Lightweight Fill Solutions to Settlement and Stability Problems on Charter Oak Bridge Project, Hartford, Connecticut

JOHN P. DUGAN, JR.

Design and construction of the Charter Oak Bridge and approaches over soft soils were complex and challenging. To solve settlement and stability problems arising from highway and bridge construction over deep deposits of soft varved clay in the Connecticut River valley the following applications of lightweight fill were made. Lightweight fill was placed for the high approach fill for the east abutment. The reduced stresses imposed in the clay layer, combined with the lightweight fill's higher shear strength compared with that of an earth fill, solved this embankment stability problem. Lightweight fill was placed in approach embankments for a replacement bridge to reduce settlements of the adjacent existing bridge. To avoid minor settlements to an aging sanitary sewer that crossed the west approach, soil above the sewer was replaced with lightweight fill. The resulting stress reduction balanced effects of additional stresses imposed by nearby fills and pile driving. The overall slope stability of a wharf, with an anchored sheet pile bulkhead, was improved by replacing existing soil with a 1.5-m (5-ft) layer of lightweight fill.

This paper summarizes applications of lightweight fill (expanded shale) to solve settlement and stability problems arising from highway and bridge construction over deep deposits of soft varved clay in the Connecticut River valley.

More than 61 200 m^3 (80,000 yd^3) of lightweight fill was placed for the 14.0-m (46-ft)-high east approach fill. The reduced stresses imposed in the clay layer, combined with the lightweight fill's higher shear strength compared with that of an earth fill, solved the embankment stability problem. Lightweight fill was placed in approach embankments for a replacement bridge to reduce settlements of the adjacent existing bridge.

To avoid even minor settlements to an aging, 2.0-m (6.5-ft)-diameter sanitary sewer that crossed the west approach, soil above the sewer was excavated and replaced with lightweight fill. The resulting stress reduction balanced effects of additional stresses imposed by nearby fills and pile driving.

The overall slope stability of a wharf, with an anchored sheet pile bulkhead, was improved by replacing existing soil with a 1.5-m (5-ft) layer of lightweight fill.

PROJECT DESCRIPTION

The new Charter Oak Bridge, which links Hartford and East Hartford, Connecticut, was opened to traffic in August 1991, 72 months from the start of design and 40 months from the start of construction. The 6-lane, 1,037-m (3,400-ft)-long, $90 million multigirder steel structure built 61 m (200 ft) south of the old bridge carries U.S. Route 5 and State Route 15 over the Connecticut River and its flood plain. The project included extensive construction of approach roads and bridges, valued at $110 million.

Haley & Aldrich, Inc., 110 National Drive, Glastonbury, Conn. 06033.

LIGHTWEIGHT FILL

Lightweight fill was expanded shale aggregate produced by expanding shale, clay, or slate by heating in a rotary kiln to approximately 1149°C (2,100°F). The expanded, vitrified mass was then screened to produce the desired gradation. The pores formed during expansion are generally noninterconnecting. The particles are subgranular, durable, chemically inert, and insensitive to moisture.

For this project, the following gradation was specified

Square Mesh Sieve Size	*Percent Passing by Weight*
25.4 mm (1 in.)	100
19.0 mm (¾ in.)	80–100
9.5 mm (⅜ in.)	10–50
No. 4	0–15

For design, a unit weight of 961 kg/m^3 (60 lb/ft^3) and an angle of internal friction of 40 degrees were used.

The lightweight fill was placed in 0.61-m (2-ft)-thick lifts and compacted with four passes of a relatively light 4.5-Mg (5-ton) vibratory roller operating in vibratory mode. The compaction effort was designed to prevent overcompaction, which could result in breakdown of particles leading to a more well-graded material with higher-than-desirable unit weight.

SUBSURFACE CONDITIONS

The site is in the floodplain of the Connecticut River. Subsurface conditions, in the order of increased depth, are

- Existing fill, (a) random fill [1.5 m (5 ft) to more than 4.6 m (15 ft) thick] containing man-made and discarded organic material and (b) roadway fill that is relatively free of nonmineral material.
- Alluvial sand and silt stratum consisting of floodplain and channel deposits 9.1 to 12.2 m (30 to 40 ft) thick.
- Very soft to soft, varved clay and silty clay, in regular layers 6.3 to 12.7 mm (¼ to ½ in) thick, [more than 25.4 mm

(1 in) thick at some locations], deposited in glacial Lake Hitchcock during the Pleistocene epoch. These deposits are approximately 10.7 m (35 ft) thick on the west side and from about 27.5 to 45.8 m (90 to 150 ft) thick on the east side of the river. Compressibility, stress history, and undrained shear strength data are given in Table 1. For other engineering properties, see work by Smith (*1*).

- Glacial till stratum consisting of dense to very dense sandy silt with subordinate coarse to fine gravel, clay, and occasional cobbles.
- Groundwater levels within the alluvial sand and silt and approximately 1.5 m (5 ft) above normal level in the Connecticut River.

EMBANKMENT STABILIZATION

If constructed of earthen material 2,002 kg/m³ (125 lb/ft³), the maximum 14.0-m (46-ft)-high embankment for the Charter Oak Bridge's east approach would not have an acceptable safety factor against slope instability. The safety factor against slope failure toward the adjacent Hockanum River, using earth fill, was estimated to be only 1.0 to 1.1 (Figure 1).

Many stabilization alternatives were considered. A toe berm placed in the river was the most economical but rejected to avoid delays that would occur because of time required to obtain environmental permits. Therefore, it was decided to construct the embankment of lightweight fill. The 62 730 m³ (82,000 yd³) of lightweight fill is one of the largest quantities of lightweight fill placed for one project in the United States.

Lightweight fill significantly reduced stresses in the weak varved clay. Even so, it was necessary to excavate a portion of the approach fill to the existing bridge to provide the design safety factor of 1.25. The lightweight fill's 40 degree angle of internal friction was higher than provided by earth fill, which increased resisting forces along the potential failure plane.

TABLE 1 Compressibility and Strength Parameters for Varved Clay at East Abutment

The clay is overconsolidated by at least 3.5 KPa (3.5 kips/ft²) at all depths.

<u>Compression Ratio</u>		
Virgin compression	0.31 to 0.37	
Recompression	0.03	
<u>Coefficient of Consolidation</u>		
Normally consolidated	0.0004 cm²/sec (0.04 ft.²/day)	
Overconsolidated	0.0037 cm²/sec (0.37 ft.²/day)	
<u>Coefficient of Secondary Compression</u>		
El. 0 to -30	1.06% per log cycle time	
El. -31 to -60	0.87% per log cycle time	
Below El. -60	0.98% per log cycle time	
<u>Coefficient of Horizontal Permeability</u> / Coefficient of Vertical Permeability	=5	
<u>Shear Strength, $s_u = S(OCR)^m \sigma_v$</u>		
	<u>S</u>	<u>m</u>
Undrained	0.19	0.7
Plane Strain Compression	0.21	0.8
Plane Strain Extension	0.20	0.75
Direct Simple Shear	0.14	0.7

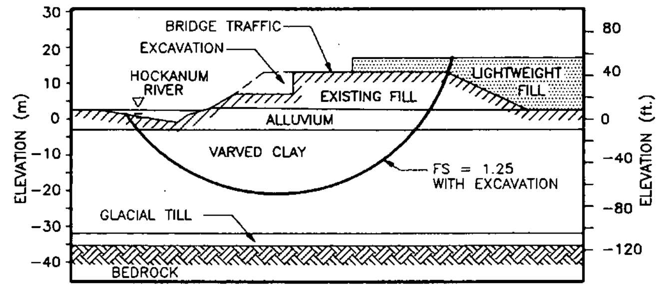

FIGURE 1 Slope stability for east abutment. Final conditions with lightweight fill.

Another benefit of the lightweight fill was the significantly reduced settlement, compared with an earth fill. The total settlement, over the first 15 years, of a lightweight fill embankment was predicted to range from 0.43 to 0.64 m (1.4 to 2.1 ft), compared with estimates of up to 1.98 m (6.5 ft) for earth fill. Observed settlement at the east abutment over a year is in line with the predicted values. Hence, the surcharge fill and vertical drains that were planned to speed consolidation of an earth fill were unnecessary. Nevertheless, the lightweight fill technique cost an additional $2 million in construction compared with the more conventional earth fill/berm/surcharge design.

SETTLEMENT REDUCTION AT EXISTING BRIDGE

A part of the overall project was replacement of Route 15 over Main Street in East Hartford, Connecticut, with a new bridge—a single-span structure 55.8 m (183 ft) wide, at the existing bridge, but extending 21.4 m (70 ft) north and 7.6 m (25 ft) south. Plans called for stage construction, with traffic maintained on the existing bridge while the north section of the new bridge was built. Then traffic was carried entirely on the north half of the new bridge while the existing bridge was being demolished and the south half of the bridge being built. Lightweight fill made it possible to keep the existing bridge in service while the north portion of the new bridge was being built and to avoid more expensive alternatives to prevent settlement.

The existing bridge is supported on spread footings bearing on a sand layer over approximately 42.7 m (140 ft) of soft varved clay. A recent inspection had reported 7.6 cm (3 in.) settlement of the west abutment and rotation and horizontal movements of both abutments of the single-span bridge. Temporary corrective repairs were planned; however, there was little tolerance for additional deflections.

Although the new bridge was designed to be supported on deep end-bearing piles, the 7.6-m (25-ft)-high approach fills would increase stresses and lead to settlements in the clay beneath the existing bridge. If an earthen embankment was used, predicted bridge settlements ranged from 1.3 to 5.1 cm (½ to 2 in.), which were considered intolerable. The project was therefore designed using lightweight fill for portions of the approach embankments within 22.9 m (75 ft) of the existing bridge. The lightweight fill reduced stress increases in the clay, lowering predicted settlements of the existing bridge to tolerable limits, to approximately half the magnitudes for earth fill. Measured settlements of the two bridge abutments, during the 1½-year period between embankment placement and demolition of the bridge, were 0.16 cm (¾ in.) and 0.22 cm (1 in.), which are within the range expected for the lightweight fill.

The lightweight fill option was significantly less expensive than underpinning the existing bridge and lengthening the new bridge to provide greater distance between the approach fills and the existing structure.

SETTLEMENT PREVENTION AT EXISTING SEWER

A 2.0-m (6.5-ft)-diameter sewer crosses the existing and new bridge alignments between the west abutment and Pier 1. This 60-year-old cast-in-place concrete pipe founded in the loose silty alluvium is underlain by varved clay (Figure 2). Preload fill for construction of the bridge, adjacent pile driving, and new alignment of I-91 northbound required up to 6.1 m (20 ft) of fill over the sewer and would cause settlements in the varved clay and unacceptable movements in this old pipe.

The most severe settlement problem was solved by designing a pile-supported bridge to carry I-91 over the sewer pipe. Nevertheless, stress increases in the clay from the adjacent approach fills and the effects of pile driving were estimated to cause 2.5 to 5.1 cm (1 to 2 in.) of settlement beneath the pipe. To prevent pipe settlement, 1.5 m (5 ft) of alluvium from above the pipe was replaced with lightweight fill. This decreased the effective stress in the clay below the pipe by approximately 300 P (300 lb/ft^2) and counteracted settlement effects from the other sources. No significant pipe settlement was measured.

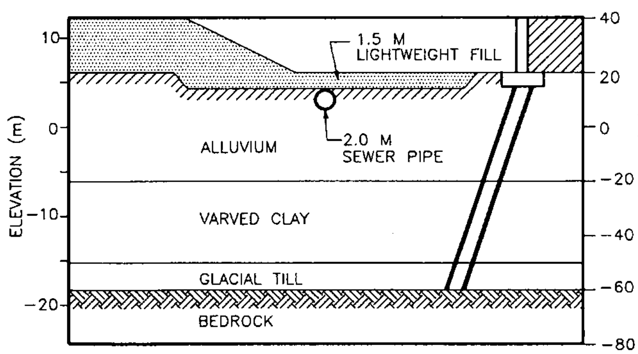

FIGURE 2 Lightweight fill above MDC sewer pipe.

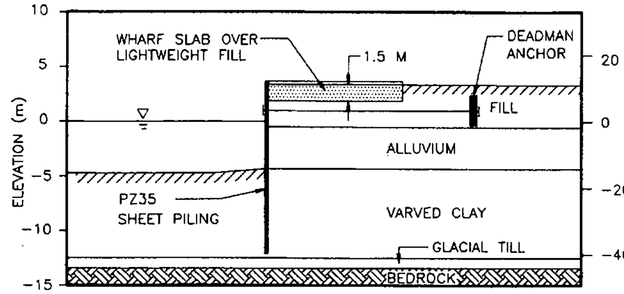

FIGURE 3 Lightweight fill placed to improve stability for wharf's sheet pile bulkhead.

WHARF STABILIZATION

The project included construction of a wharf and boat launch ramp along the west shore of the Connecticut River south of the Charter Oak Bridge. Lightweight fill was designed to provide stability for the wharf's anchored sheet pile bulkhead.

The bulkhead retains 7.6 m (25 ft) of soil above dredge level in the river (Figure 3). Stability analyses of circular failure surfaces indicated an unacceptably low factor of safety. As an alternative to anchoring a stiffer wall into underlying bedrock, a layer of lightweight fill was designed to reduce stresses in the weak varved clay and alluvium deposits and increase the factor of safety for overall slope stability to 1.25. The design called for replacing existing soil with a 1.5-m (5-ft) thickness of lightweight fill. The 0.2-m (8-in.)-thick reinforced concrete wharf slab was placed on a 0.3-m (12-in.)-thick layer of compacted gravel fill over the lightweight fill.

CLOSING

Design and construction of the Charter Oak Bridge and approaches over soft soils proved to be complex and challenging. Lightweight fill was an invaluable tool to increase slope stability and reduce settlements, both for facilitating the new construction and protecting sensitive existing structures.

REFERENCE

1. Smith, A. D. Design of the Charter Oak Bridge Embankment. *Proc., ASCE Specialty Conference on Stability and Performance of Slopes and Embankments*, 1992.