SCIRT Rebuilding Infrastructure

LEARNING LEGACY

Lessons learned from one of New Zealand's most challenging civil engineering projects: rebuilding the earthquake damaged pipes, roads, bridges and retaining walls in the city of Christchurch 2011 - 2016.

Pipe Installation Options Report

Story: Alternative Options for Pipe Installation

Theme: Construction

A report reviewing pipe installation specifications and recommending alternatives that could improve standard specifications.

This document has been provided as an example of a tool that might be useful for other organisations undertaking complex disaster recovery or infrastructure rebuild programmes.

For more information about this document, visit www.scirtlearninglegacy.org.nz

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Pipe Installation Options Report

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Contents

Appendices

Revision History

Revision	Date	Name	Brief Description
1	10 Jun 2013	Tony Gordon	Appendix A to draft Scope & Standards Committee paper SS211.
2	12 Jun 2013	Tony Gordon	Revision after discussion with Asset Owners. Appendix A to Scope & Standards Committee paper SS211.
3	22 Jul 2013	Tony Gordon	Pipe design, embedment, geotextile embedment wrapping and references appendices added.
4	1 October 2013	Tony Gordon	Additional information added
5	30 Oct 2013	Tony Gordon	Updated and reviewed
6	24 Feb 2014	Tony Gordon	Appendix F (draft specification) modified
7	23 Sep 2014	Tony Gordon	Appendix F (draft specification) modified
8	18 Feb 2015	Tony Gordon	Minor amendments to appendices
9	25 Nov 2016	Tony Gordon	Minor amendments to wording

Abbreviations

Abbreviation	Description
AC	Asbestos-cement
ACPA	American Concrete Pipe Association
AS	Australian Standard
AS/NZS	Joint Australian/New Zealand Standard
BS	British Standard
CCC	Christchurch City Council
CCTV	Close circuit television
CI	Cast iron
CLS	Concrete lined steel
CONC	Unreinforced Concrete Pipe
CPAA	Concrete Pipe Association of Australasia
CWW	Christchurch City Council Water & Waste Unit
ECan	Environment Canterbury
EN	European Standard
EW	Earthenware
GRP	Glass Reinforced Plastic (naming varies)
HDPE	High-density polyethylene
IDS	Christchurch City Council Infrastructure Design Standard
MH	Manhole
NAASRA	National Association of Australia State Road Authorities
NZS	New Zealand Standard
PE	Polyethylene
PM	Pressure Main
PVC-U	Unplasticised Polyvinyl Chloride (common ‘PVC’)
RAMM	Road Assessment and Maintenance Management (database)
RCRRJ	Reinforced Concrete Rubber Ring Jointed

Executive Summary

Christchurch is built on flat, low-lying and originally swampy ground. The consequences of that to achieving satisfactory drainage of the city are well documented, albeit not well understood and allowed for by recent immigrants to the city who are now heavily involved in the largest single drainage project the country has ever seen – the rebuilding of a significant section of Christchurch's underground drainage network following the 2010-2011 earthquakes.

Ground conditions in Christchurch make installation of underground infrastructure difficult and consequently expensive. The scale of the rebuild project multiplies these complexities. Methods applied pre-earthquake, although seen as a practical response to the issues at hand, when up-scaled significantly are adding cost to what is already a costly exercise. Some post-earthquake modifications to these methods, some of which take a solution suitable for a worst-case scenario and apply that city-wide, add to the complexities of pipe installation and consequently increase the cost, without significantly reducing the risks to the installed asset.

This assessment looks at some of the current Council Standards in the light of some New Zealand and international Standards and also at some of the post-earthquake modifications in light of our experience to date. Alternatives are recommended as a means of providing better overall value.

The recommendations include changes to Council's Construction Standard Specification or to SCIRT's authorisation to allow greater flexibility when choosing pipe and embedment materials, and removing or using certain post-earthquake CSS modifications on a site-specific basis.

1 Overview

1.1 Reason for Assessment

Christchurch ground conditions are very difficult to work in. The city has been built on flat land with high water table levels on ground that was once predominantly swamp. The formation of the Christchurch Drainage Board by legislation in the 1870s is testimony to the problems the city has had since its beginning.

The poor and permeable ground with high water table levels makes the digging of trenches and the installation of underground pipework a difficult and costly operation. These difficulties and subsequent expenses are multiplied in the post-earthquake scenario by the scale of the rebuild project and the large amount of resources needed to complete the task. In pre-earthquake 'business-as-usual' the amount of work being carried out was comparatively small and there were local contractors familiar with the conditions. Post-earthquake there has been an influx of new drainage contractors who although experienced in areas outside Christchurch are not familiar with the complexities of these local conditions.

The consequences of this are many, but three significant ones are:

- Low quality installations
- Slow installations
- Costly installations

It is not good enough to demand better quality from the industry; the methods specified need to be examined to determine if they are necessary to achieve the required result, and if not, alternatives need to be considered to allow innovative and/or cost saving approaches to be adopted. The purpose of this assessment has been to look at some of the current specification requirements associated with the pipe installation and to look for alternatives that could improve on the points bulleted above.

1.2 Scope of Assessment

The installation of a pipe underground is a complex process that involves a number of different operations, each of which have an impact on the ease and effectiveness of the installation. These include the following:

- The ground with high water table levels requires dewatering
- The sides of the excavation need supporting (for safety and to maintain a manageable site)
- The trench foundation needs to be able to support the pipe installation
- The pipe needs to be installed in a way that supports it and ensures a long asset life
- The trench needs to be backfilled with material, in a way that results in good surface restoration and long-term stability (i.e. not sinking over time)
- The surface needs to be restored to at least its original condition

The scope of this assessment and report concerns the pipe installation operation only, looking primarily at drainage pipes rather than water supply pipes, although the principles are the same for both. It is also only focused on typical installations; there will always be specific cases that require specific considerations, such as some of the recent works on large diameter pressure mains.

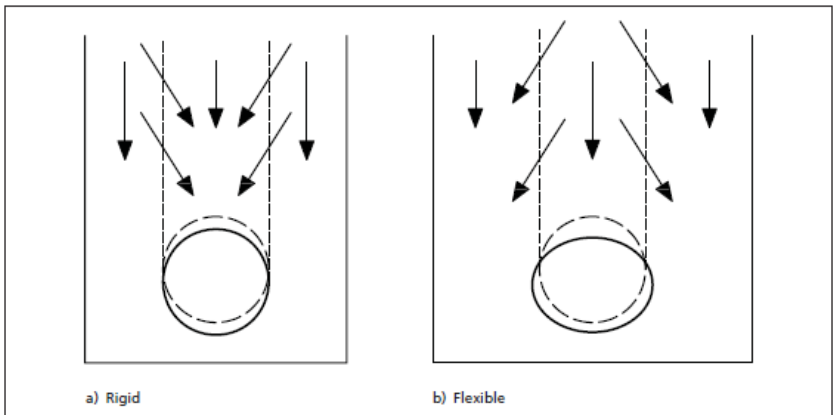
2 Pipeline Design

2.1 Pipe Installation Requirements

The following text taken from British Standard BS 9295:2010 *Guide to the Structural Design of Buried Pipelines* gives a broad background to the structural behaviour of different pipe materials:

> Pipe materials are divided for structural design purposes into three categories.
>
> - Rigid;
> - Semi-rigid;
> - Flexible.
>
> The behaviour of these materials depends upon both their inherent response to external loading and their interaction with surrounding soils.
>
> Rigid pipe materials have a small deflection on loading, which is too small to develop any lateral earth pressures. Load is taken by the pipeline and bending moments are developed in the pipe walls. Rigid pipes also attract an amplified backfill load upon burial and obtain a reaction from their bedding in response. Semi-rigid pipe materials tend to exhibit a range of behaviour from rigid to flexible. Flexible pipe materials deflect towards an oval shape in response to loading surrounding embedment.
>
> When a pipeline is installed, the ground is disturbed. Settlement of the disturbed soil occurs in the pipe trench even after backfilling is complete.
>
> A rigid pipe is stiffer than the surrounding soil and when consolidation of the backfill takes place in the pipe zone, the soil to the sides of the pipe tends to settle more than the soil over the pipe. By friction, load is transferred to the column of soil over the pipe (geostatic load, *cH*) meaning that the pipe is attracting more load than just the geostatic load. In response to this, a rigid pipe might settle marginally into its bedding.
>
> A flexible pipe is less stiff than the surrounding soil, so when buried, the column of soil over the flexible pipe settles more than the columns of soil to the sides. The effect of this is that the flexible pipe will deflect on loading, but will also tend to shed load away from itself.
>
> Figure 2 illustrates rigid and flexible pipe behaviour.

Figure 2 **Rigid and flexible pipe behaviour**



NOTE Displacement and deflection exaggerated for illustrative purposes.

> Over time all these effects within the trench tend to disappear. From a backfill load point of view, the worst loading condition for a rigid pipe is when it is newly installed in the ground and the columns of soil to the sides of the pipe are transferring load onto the pipe.
>
> Conversely, the highest predicted backfill load for a flexible pipe is after all the beneficial shedding of load has taken place.

The fundamental basis of design is the interactive system consisting of the pipe and the surrounding soil (BS EN 1295, clause 5.1). Design codes in New Zealand and overseas are based on this principle.

2.2 Christchurch City Council Standards

Christchurch City Council has over the years developed its own design and installation Standards and these are outlined in two key publications: the Infrastructure Design Standard (IDS) and the Civil Engineering Construction Standard Specification (CSS).

Acceptable pipe materials are covered in an Approved Materials list that is available from the Council website and regularly updated.

Drainage pipe installation requirements are predominantly covered in IDS Part 6 *Wastewater Drainage*. (Part 5 *Stormwater and Land Drainage* refers to Part 6 for pipeline design) and CSS Part 3 *Utility Drainage*.

Regarding pipeline design, the IDS states:

> Use the manufacturer's material specifications, design charts or computer models to design bedding and haunching, unless these provide a lesser standard than would be achieved through applying the requirements of CSS: Part 3. (Clause 6.13)

Structural design is to

> "withstand all loads, including hydrostatic and earth pressure and traffic, in accordance with the Bridge Manual and design loadings. Design structures exposed to traffic to HN-HO-72 loading." (Clause 6.6.3)

CSS Part 3 includes standard installation details for rigid and flexible pipes in standard details SD344 (see Appendix A). For flexible pipelines, this detail includes the use of NZTA M/4 AP20 bedding and embedment material, geotextile wrapping of all pipe joints (including laterals) and geotextile wrapping of the embedment material in areas where the Liquefaction Resistance Index (LRI) is 0, 1 or 2 (IDS Part 6: Wastewater Drainage Clause 6.2.6 and 6.13). Significant areas of the city have these LRI values. Concrete pipes do not need the embedment wrapping, although joints are still to be wrapped.

CSS Part 3 Clause 8.5.1 Haunching and Surround states what is required for embedment compaction:

> Haunching shall be in accordance with SD 344. Haunching and surround shall be compacted to the greater of the manufacturer's requirements or a minimum dry density of 2,050 kg/m^3 at any point on any haunching constructed of M/4: AP20 materials.

As noted above, the Approved Materials list gives the pipe requirements. At the time of writing the requirements for PVC gravity wastewater pipes include the following:

> Pipes sized DN100 to be minimum SN16 grade. Pipes sized DN150 to be minimum SN16 grade. Pipes sized DN 225 and above to be minimum SN8 grade.

For PE gravity wastewater pipes the requirements are:

Pipes sized DN110, DN125 to be minimum SN16/SDR17 grade. Pipes sized DN180 to be minimum SN8/SDR21 grade. Pipes sized DN250 and above to be minimum SN4/SDR26 grade.

Of note within the context of this report is the absence in these standard provisions of a direct link between the pipe material requirements and the embedment requirements which, as noted in Section 2.1, are integrally linked.

2.3 Comparisons with Other Standards

2.3.1 New Zealand and International Standards

There are a number of New Zealand Standards that deal with pipeline installations but the three of most interest when it comes to pipeline design are:

AS/NZS 2566.1:1998 Buried flexible pipelines Part 1: Structural design

AS/NZS 2566.2:2002 Buried flexible pipelines Part 2: Installation

AS/NZS 3725:2007 Design for installation of buried concrete pipes

These joint Australia/New Zealand Standards cover the design and installation of pipelines and include specific clauses for the design of the interaction between the pipe and the surrounding soil and installation requirements to ensure that the assumptions made in the design are met in the installation.

There are many foreign design and installation guidelines, but those that we here in New Zealand would typically refer to (European and American Standards) are all based on the same theory. They are however not necessarily consistent when it comes to some of the installation details (see below).

Over time, the understanding of the pipe/soil interaction is growing and new materials are constantly coming onto the market, so all of these Standards are constantly evolving. For example there was a significant change in bedding design between the 1989 and 2007 versions of AS/NZS 3725, a change that is not reflected in the CSS detail.

2.3.2 Embedment Requirements

Of particular interest for this assessment are the installation requirements for the embedment material given in the Standards. AS/NZS 2566.2 gives three tables of gradings for acceptable embedment material, one for cohesionless native soils (Table G1), one for processed aggregates (Table G2) and one for other materials (crushed rock and sand, Table G3). AS/NZS 3725 gives one acceptable grading for bed and haunch zones (Table 6) that is the same as Table G1 in AS/NZS 2566.2.

The international Standards have different gradings specified; there is no uniformity. The reason for this is that the material grading is not important in itself. What is important is the support that the material gives to the pipe. To that end, most of the Standards state a relative compaction requirement, and in those there is a greater degree of uniformity.

Members of the Standards committee for both AS/NZS 2566 and AS/NZS 3725 have been approached about the origin of, and significance of, the gradings given in the Standards. There is no clear path of how the gradings were selected. Those in Table G2 of AS/NZS 2566.2 have been taken from the Concrete Aggregates standard; the origin of the Table G1/Table 6 grading is unknown. The Concrete Pipe Association of Australasia (CPAA), that has a significant role to play in the development of AS/NZS 3725 has recently recognised the unnecessary limitation on embedment grading given in the standard; AS/NZS 3725 states that if the material used does not meet the grading of Table 6, the designer is to use modified bedding factors, effectively de-rating the strength of the installation. Although unaltered in the Standard, the CPAA has recently released a guideline *Selecting Materials for Bedding Steel Reinforced Concrete Pipe* which states

"Select fill complying with the generic soil classes as defined in AS 1726 and shown in Table 1 of AS/NZS 3725 … but not complying with the particle size distribution of Tables 6 and 7 of AS/NZS 3725 may be used in the bed, haunch, and side zone". There are four provisos, relating to material size and shape, fines migration and confirmation of compaction achievement.

AS/NZS 2566.2 states that "the material in the embedment zone may consist of selected cohesionless soils (see Appendix G)" (clause 5.4.2.1). In Appendix G it states that "imported cohesionless embedment material with grading specified in Table G2 ... and G3 will *facilitate* the achievement of the soil moduli given in Section 3 of AS/NZS 2566.1" (italics added). The material gradings are therefore given not as a requirement but as a recommendation.

The UK Water Industry Information & Guidance Note IGN 4-08-01 *Bedding and Sidefill Materials for Buried Pipelines* gives good guidance on embedment materials. In Section 3 it states:

"Ideal bedding and sidefill material should have the following general properties:

(a) it should be easy to scrape or shovel to form a bed on which to lay a pipe, and also be easy to distribute uniformly beneath the haunches of a pipe by tamping;

(b) it should require little or no compactive effort;

(c) the largest particle size should not be excessive in relation to the pipeline diameter otherwise impact damage and concentrated point loading can occur;

(d) it should not contain particles with sharp edges when used with those pipes or pipe coatings that are susceptible to damage;

(e) the grading should be such that water passing through will not encourage fine materials to be carried away and thus reduce the support for the pipeline;

(f) it should not break up when wetted or compacted;

(g) it should not cause corrosion or degradation of the pipes, fittings, coatings and jointing materials with which it is in contact;

(h) it should be sufficiently stable, when laid and compacted, to support the pipeline in the correct position both during and after laying;

(i) it should be chemically durable and not react with, the soil, groundwater, pipe or coating."

It goes on to say "It will seldom be possible to select a material that will have all the ideal properties described in Section 3."

To this list we would add that the material must not be prone to liquefaction.

Of note in reviewing the standard requirements for embedment materials is that in no instance is there a reference to the need to use crushed materials. IGN 4-08-01 *Bedding and Sidefill Materials for Buried Pipelines* states that "The compactive effort required to achieve the desired degree of compaction will be principally influenced by angularity in coarser materials such as gravels and by moisture content in finer materials such as sands. Angular materials will require greater compactive effort." It also states that "Good alignment of heavy pipes will be more easily achieved by the selection of angular bedding materials as these will help ensure stability during installation." AS/NZS 2566.1 Supplement states in C3.3.2 that "Gravels consisting of rounded particles are less stable than crushed aggregates." So the choice of the degree of angularity is a trade-off between stability in the trench and the compactive effort required.

NZTA M/4 AP20, as specified in the CSS, does not match any of the grading curves given in the Standards. Some of the reasons for specifying M/4 are that it does not allow migration of fines

from the adjacent native soil and that as a roading material it allows a standardisation of aggregate mixes and lessens the risk of confusion on site. As a roading material it is not designed for use in trenches; it is better above ground in dry conditions (it is moisture sensitive) where compaction equipment can be used over wide areas.

Some contractors advise that M/4 is not easily compacted, particularly where there is moisture present as is often the case in the trench base. As noted in (b) above, an ideal embedment material will require little compactive effort. Misko Cubrinovski of the University of Canterbury has pointed out that for a material to be easily compactable it requires a small difference between its void ratio in its loosest state and its void ratio in its most compact state. Materials that have that characteristic are typically coarse gravels with low fines content. Use of an easily compacted material will make it less likely that the compaction specification will not be met and speed up the pipe installation process.

In a recent report written by Emily Craigie of Fulton Hogan, in which she proposed the use of alternative materials, she wrote:

> "The supply of suitable virgin gravel for M/4 is … restricted to the top 5 m of all quarried pits. The Top Layer also has other uses, making it a very sought after commodity. Using the sand rich Top Layer for M/4 competes with the production of sand – a far higher value product that is a more profitable stream of revenue for the quarry.
>
> Given the high demand for Top Layer alluvial gravels in Canterbury for M/4 for basecourse in unbound granular pavements and sand production, it is prudent to seek alternatives for use as bedding materials. Newer gravels (Top Layer) are not a finite resource and a sustainable approach must be taken to ensure there are sufficient quantities to carry Canterbury into the future. It would be wise for the use of M/4 to be restricted to basecourse construction where its particle interlock and impervious materials properties are essential. Using a premium product such as M/4 in the bed of trenches is a waste of valuable resource. Its characteristics well exceed the requirements of a bedding material."

Based on the Standard requirements, consideration of the pipe-soil interactions and the issues around availability and usability of materials, it seems that it makes good sense to re-evaluate the requirement to use M/4.

2.4 Post-earthquake Modifications to the CSS

The earthquakes of 2010-2011 caused an enormous amount of damage to the underground infrastructure, some of which had survived in service for over 100 years. Post-earthquake, in the light of some of this widespread damage and with works beginning on the infrastructure rebuild, modifications were made to the Council's Standards to avoid rebuilding infrastructure that could fail again in the same way in a future earthquake or aftershock. In the absence of much information on the causes and frequency of failures, understandably some of these modifications were conservative and applied on a 'one-size-fits-all' basis. Each of these modifications added cost to the rebuilding of the infrastructure.

Now with more knowledge (although still incomplete) of the failure mechanisms and with the areas of the city that suffered the worst damage zoned 'Red' by the Canterbury Earthquake Recovery Authority (CERA), a more pragmatic approach can be taken. Some of these modifications do not reduce risk in typical installations; in fact in some cases they add risk. Going forward, each modification needs to be justified on its own merits and be judged to be value for money if it is to be applied.

The post-earthquake modifications that apply to the pipe installation are:

- The strength of pipe required

The strength of pipe modification was an increase in pipe 'class' for PVC-U gravity pipes. It was brought in to provide greater security against pipes breaking or deforming under earthquake loading. There was some evidence of excess pipe deflection but subsequent investigations have not shown much structural damage to flexible (PVC) pipes at all. The instances of pipe deflection are isolated and more likely an installation fault rather than an earthquake response. As noted above, the pipe strength is only part of the pipe-soil interaction, embedment being another that this modification does not consider.

- The wrapping of all pipe joints

  Following the earthquakes there were significant operational problems associated with the inflow of liquefaction silt and debris into many of the city's drainage pipes. In a measure aimed at reducing this in future earthquakes, Council's Standards were modified to include wrapping of all pipe joints with geotextile. The geotextile is tied to the pipe either side of a joint and is there to stop the inflow of material into an open joint. There is however very little evidence that flexible pipes actually pulled apart (except in Red Zones or areas of lateral spread). The evidence of joint failures in rigid (earthenware, asbestos cement and concrete) pipes is however more compelling.

- The wrapping of all embedment in liquefaction-prone areas

  The wrapping of pipe embedment material is a measure designed to ensure the long-term stability of the embedment in liquefiable ground (LRI 0 to 2) following future earthquake events. This modification may introduce risk that ultimately may be higher than the risk it is seeking to mitigate. Typically the pipe trench is shielded or sheet-piled and it is very difficult in the local conditions (principally in the wet) to install the embedment (which is in the trench base) in the fabric in a way that ensures that there are no voids outside the fabric. These voids would have the effect of reducing the capacity of the embedment to do what it is designed to do. The fabric does have one advantage in that it allows the use of more open-graded material to be used in the embedment which is easier to install, although not currently allowed in the Council Standards.

3 Options for making changes

3.1 Pipe strength

The design methodologies outlined in the New Zealand and foreign Standards have the designer consider the installation as a whole in recognition of the pipe-soil interaction. The greater the support offered by the embedment (and surrounding ground), the weaker the pipe can be. Conversely, where the support offered by the embedment is poor, the stronger the pipe must be. Given the conditions that will occur on site, the designer can vary the specification of both the pipe and the embedment. Currently the CSS does not allow for this consideration, with strong pipe and strong embedment both specified.

A significant difficulty experienced on sites in the city is the achievement of the specified embedment compaction standard. Where the designer has liberty to vary the pipe/embedment equation, this site constraint would likely lead to an easing of the compaction requirement and a strengthening of the pipe. An analysis based on AS/NZS 2566 of the typical pipe sizes being used in the wastewater rebuild (DN150, DN175 and DN225 PVC-U pipes installed at depths between 1.5 m and 3.5 m with high water table) with uncompacted embedment, loose native soil and NZTA HO wheel loadings has shown that SN16 pipe (the strongest readily available pipe) would be sufficient in all cases (see Appendix C).

Suppliers have been asked for an indication of cost to increase the pipe class from the currently specified SN8 (post-earthquakes the DN150 is already SN16). The indication is that the additional cost is less than $5/m for DN175 and DN225. This cost difference is insignificant when compared to the cost of time spent in trying to achieve the high compaction requirement.

3.2 Embedment

In line with the comments made above about embedment materials, the use of M/4 and what can be achieved using stronger pipe, alternative embedment materials need to be considered. As noted there is no 'magic formula' for embedment gradings; rather what can be achieved with the material (see the list in 2.3.2 above) is more important. There are a number of available materials that can be procured easily and cheaply that could be suitable. Emily Craigie writes that:

> "Pea metal is in plentiful supply around Canterbury and is used by many other local councils around the country as embedment material. As a by-product of rounds production it has no commercial use, and is stockpiled in vast quantities around the city. Pea metals self-compacting properties, along with its insensitivity to water, make a significant impact on the productivity of pipe laying. The use of geotextile filter fabrics is encouraged to prevent the migration of fines from the native soil into the trenched zone. Geotextile fabrics also confine the bedding material, preventing lateral movement into the surrounding soil.
>
> Another suitable alternative for embedment material in Christchurch is Drainage 19-5, an aggregate created from the crushing of 20/40 tailings. … 20/40 tailings are a readily available resource that is not only self-compacting and workable in wet conditions; it also has broken faces that provide stability and strength.
>
> … the issue of appropriate embedment material is significant. It is careless to use premium basecourse aggregates for a role that may just as efficiently be filled by an alternative, lower-cost, sustainable material."

The degree of compaction needs to be considered and what is achieved in the field needs to be checked to ensure that the compaction specified is achieved. During this assessment, a field trial was set up using an AS/NZS 2566 Table G2 material. The specification for the trial quoted the requirements of the Standard for material grading and compaction and also the testing of the achieved density. The testing specified (AS/NZS 2566.2 clause 5.6.3.2) required the determination of the 'Density Index' (referred to as Relative Density in NZS 4402 Test 4.2.3). The methods offered in the Standard are sand replacement, water displacement, or the use of a nuclear surface moisture-density gauge (nuclear densometer (ND)). The open-graded nature of the material being used made the use of the ND impractical (there was a high void ratio and a hole made in the material to enable the test would not remain open) and neither of the other methods could be done with this material in the field. Tests could however be done in a laboratory setting where trials of method and results could lead to a satisfactory method specification for use of the material.

3.3 Joint wrapping

As noted in Section 2.4 above, there is little evidence that application of this post-earthquake modification is actually reducing any risk. The obvious response to this is to remove the requirement unless the specific site experience indicates that the new pipes are at risk of pulling apart.

3.4 Embedment wrapping

As noted in Section 2.3.2 above, one of the requirements of a suitable embedment material is that "the grading should be such that water passing through will not encourage fine materials to be carried away and thus reduce the support for the pipeline". Where more coarse and open-graded material is used in the embedment zone the use of a geotextile material mitigates against the movement of fines.

Whether the use of geotextile provides greater security against loss of support in an earthquake would be very dependent on the conditions at the site. As noted in Section 3.1 above, an installation could be made that is less dependent on the support that the embedment gives. The liquefaction risk varies widely

across the city, so even if in certain circumstances the use of the geotextile provides some risk mitigation, the use of it in all situations is not necessary.

3.5 Site Specific Risk Assessments

The wholesale application of rigid standards does not actually provide the best value outcome. Risk cannot be avoided, but it can be managed to an acceptable level. That level needs to be agreed between the Designer and the Asset Owner. Once agreed, suitable mitigation measures can be put in place. With the growing knowledgebase of information post-earthquake, we are in a position now to re-evaluate many of the post-earthquake standards and choose what to do where.

As the focus of the rebuild shifts from east to west, ground conditions are changing. There is constantly increasing geotechnical knowledge that is taking us beyond the LRI (which although a good tool, is based on immediate post-earthquake surface observations, not geotechnical testing) and providing better pictures of the site specific risks.

It makes sense to have a 'toolbox' of solutions that can be used following site-specific risk assessments.

4 Further Work Required

As noted in Section 1.2 above, the installation of a pipe underground is a complex process that involves a number of different operations, each of which have an impact on the ease and effectiveness of the installation. The following issues have been identified as problem areas in design and in the field and they need resolution. Together with changes in the pipe installation requirements, their resolution will help provide a cost-effective way forward both for the infrastructure rebuild and future works in the city.

- Soft trench foundations
- Trench shielding/shoring
- Dewatering design and installations

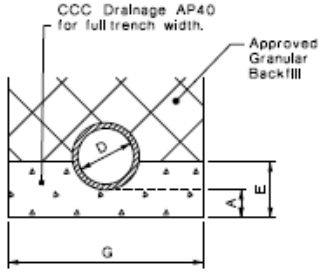
5 Recommendations

It is recommended that the following changes be introduced to the CSS or to SCIRT's authorisation:

- That SCIRT be authorised to develop and use alternative pipe - embedment designs that make the best use of the pipe-embedment interaction leaving open the opportunity to choose stronger pipe and lower-level-compaction embedment where the ground conditions and the economies justify it
- That the use of alternative embedment materials that meet the design requirements be allowed. These materials may change over time, depending on availability from different quarries and on-going field experience.
- That where these alternative embedment materials are open-graded, compaction be controlled by a method specification related to the particular equipment used
- That joint wrapping be removed as a requirement unless the specific site experience indicates that the new pipes are at risk of pulling apart
- That embedment wrapping only be applied where necessary to avoid fines migration or where, taking into account the site-specific design (pipe strength and embedment density) and local liquefaction risk, it can be shown to have a significant risk mitigation effect

A

Appendix A CSS Detail SD344 Pipe Embedment Details



TYPE M
Metal Haunching

PIPE Φ D	DEPTH A	E	G
100	75	145	450
150	100	170	650
200	100	200	700
225	100	200	700
250	100	200	800
300	100	200	800
375	100	200	900
450	120	250	1000
525	120	250	1100
600	150	300	1200
675	150	300	1300
750	150	350	1300
825	150	350	1400
900	150	350	1500
975	150	350	1600
1050	150	400	1700
1200	150	400	1900
1350	150	450	2100
1600	150	450	2400
1800	150	500	2600
2100	150	500	2900

NOTES:

1. Lime stabilise haunching where the trench backfill is lime stabilised.

Christchurch City Council

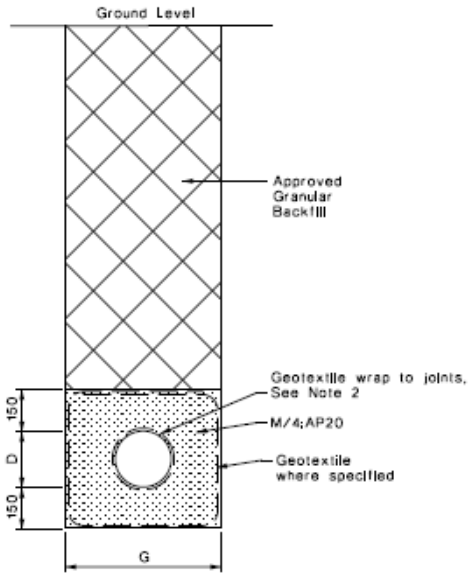
PIPELAYING HAUNCHING DETAILS FOR CONCRETE PIPES

ISSUE DATE MAR 2013

SD344

SHEET 1 of 3

DS03440/F



NOTE:

1. Where specified the haunching shall be fully wrapped in accordance with TNZ F/7 in geotextile of strength class C.
2. Wrap pipe to 0.5m each side of all joints, including laterals in the specified geotextile. Secure the geotextile snugly to the pipe using cable ties or similar.
3. Suitable for soils with an allowable bearing pressure over 50kPa.

TYPE P
Standard Haunching

Nominal Pipe Diameter DN	Trench Width *G
100	450
150	500
175	550
225	600
300	650
375	750

* G may be increased in very soft ground.

Christchurch City Council

PIPELAYING HAUNCHING DETAILS FOR FLEXIBLE AND CERAMIC PIPE

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B

Appendix B AS/NZS 2566.2:2002 Appendix H

APPENDIX H

EMBEDMENT AND FILL MATERIALS—COMPACTION

(Informative)

H1 COMPACTION METHODS

Table H1 covers compaction methods for all soil types. It is sequenced in order of the increasing compactive effort required to achieve a given soil stiffness or modulus, that is, the materials at the top of Table H1 are the easiest to compact. In practice, the highest soil moduli will be achieved using gravels and coarse-grained sands, as these require much less compactive effort to achieve a high soil stiffness. See Clause 5.4.2 and Clause 5.4.3 for embedment material selection and Clause 5.6 for compaction control. Table H2 gives quantitative parameters that may provide guidance on the potential compaction performances of embedment material.

TABLE H1

TYPICAL COMPACTION AND CONTROL METHODS FOR ALL SOIL TYPES

Description	Symbol	Typical relative compaction control methods
Gravel — single size	GP	Gravels provide high moduli regardless of moisture content during or after compaction with minimal effort. Being highly permeable, they are often used for ground water control. They have to be used in conjunction with geotextile filter fabric where particle migration is a possibility For gravels, sands and coarse-grained soils with <5% fines, the required relative compaction can usually be achieved by dumped placement. After placement, the material should be worked to ensure all voids, especially at haunches are filled. Where compaction is required use hand tampers, surface plate vibrators, vibratory rollers or internal vibrators. Compacted lift thickness should not exceed 300 mm. Where hand tampers or internal vibrators are used, the lift thicknesses should not exceed 150 mm, the length of the vibrator, or half the pipe diameter Density determination for low fines soils should be by density index (I_D). Density determination for well-graded gravel/sand mixtures (GW) may also be determined using dry density ratio (RD)
Gravel — graded <15% and sand ≤5% fines (i.e., 'few' fines)	GW, GP, SW, SP and GP-SP	
Sand & coarse-grained soil with between 5% and 12% fines (i.e., 'some' fines)	GP, SW, SP and GM-GL, GC-SC	For sands and coarse-grained soils with 5% to 12% fines, which may behave as where they are either high or low fines content, methods of compaction and density determination should be those that give the higher in-place density. That is for SW and SP soils with higher fines content, standard dry density ratio (R_D) may be used where test results show a well-defined compaction curve. Alternatively, the Hilf density ratio (R_{DH}) is a rapid compaction control test method that will give results numerically similar to the dry density ratio, i.e., $R_D \approx R_{DH}$ within 1 h of sampling. See also Notes to Clause 5.6.3.3 for indirect test methods Layer thickness should not exceed 150 mm or half the pipe diameter, whichever is the greater

(continued)

TABLE H1 *(continued)*

Description	Symbol	Typical relative compaction control methods
Coarse-grained soil with >12% fines (i.e., 'significant fines')	GM,GC,SC, SM and GM-SC,GC-SC	These materials cannot be used where water in the trench will prevent the specified placement and relative compaction being achieved. They are more difficult to place and compact in the haunch zone and should only be considered for shallow pipelines not subject to superimposed live loads Where the soil has a significant amount of fines, compaction using impact tampers or sheepsfoot rollers (in embankments) is required. Layer thickness should not exceed 150 mm or half the pipe diameter, whichever is the greater. Moisture content needs to be within 2% of the optimum for satisfactory relative compaction Standard dry density ratio (R_D) may be used for compaction control in conjunction with a nuclear density gauge or dynamic cone penetrometer counts which require calibration for site control of embedment material density. Alternatively the Hilf density ratio (R_{DH}) is a rapid compaction control test method which will give results numerically similar to the standard dry density ratio i.e. $R_D \approx R_{DH}$ within 1 hour of sampling. See also Notes to Clause 5.6.3.3 for indirect test methods
Fine grained soil (LL <50%) medium to no plasticity with more than 30% coarse-grained particles	CL, ML and mixtures ML-CL, ML-MH	These materials cannot be used where water in the trench will prevent proper placement and compaction. They are more difficult to place and compact in the haunch zone and should only be considered for shallow pipelines not subject to imposed live loads Where the soil has a significant amount of fines, compaction using impact tampers or sheepsfoot rollers is required. Layer thickness should not exceed 150 mm or more than half the pipe diameter, whichever is the greater. Moisture content needs to be within 2% of the optimum for satisfactory compaction Standard dry density ratio (R_D) may be used for compaction control in conjunction with a nuclear density gauge or dynamic cone penetrometer counts which require calibration for site control of embedment material density. Alternatively, the Hilf density ratio (R_{DH}) is a rapid compaction control test method, which will give results numerically similar to the standard dry density ratio, i.e., $R_D \approx R_{DH}$ within 1 h of sampling. See also Notes to Clause 5.6.3.3 for indirect test methods
Fine-grained soil (LL <50%) medium to no plasticity with <30% coarse-grained particles	CI, CL, ML and mixtures ML-CL, CL-CH and ML-MH	Under special circumstances these soils may be accepted as embedment material for shallow trunk water mains in open country where cohesionless materials are not readily available. They are difficult to use at higher relative compaction such as under roadways or at greater cover heights. That is, they have to be compacted at a moisture content close to the optimum for satisfactory results. Compaction methods are as for the fine-grained soils above
Fine grained soil (LL> 50%) medium to high plasticity	OL,OH, CH, MH and CH-MH	Not suitable for embedment material in normal installations

NOTE: The Clegg impact soil tester may offer an alternative to relative compaction monitoring as the Clegg impact value (CIV) can be correlated directly with the soil stiffness modulus. It is not suitable for coarse aggregates.

C

Appendix C Flexible Pipe Design

1 Pipe Design

1.1 Design Basis

The structural design of flexible pipelines in accordance with AS/NZS 2566.1:1998 Buried flexible pipelines Part 1: Structural design follows a sequence that is defined in Section 5.1.1 of the Standard.

Based on

1. pipe characteristics, i.e. wall thickness and profile, diameter and material;
2. soil stiffness of the embedment and native soil; and
3. type and magnitude of external and internal loadings

the design method calculates the predicted vertical deflection, strength and buckling. These are then compared to the maximum allowable values and one or more of the above parameters are varied to achieve a satisfactory design.

1.2 Pipe characteristics

Pipe characteristics are defined either in the Standard (Table 2.1) or provided by the product manufacturer. For the design assessments carried out here on PVC-U pipes, Table 2.1 has been used.

One of the calculated values in the analysis is the ring bending stiffness. AS/NZS2566.1 states in the Supplement clause C2.2 that “Ring-bending stiffness is an indication of the ability of the pipe to resist deflection. … Ring-bending stiffness has an influence on the deflection, strain and buckling performance of the pipe when buried in the ground, although this is normally of less significance than the stiffness of the embedment. However, where weak or soft soils exist or where there is a high water table, pipe ring-bending stiffness becomes significant.” It goes on to say “Generally, the long-term design calculations for ring-bending stiffness should use the 2-year moduli values, except that in either weak native soils or poor embedment conditions with a high water table, the 50-year values should be used.” Note that ‘Long-term’ refers to the duration of the applied loading; it is independent of the age of the asset.

The effect of using the 50-year rather than the 2-year value negatively impacts the load bearing ability of a pipeline. The conditions where the 50-year value should be used are not believed to be those likely to occur in the long term in newly laid pipes in Christchurch. Earthquake events resulting in liquefaction and weak soil are short-term events. Although the improper use of trench shoring could result in poor embedment, to design for all of the worst case scenarios occurring together is considered too conservative.

1.3 Soil Stiffness

Soil stiffness is the parameter over which there has been the most discussion with regard to local pipe designs. The ‘effective combined soil modulus’ used in the pipe designs is a function of the native soil modulus, the embedment soil modulus and the trench width relative to the pipe diameter. Typical values for the moduli are given in Table 3.2 of AS/NZS 2566.1:1998.

The modulus (E′ in AS/NZS 2566) goes by a number of names (modulus of passive resistance, modulus of soil reaction, Spangler modulus) and “is not a fundamental engineering property of the soil and cannot be directly measured. It is a semi-empirical parameter which is a function of the pipe and soil system (and not the soil alone)” (BS 9295:2010).

A composite modulus, based on both the native soil modulus and the embedment soil modulus is used in the design calculation. The derivation of the composite or combined modulus is defined by chart, graph and/or formula in the various codes. These derivations differ slightly between codes (see plots at the end of this appendix) but are consistent in that the impact of the native soil modulus reduces with increasing embedment width. Where embedment width is greater than about five times the pipe outside diameter (AS/NZS 2566.1 uses 5; BS EN 1295-1:1997 uses 4.3), the native soil modulus has no impact.

The values of the embedment soil modulus (E'_e in AS/NZS 2566) are typically tabled in a form that relates soil type and placement density. The values that appear in many codes are based on a table of values first published in 1977 by Amster Howard ('*Modulus of Soil Reaction Values for Buried Flexible Pipe*', Journal of Geotechnical Engineering, ASCE, Vol 103, No GT1, 1977). The values were based on back-calculations of measured horizontal deflections using the formula M. G. Spangler derived (Iowa Formula) for predicting the horizontal deflection of pipes. More recent work by Howard that has measured vertical deflections has resulted in the suggested modification of some of these values (Howard, '*The Reclamation E' Table, 25 Years Later*', 2006). Howard makes the point that the measurements taken typically had wide variation, a function of "inherent variations in soils and installation procedures" (Howard, 2006).

The question here in Christchurch has been what values to use in our sometimes-liquefiable soils. The selection of an embedment modulus E'_e is reasonably straightforward. All embedment material used is non-cohesive, so the choice of modulus comes down to identifying the material condition. AS/NZS 2566.1 Table 3.2 gives a range of values for different embedment density from uncompacted material through to material compacted to varying degrees (85-100% MDD or 50-80% DI). For gravel or sand and coarse grained soil with less than 12% fines (<0.075 mm) the values range from 1 MPa for uncompacted to 14 MPa for highly compacted. The Howard modified values for 'dumped' embedment are 1.4 MPa for sand and gravels with 12% or less fines, 1.1 MPa for sands and gravels with 13% or more fines or sandy or gravelly silts and clays with 30% or more sand and/or gravel (an increase on the earlier figure), and 0.3 MPa for clays and silts with less than 30% sand and/or gravel (CL and ML soils).

The selection of native soil modulus (E'_n in AS/NZS 2566) has been seen as more problematic because of the potential risk of liquefaction (the liquefaction risk for imported non-cohesive embedment is considered too low to warrant consideration for general designs). BS EN 1295-1 has a table specific to native soils (Table NA1). This table gives modulus values for gravel, sand, clayey silty sand and clay in varying states from very dense to very loose. For very loose clayey silty sand, the modulus value is 0.5 to 1.5 MPa.

In a more recent work (Amster Howard, '*Composite E Prime*', ASCE Conference Pipelines 2009), Howard suggests that native soil materials where the SPT blow number is less than five cannot be counted on to provide any significant side support, and therefore a native soil modulus of 0 MPa should be used. There are many instances in Christchurch where the native soil SPT value would be less than five.

The UK Water Industry Specification WIS 4-08-02 *Specification for Bedding and Sidefill Materials for Buried Pipelines*, when tabulating values for the modulus states that for "any situation where bedding and sidefill trench material must be placed and compacted within temporary trench support, the value chosen for E′ should be that associated with uncompacted material." BS 9295:2010 states that for "flexible pipes, the void formed by removing the trench support system between the trench and the backfill will reduce support from the native soil significantly and increase pipe deflection".

So it seems logical that in liquefiable ground, and at depth where a trench support system is being employed, a very loose native soil value and uncompacted embedment value could exist. Analysis using the moduli values for these that are quoted above (0.5 MPa for E'_n and 1.1 MPa for E'_e) has been done and for the minimum trench widths given in the CSS, the pipe design works for pipes up to DN300, i.e.

the pipes perform within their allowable limits (see tabulated analysis below). The pipe design doesn't work for an E'_n value of 0 MPa, unless the embedment soil modulus E'_e can be relied upon, i.e. the embedment width is at least five times the pipe outside diameter. For an E'_n of 0.3 MPa, equivalent to the embedment modulus for uncompacted CL and ML soils, the design works for embedment widths around four times the pipe diameter for pipes at 3.5 m deep, and works at the narrow CSS trench widths (see SD344 Sheet 2, copied into Appendix A above) for pipes at 1.5 m deep.

All of the Christchurch pipe installations over 1.5 m deep are in trenches that are supported with some form of trench shoring. Typically these are of a width that results in the pipe being embedded in material that is close to or exceeds the five-times-diameter figure, at least for pipes up to and including DN225.

The narrow trench width values given in the CSS appear to be nominal. These values do not correspond to the values given in AS/NZS 2566, being wider for pipes up to DN225 and narrower for larger pipes. In the latter case, there is potential in too narrow trenches for the pipe installation to suffer as a result of inadequate positioning of embedment material in the haunch zone below the pipe spring line. Also, depending on the site conditions, the effective composite soil modulus can be increased where the trench width is wider.

1.4 Loading and Pipe Stiffness

The design assessments have assumed the following soil loadings and pipe stiffness:

Trench fill:	22 kN/m^3
External hydrostatic loads:	water table at the ground surface
Internal pressure:	zero
Superimposed live loads:	HO wheel loading from NZTA's HN-HO-72 loading (refer IDS Part 6 Wastewater Clause 6.6.3) using the load distribution and live load impact factor of AS/NZS 2566.1
Ring-bending stiffness	2-year value

The choice of HO wheel loads, rather than the full HO loading (which includes a uniform load (UDL) as well as the wheel load), is in keeping with advice received from NZTA (the UDL is included to account for long span shear and moment effects, something not needing consideration for general pipe design). The NZTA Bridge Manual specifies load distribution according to AS 5100.2. This is different from the load distribution used in the pipe Standards. The NZTA Bridge Manual live load impact factor is also different from that contained in AS/NZS 2566, the latter being more conservative. For HO loading and at 3.5 m depth, these differences are not significant.[1]

1.5 Analyses Results

Tabulated results of the analyses are in the following section. They show that for:

- PVC-U pipes
- Diameters DN150-DN300
- Pipe stiffness SN16
- Very loose clayey silty sand native ground (E'_n=0.5 MPa)
- Uncompacted gravel, sand or coarse-grained embedment material (E'_e=1.1 MPa)

[1] For a more comprehensive discussion of vehicle live loads, see later SCIRT report *Vehicle Loading for Pipe Design*.

- Trench installations with trench width in keeping with the current CSS
- Depths to 3.5 m
- HO wheel loading

the pipes perform within their allowable limits of deflection, strain and buckling pressure.

As noted in Section 1.3 above, the pipes also perform at 3.5 m depth within their allowable limits with a lower E'_n value of 0.3 MPa but with a wider embedment which typically will be achieved within a trench support system.

Where the native soil cannot be relied upon to provide any support e.g. in highly liquefiable or peaty soils, it would be advisable to ensure that the embedment width is about five times the pipe outside diameter. For pipe sizes up to DN225, this width is likely to be provided by default where a trench support system is used.

1.6 Design for New Pipelines

New pipeline installations should result in a higher embedment modulus than that used in the analysis referred to above. If the density of the compacted embedment achieves a Density Index of 60%, or the equivalent 90% of MDD (see Appendix D), for sand and coarse-grained soil with less than 12% fines, an embedment modulus of 5 MPa can be assumed (AS/NSZ 2566 Table 3.2). If trench widths are assumed to be the greater of either the minimums specified in CSS or AS/NZS 2566, and using a native soil value of 0.5 MPa, SN16 PVC-U pipes up to DN475 perform within their allowable limits.

In most cases the soil stiffness will exceed the low value of 0.5 MPa. Where the value is higher there will be opportunity to choose different pipe stiffnesses. For these cases, for PVC-U pipes greater than DN475 and for flexible pipes of other materials, specific design will be required.

Structural Design Check of Buried Flexible Pipelines of Different SN Ratings, in accordance with AS/NZS 2566.1

Whether analysis shows acceptable deflection, strain, and resistance to buckling and combined loading:		Fail	Fail	Pass	Fail	Fail	Pass	Fail	Fail	Pass	Fail	Fail	Pass	
DESCRIPTION	**Symbol**	**DN150 PVC**			**DN175 PVC**			**DN225 PVC**			**DN300 PVC**			**Unit**
DN		150	150	150	175	175	175	225	225	225	300	300	300	-
Class		SN4	SN8	SN16	SN4	SN8	SN16	SN4	SN8	SN16	SN4	SN8	SN16	-
Internal diameter	D_i	0.152	0.151	0.148	0.190	0.188	0.185	0.238	0.235	0.231	0.300	0.297	0.291	m
External diameter	D_e	0.160	0.160	0.160	0.200	0.200	0.200	0.250	0.250	0.250	0.315	0.315	0.315	m
Thickness (minimum)	t	0.0041	0.0049	0.0062	0.00495	0.0062	0.0077	0.00625	0.00765	0.00955	0.00785	0.0093	0.0123	m
Moment of inertia for ring bending	I	0.006	0.010	0.020	0.010	0.020	0.038	0.020	0.037	0.073	0.040	0.067	0.155	$10\text{-}6m^4/m$
Initial (3-minute) ring-bending modulus of elasticity	E_b	3200	3200	3200	3200	3200	3200	3200	3200	3200	3200	3200	3200	MPa
Long-term ring bending modulus of elasticity (50-years)	E_{bl}	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	MPa
Diameter of neutral axis	D	0.156	0.155	0.154	0.195	0.194	0.193	0.244	0.243	0.241	0.308	0.306	0.303	m
Ring-bending stiffness	S_{DI}	4823	8360	17367	4339	8691	17040	4473	8346	16624	4434	7479	17821	N/m/m
Long term (50-year) ring-bending stiffness	S_{DL50}	2110	3657	7598	1898	3802	7455	1957	3651	7273	1940	3272	7797	N/m/m
Ratio of long term (2-year) to initial (3-minute) ring-bending stiffness	S_{DL2}/S_{DI}	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	0.517	-
Long term (2-year) ring-bending stiffness	S_{DL2}	2492	4320	8974	2242	4491	8805	2311	4312	8590	2291	3864	9208	N/m/m
Poisson's ratio	υ	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	-
LIMITING PARAMETERS FOR THE PIPE														
Allowable long-term vertical deflection	Δ_{yall}/Δ	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	-
Allowable long-term ring bending strain	ε_{ball}	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	-
Design factor for buckling	F_s	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	-
Factor of safety for														
- long-term internal pressure	η_p	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	-
- long-term ring bending strain	η_b	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	-
- long-term combined loading	η	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-
SITE CONDITIONS														
Cover	H	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	m
Native soil modulus	E'_n	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	MPa
Embedment soil modulus	E'_e	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	MPa
Width of trench at the springline	B	0.5	0.5	0.5	0.55	0.55	0.55	0.6	0.6	0.6	0.65	0.65	0.65	m
Height of water surface above top of pipe	H_w	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	m
Internal working pressure	P_w	0	0	0	0	0	0	0	0	0	0	0	0	MPa
Internal vacuum	q_v	0	0	0	0	0	0	0	0	0	0	0	0	kPa
Unit weight of trench fill	γ	22	22	22	22	22	22	22	22	22	22	22	22	kN/m^3
Buoyant weight of trench fill	γ_{sub}	13.71	13.71	13.71	13.71	13.71	13.71	13.71	13.71	13.71	13.71	13.71	13.71	kN/m^3
DESIGN DEAD LOAD AND LIVE LOADS DETERMINATION														
Design load due to external dead loads	w_g	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	77.00	kPa

Design load due to superimposed dead loads	w_{gs}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	kPa
Design load due to external live loads - road loading														
HN-HO-72 Loading		HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	
- wheel load	P	120	120	120	120	120	120	120	120	120	120	120	120	kN
- sum of wheel loads (single axle)	ΣP	240	240	240	240	240	240	240	240	240	240	240	240	kN
- contact area parallel to direction of travel	a	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	m
- contact area perpendicular to direction of travel	b	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	m
- distance between centre-lines of wheel load	G	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	m
HO Loading - Alternative a														
- length of base of load prism measured in relation to the direction of travel of the vehicle -														
- perpendicular	L_1	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	
- parallel	L_2	5.275	5.275	5.275	5.275	5.275	5.275	5.275	5.275	5.275	5.275	5.275	5.275	
- live load impact factor	α	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	
- average intensity of design live loads - Alternative a	w_q	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	
HN/HO Loading - Alternative b														
- length of base of load prism measured in relation to the direction of travel of the vehicle -														
- perpendicular	L_1	8.075	8.08	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	8.075	m
- parallel	L_2	5.675	5.68	5.675	5.675	5.675	5.675	5.675	5.675	5.675	5.675	5.675	5.675	m
- live load impact factor	α	1.1	1.10	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	-
- average intensity of design live loads - Alternative b	w_q	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	
- Maximum average intensity of design live loads (worse case)	w_q	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	kPa
DETERMINE EFFECTIVE SOIL MODULUS														
E'_e/E'_n		2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	-
B/D_e		3.12	3.12	3.12	2.75	2.75	2.75	2.40	2.40	2.40	2.06	2.06	2.06	-
Design Factor	D_f	1.01	1.01	1.01	0.90	0.90	0.90	0.79	0.79	0.79	0.65	0.65	0.65	-
Leonhardt correction factor	ζ	0.74	0.74	0.74	0.69	0.69	0.69	0.65	0.65	0.65	0.60	0.60	0.60	-
Effective soil modulus	E'	0.81	0.81	0.81	0.76	0.76	0.76	0.71	0.71	0.71	0.66	0.66	0.66	MPa
DETERMINE DEFLECTION														
Predicted long-term vertical deflection	Δ_y/D	11.99%	9.90%	6.86%	12.93%	10.10%	7.12%	13.43%	10.67%	7.42%	14.14%	11.65%	7.29%	-
	Therefore deflection is	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	
DETERMINE STRAIN														
Shape factor	D_f	3.25	3.15	3.07	3.27	3.14	3.07	3.24	3.13	3.07	3.23	3.14	3.06	-
Effective wall thickness of pipe	t_{es}	0.004	0.005	0.006	0.005	0.006	0.008	0.006	0.008	0.010	0.008	0.009	0.012	m
Predicted long-term ring-bending strain	ε_b	1.02%	0.98%	0.85%	1.07%	1.01%	0.87%	1.11%	1.05%	0.90%	1.16%	1.11%	0.90%	-
	Therefore strain is	**No good**	**Ok**	**Ok**	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	
DETERMINE EFFECTS OF EXTERNAL LOADING INCLUDING HYDROSTATIC PRESSURE AND INTERNAL VACUUM														
Buckling pressure on pipe for -														
Unit weight of external liquid	γ_L	10	10	10	10	10	10	10	10	10	10	10	10	kN/m^3

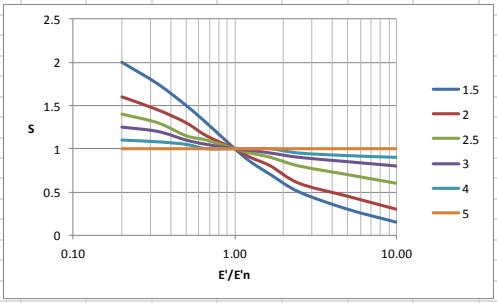
H ≥ Hw		91	91	91	92	92	92	92	92	92	93	93	93	kPa
H < Hw		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Allowable buckling pressure (see Item 18) -														
H < 0.5 m	q_{all1}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	kPa
H ≥ 0.5 m	q_{all1}	28	48	101	25	50	99	26	48	96	26	43	103	
	q_{all2}	47	57	72	44	55	69	42	52	65	40	48	64	
	Max q_{all1} or q_{all2}	47	57	101	44	55	99	42	52	96	40	48	103	kPa
	Therefore buckling is	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	**No good**	**No good**	**Ok**	
DETERMINE EFFECTS OF COMBINED LOADING														
Re-rounding coefficient (P_w<3.0MPa)	r_c	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	-
P_w / $h_p P_{all}$		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	m
r_c e_b / h_b e_{ball}		0.488	0.468	0.404	0.509	0.482	0.416	0.531	0.502	0.430	0.555	0.529	0.431	-
Addition of above two items		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
	Therefore combined loading is	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	

Comparison of Factors Used to Determine Effective/Combined Soil Modulus for Pipe Design

Howard

Soil Support Combining Factor

	B/D	1.5	2	2.5	3	4	5
E'n/E'	E'/E'n						
0.1	10.00	0.15	0.3	0.6	0.8	0.9	1
0.2	5.00	0.3	0.45	0.7	0.85	0.92	1
0.4	2.50	0.5	0.6	0.8	0.9	0.95	1
0.6	1.67	0.7	0.8	0.9	0.95	1	1
0.8	1.25	0.85	0.9	0.95	0.98	1	1
1	1.00	1	1	1	1	1	1
1.5	0.67	1.3	1.15	1.1	1.05	1	1
2	0.50	1.5	1.3	1.15	1.1	1.05	1
3	0.33	1.75	1.45	1.3	1.2	1.08	1
5	0.20	2	1.6	1.4	1.25	1.1	1



E'com = S E'

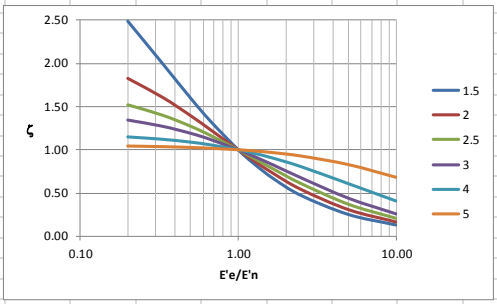
E'com = composite modulus of soil reaction

E' = modulus of soil reaction for the embedment material

AS/NZS2566

Leonhardt Correction Factor ζ

B/D	1.5	2	2.5	3	4	5
Δ_f	0.363372	0.625782	0.824176	0.979432	1.206758	1.365188
E'_e/E'_n						
10.00	0.13	0.16	0.21	0.26	0.41	0.68
5.00	0.25	0.31	0.37	0.44	0.61	0.83
2.50	0.47	0.54	0.61	0.68	0.80	0.93
1.67	0.67	0.73	0.78	0.82	0.90	0.97
1.25	0.84	0.88	0.90	0.93	0.96	0.99
1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.67	1.33	1.23	1.17	1.12	1.06	1.02
0.50	1.60	1.39	1.27	1.19	1.09	1.03
0.33	1.99	1.61	1.40	1.27	1.12	1.04
0.20	2.49	1.83	1.52	1.34	1.15	1.04



$E' = \zeta E'_e$

E' = effective combined soil modulus

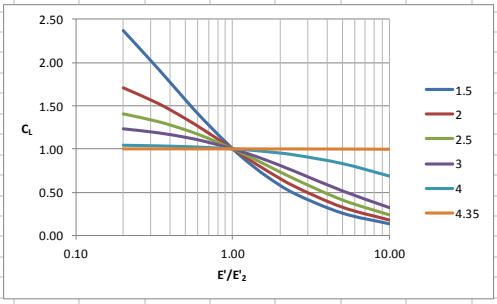
E'_e = embedment soil modulus

Where B > 5D adopt ζ=1

BS EN 1295

Soil Modulus Adjustment Factor C_L

B_d/B_c	1.5	2	2.5	3	4	4.35
E'_2/E'_3						
10.00	0.13	0.18	0.24	0.32	0.69	1.00
5.00	0.26	0.33	0.41	0.51	0.83	1.00
2.50	0.48	0.56	0.65	0.74	0.93	1.00
1.67	0.67	0.74	0.81	0.86	0.97	1.00
1.25	0.85	0.89	0.92	0.94	0.99	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.67	1.32	1.21	1.14	1.09	1.02	1.00
0.50	1.57	1.35	1.22	1.13	1.03	1.00
0.33	1.93	1.53	1.32	1.19	1.04	1.00
0.20	2.37	1.71	1.41	1.23	1.04	1.00



$E' = E'_2 C_L$

E' = overall modulus of soil reaction

E'_2 = embedment soil modulus

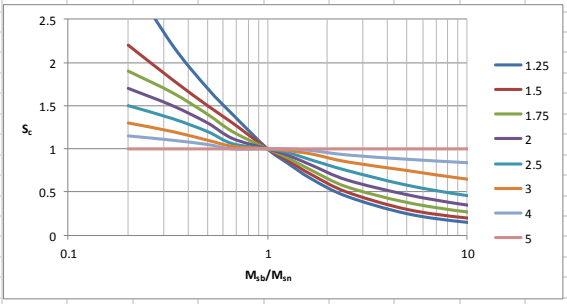
E'_3 = native soil modulus

Where $B_d > 4.3B_c$ the value of C_L is 1

ISO/TR 10465-2:2007(E)

Table 7 — Values for the soil support combining factor, S_c

	b/d	1.25	1.5	1.75	2	2.5	3	4	5
M_{sn}/M_{sb}	M_{sb}/M_{sn}								
0.005	200	0.02	0.05	0.08	0.12	0.23	0.43	0.72	1
0.01	100	0.03	0.07	0.11	0.15	0.27	0.47	0.74	1
0.02	50	0.05	0.1	0.15	0.2	0.32	0.52	0.77	1
0.05	20	0.1	0.15	0.2	0.27	0.38	0.58	0.8	1
0.1	10	0.15	0.2	0.27	0.35	0.46	0.65	0.84	1
0.2	5	0.25	0.3	0.38	0.47	0.58	0.75	0.88	1
0.4	2.5	0.45	0.5	0.56	0.64	0.75	0.85	0.93	1
0.6	1.67	0.65	0.7	0.75	0.81	0.87	0.94	0.98	1
0.8	1.25	0.84	0.87	0.9	0.93	0.96	0.98	1	1
1	1	1	1	1	1	1	1	1	1
1.5	0.67	1.4	1.3	1.2	1.12	1.06	1.03	1	1
2	0.5	1.7	1.5	1.4	1.3	1.2	1.1	1.05	1
3	0.33	2.2	1.8	1.65	1.5	1.35	1.2	1.1	1
5	0.2	3	2.2	1.9	1.7	1.5	1.3	1.15	1



where:

b is the trench width at the spring-line, in m

d is the pipe diameter, in m

M_{sn} is the native constrained-soil modulus, in N/m^2

M_{sb} is the embedment constrained-soil modulus, in N/m^2

NOTE Intermediate values for S_c can be determined by linear interpolation between adjacent values.

D

Appendix D Embedment Materials

Pipe design is dependent on soil stiffness. The parameter used in analysis using AS/NZS2566.1 that reflects this is the soil modulus. As noted in Appendix C above, pipe design based on low moduli values can work in some situations. These low values are based on very loose native soil and uncompacted embedment material. Although this may be acceptable for the pipe installation, there is risk that the use of loose material may result in trench settlement (one of the reasons for Christchurch City's use of M/4 material originally), so some compaction is necessary.

Standards New Zealand produced SNZ HB 2002 *New Zealand Handbook Code of Practice for Working on the Road* in 2003. The handbook was developed "as a Code of Best Practice to ensure that public utility corridors are accessed and reinstated in an acceptable manner." (Forward). Appendix L of the handbook is 'Requirements for Trench Reinstatement Works' (Informative). Within this appendix there are a number of diagrams that show typical examples of requirements for reinstatement works. All of these diagrams show backfill compacted to 90% MDD below 1.5 m below the road surface, with material above that being compacted to 95% MDD. On this basis it is assumed that achieving the same compaction standard for pipe embedment, i.e. 90% MDD deeper than 1.5 m or 95% MDD if less than 1.5 m to the surface, is an acceptable compaction standard for the embedment component of the trench backfill. This has been agreed to by the SCIRT Asset Owner Representative (Roading).

What is wanted then for pipe installation is a material that can easily be compacted to this standard. As noted in the Section 2.3.2 of the main report:

> "Ideal bedding and sidefill material should have the following general properties:
>
> (a) it should be easy to scrape or shovel to form a bed on which to lay a pipe, and also be easy to distribute uniformly beneath the haunches of a pipe by tamping;
>
> (b) it should require little or no compactive effort;
>
> (c) the largest particle size should not be excessive in relation to the pipeline diameter otherwise impact damage and concentrated point loading can occur;
>
> (d) it should not contain particles with sharp edges when used with those pipes or pipe coatings that are susceptible to damage;
>
> (e) the grading should be such that water passing through will not encourage fine materials to be carried away and thus reduce the support for the pipeline;
>
> (f) it should not break up when wetted or compacted;
>
> (g) it should not cause corrosion or degradation of the pipes, fittings, coatings and jointing materials with which it is in contact;
>
> (h) it should be sufficiently stable, when laid and compacted, to support the pipeline in the correct position both during and after laying;
>
> (i) it should be chemically durable and not react with, the soil, groundwater, pipe or coating."

Also as noted in Section 2.3.2, for a material to be easily compactable it requires a small difference between its void ratio in its loosest state and its void ratio in its most compact state. This characteristic is captured in the New Zealand PVC pipe installation standard (NZS 7643:1979 *Code of practice for the Installation of Unplasticized PVC Pipe Systems*), the now withdrawn NZS 4452:1986 *Code of practice for the construction of underground pipe sewers and drains* and the UK Water Industry Specification

WIS 4-08-02 *Specification for Bedding and Sidefill Materials for Buried Pipelines*. In these publications, the test for embedment suitability is the determination of what is called the 'compaction fraction'. The test method in all cases is basically the same. The method given in WIS 4-08-02 is as follows:

1. Apparatus

1.1 Open-ended cylinder

Approximately 250 mm long and 150 mm (+ 10 mm, – 5 mm) internal diameter (150 mm diameter pipe is suitable).

1.2 Metal rammer

Metal rammer with striking face approximately 40 mm diameter and weighing 0.8 kg to 1.3 kg.

1.3 Measuring rule

2. Method

Obtain a representative* sample more than sufficient to fill the cylinder (about 10 kg). It is important that the moisture content of the sample should not differ from the bulk of material at the time of its use in the trench.

Place the cylinder on a firm flat surface and gently pour the sample material into it, loosely and without tamping. Strike off the top surface level with the top of the cylinder and remove all surplus spilled material. Lift the cylinder up clear of its contents and place on a fresh area of flat surface. Place about one quarter of the material back in the cylinder and tamp vigorously until no further compaction can be obtained. Repeat with the second quarter, tamping as before, and so on for the third and fourth quarters, tamping the final surface as level as possible. Tamping should not be so vigorous as to break the material being compacted.

3. Determination of compaction fraction

Measure from the top of the cylinder to the surface of the compacted material. This distance divided by the height of the cylinder gives the compaction fraction of the material under test.

* To obtain a representative sample about 50 kg of the material to be tested should be heaped into a cone shape on a clear surface after turning over the material three times. Flatten the top of the cone then divide with a spade vertically down the centre into four quarters. One pair of the opposite corners is discarded and the other pair of opposite quarters remixed into a cone shape. This procedure is repeated until the required mass of sample remains.

The New Zealand Standards, where compaction of each layer is with either 10 or 20 blows, give an acceptance figure for the compaction fraction of 0.1. The UK Water Industry Specification, where compaction is to be "until no further compaction can be obtained", gives an acceptance figure for non-pressure pipelines of 0.15. It is proposed that this latter test be used, with a compaction fraction of 0.15 being the acceptance level.

Compaction of well graded material can be measured by field determination of % MDD without too much difficulty. Measurement of % Density Index of more open material is not practical in the field. What is proposed for these materials is a compaction trial to "demonstrate the adequacy of the proposed compaction method to achieve the compaction parameters specified" (AS/NZS 2566.2:2002, Clause 5.6.2). The expectation is that with a Density Index of 60% specified and a low compaction fraction material used, there should be no difficulty achieving the compaction specified, but this needs

confirmation. Once confirmed, it will be easy to determine the method of compaction to be used in the trench.

In addition to these compaction requirements AS/NZS 2566.2 gives size requirements. These are given to ensure good pipe support and to avoid impact damage and concentrated point loading. The sizes given are 14 mm for DN100 pipes (e.g. a typical property wastewater lateral) and 20 mm for DN150 and larger pipes.. The M/4 embedment has 100% passing the 19 mm sieve and about 80% - 90% passing the 14 mm sieve so is close to the Standard's sizing requirements. These sizing requirements should be maintained, although for DN100 laterals which are typically no deeper than 2.5 m and therefore have a greater safety factor against deflection and buckling, the use of a slightly coarser material is unlikely to create a problem.

On the issue of material grading, as noted in Section 2.3.2 above, the grading is not the significant factor – it is a recommendation to 'facilitate' achievement of the soil moduli. The Concrete Pipe Association of Australasia guideline on selecting embedment materials and the American Concrete Pipe Association publications recommend the use of the generic soil classes GP, GW, SP or SW for high quality installations. Appendix H of AS/NZS 2566.2 states that the required relative compaction of these low fines aggregates is relatively easy to achieve.

E

Appendix E Use of Geotextile Embedment Wrap

IDS (2013) Part 6: Wastewater Drainage Clause 6.13 *Haunching and Backfill* calls on the designers of drainage systems to "specify wrapping of the haunching for plastic pipes and laterals in Liquefaction Risk zones 0, 1 and 2" and to "Consider wrapping where the proposed pipeline extends out of Liquefaction Risk zone 2." CSS Part 3: Utility Drainage in SD344 Sheet 2 captures this detail when it states "Geotextile wrap where specified".

These modifications came about post-earthquake in an attempt to improve the resilience of the newly installed pipelines. In part this was because it was thought that "Wrapping may improve the longitudinal strength of the pipeline, reducing potential alterations in grade" (IDS Part 6 Clause 6.13). This longitudinal strength improvement has no theoretical basis and has been challenged by senior geotechnical professionals and recognised academics (including Misko Cubrinovski of Canterbury University and Professor Thomas O'Rourke of Cornell University).

There has also been a thought that the use of the embedment wrap may provide stability to the embedment in an earthquake when the ground around the embedment liquefies. This may occur although there is no evidence that it did occur and contribute to pipe failures in the earthquakes.

The requirement to wrap the embedment may introduce risk that ultimately may be higher than the risk it is seeking to mitigate. Typically the pipe trench is shielded or sheet-piled and it is difficult in the local conditions to install the embedment (which is in the trench base) in the fabric in a way that ensures that there are no voids outside the fabric. Over time (or at the time of trench shoring removal) the presence of these voids is likely to result in a weakening of the pipe embedment. Alternatively, if there is no fabric, the embedment material can more easily fill the voids during construction, reducing the risk of post-construction voids.

In pipe design and installation Standards, the use of geotextile wrap is confined to situations where the movement of fine materials in the trench base and sides can cause a loss of the side support integrity. This is typically where the embedment or native ground gradings are such that this movement of fines can occur. Standards (e.g. AS/NZS 2566.2 Appendix I) and texts give guidance on the gradings necessary to prevent fines movement. If these gradings are not achieved and fines movement is therefore a possibility, the question arises as to when the conditions exist for this to occur. The presence of water in itself does not lead to fines movement; what is needed is water movement. This movement could occur during construction, immediately post-construction (e.g. with the shutting down of dewatering equipment) or sometime after construction e.g. if the trench acts as a conduit for water movement. All of these instances can be countered in a way that doesn't involve the use of geotextile. During construction an efficient dewatering system can (should) be used to avoid water in the trench, dewatering equipment can be progressively shut down at the end of construction, and the use of water stops can inhibit the flow of water along the trench.

As noted in Appendix C, pipe design based on low moduli values can work in some circumstances. Where these circumstances exist, the loss of embedment support caused by fines movement may not affect the pipe itself, albeit that the pipe grade may be impacted by differential movement along the pipe bed, as may the backfill and ultimately the surface levels.

The use of coarse aggregates for pipe embedment has the advantage of requiring less compactive effort to achieve satisfactory pipe support (see Appendix D). In the local Christchurch environment, these open materials could allow the movement of fines. A balance needs to be found between the benefits of using the open material (faster production and higher quality compaction) and the potential risks of fines

movement. In some circumstances, the use of geotextile as part of a pipe installation may be the optimum solution, but each case will need to be considered on its own merits.

F

Appendix F Proposed Specification[2]

1 Flexible Pipe Embedment Specification

1.1 Scope

The following clauses apply to pipe installations except for hillside areas where special conditions apply. Hillsides are defined as any location where either the pipe gradient or surface slope directly upstream or downstream is steeper than 1 in 20 (see IDS Part 6 – Roads, Clause 6.13.3).

1.2 Embedment Material

1.2.1 Options

Embedment material shall be one of the following:

- NZTA M/4 AP20
- CCC Embedment AP20 (see below)
- With specific Designer approval, low-fines gravels or gravel-sand mixtures with a Compaction Fraction (CF) of less than 0.15 (see Section 1.4).

The maximum particle size shall be 20 mm.

1.2.2 CCC Embedment AP20

Sieve Size	Percent Passing
19.0 mm	100
9.5 mm	43 – 63
4.75 mm	20 – 40
2.36 mm	0 – 25
1.18 mm	0– 15
0.600 mm	0– 10
0.300 mm	0– 5
0.150 mm	0– 2

50% of the aggregate by weight shall have 2 or more broken faces.

The grading shall produce an even curve.

Aggregate shall be free of deleterious material.

1.2.3 Low-fines Gravel and Gravel-sand Mixtures

Gravel and gravel-sand mixtures shall be gravels with more than 50% larger than 2.36 mm, from groups GW or GP as defined in AS 1726 and as follows:

[2] This was updated in September 2014.

Group Symbol	Typical Names	Field investigation Sand and Gravels	% < 0.075 mm
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Wide range in grain size and substantial amounts of all intermediate sizes, not enough fines to bind coarse grains, no dry strength	0 – 5
GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines, uniform gravels	Predominantly one size or range of sizes with some intermediate sizes missing, not enough fines to bind coarse grains, no dry strength	0 – 5

1.3 Embedment Compaction

The following embedment compaction requirements replace those of Clause 8.5.1 of CSS Part 3 – Utility Drainage.

Where pipe is beneath a carriageway and with less than 1.5 m cover, compact the embedment material to a Density Index of 70%. Otherwise compact the material to a Density Index of 60%. Determine the Density Index in accordance with AS 1289.5.6.1 (equivalent to Relative Density in NZS 4402.4.2.3).

Dry density ratio may be used as a compaction measure for M/4 AP20 and CCC Embedment AP20 and well-graded gravel-sand mixtures (GW) where the field dry density is to be 95% and 90% of the maximum dry density respectively. Determine the maximum dry density in accordance with NZS 4402.4.1.1, New Zealand Standard Compaction Test.

Low-fines gravels or gravel-sand mixtures with a CF of less than 0.15 require light compaction but do not require compaction testing in the field as with light compaction the required Density Index will be achieved.

1.4 Compaction Fraction[3]

Test the CF for compliance at a frequency of at least one test for every 500 m^3 of material. Determine the Compaction Fraction using the following procedure:

Apparatus

- Open-ended cylinder — Approximately 250 mm long and 150 mm (+ 10 mm, – 5 mm) internal diameter (150 mm diameter pipe is suitable).
- Metal rammer — Metal rammer with striking face approximately 40 mm diameter and weighing 0.8 kg to 1.3 kg.
- Measuring rule

Method

Obtain a representative* sample more than sufficient to fill the cylinder (about 10 kg). It is important that the moisture content of the sample should not differ from the bulk of material at the time of its use in the trench.

Place the cylinder on a firm flat surface and gently pour the sample material into it, loosely and without tamping. Strike off the top surface level with the top of the cylinder and remove all surplus spilled material. Lift the cylinder up clear of its contents and place on a fresh area of flat surface. Place about

[3] This procedure is derived from the UK Water Industry Guideline WIS 4-08-02 February 1994: Issue 1.

one quarter of the material back in the cylinder and tamp vigorously until no further compaction can be obtained. Repeat with the second quarter, tamping as before, and so on for the third and fourth quarters, tamping the final surface as level as possible. Tamping should not be so vigorous as to break the material being compacted.

Determination of compaction fraction

Measure from the top of the cylinder to the surface of the compacted material. This distance divided by the height of the cylinder gives the compaction fraction of the material under test.

* To obtain a representative sample about 50 kg of the material to be tested should be heaped into a cone shape on a clear surface after turning over the material three times. Flatten the top of the cone then divide with a spade vertically down the centre into four quarters. One pair of the opposite corners is discarded and the other pair of opposite quarters remixed into a cone shape. This procedure is repeated until the required mass of sample remains.

1.5 Embedment Placement

Placement and compaction of all layers must be in layers not exceeding 250 mm compacted thickness unless field trials show that the specified compaction can be obtained with thicker layers. Where hand tampers or internal vibrators are used, the compacted lift thickness should not exceed 150 mm, the length of the vibrator, or half the pipe diameter.

2 Control of Soil Particle Migration in Trenches

2.1 General

Field experience has shown that soil particle migration can result in significant loss of pipe support leading to serious instability of a pipeline (refer to AS/NZS 2566.2 Appendix I). In addition, it can lead to ground settlement. It is therefore important to mitigate against this migration.

Where coarse gravels are used as embedment material and there is a risk of water movement (and therefore soil movement) through the material, take measures on-site to control the movement of water through the pipe embedment. Such measures would include the use of a well-designed dewatering plan. Where the risk of soil migration remains, one of two options is to be used to mitigate the risk:

1. Wrap the embedment material (the bedding, the haunching and the overlay) in a geotextile (see Section 2.3 below)
2. Construct trench stops at intervals along the trench

The spacing of trench stops will be very dependent on the specific site conditions. As an indication, it would be expected that trench stops be constructed at not more than 50 m spacings.

Extend the trench stops into the foundation raft if one is constructed using coarse materials.

2.2 Trench Stops

Construct trench stops at locations specified on the drawings.

Trench stops shall be constructed from either ‘firm mix’ (CSS Part 1 Clause 31.13) or bagged aggregate as per SC6316.

2.3 Embedment-Wrapping Geotextile

Where the pipe embedment is to be wrapped, use a non-woven geotextile filter fabric made from filaments of synthetic fibres, which meets the following requirements:

Properties	Test Method	Units	Value
Mean values of mechanical properties			
Mass per unit area	AS 3706.1	g/m^3	≥ 140
Trapezoidal tear strength	AS 3706.3	N	≥ 180
'G' Rating	*	G*	≥ 1000
Grab tensile strength	AS 2001.2.3	N	≥ 400
Mean hydraulic properties			
Pore size – dry sieving O_{95}	AS 3706.7	μm	≤ 250
Permittivity	AS 3706.9	s^{-1}	≥ 0.5
Flow rate under 100 mm head	AS 3706.9	$L/m^2.s$	≥ 50

* G rating (Geotextile robustness rating) = $\sqrt{(Lh_{50})}$

where

L = plunger failure load (N), as determined by AS 3706.4

h_{50} = normalised drop height (mm), as determined by AS 3706.5

(Reference: AS/NZS 2566.2 Appendix J)

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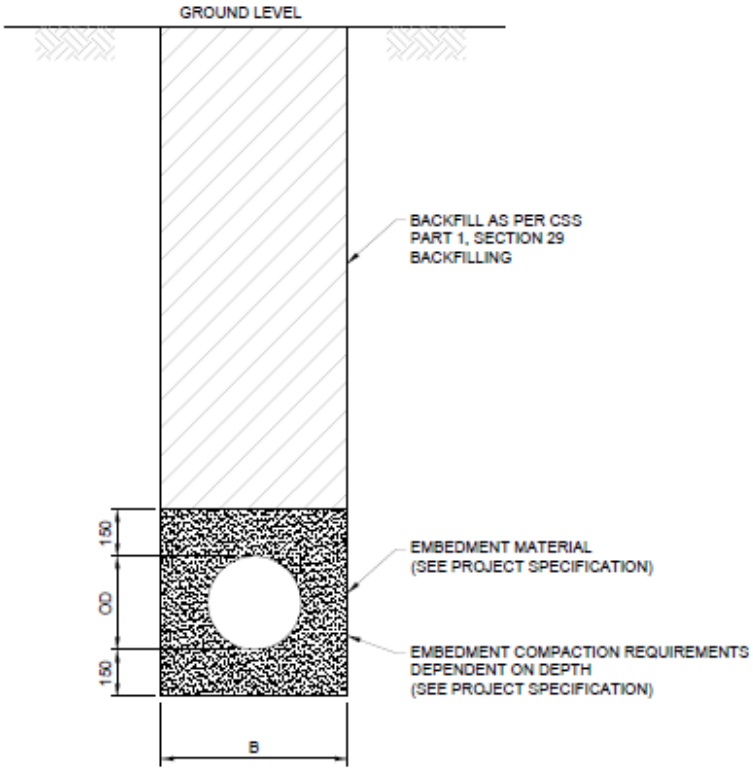

PIPE OUTSIDE DIAMETER OD (mm)	MINIUMUM TRENCH WIDTH B (mm)
≤ 300	OD + 350
> 300, ≤ 450	OD + 400
> 450, ≤ 900	OD + 600

FOR PVC-U PIPES

NOMINAL PIPE DIAMETER DN	MINIMUM TRENCH WIDTH B
100	460
150	500
175	550
200	575
225	600
250	630
300	700
375	800
475	1100

NOTES:

1. SEE PROJECT SPECIFICATION FOR EMBEDMENT MATERIAL DETAILS.
2. WHERE THERE IS AN IDENTIFIED RISK OF SOIL PARTICLE MIGRATION, EITHER WRAP THE WHOLE EMBEDMENT IN GEOTEXTILE OR CONSTRUCT TRENCH STOPS. SEE PROJECT SPECIFICATION FOR DETAILS.
3. FOR NON-PRESSURE PVC UP TO 3.5m DEEP, PIPE CLASS TO BE SN16 FOR DIAMETERS DN100 - DN475. OTHER CASES REQUIRE SPECIFIC DESIGN.

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PIPELAYING HAUNCHING FOR FLEXIBLE PIPES

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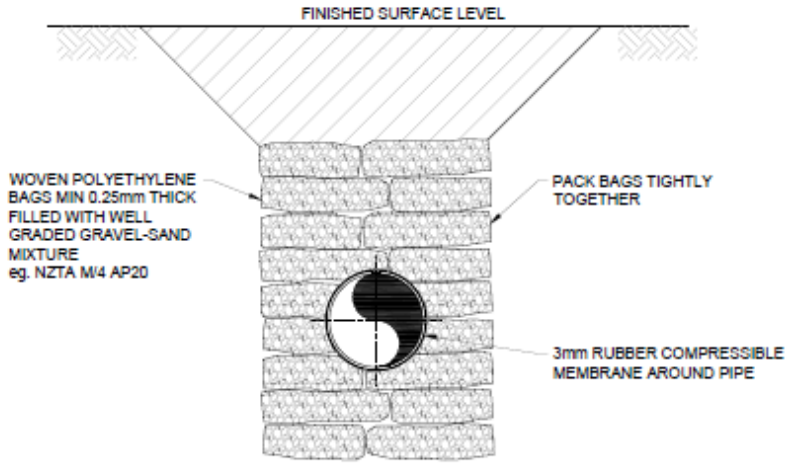

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DISTRIBUTION	INITIAL	DATE
DESIGNER		
DESIGN REVIEW		
DRAFTING CHECK		
TECHNICAL REVIEW		

NOTES:

1. PLACE BAGS AROUND AND ABOVE THE PIPE SO AS TO GIVE CLOSE CONTACT WITH THE PIPE, TO FILL THE FULL TRENCH WIDTH AND COVER THE FULL DEPTH OF EMBEDMENT AND FOUNDATION RAFT IF USED.
2. DO NOT DEFORM PIPES DURING PLACEMENT OF BAGS.
3. SEAL BAGS TO PREVENT LEAKAGE OF CONTAINED MATERIAL.

SCIRT Rebuilding Infrastructure

BAGGED TRENCH STOP

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G

Appendix G References

AS/NZS 2566.1:1998 Buried flexible pipelines Part 1: Structural design

AS/NZS 2566.1 Supp1:1998 Buried flexible pipelines Part 1: Structural design - Commentary

AS/NZS 2566.2:2002 Buried flexible pipelines Part 2: Installation

AS/NZS 3725:2007 Design for installation of buried concrete pipes

SNZ HB 2002:2003 Code of Practice for Working in the Road

NZS 4402 Methods of testing soils for civil engineering purposes

NZS 4452 Code of Practice for the Construction of Underground Pipe Sewers and Drains

NZS 7643:1979 Code of Practice for the Installation of Unplasticized PVC Pipe Systems

BS EN 1295-1:1997 Structural design of buried pipelines under various conditions of loading – Part 1: General requirements

BS EN 1610:1998 Construction and testing of drains and sewers

BS 9295:2010 Guide to the structural design of buried pipelines

IGN 4-08-01 Bedding and Sidefill Materials for Buried Pipelines, UK Water Industry Information & Guidance Notes

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Howard, Amster, 2011, “Composite E Prime”, Technical Note – a Supplement to Pipeline Installation, obtained from http://www.amsterhoward.com/.