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KENTUCKY TRANSPORTATION CENTER

College of Engineering

USE OF ULTRA-LIGHTWEIGHT GEOFOAM TO REDUCE STRESSES IN HIGHWAY CULVERT EXTENSIONS

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USE OF ULTRA-LIGHTWEIGHT GEOFOAM TO REDUCE STRESSES IN HIGHWAY CULVERT EXTENSIONS

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16. Abstract

Culvert extension under highway embankment construction is a regular and important practice when roadway widening occurs. At some existing sites, concrete thickness and reinforcing steel of culvert tops and walls were stepped-down in sections of the culvert under the embankment slopes. The part of the culvert positioned under the embankment slopes was constructed weaker because the stresses under the portions of the slopes are much less than the stresses acting on the culvert section located under the main portion of the embankment. When additional fill is placed over the culvert due to roadway widening, much greater stresses are imposed on the weaker portions of the culvert. To accommodate the increased stresses on the weaker portions of the culvert, lightweight material will be placed above the weaker portions of the culvert in the fields. Before construction begins, numerical analysis using FLAC 4.0 (Fast Lagrangian Analysis of Continua) was performed to predict stresses on the culvert. Results of the analysis show that geofoam 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 geofoam was placed above the culvert. Placing geofoam above the culvert reduces the concentrated stresses at the top and bottom significantly. The stress reduction is a function of the size of geofoam and the distance between top of culvert and geofoam. To obtain an optimal practical situation, a numerical model was created to thoroughly analyze these factors. By considering these factors, effectual curves are obtained from the numerical analysis. When geofoam is placed directly on top of the culvert, the results indicate that the concentrated stresses at the top and bottom will be minimized, but it will require excavating the fill and replacing it with geofoam. The optimal situation for each culvert should be analyzed case by case. On the other hand, foam concrete can reduce load on the culvert if it is placed correctly. Valuable results using geofoam and foam concrete to reduce loads on a culvert are discussed in this report.

17. Key Words **Stress reduction, culvert, Geofoam, EPS, numerical analysis, FLAC, Fast Lagrangian Analysis of Continua, buried structure, highway, embankment.**		**18. Distribution Statement** **Unlimited, with approval of the Kentucky Transportation Cabinet**	
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EXECUTIVE SUMMARY

Culvert extension under highway embankment construction is a regular and important practice when roadway widening occurs. At some existing sites, concrete thickness and reinforcing steel of culvert tops and walls were stepped-down in sections of the culvert under the embankment slopes. The part of the culvert positioned under the embankment slopes was constructed weaker because the stresses under the portions of the slopes are much less than the stress acting on the culvert section located under the main portion of the embankment. When additional fill is placed over the culvert due to roadway widening, much greater stresses are imposed on the weaker portions of the culvert.

To accommodate the increased stresses on the weaker portions of the culvert, lightweight material will be placed above the weaker portions of the culvert in the field. Before construction begins, numerical analysis was performed using FLAC 4.0 (Fast Lagrangian Analysis of Continua) to predict stresses on the culvert. Results of the analysis show that geofoam, or EPS, is very effective in reducing vertical stresses above and below the culvert. Areas of high stress concentrations exist at the top and bottom of the concrete culvert when geofoam is not placed above the culvert. Placing geofoam above the culvert reduces the concentrated stresses at the top and bottom significantly. A softer EPS is more efficient than harder EPS in reducing loads on a culvert. Using a softer EPS creates more deformation under fill soil pressures than a harder EPS. The increased deformation from the softer EPS generates a stronger arching effect above the culvert. Therefore, loads on the culvert will be reduced more notably.

Stress reduction is a function of the size of geofoam and the distance between the top of the culvert and geofoam. To obtain an optimal practical situation, a set of numerical models was created to thoroughly analyze these factors. By considering these factors, effectual curves are obtained from the numerical analysis. When geofoam is placed directly on top of culvert, the results indicate that the concentrated stresses at the top and bottom will be minimized, but it will require excavating the fill and replacing it with geofoam. The optimal situation for each culvert should be analyzed case by case.

For comparison, foam concrete is analyzed to determine the effectiveness of this material in reducing loads on a culvert. Both lightweight materials, EPS and foam concrete, can be used to reduce loads on a culvert if they are used correctly. In the situation of placing lightweight material above the culvert only, opposite trends are observed between foam concrete and EPS. A certain width of foam concrete is required to reduce loads on a culvert when foam concrete is placed directly on the culvert. Otherwise, loads on the culvert are increased. Placing EPS above the culvert is more efficient in reducing loads on the culvert than placing foam concrete when the widths of EPS and foamed concrete are equal. Even the thickness of EPS is thinner than the thickness of foam concrete. In the case of placing lightweight materials around all sides of the culvert, EPS and foam concrete function different mechanically in reducing loads on a culvert. When foam concrete is used, it strengthens the culvert, as indicated by the analysis. As the thickness of the foam concrete is increased, the whole structure (the original culvert plus the added foam concrete) becomes stronger. In contrast to the mechanical behavior of the foam concrete, EPS used in a manner similar to the foam concrete creates an arching effect. The arching effect redistributes the load in the surrounding fill soil adjacent to the culvert walls. A 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 a larger deformation, which produces a bigger positive arching effect, as shown by the assumed elastic-plastic model when stress on the EPS is beyond the elastic range. This positive arching effect will reduce pressure on the culvert even more.

INTRODUCTION

Culvert extension (Figure 1) under highway embankment construction is a regular and important practice when roadway widening occurs. At some existing sites, the thicknesses of culvert ceiling and walls were stepped-down in size when portions of the culvert were located under the embankment slopes. In this situation, parts of the culvert positioned under the embankment slopes were designed for smaller loads than those acting on the culvert located under the main portion of the embankment. However, when roadway widening occurs much larger loads are imposed on the weaker portions of the culvert due to additional weight of added fill. To accommodate the increased loads on the weaker portion of the culvert, ultra-lightweight geofoam will be placed around the weaker portions of a culvert.

Based on Spangler's research (Spangler, 1958), the supporting strength of a buried structure depends primarily on three factors: the inherent strength of the buried structure; the distribution of the vertical load and the bottom reaction; and the magnitude and distribution of lateral earth pressures, which may act against the sides of the structure. The latter two factors are greatly influenced by the character of the bedding on which the buried structure is founded and by the backfilling against the culvert sides. The relative stiffness of the buried structure and materials placed around it controls the magnitude and distribution of earth pressures on the buried structure. To reduce large vertical earth pressures on buried structures, the imperfect ditch method of construction introduced by Marston (Handy and Spangler, 1973) can be used. This method has considerable merit from the standpoint of minimizing the load on a culvert under an embankment. Expanded polystyrene (EPS, or geofoam) can be used as the compressible material in the ditch above the top of the culvert to promote positive arching (Vaslestad et al., 1993). EPS has low stiffness and exhibits a desirable elastic-plastic behavior. When the embankment is constructed, the soft zone compresses more than its surrounding fill, and thus positive arching is induced above the culvert. Areas of high stress concentrations exist at the top and bottom of the concrete culvert when the imperfect ditch, backfilled with a compressible

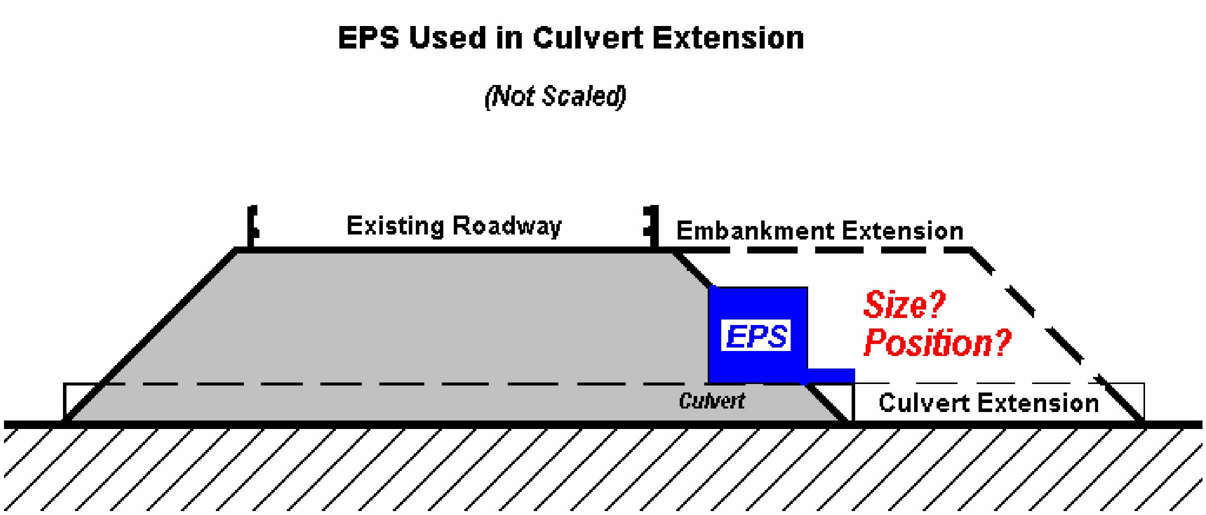

Figure 1. Culver extension

material, such as geofoam, is not used above the culvert. Placing geofoam above the culvert reduces the concentrated stresses at the top and bottom significantly (Sun et al., 2005). The stress reduction is a function of the size of geofoam and the distance between top of culvert and geofoam. To thoroughly analyze theses factors and obtain an optimal practical situation, various numerical models were created, analyzed, and discussed as follows.

OBJECTIVES

The objectives of this study are to examine the use of geofoam as an alternative lightweight material when roadways are widened and culverts, which were built employing the stepped down method of construction, must be extended, and to develop guidelines for using ultra-lightweight geofoam in highway culvert extension design. In this interim report, the loads on the top, sidewall, and bottom of the culvert were studied. Two different fill materials, sandy with silty clay and Russell Clay, were investigated. Different sizes of geofoam and varied distances between geofoam and culvert were examined in numerical models. By considering all factors above, effectual curves were obtained from the numerical analysis. Foam concrete and geofoam were built into two sets of models created from two sections cut from a real culvert extension project. Comparisons of load reduction data were obtained and discussed.

NUMERICAL ANALYSIS USING FLAC

Design of a culvert extension requires the consideration of existing culvert parameters and surrounding conditions. The purpose of this analysis is to investigate load changes created by the placement of EPS around the culvert. To examine the load changes, a two-dimensional, finite difference computer program, FLAC (Version 4.0, Itasca) was used. By varying the size of EPS, distance between culvert top and EPS bottom, and height of the extended fill, hundreds of numerical analyses were performed to identify the optimal situation as a function of the EPS size and position. Numerical analyses were also conducted to investigate the effect 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, a half space was considered for this symmetrical problem. Four different fill heights were modeled to investigate the effect of varying the fill height (Figure 2). Models were evenly meshed for easily changing the position of EPS. The culvert was treated as a beam element with hinges on the upper and bottom corners. Interface elements were used between the culvert and soils or EPS.

Properties of concrete, Sandy with Silty or Clayey Material, 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. EPS and Soft EPS are two typical geofoams available on market. Russell clay is an in situ fill soil used in Russell County,

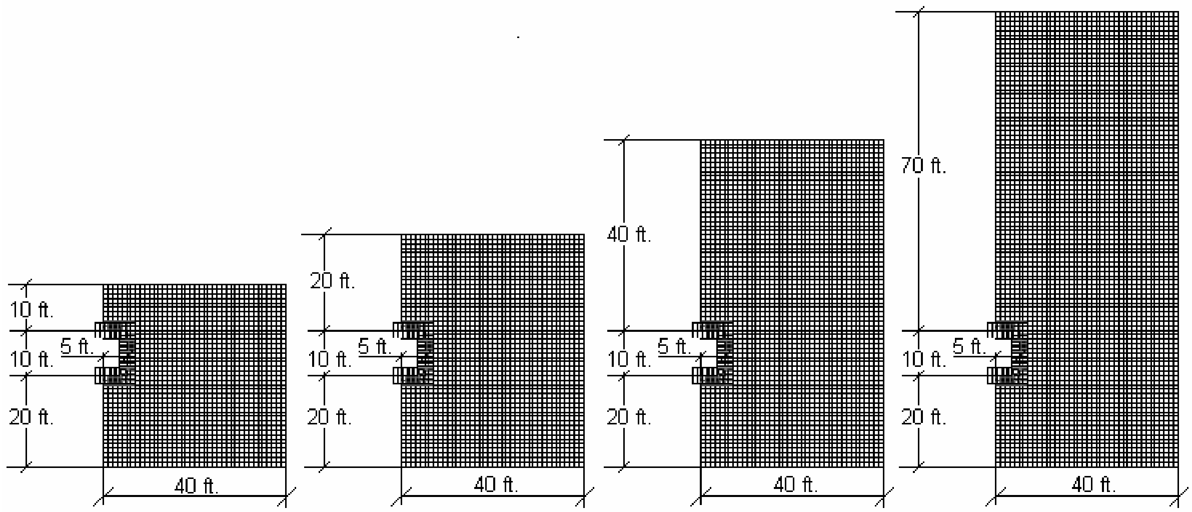

Figure 2. Numerical models for parametric studies

Kentucky around the culvert. 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, EPS and soft EPS (smaller density) were also modeled as linear-elastic materials. 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.

Table 1. Material Properties

Material	Elastic Modulus E		Poisson's	Mass Density		Cohesion C		Frictio
	(psf)	(MPa)	Ratio υ	(pcf)	(kg/m³)	(psf)	(kPa)	ϕ
Concrete	5.43E+08	26000	0.35	156	2499			
Foam Concrete (45)	2.26E+07	1081.33	0.2	45	721			
EPS	1.33E+05	6.36	0.1	1.35	22			
Soft EPS	1.33E+04	0.64	0.1	1.26	20			
Sandy with Silty	8.35E+05	40	0.25	131	2100	2.09E+01	1	35
Russell Clay	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°

Analyses of Loads on Culvert Using Different Sizes of EPS at Varied Positions

To investigate the effects of earth pressure on the buried structure for the culvert extension case, different thicknesses of EPS were placed at selected distances above the top of the culvert. To reduce load acting on the culvert wall, EPS measuring 2 feet in width was placed at the side of the culvert. The load reductions were greatly influenced by the fill soil. Two types of fill soils, Sandy with Silty or Clayey Materials and Russell clay, were modeled and analyzed.

Load reduction using sandy with silty as fill soil

Typical results using the sandy with silty or clayey soil as fill material, paired with different combinations, are shown in Figures 3 through 16.

As shown in Figure 3, the maximum moment reductions on top and bottom of the culvert exhibit the same reduction trends, that is, as the distance between the top of the culvert and soft EPS decreases, the moment reduction increases in both cases. The amount of reduction of the top moment for this particular case decreased from 41.2 percent to 14.6 percent when distances between the top of the culvert and EPS ranged from 0 to 10 feet. Reduction of maximum moment on the culvert sidewall exhibited a trend opposite to the trend observed for changes in the top and bottom moments. When distances between the culvert and EPS ranged from 0 to 10 feet the amount of reduction of the maximum moment increased from 20.6 to 26.7 percent.

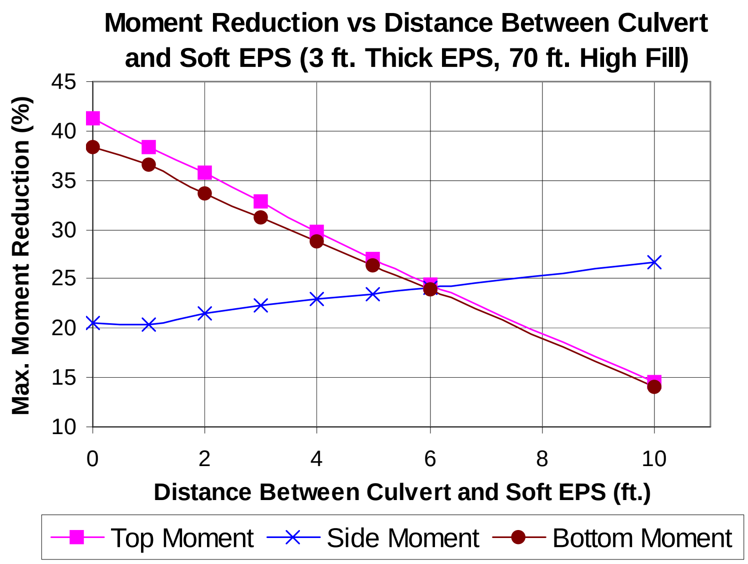

Figure 3. Moment reduction trends around culvert when soft EPS is used for sandy with silty

Changes of the maximum moment at the top of the culvert under a fill height of 70 feet versus the variation of EPS thicknesses are shown in Figure 4. As the EPS thickness increases, the reduction of the maximum top moment increases. The moment reduction includes the effects of two factors: weight reduction, due to ultra light EPS replacing a much heavier soil in the trench and the arching effect. Moment reduction due to the arching effect only is shown in Figure 5. As shown in Figure 5, the top moment reduction gradient of EPS thicknesses ranging from 6 to 10 feet is much smaller than the reduction gradient occurring for EPS thicknesses ranging from 2 to 6 feet. This means that the top moment reduction due to the arching effect will not increase after a certain thickness of EPS is reached. The maximum moment reduction on the sidewall, contrary to maximum moment at the top of the culvert, will decrease as the EPS thickness

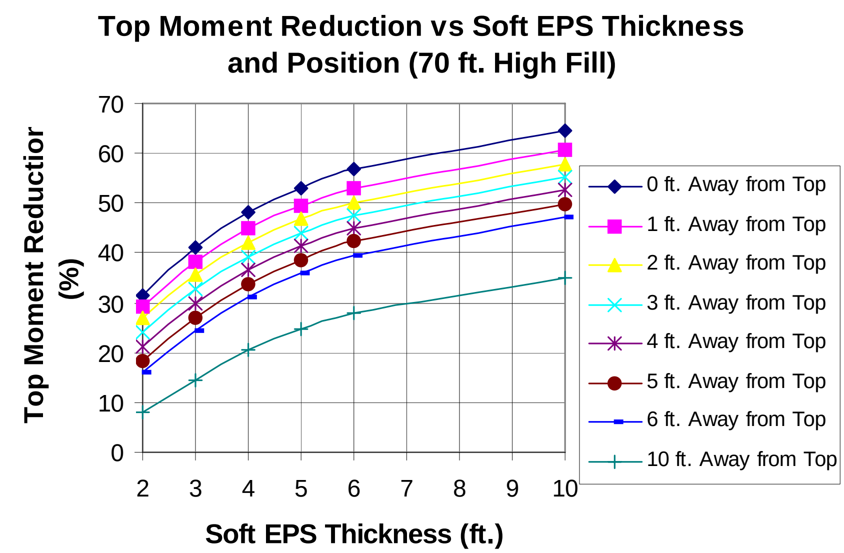

Figure 4. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (High Sandy with Silty fill)

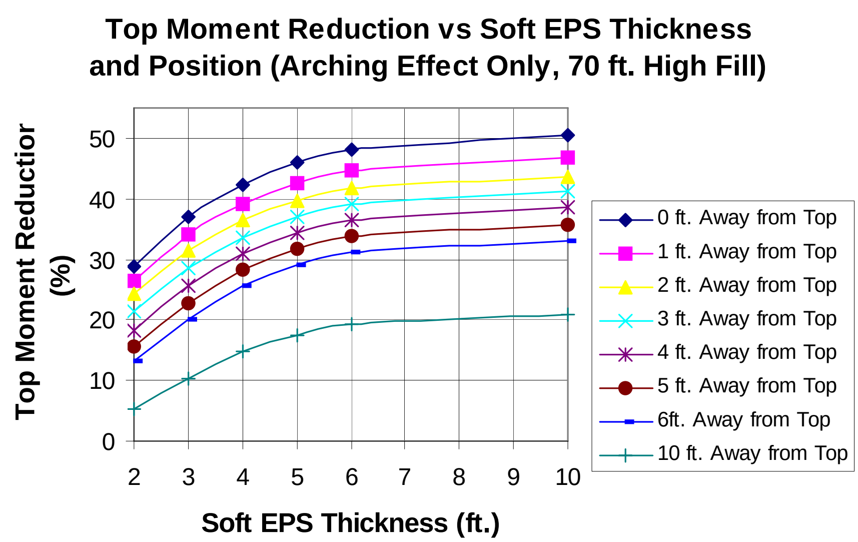

Figure 5. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (High Sandy with Silty fill; Arching effect only)

increases (see Figure 6), and, will step up when distance between EPS and top of culvert increases (see Figure 7).

For a culvert under a fill height of 20 feet, the trend of total moment reduction, including weight reduction and arching effect, is directly proportional to EPS thickness growth (Figure 8).

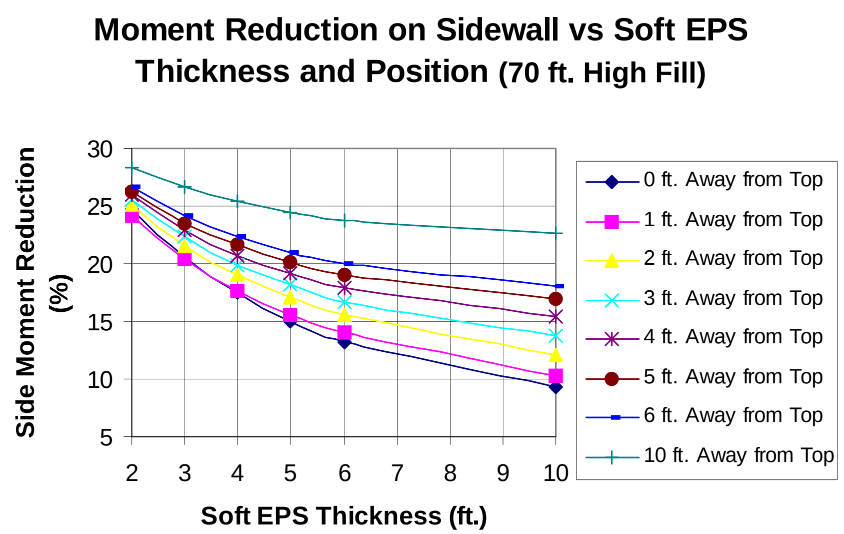

Figure 6. Changes of maximum moment reduction on sidewall of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (High Sandy with Silty fill)

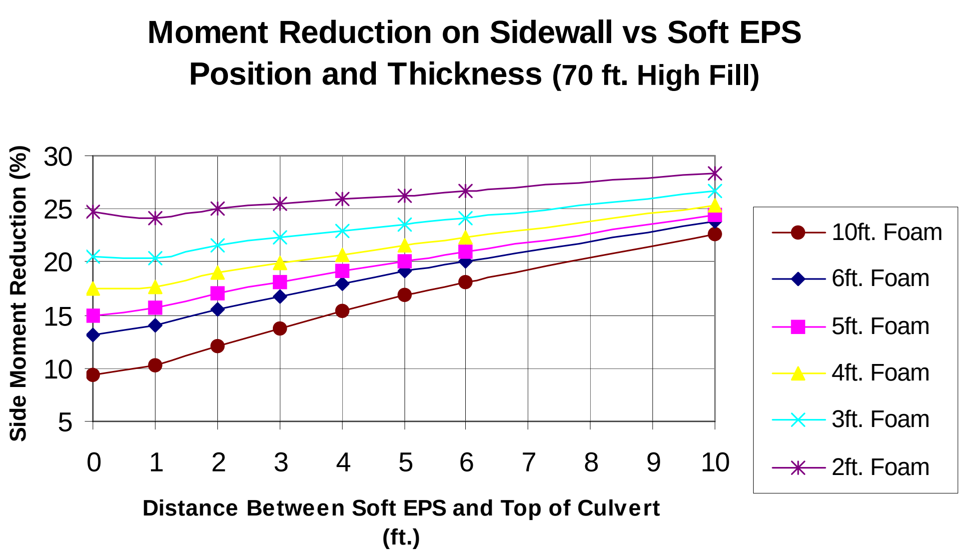

Figure 7. Changes of maximum moment reduction on sidewall of culvert as a function of distance between soft EPS and culvert and soft EPS thickness (High Sandy with Silty fill)

However, as shown in Figure 9, reduction of the maximum top moment decreases when EPS thickness exceeds 5 feet. That means, in this particular case of a fill height of 20 feet, benefits obtained from the arching effect diminish after the thickness exceeds 5 feet. The maximum moment reduction on the sidewall has a similar trend as that under a 70-foot high fill (Figures 10 and 11).

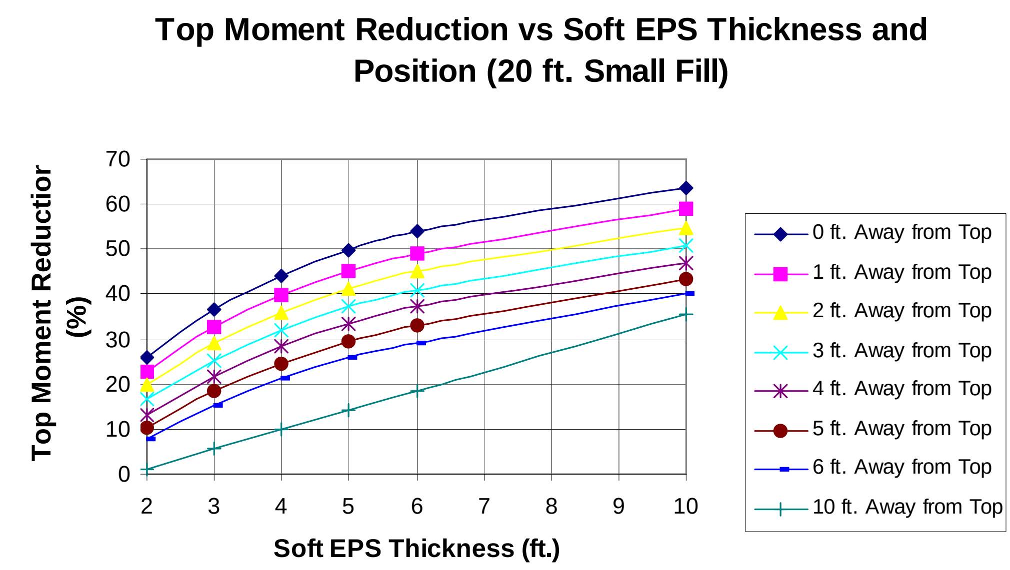

Figure 8. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (Small Sandy with Silty Fill)

Based on a constant thickness of 10 feet of EPS, relationships between total reduction of maximum top moment and fill height are shown in Figure 12. Total reduction of the top moment for a selected distance between EPS and culvert does not significantly change as the height of fill increases. In contrast, as shown in Figure 13, the arching effect plays a more important role as the fill height increases. This indicates that the unit weight factor of EPS is predominately more

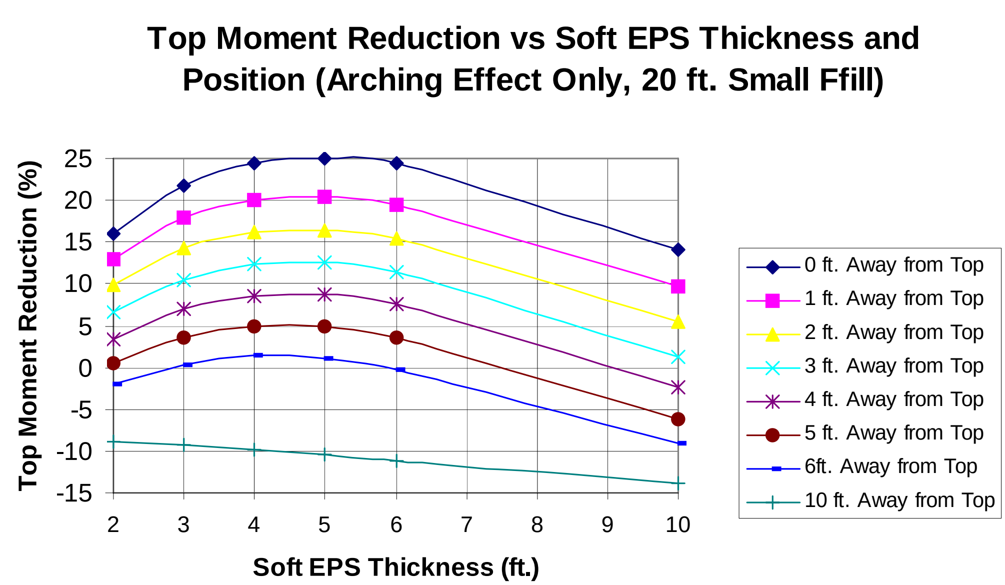

Figure 9. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (Small Sandy with Silty fill; Arching effect only)

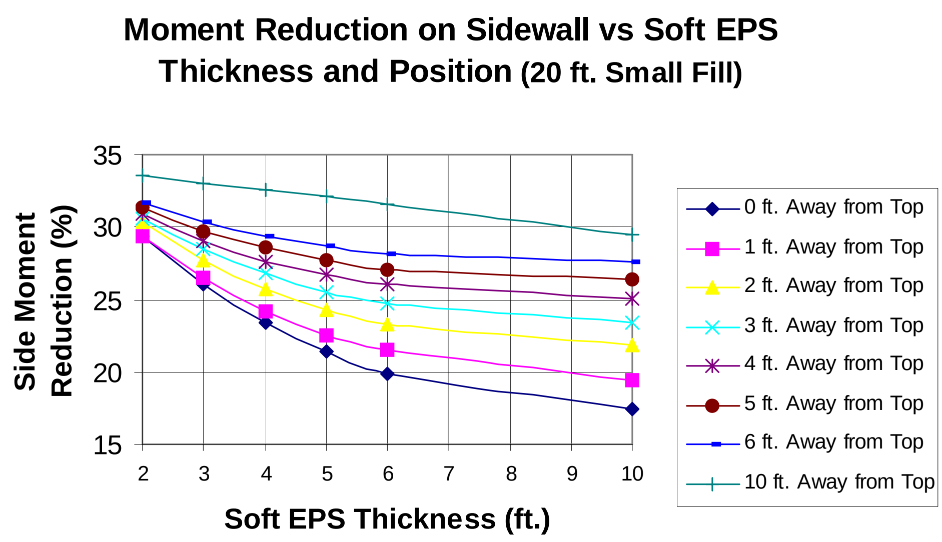

Figure 10. Changes of maximum moment reduction on sidewall of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (Small Sandy with Silty fill)

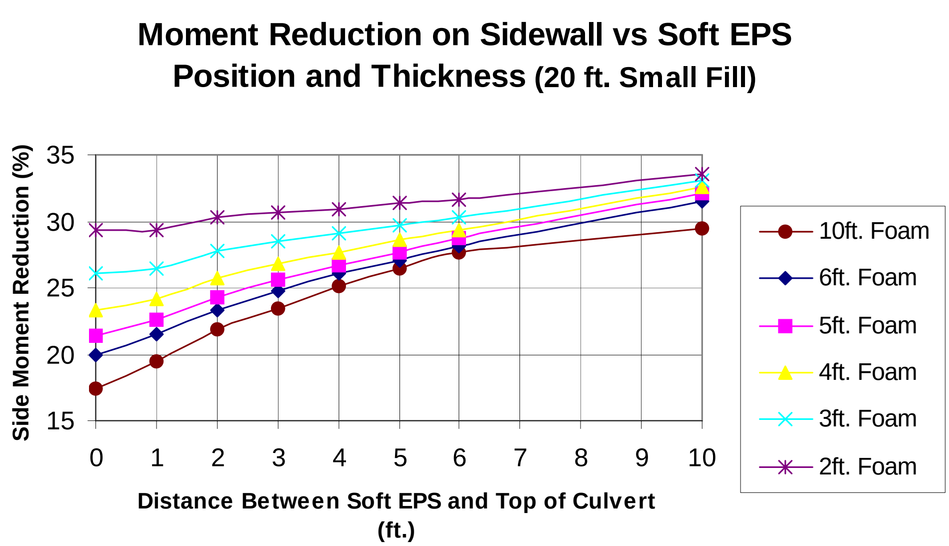

Figure 11. Changes of maximum moment reduction on sidewall of culvert as a function of distance between soft EPS and culvert and soft EPS thickness (Small Sandy with Silty fill)

important than the arching affect when the fill height is small. When the fill heights are much larger, arching is more effective than unit weight in reducing the top culvert moment. As shown in Figure 14, the maximum moment reduction on the sidewall will be linear and becomes smaller as the fill height increases. As shown in Figure 15, the maximum moment reduction on the sidewall rises when the distance between EPS and top of culvert increases.

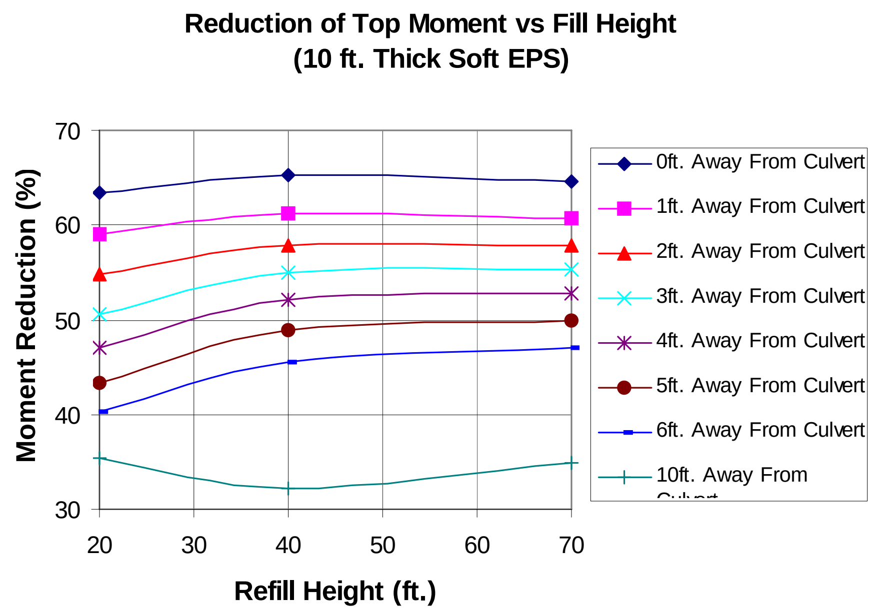

Figure 12. Changes of maximum moment reduction on top of culvert as a function of fill height and distance between soft EPS and culvert (Sandy with Silty fill)

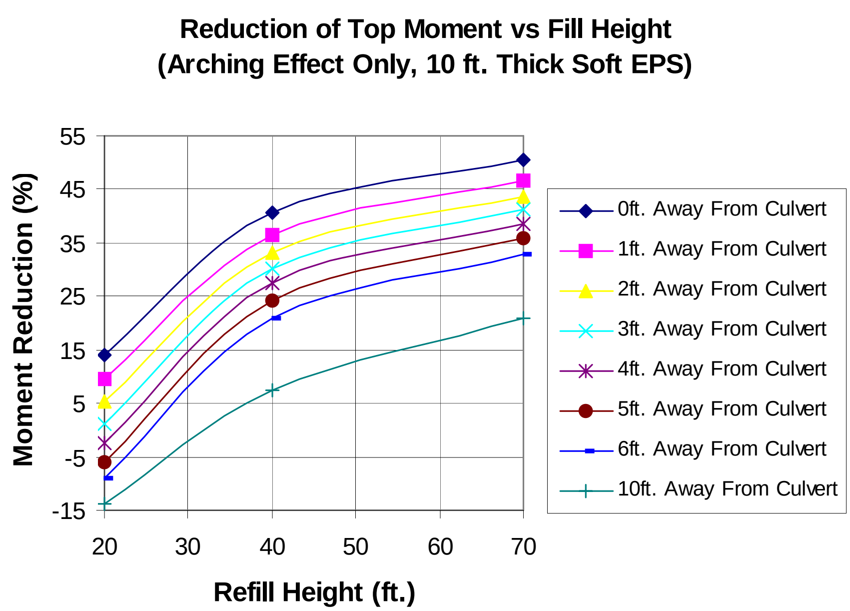

Figure 13. Changes of maximum moment reduction on top of culvert as a function of refill height and distance between soft EPS and culvert (Sandy with Silty fill, arching effect only)

Load reduction is also observed from contours of maximum principal stress, as shown in Figure 16. Comparing stress contours of culverts with and without EPS, the lower stress zone is extended to the culvert top, side, and bottom for the situations with EPS. The thicker the EPS, the deeper the lower stress area is projected in this specific case. In the case where EPS is not

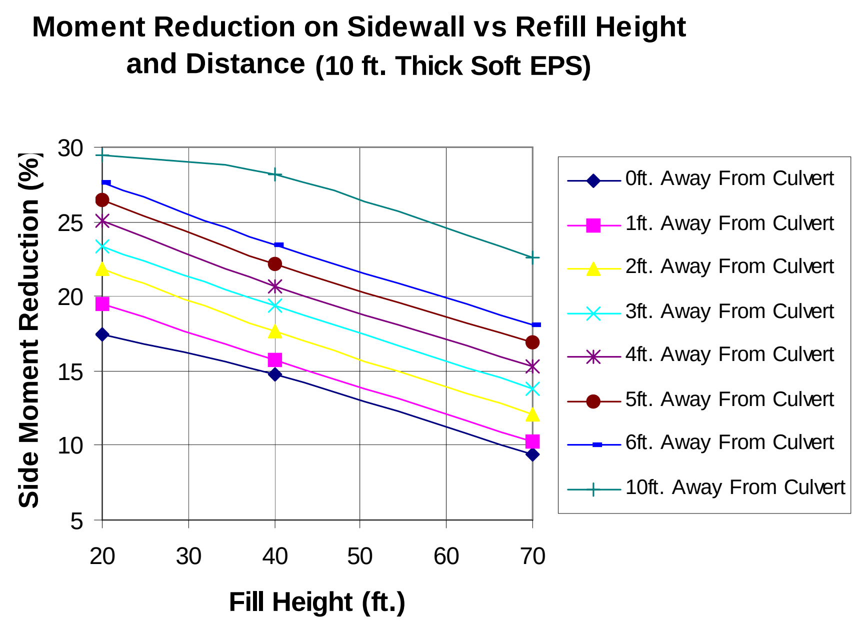

Figure 14. Changes of maximum moment reduction on sidewall of culvert as a function of fill height and distance between soft EPS and culvert (Sandy with Silty fill)

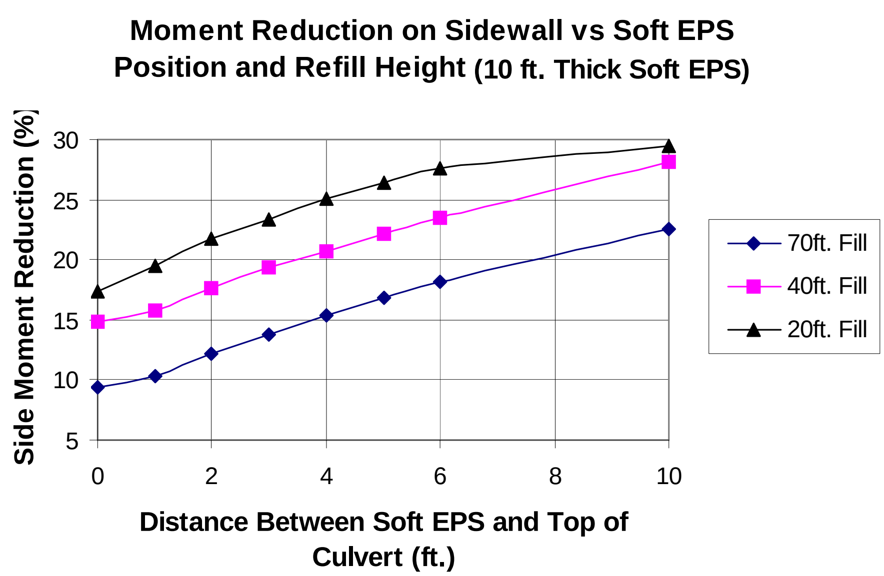

Figure 15. Changes of maximum moment reduction on sidewall of culvert as a function of distance between soft EPS and culvert and fill height (Sandy with Silty fill)

used around the culvert, the stress concentration is observed on the culvert top. When EPS of a thickness of 2 feet is placed on the top of culvert, the stress concentration on the top of culvert is almost removed. There is small stress concentration only on a small area around the culvert corner (see middle contour of principal stress in Figure 16).

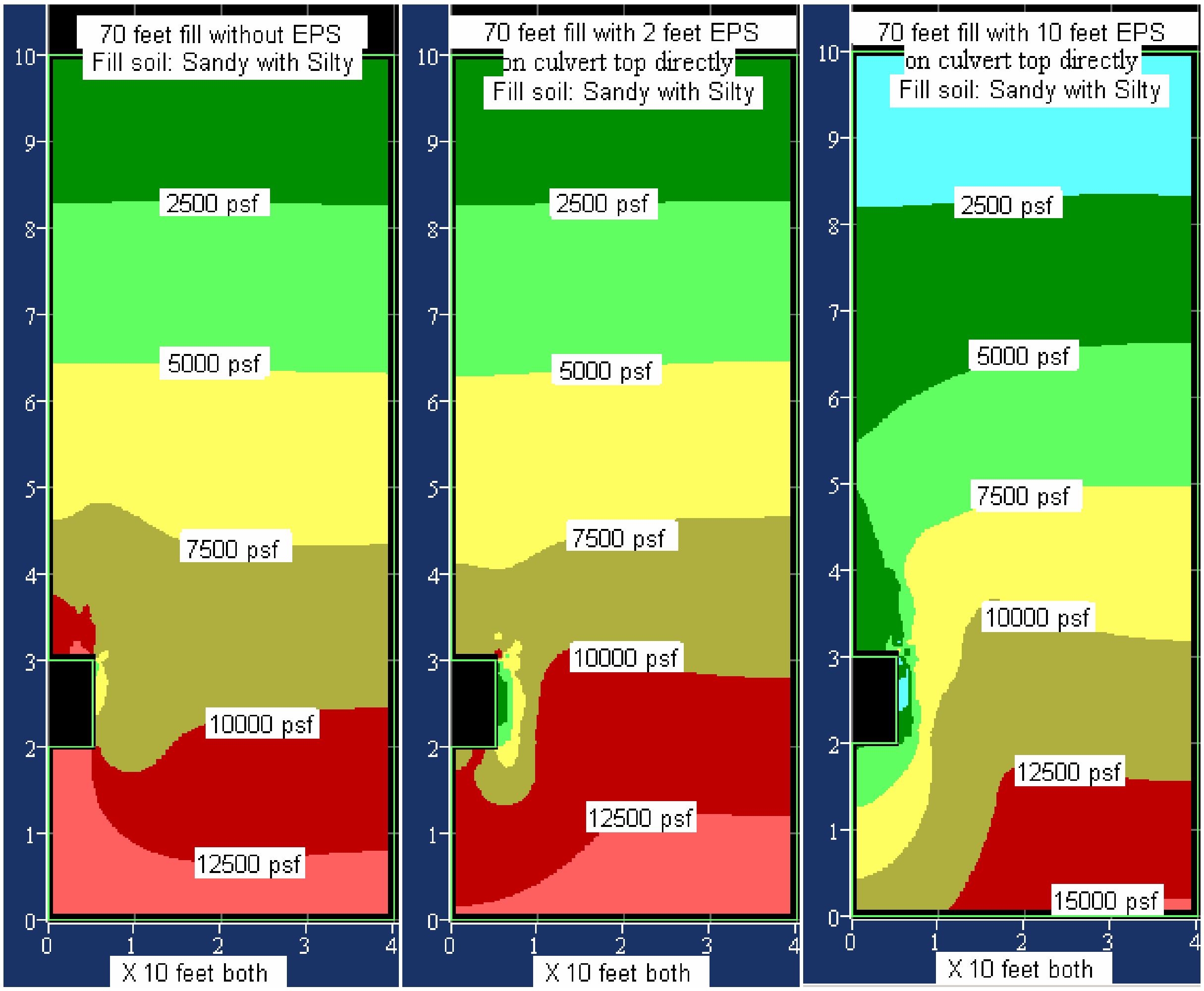

Figure 16. Contours of maximum principal stress without and with different sizes of EPS on the top of culvert (Using Sandy with Silty as fill)

Load reduction using Russell clay as fill soil and two different EPSs

Typical results using Russell clay as fill material, paired with two different EPSs and different parameter combinations, are shown in Figures 17 through 43. Compared to case of using sandy with silty soil as fill, the general load reduction trends for the Russell clay are similar to the trends observed when the sandy with silty soil is used as fill. The reduction effect is smaller when normal EPS is used in the Russell clay case, whereas the reduction effect is much bigger when soft EPS is used instead of normal EPS.

Figures 17 and 18 show the moment reduction trends for the same Russell clay fill soil, same fill height at 70 feet, and the same thickness (3 feet) for two different types of EPS. When EPS was used, the reduction of moment on the culvert top varied from 14.4 to -1.7 percent, as the distance between culvert and EPS changes from 0 to 10 feet. When soft EPS was used, the reduction of moment on the culvert top varied from 73.4 to 40.7 percent, as the distance between culvert and soft EPS changed from 0 to 10 feet. For the moment reduction on the sidewall, an opposite trend was observed when compared to the trend observed on the culvert top. When the distance between culvert and EPS changed from 0 to 10 feet, those reductions increased from 9.3 to 18.1 percent and from 37.6 to 52.1 percent for EPS and soft EPS respectively.

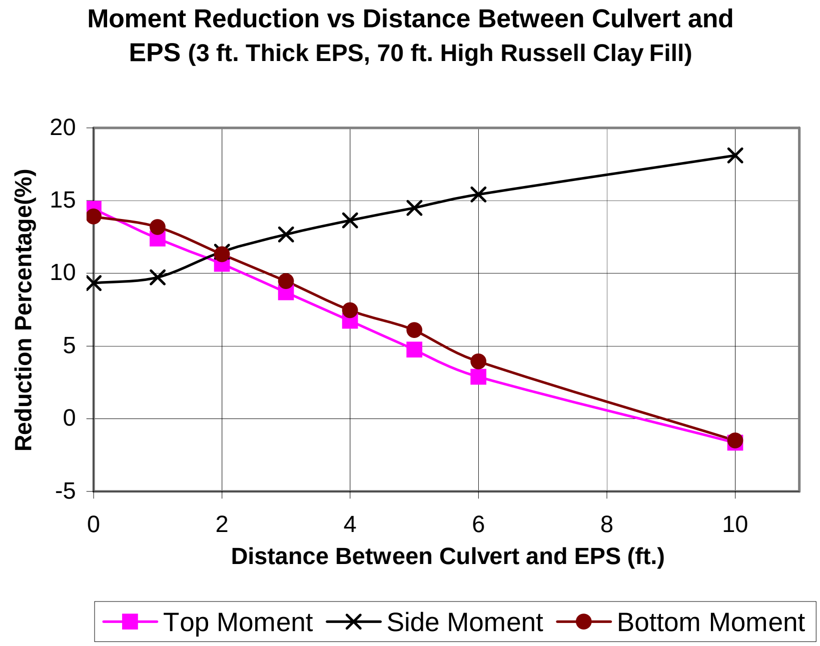

Figure 17. Moment reduction trends around culvert when EPS is used for Russell Clay

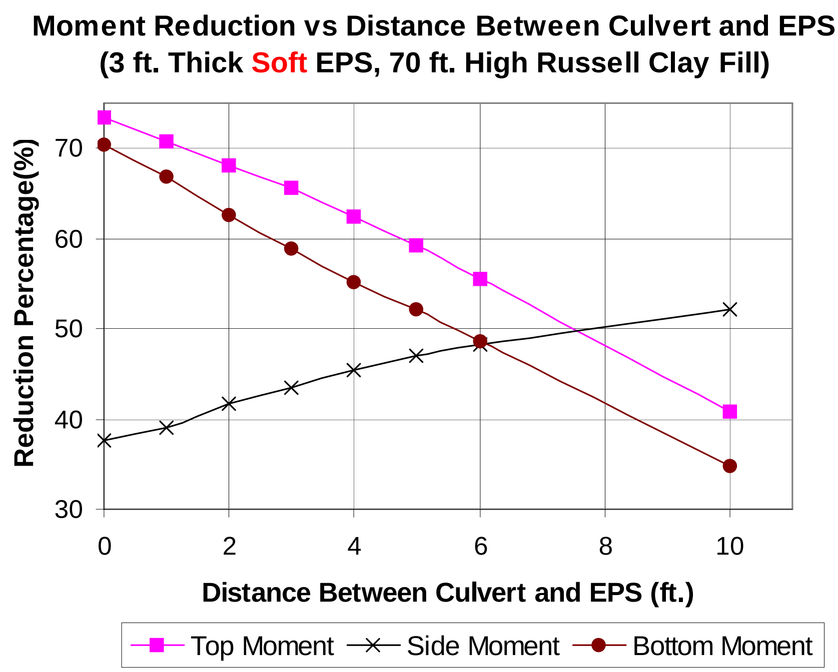

Figure 18. Moment reduction trends around culvert when soft EPS is used for Russell Clay

Changes of the maximum moment at the top of the culvert under a fill height of 70 feet versus the variation of EPS thicknesses are shown in Figures 19 and 20, respectively, for EPS and soft EPS. Much higher load reduction was obtained when soft EPS was used. As the EPS thickness increases, the reduction of the maximum top moment increases. The gradient of maximum

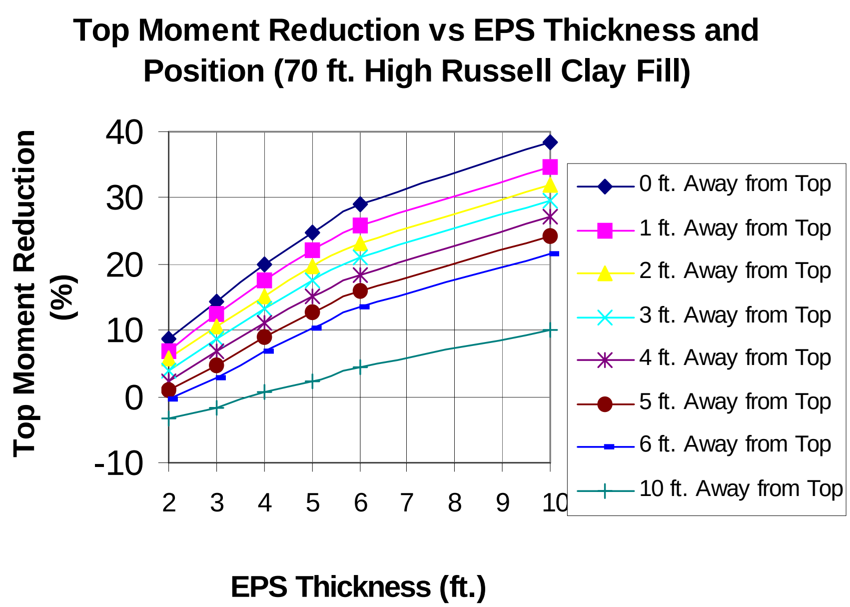

Figure 19. Changes of maximum moment reduction on top of culvert as a function of EPS thickness and distance between EPS and culvert (High Russell Clay fill)

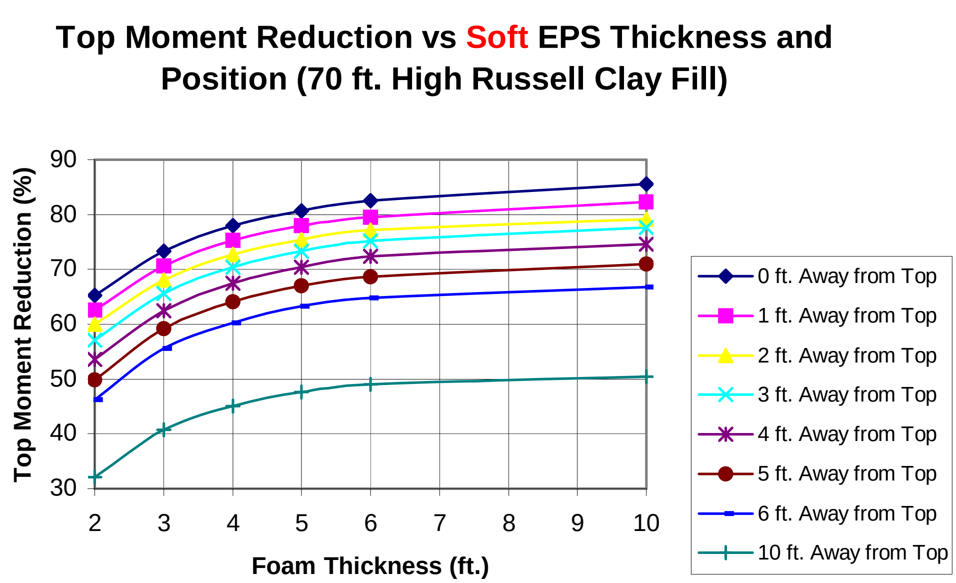

Figure 20. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (High Russell Clay fill)

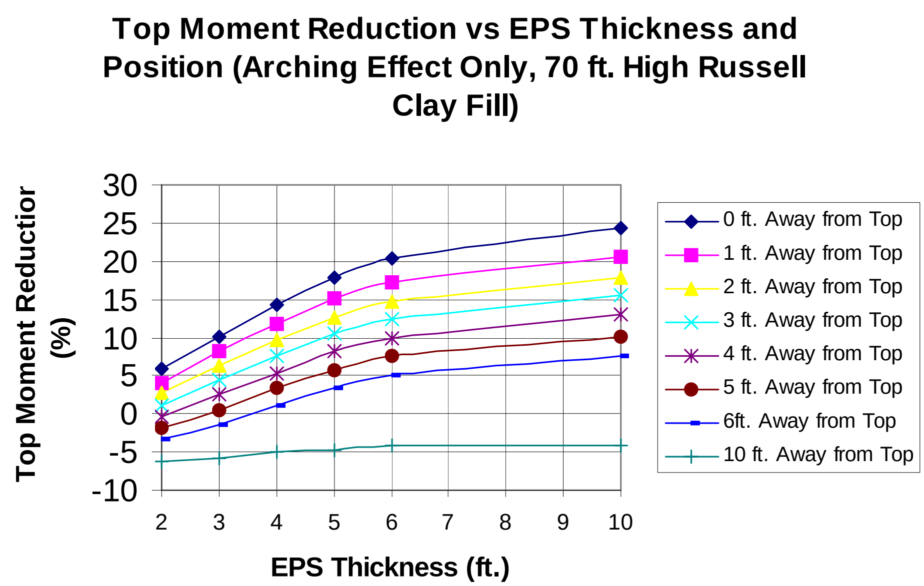

Figure 21. Changes of maximum moment reduction on top of culvert as a function of EPS thickness and distance between EPS and culvert (High Russell Clay fill; Arching effect only)

moment for soft EPS is much smaller than the gradients observed for the harder EPS when the thickness of the geofoam is thicker than 6 feet. This means that soft EPS is more efficient than the harder EPS for reducing load on the culvert top. Moment reductions due to the arching effect only are shown in Figures 21 and 22 for EPS and soft EPS, respectively. As shown in Figure 22, the top moment reduction gradient is negative when thickness of soft EPS is thicker than 6 feet. This means that the top moment reduction due to the arching effect will decrease after a certain thickness of soft EPS is reached for this particular case. The maximum moment reduction on the sidewall, contrary to maximum moment at the top of the culvert, will decrease as the EPS thickness increases (see Figure 23), and, will step up when distance between EPS and top of culvert increases (see Figure 24). However, when soft EPS is used, the maximum moment reduction on the sidewall will increase as the soft EPS thickness is thicker than 6 feet and distance between EPS and culvert is more than 2 feet away from top of the culvert (see Figure 25). Corresponding to this point, the reduction of top moment starts to step down. When soft EPS is used, the maximum moment reduction on the sidewall rises when the distance between soft EPS and top of culvert increases (Figure 26). That trend is similar to the case where normal EPS is used.

For a culvert under a fill height of 20 feet, the trends of total moment reduction, including weight reduction and arching effect, are directly proportional to EPS thickness growth (Figures 27 and 28 for EPS and soft EPS, respectively). The gradient of maximum reduction becomes smaller when thickness of soft EPS was greater than 6 feet (Figure 28). As shown in Figures 29 and 30, reductions of the maximum top moment due to the arching effect only decrease when EPS thickness exceeds 5 feet and 3 feet, respectively, for EPS and soft EPS. This means, in these particular cases under a fill height of 20 feet, benefits obtained from the arching effect diminish after the thickness exceeds certain dimensions. The maximum moment reduction on the sidewall has a similar trend as that under observed for the 70-foot high fill (Figures 31 through 34). Except for the case where soft EPS is used, when the distance between top of culvert and soft EPS is 6 feet or higher, that reduction will stay constant at a value of about 79.5 percent, no matter what thickness of soft EPS is used.

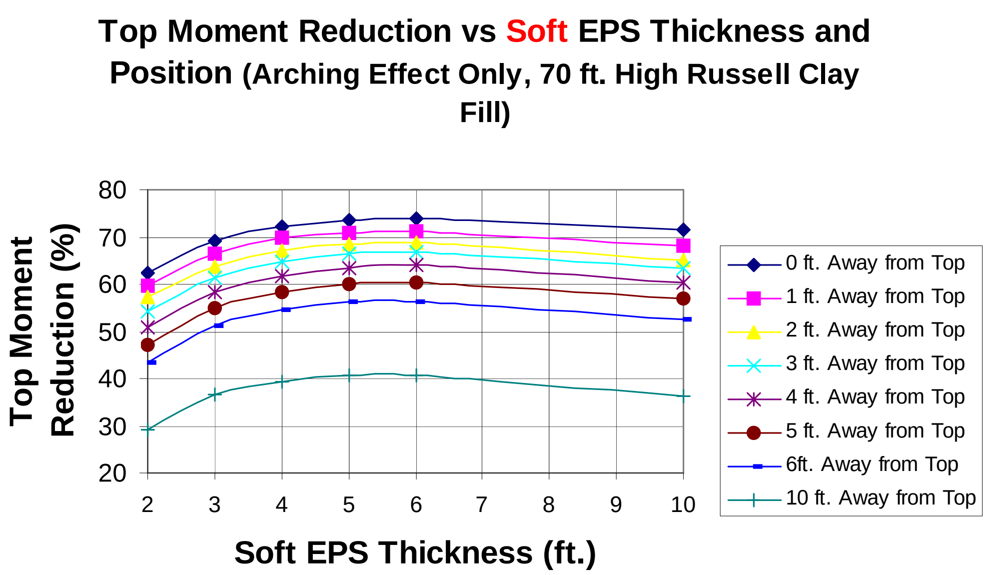

Figure 22. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (High Russell Clay fill; Arching effect only)

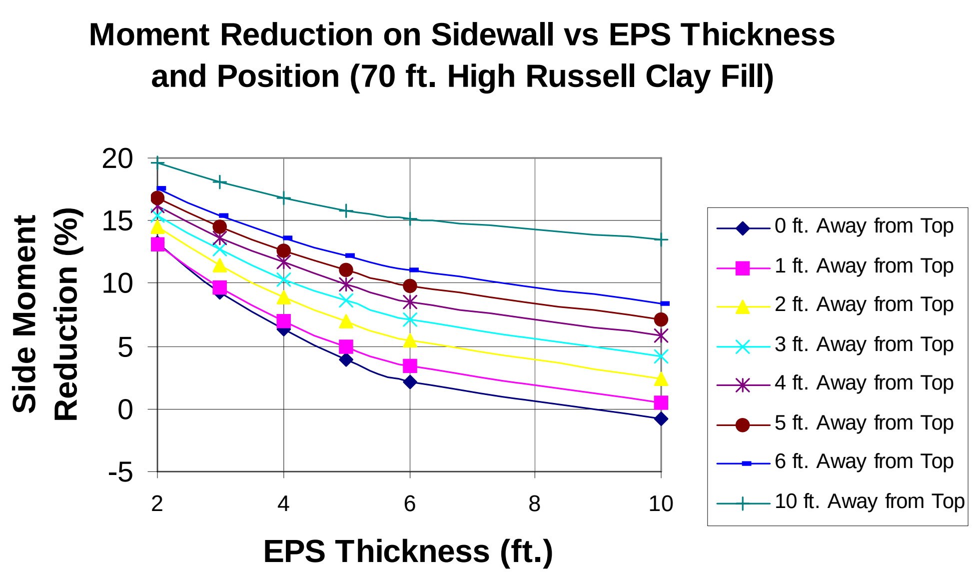

Figure 23. Changes of maximum moment reduction on sidewall of culvert as a function of EPS thickness and distance between EPS and culvert (High Russell Clay fill)

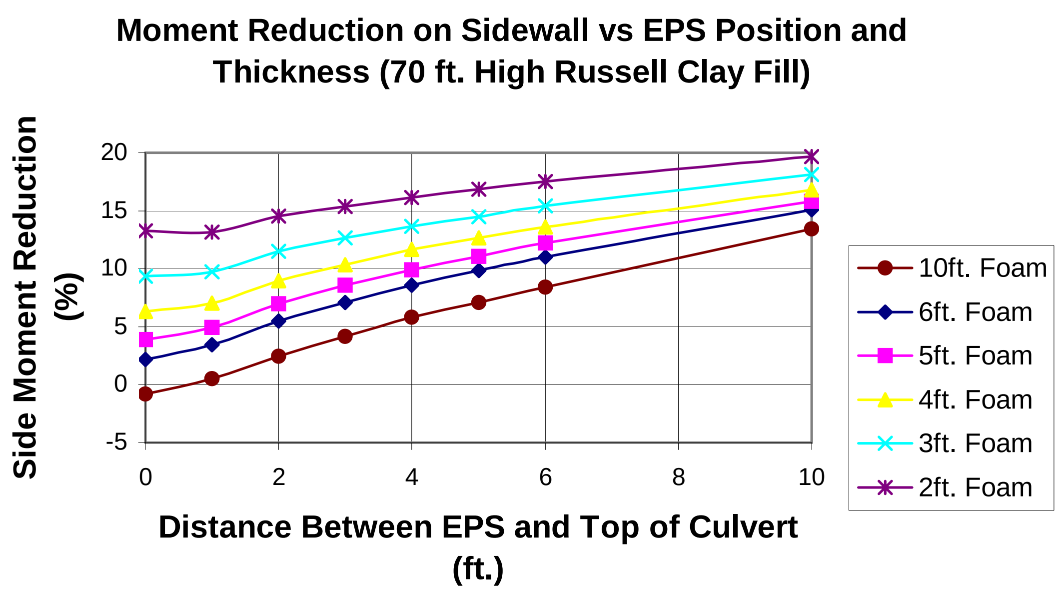

Figure 24. Changes of maximum moment reduction on sidewall of culvert as a function of distance between EPS and culvert and EPS thickness (High Russell Clay fill)

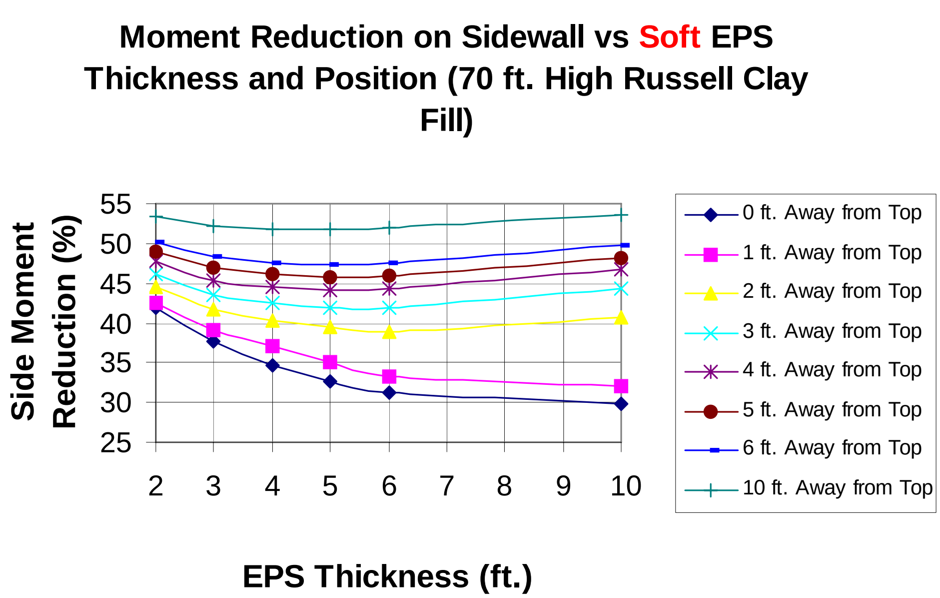

Figure 25. Changes of maximum moment reduction on sidewall of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (High Russell Clay fill)

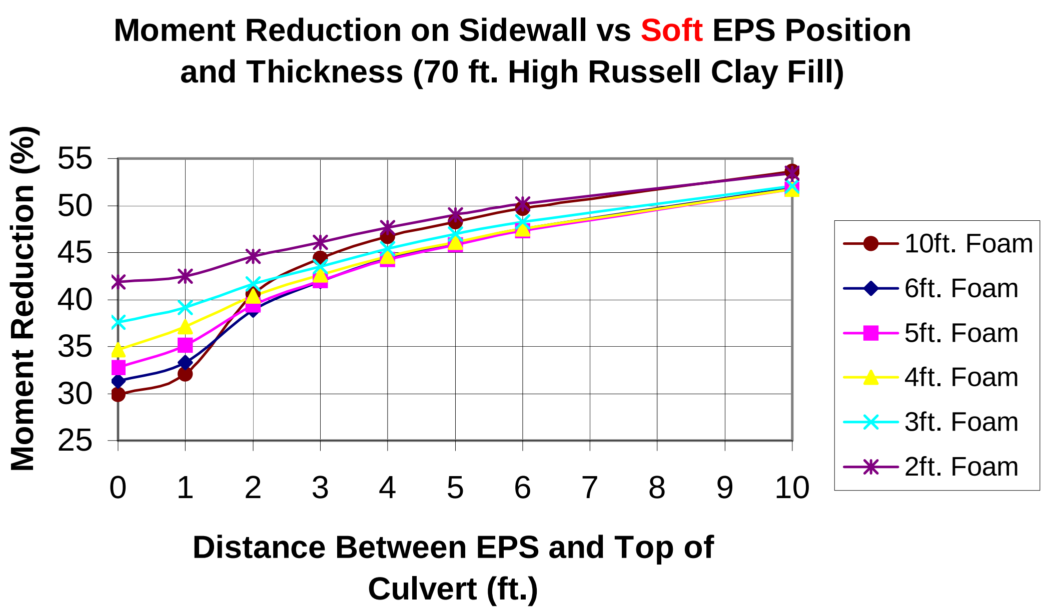

Figure 26. Changes of maximum moment reduction on sidewall of culvert as a function of distance between soft EPS and culvert and soft EPS thickness (High Russell Clay fill)

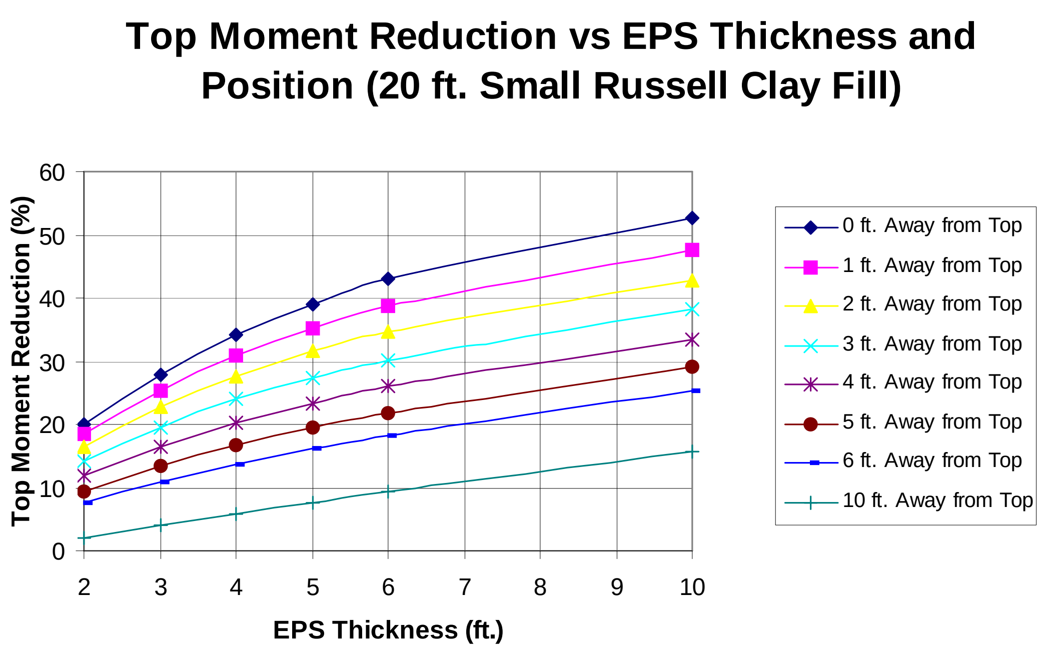

Figure 27. Changes of maximum moment reduction on top of culvert as a function of EPS thickness and distance between EPS and culvert (Small Russell Clay Fill)

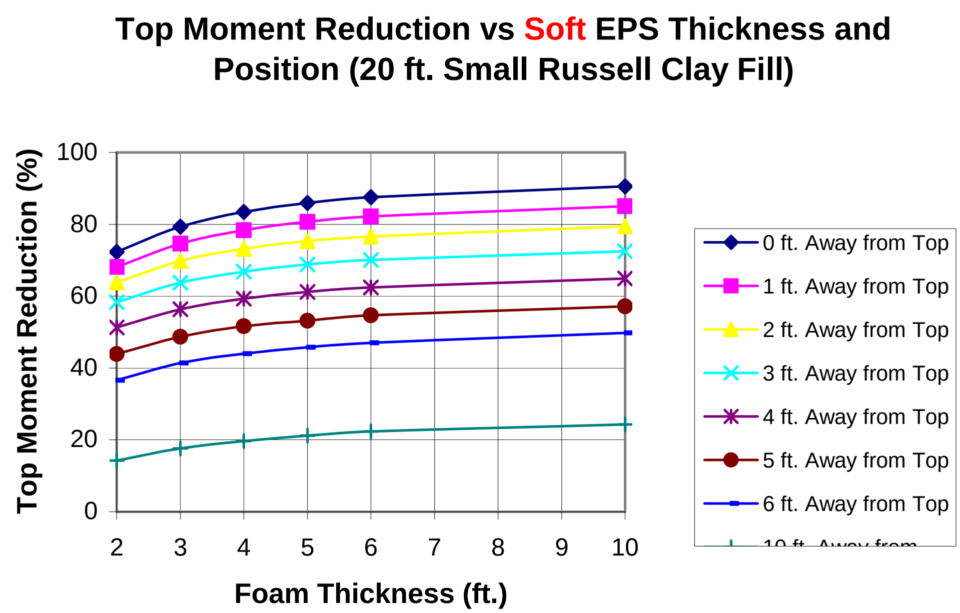

Figure 28. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (Small Russell Clay fill)

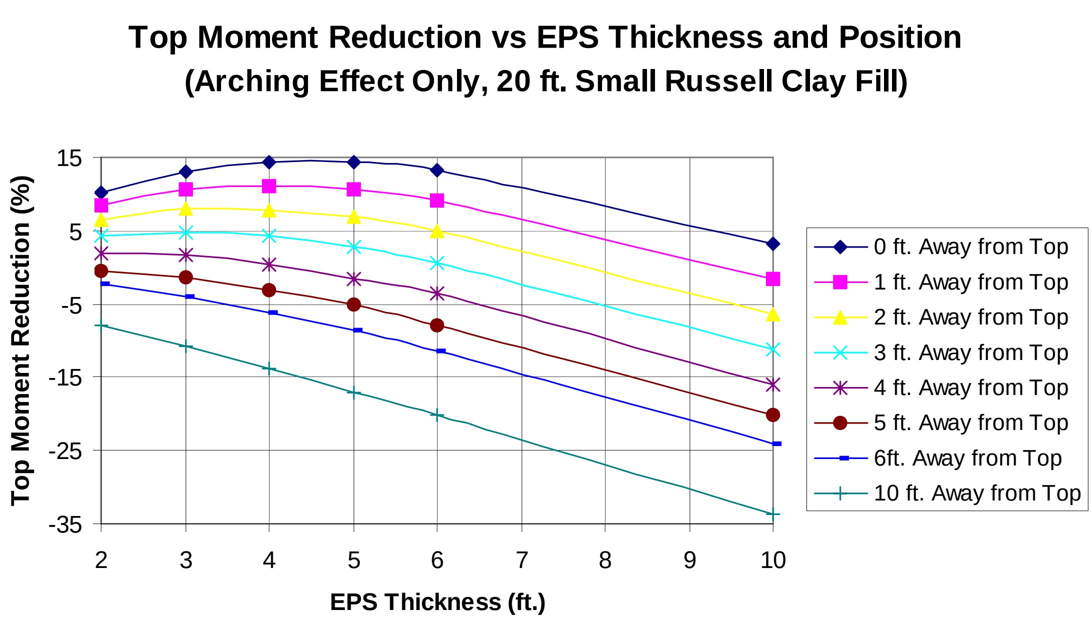

Figure 29. Changes of maximum moment reduction on top of culvert as a function of EPS thickness and distance between EPS and culvert (Small Russell Clay fill; Arching effect only)

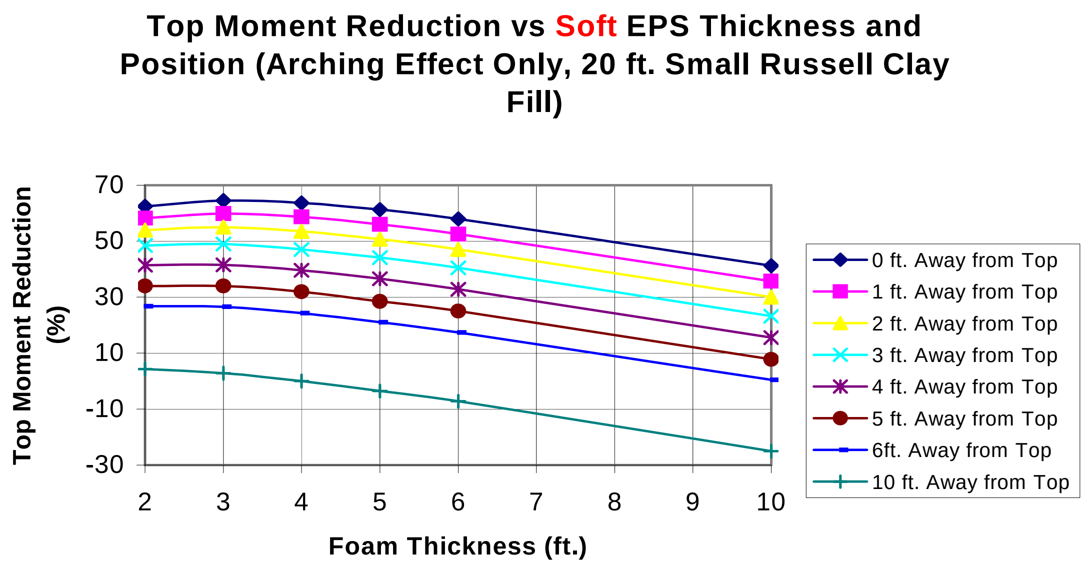

Figure 30. Changes of maximum moment reduction on top of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (Small Russell Clay fill; Arching effect only)

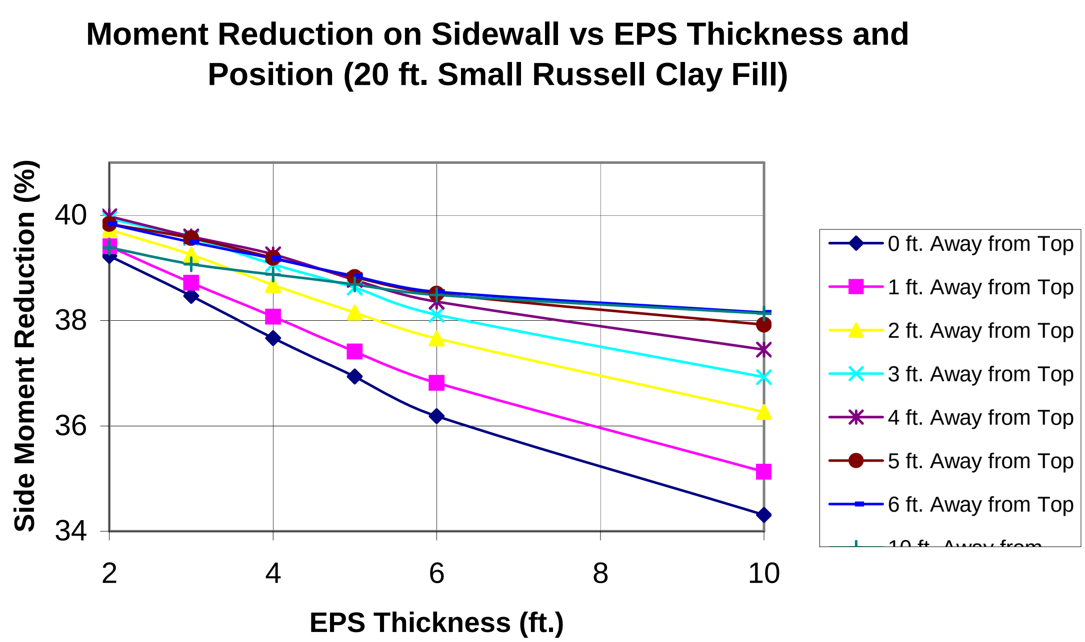

Figure 31. Changes of maximum moment reduction on sidewall of culvert as a function of EPS thickness and distance between EPS and culvert (Small Russell Clay fill)

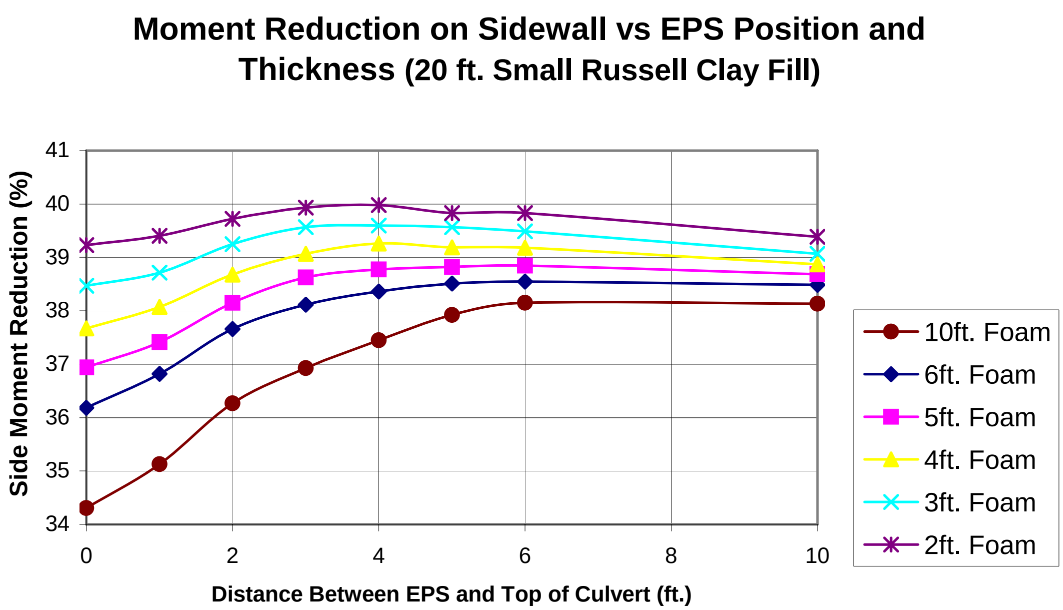

Figure 32. Changes of maximum moment reduction on sidewall of culvert as a function of distance between EPS and culvert and EPS thickness (Small Russell Clay fill)

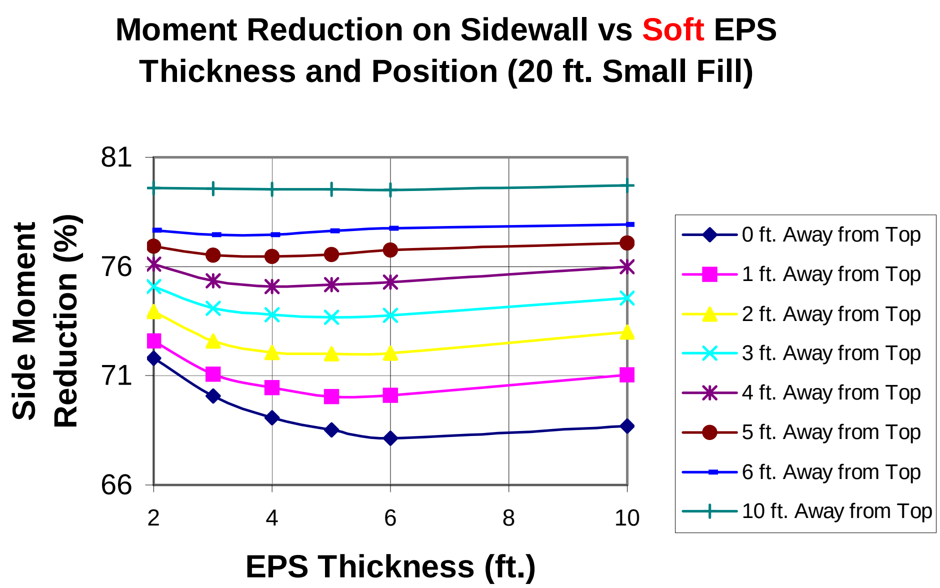

Figure 33. Changes of maximum moment reduction on sidewall of culvert as a function of soft EPS thickness and distance between soft EPS and culvert (Small Russell Clay fill)

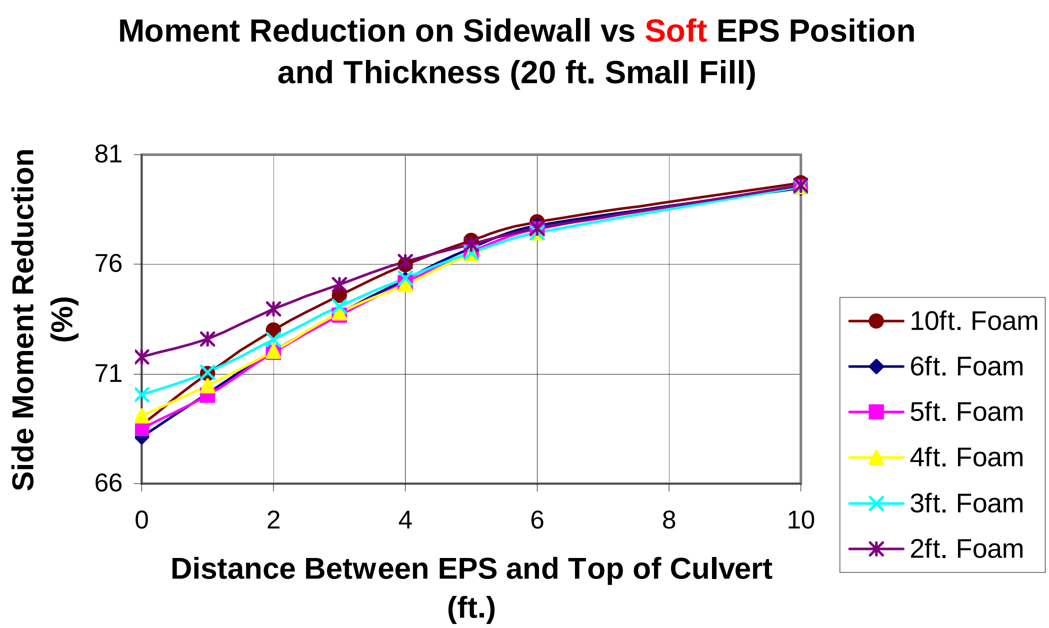

Figure 34. Changes of maximum moment reduction on sidewall of culvert as a function of distance between soft EPS and culvert and soft EPS thickness (Small Russell Clay fill)

Based on a constant thickness of 10 feet of EPS, relationships between total reduction of maximum top moment and fill height are shown in Figures 35 and 36 for EPS and soft EPS, respectively. Total reduction of the top moment for a selected distance between EPS and culvert does not significantly change as the height of fill increases. In contrast, as shown in Figures 37 and 38, the arching effect plays a more important role as the fill height increases. This indicates that the unit weight factor of EPS (or soft EPS) is predominately more important than the arching effect when the fill height is small. When the fill heights are much larger, the arching is more effective than unit weight in reducing the top culvert moment. The trends of maximum moment reduction on sidewall for both EPS and soft EPS situations are similar to the case where sandy with silty soil is used as fill. As shown in Figures 39 and 40, the maximum moment reductions on the sidewall will become smaller as the fill height increases. As shown in Figures 41 and 42, the maximum moment reduction on the sidewall rises when distance between EPS and top of culvert increases.

Similar to the case of using sandy with silty soil as fill, the load reduction is also observed from contours of maximum principal stress, as shown in Figure 43. Comparing stress status under two different geofoams (EPS and soft EPS) lower stress extends to an area around the culvert. There still exists a high-stress region on the culvert when 2 feet of harder EPS is used, as shown in the second contour in Figure 43. Whereas 2 feet of soft EPS is used, stress on the culvert is reduced more than 50 percent (see third contour in Figure 43). Even reduction effect when 2 feet soft EPS used is larger than reduction effect when 10 feet EPS used, as shown in third and fourth contours in Figure 43. Obviously, the largest stress reduction is obtained when 10 feet soft EPS is directly placed on top of culvert (fifth contour in Figure 43).

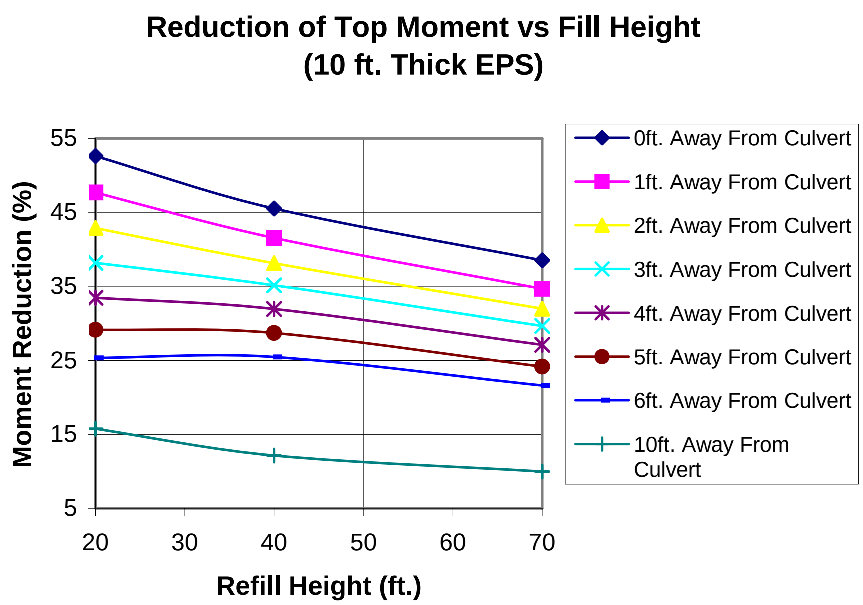

Figure 35. Changes of maximum moment reduction on top of culvert as a function of fill height and distance between EPS and culvert (Russell Clay fill)

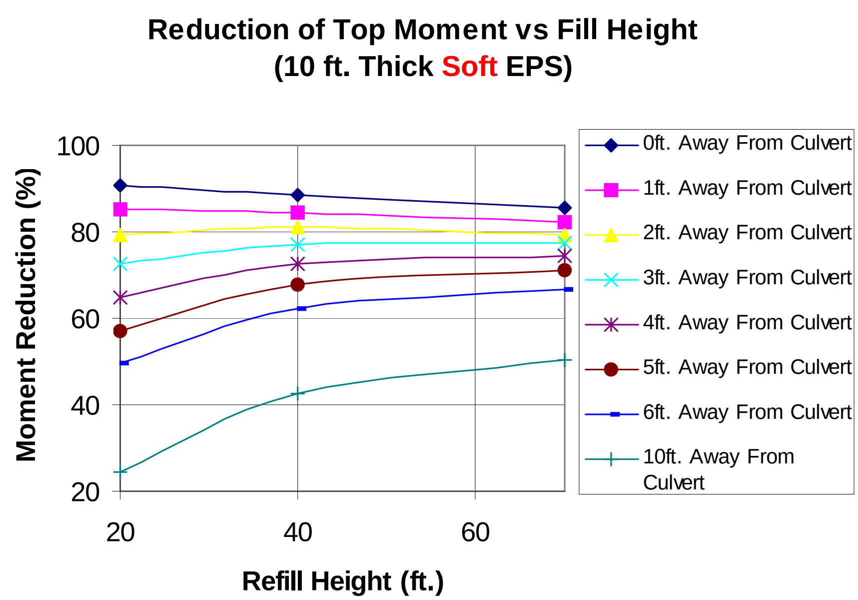

Figure 36. Changes of maximum moment reduction on top of culvert as a function of fill height and distance between soft EPS and culvert (Russell Clay fill)

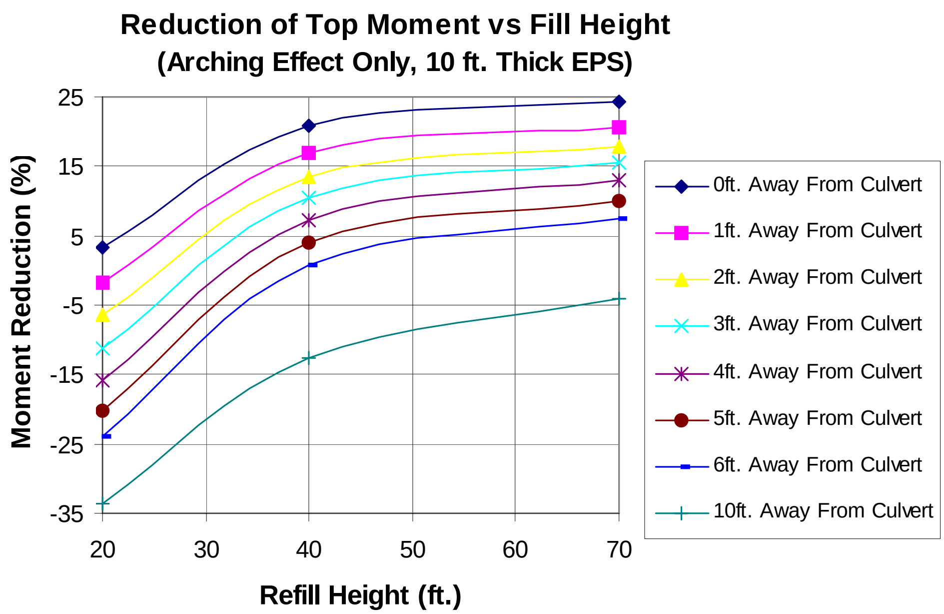

Figure 37. Changes of maximum moment reduction on top of culvert as a function of refill height and distance between EPS and culvert (Russell Clay fill, arching effect only)

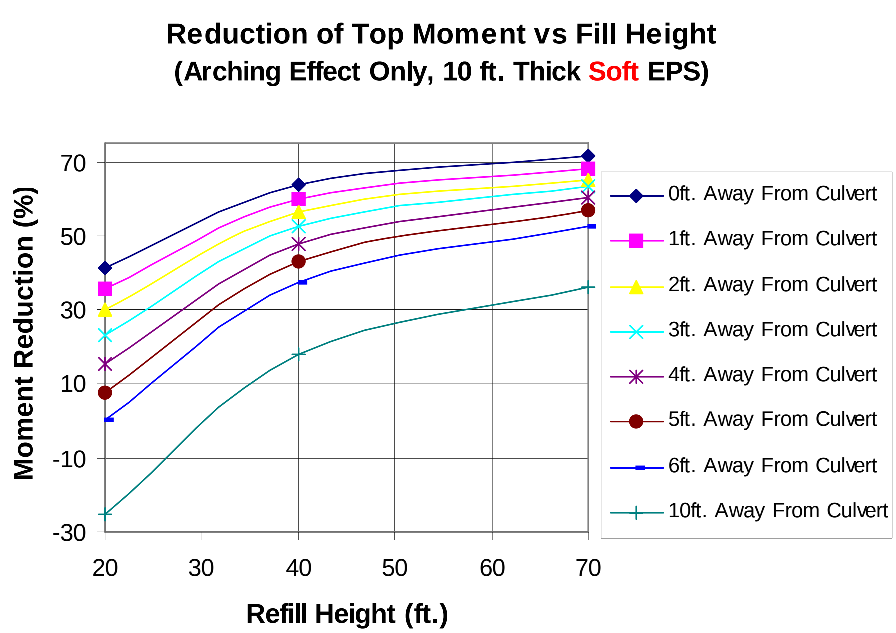

Figure 38. Changes of maximum moment reduction on top of culvert as a function of refill height and distance between soft EPS and culvert (Russell Clay fill, arching effect only)

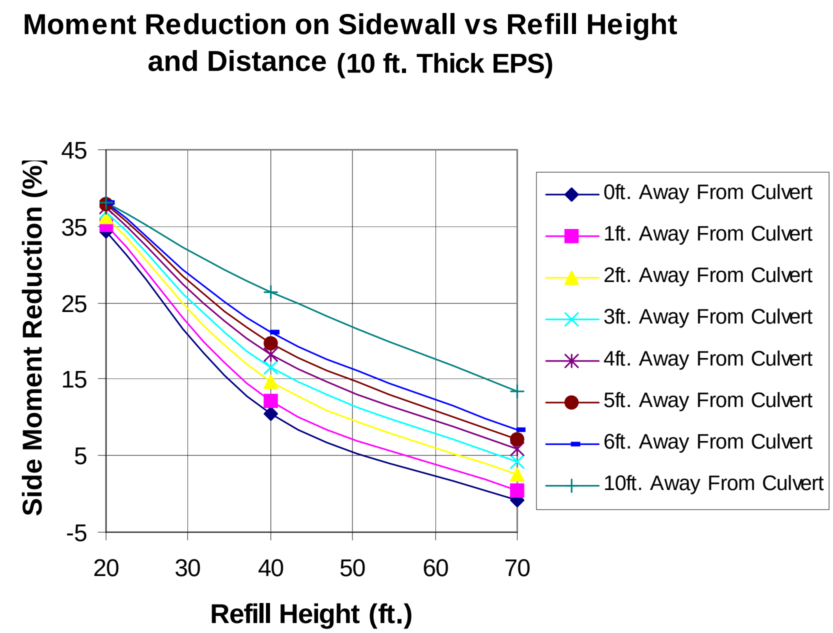

Figure 39. Changes of maximum moment reduction on sidewall of culvert as a function of fill height and distance between EPS and culvert (Russell Clay fill)

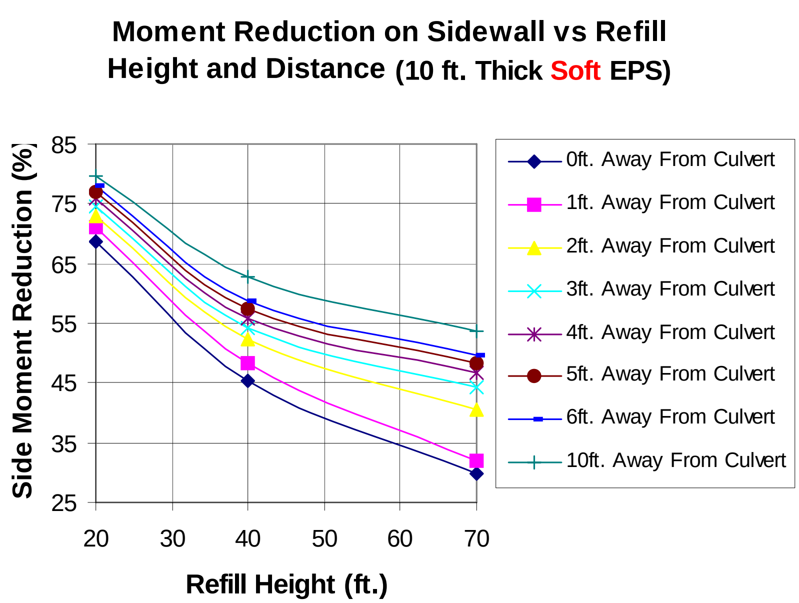

Figure 40. Changes of maximum moment reduction on sidewall of culvert as a function of fill height and distance between soft EPS and culvert (Russell Clay fill)

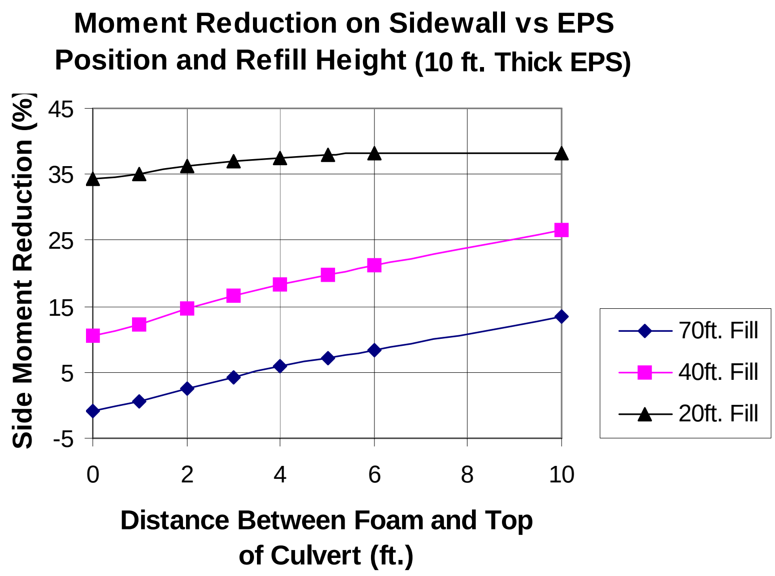

Figure 41. Changes of maximum moment reduction on sidewall of culvert as a function of distance between EPS and culvert and fill height (Russell Clay fill)

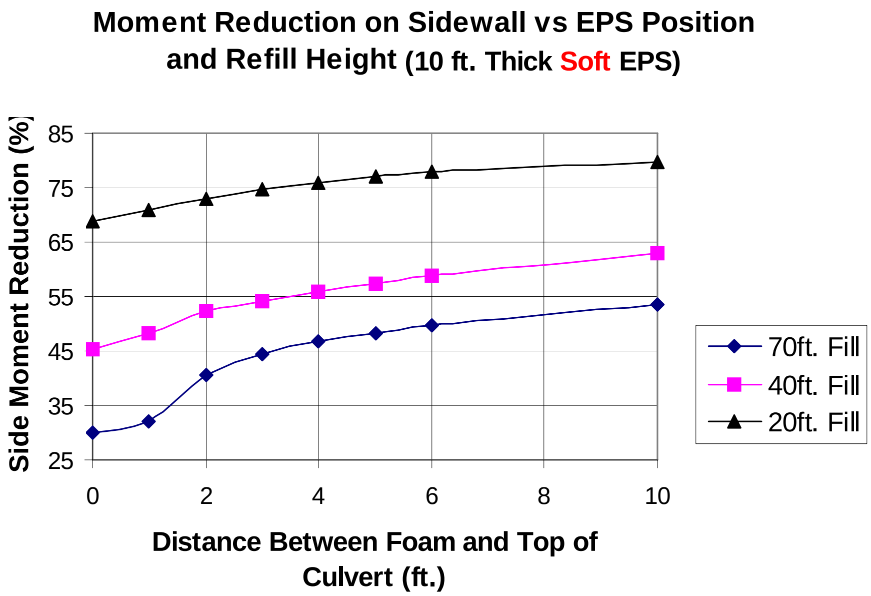

Figure 42. Changes of maximum moment reduction on sidewall of culvert as a function of distance between soft EPS and culvert and fill height (Russell Clay fill)

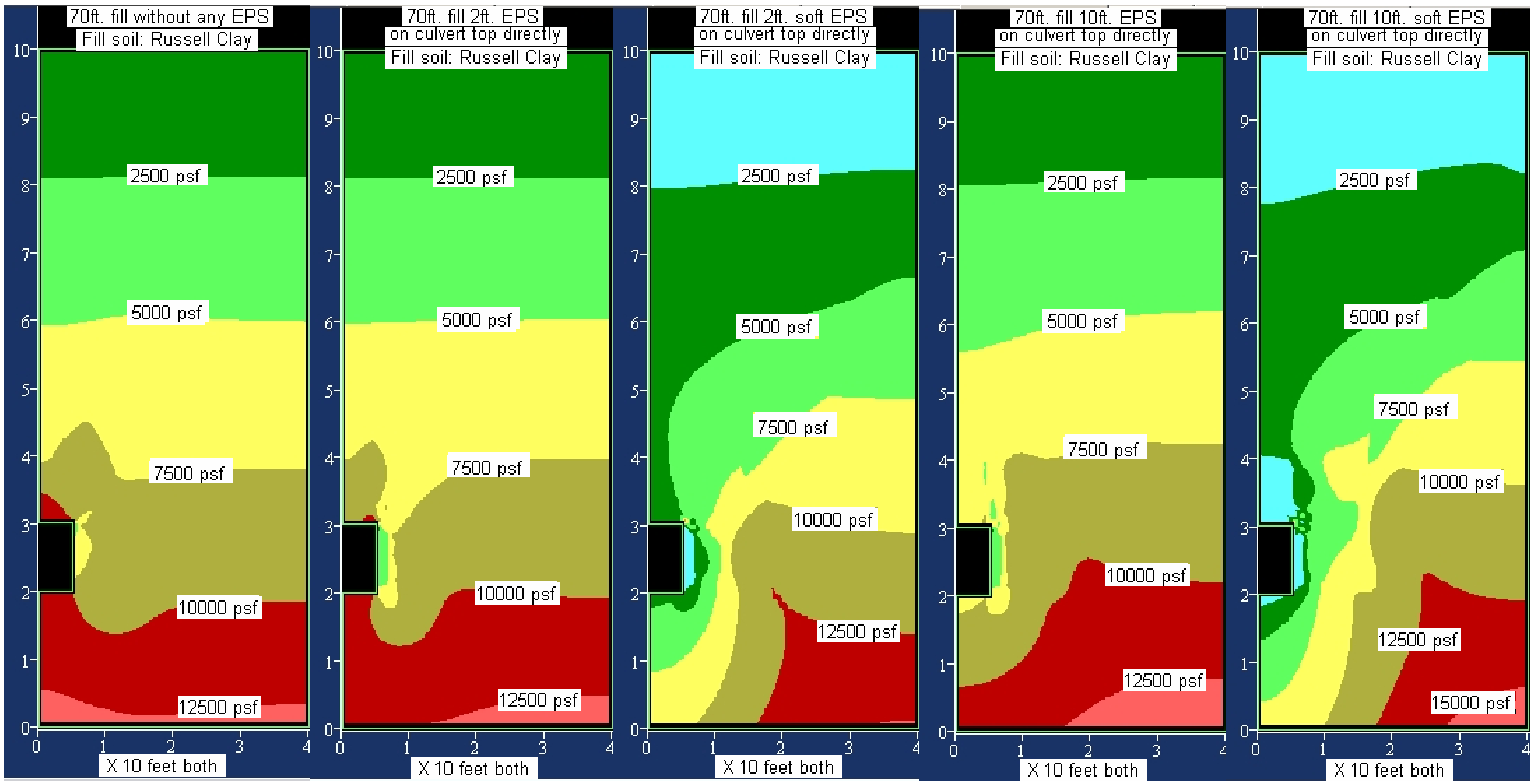

Figure 43. Contours of maximum principal stress without and with different sizes of EPS/soft EPS on the top of culvert (Russell clay is used as fill soil)

Comparing Loads on Culvert Using Foam Concrete and EPS

To compare loads on a culvert using different lightweight materials, foam concrete and EPS, two sets of models were created from two sections cut from a real culvert extension project, as shown in Figure 44. For both sections, loads on the culvert when the Russell clay was used only were calculated first. Then, the two lightweight materials were modeled in different sizes and different positions to get varied loads on the culvert. Comparing the loads produced using the two EPS materials and the Russell clay only, load reduction percentages are obtained and discussed.

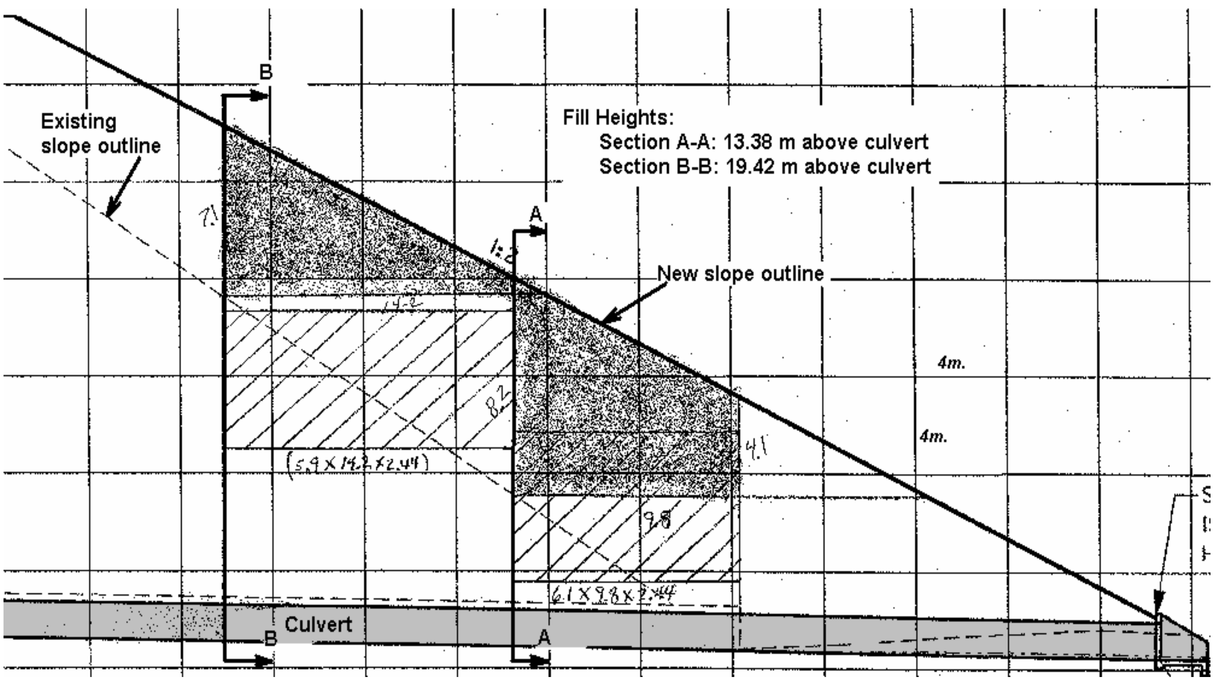

Figure 44. Sections A-A and B-B located on a real culvert extension site

Section A-A is located at a position near the end of culvert. The lightweight materials were placed directly on the culvert. Numerical models shown in Figures 45 and 46 were analyzed using foam concrete with a height of 6.1 m and EPS with a height of 0.9 m, and assuming various widths of the materials (1.5, 2, 3, and 4 times the width of the of culvert, respectively). The results are shown in Figure 47. The loads on top and bottom of the culvert increased at 6.2 and 6.6 percent, correspondingly, when foam concrete is 1.5 times the culvert width. Only the load on the sidewall decreased at 6.6 percent for this situation. The amount of load reduction is proportional to the width of foam concrete (See Figure 47). The maximum load reduction was obtained when width of foam concrete is 4 times the culvert width in this analysis. On the other hand, the greatest reductions (76.7 and 75.5 percent, respectively) of loads on top and bottom of the culvert occurred when the width of the EPS was 1.5 times the width of the culvert. However, load on the sidewall increased 16.2 percent under this condition. As the width of the EPS increases, load reductions on top and bottom of the culvert become smaller; load reduction on the culvert sidewall becomes larger (See Figure 47). When the width of EPS is 4 times the

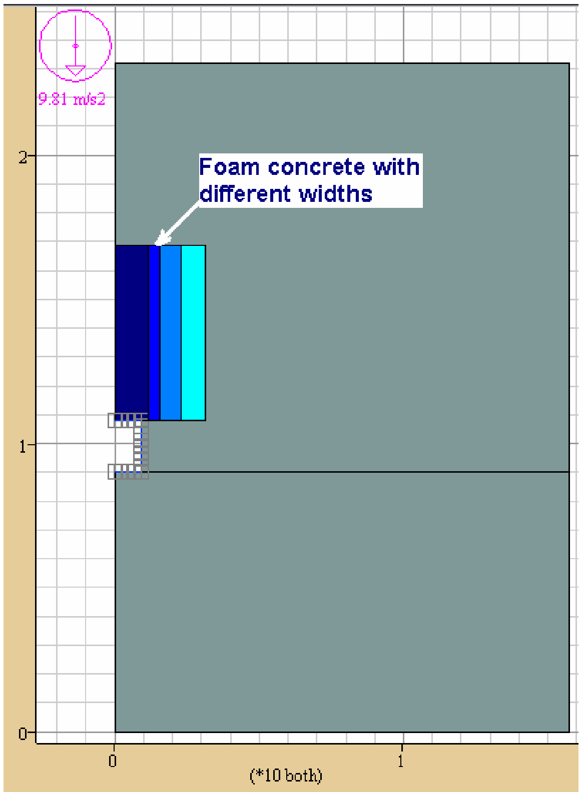

Figure 45. Foam concrete at height of 6.1m and varied width on section A-A

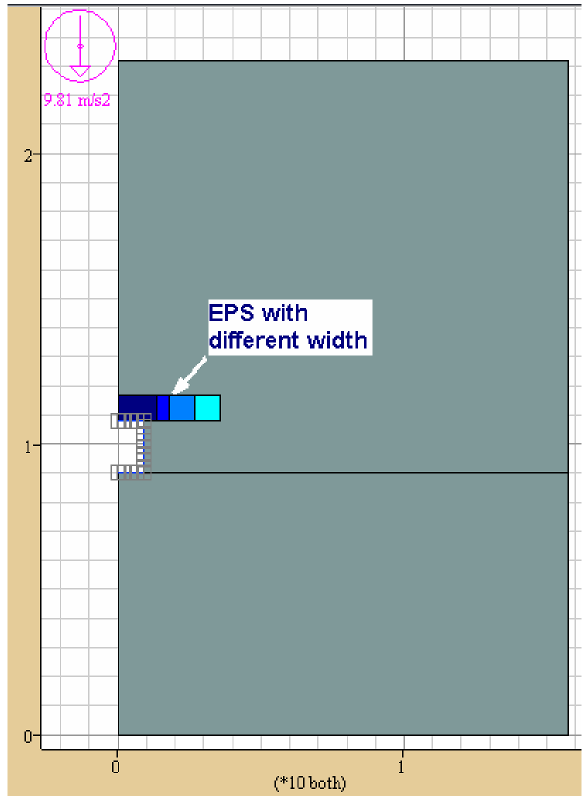

Figure 46. EPS at height of 0.9m and varied width on section A-A

width of the culvert the load reductions are 53.6, 44.6, and 54.4 percent for top, sidewall and bottom of the culvert, respectively. Those load reductions are more than 2 times greater than load reductions obtained when foam concrete is used on the top of the culvert.

The effect of placing EPS at the sides of the culvert was investigated in another numerical model shown in Figure 48. Three different cases-- without EPS, EPS of a thickness of 0.225 meters, and EPS of a thickness of 0.45 meters-- were studied. Considering the two cases, without EPS and EPS of a thickness of 0.25, the results shown in Figure 49 indicate that a large increase, or jump, occurs in the load reduction on the sidewalls. Numerically, the load reduction jump goes from more load of 26.5 (negative value) percent for the case of no EPS to a load reduction value of 28.0 percent less load (positive value) for the case when a thickness of EPS of 0.225 meters is used. The load reduction on the sidewall continues to increase when the thickness of the EPS is increased from 0,225 meters to 0.45 meters. Under this condition, both directions, vertically and horizontally, benefit from the arching effect. These analyses illustrate the most efficient way to reduce loads all around the culvert.

Another set of analyses was performed to investigate load reduction on culvert using a different layout of lightweight material. As shown in Figure 50, both lightweight materials, foam concrete and EPS, were placed around the culvert. Three different thicknesses, 0.45, 0.90, and 1.35 meters, were modeled and investigated. The results shown in Figure 51 indicate that

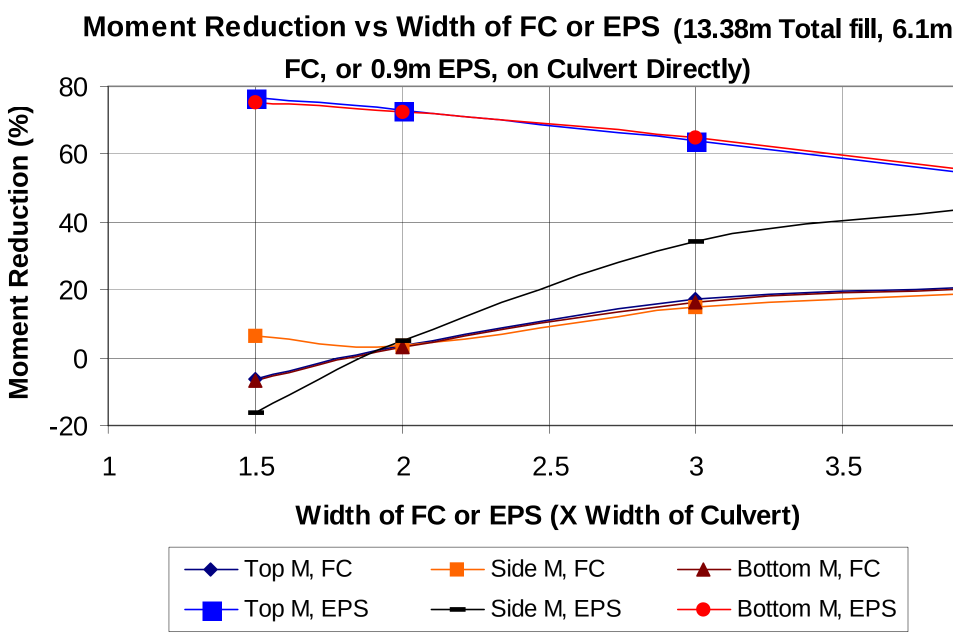

Figure 47. Opposite trends of moment reduction are observed when foam concrete or EPS are used on top of culvert directly

the load reductions around all sides are proportional to thickness of lightweight material. Smaller gradient of load reduction exists when thickness increases. Load reduction is bigger by using foam concrete except thinner, 0.45 meters of, lightweight material used for this case. Two different mechanical principals are functioned to reduce load on culvert. When foam concrete is used, foam concrete strengthens the culvert. Whereas EPS is used, EPS will create arching effect. This arching effect makes load to redistribute to surround fill soil. As a result, load on culvert is reduced.

Section B-B located at upper position on the embankment. It needs extra excavation if the lightweight materials were placed on culvert directly. To minimize excavation, lightweight materials are placed 7.425 meters away from top of culvert. Total fill height from top of culvert to surface of slope is 19.42 meters.

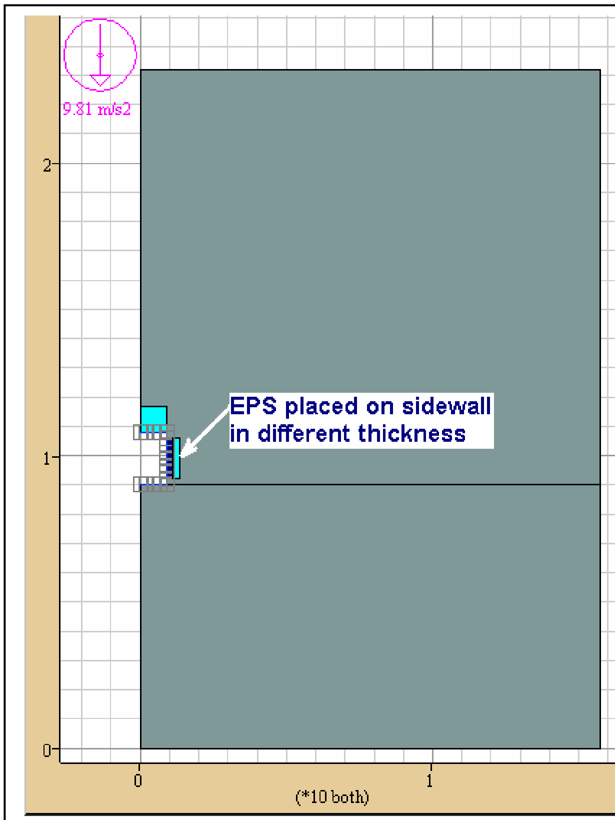

Figure 48. Model for investigating the effect of putting EPS aside sidewall

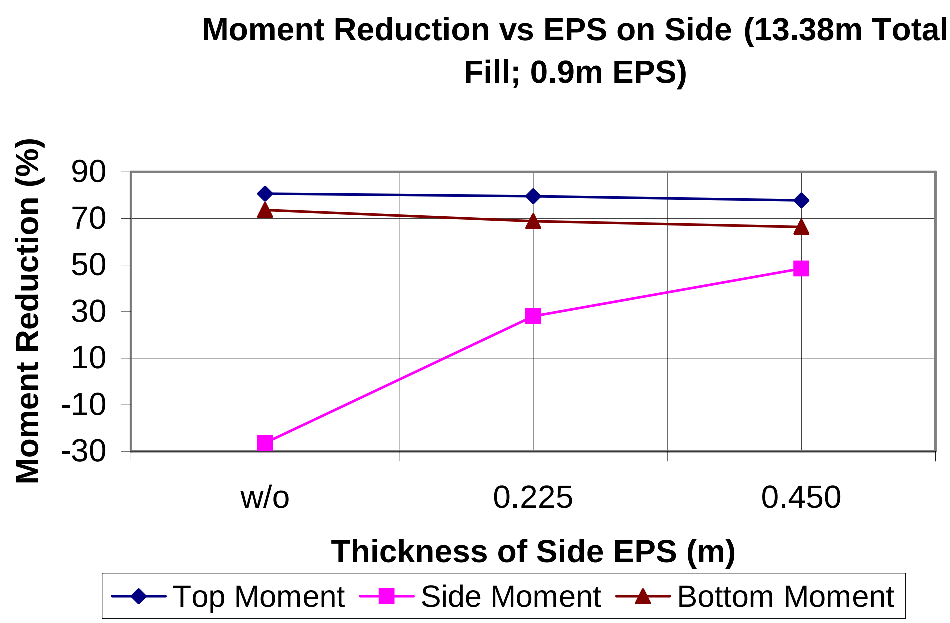

Figure 49. Moment reduction affected by putting EPS aside culvert (On section A-A)

Using foam concrete of a height of 5.9 meters and EPS of a height 4.5 meters, and varying the widths of the materials—1, 1.5, 2, 3, 4, and 8 times the width of the culvert--numerical models, as shown in Figures 52 and 53, were analyzed. Results are shown in Figure 54. The trends of the load reduction for both foam concrete and EPS are the same. The amount of load reduction is proportional to the width of foam concrete or EPS (See Figure 54). As shown in Figure 54, the load reduction created by the EPS is greater than the load reduction created by the foam concrete.

When the width of EPS is 4 times the culvert width the load reductions are 26.4, 25.2, and 27.0 percent for the top, sidewall and bottom of culvert, respectively. When foam concrete is used at a similar condition, the load reductions are 13.0, 16.8, and 13.7 percent for the top, sidewall and bottom of culvert respectively.

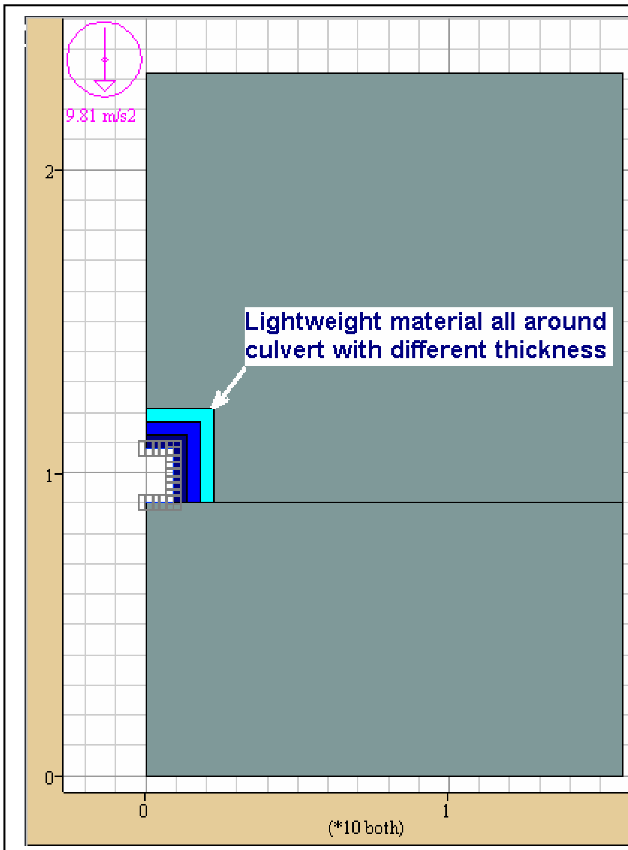

Figure 50. Model for investigating the effect of placing lightweight material around culvert

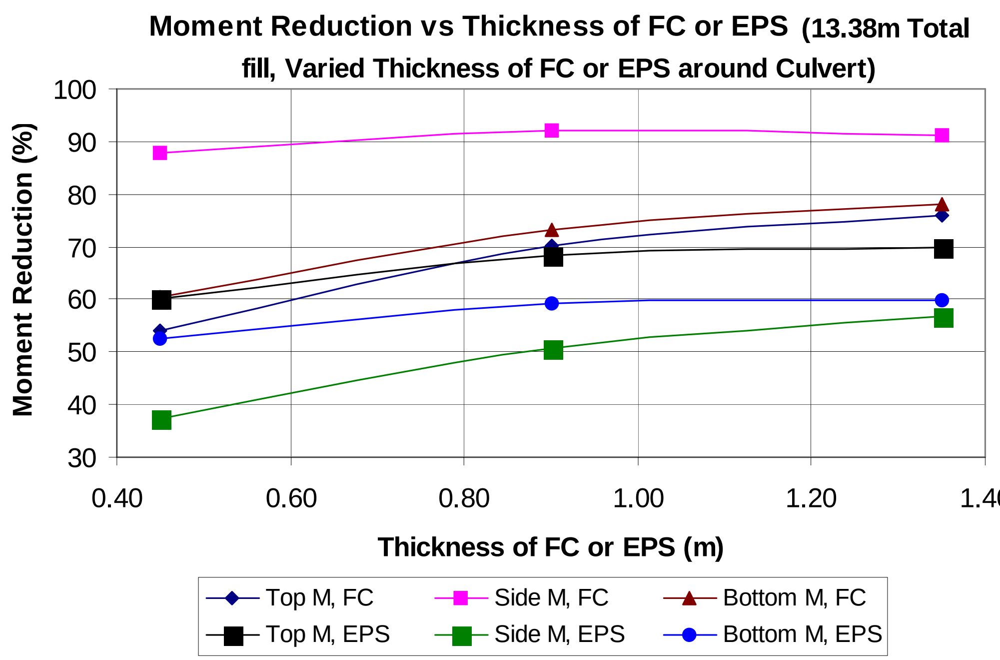

Figure 51. Changes of moment reduction as a function of thickness around culvert

If extra excavation is considered, lightweight materials can be placed closer to the top of culvert. Numerical analyses were performed using models consisting of foam concrete of a thickness of 5.9 meters and a width of 2 times the culvert width and EPS of a thickness of 2.25 meters and a width of 2 times the width of the culvert, and assuming different distances between the top of the culvert and lightweight materials of 0.675 meters, 2.925 meters, 5.175 meters, and 7.425 meters (see Figures 55 and 56). Results shown in Figure 57 reveal that the largest load reduction occurs when the lightweight materials become closer to the top of the culvert. EPS produces a larger load reduction than the reduction produced by the foam concrete even thought the thickness of the EPS is only 2.25 meters compared to the thickness of foam concrete, which is 5.9 meters. Using EPS is more efficient than using foam concrete.

Similar to analyzing the top of section A-A, the effect of placing EPS at the side of the culvert is also investigated in another numerical model (Refer to Figure 48). The same strategy for analyzing the top of section A-A was used and three different cases were studied. These included without EPS, EPS of a thickness of 0.225 meters, and EPS of a thickness of 0.45 meters. Results shown in Figure 58 indicate that a big jump in load reduction occurs among the three cases. From no EPS thickness to the case of using EPS of a thickness of 0.225 meters, the load reduction jumps from -14.9 percent (a negative value or more load) to 27.1 percent (positive value or less load). The load reduction on the sidewall continues to increase when a thicker EPS (0.45 meters) is used at the side of the culvert. Under this condition, load reduction in both directions, vertically and horizontally, benefit from the arching effect. It shows the most efficient way to reduce loads all around culvert.

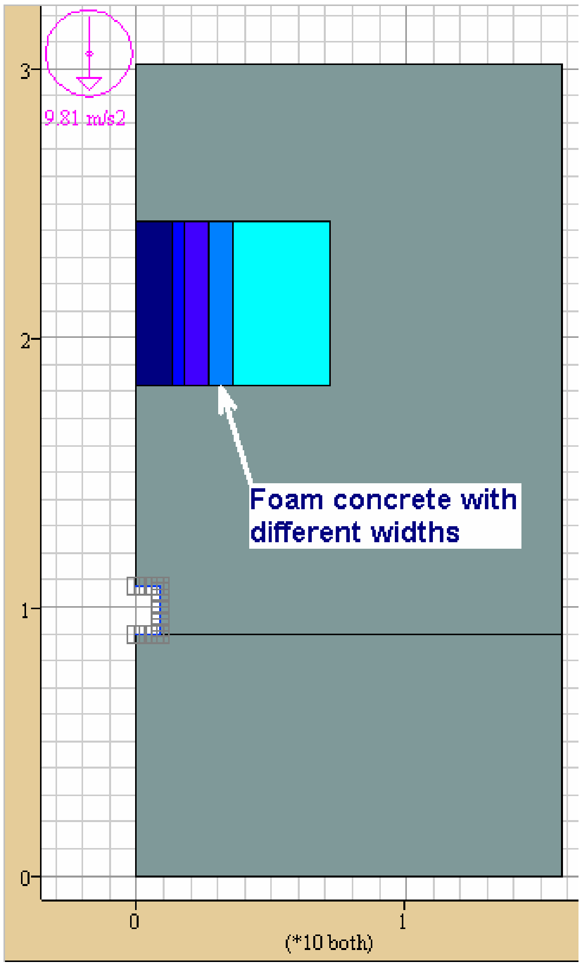

Figure 52. Foam concrete at height of 5.9m and varied width on section B-B

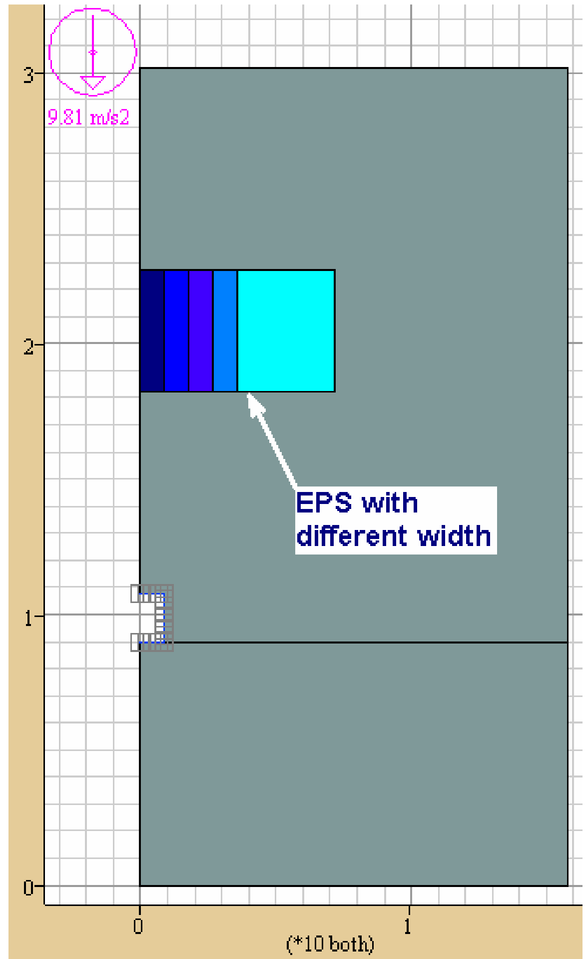

Figure 53. EPS at height of 4.5m and varied width on section B-B

Another set of analyses, similar to those used in examining section A-A, was performed to investigate load reduction on the culvert using a different layout of lightweight materials. As shown in Figure 50, both lightweight materials, foam concrete and EPS, were placed around the culvert. Three different thicknesses, 0.45, 0.90, and 1.35 meters, were modeled and investigated. The results shown in Figure 59 indicate that the load reductions around all sides are proportional to the thickness of lightweight material. Smaller gradient of load reduction, even a negative gradient of load reduction occurs, after an EPS of thickness of 0.90 meters is reached. EPS creates more load reduction than the load reductions created by the foam concrete. Two different mechanical principals are involved when the two different materials are used. Foam concrete strengths the culvert. As the thickness of foam concrete increases, the stronger the whole structure (the combination of the original culvert and added foam concrete) becomes. Whereas, EPS creates an arching effect. This arching effect causes a redistribution of loads in the surrounding fill soil. As the width of EPS increases, the arching effect becomes smaller. Both approaches reduce the load on the culvert.

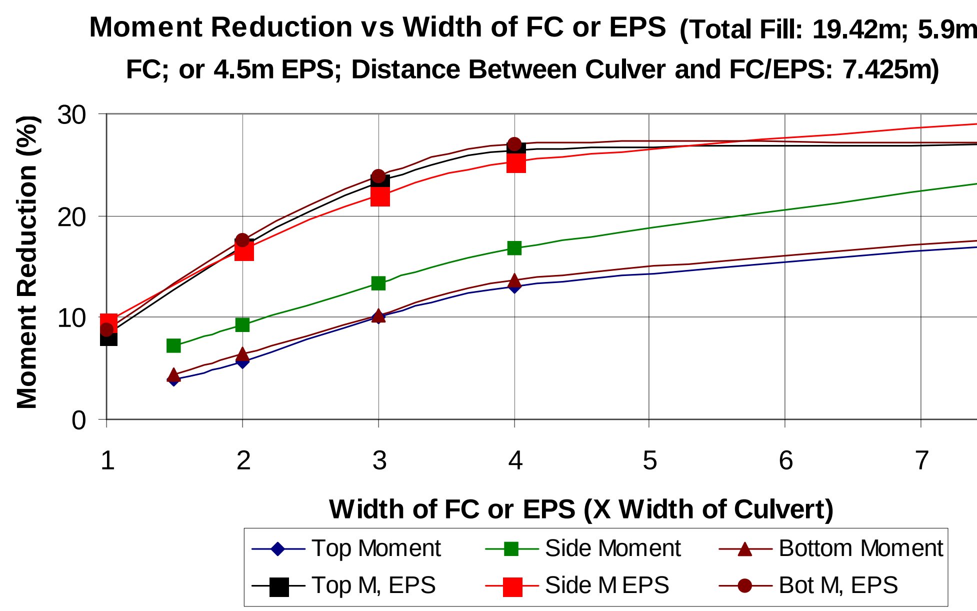

Figure 54. Changes of moment reduction as a function of lightweight materials' width on section B-B

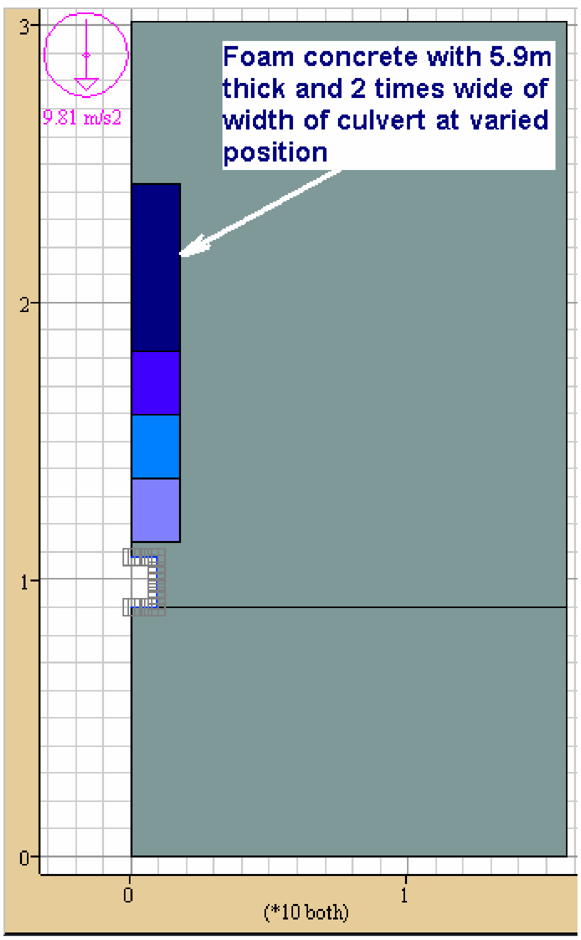

Figure 55. Foam concrete at 5.9m high and 2 times wide of culvert located varied position on section B-B

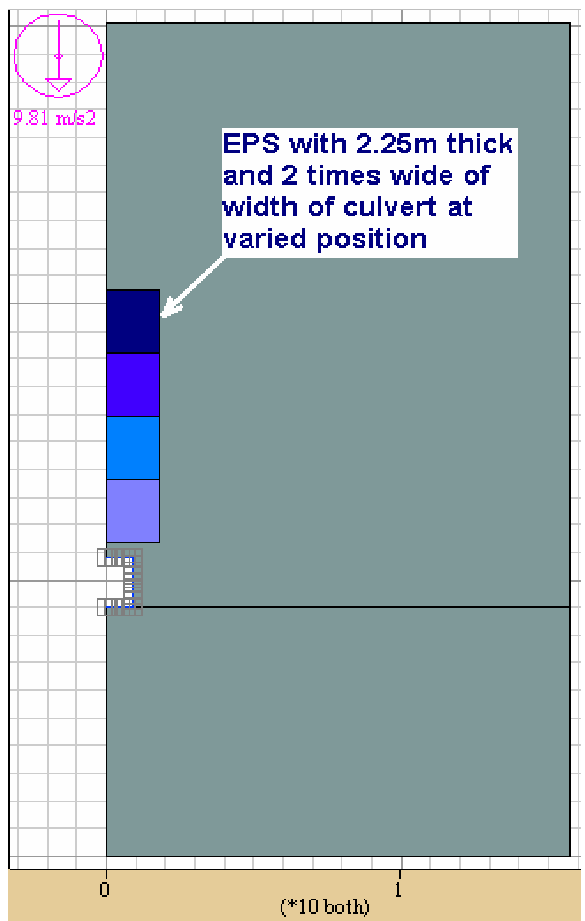

Figure 56. EPS at 2.25m high and 2 times wide of culvert located varied position on section B-B

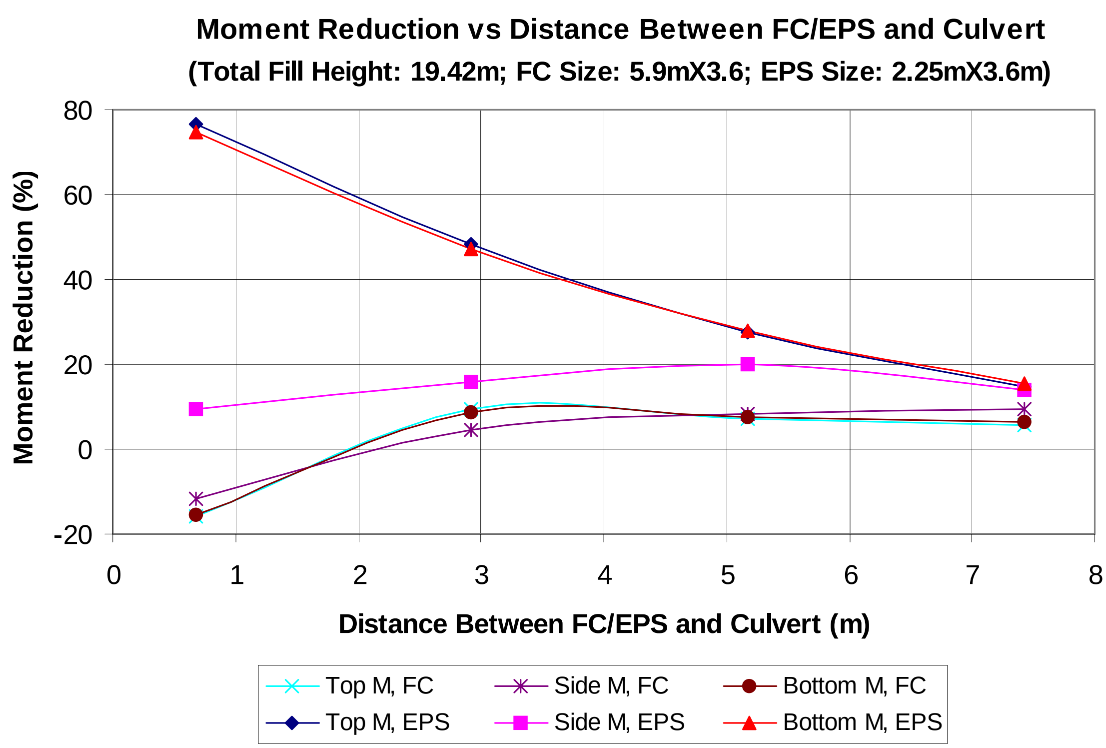

Figure 57. Changes of moment reduction as a function of distance between culvert and lightweight materials on section B-B

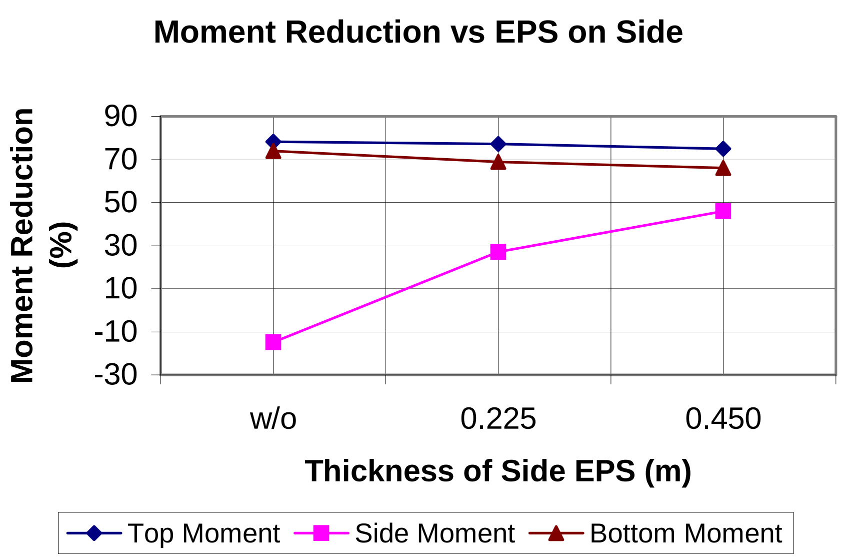

Figure 58. Moment reduction affected by putting EPS aside culvert (On section B-B)

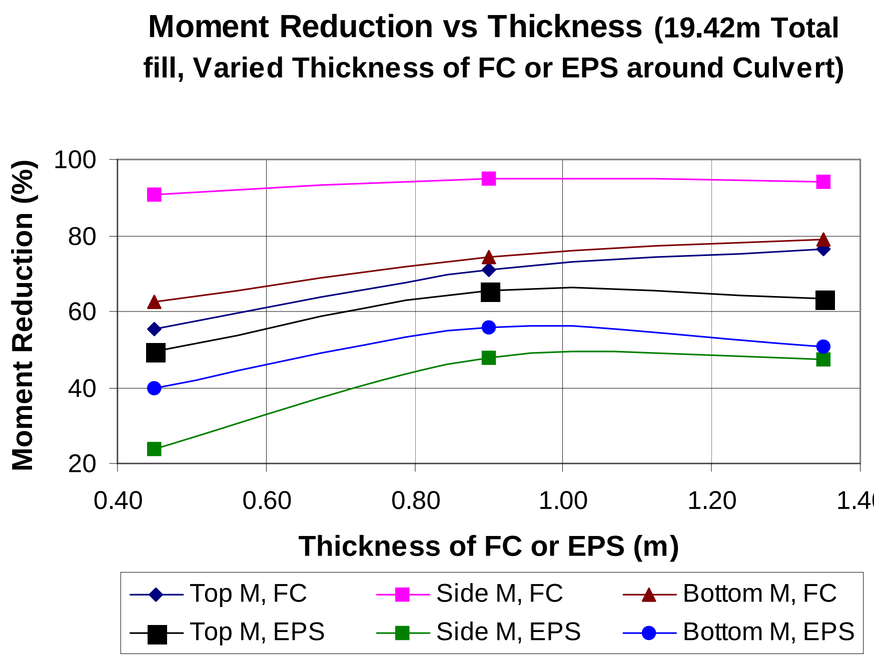

Figure 59. Changes of moment reduction as a function of thickness around culvert

CONCLUSIONS AND DISCUSSIONS

Results of the numerical analysis showed that geofoam can greatly reduce vertical soil pressures above and below a culvert. When geofoam is not placed above the culvert, areas of high stress concentrations occur at the top and bottom of the concrete culvert. By placing geofoam above and at the sides of the culvert, the maximum moments around the culvert can be reduced significantly. In these numerical model analyzes, placing geofoam of a thickness of 2 feet at the sidewall of the culvert wall reduces the load in all cases. Otherwise, the load on the sidewall increases because of the arching effect. The same moment reduction trends were observed on the top and bottom of the culvert. An opposite moment reduction trend was observed for the sidewall. The distance between geofoam and top of the culvert is a notable factor. The most efficient way to reduce top moments could be obtained by placing geofoam on the top of the culvert directly. On the other hand, culvert extension projects must deal with the existing structure. By placing geofoam directly on the top of culvert, more excavation is required. That is not efficient economically. Therefore, an optimal practical situation should be decided by considering both technical and economical issues.

Fill soil plays a notable role in reducing load on a culvert. The relative differences in the elastic moduli between fill soil and lightweight material is a key factor. Considerable load reduction is obtained as the difference between elastic moduli of fill soil and lightweight material increases. Generally, gravel and sand exhibit better behavior in creating load reduction than clay or silty clay.

The optimum effect of positive arching is obtained by placing geofoam on top of the culvert. Large and significant reductions on top and bottom moments may be achieved using this approach. In the analyses of a large fill (70 feet high), a reduction of moments due to the arching effect reached a certain limit when the thickness of geofoam reached a certain value. In the analyses of a small fill (20 feet high), a negative arching effect was found when the thickness of geofoam is over a certain amount, depending on the combination of different fill soil and different hardness of geofoam. In small fills, small unit weight of geofoam plays a more significant role in reducing loading than arching. As a result, the benefit of geofoam is not as effective as in the case where both the unit weight factor and the arching effect are combined.

Soft EPS is more efficient than harder EPS in reducing load on a culvert. It will create more deformation under fill soil pressure. That deformation generates a stronger arching effect above the culvert. Therefore, load on culvert will be reduced more notably.

Both lightweight materials, EPS and foam concrete, can be used to reduce load on a culvert if they are used correctly. In the situation of placing lightweight material above the culvert only, opposite trends are observed between foam concrete and EPS. A certain width of foam concrete is required to reduce the load on the culvert when foam concrete is placed directly on the culvert. Otherwise, load on the culvert increases. Placing EPS above the culvert is more efficient in reducing load on the culvert than placing foam concrete when their widths are same, even when the thickness of EPS is thinner than the thickness of foam concrete.

In the case of placing lightweight materials around all culvert sides, and besides the effect obtained from the smaller unit weights of the lightweight materials, two different mechanical principals are involved in reducing the load on the culvert. Foam concrete strengthens the culvert. As the thickness of the foam concrete increases, the stronger the whole structure (the combined foam concrete plus the original culvert) becomes. In contrast to the strengthen effect provided by foam concrete, EPS creates an arching effect. This arching effect causes a load redistribution in the soil surrounding the culvert. After a certain width of EPS is reached, the arching effect diminishes as the width of the EPS increases.

Linear-elastic models were used to simulate the geofoam stress-strain behavior in all numerical analyses. As noted earlier, geofoam exhibits desirable elastic-plastic behavior during compression. Geofoam creates a larger deformation, which develops a higher positive arching effect under an elasto-plastic model, than foam concrete, especially when stress on the geofoam is beyond the elastic range. The positive arching will further reduce the pressure on the culvert.

The ground water table is an important factor but was not considered in the analysis. Considering the high fills above the culvert, the ground water table may be above the culvert and have some non-negligible effect on the stress distribution around the culvert.

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