CONSTRUCTABILITY BENEFITS OF THE USE OF LIGHTWEIGHT FOAMED CONCRETE FILL (LFCF) IN PAVEMENT APPLICATIONS

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ABSTRACT

Lightweight Foamed Concrete Fill (LFCF), also known as cellular concrete, has been growing in use in transportation infrastructure projects over recent years. LFCF is a versatile construction material that has now been in use for over 30 years. A number of recent road rehabilitation projects have demonstrated some of the benefits of use. With a greater emphasis on sustainability on all provincial and municipal road projects, new solutions are being sought to minimize the generation of waste and deliver better performing pavements that require less maintenance interventions. Roads over peat and organic deposits pose challenges for road agencies. They are subject to continual and long term settlements that necessitate frequent patch repairs. The downside of such repairs is that the additional weight of the new asphalt, triggers further settlement. Traditionally, permanent solutions have necessitated the total reconstruction of the road section and removal of the underlying organic layers. This is expensive, creates huge traffic disruptions, generates waste and consumes large volumes of aggregate for the reinstatement. The use of lightweight fill offers an alternative as it allows the pavement to be 'floated' above the organic layer. However, the traditional lightweight materials, such as polystyrene, have been prohibitively expensive for such applications. In recent years, LFCF has been successfully used as a cost effective solution in road works. LFCF is a foamed, pumpable, cementitious fill with a density of only 475 kg/m^3, about a quarter of that of conventional granular fill. With a compressive strength of at least 0.5 MPa, it has sufficient strength to support pavement loads. However, the real advantages relate to constructability, since the material can be installed very quickly, minimizes excavation time, can be placed in winter and does not require conventional compaction or associated testing. This paper will provide an overview of the use of LFCF for road works, including typical specifications, quality control/assurance requirements, and performance based on a number of case study applications.

1. INTRODUCTION

Lightweight Foamed Concrete Fill (LFCF), also known as cellular concrete, is a foamed, pumpable, cementitious fill with a density of 475 to 600 kg/m^3. This is only about a quarter of the density of conventional granular fill. The concept was originally developed in Sweden in the early 1900s but it was only after the Second World War that the technology gained traction. The foaming technology improved significantly in the 1990s and the uses and applications for the product have grown continuously since then. Essentially it is a concrete made with hydraulic cement, water and a pre-formed foam. The mixtures can include fine aggregates, flyash and chemical admixtures. Different processes and plant can be used to produce cellular concrete, a common method is as follows:

- Foam concentrate is diluted with water
- The pressurized mixture is forced through an engineered foam generator nozzle
- Pre-formed foam with the texture of shaving cream moves from the nozzle into a mixture of cement and water (i.e. a slurry)
- The result is fresh low density cellular concrete mix.

The texture of the product during placement can be seen from Figure 1.

Figure 1: Foamed cellular concrete being discharged from a pipe

Cellular concrete has many applications in construction. These include:

- Annular grout for tunnels, water and sewer lines
- Tunnel backfill and annular fills
- Soil stabilization
- Fill for abandoned underground tanks and pipelines
- Fill for abandoned mines
- Tremie applications
- Bridge approach and landslip repair fills
- Arrester material at end of runway which crushes and stops overshooting aircraft
- Retaining wall backfills
- Sound walls and insulation

One of the more high profile applications for cellular concrete fill is as backfill for mechanically stabilized earth (MSE) walls. A recent example was on the Chief Peguis Trail Extension Public Private Partnership Project in Winnipeg (Loewen et al, 2012). On this project the lightweight cellular concrete backfill was used, up to five meters in depth, to compensate for low strength foundation soils. Its use also allowed for accelerated construction, including some winter works. The cellular concrete was also used around integral abutments. It was also used extensively for MSE wall backfill on the Rt. Hon. Herb Gray Parkway Project in Windsor, Ontario, where the walls were supported on relatively low strength silty clay foundation soils. The authors have also designed lightweight cellular concrete as underslab fill in a large distribution warehouse, where it proved cost effective in reducing the cost of polystyrene insulation.

This paper describes an application in road construction. Frequently, roads and highways constructed over peat, organics and soft soil deposits undergo continual and long term settlements that necessitate frequent patch repairs. The hot mix asphalt patches add further load to the pavement structure and result in further settlement. Obviously, the most effective solution would be to remove the compressible materials, however, if the thicknesses of these layers are greater than about one meter, this option becomes prohibitively expensive.

LFCF represents an alternative to the traditional full depth reconstruction approach by allowing the pavement to be "floated" above the compressible layer. Full depth reconstruction is expensive and disruptive to the travelling public by necessitating full road or extended lane closures. It also requires extensive environmental impact mitigation measures, generates large quantities of excess material requiring disposal and requires large quantities of imported backfill materials. With the growing emphasis on sustainability on all provincial and municipal road projects, new solutions are being sought to minimize the generation of waste and deliver better performing pavements that require less maintenance interventions.

LFCF is produced from a “slurry” base material supplied from a conventional ready-mix concrete supplier or produced from bulk cement powder on site. It is then “expanded” onsite using a proprietary foaming agent and with the addition of air. Chemical admixtures or fibres can be added to the mix design to adjust the foam properties and to meet specific project specifications and requirements.

This paper provides an overview of the use of LFCF for road works including typical specifications, quality control/assurance requirements and the performance of LFCF on a select case study application.

2. TESTING PROCEDURES AND QUALITY CONTROL (QC)

Testing procedures should be consistent with, or exceed the requirements of the American Society for Testing and Materials (ASTM), Canadian Standards Association (CSA) and the American Concrete Institute (ACI). Relevant ASTM standards include C495, C796 and C869 (2011 and 2012). A non-standard Special Provision should be included in the construction Contract to detail the project specific LFCF specifications and requirements. It is recommended that the contractor retain the services of an experienced Quality Verification Engineer (QVE) to independently verify the accuracy of the shop drawings and feasibility of the construction approach. While the process of LFCF placement is very efficient and safe, because it involves pumping a slurry from a mobile plant to the site, an environmental protection strategy should be included as part of the work.

The LFCF is comprised of Portland cement, water and a foaming agent. Synthetic fibre or glass fibre can be added to adjust the tensile strength properties to meet specific project requirements. Some typical standards and testing requirements are summarized in Table 1.

Table 1: Material Testing Standards

Material/Process	Relevant Standards and Testing	Products/Comments
Portland cement (Slurry) • Compressive Strength • Density	CAN/CSA A3001	Types GU, HE, HS or InterCem GUb
Mixing of Water	CSA A23.1	
Synthetic Fibre (monofilament)	ASTM C1116	12 to 19 mm length
Glass Fibre	As approved by LFCF contractor/supplier	Various proprietary
Foaming Agents	ASTM C869, ASTM C796	Various proprietary

The key quality control parameters are density and compressive strength of the hardened mix. The wet densities are monitored in the field during placement as well as the temperature of the mix. Sets of standard 75 mm diameter by 150 mm high test cylinders are cast for compressive strength testing. The routine density measurements are recorded and assist in monitoring the consistency of the mix as discharged.

When sources of any of the materials for cellular concrete, such as cement and other additives are changed, or there are no historical data available for specific uses, trial batches are necessary to develop the optimum cellular concrete mixture.

3. PRODUCTION REQUIREMENTS

LFCF should only be produced and installed by a specialty contractor with previous experience. All delivery equipment must be cleaned and rinsed and completely emptied of concrete or aggregates prior to mixing and transporting slurry for the production of LFCF. The density of the slurry from the concrete supplier should be checked and verified onsite before placement. Supplementary cementing materials, fillers, fibres, chemical admixtures should be added after the required density has been confirmed.

If slurry is produced from bulk powder onsite the mix water and bulk powder should be measured within a tolerance of 2% of the mix design value. The mixers must have enough power to provide complete mixing and be free of foreign material or previously hardened material. Density of the slurry should be measured at least once per production run.

Expansion (addition of air into the slurry) should be completed by the LFCF contractor/supplier. Daily delivery tickets should be reviewed and signed by the client's representative to confirm the actual volumes placed.

Slurry is the base material for producing cellular concrete (supplied by a concrete ready-mix producer) and should be checked by the LFCF contractor/supplier to ensure that it matches the mix design. Each truck must be tested to evaluate the density and viscosity.

Table 2 summarizes a typical QC testing program suitable for use when placing LFCF for roadworks.

Table 2: Typical QC Program

Material Property	Frequency	Acceptance Criteria	Comments/ Additional Requirements
Density	• One per batch or every 10 m^3 • For continuous production every 50 m^3 or once per 20 minutes	Within 10% of design density	
Compressive Strength	• One sample per 100 m^3	Meets or exceeds design strength	• Cast in 75x150 mm cylindrical moulds. • Store in an undisturbed condition within 15 m of casting area. • Initial curing temperate of 25 to 30ºC for 24 to 96 hours. • Cure in 80% to 100% humidity room at 18 to 27ºC.

4. WEATHER CONSIDERATIONS

LFCF can be placed during freezing conditions if measures are taken to protect the LFCF from freezing until sufficient strength has been attained. This can be accomplished by using hydration aids including the use of polyethylene sheets and insulating tarps or heating and hoarding to maintain the LFCF above 4ºC. Cold weather protection measures are not required when the minimum daily temperature is not expected to drop below 0ºC. A site specific evaluation should be completed if sub-zero temperatures are anticipated during construction to reduce the project risk.

Placement of LFCF can proceed in light rain but the pour should be cancelled in heavy rain.

5. SITE CONDITIONS

Groundwater seepage control of all excavations is required before the placement of LFCF and should be continuous until the granular materials are placed above to avoid floatation. Any standing water in the excavation needs to be removed. The base of the excavation should be relatively stable for placement and free of deleterious materials. Since the LFCF is placed by discharge from a hose, heavy equipment is not required to enter the excavation. The sides of shallow excavations can be cut vertically or formwork may be needed for deeper excavations. As a best practice, a site sketch including a description of the soil base, weather conditions and photographs of the base should be included as part of the QC program and for record purposes.

6. LFCF PLACEMENT

Over 300 m^3 of LFCF can be placed per day, even late in the season. The lift thicknesses are typically 250 to 300 mm as this allows curing overnight so that the next lift can be placed the following day.

The wet-mix equipment must be able to receive slurry on-site into the equipment and process it continuously during ready-mix supply, and pump it through hoses or pipes up to a flat lineal distance of 200 metres. LFCF must be pumped by a positive displacement pump. A foam generator is used to continuously produce pre-formed foam, which is injected and mixed with the cementitious slurry downstream of the positive displacement slurry pump. The equipment needs to be calibrated to produce a precise, consistent and predictable volumetric rate of foam with stable uniform micro-bubbles.

LFCF can be placed with a maximum slope of 1%. Slopes greater than 1% require profiling by creating steps for the LFCF with formwork.

7. BACKFILL

Backfilling can be continued once the LFCF can support foot traffic. Construction traffic consisting of up to a vibratory roller weighing 5,500 kg is allowed after the first lift (350 mm) of backfill is placed. If no vibration is used a 150 mm backfill lift may be used. Geogrids can be set directly into the upper portion of the LFCF mass to strengthen the material to allow construction traffic on the surface earlier. However, this should generally not be necessary.

8. TRANSITIONS

Properly designed transitions are fundamental to the long term performance of a pavement incorporating LFCF. LFCF pavement has significantly different density and thermal properties to a conventional granular pavement. As such, in northern climates the transitions must be designed to accommodate the differential performance due to frost action. A further complication is introduced since the end of the LFCF section typically corresponds to the end of the problematic foundation support which necessitated the use of the LFCF. As frost is unlikely to penetrate through the LFCF pavement due to its high porosity, reverse heaving of the transitions can occur. This can be mitigated through a combination of the use of granular transition tapers and lateral drainage of the subbase directly adjacent to the LFCF. If geogrids are utilized in the upper portion of the LFCF mass they can be extended along the top of the granular subbase used to construct the transition.

For most applications 10 horizontal to 1 vertical granular transitions will provide adequate performance; however, the subgrade material directly adjacent to the LFCF mass should be sampled and its susceptibility to frost heave evaluated. Frost susceptibility evaluation methods differ greatly for individual provincial agencies. One accepted method is the Frost Susceptibility Criteria provided in the Transportation Association of Canada (TAC) Pavement Asset Design and Management Guide (TAC, 2013) originally published in Chamberlain, (Chamberlain,1981) which classifies soil as acceptable, borderline or unacceptable. If the adjacent subgrade material is borderline or unacceptable, consideration should be given to increasing the granular taper configuration to 20 horizontal or even 40 horizontal to one vertical. The diameter to the subdrain directly adjacent to the LFCF mass should also be increased.

9. CASE STUDY – HIGHWAY 9 SETTLEMENT, TOWNSHIP OF KING, ONTARIO

LFCF was utilized in October of 2014 to remediate an area of settlement along Highway 9, directly adjacent to a tributary of the Holland Drainage Canal, approximately 1.5 km west of Highway 400, north of Toronto. This site is located in the physiographic region known as the Schomberg Clay Plains (Chapman and Putnam, 1984) and thick organic deposits are commonly encountered. Based on the construction and maintenance history, sinkholes and settlement were a recurring maintenance challenge, being repaired in 2009 and problems developing again in 2014 shortly after dredging of the adjacent canal. The settlement was limited to the eastbound lanes of the highway. Geotechnical investigations completed in 2014 encountered pavement structure and embankment fill to depths ranging from 3.7 to 7.0 m underlain by organic material (peat) (Stantec, 2014). Based on nearby investigations, the underlying inorganic soil consists of soft to firm clayey silt to silty clay or compact silt and sand. The groundwater was encountered at depths ranging from 1.5 to 2.3 m below the top of pavement. As asphalt padding to temporarily repair the settlement would result in additional loading and further settlement, this repair strategy would result in continued maintenance interventions and costs, likely on an annual basis. LFCF was selected as an economical and sustainable remediation treatment to arrest the continued settlement and reduce safety concerns and maintenance costs.

The settlement remediation treatment involved excavation over a length of approximately 100 m (including transitions) to a depth of 1.5 m to provide for 200 mm of hot mix asphalt, 200 mm of Ontario Provincial Standard and Specifications (OPSS) Granular 'O' and 1100 mm of LFCF. A photograph of the excavation to a 1.5 m depth and subgrade preparation is shown on Figure 2.

Figure 2: Excavation and Base Preparation

For this project the subgrade fill material had a relatively low permeability so a polyethylene sheet was not applied to reduce the loss of the LFCF. Eastbound traffic was temporarily staged into the westbound lanes (one lane of traffic in each direction) to complete the work. The excavation was divided with shoring into four sections to facilitate staged LFCF placement. A photograph of the LFCF placement in progress in shown on Figure 3.

Figure 3: LFCF Placement

A biaxial geogrid with a minimum tensile strength of 8.0 kN/m was installed at a depth of 0.3 m below the top of the LFCF. A photograph of the LFCF with the geogrid installed is shown on Figure 4.

Figure 4: Geogrid Installation

Since the material properties of the LFCF and adjacent embankment fill will vary, properly designed transitions are critical to mitigate the effects of differential performance. For this project, the granular subbase (OPSS Granular B, Type II) was tapered from the bottom of the LFCF at 10 horizontal to 1 vertical to the existing subgrade, and a subdrain installed transversely at the end of LFCF and longitudinally on the highway centreline side to capture water that could pond against the LFCF. Two transverse asphalt step joints were provided over a minimum distance of 5 m (40 mm and 90 mm depth) to tie-in to the paving limits.

Table 3 lists the QC specifications that were used for the LFCF placement and the QC results summary:

Table 3 – Project Specifications and QC Results

Item	Project Specification Requirements	Range Observed During QC Testing	Average Observed During QC Testing
Minimum Unconfined Compressive Strength	1.0 MPa @ 28 days	0.9 to 1.7 MPa	1.3 MPa
Wet Cast Density	523 to 578 kg/m^3	525 to 580 kg/m^3	550 kg/m^3
Air Temperature	Protection required for sub-zero temperatures	10 to 17ºC	14ºC
Cellular Concrete Temperature		22 to 26ºC	24ºC
Max. Lift Thickness	500 to 600 mm	300 to 500 mm	N/A

The LFCF placement was completed over three days and a total of 905 m^3 was placed.

The pavement transition consisted of a 10H:1V granular transition with a 100 mm diameter perforated subdrain placed in a 300 x 300 mm trench wrapped in a Class I non-woven geotextile with a FOS of 40-80 µm and backfilled with 19 mm clear stone.

The use of LFCF eliminated the need for deep sub-excavation of the organic material and reduced the required excavation depth to 1.5 m. The benefits of the reduced excavation include simplified traffic staging, considerable reduction in the amount of excess material requiring disposal, reduced backfill materials required, reduced construction time and reduced impact on the adjacent canal and wetlands.

Photographs of the condition of the pavement approximately one year after the completion of the construction are provided in Figures 5 and 6.

Figure 5: Completed pavement, one year after construction

Figure 6: Completed pavement incorporating LFCF

One year after completion of the work the pavement is performing well. The transitions have only slight differential performance that is barely perceptible to the travelling public. The use of the LFCF reduced costs, lessened impact on traffic and the public, increases operational safety and will reduce ongoing maintenance costs. The installation of the LFCF was performed quickly and efficiently and no problems were encountered during construction.

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