State of Ohio Environmental Protection Agency

Geotechnical Resource Group (GeoRG)

Geotechnical and Stability Analyses for Ohio Waste Containment Facilities

September 14, 2004

THIS POLICY DOES NOT HAVE THE FORCE OF LAW.
Cover photos:
(Left) Division of Emergency and Remedial Response - CERCLA closure site failure.
(Top Right) Division of Solid and Infectious Waste Management - commercial municipal solid waste landfill failure.
(Bottom Right) Division of Surface Water - captive waste water ash impoundment berm failure.
ACKNOWLEDGEMENTS

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Thanks also to Ohio Department of Natural Resources, Division of Geological Survey for permission to use two of its publications as appendices to this policy.

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September 14, 2004 - The following pages were revised on September 27, 2005: 2-5, 7-2, 9-15, and 9-16
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FOREWORD

READ THIS FIRST

This policy is designed to assist owners of regulated waste containment facilities in demonstrating that stability requirements set forth in Ohio EPA’s rules have been satisfied. The information provided in this policy may be applied to all plans, applications, or requests submitted to any division of Ohio EPA for approval, concurrence, or comment. This policy is particularly applicable to waste containment facility designs that include natural or engineered components where the movement of soil, rock, waste, geosynthetics, or other materials may occur because of gravitational influence.

The information in this policy will be useful to anyone proposing any excavating, stockpiling, filling, or construction activity that is at, or close to, an Ohio EPA regulated waste containment facility.

The information contained herein is intended to apply to design, requests for authorization, construction, and closure of waste containment facilities to assist facilities in satisfying Ohio EPA’s rule requirements for demonstrating stability. However, the applicable statutes and rules should also be consulted directly, as this policy is intended to ensure the activities undertaken to demonstrate stability satisfy the requirements of the appropriate statutes and rules. In addition, individual site-specific circumstances may exist that affect the stability analyses for any given facility, thereby requiring alternatives to the procedures and methods included in this policy to be used by the responsible party.

This policy recommends specific items be included in geotechnical and stability analyses and includes definitive performance criteria established by rule to use for documenting stability to Ohio EPA. This policy addresses when stability analyses are needed, the content of geotechnical and stability analyses reporting documents, subsurface investigation, materials testing, static and seismic stability analyses, and certain other geotechnical analyses.

Any examples or case studies referred to in this policy are intended to demonstrate how compliance may be achieved, but are not intended to establish a requirement for how the applicable statutes or rules must be satisfied. The methods and procedures included in this policy have been evaluated by Ohio EPA and have been shown to be useful for demonstrating that a waste containment facility will meet the rule requirements for stability. Alternative methods or procedures may be used if they are fully documented as being valid and appropriate for demonstrating compliance with stability requirements in rule and are acceptable to Ohio EPA.
THE USE OF REQUIREMENTS VS. RECOMMENDATIONS

This policy describes requirements when:

• a specific or general Ohio statute or rule exists that includes the requirement,

• published standards, such as American Society for Testing and Materials (ASTM) methods, contain the requirement, or

• the assumptions of a theoretical model or method being used for analysis and/or calculations require it for the analysis or calculations to be valid and applicable.

Requirements are notated in this manual with language such as "shall," "must," or "required."

This policy describes recommendations when:

• none of the above criteria apply,

• published standards or state of the practice offer multiple acceptable alternatives, or

• the state of the practice is not sufficiently developed to provide a definitive selection of a best practice. When this occurs, the manual reflects the best understanding of a current approach that seems appropriate for use in Ohio.

Recommendations are notated in this manual with such language as "should," "may," or "recommends."

Responsible parties are obligated to comply with rule requirements even if the same activities are included in this policy as recommendations.
DEFINITIONS AND ACRONYMS

Throughout this policy the defined words and phrases are italicized to remind the reader that the terms are defined. Although not necessarily defined in Ohio’s regulations, the following definitions are useful for understanding this policy.

AASHTO American Association of State Highway and Transportation Officials.

ASCE American Society of Civil Engineers.


Bedrock Solid rock underlying unconsolidated materials (soil units). Syn: consolidated stratigraphic unit.

Book values Values derived from charts, tables, or other generalized presentations of data found in textbooks, periodicals, and manuals. Book values often represent broad generalities derived from data that are unlikely to accurately portray localized site-specific conditions, but may be useful when used in a very conservative manner and in accordance with proper assumptions. For example, using book values to estimate the shear strength of competent bedrock is likely to be appropriate.

Borings Any means of mechanical penetration into the subsurface for the purposes of characterizing material properties or collecting material samples.

CERCLA Comprehensive Environmental Response, Compensation, and Liability Act

Compressible layer Soil or filled materials that may settle after establishing a facility, and may continue to settle after a facility has closed.

Conformance testing Testing conducted before construction on samples from materials that will be used during construction, the results of which are compared to the approved design specifications to ensure that the materials used in construction will perform as required. Syn: Preconstruction testing

Consolidated material See: Bedrock.

Consolidated stratigraphic unit See: Bedrock.

CPT Cone Penetrometer Test.

Critical layer A potentially liquefiable layer, or a thickness of soil or waste material that has a drained or undrained shear strength that may cause a failure if all or part of the mass of a facility were suddenly put in place. Critical layers may be only a few inches thick to tens of feet thick. Critical layers may include parts of one or more stratigraphic soil units.
An example of a typical landfill progression showing internal, interim, and final slopes, and the facility bottom. These types of slopes may also be present at other types of waste containment facilities.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>FML</td>
<td>Flexible membrane liner. Syn: Geomembrane</td>
</tr>
<tr>
<td>fps</td>
<td>Feet per second.</td>
</tr>
<tr>
<td>FS</td>
<td>Factor of safety.</td>
</tr>
<tr>
<td>GCL</td>
<td>Geosynthetic clay liner.</td>
</tr>
<tr>
<td>GDL</td>
<td>Geocomposite drainage layer.</td>
</tr>
<tr>
<td>HDPE</td>
<td>High density polyethylene.</td>
</tr>
<tr>
<td>Higher quality data</td>
<td>Data produced from laboratory methods or cone penetrometer tests (CPTs) that, when properly conducted, provide the most definitive measurements obtainable of the characteristics of a specimen.</td>
</tr>
<tr>
<td>Interim slopes</td>
<td>Slopes that exist at a waste containment facility because of daily filling or because a phase or unit has reached its limits, including cover soils. An interim slope will exist for only part of the facility life and is not part of the engineered components of the facility (see Figure f-1 on page xii).</td>
</tr>
<tr>
<td>Internal slopes</td>
<td>Slopes excavated below grade and/or constructed using berms, including, as applicable, the liner/leachate collection system, protective layers, and other engineered components (see Figure f-1 on page xii). Interfaces on internal slopes that exceed a grade of five (5) percent must be assigned residual shear strength during deep-seated failure analysis, but may be assigned peak shear strength during shallow failure analysis, if appropriate.</td>
</tr>
<tr>
<td>Lower quality data</td>
<td>Data produced by field testing (other than CPTs) that are good for relative comparison of characteristics, but even when the test is run properly, do not necessarily provide a definitive measurement of the characteristic. Examples of methods that produce lower quality data include, but are not limited to, blow counts and pocket penetrometers.</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal solid waste.</td>
</tr>
<tr>
<td>OCR</td>
<td>Overconsolidation ratio.</td>
</tr>
<tr>
<td>ODNR</td>
<td>Ohio Department of Natural Resources.</td>
</tr>
<tr>
<td>ODOT</td>
<td>Ohio Department of Transportation.</td>
</tr>
<tr>
<td>Overall settlement</td>
<td>The settlement of an entire waste containment facility, as it relates to facility geometry, appurtenances, pipes, roads, culverts, leachate drainage ways, and surface water drainage ways.</td>
</tr>
<tr>
<td>pcf</td>
<td>Pounds per cubic foot.</td>
</tr>
</tbody>
</table>
**Peak shear strength**  
The maximum shear stress recorded during a shear test as strain is increased (see [Figure f-2](#) on page xiv).

**Phreatic surface**  
A surface that represents the water level in an unconfined saturated zone. Examples: saturated portions of soil or waste that are not confined by an overlying layer; the surface created by leachate on a landfill liner; the water level in a waste water lagoon; or the saturated portion of a clay soil layer, all create phreatic surfaces. Syn: Water table.

**Piezometric surface**  
A surface that represents the actual pressure head relative to a confined saturated zone. For example, the surface created by water level readings from wells screened in a saturated sand overlain by heavy clay such that the water level surface is measured above the top of the sand. Syn: Potentiometric surface.

**Primary consolidation**  
See: Primary settlement.

**Primary settlement**  
The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to a squeezing out of water from the void spaces of the mass and accompanied by a transfer of the load from the soil water to the soil solids (ASTM D 653). Syn: Primary consolidation.

**Protective layer**  
A layer made of soil or granular material designed to protect underlying geosynthetics and recompacted soil layers from damage due to construction, operations, maintenance, freezing, or weathering. Examples of protective layers include, but are not limited to, a granular leachate collection layer with underlying geotextile cushion layer, a soil layer placed on top of a drainage layer in a cap, or a granular material with an underlying geotextile cushion layer used to protect lagoon and pond liners.

**psf**  
Pounds per square foot.

**QA/QC**  
Quality assurance and quality control.

**Residual shear strength**  
The steady state shear stress recorded after the strain is increased beyond the peak shear strength of a specimen (see [Figure f-2](#) on page xiv). Residual shear strength is measured or can be conservatively estimated based on the results of applicable tests.
Responsible party  
The persons in control of the property, facilities, and activities that occur at a waste containment facility, including, but not limited to, applicant, permittee, owner, operator, or potentially responsible party (PRP).

RSL  
Recompacted soil layer (liner or barrier layer depending upon context).

Sample  
**noun:** Used in this manual to describe a volume of material from which specimens are prepared for testing. One sample may provide one or more specimens for testing. **verb:** Used in this manual to refer to the activities necessary to collect samples of materials.

Saturated  
**a:** for shallow failure analysis: the protective layers over a cap drainage layer or over a geocomposite leachate collection layer are at field capacity, and are discharging water to underlying drainage layers at a rate equal to the effective hydraulic conductivity of the protective layer. When a protective layer is a leachate collection layer prior to waste placement, then saturated means the state when head exists due to the occurrence of a design storm. **b:** for laboratory methods: a specimen has, to the extent possible, all voids full of water. **c:** for subsurface conditions, one or more soil units, or part of a soil unit has most of the voids filled with water.

Secondary compression  
See: Secondary settlement.

Secondary settlement  
The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to the adjustment of the internal structure of the soil mass after most of the load has been transferred from the soil water to the soil solids (ASTM D 653). Syn: secondary compression.

Soil stratigraphy  
The vertical and lateral or spatial arrangement of soil units at a facility.

Soil unit  
**a:** A discrete layer or body of unconsolidated material that can be readily and consistently distinguished from adjacent materials based on one or more characteristics or features, usually composition (e.g., grain size distribution, mineralogy, or percent organic material); structure (e.g., layering, interbedding, or fracturing/jointing); and/or soil engineering (physical) properties (e.g., plasticity, bulk density, or permeability). Depending on facility conditions, designation of layers or bodies of minespoil or fill materials as soil units may be appropriate. Individual soil units might not be laterally continuous across a facility. **b:** a stratum of soil within the soil stratigraphy of the facility. Syn: Unconsolidated stratigraphic unit.

Specimen  
A specific volume of material subjected to testing. For example, a volume of soil material trimmed out of a sample and placed into a triaxial compression apparatus to be tested for shear strength.

SPT  
Standard Penetration Test.
**Strain incompatibility**
The condition that exists when the displacement necessary to mobilize the peak internal or peak interface shear strength is different for two or more materials that comprise a composite system, such as a berm and its foundation, or different layers of a composite liner system. If *strain incompatibility* is not taken into account, it may cause computer modeling software to overlook the critical failure surface.

**Total settlement**
The settlement at any given point caused by the sum of immediate, primary, and secondary settlement.

**Unconsolidated**
In geology, used to differentiate between bedrock (consolidated material) and other materials such as weathered bedrock and soils (unconsolidated material). This is different from the geotechnical terms of “unconsolidated,” “normally consolidated,” and “overconsolidated” used to describe the stress history of a soil material.

**Unconsolidated Stratigraphic Unit**
See: Soil unit.

**Undrained conditions**
The state that exists when a soil layer experiences excess pore water pressure. This occurs during loading of a compressible layer of saturated soil and may occur during loading of a compressible layer of partially saturated soil.

**Undrained shear strength**
The shear strength exhibited by a saturated soil when experiencing an increase in stress that causes excess pore water pressure to develop. *Undrained shear strength* is used for conducting a total stress analysis.

**Unsaturated**
- **a:** As used in shallow failure analysis, it means that the protective layer over a cap drainage layer or a protective layer over a geocomposite leachate collection layer has not reached field capacity, and is not discharging sufficient water to the drainage layer to create head on the underlying layer. When the protective layer is the leachate collection layer, it means that no head exists within the collection layer.
  - **b:** As used in discussing laboratory methods, it means that a specimen has a measurable amount of void space that is not filled with water.
  - **c:** As used in the discussion of subsurface in situ conditions, it means that no portion of a soil unit has most of the voids filled with water.

**USACOE**
United States Army Corps of Engineers.

**USDA**
United States Department of Agriculture.

**USGS**
United States Geological Survey.

**USCS**
Unified Soil Classification System.

**UU**
Unconsolidated-undrained.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td><strong>Waste containment facility</strong></td>
<td>One or more tracts of land that contain one or more waste containment units. This includes, but is not limited to, facilities regulated by Ohio EPA under the authority of Ohio Revised Code Chapters 3734, 6111, and 3714, and Federal Regulations, such as RCRA and CERCLA.</td>
</tr>
<tr>
<td><strong>Waste containment system</strong></td>
<td>One or more engineered components used singly or in aggregate to control waste that has been placed onto or into the ground.</td>
</tr>
<tr>
<td><strong>Waste containment unit</strong></td>
<td>A group of waste containment systems or a discrete area within a facility used for storage, treatment, or disposal of wastes, such as waste piles, landfills, surface impoundments, and closure units.</td>
</tr>
</tbody>
</table>
References


BASIC CONCEPTS OF SLOPE STABILITY

Slope and foundation materials can move due to shearing stresses created within a material or at material interfaces by external forces (e.g., gravity, water flow, tectonic stresses, seismic activity). This tendency is resisted by the shear strength of the materials and interfaces and is expressed by the Mohr-Coulomb theory as:

\[ \tau_f = c + \sigma \cdot \tan \phi \] (see Figure f-3 on page xx)

where \( \tau_f \) = shear strength of material,
\( c \) = cohesion strength of material,
\( \sigma \) = normal stress applied to material, and
\( \phi \) = friction angle.

In terms of effective stress (drained condition):

\[ \tau'_f = c' + (\sigma - u) \tan \phi' \]

where \( \tau'_f \) = shear strength of material,
\( c' \) = effective cohesion strength of material,
\( \sigma \) = normal stress applied to material,
\( u \) = pore water pressure, and
\( \phi' \) = friction angle in terms of effective stress.

The relationship between the angle of failure and the internal angle of friction can be described as:

\[ \alpha = 45^\circ + \frac{\phi}{2} \] (see Figure f-3 on page xx)

where, \( \alpha \) = angle of failure in the material, and
\( \phi \) = friction angle.
Symbols for Figure f-3.

- $\tau_f$ = shear strength of material,
- $c$ = cohesion strength of material,
- $\sigma$ = stress applied to material,
- $\sigma_1$ = major principal stress,
- $\sigma_3$ = minor principal stress,
- $\phi$ = friction angle, and
- $\alpha$ = angle of failure in the material.

References
