Lightweight Foamed Concrete Fill

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Since 1981 the New York State Department of Transportation (NYSDOT) has used lightweight foamed concrete fill (LFCF) to reduce loads on clayey and organic soils that are weak and highly compressible. LFCF is also used to reduce lateral loads on abutments and retaining walls. To date, it has been used successfully in place of conventional fill on seven projects involving 12 placement areas: 10 permanent bridges, 1 temporary detour bridge, and 1 set of existing retaining walls. LFCF, typical applications, and placement, as well as quality assurance and testing, are described. NYSDOT specifications, design considerations, and a comparison with another lightweight fill are discussed, and NYSDOT's experiences with LFCF and its performance are summarized.

New York State soils are complex and variable. Of greatest concern are clayey and organic soils, which are weak and highly compressible and may result in differential settlement or embankment foundation instability, or both. Weakness and compressibility of embankment foundation soils can also induce drag on pile foundations and intolerable lateral loads on abutments and retaining walls. New York uses lightweight foamed concrete fill (LFCF) to minimize or eliminate these geotechnical issues.

LFCF is a low-density cellular concrete consisting of a portland cement matrix containing uniformly distributed, noninterconnected air voids (Figure 1). These are introduced into the matrix by a foaming agent, facilitating development of wet-cast densities ranging from 288 to 1280 kg/m^3 (18 to 80 pcf) and corresponding 28-day compressive strengths from 69 to 2067 kPa (10 to 300 psi).

At present, two suppliers have submitted product information and samples containing their foaming agent to the New York State Department of Transportation (NYSDOT) Materials Bureau for evaluation and approval. (These foaming agents are Elastizell Concentrate, supplied by Elastizell Corporation of America, Ann Arbor, Michigan, and Mearl Geofoam Liquid, supplied by Mearl Corporation of Roselle Park, New Jersey.) New York's experiences are limited to use of these two products.

TYPICAL APPLICATIONS

NYSDOT uses this fill to prevent increased loads on embankment foundations. This is based on the concept of "balanced" excavations (*1*). By removing a quantity of existing fill or natural material and replacing it with no more than an equal weight of lighter fill to the required grade line, no additional load is applied to the foundation soil. For example, if 0.3 m (1 ft) of existing material with a density of 1920 kg/m^3 (120 pcf) is excavated, 0.9 m (3 ft) of lightweight fill with a density of 640 kg/m^3 (40 pcf) can be placed without inducing any additional loads on the foundation soils.

LFCF is also used as a backfill to prevent increased lateral loads on existing abutments and retaining walls. In some placements, a denser LFCF layer is used as a footing base. Some placements also involve a dense top lift on which a reinforced concrete pavement is directly placed.

PLACEMENT

In preparation for placing LFCF, forms are positioned as needed around the perimeter of the placement area. The type of form used depends on the contractor's experience with the product and the job site restrictions. The formwork often consists of nothing more than sheets of plywood leaning against stakes that have been tapped into the ground or a previously placed lift of LFCF fill. In many instances, the placement perimeter is bounded by a structure, such as an abutment or retaining wall, or by the excavation. Consequently, the only form required would be at the open end of the excavated area. If the placement area is large, the contractor will occasionally separate it into smaller areas by using temporary interior forms (Figure 2).

Preparation of the fill requires the following equipment (Figure 3): a unit to dilute and mix the foaming agent, a mixing/calibrating unit, a cement truck with a hopper to measure the cement, and a water tanker (if a local source is not available).

The process begins by measuring the foaming agent (usually based on experience), placing it in a dilution chamber, adding water, and mixing. The resulting foam is then routed to a mixing/calibrating unit, where a measured amount of cement is added. The fill is then pumped through a hose to the placement area. At this stage, the fill is sampled at the point of placement by the on-site supplier's representative and a NYSDOT inspector to ensure conformity to the required maximum wet-cast density. If necessary, proportions are adjusted.

Fill placement is limited to lifts of no more than 0.6 m (2 ft) for two reasons

1. Typically, the worker places the fill by laying the hose on the ground and slowly shuffling through the puddling fill to minimize voids next to structures or formwork (Figure 4). Limiting placement depth to 0.6 m (2 ft) makes this easier.
2. With depths greater than 0.6 m (2 ft), excessive heat of hydration may develop, negatively affecting LFCF air void content.

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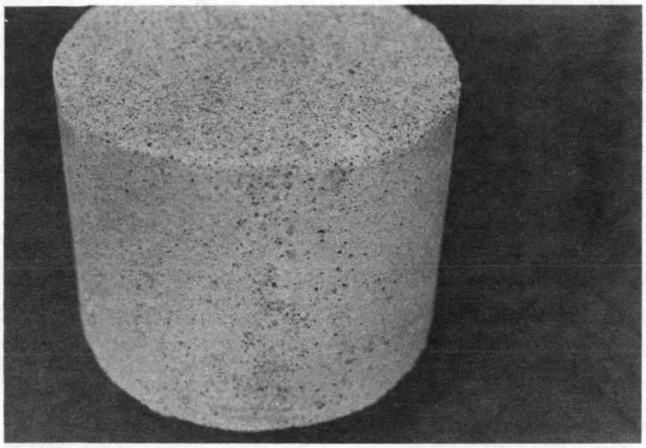


FIGURE 1 Sample of LFCF.

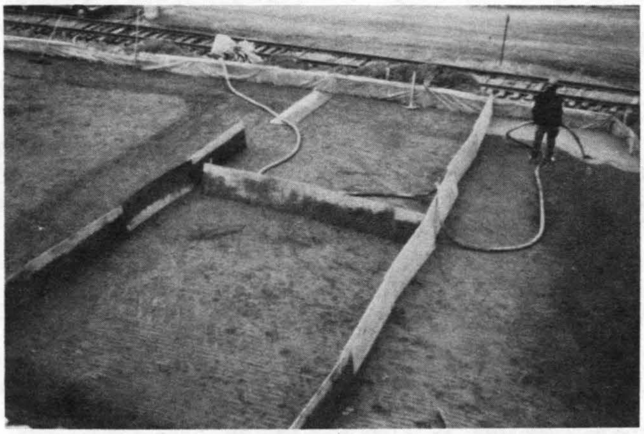


FIGURE 2 Temporary forms used in placement area (2).

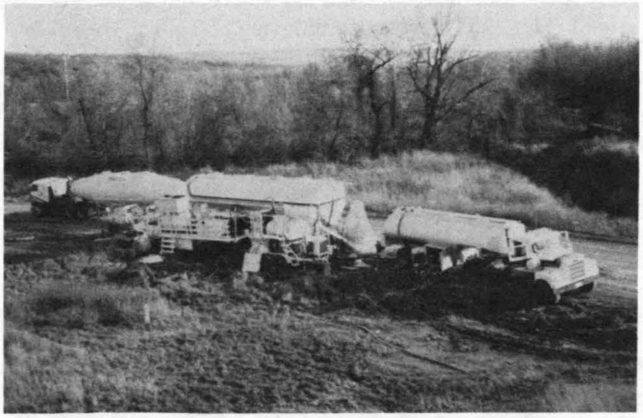


FIGURE 3 Equipment (2).

FIGURE 4 Placement of LFCF (2).

Before each lift sets up, the surface is sacrificed with a broom or rake (Figure 5), providing a roughened surface on which to place the next lift. Each subsequent lift is placed after a minimum 12-hr waiting period.

QUALITY ASSURANCE AND TESTING

To ensure that the maximum wet-cast-density requirement is being met, a density test is run on fill samples gathered at the point of placement. These are taken from the initial mix and every 30 min thereafter. To check density, a cylinder of known weight and volume is filled with the LFCF. The filled cylinder is then weighed (Figure 6) and the density calculated. On the basis of the test results, the process is adjusted as necessary.

Several factors can affect the mix. For example, as noted by Douglas (1), the amount of foaming agent added governs the number of air voids in the fill, but mix temperature governs their size. In addition, if the placement hose and the distance pumped exceeds about 244 m (800 ft), the air voids break down.

Compressive strength is evaluated by both the supplier and NYSDOT Materials Bureau of samples gathered at the point of placement. The supplier takes four 8- × 15-cm (3- × 6-in.) cylinders for each day's placement or each 61 m^3 (80 yd^3) of fill placed. NYSDOT takes four 15- × 30-cm (6- × 12-in.) cylinders for each day's placement or each 77 m^3 (100 yd^3) of fill placed. Although both the supplier and NYSDOT

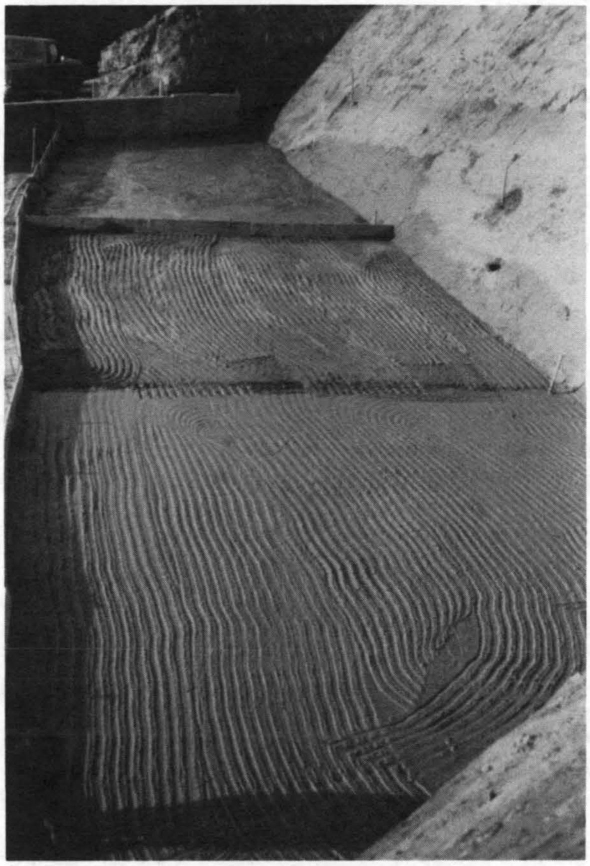


FIGURE 5 Scarified surface of lift (*2*).

run 28-day compressive tests, NYSDOT results govern. Additional samples are often gathered for compressive tests at 7- and 14-day intervals.

On at least two projects, some larger NYSDOT samples have failed to meet minimum 28-day compressive strength. In each case, the supplier's smaller samples have exceeded the minimum requirement. NYSDOT is currently gathering data to correlate sample size and compressive strength. Data are also being collected on the 7- and 14-day breaks to correlate compressive strength results with the 28-day breaks.

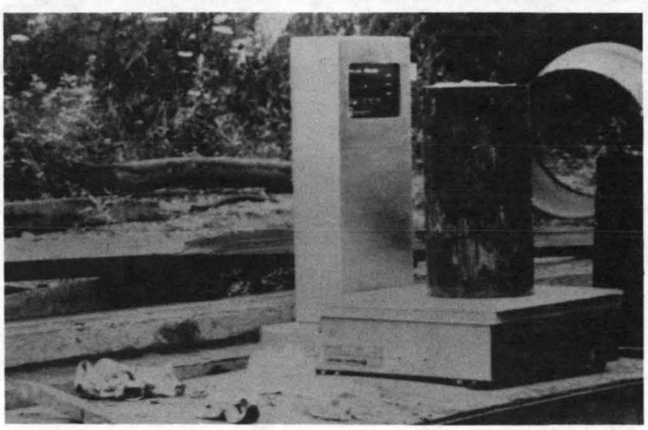


FIGURE 6 Field density testing (*1*).

NYSDOT SPECIFICATIONS

Although LFCF is available in a wide range of densities, NYSDOT specifications restrict its use to one of two densities, identified as Types A and B. These densities produce adequate strengths, and meet the requirement for reduced loads. Current specifications are for a maximum wet-cast density of 480 kg/m^3 (30 pcf) for Type A and 672 kg/m^3 (42 pcf) for Type B. Contract plans indicate which, if not both, is to be used for the project and where it will be placed.

COMPARISON WITH OTHER LIGHTWEIGHT FILLS

To reduce loads, NYSDOT also considers using expanded shale or slag with an in-place density from 880 to 1280 kg/m^3 (55 to 80 pcf), which is two to three times greater than that of the LFCF. Consequently, the excavation requirements for using expanded shale can be as much as 50 percent greater and frequently involve excavating below the groundwater or tide level. This also adds additional costs of dewatering and cofferdams.

The cost of expanded shale or slag ranges from \$30 to \$40/m^3 (\$40 to \$50/yd^3). LFCF costs typically range from \$50 to \$70/m^3 (\$67 to \$94/yd^3). Overall, lightweight costs vary with the quantity required for the project, contractor's experience with the product, and hauling distance.

Ultimately, the decision of which lightweight fill to use is based on economics, project site constraints, and availability.

DESIGN CONSIDERATIONS

When the use of LFCF was first considered, several questions about placement arose. Was LFCF feasible in an urban project with extremely high traffic volumes or in a project with limited space for staging? Could utilities be installed in the placement area? Could roadway grades, slopes, and profiles be met with this fill? With respect to fill performance, once placed how would it be affected by water? Could it be placed below the groundwater table? Would it float? Would it become saturated and increase in density if exposed to groundwater or infiltration through the pavement surface, or both? Would it be susceptible to freeze-thaw cycles? How would the fill be affected by traffic loading, especially in high-volume areas? Could pavement be placed directly on the fill?

Resolution of these questions—explained in detail by Douglas (*1*)—and subsequent experience with LFCF produced a list of design considerations now used by NYSDOT. Placement of LFCF in areas with high-traffic volumes, where offsite detours are impractical or where staging areas are limited, poses no difficulty. Preparation and placement of the fill require only four pieces of equipment (as previously listed) or less if some of the units are self-contained or combined. If there are many placement areas, it is frequently possible to cover them from one staging area.

Utility installation in the placement area is easily accommodated by setting utility pipes on temporary supports (Figure 7). Or (if allowed by the sequence of operation), when the fill has risen to just below the utility elevation, temporary

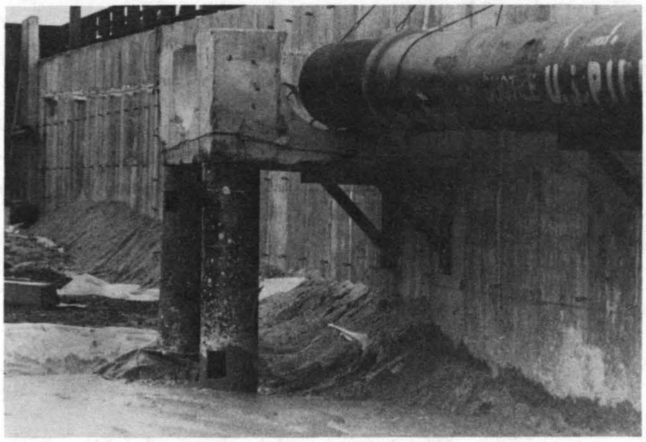


FIGURE 7 Utility placement (*1*).

blocking or bracing can hold the pipe in place as the fill is placed around it. Postconstruction utility installation, to meet future needs, can be accomplished by excavating the fill with a backhoe, jackhammer, or even hand tools. Pipe jacking or boring operations are other possibilities.

Grades and profiles can be established by placing the fill in stepped 15-cm or 0.3-m (6-in. or 1-ft) lifts (Figure 8) that are then trimmed and overlain with an asphalt truing-and-leveling course. Another method includes slightly overpouring the top lift and then removing the excess with hand tools. To establish a side or end slope, the fill can be placed in stepped lifts and topped with conventional fill, topsoil, or slope protection (Figure 8). In yet another method (for profiles or grades up to about 5 percent), a thickening agent can be added to the fill mix design. Because LFCF has the characteristics of a solid sponge and low density is a specific requirement in most projects, water absorption potential can be a concern. It was suggested (*1*), however, that ratios of exposed surface area to total volume for the laboratory samples and larger construction applications were not comparable; absorption of water in placement above high tide and groundwater level would not significantly increase loading on the foundation soils. This also reduces any potential for buoyancy. It was also concluded that overlying subbase or pavement, or both, is sufficient to keep the fill in place.

To prevent water absorption or buoyancy, however, NYSDOT places LFCF above normal groundwater and high-tide elevations. To compensate for occasional extremes of these elevations and prevent absorption of infiltration through the roadway surface, several techniques were identified to limit exposure of the LFCF surface area. The bottom of the placement area can be lined with a sheet of polyethylene. If the fill is not placed directly against the backs of wingwalls, concrete curtain walls can be built to protect the sides of the placement. Water flow between the interface of the fill and the curtain wall can be prevented by casting a waterstop into both. The top of the fill can be sealed with an asphalt emulsion. Asphalt hot mix also works but is considerably more tedious to apply. Drainage can be enhanced by placing underdrains at the base of the curtain walls, wingwalls, abutments, and at the pavement edge. Geotextile, however, should not be used with drainage—the fill will seal the fabric.

Freeze-thaw concerns were also addressed. By using any or all of the techniques described, very little water is likely to find its way to the fill. Furthermore, subbase or in some placements a lift of denser LFCF placed on top of the less dense LFCF acts as insulation from freezing temperatures.

Although it was believed that LFCF would respond at least as well as compacted subbase in areas of high traffic volumes, a top lift of denser LFCF was recommended to provide some performance insurance. As for placing the concrete pavement on the fill, there was speculation that the asphalt emulsion would allow the pavement to move over the fill if subjected to heavy traffic. For such a situation, it was recommended that the pavement slab be keyed into the underlying fill (Figure 9).

In some placement areas, the fill must have sufficient compressive strength to support footing or construction loads (Figures 8 and 10). In others, the primary consideration is frequently the low density. In this type of placement, when it is in place, the fill needs only to be as strong as compacted embankment material.

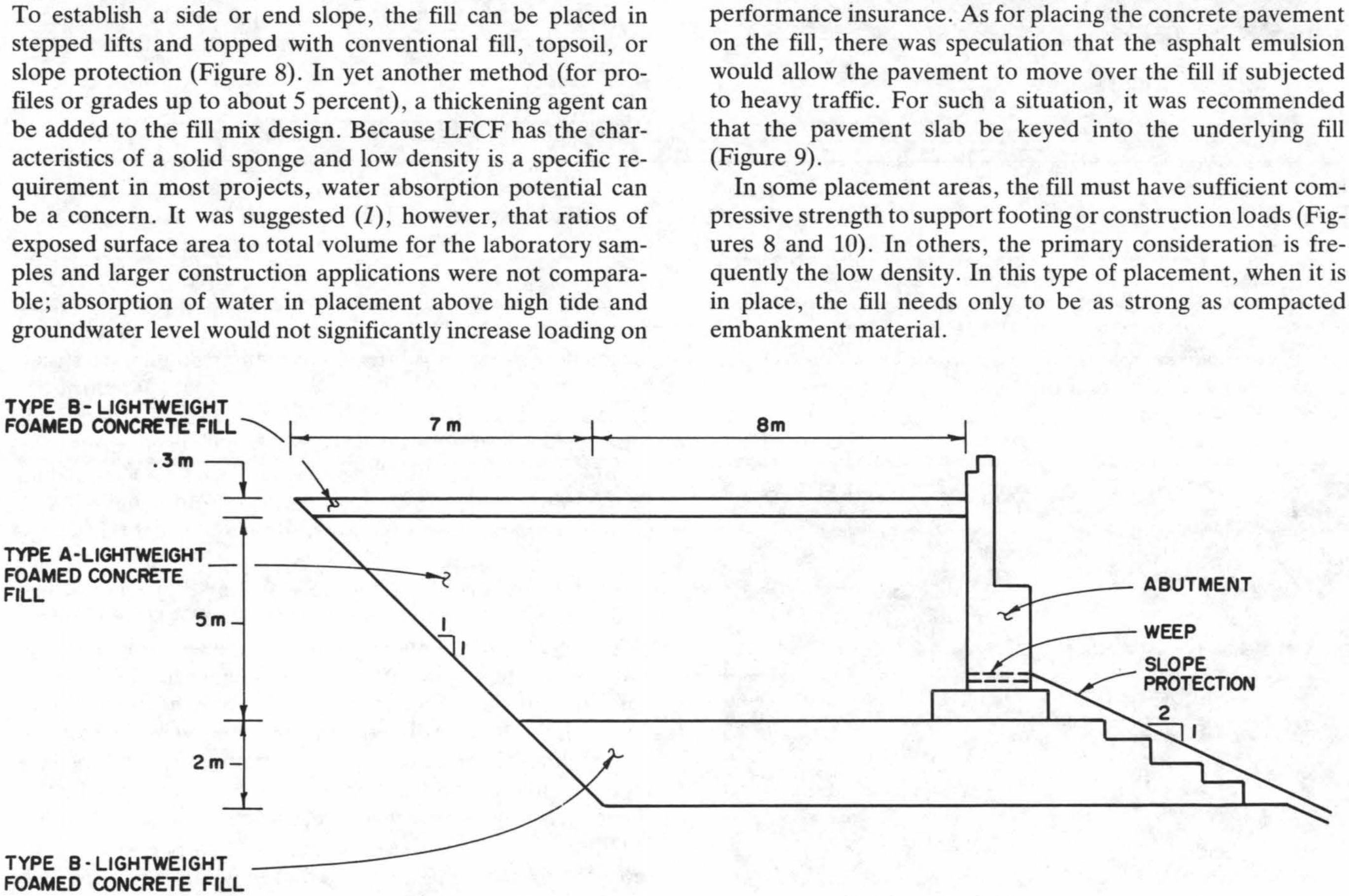
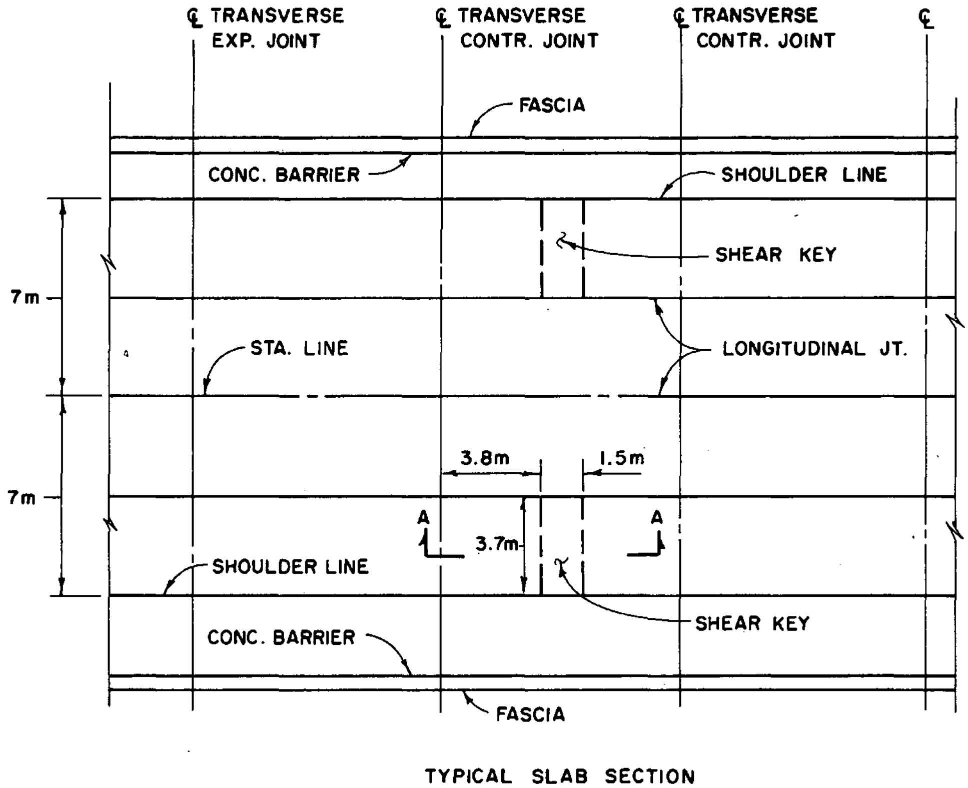


FIGURE 8 LFCF layered, stepped, and under a footing.



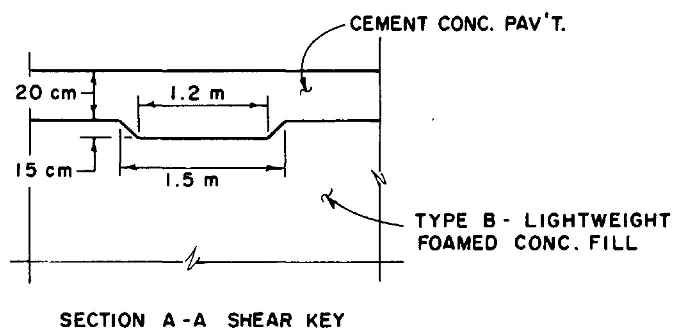


FIGURE 9 Shear key of reinforced concrete slab into LFCF (*1*).

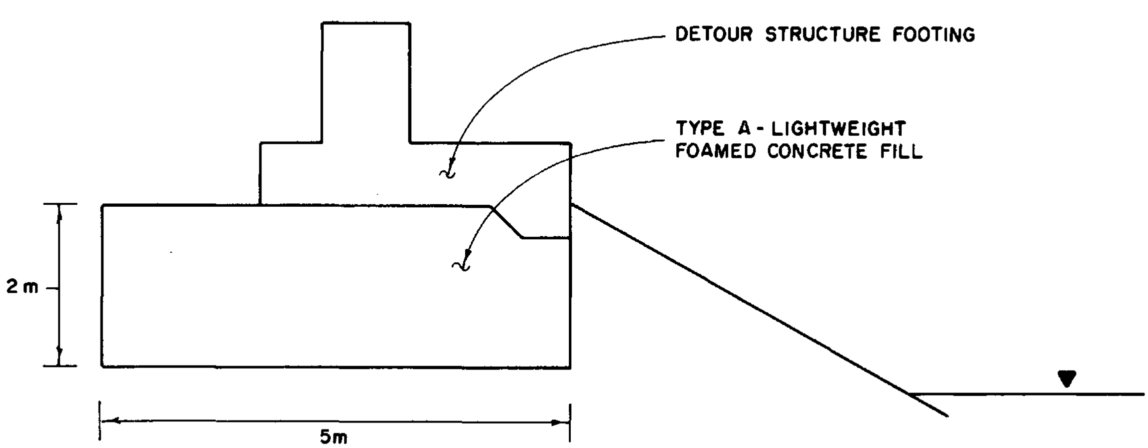


FIGURE 10 LFCF under detour structure footing.

EXPERIENCES WITH LFCF

Since 1981 NYSDOT has used the fill on seven projects, involving 12 placement areas. Although the areas varied somewhat in soil profile, bearing capacity, and embankment height, they were similar in the need to minimize loading on foundation soils or existing structures. Douglas (*1*) and McGrath (*2*) documented two of the earliest projects. Two other placement areas are described. Typical placement details are shown in Figures 8, 9, 10, 11, 12, and 13.

Pine Island Turnpike

To replace a structure carrying the Pine Island Turnpike over Pochuck Creek in the Town of Warren, Orange County, New York, an on-site detour embankment and structure were planned, to be placed beside the existing embankment and structure.

NYSDOT geotechnical engineers familiar with the area anticipated settlement difficulties. Subsequent subsurface explorations verified their concerns—the foundation soils consisted of 2 m (7 ft) of peat over 1 to 3 m (3 to 10 ft) of silty sand and 8 m (25 ft) of silty clay.

Settlement analyses for the 3-m (9-ft) approach embankments to the detour structure estimated 0.6 m (2 ft) of settlement and potential for failure of the approach embankment endslopes into the creek. Estimated settlement and failure potential jeopardized the detour structure.

As a lump-sum bid item, the contractor was responsible for design of the detour embankment and structure. To alert the contractor, a note was placed in the contract plans calling attention to the very low bearing capacity of the foundation soils.

On the basis of this information, the contractor's design consultant recommended that natural soil be replaced with LFCF [maximum wet-cast density of 672 kg/m^3 (42 pcf) and minimum 28-day compressive strength of 689 kPa (100 psi)] in the area under the detour structure footing (Figure 10). This replacement area was the width of the footing, 2 m (5 ft) deep, and 5 m (15 ft) from the front of the footing, which was 3 m (10 ft) wide, to 2 m (5 ft) behind the back of the footing.

No special provisions were made for the detour approach embankments. The contractor chose to maintain the roadway profile using additional shimming with asphalt rather than attempt to minimize the settlement. No provisions were made to prevent absorption of groundwater or infiltrating surface water. Because this was a temporary detour, potential short-term absoption was not considered a problem.

Route 150

An existing two-span structure carrying Route 150 over the Amtrak Railroad and Brookview Station Road in the Town of Schodack, Rensselaer County, New York, was replaced

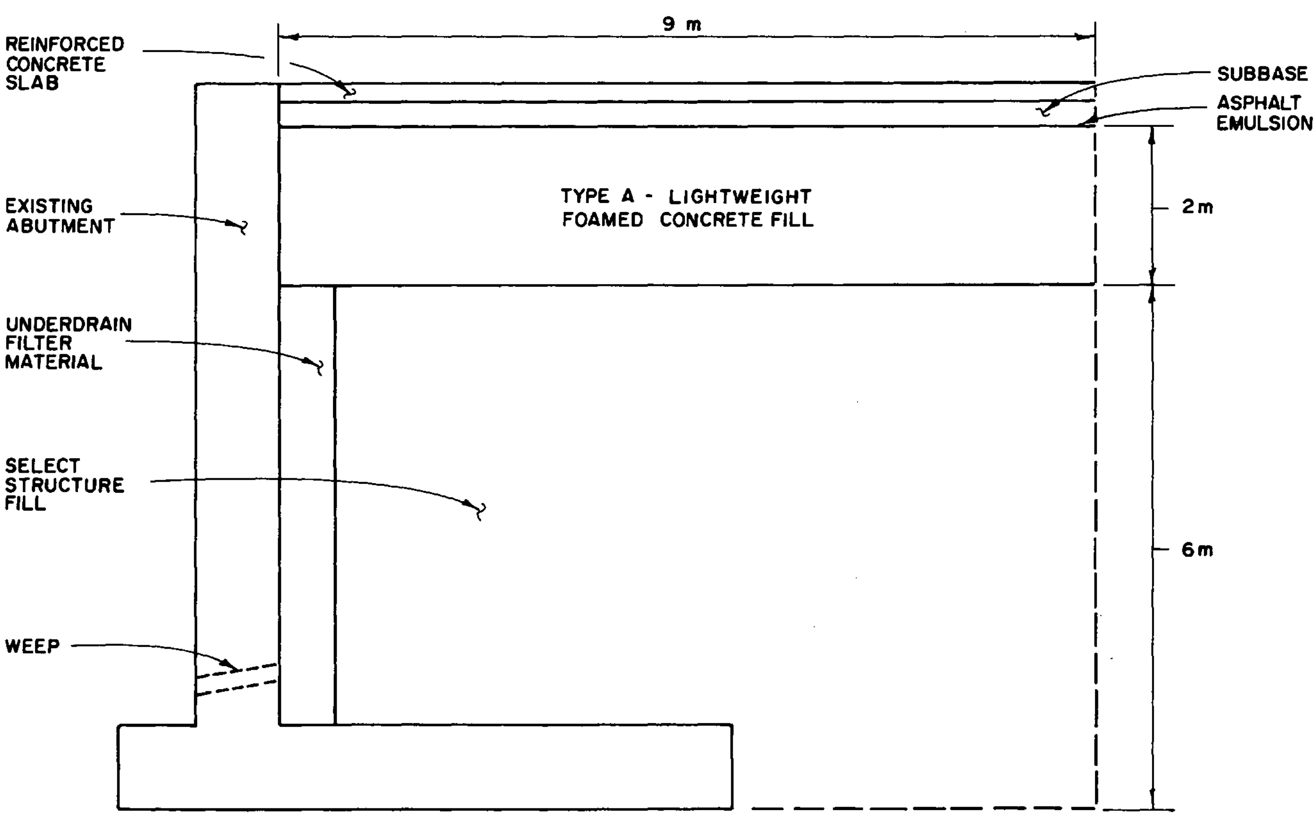


FIGURE 11 LFCF behind existing abutment with asphalt emulsion seal on top lift.

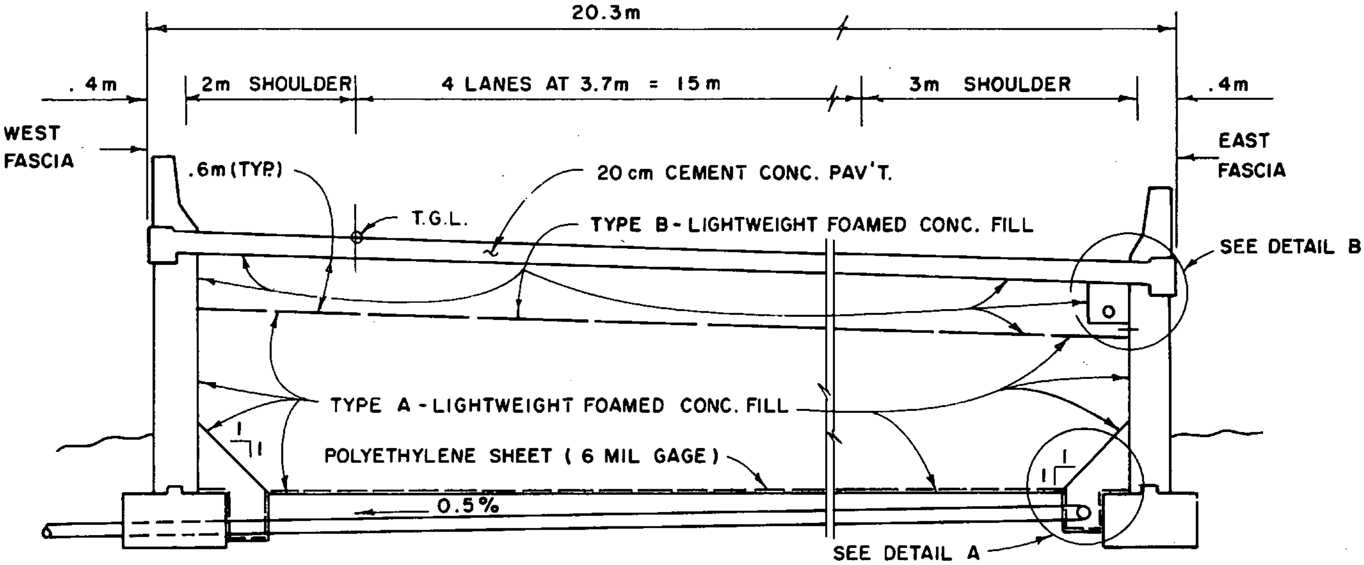


FIGURE 12 LFCF, underdrains, polyethylene sheeting, and waterstop (*1*). Details A and B are enlarged in Figure 13.

with a single-span structure. Because the existing laid-up stone abutments built in 1899 were still structurally sound, they were modified to support the new superstructure.

To accommodate the increased height of the new superstructure, it was necessary to increase the grade of the approach embankments by 1 m (3½ ft)—8- to 9-m (26- to 28-ft) high approach embankments on 9 to 10 m (28 to 33 ft) of very soft to soft clay and silty clay underlain by loose to very compact silt. Analyses of foundation soils under the existing abutments, however, indicated the soil was not capable of supporting the increased design loads.

To reduce the proposed loading, LFCF, with a maximum wet-cast density of 480 kg/m^3 (30 pcf) and a minimum 28-day compressive strength of 276 kPa (40 psi), was chosen to replace the conventional fill for 9 m (30 ft) behind each abutment (Figure 11). Replacement depth on the west side was a little less than 2 m (6 ft) and a little more than 2 m (8 ft) on the east.

To minimize any effect by water, a column of underdrain filter material 0.6 m (2 ft) thick was placed under the LFCF and against the back of each abutment. Weeps outletted through the abutments. The LFCF top surface was sealed with an asphalt emulsion. The overlying pavement section consisted of 30 cm (12 in.) of subbase topped by a reinforced concrete approach slab.

Contract plans specified a crown of 6 mm (¼ in.) to 0.3 m (1 ft) of roadway profile. To accomplish this, the last lift of LFCF was slightly overpoured and smoothed. After setting, excess LFCF was easily removed with hand tools.

To facilitate timely placement of the new superstructure, additional cylinders were taken during the LFCF placement to evaluate 7-day compressive strength. The 7-day break results, from 241 to 531 kPa (35 to 77 psi), were deemed close enough to the required 276 kPa (40 psi) to allow the contractor to proceed.

To minimize damage to the 2-week-old LFCF top lift, 2 × 3 m (8 × 10 ft) pads constructed of three crisscrossed layers of 5 × 19s (2 × 6s) were placed 2 m (8 ft) from each abutment backwall. On these, a 127-Mg (140-ton) crane was placed on the east end and a 91-Mg (100-ton) crane was placed on the west end. Planking was also placed under each crane outrigger. Beams for the new superstructure were then lifted into place. This technique worked well—no visible damage occurred to the LFCF.

PERFORMANCE

Monitoring of each placement area varies after completion of a project. Some areas are heavily monitored with slope indicators, settlement platforms, and survey hubs. Other areas have only a few survey hubs. Still others are given only a visual check for cracks or undergo a rideability reading. Monitoring depends on site movement history and amount of movement anticipated.

To date, although one placement area has undergone anticipated long-term settlement of as much as a meter (several feet), the LFCF has performed well. Settlements are minimal and no movement of original structures has been noted. There is no indication of water absorption or failure of the fill caused by traffic loading. Furthermore, as noted by McGrath (*2*), at least one placement area was left open and exposed during winter and had no sign of deterioration.

CONCLUSIONS AND RECOMMENDATIONS

Douglas (*1*) and McGrath (*2*) present conclusions and recommendations that have resulted in current NYSDOT specifications and design considerations. LFCF has proved to be an effective lightweight fill for areas with underlying weak and compressible clayey and organic soils. It has also been effective as backfill for existing abutments and retaining walls that are unable to withstand additional loads.

It is recommended that the specialty contractor have documented experience with the product. Successful LFCF mix-

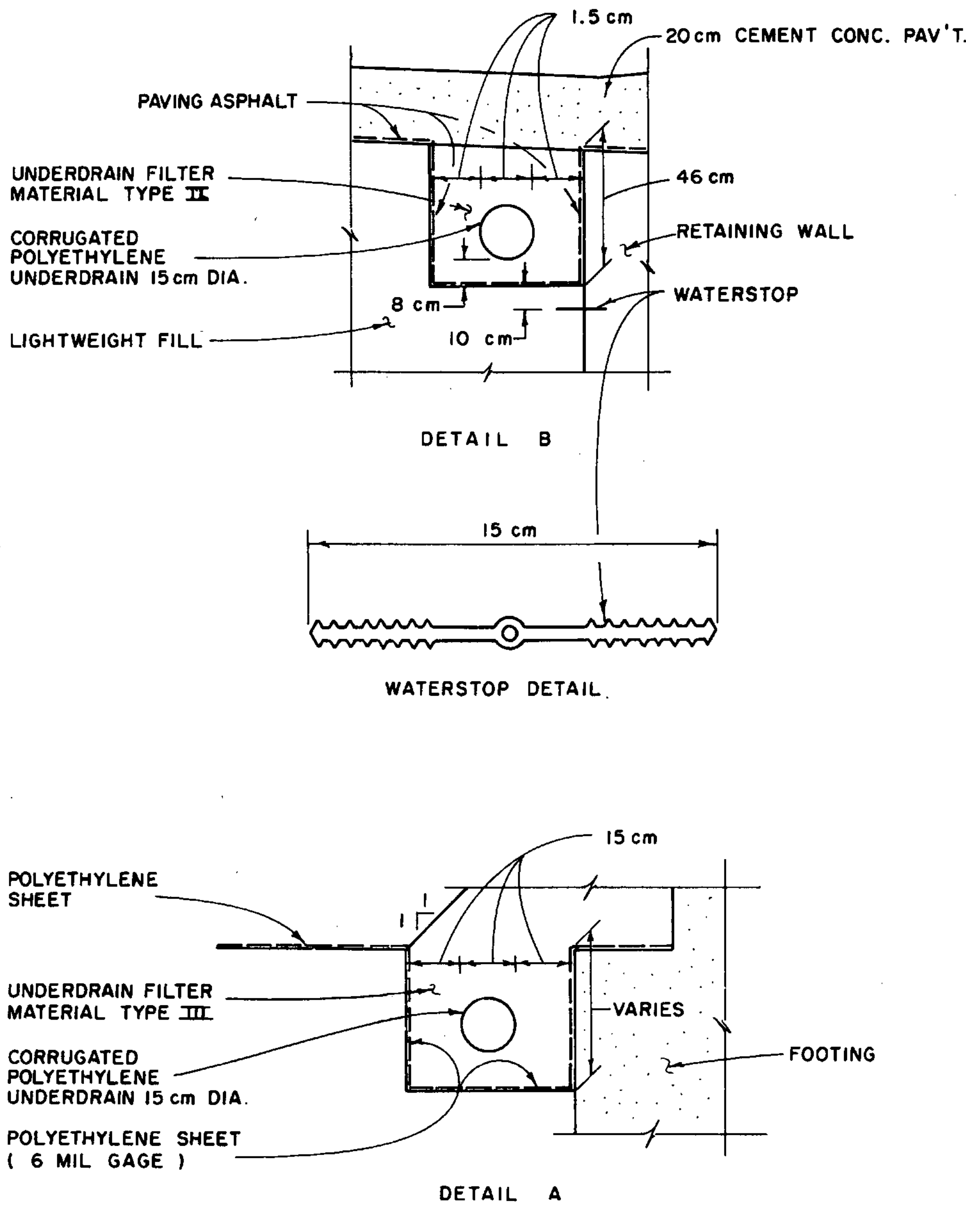


FIGURE 13 Details of underdrains and waterstops (*1*).

ing and placing depends very much on experience. It is also recommended that the supplier's representative be on site during initial placement to ensure proper mix design and answer questions throughout construction.

Finally, a correlation needs to be established between the different sizes of samples taken by the supplier and owner. A correlation also must be established between compressive strengths of any 7- and 14-day tests and the required 28-day tests.

ACKNOWLEDGMENTS

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