NON-TRADITIONAL MATERIALS FOR TRENCH & BRIDGE ABUTMENT BACKFILL

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NON-TRADITIONAL MATERIALS FOR TRENCH & BRIDGE ABUTMENT BACKFILL

S.M. BRUCE & G.H. ROWE
Works Central Laboratories,
Lower Hutt, New Zealand

AN IMPORTANT NOTE FOR THE READER

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EXECUTIVE SUMMARY

Introduction
An overview of non-traditional backfill materials has been compiled from material identified in an international literature search, and carried out in 1992.

Backfill settlement associated with trench excavation or bridge abutments increases surface roughness in the pavements of New Zealand roads. Conventional granular backfill materials can be used successfully if properly selected and appropriately compacted, but neither is consistently achieved with such materials.

To overcome the problems encountered with conventional backfill materials, alternative non-traditional backfill materials have been considered in this report. Materials include controlled low strength materials (CLSM), foamed concrete, fly ash, wood waste, expanded polystyrene (EPS), and various miscellaneous materials.

General information as well as composition, properties, advantages, limitations, and typical applications are presented for each material. The properties determine the backfilling application for which each non-traditional material is best suited.

Non-Traditional Materials
CLSM and *foamed concrete* are cementitious slurries offering significant labour savings in their placement and reduced maintenance costs. Use of these materials in conjunction with narrow trenching methods has potential.

Fly ash, wood waste and *EPS* are all lightweight materials particularly suited for construction of road embankments over compressible foundation soils. Fly ash is likely to be the least suitable of these materials in New Zealand as currently it is available from only one source.

Miscellaneous materials are commonly locally derived wastes or naturally occurring materials offering advantages of light weight and low cost. These materials include kiln dust, blast furnace slag, expanded lightweight aggregate, scoria, pumice, shredded rubber, logs, and construction waste.

Conclusions
Many of these non-traditional backfills are relatively new in New Zealand, and a potential limiting factor to their use is resistance to the introduction of new technology.

To ensure their successful introduction, designers, specifiers and contractors need relevant information in order to understand both the advantages and limitations of these materials.

Also before extensive use is made of these materials, further research should be carried out to assess whether their performance meets Transit New Zealand requirements.

Recommendations

1. Non-traditional backfill materials are considered to be suited to the following specific applications:
   - trench backfilling - CLSM, foamed concrete;
   - bridge abutment backfilling - CLSM, foamed concrete, EPS;
   - road construction over weak sub-grade - foamed concrete, EPS, wood waste, fly ash, shredded tyres, scoria, pumice, other miscellaneous materials.

2. Further research should be considered to promote the use of these materials under New Zealand conditions.

   Such research may not necessarily involve extensive testing as much testing may have been carried out in other countries already, that is well documented. The research may only involve adopting specific overseas guidelines or standards, and producing notes to cover their use in New Zealand.

   If research is considered necessary, it should involve the following steps:
   - Set up monitoring trials of these materials.
   - Evaluate material properties and construction methods.
   - Evaluate cost and performance benefits to compare with those of traditional materials.
   - Determine specific uses for particular materials.
   - Determine availability of materials, both now and with any increase in demand.
   - Determine design parameters.
   - Produce guidelines for the use of these materials.
   - Produce and adopt material and construction specifications.
   - Determine and adopt quality control procedures and methods of test.

3. The considerable advantages offered by CLSM for trench and bridge abutment backfilling should be recognised, and priority should be given to CLSM when considering any further research.

ABSTRACT

An overview of non-traditional backfill materials has been compiled from material identified in an international literature search carried out in 1992. Materials considered include controlled low strength materials (CLSM), foamed concrete, fly ash, wood waste, expanded polystyrene (EPS), and various miscellaneous materials. General information as well as composition, properties, advantages, limitations and typical applications are presented for each material. The properties determine the backfilling application to which each material is best suited. Most of these materials have potential for use in New Zealand provided their advantages and limitations are recognised and understood by would-be users.

1. INTRODUCTION

Backfill settlement associated with trench excavation or bridge abutments causes problems in New Zealand roads. It is manifested as surface roughness in the form of abrupt vertical offsets to the pavement seal and the deformation of the base pavement layers. In addition, ponding occurs locally at the settlement area and at the pavement "downstream" from the offset which creates a potential route for the ingress of water below the pavement.

Settlement of this type has long been recognised as a particular problem at bridge approaches. To overcome settlement, a concrete slab is often positioned across the carriageway. The slab sits on a corbel along the rear of the abutment, to which it is tied, and it slopes gently back into the backfill. The slab is primarily to prevent the effects of backfill settlement accumulating excessively in the surface layers of the road pavement. Such slabs have been part of the design of bridges since before 1960 (Chapman, pers. comm. 1992). They also have the effect of preventing gross loss, or settlement, of abutment backfill during seismic events.

Conventional backfill comprising materials like basecourses, suitable clays and graded sands can be used successfully if properly selected and appropriately compacted. "Unsuitable" conventional fill materials may be made serviceable using stabilisers such as cement or lime. All these backfill materials must be compacted mechanically, a labour intensive process requiring adequate supervision and testing to ensure that only minimal settlement will occur in the compacted material. A survey of trench reinstatement practices used in New Zealand (compiled by Duffill, Watts and King 1989) indicated that 78% of all roading authorities reported some instance of trench collapse caused by backfill subsidence or deformation. Other important findings of this study included:

- the very high proportion (80%) of authorities that issued formal specifications but did not enforce them; and

- the high incidence (70%) of subjective measurements that were applied to determine the compaction standard achieved, the foreman's heel print being the most usual standard applied.

Similar problems with traditional backfill materials have been identified by Horne (1985) who, in a review of United Kingdom (UK) law regarding streetworks, concluded that:

The key to good reinstatement is the quality and compaction of the backfill material. However, it is difficult to imagine any changes in the design of tamping compacting plant, or in the practices of those undertaking these operations, that would ensure the desired end result of a non-settling first time reinstatement. Therefore, new methods must be employed if a standard of backfilling is to be achieved that will allow almost immediate, permanent surfacing. Any proposed new methods preferably should be equally effective in all ground conditions and sizes of excavation, and should eliminate human error as far as possible.

Because of these problems with traditional materials, designers have considered non-traditional backfill materials. These materials provide a range of options which have been developed locally within several countries to overcome specific backfilling problems or, in many cases, to utilise waste materials. The materials fall into the following categories:

1. Controlled low strength materials (CLSM): flowable cementitious materials commonly containing fly ash, cement and water.

2. Foamed concrete: flowable cementitious material made by blending cement, sand or fly ash, and water with a pre-formed foam.

3. Fly ash.

4. Wood waste.

5. Expanded polystyrene (EPS).

6. Miscellaneous materials: materials that include shredded rubber, blast furnace slag, kiln dust, expanded lightweight aggregate, scoria, pumice, and construction waste such as porous concrete and bricks.

Although all these materials are intended for backfilling, each is better suited to different applications. For example, flowable cementitious materials are particularly appropriate for trench backfilling and have been developed in conjunction with narrow trenching methods (Coates 1988), whereas other methods are more appropriate for bulk backfilling if the foundation soils are compressible.

Of real interest is the application of overseas technology in New Zealand. For example, backfilling methods utilising waste products may be of limited use since products such as fly ash are produced in only relatively small quantities in New Zealand and are currently from one principal source.

Each of these backfill materials is considered in this report, with a description of the material, its composition, properties, advantages, limitations, typical applications with examples and, where applicable, comments on its suitability for use in New Zealand conditions.

2. CONTROLLED LOW STRENGTH MATERIALS (CLSM)

2.1 Background

CLSM are flowable cementitious materials commonly consisting of sand, fly ash, cement and water, used primarily as backfill in place of conventional compacted fill. CLSM mixtures may be used to replace pavement bases, sub-bases and sub-grades.

The term CLSM has been adopted by the American Concrete Institute (ACI) but the material was originally introduced to the market under the trade name K-Krete (Brewer 1976), a patented material process developed by the Detroit Edison Company, Detroit, Michigan, with the Kuhlman Corporation, Toledo, Ohio. Because of the material's success in the US similar materials have been developed in the US and other countries and sold under a variety of trade names: Flowable Fill, Flowable Fly Ash, Lean Mix Backfill, Ready-Mixed Flowable Fill (RFF), Fillcrete, Trucrete, Flo-Fill, Lean Concrete Trench Backfill, Unshrinkable Fill, Controlled Density Fill (CDF) and so on.

Owing to the commercial nature of these materials, the early producers soon realised that technical information about this product was not being properly developed or transferred to the public (Brewer and Hurd 1991). To overcome this, *ACI Committee 229 : Controlled low strength materials (CLSM)* was formed. The mission of the committee was to develop recommendations and applications for proportioning, transporting and placement of CLSM, and a report was produced in 1994 (ACI 1994).

CLSM are defined as fill materials with a 28-day compressive strength of 8.3 MPa or less. However, in most CLSM applications the 28-day compressive strength should be 2.1 MPa or less (Adaska and Krell 1992) to allow it to be excavated in the future. Brewer and Hurd (1991) suggested CLSM for trench reinstatement should attain a 28-day compressive strength of 0.7 MPa as the maximum limit for a diggable backfill.

CLSM is currently marketed in many areas of New Zealand by Firth Certified Concrete, under the trade name Firth Flowable Fill (Browne 1992).

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2.2 Composition

The materials used in CLSM vary depending on their local availability and the specific application requirements. The predominant materials used include sand, cement, fly ash and water. In some regions of the US, coarse aggregate with up to 38 mm maximum size is used, whereas in other regions no aggregate is included at all (Adaska and Krell 1992). Brinkley (1990) described the successful use of a backfill slurry in Arizona that contained 9.5 mm aggregate, cement and water only because fly ash was not available locally. McLaren and Balsamo (1986) recognised four different CLSM mixes marketed in the US in 1986:

- High ash slurry: a flowable backfill which uses approximately 5% cement, 95% class F fly ash (according to ASTM C618-96 (ASTM 1996) classification), and a high water content.

- Lean mix: a mix with low cement content and aggregate.

- Foamed mix: a mix having low density because of large amounts of entrained air, used for applications requiring a minimal load. Such materials are produced by incorporating a pre-formed foam into the mix. In Chapter 3 of this report they are considered under the separate category of Foamed Concrete.

- Class C ash: a flowable backfill which achieves high strength without cement but may need a chemical retarder to control flash or rapid setting.

Fly ash (as it is called in the US but which is known as pulverised fuel ash (PFA) in the UK) is utilised in most CLSM mixes. It is a product of pulverised coal burnt in electricity generating plants where mineral impurities fuse in the exhaust gases. Fly ash particles are predominantly silt-sized glassy spheres with some coarser particles of unburned carbon. The spherical nature of the particles increases their flowability, and for this reason fly ash is a common component of CLSM (Balsamo 1987).

An added advantage of fly ash is that they are *pozzolans*. ASTM C618-96 defines a pozzolan as:

> *siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (a by-product of cement hydration) at ordinary temperatures to form compounds possessing cementitious properties.*

Based on chemical characteristics, ASTM C618-96 recognises two types of fly ash:
- Class F fly ash has pozzolanic properties, but unless it is mixed with a small amount of cement it will not harden.

- Class C fly ash, in addition to having pozzolanic properties, is also hydraulic (i.e. reacts with water to form a solid) primarily because it has a higher content of calcium oxide. Class C fly ash from some sources has a very rapid and self-

hardening capacity accompanied by rapid heat evolution, a condition known as *flash set* (Balsamo 1987). To overcome this problem a CLSM prepared with class C fly ash may require the use of a set retarder.

The CLSM Firth Flowable Fill utilises fly ash from the Huntly Power Station. In chemical analyses undertaken by Cement and Concrete Association of New Zealand (C&CANZ 1989), Huntly fly ash shows the characteristics of a class C material, i.e. it shows hydraulic properties.

Mix proportions of CLSM vary with the type of application. For flowable materials containing aggregate (a Lean Mix as defined by McLaren and Balsamo (1986)), mix proportions of a product (Larsen 1990) marketed under the trade name K-Krete contains:

sand	1305-1661 kg/m^3
fly ash	166-297 kg/m^3
cement	24-119 kg/m^3
water	350-400 kg/m^3

Lasater (1990) gave the following mix proportions of another commercially available material:

fine aggregate	908-1453 kg/m^3
fly ash	114-159 kg/m^3
cement	14-45 kg/m^3
water	159-363 kg/m^3

In high ash slurries (i.e. having high ash content), fly ash makes up between 94% and 97% of the dry components (by weight) with between 3% and 6% cement (by weight of dry components) and a water:solids ratio (by weight) of 0.4 to provide suitable fluidity but to limit bleeding (Balsamo 1987). Naik et al. (1990) stated that, to produce a flowable fly ash slurry with excellent flowability and compressive strength in the range 0.345 to 0.690 MPa, the cement content should be 59 ±30 kg/m^3 and the water content about 454 kg/m^3. Mix characteristics can also be adjusted using concrete admixtures. Janardhanam et al. (1992) reported the development of a high ash slurry incorporating both a superplasticiser to adjust the fluidity and an accelerator to allow early trafficking.

No specific mix design information is available on Firth Flowable Fill, but Browne (1992) indicates it contains cheap aggregates unsuitable for use in structural concrete, with particle sizes ranging from 7 mm down to 5-10% passing a 150 μm sieve.

2.3 Properties

The important properties of CLSM as a backfill material can be divided into short-term properties which are those affected by the slurry in its fresh state, and long-term properties which relate to its performance after hardening.

2.3.1 Short-Term Properties

1. Ability to Flow

This property is a significant feature of CLSM because a flowable mix for a backfill application will eliminate most of the labour required for placing. A material with a slump (NZS 3112: Part 1: Section 5: 1986) of 100-150 mm or less means that the material will remain in place and be suitable for embankment construction and the backfilling of trenches on steep grades (Funston and Krell 1985). A material with a slump of 180-250 mm will flow long distances from its discharge point, penetrating fine cracks and encapsulating anything in its path. Such a mix is more applicable to trench reinstatement.

Firth Flowable Fill has a typical spread (NZS 3112: Part 1: Section 11: 1986) of 350-500 mm (Browne 1992) which makes it suitable for trench reinstatement.

2. Hardening Time

Hardening time is the approximate time for a CLSM to change from a plastic state to a hardened state which has sufficient strength to support the weight of a person (ACI 1994). This time is greatly influenced by the amount and rate of bleed water that is released from the material. When this excess water leaves the mixture, solid particles realign into intimate contact and the mixture becomes rigid.

Hardening must occur slowly enough to allow time to mix, haul and place the backfill, but fast enough to allow traffic loading within a reasonable length of time. The time can be as short as 1 hour, but generally is 3-5 hours under normal conditions. As the setting of class F fly ash mixtures relies on the addition of cement, increasing the cement content will reduce the hardening time. However, increased cement content will increase compressive strength and this may compromise future excavation. The use of commercially available set accelerators has been investigated by Janardhanam et al. (1992) and, although rapid hardening cements have also been used, cost may make the use of either of them uneconomic. The flash setting characteristics of some class C fly ashes must also be addressed.

3. Bleeding

CLSM are slurries with high water content, and consequently bleeding of water is usually high. The extent of bleeding depends on mix design and the fluidity required in a particular application. Settlement caused by bleeding has been reported to be in the order of 1-2% (McLaren and Balsamo 1986, Krell 1989). This settlement occurs before the cementitious constituents have set and no further shrinkage is likely to occur. For trench backfilling, bleed water can be expected to dissipate into the surrounding fill. However, when filling a sealed container (e.g. an abandoned underground tank), bleed water may need to be removed after which a second backfill application may be required (Balsamo 1987).

4. Heat of Hydration

Heat of hydration is a potentially destructive problem although very few workers mention it. Balsamo (1987) states:

Heat of hydration is proportional to the rate of hydration. A high heat of hydration in massive fills can cause detrimental cracking. Class F fly ash has a slow rate of hydration that allows heat to dissipate before it can build up. Heat of hydration may need to be controlled in class C backfills by limiting strength, retarding set, or placing the fill in lifts.

Cracking in any form is undesirable as it creates a potential route for water penetration beneath the pavement surface.

2.3.2 Long-Term Properties
1. Strength
As discussed in Section 2.1 of this report, the 28-day compressive strength of CLSM should be in the range of about 0.5-2.0 MPa to allow for future excavation of the material. Firth Flowable Fill has a compressive strength of 1.0-2.5 MPa (Browne 1992). CLSM, as with other cementitious materials, will continue to gain strength after 28 days. McLaren and Balsamo (1986) report 28-day strengths of 0.170-0.515 MPa, increasing to 0.690-1.24 MPa in one year.

For applications such as bridge abutment backfilling, future excavation of the backfill may be of little concern and higher cement contents may be considered. However, such mixes require careful design to minimise heat of hydration and maximise cost advantage.

2. Durability
CLSM mixtures are not designed to resist freezing and thawing, abrasive or erosive forces, or aggressive chemicals (Adaska and Krell 1992). In most backfilling applications erosion and abrasion are unlikely to be a problem as the material is contained on all sides. If exposed, the backfill will be prone to dusting and abrasion, and will require a protective cover such as a trafficable pavement or granular material.

The freeze-thaw durability of CLSM increases with increasing strength. Balsamo (1987) considered materials with a compressive strength of 1 MPa ..... *may not have adequate freeze-thaw durability to function properly above the frost line.* Laboratory freeze-thaw tests carried out in accordance with ASTM C666-84 (Janardhanam et al. 1992) showed that a class F fly ash mix containing 10% cement had no significant compressive strength loss after 14 test cycles.

Krell (1989) reported on the use of CLSM containing 5% cement and that some deterioration occurred when it was placed in a zone of total water saturation subjected to severe winter freezing. However, he also states ... *All the evidence seen in the field to date indicates that a 5% Portland cement mixture should perform as a road base under severe winter conditions.*

Freeze-thaw durability is unlikely to be a significant concern for CLSM use in New Zealand apart from in Central Otago and central North Island.

3. Density

The density of hardened CLSM ranges between 1440 and 2400 kg/m^3, depending on the mix design. Mix design variations will also control the fresh density. Browne (1992) indicates that Firth Flowable Fill has a wet density of 2200 kg/m^3. Lightweight materials can be used in applications where foundation soils are compressible and the use of granular backfill would result in settlement.

4. Permeability

The permeability of a fly ash slurry mix is determined by the permeability of the pore space in the cementitious material. Permeability is inversely proportional to strength over a wide range of values. Typical values are 10^{-4} to 10^{-7} cm/sec (McLaren and Balsamo 1986). These values are less than the permeability of granular backfill. This may be considered an advantage in applications where preventing the ingress of water below a pavement is desirable. If used extensively as a sub-grade material, CLSM may reduce drainage from the pavement basecourse layers.

5. Shrinkage

Shrinkage and shrinkage cracks do not affect the performance of CLSM. Typical linear shrinkage is in the range of 0.02-0.05% (ACI 1994).

6. Bearing Capacity

When used as bridge abutment backfill or for trench reinstatement, CLSM is required to perform as a sub-grade material. As such, its bearing capacity is of interest for pavement design. Adaska and Krell (1992) considered that in terms of allowable bearing pressure, which is a common criterion for measuring the capacity of soil to support a load, a CLSM with a strength of 0.69 MPa is equivalent to a well compacted fill.

Janardhanam et al. (1992) carried out California bearing ratio (CBR) tests in accordance with ASTM D1883-73 (ASTM 1973) on CLSM samples with cement contents of 8%, 10% and 12% (by weight). Figures 2.1 and 2.2 show the CBR values for dry-cured and wet-cured samples. Principal conclusions from this work were that the penetration resistance of the mix improved with curing and the CBR values were reasonably high, suggesting the mix would exhibit little backfill settlement.

An alternative approach to CBR testing of sub-grades is a mechanistic approach based on elastic layer theory. This theory better simulates the dynamic wheel loads induced by traffic on the pavement. Lasater (1990) carried out resilient modulus testing on CLSM in accordance with AASHTO T274-82 (1986) in which a cylindrical specimen is subjected to repeated dynamic loads and confining pressures representative of field conditions. Sub-grades with resilient modulus values greater than 104 MPa are considered "excellent" materials. The CLSM tested (Lasater 1990) exhibited stiffnesses well in excess of typical pavement sub-grades. A mix containing 24 kg/m^3 cement showed a resilient modulus of 286 MPa. No plastic deformation (settlement) problems were encountered after loading 612,000 equivalent single axle loads on this mix.

Figure 2.1   CBR test results for dry-cured samples (taken from Janardhanam et al. 1992).
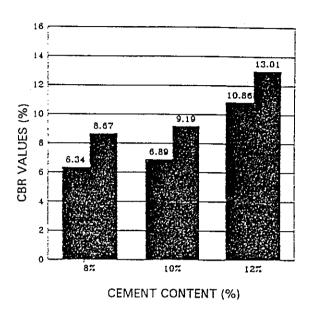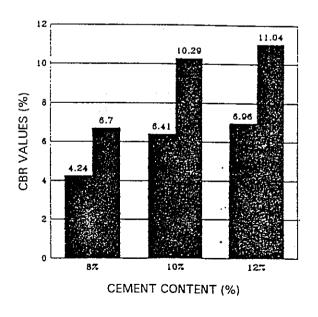

Figure 2.2   CBR test results for wet-cured samples (taken from Janardhanam et al. 1992).

Left bar   =   0.1 inch penetration
Right bar   =   0.2 inch penetration

For trench reinstatement applications, the structural support capability of CLSM above buried pipes is of interest. Peindl et al. (1992a, b) compared a CLSM backfill with a normal compacted soil backfill in a full scale trial consisting of parallel trenches traversing a service road. Instrumented pipe assemblies were installed in the trenches and monitored for both static and dynamic loads. For both conditions the CLSM performed as well as or better than the compacted soil backfill where surface strains and joint loads increased with continued compaction, under normal loading. In contrast, surface strains and joint loads decreased with time for the CLSM as the material cured further and became a stronger structural component.

2.3.3 Environmental Impact

The use of fly ash raises some concerns about its environmental impact. Because of the fine particulate nature of the material, some regional authorities in the US consider sewers and stormwater drains may become blocked if the fly ash migrates from the site. In addition, fly ash contains a variety of metals (e.g. Mo, Se, As, Cr, Zn, B, etc.) which condensed on the ash particles as flue gases carried them out of the furnace combustion zone. If leaching makes these metals mobile, they may cause ground water contamination.

Neither chemical nor particulate pollution is likely from fly ash once it is incorporated in a hardened CLSM. The particles are effectively bonded into the matrix of the slurry and will not migrate significantly (McLaren and Balsamo 1986).

2.3.4 Cost

Several workers have analysed the cost of CLSM in comparison to conventional fill materials (Lasater 1990, Brewer and Hurd 1991, Funston et al. 1984). The costs vary from state to state within the US, as they are related to fluctuations in material cost and availability. Generally, the material cost of CLSM is greater than conventional backfill materials (Adaska and Krell 1992).

However, the use of CLSM involves significant savings of labour costs since no stockpiling, compaction, or levelling of fill are required, and there is potentially less excavation with the use of narrower trenches.

Brewer and Hurd (1991) describe a method for determining the cost of CLSM. Using this method, CLSM was some 4% more expensive than conventional backfill based on a standard trench width, but cost could be further reduced for CLSM using a narrower trench. Other cost advantages of CLSM which are difficult to quantify include reduced road closure time and lower long-term maintenance costs. The significant on-site time saving using CLSM is likely to be a factor in its selection.

In New Zealand, the cost of Firth Flowable Fill as of March 1993 was NZ$90-$100/cubic metre (Davidson, pers. comm. 1993).

2.4 Advantages

- Compaction is not required, thus minimising labour costs.

- Stockpiling of fill is not required.

- Narrower trenches can be used, thus reducing excavation costs.

- Worker safety is improved because activities within trenches are minimised.

- Placement can be quick and traffic loads can be supported within several hours, thus minimising road closure time.

- Conventional ready mix plant is used for mixing, transportation, and placement.

- Placement can be in wet/cold or hot/dry weather.

- Waste material is utilised.

- Material is self levelling.

- Pipe joints are sealed.

- Conventional equipment can be used for excavation.

- Voids around services and beneath overhung surfaces are completely filled.

- Free-standing water is displaced.

- Mix design can be adjusted to suit different applications and local availability of materials.

- Fly ash, if used, is effectively bonded into the matrix of the slurry and unlikely to release hazardous leachates.

- Density is low, in comparison to that of conventional fill materials, therefore it is useful above compressible foundation soils.

- Lateral loads against retaining walls are reduced once set.

- Colour can be added to identify embedded utility.

- Settlement is reduced.

2.5 Limitations

- Class C fly ash may develop high heat of hydration and be subject to flash setting.

- Unacceptably high strengths may be produced, which are too high to allow excavation.

- Placements require support on all sides.

- Freeze-thaw durability decreases with low strength mixes.

- Pipes or other buoyant objects may float.

- High lateral stresses develop against retaining walls and pipes when slurry is in a fluid state.

- Excavated material must be removed from site.

- Currently not available in all areas of New Zealand.

2.6 Applications

For roading applications the use of CLSM falls into three main categories:
- trench backfill,
- retaining wall or bridge abutment backfill, and
- fill for abandoned underground structures.

Other uses include
- placing of railway embankments underwater,
- filling scour voids under bridge piers,
- fill for erosion control mats, and
- foundation support for the pedestal portion of footings.

Buss (1989) reports a method for converting small bridges into culverts where pipes and retaining walls are placed beneath the bridge deck, and the gap between these and the deck is filled with CLSM.

The use of fly ash slurries extends to the construction of artificial islands (Kawasaki et al. 1992), and Funston and Krell (1985) provided a good summary of CLSM applications.

Trench backfill: this is the most common use of CLSM. Balsamo (1987) described its use in the 26.6 km long McGee Creek Aquaduct in Oklahoma. In this case a class C fly ash mixture attaining a 14-day compressive strength of 0.69 MPa was used to bed large diameter steel pipes. It was placed in the trench in two lifts, then overlain with soil previously removed from the trench. The contractor chose CLSM to

increase speed of placement, reduce labour and equipment costs, and to provide a more uniform bedding. The use of class C fly ash without Portland cement resulted in a 40% cost saving for the material.

Bridge abutment backfill: CLSM was used by the Pennsylvania Department of Transportation to overcome labour intensive compaction procedures (Balsamo 1987). A considerable advantage of CLSM in this application is that the hardened slurry exerts less lateral loading behind retaining walls than do natural soils. Formwork must be provided which can resist the high lateral loads exerted by the fluid material during placement. This results in additional cost, although this may be reduced to some extent by placing the slurry in several lifts.

Fill for underground structures: CLSM has been used as fill material to overcome the considerable cost of removing underground tanks. Few other materials are suitable for this application. The slurry may need to be placed in two lifts to fill any voids left by bleeding, in order to ensure structural support. To fill three tanks of a total volume of 11.4 m^3 with CLSM, Larsen (1990) reported the contract price was only 14% of the cost of tank removal.

3. FOAMED CONCRETE

3.1 Background

Foamed concrete or low density CLSM (ACI 1994) is a free flowing lightweight concrete made by blending cement, sand and/or fly ash and water with a pre-formed foam. The material is a similar product to CLSM considered in Chapter 2 of this report except that the pre-formed foam provides it with additional lightweight properties. Foamed concrete offers similar labour saving advantages as CLSM because no compaction is required. The development of foamed concrete has been primarily in Europe, especially The Netherlands, and the UK.

Historically, foamed concretes have been considered as lightweight building materials offering superior thermal and acoustic insulation properties. Graf (1949) produced a benchmark paper on this topic and included results from research undertaken in the 1930s. Research into foamed concrete in New Zealand has been undertaken by Boult (1978a), utilising proteinous resin from abattoir waste as the foaming agent. The material was considered as a building material and included in cladding panels that were field trialled in Indonesia (Boult 1978b), but it was not assessed as a backfill material.

According to the New Zealand Concrete Industry Guide (C&CANZ 1993), foamed concrete is available under the trade names Foamcrete (Firth Industries Ltd) and Mearlcrete (Ready Mixed Concrete Ltd). Browne (1992) indicated that foamed

concrete is available from New Zealand Foamed Concrete Ltd. The use of foamed concrete for trench reinstatement in New Zealand is likely to be limited now that CLSM have become available, because foamed concrete is significantly more expensive to produce than CLSM (Davidson, pers. comm. 1993). Also the foam-generating plant is not available throughout New Zealand. However, the low density of foamed concrete gives it some advantages over CLSM, particularly where backfilling is required over compressible foundation soils.

Foamed concrete, like CLSM, is particularly suited to the backfilling of narrow trenches. It can be used to replace pavement bases, sub-bases and sub-grades, and the asphaltic surface layer can be placed directly onto this material.

3.2 Composition

Foamed concrete is produced by incorporating a metered volume of pre-formed foam into a cement paste or mortar mix of known volume and density. The foam is produced by a foam generator in which a concentrate diluted with water is forced through a restriction to produce the foam. The most commonly used foam concentrates are based on protein hydrolyzates or synthetic surfactants. The concentrates are formulated to produce stable air bubbles that resist bursting during the mixing, placing and hardening of the concrete. Between 75% and 85% of the bubbles are 0.3-1.5 mm in diameter (BCA 1991).

Foamed concrete can be produced either by batch or continuous mixing. With batch mixing, the mortar is manufactured at a ready mix plant and transported to the site in truck mixers. A separately produced foam is added to the mortar on site. With continuous mixing, the dry constituents are delivered to the construction site then mixed with water and the separately produced foam. Batch mixing is best suited to small scale trench reinstatement projects, whereas continuous mixing offers excellent quality control for use on large construction sites.

Foamed concrete with dry densities below 600 kg/m^3 contain cement, foam and water or cement, fly ash, foam and water (BCA 1991). Higher densities are produced by adding sand. Typical mix designs to achieve a range of densities are shown in Table 3.1. Foamed concrete for trench reinstatement must have relatively low ultimate strength to allow re-excavation yet develop sufficient early strength to allow early resurfacing. A mix design meeting these requirements is likely to have a density between 1200 and 1400 kg/m^3, with cement contents between 275 and 400 kg/m^3.

In most foamed concretes ordinary Portland cement is used as the binder, but for faster development of strength, rapid hardening Portland cement may be used. Setting times can be shortened by using accelerating mixtures.

Table 3.1   Typical mix designs for foamed concrete (taken from BCA 1991).
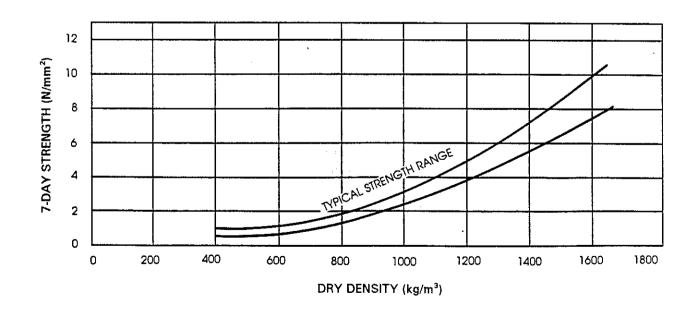
Property	Mix 1	Mix 2	Mix 3	Mix 4
Wet density (kg/m^3)	500	900	1300	1700
Dry density (kg/m^3)	360	760	1180	1550
Cement (kg/m^3)	300	320	360	400
Sand (kg/m^3)	-	400	780	1130
Base mix w/c ratio	Between 0.5 and 0.6			
Air content (%)	78	62	45	28

w/c = water/cement ratio

3.3   Properties

Foamed concrete shows similar properties to normal dense concrete in that its compressive strength will depend on density, water/cement ratio, and cement content. A range of hardened densities can be produced with a corresponding range of compressive strengths. Figure 3.1 shows the relationship between 7-day strength and dry density of foamed concrete.

Figure 3.1   The relationship between compressive strength and dry density for foamed concrete (taken from BCA 1991).

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Based on research carried out at the BCA and elsewhere, the BCA (1991) have published typical properties of foamed concrete, and these are included in Table 3.2.

Table 3.2   Typical properties of foamed concrete (BCA 1991).

Dry density (kg/m³)	7 day compressive strength (MPa)	Thermal conductivity (W/mK)	Modulus of elasticity (kN/mm²)	Drying shrinkage (%)
400	0.5-1.0	0.10	0.8-1.0	0.30-0.35
600	1.0-1.5	0.11	1.0-1.5	0.22-0.25
800	1.5-2.0	0.17-0.23	2.0-2.5	0.20-0.22
1000	2.5-3.0	0.23-0.30	2.5-3.0	0.18-0.15
1200	4.5-5.5	0.38-0.42	3.5-4.0	0.11-0.09
1400	6.0-8.0	0.50-0.55	5.0-6.0	0.09-0.07
1600	7.5-10.0	0.62-0.66	10.0-12.0	0.07-0.06

The thermal conductivity is between 5% and 30% that of dense concrete, confirming its superior insulating properties. The modulus of elasticity of foamed concrete is significantly less than that of dense concrete. The drying shrinkage is relatively high, but when used as backfill in a trench is unlikely to fully dry out. Shrinkage may later lead to discontinuous microcracks, but experience in other countries suggests that the microcracks do not lead to reflective cracking through the asphalt topping, at least not in the first two years (Hudson 1990).

Foamed concrete shows good resistance to the effects of freeze-thaw because of its cellular structure. Specimens taken from foamed concretes with dry densities between 800 and 1400 kg/m³ suffered no damage when subjected to a freeze-thaw regime with a temperature range of −18°C to +20°C (BCA 1991).

The suitability of foamed concrete to carry the loading expected on a trafficked pavement has been proved in practice in the UK. For trench reinstatement a further concern is that a pipe will experience deflection in a trench backfilled with foamed concrete when the pavement above is subjected to dynamic loading. A trial has been undertaken where the deflection of a 200 mm diameter buried pipe was measured under dynamic loads exerted by an 8 tonne axle (Taylor 1988). Foamed concrete induced significantly less deflection of the pipe than traditional granular fill.

Foamed concrete, like CLSM, is likely to be less permeable than granular backfill. If used extensively as a sub-grade material, foamed concrete may prevent the pavement basecourse from properly draining. However, this problem is unlikely to be of major concern when foamed concrete is used to backfill narrow trenches.

Quality control testing should be carried out when making and using foamed concrete, and properties which should be measured include fresh density and compressive strength. Hudson (1990) suggested that wet foamed concrete should be within ±50 kg/m^3 of the design density.

3.4 Advantages

Many of the labour- and time-saving advantages of foamed concrete are shared by CLSM, as detailed in Section 2.4 of this report. Both materials offer the benefits of flowability with no need for compaction. For the sake of completeness, the advantages of foamed concrete include:

- Compaction is not required, thus minimising labour costs.

- Stockpiling of fill is not required.

- Narrower trenches can be used, thus reducing excavation costs.

- Worker safety is improved because activities within trenches are minimised.

- Placement can be quick and traffic loads can be supported within several hours, thus minimising road closure time.

- Conventional ready mix plant is used for mixing, transportation, and placement.

- Placement can be in wet/cold or hot/dry weather.

- Waste material is utilised.

- Material is self levelling.

- Conventional equipment can be used for excavation.

- Voids around services and beneath overhung surfaces are completely filled.

- Fly ash, if used, is effectively bonded and unlikely to release hazardous leachates.

- Density is low in comparison to that of CLSM and conventional fill materials, therefore it is useful above compressible foundation soils.

- Lateral loads against retaining walls are reduced once set.

- Settlement is reduced.

- Resistance to freeze-thaw action.

- Little or no bleeding or segregation.

- Good thermal insulation and sound absorbing properties.

3.5 Limitations

- Specific foam-generating plant is required.

- Freestanding water cannot be displaced.

- Potable water supply is required - organic contaminants can disrupt the quality of foam produced.

- Some foams are temperature sensitive.

- Workability of base mix must be carefully controlled - a base mix which is too stiff may cause the foam to collapse.

- Placements require support on all sides.

- Pipes may float.

- High lateral stresses develop against retaining walls and pipes when slurry is in a fluid state.

- Excavated material must be removed from site.

- Material is not available in all areas of New Zealand.

3.6 Applications

For roading purposes, foamed concrete is used in similar applications to CLSM, i.e.
- trench backfill,
- retaining wall and bridge abutment backfill, and
- fill for abandoned underground structures.

Other uses include
- blinding under floors to provide thermal and sound insulation,
- lightweight roof screed,
- lightweight material to stabilise embankment slopes,
- cores for precast insulating sandwich panels, and
- support for tank bottoms.

An interesting roading project in which foamed concrete has been used is in the arterial road construction as part of the Canary Wharf project in London Docklands (Van Deijk 1991). This project involved the construction of a road over clay, limestone and sand layers where the first load bearing level was some 18 m below ground level. The use of normal granular material would have imposed considerable load with unacceptable settlement. For this reason a *raft foundation* of foamed concrete was used over settlement-reducing skin friction piles. The use of foamed concrete also reduced the lateral loads on an adjacent retaining wall. The project involved the use of two layers of foamed concrete: a 1.5 m deep layer with a hardened density of 480 kg/m^3 and a 28-day compressive strength of 0.27 MPa; overlain by an 0.5 m layer with a density of 670 kg/m^3 and a 28-day compressive

strength of 0.87 MPa. Use of foamed concrete in this application demonstrates its usefulness for bridge abutment backfilling, especially where foundation soils are weak.

Foamed concrete has been used in conjunction with mechanised laying of gas mains in the UK (Coates 1988). Its use has allowed the development of narrow trenching methods because no backfill compaction is required. The specific equipment developments include the use of tungsten-tipped road trenching machines, removal of spoil by suction or using a narrow excavator bucket with ejection plate, followed by mechanical laying of the gas main. The foamed concrete used was sold under the brand name Trufoam, which is based on a 2:1 sand/cement ratio giving a hardened density of 1300 kg/m^3 and a 7-day strength of 5 MPa.

The most significant potential use of foamed concrete in New Zealand as a backfill material is in conjunction with the development of narrow trenching methods for placing utilities.

4. FLY ASH

4.1 Background

Coal-fired power plants in the US, UK and Europe produce millions of tonnes of fly ash annually, but only a fraction of it is productively re-used. The balance must be disposed of in impoundments and landfills at great expense (Martin et al. 1990). An alternative application which utilises large volumes of ash is in structural fly ash embankments, typically for bridge approaches. The fly ash is compacted in a similar manner as standard granular fill so does not have the labour-saving advantages of slurried fly ash materials.

In terms of an engineering material, fly ash is not the first choice for bridge abutment backfill application. Significant difficulties are involved with its use, including compaction methods, the environmental impact of leachates, low freeze-thaw durability, sub-surface erosion, high compressibility, and low shear strengths. Cost is also a primary concern and, with the low cost of conventional backfill materials and similar labour rates for placing, fly ash is likely to be a viable option only if it is used close to its source, i.e. where no significant cartage is involved. Fly ash also shows some useful engineering properties in that it can be self-cementing and is lightweight, but its use is prompted primarily by the waste disposal problem it solves. For this reason Federal and state agencies in the US actively promote its use.

The use of fly ash as a fill material is likely to be limited in New Zealand because a consistent supply is available only from one source, the Huntly Power Station.

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4.2 Composition

Both class C and class F fly ashes are used in this bridge abutment backfill application. However, the more reactive class C ashes are generally considered more saleable for other uses and therefore are less likely to be available for use as embankment fill. Also the self-cementing characteristics of some fly ashes is a property that requires some time to develop after placement, and cannot be relied on to develop early backfill strength. The development of this strength with time does improve the backfill's cohesion and reduce lateral loads on retaining walls.

Primarily, fly ash for backfilling relies upon its internal friction and "apparent cohesion" between the fly ash particles for shear strength (Bognacki and Haag 1980). This cohesion develops from the capillary surface tension in the small amount of water held in the voids in the damp fly ash. Above an optimum moisture content this cohesion disappears, and if completely saturated fly ash can behave as a liquid. Consequently in the design and construction of structural fly ash fills, it is essential to keep the ash well drained and to ensure that a high degree of compaction is obtained to restrict pore water pressures.

Huntly fly ash shows the characteristics of a class C material and has demonstrable hydraulic properties, so it is likely to improve the cohesion of a backfill. However, very little information has been published regarding its properties, although the composition is known to vary significantly depending on the source of coal being fired. The self-cementing characteristics of Huntly fly ash cannot therefore be guaranteed and, if it is to be used in structural embankments, it would be prudent to consider Huntly fly ash as a class F material.

4.3 Properties

The size grading of fly ash is similar to natural silts. Therefore, before data became available on the geotechnical performance of fly ash, its behaviour was assessed on criteria established from the testing of natural silts. Natural silts are weather-sensitive, prone to dusting and sub-surface erosion, drain poorly, show low freeze-thaw resistance, have high compressibility and low shear strength (Martin et al. 1990). Based on these criteria then, fly ash was predicted to perform poorly.

However published information on fly ash is now available with Martin et al. (1990) providing a good summary of the papers. Based on this information the mechanical behaviour and compaction characteristics of fly ash have been found to be more like those of fine sands rather than of silts (Martin et al. 1990).

The detailed geotechnical properties of fly ash will not be considered in this report because its use is likely to be restricted in New Zealand. Properties such as compaction, permeability, shear strength, CBR, compressibility, suitable vibration for compaction, penetration and tensile deformation have been assessed by several workers (Chae and Snyder 1977, Seals et al. 1977, Martin et al. 1990, Indraratna et

al. 1991). The results of their testing have shown that fly ash is practical for use as a construction material, providing drainage and effective protection from rainwater run-off are considered. Fly ash does not possess the properties required for use as a roading basecourse. Its principal application in roading applications is as fill for bridge approach embankments.

Apart from the engineering properties of fly ash, other factors likely to influence its applications include the density of the compacted material, freeze-thaw durability, and its environmental impact.

4.3.1 Density
Bognacki and Haag (1980) reported the as-constructed density of fly ash in a railway embankment to be 91 lb/ft³ (1460 kg/m³) using ash from the Amos generating plant, West Virginia. This density is likely to vary to some extent depending on the source of the fly ash and its moisture content but, overall, fly ash may be regarded as a lightweight material suitable for use over compressible foundation soils.

4.3.2 Freeze-Thaw Durability
Silt-sized materials have been found to be particularly troublesome with respect to formation of ice lenses in the sub-grade (Martin et al. 1990). Compacted silt and fly ash have the ability to retain more moisture in their pores than coarser grained materials. Moisture retention alone is not a problem above the water table where ice can form in the air-filled voids, but a problem does arise if water wicks up from a shallow water table and fills the voids. The problem can be overcome by provision of adequate drainage below the fly ash layer and by its encasement in an insulating soil blanket.

4.3.3 Environmental Impact
The environmental impact of uncontrolled run-off from a fly ash backfill in an embankment is more severe than from normal fill because of its chemical composition. Water moving through fly ash backfill will dissolve heavy metals on the fly ash particles forming leachates that can cause ground water contamination.
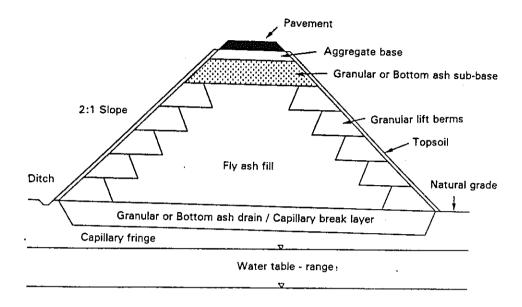
Fly ash can be assessed for its leaching characteristics using the US Environmental Protection Agency (EPA) EP toxicity test (Martin et al. 1990). Only fly ashes showing safe leaching characteristics should be used as fill materials.

The fly ash particles themselves also pose an environmental problem of suspended solids in run-off water. Consequently any run-off must be channelled to a sedimentation pond.

To minimise the potential for environmental problems, fly ash embankments should be designed to allow rapid removal of surface water to prevent intrusion of ground water into the compacted layers. A suitable fly ash embankment construction is shown in Figure 4.1. Fly ash is essentially the bulk fill material, protected from erosion by granular materials and separated from a base drain with a synthetic barrier.

Figure 4.1   Composite fly ash and sand embankment (from Martin et al. 1990).
Embankment would also include a sedimentation pond to capture run-off and a
synthetic barrier between the basal drain and the fly ash fill.

4.4   Advantages

•   High volume utilisation is made of an otherwise waste material.

•   Material is a cheap source of fill when used local to source.

•   Conventional equipment can be used for compaction.

•   Material is suitable as backfill in a suitably designed embankment.

4.5   Limitations

•   Material is susceptible to wind and surface water erosion.

•   Sedimentation ponds are required to restrict deposition of suspended particles.

•   Heavy metal leachates have potential environmental impact.

•   Freeze-thaw durability is low.

•   Material has potential to act as a liquid if saturated.

•   Availability, and hence applicability, are limited in New Zealand.

•   Specific design is required.

4.6   Applications

The major application of fly ash as a structural fill material is in road and rail embankments, and the success of these uses means it is appropriate as bridge abutment backfill.   In addition, technical bulletins issued by the Ash Marketing Group of the Central Electricity Generating Board (CEGB) in Britain detail the use of fly ash in underfilling redundant bridge spans. The fly ash is placed between concrete retaining walls using conventional earth-moving machinery, then the remaining cavity is topped up with a fly ash slurry. In both these applications the backfill can be designed to overcome the limitations of fly ash as structural fill, particularly with regard to its environmental and structural instability related to ground water and surface run-off.

Fly ash is an inappropriate material for trench backfilling except as a component of CLSM and foamed concrete.

5.   WOOD WASTE

5.1   Background

The use of wood waste in roading construction has been recorded in British Columbia, Canada (Coulter 1975), Washington (Jackson 1980) and Idaho States in the US, and in Norway and Sweden. Sawdust has been used in two principal roading applications:

- for landslide correction or reconstruction, or

- to construct embankments over soft foundation soils.

An example of a major application of the material was the construction of the Burnaby Freeway section of the Trans Canada Highway between 1959 and 1963 in British Columbia.

Wood waste has been utilised in New Zealand to stabilise a road across a landslide in the Wairarapa, and was used by Hamilton City Council for a road constructed over peat soils (Robson 1985). No other New Zealand applications are known. The use of wood waste relies upon its availability, as in forested regions serviced by sawmills where there is virtually an unlimited supply. Its use in many cases is influenced by this local availability of a cheap waste material that is also suitable to overcome road construction problems. For example, the regions actively utilising wood waste in road construction in North America are in general heavily forested.

5.2   Composition

Using North American terminology, three kinds of wood waste are recognised as being useful for roading construction:

- Sawdust - predominantly granular with particles in the order of 6 mm or less.

- Hog fuel - a combination of wood fibres, sawdust, pieces of wood up to 300 mm long and bark. Hog fuel is a material which is *hogged* in a hammer mill to produce fuel for steam boilers.

- Bark - of variable size up to 100 mm in diameter.

Wood waste is inherently a variable material. Its nature is dependent as much on the species of timber being cut in the sawmill as it is on the milling process being used. Wood waste can vary from day to day in the same mill and between mills, so some care must be taken when specifying the material.

Most wood waste in New Zealand is derived from soft wood species. Wood waste appropriate for road construction comes from the initial processing of felled trees, but wood waste derived from the machining of treated timber is inappropriate for use in roading construction.

Wood waste in an aerobic condition will begin to decay, releasing carbon dioxide and a substantial amount of heat. Such aerobic conditions occur in stockpiled wood waste. Jackson (1980) reported a temperature rise to over $38°C$ in an embankment constructed from sawdust sourced from a stockpile that had begun to decay. To prevent this rise in temperature only fresh wood waste should be used.

The Washington Department of Transportation (in Jackson 1980) has included the following clause in a specification for sawdust fill:

> *The sawdust borrow shall consist of 100% fresh wood fibres, such as sawdust, hog fuel or wood chips. Partially decomposed or decomposing wood fibre, as indicated by temperatures above ambient, will not be allowed. The material shall be tested by the engineer and shall not have a temperature greater than 70°F or greater than ambient temperature, whichever is higher. No composition wood products such as particle or chip board, pressed hardboard, or presto-log fragments shall be used in this embankment. Maximum particle size will be 1 foot in the greatest dimension. Sufficient smaller sized material shall be used to produce a uniformly dense fill.*

5.3   Properties

Wood waste materials are likely to have unusual strength and compressibility characteristics because of their fibrous and cellular nature. The use of wood waste also raises concerns regarding degradability, possibility of spontaneous combustion, and the environmental impact of leachates.

5.3.1   Strength
Several workers have considered the strength characteristics of wood waste. Lea and Brawner (1963) reported an angle of internal friction of 50° for sawdust determined by direct shear tests. Using drained triaxial specimens, Jackson (1980) reported an angle of internal friction of 25° to 27°, and Coulter (1975) gave an angle of 27.5°.

The strength of the material depends on the density of the compacted specimen. The density itself is dependent on the situation for which the fill is used. In an effort to restrict the possibilities of degradation and spontaneous combustion, wood waste is invariably used below the water table where conditions are almost anaerobic. Wood has the capacity to absorb water so the density is likely to change with time. Jackson (1980) reports in situ wet densities of about 950 kg/m^3 in a sawdust embankment in Raymond, Washington. Coulter (1975) measured in-situ bulk densities of 400-510 kg/m^3 in an embankment in British Columbia, but considers summer drying may have reduced this value. If used above the water table, wood waste is normally encapsulated in polythene sheeting to maintain anaerobic conditions, and in this state will probably remain at its placement moisture condition.

The bearing capacity of a sawdust embankment has been calculated using data from plate bearing tests, rebound deflection and seismograph (Jackson 1980). These results *... equate roughly to a CBR of 1*. Consequently wood waste embankments must be capped with a load-bearing granular material. Jackson (1980) indicated a minimum thickness of 600 mm of granular material is required, and more if the trafficking warrants it.

5.3.2   Consolidation
The Washington Department of Transportation (in Jackson 1980) requires placement and compaction to be achieved in the following manner:

> *The lightweight fill may be constructed by end dumping of trucks or any other method approved by the engineer. Compaction shall be obtained by routing D7 or D8 caterpillar type tractor or equivalent over the entire surface of each lift two times or to the satisfaction of the engineer. Placement and compaction shall be in layers not to exceed 1 foot of uncompacted depth. Compaction equipment shall weigh a minimum of 33,000 pounds (15 tonnes).*

Instantaneous compression under 2400 mm of granular fill has been measured to be about 15% of the wood waste depth (Coulter 1975). Post-construction consolidation can be expected to be 3-4% of the total depth of fill, i.e. some 200 mm in a 6 m deep embankment (Jackson 1980). This amount of settlement is clearly a significant maintenance factor on a trafficked road surface. Increased long-term maintenance costs are, however, an anticipated expense of wood waste embankments. These costs are readily accommodated when the construction cost saving of using a wood waste embankment over other more expensive options.

5.3.3   Environmental Impact
Leachates from wood waste have the potential to contaminate ground water. The soluble extracts include sugars, acids, tannins and phenols which produce a liquid with a high metal ion content and low pH, that may be toxic in sufficient concentrations. Evidence on the impact of these leachates is conflicting. Jackson (1980) considered water draining from an embankment will be relatively uncontaminated within six months to a year but Coulter (1975) regarded cedar to release toxic leachates and recommended the use of hardwood species only for fill below the water table. Before wood waste is used in New Zealand the leachate released by timbers cut from commonly grown species must be analysed, and its level with regard to water contamination restrictions must be considered.

5.3.4   Spontaneous Combustion
The use of wood waste has been mainly below the water table where anaerobic conditions restrict the possibility of spontaneous combustion and degradation. In aerobic conditions however, before spontaneous combustion will occur the temperature within wood waste must exceed 230°C. The mechanisms involved in reaching that temperature are debatable.

The use of wood waste (to 1992) in North America has been in coastal areas where rainfall is high, temperatures are moderate, and the embankments have been compacted to give relatively high densities and anaerobic conditions. The risk of spontaneous combustion is therefore low, but in drier, warm regions or where compaction has been inadequately controlled the risk is higher (Jackson 1980).

5.3.5   Degradation
Under anaerobic conditions, either below the water table or encapsulated to exclude air, wood will degrade slowly. Temperatures are likely to rise slowly and methane gas will be given off. This degradation is unlikely to significantly alter the performance of an embankment. On the Burnaby Freeway, Benkelman Beam rebounds measured over about 8 years have shown no significant change (Coulter 1975).

Degradation of timber in aerobic conditions is a well documented process. In an embankment, aerobic degradation would result in high temperatures and release of carbon dioxide and, with time, the physical structure of the material will alter. Therefore embankments are recommended to be constructed so that the wood waste is maintained in an anaerobic condition.

5.4 Advantages

- Material is readily available in commercially forested areas.

- Utilisation is made of an otherwise waste material.

- Material is lightweight.

- Material is a cheap and simple construction alternative.

- Conventional methods are used for compaction.

- Quick "emergency" reconstruction is possible on roads affected by landslides.

5.5 Limitations

- Anaerobic conditions are required to suppress spontaneous combustion and degradation.

- Leachates have potential environmental impact.

- Maintenance costs are increased.

- Life expectancy of wood waste embankments is only about 15 years (Jackson 1980).

- Use is limited to areas around sawmills.

5.6 Applications

As outlined in Section 5.1 of this report, the principal applications for wood waste in roading is for landslide correction or reconstruction, or to construct embankments over soft foundation soils. It is not appropriate for trench backfilling for which more appropriate materials exist.

Initially the reconstruction of roading over landslides with wood waste was used as a temporary "emergency" measure to minimise road closures. The technique, however, has been adopted as a more permanent measure as it offers a quick, simple and cheap alternative to difficult engineering problems. Typically construction involves contouring and stabilising the old slide surface, installation of internal drainage, and reconstruction of the missing section with wood waste. This section is then capped off with granular fill. Wood waste has also been used in an attempt to stabilise active, slow moving landslides (Jackson 1980). However, continued patching to maintain the road grade resulted in pavement depths up to 2400 mm deep, heightening the risk of a total embankment failure caused by increased dead load.

Coulter (1975) reported the use of polythene sheeting to encapsulate wood waste materials above the water table, the first use of such a technique.

The construction of a wood waste embankment over soft foundation soils in Raymond, Washington, was an alternative to removing 6-8 m of existing material and replacing it with crushed rock (Jackson 1980). The use of wood waste resulted in significant time and cost savings. Performance of the embankment in its first three years of service was within the design parameters set for that job.

6.   EXPANDED POLYSTYRENE

6.1   Background

Expanded polystyrene (EPS) has been used extensively in Norway following research and development by the Norwegian Road Research Laboratory. Skuggedal and Aaboe (1991) reported more than 150 projects had been undertaken using EPS as a fill material, a total volume of about 250,000 m³. The use of EPS has been recorded in the US (Coleman 1974) and UK (Anon 1986), and its suitability for use in Germany has been investigated (Behr and Hurtgen 1990).

Polystyrene is an ultra-lightweight fill material with an initial density of 20 kg/m³ which is substantially lighter than other lightweight materials (e.g. wood waste). It has been used for extremely unstable subsoil conditions where other lightweight materials were too heavy, and alternative construction methods such as continuous piled rafts were time-consuming and expensive. A common use of EPS in Norway is building up road embankments adjoining bridge abutments over soft foundation soils. Embankments up to 6 m high have been constructed in this manner.

EPS has been used on several occasions on New Zealand state highway projects involving construction over soft soils. One of the earliest cases was where EPS was used for the north abutment of Neilsons Bridge in Northland (State Highway 10) in 1983 (Jennings, pers. comm. 1993).

6.2   Properties

6.2.1   Density and Strength
The density of the EPS most commonly used in Norway is 20 kg/m³. A design value of 100 kg/m³ is applied in stability and settlement calculations to allow for some increase in water content over its serviceable life. Rygg and Sorlie (1981) reported a moisture content in an EPS sample taken from below the water table of 8% by volume.

The low density of EPS makes it easy to handle. A block with dimensions 0.5 x 1.0 x 3.0 m has a mass of about 30 kg, which is easily handled by one person. It also allows large volumes of EPS to be moved by crane or truck.

EPS, with a density of 20 kg/m^3, should give a compressive strength of 100 kN/m^2 at maximum 5% deformation. This is equivalent to a sub-grade soil similar to clay or silt (Frydenlund and Aaboe 1988).

In terms of pavement design, EPS is a fill material above which a conventional flexible pavement is constructed. Two types of pavement are used:

1. A flexible pavement over EPS fill, with a 100-150 mm thick slab of reinforced concrete placed between the EPS fill and the pavement (see Figure 6.2). This is common practice in Norway. The concrete slab provides bearing capacity and protects the EPS from the dissolving action of petrol and oil. Using this method, a pavement thickness, including the concrete slab, of 500 mm will suit annual average daily traffic of 1000 to 10,000 vehicles for 10 tonne axle loads (Frydenlund and Aaboe 1988).

2. A thicker flexible pavement (i.e. >150 mm) is constructed over EPS fill, with polyethylene sheeting placed between the EPS fill and the pavement (see Figure 6.1). The polyethylene sheeting protects the EPS from petrol and oil. Appropriate equipment must be used for initial placement of pavement layers to ensure that the EPS blocks are not crushed.

6.2.2   Durability

EPS foams are not resistant to petroleum-based liquids and this raises some concerns if petrol spillage occurs in a traffic accident. Although the chances of this occurring on the relatively small area of a bridge abutment are small, if an accident should happen, the EPS is protected by a concrete slab or polyethylene membrane plus the overlying pavement thickness.

Chemically, EPS is a stable material and thus is unlikely to have any adverse environmental impact. Testing of samples retrieved from existing fills showed no sign of strength reduction, and in some cases compressive strength showed a slight increase (Rygg and Sorlie 1981). Load cycling tests showed that EPS will withstand an unlimited number of load cycles provided the loads are kept below 80% of the compressive strength (Frydenlund and Aaboe 1988). EPS is resistant to biological attack from bacteria and enzymes and, although soft enough to be excavated by burrowing animals, in most applications it is encased by granular pavement materials or soil on embankment slopes. The softness of the material means some care is required during construction as machinery cannot be directly manoeuvred on the fill. It also offers some advantage as the blocks can be readily formed by hand saw, knife or chain saw to required shapes.

EPS is not fire resistant, and when exposed to air and a source of fire has the potential to ignite. Once the EPS is in place below a pavement and soil embankment, and oxygen availability is restricted, the possibility of this occurring is low. However, EPS can be designed to be self-extinguishing at some extra cost, and this should be considered if the material will be exposed to the air for a long period during construction.

6.2.3 Insulation

EPS is an insulating material and will insulate the road surface from the sub-grade. This may cause icing of the road surface above the EPS fill since no heat will transfer from the sub-grade. If a particular stretch of road is considered susceptible to freezing, the thickness of the flexible pavement overlying the EPS can be increased to reduce the tendency for icing.

6.2.4 Cost

The 1988 cost of EPS in Norway was US\$30-35/m^3 (Frydenlund and Aaboe 1988) which means it is not a cheap material compared to more traditional fill materials. However, it has several cost saving advantages. Initially, in some situations, EPS is the only material light enough to be used, as the alternative would be a considerably more expensive piled raft. In situations where other lightweight materials may be as suitable (e.g. wood waste) they may not be readily available. However EPS has extremely low density, and is therefore cheap to transport, with the limiting factor being freight volume rather than freight load.

6.3 Advantages

- Very low density.

- Simple construction method.

- Cheap to transport.

- Easily handled.

- Readily shaped.

- Biologically resistant.

- Good stability - no signs of strength reduction occurring in existing fills.

6.4 Limitations

- High initial material cost.

- Buoyancy problems where water table is high.

- Flammable.

- Insulates overlying pavement from sub-grade, and thus causes icing.

- Dissolved by petroleum-based liquids.

- Not appropriate for trench backfill.

6.5   Applications

The applications for EPS take advantage of its ultra-lightweight. To overcome soft foundation soils the material has been used to construct road embankments against bridge abutments, build up unstable roads in peat soils across swamps, and to establish roads across unstable scree slopes. EPS also offers considerable advantages in reducing lateral loads against retaining walls and bridge abutments. Frydenlund and Aaboe (1988) saw considerable scope for the use of EPS as fill against vertical walls combined with the reinforced earth concept. They considered this could lead to the use of higher walls and their application on hillsides without creating stability problems. Where conventional road construction would involve long soil embankments in combination with culverts, the length of the culverts and the volume of fill could be reduced by using vertical walls in combination with EPS fill. Two typical applications of EPS are described in Sections 6.5.1 and 6.5.2.
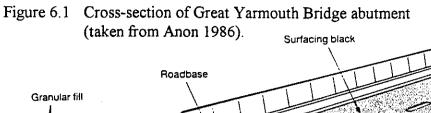
6.5.1   Great Yarmouth Bridge, UK
The first documented use of EPS in the UK was in a road embankment–bridge abutment fill in Great Yarmouth (Anon 1986). The geology at this site consists of up to 20 m of soft clays and silts, within which is a layer of peat and very organic clays. Initially two design solutions were considered. First was a low capital cost scheme using conventional construction methods, but this would have caused settlement in service and so have high maintenance costs. A second involved construction on a continuous piled raft which offered high capital but low maintenance costs. Both were rejected in favour of a solution incorporating EPS which would accelerate consolidation of the subsoil, reduce long-term settlement, and remove large differential settlements.

A cross-section of this abutment is shown in Figure 6.1. The subsoil consolidation was planned to occur mainly during the construction period by the installation of vertical wick drains and a granular drainage blanket below the embankment to carry ground water to adjacent ditches. The combined mass of the embankment is sufficient to overcome uplift from hydraulic pressure caused by the proximity of the water table.
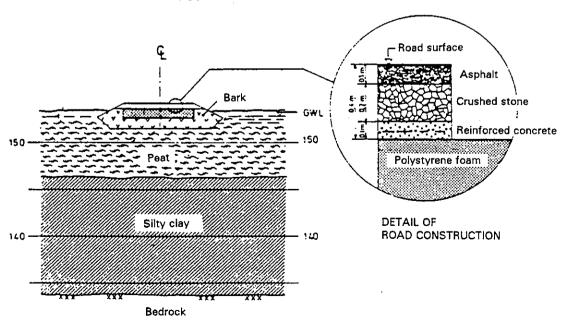
6.5.2   Road Across a Bog, Solbotmoan, Norway
This road crosses a boggy area and has a significant history of settlement. To maintain the level of the road above the water level, conventional granular fill was added until the sub-grade level had subsided 1.7 m (Rygg and Sorlie 1981). The rate of settlement was increasing and cracks in the road surface indicated it was in danger of collapse. The geology in this area is some 20 m of soft silty clay overlain by 7 m of peat. To elevate the road above the water level with granular materials would add further load to these soft materials, accelerating the rate of settlement.

As an alternative, an embankment was constructed using lightweight materials with bark up to ground-water level, overlaid with EPS foam, a reinforced concrete slab, then topped by a flexible pavement. A cross-section of this construction is shown in Figure 6.2. After five years' service since the repair the settlement ranges from 0 to 80 mm and the rate of settlement is reducing.

Figure 6.1   Cross-section of Great Yarmouth Bridge abutment
(taken from Anon 1986).

Surfacing black

Roadbase

Granular fill

Sub-base

Polyethylene
sheeting

Styrofoam fill

Pulverized fuel
ash (PFA)

Granular drainage
blanket

Polyester
sheeting

Figure 6.2   Cross-section of Solbotmoan Road embankment
(taken from Rygg and Sorlie 1981).

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Bark

GWL

150

150

Peat

Silty clay

140

140

Bedrock

Road surface

Asphalt

Crushed stone

Reinforced concrete

Polystyrene foam

DETAIL OF
ROAD CONSTRUCTION

7.   MISCELLANEOUS MATERIALS

The non-traditional backfill materials considered in Chapters 1 to 6 of this report dominate the subject matter considered in the surveyed literature. Brief references are made to other backfill materials but few details are given. In many cases these materials are locally derived wastes which form a local disposal problem or are naturally occurring materials peculiar to an area. In most cases these backfills involve few technical advances as they are used like a conventional granular material and are compacted as such.

The main advantages of many of these miscellaneous materials is they are lightweight, inexpensive, and their use overcomes a disposal problem. None of these materials are particularly suited to trench or bridge abutment backfills, but have been included to complete the available information on lightweight materials.

The miscellaneous materials include kiln dust, blast furnace slag, expanded lightweight aggregate, scoria, pumice, shredded rubber, logs, and construction waste such as porous concrete and bricks. Kiln dust and blast furnace slag are waste materials similar to fly ash, and are likely to have limited availability in New Zealand. Scoria and pumice are lightweight volcanic rocks available in volcanic regions in the North Island. Extensive use has been made of pumice and scoria materials in New Zealand applications where lightweight fills were required (Jennings, pers. comm. 1993). Both materials are likely to have been used as backfills local to their source. Cedar logs have been used overseas (Coleman 1974) and punga logs have been used in New Zealand to form lightweight rafts over swampy compressible soils. Construction waste is likely to be used only for roading constructions that are directly related to a demolition site.

Tyres are a high volume waste material which are readily available and inexpensive for use as a lightweight fill. As a backfill material the tyres are shredded into dimensions of 150-200 mm wide and 300-600 mm long. The material is placed in 600-900 mm deep lifts and compacted with a bulldozer. There are significant concerns about the release of toxic leachates from shredded tyres, particularly when used below the water table. Kohlnhofer and Marti (1992) reported that the Minnesota Pollution Control Agency (MPCA) guidelines for the use of shredded tyres included the following:

- Shredded waste tyres can be used in road construction or repair if the tyre shreds will be above the water table and not in contact with ground water. Tyre shreds cannot be used below the water table.

- Roads and road slopes must be designed and constructed to reduce water infiltration and to promote surface water drainage away from the road bed, to minimise the amount of surface water seeping through the shredded tyres.

- A synthetic geotextile fabric is recommended above and below the areas where shredded waste tyres are used. The fabric will prevent movement of soil into the tyre shreds, and will hold the tyre shreds in place.

- Tyre shreds must be covered by a low permeability surface to reduce seepage of surface water.

8. CONCLUSIONS

Several non-traditional backfill materials that may have some application for roading construction and maintenance in New Zealand have been described. None of these materials are currently used on a regular basis in New Zealand, although most are readily available. The one material that is not readily available is fly ash from Huntly Power Station, which is most suited for use only near its source because of high cartage costs. CLSM are a recent addition to local ready mix concrete operations, and are available in many areas of New Zealand.

Each of the materials considered is appropriate for use in certain applications provided the limitations of each is recognised. The three principal applications identified in the surveyed literature are as
- trench backfilling,
- abutment backfilling,
- road construction over weak sub-grades.

All these materials have gained acceptance in some region of the world, prompted by a need to utilise a waste product and/or a requirement to solve a geotechnical problem. Before they are used, the geotechnical performance of each of these backfills will require evaluation and testing to New Zealand roading specifications. The performance of the backfills could not be fully evaluated from the data in the surveyed literature because of the variety of test methods and the range of acceptance levels applied in each country.

Perhaps the most significant limiting factor to the use of non-traditional backfill materials is the resistance to new ideas. For their use and acceptance to be completely successful, designers, specifiers and contractors must understand both the advantages and limitations of these non-traditional materials.

In summary, the non-traditional backfill materials considered and their suitability for different and specific uses are:

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- **Controlled low strength materials (CLSM).** Flowable cementitious materials particularly suitable for trench reinstatement and bridge abutment backfill with appropriate design. Offers exciting possibilities in
  - development of narrow trenching methods,
  - reduction of labour costs for backfilling, and
  - minimising long-term maintenance costs.

- **Foamed concrete.** Flowable cementitious materials combined with a pre-formed foam produced by a foam-generating plant. Used extensively in the UK for trench reinstatement, but unlikely to be competitively priced in New Zealand in comparison to CLSM. Useful as a backfill over compressible foundation soils.

- **Fly ash.** Material used extensively in other countries for construction of road embankments and underfilling of redundant bridge spans, but likely to be of limited use in New Zealand because it has restricted availability.

- **Wood waste.** A lightweight waste product that should be readily available in New Zealand. Particularly suited for re-establishing road embankments across landslide debris and over compressible foundation soils. It should be restricted to use below the water table, i.e. anaerobic conditions, to limit the potential for degradation and spontaneous combustion. Offers a simple, cheap construction method but high maintenance costs are likely because of settlement.

- **Expanded polystyrene.** An ultra-lightweight material with advantages over other lightweight materials because of its low density. Suitable for use over very soft foundation soils, particularly for constructing high bridge embankments. Easily handled and transported. Limited by cost, flammability, icing problems caused by its insulation properties, and its solubility in petroleum-based liquids.

- **Miscellaneous materials.** These include kiln dust, blast furnace slag, expanded lightweight aggregate, scoria, pumice, shredded tyres, logs, and construction waste. Their main advantages are that they are lightweight, of low cost and provide solutions to local waste disposal problems. Shredded tyres are a universally available waste product but they cause some concern regarding the release of toxic leachates when used below the water table.

9. RECOMMENDATIONS

Recommendations arising from this research are that:
1. Non-traditional backfill materials are considered to be suited to the following specific applications:
   - trench backfilling - CLSM, foamed concrete;
   - bridge abutment backfilling - CLSM, foamed concrete, EPS;
   - road construction over weak sub-grades - foamed concrete, EPS, wood waste, fly ash, shredded tyres, scoria, pumice, other miscellaneous materials.

2. Further research should be considered for promoting the use of these materials under New Zealand conditions.

Such research may not necessarily involve extensive testing as much testing may have been carried out in other countries already, that is well documented. The research may only involve adopting specifiic overseas guidelines or standards, and producing notes to cover their use in New Zealand.

If research is considered necessary, it should involve the following steps:

- Set up monitoring trials of these materials.

- Evaluate material properties and construction methods.

- Evaluate cost and performance benefits to compare with those of traditional materials.

- Determine specific uses for particular materials.

- Determine availability of materials, both now and with any increase in demand.

- Determine design parameters.

- Produce guidelines for the use of these materials.

- Produce and adopt material and construction specifications.

- Determine and adopt quality control procedures and methods of test.

3. The considerable advantages offered by CLSM for trench and bridge abutment backfilling should be recognised, and priority should be given to CLSM when considering any further research.

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