average tire diameter, inflated and unloaded, inches
DCF	Deflection correction factor, dimensionless
EF	Engine factor, dimensionless
GF	Grouser factor, dimensionless
h	Average tire section height, inflated and unloaded, inches
h _c	Minimum ground clearance, inches
n	Average number of tires per axle
TEF	Traction element factor, dimensionless
TF	Transmission factor, dimensionless
w	Average axle loading, pounds
WF	Weight factor, dimensionless
WLF	Wheel load factor, dimensionless
	Average hard surface tire deflection, inches

c. Tire deflection was not considered in the early NATO Reference Mobility Model (NRMM) development and most of the tires used in military applications had tire deflections around 15 percent of the tire section height. With central tire inflation systems and radial tire use commonplace on military vehicles, tire deflection can be considerably more than 15 percent and U.S. Army Engineer Research and Development Center (ERDC) developed a Deflection Correction Factor (DCF) to account for tire deflection effects on the vehicle cone index. The DCF is represented by the following equation.

$$D = \frac{h_c}{h} \quad \text{Equation 5}$$

d. The deflection correction factor tends to normalize VCI to a performance magnitude at 15 percent tire deflection and is multiplied to the original equations empirically developed to predict the vehicle cone index (VCI) as a function of mobility index (MI). Significant field experimentation, mobility research, and methodology were used to generate these relationships over a variety of vehicles. The formulae are presented below based on the mobility index value. Statistical error and confidence in this method were verified and presented in ERDC literature²⁵. The Vehicle Cone Index, single pass, is a function of the following:

$$VCI_1 = f(MI, DCF) \quad \text{Equation 6}$$

where:

$$MI_w \leq 115 \quad VCI_1 = [11.48 + 0.2MI - 39.2/(MI + 3.74)] * DCF$$

$$MI_w > 115 \quad VCI_1 = (4.1MI^{0.446}) * DCF$$

e. Calculation of the mobility index and the estimate of VCI_1 for tracked vehicles are presented below:

$$MI_T = [(CPF*WF)/(TRF*GF) + WLF - CF](EF)(TF) \quad \text{Equation 7}$$

$$CPF = w/(2lb)$$

$$TRF = b/100$$

$$WLF = w/(10NA_s)$$

$$CF = h_c/10$$

$$GF = \begin{cases} 1.0 & \text{if grouser height} < 1.5 \text{ inch} \\ 1.1 & \text{if grouser height} \geq 1.5 \text{ inch} \end{cases}$$

$$EF = \begin{cases} 1.0 & \text{if } H_p/\text{ton} \geq 10.0 \\ 1.05 & \text{if } H_p/\text{ton} < 10.0 \end{cases}$$

$$TF = \begin{cases} 1.0 & \text{for a transmission without a manual clutch} \\ 1.05 & \text{for a transmission with a manual clutch} \end{cases}$$

$$WF = \begin{cases} 1.0 & \text{if } 0 \leq w < 40,000 \text{ lb} \\ (w/1000)/(24.84 + 0.379 * w/1000) & \text{if } w > 40,000 \text{ lb} \end{cases}$$

f. The nomenclature and units of measure used in the tracked vehicle MI calculation is presented in Table 3.

g. The Vehicle Cone Index, single pass, is calculated using the following empirical relation:

$$VCI_1 = 7.0 + 0.2 MI_T - 39.2/(MI_T + 5.6) \quad \text{Equation 8}$$

TABLE 3. MOBILITY INDEX NOMENCLATURE (TRACKED VEHICLE)

VARIABLE	DESCRIPTION
b	Width of track element in contact with the ground (one side), inches
CF	Clearance factor, dimensionless
CPF	Contact pressure factor, dimensionless
A _s	Area of one track shoe (in. ²) (See Note)
EF	Engine factor, dimensionless
GF	Grouser factor, dimensionless
h _c	Minimum ground clearance of suspension element, inches
N	Total number of roadwheels on tracks in contact with the ground (both sides)
TRF	Track factor, dimensionless
TF	Transmission factor, dimensionless
w	Weight beneath suspension assembly (track pair), pounds
WF	Weight factor, dimensionless
WLF	Wheel load factor, dimensionless
l	Length of track element in contact with the ground (one side), inches

NOTE: If a track does not have identifiable shoes, compute the area using the sprocket pitch as the length (in.) multiplied by the single total width (in.) in contact with the ground.

4.10 North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM).

The NRMM is a computer-based simulation that uses physical data collected from the vehicle under test. These parameters define the vehicle's weight, size, mobility, and performance attributes. The input parameters are listed in paragraph 5.10 with an appropriate TOP for collection. Various terrain models have been developed for NRMM to represent areas of interest around the globe, and vehicles are typically run in various seasonal and weather scenarios for each area. Detailed information about NRMM use is provided in reference 26.

5. DATA REQUIRED.

5.1 Tractive Effort/Drawbar Pull on Hard Surface.

The following vehicle performance data are required. Additional driveline temperatures and pressures may be needed to insure proper vehicle operation. If the test vehicle is equipped with a data bus, the CAN data should be monitored and recorded. The data bus can provide key information for performance and mobility tests, including gear ranges selected and attained, torque converter status, throttle position, relative power and torque values, traction control status, etc. The validity of the data bus information must be verified or the source of data documented.

- a. Vehicle test weight, kg (lb).
- b. Drawbar pull, kN (lbf).

- c. Sprocket output torque, N-m (lb-ft).
- d. Driveshaft torque, N-m (lb-ft).
- e. Sprocket or driven wheel speeds, rpm.
- f. Engine speed, rpm.
- g. Rolling distance, m/rev (ft/rev).
- h. Sprocket radius or loaded wheel radius, m (ft).
- i. Driveline gear ratios.
- j. Traction control on/off.
- k. Torque converter locked/unlocked.
- l. Tire pressure or track tension, as applicable.

5.2 Drawbar Pull in Soft Soil.

a. In addition to the data required in paragraph 5.1 the following data are required for soft soil tests. Cone penetrometer surveys are conducted from the surface to approximately 30 cm (12 in.) below the anticipated vehicle sinkage depth. Sufficient data are collected to characterize each test site. Spot checks are conducted during testing to assure that the soil conditions are not changing. Sieve analysis data are recorded using DD Form 1206 and the grain size distribution - aggregate grading chart. DD Form 1207 will be used to present the data graphically.

b. A minimum of 10 moisture samples will be taken, distributed along the length of each test lane. Additional samples are obtained periodically during the testing. Moisture sampling should be taken at the surface and at 15 cm (6 in.) depth intervals at each location. This is to ensure the moisture is consistent throughout the soil depth and in the critical layer.

- (1) Cone penetrometer vs. depth for each test lane.
- (2) Percent moisture content vs. depth.
- (3) Sieve analyses are conducted for 10 locations for each representative soil condition.
- (4) USCS soil classification.
- (5) Vehicle sinkage at the point of immobilization.

- (6) Re-weigh the vehicle if significant soil is collected on the vehicle.

5.3 Crossing Velocity/Acceleration Test.

Each test environment is characterized to capture the data described in paragraph 5.2. Vehicle performance data are presented below. If the test vehicle is equipped with a data bus, the CAN data should be monitored and recorded. The data bus can provide key information for mobility tests, including gear ranges selected and attained, torque converter status, throttle position, relative power and torque values, traction control status, etc. The validity of the data bus information must be verified or the source of data documented.

- a. Vehicle test weight, kg (lb).
- b. Maximum speed obtained for each lane condition, km/hr (mph).
- c. Time to specific ground speed intervals, seconds.
- d. Time to maximum speed, seconds.
- e. Sprocket output torque, N-m (lb-ft).
- f. Driveshaft torque, N-m (lb-ft).
- g. Sprocket or driven wheel speeds, rpm.
- h. Engine speed, rpm.
- i. Driveline gear ratios.
- j. Traction control on/off.
- k. Torque converter locked/unlocked.

5.4 Steering Mobility.

The course dimensions are recorded as well as the soil preparation and resulting soil strength and moisture content. If the test vehicle is equipped with a data bus, the CAN data should be monitored and recorded. The data bus can provide key information for mobility tests, including gear ranges selected and attained, torque converter status, throttle position, relative power and torque values, traction control status, etc. The validity of the data bus information must be verified or the source of data documented.

- a. Vehicle test weight, kg (lb).
- b. Entrance, average, and exit ground speed, km/hr (mph).

- c. Engine speed, rpm.
- d. Sprocket or wheel speeds, rpm.
- e. Steering wheel angle (SWA), degree.
- f. Steering wheel rim force, N (lbf).
- g. Pitch rate (θ), deg/sec.
- h. Roll rate (ϕ), deg/sec.
- i. Yaw rate (Ψ), deg/sec.
- j. Time to negotiate the course, seconds.
- k. Tire pressure, kilopascals (kPa) (psi) or track tension, as applicable.
- l. Vehicle sinkage at the point of immobilization, cm (in.).
- m. Re-weigh the vehicle if significant soil is collected on the vehicle.

5.5 Bead-slip.

The following data are required for quantifying tire to rim bead slip in soft soil environments.

- a. Vehicle test weight, kg (lb).
- b. Drawbar pull, kN (lbf).
- c. Driveshaft torque, N-m (lb-ft).
- d. Driven wheel speeds, rpm.
- e. Engine speed, rpm.
- f. Rolling distance, m/rev (ft/rev).
- g. Loaded wheel radius, m (ft).
- h. Tire pressure, kPa (psi).
- i. CTIS setting, if equipped.
- j. Relative angular displacement of tires and rims, degrees.

5.6 Military Tire Bead Unseating.

Record the following:

- a. Vehicle test weight, kg (lb).
- b. Wheelbase, m (ft).
- c. Turning diameter, m (ft).
- d. Average vehicle speed, km/hr (mph).
- e. Total distance to air loss, km (mi).
- f. Number of laps.
- g. Total time to air loss, seconds.
- h. Measured air loss, kPa (psi).
- i. Measured rut depth, cm (in).
- j. Measured ambient and surface temperatures, °C (°F).
- k. Measured inflation pressure at start and finish, kPa (psi).
- l. Measured Cone Index (CI) of the test area berm soil before and after each test sequence.

5.7 Track Misguiding Test.

Record the following:

- a. Vehicle test weight, kg (lb).
- b. Ground contact length, m (ft).
- c. Turning diameter, m (ft).
- d. Average vehicle speed, km/hr (mph).
- e. Number of laps.
- f. Measured rut depth, cm (in.).
- g. Measured ambient and surface temperatures, °C (°F).

h. Measured Cone Index (CI) of the test area berm soil before and after each test sequence.

5.8 Vehicle Cone Index, Single Pass (VCI₁).

Record the following at the point of vehicle immobilization. The cone index measurements are collected near the area of immobilization but outside the area of disturbed soil created by the vehicle passes. Figure 8 shows the soil measurement locations relative to the immobilized test vehicle.

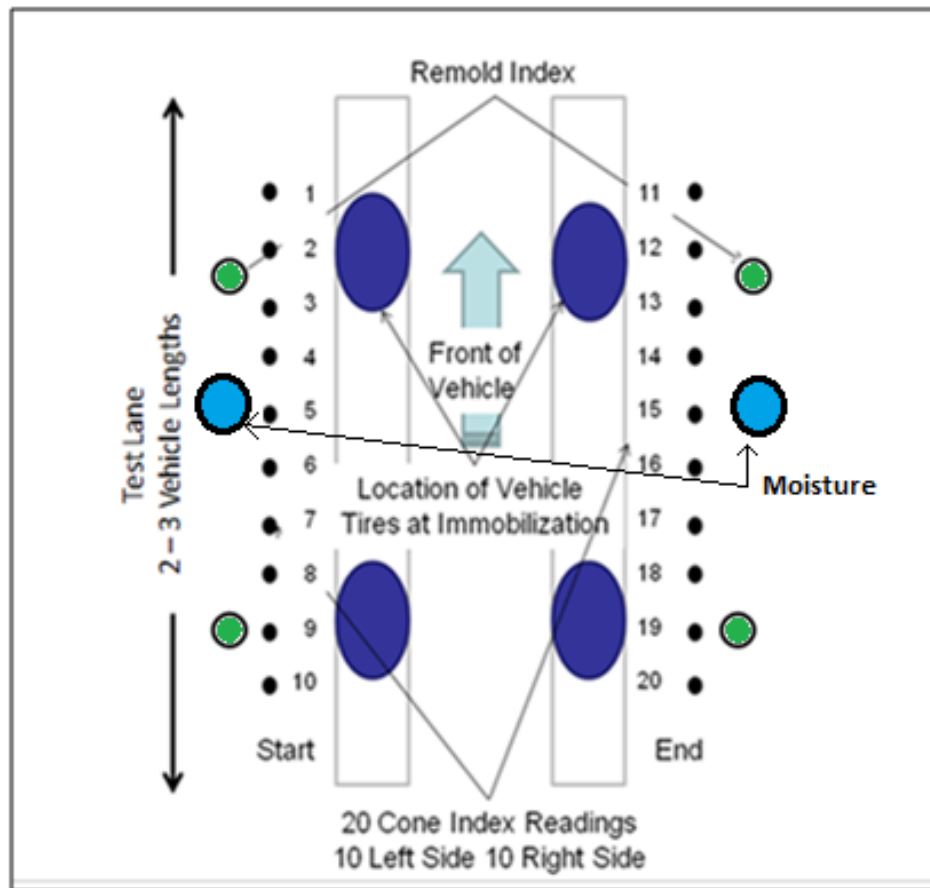


Figure 8. Relative locations of soil measurements.

- a. Ground speed, km/hr (mph).
- b. Number of passes.
- c. Twenty cone index locations as a function of depth.
- d. Four remolding index readings at three depths to include near surface and each six-inch soil layer.
- e. Two moisture readings at three depths to include near surface and each six-inch soil layer.
- f. Vehicle sinkage, cm (in.).
- g. Vehicle attitude (trim), degrees.
- h. Tire pressure kPa (psi) or track tension, as applicable.

5.9 Estimation of Vehicle Cone Index Using Mobility Index.

- a. The following data are required to compute a mobility index for each wheeled vehicle configuration.
 - (1) Average tire section width, inflated and unloaded, inches.
 - (2) Average tire diameter, inflated and unloaded, inches.
 - (3) Average tire section height, inflated and unloaded, inches.
 - (4) Minimum ground clearance, inches.
 - (5) Average number of tires per axle.
 - (6) Average axle loading, lb.
 - (7) Average hard surface tire deflection, inches.
 - (8) Rated engine power, horsepower (Hp).
- b. The following data are required to compute the mobility index for each tracked vehicle configuration.
 - (1) Width of track element in contact with the ground (one side), inches.
 - (2) Area of one track shoe, in.².

- (3) Grouser height, inches.
- (4) Minimum ground clearance of suspension element, inches.
- (5) Total number of roadwheels on tracks in contact with the ground (both sides).
- (6) Vehicle test weight, lb.
- (7) Unsprung weight, lb.
- (8) Length of track element in contact with the ground (one side), inches.
- (9) Rated engine power, Hp.

5.10 North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM).

Specific vehicle attributes and performance data are presented for the NRMM in Table 4. The specific TOP is also cited for reference.

TABLE 4. NRMM INPUT DATA

VEHICLE ATTRIBUTE OR PERFORMANCE DATA	REFERENCE
Vehicle characteristics	TOP 02-2-500
Number of axles	
Spacing between wheel centers	
Last axle/roadwheel to hitch point	
Number of tires per axle	
Unsprung weight of each wheel assembly	
Tire specification as installed on vehicle	
Manufacturer	
Model	
Size	
Type	
Recommended tire pressure(s)	
Engine performance characteristics	
Make/model and manufacturer of engine	
Engine type (i.e. 2-stroke diesel, turbine, etc.)	
Number of cylinders (if applicable)	
Engine torque vs. engine speed characteristic	
Maximum net power	
Maximum net torque	
Engine displacement	
Transmission	
Make/model and manufacturer of transmission	
Gear ratios for: transmission, transfer case, hub end reduction, sprocket, and differential(s)	

TABLE 4. CONTINUED

VEHICLE ATTRIBUTE OR PERFORMANCE DATA	REFERENCE
Estimated transmission efficiency	TOP 02-2-500
Torque converter characteristics	
Torque converter lockup in gear(s)	
Physical characteristics	TOP 02-2-500
Vehicle length	
Vehicle width	
Vehicle height	
Vehicle pushbar height above ground	
Pintle height above ground	
Frontal area	
Ground clearance at each axle or roadwheel station	
Ground clearance profile	
Weight distribution	TOP 02-2-801
Center of gravity (CG)	TOP 02-2-800 ²⁷
Longitudinal distance from rear axle or sprocket centerline	
Lateral distance from vehicle centerline	
Vertical distance measured from the ground	
Longitudinal and vertical distance of CG to driver's seat	
Moment of inertia	TOP 02-2-600 ²⁸
Pitch mass moment of inertia about sprung mass CG	
Tire damping rate	TOP 2-2-704A
Driver's eye height above ground	TOP 01-2-610 ²⁹
Braking coefficient <i>or</i> Stopping distance from XX speeds	TOP 02-2-608 ³⁰
6 Watts driver's seat absorbed power speed limit (RMS vs. speed)	TOP 01-1-014A CNI ³¹
2.5 g's driver's seat (obstacle height vs. speed)	
Spring force-deflection characteristics	
Damper force-velocity characteristics	
Suspension type (independent, bogie, etc.)	
Towing resistance coefficient	TOP 2-2-605 ³²
Aerodynamic drag coefficient	

5.11 Meteorological Data Requirements.

The following meteorological data are measured and recorded hourly for all soft soil mobility tests:

- a. Temperature.
- b. Humidity.
- c. Precipitation.

- d. Wind speed and direction.

6. PRESENTATION OF DATA.

6.1 Tractive Effort/Drawbar Pull on Hard Surface.

Tractive effort, drawbar pull, drawbar power, and wheel/track slip should be presented graphically as a function of true ground speed. Tractive effort and drawbar pull data normalized to vehicle weight are also plotted. Vehicle specifications for mobility and cooling system performance are usually presented in the form of tractive effort/vehicle weight. The track or wheel slip should be presented graphically as a function of drawbar pull. The drawbar pull and associated tractive effort should be noted for the 20 percent slip value. The torque converter speed ratio calculated from the engine speed, wheel speeds, and gear ratios should be presented as a function of true road speed and the measured drawbar pull. Each graph should also include the following information.

- a. Vehicle test weight, kg (lb).
- b. Track tension or tire pressure, kPa (psi).
- c. Date of test.
- d. Odometer reading and/or engine hours.
- e. Driveline configuration.

6.2 Drawbar Pull in Soft Soil.

In addition to the graphs described in paragraph 6.1, the following data are presented for soft soil tests. Sieve analysis data are recorded using DD Form 1206 and the grain size distribution - aggregate grading chart. DD Form 1207 will be used to present the data graphically. Each graph should also include the following information.

- a. Vehicle test weight, kg (lb).
- b. Track tension or tire pressure, kPa (psi).
- c. Soil type (USCS designation).
- d. Moisture content.
- e. Test area.
- f. Date of test.

- g. Odometer reading and/or engine hours.
- h. Driveline configuration.

6.3 Crossing Velocity/Acceleration Test.

a. Data are presented in graphic and tabular format presenting the time to speed characteristics as a function of ground speed. Each graph should also include the following information.

- (1) Vehicle test weight, kg (lb).
- (2) Track tension or tire pressure, kPa (psi).
- (3) Maximum speed, km/hr (mph) and time to reach maximum speed in seconds.
- (4) Soil type (USCS designation).
- (5) Moisture content.
- (6) Test area.
- (7) Date of test.
- (8) Odometer reading and/or engine hours.
- (9) Driveline configuration.

b. For the sustained speed tests the computed motion resistance and power losses are plotted as a function of true ground speed. Normalized resistance and power loss values such as direct ratios, lb per ton, or Hp per ton are useful methods to present data for comparison of different vehicle designs or configurations. If the contribution of soil resistance is of interest the paved and off-road data must be plotted together as a function of ground speed. Each graph should also include the following information.

- (1) Vehicle test weight, kg (lb).
- (2) Track tension or tire pressure, kPa (psi).
- (3) Average vehicle sinkage, cm (in.).
- (4) Soil type (USCS designation).
- (5) Moisture content.
- (6) Test area.

- (7) Date of test.
- (8) Odometer reading and/or engine hours.
- (9) Driveline configuration.

6.4 Steering Mobility.

a. The following data are presented in tabular format for each soil condition used. Speed based comparisons steering wheel angle, steering effort, and vehicle reactions should be presented graphically.

- (1) Entrance, average, and exit ground speeds, km/hr (mph).
- (2) Range of steering wheel angle (SWA), degree.
- (3) Range of steering wheel rim force, N (lbf).
- (4) Maximum pitch rate (θ), deg/sec.
- (5) Maximum roll rate (ϕ), deg/sec.
- (6) Maximum yaw rate (Ψ), deg/sec.
- (7) Time to negotiate the course, seconds.
- (8) Tire pressure, kPa (psi) or track tension, as applicable.

b. The following information should also be presented for each test site and vehicle configuration.

- (1) Vehicle test weight, kg (lb).
- (2) Track tension or tire pressure, kPa (psi).
- (3) Average vehicle sinkage, cm (in.).
- (4) Soil type (USCS designation).
- (5) Moisture content.
- (6) Test area.
- (7) Date of test.
- (8) Odometer reading and/or engine hours.

(9) Driveline configuration.

6.5 Bead-slip.

Data are presented in a tabular format for the bead-slip tests. If tests are conducted in an off-road environment the soil and vehicle sinkage should be documented.

- a. Vehicle test weight, kg (lb).
- b. Maximum drawbar pull, kN (lbf).
- c. Driveshaft torque, N-m (lb-ft).
- d. Calculated wheel or track slip.
- e. Track tension or tire pressure, kPa (psi).
- f. CTIS setting, if equipped.
- g. Relative angular displacement of tires and rims, degrees.

6.6 Military Tire Bead Unseating.

The dimensions of the “figure 8” test course should be identified in the narrative as they are vehicle specific and based off the vehicles wheelbase and turning diameter. For each vehicle configuration the test vehicle the maximum, controllable safe speed will be noted or the speed obtained where an air loss of 7 kPa (1 psi) has occurred. The soil strength profile, moisture content, USCS designation, and amount of vehicle sinkage will be noted for each test condition.

6.7 Track Misguiding Test.

The dimensions of the “figure 8” test course should be identified in the narrative as they are vehicle specific and based off the vehicles ground contact length and turning diameter. Any buildup of soil between the track, suspension, and hull will be photographed. A narrative describing the operation of the vehicle, prior to the track misguide, will be provided. A description of the track tension procedure and measurement will also be included.

6.8 Vehicle Cone Index, Single Pass (VCI₁).

a. VCI is reported to integer precision. The soil strength data requires uniform or uniformly increasing soil strength for the first 46 cm (18 in.) and is preferred for the 46 – 91 cm (18 – 36 in.) layers. Inconsistent layers, high water tables, foreign objects, or hard pans may affect the trafficability data. Plots of average cone index versus depth for all of the test lanes should be presented to visually show soil consistency (or lack thereof).

b. Single pass VCI generally requires interpretation based on an upper bound assessment from numerous test runs with lanes of a variety of soil strength profiles. The critical soil layer is associated with a specific type and weight vehicle, although exceptions do occur. The normal critical layer for various vehicle types and weights, assuming tests are conducted in fine-grained soil are presented in Table 5.

TABLE 5. NORMAL CRITICAL LAYER BASED ON VEHICLE WEIGHT/TYPE

VEHICLE	CONFIGURATION	CRITICAL LAYER (inches)
Wheeled	Wheel load under 2,000 lb	3 - 9
	Wheel loads between 2,000 and 15,000 lb	6 - 12
	Wheel load over 15,000 lb	0 - 12
Tracked	Ground contact pressure less than 4 psi	3 - 9
	Weight less than 100,000 lb	6 - 12
	Weight greater than 100,000 lb	0 - 12

c. Data are plotted showing successful number of passes versus soil strength. The following “rules” are used for VCI₁ determination.

(1) Remove suspect lanes from the analysis, both during the data collection in the field and in the analysis.

(2) Approximate average Rating Cone Index (RCI) values by rounding up the product of the Remolding Index (RI) and the Cone Index (CI) to the next integer value.

(3) Use the critical layer presented in Table 5 unless a different soil layer provides a clearly superior correlation.

(4) Drop Layer Rule - Use the RCI of the critical layer unless the layer directly below this has a lower soil strength.

(5) Potentially ignore zero-pass lanes that have measured RCI values higher than the 10 pass lanes.

(6) Use as a minimum of the highest legitimate zero pass RCI plus one.

6.9 Estimation of Vehicle Cone Index Using Mobility Index.

Using the formulae presented in paragraph 4.8 compute a mobility index. Compute the VCI₁ estimate using the mobility index appropriate formula. Data can be used as a site preparation tool for developing the required soil strength profile needed for testing or as validation of field VCI₁ testing.

6.10 North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM).

Vehicle characteristics collected for NRMM should be coordinated with the requestor. Typically characteristics can be provided in a tabular format while performance data are provided in graphic format. Electronic data file formats are preferred.

APPENDIX A. GLOSSARY.

Term	Definition
Atterberg Limits	A series of laboratory measurements to determine the critical water content of a fine-grained soil defined by its plastic limit, liquid limit and plasticity index. The Atterberg limits are used to distinguish between silt and clay, and to catalog different types of silt and clay.
Coarse-Grained Soil	A soil of which more than 50 percent of the grains, by weight, will be retained on a No. 200 sieve (smaller than 0.074 mm and larger in diameter).
Cone Index (CI)	An index of soil strength (shearing resistance) obtained using a trafficability cone penetrometer as a function of soil depth ³³ .
Critical Layer	A soil layer below the natural terrain surface that provides the greatest influence on vehicle traction and floatation.
Drawbar Pull	Drawbar pull provides a measure of the reserve power available to a vehicle (in excess of that required for vehicle propulsion on a level road) for acceleration, towing, or hill climbing.
Fine-Grained Soil	A soil of which more than 50 percent of the grains, by weight, will pass a No. 200 sieve (smaller than 0.074 mm in diameter).
Key System Attribute (KSA)	Performance attribute of a system considered important to achieving a balanced solution/approach to a system, but not critical enough to be designated as a Key Performance Parameter (KPP).
Key Performance Parameter (KPP)	Performance attribute of a system considered critical or essential to the development of an effective military capability.
Liquid Limit (LL)	The lowest moisture content at which soil behaves like a liquid.
Mobility	The overall capability of a vehicle to efficiently move from place to place while retaining its ability to perform its primary mission.
NATO Reference Mobility Model (NRMM)	The NRMM is a computer model used to characterize the ability of ground vehicles to move in various operational settings. Based on many years of field and laboratory work by the USACE Waterways Experiment Station (WES), the Army Tank-automotive Command (now the U.S. Army Tank-automotive and Armaments Command), and contributions from NATO members, NRMM considers terrain,

APPENDIX A. GLOSSARY.

road, tactical gap attributes, vehicle geometries, and human factors. The fundamental output is a mobility forecast based on speed predictions keyed to specific areal units of terrain and to specific portions of a road network³⁴.

Plastic Limit (PL)	The lowest amount of moisture needed to roll a fine grained soil sample into a 1/8 in. diameter thread without having it crumble. Plasticity is the ability of a soil to deform without cracking or failing.
Plasticity Index (PI)	PI defines the region where soil exhibits plastic properties. Soils with a high PI tend to be clay soils.
Rating Cone Index (RCI)	An index of soil strength that includes consideration of the sensitivity of soil to strength losses as a result of vehicle traffic. It is defined as the product of the cone index (CI) and the remold index (RI) for a particular layer of soil.
Remold Index (RI)	An index of the sensitivity of soil to strength losses under vehicle traffic obtained using specific field test procedures and trafficability equipment.
Sand With Fines, Poorly Drained	A sand in which water content greatly influences the trafficability characteristics. These soils react to traffic in a manner similar to fine-grained soils. They usually contain 7 percent or more of material passing the No. 200 sieve.
Sinkage	The depth to which the traction elements penetrate the terrain, measured normal to the original undisturbed surface.
Tractive Effort	The maximum force available for propulsion at the driving wheels or sprocket for a given ground speed.
Trafficability	The ability of the local terrain to support passage of vehicles.
Unified Soil Classification System	A methodology used to identify soil type using a two-letter designator. The prefix indicates the main soil type; gravel, sand, silt, clay, organic, or peat and the suffix indicates the subdivisions within each main soil type to include; well graded, poorly graded, silty, clayey, liquid limit less than, or greater than 50 percent.
Vehicle Cone Index (VCI)	The minimum soil strength required for a vehicle to consistently make a specific number of passes. Consideration is most often given to the single pass (VCI ₁) and fifty pass (VCI ₅₀) conditions.

APPENDIX B. ABBREVIATIONS.

APG	Aberdeen Proving Ground
ASTM	American Society for Testing and Materials
ATC	U.S. Army Aberdeen Test Center
ATEC	U.S. Army Test and Evaluation Command
AVTP	Allied Vehicle Testing Publication
C	Celsius
CF	clearance factor (mobility index)
CG	center of gravity
CI	cone index
cm	centimeter
CPF	contact pressure factor (mobility index)
CTA	Churchville Test Area
CTIS	central tire inflation system
D&PS	Development and Proof Services
DA	Department of Army
DCF	Deflection Correction Factor (mobility index)
DD	Department of Defense
DOF	degree of freedom
DOT	Department of Transportation
DTIC	Defense Technical Information Center
DTP	Detailed Test Plan
EF	engine factor (mobility index)
ERDC	U.S. Army Engineer Research and Development Center
F	Fahrenheit
FM	Field Manual
ft	feet
GF	grouser factor (mobility index)
GPS	global positioning system
GSL	Geotechnical and Structures Laboratory
GVW	gross vehicle weight
HDS	high density survey
HMMWV	high mobility multipurpose wheeled vehicle
Hp	horsepower
in.	inch
in-lb	inch pound

APPENDIX B. ABBREVIATIONS.

km/hr	kilometers per hour
kN	kiloNewton
kPa	Kilopascal
KPP	Key Performance Parameter
KSA	Key System Attribute
ks	knots
lb	pound
lbf	pounds force
LiDAR	Light Detection and Ranging
LL	liquid limit
m/s	meters per second
m	meter
MH	silt of high plasticity, elastic silt
MI	mobility index
MIL-STD	Military Standard
mm	millimeter
mm Hg	Millimeter of mercury
mph	miles per hour
MTA	Munson Test Area
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technology
NRMM	NATO Reference Mobility Model
PI	plasticity index
PL	plastic limit
psi	pounds per square inch
PSTIAC	Pavements and Soil Trafficability Information Analysis Center
PTA	Perryman Test Area
RCI	rating cone index
RI	remolding index
RMS	root mean square
rpm	revolutions per minute
SAE	Society of Automotive Engineers
SC	clayey sand
SM	silty sand
SOP	Standard Operating Procedure
SP	poorly graded sand

APPENDIX B. ABBREVIATIONS.

SW	well graded sand
SWA	steering wheel angle
SWIFT	Spinning Wheel Integrated Force Transducer
TDR	Time-Domain Reflectometry
TE	tractive effort
TEF	traction element factor (mobility index)
TF	transmission factor (mobility index)
TM	Technical Manual
TOP	Test Operations Procedure
TRF	track factor (mobility index)
USCS	Unified Soil Classification System
VCI	Vehicle Cone Index
VCI ₁	Vehicle Cone Index, Single Pass
WES	Waterways Experiment Station
WF	weight factor (mobility index)
WLF	wheel load factor (mobility index)
YTC	U.S. Army Yuma Test Center

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APPENDIX C. DATA FORMS.

TRAFFICABILITY TEST DATA											
1. TEST LOCATION/DATE/TIME					2. TYPE OF VEHICLE/WEIGHT						
3. CONE INDEX (CI) VALUES											
a. TEST NUMBERS		b. DIAL READINGS AT DEPTH									
		0"	6"	12"	18"	24"					
1											
2											
3											
4											
5											
AVERAGE											
NORMAL or ABNORMAL PROFILE											
c. $CI_1 =$		3-9"		9-15"		15-21"					
d. $CI_{50} =$											
e. CRITICAL LAYER FOR 1 VEHICLE					f. CRITICAL LAYER FOR 50 VEHICLES						
4. REMOLDING INDEX (RI) VALUES											
	a. LAYER		LAYER		LAYER		LAYER				
b. DEPTH	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
1"											
2"											
3"											
4"											
c. AVERAGE											
d. RI = AFTER/BEFORE											
e. RI FOR 1 VEHICLE					f. RI FOR 50 VEHICLES						
g. RATING CONE INDEX (RCI) $RCI_1 = CI_1 \times RI_1 =$ $RCI_{50} = CI_{50} \times RI_{50} =$					h. SOIL CONDITION (Description)						
j. VEHICLE CONE INDEX (VCI) $VCI_1 =$ /CG $CI \geq VCI$					i. WEATHER CONDITIONS (Description)						
$VCI_{50} =$ /FG & RS $RCI \geq VCI$											
WILL 1 VEHICLE PASS (check one)			YES		NO	k. TYPE OF SOIL (check one)			FG		CG
WILL 50 VEHICLES PASS (check one)			YES		NO	l. SOIL STRENGTH PROFILE (check one)			Normal		Abnormal
5. TESTED BY:			6. COMPUTED BY:				7. CHECKED BY:				

DD FORM 2641, AUG 93

Figure C-1. DD Form 2641, Trafficability.

APPENDIX C. DATA FORMS.

GRAIN-SIZE ANALYSIS (SIEVE METHOD)						
1. PROJECT				2. DATE		
3. JOB NUMBER		4. EXCAVATION		5. DATE COMPLETED		
6. NOTES ABOUT SAMPLE/DESCRIPTION				7. SAMPLE NUMBER		
				8. ORIGINAL SAMPLE WEIGHT		
9. PREWASHED <input type="checkbox"/> YES <input type="checkbox"/> NO		10. + #200 SAMPLE WEIGHT, WASHED		11. - #200 SAMPLE WEIGHT, WASHED		
12. SIEVE SIZE	13. SIEVE WEIGHT	14. SIEVE-SAMPLE WEIGHT	15. WEIGHT RETAINED	16. CUMULATIVE WEIGHT RETAINED	17. PERCENT RETAINED	18. PERCENT PASSING
19. TOTAL WEIGHT RETAINED IN SIEVES <i>(Sum of column 15)</i>			24. ERROR <i>(8-23)</i>		25. ERROR IN PERCENTAGE $\left(\frac{24}{8} \right) \times 100 =$	
20. WEIGHT SIEVED THROUGH #200 <i>(Weight in pan)</i>						
21. WASHING LOSS <i>(8 - [10 + 11])</i>						
22. TOTAL WEIGHT PASSING #200 SIEVE <i>(20 + 11)</i>						
23. TOTAL WEIGHT OF FRACTIONS <i>(19 + 22)</i>						
26. PERCENT GRAVEL (% G)		27. PERCENT SAND (% S)		28. PERCENT FINES (% F)		29. DECIMAL FINES (% F ÷ 100)
30. REMARKS						
31. TECHNICIAN <i>(Signature)</i>			32. COMPUTED BY <i>(Signature)</i>		33. CHECKED BY <i>(Signature)</i>	

DD FORM 1206, DEC 1999
PREVIOUS EDITION IS OBSOLETE.

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Figure C-2. DD Form 1206, Grain-Size Analysis (Sieve Method).

APPENDIX C. DATA FORMS.

1. PROJECT

2. DATE

GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADATION CHART

100

90

80

70

60

50

40

30

20

10

0

PERCENT PASSING

100

90

80

70

60

50

40

30

20

10

0

PERCENT RETAINING

3

2

2 1/2

1 1/2

1

3/4

1/2

1/4

4

10

15

20

30

40

50

60

80

100

140

200

SIZE (inches)

SIEVE NUMBER

100

50

20

10

5

2

1

0.5

0.2

0.1

0.05

0.02

0.01

0.005

0.002

0.001

GRAIN SIZE IN MILLIMETERS

HYDROMETER ANALYSIS

EXCAVATION NUMBER

SAMPLE NUMBER

LL

PL

PI

C_u
(D_{60}/D_{10})

C_c
($D_{30}^2/(D_{60} \times D_{10})$)

SOIL DESCRIPTION/REMARKS

CLASSIFICATION (USCS)

3. TECHNICIAN (Signature)

4. PLOTTED BY (Signature)

5. CHECKED BY (Signature)

DD FORM 1207, DEC 1999

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Figure C-3. DD Form 1207, Grain Size Distribution Graph - Aggregate Gradation Chart.

C-3

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APPENDIX E. APPROVAL AUTHORITY.

CSTE-TM

11 February 2016

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 02-2-619A Soft Soil Mobility, Approved for Publication

1. TOP 02-2-619A Soft Soil Mobility, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP describes methods used to measure, analyze, and report the severity/condition of test environments and perform tests of traction and floatation of wheeled and tracked vehicles operating in low soil strength conditions. Data required to support the North Atlantic Treaty Organization Reference Mobility Model are also presented and defined.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at <https://vdls.atc.army.mil/>.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Directorate (TEDT-AT-AD), U.S. Army Aberdeen Test Center, 400 Collieran Road, Aberdeen Proving Ground, Maryland 21005. Additional copies can be requested through the following website: <http://www.atec.army.mil/publications/topsindex.aspx>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.