The construction of forest roads and landings in steep country often requires the construction of embankment fills. Poorly compacted fills present a slope stability risk and can be prone to slumping and sediment generation.

Compaction is an essential earthworks process to ensure that the strength and stability requirements of road or landing formations are achieved.

The aim of the compaction process is to increase the soils’ shear strength, limit future settlement and reduce permeability.

*Skid site constructed of a well graded granular fill material – note the range of particle sizes.*
Earthworks Construction
1.4 Fill Placement and Compaction

**Scope**
This guide covers the construction of embankments *fills* and outlines best practice techniques for placing and *compacting fill*. It should be read in conjunction with FPG EC #1 Planning and Design, FPG EC #2 Stripping and Clearing and FPG EC #3 Bulk Earthworks. Users of the guide are also referred to the following reference documents:

- National Environmental Standards for Plantation Forestry (regulations 22-35)
- NZTA Standard Specification F/1 – Earthworks Construction
- Guideline for the Field Classification and Description of Soils and Rock for Engineering Purposes: NZ Geotechnical Society, December 2005
- NZS 4402.4.1:1986 Methods of testing soils for civil engineering purposes – Part 4 Soil Compaction tests

**Fill construction materials**
*Fill* placement and *compaction* methods will depend on the available material and the structural requirements of the *fill*. Distinction needs to be made between cohesive and non-cohesive (granular) *fill* materials.

**Cohesive soils** – fine grained soils with a high clay content where the particles of the soil bond to one another.

A quick and simple way to test whether or not a soil is a clay is to moisten the soil sample and test its pliability with your hands. A clay content is indicated if the moist soil feels sticky and continues to stick to your hands or when rolled into a ‘snake-like’ form it stays connected without splitting.

**Granular soils** – are relatively coarse-grained soils, such as *sand* (particle size of 0.06 mm to 2 mm) and *gravels* (particle size between 2 mm and 200 mm), where the particles lie side by side without bonding. Most pumice material will be classified as granular.

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**Clay content test**
Simple test for clay content – soil rolled into a snake by hand holds its form.
Operational planning and management

The suitability of the in-situ soils should be assessed against the fill requirements prior to earthworks commencing. Fills should be classified as structural (load bearing) and non-structural (landscape fill). The planning process should optimise the use of materials (notably achieve cut to fill balance and reduce unnecessary cut to waste) and confirm what soil material is not suitable for bulk fill.

Often there will be more than one soil type on a construction site. Consideration will need to be given to how best to manage the range of soil types that may be present. Fill design should consider how soils will be mixed (and behave) depending on the site geology and geography and the contractor’s construction methodology.

Batter slope and compaction are integral components of embankment fill stability. Steeper batter slopes require a higher shear strength to maintain stability. It is important that fills are not over-steepened relative to the soil strength that can be achieved. Compaction needs to be optimised to ensure that the soil strength and batter slope stability is achieved.

Fill batters should be overfilled to support earthmoving equipment and allow compaction plant to compact the full width of the design cross-section and then trimmed back to the design batter slope as the fill is built up. This will ensure the full width, including the outer edge of the fill, is effectively compacted.

Batter slope and compaction requirements should be provided to the contractor in the project prescription.
**Operational planning and management continued**

**Fill placement**

*Fill* material should be spread and *compacted* in layers of uniform quality and thickness across the full cross-section for the road/skid.

The thickness of each layer shall be limited to ensure that the required level of *compaction* is achieved for the full depth of each layer. The following maximum layer thicknesses are recommended:

<table>
<thead>
<tr>
<th>Nominal maximum particle size</th>
<th>Maximum layer thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 100 mm</td>
<td>200 mm</td>
</tr>
<tr>
<td>100 mm to 200 mm</td>
<td>1.5 times the 85th percentile size</td>
</tr>
<tr>
<td>Over 200 mm</td>
<td>Determine on site</td>
</tr>
</tbody>
</table>

The movement of all construction vehicles and other traffic should, where practicable to do so, be evenly distributed over the full width of the *filling* area, so as not to damage or overstress the construction.

**Compaction processes**

*Compaction* is the process of increasing the density of a soil by packing the particles closer together through the application of external forces. Specialist *compaction* equipment (such as steel drum rollers, pneumatic-tire rollers, sheep foot or cleated rollers) is necessary. *Compaction* cannot be effectively achieved by tracked machinery as tracks distribute the load over a wider area effectively minimising *compaction*. *Compaction* processes vary for cohesive and granular material.

**Cohesive soils**

*Compaction* of cohesive soils is achieved by impact and weight to break down the ‘cohesive’ bonds to increase the soil density. Kneading *compactors* with high point loads, such as *sheep* and *pad foot rollers* are required for cohesive soils (see photo overleaf).

The strength of cohesive soils is influenced by moisture content. *Compaction* should be carried out at the optimum moisture content (OMC) to produce a required *compaction* outcome (maximum dry density – MDD). The general rule of thumb is, that if materials are *compacted* at OMC, then the MDD should be achievable.

A rough check for most materials is to squeeze a lump in the hand and, if it just holds together when pressure is taken off and the material does not stick to the fingers, the water content will be approximately at optimum.
Compaction processes continued

Notes:
1. If cohesive material is rolled when it is too wet or too dry for efficient compaction, the consequences can be high air void and lower short and long term strength. Further rolling is of limited value and may be detrimental to the fill stability.
2. Cohesive soils placed in fills when drier than optimum moisture content may appear to have good strength but may suffer a marked reduction in strength when wetted at a later date.

Site management should consider soil water content and apply any corrections necessary to facilitate soil placement and compaction to satisfy the strength and stability requirements of the fill. In some materials a significant gain in strength is obtained if the water content is adjusted to be nearer optimum. The feasibility and economics of changing in-situ water content should be considered during the operational planning phase.

Soil compaction machinery

Pad foot roller suitable for compacting cohesive soils.

Granular soils

Compaction of granular soils can be carried out with static compactors that simply apply weight and tend to compact from the bottom of the layer up; vibratory compactors that use a mechanical action to consolidate soil particles; impact compactors that use a high-amplitude whack to compact material.

Granular fills are usually suitable for fill construction as strength is usually adequate over a range of moisture conditions.
Compaction testing and field monitoring

The following are recognised methods for testing the quality of fill materials and construction. The specific tests and testing frequency should be determined during the planning and design phase and reflect the scale and complexity of the earthworks, and the consequence of the fill failing.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test description</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-situ density</td>
<td>&quot;Rapid&quot;</td>
<td>NZS 4407:1991, Test 4.2.1 (Nuclear Densometer Direct Mode)</td>
</tr>
<tr>
<td></td>
<td>&quot;Fully Specified&quot;</td>
<td>NZS 4407:1991, Test 4.2.2 (Nuclear Densometer Backscatter Mode)</td>
</tr>
<tr>
<td>MDD &amp; OMC determination</td>
<td>Standard Compaction</td>
<td>NZS 4402: 1986, Test 4.1.1</td>
</tr>
<tr>
<td></td>
<td>Heavy Compaction</td>
<td>NZS 4402: 1986, Test 4.1.2</td>
</tr>
<tr>
<td>Strength</td>
<td>Scala Penetrometer</td>
<td>NZS 4402: 1986, Test 6.5.2</td>
</tr>
<tr>
<td></td>
<td>Pilcon Shear Vane</td>
<td>NZ Geotechnical Society Inc “Guideline for hand held share vane”</td>
</tr>
<tr>
<td></td>
<td>Clegg Impact Test</td>
<td>ASTM D5874-95</td>
</tr>
<tr>
<td>Permeability</td>
<td>Laboratory Triaxle Permeability</td>
<td>Based on Head, Vol. 3, 1988, Section 20.4.2</td>
</tr>
<tr>
<td>Solid density</td>
<td>Solid Density</td>
<td>NZS 4402: 1986, Test 2.7.1</td>
</tr>
<tr>
<td>Moisture content</td>
<td>Moisture Content</td>
<td>NZS 4402:1986, Test 2.1</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td>PSD Wet Sieving</td>
<td>NZS 4402:1986, Test 2.1</td>
</tr>
<tr>
<td></td>
<td>Hydrometer</td>
<td>NZS 4402:1986, Test 2.1</td>
</tr>
</tbody>
</table>

The following field testing equipment is considered suitable for compaction testing on most forest earthworks projects:

- Scala Pentrometer – strength testing in cohesionless soils. Results are converted into an ‘inferred CBR’.
- Shear Vane – strength testing in cohesive soils. The results are expressed in kPa.
- Clegg Impact Test – testing surface hardness or stiffness. The result (impact value) can be used as an indication of compaction but is not a direct measurement. Impact values can be converted into an inferred CBR (Inferred CBR = 0.07 x (IV)^2).
- Nuclear Densometer – testing of water content and percentage compaction (if MDD target is provided).
Earthworks Construction

1.4 Fill Placement and Compaction

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Other Practice Guides in this series

1.1 Planning and Design
1.2 Clearing and Stripping
1.3 Bulk Earthworks
1.4 Fill Placement and Compaction

Visit: https://docs.nzfoa.org.nz/forest-practice-guides/ to view all guides