



ALASKA DEPARTMENT OF TRANSPORTATION

Evaluation of Alternative Embankment Construction Methods

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The goal of this research is to examine innovative materials and methods, economically applicable to sub-arctic and arctic sites, that will help produce more high quality construction results for a given level of funding. Alternatives discussed in this report include: foundation pre-thawing, thermosyphons, air-cooled embankments, geobags/geotubes, membrane encapsulated soil layers, chemical stabilization, geogrids, EPS block, foamed concrete, shredded tires/tire bales, and wood chips/sawdust.

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Abstract

Arctic and sub-arctic regions of Alaska offer some of the more remote, unpopulated and inhospitable terrains on Earth. Poor foundation conditions at rural construction sites routinely consist entirely of ice-rich permafrost. Candidate fill materials found at remote project sites are often very high in moisture, and/or frozen, and/or too fine to be of practical use anyway. When acceptable foundation conditions and fill materials are not available, alternative materials and/or methods are needed. Construction infrastructure is virtually nonexistent in some areas where suitable construction materials normally must be shipped by barge or flown to a project site. This is a very expensive proposition indeed. For example, replacement fill shipped from a remote location to a construction project in western Alaska can cost 10 to 12 times more than if suitable local materials were available.

The goal of this research is to examine innovative materials and methods, economically applicable to sub-arctic and arctic sites, that will help produce more high quality construction results for a given level of funding. Alternatives discussed in this report include: foundation pre-thawing, thermosyphons, air-cooled embankments, geobags/geotubes, membrane encapsulated soil layers, chemical stabilization, geogrids, EPS block, foamed concrete, shredded tires/tire bales, and wood chips/sawdust.

1. INTRODUCTION

Arctic and sub-arctic regions offer some of the more remote, unpopulated and inhospitable terrains on earth. Population-support infrastructure is virtually nonexistent in some areas where most materials must be shipped by barge or flown in to rural Arctic sites at significant cost. Small airplanes equipped with wheels, floats, or skis, depending on season and/or airport conditions, are often the most reliable shipping agents. As populations of remote regions increase, demands for construction of more reliable shipping infrastructure increases as well. Reportedly, as of 2005, 1.2 billion people live in cold regions (1).

There is a constantly growing demand for better transportation to ensure a supply of fuel, food and similar items, but also to promote development of natural resources, and local economies. For example, bush communities in Alaska are supplied chiefly by aircraft. Landing locations are limited. Many airfields offer an 1,800-foot rutted, unsurfaced strip subject to muddy conditions, freezing temperatures, and limited lighting. The Federal Aviation Administration would like to see 3,200-foot paved airfields. The limited availability of desirable construction materials near many construction sites tends to thwart such projects. Local materials can require expensive remediation or replacement (material importation) in order to build better and larger airstrips, stabilize river embankments and construct roads and bridges. Invariably, both options are very expensive. Additionally, the skilled labor pool at remote sites is often small, another factor driving up costs of construction. Moreover, the construction season is short.

The Arctic and sub-arctic climate and materials pose difficulties for construction efforts. Permafrost begins thawing after the natural surface covering is removed. When fine grained permafrost materials are excavated and used as embankment fill, excess water continues to saturate these silt or organic silt fills sometimes after many years of applying embankment drying techniques including periodic vibration and surcharging, and use of chemical agents (2). For many years, such embankments may lack the bearing capacity to support infrequent loadings of transient vehicle traffic, let alone the construction of large structures. In addition, long seasons of intense freezing promote severe frost heaving even in areas without permafrost. Importing fill is expensive. Replacement fill for the poor soil conditions common to Arctic environs runs 10 to 12 times that of the cost of using locally available silty soils in the Yukon-Kuskokwim Delta, for example, or \$60-\$75/m³ (2).

In order to speed development of long-term infrastructure in cold regions, governments must optimize use of available funding. Surveys of alternate embankment construction methods are aimed at both reducing the cost of remote regions embankment construction, and improving the embankment's long-term performance. The goal is to optimize selection of materials and construction methods so that more projects can be built to a higher level of quality for a given level of funding.

2. BACKGROUND

2.1. Cold Regions Construction of Embankments in Poor Soil

2.1.1. Poor Soil Characteristics

Excavated materials that will provide subgrade-equivalent soils suitable for embankment or similar-purpose construction must possess sufficient strength to support desired vehicle loadings or structures. Beyond strength, desirable soils possess good drainage capacity, as well as properties that promote minimal compressibility, settlement, and long term creep. Categories of soils that generally fulfill the requirements of desirable subgrade soils for embankments include most soils with high gravel contents, low moisture percentages, and only small quantities of silt, clay, or organic materials. Silty, clayey, or excessively organic soils may fail to satisfy the requirements for desirable subgrade materials, especially if they are high in moisture. Such soils tend to lack both the requisite shear strength and resistance to consolidation or long term creep. Silt, clay, and organic soils have poor drainage properties, and tend to retain moisture. Soils with high moisture contents tend to initially consolidate (short term settlement) much more than comparable soils with less water. Similarly, these fine grained and /or organic rich soils offer the specter of creep (long term settlement), and (except for clay) may be very sensitive to freeze-thaw cycles as well. Some fine grained soils also have a susceptibility to certain dynamic driving frequencies, such as are produced by earthquakes. Earthquakes or other sources of vibration, can render susceptible soils ‘quick,’ or liquefied. Liquefied soils lose all shear strength, a situation leading to damage of embankments or structures originally supported on such soils (3).

Finding usable fill material can be difficult and expensive process. In Alaska, it is not uncommon to barge material from somewhere far distant during the mid-summer months when the rivers are free of ice. Many once-productive materials pits are becoming exhausted, and embankment fill is becoming increasingly difficult to find. There have been numerous contractual claims in Alaska due to pit failures.

2.1.2. Technical Challenges of Cold Regions

A significant feature of the sub-arctic climate is the mean annual air temperature or around zero degrees Celsius or lower (4). Even where the annual air temperature is just above freezing, vegetation type and density, north facing soils, drainage, soil type, snow cover, and other localized meteorological effects may depress the mean annual ground surface temperature to below zero, resulting in discontinuous permafrost (3). The same hillside may have permafrost on the north face but not on the south face. With mean annual temperatures solidly below freezing, as cold as -10 °C, continuous permafrost extends over most regions of the arctic, and, at some locations, to depths of hundreds of meters.

Yet shifts toward higher mean annual temperatures put the discontinuous permafrost zones in jeopardy and affect the lower latitudes of the continuous permafrost zone. The Geophysical Institute of the University of Alaska records meteorological data from observation stations

across the state. A reliable meteorological record exists from 1949. The mean temperature increase across the state since 1949 has been about 3.3°C. Much of the temperature increase can be attributed to a phase shift of the Pacific Decadal Oscillation in 1976, but significant winter-time warming is evidenced in the Interior of Alaska (5). The greatest wintertime increases in temperature occur in Interior Alaska: 4.4°C in McGrath, 4.8°C in Gulkana, 4.8°C in Fairbanks, 4.9°C in Bettles, and 5.2°C in the Big Delta (5).

Much of interior Alaska is underlain by discontinuous permafrost. The region is highly sensitive to small changes in temperature (6). The warming conditions could exacerbate the anthropogenic effects of building in the arctic and sub-arctic regions. Evidence suggests that the wintertime warming trend is not limited to the North American continent (7).

Thawing ice-rich (thaw-unstable) permafrost soils of the arctic and sub-arctic causes settling and embankment instabilities leading to premature failure of existing structures. Future construction must be sensitive to the existence of warm, thaw-unstable permafrost soils. Perhaps if current wintertime warming trends continue, even continuous permafrost zones might disappear in time, thus leading to countless foundation and embankment failures.

Notwithstanding a warming trend, winters are still long and cold in Arctic regions. Typical construction seasons in the interior of Alaska, for example, last from spring thaw in early to mid-May, until fall freeze-up, usually in October. Conditions further north hamper construction activities even more by limiting excavation and material placement to much shorter periods. Coastal Arctic regions tend to have very wet summers. Too much rain limits the types of materials that may be used in embankment stabilization, and may slow construction.

2.1.3. Natural Ground (Foundation Soils) Improvement

Excessive lateral spreading, excessive vertical settlement, liquefaction, and erosion are the four common paths to embankment failure. Current foundation improvement practices to increase embankment stability can be categorized as follows (8):

- Reducing the applied load on the foundation
- Replacing the problem foundation soils with more competent materials
- Increasing shear strength and reducing compressibility of the foundation soil
- Transferring load to more competent soils via a deep foundation system
- Reinforcing the soft foundation soil and/or the embankment
- Providing lateral stability

Evaluations of soft ground treatment alternatives considers the following factors (9):

- The operating criteria for the embankment (e.g., stability requirements, allowable total and rate of settlement, level of maintenance, etc) to establish improvement required in terms of soil properties
- Area, depth, and total volume of soil to be treated
- Soil type and its initial properties
- Availability of construction materials (or distance to transport materials)

- Environmental factors such as waste disposal, erosion, water pollution and effects on adjacent facilities and structures
- Local experience and preference
- Mobilization and availability of equipment
- Time available
- Cost

According to an Internet document released by the NCHRP, “Geofoam Applications in the Design and Construction of Highway Embankments,” settlement is the predominating factor in selecting a ground treatment method. Settlements of up to 0.6 m have been accepted as reasonable (for some applications) if the settlements are uniform, occur slowly over time, and do not take place next to a pile-supported structure (10).

Alternative embankment construction methods selected for further consideration in Alaska are:

- Pre-Thawing
- Thermosyphons
- Air-Cooled Embankments
- Geobags and Geotubes
- Membrane Encapsulated Soil Layer (MESL technology)
- Chemical Stabilization
- Geogrid Reinforcement
- Geofoams (EPS block)
- Foamed concrete
- Shredded Tires/Tire Bales
- Wood Chips

3. ALTERNATIVE EMBANKMENT CONSTRUCTION METHODS

3.1. Treatments for Soft or Otherwise Poor Foundation Conditions

3.1.1. Permafrost Ground

Permafrost is insulated by the topsoil and ground cover layers. In many areas of the sub-arctic, vegetation types combine to create permafrost protection much better than a simple insulative effect. Larger vegetation such as trees provides shading from direct solar heating, while a mossy surface covering promotes evaporation of surficial moisture. During the warm summer months the ground surface is thereby cooled and protected by an effective combination of shading plus evaporative cooling. When the vegetation and topsoil are removed, the insulation, shading, and evapotranspiration effects are lost, and the permafrost must equilibrate to the higher local ground temperature. If that higher ground temperature is above freezing, the consequent thawing of icy soils can continue for perhaps many years. Resultant thaw-consolidation and loss of shear strength of foundation soils leads to numerous

forms of embankment failure types including settlements, various types of cracking, and ranging through severe sideslope failures.

3.1.1a. Pre-Thawing

In continuous permafrost zones, keeping the permafrost stable is most likely to be the method of choice. In discontinuous zones, it may be desirable to thaw the permafrost in advance of construction. Complete removal of the vegetation and topsoil layer, plus proper drainage measures, can ensure the permafrost does not return, leading to a more stable embankment.

The typical pre-thaw process involves scraping the local soil off the top of the permafrost and leaving the permafrost exposed and uninsulated. A study of pre-thaw by the Alaska Department of Transportation and Public Facilities (AKDOT& PF) at a site near Fairbanks indicated that simply stripping the vegetative layer of organic silt soils [moisture content (ω) = 50 to 65 % by dry weight of soil] increases the thaw depth to 1.7 m after two years and 2.4 m after four years, with surface settlements of 0.3 m after the first two years. Placement of 6-mil black polyethylene film over the exposed site increased thaw depths by 15 percent. A 0.3 m layer of gravel resulted in similar increases in thaw, but also increased settlement by about 15 percent as well (2).

3.1.1b. Thermosyphons

Using thermosyphons and air-cooled embankments, engineers aim at maintaining the permafrost at below-freezing temperatures. Under some conditions, in very cold areas, insulation may accomplish the same thing. If the permafrost remains frozen, it is effectively stable except for the possibility of long term creep. However, if climactic conditions continue to exhibit annual small temperature increases, as has been the case over the last several decades, the performance of the three methods can be estimated only if good thermal modeling is done. Foundation temperature (and therefore foundation strength) can be forecast only through accurate thermal modeling over a time scale period that represents the intended service life of the embankment (11). Be aware that thermal modeling predictions are no better than the validity of the input values used in the modeling process. At best, long term modeling provides only a “best guess” as to future ground temperatures.

Thermosyphons are 2-phase natural convection tubes partially filled with a purified liquid such as ammonia, carbon dioxide or propane in equilibrium with its gas phase. Thermosyphons may be installed nearly horizontally belowground. A construction project at Bethel airfield installed thermosyphons in trenches 2.7 m apart at the base of the embankment. The thermosyphon pipes were subsequently covered with a layer of polystyrene insulation and backfilled. Russian studies indicate that even very long thermosyphons, up to 90 m in length, may be used when placed in trenches. Thermosyphons are currently in use refrigerating support pilings on the Alyeska Pipeline (2).

3.1.1c. Air-Cooled Embankments (ACE)

Researchers at the University of Alaska, Fairbanks, are pioneering the use of embankments containing highly porous layers of large rock to cool foundation soils. Wintertime cooling occurs by means of convective cells of cold air movement that develop within the porous embankment layers. This concept is being evaluated at three road sites near Fairbanks (12). According to Esch and Stangle, “Crushed rock or ‘boulder rejects’ from processing of gravels can be used. Rock from 15 to 25 cm in size has been used to date, although 10 to 20 cm rocks can be used. Minimum layer thicknesses of 0.6 m appear necessary to promote establishment of the convection cells and obtain the cooling effect, with 0.9 m layers providing more effectiveness.” Because of the angularity of its individual rock pieces, rock fill material has a very high shear strength and is therefore very strong compared to most fill materials. And due to the comparative large volume of void spaces within coarse rock fills, such embankments are relatively light (low density) when compared to embankments composed of conventional dense graded fill (2).

Currently, the rock is placed at the bottom of the excavation, in a layer 0.6 to 0.9 m thick, and capped with a geotextile layer to protect the void spaces from intrusion from fines. On top of the ACE layer is placed a 25 to 35 cm layer of crushed gravel surfacing.

ACE has proven effective so far in cooling the foundation soils over several years. During convective air cycling, cold air in voids at the top of the rock layer sinks to the bottom of the layer. This air movement displaces ground-heated warm air at the bottom of the rock layer which moves upwards. Upon reaching the top of the rock layer, the warm air cools and the cycle begins over again. In summer, the convection process stops because of the warm temperature at the top of the ACE layer. The cold air stays at the bottom of the ACE layer, and the ACE void spaces act as insulation. This technology is new, very few sites exist, and the long term viability of the ACE system has not been confirmed.

A project construction off Geist Road near Fairbanks, includes a design that combines thermosyphons with an ACE layer (13, 14). Monitoring and analyzing the long term performance of this state-of-the-art design will help engineers understand if such systems are a cost effective way of improving embankment stability at warm permafrost sites.

3.1.2. High Moisture Content Foundation or Fill Materials

3.1.2a. Geodrains

Geodrains provide artificial drainage in soils which lack sufficient porosity. Known also as wick drains, they are a flattened tube drain formed of a nonwoven geotextile wrapped around a plastic core. The geotextile prevents the drain from clogging with fines, and the plastic core channels the water out of the soil. The design of the plastic core determines the flow rate capacity and resistance to crushing. Additional design is required to ensure that the exit end of the geotube remains clear of ice and soil intrusion (2).

Proper design and installation of geotubes may accelerate foundation consolidation in order to minimize primary and post-construction settlement. According to Esch and Stangl, combinations of sheet drains with collector subdrain pipes leading to sumps or drainage outlets are likely to perform best. However, the moisture retention properties of organic silts and clays are formidable opponents to proper drainage. More experimental data is required.

Any drainage program aimed at increasing embankment stability is likely to take at least a season to dry out the soils. Additionally, the equipment for the installation of the geotubes must be transported to the site. The drainage season is short, and thus the job site may be left to consolidate over a period of several years.

3.1.2b. Geobags and Geotubes

Large geotextile tubes and bags may be used to contain and dewater fine-grained soils such as sands, silts, and sewage sludge. Large tubes are constructed of geotextiles appropriate in strength and filtration capabilities. The design of the geotextile tubes depends on the results of experiments with samples of the actual soil to be dewatered. A small dredge could liquefy silty, clayey, organic soils and pump them into the tubes. The tubes are placed where the fill must go in the embankment, filled with the soils to the 40-60 percent level, and then allowed to drain. Drainage occurs quickly, due to the shorter path of travel for water allowed by the tube's geometry. The soil is retained in the tubes and/or bags. The soil and geotextile wrap forms a relatively stiff and strong unit. Geobags and geotubes avoid the need for haul roads and hauling equipment, and minimize excavation (2).

3.1.2c. Membrane Encapsulated Soil Layer (MESL)

The MESL technique typically begins with the soil being spread out in the sun to dry. The soil is then encapsulated in impervious membranes to protect the soils from moisture acquisition. Generally it accommodates the same kinds of materials used to fill geobags and geotubes, e.g., silty, clayey and/or organic soils with very high moisture contents.

A study performed by Dave Esch indicates that soils will not drop naturally below 30-35% moisture even when in place for 10 years in a tall embankment (15). Continually wet and cold conditions would make it increasingly difficult but not impossible to utilize this method. Future field evaluations will determine if the method is economically suitable for application in arctic or sub-arctic areas.

There are some alternatives to solar heating that could be used to expedite the drying of the soil, such as chemical drying agents. It would be necessary to field test specific drying agents on actual project soils. MESL construction is not feasible if the soils are not readily dryable to the point where they can be encapsulated—given the weather conditions at a specific project site. MESL construction involves much more excavation and materials handling than normal construction methods might require. The soil must first be excavated, then spread and dried in some manner. Most likely, large earth moving equipment will be required to periodically turn over the soil, regardless of the drying method employed. Subsequently, the soil must be transferred from the drying location and carefully placed into

the MESL membrane. Membrane material is vulnerable to damage from heavy equipment, and a significant number of torn areas would destroy the effectiveness of the MESL. The cost savings from not importing acceptable fill may be exceeded by the extra labor and equipment expenses for multiple handlings of the local soils. There is also an appreciable design risk factor due to the experimental nature of the unproven MESL concept.

Although MESL construction is possible, it may be economically impractical. It does not appear to be an obviously useful construction option at the time of this writing. Further research is needed to examine the economics and mechanical viability of this design technique.

3.1.3. Silts and Clays with Organics, High Water Content and/or Insufficient Strength

3.1.3a. Chemical Stabilization

Chemicals can be used to accelerate the drying of the soil. A Corps of Engineers report describes soil-drying methods (8, 16):

Various methods can be used to dry the soils. Chemical methods can be done quickly and, if properly done, are well suited for Army engineers. Lime is the best chemical to use with clayey soils. A method to dry silty sands needs to be developed.

A potentially attractive method to make silty sands act drier involves the use of commercially available super absorbent polymers. The polymers don't actually dry the soil; they concentrate the water in the absorbent and dry the surrounding soil matrix. They have potential benefits and drawbacks. The benefits are: 1) only a small amount (between 0.15 and 0.5 percent) of absorbent is needed, 2) they are relatively safe to handle, 3) they have a minimal impact on the environment, 4) they are very fast acting, and 5) they are unaffected by the cold. A drawback is that the swelled absorbent is spongy, thereby making the soil spongy. The wetter the soil is to begin with, the spongier the soil will be after the absorbent is added. The absorbents absorb less as the confining pressure is increased. This means a truck could not park on the absorbent-treated soil because it would force the water out of the absorbent. Absorbents also degrade with time. It is possible to add too much absorbent, which would over-dry the material and make it friable. However, even with the disadvantages, absorbents are a potential drying agent for MESLs with a short design life and a silty sand fill soil.

It will be necessary to field test the drying agents on samples of the actual soils intended for project use.

3.1.3b. Geogrid Reinforcement

Geogrids were developed after the successful use of geotextiles for soil reinforcement had been established. Geogrids are so called “high modulus” geosynthetics. That is, upon loading, geogrids do not require great strain (stretch) to develop maximum strength as most cloth-like geotextiles do (9). The first geogrid embankment reinforcement project was in 1981. The popularity of geogrids has grown since with hundreds of completed projects as early as the mid-1980s (8). Though geogrids have grown popular, most applications center around slope stabilization, vertical slope reinforcement, and retaining wall projects. Embankment stabilization has been a less common application of this material.

Geogrids are polyolefin products. These semi-rigid polymer-based grids are light and easy to transport and install. They can be used in a soil environment having a pH greater than three, and can accommodate a broad range of soil types. Geogrids require no special fills or protection, though they are degraded by ultraviolet. Some polymer reinforcement types are vulnerable to hydrolysis so drainage measures are suggested (9).

The cost is generally estimated on a square meter basis, and can range (as of 2003) from \$2.50 to \$12.00 per m³. Several layers of geogrid may be required were a high level of reinforcement is necessary and/or with a thick embankment. Geogrids provide no thermal benefit (9).

3.2. Lightweight Fills

Compacted densities of sands, silts and clays generally range from approximately 1,800 to 2,200 kg/m³ (17). By using lightweight fills in place of undesirable soils, the magnitude of the load of the embankment on the foundation can be reduced. The reduction in applied load increases embankment stability and decreases settlement. Depending on the density of the lightweight fill, the embankment also gains increased resistance to seismic activity due to the decreased inertia of a lighter soil. Nearly all lightweight fill materials have a density less than that of conventional soils, but they vary from as high as 1,500 kg/m³ for boiler slag, to 12 kg/m³ for EPS block geofoam. Unlike the other embankment methods discussed, lightweight fills pose some environmental concerns. Principal concerns focus on the possibility that leachate from the manmade materials could enter the groundwater. However, these environmental concerns remain largely unsubstantiated.

3.2.1. Expanded Polystyrene (EPS Block) and Extruded Polystyrene (XPS Block)

Expanded polystyrene (EPS block) is a closed-cell plastic classified as a geofoam, or a gas-expanded closed-celled nonporous material. It is lightweight, ranging in densities from 12-32 kg/m³. The predominant geofoam material used as lightweight fill in road construction is EPS block (10). Extruded polystyrene (XPS block) has been used to a limited extent as lightweight fill in the U.S.A., Japan, and the United Kingdom. Applications worldwide have shown that XPS is not cost-effective for use as lightweight fill. If the conditions warrant, it

may be appropriate to use XPS, though generally it will prove too expensive for all but certain scenarios such as exist in the Yukon-Kuskokwim (Y-K) Delta of Alaska. About 50 percent of the surface of the Y-K Delta is covered by water. Much of the subsurface soil is of course saturated, making this area a potential candidate for these low density plastic fill materials.

EPS block is normally the preferred plastic block material for use as a lightweight fill (10). It is extremely adaptable, coming in a range of densities (strengths), block sizes and even block shapes. The compressibility and elasticity of EPS block is similar to that of conventional soils and consequently it will behave similar to the standard fill materials under dynamic and static loading. It possesses uniform and known material properties because it is manufactured to standard specifications. The extremely low density (about 1 percent of conventional soils) reduces inertial forces, providing additional seismic stability, and lateral loading on adjacent structures. EPS block is easy and quick to install, and can be placed in any weather. It has a proven track record of use in the US that dates back 40 years to the mid-1960s. In addition to the United States, EPS block is used as a lightweight fill across the globe, including Scandinavia, China, Russia, Chile, Japan.

EPS can be manufactured to meet specific design strengths to satisfy a variety of purposes. It is commonly used as a structurally-competent insulation layer, for slope stabilization, and as a lightweight fill. The first use of EPS block consisted primarily of insulation for road embankments in northern hemisphere countries that suffered from significant frost heave (18). When used generally as an insulation, the properties of the material protect the soil from extremes of temperature. Depending on the situation, it either kept frozen soils frozen, or thawed soils thawed, thus minimizing the effects of frost heave and differential settlements due to the thawing of ice-rich permafrost.

EPS is expensive. The freight-on-board (FOB) cost of EPS block ranges from \$35.00 to \$65.00 per m³ depending on factors such as production density, percentage of EPS that is recycled, and additives such as insecticides. Installed costs reported in the continental US range from \$39-\$104/m³ (10). Expect transportation costs to make EPS more expensive in cold regions. EPS block is also vulnerable to long-term exposure to ultraviolet radiation. A cover must be provided if the EPS will require long term storage. Petroleum products degrade polystyrene block. Designs can call for various types of coverings or coatings if long term protection against petroleum-based chemicals is required. Many Departments of Transportation require a concrete cap which adds additional expense. EPS will absorb water underground. After 10 years, expect the EPS to have a density of approximately 75 to 100 kg/m³, a fact which must be taken into consideration when designing embankments that incorporate these materials (8).

The remarkable lightness of EPS is its primary virtue in terms of seismic stability and its use as a lightweight fill to reduce foundation load. The very low density also produces in a significant buoyant force when EPS is submerged or placed in completely saturated soils. Unless buoyancy is taken into consideration in design, geofoam embankments may fail because of hydrostatic uplift and hydrostatic sliding and overturning. During construction, if

EPS blocks are not secured in some fashion, they may be vulnerable to overturning from wind.

Embankment construction with EPS must account for the material's few inherent drawbacks. However, solutions are usually quite simple compared to problems encountered with other lightweight fills, or other embankment construction methods. When EPS must be stored for longer than several months, store it in an enclosure or covered. Use some form of impermeable covering over the top of the EPS portion of the embankment to protect the EPS from petroleum spills. When multiple layers of the EPS blocks are placed, stagger the joint lines of succeeding layers and/or use other placement configurations that prevent continuous vertical joints and provide overturning resistance. Provide a mechanical connection between blocks to prevent overturning and promote shear resistance. Top with a soil cap sufficient to provide a minimum safety factor of 1.3 against uplift if the design must address a buoyant environment (8). A soil cap will protect the EPS-block from ultraviolet light, and also provide some protection from possible petroleum exposure. Manufacturers' design aids provide necessary information for assembling and protecting the blocks to meet various design objectives.

Even though expensive, EPS may be cost effective. Due to the very low density of the material, less volume of EPS is required than of any other material to achieve the same reduction in applied load. Say, for example, the weight of a 5 meter thick embankment had to be reduced by half. One of the replacement fill candidates is EPS block having a 20 kg/m^3 density, while the other alternative is a light weight aggregate at $1,000 \text{ kg/m}^3$. The embankment fill to be replaced as an average density of about $2,000 \text{ kg/m}^3$. The question is what thickness of the original 5 meter embankment thickness would have to be replaced using each of the two alternative replacement fill materials? The final thickness of the embankment must remain 5 meters, and we will simplify this example by assuming that the sides of the embankment are vertical. A bit of simple algebra shows: 1) for the EPS alternative, 2.52 meters of the original embankment would have to be removed and replaced by EPS, and 2) for the light weight aggregate alternative, the entire original 5 meter embankment thickness would have to be removed and replaced by 5 meters of light weight aggregate. Through such examples it can be shown that the high unit volume price of EPS may be offset by the reduction in overall required volume compared to other lightweight fill alternatives.

There are only a few EPS block manufacturers. The manufacture of expanded polystyrene block is done in two steps. EPS in its raw form is commonly referred to as beads, or resin. The polystyrene beads are about the size of grains of sand and are mixed with a hydrocarbon, usually pentane. The pentane is the *blowing agent* used to expand the polystyrene into its block form. The first manufacturer, termed the *resin supplier*, supplies this product to the second manufacturer called the *molder*. The final product is a block-molded EPS with varying dimensions. The other option is shape-molded EPS, which can come in a variety of forms limited only by the capabilities of the manufacturer and the imagination of the buyer, and will increase the unit cost. Manufacturing EPS requires expanding the beads. During expansion, volume increases by a factor of 40 to 50. After the EPS is expanded within the mold, it is removed from the mold and allowed to season. The time required for seasoning

ranges from half a day to several weeks. Seasoning can be accelerated by increasing the temperature of the storage room (18, 19).

Environmental concerns are minimal with EPS. Polystyrene is fairly inert, and is used for things as commonplace as the Styrofoam cup (20). Hydrocarbons used as the blowing agent are naturally occurring, unlike fluorocarbon gases used for other types of plastic foams. There is no known documentation of environmental side effects such as chemical leeching into the groundwater after construction, or release of ozone-damaging gasses during production of regular EPS (19).

EPS blocks are an attractive fill option for a number of reasons. This type of lightweight embankment performs very well on wet unstable ground, a desirable characteristic due to the abundance of wetlands and poor soil in cold regions. The insulative properties of foam blocks will minimize heat transfer into the frozen ground, thus reducing the potential for embankment settlements due to thaw-consolidation of ice-rich permafrost soils. Embankment settlement is further minimized. The exceptionally low density of an EPS embankment insures minimal settlement of the embankment when insulation effect alone fails to keep the permafrost foundation soils frozen. Finally, the ability to construct an embankment quickly and under adverse conditions is of great benefit in a climate with a very short, unpredictable construction season.

EPS block embankment can be used in cold regions. The overriding question however is whether the technology can be used in a cost-effective manner. One option is to have the EPS manufactured in a central urban location like Anchorage or Fairbanks. The final product could then be shipped relatively inexpensively to construction sites throughout Alaska. Another option would be to have a portable plant. The resin could be shipped in its raw form, and expanded, or “popped” on-site, reducing the shipping volume by a factor of 40 to 50. A portable plant would likely prove the more efficient method for bringing geofoam to remote areas of Alaska. All of the geofoam embankments constructed in the US have required transportation of EPS blocks from permanently-located suppliers. Of course the distance between manufacturer and construction project site heavily influenced the delivered cost of the EPS block.

An NCHRP contractor questionnaire identified the fact that 35 to 45 percent of the cost of EPS block went to labor required for placing the geofoam.

Incidental savings derived from using EPS block:

- Possibly eliminating surcharging and staged construction
- Decreased maintenance costs resulting from reduced embankment settlement
- Less degradation of foundation soils may significantly increase embankment life
- Ease of construction decreases mobilization and labor costs
- Reduced risks of environmental violations/fines
- Possible reduction of repair costs in the event of seismic activities

3.2.2. Foamed Concrete

Foamed concrete is used by the Army Corp of Engineers as tunnel lining and annular fill. The concept of using pumping equipment to entrain gas through the injection of foaming agents developed in the 1930s (8). As a man-made material, its physical properties and behavior are well-known. It is generally produced on-site, which allows superior quality control and immediate placement.

Foamed concrete varies in density from 335 to 770 kg/m³. Reported costs are \$55.00 to \$85.00 per m³ according to the *Ground Improvement Technical Summary I*, and \$65.00 to \$95.00 according to *A Compendium of Ground Modification Techniques* (8). There is no sand or stone in the foamed concrete.

The foamed concrete is placed in lifts of 0.3 to 1.2 m or more. It sets like traditional concrete, and is prepared using the same water/cement ratio as typical concrete. Specialized firms prepare the foamed concrete onsite. Only one experienced individual is needed to operate the mixing equipment. The compressive strength of foamed concrete varies proportionally with the manufactured density, but no compaction is required. However, in areas with freeze/thaw cycles, lower-density foamed concrete should be kept below the freeze/thaw depth (the active layer), otherwise higher-density foamed concrete should be used. Densities higher than 577 kg/m³ appear to perform well when subjected to repeated freeze/thaw cycles (8).

Air or gas entrainment of the concrete decreases the density, and increases the buoyancy. In saturated areas, low density foamed concrete is susceptible to buoyancy forces—as is geofoam. The same solution applies. A sufficient soil cap will protect the foamed concrete from uplift, while also minimizing degradation of the foamed concrete.

Saturation by water should be prevented through adequate drainage. Some absorption of water into the voids occurs which negatively effects density and compressive strength. As with normal concrete, hydration is slowed and adversely affected by cooler temperatures, thus pours may be hampered as necessitated by weather conditions at the construction site.

Foamed concrete is used in residential construction as a wall system because the air-entrainment produces insulation properties. An insulative form of concrete should help maintain a stable permafrost regime.

3.2.3. Shredded Tire and Tire Bale Fills

Tire rubber is a thermosetting polymer. The physical properties of these materials are very useful for tires, but of concern environmentally. Thermosets may be formed only once. They cannot be remelted and reformed into new objects. Thus more than 3 billion tires fill landfills across the US, providing breeding grounds for insects, and posing a fire hazard. About seventy five percent of tires produced annually are now recycled into various forms. Roughly 5 percent of recycled tires are shredded (21).

Waste tires are one of several recycled materials that prove suitable for light fill applications. It is denser than foamed concrete, ranging from 720 to 960 kg/m³, yet still considerably lighter than conventional fill soils. As a recycled material, most of the cost is in transportation and construction. Where available, shredded rubber costs approximately \$20-\$30 per m³ with in-state transportation cost included. Weather is not a criterion for installation. Some cold regions have rebates for using recycled products in construction. The shredded tire fills are porous and will not decay. Perhaps most importantly, shredded tires serve as a form of insulation and offer vibratory damping, thus providing protection with respect to permafrost foundation soils and damage from seismic activity (21).

Although it is an effective method of disposing of tire waste, there are some inherent problems with using shredded tires as fill. The steel in the tires is believed to elevate the iron and manganese levels of the groundwater, and may affect the taste of water. However, the Chelsea Center for Recycling concludes, “recycled rubber derived from scrap tires is a safe recyclable material” primarily because leachate levels remained quite low, for example, lower than asphalt samples tested at the same time in all categories (21). The Ground Improvement Technical Summary I (8) also reports rubber shreds releasing higher concentrations of metals when immersed in an acidic environment, i.e., metals such as barium, cadmium, chromium, lead, selenium, and zinc. In neutral solutions, tires do not appear to leach contaminants. In basic solutions, tire rubber releases more total petroleum hydrocarbons (TPH) and polynuclear aromatic hydrocarbons (PAH) (21). The concentrations of the contaminants leached are not dangerously high, but pose a possible environmental and health concern over time nonetheless. The suggested remedy is to keep the tire rubber above the groundwater table as a precaution (8).

Shredded tires are compressible. In testing, a strain of 10 percent resulted when shredded tires were subjected to vertical stresses ranging from 50 to 380 kPa. Under load, shredded tires will compress and consolidate. In order to use shredded tires for lightweight fill applications, anticipate a 35 percent volume reduction during compaction, plus another 10 percent shrinkage under loading of soil cover and pavement base course. The Federal Highway Administration recommends that compaction equipment make multiple passes because compressibility decreases after 5 to 8 cycles of loading. Additionally, use a minimum 0.9 m thick soil cap on the top and side slopes to minimize post-construction settlement and provide confinement (8, 22).

Metal in the recycled tires makes it impossible for rubber-tired construction vehicles to traverse the fill without damage. Compact using sheepsfoot rollers, smooth drum rollers or by repeated passes with a D8 dozer. It has been found that no more than 3 m of depth should be placed due to the possibility of spontaneous combustion, and it is recommended that no more than 0.9 m of shredded rubber be placed at once (8).

Though use of shredded tires in embankment construction is a useful way to save space in landfills and reduce breeding grounds for insects, the practice is not practical for areas with long shipping distances. Affordability rests in the fact that the shredded tires are a waste product, and thus most of the cost is in shipping and construction. The compressibility of the

material requires that shredded rubber must be shipped in quantities about 54 percent greater than the initial volume to be filled (assuming a 35 percent shrink factor). Cold regions, though growing, often do not have the population base to supply tires in great enough quantities for embankment construction. The tires must then either be stockpiled and/or gathered from several different sources in the region, or shipped from larger population centers at greater expense. Stockpiling also adds administrative expense, as well as the need to find space to store and process the tires. More remote regions may have difficulty supporting, supplying or transporting the large equipment necessary to compact the rubber. Using shredded tires requires the additional expense of a geotextile both above and below the fill to prevent fines infiltration. Cold regions tend to have delicate ecosystems that may require additional environmental permits.

Alternatively, a new method of recycling tires as lightweight fill is in development. In place of shredded tires, 100 whole tires are tied together to form a 'bale' which is then placed in the embankment as blocks of lightweight fill. The Colorado Department of Transportation (CODOT) reports that prior to its efforts, only two laboratory studies from 2000, both unpublished, existed on tire bales, testing unconfined compression and short term creep. CODOT completed eight experiments on eight typical tire bales through a contract with GeoTesting Express in 2004 and 2005, and concluded that tire bales are a viable lightweight fill (21). Tire bales are the least-researched of all the alternative embankment fill materials currently in publication.

Tire bales hold considerable advantages over shredded tires. They require less skilled workers and equipment. Less processing reduces a critical expense. Storage is simpler than for shredded tires. And placement is simplified.

No long-term performance criteria have been established. Long-term performance remains unknown. Performance criteria and design procedures need to be developed through study of full scale tire-bale embankments. A few cases of tire bales used as embankment fill have been reported. The city of Fort Worth, Texas used tire bales to repair a failed side slope. The city determined that use of tire bales combined with bioengineering instead of repairing the side slope traditionally had resulted in a comparative two to three fold increase in the factor of safety. Chautauqua County in New York State has received a Beneficial Use Designation from the New York State Department of Environmental Conservation after the successful performance of five tire-bale projects built starting in 1999. Incidentally, Chautauqua County successfully used prison labor to cut costs (21).

The tire bales have been filled with sand and native soil (21). It seems that tire bales could function as embankment stabilization and lightweight fill, by simply covering the bales with local fill, cutting the expenditure of importing replacement fill entirely.

The estimated cost for tire-bale construction is \$3.70 to \$9.70 per m³ (21). The figure reflects in-state transportation costs, and an in-state construction rebate for the use of recycled tires. However, given Alaska as an example, where replacement fill can cost up to \$105 per m³, even a significant increase in cost could still yield large savings.

3.2.4. Wood Chips

Unlike geofoam, wood chips can be obtained from within every cold region, principally because most cold regions such as Alaska, Russia and Canada possess significant timber industries. Wood chips are a waste material, thus use as a fill material constitutes an environmental benefit. Wood chips can be hog fuel, sawdust, or planer chips. Density installed varies from 720 to 960 kg/m³. Estimated costs range from \$12.00 to \$20.00 per m³. Wood chips, like geofoam, shredded and tire bales, and foamed concrete, provide ground insulation. Wood chips can be placed in any weather (8).

Wood chips are susceptible to chemical heating and even spontaneous combustion if stored in sufficient quantities. The FHWA recommends a maximum fill height of no more than 5 meters and taking precautions to minimize air infiltration. Wood chips are even more compressible than shredded tires. Prepare for a 40% reduction in volume between haul and final compaction. The potential effects of wood chips on the water table are more problematical than for tire leachate. As a biodegradable material, wood chips act as an eutrophication agent like algae in rivers and lakes, by using available oxygen. The leachate lowers groundwater pH, making it increasingly acidic. Therefore, the wood chips must be protected from coming in contact with surface and groundwater water for both longevity and environmental reasons. Prudent wood chip design will minimize water infiltration through drains and capping, treat leachate, and place barriers between wood chip fill and surface runoff. Large void spaces may cause post-construction embankment settlement problems. Limit wood particle size to about 50 mm and smaller. Sideslopes should be 1.5H:1V or flatter (8).

Evidence indicates that wood chip embankments can be surprisingly robust, with a useful design life that may exceed 50 years. Decay of well compacted wood fills is a slow process and progresses from the external boundaries of the fill inwards. According to the Washington Department of Transportation, sawdust piles approximately 70 years old have been observed with a two to three foot thick layer of decomposing sawdust on the outside, and an inner core that remained fresh (8).

4. CONCLUSIONS

Research indicates that alternatives to traditional embankment construction methods and fill materials exist. Alternatives discussed in this report include:

- Pre-thaw
- Thermosyphons
- Air-Cooled Embankments (ACE technology)
- Geobags and Geotubes
- Membrane Encapsulated Soil Layer (MESL technology)
- Chemical Stabilization
- Geogrids

- EPS block
- Foamed concrete
- Shredded Tire and Tire Bales
- Wood Chips

All appear to have possible applications over the broad range of northern region soils and climates.

New embankment fill alternatives that may offer high potential for practical application in Alaska include EPS block, tire bales, or foamed concrete. These provide at least some degree of permafrost protection, while providing reinforcement against shear stresses and reducing embankment loads. EPS block geofoam and foamed concrete decrease susceptibility to seismic damage as a function of decreased inertia. Tire bales are expected to behave similarly to damp seismic behavior, but existing data cannot validate that assumption. These are manmade materials with known chemical and physical properties.

EPS geofoam is the most widely used embankment construction material of the three, and the most thoroughly studied. At present, EPS block appears to be a very attractive embankment fill substitute with respect to ease of construction, structural/thermal performance, and longevity. It is also the material that would likely be the most expensive to ship to a project site in rural Alaska. However, the high cost of this material may prove economically acceptable over the course of the embankment life. An objective opinion as to economic viability can be established (or rejected) only after the designer compares this alternative against use of conventional fill materials with a comprehensive lifecycle cost analysis. With the intension of perhaps lowering the cost of EPS block, further research should evaluate the possibility of developing a portable EPS plant. An alternative would be to cooperate with other government agencies to develop one or more central plants to serve EPS demand.

Foamed concrete's primary advantages are minimal construction labor and reasonable shipping costs for materials. The concrete is air-entrained on site, and there is no gravel in the cement-sand slurry that must be transported to the construction site. Only one trained operator and some portable specialized machinery is required to mix the gaseous foam and the cement-water slurry. Placement is the same as regular concrete, making construction a straight forward process. Foamed concrete, when produced at sufficient density, provides good load support. It does not compress under normal loadings. Low temperatures characteristic of central and northern Alaska limits the seasonal window for foamed concrete construction. The question of durability with respect to a design life of severe freeze/thaw cycling must be addressed by further research.

Tire bales offer promise. Tire bales require minimal handling. Waste tires may be available within the region of interest. Storage is simple. Placement involves moving bales of 100 tires. Placement of tire bales requires heavy equipment, but the process proceeds quickly. Leachates obtained from masses of whole tires (as used in tire bales) appears to be less than that from similar volumes of shredded tires. Tire bale construction provides insulation, shear resistance, seismic protection, and allows for some utilization of local fill. Further research can investigate the possibility of establishing one or more Alaska facilities for storing and

processing used tires, possibly in conjunction with operations at local landfills. Currently, all companies who sell or replace tires pay a tipping fee for the disposal of old tires. Since a great deal of research has been conducted on both foamed concrete and EPS block, perhaps it may be worthwhile to focus a future research effort on tire bales.

5. SOME FINAL CONSIDERATIONS

In many areas of Alaska fill materials normally used for embankment construction can be so expensive that many worthwhile construction projects may appear economically untenable. But not all of the cost of building highways, bridges, airports and stabilizing hillsides and river banks in the cold regions lies in the purchase and transport of materials and labor. Efficient management practices, well-organized permit applications, and streamlined design processes can save considerable sums of money—sometimes offsetting the high cost of construction materials.

Avoiding construction methods that require double mobilizations saves on mobilization fees, saves half the transport costs, and saves time. Recognizing that just like energy-efficient homes, a higher initial investment can often return many times its initial cost in reduced maintenance and replacement costs. There may be increased external benefits such as fewer accidents, a better environment, or happier end users. Close coordination and cooperation with contractors can lead to a more efficient use of time, materials and labor, in effect, saving money through attention to detail. Full knowledge of available technologies can expedite development of effective designs, save time, and perhaps even streamline the environmental permitting process.

New technologies will save money and improve construction quality. Practical research is the key to continuing technical advancement into applications of new materials and methods for constructing embankments in Alaska's arctic and sub-arctic.

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