

TECHNICAL GUIDELINE**GENERAL TECHNICAL INFORMATION FOR
GEOTECHNICAL DESIGN**

~ Part A ~
Compaction



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No Changes Required In the January 2007 Edition

The following lists the major changes to the November 2004 edition of TG 10a:

1. Nil

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Referenced Documents

AS 1289 Methods of Testing Soils for Engineering Purposes

Section 1: Scope

Section 2: Effects of Vibrations

Compaction of Pipe Trench Fill using Vibrating Plates/Wheels & Notes on Risk of Damage to the Pipe and Adjacent Structures

2.1 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).

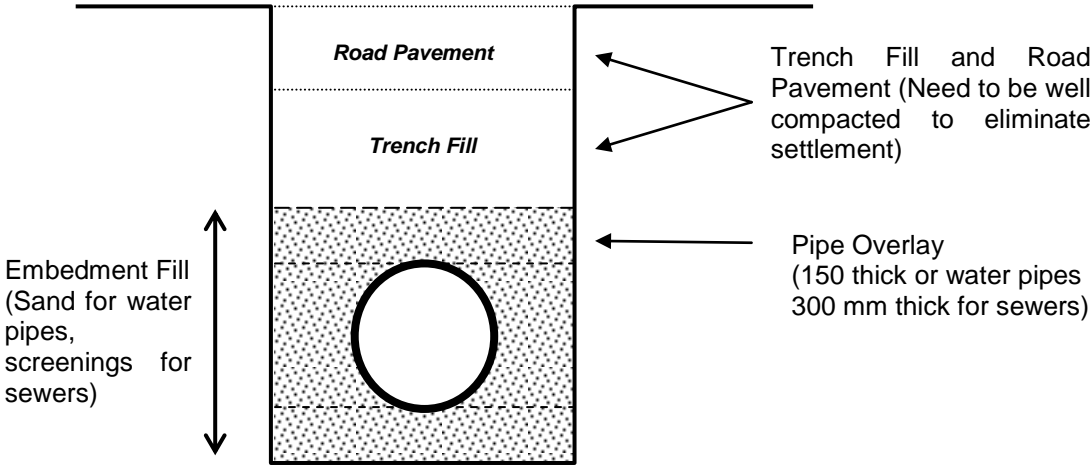


Figure 2.1 - Illustration of Trench

The author of these notes is not aware, so far, of any reports of pipes being damaged due to the use of this type of compaction equipment.

Indeed, it is still usually a struggle to get the specified density down the full depth of the trench fill – usually because contractors to 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.”

2.2 Risk Damage to Structures

It is almost impossible for vibrating compaction equipment to cause cracking in an adjacent structure such as a house – despite the fact that homeowners have sometimes accused it of doing just that.

To illustrate why this is so it is useful to compare the intensity of the vibrations from vibrating compaction equipment with those from earthquakes, and to consider the damage likely to be caused by each. But first it needs to be understood that the damage caused by vibrations depends not only on the **intensity** of the vibration but also on the **sensitivity** of the structure.

The **intensity** of an earthquake is described by the Modified Mercalli Intensity scale. This scale describes intensity in terms of “observed effects” and runs from 1: “Not felt, except under especially favourable circumstances.” to 12: “Near total damage. Objects thrown into the air”.

Records show that a typical “heritage” house constructed in the inner suburbs of Adelaide in the early days of settlement (1870s) would have suffered the following earthquakes:

Table 2.1 - Earthquake Intensity and Effects Observed

Number of Earthquakes	Modified Mercalli Intensity	Typical Effects Observed for this MMI
1	7	Difficult to stand. Noticed by car drivers. Furniture broken. Damage to masonry D, some cracks in masonry C. Waves on water. Small slides and caving in along sand and gravel banks. Note: This was the 1954 earthquake.
1	6	Felt by all. Many frightened and run outdoors. People walk unsteadily. Windows, dishes, glassware broken. Small items fall from shelves. Pictures off walls, furniture moved or overturned. Weak plaster and masonry D cracked. Trees shaken visibly. Note: This was the 1902 earthquake.
2	5	Felt outdoors, direction estimated. Sleepers wakened. Small unstable objects displaced or upset. Doors swing closed or open. Pictures move. Liquids disturbed, some spilled. Some cracked plaster. Note: These were the 1883 and 1914 earthquakes.
6	4	Vibrations like a passing heavy truck. Sensation like an object striking walls. Windows, dishes and doors rattle, crockery clashes. Standing cars rock. In upper ranges, wood walls and frames creak.
25	3	Felt indoors. Hanging objects swing. Vibrations like a passing light truck. Duration estimated. May not be recognised as an earthquake.
Many	2	Felt by persons at rest, on upper floors, or in favourable places.

Now, a homeowner will often claim that vibrations from the compaction equipment could be felt when standing on a solid floor such as a tiled veranda, but never that they set "hanging objects" (such as pendant lights) swinging. So it would seem that the veranda might be considered a "favourable place", indicating a vibration intensity equivalent to an MMI of up to 2.

But because nothing swung it is unlikely that the vibration intensity would have been as high as those of an MMI of 3 (although of course the relatively high frequency of compaction equipment vibrations reduce the tendency of things to swing.)

The sensitivity of a masonry structure to earthquake vibrations is classified as A, B, C or D (worst).

Our typical heritage house, when newly built, may have just been up to the standards of "Masonry Class C", which is defined as "Ordinary workmanship and mortar; no extreme weaknesses, but neither reinforcement or design against lateral force."

But over the years it would certainly have deteriorated to "Masonry Class D", which is defined as "Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally". It is therefore likely that it has had very poor

resistance to damage by earthquakes or soil movements for at least the last half of its life

Combining the concepts of “intensity of vibration” with “sensitivity of the structure”, it can be seen that our typical Adelaide heritage house:

- Would already have been exposed to some 35 earthquakes greater than the MMI of 3 it takes before vibrations are felt indoors.
- Would already have been exposed to 4 earthquakes greater than the MMI of 5 it takes to crack plaster in such a house.
- Would already have been exposed to 2 earthquakes greater than the MMI of 6 it takes to crack the “Masonry Class D” such a house would be built of.
- Would already have been exposed 1 earthquake greater than the MMI of 7 it takes to damage the “Masonry Class D” such a house would be built of?

So, from the above arguments it would appear that it is almost impossible for even a sensitive old house to suffer even cracked plaster from the vibrations from compaction equipment, but it is almost certain that it would have suffered major cracking in its masonry due to earthquakes.

In Adelaide of course it is far more likely that reactive soil movement would have cracked the house, and it is also often true that homeowners simply do not notice the cracks until the vibrations from the compaction equipment prompt them to look (or to try for a claim).

2.3 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 adjacent structures.
- 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 is 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.

This "Technical Note" was prepared by Ed Collingham, 29/08/2003
(Ex Principal Engineer Geotechnical)

Based on a report for a damage claim in North Adelaide in 2003

Section 3: Field Consistency & AHBP

Field Identification Tests for the Consistency of Soils and Allowable Horizontal Bearing Pressures for Anchor and Thrust Blocks in the Table below:

Table 3.1 Field Identification Tests

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
ROCK	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 750 mm.

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

This "Technical Note" was prepared by Ed Collingham, 27/03/2002
(Ex Principal Engineer Geotechnical)

Section 4: The Compaction of Pipe Side Support Sand by Flooding

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.

4.1 The Sand Must Be Free Draining

Compaction by flooding occurs only during rapid draining after saturation, not during the flooding itself. Not all sands which comply with DS4(b) 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 (see Note 1 of AS 1289.E5.1), 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.

4.2 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 watertable must also be at least 1 m beneath the trench floor.

4.3 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.

4.4 The Trench Walls Must Be Stable

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

4.5 The Pipe Must Not Become Buoyant During Flooding

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

4.6 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.

4.7 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.

This "Technical Note" was prepared by Ed Collingham, 13/01/2003
(Ex Principal Engineer Geotechnical)

Section 5: Modified and Standard Compaction – Which to Specify When

Density should only be specified in terms of **modified compaction** where high quality materials are being used AND very high performance is required (for example 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 quality materials are being used AND/OR only moderate performance is required (for example where sandy soils are being used for trench fill). If only moderate performance is required it is not appropriate to simply specify a low percentage (eg 92%) of modified maximum dry density. A high percentage (eg 98%) of standard maximum dry density should be specified instead.

The main reason for this is to ensure **control of the performance** of the compacted material. Performance (such as strength or potential for settlement) is usually only reliably known at 100% of the reference density. For densities below about 95% of the reference density performance may become unacceptably poor for some materials, excessively high for other materials, or unpredictable if the material is not tightly specified (see examples below for 92% of modified maximum dry density). Therefore densities less than about 96% of modified maximum dry density should never (and need never) be specified.

For some **sandy materials** the difference between standard and modified maximum dry density can be as low as 1%. For such materials 92% of modified maximum dry density (intended to imply moderate performance) would only be equal to 93% of standard maximum dry density, which might be so loose for such material that it might settle severely on loading.

For **sand and clay mixtures** the difference between standard and modified maximum dry densities can easily be as high as 8%. In which case 92% of modified maximum dry density (intended to imply only moderate performance) would actually be equal to 100% of standard maximum dry density, which would give unintentionally high performance and would be quite difficult and costly to achieve in the field.

For **high plasticity clay** materials the difference between standard and modified maximum dry density can be as high as 13%. In which case 92% of modified maximum dry density (intended to imply only moderate performance) would actually be equal to 105% of standard maximum dry density. This would give excessively high performance (in terms of settlement at least) and be almost impossible to achieve in the field.

Other problems associated with specifying low percentages of modified maximum dry density instead of higher percentages of standard maximum dry density are: (1) The **higher cost** of the modified compaction test – it involves imparting to the sample 4.5 times the energy of the standard compaction test. (2) The **breaking-down of particles** in the laboratory test that would not be broken down by the compaction in the field – the material being tested effectively becomes different to that in the field. (3) The **optimum moisture content** indicated by the test is not relevant in the field (it would be several percent too low).

This “Technical Note” was prepared by Ed Collingham, 09/01/2001
(Ex Principal Engineer Geotechnical)

Section 6: Spec Clauses for the Compaction of Calcrete or Rock Rubble

Materials in the core and freeboard zone shall be compacted to not less than 95% of their standard maximum dry density (AS 1289.5.1.1).

Materials in the shoulder zones shall be compacted to not less than 93% of their standard maximum dry density (AS 1289.5.1.1).

Tenderers shall submit with their tender, details of the method and plant they propose to use to achieve the specified densities for each material in each zone.

The details of the methods shall include: the material selection and pre-treatment procedures; the moisture conditioning requirements; the placement layer thickness; the type and model of compaction plant; and the number of passes of the compaction plant.

The Contractor shall demonstrate on a trial area, to the approval of the Superintendent's Representative, that the proposed methods will achieve EITHER the specified densities, OR, where the material is rock spoil or other material not amenable to compaction control testing by any of the methods in AS 1289, the equivalent performance as judged by the Superintendent's Representative.

The Contractor shall then win, place and compact all fill in accordance with the approved methods, and shall, if necessary, further compact all core zone materials to the specified

This "Technical Note" was prepared by Ed Collingham, 09/06/2000
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Section 7: Shear Strength vs Moisture Content

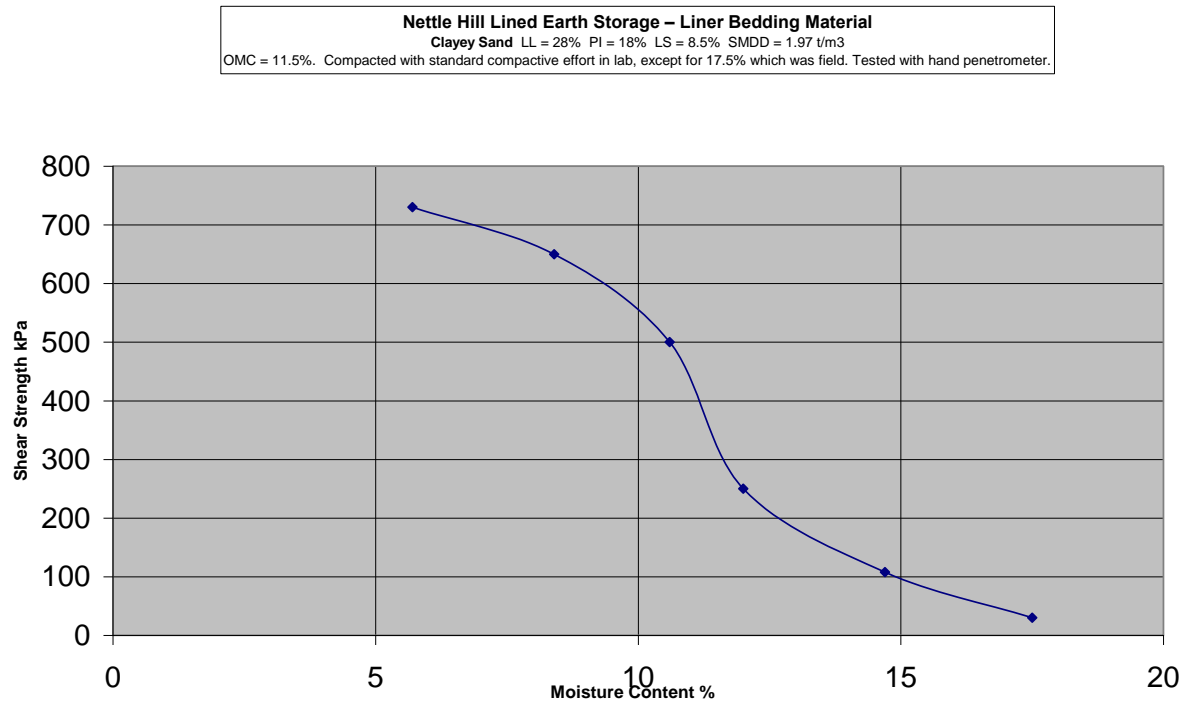


Figure 7.1 Graph of Shear Strength vs Moisture Content

This "Technical Note" was prepared by Ed Collingham, 14/06/2002
(Ex Principal Engineer Geotechnical)