SA Water

Engineering

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General Technical Information for Geotechnical Design - Compaction

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Only the current revision of this Guideline should be used which is available for download from the SA Water website.

Significant/Major Changes Incorporated in This Edition

This is the first issue of this Technical Guideline under the new numbering format. The original version of the document was last published in 2007 with the name of General Technical Information for Geotechnical Design Part A – Compaction (TG 10a). A full version history of this document is given in Document Controls. The major changes in this revision include the following items:

- Addition of Section 3, to introduce the fundamental concepts of compaction
- Major revision of Section 4 (formerly Section 5 in TG 10a)
- Minor revision of Section 5 (formerly Section 2 in TG 10a)
- Minor revision of Section 6 (formerly Section 4 in TG 10a)
- Minor revision of Section 7 (formerly Section 3 in TG 10a)
- Major revision of Section 8 (formerly Section 7 in TG 10a)
- Section 6 of TG 10a is removed from TG 0632.

Document Controls

Revision History

Revision	Date	Author	Comments
0	2004	Ed Collingham	First Issue of TG 10a
1	10/1/2007		Nil
2	15/8/2019	Moji Kan	Major Revision, Reformatting to TG 0632

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1 Introduction

SA Water is responsible for operation and maintenance of an extensive amount of engineering infrastructure.

This guideline has been developed to assist in the design, maintenance, construction, and management of this infrastructure.

1.1 Purpose

The purpose of this guideline is to detail minimum requirements to ensure that assets covered by the scope of this guideline are constructed and maintained to consistent standards and attain the required asset life.

1.2 Glossary

The following glossary items are used in this document:

Term	Description
AHBP	Allowable Horizontal Bearing Pressure
I_D	Density Index
MDD	Maximum Dry Density
MMDD	Standard Maximum Dry Density
OMC	Optimum Moisture Content
SA Water	South Australian Water Corporation
SMDD	Modified Maximum Dry Density
TG	SA Water Technical Guideline
TS	SA Water Technical Standard

1.3 References

1.3.1 Australian and International

The following table identifies Australian and International standards and other similar documents referenced in this document:

Number	Title
AS 1289.5.1.1	Determination of the dry density/moisture content relation of a soil using standard compactive effort
AS 1289.5.2.1	Determination of the dry density/moisture content relation of a soil using modified compactive effort
AS 1289.5.6.1	Compaction control test - Density index method for a cohesionless material

1.3.2 SA Water Documents

The following table identifies the SA Water standards and other similar documents referenced in this document:

Number	Title
TS 0004	Packing Sand for Pipe Laying and Trench Fill

1.4 Definitions

The following definitions are applicable to this document:

Term	Description
SA Water's Representative	The SA Water representative with delegated authority under a Contract or engagement, including (as applicable): • Superintendent's Representative (e.g. AS 4300 & AS 2124 etc.) • SA Water Project Manager • SA Water nominated contact person
Responsible Discipline Lead	The engineering discipline expert responsible for TG 0632 defined on page 3 (via SA Water's Representative)

2 Scope

The scope of this document is to provide guidelines for the geotechnical design of compaction in earthworks, mainly related to the backfilling material around pipes installed in in-ground trenches for SA Water infrastructure.

3 Introduction

Soil compaction is a process of mechanical densification of soil by pressing the soil particles close to each other and removing the air between them. The moisture content of a soil has a major impact on how well the soil will compact. When a soil is completely dry it will not compact to its greatest possible density because of friction between the soil particles. As the moisture content increases, the water lubricates the soil, allowing it to move more easily into a compact state and the density increases. Eventually the soil is compacted to its greatest possible dry density (the Maximum Dry Density, or MDD) and the moisture content at which this happens is referred to as the Optimum Moisture Content (OMC). If the soil is wetted further, the extra water replaces some of the solid soil particles and the dry density reduces as there is less material present. For a particular compaction effort, the dry density of soil increases with the moisture content of the soil up to the optimum moisture content beyond which it decreases. When the compaction effort increases, the optimum moisture content decreases. The relationship between dry density and water content is usually represented by a graph.

4 Modified and Standard Compaction

Standard compaction testing method (also known as Proctor test) was developed to determine the maximum density and optimum moisture content of soils. The fundamental theory is that in a controlled environment (or within a control volume), the soil could be compacted to the point where the air could be removed, simulating the effects of a soil in situ conditions. From this, the dry density could be determined by simply measuring the weight of the soil before and after compaction, calculating the moisture content, and furthermore calculating the dry density.

In 1950s, the modified compaction test was developed. This was due to the fact that larger and heavier compaction equipment, e.g. large vibratory compactors and heavier steam rollers, were being developed, therefore compaction standard with higher compaction effort and applied energy to the soil were necessary. The standard test was therefore modified to simulate the change in the density of the soil closer to those obtained by larger rollers and compactors used in larger projects and highways. During the 1970s and early 1980s the modified test became more widely used. Ever since however both Standard and Modified compaction tests are still in place, due to availability of both low energy (e.g. hand held, non-vibratory or light) and high energy (e.g. heavy vibratory) rollers and compactors.

AS 1289.5.1.1 sets out a method for the determination of the relationship between the moisture content and the dry density of a soil, when compacted using standard compactive effort (596 kJ/m^3), in which a standard rammer is dropped on soil in a mould. In a standard compaction test, each sample is compacted in three layers, each by 25 blows of 2.5 kg rammer falling 300 mm on the soil. The maximum dry density obtained by this testing method is referred to as SMDD.

AS 1289.5.2.1 sets out a method for the determination of the relationship between the moisture content and the dry density of a soil, when compacted using modified compactive effort (2703 kJ/m^3). In the modified compaction test 25 blows of 4.9 kg rammer falling 450 mm are used to compact 5 layers of soil. The maximum dry density obtained by this testing method is referred to as MMDD.

In both testing methods (Standard and Modified) compaction is conducted over a range of moisture contents to establish the maximum mass of dry soil per unit volume achievable for this compactive effort, and its corresponding moisture content. The procedure is applicable to that portion of a soil that passes the 37.5 mm sieve. Soil that passes the 19.0 mm sieve is compacted in a 105 mm diameter mould. Soil that contains more than 20% of material retained on the 19.0 mm sieve is compacted in a 152 mm diameter mould.

Density should be specified in terms of **modified compaction** where high compactive effort is supposed to be applied on soil (e.g. where quarry materials such as crushed rock are being used to make a road pavement).

Density should be specified in terms of **standard compaction** where lower compactive effort is supposed to be applied on soil (e.g. where low energy compactors are used to place sandy soils in trench fill). In general, the standard compaction test is suitable for small roads, small buildings and backfills.

5 Effects of Vibrations

This section of these Guidelines refers to the compaction of pipe trench fill using vibrating plates/wheels and notes on risk of damage to the pipe and adjacent structures. This is mainly based on a "Technical Note" which was prepared by Ed Collingham (Ex Principal Engineer Geotechnical) on 29/08/2003, with minor changes.

5.1 Risk of damage to the pipe

Vibrating plates or wheels that attach to the arms of excavators are now commonly used for the compaction of the trench fill and road pavement materials in pipe trenches.

These devices need to be able to apply enough compactive effort to the trench fill and road pavement materials to ensure that the road surface will not settle under future traffic loading. This means that they need to apply somewhat more compactive effort to the materials in the trench than traffic would over the next twenty years or so.

But at the same time they must not apply too much more, otherwise they might damage the newly laid pipes, which are relatively delicate and are only separated from the trench fill by a 150 mm layer of sand (water pipes) or a 300 mm thick layer of screenings (sewers), as shown in Figure 1.

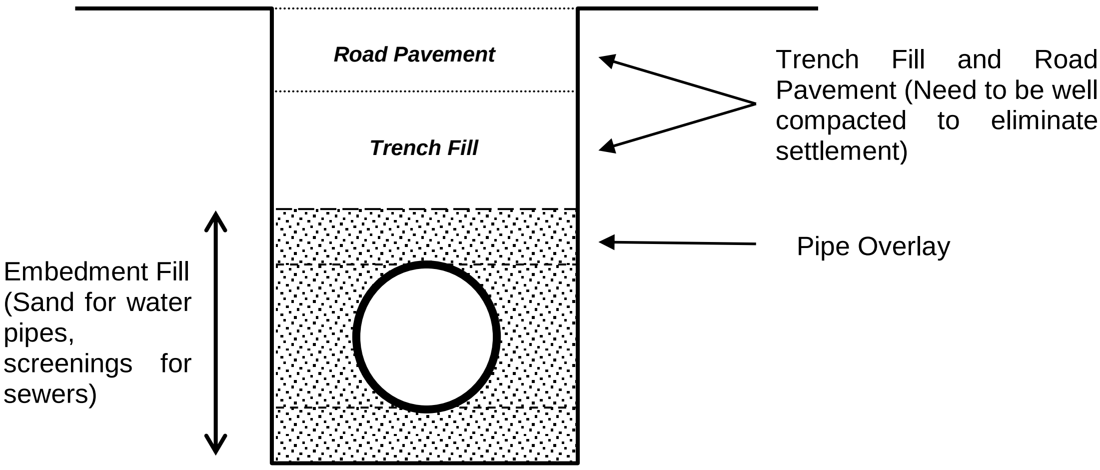

Figure 1: Illustration of trench fill components

It is still usually a struggle to get the specified density down the full depth of the trench fill – usually because contractors try to compact the fill in too thick a layer.

But this in itself provides another perspective on the risk of damage to the pipe, the argument being as follows. "If the energy being imparted to the trench fill just above the overlay was not sufficient to compact the trench fill there to the specified density, then it is also unlikely that it would have been sufficient to damage the pipe."

5.2 Perception of vibration – resonance and airborne noise

It has been argued above that the energy of the vibrations from vibratory compaction equipment used to compact trench fill materials is insufficient to damage the relatively delicate pipes immediately below – as illustrated by the fact that it usually takes several passes of the plate/wheel and careful control of moisture content just to achieve the required density in the layer of fill material being compacted.

These statements beg the question as to why be it that casual observers regularly tend to overestimate the impacts of such equipment.

It is suggested that there are two possible reasons – noise and resonance.

Noise: Vibratory compaction equipment emits a fairly high level of acoustic energy. This purely air-borne sound can have quite a strong psychological impact even though it has no significant mechanical impact on structures.

Resonance: Resonance is where an object vibrates unusually strongly in response to a low-level but sustained stimulus at a particular frequency.

Vibratory compaction equipment operates at a fairly constant frequency and so can readily excite objects that resonate at that same frequency.

The types of objects that resonate at the frequency of vibration of most trench compaction equipment (which is 50 hertz or so) are in the small to medium size range. This range includes cupboards (causing delicately balanced doors to rattle against their frames), or shelves (causing touching drinking glasses to rattle together), or sometimes even suspended timber floors (causing vibrations that might be felt through the feet).

Larger and more massive objects resonate at much lower frequencies than those generated by vibratory compaction equipment. For example, a two-storey house might resonate at about 6 hertz, which is some three octaves lower than the frequency at which typical trench compaction equipment vibrates, and so the house itself will not resonate in response to such equipment.

6 The Compaction of Pipe Side Support Sand by Flooding

6.1 Requirements and limitations of the technique

Under the right conditions, and by using the right techniques, it is possible to achieve a reasonable engineering density in sand by "flooding". Flooding may therefore be appropriate as an alternative to, or along with, mechanical compaction of pipe side support sand. The requirements for successful compaction by flooding are discussed below. Note that it will rarely be possible to achieve these requirements in practise, and so it must be recognised that this technique has limited application.

6.2 The sand must be free draining

Compaction by flooding occurs only during rapid draining after saturation, not during the flooding itself. Not all sands will be sufficiently free-draining to permit compaction by flooding. If the sand is too fine, or contains too many fines, it will not be suitable.

Note: Free-draining sand will often be very clean, in which case the Density Index (I_D) test (AS 1289.5.6.1) must be used to determine its density instead of its Dry Density Ratio. A Density Index I_D of 75% may be taken as equivalent to 95% of SMDD.

6.3 The trench floor must also be free draining

For flooding to be an effective technique for the compaction, the water must be able to drain *vertically* and *freely* into the trench floor. To be sufficiently free-draining the trench floor must therefore consist of sand at least as permeable as the pipe side support sand for a depth of at least 1 m beneath the trench floor, and the water table must also be at least 1 m beneath the trench floor.

6.4 The supply of water must be sufficient to inundate the sand

The rate of supply of flooding water should be sufficient to fully saturate as well as pond temporarily on top of the area being compacted. To achieve this "inundation" it may be necessary to bag-off sections of the trench.

6.5 The trench walls must be stable

If the trench walls are sandy and not sheeted, they will be susceptible to collapse during flooding.

6.6 The pipe must not become buoyant during flooding

Fill the pipe with water and/or load it with sandbags etc. before flooding.

6.7 The sand must be compacted in layers

The layer thickness will depend on the nature of the sand, the rate of supply of water, the drainage conditions, etc. A reasonable maximum compacted layer thickness for side support material is 150 mm. Whether compacting by flooding or any other means, the pipe overlay material must not be placed until all of the pipe side support sand has been compacted to the top of the pipe.

6.8 A trial must be run

A trial must be run to demonstrate that the specified density can be achieved with the sand proposed for use, and under the range of conditions that will apply on site, and to refine the details of the procedure to be followed by the operators.

7 Field Consistency & AHBP

Field identification tests for evaluation of the consistency of soils and recommended values for allowable horizontal bearing pressures (AHBP) for anchor and thrust blocks are given in Table 1.

Table 1: Field identification tests and allowable horizontal bearing pressure

Trench Wall Material		**Field Identification Test (1)**	**Allowable Horizontal Bearing Pressure (2) (kPa)**
CLAYS	Very Soft Clay	Easily penetrated 40 mm with fist	(3)
	Soft Clay	Easily penetrated 40 mm with thumb	(3)
	Firm Clay	Moderate effort needed to penetrate 30 mm with thumb	(3)
	Stiff Clay	Readily indented with thumb but penetrated only with great effort	50
	Very Stiff Clay	Readily indented by thumbnail	100
	Hard Clay	Indented with difficulty by thumbnail	200
SANDS	Loose Clean Sand	Takes footprint more than 10 mm deep	(3)
	Medium-Dense Clean Sand	Takes footprint 3 mm to 10 mm deep	50
	Dense Clean Sand or Gravel	Takes footprint less than 3 mm deep	100
ROCKS	Broken or Decomposed Rock	Diggable. Hammer blow "thuds". Joints spaced less than 300 mm apart.	100
	Sound Rock	Not diggable with pick. Hammer "rings". Joints spaced more than 300 mm apart.	200
UNCOMPACTED FILL DOMESTIC REFUSE		Observation and knowledge of the history of the site.	(3)

1. All field identification tests must be done on a freshly exposed, damp, hand-trimmed area of the trench wall by an engineer / technical officer competent in such work. Care must be taken to ensure that the soil in the test area was not compacted or loosened during the excavation. If the soil in the trench floor is very dry at the time the trench is opened, the test area must be flooded and time allowed for the water to be absorbed by the soil before trimming and testing.

2. For anchors and thrust blocks with the centre of thrust about 1 m below the surface as occurs with SA Water reticulation systems where normal cover to the pipe is at least 750 mm. These values are not applicable to structures located at shallower depths than those specified, for such cases seek advice of a qualified geotechnical engineer.

3. Standard values cannot be used - specialist geotechnical investigation and design are required.

8 Shear Strength vs Compaction Moisture Content

Reduction of void ratio and increase in relative density directly affect the shear resistance of granular soils. In general, the strength of granular soils increases with compaction.

Compaction changes the structure of cohesive soils which directly affects the strength of these soils. The strength of cohesive soils is directly related to the moisture content; higher strength is generally related to lower moisture content. The rate of reduction in strength is larger in the wet side of the OMC. In other words, if two samples are compacted to the same dry unit weight, one on the dry side and one on the wet side of the OMC, the soil compacted on the dry side shows larger strength. Figure 2 below shows results of a test sample conducted on clayey sand materials of the liner bedding in Nettle Hill lined earth bank storage. The OMC in this case was 11.5%. The above-mentioned trend is obviously observed in this test; higher shear strength on dry side of OMC and lower shear strength on wet side of OMC can be seen, with larger rate of shear strength reduction on the wet side of OMC.

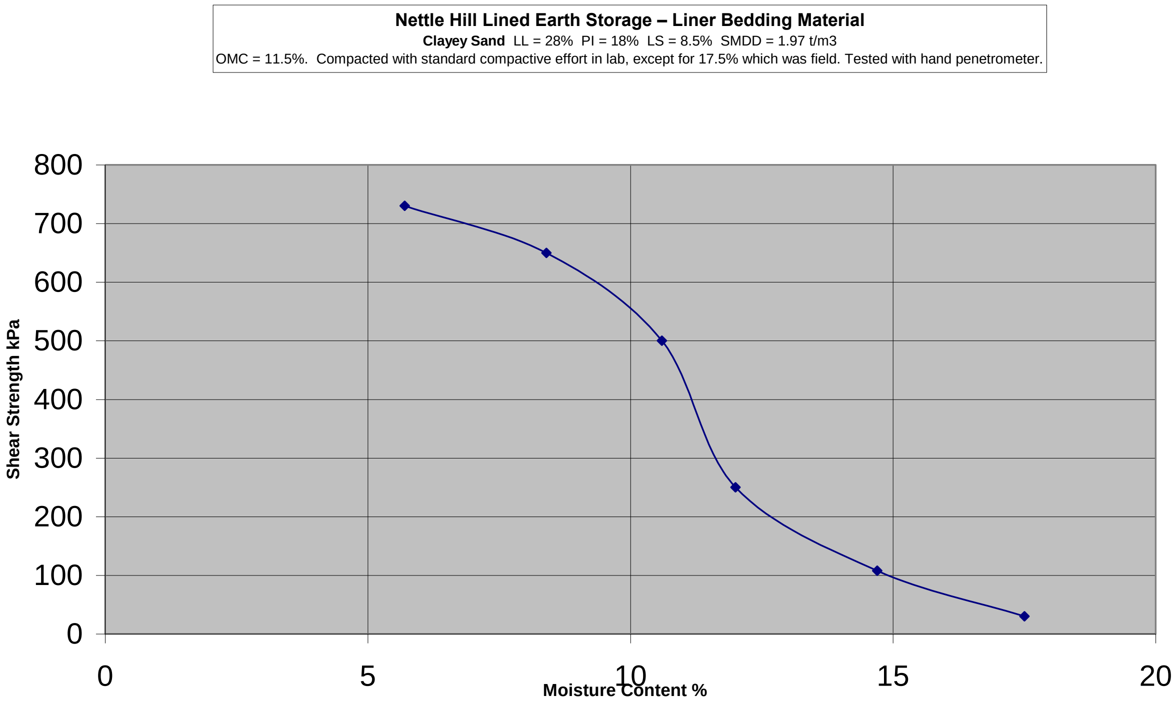

Figure 2: Shear Strength vs Compaction Moisture Content (test reported by Ed Collingham, 14/06/2002)