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**REDUCTION OF STRESSES ON THE BURIED RIGID HIGHWAY  
STRUCTURES USING THE IMPERFECT DITCH METHOD AND  
EXPANDED POLYSTYRENE (GEOFOAM)**





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# **REDUCTION OF STRESSES ON BURIED RIGID HIGHWAY STRUCTURES USING THE IMPERFECT DITCH METHOD AND EXPANDED POLYSTYRENE (GEOFOAM)**

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

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<b>16. Abstract</b> The study of earth pressure distribution on buried structures has a great practical importance in constructing highway embankments above pipes and culverts. Based on Spangler's research, the supporting strength of a conduit depends primarily on three factors: 1. the inherent strength of the conduit; 2. the distribution of the vertical load and bottom reaction; and, 3. the magnitude and distribution of lateral earth pressures which act against the sides of the structure. Considering high fills above them and high earth pressures they may experience, rigid culverts are usually used underneath highway embankments. To reduce high vertical earth pressures acting on a buried structure, ultra-lightweight Geofom will be placed above a culvert in the field, at Russell County, KY. Before construction began, numerical analysis using FLAC 4.00 (Fast Lagrangian Analysis of Continua) had been performed to predict stresses on the culvert. Results of the analysis show that Geofom has a great effect in reducing vertical stresses above and below the culvert. There are areas of high stress concentrations at the top and bottom of the concrete culvert if no Geofom was placed above the culvert. After placing Geofom above the culvert, the concentrated stress at the top can be reduced to 28 percent of the stress without Geofom. The high stress at the bottom of culvert can be reduced to 42 percent of the stress without Geofom. Stresses on the two sidewalls of the culvert were observed to have no significant change in values with and without Geofom.			
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**TABLE OF CONTENTS**

LIST OF FIGURES ..... vii

LIST OF TABLES ..... ix

EXECUTIVE SUMMARY ..... xi

INTRODUCTION ..... 1

OBJECTIVES ..... 2

SITE DESCRIPTION ..... 2

NUMERICAL ANALYSIS USING FLAC..... 4

    Numerical Model and Properties of Materials ..... 5

    Calibration of the Numerical Model ..... 5

    Analyses of Stresses on Culvert Using Different Sizes of EPS ..... 6

CONCLUSIONS AND DISCUSSIONS ..... 7

ACKNOWLEDGMENTS ..... 8

REFERENCES ..... 8



**LIST OF FIGURES**

Figure 1. Imperfect ditch culvert traditional installation ..... 2

Figure 2. Typical Stress-Strain curve for EPS ..... 2

Figure 3. Same width EPS on culvert..... 3

Figure 4. 1.5 times culvert width EPS..... 4

Figure 5. Model mesh..... 5

Figure 6. Calibration of the numerical model..... 6

Figure 7. Comparison of maximum pressures on culvert with and without EPS..... 6

Figure 8. Comparison of maximum moments on culvert with and without EPS ..... 7



**LIST OF TABLES**

Table 1. Material Properties.....5



## EXECUTIVE SUMMARY

Construction of highway embankments above highway pipes and culverts has a great practical significance because of stresses imposed by the fill on the buried structure. Relative stiffness of the culvert and fill controls the magnitude and distribution of earth pressures on the buried structure. The vertical earth pressure on a flexible culvert, or a culvert with a yielding foundation, is less than the weight of the soil above the culvert due to positive arching. However, the vertical earth pressure on a rigid culvert with a non-yielding foundation is greater than the weight of the soil above the structure because of negative arching. Based on Spangler's research, the supporting strength of a conduit depends primarily on three factors: first, the inherent strength of the conduit; second, the distribution of the vertical load and the bottom reaction; and third, the magnitude and distribution of lateral earth pressures which may act against the sides of the structure. To reduce large vertical earth pressures on buried structures, the imperfect ditch method of construction was introduced by Marston (Handy and Spangler, 1973). This method has considerable merit from the standpoint of minimizing the load on a culvert under an embankment. This method involves installing a compressible layer above the culvert within the backfill. Expanded polystyrene (EPS, or Geofoam) can be used as the compressible material to promote positive arching (Vaslestad et al., 1993). EPS has low stiffness and exhibits the desirable elastic-plastic behavior. To investigate different pressures on the culvert due to EPS (Geofoam), three different sections have been selected from the same culvert. On the first section, 2 feet of EPS is placed above the culvert. The width of EPS is the same as the top of the culvert. On the second section, EPS is placed above the culvert directly at 2 feet thickness and the width is 1.5 times the culvert width. The third section will be a conventional one, which is used as a reference section for the other two sections with EPS. These three sections will be instrumented to measure stresses on the top and sides. Strain of the top slab will also be measured. Three "sister" reinforcing steel bars containing strain gages will be placed in the culvert during construction. Twelve earth pressure cells will be placed on the top and one side of the structure. This analysis investigates the pressure changes when EPS is used on the top of the culvert using the two-dimensional finite difference program FLAC (Version 4.0, Itasca). A set of computer runs identified the optimal situation as a function of the EPS size and position. Results of the numerical analysis show that EPS has a great effect in reducing the vertical soil pressures above and below a culvert. When EPS is not placed above the culvert, areas of high stress concentrations occur at the top and bottom of the concrete culvert. After placing EPS above the culvert, the concentrated stress at the top of the culvert can be reduced to 28 percent of the concentrated stress without EPS. The highest stress at the bottom of culvert can be reduced to 42 percent of the highest stress without EPS. Whether EPS is used or not used, the model analysis shows that the maximum moment acting on the sidewall does not change significantly. Although the maximum moment acting on the sidewall is higher when EPS is used, the value is still below the design value used by the Kentucky Transportation Cabinet. The linear-elastic model was used to simulate the EPS stress-strain behavior in this numerical analysis. As pointed out earlier, the EPS exhibits desirable elastic-plastic behavior during compression. The EPS creates larger deformation, which makes bigger positive arching effect, under elastic-plastic model when stress on EPS is beyond elastic range. This positive arching effect will reduce pressure on the culvert even more.

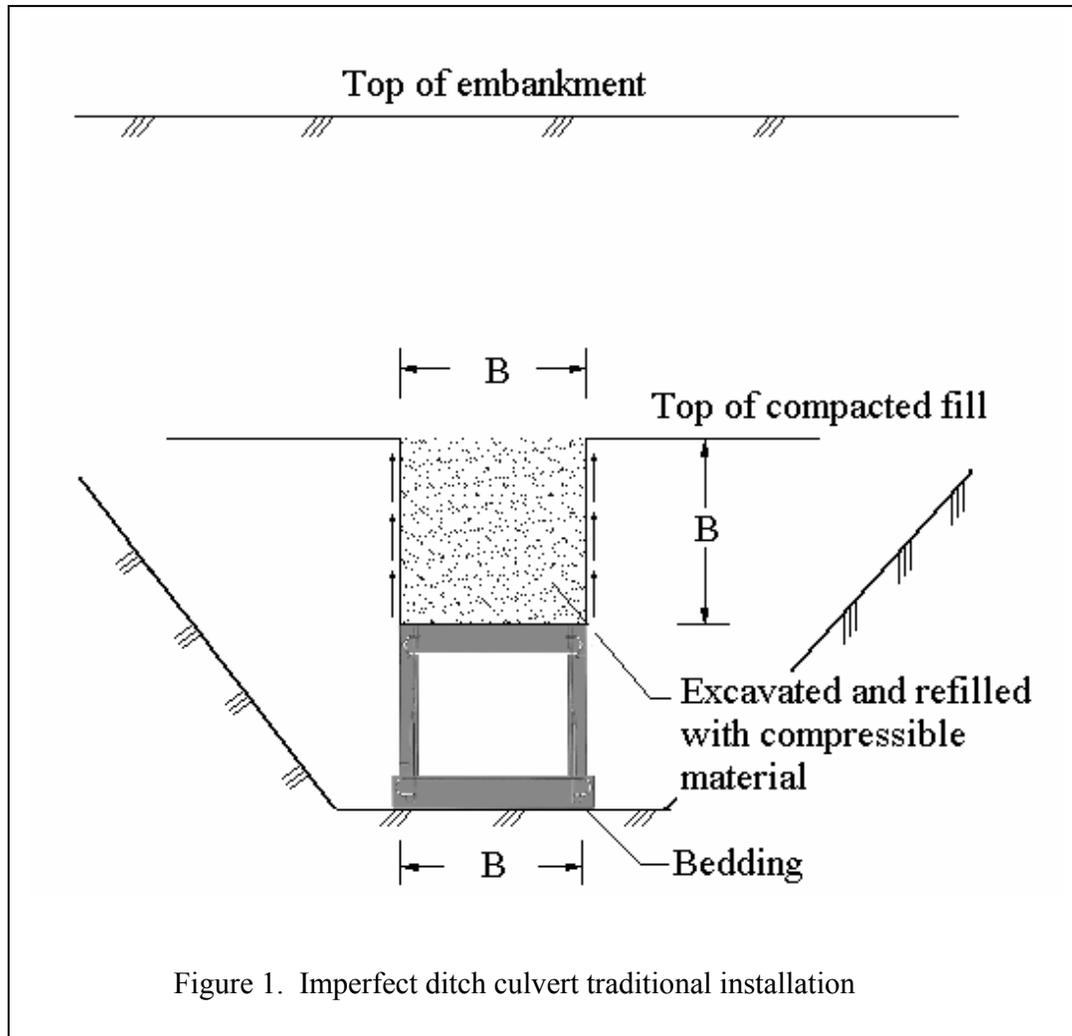
## INTRODUCTION

Construction of highway embankments above highway pipes and culverts has a great practical significance because of stresses imposed by the fill on the buried structure. Relative stiffness of the culvert and fill controls the magnitude and distribution of earth pressures on the buried structure. The vertical earth pressure on a flexible culvert, or a culvert with a yielding foundation, is less than the weight of the soil above the culvert due to positive arching. However, the vertical earth pressure on a rigid culvert with a non-yielding foundation is greater than the weight of the soil above the structure because of negative arching. Experiments by Marston (Spangler, 1958) showed that loads on rigid embankment culverts were some 90 to 95 percent greater than the weight of the soil directly above the structure. In model tests performed by Hoeg (1968), the crown pressure was about 1.5 times the applied surcharge. Penman et al. (1975) measured the earth pressure on a rigid reinforced concrete earth pressure below 174 feet of rock fill and found that the vertical earth pressure on the culvert crown was about 2 times the overburden stress due to the fill above the top of the culvert.

Based on Spangler's research, the supporting strength of a conduit depends primarily on three factors: first, the inherent strength of the conduit; second, the distribution of the vertical load and the bottom reaction; and third, the magnitude and distribution of lateral earth pressures which may act against the sides of the structure. The last two of those factors are greatly influenced by the character of the bedding on which the culvert is founded and by the backfilling against the sides. Considering the high fills above them and the high earth pressure they may experience, rigid culverts are usually used underneath highway embankments. To reduce large vertical earth pressures on buried structures, the imperfect ditch method of construction was introduced by Marston (Handy and Spangler, 1973). This method has considerable merit from the standpoint of minimizing the load on a culvert under an embankment. Figure 1 shows a sketch of the traditional installation of the imperfect ditch culvert.

This method involves installing a compressible layer above the culvert within the backfill. In field construction, the culvert is first installed as a positive projecting conduit and then surrounded by thoroughly compacted backfill. Next, a trench is dug in the compacted soil directly above the culvert. The trench is backfilled with compressible material, or organic fill, creating a soft zone. When the embankment is constructed, the soft zone compresses more than its surrounding fill, and thus positive arching is induced above the culvert. Traditionally, organic material such as baled straw, leaves, old tires (used in France), or compressible soil, have been used. Very little quantifiable data is available about the stress-strain properties of the soft organic materials. Also, the long-term stability and performance of the organic material was also questioned.

Expanded polystyrene (EPS, or Geof foam) can be used as the compressible material to promote positive arching (Vaslestad et al., 1993). EPS has low stiffness and exhibits the desirable elastic-plastic behavior. An unconfined compressive strength test was conducted on EPS by University of Kentucky Transportation Research Center and the result shows its stress-strain behavior is very similar to the one of an ideal elastic-plastic material (Figure 2). The maximum compressive strength of EPS obtained from the test is about 3.0 ksf. Young's modulus in the linear range is 133 ksf.

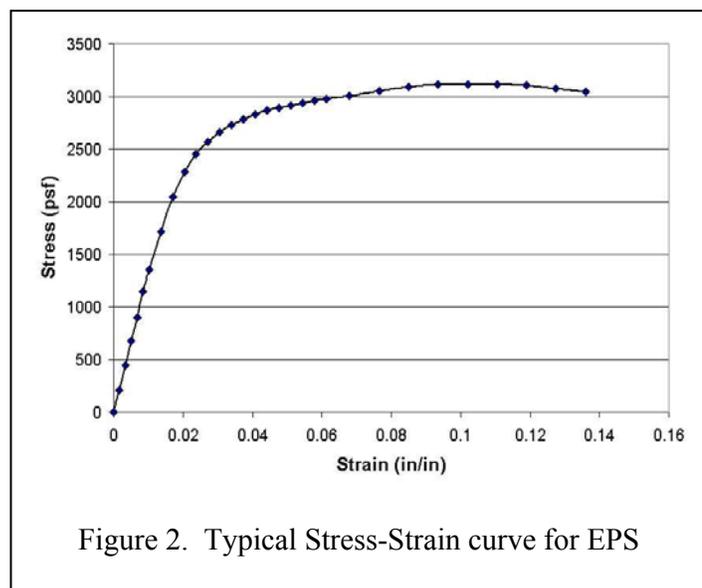


## OBJECTIVES

The objective of this study is to examine the use of expanded polystyrene (geofoam) and the imperfect ditch method for reducing the vertical stresses on rigid buried highway structures, such as pipes and culverts. In this interim report, theoretical analysis provide a firm confident result supporting in-situ test.

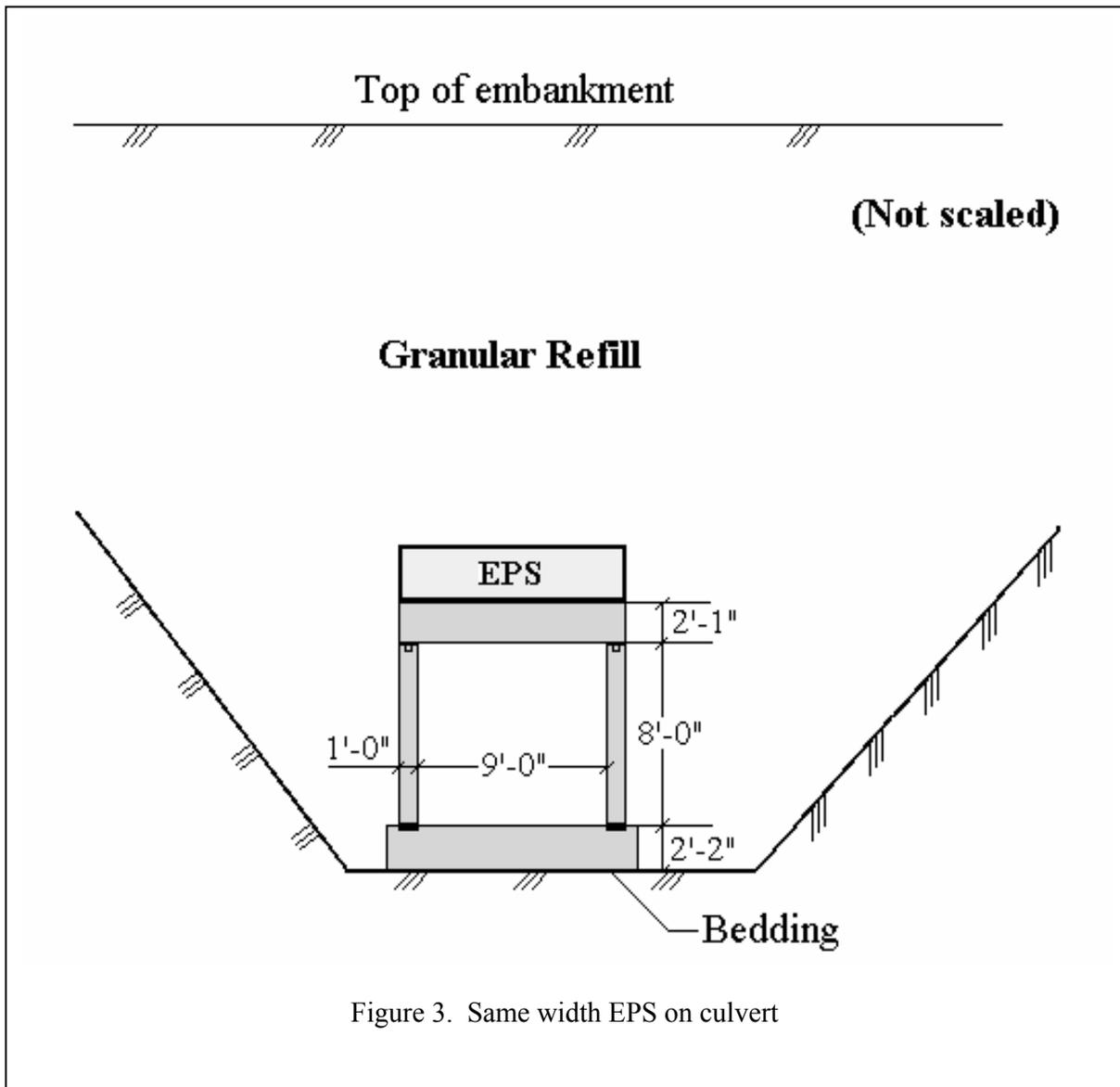
## SITE DESCRIPTION

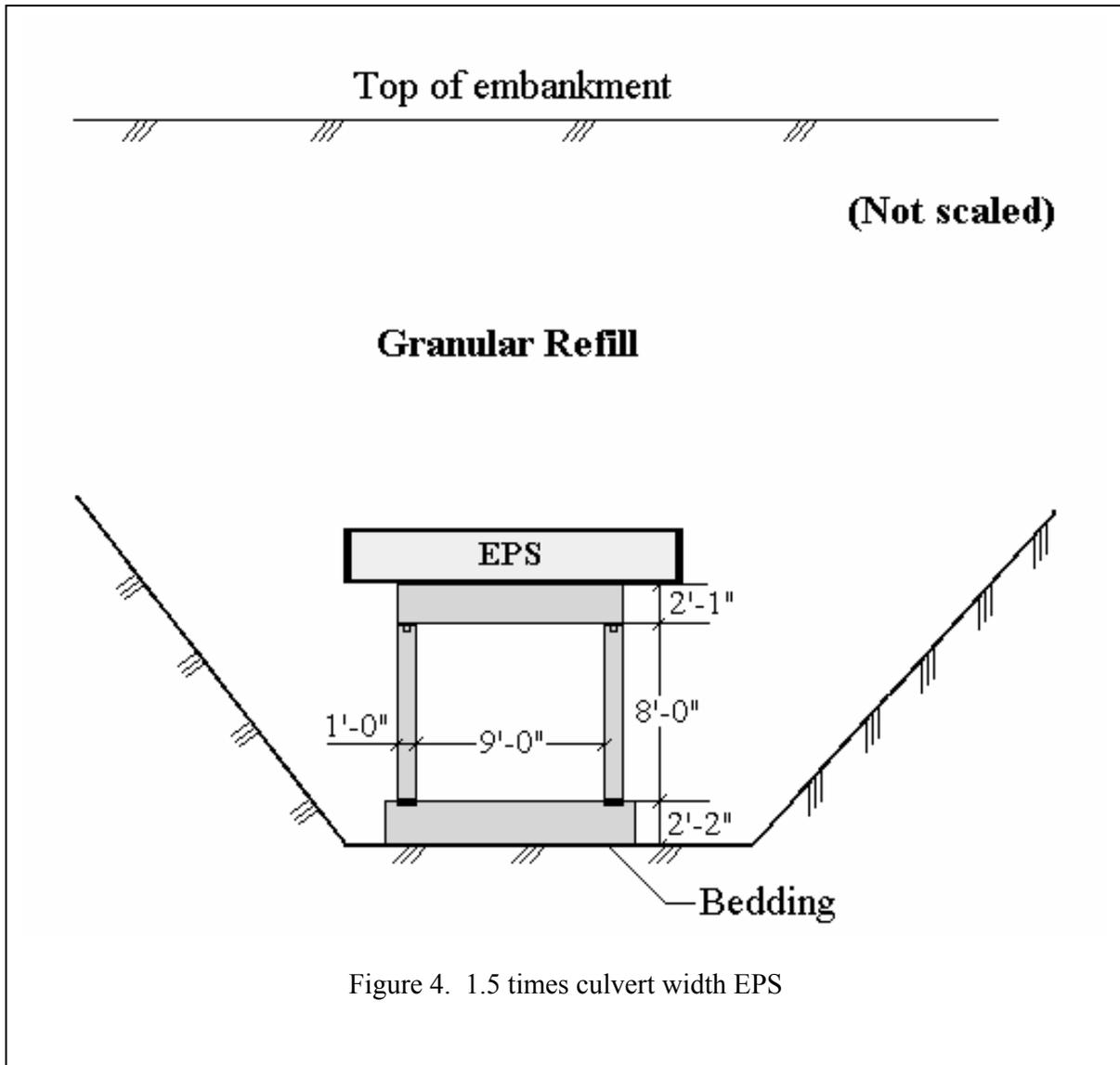
A culvert, selected for theoretical analyses and eventually instrumentation, is located on the Jamestown Bypass (US



127) in Russell County, Kentucky. Rock cores taken from this location revealed fossiliferous limestone with many shale laminations which the culvert will be constructed on. The culvert is a cast-in-place box culvert. The inner width of the structure is 9 feet and the wall thickness is 1 foot. The inner height is 8 feet and the ceiling thickness is 2 feet and 1 inch. The bottom thickness of the slab is 2 feet and 2 inches. It is continuously placed on an unyielding foundation, has a total length of 370 feet, and crosses a valley beneath an embankment of compacted backfill up to 54 feet above the culvert.

To investigate different pressures on the culvert due to EPS (Geofoam), three different sections have been selected from the same culvert. On the first section, 2 feet of EPS is placed above the culvert. The width of EPS is the same as the top of the culvert (11 feet) as shown in Figure 3. On the second section, EPS is placed above the culvert directly at 2 feet thickness and a width of 16 feet, which is 1.5 times the culvert width as shown in Figure 4. The length of both sections is 20 feet. The EPS sections are located where the fill is highest, 54 feet. The third





section will be a conventional one, which is used as a reference section for the other two sections with EPS. These three sections will be instrumented to measure stresses on the top and sides. Strain of the top slab will also be measured. Three “sister” reinforcing steel bars containing strain gages will be placed in the culvert during construction. Twelve earth pressure cells will be placed on the top and one side of the structure.

### NUMERICAL ANALYSIS USING FLAC

The purpose of this analysis is to investigate the pressure changes when EPS is used on the top of the culvert using the two-dimensional finite difference program FLAC (Version 4.0, Itasca). A set of computer runs identified the optimal situation as a function of the EPS size and position. Numerical analyses were also conducted to investigate the effects of using different combinations of elastic modulus, Poisson's ratio, cohesion, and angle of internal friction of the backfill.

## Numerical Model and Properties of Materials

Solving a problem using FLAC involves thousands of iterations. To speed up the iteration calculation, half space has been considered for this symmetrical problem (Figure 5). The culvert is treated as a beam element with hinges on upper and bottom corners. Interface elements are used between culvert and soils or EPS.

The properties of materials, except EPS, used in the analyses were based on data shown in the report by the Commonwealth of Kentucky Transportation Cabinet, Department of Highways, Division of Bridge Design. They represent typical values used in design practice.

The backfill soil was modeled as a cohesionless material using FLAC plastic constitutive model that corresponds to a Mohr-Coulomb failure criterion.

Bedrock and concrete were modeled as linear-elastic materials. Considering model availability in FLAC, EPS is also modeled as a linear-elastic material. In this imperfect ditch approach, this model will create more conservative results. The specific material properties used in the FLAC software are listed in Table 1.

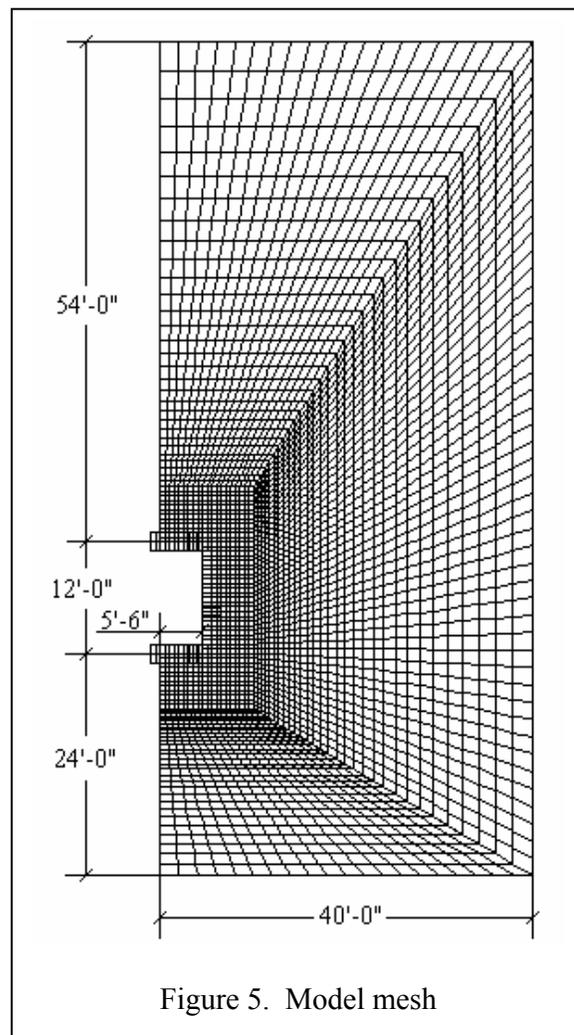


Figure 5. Model mesh

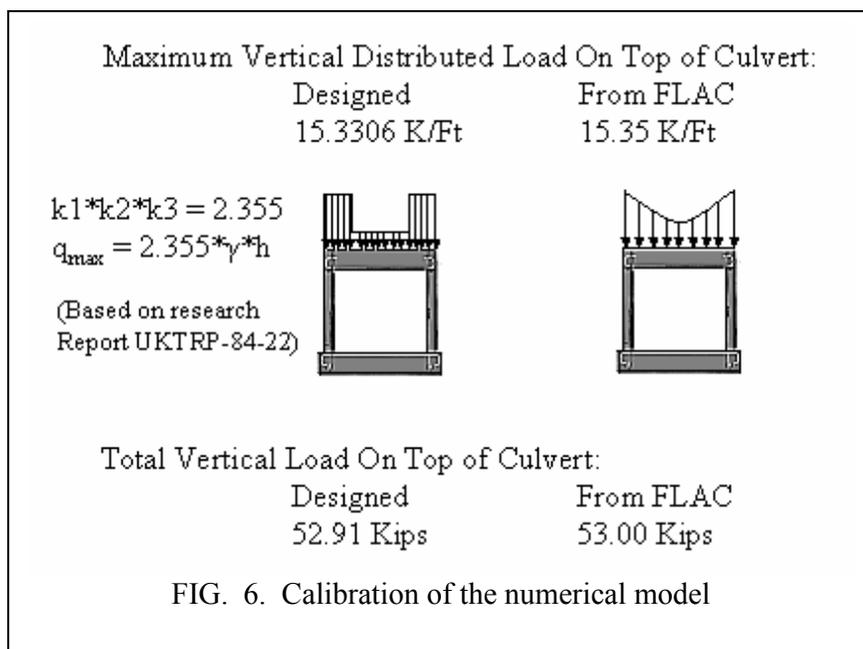
TABLE 1. Material Properties

Material (1)	Elastic Modulus E (psf) (2)	Poisson's Ratio $\nu$ (3)	Mass Density (pcf) (4)	Friction Angle $\phi$ (5)
Concrete	$543 \times 10^6$	0.35	156	
EPS	$0.133 \times 10^6$	0.1	1.35	
Sandy Gravel	$4.177 \times 10^6$	0.35	120	$34^\circ$
Bedrock	$108 \times 10^6$	0.25	120	

## Calibration of the Numerical Model

Roughly described properties used in job site backfill material yield some uncertain factors for numerical analysis. Varied sizes of EPS makes the analyses more complicated. Based on original design conditions, the numerical model was calibrated by adjusting interface parameters between culvert and backfill, and trying different combinations of elastic modulus, Poisson's ratio, and the angle of internal friction of the backfill. The maximum pressure and total vertical

load on top of the culvert obtained from numerical modeling are adjusted to the numbers shown in the report by the Commonwealth of Kentucky Transportation Cabinet, Department of Highways, Division of Bridge Design (Figure 6).

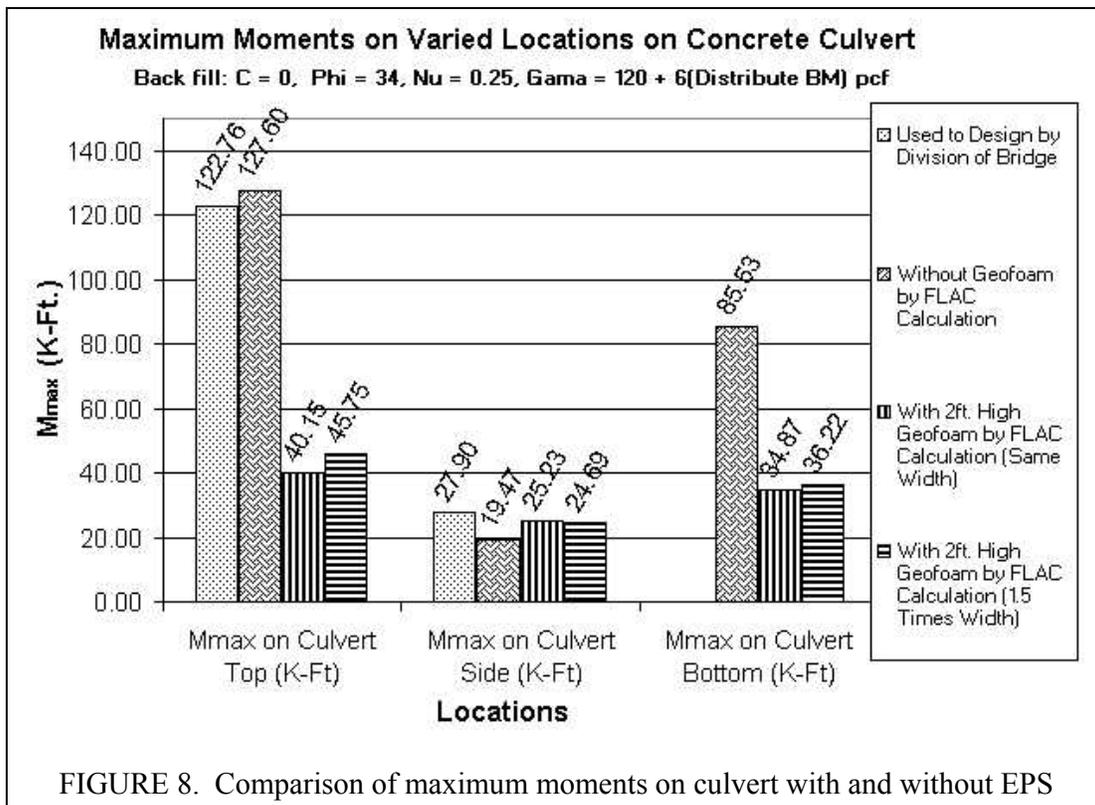
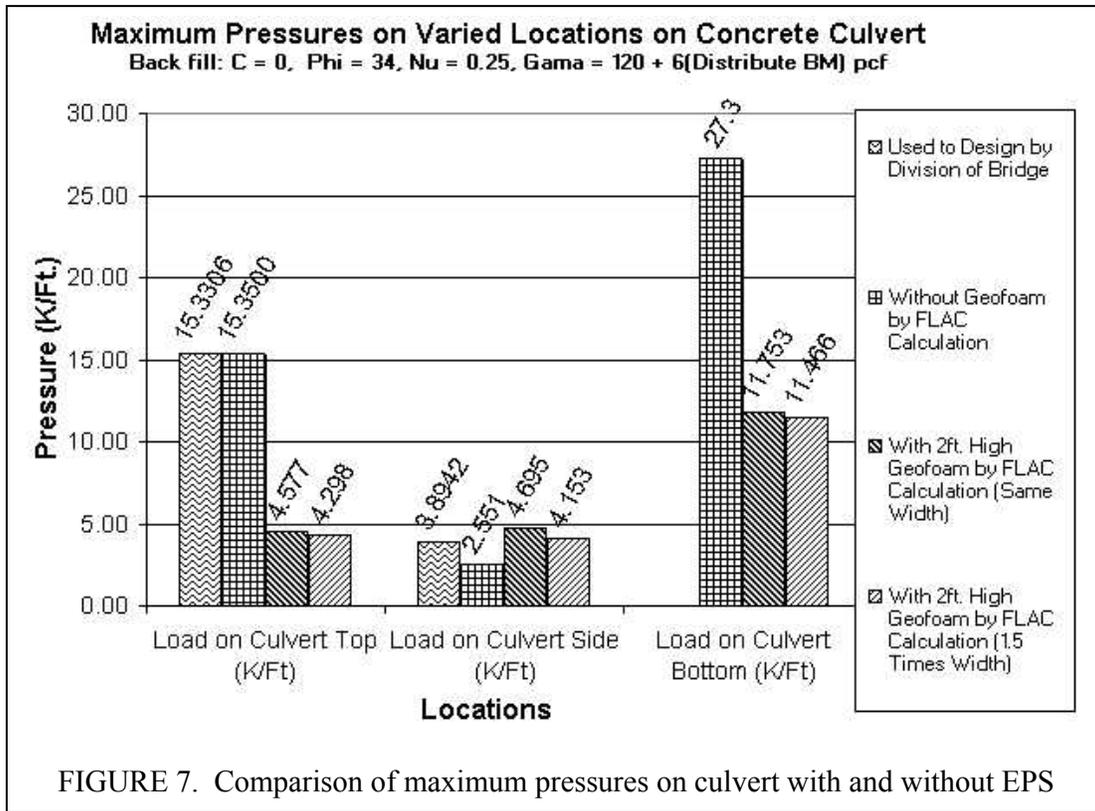


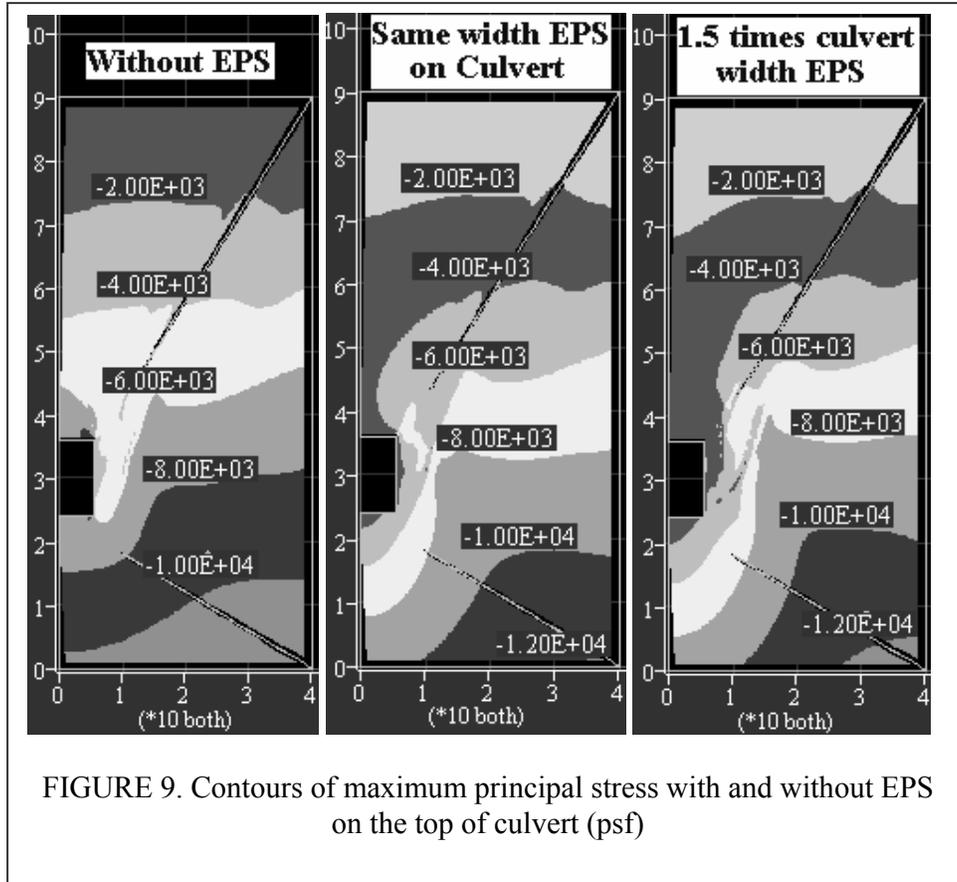
### Analyses of Stresses on Culvert Using Different Sizes of EPS

To investigate the effects on the earth pressure in a backfill using the imperfect ditch method, EPS is placed above the culvert directly. Two sets of parametric studies were used to investigate stress distributions with different combinations of elastic modulus, Poisson's ratio, cohesion, and friction angle for backfill under two different sizes of EPS (Figures 3 and 4). Typical results, corresponding to design loads, are shown in Figures 7 through 9.

The numerical results show that the maximum pressure at the top of culvert, with EPS width 1.5 times the culvert width, is reduced to 4.298 kips/ft, which is 28 percent of the maximum pressure without EPS. When width of EPS equals the width of culvert, the maximum pressure at the top of culvert is reduced to 4.577 kips/ft, which is 30 percent of the maximum pressure without EPS (Figure 7). The maximum moment on the top of culvert is decreased to 40.15 kip-ft/ft, which is 32 percent of the maximum moment without EPS (Figure 8). The interesting point is that the maximum moment is smaller when EPS width is the same as the culvert width (Figure 8). The possible reason to explain this result is that narrower EPS creates a larger arching effect.

The maximum pressure at the bottom of culvert is reduced to 11.466 kips/ft, when the EPS width is 1.5 times the culvert width, which is 42 percent of the pressure without EPS. In the situation where width of EPS equals to width of culvert, the maximum pressure at the bottom of culvert is reduced to 11.753 kips/ft, which is 43 percent of the maximum pressure without EPS (Figure 7). The maximum moment on the bottom of culvert is decreased to 34.87 kip-ft/ft, when width of EPS equals width of culvert, which is 41 percent of the maximum moment without EPS (Figure 8).





The maximum pressure on the sidewall of culvert is increased to 4.695 kips/ft, which is 84 percent more than the pressure without EPS, when EPS width equals culvert width. In the situation where width of EPS is 1.5 times the width of culvert, the maximum pressure on the sidewall of culvert is increased to 4.153 kips/ft, which is 63 percent more than the maximum pressure without EPS (Figure 7). But, comparing with the design load used by the Kentucky Transportation Cabinet, those values are increased 21 percent and 6.6 percent for the same EPS width as culvert width and EPS width being 1.5 times the culvert width, respectively. The maximum moment on the sidewall of the culvert was a 30 percent more when the widths of EPS and the culvert are the same. But, that value is still 9.6 percent lower than the design value used by the Kentucky Transportation Cabinet (Figure 8).

The stress reduction is also observed from contours of maximum principal stress as shown in Figure 9. Comparing stress contours between with and without geofoam, the lower stress zone is extended to culvert top, side, and bottom for the situations with geofoams. The wider the geofoam, the deeper the lower stress area is projected in this specific case.

## CONCLUSIONS AND DISCUSSIONS

Results of the numerical analysis show that EPS has a great effect in reducing the vertical soil pressures above and below a culvert. When EPS is not placed above the culvert, areas of high stress concentrations occur at the top and bottom of the concrete culvert. After placing EPS

above the culvert, the concentrated stress at the top of the culvert can be reduced to 28 percent of the concentrated stress without EPS. The highest stress at the bottom of culvert can be reduced to 42 percent of the highest stress without EPS. Whether EPS is used or not used, the model analysis shows that the maximum moment acting on the sidewall does not change significantly. Although the maximum moment acting on the sidewall is higher when EPS is used, the value is still below the design value used by the Kentucky Transportation Cabinet.

The linear-elastic model was used to simulate the EPS stress-strain behavior in this numerical analysis. As pointed out earlier, the EPS exhibits desirable elastic-plastic behavior during compression (Figure 2). The EPS creates larger deformation, which makes bigger positive arching effect, under elastic-plastic model when stress on EPS is beyond elastic range. This positive arching effect will reduce pressure on the culvert even more. The ground water table is an important factor but not yet considered in the analysis due to the lack of field information. Considering the high fills above the culvert, ground water table may be above the culvert and have some non-negligible effect on the stress distribution around the culvert.

### ACKNOWLEDGMENTS

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