Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 05-R28	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Field Study of Integral Backwall with Elastic Inclusion		5. Report Date April 2005
		6. Performing Organization Code
7. Author(s) Edward J. Hoppe, Ph.D., P.E.		8. Performing Organization Report No. VTRC 05-R28
9. Performing Organization and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 54168
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation FHWA 1401 E. Broad Street P.O. Box 10249 Richmond, VA 23219 Richmond, VA 23240		13. Type of Report and Period Covered Final August 1999–January 2005
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Jointless construction is considered an effective design option to reduce bridge maintenance costs and resist seismic loads. Although these attributes make the integral bridge an increasingly popular choice, soil-structure interaction issues unique to this type of design remain unresolved. Of particular concern is the excessive settlement of approach embankments, resulting from the repetitive, thermally induced cyclic movements of the superstructure. In many cases, rectifying this condition can be expensive because the integral bridge approach slab (if provided) cannot be overlaid with pavement.

To address this soil-structure interaction problem, the Virginia Department of Transportation conducted a study designed to test the feasibility of using elastic inclusion at the integral backwall. The design was completed in mid-1997, and the bridge was opened to traffic in October 1999. The bridge was constructed with elasticized expanded polystyrene (EPS) attached to the backwall. The structure has been monitored continuously for 5 years.

Significantly attenuated lateral earth pressures have been recorded at the backwall, and the settlement of the approach fill has been tolerable. Field data indicate that the elasticized EPS layer has been functioning effectively in allowing the superstructure to interact with the adjoining select backfill material. The use of elasticized EPS in conjunction with a well-compacted granular backfill offers a cost-effective way of minimizing settlements at bridge approaches.

17 Key Words Integral bridge, jointless bridge, integral backwall, semi-integral, elasticized EPS, elastic inclusion, bridge approach, approach slab.	18. Distribution Statement No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 36	22. Price

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FINAL REPORT

FIELD STUDY OF INTEGRAL BACKWALL WITH ELASTIC INCLUSION

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ABSTRACT

Jointless construction is considered an effective design option to reduce bridge maintenance costs and resist seismic loads.   Although these attributes make the integral bridge an increasingly popular choice, soil-structure interaction issues unique to this type of design remain unresolved. Of particular concern is the excessive settlement of approach embankments, resulting from the repetitive, thermally induced cyclic movements of the superstructure. In many cases, rectifying this condition can be expensive because the integral bridge approach slab (if provided) cannot be overlaid with pavement.

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FINAL REPORT

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INTRODUCTION

Jointless construction is considered an effective design option to reduce bridge maintenance costs. It is also regarded as being well suited to resist seismic loads.[1]   Although these attributes make the integral bridge an increasingly popular choice, soil-structure interaction issues unique to this type of design remain unresolved. Of particular concern is the excessive settlement of approach embankments, resulting from the repetitive, thermally induced cyclic movements of the superstructure. In many cases, rectifying this condition can be fairly expensive because the integral bridge approach slab (if provided) cannot be overlaid with pavement.

To address this soil-structure interaction problem, the Virginia Department of Transportation (VDOT) conducted a study designed to test the feasibility of using elastic inclusion at the integral backwall. The design was completed in mid-1997, and the bridge was opened to traffic in October 1999. The structure had been monitored continuously for 5 years.

PURPOSE AND SCOPE

The objective of this study was to test the concept of an elastic inclusion, in this case, in the form of elasticized expanded polystyrene (EPS), serving as an interface between a rigid structure and a stiff backfill material. The elastic inclusion is intended to accommodate thermally induced lateral movement of the superstructure with the main purpose of reducing the approach fill settlement. In addition, the role of the elastic inclusion is to reduce earth pressures acting on the structure. Long-term field monitoring included automated measurements of earth pressures acting on the backwall and the resulting strains exerted on steel girders. The thickness of the EPS layer was also measured periodically to determine if the material creeps over time.

METHODOLOGY

Description of Bridge

The project involved a replacement bridge on Route 60 over the Jackson River in Alleghany County, Virginia, as shown in Figure 1. The integral backwall (semi-integral) bridge is 100 m (331 ft) long and 16.6 m (54.5 ft) wide (overall), with three-span continuous steel plate girders and no skew. Fixed bearings are provided over two piers, and expansion bearings are
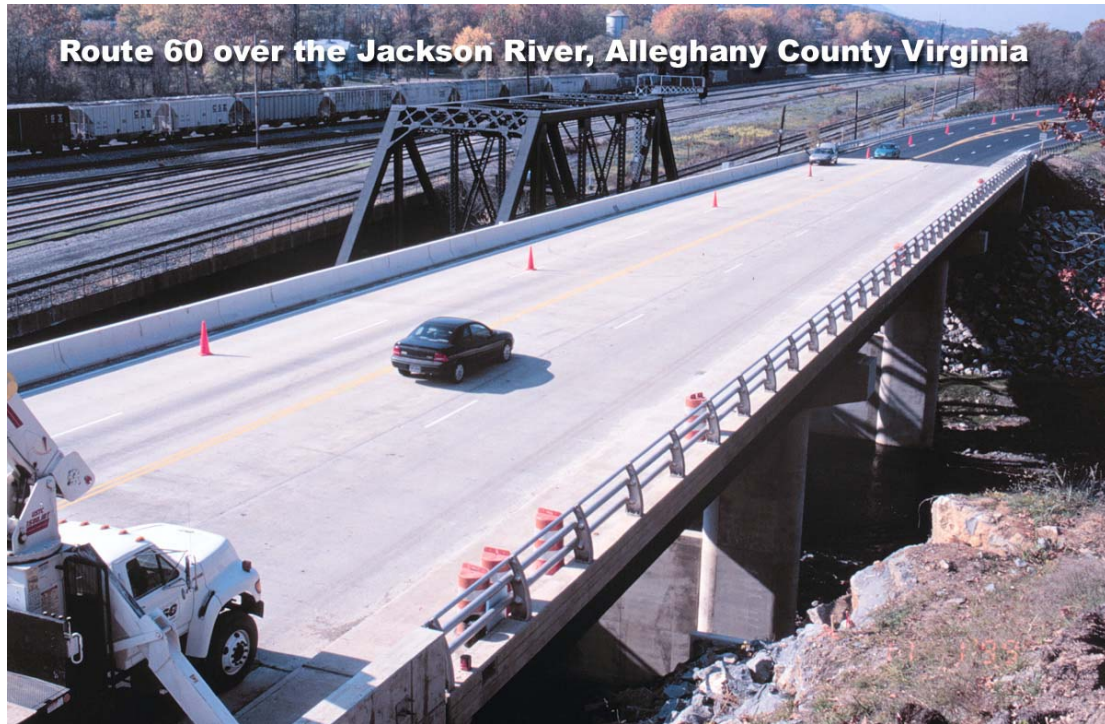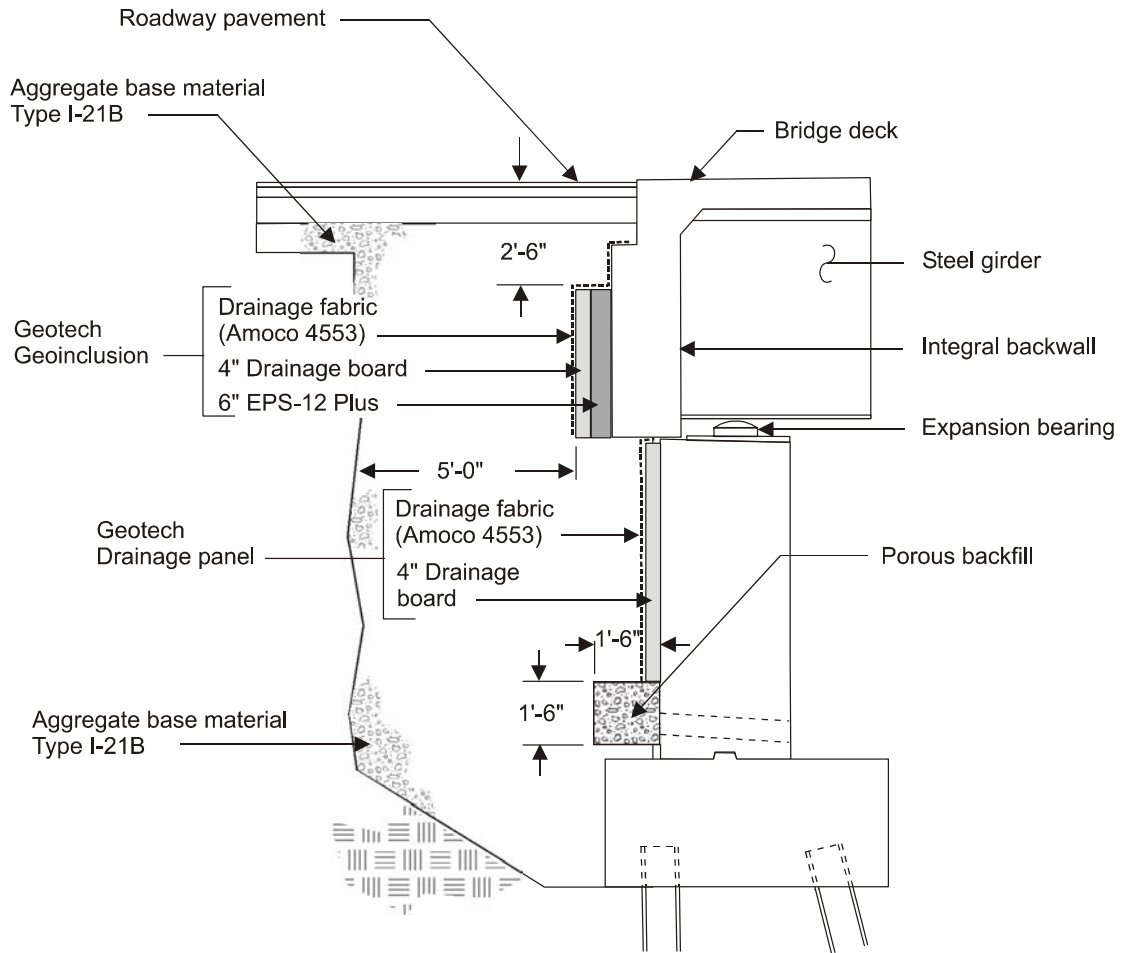
Figure 1. Integral Backwall Bridge

installed at abutments. There are no approach slabs constructed at the bridge. The average daily traffic is 12,771 vehicles with 7 percent trucks (2002 traffic data).
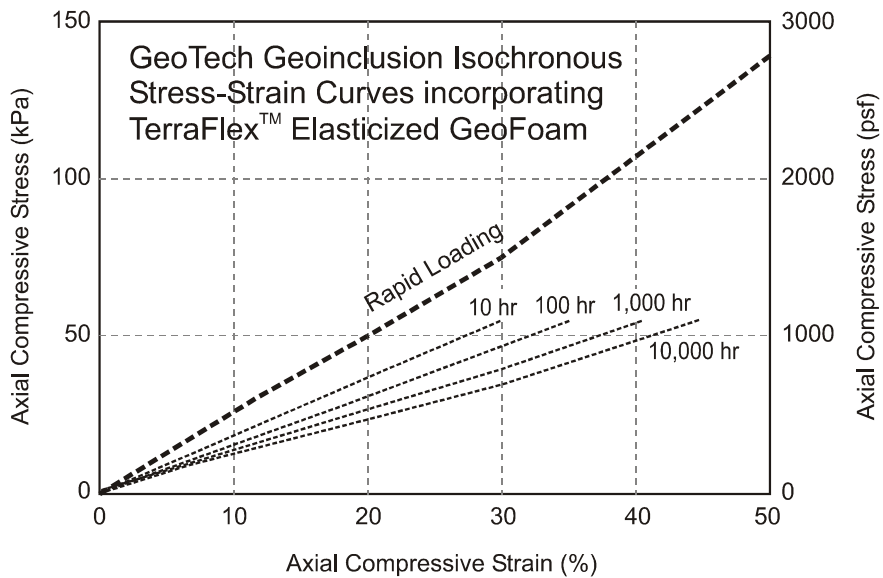
One bridge abutment was supported on steel piles (HP 10 x 42) driven to bedrock. The underlying soil is approximately 10 m (33 ft) of clay and silty sand fill with N-values ranging between 5 and 13, underlain by 3 m (10 ft) of clayey sand natural soil with an N of 50, and limestone bedrock. The other abutment was cast directly on bedrock.

The experimental detail involves a layer of elasticized EPS 0.25 m (10 in) thick placed on the back of integral backwall to absorb a limited range of movement without adversely impacting the adjoining embankment fill. The EPS material terminates at 0.76 m (2.5 ft) below grade, as shown in Figure 2. This distance was selected arbitrarily to allow space for placement of one earth pressure sensor to measure backfill stress acting directly on the backwall. Two other pressure sensors were installed at the backwall, behind the EPS layer. A separation geotextile was placed on the EPS layer to prevent damage from the adjoining granular backfill material. Elastic drainage board was also installed at the back of the shelf abutment, below the integral backwall.

The elastic inclusion was composed of a layer of glued polystyrene porous drainage material 0.10 m (4 in) thick, laminated with a layer of elasticized polystyrene block 0.15 mm (6 in) thick. According to the manufacturer, the stress-strain behavior of both layers is essentially identical. The material cost was quoted at $21.53/m^2 ($2.00/ft^2) in 1997. Material properties, as provided by the manufacturer, are shown in Figure 3.

Roadway pavement

Aggregate base material
Type I-21B

Bridge deck

2'-6"

Steel girder

Geotech
Geoinclusion

Drainage fabric
(Amoco 4553)

4" Drainage board

6" EPS-12 Plus

Integral backwall

Expansion bearing

5'-0"

Geotech
Drainage panel

Drainage fabric
(Amoco 4553)

4" Drainage
board

Porous backfill

1'-6"

Aggregate base material
Type I-21B

1'-6"

Figure 2. Abutment Cross Section

GeoTech Geoinclusion Isochronous
Stress-Strain Curves incorporating
TerraFlex™ Elasticized GeoFoam

Rapid Loading

10 hr   100 hr   1,000 hr

10,000 hr

Axial Compressive Stress (kPa)

Axial Compressive Stress (psf)

Axial Compressive Strain (%)

Figure 3. Elasticized EPS Properties (reprinted with permission of GeoTech Systems Corporation).

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Figure 4 shows the elastic inclusion, covered with geotextile fabric, installed at the bridge backwall. VDOT Type I-21B well-graded aggregate backfill material was used at the abutment. It had a grain size distribution as shown in Table 1. Granular backfill was compacted in lifts of approximately 0.20 m (8 in) each, with a hand-operated compactor used in the direct proximity to the backwall.

Figure 4. Elasticized EPS at the Backwall

Table 1. Grain Size Distribution of Backfill Material–VDOT Type I-21B

% Finer than:

| 50.8 mm	2 in	100.0%
25.4	1 in	92.5
19.05	3/4 in	81.0
9.525	3/8 in	57.7
4.76	No. 4	40.6
2.00	No. 10	24.5
0.42	No. 40	10.5
0.074	No. 200	5.9

Instrumentation

Electronic instrumentation included earth pressure cells installed at the backwall, strain gages attached to girder flanges, linear displacement transducers measuring girder movement

relative to the anchor bolt, and tiltmeters recording the shelf abutment rotation. Earth pressure cells and strain gages were of the vibrating-wire type for long-term stability. All sensors were interfaced with Campbell Scientific CR-10X dataloggers, sampling every hour. Figure 5 shows the locations of earth pressure cells installed at the integral backwall. These cells were positioned at 0.63 m (2.08 ft), 1.12 m (3.67 ft), and 1.60 m (5.25 ft) below grade and at a 6.3-m (20.6-ft) horizontal distance from the wingwall face. The uppermost cell (sensor 1) was in direct contact with the backfill material. The remaining cells (sensors 2 and 3) were placed behind the EPS layer. All pressure cells were recessed in the backwall, with the sensing surface flush with the backwall surface.

A simple telltale gage was installed to measure the thickness of the elastic inclusion in service. This gage consisted of a 200 by 200 by 2 mm (8 by 8 by 0.09 in) aluminum plate attached to the face of EPS, with a connecting stainless steel threaded rod of 5 mm (3/16 in) diameter, protruding through the opening in the backwall, as shown in Figure 6. The gage was located at approximately the same depth as the earth pressure sensor 3, but with a small horizontal offset of 0.45 m (18 in). Periodic measurements of the length of the protruding rod (distance x) indicated the magnitude of EPS compression. These manual measurements were typically conducted during the hottest and coldest times of the year to reveal the full range of EPS working strains and to detect signs of the material creep. All ambient air temperatures were recorded under the deck, in the proximity of the backwall. These temperatures were typically more moderate (cooler in the summer and warmer in the winter by about 8 to 10 degrees) than were topside readings.
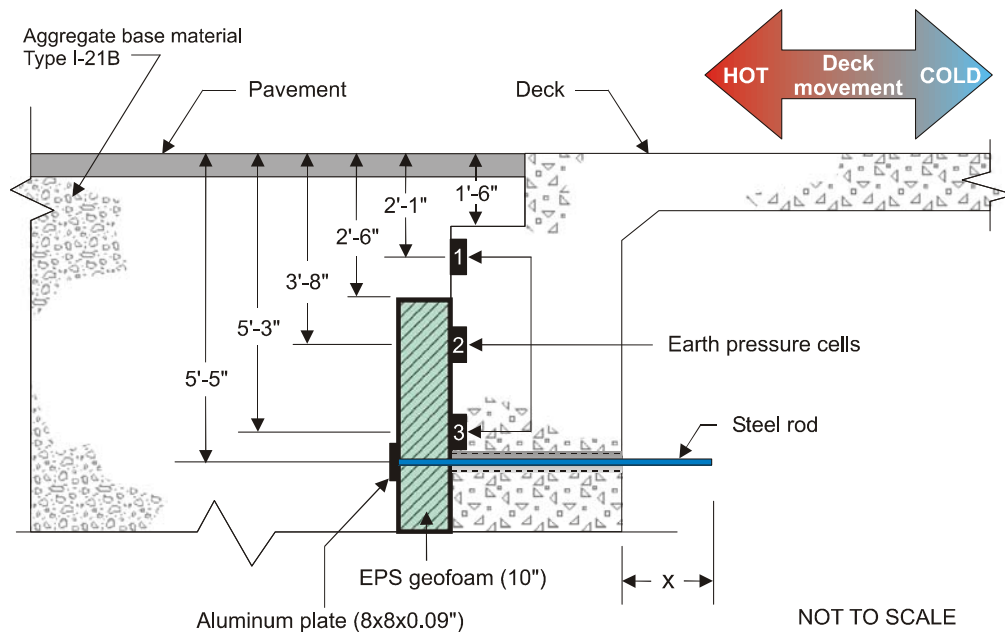
Figure 5. Integral Backwall Instrumentation

Figure 6. EPS Rod and Lower Flange Strain Gage

Two strain gages were installed at the end of one girder, between the bearing assembly and the backwall. One gage was placed on the top flange, 89 mm (3.5 in) away from the web and 160 mm (6.3 in) away from the stiffener. The other was placed on the lower flange, 101 mm (4 in) away from the web and 210 mm (8.3 in) away from the stiffener, as shown in Figure 6.

Linear displacement transducers (LVDT) were attached to record girder movement relative to the anchor bolt. Since the shelf abutment can be displaced because of a finite friction in the expansion bearing, tiltmeters were also installed to record the magnitude of abutment rotation.

RESULTS

Cyclic stress-strain tests were conducted at the Virginia Military Institute (VMI) on EPS samples provided by VDOT.[2] The results are shown in Figure 7. A new sample was used for each cyclic test, and each specimen was loaded for a total of 6 cycles in 48 hours. The change in slope at a stress level of approximately 270 psf (13 kPa) was traced to a change in the stiffness of the measuring device. It is important to recognize that neither the VMI test results nor the ones presented in Figure 3 reflect the ASTM D1621 Standard Test Method for Compressive Properties of Rigid Cellular Plastics, which specifies the loading rate of 2.5 mm/min (0.1 in/min) for each 25.4 mm (1 in) of specimen thickness.
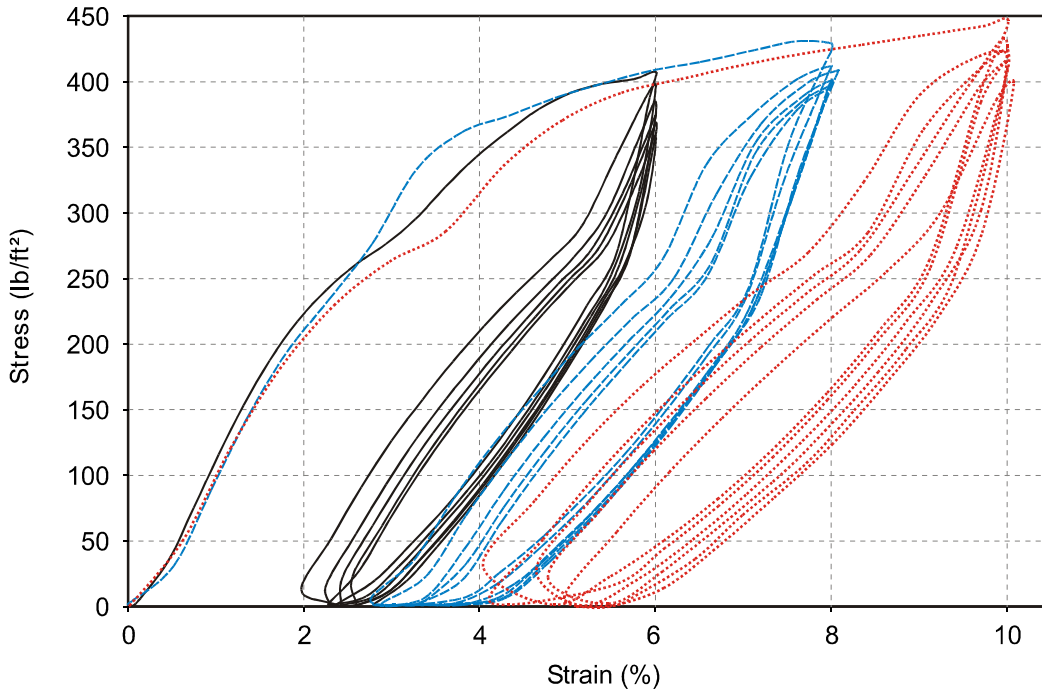
Figure 7. Cyclic Stress-Strain Properties of the Elasticized EPS

Backfill behind the instrumented bridge abutment was compacted on 8/11/1999. Immediately after compaction, the EPS strain was 11 percent, resulting from the lateral pressure exerted by the backfill material, coupled with compaction-induced stresses. Approximately 2 weeks later, on 8/25, the strain relaxed to 8 percent, with the ambient air temperature about 3 degrees lower. Subsequently, the observed pattern was that of EPS strain increasing and decreasing with the rising and falling of the air temperature.

Figure 8 shows the strain-temperature-time behavior of the elastic inclusion from November 1999 to January 2005. The graph shows data points reflecting measurements made during the highest, lowest, and mid-range of recorded ambient air temperatures. Bars represent the EPS strain, and triangles mark the corresponding air temperature under the bridge. The range of working strains from 4 percent to 13 percent corresponds to 23 mm (0.9 in) of backwall movement. Numbers on the time axis indicate days elapsed from the time of backfill compaction to the end of the following year. The latest reading was taken at 1,990 days, on 1/19/2005.

The recorded range of girder displacements (LVDT measurements) relative to anchor bolt at Abutment A was 28.10 mm (1.1 in). With the estimated point of foundation pile fixity at a depth of approximately 2.5 m (8.3 ft), the shelf abutment tilt (rotation) was negligible (0.005 radian), corresponding to less than 1 mm (0.04 in) of lateral movement. Assuming that the girder displacement can be directly related to the EPS compression, the resulting strain ranged between 2.4 percent and 13.4 percent during the 5 years of monitoring.
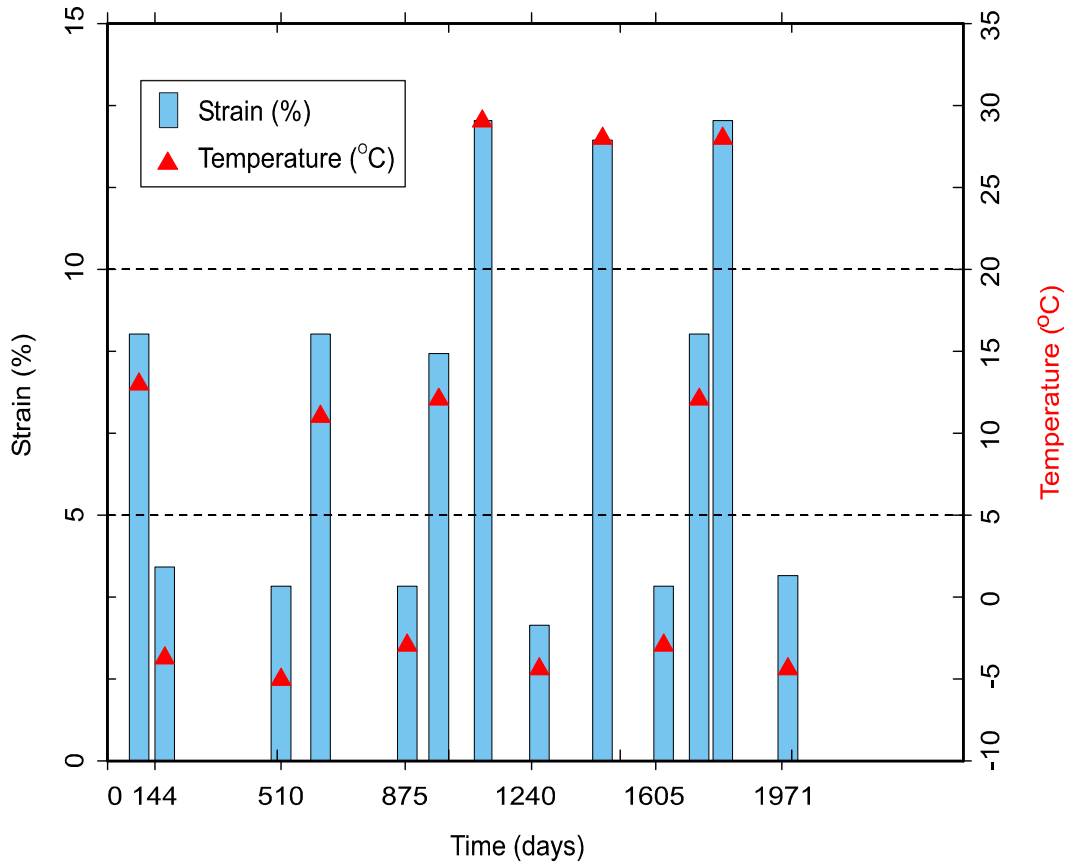
Figure 8. Strain-Temperature-Time Behavior of Elasticized EPS

The average displacement range at both abutments was 22.5 mm (0.89 in), but substantially greater movements were observed at Abutment A. Records indicate that the range of superstructure movements at Abutment A was 52 percent greater than at Abutment B. Possible explanations for this phenomenon involve abutment location and stiffness of pier supports. The bridge is constructed on a vertical curve, with Abutment A situated lower than Abutment B.

The largest sensor 1 pressure reading of 417.8 kPa (8,723 psf) was recorded on 4/18/2004. Figure 9 shows earth pressure data for the period 4/13/2004 to 4/20/2004. As may be seen from the air temperature record, this was a period of a rapid warm-up from approximately 10 to 26 ^{o}C (50 to 80 ^{o}F), following a prolonged period of cool weather. At the same time, pressures registered by sensors 2 and 3 (behind the EPS) were much lower.

In the following week, the air temperature stabilized in a relatively narrow range of approximately 18 to 26 ^{o}C (64 to 80 ^{o}F), as shown in Figure 10. The maximum pressure at sensor 1 was only a fraction of the previous spike, and pressures at other sensors reached similar levels at the corresponding air temperatures. It appears that after the initial backfill resistance was "broken" by the expanding superstructure, the subsequent "peaks" were greatly reduced. This pattern of earth pressure behavior was observed at other times. The next largest earth pressure reading at sensor 1 was 339 kPa (7,077 psf), recorded on 4/16/2002.

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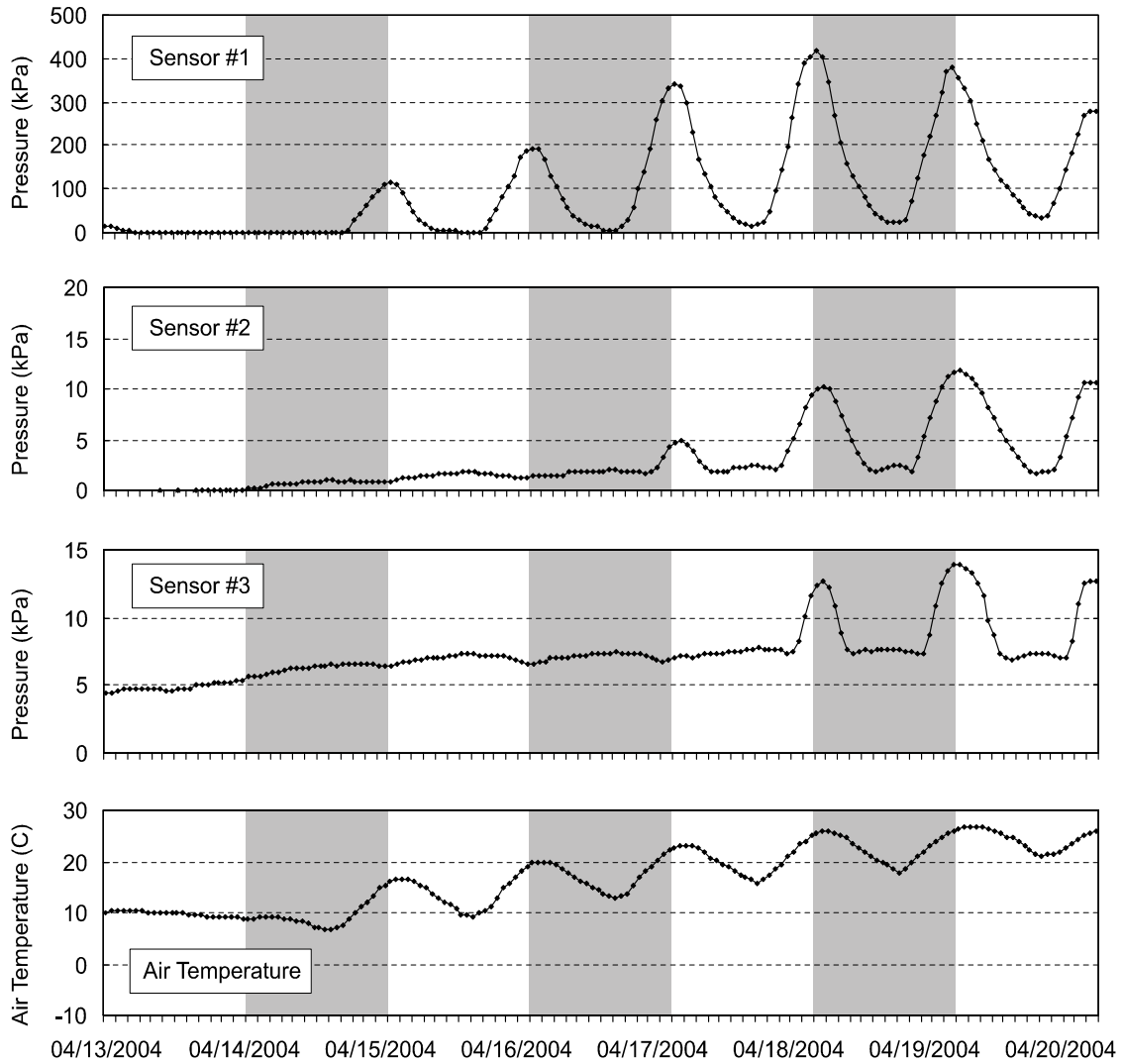
Figure 9. Earth Pressures from 4/13/2004 to 4/20/2004

The largest recorded earth pressures at sensors 2 and 3 were 19.7 kPa (411 psf) and 22.5 kPa (470 psf), respectively. Pressures of this magnitude were reached repeatedly during prolonged periods of summer hot weather, with air temperatures hovering around 30 $^{\circ}$C (90 $^{\circ}$F), as shown in Table 2. At the same time, there was a noticeable trend of increasing earth pressures at sensor 1, most likely attributable to increasing backfill compaction.
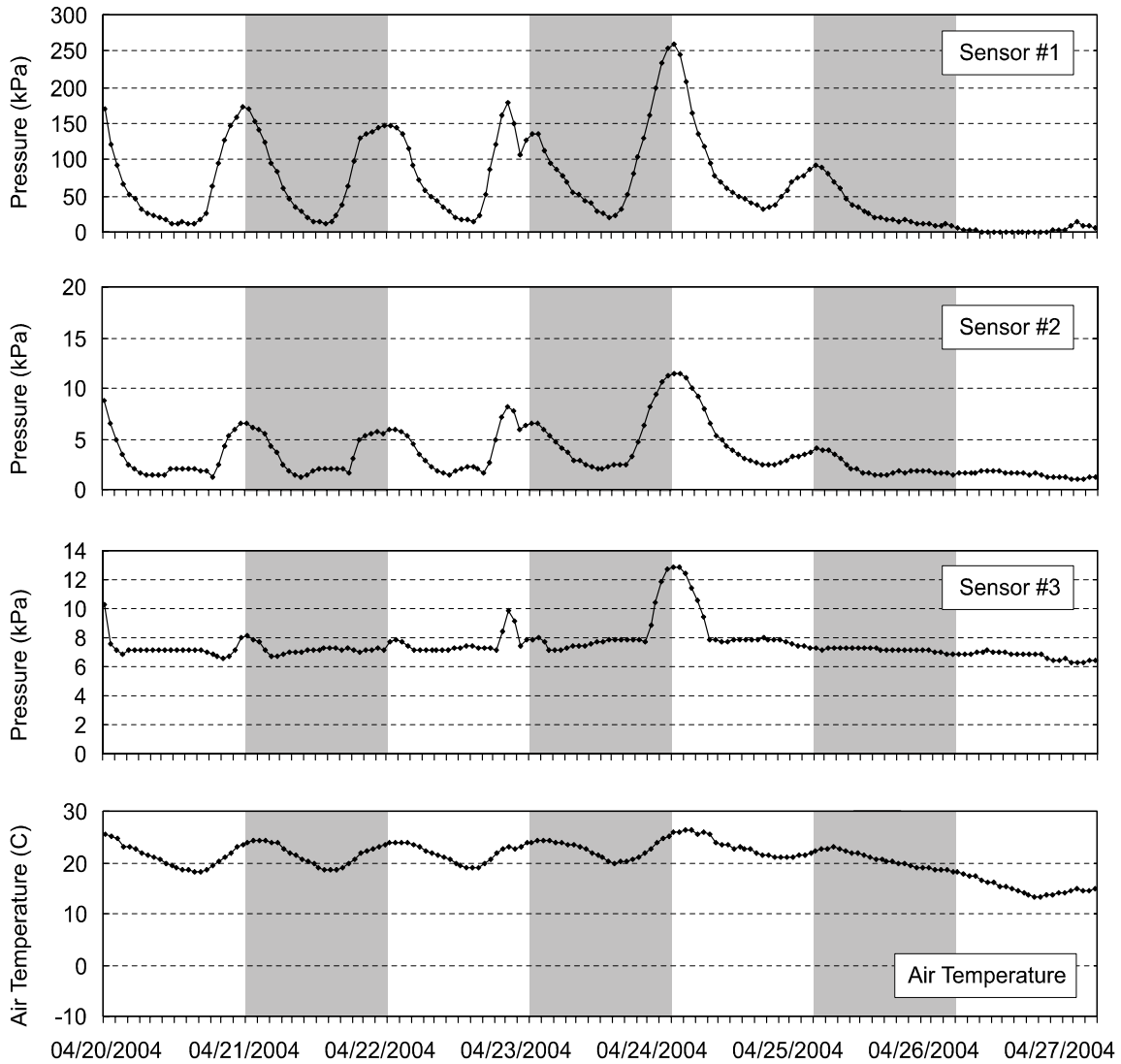
**Figure 10. Earth Pressures from 4/20/2004 to 4/27/2004**

Table 2. Earth Pressures

Date	Time	*p1 (kPa)*	p2 (kPa)	p3 (kPa)	Air Temp. (°C)
6/11/2000	17:00	*148.0*	18.4	21.5	31.8
6/13/2000	17:00	*141.6*	18.1	21.5	32.4
6/20/2001	18:00	*129.3*	18.7	22.4	31.8
6/05/2002	18:00	*295.0*	18.8	21.9	32.8
7/05/2002	18:00	*248.0*	19.0	22.0	33.7
6/17/2004	18:00	*301.5*	18.9	21.0	31.2
7/06/2004	19:00	*295.9*	19.5	21.2	33.6

Figure 11 shows girder strains caused by earth pressure only, spanning the time period of 4/13/2004 to 4/20/2004, and corresponding to the stresses displayed in Figure 9.

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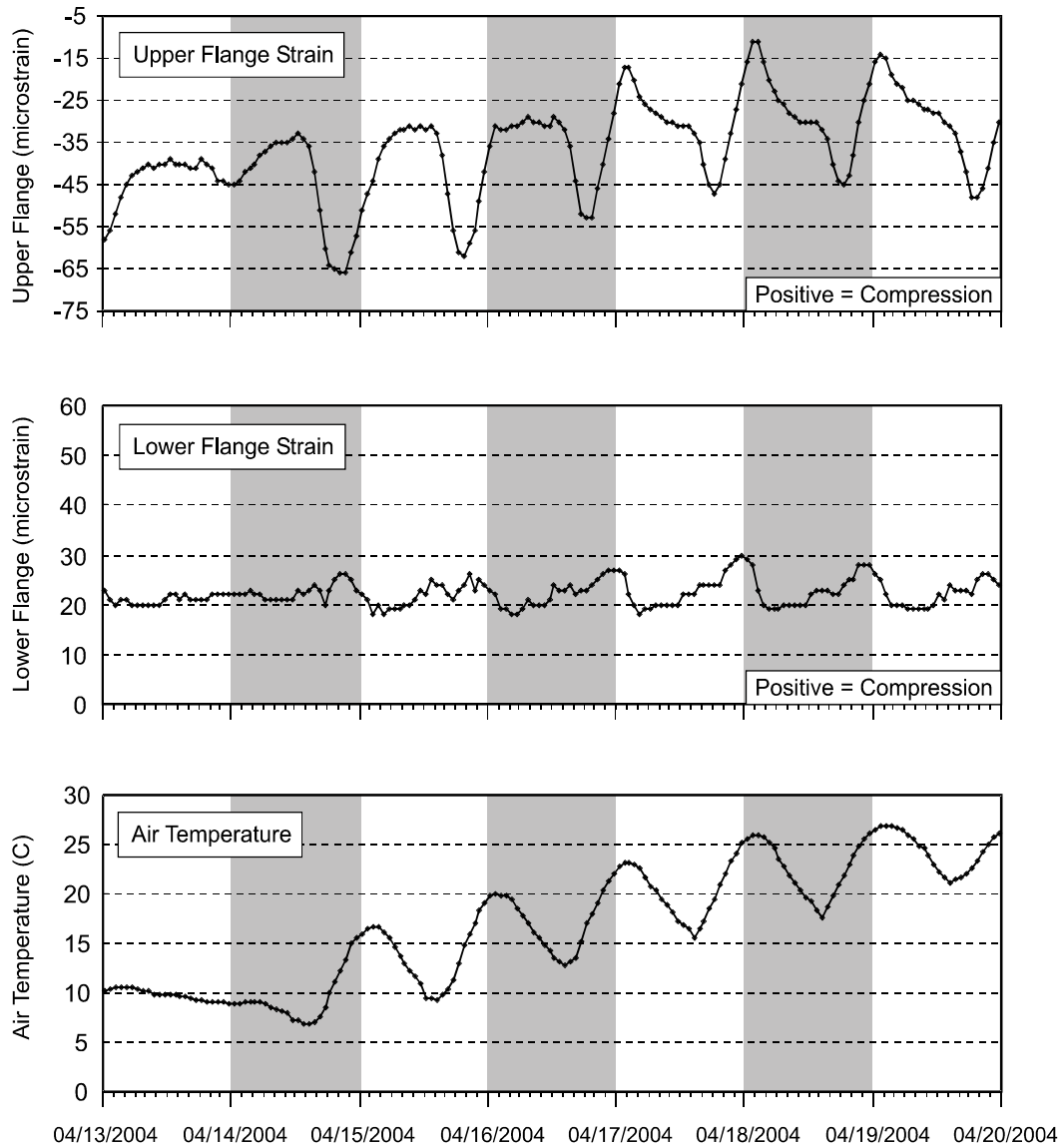
Figure 11. Girder Strains from 4/13/2004 to 4/20/2004

Compressive stresses were recorded in the lower flange, and the upper flange experienced a tensile stress. This condition was caused by the location of the resultant earth force relative to the composite neutral axis of the superstructure. Figure 12 shows an estimated earth pressure distribution behind the backwall, and Table 3 shows locations of the resultant earth force, relative to the top of bridge deck (distance y), for two cases of earth pressures recorded at sensors 1, 2, and 3. Table 4 shows maximum and minimum recorded girder strains caused by earth pressure.
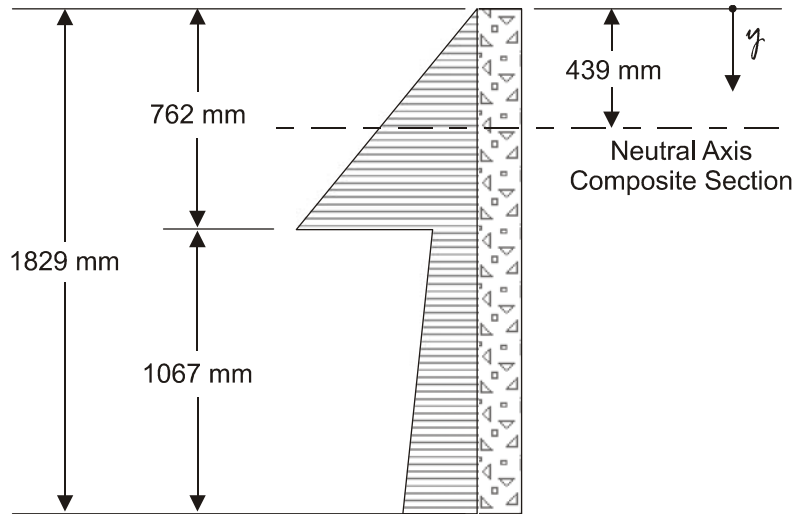
Figure 12. Estimated Earth Pressure Distribution Behind the Backwall

Table 3. Resultant Earth Force Locations

Case No.	p1 (kPa)	p2 (kPa)	p3 (kPa)	Resultant Earth Force Location - y (mm)
1	295	19.6	21.2	619
2	417.8	10.1	12.4	556

Table 4. Girder Strains Caused by Earth Pressure

| Flange	Max. Strain (με)	Min. Strain (με)
Upper	12	-80
Lower	42	0

Strains observed in the lower flange generally correlated well with earth pressures exerted behind the backwall. This close correlation was not evident at the upper flange. Upper flange strains appear to be strongly influenced by thermal gradients developed across the bridge deck. Figure 13 shows girder strains for a time period when earth pressures at sensors 1 and 2 were practically negligible and the earth pressure at sensor 3 varied in a narrow range between 5 and 6 kPa (104 to 125 psf). It can be seen that the upper flange strain largely reflects ambient air temperature fluctuations.

Approach elevations were monitored periodically between 11/1/1999 and 12/16/2004, as shown in Figure 14. Since the bridge was opened to traffic at the beginning of November 1999, the approach pavement was patched only once in the immediate vicinity of the bridge as a result of excessive differential settlement. The remedial work, consisting of placing approximately 50 mm (2 in) of asphalt plant mix over a strip of roadway 0.6 m (2 ft) wide, was performed on 9/5/2002. Figure 15 shows the resulting patch.
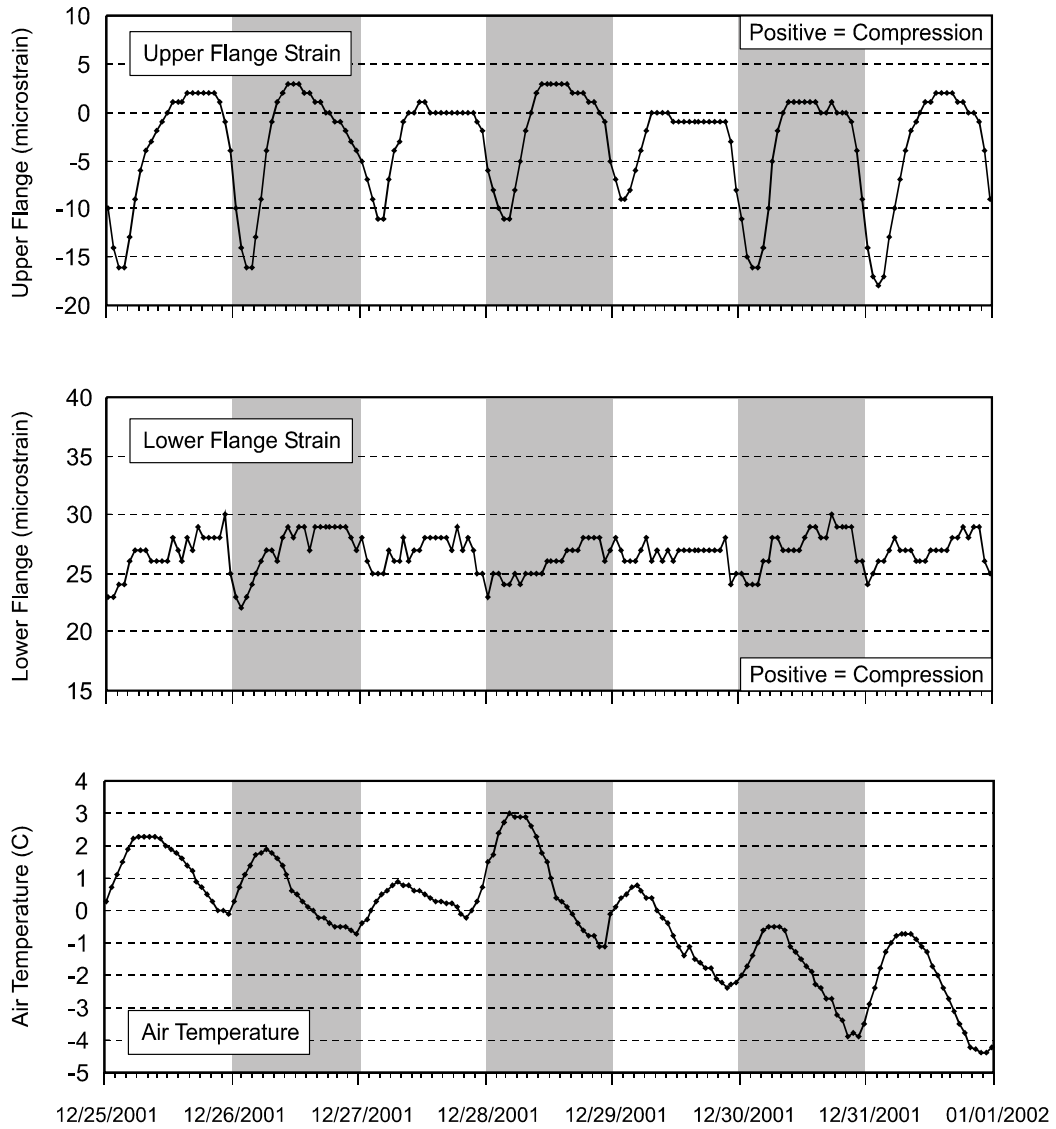
Figure 13. Girder Strains from 12/25/2001 to 1/1/2002

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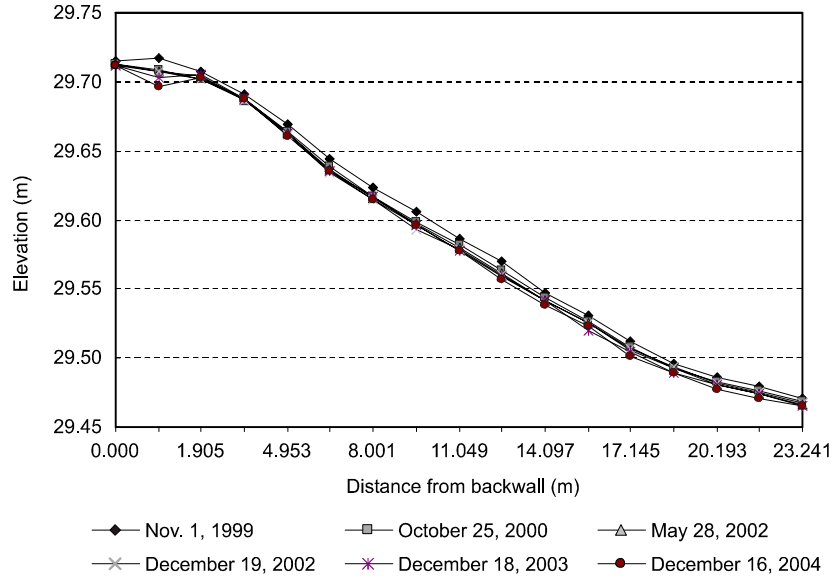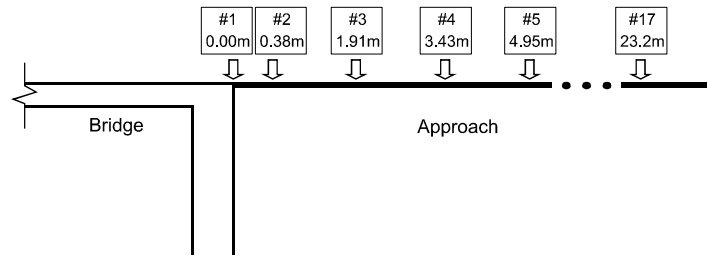
Figure 14. Approach Elevations

Figure 15. Approach Patch

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Laboratory direct shear tests conducted at the interface of granular backfill and a concrete specimen yielded a residual friction angle of 31 degrees. The concrete specimen was coated with the same type of waterproofing compound as was the integral backwall (SurePoxy LMLV). A residual friction angle of 35 degrees was measured for the uncoated concrete-backfill interface. Tests were performed at Virginia Tech using the large direct shear box[3] with internal dimensions of 635 by 406 by 25 mm (25 by 16 by 1 in).

All project data involving field measurements may be seen at http://matrix.vtrc.virginia.edu/Integral_60_Jackson/.

DISCUSSION

The magnitude of the actual passive earth pressure acting on the integral bridge in service has been a subject of a debate. It is important to recognize that depending on the theory used, estimates can vary widely. Wasserman[4] advocates the use of the Rankine theory to calculate passive pressure in a conservative way. Duncan and Mokwa[5] propose the log spiral theory and claim that passive pressures can induce large loads in integral bridges. Thippeswamy et al.[6] recommend neglecting earth pressure loads altogether in the analysis and design of jointless bridges. More field studies are needed to resolve this issue. Passive loads can be of concern at relatively tall integral abutments. The *Canadian Foundation Engineering Manual*[7] states that a compacted backfill requires very little movement to generate fully passive conditions.

In addition to reducing passive earth pressures, the purpose of an elastic inclusion is to absorb cyclic backwall movements without disturbing the adjacent backfill material, which typically results in amplified settlement. This problem manifested itself at the integral backwall bridge on Route 257 over I-81 in Rockingham County.[8] Figure 16 shows the approach pavement that has been repeatedly patched because of persistent settlement. The bridge is approximately the same length as the one monitored in this study, but with no elastic inclusion installed at the backwall.

Figure 16. Roadway Approach at the Route 257 Integral Backwall Bridge

Approach settlement behind a bridge abutment can be minimized by a thorough compaction of a well-graded granular backfill; however, the resulting stiffness of such material can result in a generation of substantial passive pressures at the integral structure. Consequently, the design must either accommodate these elevated stresses or incorporate a low-stiffness, compressible layer at the backwall-backfill interface. For optimum performance, it is essential that the backwall inclusion remain elastic in response to diurnal and seasonal movements of the superstructure.

Carder and Card [9] identified a number of potentially applicable materials for use as compressible layers. Selected candidates include polystyrene, polyethylene foam, geocomposites, and rubbers, with the suitability to the task to be verified through further research. Some of these materials were subsequently subjected to extensive laboratory testing by Carder et al.[10] Unfortunately, no data were reported on the elasticized expanded polystyrene. The authors concluded that "it has not been investigated further as it is expensive to produce and for this reason is not likely to be a cost effective solution for use on construction sites." This opinion was presumably based on the analysis of the U.K. construction environment only.

The EPS is a unique lightweight material with a density of only about 1 percent that of a traditional earth fill. It is typically manufactured in rectangular blocks. In U.S. practice, the term *geofoam* is used as a synonym for *EPS block geofoam.* A colloquial term *Styrofoam* is technically incorrect, since it is the registered trademark of a particular product line of Dow Chemical.

The report by Stark et al.[11] is intended to synthesize the state of the practice of geofoam use in roadway embankments (although it contains no references to the elasticized EPS). It identifies the need for long-term stress-strain-time-temperature testing of geofoam and recommends creep test durations of at least 20 months to extrapolate performance for a 50-year design life.

The regular EPS has been routinely used as a lightweight fill in embankment construction when low-bearing capacity soils are encountered. In Norway, more than 100 projects involving the use of EPS have been successfully completed since 1972.[12] Some of these projects involve extensive placement of EPS block at bridge approach embankments to reduce differential settlement caused by very soft foundation soil.

Regular EPS material exhibits a linear-elastic stress-strain relationship only up to approximately 1 percent.[13] EPS that has been strained beyond the yield point and then unloaded is considered "elasticized." EPS elasticized by temporary loading to between 60 and 70 percent strain subsequently exhibits linear-elastic behavior up to approximately 10 percent and linear (proportional) stress-strain behavior up to about 30 percent strain. Elasticized EPS provides greater stiffness in the direction perpendicular to the compressed axis, which can be advantageous for the support of the overlying pavement section. These properties make the elasticized EPS particularly attractive for high-strain applications. To the best of the author's knowledge, this study is the first published account of the use of elasticized EPS at integral bridges.

The horizontal earth pressure coefficient (K_h) is the ratio of the horizontal to vertical stress in the soil, defined as follows:

$$K_h = \sigma_h / \sigma_v \qquad\qquad \text{(Eq. 1)}$$

where

σ_h = horizontal stress
σ_v = vertical stress.

The maximum value of this ratio for a given soil corresponds to a state of passive failure, whereby K_h becomes the coefficient of passive earth pressure: K_p. With the backwall height of 1.8 m (6 ft), the observed movement range of 23 mm (0.9 in) corresponds to a displacement-height ratio of 0.0125, being indicative of fully passive earth pressure conditions in dense granular materials.[14]

The results of laboratory direct shear tests on the backfill-backwall interface indicate the residual interface friction angle (δ) of approximately 31 degrees. Assuming that $\tan \delta = \frac{2}{3} \tan \text{ø}$, it leads to an estimated angle of internal friction (ø) of 42 degrees for the backfill material. The relationship between the coefficient of passive earth pressure (K_p), δ and ø, as stated by Powrie,[15] is as follows:

$$K_p = \{[1 + \sin \text{ø}' \cos(\Delta + \delta)] / [1 - \sin \text{ø}']\} \times e^{(\Delta + \delta) \tan \text{Ø}'} \qquad \text{(Eq. 2)}$$

where $\sin \Delta = \sin \delta / \sin \text{ø}'$.

The equation leads to an estimated K_p of 11.9. It reduces to Rankine's expression for K_p when $\delta = 0$. For comparison, passive earth pressure coefficients computed by the Rankine, coulomb, and log spiral theories yield the resulting values of 5.0, 34.8, and 16.7, respectively. The wide range of K_p calculated by the different methods illustrates the difficulty of providing the "correct" value of earth pressure for design.

The pressure spike of 417.8 kPa (8,723 psf), registered at sensor 1, corresponds to the passive earth pressure coefficient of 27.3, based on the estimated bulk unit weight of the backfill material of 24.1 kN/m^3 (153 pcf). This translates into a substantial, although transient, passive load acting on the abutment. The pattern of observed backfill-structure interaction is that of a significant earth pressure buildup during a period of a sudden warm-up, corresponding to the superstructure expanding relatively quickly against the adjoining backfill. It is most likely indicative of a typical stress-strain behavior of a dense granular material, reaching high peak strength (and a correspondingly high internal friction angle) before decreasing to a residual strength. The magnitude of 417.8 kPa (8,723 psf) and the corresponding K_p of 27.3 should be kept in perspective. This event occurred only once in the 5-year monitoring period. A typical pattern of recorded earth pressures implies that the log spiral theory offers a reasonable approximation of K_p; however, the occurrence of very high transient earth pressures should be accounted for in the bridge design process when no elastic inclusion is incorporated.

In contrast, earth pressures are more attenuated and uniform at the backwall section covered with the elasticized EPS. Maximum ratios of horizontal to vertical earth pressures at sensors 2 and 3 are calculated at only 0.7 and 0.6, respectively. Thus, the presence of the elastic inclusion can result in a substantial decrease of mobilized earth pressures, offering opportunities for substantial cost savings in design.

Roadway approach elevation records indicate that most of the post-construction settlement took place within 1 year of opening to traffic. Embankment elevation records point to the approach zone most prone to settlement (although still manageable) extending to about 1.5 m (5 ft) beyond the backwall, where approximately 11 mm (0.43 in) of settlement occurred between 12/19/2002 (following asphalt patching) and 12/16/2004. No excessive differential settlements were observed in the remaining segment of the bridge approach, with the maximum of 14 mm (0.6 in) recorded at 12.6 m (41 ft) beyond the backwall during the 5-year monitoring period. This magnitude of settlement can be regarded as tolerable.

The lateral extent of observed settlements indicates that a relatively short approach slab would adequately serve the purpose of providing a grade transition. A shorter approach slab would be easier for the superstructure to push and pull during cyclic movements if the embankment settlement and the corresponding slab rotation at the backwall were relatively small. Large anticipated settlements necessitate the use of long approach slabs.

The use of approach slabs at integral bridges can become a particularly troublesome maintenance issue if excessive settlement occurs. The solution is to provide a better quality backfill or to eliminate the slab and rely on periodic resurfacing of the roadway. Recent U.K. practice points to a diminished use of approach slabs, and the recently constructed bridges appear to be performing well.[16]

It is very likely that relatively small embankment settlements observed in this study were attributable to the combined action of the high-quality backfill material and the elastic inclusion. Placement of the select backfill alone could have generated excessive lateral stresses attributable to a potentially high backfill stiffness. The observed performance of the elasticized EPS also suggests that it can be used to protect integral as well as conventional bridge abutments from lateral pressures exerted by the compaction equipment. Current VDOT specifications stipulate that only lightweight compactors be used in the direct proximity of a wall, but this practice often results in excessive approach settlements because of inadequate compaction (the proverbial bump at the end of the bridge). The presence of an elastic inclusion would help to dissipate lateral stresses induced by a heavier (intermediate) equipment while allowing for a more thorough backfill compaction. Matsuda et al.[17] propose that the EPS material be used to reduce earth pressure exerted during construction and to absorb dynamic loads attributable to earthquakes.

VMI cyclic laboratory test results presented in Figure 7 indicate a widening working strain range and some permanent creep at increasing strain levels. These results provide only an approximate description of the elastic inclusion stress-strain behavior because the actual strain rates and the magnitude of individual strain cycles are markedly smaller.

Field measurements of the elasticized EPS layer thickness demonstrate that in the 5 years of monitoring, the material remained elastic in the working strain range of approximately 4 to 13 percent, with no evidence of appreciable creep. It is important to realize that this type of stress-strain behavior cannot be attained with a regular (non-elasticized) EPS.

Although the results from this study look promising, it may be prudent to adopt the use of elasticized EPS cautiously for routine design work until more corroborated field data from various projects become available. Thus, a maximum EPS strain of 10 percent and a conservative value of the coefficient of the passive earth pressure (approaching the Rankine value for loosely compacted soil) may be an optimum starting point. A K_p of 4 was adopted by the VDOT Jointless Bridge Committee as the interim design value. Additional studies are needed to verify that a low K_p value can be consistently applied to the design of integral backwall covered with an elastic inclusion.

Based on the observed long-term performance of the elasticized EPS material in service, it appears that an elastic inclusion conservatively designed for a strain range of approximately 10 percent will function effectively. In designing for the appropriate level of strain, an estimated range of thermally induced movement of the backwall and a compaction-induced compression of the EPS must be taken into account. The following formula is proposed for calculating the required thickness of the elasticized EPS inclusion:

$$W = 10 \text{ x } [0.015H + 0.67\Delta T] \qquad\qquad\qquad \text{(Eq. 3)}$$

where   W = design EPS thickness (in)
             H = height of backwall (in)
             ΔT = total estimated lateral movement range at abutment (in).

For relatively high backwalls (in excess of 1.8 m [6 ft]), it may be more efficient to design the EPS layer in stages, progressively increasing in thickness with depth.

Where approach slabs are used, the EPS layer can be extended up to the underside of the slab. If no approach slab is constructed, the EPS should terminate below the pavement section, typically at the approach slab seat elevation (0.46 m [18 in] depth for VDOT design). The German code of practice[18] with regard to lightweight embankments constructed with regular EPS requires that the thickness of roadway material in contact with the upper surface of the EPS block should not be less than 0.30 m (1 ft), to allow for adequate compaction. Traditional pavement design procedures may be used, by considering the EPS to be an equivalent soil subgrade.[11] A resilient modulus value of 5 MPa (725 psi) or equivalent California Bearing Ratio (CBR) value of 2 can be assumed for a conservative pavement design.

A maximum strain of 42 $\mu\varepsilon$ was recorded at the lower flange of the girder. This strain corresponds to a compressive stress of 8.7 MPa (1260 psi) by earth pressure. Upper flange stress ranged between 2.5 MPa (360 psi) compressive and 16.5 MPa (2400 psi) tensile, largely attributable to a combination of thermal gradient across the deck and earth pressures acting behind the backwall. Stresses of this magnitude are unlikely to govern the girder design in most cases, considering the allowable 40 percent overstress for thermally induced loads, although the

bottom flange in the negative moment region may be a potential location for concern.[19]   Local flange buckling may develop if the compressive stress exceeds the yield stress.

The VDOT special provision for elastic inclusion developed as a result of this study is presented in the Appendix.   No drainage layer is specified since the required select backfill (VDOT Type I-21B material) is considered well drained. Parallel with this study, the members of the VDOT Jointless Bridge Committee developed various structural details and guidelines for the optimal design of integral bridges for VDOT.

CONCLUSIONS

- *An elastic inclusion consisting of a layer of elasticized EPS 0.25 m (10 in) thick seems to perform effectively. Field tests indicate significantly reduced earth pressures and approach settlements at the semi-integral bridge.*

- *The presence of well-compacted select backfill material at bridge approaches is essential for good results (low maintenance). The use of inferior backfill will negate the advantages provided by the elastic inclusion.*

- *There is a limited zone of increased settlement in close proximity to the backwall.   It appears that relatively short approach slabs would be sufficient to provide a grade transition.   Shorter approach slabs would be easier for the superstructure to push and pull during cyclic movements, and would exert less stress on the backwall if they settle. The alternative solution is to resurface the approach roadway occasionally. The bridge under study performed satisfactorily without approach slabs.*

- *Thermally induced lateral movements of the superstructure may not be equal at both abutments.*

RECOMMENDATIONS

1.   *Elastic inclusion should be installed on bridge backwalls and wingwalls, where large earth pressures and excessive approach settlements are a concern.*

2.   *Elastic inclusion should be specified in bridge contract documents as per the special provision included in the Appendix.*

3.   *Select backfill material, such as VDOT Type I-21B, should be placed against a wall covered with elastic inclusion. The lateral extent of the select backfill should be based on the estimated passive failure zone.*

4. *A medium-heavy roller compactor should be used to compact fully select backfill material adjoining a wall covered with the elasticized EPS. The practice of providing loosely compacted backfill behind integral backwalls should be discontinued.*

5. *The range of lateral backwall movement should be estimated separately at each abutment.*

6. *A triangular earth pressure distribution and the coefficient of passive earth pressure $K_p=4$ should be assumed for the backwall covered with the elasticized EPS. Additional long-term monitoring of select structures is recommended before reducing this K_p value for routine design.*

7. *An elasticized EPS layer should be designed not to exceed 10 percent strain. The feasibility of greater working strains should be explored through long-term monitoring of select structures.*

8. *The design thickness of the elasticized EPS layer should be determined using Equation 3.*

9. *Other elastic inclusion candidate materials (alternative products with comparable properties) should be evaluated through a series of laboratory and field tests.*

10. *Compressive stresses induced by earth pressures in the negative moment region of the bottom flange should be accounted for in the girder design.*

11. *Short approach slabs should be constructed where relatively small embankment settlements are anticipated. The currently used standard length of 6 m (20 ft) should be reduced to 3 m (10 ft) or less at integral bridges.*

12. *The no-approach-slab option should be implemented where practical and economically advantageous.*

COSTS AND BENEFITS ASSESSMENT

The use of elasticized EPS can result in reduced quantities of concrete and reinforcing steel in the backwall. For example, a bridge 76.2 m (250 ft) long and 14.1 m (46.33 ft) wide with a 3.2-m (10.5-ft) beam spacing, a 30-degree skew, and a backwall 1.9 m (6.33 ft) high would cost approximately $21,000 less if designed for a K_p of 4 instead of a K_p of 12 (currently assumed value for a granular fill).[19] The additional installed cost of the elasticized EPS would be approximately $15,000 ($240/m^2/457 mm [$200/yd^2/18 in]), based on a recently (12/15/2004) awarded contract.[20] The resulting cost saving would be approximately $6,000.

In addition, the use of elasticized EPS in conjunction with structural backfill and heavier compaction equipment is expected to result in reduced maintenance expenses associated with repairs of settling roadway approaches at integral bridges. The actual maintenance cost savings are more difficult to assess on an individual basis since they depend on a multitude of factors, such as the presence of approach slabs and the severity of the settlement problem. The average

cost of approach repairs at the Route 257 bridge (Figure 16) has been $2,300 annually.[21] Repairs have been carried out repeatedly for the past 12 years.

ACKNOWLEDGMENTS

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APPENDIX

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR ELASTIC INCLUSION
(ENGLISH AND METRIC VERSIONS)

VIRGINIA DEPARTMENT OF TRANSPORTATION

**SPECIAL PROVISION FOR
ELASTIC INCLUSION**

June 24, 2003

I. DESCRIPTION

Elastic Inclusion work shall consist of installation of an elasticized Expanded Polystyrene (EPS) and geotextile separation fabric between the back of concrete surfaces and backfill material, in accordance with these specifications and in close conformity with manufacturer's recommendations, the lines shown on the plans or as established by the Engineer.

II. MATERIALS

(a) **Elasticized Expanded Polystyrene (EPS)**: EPS shall have a size tolerance of 1/8 inch for each dimension and conform to the following:

Physical Property	Test Method	Requirements
Compressive strength	D-1621	720 psf +/-60 psf @10% strain
Water absorption	C-272	Max. 3% by volume

Physical Standard	Test Method	Requirements
Insect Resistance	D-3345-74	Resistance to ants, termites, etc.

The EPS shall be elasticized, with a linear-elastic stress-strain behavior up to 10 percent strain and linear proportional stress-strain behavior up to 30 percent strain.

The EPS shall contain no chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) or formaldehyde. It shall be chemically and biologically inert when in contact with acidic and alkaline soils. It shall be treated to prevent insect attack.

Materials shall withstand temperature variations from 0ºF to 140ºF without deforming and shall maintain their original dimensions and placement without chipping, spalling, or cracking. Material shall not deteriorate because of contact with sodium chloride, calcium chloride, mild alkalis and acids, or other ice control materials.

The EPS shall contain a flame retardant additive.

(b) **Geotextile Separation Fabric**: A non-woven geotextile separation fabric shall be placed between the EPS and the backfill material. Fabric joints shall have a minimum overlap of twelve inches. Fabric shall extend a minimum of twelve inches beyond the EPS surface and overlap with adjacent concrete surface.

The separation fabric shall have the following properties:

Physical Property	Test Method	Requirements
Grab Strength	D-4632	Min. 250 lb
Puncture Strength	D-4833	Min. 112 lb
Tear Strength	D-4533	Min. 90 lb
Permittivity	D-4491	Min. 0.5 sec^{-1}
Apparent Opening Size	D-4751	Max. No. 50 sieve

Geotextile separation fabric shall be protected from mud, dirt, dust, sunlight, and debris during transport and storage. Material shall be inert to commonly encountered chemicals; resistant to mildew, rot, insects, and rodents; and biologically and thermally stable. Geotextile separation fabric for subsurface installation shall not be exposed to direct sunlight for more than 24 hours during installation.

Tensile strength requirements are in the machine and cross-machine directions.

(c) **Adhesive**: Adhesive shall be used to bond the EPS to concrete surfaces and the separation fabric to the EPS. It shall be applied in accordance with the EPS manufacturer's recommendations.

(d) **Backfill Material:** Backfill material adjacent to the separation fabric shall be as specified in the contract documents.

III. PROCEDURES

(a) **Preparation of Concrete Surface:** Before placement of EPS, concrete surfaces shall be abrasive blast cleaned with a positive contact sandblaster or adhesives manufacturer's recommendation and approved by the Engineer to remove all non-adherent laitance, oil, grease or other foreign or deleterious matter.

(b) **Installation of Material:**

The EPS shall be attached to the back of the concrete surfaces with an adhesive compatible with the material.

The concrete surface must be thoroughly dry and clean for adhesive for the application of the EPS. Adhesive shall be applied in accordance with the adhesive manufacturer's recommendation or approval.

The separation fabric may be installed after the EPS has been installed or it may be pre-attached to the EPS. The separation fabric shall cover all exposed surfaces of the EPS.

EPS and separation fabric shall be installed in accordance with the manufacturer's recommendations.

IV.   TESTING

Elasticized EPS shall be tested by an independent commercial laboratory, to verify the material requirements specified herein. The Contractor shall provide written documentation of all tests specified. Documentation shall include style, lot, roll numbers, and actual results of each test. In addition, the name, address, phone number of the testing laboratory, and date of testing shall be provided.

Geotextile separation fabric shall be tested by an independent commercial laboratory, to verify the material requirements specified herein. The Contractor shall provide written documentation of all tests specified. Documentation shall include style, lot, roll numbers, and actual results of each test. In addition, the name, address, phone number of the testing laboratory, and date of testing shall be provided.

After the EPS has been installed and before the work has been accepted, the Contractor and Inspector shall perform a visual inspection of EPS coverage and adhesion to the concrete surface. Any area deemed unacceptable and questionable as to remaining in position during the placement of the backfill material shall be replaced or repaired, as required.

REPAIR OF FAILED AREA OF EPS: Unacceptable portion of the EPS shall be removed and the concrete surface shall be prepared and the EPS installed in accordance with this special provision. New EPS in the repair areas shall be visually inspected after curing. The cost of all additional work for repairing or replacing of the defective joint material shall be borne by the Contractor.

IV.   MEASUREMENT AND PAYMENT

Elastic inclusion, when a pay item, will be measured in square yards along the back of backwall surface area, complete-in-place, and will be paid for at the contract unit price per square yard. Such price shall be full compensation for cleaning surface, for furnishing and installing the EPS material in accordance with these Specifications and the manufacturer's recommendations, separation fabric, testing, and for all material, labor, tools, equipment and incidentals necessary to complete the work. When not a pay item, the cost thereof shall be included in the price for other appropriate pay items.

Payment will be made under:

Pay Item	Pay Unit
Elastic Inclusion (Thickness)	Square Yard

**SPECIAL PROVISION FOR
ELASTIC INCLUSION**

June 24, 2003

I. DESCRIPTION

Elastic Inclusion work shall consist of installation of an elasticized Expanded Polystyrene (EPS) and geotextile separation fabric between the back of concrete surfaces and backfill material, in accordance with these specifications and in close conformity with manufacturer's recommendations, the lines shown on the plans or as established by the Engineer.

II. MATERIALS

(a) **Elasticized Expanded Polystyrene (EPS)**: EPS shall have a size tolerance of 3 mm for each dimension and conform to the following:

Physical Property	Test Method	Requirements
Compressive strength	D-1621	34 kPa +/-3 kPa @10% strain
Water absorption	C-272	Max. 3% by volume

Physical Standard	Test Method	Requirements
Insect Resistance	D-3345-74	Resistance to ants, termites, etc.

The EPS shall be elasticized, with a linear-elastic stress-strain behavior up to 10 percent strain and linear proportional stress-strain behavior up to 30 percent strain.

The EPS shall contain no chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) or formaldehyde. It shall be chemically and biologically inert when in contact with acidic and alkaline soils. It shall be treated to prevent insect attack.

Materials shall withstand temperature variations from -20ºC to 60ºC without deforming and shall maintain their original dimensions and placement without chipping, spalling, or cracking. Material shall not deteriorate because of contact with sodium chloride, calcium chloride, mild alkalis and acids, or other ice control materials.

The EPS shall contain a flame retardant additive.

(b) **Geotextile Separation Fabric**: A non-woven geotextile separation fabric shall be placed between the EPS and the backfill material. Fabric joints shall have a minimum overlap of 300 mm. Fabric shall extend a minimum of 300 mm beyond the EPS surface and overlap with adjacent concrete surface.

The separation fabric shall have the following properties:

Physical Property	Test Method	Requirements
Grab Strength	D-4632	Min. 1100 N
Puncture Strength	D-4833	Min. 500 N
Tear Strength	D-4533	Min. 400 N
Permittivity	D-4491	Min. 0.5 sec-1
Apparent Opening Size	D-4751	Max. 0.300 mm

Geotextile separation fabric shall be protected from mud, dirt, dust, sunlight, and debris during transport and storage. Material shall be inert to commonly encountered chemicals; resistant to mildew, rot, insects, and rodents; and biologically and thermally stable. Geotextile separation fabric for subsurface installation shall not be exposed to direct sunlight for more than 24 hours during installation.

Tensile strength requirements are in the machine and cross-machine directions.

(c) **Adhesive**: Adhesive shall be used to bond the EPS to concrete surfaces and the separation fabric to the EPS. It shall be applied in accordance with the EPS manufacturer's recommendations.

(d) **Backfill Material:** Backfill material adjacent to the separation fabric shall be as specified in the contract documents.

III. PROCEDURES

(a) **Preparation of Concrete Surface:** Before placement of EPS, concrete surfaces shall be abrasive blast cleaned with a positive contact sandblaster or adhesives manufacturer's recommendation and approved by the Engineer to remove all non-adherent laitance, oil, grease or other foreign or deleterious matter.

(b) **Installation of Material:**

The EPS shall be attached to the back of the concrete surfaces with an adhesive compatible with the material.

The concrete surface must be thoroughly dry and clean for adhesive for the application of the EPS. Adhesive shall be applied in accordance with the adhesive manufacturer's recommendation or approval.

The separation fabric may be installed after the EPS has been installed or it may be pre-attached to the EPS. The separation fabric shall cover all exposed surfaces of the EPS.

EPS and separation fabric shall be installed in accordance with the manufacturer's recommendations.

IV.   **TESTING**

Elasticized EPS shall be tested by an independent commercial laboratory, to verify the material requirements specified herein. The Contractor shall provide written documentation of all tests specified. Documentation shall include style, lot, roll numbers, and actual results of each test. In addition, the name, address, phone number of the testing laboratory, and date of testing shall be provided.

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IV.   **MEASUREMENT AND PAYMENT**

Elastic inclusion, when a pay item, will be measured in square yards along the back of backwall surface area, complete-in-place, and will be paid for at the contract unit price per square yard. Such price shall be full compensation for cleaning surface, for furnishing and installing the EPS material in accordance with these Specifications and the manufacturer's recommendations, separation fabric, testing, and for all material, labor, tools, equipment and incidentals necessary to complete the work. When not a pay item, the cost thereof shall be included in the price for other appropriate pay items.

Payment will be made under:

Pay Item	Pay Unit
Elastic Inclusion (Thickness)	Square Meter