EPS STRUCTURES INNOVATIONS ON CENTRAL ARTERY/TUNNEL (CA/T) PROJECT

Hany L. Riad, Ph.D., P.E. [(1)]

Abstract

The use of Expanded Polystyrene (EPS) in block-molded form on the Central Artery/Tunnel (CA/T) Project included the first-time implementation of several innovative solutions in the construction of EPS embankment structures.

This paper addresses the use of EPS as both a lightweight fill material for highway and bridge embankments as well as a substrate for Exterior Insulation Finish System (EIFS) on several CA/T EPS embankment structures. The innovative aspects associated with the use of EPS on the CA/T Project include: implementation of newly developed NCHRP research into Project Standards, first time application of AASHTO based guidelines into the design, development of material/product specifications as well as formulation of innovative solutions to several technical challenges. These challenges centered on relatively high vertical sided and slender EPS embankment structures, founded over soft soils, subjected to AASHTO defined highway loading including periodic flooding and seismic loads. The CA/T EPS embankment structures have been constructed under tight construction schedules and traffic constraints in a dense urban environment.

1.0 INTRODUCTION

The use of EPS on the C09C2 construction contract of CA/T Project at the I-90/I-93 Southbay Interchange represents the second largest application, to date, of EPS as lightweight fill material in the United States. This construction contract consists primarily of viaducts, bridges, transition structures, embankments as well as boat and tunnel sections. This paper focuses on eight transition structures within C09C2 contract located on I-93 and connecting to I-90 and other roadways south of downtown Boston and South Station. The lengths of these transition structures range from 23 to 122 m (75 to 400 ft), with heights to 7 m (23 ft). Widths range from 8 to 24 m (25 to 75 ft).

2.0 BACKGROUND

Prior to implementing EPS as an alternative design solution, the original design of these transition structures consisted of three structural systems: Precast Concrete Bridges (PCB), Elevated Slab-on-Piles/drilled shafts (SOP), and Fill over Slab-On-Piles/drilled shafts (FSOP).

1 Professional Associate/Principal Engineer, Parsons Brinckerhoff, Boston, MA 02111; riad@pbworld.com

All original PCB and SOP designs used exterior architectural precast concrete curtain walls supported on drilled shafts on both sides. All FSOP designs included the use of cast-in-place (CIP) structural reinforced concrete walls to contain regular fill placed over the foundation slab as well as serving for architectural purposes. For each of these transition structures, the original design intended the use of drilled shafts as the primary means of foundation support.

2.1 Original Design Concepts

Schematic cross-sections of the three design concepts for the transition structures originally planned for use on the C09C2 contract are shown in Figures 1 through 3.

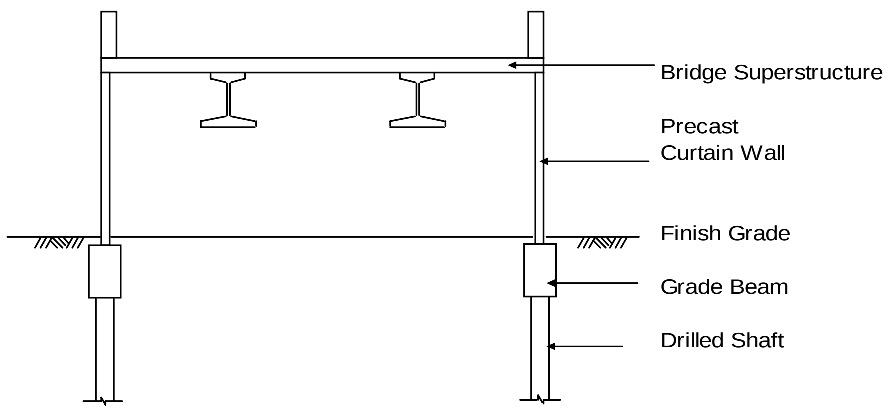

Figure 1 - Precast Concrete Bridge (PCB) Design Concept

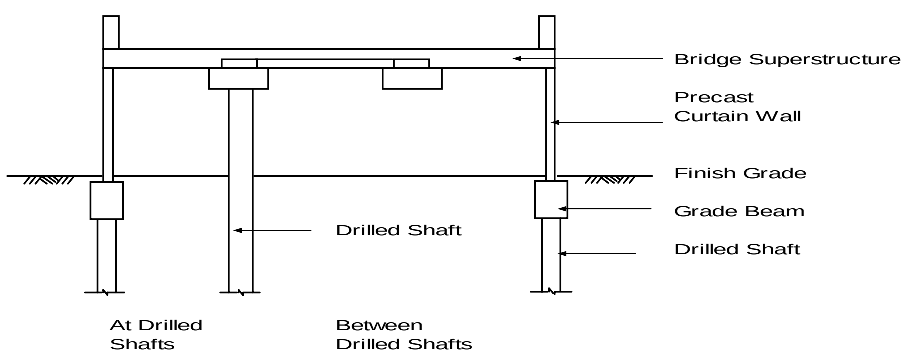

Figure 2 - Elevated Slab-on-Piles (SOP) Design Concept

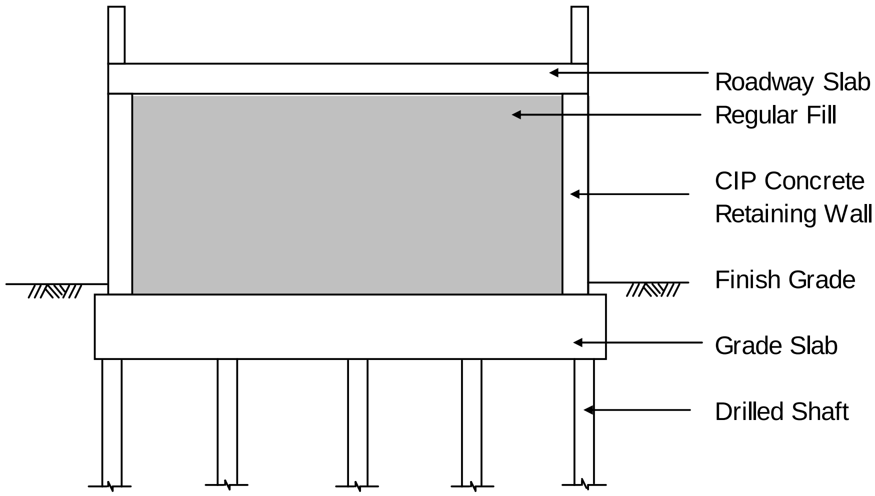

Figure 3 - Fill over Slab-on-Piles (FSOP) Design Concept

The order of magnitude of the applied dead loads resulting from superstructure girders, slabs, diaphragms, abutments and piers as well as the exterior curtain walls and supporting grade beams attributed to these three concepts was substantial. As a result, a large number and aggregate length of drilled shafts was required to support the applied dead loads.

Consequently, the objective was aimed at reducing the number of drilled shafts or, perhaps eliminating their presence altogether in some structures entirely. Achieving this objective would be extremely beneficial to the Project from the standpoint of cost savings and advancing schedule by reducing construction complexity.

3.0 REDESIGN ALTERNATIVES

Review of the three original design schemes for the transition structures concluded that the primary purpose of the numerous drilled shafts was to transfer the loads into the underlying bedrock through bypassing the upper compressible soil strata. This would, in turn, eliminate any settlement that would have occurred due to primary consolidation of the compressible soils if loaded beyond their current vertical effective overburden stresses.

Analytical evaluation of the settlement for a particular structure or curtain wall constructed to bear directly upon these compressible soils concluded that the resulting settlements were unacceptable both in their magnitude and variation.

The use of soil preloading or other ground-improvement alternative was not considered viable due to schedule constraints, traffic and construction staging requirements. Thus it became clear that for the final design alternative, there had to be no increase in the effective net stresses on the existing soils. On the other hand, soil removal or in-situ treatment of the fill and organic strata were also considered impractical. This is due to their substantial combined thickness (approximately 12 m (40 ft)) together with the limitations of schedule and site constraints. Ultimately, these factors led to the logical conclusion that directed final design towards using lightweight-fill materials.

The use of lightweight fill materials and associated load reduction is typically attractive in situations where the mass of the structure contributes predominantly to the applied loads, e.g. under gravity or seismic loading conditions. Lightweight materials offered the significant advantage of reducing long-term operation and maintenance costs attributed to mitigation of settlement damage.

3.1 Expanded Polystyrene (EPS) Structures

The alternative chosen for final design for eight of the twelve candidate transitions structures considered for redesign on the CA/T Project, was to construct embankments using a lightweight fill material consisting of Expanded Polystyrene (EPS) in block-molded form.

The use of EPS lightweight fill embankment structures as re-design solution offered superior advantages in weight, performance characteristics and schedule over other design alternatives, including other lightweight fill materials, for the following reasons:

- Despite an extraordinarily low density that is typically in the range of 15 to 30 kg/m^3 (1 to 2 lb/ft^3), which is approximately only 1 to 2% the density of soil, EPS as a material has compressive strength and stiffness properties comparable to soil and is thus capable of supporting the applicable AASHTO highway design loads.

- The significant reduction in material density compared to a traditional soil embankment results in reduced stresses due to gravity loads on the underlying soil subgrade as well as a significant reduction in seismic inertia loads on the embankment itself. Accordingly, the EPS embankments on C09C2 contract did not require any collateral ground improvement such as preloading and artificial drainage, which translated into cost and schedule savings.

- With an effective, in-place Poisson's ratio close to zero as demonstrated by observation of full-scale structures, lateral pressures on abutments and other vertical walls adjacent to an EPS fill are reduced to almost zero.

- EPS blocks offered additional schedule savings due to their ease of handling and assembly, inherent free-standing and self-supporting capability which resulted-in stability during erection, in addition to allowing construction under all weather conditions.

- Altogether, EPS embankment structures offered substantial cost savings and schedule advantages over the precast concrete bridges and associated deep foundations that would have been required to support them.

It noteworthy to highlight that EPS was pursued on CA/T Project at the suggestion of the Federal Highway Administration (FHWA). EPS technology is supported and promoted by FHWA who consider it to be an important component of its successful Ground Improvement Workshop (Demonstration Project 116) that ultimately became a National Highway Institute course.

4.0 INNOVATIVE SPECTS OF THE DESIGN

Although the use of EPS in block-molded form as lightweight fill for highway embankments has been in existence for over 30 years, the application of the EPS technology on the CA/T Project's C09C2 construction contract still allowed for the use of a number of innovations. These innovations are the primary focus of this paper and are detailed in the sections below.

4.1 Project Design Documents

Overview

The preliminary design phase for the EPS redesign alternative was performed by the Joint Venture of Bechtel/Parsons Brinckerhoff (B/PB), Management Consultant to the Massachusetts Turnpike Authority (MTA), the CA/T owner. Engineering representatives of the MTA participated extensively in this process and input was also provided by Dr. John S. Horvath, P.E. who served as a Consultant on EPS Technology to B/PB and MTA.

This process resulted in a preliminary selection of a redesign alternative for each transition structure. Final design of each was then performed by the Project's Section Design Consultant (SDC), the joint venture of Berger, Lochner, Stone and Webster (BLSW). Given the fact that the use of EPS as a permanent construction material was a new technology for the CA/T Project and considering the accelerated redesign schedule, both B/PB and the MTA in conjunction with their Consultant had ongoing participation with significant input during the final-design phase.

In particular, B/PB developed a unique, comprehensive, Project and contract specific package of design guidelines that consisted of:

- Project Design Criteria manual
- Detailed numerical design examples
- Directive Drawings depicting design directives and typical EPS details
- EPS Project Specifications addressing all applicable product, material, fabrication and construction requirements
- EIFS Project Specification

It is of interest to note that this package of technical material was developed with significant input from the results of the U.S. National Cooperative Highway Research Program (NCHRP) Project No. 24-11, which is currently known as NCHRP Report 529. As such, the C09C2 contract marked the first project use of this NCHRP research into practice.

4.2 Analysis and Design under AASHTO Loading

As best as could be determined, the CA/T Project Design Criteria marked the first time implementation of AASHTO Standard Specifications for Highway Bridges (16th Edition) into the design of an EPS highway embankment structure. AASHTO gravity and lateral loads including seismic were integrated with NCHRP research results into the final design.

The C09C2 EPS embankments were designed using the Allowable Stress Design (ASD) method and service loads, for the following AASHTO defined gravity and lateral loads:

- Dead loads (DL)
- Live loads (LL)
- Buoyancy forces (B)
- Wind loads (W) and Wind on live load (WL)
- Centrifugal forces (CF) resulting from live loads
- Seismic loads (E)

Gravity Normal Stresses

The above loads were combined using the corresponding AASHTO group-load combinations to produce the design cases of loading to which the structure may be subjected. As is typical, under gravity loading the uppermost layers of EPS blocks had the largest vertical stresses due to combined vehicle live loads and dead weight of the pavement system as shown in Figure 4.

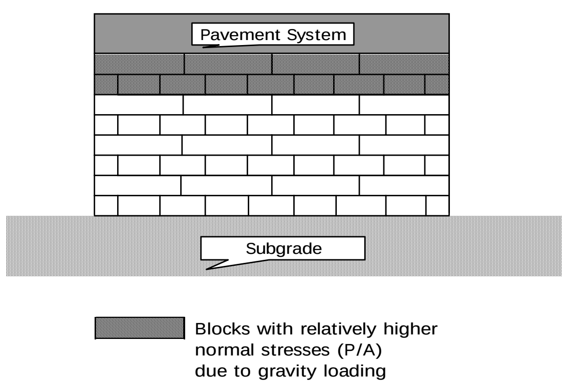

Figure 4 - Compressive Normal Stresses in EPS Blocks
due to Gravity Loads

As is now well known, this significantly impacts EPS design since there is a direct correlation between normal stresses applied to EPS and required EPS properties (including, but not limited to, density).

4.3 Secondary Lightweight Material

Conceptually, the objective of a lightweight fill redesign alternative is to minimize the aforementioned dead loads together with the transfer of all or part of these loads from being founded on drilled shafts to being supported directly on the existing soil subgrade. With the redefined supporting conditions, such lightweight fill redesign alternative could not result in any net increase in the vertical effective stresses on the existing soils. To achieve this goal, any increase in stress from the proposed structures (which was obviously unavoidable) had to be compensated by removing an equivalent mass of soil and replacing it with a lightweight-fill material. The process of removing existing soil and replace it with EPS produced two major design issues.

First, the deeper the excavation of existing soils, the deeper the bottom elevation of the EPS blocks would be, approaching and ultimately extending below the normal ground-water table. This condition resulted in increasingly larger buoyant forces on the embankment structure, which in turn significantly reduced the factor of safety against uplift. The second issue was that the deeper the bottom elevation of EPS blocks, the greater the volume of soil that would have to be removed. This in turn meant diminished savings with respect to cost and schedule or possibly even an increase in cost or schedule.

The objective of the re-design was to transform each of the three original structure types (PCB, SOP and FSOP) into a simple stand-alone embankment constructed primarily of EPS blocks underlying the roadway system that includes deck slab, traffic barriers, utilities, supporting fill and load distribution slab. However, it was obvious based on initial evaluation that the issues of buoyant forces and potentially excessive excavation would limit the number of candidate structures where the EPS alternative could be implemented.

In an effort to change this undesirable outcome, two initiatives were undertaken. The first was to reduce the load imposed by the curtain walls. The second was to reduce the buoyancy force on the EPS blocks by using a secondary, porous lightweight-fill material as an intermediate layer between the top of the existing soils and bottom of the EPS.

The broad requirements for the secondary lightweight-fill material were as follows:

- It shall contribute to the overall goal of replacing in-situ soils with a lower-density material that satisfies the criteria of no net increase in the vertical effective stresses on the existing soil subgrade.
- It shall not present the same buoyancy characteristics of EPS so that the required Safety Factors (SF) against uplift could be satisfied without excessive removal of existing soils.

Lightweight expanded clay/shale aggregate PIARC [1997] has been implemented to mitigate settlements and buoyancy issues. This material is significantly denser than EPS, however, its inherent open texture and local availability favored its use as the material of choice as a secondary lightweight-fill material on the CA/T EPS embankment structures.

The use of a secondary lightweight fill material enabled the implementation of a modified version of the preliminary re-design objective by including a layer of lightweight expanded shale underlying a stand-alone embankment constructed primarily of EPS blocks supporting the roadway / pavement system. A schematic cross-section of a typical EPS embankment structure of the CA/T Project is shown in Figure 5.

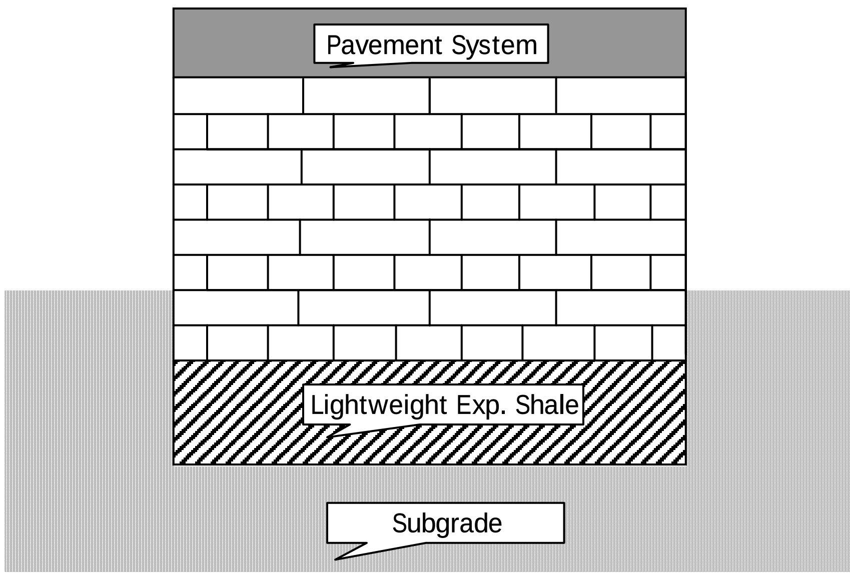

Figure 5 – Schematic Cross-Section of a Typical
CA/T EPS Embankment Structure

4.4 Seismic Analysis and Design

Seismic loading turned out to govern the design of all C09C2 EPS structures. Historically, two different behavioral modes have been considered for the behavior of an EPS highway embankment under seismic loading:

- Rigid-body sliding of a wedge of EPS blocks in the longitudinal direction of the embankment when confined behind some type of earth-retaining structure such as a bridge abutment. Conceptually, this is identical to the Mononobe-Okabe type of model used for soil.

- Flexible, horizontal sway of the entire embankment in either its longitudinal or transverse direction (the latter is usually more critical). This is modeled as a classical dynamic single-degree-of-freedom (SDOF) system and visualized as an elastic cantilever beam as shown in Figure 6. Details can be found in Horvath [1995] and Stark et al. [2000, 2002].

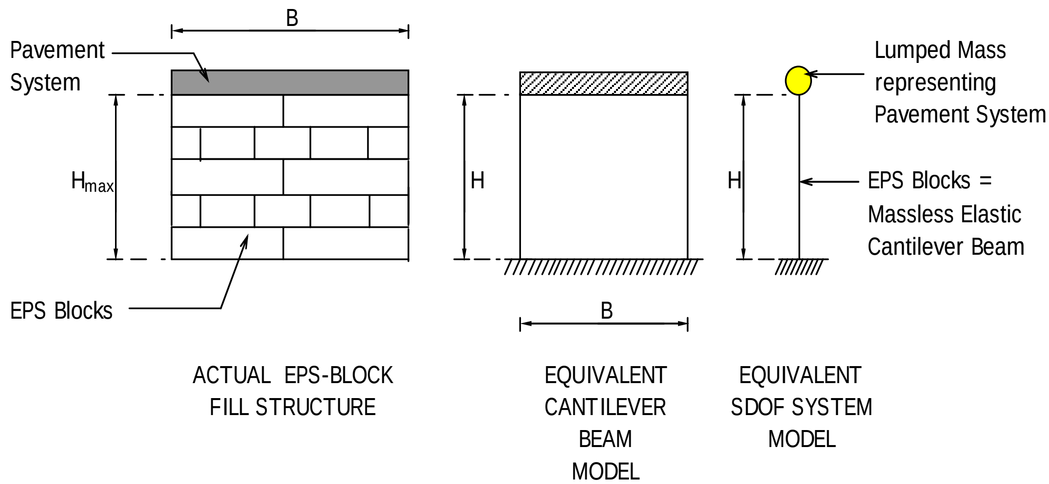

Figure 6 - Flexible Dynamic Analysis Model for EPS

Seismic Rocking

As the redesign process evolved, the CA/T design team recognized the potential for a mode of seismic behavior that is referred to hereinafter as "seismic rocking". This is defined as rigid-body rotation of the entire embankment in its shorter (transverse) direction due to the moment created by the relatively concentrated, elevated mass of the pavement system. With reference to Figure 6, this rotation would occur about an axis perpendicular to the plane of the figure.

While seismic rocking can occur with any EPS embankment, it appeared to be critical for the C09C2 EPS structures because of their relatively slender transverse cross-section. This behavior was confirmed by a coincidental review of literature [Nishi et al. 1998, Hotta et al. 1998] that was obtained at the time the C09C2 redesign work was beginning in early 2001. Seismic rocking had apparently been observed for the slender EPS structures reported in that literature but the mode itself was not recognized or identified as such. Detailed discussion of seismic rocking and other seismic design issues relevant to the CA/T – EPS structures are found in Riad, et al. [2004].

The practical relevance and importance of seismic rocking is that the lowermost/outermost portions of the EPS blocks can be subjected to relatively large vertical normal stress increases due to the rocking motion. These stresses are due to what is referred to as the 'M-c-on-I' (Mc/I) effect. Note that these dynamic stresses must be added to the vertical normal stresses due to gravity loads.

The combined effect of gravity and seismic stresses on the distribution of normal stresses is shown in Figure 7. Strong support for this combined stress distribution came from a careful review of the outcome of the dynamic shake-table test results by Nishi et al. [1998] and Hotta et al. [1998]. When the EPS blocks were removed at the end of their tests, crushing of the EPS blocks was found in exactly those areas where the stresses as shown qualitatively in Figure 7 were the largest in magnitude as determined analytically.

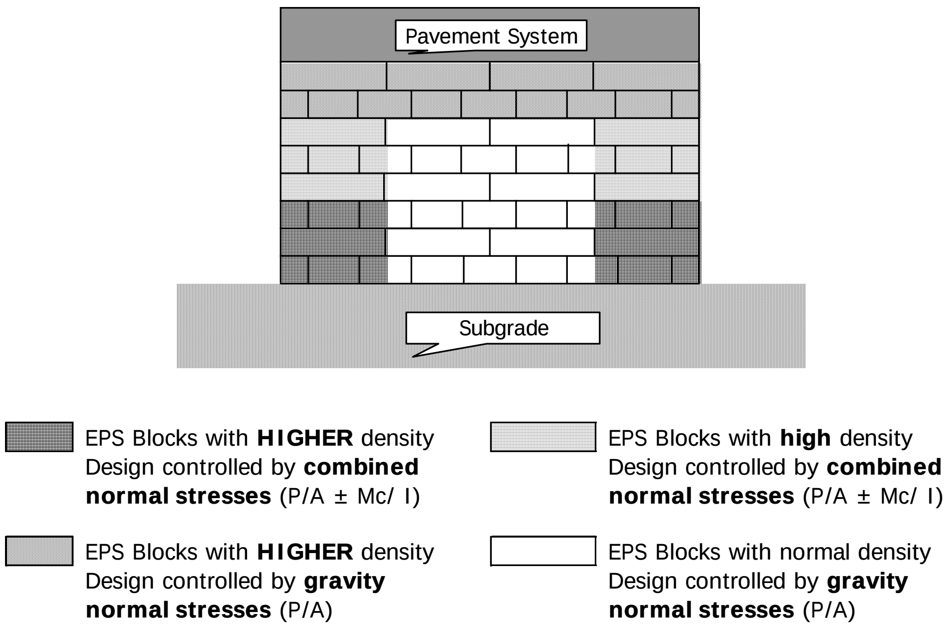

Figure 7 - Relative Compressive Normal Stresses in EPS Blocks due to Combined Seismic and Gravity Loads

Considering the stress distribution identified for the combined gravity and seismic loading conditions of Figure 7, it was decided to use a single type or grade of EPS blocks for all C09C2 embankments in the interest of satisfying both technical need and construction simplicity. Specifically, blocks with a minimum nominal density of 32 kg/m^3 (2.0 lb/ft^3) were specified.

It should be noted however that the overturning moment at the base of an embankment from the above-described Mc/I effect also may also affect the external stability of that embankment in various ways:

- Rigid-body overturning of the entire embankment
- Partial embankment liftoff or separation along horizontal EPS-block joints due to vertical tensile stresses, and
- Bearing-capacity failure due to the reduced effective area of the embankment bearing on the underlying subgrade.

Each of these constitutes a behavioral mode that required explicit consideration but did not, however, control the final design.

4.5 EPS Project Specification

As stated earlier, the CA/T - EPS Project Specification was based primarily on the findings of NCHRP Research Project No. 24-11, currently known as NCHRP Report 529 "Guideline and Recommended Standard for Geofoam Applications in Highway Embankments". Appendix C, titled "Provisional Standard (AASHTO Format)" has been of particular relevance to the CA/T – EPS Project Specification. At the initial stages of EPS re-design, the CA/T Project was provided access to the Phase I (interim) report Stark et al. [2000] for use in the preliminary design.

The provisional standard for EPS Geofoam of the NCHRP report is arguably the most revolutionary and practice oriented part of the report, as it constitutes the first known material, product and construction standard for EPS lightweight fills to be developed in the United States. Most notably, this standard is characterized by the following:

- It presents, in an AASHTO format, a comprehensive standard that addresses all EPS material properties such as Elastic Limit stress and Initial Tangent Young's Modulus that are now recognized as fundamental parameters for designing a monolithic EPS structure in small-strain applications such as lightweight fills.

- Moreover, it introduces an entirely new nomenclature for EPS that is both intuitive and useful in design. The basic nomenclature is 'EPS xx' where 'xx' is the lower-bound elastic limit stress in kilopascals. This immediately identifies the maximum long-term compressive stress that would normally be applied to the EPS. By multiplying 'xx' by 100, this gives a lower-bound estimate of the initial tangent Young's modulus of the EPS, which allows material strains to be calculated.

With this information at hand, the CA/T Project design team developed contract specifications that were tailored to specific requirements of the C09C2 Contract. As such, the CA/T Specifications introduced some enhancements to the original standard, in response to specific project needs, particularly in the areas of Contractor’s Submittals, Manufacturer Quality Control (MQC), Manufacturer Quality Assurance (MQA), block sampling, verification and testing, block handling, storage and protection and placement.

The CA/T EPS Project Specification is believed to be the first use of what will hopefully be adopted as a "future" AASHTO Standard for EPS as lightweight fill material in transportation structures applications.

4.6 EIFS Side Covering

Although an assemblage of EPS blocks with vertical sides is structurally self-stable (assuming proper block layout and other well-established design and construction details are followed), the permanently exposed sides of an EPS fill must be covered to prevent long-term surficial degradation, provide protection for the EPS blocks against fire, prevent incidental damage of the EPS blocks as well as to provide an appropriate architectural finish.

The effort to reduce the curtain-wall loads first focused on using lightweight precast concrete panels. This alternative, while viable, remained ineffective in achieving the desired level of overall improvement. Thus precast concrete curtain wall panels, which have become very popular in recent years both in the United States and elsewhere for vertical-sided EPS fills, were subsequently abandoned altogether. Efforts were concentrated on significantly lighter alternatives that would eliminate the need for supporting deep foundations.

The primary side covering alternative that was pursued by CA/T – B/PB Design Engineers involved what is formally defined as "Exterior Insulation and Finishing System" (EIFS) but is perhaps more-commonly known by the colloquial terms "synthetic stucco". EIFS is a well-proven technology that has been used worldwide for decades for the exterior walls of both commercial and residential buildings of all types and sizes.

However, as best as could be determined, EIFS had never been used as the permanent side panels for an EPS roadway fill on a transportation project. Such an application, however, was actually suggested at one of the earliest symposia on EPS in 1994 [Horvath 1995].

EIFS consists of a mesh-reinforced, two-part coating system field applied over a mounting EPS 40 board adhered to the EPS 100 blocks substrate as shown in Figure 8. The final appearance of the EIFS finish coating can be varied widely for architectural purposes. In the case of the C09C2 EPS structures, EIFS was specified with an architectural finish to create an aesthetic appearance matching that of the precast concrete curtain walls utilized on adjoining transition structures and ramps in the South Bay Interchange area of the Project.

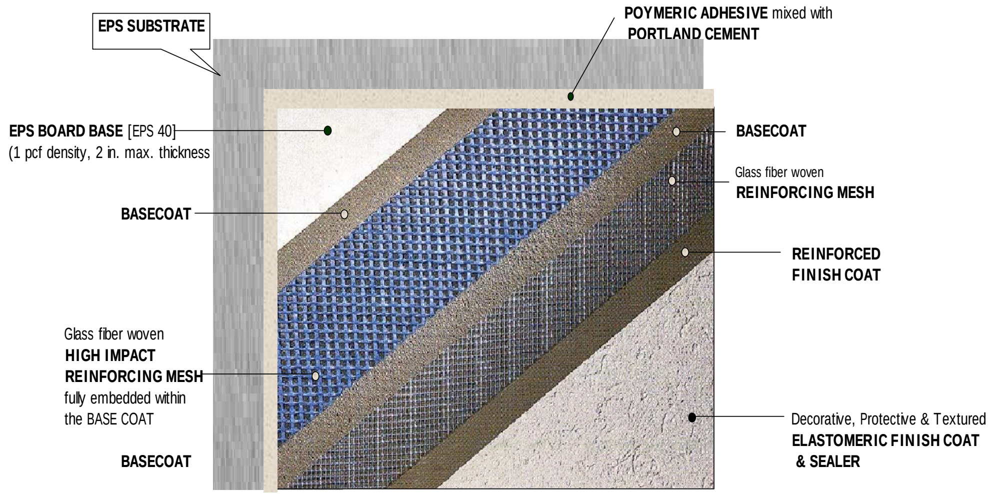

Figure 8 - Typical EIFS Cross-Section with an EPS Substrate

In addition to eliminating the precast concrete curtain walls and their deep foundations, the use of EIFS panels accomplished a number of objectives:

- EIFS achieves uniformity in appearance with other Precast concrete curtain walls of adjacent CA/T transition structures
- Final product weights approx. 1.5 psf
- The significantly lighter EIFS panels would greatly reduce applied loads on the existing subgrade, thereby raising the bottom elevation of the EPS
- EIFS with an EPS mounting board is compatible with the EPS blocks used to create the fill from the standpoint of dead loads, stiffness, deformations and other mechanical and material properties. This would minimize the potential for differential movement between the two elements
- It simplified design, construction and maintenance through elimination of the pinned connections tying the exterior panels and the load-distribution slab located at the top of the EPS blocks
- EIFS could be applied at any time after the EPS blocks are in place thereby providing a more-flexible schedule that would allow structures to open sooner to traffic

The use of EIFS as an exterior side cover, proved to be both cost-effective and advantageous to the schedule as compared to other side covering alternatives such as Shotcrete.

4.7 EIFS Fire Performance and Testing

The use of EIFS on an EPS blocks substrate offered a unique technical challenge with regard to fire performance. To date, all ASTM Standards addressing fire rating of EIFS only address its use with standard exterior wall assemblies, for example; a stud wall system with gypsum sheathing, in the substrate. As a result, an EIFS system mounted on an EPS block assembly did not match existing ASTM Standards. Though EPS block material contains a flame retardant satisfying Oxygen Index requirements of ASTM C 578, the fire resistance rating of an EPS / EIFS assembly remains yet undetermined.

A fire resistance rating is necessary is to determine the ability of a structural system to withstand exposure to a standard fire. Moreover, under the anticipated fire exposure for the assembly, the structure has to maintain its capability to carry the intended design loads.

While highway traffic will not travel directly adjacent to any of the CA/T EPS structures, interstate highway traffic will travel over such structures. Accordingly, any CA/T EPS / EIFS structure assembly must satisfy a 30 minutes fire rating requirement established by Boston Fire Department (BFD) before public traffic could be allowed to travel on any such structure. This requirement has been determined based on exposure of the structure to either of two levels of fire; a petroleum fire resulting from a fuel spill on the roadway above and falling on the assembly or a traffic accident involving a vehicle catching fire under similar exposure conditions.

Fire tests were thus determined to be necessary to assess the performance of the CA/T EPS / EIFS assembly under exposure to aforementioned two fire levels. The following performance characteristics were of critical importance:

- Ease of ignition of the assembly
- Vertical and horizontal flame spread
- Extent of structural damage to EPS
- Durability concerns

The CA/T Project solicited the services of Koffel Associates (KA), as Fire Consultants to establish fire testing test regimen, engineer and perform fire tests on a full scale mock-up assembly.

Engineers from both B/PB and KA worked closely on all aspects of the fire design criteria, fire testing, design and construction of the full scale mock-up that was constructed and eventually tested at the facilities of Omega Point Labs, in San Antonio, Texas late in 2003.

The Mock-up consisted of two EPS/EIFS wall assemblies 6 ft. thick, 20 ft. wide by 20 ft. high each, constructed using the same materials and details in conformance with the Project design drawings and approved submittals. The two EPS/EIFS walls were separated by a steel studded drywall partition 25 ft. wide and 25 ft. high. The first wall was subjected to the thermal insult of approximately 100 gallons of diesel fuel pool fire applied for a duration of 30 minutes while the second wall was subjected to stacks of wooden pallets providing a continuous fire source of approximately 4 to 6 Mw. for also a duration of 30 minutes. These two fires simulate the two fire exposure levels established by the BFD fire performance criteria previously noted.

Results of the fire tests concluded the following:

- EIFS provides significant protection for EPS
- Size of both fires is manageable at 30 minutes
- Structural damage to EPS substrate is limited and not adverse to the structural integrity or safety of EPS Embankment Structure
- Both Materials satisfied 30 minutes fire resistance requirement established by Boston Fire Department (BFD)

CA/T - EIFS / EPS Design has been accepted and approved by BFD, thus allowing the CA/T EPS structures to carry highway traffic.

4.8 Temporary Permanent Construction

A unique condition dictated by traffic staging, Project and construction schedules presented itself on one of the C09C2 EPS structures, Ramp KK. To allow for traffic heading from I-93 South to travel to I-90 West on the Massachusetts Turnpike; a temporary EPS ramp, known then as Temp Ramp KK, has been constructed to occupy nearly the same general alignment as the permanent Ramp KK. As this temporary ramp is intended to carry interstate highway traffic, its design had to satisfy all AASHTO highway geometry, civil and structural requirements. Moreover, an appropriate roadway surface, drainage and necessary safety barriers had all been provided. Cross-sections of Ramp KK / Temp Ramp KK at several stations along the alignments are shown in Figure 9.

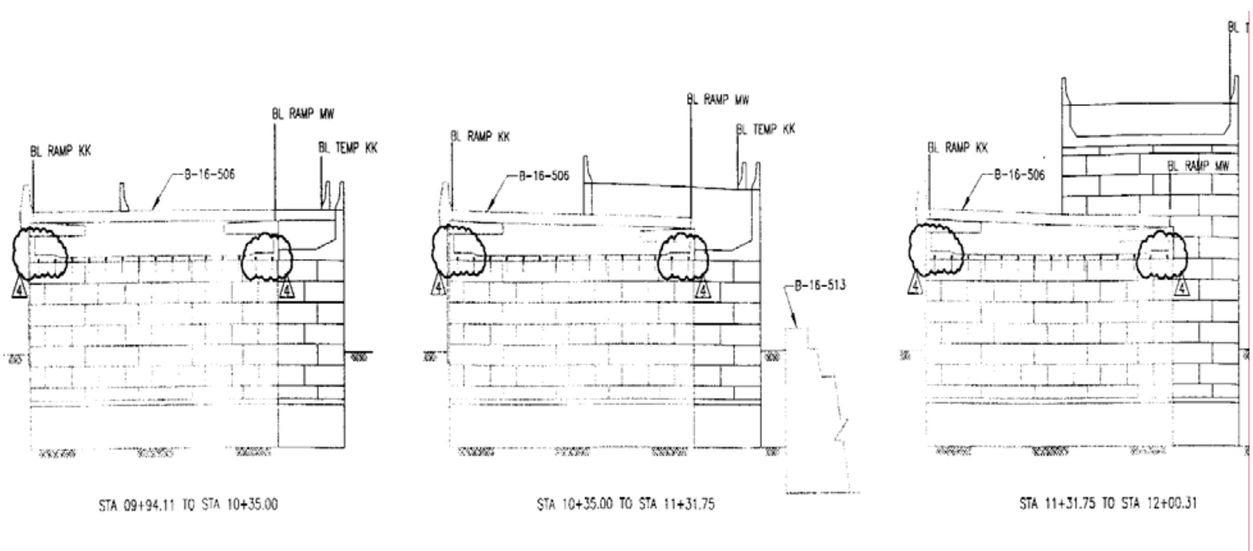

Figure 9 – Temporary / Permanent Ramp KK

Since this temporary ramp was scheduled to remain in service for more than one year, analysis and design of the temporary EPS blocks including block stability, block and joint details at the interface, construction sequencing and demolition of the temporary segment of blocks have all been tailored so as not to adversely affect the design and serviceability of the permanent ramp in the final condition, including installation of EIFS on the exposed interface surface of the EPS blocks.

The use of a temporary EPS ramp sharing nearly the same footprint with a permanent EPS ramp, as implemented on the CA/T Project, is believed to be the first ever implemented on an EPS transportation structure.

4.9 Special EPS Fill Applications

On three of the CA/T EPS Structures, however, alternative design solutions have been implemented for the exterior cover system. These alternative solutions consisted mainly of:

- Cast-In-Place (CIP) reinforced concrete walls as shown in Figure 10, acting as a diaphragm curtain wall all around the perimeter of a triangular shaped structure, encapsulating EPS blocks acting as an infill lightweight material.

Figure 10 – CIP Concrete Diaphragm Curtain Wall Solution

This solution was limited to one structure only, Ramp SSCON/X, where the introduction of EPS as an alternative lightweight fill material replacing regular fill, reduced approximately 40 drilled shafts in the mat foundation out of almost 60 drilled shafts as required by the original design. This application translated to a significant cost and schedule savings to the Project overall.

- Shotcrete applied to EPS substrate as an exterior covering system on two CA/T ramps (KK and CC) dictated by Project wide schedules to support I-93 NB interim opening to traffic in Spring 2003. Shotcrete was an alternative to EIFS in protecting EPS blocks while fire testing protocols were under development.

However, with the state of knowledge available at present, EIFS would present itself as a superior design alternative to both, a CIP wall solution or a Shotcrete exterior cover.

5.0 CONCLUSION

The innovative solutions presented herein are not limited in their applicability to the C09C2 contract or the conditions encountered on the CA/T Project exclusively. Therefore, it is anticipated that each of these innovations will find potential application on other projects both in the United States and worldwide.

EPS, lightweight expanded-shale aggregate, EIFS and shotcrete are, individually, well-established construction technologies. However, their synergistic use on the transition embankment structures of Boston's CA/T Project Contract C09C2 contract involved several innovative procedures and design details that will hopefully be useful on other projects.

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