TESTING SOIL CONDITIONS FOR VEHICLE SECURITY BARRIER TESTS

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Disclaimer

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This guidance note provides advice and considerations on determining the soil conditions when testing Vehicle Security Barriers (VSBs) installed in soil and are based on the requirements of:
ISO IWA 14-1:2013 Vehicle Security Barriers - Part 1: Performance requirement, vehicle impact test method and performance rating[1]; and
ASTM F2656-07 Standard Test Method for Vehicle Crash Testing of Perimeter Barriers[2].

Specification of soil conditions

ISO IWA 14-1:2013

For VSBs installed in a non-rigid foundation, IWA 14-1:2013 specifies that the soil grading and the bearing capacity of the soil used to form the VSB foundation are measured and recorded. Suitable gradings can be found in BS EN 12767:2007 Annex A[3] (shown in Table 1), F2656-07 and AASHTO M147-65[4].

Note: the grading stated in F2656-07 is the same as grading B of AASHTO M147-65.

Table 1: Grading from BS EN 12767

Sieve size mm (in.)	Mass percentage passing
63 (2.48)	100
31.5 (1.24)	85 – 100
16 (0.63)	55 – 90
8 (0.315)	30 – 60
4 (0.157)	15 – 45
2 (0.0787)	10 – 30
0.063 (0.0025)	2 – 7

The procedure for determining the grading of the soil is described in BS EN 933-1:2012[5] and details of the California Bearing Ratio (CBR) test are given in BS 1377 Part 4 Section 4.3[6]. As an alternative to undertaking the CBR test, an equivalent CBR can be determined from tests using a dynamic cone or drop weight penetrometer.

[1] ISO IWA 14-1:2013 Vehicle Security Barriers – Part 1 Performance requirement, vehicle impact test method and performance rating. BSI (2013).
[2] ASTM F2656-07 Standard Test Method for Vehicle Crash Testing of Perimeter Barriers. ASTM (2007).
[3] BS EN 12767:2007 Passive safety of support structures for road equipment. Requirements, classification and test methods.
[4] AASHTO M147-65 Standard Specification for Materials for Aggregate and Soil-Aggregate Sub-base, Base and Surface Courses.
[5] BS EN 933-1:2012 Tests for geometrical properties of aggregates. Determination of particle size distribution. Sieving method.
[6] BS 1377-4:1990 Methods of test for soils for civil engineering purposes. Compaction-related tests.

IWA 14-1:2013 states that the soil compaction and moisture content are to be measured and recorded not more than 72 hours before the impact test. Unlike F2656-07, IWA 14-1:2013 does not specify a depth or area for the soil that forms the VSB foundation.

The test methods used to measure the level of compaction of the soil are very similar to those stated in F2656-07. The BS versions of the moisture-density relationship and in-situ density tests can be found in BS1377 Part 4 and BS1377 Part 9[7] respectively.

BS EN 1097-5:2008[8] contains the procedure for determining the moisture content of the soil using the oven drying method. Alternatively, a nuclear density gauge or moisture meter could be used.

ASTM F2656-07

F2656-07 Clause 7.2.2 specifies the dimensions of the area to be backfilled in relation to the size of the foundation, the soil type for the backfill and the test methods to be used for the quality control of the reinstatement. The soil type recommended is a low-cohesive, well graded crushed stone or broken gravel with a particle size distribution comparable to that shown in Table 2. The material can either be in-situ material recovered from the test barrier and/or concrete footing excavation, or an imported material.

Figure 1 shows the grading envelopes for the suggested materials in BS EN 12767 and F2656-07.

Table 2: ASTM Recommended soil grading

Sieve size mm (in.)	Mass percentage passing
50 (2)	100
25 (1)	75 – 95
9.5 (⅜)	40 – 75
4.74 (0.187)	30 – 60
2.0 (0.0787)	20 – 45
0.425 (0.0167)	15 – 30
0.075 (0.0029)	5 – 20

[7] BS 1377-9:1990 Methods for test for soils for civil engineering purposes. In-situ tests.
[8] ASTM D1556-07 Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method.

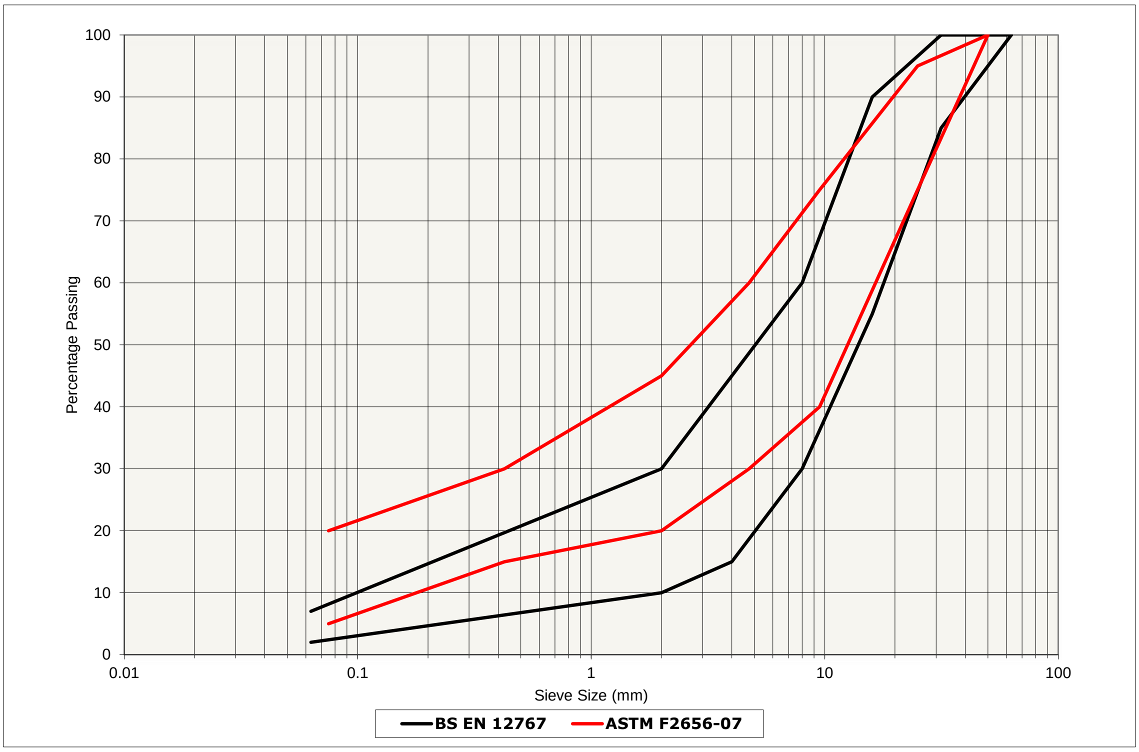

Figure 1: Comparison of grading envelopes

Clause 7.2.2 also states that the low-cohesive soil shall be either at the in-situ natural conditions or controlled and compacted 'fill' to a density of not less than 90% of the maximum dry density as determined by the test methods detailed in ASTM D1556[9], ASTM D2922[10] and AASHTO Method of Test T99[11].

In addition, if testing is conducted to replicate site soil conditions then laboratory tests should be completed to assess the in-situ density before excavation and after re-compaction to ensure that the original in-situ density conditions have been achieved.

The test methods stated in Clause 7.2.2 are as follows:

- ASTM D1556: Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method.
- ASTM D2922: Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth). (Withdrawn, replaced by ASTM D6938-10[12]).
- AASHTO T99: Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5kg (5.5lb) Rammer and a 305mm (12in.) Drop.

[9] ASTM D2922-05 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth).
[10] AASHTO T99: Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5kg (5.5lb) Rammer and a 305mm (12in.) Drop.
[11] ASTM D6938-10 Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth). (Replaces ASTM D2922).
[12] BS EN 1097-5:2008 Tests for mechanical and physical properties of aggregates. Determination of the water content by drying in a ventilated oven.

In-situ density

The in-situ density of the soil can either be measured using the sand replacement test or a nuclear or non-nuclear density gauge.

Sand replacement test

The sand replacement equipment used when testing to ASTM D1556 is shown in Figure 2[13], while Figure 3[13] shows the BS 1377 Part 9 equipment. The test consists of:

1. Exposing a flat area of the soil to be tested (either original ground or re-compacted) approximately 600mm square and trimmed to provide a level surface.
2. Brushing away any loose material.
3. Placing the metal tray on the prepared surface with the hole over the portion of the soil to be tested.
4. Using the hole in the tray as a pattern, a round hole; approximately 200mm in diameter and the depth of the layer to be tested; up to a maximum of 250mm is excavated.
5. After removing all loose material from the hole, the mass of the excavated soil is determined to the nearest 10g.
6. The pouring cylinder, which is filled with a constant mass of calibrated sand is then placed over the excavated hole so that the base of the cylinder covers the hole concentrically.
7. The shutter of the pouring cylinder is then opened to allow sand to run out.
8. When no further movement of the sand in the cylinder is observed, the shutter is closed and the cylinder is removed. The mass of sand remaining in it is determined to the nearest 10g (an allowance is made in the calculation for the volume of sand in the pouring cylinder cone).
9. The wet density of the soil can then be calculated using the volume of calibrated sand used to fill the hole and the mass of soil excavated.
10. A moisture content sample is taken from the mass of excavated soil and is subsequently used to calculate the in-situ dry density.

[13] www.controls-group.com/eng/ricerca-risultati.php?search=sand+replacement

Figure 2: ASTM D1556 Sand Replacement Equipment

Figure 3: BS 1377 Part 9 Sand Replacement Equipment

Nuclear density gauge

A nuclear density gauge (NDG) contains radioactive sources that are used for determining the density of asphalt, concrete, aggregate (usually gravel or crushed rock) and soil. In addition, it can also measure the moisture content of the soil or aggregate. A typical nuclear density gauge is shown in Figure 4[14] and it can either be used in 'backscatter' or 'direct transmission' mode, as shown in Figures 5a[15] and 5b[15]. In 'backscatter' mode, the amount of radiation that is deflected by the material is measured by placing the gauge on the surface of the material. With 'direct transmission,' the amount of radiation that passes through the material is measured by forming a hole in the material and lowering the gauge probe; the tip of which contains the radioactive source into the hole.

The nuclear gauge must be verified against the conventional sand replacement method as an initial back calculation. If it is used to automatically calculate the relative compaction, the gauge must be programed with the maximum wet density from the optimum moisture content determination. Non-nuclear density gauges are now also available and may be used to measure the soil density and moisture content.

Figure 4: Nuclear Density Gauge

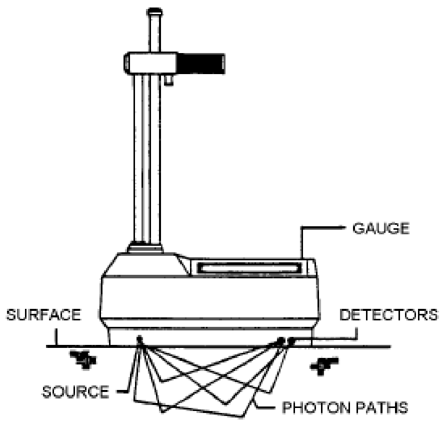

Figure 5a: Backscatter mode

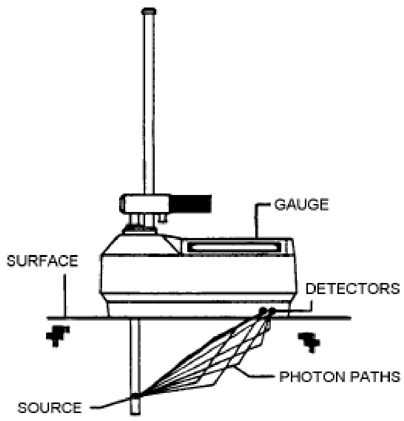

Figure 5b: Direct Transmission mode

Non-Nuclear density gauge

Owing to the regulatory and logistical difficulties associated with using nuclear gauges due to the radioactive sources they contain, several manufacturers have now developed non-

[14] www.bfi.cz/troxler[1]#lightbox
[15] www.troxlerlabs.com/downloads/pdfs/3440/3440manual.pdf

nuclear density gauges (NNDG). These generally use Electrical Impedance Spectroscopy (EIS) or Time Domain Reflectometry (TDR) to measure the soil properties.

EIS devices either work by passing an electric current through metal pins or electrodes that are driven into the material to be tested then looking at the dielectric properties of the material or by looking at the response of the soil to electromagnetic probing. The principle relies on the fact that the dielectric constant of air is much lower than that of the other soil constituents; as density/compaction increases, the combined dielectric constant increases because the percentage of air in the soil matrix decreases. The device then performs a calculation on the measured data that enables it to report the soil density and moisture content. Figure 6[16] shows an EIS soil density gauge that utilises electromagnetic probing.

Figure 6: EIS electromagnetic probing soil density gauge

TDR devices measure the travel time of an electromagnetic step pulse produced by the TDR pulse generator through four soil spikes in the ground. The four spikes are driven into the ground in a specified geometry that is governed by the use of a template. The voltage signal is analysed by specially developed algorithms to determine the apparent dielectric constant and bulk electrical conductivity of the soil, which inbuilt software relates the two properties to water content and density. Figures 7a[17] and 7b[18] show two commercially available TDR devices (other devices are available).

Figure 7a: Humboldt non-nuclear density gauge

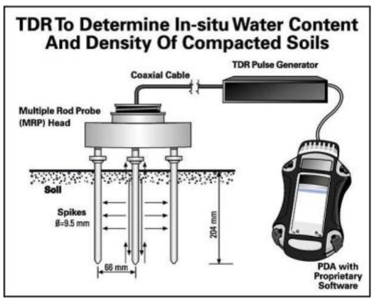

Figure: 7b: DGSI TDR device

As with the NDG, both types of NNDG device require some element of calibration against standard test methods for determining soil density and moisture content.

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[16] www.transtechsys.com/pdf/sdg200.pdf

[17] www.humboldtmfg.com/electrical_density_gauge_2.html

[18] www.durhamgeo.com/pdf/m_test-pdf/paper/CGEA%20CA%20Jan%202005.pdf

Moisture-density relationship

BS 1377 Part 4 describes three types of compaction tests, each with procedural variations related to the nature of the soil. The first is the light manual compaction test in which a 2.5kg rammer is used. The second is the heavy manual compaction test, which is similar, but gives a much greater degree of compaction by using a 4.5kg rammer with a greater drop height on thinner layers of soil, equivalent to the AASHTO T180[19] test method. The third type of test makes use of a vibrating hammer, and is intended mainly for granular soils passing a 37.5mm test sieve, with no more than 30% retained on a 20mm test sieve. For each type of test, alternative procedures apply depending on whether or not the soil contains particles susceptible to crushing during compaction.

The BS light manual compaction test is similar to AASHTO T99. Table 3 shows comparisons of the key elements of the test.

Table 3: Comparison of AASHTO T99 and BS 1377 Part 4

	AASHTO T99	BS 1377 Part 4
Weight of rammer	5.5lbs (2.495kg)	2.5kg
Distance of drop	12in. (305mm)	300mm
Number of soil layers	3	3
Diameter of mould	4in. (101.6 mm)	105mm
Rammer, blows/layer	25	27

Whilst the test methodology for the AASHTO and BS tests are similar when determining the moisture-density relationship, there are differences in the method for correcting for the coarse fraction of material.

When testing to AASHTO T99, an additional calculation explained in AASHTO T224[20] and shown in Appendix A, needs to be applied to the found dry density value to compensate for the passing 50mm retained 19mm fraction of material removed before completion of the moisture-density relationship test. This differs from BS 1377 Part 4, which compensates for the oversized fraction retained on the 37.5mm sieve by replacing this material with an equal mass of material passing the 37.5mm and retained on the 20mm sieve.

An example test report for determining the dry density / moisture content relationship is shown in Figure 8.

[19] AASHTO T180 Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54kg (10lb) Rammer and a 457mm (18in.) Drop.

[20] AASHTO T224 Standard Method of Test for Correction for Coarse Particles in the Soil Compaction Test.

Lab No: Site Ref: Project No:	

EXAMPLE ONLY

CERTIFICATE OF DRY DENSITY / MOISTURE CONTENT RELATIONSHIP
Test Method: AASHTO T099

A Customer

Client: CPNI

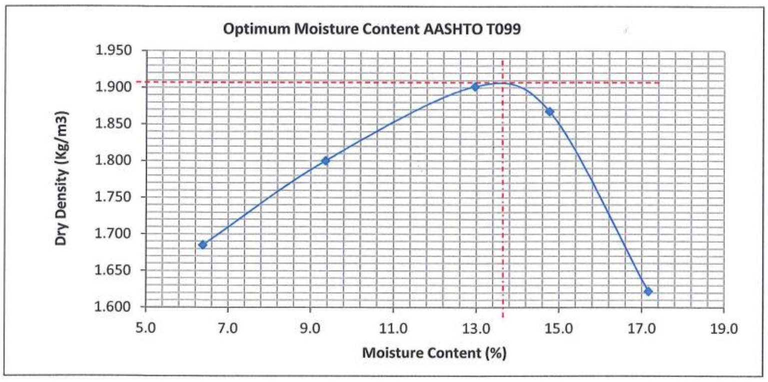
Location: F2656-07 Backfill

Material Type: Vehicle Crash Testing of Perimeter Barriers, Soil Foundation Material

Material spec: ASTM F2656-07 Table 3 **Date Sampled:**

Supplier: **Date Received:**

Source: **Date Tested:**



Remarks:

Natural Moisture Content = %	12.8	**Optimum Moisture Content = %**	13.7
Maximum Dry Density = Mg/m^3	1.908	**Insitu Dry Density= Mg/m3**	1.85
Specific Gravity=		**90% of Maximum Dry Density= Mg/m3**	1715

Distribution:

Signed:

Date of Issue:

Figure 8: Example Dry Density / Optimum Moisture Content Report

If material testing is sub-contracted out to a UK based test house, they will generally test to the BS 1377 standard. However, if testing to F2656-07, the testing should be done according to the ASTM / AASHTO standards in order to be fully compliant.

Suitable test laboratories can be found via the UKAS web site by following the link below:

www.ukas.org/testing/labsearch.asp

Details of accredited test houses and scope of testing is listed below:

Materials/Products tested	Type of test / Properties measured / Range of measurement	Standard specifications / Equipment / Techniques used	Location Code
SOILS for civil engineering purposes	California Bearing Ratio (CBR)	BS 1377:Part 4:1990	A
	Particle size distribution - wet sieving	BS 1377:Part 2:1990	A, C, D
	Dry density/moisture content relationship (2.5kg rammer)	BS 1377:Part 4:1990	A
	Dry density/moisture content relationship (4.5kg rammer)	BS 1377:Part 4:1990	A

The dry density / optimum moisture content example highlights the details to be considered, to ensure that the re-compacted soil at the test site complies with the requirements of F2656-07 Clause 7.2.2. It is important that the natural moisture content of the soils falls within an acceptable range to achieve at least 90% of the optimum dry density value. If the soil is too dry or too wet it is unlikely that a satisfactory level of compaction will be achieved.

Alternative Approach

To reduce the amount of soil testing and to provide a standard soil for all VSB tests, one recommendation is that a stockpile of suitable material is obtained and checked for compliance. This material is then reused for each VSB installation. If this approach is adopted, a standard procedure for clearing all test debris and natural in-situ soil must be established and regular checks of the moisture / density relationship and grading will need to be made and compared to the original measurements to ensure continued compliance. The stockpiled material will also need to be sheeted to prevent loss of fines and be maintained at the correct moisture content to ensure future compaction criteria are met.

Appendix A

AASHTO T224 – CORRECTION FOR COARSE PARTICLES IN THE SOIL COMPACTION TEST

Consult the current edition of AASHTO to see the procedure in its entirety and the equipment specification details.

SCOPE

This method describes a procedure for adjusting densities of soil and soil-aggregates to compensate for differing percentages of oversize particles retained on the 19mm (3/4in.) sieve.

When Method D is used, a correction shall be applied to soil-aggregates which contain more than 5% by weight of oversize. When the oversized maximum of 30% is exceeded, other methods of compaction control must be used.

REFERENCED DOCUMENTS

AASHTO T99 and T180, Moisture Density Relations of Soils
AASHTO T265, Laboratory Determination of Moisture Content of Soils
ASTM D4643, Determination of Moisture Content of Soil by Microwave Oven Heating

CALCULATIONS

Calculate the Corrected Moisture Content (MCT)

$$MCT = \frac{[(MCF \times Pf) + (MCc \times Pc)]}{100}$$

Where:

- MCT = corrected moisture content of combined fine and oversized particles, expressed as a percentage of moisture.
- MCF = moisture content of fine particles, expressed as a percentage of moisture.
- MCc = moisture content of oversized particles, expressed as a percentage of moisture (2.0%).
- Pf = percent of fine particles, by weight.
- Pc = percent of coarse particles, by weight.

Calculate moisture content to nearest 0.1%.

Example of Calculation of Corrected Moisture Content:

$$10.5\% = \frac{[(12.0 \times 85) + (2.0 \times 15)]}{100}$$

Calculate the Corrected Dry Density of the Total Sample (Dd)

$$Dd = \frac{[100 \times Df \times k]}{[(Df \times Pc) + (k \times Pf)]}$$

Where:

- Dd = corrected dry density of combined fine and oversized particles, expressed as lbs/ft3.
- Df = dry density of fine particles expressed as lbs/ft3, determined in lab.
- Pc = percent of coarse particles, by weight.
- Pf = percent of fine particles, by weight.
- k = 62.4* Bulk Specific Gravity (2.650).

Calculate in-place dry density to the nearest 0.1 lbs/ft3.

Example of Calculation of Corrected Dry Density:

$$127.2 \text{ lbs/ft}^3 = \frac{[100 \times 122.0 \times 165.4]}{[(122.0 \times 15) + (62.4 \times 2.650 \times 85)]}$$

NOTES

- Unless the actual moisture content of the oversize particles is known, 2.0% shall be used in calculating corrected moisture.
- Unless the actual bulk specific gravity of the oversize is known, 2.650 shall be used in calculating corrected dry density.

Each dry density and moisture content shall be calculated and plotted to determine optimum moisture content and maximum dry density, as specified within AASHTO T99 and AASHTO T180.

Contact us

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