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MONITORING CULVERT LOAD WITH SHALLOW FILLING UNDER GEOFOAM AREAS



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MONITORING CULVERT LOAD WITH SHALLOW FILLING UNDER GEOFOAM AREAS

by

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**In cooperation with the
Kentucky Transportation Cabinet
The Commonwealth of Kentucky
and
Federal Highway Administration**

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16. Abstract <p>Geofoam and the "Imperfect Ditch" method can be used effectively on embankment projects to reduce pressures on underground structures when sufficient fill height is available to create an arching effect. When the fill height is too shallow the arching effect cannot be created. However, the pressure acting on the underground structure can still be reduced by making use of the very small unit weight of lightweight geofoam material. In this study, stresses acting on a three-sided culvert were reduced using lightweight geofoam. Initially, the culvert had been designed to carry a 6-foot loading. During construction it was discovered that the culvert must support a 9-foot embankment loading. In an attempt to maintain the original design pressure and accommodate the increased height of backfill, the contractor proposed substituting 2 feet of the fill soil with 2 feet of ultra-light weight geofoam. To check the proposed solution, stress cells were installed on the three-sided culvert to measure actual in situ pressures. Using measured pressures acting on the culvert, a numerical model (by using FLAC 4.0) was "calibrated" to back calculate pressure for the original design situation involving the fill height of 6 feet. Using the "calibrated" properties of the fill materials, pressures were calculated for fill heights with and without geofoam. Pressures obtained from the calibrated model involving 7 feet of fill and a 2-foot layer of geofoam are compared to the pressures obtained for the 6 feet of fill.</p>			
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EXECUTIVE SUMMARY

A Conspan[®] precast culvert, which was constructed on Westport Road (KY Route 1447, Station 4 + 315) in Louisville, Kentucky, was originally designed for a 6-foot embankment loading. During construction, however, it was discovered that 9 feet of fill would be placed over the culvert. Since all sections had been prefabricated and half of the culvert was in the ground, the proposed solution by Conspan[®] to this problem of adding additional fill height was to replace 2-feet of fill with 2-feet of lightweight geofoam. Unit weight of the ultra-lightweight geofoam was only 1.35 lb/ft³. Unit weight of the soil fill replaced by the geofoam was about 123 lb/ft³, or about 91 times heavier than the unit weight of the geofoam.

As shown by past research (1, 2, 3, 4, 5, and 6), pressures acting on underground structures can be reduced very effectively when sufficient fill height is available and the imperfect ditch is incorporated into the design and it is filled with geofoam so that stress arching can occur. However, stress arching cannot be used effectively when shallow fill is designed for a culvert, or underground structure. To compensate for the added 3-feet of fill height, 2-feet of ultra-lightweight geofoam was used in an effort to prevent an increase of stresses above the design stresses that would occur under a 6-foot embankment loading.

To determine the actual stresses acting on the three-sided culvert and check the proposed solution, stress cells were mounted at three points on the top of the three-sided culvert. Using the measured pressures on the culvert, a numerical model (by using FLAC 4.0) was “calibrated” to back calculate pressures for various fill situations with and without geofoam and for the original fill height of 6 feet.

Based on in situ stress measurements and analyses of various fill situations, the following observations were made:

1. Lightweight geofoam was used successfully to reduce pressures on the culvert.
2. Pressures measured under the 7-foot embankment fill and a 2-foot layer of geofoam were larger than pressures that would have existed under a 6-foot embankment fill. Measured pressures ranged from 0.6 to 6.4 percent larger than the pressures that would have existed under a 6-foot embankment fill.

INTRODUCTION

A Conspan[®] precast culvert, which was constructed on Westport Road (KY Route 1447, Station 4 + 315) in Louisville, Kentucky, was originally designed for a 6-foot embankment loading. However, during construction it was discovered that 9 feet of fill would be placed over the culvert. Since all sections had been prefabricated and half of the culvert was in the ground, the proposed solution by Conspan[®] to this problem of increasing the fill height was to replace 2 feet of the fill with 2-feet of lightweight geofoam. Unit weight of the ultra-lightweight geofoam was only 1.35 lb/ft³. Unit weight of the soil fill replaced by the geofoam was about 123 lb/ft³ or about 91 times heavier than the unit weight of the geofoam.

Based on past research and experience (1, 2) of using geofoam in numerical modeling and culvert projects, the pressure on top of the Westport culvert would increase when 3 feet of additional fill is placed. According to the designer's report, the computer software, CANDE (based on the finite element method), was used to analyze the situation. Their solution involved using 7 feet of fill and 2 feet of geofoam to obtain grade elevation above the culvert, although the original design was based on loading resulting from 6 feet of fill. As noted in the designer's cover letter, "In the attached calculations, we have modeled the geofoam material over the precast bridge units using the CANDE soil-structure interaction program. The resulting stresses in the precast bridge units are lower than those in our original design for 6'-0" conventional fill." Apparently, the main possible reason for the above conclusion is that the CANDE program treated the fill above the culvert as a continuum material and a "beam effect" was obtained.

The use of geofoam appears to be a good solution to the problem. Considering the conditions given for this project, however, two-foot thick geofoam would not appear sufficient to reduce the pressure to the original design load resulting from 6 feet of fill. Hence, one means of addressing this issue was to mount pressure cells on top of the culvert so that the actual pressures could be measured and compared to theoretical solutions.

SITE DESCRIPTION

The culvert, modeled for theoretical analyses and selected for instrumentation, is located on KY Route 1447, Station 4 + 315, in Louisville, Kentucky (Figure 1). The culvert is a precast three-sided culvert. The inner span of the structure is 36 feet (10.97 meters) and the wall thickness is 1'-2" (about 0.36 meters). The inner apex height is 11 feet (3.35 meters) and the ceiling thicknesses are varied from 1 foot (0.3 meters) at middle to 2 feet (0.6 meters) at both corners (Figure 2). It is continuously placed on an unyielding foundation, has a total length of 132 feet (40.23 meters), and crosses a creek, beneath an embankment of compacted fill up to 7 feet (2.13 meters) and 2 feet (0.6 meters) of geofoam. The 2-foot thick layer of geofoam is placed at a position 2 feet above the culvert apex (Figure 2).

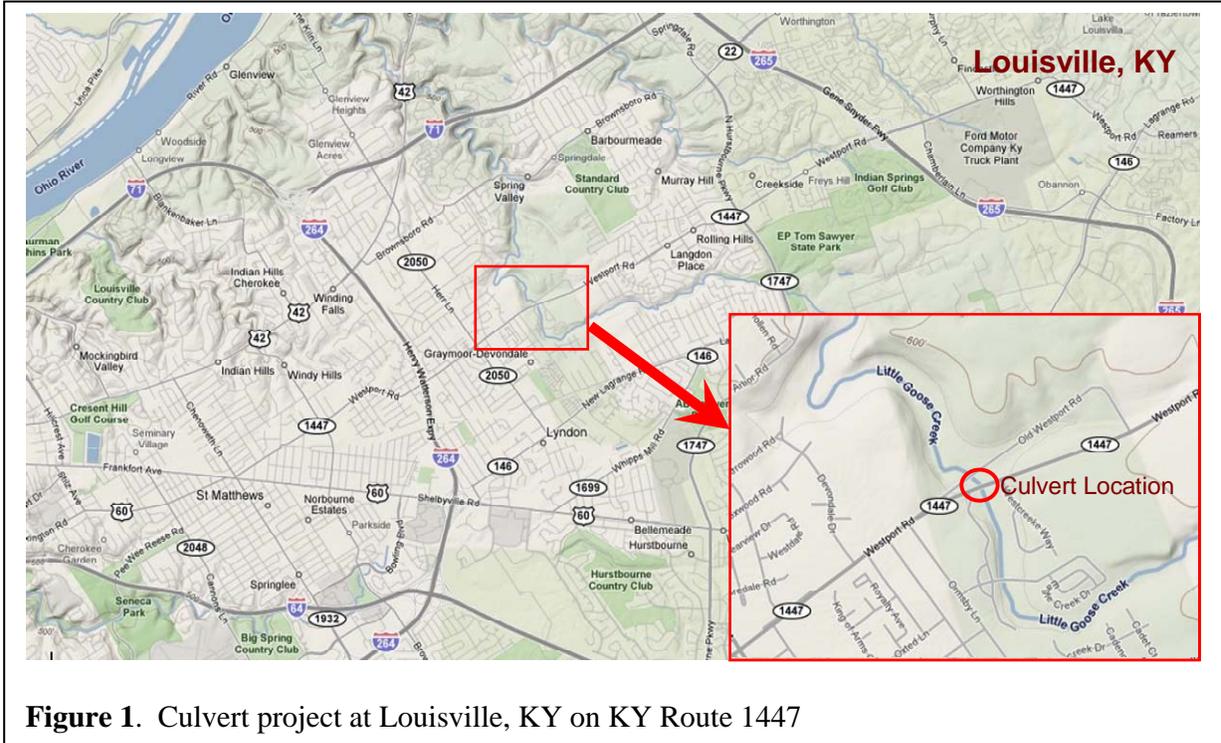


Figure 1. Culvert project at Louisville, KY on KY Route 1447

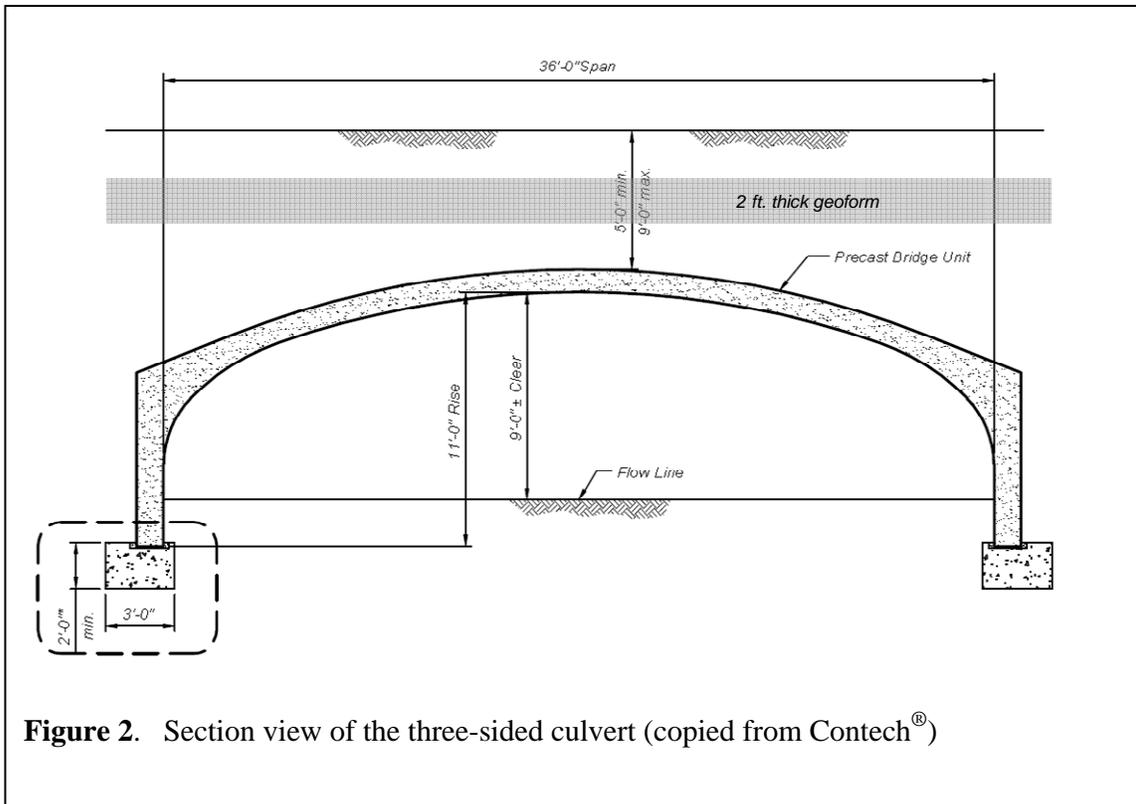


Figure 2. Section view of the three-sided culvert (copied from Contech®)

NUMERICAL ANALYSIS USING FLAC

To examine the initial loading and load changes, a two-dimensional, finite difference computer program, FLAC (Version 4.0, Itasca) was used. Three situations were modeled:

1. Six feet of fill over the three-sided culvert
2. Seven feet of fill and a 2-foot layer of geofoam over the three-sided culvert
3. Nine feet of fill over the three-sided culvert

Each model was created and analyzed to examine load changes on the culvert.

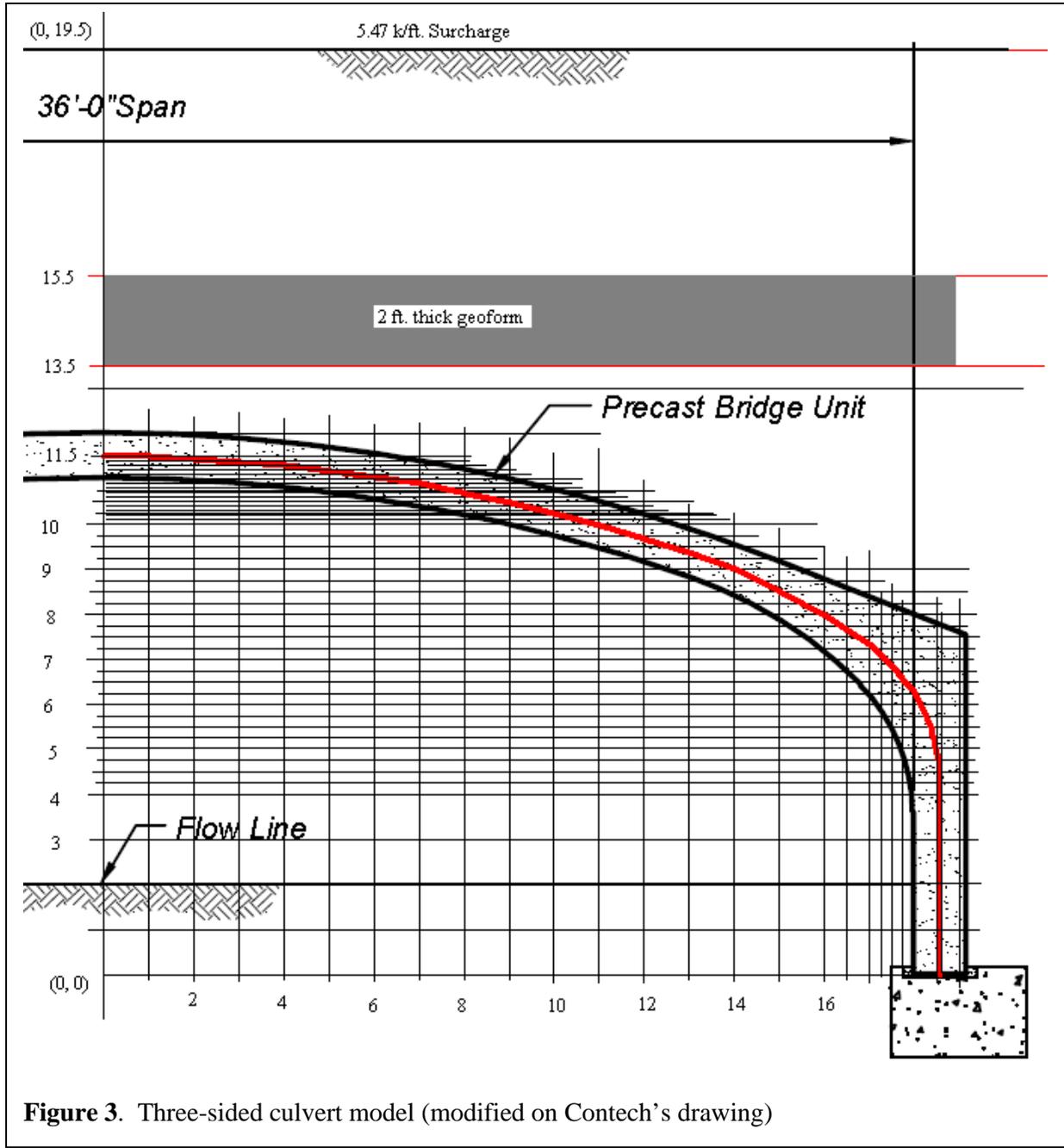
Properties of Materials

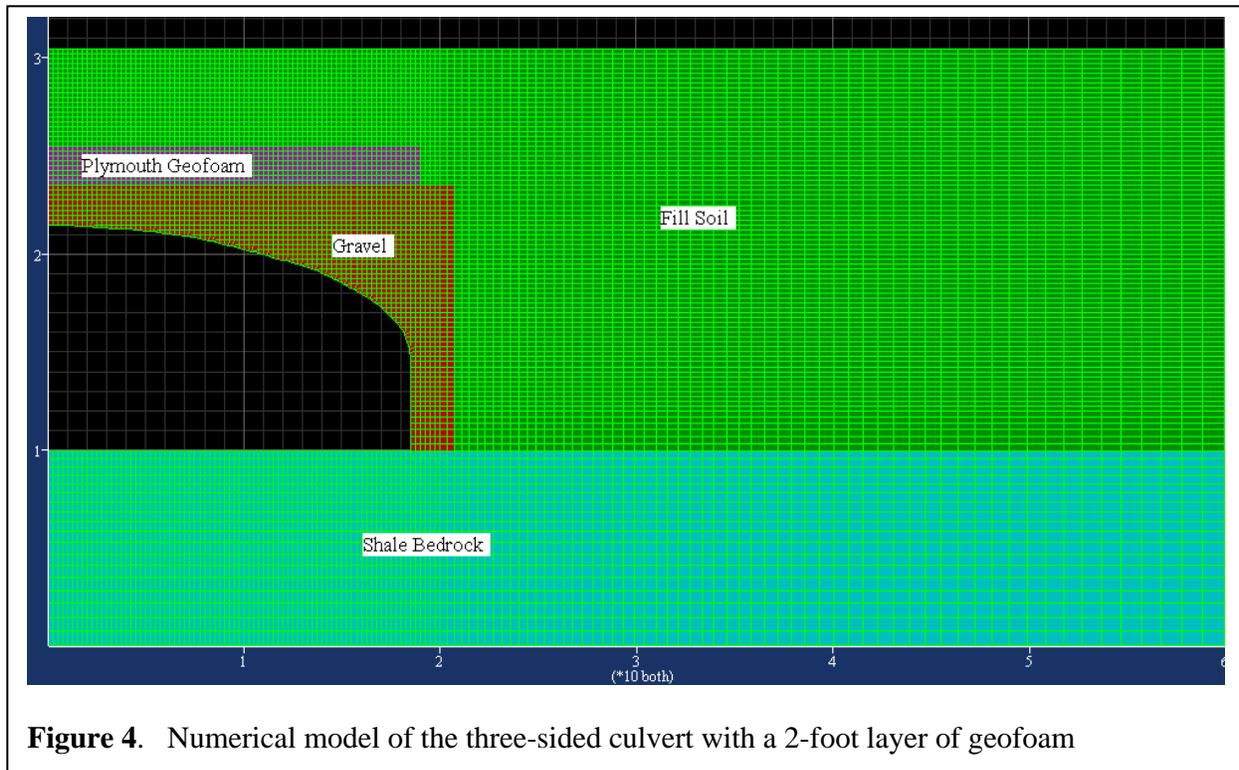
Properties of the concrete, gravel, fill soil, and shale bedrock used in the analyses were based on data made available in FLAC by the Itasca Consulting Group, Inc. They represent typical values used in geotechnical practice. Geofoam properties were obtained from a supplier, Plymouth Foam[®]. The fill soils and shale bedrock were modeled as cohesive materials using FLAC plastic constitutive model that corresponds to the Mohr-Coulomb failure criterion. Concrete was modeled as a linear-elastic material. Considering model availability in FLAC and data from the supplier, geofoam was modeled also as a linear elastic material. In this two dimensional numerical analysis, this model will yield more conservative results. The specific material properties used in the FLAC software are listed in Table 1.

Material	Elastic Modulus E		Poisson's Ratio ν	Mass Density		Cohesion C		Friction ϕ
	(psf)	(MPa)		(pcf)	(kg/m ³)	(psf)	(kPa)	
Plymouth Geofoam	1.14E+05	5.45	0.1	1.35	22			
Gravel	8.35E+05	40	0.25	131	2100	0.00E+00	0	35
Fill Soil	3.98E+05	19	0.25	123	1970	5.30E+02	25	26.2°
Shale Bedrock	2.32E+08	11100	0.29	169	2700	8.02E+05	38400	14.4°

Numerical Model Analysis

Numerical models with and without geofoam were analyzed using FLAC. The culvert was treated as an arch beam element with hinges on bottom corners. Interface elements were used between the culvert and soils. The bottom of the culvert was assumed to rest on shale bedrock. Gravel backfilled around the culvert, was 2-foot thick. The remainder of the embankment consisted of fill soil. Considering that the structure is symmetrical, and to speed up the numerical model analysis, only a half space was built into the numerical model (Figures 3 through 6).





To study load changes after the fill height was changed and to examine the effect of geofoam on the pressures acting on the culvert, the following procedure was used:

1. A numerical model of the arch-shaped culvert with 7 feet of fill plus a 2-foot layer of geofoam was “calibrated” by changing the load on top of the embankment based on data measured from the job site (Figure 4).
2. Keeping all conditions the same as in procedure 1, but removing the 2-foot layer of geofoam from the cross section and replacing it with 2 feet of fill, the finite difference program, FLAC, was run to determine the loads on the culvert. These loads are supposed to be ones without the 2-feet of geofoam above the culvert (Figure 5).
3. Keeping all conditions the same as in procedure 2 except 3-feet of fill was removed from the section, the finite difference program, FLAC, was run to determine loads on the culvert. These loads correspond to loading imposed on the culvert by 6 feet of fill—the original design (Figure 6).

Corresponding to measured points on the culvert, pressures on points A-1, A-2, and B-1, as shown in Figure 7, were investigated. These analyses are described below.

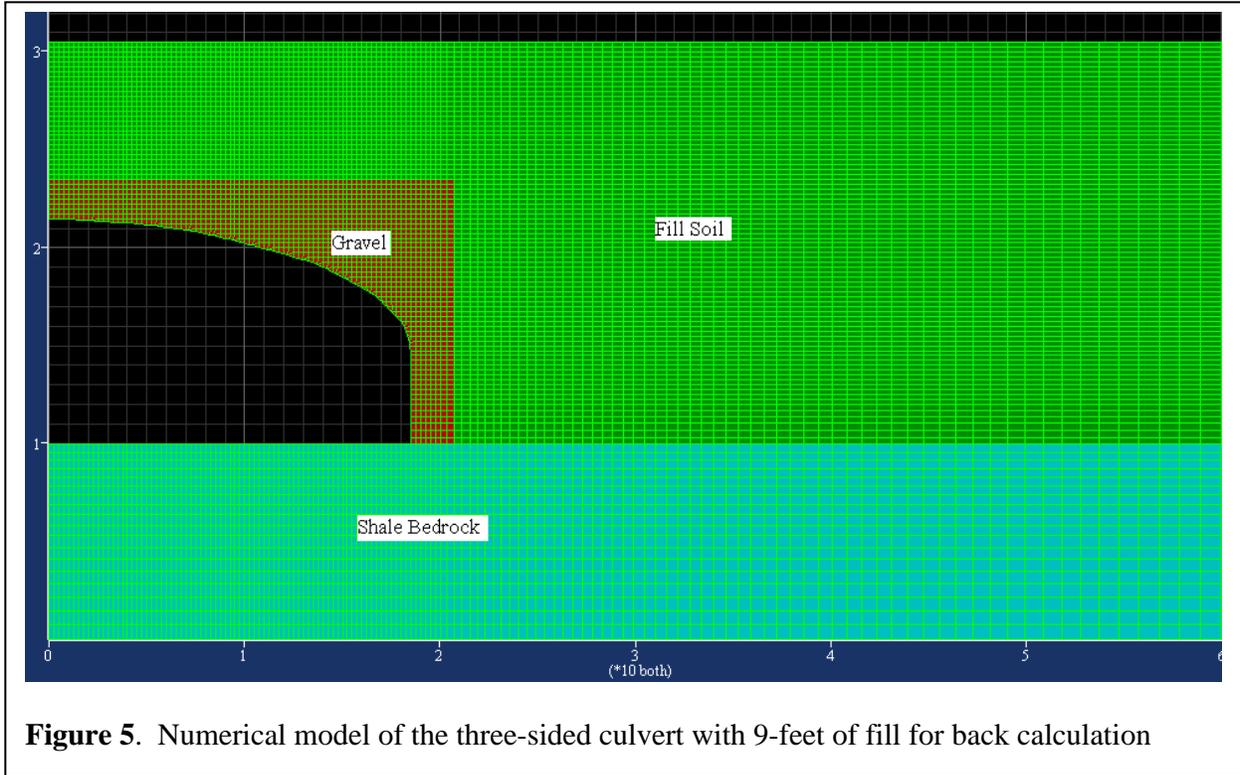


Figure 5. Numerical model of the three-sided culvert with 9-feet of fill for back calculation

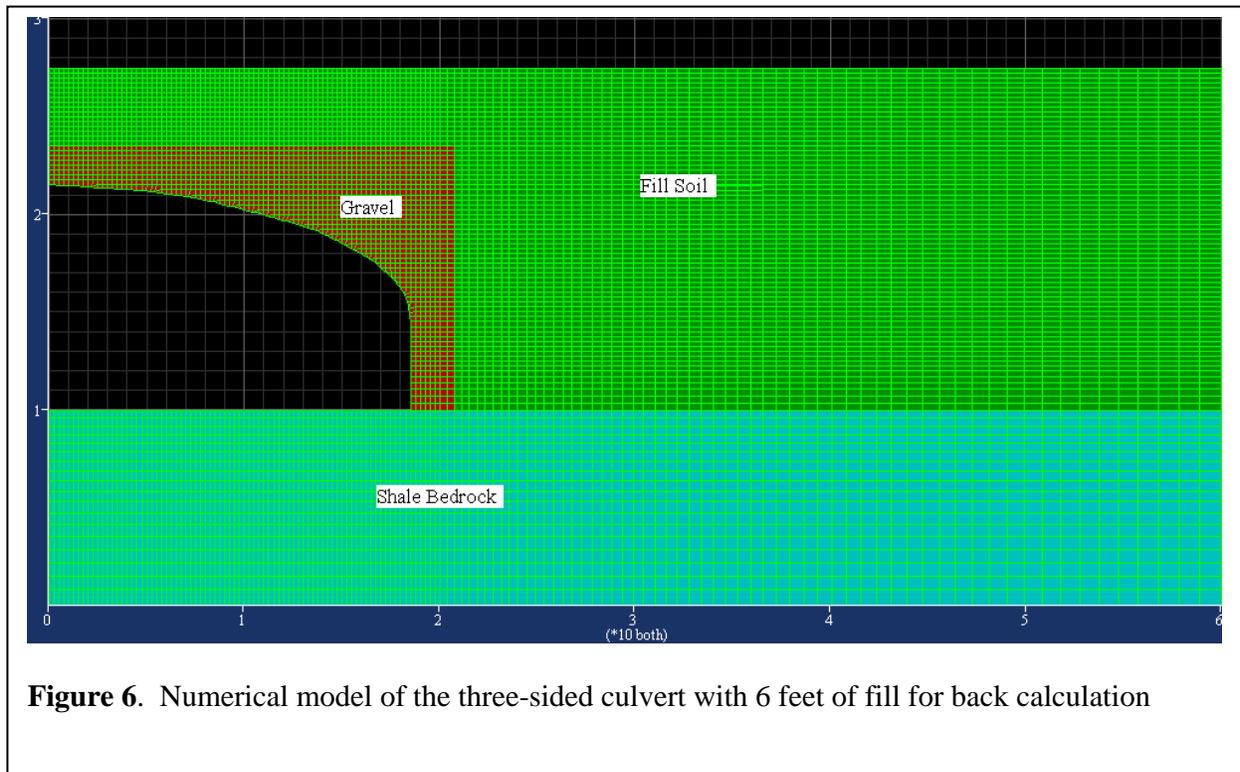


Figure 6. Numerical model of the three-sided culvert with 6 feet of fill for back calculation

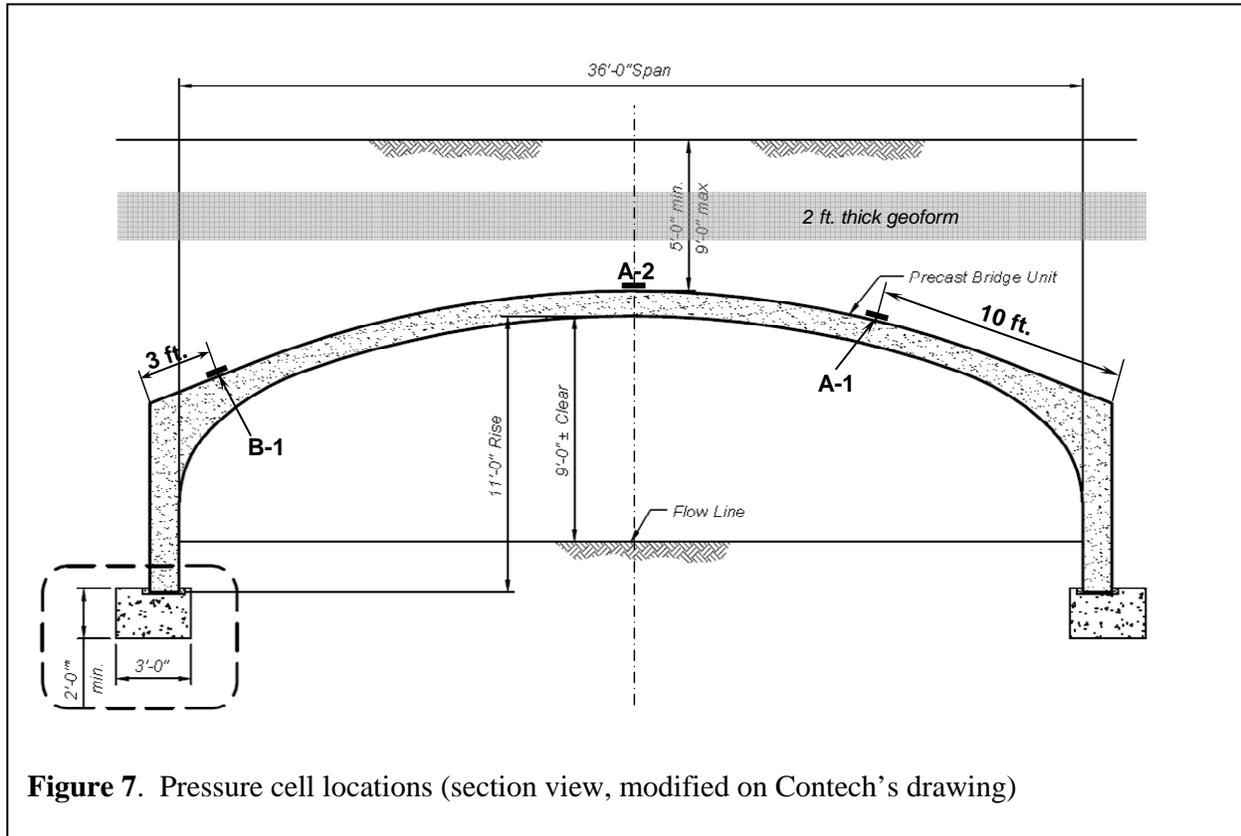


Figure 7. Pressure cell locations (section view, modified on Contech’s drawing)

Table 2 compares pressures under 7-feet of fill plus 2-feet of a geofoam layer to pressures under 6-feet of fill. The pressures under 7-feet of fill plus 2-feet of a geofoam layer are higher than pressures under 6-foot of fill for all three points. The maximum difference is 6.4 percent and occurs at the middle point of the culvert.

Table 2. Comparison of Pressures under 9 Feet of Fill with Geofoam and under 6 Feet of Fill (Original Design)

	Middle Point (A-2)		Quarter Point (A-1)		Close to Edge (B-1)	
	Pressure (psi)	Diff.	Pressure (psi)	Diff.	Pressure (psi)	Diff.
6 ft. Original Fill:	6.110		9.001		12.342	
9 ft. Fill with Geofoam:	6.501	6.391%	9.053	0.568%	12.784	3.584%

Table 3 compares pressures under 9-feet of fill (without geofoam) to pressures under 6-feet of fill. The pressures under 9 feet of fill are much higher than pressures under 6 feet of fill at all three points. The maximum difference is 25.9 percent and it occurs at the quarter point (A-1). The minimum difference occurs close to the edge (B-1) of the culvert and is 10.6 percent.

Table 3. Comparison of Pressures under 9 Feet of Fill without Geofoam and under 6 Feet of Fill (Original Design)

	Middle Point (A-2)		Quarter Point (A-1)		Close to Edge (B-1)	
	Pressure (psi)	Diff.	Pressure (psi)	Diff.	Pressure (psi)	Diff.
6 ft. Original Fill:	6.110		9.001		12.342	
9 ft. without Geofoam:	6.962	13.936%	11.330	25.864%	13.654	10.632%

Table 4 compares pressures under 7-feet of fill plus 2-feet of geofoam to pressures under 9-feet of fill without geofoam. The pressures under 7-feet of fill plus 2-feet of geofoam are lower than pressures under the 9-feet of fill at all three points. The maximum difference is 20.1 percent and occurs at the at quarter point (A-1). The minimum difference occurs close to the edge (B-1) of the culvert and is 6.4 percent..

Table 4. Comparison of Pressures under 9 Feet of Fill with Geofoam and under 9 Feet of Fill without Geofoam

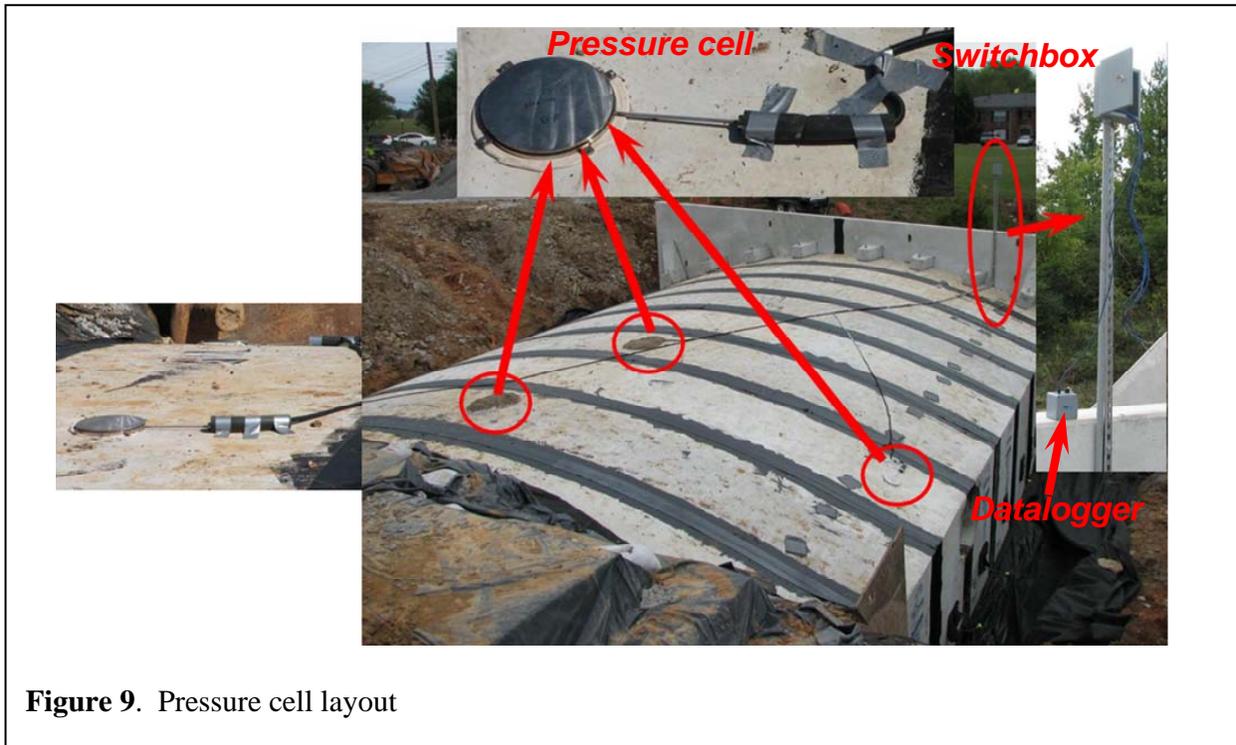
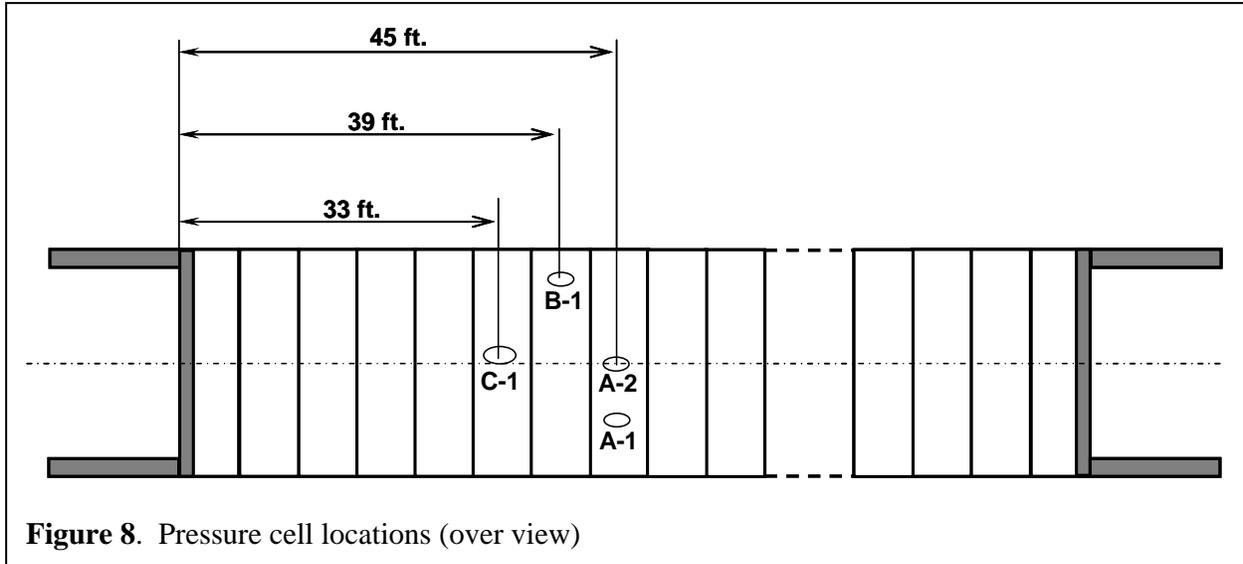
	Middle Point (A-2)		Quarter Point (A-1)		Close to Edge (B-1)	
	Pressure (psi)	Diff.	Pressure (psi)	Diff.	Pressure (psi)	Diff.
9 ft. without Geofoam:	6.962		11.330		13.654	
9 ft. Fill with Geofoam:	6.501	-6.622%	9.053	-20.098%	12.784	-6.371%

The three comparisons shown in Tables 2, 3, and 4 reveal the following:

1. Using geofoam does reduce the pressures on the culvert (Table 4).
2. Pressures measured under the 7-foot embankment fill and a 2-foot layer of geofoam were larger than pressures that would have existed under a 6-foot embankment fill (Table 2). Measured pressures ranged from 0.6 to 6.4 percent larger than the pressures that would have existed under a 6-foot embankment fill.

INSTRUMENTATION

Four pressure cells were installed on the top of the outside of the culvert (Figures 7, 8, and 9). The pressure cell wire was protected by flexible and PVC conduit, and grouped to a switch box located on the head wall at the culvert inlet. The pressure readout unit was a GK-403 manufactured by Geokon[®]. One Datalogger (one channel by Geokon[®]) is used for continuously collecting data from one of the four pressure cells. The switch box is mounted on one steel post which is fixed on the culvert headwall.



DATA COLLECTION, ANALYSIS, AND DISCUSSION

Readings of earth pressure on top of the culvert started at the beginning of October, 2007, when the contractor started filling operations. Data were collected every week during the first three weeks. After the initial three weeks, data were collected every ten days in an interval of thirty days. Since then, by-weekly data collection has continued.

Figure 10 shows the earth pressure history of the three pressure cell points on top of the culvert (Note: One of four pressure cells malfunctioned. Only three sets data are reported in this report). It indicates that pressure on the crest of arch is the most stable and lowest one. The pressure close to the top edge of the culvert is the highest and least stable one. Pressure on this point is relatively stable after the reading recorded on April 16, 2008. Pressures on all three points gradually decrease after April 1, 2008. Long-term monitoring will performed to observe this interesting trend.

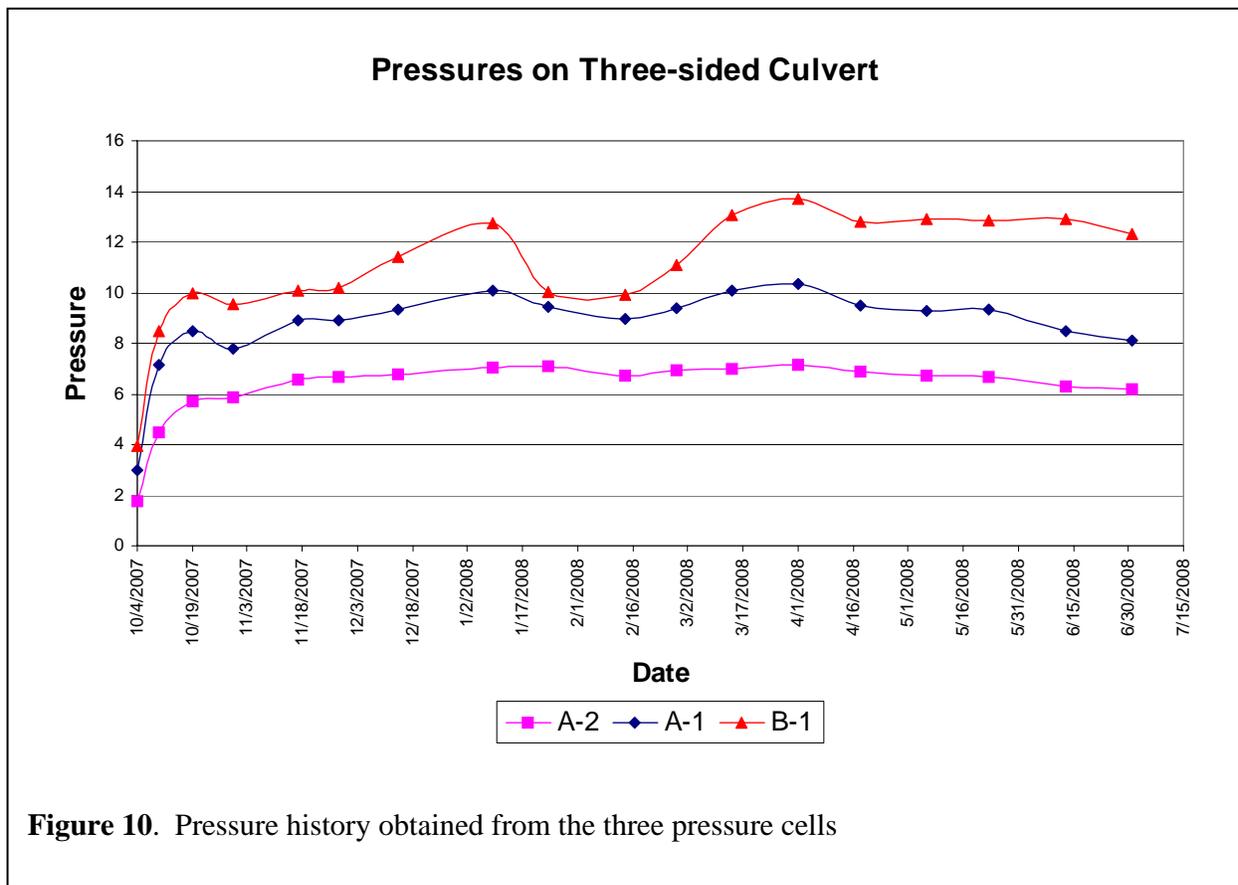


Figure 10. Pressure history obtained from the three pressure cells

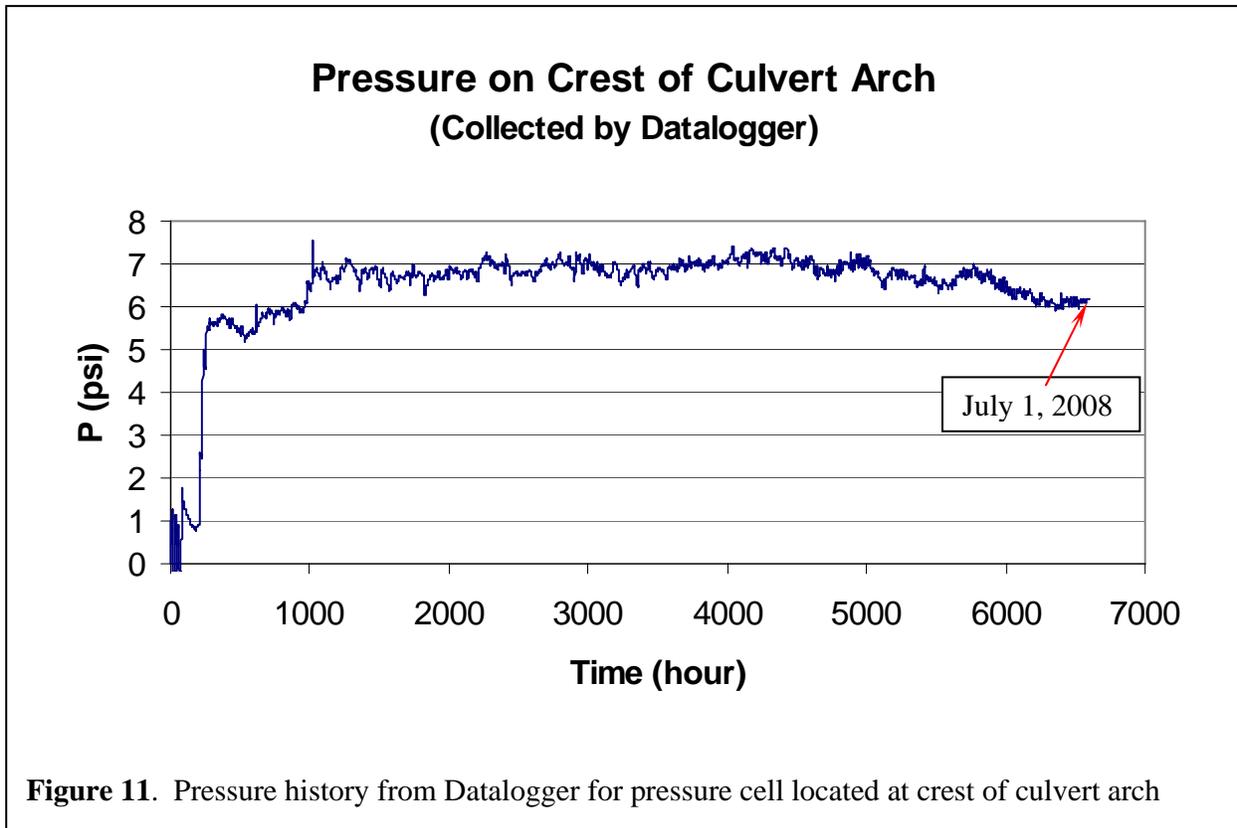


Figure 11. Pressure history from Datalogger for pressure cell located at crest of culvert arch

Figure 11 displays pressure history recorded by the Datalogger. Pressure readings are recorded automatically every two hours. The pressure cell at point of A-2 of the arch crest (see Figures 7 and 8) was traced by the Datalogger. There are some fluctuations in Figure 11. Overall, data from this pressure cell are relatively stable.

CONCLUSIONS

The averages of last five readings for all three pressure cells in Figure 10 were used to “calibrate” the numerical model. By using this numerical model, back calculations studying situations under the original design and with and without geofoam were performed. Conclusions are, as follows:

1. The use of lightweight geofoam reduced pressures acting on the culvert.
2. Pressures measured under the 7-foot embankment fill and a 2-foot layer of geofoam were larger than pressures that would have existed under a 6-foot embankment fill. Measured pressures ranged from 0.6 to 6.4 percent larger than the pressures that would have existed under a 6-foot embankment fill.

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