Use of Geosynthetics in the Design of Railroad Tracks

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An innovative approach was used for an Amtrak Northeast Corridor Improvement Project (NECIP) in Boston for track structure support to accommodate low-strength organic clay and high groundwater beneath the railroad tracks. The new track structure uses a combination of geomembranes and geotextiles to maintain groundwater at or near prevailing level to avoid settlement of adjoining structures and provide a dry, stable foundation support for the tracks. This innovative track support system cost only about 40 percent of a pile-supported concrete slab similar to that used in the section of track west of this project. Considerations that led to the combination of a conventional railroad track structure and geosynthetics are described.

Design of a 0.4-mi section of Northeast Corridor railroad tracks located in Boston, Massachusetts, required construction of three tracks on weak organic clays at about the same level as to 6 in. below the previous tracks. Special provision was made in the design to accommodate the effect of a high water table, which is generally between 1 and 3 ft below the ground surface. The project is located between Boston South Station and the Massachusetts Bay Transit Authority (MBTA) Southwest Corridor project. This segment of the Northeast Corridor will be heavily traveled, and the level of service per track projected for 1990 is 42 to 47 trains per day with a total tonnage range of from 13 to 18 million gross tons (MGTs). The project includes rebuilding track support for two adjacent Boston and Albany Railroad tracks. Construction of the track support system took place during 1985-1987.

The project site is shown in Figure 1. It is bounded on the north by the Massachusetts Turnpike and on the south by Herald Street. The Massachusetts Turnpike is founded on a reinforced concrete slab slightly above the level of the adjacent tracks extending the full length of the project. To limit settlement of the turnpike slab, the existing groundwater table is being maintained by limiting drainage beneath the turnpike concrete slab into the lower track area. Drainage of the track area is regulated by an overflow weir structure located at the outfall of the storm water drainage system. The areas north of the Massachusetts Turnpike and south of the project site are 15 to 20 ft above track level and are occupied by commercial buildings and streets.

On the south, Herald Street borders the project above a granite-faced gravity wall. The retaining wall is between 15 and 19 ft high. The gravity walls are supported on both timber piles and spread foundations on hard clay and are not particularly sensitive to groundwater level fluctuations.

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The MBTA in joint funding with the Federal Railroad Administration (FRA) is rebuilding about 5 mi of depressed rail and transit tracks known as the Southwest Corridor Project (SWCP), which interfaces with the west end of this project. The SWCP tracks in the areas overlying the soft organic clay are supported on reinforced concrete slab and steel H-piles driven to bedrock.

GEOLOGY OF THE AREA

The project lies within the Boston Basin, which contains a thick layer of fine-grained sediments deposited in late- to postglacial times. The basin was scoured in rock by glacial ice advancing from the northwest. During ice retreat, the sea level rose, inundating the basin, and Boston blue clay was laid down. Subsequently, during a late glacial period, the sea level dropped 50 to 70 ft and exposed the clay surface, producing weathering, desiccation, and erosion of the upper part of the clay. After the low-level stage, the water again rose to submerge low-lying areas of the basin within which soft marsh deposits formed.

HISTORY OF THE SITE

This project lies within an area that was once mostly covered by water, known as the Back Bay. At the time of the earliest settlement of Boston, a thin strip of land called the Boston Neck bridged the Back Bay between Beacon Hill and Roxbury, running at about the center of the project site (*1*). Nearly all of the project area was a salt marsh and was mostly under water at high tide. The colonial shoreline crossed the site in the vicinity of Washington Street. By 1814 filling had widened this area at the railroad alignment to between Shawmut and Harrison Avenues. By 1836 fill had been placed to slighly west of Tremont Street, and filling was completed at Albany Street by 1871. The Boston and Worcester Railroad was, in 1834, on an embankment through the site along the alignment of the existing Boston and Albany Railroad tracks. About 15 ft of fill was placed over the railroad alignment area for a number of years before the Boston and Worcester Railroad was constructed at the present lower grade. Test pits (*2*) have revealed that at least

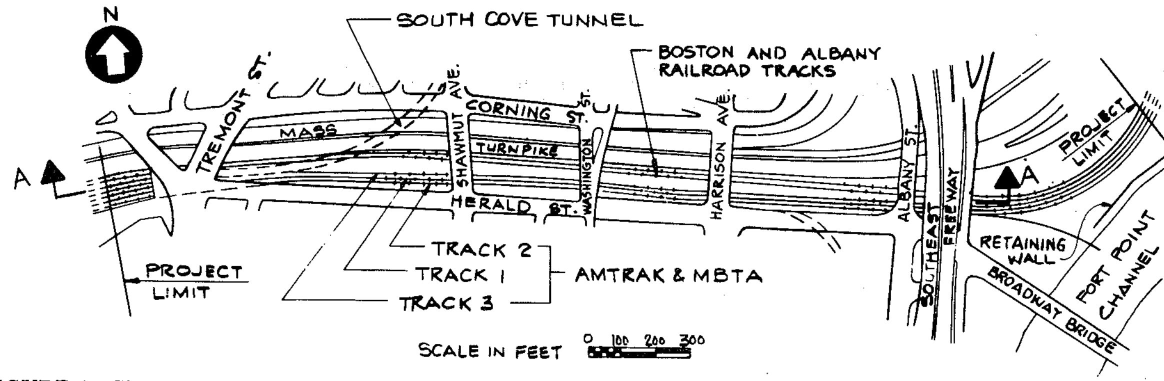

FIGURE 1 Site plan.

one of the NECIP tracks was once supported on timber piles. The track has been supported for the last 80 or more years on ballast over highly variable thicknesses and types of granular fill. In recent years, the tracks have experienced increasing misalignment and maintenance costs.

TOPOGRAPHY

Elevations used in this paper are based on the National Oceanic and Atmospheric Administration (NOAA) mean sea level datum. The existing track grade rises from Elevation -1.5 at the west interface with the SWCP, near Tremont Avenue, to Elevation +9.0 at the eastern end. Grades along the turnpike vary from Elevation -0.8 to +5.5. The area to the south of the project has grades of about Elevation +15.

EXISTING BRIDGES

There are six bridges within the limits of the project (*3*) that serve as roadway overpasses:

Bridge	*No.*
Tremont-Arlington Street	228.24
Shawmut Avenue	228.37
Washington Street	228.34
Harrison Avenue	228.41
Albany Street	228.51
Southeast Expressway	228.65

Pavement grade of the overpasses at the centerline of the tracks ranges between Elevations +19 and +25, except for the Southeast Expressway, which is about Elevation +45. In addition, two utility bridges are also located along the east side of the Shawmut and Harrison Avenue bridges.

SUBSURFACE CONDITIONS

The three distinct soil strata encountered in the project site (*1*, *2*) are shown in Figure 2. The three principal soil types are described from the surface downward in the following subsections.

Stratum F—Fill

A shallow layer of fill, ranging in thickness from 2 to 7 ft, covers the track area. The fill is made up of stone track ballast over a subballast of loose to compact coarse to fine sand and gravel with varying amounts of silts, ashes, brick, and wood.

Stratum O—Organic Clay

This stratum is up to 19 ft thick west of Tremont Avenue and east of Albany Street, but it pinches out east of Shawmut Avenue and east of Washington Street. The absence of organic soils in the middle of the project reflects the Boston Neck described earlier. This stratum consists of medium gray organic silty clay, trace shells, and fine sand. Natural moisture content varies between 28 and 59 percent, generally higher at Elevation -20, which indicates a thin seam of peat.

Stratum C—Boston Blue Clay

This layer is made up of stiff to medium green-gray silty clay. The surface of this deposit was generally stiffened by drying and oxidized to a green-brown or yellow color during a depressed sea level. The natural moisture content varies from 15 to 49 percent with desiccated clay having water contents of 30 percent or less.

SOIL PROPERTIES

The engineering properties of the various soil strata used in the design and analysis of the various alternatives are given in Table 1.

GROUNDWATER LEVEL

Groundwater levels in the project site are slightly affected by the open waters of the Charles River to the north and Fort Point Channel to the east. In general, the groundwater level within the trackbed sloped from Elevation -2.0 at the west end to about Elevation -1.0 at Washington Street, rising to Elevation +1.5 near the Southeast Expressway. The city of

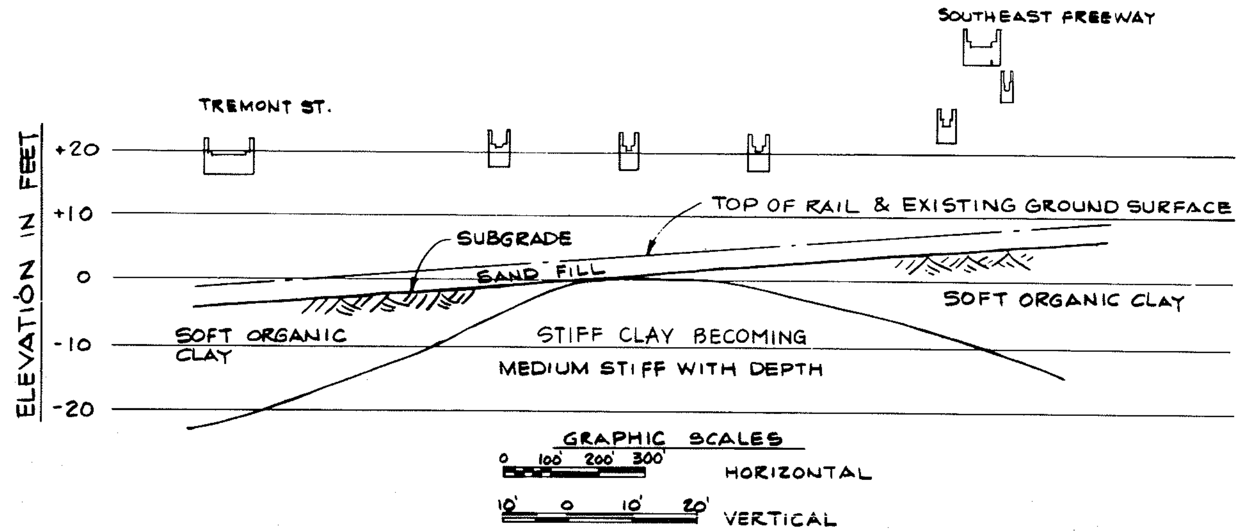

FIGURE 2 Geologic profile.

TABLE 1 ENGINEERING PROPERTIES OF SOILS

	Stratum		
Soil Property	F	C	O
Total weight (pcf)	115	—	—
Submerged weight (pcf)	55	60	40
Friction angle (degrees)	30	—	—
Shear strength (ksf)	—	2.0-3.0	0.6
Base friction factor (F)	0.45	—	—
Adhesion strength (psf)	—	750-1200	500
Bearing capacity (tsf)	2.5	2.0-3.0	0.6
Recompression index	—	.02	.06
Subgrade modulus (kcf)	—	120	50

Boston code requires that prevailing groundwater levels be unaffected by future developments to avoid settlement and damage to existing untreated wood piling caused by groundwater lowering.

Construction of the Massachusetts Turnpike just north of the site between 1962 and 1965 was done in a manner that maintained existing groundwater levels. The highway structural system was designed as a watertight section with a reinforced concrete base slab 2 to 3 ft thick founded on an impervious foundation with cantilever retaining walls along the north side. The subgrade was covered by polyvinyl plastic sheet, a 4-in. working mat, and a concrete structural slab with water stops. Before construction of the turnpike, the water level in the trackbed was allowed to rise to Elevation -1.0 before the drains became effective. This minimum water level is presently being regulated by a weir overflow structure located at the eastern limits of the turnpike.

DESIGN ALTERNATIVES

To select the most cost-effective type of trackbed, various conventional support structures were investigated. The designs for all alternatives were based on Cooper E-80 loads. Maximum deflection of the track under train loading was not to exceed 0.375 in. In addition, analysis of the tracks for E-60 loading was done to evaluate the response of a conventional ballasted track support system to presently planned loading. In the preliminary design analysis, use of a ballastless track support system was eliminated from further consideration. Unusually large differential settlement, due to the variable thickness of soft organic clay, would have made it difficult to maintain track gage tolerances.

The various types of track support systems investigated for this project are briefly described next.

Pile-Supported Concrete Slab

This scheme consisted of a 24-in. reinforced slab supported on steel or concrete piles more than 100 ft long driven to bedrock. Although this type of construction would have resulted in the least deformable track support and negligible differential settlement, the cost of this alternative was high compared with that of other options (Table 2). To reduce the cost of this alternative, low-capacity timber piles extending to underlying Boston blue clay were also considered. The cost for this option was less than for deep piles, but it was also found to be excessive.

Concrete Slab Supported on Shallow Soils

As a second step in the design analysis, track support by a concrete slab over the thick layers of organic clay and Boston blue clay was considered. This approach is similar to that used for the adjacent Massachusetts Turnpike. Trackbed response was analyzed by the ILLI-TRACK and ILLI-SLAB computer programs developed at the University of Illinois. The finite-element program for ILLI-SLAB employs a Winkler-type subgrade and can be used to study variable subgrade support and multiwheel loading at any position on the loaded surface. This model has been validated and

TABLE 2 COST COMPARISON OF DESIGN ALTERNATIVES

Alternative	Estimated Cost[a] ($ millions)	Cost/ft of Track ($)
Concrete slab supported on piles	12.5	800
Concrete slab on grade	8.5	550
Ballast section with geotextiles	4.8	310

[a]Costs include all drainage improvements and special treatment at ends of section and at some bridge abutments.

extensively used in various studies (*4-7*). Concrete slab thicknesses of 18, 24, and 30 in. were analyzed. The maximum deflections in all three slab thicknesses under E-60 and E-80 loading were less than the maximum track deflections of 0.25 and 0.375 in., respectively, recommended by the American Railway Engineering Association (AREA). The estimated maximum deflection and extreme tension and compression stress from bending moments for a 24-in.-thick unreinforced concrete slab over organic clay, for two tracks loaded simultaneously, were

	E-60	*E-80*
Maximum deflection (in.)	0.19	0.36
Maximum bending stress (psi)	165	194

Although bending stress and deflection of an 18-in.-thick concrete slab were less than the AREA allowable values, the subsoil information indicated that there may be localized pockets of organic clay that are more deformable than assumed. It was assumed that a 24-in.-thick concrete slab would have the necessary capacity to bridge the softer areas.

A fundamental assumption in the ILLI-SLAB analysis is that the slab cross section is uncracked and flexural stresses are resisted exclusively by concrete. This requirement is satisfied by maintaining flexural tension stress less than the modulus of rupture of the concrete. This condition was met by the 24-in.-thick concrete slab under E-80 loadings for a 4,000-psi concrete with a modulus of rupture of 474 psi. The computed flexural tension stress of 194 psi, for E-80 loadings, yielded a safety factor of 2.4. Because the flexural stress was within the maximum allowable, steel reinforcement was not required. However, longitudinal steel equal to about 0.2 percent of the concrete area was included for crack control. Transverse steel equal to about one-fourth of the longitudinal steel was provided.

As shown in Figure 2, the groundwater level through parts of the project site is near the surface of the trackbed and is required to be maintained during and after construction of the project. It was proposed to do this by adding low walls at the sides of the concrete slab and water stops in both longitudinal and transverse joints so that a watertight "boat" section would be formed.

Transition from Pile-Supported Construction

Tracks in the adjoining SWCP section are supported on a continuously reinforced concrete slab founded on steel H-piles driven to bedrock. The SWCP section extends further below the groundwater table; water stops are used between joints in the slab and abutting concrete retaining walls to form a long boat section to limit drawdown. Within this project, 132-lb rail supported on concrete ties and a 24-in. layer of ballast over the concrete slab are being provided. Because the concrete boat section will be supported on piles, track deflection through this section will be negligible. Direct connection of the track slab-on-grade with the nonyielding boat slab would have resulted in high rail stresses and fatigue at the interface.

To provide a transition between the two projects, a 50-ft discrete segment of reinforced concrete slab was introduced. The west end of the slab is supported on six 100-ton steel piles and the east end is founded directly on the subgrade. This transition concept is similar to the one used in approach slabs for highway bridges. The length of the transition was chosen so that the leading trucks of the shortest train cars will have crossed the transition slab before the trailing trucks begin to ride on this segment. This would accomplish partial loading of the transition slab, resulting in a further reduction of track deflection between the SWCP piled structure and the slab-on-grade. The piled west end was provided with elastomeric material with keeper bars between the pile cap and the concrete slab so that rotational movement of the transition slab is possible.

As shown on Figure 2, the 1,130-ft section between Shawmut Avenue and Harrison Avenue Bridge is directly underlain by stiff yellow clay. The ILLI-TRACK analysis showed that 36-in. conventionally ballasted track construction on stiff clay would be comparable to slab-on-grade on soft organic materials. Because the groundwater level in this area was high, cut-off walls on both sides of the ballasted track section were specified to protect the track support structure from inflowing groundwater. Steel sheet pile or slurry cut-off walls were proposed to penetrate at least 15 ft below the bottom of the excavations.

Geosynthetic Ballast Mat over Shallow Soils

The cost of the concrete slab-on-grade track support was estimated at $8.5 million for a 3,095-ft length containing five tracks. It was therefore decided to explore the use of conventional ballasted track support with suitable geosynthetics for added stability, improved drainage, and groundwater level control. A typical cross section is shown in Figures 3 and 4. Because the tracks through the project have

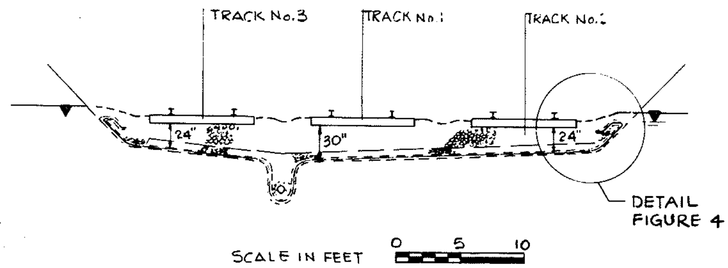

FIGURE 3 Typical cross section.

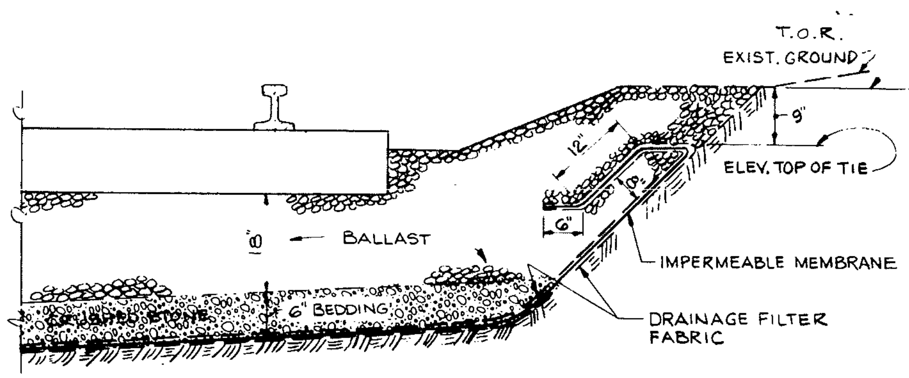

FIGURE 4 Detail.

been directly supported on the existing subsoils in the past, some improvement of the soil strength and stiffness over the years should have resulted. In the design and construction of the new track structure an attempt was made to preserve the in situ properties of subsoils that had been subjected to train live loads in the past. Excavation for installation of new ballast was planned to minimize disturbance of the existing subgrades.

Analysis of Deflection Under Train Loading

The analysis of rail deflection was based on a minimum depth of 24 in. of ballast below the bottom of ties. Estimated live loads were based on AREA criteria for E-80 and E-60 train loads on embankment fills. The following vertical stress and corresponding deflections were estimated in the organic clay for a 24-in.-thick ballast:

	E-80	*E-60*
Live and dead load (ksf)	1.90	1.20
Estimated deflection (in.)	0.455	0.300

These track deflections are about 15 percent higher for the E-60 loading and 18 percent higher for E-80 loading than recommended for conventional ballasted tracks. The actual ballast thickness specified is generally greater than the 24 in. assumed in the estimate, ranging between 30 in. in the middle of the center track to a minimum of 24 in. under the outer rails of the outside tracks. The increased ballast thickness will further reduce the estimated deflection.

This scheme has a large cost advantage over the other two schemes (Table 2). Although a ballast-supported track will result in somewhat higher track deflection than other alternatives, that scheme will meet the functional requirements at much lower cost. Ballast strain hardening due to repeated dynamic train loadings in conjunction with periodic track resurfacing during the initial phases of service should further improve track performance.

Transition Conditions

The critical transition in this alternative is also at the interface with the SWCP section on the west end. The concrete slab transition used with this scheme is similar to that previously described for the slab-on-grade alternative. It is shown in Figure 5. However, the first 80 ft of the ballast section east of the transition will be reinforced with a single layer of Tensar geogrid to minimize localized higher track deflections due to the change in track support. A second layer spans the transition for 30 ft. The location of the geogrid is shown in Figure 6. The use of geogrid reinforcement is an experimental attempt to provide a stiffer subgrade modulus in this transition under dynamic train loading.

The Tensar grid structures are produced using a manufacturing technique that orients the long chain molecules within the polymers and increases the tensile strength of the polymer. The geogrid used was Tensar SS2 that has the physical and mechanical properties (*8*) given in Table 3.

The geogrid is specified to be installed in the ballast at a depth of 18 in. below the ties so that it is below the 12- to 14-in. undercutting depth of ballast cleaning machines. In essence, the transition from the SWCP will be accomplished in two stages: initially by a 50-ft section of concrete slab supported at the west end on 100-ton piles and then by an additional 80-ft segment of ballast section reinforced with geogrids.

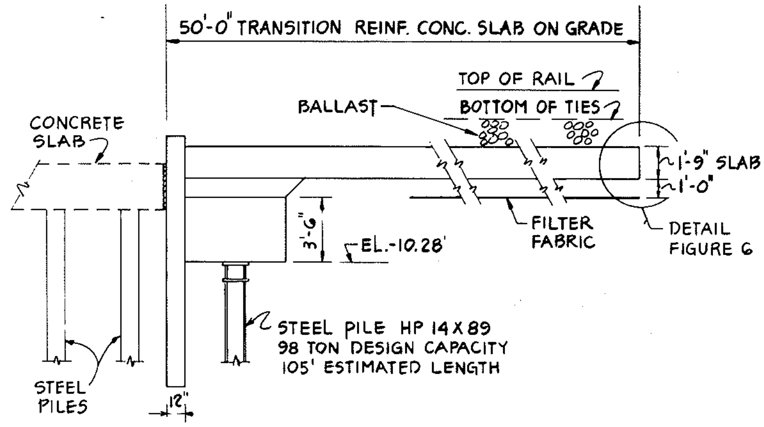

FIGURE 5 Concrete slab transition.

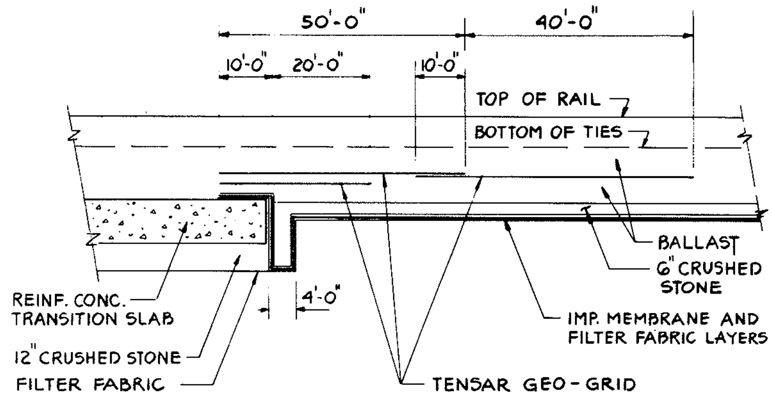

FIGURE 6 Concrete slab and ballast transition.

TABLE 3 PHYSICAL AND MECHANICAL PROPERTIES OF TENSAR SS2 GEOGRID

Roll width (ft)	9.8
Roll length (ft)	164
Weight (lb)	102
Aperture size (in.)	1.0[a]/1.3[b]
Thickness of rib (in.)	0.04
Thickness of junction (in.)	0.15
Tensile strength (lb/ft) at	
2% strain	590/1015
5% strain	950/1690
Ultimate	1170/2100
Initial tangent modulus (kip/ft)	30.6/68.1

[a]Machine direction.
[b]Cross machine direction.

Dissipation of Static and Dynamic Pore Pressure

The proposed bottom of ballast of this on-grade track support will be below the existing groundwater level between Elevations -6 and 0 over most of the 2,425-ft length. The city of Boston code requires that the groundwater level not be lowered below Elevation -0.65. To keep the ballast dry and maintain the surrounding groundwater at prevailing levels, an impermeable geomembrane will be installed beneath the full length of the track structure. The ends of the impermeable geomembrane are extended above the water table on both sides to form a flexible boat section shown in Figures 3 and 4.

Because the dynamic load applications will tend to compress the water-saturated subsoils, the associated excess water pressures need to be rapidly dissipated to maintain the effective stresses. The underlying organic soil and Boston blue clay have an estimated permeability of 2×10^{-6} ft/min. Assuming an excess water head of 2 ft and a flow path of one-half of trackbed width or 25 ft, the required in-plane transmissivity and cross-plane permittivity are estimated as follows:

1. Estimate maximum flow into the geotextile under train loading using a 20-ft-thick clay layer and Darcy's formula:

$$q = kiA \tag{1}$$

where

q = flow rate (ft^3/min/ft of track),
k = permeability coefficient (ft/min),
i = hydraulic gradient (ft/ft), and
A = area of fabric.

Average excess hydraulic head at middepth of clay layer from E-80 train live load = $(1{,}900 - 2 \times 150)/(2 \times 62.4) = 12.8$ ft and

$$q = 2 \times 10^{-6} \times (12.8/20) \times 25 \times 1$$
$$= 3.2 \times 10^{-5} \text{ ft}^3/\text{min/ft}$$

2. Calculate required in-plane fabric transmissivity (*9*) for static loading:

$$q = K_p i_p W t \quad (2)$$

$$\theta = K_p t \quad (3)$$

where

K_p = permeability coefficient in the plane of the fabric (ft/min),
i_p = hydraulic gradient in the plane of the fabric (ft/ft),
W = width of fabric (ft),
t = thickness of fabric (ft), and
θ = transmissivity (ft^2/min).
i_p = 2 ft (maximum)/25 = 0.08

and

$$\theta = q/i_p W$$
$$= 3.2 \times 10^{-5}/0.08 \times 1 = 4 \times 10^{-4} \text{ ft}^3/\text{min/ft} \quad (4)$$

3. Factor of safety = θ (fabric)/θ (required)

$$= 8 \times 10^{-3}/4 \times 10^{-4} = 20$$

The required in-plane transmissivity for dynamic train loading was estimated to be 10 times the static value due to fabric compression and an average 12.8-ft increase in excess water head within the soil. This is equivalent to the full AREA dynamic E-80 engine loading distributed over the trackbed as a short-term pore pressure increase.

4. Calculate required cross-plane fabric permittivity (*10*):

$$\psi = k/t = q/(h \times A)$$
$$q = KiA = 2 \times 10^{-6} \times 12.8/20 = 1.28 \times 10^{-6} \text{ ft}^3/\text{min}/\text{ft}^2 \times 60 \text{ sec/in.} = 7.7 \times 10^{-5} \text{ ft}^3/\text{sec/ft}^2$$

and

$$\psi = 7.7 \times 1^{-5}/0.2 \times 1 \times 1) = 3.8 \times 10^{-4} \text{ min}^{-1}/\text{ft}^2$$

5. Check against actual permittivity of the available geotextiles:

k = 6 in./sec
t = 0.21 in.
ψ = $k/t \times 28.6$ sec^{-1}/ft^2

Factor of safety = $28.6/3.8 \times 10^{-4} = 7.5 \times 10^4$

The fabric selected is estimated to have a gradient ratio of less than 3.0 for these subgrade soils to limit clogging and has an initial permittivity well above that required. Hoechst Trevira 1155 spunbound polyester was used. It has the following properties (*11*):

Property	*Value*
Thickness unloaded (in.)	0.21
Weight (oz/yd^2)	16
Puncture strength (lb)	225
Burst strength (psi)	750
Effective opening size (microns)	100-140
In-plane transmissivity (ft^2/min) at normal loading of 1,900 psf	8×10^{-3} ft^3/min/ft
Cross-plane permittivity (min^{-1})	28.6 sec^{-1}/ft^2

DESIGN DETAILS

Track Support System

The track support system is made up of 133-lb RE rails supported on 7-in. × 9-in. × 8-ft 6-in. timber crossties spaced at 19-in. centers. The crossties are supported on ballast ranging from 24 in. under the outer tracks to a maximum of 30 in. between Tracks 1 and 3. An impervious membrane of nylon-reinforced rubber, 36 mils in thickness, is being used over the subgrade soils to prevent seepage of groundwater directly into the ballast. The impervious geomembrane consists of a minimum of three plies of black Hypalon and two plies of nylon reinforcement. The number of seams to be field installed is being minimized by planning to expose sections of the subgrade to match the factory-available lengths of the impervious liners. The nylon reinforcing fabric (scrim) is 10 by 10, 1000-denier, industrial grade.

The track ballast being used on the NECIP projects is in accordance with AREA Specification 24, which is generally coarse graded with a maximum size of 3-1/2 in. The impermeable membrane was protected from damage by covering it with a layer of 16-oz/yd^2 filter fabric before a 6-in. layer of crushed stone with a maximum size of 1/2 in. was placed. The 16-oz/yd^2 drainage filter fabric layer discussed in the previous section is being provided beneath the geomembrane to permit drainage of groundwater higher than the top of ties by spillage into the ballast drainage system as shown on Figure 4. The drainage fabric will also dissipate excess hydrostatic pressure, which may be generated from dynamic train loadings. The in-plane transmissivity of the drainage filter fabric under dead and live loading of 1,900 psf is sufficient to provide effective dissipation of the pore pressures (*12*). Because the subsoils are cohesive clays, it was not necessary to provide a bedding sand layer between the filter fabric and the subsoils. Disturbance of subsoils will be minimized by not permitting the operation of excavation equipment on the subgrade. The extent of excavation each day is limited to the distance that can be covered with new construction within 24 hr.

Site Drainage

The site was previously drained by a system of surface inlets and a closed drain line located near the centerline of Track 3.

The drain line ranged between 24 and 52 in. in size. The old drainage lines terminated in a reservoir from which water was pumped into the tidal basin. The old drainage system operated poorly and much of it will be affected by the new scheme.

Drainage of the ballast section from within the envelope of the impervious geomembrane will be through 12-in. perforated collector drains in a depressed part of the ballast section. The collector drains are fed at intervals into a main storm drain, which is located below the impervious geomembrane. The storm drain will direct all of the rainfall runoff from within the impermeable ballasted boat section to a new pump station near Washington Avenue. Drainage water is pumped to Fort Point Channel via an 18-in. force main.

Drainage pipe penetrations through the impermeable membrane are heat sealed using a boot of Hypalon between the hole and the pipe to prevent leakage into the envelope. The impermeable membrane extends up the side of the boat section to the level of the top of the railroad ties as shown in Figure 4. Examination of water levels and quantities of flow before and during construction indicates that groundwater will flow into the ballasted section only occasionally when water levels rise above this level.

MONITORING AND INSTRUMENTATION

Five piezometers have been installed to monitor static water levels in the subgrade soils during and after construction. Three vibrating-wire piezometers (Irad gauge model PWS-25) were installed directly beneath the impermeable membrane to measure the rate of dissipation of pore water pressure beneath the fabric during dynamic train loading. Two additional vibrating-wire piezometers were installed 4 ft deeper to provide control readings for comparison with those of the shallow piezometers.

Control points were established on the track structure to permit measurement of permanent track deformation. Deformation of track under train loading will also be observed by photographing scales mounted on the track structure with an intermediate target as a control elevation. Rapid-sequence photography will permit measurement of deflection while a train is passing.

Track monitoring during 1986 and 1987 will provide information to confirm design assumptions.

CONCLUSIONS

Use of newly developed methods for estimating track deflections under train loading and use of layers of geosynthetics in a relatively new way have permitted construction of track structures over low-strength organic clays at a much lower cost than the more conventional pile-supported and concrete slab-on-grade alternatives. This system will maintain the present groundwater level. Special provisions were made for a smooth transition between the adjacent pile-supported slab and the geosynthetic envelope section. The transition included experimental use of a geogrid reinforcement within the ballast section. The performance of this section under train loading has been observed since construction. Preliminary results indicate satisfactory performance.

ACKNOWLEDGMENTS

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