GUIDELINES

for Improved Trench Reinstatement Programs and Work Practices

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Prepared by:
Allan Widger, M.Sc., P.Eng.
Elena Zabolotnii, Engineer-In-Training
Clifton Associates Ltd.

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EXECUTIVE SUMMARY

These guidelines have been commissioned by the public-private partnership Communities of Tomorrow on behalf of a number of Saskatchewan urban communities. The purpose of these guidelines is to provide the urban communities with information on better trench reinstatement practices and programs.

The high rate of trench reinstatement failures has created a need for these guidelines, especially within the smaller urban municipalities, which have limited means of testing and quality control. Root causes for trench reinstatement failures include incorrect construction methods and poor backfill materials. The failure types include trench settlement, differential soil movement at or adjacent to the trench reinstatement, frost heaving and pavement failures.

Suitable materials used for backfill material include:

- Common soils and manufactured unbound granular materials. Issues related to these materials include poor compaction and moisture retention due to fines content.
- Hydraulically or bitumen-bound granular materials. Poor compaction is also an issue for these classes of material. The benefits of using them include an improved soil bearing capacity.
- Low strength and foamed concretes. These materials do not require compaction and do not pose settlement issues. They are relatively expensive and may create moisture barrier and frost heaving issues.

Testing needs and options vary depending on the backfill material choice. Compactable backfill materials generally have the highest testing requirements, with preliminary lab testing and in-situ testing being a part of the standard procedure. Simplified testing of compactable backfill materials consists of in-situ compaction testing to establish required compaction efforts. Testing needs for low-strength and foamed concrete materials consist of strength testing, usually at 28 days.

General principles for trench reinstatement are as follows:

- Preparatory works consist of gathering information on the road and soil conditions in order to decide what materials and methods are best suited for the job. Data sources may include database inquiries, subgrade drilling and testing, and materials and method selection.

- Appropriate backfill materials should be selected. Field staff should be trained in matters of soil characterization, as well the properties and applicability as backfill of available materials.
- Excavation works should be conducted in a manner minimizing disturbance to surrounding subgrade and pavement. The excavation area should be as small as practical. Proper sizing of excavation equipment is the key to keeping the excavation small and clean.
- Backfilling with compactable materials should only be completed after all loose or disturbed material is removed. A combination of layered backfill materials can be used, with the lower quality materials being placed to the bottom. Backfill materials should be placed in lifts not exceeding 300 mm. Backfill materials should be spread along the edges of the trench rather than in the middle to avoid over-compaction of the center and under-compaction of the edges. Selecting the proper type and size of compaction equipment is the key to good and uniform compaction.
- Backfilling with low-strength or foamed concrete materials does not require compaction or vibration. Around pipes, the material should be placed in lifts to avoid flotation; bracing for the pipes can be used as well.

One-step trench reinstatements can be completed under suitable weather, moisture and traffic conditions. This approach offers cost savings over staged reinstatements, but is more prone to long-term settlement. Staged reinstatements are used where the initial repairs are conducted in adverse conditions, or can be a part of road maintenance planning. This method mitigates short-term settlement and differential movement by allowing the material to settle before the repair is finalized.

Microtrenching is a new technology which allows for fast installation of underground cable with minimal ground disturbance and often at a lower cost.

Where possible, trenchless technologies should be considered as an alternative to trenching works.

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1. INTRODUCTION

This report has been commissioned by the public-private partnership Communities of Tomorrow on behalf of a number of Saskatchewan urban communities with the goal of developing a set of guidelines on improved trench reinstatement programs and work practices.

The main focus of these guidelines is the reinstatement of small (<2 m width) open cut trenches. A secondary focus is to provide guidance on reinstating large new water or sewer main trenches and shallow utility trenches. The guidelines focus on asphalt pavements; however, most of the information can be applied to concrete pavements as well.

To develop these guidelines, a world-wide review of available materials and practices for trench reinstatement was undertaken, with special focus on jurisdictions with climate similar to Saskatchewan. Contractors and equipment producers familiar with trench reinstatement works, equipment and materials have been consulted in the course of development of these guidelines. No new research was undertaken.

1.1 BACKGROUND

The various problems associated with the excavation and backfilling of utility cuts are a major cause of shortened pavement life. An Iowa survey of municipal authorities indicates an average utility trench restoration life of less than two years (see Schaefer, V. et al, 2005).

1.2 TRENCH REINSTATEMENT FAILURE ROOT CAUSES

Traditional trench reinstatement methods such as one-step or staged backfill repairs have shown, over time, a number of common deficiencies. These are commonly traced to the following root causes discussed below.

1.2.1 Construction Methods

Excavation and backfilling methods and equipment control material placement.

Poor construction methods may create numerous issues such as:

- Disturbance of adjacent material during excavation.
- Failing to protect the trench walls from loss of material.
- Failing to start repair on undisturbed material.
- Placing compactable backfill material in lifts exceeding 300 mm between compactions (see insert).
- Exercising no density or moisture control when placing backfill.

Section 1.2.1

A study of Iowa trenching practices found, when studying trench backfill compaction, “a trend of high CBR values at approximately 1.5 feet (0.457 m) from the top of the layer below the surface layer, as the surface layer is usually disturbed. Then the CBR values reduce with depth (...) as the effect of compaction decreases with depth for large lift thicknesses. This reiterates the importance of lift thicknesses being less than or equal to 12 inches” (0.3 m) (Schaefer, V. Et al, xvi).

Section 1.2.1 – Excavation Methods

Badger Daylighting Ltd. has developed its own methods of trenching using hydrovac technology. Some of the claimed benefits include:

- Installation at sites with limited access.
- Minimization of ground disturbance.
- Lower restoration costs.
- Safer access to existing buried utilities.

The picture below, reproduced from www.badgerinc.com, shows a water pipe installation via "slot-trenching;" the company claims to have dug trenches up to 3000 ft (915 m) long.

In wintertime, excavating frozen ground using a backhoe can pose a number of challenges. Hydrovac technology offers an alternative solution. It consists of slot-trenching the excavation area (which is cleared of asphalt pavement in advance using a saw) in a grid pattern, then "plucking" the frozen cubes of soil. The technology should not be used around buried utilities, which should be hydrovaced by traditional methods in advance (Coburn, L., 2012).

Traditional excavation methods, when applied improperly, may create issues which can cause failures down the road. For example, breaking the pavement instead of sawing through it first creates areas of weak subgrade near the trench cut. Lifting the backhoe bucket upward rather than cutting downward may result in additional disturbance to the adjacent material, weakening it and making it prone to settling and failure.

Placing the construction equipment too close to the edge of the cut is another common construction issue; it results in pavement damage at the perimeter of the trench (see Schaefer, V. et al, 2005).

Emerging technologies such as trenching using a hydrovac may offer benefits over traditional methods (see insert).

1.2.2 Poor Backfill Materials

The reuse of saturated in-situ materials such as clays often results in settlement: the high moisture levels in the in-situ materials weaken them and reduce their compaction properties (see Schaefer, V. et al, 2005). In-situ materials may also lack uniformity, leading to problems with moisture distribution through the trench reinstatement profile, resulting in shrinkage or swelling as pore pressure equilibrium is achieved over time.

1.2.3 Choice of Trench Location

Where flexibility on the location exists, a number of factors should be considered:

- Ground elevation and moisture conditions: generally, trenches tend to perform better in dry conditions, so selecting a high ground location or a location where the water table is generally low presents a long-term advantage.
- Locations outside the wheelpath: pavement failure due to moisture and improper soil compaction is triggered by loads applied on pavement, namely by traffic. For longitudinal trenching, locations outside the wheelpath, or even outside the lanes (e.g. on the shoulder, sideslope or backslope) are preferred. For trenches crossing an entire road width, roadways with the least truck traffic volume are the preferred choice.

1.3 TRENCH REINSTATEMENT ISSUES

The common issues related to trench reinstatement are discussed below. Issues specific to methods and materials are addressed throughout the report.

1.3.1 Initial Settlement

Initial settlement starts immediately after the fill is placed, and continues until the material comes to equilibrium with no excess pore pressure.

1.3.2 Long-Term Settlement

It has been long observed and documented that "many trenches exhibit further long-term settlement in the 7 - 10 year timeframe following the formation of a trench in the road. This phenomenon is known as long-term damage caused by further ongoing settlements and collapse of any bridging which is not always practical to fully eliminate at the temporary back filling and permanent reinstatement stages" (DELG 2002). Lack of compaction or non-uniform compaction is the most common cause of long-term settlement.

Differential soil settlement in the backfilled trench and around it produces an inconsistent road profile, creating a road hazard and diminishing road user satisfaction.

1.3.3 Frost Heave and Moisture Conditions

Due to the uneven distribution of moisture throughout the trench cut as compared to the rest of the road structure, frost heaving and differential movement is often noted at restored trench locations. Reasons for this include:

- Poorly matched subgrade, subbase and base materials. The different materials in the road layers have varying water-draining properties; when the road structure is not restored to match the existing structure, the flow of water through the beds may be impeded or the repair may collect water.
- High fines content in unbounded fill material: this impedes the water from draining.
- Where the backfill material has a moisture content that is different from the adjacent subgrade, it may shrink or swell over time as it comes to pore pressure equilibrium with the surrounding subgrade.
- Where the backfill material has a moisture content that is different from the adjacent subgrade, it may heave due to frost action to a larger or lesser extent than the surrounding subgrade, creating differential movement of the surface.

1.3.4 Pavement Failures

Edge Failures: The breakage of the pavement surface adjacent to the utility cut is a common problem. It can occur during the trenching works or later on. There are several complementary mechanisms by which edge failures occur:

- The disturbance of material adjacent to excavation by construction equipment may reduce its bearing capacity, resulting in pavement failure.
- Loss of material along the edge of excavation can occur at or near the pavement surface, especially in vertical or nearly vertical trenches. Granular material may erode away, leaving unfilled gaps under the pavement (Emery, J.J. et al, 1987). Conventional compaction equipment cannot be adequately used close to the trench edges or to infill the voids.
- Heavy equipment driving close to the edge of the cut, where the pavement is not fully supported, causes pavement cracking of loss of density in the subgrade, resulting in pavement failures.

Potholes: Where material settlement has occurred after trench reinstatement works, the depression in the road surface allows for water ponding, leading to moisture infiltration into the subgrade and subsequent road failures. Also, failure to seal the trench repair edges leads to water infiltration into the subgrade, causing potholes.

2. MATERIALS USED FOR TRENCH REINSTATEMENT

2.1 MATERIAL SELECTION

Under ideal conditions, trench reinstatement processes would remove and replace materials to the location and condition they were in prior to the disturbance. Since this is not practical, materials should be selected in a manner that will allow proper placement and result in acceptable performance.

2.2 COMMON MATERIALS OR BORROW MATERIALS

Common in-situ materials are excavated from the trench whereas borrow materials are similar materials from a local borrow pit or stockpile. Plasticity and fines content are the two biggest concerns related to common materials.

Plasticity determines how the material's strength changes with its moisture content.

Fines contribute to water retention, increased capillary action, and diminish the draining properties. Water retention in the backfill material then leads to frost heaving and pothole formation, ultimately leading to pavement failure. Therefore, the fines content of the backfill material should match that of the existing subgrade. See insert for examples of fines definition and allowable content. See Section 7 for field soil identification and classification chart, as well as for some simple tests for determining material plasticity and moisture content.

Common materials tend to have a defined use in trench backfill. Notably, their use is limited to "dry trench conditions" or disallowed in places where "water condition (...) may cause instability" (Iowa DOT SUDAS Spec. Section 3010-2.03). Where common materials have a moisture content that is too high to allow proper compaction, the material can be modified using additives such as lime, fly ash, cement of a combination thereof. This modification changes the plasticity and workability of the material, and provides some cementing action, increasing the material's strength (see Section 2.6).

2.2.1 Unsuitable Backfill Materials

Unsuitable backfill materials include:

- Topsoil.
- Large rocks (diameter > 0.15 m).
- Frozen soil.

Section 2.2

The Iowa DOT SUDAS Spec. Section 3010-2.03 (see Attachments) defines a number of common backfill materials, their requirements and uses. Among these, the following backfill material types are distinguished:

- Natural coarse-grained soils with fines such as silty gravels or sands and clayey gravels or sands. These are allowed for use as backfill material where water conditions in trench may cause instability.
- Natural fine-grained inorganic soils such as inorganic silts or low to medium plastic clays. These are allowed as backfill material in dry conditions only.
- Natural fine-grained inorganic, high plastic silts and clays with a liquid limit > 50%. These are allowed as trench backfill material in dry conditions only, and should not be permitted in the pipe embedment zone.

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Section 2.3

The maximum limit allowed by Iowa DOT of fines content (i.e. percentage passing sieve no. 200) in the backfill material is 10% (see Schaefer, V. et al, xvi).

The Nanaimo Engineering Standards and Specifications Section 4.20 limits the content of fines passing a sieve with an opening of 0.075 mm, to 8%.

- Stumps, logs, branches, roots and brush.
- Construction waste, metal or trash.
- Contaminated soils.
- Soils with organic content, smell or staining.

Any of the above materials should be removed from the trench and disposed of.

2.3 UNBOUND GRANULAR MATERIALS

Natural or manufactured granular material is used as bedding and backfill. Most commonly, subbase and base materials are used. Granular materials have an advantage over common materials in that they have a higher strength and retain that strength over a wide range of moisture contents, specifically when confined under pavement or in a trench. A granular material's strength depends on its particle gradation and the amount of interlocking between the particles. Crushed granular material has a higher proportion of angular faces than screened granular material, resulting in better particle interlocking. All granular materials have larger voids than common materials, resulting in less capillary action and a potential for less changes in moisture content due to frost action.

When using granular backfill materials for trench reinstatement works, the goal of testing is to ensure that proper compaction has been achieved. Proper compaction can be defined in a number of ways:

- A level of compaction matching the compaction of adjacent materials.
- A level of compaction specified by material specifications.

2.3.1 Virgin Aggregate Mixes

Crushed, screened and blended virgin granular aggregate is the traditional choice for trench backfill material. Where using it in a road structure where subbase and base layers are present, it is advisable to match the subbase and base specifications in order to avoid moisture-related issues (see Section 2.3). Where no specification for the road's granular materials is known or can be obtained by sampling and testing, granular backfill material specifications such as the ones provided in the local pavement standard and specifications can be followed (see Appendices 1 and 2 for SK MHI specifications for base and subbase granular materials).

2.3.2 RAP Aggregates and Blends

Unbound granular aggregate materials containing up to 100% reclaimed asphalt or concrete material can be used as a substitute for the virgin aggregate mixes in backfilling trenches (see insert). Reclaimed asphalt material contains bitumen which tends to lend the material some cohesiveness and durability while remaining pervious.

2.4 TRENCH REINSTATEMENT ISSUES RELATED TO THE USE OF COMMON SOILS AND GRANULAR MATERIALS AS BACKFILL

When improperly selected and installed, granular materials and common soils may pose a number of trench reinstatement issues as discussed below.

Short and long-term settlement issues are most commonly related to poor material compaction either in the trench itself or immediately beside it. This can be the result of the following:

- Disturbance of the material at the bottom or sides of the excavation.
- The compaction equipment is too large for the trench, resulting in the inability to reach all areas and compact them properly. This can be addressed by specifying appropriately sized compaction equipment.
- The compaction equipment is overused at the center of the trench and underused at the edges, resulting in uneven compaction levels.
- The backfill material is added in lifts exceeding 300 mm or in lifts unevenly distributed across the trench, resulting in poor compaction at the bottom of the lifts.
- The material is under-compacted in the hard-to-get areas such as beneath and around the utility, in the corners of the trench and at the bottom of the slopes.
- There is loss of material at the cuts adjacent to the trench. This can be addressed through proper trench wall support and by avoiding driving heavy equipment close to the trench edges.

Frost heaving and road failures may result from a combination of poor material selection and poor backfill compaction which allow elevated moisture levels in the trench backfill material. The latter is related to the following issues:

- An excess of fines in the backfill material may impede water from draining freely and increase the effects of capillary suction. This can be addressed by following the appropriate material specifications for soils, specifically their specified maximum

Section 2.3.2

The City of Saskatoon, Saskatchewan, uses granular material backfill with up to 100% reclaimed asphalt pavement content to backfill utility cuts. In the City's experience, such backfill material is more durable than virgin aggregate material used for the same purposes. The City of Regina, Saskatchewan, also successfully uses reclaimed asphalt pavement material to backfill trench cuts (Widger, A. et al, 2012, p.24).

A Texas study of the crushed concrete materials for paving and non-paving applications has determined that 100% crushed concrete material fines "meet the present requirements for TxDOT Item 400 backfill," and recommends this material for use in pipe backfill and cement stabilized backfill (Lim, S. Et al, 2001, p.127). The same study, when testing crushed concrete material for base course applications, determined the following (see p.130 of the report):

- An excessive capillary rise was observed for crushed concrete mixtures under a continued soaking condition, indicating possible moisture susceptibility of the mixture. However, the strength test results indicated that crushed concrete mixtures are not so highly moisture susceptible as suggested by the absorptive properties.
- Crushed concrete mixtures always showed higher strength than conventional mixtures. Test results support the use of crushed concrete materials, including CPCC fines in flexible base mixtures.

Section 2.6

The European Standards for Hydraulically Bound Mixtures are found in Specification EN 142227, which includes a description of permitted constituents, mixture types and laboratory mechanical performance classification for the following HBM types (From Hydraulically Bound Mixtures site):

- Cement bound granular mixtures.
- Slag bound mixtures.
- Fly ash bound mixtures.
- Fly ash for hydraulically bound mixtures.
- Hydraulic road binder bound mixtures.
- Soil treated by cement.
- Soil treated by lime.
- Soil treated by slag.
- Soil treated by hydraulic road binder.
- Soil treated by fly ash.

percent of fines, and by testing the supplied material before its placement.

- An unevenly restored road structure: subgrade, subbase and base layers of a road differ drastically in their particle size distribution properties, with finer materials being located below coarser ones. In a restored trench where these layers were not restored to the elevations of existing layers, water barriers or lenses can be created.

2.5 BITUMEN-BOUND MIXES

Bitumen-bound mixes are manufactured granular materials which are stabilized through the addition of bitumen. Such mixtures are known to have better strength and bearing capacity than un-stabilized soils and aggregates. Base aggregate materials mixed with small amounts of bitumen are also known as “black base” or “asphalt-bound base.” They may contain both virgin aggregate and recycled asphalt pavement material. The addition to the asphalt-bound base material of fly ash, Portland cement and rejuvenators can further improve its properties.

Asphalt-bound mixes are also used to finish the repairs at the pavement surface. The mix should be designed to the expected loading and the thickness should be based on the required surfacing structure. Thicker is not necessarily better for asphalt layers, as thicker lifts are more difficult to compact. A good compaction of the asphalt concrete layer can be achieved by placing and compacting the material in layers not exceeding 60 mm.

2.6 HYDRAULICALY BOUND MIXES (HBM)

Hydraulically bound mixes, known also as soil cements or cement treated materials, are materials which have been stabilized with the use of cement, fly ash, lime, gypsum, granulated blast-furnace slag or steel slag, and other stabilizers. The stabilization process includes chemical reactions (such as hydration in the presence of water) which result in the formation of cementing agents (WRAP, 2007, p.12). Soils used to produce hydraulically bound mixtures include virgin granular aggregates, common excavated materials and recycled materials (HBM site, 2012) such as crushed concrete.

The advantage offered by this technology is that it improves the trench backfill material (such as wet common materials) properties such as strength, stiffness and durability (WRAP, 2007, p.13) while binding moisture. The moisture is bound in the course of the hydration reaction during which water binds with cement, forming crystals (which are the hydration products) around the aggregate. Therefore, hydration reactions in a cement-stabilized soil decrease the amount of available water, drying the material while strengthening it.

2.7 ISSUES RELATED TO THE USE OF STABILIZED SOILS IN TRENCH REINSTATEMENTS

Hydraulically or bitumen-bound mixes address a number of problems related to the use of common soils and granular materials as backfill, such as bearing capacity and moisture. The stabilizing constituents must be considered in terms of impacts on the utility. Where the utility is a non-protected metal pipe, the constituents should be non-corrosive. Where the utility is fabricated with plastic, the constituents should be non-abrasive.

It should be noted that stabilized materials have plasticity and moisture characteristics that are entirely different from adjacent subgrade. This may result in differential shrinkage, swelling and frost action.

2.8 LOW-STRENGTH CONCRETE

Low-strength concrete, also known as “controlled density fill,” “flowable mortar,” “unshrinkable fill” and “flowable fill,” is a trench backfill material which possesses a number of desirable properties as discussed below:

- It does not require compaction, it does not settle, and there is a documented history of satisfactory performance as a trench backfill material (Emery, J. J. et al, 1987).
- It has strength and durability, ability to be excavated in the future, little required field inspection, minimal traffic delay, year round usage, and lower placement costs as a result of self-compacting properties (i.e., no compaction equipment needed and therefore construction of narrow trenches) (Schaefer V. et al, 2005).
- Its use, when compared to traditional materials such as sand and clay, results in significantly reduced stresses in pipe under traffic loading (Zhan, C. et al), potentially reducing the risk of pipe breakage.

Some of the disadvantages of using low-strength concrete fill include a higher initial cost and a potential for pipes to float, an effect that can be avoided by placing the fill in lifts (ACI, 1994). Low-strength concrete fill may also have significantly different moisture characteristics compared to adjacent soils, resulting in differential heave or shrinkage. In addition, concrete may have different thermal characteristics than adjacent materials, resulting in different surface icing conditions or frost heaving.

The desired material properties of low-strength concrete as a fill material include (see insert for more examples):

- A minimum 0.07 MPa strength within 24 hours.

Section 2.8 – The Use of Crushed Concrete Material as Aggregate in Low-Strength Concrete

A Texas study of the crushed concrete materials for paving and non-paving applications tested the use of crushed concrete fines material to substitute conventional aggregate in flowable fill, and determined that it can be used for this purpose. Some of the key findings of the study regarding the use of crushed concrete fines in this application are summarized below:

- Due to the large amount of - No. 200 material in the CPCC fines, it was difficult to entrain air into flowable fill mixtures containing this material. Therefore, trial mixing is recommended when air entrainment is desired.
- The high level of - No. 200 material in the CPCC fines increased the water demand of flowable fill using CPCC fines.
- For the same mixture proportions, flowable fill with CPCC fines was weaker than flowable fill using conventional aggregates. Increasing the cement content of the mixtures compensated for the strength decrease due to the increased water demand (Lim, S. Et al, 2001, p. 132).

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“Based on long-term Winnipeg experience (...), unshrinkable fill <with specifications provided in Section 2.8> was subjected to extensive field trials and cost analyses (...) and is now required for all <Metropolitan Toronto> utility cut restorations” (Emery, J. et al, 1985).

While it is generally agreed that backfill concrete should be lightweight and low-strength (so that it can be excavated later on), various road agencies publish specifications which differ in terms of specified strength and added cement quantities. See below two example concrete backfill material specifications.

The Nanaimo Engineering Standards and Specifications Section 4.21 state that “concrete for pipe base, encasement or backfill shall have a minimum compressive strength of 20 MPa at twenty-eight (28) days.” Section 4.24 of the same document provides a design mix for low-strength concrete fill with a required compressive strength of 0.5 MPa at 28 days, and a slump of 150-200 mm. See this document in Attachments for details.

The Iowa DOT uses the term “concrete low strength materials” (CLSM) to describe low strength concrete backfill material. The specification for the material include 100 lb/yd^3 (59 kg/m^3) of cement, 300 lb/yd^3 (178 kg/m^3) of fly ash, 2600 lb/yd^3 (1543 kg/m^3) of fine aggregate, and about 585 lb/yd^3 (347 kg/m^3) of water (see ACI, 1994 for complete specifications and other information).

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The StableFlow^{tm} technology, by Cellular Concrete Technologies LLC, of Irvine, CA, is a foamed concrete product with a claimed air content of 76%, density of 30 lb/ft^3 (480 kg/m^3) and meets the requirements of excavatable concrete with cured strength below 150 psi (1030KPa) (see Cellular Concrete Technologies, 2011).

- A maximum 0.4 MPa strength at 28 days.
- A slump of 160 to 200 mm (Emery, J. J. et al, 1987).

Typical low-strength concrete fill material specifications stipulate 25 kg of cement per m^3 of fill and standard concrete aggregates (or about 1% w/w); the area must be protected for 24 hours (Emery, J. J. et al, 1987).

Low-strength concrete is especially suitable for narrow or small trench backfilling, and requires no compaction equipment or in-situ compaction testing. Recycled crushed concrete material can be used as aggregate for low-strength concrete (see insert on previous page).

2.9 FOAMED CONCRETE

Foamed concrete, also known as “lightweight concrete,” is a form of concrete where the air content is increased by use of air entrainers. This material is suitable as trench backfill, especially in areas where soil stability is a problem and lightweight backfill material may alleviate some of the risk.

Like low-strength concrete, this material is flowable, requires little or no compaction (and thus no compaction equipment or testing), can be excavated and is suitable for small or narrow trenches. Foamed concrete sets quickly, making it possible to resurface the road in a matter of hours. The disadvantages of foamed concrete are similar to the disadvantages of low-strength concrete, discussed in the previous section. Foamed concrete is noted for very good insulating properties relative to unbound materials, a characteristic which may lead to differential frost action. However, a high groundwater table in the area may be a concern as foamed concrete has a higher porosity, and by extension, a higher capacity to store water, than common and granular soils.

The UK Manual of Contract Documents Series 1000 specifies the following parameters for foamed concrete (see p.29):

- A minimum 7-day compressive strength of 0.4 MPa and a maximum 7-day compressive strength of 1.0 MPa.
- A maximum aggregate size of 6.3 mm, unless larger aggregate can be shown as practical.

Foamed concrete has a high voids content and, by extension, an increased potential for water retention. While this does not impact the fill itself, it may impact the adjacent materials in terms of moisture and frost action.

2.10 TRENCH REINSTATEMENT ISSUES RELATED TO USE OF LOW-STRENGTH CONCRETE AND FOAMED CONCRETE AS BACKFILL MATERIAL

Low-strength concrete and foamed concrete eliminate settlement problems in the area of the trench cut. However, soils in the vicinity of the cut continue to exhibit both seasonal differential movement associated with freeze-thaw cycles, and settlement where soil disturbance or poor soil compaction exists. This problem is intensified by the differential in the water-conducting properties of the concrete and adjacent soils, which create moisture barriers and cause the moisture to concentrate at the cut edges.

This problem cannot be resolved at the time of trench reinstatement as it is not caused by the concrete backfill but rather by the surrounding materials. This issue is best addressed by correct structural road design, which specifies appropriate base and subbase materials with free-draining properties, placed uniformly throughout the cross-section of the road structure, allowing for lateral water drainage. Consequently, it is expected that deficiencies such as differential soil movement adjacent to a concrete-filled trench cut are more likely in road structures, where the asphalt concrete mat is placed directly on compacted earthen material; such materials generally exhibit higher plastic properties.

2.11 GEO-SYNTHETICS

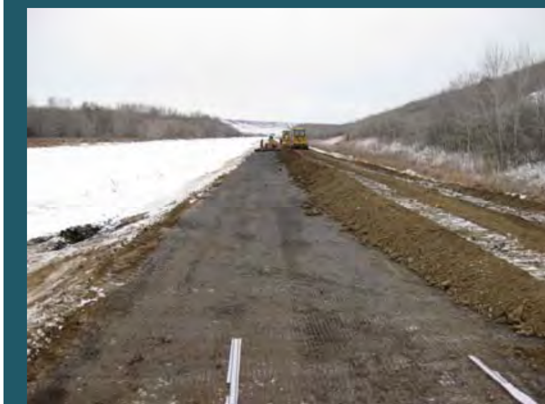
Geo-synthetics are polymeric materials used to solve civil engineering problems. There are six main geo-synthetics categories which can be used to improve trench restorations.

Geo-textiles are woven or non-woven fabric-like materials which provide particle separation. They are typically placed on the top of the compacted common soil layer, directly beneath the granular material Geo-textiles are commonly used to prevent fine particles from migrating upward into granular beds in wet areas, and are especially useful in areas with a high seasonal water table, where the granular layers may otherwise lose some of their free-draining properties due to and increased fines content. Geo-textiles also lend some strength to the subgrade, but due to some elasticity of the fabric, they need to deform (stretch) in place before this happens.

Geo-grids are extruded rectangular grid structures which provide longitudinal and lateral rigidity. They are used to improve the strength of subgrade where it is weakened by moisture or poor soil conditions. They are installed at depths of 100-600 mm below the road surface in the granular material or bitumen-stabilized granular material. They

Section 2.11

The picture below, courtesy of Clifton Associates Ltd., shows Morsky Construction Ltd. installing geo-grid in a gravel road section at the Muscowpetung First Nation Reserve. This road section was located adjacent to a section of land which was under water for a significant period of time, and has failed due to wet conditions. The geo-grid has lent the road structure sufficient stability to perform satisfactorily after the repairs have been completed.



Geo-grids such as in the picture above have significant lateral and longitudinal tensile strength, while its structure allows interlocking with the granular material which keys it into place. Geo-grids can be used over extended road lengths or in localized spots, such as trench cuts, where subgrade and moisture conditions negatively impact the road's performance.

improve the bearing capacity of the subgrade by confining the material, and add tensile strength without deformation normally required by a geo-textile.

Geo-nets are extruded net-like materials with two, three or more rigidity planes (or axes) which are used for water drainage in such applications as landfill leachate collection.

Geo-foam represents expanded or extruded polystyrene and is used as lightweight filler or backfill. Geo-foam can minimize settlement of underground utilities placed under high fills by reducing the load on them.

Geo-cells (see insert on p.28) are three-dimensional structures designed for erosion control and structural reinforcement. In utility cut restorations, they are suitable for road resurfacing applications. They are installed at the surface of the restoration, flush with the surrounding pavement, and then filled with granular material. Geo-cells confine the granular material and improve the pavement bearing capacity.

Geo-composites are combinations of any of the above geo-synthetics with the purpose of combined applications. For example, geo-grids and geo-cells are commonly combined with geo-textile materials which are normally installed at the bottom. The function of the geo-textile in the composite is to prevent the migration of poorer quality (finer) particles into the upper layers of the road structure.

2.12 PAVEMENT SURFACE MATERIALS

When restoring the pavement surface during trench restoration works, high-quality permanent patching materials matching the pavement type must be used (Emery, J. J. et al, 1987). High quality base materials with a high proportion of fractured face result in good particle interlocking and high strength. Asphalt concrete materials with a good mix design and high stability will provide high strength even if density is not fully achieved due to construction conditions. The high strength mixes are also able to withstand the impact loading which may be associated with bumps associated with surface irregularities, settlement or differential movement.

To mitigate reflective cracking from developing along the trench edges, fibreglass paving mat or tape can be embedded between the lifts of the asphalt concrete structure.

3. TESTING METHODS

Two types of testing are distinguished: laboratory testing and field testing. Testing requirements depend on the backfill material used, with the overall purpose to ensure compliance with material and placement specifications.

For soil and granular materials, the purpose of laboratory tests is:

- Determining the properties of the material in order to find whether it is suitable as backfill.
- Determining the optimal moisture and compaction levels.

One concern with testing is that trench reinstatements are typically small and may have variable materials, so having representative tests can be a challenge.

Laboratory testing is done prior to the placement of backfill in the trench. Field testing follows laboratory tests and occurs at the time of backfill material placement and compaction. The purpose of field testing is to determine whether the minimum required compaction levels have been achieved throughout the backfill thickness. For unbound materials, the intent of any quality control field testing is to ensure that the material is at a suitable moisture condition for compaction and that adequate compaction is achieved. A material that is too wet or too dry can be difficult to compact properly and may not perform well (see insert).

For low-strength concrete fill material, laboratory testing is generally done at the stage of the mix design and in the field to ensure quality control. The field testing program includes slump tests and air content testing, as well as the collection of sample concrete cylinders; these are used later in the laboratory to determine 7-day and 28-day strengths.

3.1 LABORATORY TESTING

Following are some typical laboratory tests used for the purpose of characterizing unbound backfill materials such as common soils and manufactured granular material.

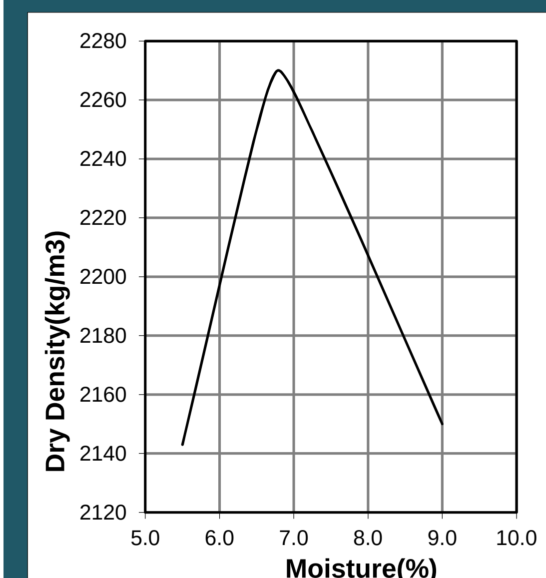
Sieve Analysis: this test determines a granular material's particle size distribution and gradation. Larger particle sizes indicate a stronger material, whereas a uniform distribution indicates good compaction and draining properties. See Appendix 1-2 for example material specifications for granular material.

Section 3.1 – Proctor compaction test

Two Proctor compaction tests are distinguished, Standard Proctor and Modified Proctor. Both measure the maximum dry density of a compacting material, and the corresponding optimum moisture content, with the main difference being that the Modified Proctor specifies a higher compaction effort, resulting in higher maximum dry densities. The optimum moisture content is the water content at which the soil compacts best; soils that are too dry are insufficiently lubricated for soil particles to slide about and compact, whereas soils that are too wet are too lubricated for particles to key in place.

See below an example of a Standard Proctor testing curve, courtesy of Clifton Associates Ltd. Note the maximum (peak) dry density of 2,270 kg/m^3, read on the Y-axis, and the corresponding optimum moisture content of 6.8%, read on the X-axis. The maximum dry density is the compaction level that is desirable to achieve in field. Note that for moisture levels different from optimum, the maximum dry density achieved for the same compaction effort is always lower. In practice, this means that soils that are too wet or too dry, will not compact as well and will be prone to settlement over time.

The compactive effort required to achieve a certain density varies with moisture as well. Soil that is drier or wetter than optimal requires a higher compactive effort.



Section 3.2.1

Typical Standard Proctor dry density values differ depending on the material. In Saskatchewan, typical Standard Proctor values fall in the range of 2,100 – 2,400 kg/m^3 for granular materials (Tam, 2013) and in the range of 1,400 – 1,500 kg/m^3 for high-plastic clays, although for the latter they can be as low as 1,350 kg/m^3 (Latimer, 2012).

Section 3.2.1

The picture below, reproduced from humboldtmfg.com, shows a Humboldt's HS-5001EZ Nuclear Density Gauge. Gauges such as this one are used to test moisture and soil density. While they are typically used in conjunction with a Proctor Test, they can be used without such testing as discussed in Section 3.2.1.

Costs: New nuclear density gauges cost around CAD $8,000-9,000. Used nuclear density gauges can be occasionally purchased and run around CAD $5,000-7,000. There are regulated storage and transportation requirements for nuclear density gauges which will add to the cost of use; a radiation safety officer must be on staff as well. Radiation safety and TDG training are also necessary for all staff using nuclear density gauges.

Unified Soil Classification: this test classifies common type materials and their properties such as plasticity, and can help determine if the material is suitable as trench backfill (see Section 4.1).

Proctor Compaction Test: this test determines the optimal moisture content to achieve the maximum compaction. Backfill materials which have not been compacted to the required Proctor density are prone to settling (see insert on previous page).

3.2 IN-SITU FIELD TESTING

3.2.1 Nuclear Density Gauge

The nuclear density gauge is used to find (a) the dry density and (b) the moisture content of backfill material after compaction. It is used to determine the compaction level of the backfill material after it has been placed and compacted, and compare it to the laboratory-determined Proctor compaction levels. A nuclear density gauge provides the most direct means of testing backfill compaction. It can measure compaction to depths up to 300 mm.

Average compaction levels below 100% standard Proctor in the top layers, and below 98% in the mid layers are indicative of likely trench settlement issues in the future. Alternatively, 95% modified Proctor compaction is admissible since it represents 95% of a higher value (see Nanaimo Engineering Standards and Specifications, Sect. 4.14, p.4-9). Some literature suggests somewhat lower minimum compaction levels at 95% standard Proctor (see Kim, H. et al, 2010, p.239). Also, lower compaction levels such as 95% standard Proctor are acceptable at depths below 600 mm.

The nuclear density gauge can be used to test compaction without Proctor testing for base compaction values. This is done by repeatedly taking dry density readings of the soil after some compaction works have been performed. Compaction is continued until density no longer increases significantly. A good compaction effort is achieved when two consecutive readings, taken before and after a compaction effort, do not differ by more than 0.2% (4.2-4.4 kg/m^3 for typical Saskatchewan granular materials and 2.8-3.0 kg/m^3 for typical Saskatchewan high-plastic clays). It is important to understand that this testing allows maximum compaction *at present moisture conditions*, which may be different from the optimum ones; as a result, the compaction level may be lower than desirable. It should also be noted that it is possible to over-compact some materials, which results in a drop of dry density.

3.2.2 Dynamic Cone Penetrometer Testing

The dynamic cone penetrometer (DCP) testing consists of measuring the rate of soil penetration by a device with a controlled weight, shape and drop height. The resulting rate of penetration (referred to as penetration index), in mm/blow, is correlated with the CBR of the soil.

The test allows measuring the strength of the soil to depths of up to 2-3 m below surface. For tested backfill materials, soil strength can be correlated with the degree of compaction. The test can also be used to compare compacted material to adjacent materials with similar plasticity.

While DCP testing offers some advantages over nuclear gauge testing, such as safety, training requirements and ease of transportation, it does not offer a simple way to correlate test results to soil compaction. A study of the use of DCP as means of measuring soil compaction suggests that it can be used to estimate in-situ soil compaction using three models developed for three types of soil (see Kim, H. et al, 2010, p.239-240). DCP testing cannot be used to test coarse granular materials.

3.2.3 Light Weight Deflectometer

The light weight deflectometer, also known as the portable falling weight deflectometer, measures the vertical deflection of the pavement surface in response to a controlled load. This test helps detect voids or poorly compacted soils under the pavement surface. This apparatus is designed for use on paved surfaces, but can be used on any other uniform surface such as compacted soil.

The test is used to evaluate the long-term performance of reinstated trenches. A study by the ERES Consultants Inc. for the City of Burlington, Vermont "achieved little success in presenting a quantitative measure (...) to provide statistically significant conclusions" (Zeghal et al) on the pavement condition for the purpose of evaluating utility cut reinstatements.

Similar to nuclear density gauges, portable falling weight deflectometers can be used in trench reinstatement to establish a relative measure of compaction to determine the required compactive effort for the same type of material.

3.2.4 Clegg Hammer

This test is an alternative to the nuclear density gauge testing. It uses a falling weight to measure "the peak deceleration of the falling hammer, which is correlated to the stiffness or shear strength of the

Section 3.2.2

A study of Iowa trenching practices found that DCP testing yields higher CBR values near the center of the excavated areas when compared to CBR values obtained near the edge of the trench. This finding was mirrored by FWD tests which showed higher deflection values at the trench edges.

This indicates that smaller compaction equipment may be needed to achieve uniform compaction throughout the trench (Schaefer, V. Et al).

Section 3.2.2

Dynamic cone penetrometers cost in the range of CAD $1,000-2,000. Training requirements are fairly basic, with step-by-step instructions available from a number of sources such as MHI's Standard Test Procedures Manual 240-20 (see Appendix 6).

Section 3.2.3

The picture below of a light weight deflectometer is reproduced from Ontario's Transportation Technology Transfer Digest- Summer 2010- Vol. 16, Issue 3 (Ontario Transportation). Light weight deflectometers are a smaller version of the truck-mounted falling weight deflectometers used to measure pavement deflection (bending).

Section 3.2.4

The Clegg Impact Value has been empirically correlated in a number of studies to CRB values, which in turn measure the strength of subgrade. Some of the empirical correlations are shown in the table below, reproduced from Kim, H. et al, 2010, p.59.

Research Test condition	Material tested	Correlation equation
Clegg (1980, 1983)	In situ /Base course	$CBR = 0.072(CIV)^{2}$
Mathur and Coghlans (1987)		$CBR = 0.1085(CIV)^{1.863}$
Al-Amoudi et al. (2002)	Lab & In situ	$CBR = 0.1691(CIV)^{1.695}$

material (...); the output is displayed terms of the Clegg Impact Value (CIV)" (Kim, H. et al, 2010, p.57). A minimum CIV of 18 is needed to ensure proper compaction beneath a pavement surface (Schaefer, V. et al, 2005).

While the Clegg Hammer testing offers some advantages over nuclear gauge testing, such as safety, training requirements and ease of transportation, a recent study of the use of Clegg Hammer as means of measuring soil compaction suggests that it cannot be used as a compaction quality control tool without some changes to the data acquisition and tool itself (see Kim, H. et al, 2010, p.245). Clegg hammers are a suitable tool for establishing relative compaction levels to determine the required compaction effort for the same material.

3.2.5 GeoGauge

The geogauge helps determine inconsistencies in the level of soil compaction. This tool is used on site during backfill compaction to complement density readi

ngs taken with a nuclear density gauge. It allows identifying weak or poorly compacted areas on the spot.

3.2.6 Electrical Density Gauge

Like the nuclear density gauge, the electrical density gauge tests compaction and moisture levels in soil. The testing is done by means of high frequency radio waves traveling between electrodes driven into soil.

While this technology has been available on the market for some time, older models tend to be less reliable than nuclear density gauges (Latimer 2012). A new model developed by Humboldt Mfg. Co. (see Humboldt, 2012) has been recently ASTM-D7698 approved and may provide a viable alternative to nuclear density gauges.

3.3 TESTING OPTIONS FOR SMALLER AGENCIES

For unbound backfill materials, testing or quality control processes should be adopted that allow control of placement, moisture content and adequate compactive effort to achieve appropriate material density. This can be achieved through specifying a moisture content based on material classification testing and on relative density, which is correlated to a compactive effort.

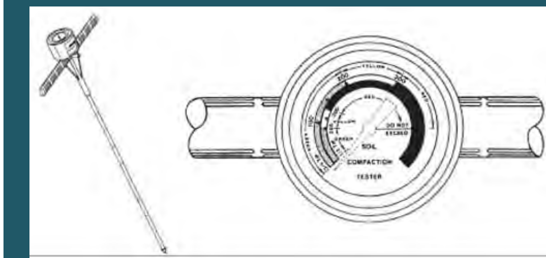
The compactive effort should be specified and the compaction measured by any of the described methods. This is accomplished by applying the compactive effort, testing and then re-compacting until no increase in the test results occur. A site-specific compactive effort is then established.

Even for small projects where no lab testing or field testing equipment is available, staff should provide the best materials and compactive effort possible under the circumstances. Simple visual material identification tools and moisture testing techniques should be employed to determine if the material is in the correct moisture range for proper compaction. Relative density can be determined using something as simple as a large screw-driver or a piece of re-bar with welded cross-pieces to act as a probe. Once a reasonable compactive effort has been applied to the backfill material as it is placed, the probe is forced into it to the depth of the lift. For a properly compacted lift, penetration should become more difficult with depth. If the probe penetrates too easily, additional compactive efforts, followed by testing, are required. The probe can be used to establish the compaction of the subgrade surrounding the trench; only undisturbed material should be tested for compaction levels.

Pressure-gage equipped soil penetrometers (see insert) are used to test soil compaction in agricultural applications, and could be potentially adapted to check soil compaction for trench restorations.

Section 3.3 – Simple compaction tests

A penetrometer is a simple tool for soil compaction testing; it costs around $200. It has a graded shaft and a pressure gauge. It is used in agriculture to check the subgrade compaction, but it could be adapted to evaluate soil compaction in trench reinstatement works (see Duiker, S.W.)



4. METHODS AND EQUIPMENT FOR TRENCH REINSTATEMENT

4.1 PREPARATORY WORKS

The intent of preparatory works is to investigate the soil conditions at the proposed trenching site, determine the method of utility installation and trench reinstatement, and select the appropriate backfill material. The investigation of soil conditions may include collecting information about the road structure and investigative drilling, complete with sample collection. It is also advisable to survey the road profile for construction stakeout and final survey purposes.

Preliminary lab testing of subgrade materials can provide information on the base, subbase and subgrade compositions, as well as provide indication of current moisture conditions and information on whether the common material can be re-used as backfill.

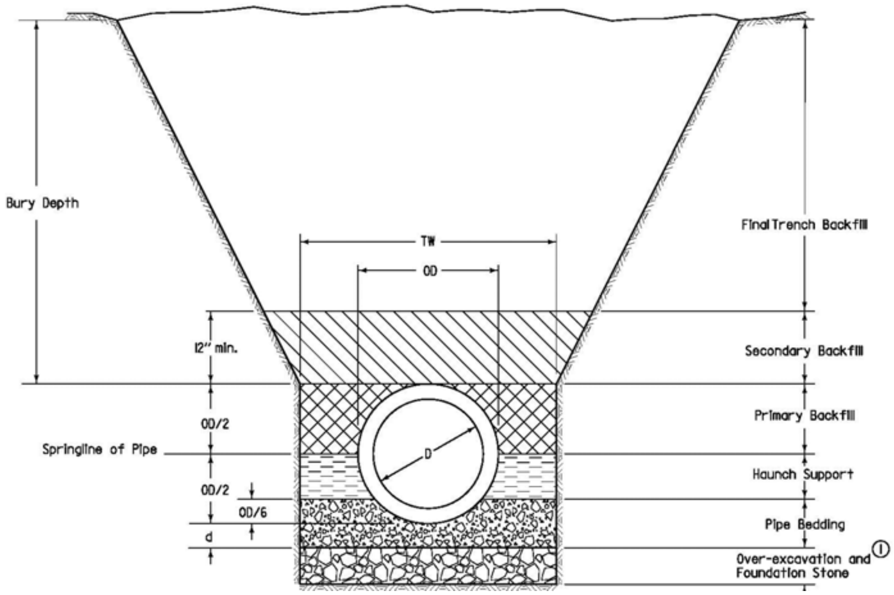
4.2 GENERAL PRINCIPLES FOR OPEN TRENCH CUTS

4.2.1 Material Selection

When using compactable backfill material such as common borrow, excavated in-situ materials or granular materials, both bound and unbound, compaction quality control is essential. Generally, the use of compactable backfill material will require a larger trench. In general terms, hydraulically bound materials offer a potential advantage over their unbound counterparts, lending themselves to use as structural layers. Research has shown that hydraulically bound materials with a compressive strength over 3MPa can be considered resistant to frost heave (WRAP, 2007, p.16).

Geo-synthetic materials are used in conjunction with compactable backfill materials to provide added tensile strength to the structure and/or provide particle separation.

Low-strength concrete and foamed concrete are especially suitable for one-step trench reinstatement works, as they do not require compaction and do not exhibit subsequent settlement (provided that the bottom and sides of the excavation are undisturbed). Their use also generally results in smaller trenches.



Low-strength and foamed concrete materials can also be used in conjunction with compactable backfill materials as pipe embedment and encasement materials (see Iowa DOT (8), 2009, and Iowa DOT Section 3010, p.7). The benefit of using this material around the utility is that, having no need for compaction, it minimizes the risk of damage to the utility from compaction equipment while providing adequate support and encasement.

4.2.2 Excavation Works

Prior to excavation works, a utility locate request must be made and the surrounding facilities must be protected as required. Cut the edge of excavation in a straight line to avoid road surface deterioration (Emery J. J. et al, 1987). On sideslopes or other adjacent green areas affected by the repair, remove and stockpile topsoil if such is present. Excavate all unsuitable backfill material (see Section 2.2.1) at least 0.15 m below and on each side of the pipe, and restore trench dimensions by using bedding or stabilization material (Iowa DOT Section 3010). Keep the excavation free of water. Use excavation equipment or processes that do not disturb materials adjacent to excavation. This means excavating from trench ends rather than from sides, so that the material is not pulled up. Keep equipment away from the edges of excavation. Bracing the trench walls is essential to avoid collapse and loss of material in the immediate vicinity of the cut. For water, sewer and other pipes with potential for flotation, use pipe restrains (see Iowa DOT (3), 2009).

The choice of excavation equipment depends on soil and weather conditions and size of the excavation among other things. It is generally desirable to keep the trench size as small as practical. This can be achieved by substituting or supplementing traditional excavation equipment with smaller excavation equipment such as mini-backhoes or trenching bucket attachments for excavators

Section 4.2 – Backfilling

The drawing to the left, reproduced from Iowa DOT Section 3010, shows the excavation and backfill zones.

The zone of over-excavation and foundation stone is located below the desirable bottom of the trench. This zone requires excavation only when the material is entirely unsuitable for trench backfill – for example, it is too wet, loose, or contains large rocks.

The pipe bedding zone, with a depth of 1/3 of the pipe outside diameter as recommended by Iowa DOT Section 3010, is located directly beneath the utility. The haunch support is located above the bedding zone and up to the pipe's middle. These zones are commonly under-compacted; failures often start here. Adequate compaction in these zones can be achieved through the use of smaller compaction equipment. Alternatively, they can be backfilled with materials not requiring compaction, such as low-strength concrete.

See Section 3.05 of Iowa DOT 3010 for information on suitable materials and required compaction levels for all zones.

Section 4.2 – Trench Excavation Equipment

Trenching bucket attachments for excavators, such as the ones pictured below (reproduced from www.hiremax.co.nz), come in a variety of widths, allowing for proper sizing in accordance with the planned trench size.

V-notched excavator trenching buckets such as the one pictured below (V-Raptor Bucket from Leading Edge Attachments) will help excavating a trench with sloped sides without over-excavating or disturbing the bottom.

(see insert), or replacing it altogether by using alternative excavating technologies such as hydrovac (see insert in Section 1.2.1).

4.2.3 Backfilling with Common Materials, Unbound Granular Materials, Hydraulically Bound Materials or Bitumen-Bound Materials

When backfilling, remove all unsuitable, loose or undermined material (Emery J. J. et al, 1987). While it is not necessary to use the same backfill material through the entire cut, the general order of materials placement is as follows, listed from bottom to top (from WRAP, 2007, p.15-16):

- In the backfill zone at the bottom of the trench, use common cohesive material with a CBR of 2-4%, or a hydraulically bound material with a soaked CBR of min. 2%.
- In the mid-backfill zone, a cohesive or granular material with a CBR of 4-7%, or a hydraulically bound material with a soaked CBR in the same range.
- In the upper backfill zone, a granular material or a hydraulically bound mix with a CBR value of 7 to 15%.
- In the capped zone, a graded granular or hydraulically bound material with a CBR value of 15-30%.
- In the subbase and base zones, a graded subbase or base material or equivalent hydraulically bound material with a CBR value above 30%.

Place compactable backfilling material in lifts not exceeding 300 mm to ensure proper compaction (see Schaefer, V. et al, 2005). Use smaller compaction equipment to reach confined areas or areas close to the trench edges, as these tend to be less compacted (see Schaefer, V. et al, 2005). During backfilling and compaction, pull down any loose material from the edge of the trench. Attempt to compact edges first and then work towards centre.

A common deficiency pertaining to backfill material placement consists in dumping it in the center of the trench and then not distributing it properly towards the edges. Distributing the backfill uniformly, as it is placed, throughout the trench, or placing more backfill material along the perimeter than in the center (eventually levelling it out towards the surface) alleviates the problem of poor compaction along the trench perimeter and around the utility. Backfill materials should be dumped along the edges rather than in the middle to avoid over-compaction of the center and under-compaction of the edges.

Proper compaction equipment sizing is the key to good backfill compaction, with most compaction issues being in some way related to inappropriately selected equipment. Suitable alternatives to traditional compaction equipment such as compaction rollers which are smaller and are specifically designed for compacting small and hard-to-access areas include compaction wheels, compaction plates, rammers and plate compactors (see insert).

Compaction equipment must also be selected to match the soil type. Sheep-foot compactors and rammers are used for cohesive soils such as clays, whereas vibratory compactors and rammers are suitable for granular soils.

4.2.4 Backfilling with Low-Strength Concrete or Foamed Concrete

Prior to placing the concrete in the trench cut, the bottom and the sides of the excavation should be cleared of any loose and disturbed material. This is especially important because concrete is not compacted and will not compact any soil it comes in contact with.

Low-strength concrete backfill does not require compaction or internal vibration, as its fluidity is sufficient to ensure proper compaction under its own weight. Low-strength concrete can be placed continuously in all applications with the exception of filling around pipes. Where areas around pipes are filled with concrete, it is recommended to place the concrete in lifts to prevent pipes from floating (PCA, 2012). Pipe bracing can also be used to prevent floating. Where the material requires pumping, a higher cementitious content may be required, which may increase its strength (CCAA, 2008) above specification and render it non-excavatable.

4.2.5 Backfilling with Combined Materials

Issues associated with compaction around the utility include poor access for equipment and risk of damage to the utility, especially where pipe bracing is necessary. This makes low-strength concrete and foamed concrete attractive choices of backfill material for bedding and haunch support (see insert on p.25). Once the concrete has set, the trench can be backfilled and compacted with compactable materials as discussed earlier (PCA, 2012).

4.2.6 Repaving

Repaving is the final step of a trench reinstatement process. Two types of pavement restoration are distinguished: temporary and permanent. Temporary restoration is done when conditions (such as weather) do not allow for permanent resurfacing to be done, or when planned surface rehabilitation works are scheduled for the road section where

Section 4.2 – Equipment for Backfilling with Compactable Materials

Compaction wheels attached to excavators come in a range of sizes and types. Arrowhead Rockdrill wheels (pictured below) come as pad foot or sheep foot types, and can be used in trenches as narrow as 200 mm (arrowheadrockdrill.co.uk, 2012). Also see Appendix 3 for Hensley® compaction wheel specifications.

Compaction, or tamper, plates which are attached to excavators are another small compaction equipment option. The Arrowhead Rockdrill plate pictured below can be used in trenches as narrow as 200 mm.

Rammers are especially suitable for compaction of cohesive soils (such as in-situ clays) in small areas, whereas vibratory compactors work well for non-cohesive granular soils (Concrete Decor, 2012).

Section 4.2.6 - Repaving

GravelPave[2] and BodPave40 are plastic subsurface reinforcement structures (also referred to as geo-cells) which are placed flush with the road surface and then filled with granular material. Depending on specification, these or similar materials can withstand significant traffic loading and are known to be used to construct emergency fire lanes and parking lots. The picture below, reproduced from www.terram.com, shows the installation of BodPave 40.

Section 4.2.6 Repaving

The local gas company in the City of London, Ontario, has adopted the method of road surface restoration using interlocking concrete pavers developed by the Interlocking Concrete Pavement Institute, first as a temporary measure and later, following good performance, as a permanent resurfacing method (Zeghal, M. et al). It is desirable to match the surface properties of the repair, such as friction, with those on the adjacent road sections – so, for asphalt pavement roadways, at the repair area, a microsurfacing, chip seal, cold mix or hot mix patch can be placed immediately or at a later time.

the trench repair is located. Temporary pavement restoration options include:

- Placing granular base or reclaimed asphalt concrete as a surfacing layer and sealing it. Alternatively, the seal can be substituted with a thin layer of cold mix or a material designed for repairs in adverse weather.
- Placing a geo-cell material (see insert, top of page) flush with the adjacent surface and filling it with granular material.
- Installing interlocking concrete paving slabs (see insert, bottom of page).
- Using a layer of low-strength concrete with the intent of excavating and replacing it at a later time.

Permanent resurfacing consists of restoring the road surface to its initial state. It is recommended that the surfacing materials are matched with those on the adjacent road sections to ensure that no differential moisture-locking, drainage, friction and other key pavement characteristics are introduced on the repair section. All cut edges should be sealed. Embedding fibreglass tape between the asphalt concrete lifts will minimize reflective cracking.

4.3 ONE-STEP TRENCH REINSTATEMENT

One-step open trench reinstatement refers to trench reinstatement methods where all trenching and reinstatement works are done in the same construction phase, with no additional works required at a later time.

One-step reinstatement is generally possible for the following circumstances:

- Suitable construction weather, including outdoor temperatures which allow for proper backfill placement, compaction, curing etc.
- Suitable moisture and water table conditions at the location of the trench.
- Suitable traffic conditions, meaning that at the time of repairs, the works can be conducted while providing the public with safe passing or detouring options.

Advantages of this method include potential cost savings due to only one mobilization event and less traffic disruption. The disadvantages include poor compaction and a higher risk of settlement of the repair over time.

4.4 STAGED TRENCH REINSTATEMENT

Staged trench reinstatement is used in circumstances where one-step reinstatement cannot be done. This may happen for reasons of adverse weather or season, in emergency repairs, or be part of a trench reinstatement method designed to mitigate short and long-term settlement.

In staged trench reinstatement, the first step is the temporary repair, when backfill material is placed into the cut, compacted to the best ability, and a temporary road surface is created to seal the repair and provide a driveable surface. Where low-strength concrete is used, it can be installed up to the road surface level to act as a temporary wearing surface, with the intent of milling it down and replacing it with a permanent surfacing option at a later time. Alternatively, paving stones can be used as a temporary wearing surface.

Permanent repairs are completed when the conditions around the trench allow for proper restoration. Permanent repairs consist in re-excavating the trench and restoring it as described in Sections 4.2.1 to 4.2.6.

It is important to note that in staged trench reinstatement, it is assumed that the backfill placed during the temporary repair is not compacted properly and must be re-compacted or replaced.

The advantages of staged trench reinstatement include:

- The ability to better address short-term settlement and moisture equilibrium by letting them occur prior to final repairs.
- The ability to schedule final repairs during a suitable season and weather conditions, as well as when suitable backfill materials are available.
- The ability to extend the repair to the adjacent pavement in order to level out any differential movement, and also to reduce the potential of pavement cracking along the edges of the repair.

The disadvantages include potentially higher costs of repair and repeated traffic disruption.

4.5 ISSUES RELATED TO EXCAVATED TRENCH REINSTATEMENT METHODS

Trench reinstatement issues discussed in Sections 1.3.1 to 1.3.4 are noted at trench repair locations where traditional reinstatement methods are used and are largely the result of poor backfill material compaction. However, discussions with practitioners reveal that lack of knowledge about compaction needs and requirements is not

Section 4.5

In larger road agencies, trench reinstatement and road maintenance works are commonly assigned to different crews and/or contractors. As a result, a lack of ownership over the repairs' long-term performance issues is noted (Ritchie, 2012). To encourage road crews to take ownership over their work's performance, some kind of accountability mechanism may be helpful. Tendering the trench reinstatement and pavement restoration works under the same contract is an example of such mechanism.

Section 4.7

Micro-trenching minimizes the roadway damage by limiting the cut to a width of 10 to 30 mm wide and about 150 mm deep as shown in the picture below.

The fibre-optic cable is placed into the micro-trench along with a tracing cable.

The trench is backfilled with a suitable crack sealant.

The three photographs above are reproduced from Stirling Lloyd Technical Advice Note 11-09. See this document in Attachments for more information. In the last picture, note the darker line along the road marking the finished seam.

generally at the root of poor compaction. Repair and maintenance planning practices, scheduling and responsibility assignment are some of the noted root causes for poor repairs (see insert). Other important root causes of poor repair include lack of good backfill material and lack of knowledge and training on proper backfill material selection.

4.6 OLD TRENCH REPAIR

Old trench areas typically require repairs after a period of time due to some type of deformation or failure that is impacting traffic. In the case where only the trench is being repaired, the hot mix over the trench can be milled out using a small milling machine. The depth of milling would be dependent on the deformation that has occurred in the trench backfill. The intent would be to mill deep enough to allow a uniform lift of new mix to be laid into the trench area. The milling should extend a minimum of 100 mm into the adjacent pavement. Fibreglass reinforcement can be added at the depth of mill below the asphalt concrete lift to reduce reflective cracking.

When an old trench is repaired as part of roadway rehabilitation, the above described method should be used on the trench prior to placing the overlay over the entire surface. Paving over a deformed trench usually results in none uniform mat thicknesses and variations in density that can result in early rutting or deformation of the surface at the trench.

4.7 MICRO-TRENCHING

Micro-trenching is an emerging technology developed in response to the need to install fibre-optic cable in a fast and efficient manner. It consists of cutting “a narrow slot of typically 10 – 30 mm wide and around 150 mm deep that may extend for many kilometres” (Stirling-Lloyd, p.2).

For flexible pavements, the micro-trench is backfilled with crack-sealing materials which are flexible but provide sufficient support to prevent the collapse of the cut asphalt concrete edges. The speed and small cut volume makes this technology unsuitable for hot mix asphalt concrete backfill application, leaving the option of emulsions or cold mixes.

A disadvantage of this technology is that, being located so close to the pavement surface, it may sustain damage during pavement rehabilitation works, depending on the scope and type of rehabilitation.

4.8 TRENCHLESS TECHNOLOGIES

Multiple trenchless technologies have been recently developed to offer a solution for utility installation without disturbing the roadway surface. While a detailed discussion of trenchless technologies is outside the scope of this report, a brief overview of the current methods and their advantages and disadvantages over trenching methods can be useful to practitioners.

4.8.1 Impact Mole Trenching

This is probably the simplest trenchless technology. It consists of an impact mole with a cone-shaped head, placed on a launch cradle. A hammer head, generally powered by air and located in the shaft of the mole, is driving it in. The resulting trench is 15-25% larger than the pipe it is intended for (see ISTT (3), 2012).

Impact mole trenching is suitable for cohesive soils such as clay. It is generally intended for smaller diameter pipes and cables.

An impact mole assembly includes the following pieces of equipment:

- A head assembly with a cone-shaped or chisel tip. The assembly is attached to the front of the impact mole.
- An impact mole with a hollow shaft hosting a hammer head.
- A launch cradle hosting the impact mole. The cradle helps position, direct and launch the mole.
- An air compressor and hose assembly which drives the hammer.

Newer versions of impact moles allow for some steering and tracking through various devices built into the mole (for more information, see ISTT (3), 2012).

4.8.2 Horizontal Directional Drilling (HDD)

HDD is a trenchless technology that employs a drilling rig to install a pipe in a two-step process. First, a pilot bore is created along a planned path using both thrust of the drill to change direction, and rotation of the drill rods and bit to advance in that direction. After the pilot bore is completed, a backreamer is attached to the end of the drill string, followed by the desired flexible or semi-flexible utility product pipe (Najafi et al, 2005, p.27).

This method is used for the installation of service connections to residences and buildings, pipes and cables under roadways and rivers. HDD is best suited for installing pressure pipes and conduits where precise grades are not required (ISTT (2), 2012).

Section 4.8 Trenchless Technologies

The picture below, by Jeff Gander, reproduced from Najafi et al, 2005, shows a successful culvert installation which employed the pipe jacking technique on Route 63 Site in the City of Macon, Missouri.

The picture below, by Russell Humphrys, reproduced from Najafi et al, 2005, shows the emerged leading end of a pipe installed in an evaluation project using the open-faced pipe ramming technique. Note the reinforced leading edge of the pipe, and bentonite feed line at the top of the pipe.

The picture below, by Chris Wilke, shows the installation of a culvert on Provincial Highway No. 1 near its intersection with Lewvan Dr. In Regina, Saskatchewan, using the open-faced ramming method. Note the auger used to remove the soil inside the pipe. Picture courtesy of Clifton Associates Ltd., 2011.

Section 4.8 Trenchless Technologies contd.

The four pictures below, by Grant Gilliss, courtesy of Clifton Associates Ltd., show the installation of a water pipe over 1 km length using the “boring” method. The entry and exit points of the pipe are excavated, then a boring machine drives the cutting head in, followed by the pipe. The maximum length over which the pipe can be driven from one end is limited by the equipment driving pressure; however, technological advancement is continuously increasing this limit.

Note in the picture above the cracked soil resulting from over-pressurisation.

An HDD assembly includes the following components (for more information, see ISTT (2), 2012):

- A directional drill rig sized for the job at hand.
- Drill rods linked together to form a drill string for advancing the drill bit and for pulling back reamers and products.
- A transmitter/receiver for tracking and recording the location of the drill and product.
- A tank for mixing and holding drilling fluid.
- A pump for circulating the drilling fluid. Other components of an HDD operation include bits, reamers, swivels and pulling heads.

Horizontal directional drilling can also be performed using hydrovac technology.

4.8.3 Pipe Jacking

In this trenchless technology, the jacks located in the drive shaft propel the pipe. The jacking force is transmitted through pipe-to-pipe interaction to the excavating face. When excavation is accomplished, spoil is transported through the jacking pipe to the drive shaft by manual or mechanical means. Both excavation and spoil removal processes require workers to be inside the pipe during the jacking operation. Usually, the minimum recommended diameter for pipe installed by pipe jacking is 42” (1.07 m) (Najafi et al, 2005, p.4).

4.8.4 Pipe Ramming

This method is limited to steel pipe only; two categories of pipe ramming are distinguished (see Najafi et al, 2005, p.12):

- Open-faced, intended for larger pipes (typically up to 1.5 m). In this technique, the pipe leading edge is reinforced and rammed through the soil. After the pipe is installed, the soil that has entered the pipe is removed either by forced air, water or using an auger inside the pipe (see insert).
- Closed-face, intended for pipes under 0.2 m in diameter. In this technique, a cone-shaped head is welded to the leading pipe edge, which is then rammed in. With this method, a minimum of 0.3 m of cover should be present to avoid heaving. In Saskatchewan, the Ministry of Highways and Infrastructure requires a minimum of 0.5 m of cover, plus pavement.

4.8.5 Auger Boring

Horizontal auger boring can be used to install small diameter pipes. The method uses a boring machine which drives an auger flight or set of flights, outfitted with a leading cutter head. This method is suitable for installing steel casing pipe in relatively soft stable ground conditions such as clay or soils containing cobbles located above the water table. The auger boring process retains the soils within the casing, which reduces the likelihood of ground settlement from excavation, making auger boring a popular option for installing utilities under railroads, highways, and levies where settlement is a concern (ISTT (1), 2012).

This method is used for pipes placed horizontally in a straight line. To achieve higher grade and alignment precision, this method can be enhanced by using a pilot tube containing a specially designed theodolite guidance system to guide the installation of pipes (Najafi et al, 2005, p.21).

An auger boring assembly includes the following components (see ISTT (1), 2012):

- A boring machine which drives an auger chain or flight.
- The auger flight or chain, outfitted with a cutting head.
- Tracks which position and direct the auger.
- Casing pipes which can be added in series with the advancement of the auger.

4.9 LOW-DIG TECHNOLOGY

The low-dig technology is a composite approach to installing or repairing utilities which combines trenching and trenchless technologies to minimize the trenching volume.

It consists of trenching small pre-planned areas to gain access to key utility installation points. The utilities are then installed up to the next trenched access point using a suitable trenchless technology. See an example of a low-dig technology application in the insert on p.32, where a combination of the boring method and access trench excavation was used.

4.10 LOCALIZED REPAIRS

A variety of technologies are available for localized repairs of existing utilities, which eliminate or minimize the trenching needs. It is worthwhile considering these repair options prior to proceeding with open trenching for utility repairs.

4.10.1 Chemical Stabilization

Chemical stabilization is a process developed in Hungary for sewer repairs. The section to be repaired is isolated and then filled from a manhole with a chemical solution, typically sodium silicate. After a pre-determined interval to let the chemical soak in, the solution is pumped out, and a proprietary chemical is pumped in, which reacts with the residue of the first solution to form a waterproof resin (UKSTT, 2012).

4.10.2 Resin Injection

Resin injection is a process of repairing water and sewer pipes by means of injecting some resin (like epoxy resin or mortar) which eventually cures, sealing leaks (UKSTT, 2012).

4.11 CLEAN-UP

Cleaning up the site after the restoration works are complete is not just a matter of good housekeeping, as some of the deficiencies associated with a site left un-cleaned have a bearing on the trench reinstatement performance.

4.11.1 Drainage

Where satisfactory drainage patterns at the trench location existed prior to the works, they should be restored. Where poor drainage patterns persisted prior to the works, drainage should be improved to avoid water ponding. If minor in nature, drainage improvements can be done as part of clean-up; if major, they should be brought to the attention of road maintenance planners and made part of scheduled works.

Drainage restoration works should be performed at the end of every stage of trench restoration. As part of these works, all ditches or drainage paths along curves should be cleaned of all spoil, leftover excavation and backfill materials. Such materials contribute to road failures in two ways: by impeding the water from running freely and by holding water on the top of the pavement. Culverts and manholes should be left clean and functional. Drainage path gradients should be restored to maintain positive drainage towards the culverts or manholes. This means that the restored surface should not be a “hump” in the way of running water.

4.11.2 Erosion Control

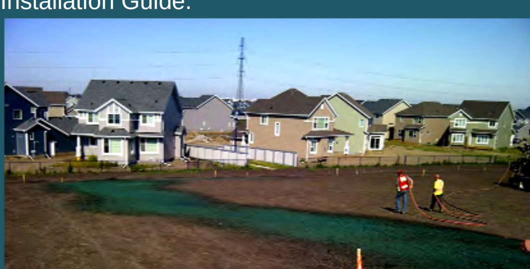
Restoring topsoil and vegetation in excavated areas which could erode is necessary from a road performance point of view. Such areas include, but are not limited to, ditches and sideslopes. Where topsoil was disturbed by the works, it has to be re-spread and seeded if possible. Especially on slopes and drainage paths, soil armouring controls such as erosion blankets or hydraulic mulch (see inserts) may be necessary to prevent the formation of erosion gullies and the infiltration of water into the subgrade, followed by subsequent road failure.

Section 4.11.2 Erosion Control

The installation of erosion control blankets over topsoil and seed stabilizes and strengthens the surface until such time that vegetation is established and roots create a protective layer. The picture below, courtesy of Clifton Associates Ltd., show the installation of a coconut straw erosion control blanket on the slope of Provincial Highway No. 1 at Belle Plaine, Saskatchewan in October 2011.

Hydraulic mulch application is another erosion control option which creates a protective layer until a vegetative protective cover and a root zone are established. Hydraulic mulch is typically sprayed on following hydro-seeding; an example of hydraulic mulch application is shown below, reproduced from Iowa DOT Erosion and Sediment Control Field Guide.

The picture below, courtesy of Nilex Inc., shows the installation of MulchMax hydraulic mulch, which allows the simultaneous application of seed and mulch. See Appendix 7 for MulchMax Installation Guide.



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5. SUMMARY

5.1 BENEFITS AND DRAWBACKS

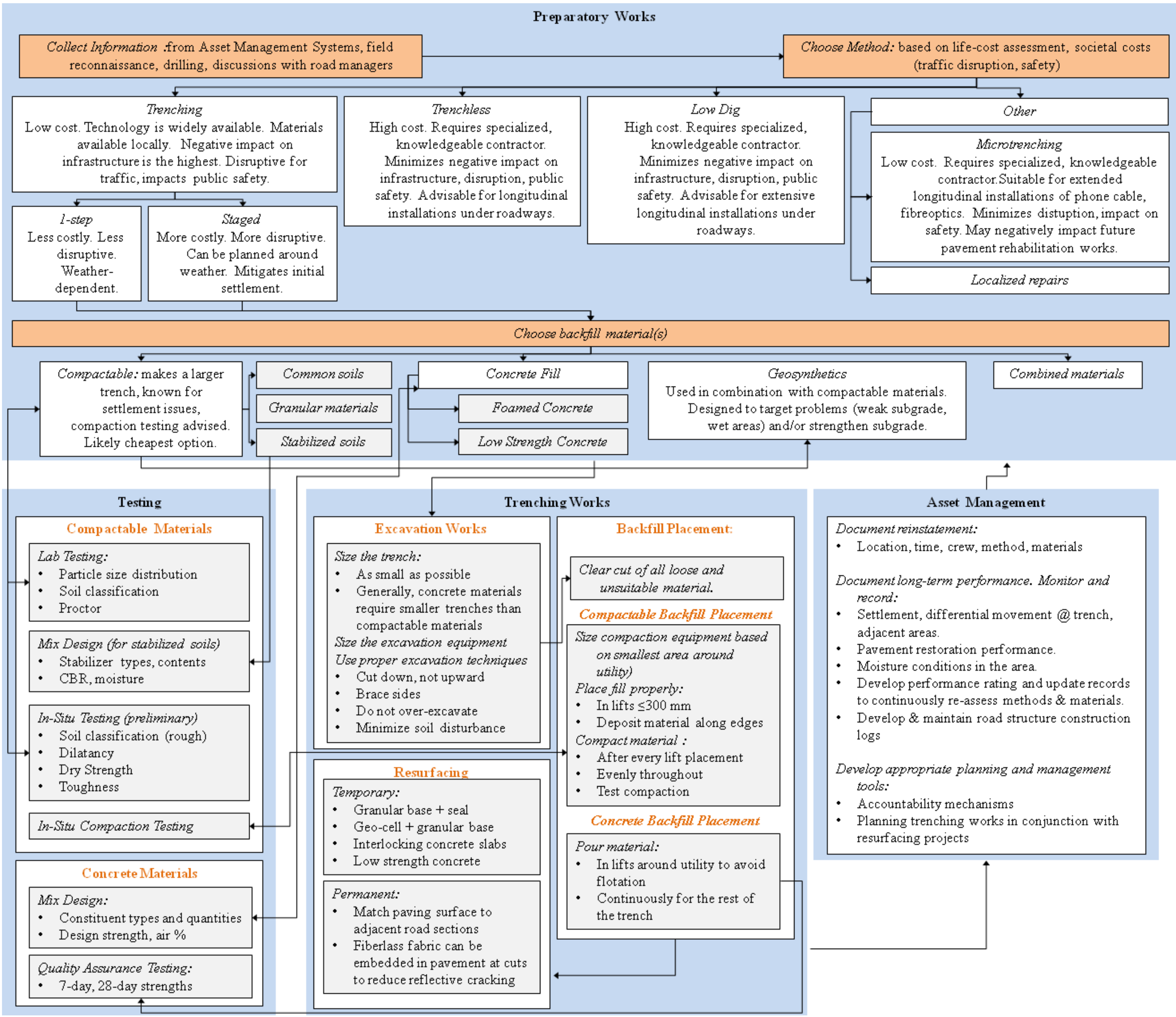
Where an excavation is required in an existing roadway, there is the potential for short and long-term traffic disruption and maintenance costs. Elimination of the excavation by use of trenchless technology is the desired approach. When this approach is not practical, then the considerations stated below appear to have the most potential to minimize impacts.

- ***Low-strength Concrete Fill Material*** was found to be "generally cost effective compared to properly compacted and inspected granular backfill" (Emery, J. et al, 1985). Cost savings are realized through smaller cuts and good long-term performance.
- ***Foamed Concrete*** was found to be highly cost-effective in terms of labour and equipment (EAB Associates) as compared to traditional trench reinstatement methods.
- ***Microtrenching*** can be "up to 30 times faster and only 20% of the cost of traditional trenching" (Stirling Lloyd, p.1). Its biggest advantage consists of the elimination of trench backfilling and all associated problems.
- ***Training Related to Material Identification, Selection and Placement*** was found to be an effective solution to most emergency or small utility excavation. Identification of the excavated material type and its moist conditions are critical in determining if it is suitable to use for backfilling the excavation. If it is not suitable then an appropriate common borrow or granular material can be selected that suits the conditions. Proper placement and compaction methods for the material can then be selected.
- ***One-Step Trench Reinstatement*** is a cheaper option than staged reinstatement. It also offers non-monetary advantages such as lesser traffic disruption. One-step reinstatements can only be done in suitable weather and moisture conditions.
- ***Staged Reinstatement*** is a more expensive option compared to one-step reinstatements. This approach helps mitigate short-term settlement and differential movement, as well as road surface failures at the trench edges.

Cost Considerations: while the conventional wisdom is that costs of traditional trench reinstatement methods are lower than those of low dig or trenchless technologies, the comparative costs of these alternatives are highly circumstantial and should be assessed on a per case basis.

5.2 PROCESS FLOWCHART

A process flowchart of trench reinstatement works is provided below.



6. AREAS OF FUTURE RESEARCH

In the research phase of the development of these guidelines, a number of promising technologies have been identified which are not known to have been thoroughly tested either in a Saskatchewan setting or specifically in trench restoration applications. For that reason, these technologies cannot be immediately recommended for use but require pilot testing to determine their usability for trench restorations in Saskatchewan climatic and soil conditions.

- ***Microtrenching*** is a technology with many potential advantages such as cost and time savings, as well as the elimination of trenching and associated issues. Prior to recommending this technology for implementation, it has to be field-tested to determine long-term performance with various backfill materials.
- ***Electric Density Gauge*** is a technology which, if proven sufficiently reliable, may significantly simplify the quality assurance testing for in-situ soil compaction. It is recommended that a pilot project testing the ASTM-approved electric density gauges in Saskatchewan conditions be initiated.
- ***Soil Penetrometers, or Soil Compaction Testers,*** are currently used in agriculture to evaluate soil compaction. As they may present a simple way to evaluate backfill material compaction in trench reinstatement works, it is worthwhile investigating their use in this capacity.

In the stakeholder meetings, low-tech soil compaction and moisture content testing alternatives have been suggested to have the potential to improve the overall quality of trench restorations. The reason to that lies in the fact that smaller municipalities do not always have the facilities, equipment and trained staff to perform full-range soil identification and compaction testing. Of the range of tests involved, low-tech compaction and moisture content testing have the greatest potential to impact the quality of trench reinstatements. As no viable low-tech testing alternatives for these have been identified, the following technology gaps have been noted:

- ***A Need for a Low-Tech Tool to Measure Soil Compaction*** has been identified. The desirable outcome would be a tool capable of measuring relative density as the soil is being compacted, and determine when maximum compaction is achieved.
- ***A Need for a Low-Tech Tool to Measure Soil Moisture*** has been identified. Alternatively, proper training on material identification and characterization may eliminate the need for such tool.

7. TRAINING

For various reasons such as cost and availability, compactable materials are the most used type of backfill in spite of all known issues associated with them. Most trench reinstatement crews generally know that, for compactable materials, poor compaction is at the root of poor trench reinstatement performance. However, as already discussed in these guidelines, poor compaction is not just a result of a poor compacting effort. Soil and moisture conditions, soil type, fines and water content, equipment size, and even the way the backfill is dumped in, all have an impact on compaction; simply applying more compacting effort to an unsuitable material under unsuitable conditions will not do the trick.

Therefore, crews should be trained in matters of proper trench reinstatement so that they can make educated choices with regard to backfill material, equipment types and work practices. As a minimum, the competence areas discussed below should be covered by training.

- ***Soil Testing*** skills should be developed to the extent of determining the visual classification of materials and characterization of content. Soils identification and characterization would improve material selection and placement.
- ***Soil Stabilization:*** as a minimum, crews should be educated in matters of soil stabilization options and the impacts such treatment has on soil bearing capacity and moisture stabilization.
- ***Best Work Practices and Alternatives to Traditional Trenching, Including Materials and Methods*** discussed in these guidelines should be known to the crews to ensure that they will be considered if the circumstances are suitable.

A *Field Guide for Visual Soil Identification and Moisture Classification of Soils* is provided on p.40-41 of this report as a training aid for staff involved in selecting the trench backfill materials.

Field Guide for Visual Identification and Moisture Classification of Soils

		Soil Types / Names	Field identification			Grain Size, mm	Moisture Sensitivity	Plasticity	Feel or Smear	CBR, %	Backfill Application
Coarse-grained soils - >50% retained on Sieve No. 200	Clean gravels	Well-graded gravels, gravel-sand mixes, little or no fines	Wide range of grain sizes, considerable amounts of all intermediate particle size			5+	low to none	n/a	pebbles & stones	15-25	all layers
		Poorly graded gravels, gravel sand mixes, little or no fines	Predominantly one size of particles, or intermediate particle sizes missing or under-represented					n/a	one-size pebbles	7-15	bottom and intermediate layers
		Silty gravels and sands	Non-plastic fines or fines with very low plasticity			mixture of 5+ and non-visible particles	low	n/a or very low	gritty, may smear on	4-7	bottom layers
		Clayey gravels and sands	Plastic fines - for identification procedures, see below				low to medium	n/a or very low		4-7	bottom layers
	Clean sands	Well-graded sands, gravelly sands, little or no fines	Wide range of grain sizes, considerable amounts of all intermediate particle size			<5, all particles visible to eye	low; at low moisture levels, strength increases	n/a	gritty	12-20	all layers
		Poorly graded sands, gravelly sands, little or no fines	Predominantly one size of particles, or intermediate particle sizes missing or under-represented					n/a	gritty	7-15	bottom and intermediate layers
		Silty sands, silt and sand mixes	Non-plastic fines or fines with very low plasticity			mixture of <5 and non-visible particles	low	n/a or very low	gritty, may smear on finger	4-7	bottom layers
		Clayey sands, clay and sand mixes	Plastic fines - for identification procedures, see below				low to medium	very low		4-7	bottom layers
			Identification for soil fraction passing Sieve No.								
			Dry strength (crushing char.)	**Dilatancy (reaction to shaking)**	**Toughness (Consistency)**						
Fine-grained soils - >50% passing Sieve No. 200		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands	none to low	quick to slow	none	non-visible particle size; crumbly	medium	low	will smear on finger	3-5	bottom layers only
		Inorganic clays with low or medium plasticity; gravelly clays; sandy clays; silty clays	medium to high	none to very slow	medium	non-visible particle size; may crumble	medium to high		slight shine	3-5	bottom layers only
		Organic silts; organic silty clays	low to medium	slow	slight		medium	low	slight shine	2-3	bottom layers only
		Inorganic silts; elastic silts; micaceous and diatomaceous fine sandy or silty soils	low to medium	slow to none	slight to medium		medium		slight shine	2.5-4	bottom layers only
		Inorganic clays; fat clays - high plasticity	high to very high	none	high	non-visible particle size	high	high	shiny	2-4	bottom layers only; not a preferred option
		Organic clays; organic silts	medium to high	none to very slow	slight to		high	medium to high		2-3	do not use
		Peat and other highly organic soils	Easily identifiable by colour (black or bluish black), organic (swampy) odour, spongy feel, often fibrous texture			non-visible particle size; visible organic inclusions may be present	high			<2	do not use

Table above adapted from various sources

Field Identification Procedures for Fine-Grained Soils and Fractions
These procedures are to be performed on the minus No. 40 sieve size particles (~1/64") - simply remove by hand coarse particles which would interfere with the tests
1. Dilatancy (reaction to shaking)
After removing the particles larger that Sieve No. 40, prepare a pat of moist soil with a volume of ~1/2 cubic inch. Add enough water if necessary to make the soil soft but not sticky. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive result consists of the appearance of water on the surface of the pat, which changes to a livery consistency and becomes glossy. When the sample is squeezed between fingers, the water and gloss disappear from the surface, the pat stiffens and finally breaks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the characted of the fines in a soil. Very fine clean sands give the quickest and most distinct reaction, whereas plastic clays show no reaction. Inorganic silts such as rock flour show a moderately quick reaction.
2. Dry strength (crushing characteristics)
After removing particles larger than Sieve No. 40, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air, and then test its strength by breaking and crumbling it between the fingers. The strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity. High dry strength is characteristic for inorganic clays of high plasticity and fat clays. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sands feel gritty, whereas a typical silt has the smooth feel of flour.
3. Toughness (consistency near plastic limit)
After removing particles larger that Sieve No. 40, a specimen of soil of ~1/2 cubic inch is molded to a consistency of putty. If too dry, water must be added; if sticky, the specimen must be spread out in a thin layer and allowed to lose some moisture through evaporation. Then the specimen is rolled out by hand on a smooth surface or between palms to a thread about 1/8 inch in diameter. The thread is then folded and re-rolled repeatedly. During this manipulation, the moisture content is gradually reduced and the specimen stiffens, finally losing its plasticity and crumbling when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action comtinued until the lump crumbles. The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction of the soil. Weakness of the thread at the plastic limit and quick loss of cohesion of the lump below the plastic limit indicate either inorganic clay with low plasticity, or materials such as kaolin-type clays and organic clays. Highly organic clays have a very weak and spongy feel at the plastic limit.
Table above adapted from various sources

8. CONCLUSIONS AND RECOMMENDATIONS

Following are the guidelines conclusions and recommendations, listed in order of impact on trench reinstatements.

8.1. BEST TRENCH REINSTATEMENT PRACTICES

The practices listed further are known to have a positive impact on trench restoration and road performances:

- Conducting site investigation and preparatory works to select the most suitable method and material.
- The best backfill is the one that matches the soil type, compaction and moisture characteristics of the surrounding subgrade.
- Keep trench size as small as practical:
  - Low-strength and foamed concretes generally require smaller trenches than compactable backfills.
  - Plan for appropriately sized excavation and compaction equipment. The smallest size of excavation equipment is set by the most narrow excavation area, whereas for compaction equipment is generally defined by the area around the installed utility.
  - Micro-trenching should be considered if possible.
  - Trenchless installations or repairs such as chemical stabilization or resin injections should be considered where possible.
- Prior to excavation, cut the asphalt concrete pavement to protect the edge of excavation.
- Minimize soil disturbance:
  - Excavate by cutting down, not upward.
  - Use bracing if required.
  - Do not ride equipment at the edge of excavation.
  - Keep the excavation free of water.
- When backfilling with compactable materials:
  - Place and compact material in lifts not exceeding 300 mm.
  - Place material at the edges of the trench rather than in center to avoid over-compaction at the center and under-compaction at the perimeter of excavation.
  - Test compaction if possible; even a simple compaction test is better than no testing. Use simple compaction tests to ensure an even degree of compaction at the

center and perimeter of excavation. The material at the bottom of the trench requires a lesser degree of compaction than closer to the surface.

- When backfilling with low-strength or foamed concrete, place backfill in lifts around pipes to avoid flotation. Pipes can be additionally braced.

8.2. LOW-STRENGTH CONCRETE FILL MATERIAL

Low-strength concrete fill material has been repeatedly shown to be an excellent alternative to soil or granular materials used for trench backfill. Benefits of its use include, but are not limited to the following:

- No settlement.
- Smaller trenches.
- Elimination of compaction testing requirements.
- Elimination of compaction equipment.
- Durability and strength.
- Reduced loading on pipes.

It is recommended that pilot testing projects are set up in Saskatchewan to determine the best formulation and procedures for this application. It is recommended that the material is placed in lifts to avoid pipe flotation.

8.3. TRAINING

Gaps in staff training pertaining to soil characterization, testing, and material and method selection should be addressed through training programs and materials. Appropriate training materials should be developed for this purpose. This will enable field staff to make competent decisions related to backfill material use, placement and compaction.

8.4. REPAIR AND MAINTENANCE PLANNING PRACTICES

- It is recommended that in agencies where trench reinstatement works and road maintenance responsibilities are not assigned to the same crew or contractors, a mechanism of accountability is developed to encourage responsibility ownership over the performance of the repair.
- Timing or scheduling trench reinstatement repairs in advance of road surfacing projects will contribute to subgrade uniformity both in terms of material and compaction.

8.5. HYDRAULICALLY BOUND MIXTURES

Hydraulically bound mixtures offer some potential advantages over their unbound counterparts:

- HBMs with a compressive strength over 3MPa are considered resistant to frost heave.
- HBMs allow the re-use of common materials where normally they would be deemed unusable otherwise. This reduces costs of backfill material, transportation and disposal.

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PHOTO CREDITS:

Cover page: the picture of Trenchmix trench arisings treated with lime and coal fly ash being compacted at a trench reinstatement location on Tixall Road, Stafford, UK, is reproduced from the Hydraulically Bound Mixtures site http://www.hydraulicallyboundmixtures.info/gallery010.php accessed November 2012.

Section 1.2.1: a picture of water pipeline installation using the method of "slot trenching" is reproduced from the Badger Daylighting Ltd. site http://www.badgerinc.com/services/slot_trench.html.

Section 2.11: a picture of geo-grid installation in a road structure by Morsky Construction Ltd. provided by Clifton Associates Ltd., 2011.

Section 3.1: the example graph of a Standard Proctor test was provided by Clifton Associates Ltd., 2012.

Section 3.2.1: the picture of Humboldt's HS-5001EZ Moisture/Density Gauge is reproduced from http://www.humboldtmfg.com/c-1-p-2-id-1.html accessed December 2012.

Section 3.2.3: the picture of a light weight deflectometer is reproduced from Ontario's Transportation Technology Transfer Digest — Summer 2010 — Vol. 16, Issue 3, Ontario Transportation, http://www.mto.gov.on.ca/english/transtek/roadtalk/rt16-3/ accessed December 2012.

Section 3.3: a diagram of a soil penetrometer is reproduced from "Diagnosing Soil Compaction Using a Penetrometer (soil compaction tester" (Duiker, S. W.).

Section 4.2: a figure of the backfilling zones is reproduced from Iowa DOT Section 3010 (Figure 3010.101).

Section 4.2: a picture of five trenching buckets is reproduced from Hiremax Ltd, http://www.hiremax.co.nz/shop/excavatorsandattachments/excavatorattachments/trenchbuckets.html accessed November 2012.

Section 4.2: a picture of the V-Raptor v-notched trenching bucket reproduced from Leading Edge Attachments, http://leattach.com/raptorbucket.html , accessed December 2012.

Section 4.2: pictures of a sheep foot compaction wheel excavator attachment and a tamper plate are reproduced from Arrowhead

Rockdrill http://www.arrowheadrockdrill.co.uk/compaction-wheels.php#40cc , accessed November 2012.

Section 4.2: a picture of BodPave40 installation is reproduced from Fiberweb Geosynthetics Ltd, http://www.terram.com/products/porous-plastic-pavers/bodpave-40-porous-grass-gravel-paving-grid.html accessed November 2012.

Section 4.7: three pictures of microtrenching reproduced from Stirling-Lloyd Technical Advice Note 11-09.

Section 4.8: a picture of two culverts installed using the “pipe jacking” technique is reproduced from the report “Preparation of Construction Specifications, Contract Documents, Field Testing, Educational Materials, and Course Offerings for Trenchless Construction” (Najafi et al, 2005).

Section 4.8: a picture of a culvert installed using the “pipe ramming” technique is reproduced from the report “Preparation of Construction Specifications, Contract Documents, Field Testing, Educational Materials, and Course Offerings for Trenchless Construction” (Najafi et al, 2005).

Section 4.8: a picture of a culvert installed at Provincial Highway No. 1 in Regina, Saskatchewan, using the “pipe ramming” technique is provided by Clifton Associates Ltd., 2011.

Section 4.8, contd.: four pictures of a water pipe installation using “boring” are provided by Clifton Associates Ltd., 2011.

Section 4.11: two pictures of straw erosion control blanket installation at Belle Plaine, SASKATCHEWAN provided by Clifton Associates Ltd, 2011.

Section 4.11: a picture of hydraulic mulch application reproduced from p.29 of Iowa DOT Erosion and Sediment Control Field Guide, April 2012.

Section 4.11: a picture of Nilex MulchMax hydraulic mulch application is provided by Ian Corne, Nilex Inc., November 2012.

DEFINITIONS AND ABBREVIATIONS

CBR	California Bearing Ratio, a measure of soil strength with values of 0-10 for soils with low bearing strength such as clays and silts. The standard test for CBR is made on crushed California limestone, with a value of 100 assigned to it.
Cement-Treated Material	Hydraulically Bound Mixture
CIV	Clegg Impact Value, equal to 98.1 m/s2
Compactable Backfill Materials	In this report, compactable backfill materials encompass the following backfill materials: common soils, granular materials, hydraulically bound soils and bitumen-bound soils.
Controlled Density Fill	Term used for low strength concrete fill
Controlled Low Strength Materials (CLSM)	Term used for low strength concrete fill
Fines	For soil identification purposes, fines are defined as soil particles passing the No. 200 Sieve (particle diameter < 0.071 mm)
Flowable Fill / Mortar	Term used for low strength concrete fill
Fly Ash Slurry	Term used for low strength concrete fill
HDD	Horizontal Directional Drilling
K-Crete	Term used for low strength concrete fill
Lightweight Concrete	Foamed Concrete
Overbreak	The breakage of pavement surface adjacent to the utility cut
Plastic Soil-Cement	Term used for low strength concrete fill
Soil-Cement	Hydraulically bound mixture
Soil-Cement Slurry	Term used for low strength concrete fill
Soil Stabilization	The process of soil modification by way of mixing additives (such as cement or bitumen) into the soil to improve its properties, particularly bearing capacity. Hydraulically or bitumen-bound soils are stabilized soils.
Trench Arisings	In-situ material obtained via excavation from the trench
Unshrinkable fill	Term used for low strength concrete fill

APPENDICES