Construction of compacted soil liners at Horotiu Landfill

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ABSTRACT

A clayey silt, derived from completely weathered Siltstone, was used to construct compacted soil liners for a landfill base and final cover at the Horotiu Landfill, New Zealand. The soil had highly variable maximum dry density and optimum water content, which made it difficult to set the compaction targets for conventional specifications. We developed an alternative specification that used maximum air voids as the main means of verifying adequate compaction. Observations from construction and extensive quality control and quality assurance testing are given.

1 INTRODUCTION

Opus International Consultants Ltd (Opus) was commissioned by Hamilton City Council to design the 2.9ha Stage 6B extension to the Horotiu landfill and to provide quality assurance (QA) services for the construction of the landfill and associated 10ha of final cover.

The landfill design incorporates a compacted soil liner within the base liner and the final cover. As part of our QA role, we carried out investigation and laboratory testing of the soil to be used for the compacted soil liner and final cover, and extensive testing during construction.

The soil used for construction was a completely weathered Siltstone. This paper presents the results of the testing, the specification adopted for the compaction of the soil to create the low permeability liners, and our observations from the construction to date.

The Horotiu Landfill is situated 13km north of Hamilton and 100km south of Auckland, in the North Island of New Zealand. The soil for the liner and final cover was sourced from the Perry Aggregates quarry, approximately 1km west of Ngaruawahia and about 5km northwest of Horotiu Landfill.

2 REGIONAL TOPOGRAPHY, GEOLOGY AND SOIL MAPPING

The Horotiu Landfill is situated on the Waikato River plains. The plains were formed from alluvial deposition of mainly sandy soils of Quaternary age (Kear & Schofield, 1966), mainly associated with volcanic activity in the central North Island.

The Hakarimata Ranges run northeast-southwest and define the western extent of the Waikato River plains in this area. The geological map for the area (Kear & Schofield, 1966) shows the source of the soil for the liner and final cover to be within the Hakarimata formation, which is described as well bedded fossiliferous sandstones, siltstones, and conglomerates.

Published soil mapping (Bruce, 1978) shows the local soil to be Kaawa Hill Soils. These are deeply weathered from the parent material and often pink or red in colour. Fragments of highly weathered rock are scattered throughout the soil but fragmented fresh rock is rare. A thin cover of volcanic Ash sometimes occurs on ridges and upper slopes.

3 DESIGN REQUIREMENTS FOR COMPACTED SOIL LINERS

The compacted soil liners at the site are used as:

- the main barrier to ingress of rainwater into the landfill as part of the final cover, and
- an important part of the composite base liner system to prevent leakage of leachate from the landfill.

The main performance requirements for the compacted soil liners were set out in the resource consent for the landfill (Waikato Regional Council, 2003), and relate to maximum permeability, as outlined in Table 1. About 70,000m^3 (in place) of soil was required to construct the liners.

Table 1: Design Requirements for Compacted Soil Liners

Compacted soil liner	Maximum Permeability	Minimum Thickness	Other requirements
Base Liner	10^{-8}m/s	0.35m	High plasticity
Liner within Final Cover	10^{-7}m/s	0.60m	Low shrinkage potential, high plasticity

4 INVESTIGATION & LABORATORY TESTING OF LINER BORROW SOURCE

The landfill had previously been a sand mine, and there were no clay or silt soils on-site or within the vicinity of the site that were suitable for use as compacted soil liners.

Overburden from a rock quarry, 5km from the landfill, had been used for construction of liners on previous stages of the landfill, and was the most convenient source of suitable soil.

We carried out investigation pits to examine the near surface ground conditions and obtain samples of the soil for testing to determine its suitability for use in compacted soil liners. The original source testing (Table 2) was supplemented by additional testing during construction as the borrow areas were extended.

The main soil encountered was completely weathered Siltstone (Kaawa Hill Soil), typically described as clayey Silt, stiff, moist, yellowish reddish brown. The soil exhibited some highly fissured relic rock structure (ie: less weathering) with depth, although this was highly variable.

Table 2 summarises the laboratory testing carried out to confirm the suitability of the soil for use as a liner. Figure 1 summarises the compaction testing for the soil, and shows the highly variable optimum water content, natural water content and maximum dry density.

Table 2: Laboratory source testing of Kaawa Hill Soil for use as compacted soil liner

Sample	Nat WC	Opt WC	Max Dry Density	Grading Coarse	Grading Silt	Grading Clay	Liquid Limit	Plastic Limit	PI	Linear Shrinkage
	%	%	t/m^3	%	%	%	%	%	%	%
1	43.1	42	1.22	7	43	50	93	43	50	21
2	40.1	34	1.31	18	54	28	67	42	25	13
3	41.9	38	1.21	18	63	19	56	45	11	9
4	43.7	35	1.3	18	50	32	67	43	24	13
5	44.3	39	1.269	15	63	22	88	42	46	-
6	44.8	32	1.305	-	-	-	55	41	14	-
7	35	34	1.35	15	63	22	52	36	16	8
8	31.4	29	1.435	8	50	42	60	29	31	13
9	40.7	38	1.265	8	64	28	60	43	17	10
10	41.8	33	1.267	22	56	22	57	39	18	9
11	35.9	30	1.31	38	48	14	51	36	15	7

Pinhole dispersion tests indicated the soil was non-dispersive. Solid Particle Density varied from 2.67 t/m^3 to 2.79 t/m^3, and was typically 2.75 t/m^3. The permeability of samples compacted to various standards was from 4×10^{-10}m/s to 6×10^{-8}m/s. The linear shrinkage appeared to increase with higher clay content. The variability of the soil was mainly thought to be due to variable weathering.

Figure 1: Compaction testing of source soil

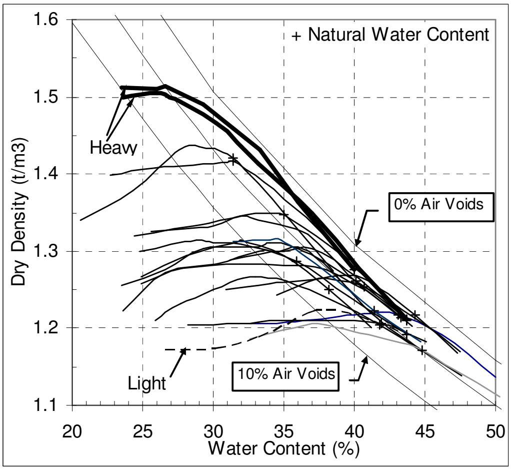
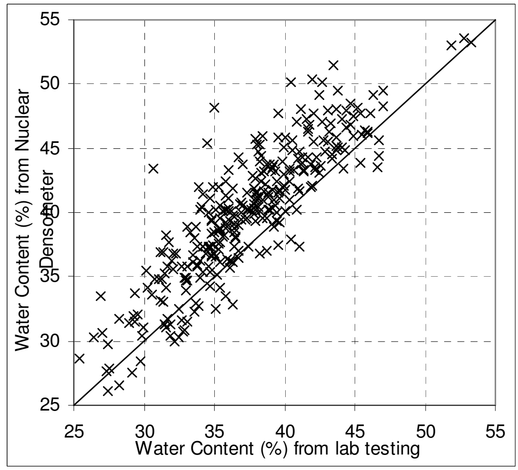


Figure 2: Water content testing



5 SUITABILITY OF SOIL FOR USE AS LANDFILL LINER AND COVER

The source testing confirmed that the soil could be compacted to satisfy the permeability requirements over a reasonably wide range of water contents. The main challenge was to develop a specification for compaction control that allowed for the highly variable optimum water content, natural water content and maximum dry density.

All the samples were wetter than standard optimum water content (Figure 1), by up to 12%, and 5% on average. Our experience suggests soils much wetter than about 10% above optimum can be difficult to compact, so we allowed to selectively waste the wetter soils from the borrow.

6 SPECIFICATION FOR COMPACTION

To ensure low permeability is achieved, conventional specifications for soil liners usually require compaction of the soil to a minimum dry density and within a specified range of water content (eg: 98% of maximum dry density at Standard compaction and water content from optimum to optimum +4%). This form of specification was not appropriate for the Kaawa Hill Soils as the highly variable soil properties made it impractical to set the required compaction targets for maximum dry density and optimum water content.

Daniel and Koerner (1995) describe a procedure for developing a compaction specification tailored to compacted soil liners. This procedure proved difficult to apply to the highly variable soils used at Horotiu, although their "line of optimums" gives a similar constraint to using air voids to control the compaction, as we eventually did.

The specifications used for compaction of the clay liners are summarised in Table 3 and discussed below.

Table 3: Summary of compaction specifications

Compacted Soil Liner	Compaction Specification
Base Liner	Min 100% of dry density at standard compaction at field water content Max 5% air voids Min vane strength = 80kPa
Cover Liner Phase 1	Min 95% of dry density at standard compaction at field water content Max 7% air voids Min vane strength = 70kPa
Cover Liner Phase 2 (under construction)	Max 6% air voids Min vane strength = 70kPa

For the Stage 6B base liner we adopted a specification that had been used previously at the landfill (CH2M Beca, 2001) which required compaction of the soil to:

- the minimum density achieved under Standard compaction at the natural water content
- maximum air voids of 5%
- minimum hand vane strength of 80kPa.

A similar specification was used for Phase 1 of the final cover, with some reduced criteria to reflect the lower permeability requirement.

These specifications proved effective for compaction control, but required a “one point” standard compaction test to be carried out for each field density measurement, which slowed the approval of the compaction and was costly.

Based on our analysis of the results from the ongoing testing during construction (Section 8), for Phase 2 of the cover liner we developed the following simpler specification that avoided the requirement for the one point standard compaction tests:

- maximum air voids of 6%
- minimum hand vane strength of 70kPa.

The maximum air void criteria ensures the soil is compacted to an adequate density and not too dry. The minimum hand vane strength criteria acts as a restraint on compacting the soil too wet. This latest specification has worked well in the construction to date.

There was considerable variability in the measured solid particle density (2.67 t/m^3 to 2.79 t/m^3, typically 2.75 t/m^3). For air voids calculation from the Nuclear Densometer (NDM) measurements during construction we assigned solid particle density values to the various soils based on field observations.

7 CONSTRUCTION

Construction of the base liner took place from May 2005 to February 2006, with a significant hold period during winter 2005. Phase 1 of the cover liner was constructed from May to December 2005 and also included a significant hold period during winter 2006. Construction of the Phase 2 of the cover liner began in January 2006 and is currently about 30% complete.

A trial pad of base liner was constructed as part of the source approval process, and helped us confirm the suitability of the Kaawa Hill Soils and the unsuitability of the Ash soils, and establish an effective compaction methodology.

The soil from the quarry source was inspected on arrival at the landfill to ensure it was not contaminated by the underlying sandy, blocky, less-weathered Siltstone.

The methodology for constructing the liner generally involved excavating the soil from the quarry with an excavator and bulldozer, then loading into articulated truck and trailers for the 5km road trip to the landfill site. The soil was spread using a small bulldozer, then 18 tonne and 12 tonne sheepsfoot rollers were used for main compaction of the base and cover liners respectively. A smooth drum roller was used to obtain a smooth finish on completion. The bulldozer was also used to tow discs to encourage drying when needed.

Hamilton has an average annual rainfall of about 1200mm, with about 120mm and 90mm per month in winter and summer respectively. During construction up to 180mm of rain fell in the wettest month (July 2005), with 61mm falling during one day in September 2005. During winter there were about 10 days per month of significant rainfall (over 3mm per day).

Rainfall and lack of suitable weather for soil drying significantly slowed construction, mainly during winter but at other times of heavy rainfall as well. Thin plastic sheeting (silage wrap) was successfully used to help shed rain from the unfinished liners. Desiccation cracking, mainly surficial, occurred during warm dry periods. The silage wrap also proved useful in protecting the finished liners from drying. Any cracked areas were treated by watering, discing and re-compaction.

8 TESTING DURING CONSTRUCTION

Over 300 Nuclear Densometer tests (NDM), corresponding water content and "one-point" Proctor tests, and 76 constant head permeability tests have been carried out to date as part of the Quality Control and Quality Assurance work for the construction. Summary plots of the results are given below and discussed in this section.

The NDM over-estimated the water content of the soil by 3% on average, and between -2% and +7% generally (Figure 2). This confirmed that laboratory testing was required to accurately determine the compacted water content.

The testing shows the wide range of water content and dry density for the compacted soil liners (Figure 3). We believe this mainly reflects the variability of the soil, although changeable construction practice (watering, drying, different equipment etc) would also have played a part.

Although similar plant, methodology and soil were used to construct the cover liner, it typically achieved a lower density than the base liner (Figure 3). This is probably because it had a lower compaction requirement, was constructed on a thin intermediate cover over waste, and was slightly wetter.

Figure 3: Field compaction testing

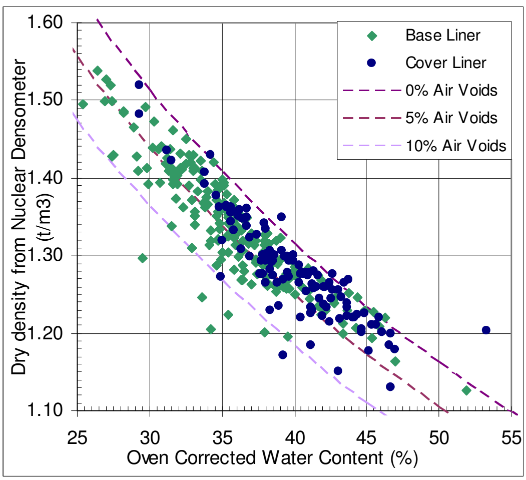
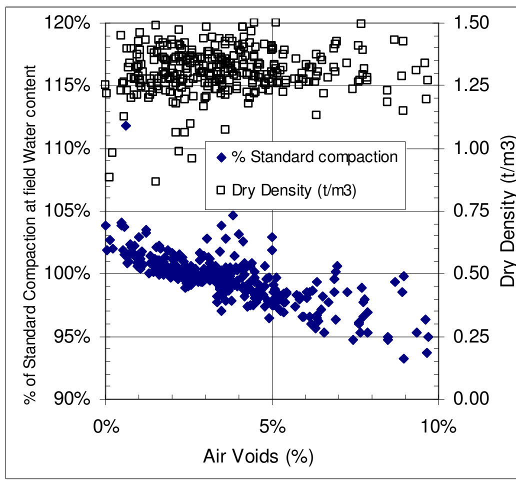


Figure 4: Air voids as an indicator of compaction



The air voids calculated from the NDM measurements (corrected for water content as measured in the lab) were a poor indicator of the dry density, as one would expect (Figure 4). However, air voids proved to be a good indicator (Figure 4) of the degree of compaction (insitu dry density divided by the dry density at Standard compaction at insitu water content). We used this relationship to demonstrate that the soil had been well compacted and would achieve low permeability without the requirement for "one-point" Proctor testing (Section 6).

Permeability of $3x10^{-7}$m/s to $3x10^{-10}$m/s were achieved in the 76 QA/QC permeability tests on thin-walled push tubes from the constructed liner, with only five exceeding the specified maximum permeability. Of these failures, three also failed to meet the compaction specification once the final test results were calculated. Both of the remaining results, part of the final cover liner, had air voids of 6.9%, just satisfying the 7% maximum enforce at that time. All the failed areas were re-compacted and re-tested, and then meet the specification.

Push tubes were used to sample the constructed clay liner for permeability testing. The mass and volume of the samples were measured, to check the accuracy of the field density measurements using the NDM. While the average over about 70 tests was very good, errors of up to ±5% were recorded.

The testing did not show any strong correlation between permeability and either air voids, dry density or water content, although this may have become more apparent if there had been permeability tests over a wider range of these parameters.

The hand vane specification had been intended to prevent the soil from being compacted too wet, as this could lead to higher permeability. However, during construction we found it was not practical to compact the liners with vane strengths below the specified 70kPa to 80kPa, as the soil weaved too much.

9 CONCLUSIONS

From the testing to date and our observations during construction of the compacted soil liners, we conclude:

1. Clayey Silt, derived from a completely weathered Siltstone, can be used to construct a low permeability compacted soil liner.
2. Air voids can be a good indicator of the degree of compaction of fine grained soils.
3. A specification using maximum air voids and minimum hand vane strength can be used to control compaction of fine grained soils with variable compaction characteristics.
4. For the Kaawa Hill soils, and other similar soils, field water content measurements using the NDM should be verified by laboratory testing, as significant inaccuracies can occur.
5. Significant down time should be allowed for when constructing compacted soil liners in a wet climate.

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