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Effect of valley on behavior of reinforced earth retaining structures

Fan, C.-C. & Kang, C.-F.
Dept. of Construction Engrg., National Kaohsiung First University of Science and Technology, Taiwan

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ABSTRACT: Behavior of reinforced earth retaining structures on a valley is inherently a 3-D problem due to irregular valley topography. Three-dimensional behavior of a reinforced earth retaining structure on a V-shaped valley is investigated in terms of reinforcement stress and deformation using a three-dimensional non-linear finite element analysis. Reinforcement settlement is not uniform after completion of the structure. Reinforcements of the structure deform like a bent beam in a horizontal plane. Reinforcement stress in the minor direction is noticeably mobilized due to three-dimensional effect and is mostly concentrated at the central-front area of the reinforcement, in addition to the tensile stress developed in the principal direction.

1 INTRODUCTION

Reinforced earth retaining structures are one of the commonly used retaining structures built on a valley to retain dumped materials or to increase usable area in landfill projects. Two reinforced earth retaining structures, used for retaining dumped materials, built on a valley collapsed in a torrential rainfall in northern Taiwan in 1998 (Fan and Chou, 2002). One of the major findings in the field investigation for the two failure cases is that tensile rupture in the reinforcement was identified in the minor direction, i.e. the direction perpendicular to the direction in which the valley runs. In other words, reinforcement stress in the minor direction may be noticeably mobilized in addition to the tensile stress normally considered in the principal direction. In addition, Lee et al. (1994) reported a failure case of four reinforced soil walls built as the embankments of a highway. One of the failed walls was rested in the center of a ravine at its deepest part and contained a convex corner. The pronounced three-dimensional geometry produced non-uniform displacements in the wall and was believed to be one of the reasons causing failure.

Schematic diagram of a reinforced earth retaining structure situated on a V-shaped valley is illustrated in Figure 1. Geometric cross-sections of the reinforced earth retaining structure at various locations along the valley are different. Reinforced earth retaining structures on a valley is intrinsically a three-dimensional problem rather than a two-dimensional plane strain problem because the driving forces on back of the structure is not uniform. Research effort on the three-dimensional effect of slope stability problems has been carried out over the past few decades (Leshchinsky and Baker 1986; Stark an Eid 1998; Huang et al. 2002). In addition, three-dimensional analyses for stability of earth-rockfill dams on a canyon have also been carried out to investigate the three-dimensional behavior of earth-rockfill dams (Mejia 1989; Belyakov 1989; Yu 2005). However, three-dimensional behavior of reinforced earth retaining structures built on a valley terrain has limited study so far.

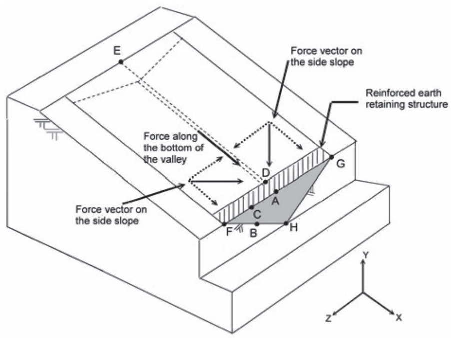


Figure 1. Schematic diagram of a reinforced earth retaining structure on a V-shaped valley.

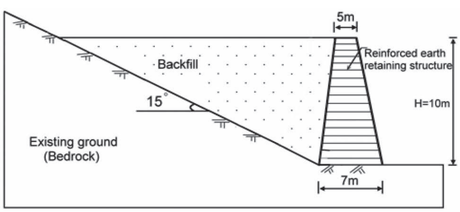
Behavior of reinforcement stress and deformation of a reinforced earth retaining structure on a V-shaped valley was investigated by taking into account three-dimensional effect in this paper. Construction procedures of the structure were simulated using the three-dimensional non-linear finite element model.

2 NUMERICAL MODELING

2.1 *Three-dimensional finite element model*

The three-dimensional finite element program "PLAXIS 3DT" (PLAXIS B.V. 2002) was used to generate the numerical model for analysis of a reinforced earth retaining structure on a V-shaped valley. Construction procedures of the structure and backfilling process in a valley were simulated in the finite element analysis. Three-dimensional finite element mesh for the terrain of a V-shaped valley was generated prior to construction of the structure. Geometry of the valley is symmetric about the bottom of the valley. Gradients of the bottom and side slope of the valley are 15° and 45°, respectively. Top width of the V-shaped valley is 20 m. The geologic condition for the existing valley was presumed to be competent bedrocks.

Geometry of the cross-section of the reinforced earth retaining structure, used in this research, at the bottom of a valley is shown in Figure 2. The structure has a height of 10 m at bottom of the valley, and bottom and top widths of the structure at this cross-section are 7 m and 5 m, respectively. Vertical spacing of the reinforcement is 0.5 m. A total of 21 layers of reinforcements were placed in the reinforced earth retaining structure. Three-dimensional finite element mesh for the structure along with the backfill in the valley is shown in Figure 3. The mesh consists of 40392 wedge elements and has been examined to eliminate the influence of mesh's size on the results of the analyses. Number of nodal points and stress points in the mesh are 105302 and 242352, respectively. The front boundary of the mesh, i.e. the right-most y-z plane in Figure 3, was set to be 20 m away from the front face of the structure to minimize the influence of valley's downstream on the behavior of the structure. The front and back boundaries of the mesh in the y-z plane are fixed against displacements in any direction. Both of the boundaries in the x-y



Note: the dimension is not to scale.

Figure 2. Cross-section of the reinforced earth retaining structure at the bottom of the valley used in this research.

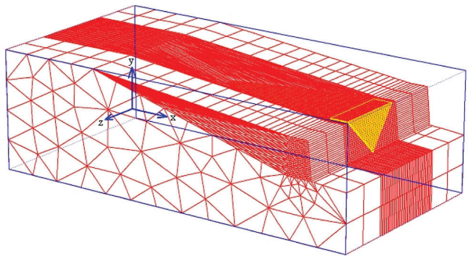


Figure 3. Three-dimensional finite element mesh of a reinforced earth retaining structure on a V-shaped valley at the end of the backfilling stage.

plane are only fixed against displacements in the z-direction. The initial stress condition for the existing ground of the valley was generated using the procedure of gravity loading. Additionally, water level is not taken into account in the finite element model.

2.2 *Modeling of existing bedrocks, backfills, and reinforcements*

Soil and bedrock elements used in the finite element model are 15-node wedge element, and each wedge element contains six stress points. The Mohr-Coulomb constitutive model was used to model the stress-strain behavior of the soil and the bedrock. Material parameters for backfill of the reinforced earth retaining structure, the backfill in the valley, and the existing bedrock are listed in Table 1. The material parameters used for the backfill are frequently seen in the engineering practice. In addition, the parameters used for the bedrock may conservatively represent the behavior a competent rock, e.g. sandstone.

Table 1. Material parameters used in the finite element analyses.

Backfill		Existing bedrock	Reinforcements
Reinforced structure	In the valley		
γ_{dry} = 18 kN/m^3	γ_{dry} = 15 kN/m^3	γ_{dry} = 23 kN/m^3	EA = 2000 kN/m
γ_t = 21 kN/m^3	γ_t = 19 kN/m^3	γ_t = 23.6 kN/m^3	
c = 10 kPa	c = 10 kPa	c = 10^4 kPa	
ϕ = 35°	ϕ = 28°	ϕ = 35°	
E_s = 60 × 10^3 kPa	E_s = 40 × 10^3 kPa	E_s = 20GPa	
ν = 0.3	ν = 0.25	ν = 0.3	

The reinforcement in the FE analysis was modeled as a structural element. A two-dimensional 8-node quadrilateral element with three degrees of freedom per node was used to simulate the behavior of reinforcements (reinforcing elements). Reinforcing elements can sustain only tensile forces and were modeled as elastic materials. Axial forces in x-coordinate and z-coordinate are calculated at the Gaussian stress points of reinforcing elements. Elastic axial stiffness (EA) is the only material parameter for the reinforcing element and is entered in unit of force per unit width because the material is considerably thin. Normally, axial stiffness of reinforcements can be determined as the ratio of the applied force in the longitudinal direction to the elongation of the material from the test of tensile strength if the plot of these two data is approximate in a linear relationship. A typical value of 2000 kN/m was used as the axial stiffness of reinforcements (e.g. geogrid) in the analysis. In addition, tensile stresses developed in the reinforcement were checked to ensure it is less than the ultimate tensile strength of the material to justify the elastic modeling for the reinforcement. No interface elements were used between the reinforcement and the soil mass because the reinforced earth retaining structure considered in this paper is in wrapped-around type of construction. Additionally, the backfill in the valley is confined by the bedrock and the structure, and the relative displacement between the bedrock and the backfill is considered negligible. Thus, interfaces were not used at the boundary between the bedrock and the backfill.

2.3 *Construction procedures*

Construction simulation of a reinforced earth retaining structure in the finite element analysis is similar to that in waste disposal projects, which the structure is used for retaining waste materials. Reinforcements and backfill are placed alternately until the full height of the structure is reached. Backfill, with a thickness of 2m at each step, is then filled up in the valley until its elevation reaches the top of the structure.

3 THREE-DIMENSIONAL BEHAVIOR

3.1 *Deformation*

Reinforcement settlements at a number of selected levels are shown in Figure 4 after completion of the structure. At the upper half of the structure (the top to the 10th level), the maximum settlement takes place at the central area of the reinforcement. However, the maximum settlement is located at the area close to the central front and back faces of the reinforcement at the lower half of structure (the elevation lower than the 10th level), and it is symmetric about the center of the reinforcement. Distribution of the settlement at each level of the reinforcement is not uniform after completion of the structure, and it is primarily attributed to the irregular valley's topography.

Deformed shape of the reinforcement in the horizontal direction (x-z plane) at a number of selected levels is shown in Figures 5(a) and 5(b) after completion of the structure and at the end of the backfilling stage, respectively. The deformed shape of the reinforcement after completion of the structure is similar on its front and back faces, and the central part of the reinforcement at the front and back faces undergoes more horizontal displacement than its ends by the valley sides. At the end the backfilling stage, the horizontal displacement at the front face is more than that at the back face, especially at the lower half of the structure. The bent shape in the reinforcement is primarily resulted from the non-uniform distribution of driving forces on back of the structure.

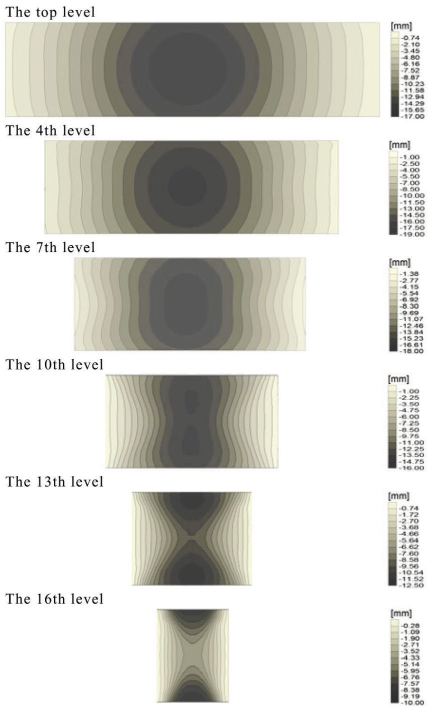


Figure 4. Contour plots of reinforcement settlement after completion of reinforced earth retaining structures.

Figure 6 shows the contour plot of the normal stress exerted on back of the structure at the end of the backfilling stage using the 3-D finite element analysis. The distribution of the normal stress is not uniform. The normal stress close to the valley sides is greater than that at the central area at a given elevation due to the driving forces on the side slopes of the valley. Sum of the normal stress for the cross-section at mid-width of the valley is greater than that at any other cross-sections. However, the distribution of normal stresses may rely on the geometry of the valley, including gradient of the valley's bottom, gradient of the side slope, and valley width, etc.

3.2 *Reinforcement stress in the principal direction*

Distributions of reinforcement stress (F_x) in the principal direction (parallel to ED line in Figure 1)at a number of selected levels after completion of the structure and at the end of the backfilling stage are

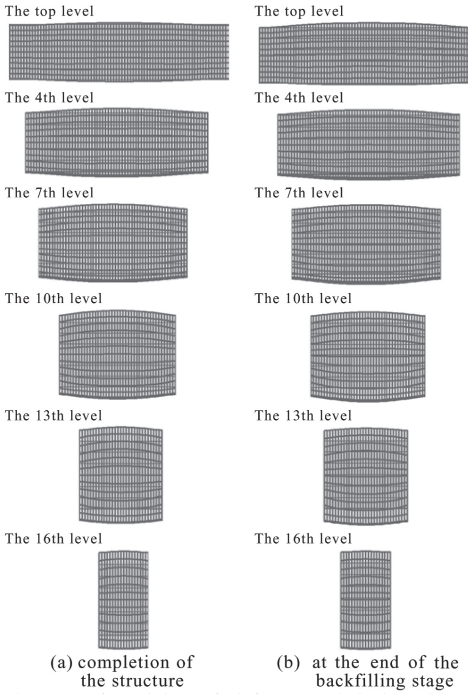


Figure 5. Deformed shape of reinforcements in horizontal (x-z) plane (scaled up to 150 times).

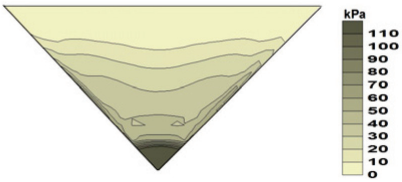


Figure 6. Contour of the normal stress on back of the structure at the end of the backfilling stage.

shown in Figures 7 and 8, respectively. The maximum reinforcement stress ($F_{x\text{-}max}$) at the upper levels, i.e. the top to the 7th level, takes place at the area near one-quarter reinforcement length from the valley sides after completion of the structure. The maximum reinforcement stress ($F_{x\text{-}max}$) at the 10th to the 13th level, i.e. around the mid-height of the structure, is located near the central part. However, the maximum reinforcement stress ($F_{x\text{-}max}$) at the lower level of the structure is mobilized close to its front and back faces.

Non-uniform settlement and deformation, induced in the construction of the structure, at each level of the reinforcement play important roles in the distribution of the reinforcement stress in the principal direction. It is noted that the maximum reinforcement stresses below the 7th level (about 2/3 height) at the end of the backfilling stage are close to those after completion of the structure. Thus, the reinforcement

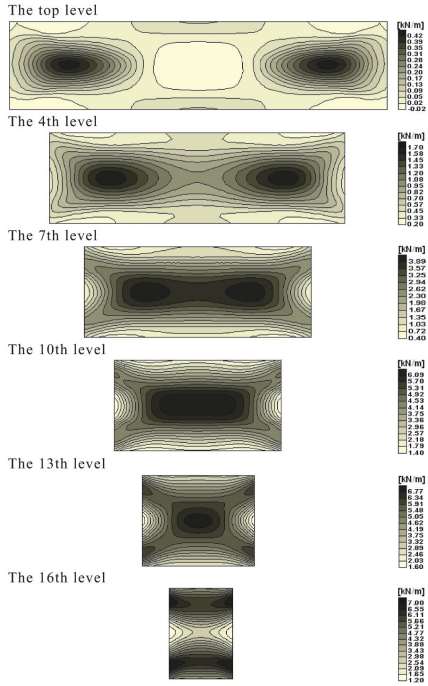


Figure 7. Contour plots of reinforcement stress in principal direction after completion of the structure.

stress in the principal direction is mostly developed during the construction stage of the reinforced earth retaining structure. The backfilling stage has a slight influence on the mobilization of the reinforcement stress in the principal direction.

3.3 *Reinforcement stress in the minor direction*

Contour plots of the reinforcement stress (F_z) in the minor direction (the direction perpendicular to ED line in Figure 1) at a number of selected levels are shown in Figures 9 and 10 for various construction stages. The maximum reinforcement stress ($F_{z\text{-}max}$) above the mid-height of the structure is located at the area by the valley sides after construction of the structure. This is mainly attributed to two reasons: (1) non-uniform settlement takes place during the construction of the structure; (2) the end effect of the structure by the valley sides result in local extension in the reinforcement. It is, however, noted that reinforcement stress (F_z) is developed to some amount at the central front and back faces below the mid-height of the structure after the construction of the structure. In addition, the distribution of reinforcement stress (F_z) at the end of the backfilling stage shows that the stress is also noticeably mobilized at the central front area below the mid-height of the structure.

The "valley effect" plays an important role in the mobilization of reinforcement stress (F_z) in the minor

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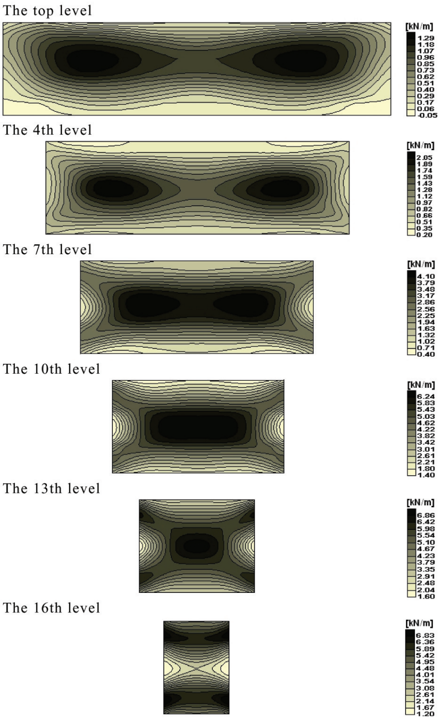

Figure 8. Contour plots of reinforcement stress in principal direction at the end of the backfilling.

direction at the central front area of the reinforcement. A schematic diagram of likely forces on back of a reinforced earth retaining structure in a valley is shown in Figure 1, and illustrates that driving forces on the side slopes affect the distribution of the force on back of the structure, in addition to the driving force in direction parallel to the bottom of the valley.

The behavior of stresses and deformations developed in a reinforced earth retaining structure on a valley is inherently a 3D problem rather than a 2D plane strain problem. The major sources of the three-dimensional effect are attributed to a number of factors: (1) the geometric cross-sections of the structure are different at various locations; (2) the driving force on back of the structure is non-uniform; (3) the ends of the structure by the valley sides offer restraint to the structure.

4 CONCLUSIONS

The three-dimensional behavior of a reinforced earth retaining structure on a V-shaped valley was presented in this paper in terms of reinforcement deformations and stresses. The quantitative results, however, in this paper are limited to the structure with a height of 10 m and a width of 7 m and 5 m at its bottom and

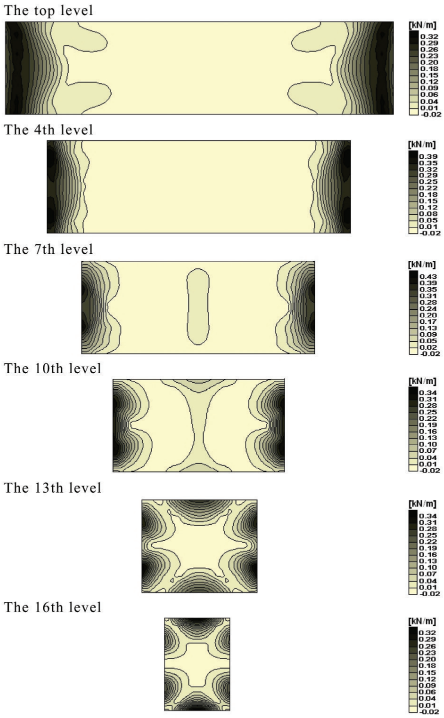

Figure 9. Contour plots of reinforcement stress in the minor direction after completion of the structure.

top, respectively, for the cross-section at mid-width of the valley. The gradients of the side slope and the valley's bottom are 45° and 15°, respectively. A three-dimensional finite element model was used to generate the topography of a V-shaped valley and to simulate the construction of the reinforced earth retaining structure. Major findings of this research are summarized as follows.

(1) Distribution of the reinforcement settlement after completion of a reinforced earth retaining structure on a valley is not uniform. After completion of the structure, the maximum settlement takes place at the central area of the reinforcement at the upper half of the structure. The maximum settlement is located close to its central front and back faces at the lower half of structure, and it is symmetric about the center of the reinforcement. This is primarily attributed to the irregular valley's topography.
(2) The normal stress on back of the structure on a valley is in a non-uniform distribution. The normal stress at the central area of the retaining structure is less than that close to the valley sides at a given elevation due to the additional forces induced along side slopes of the valley.
(3) Three dimensional effect of a valley results in a

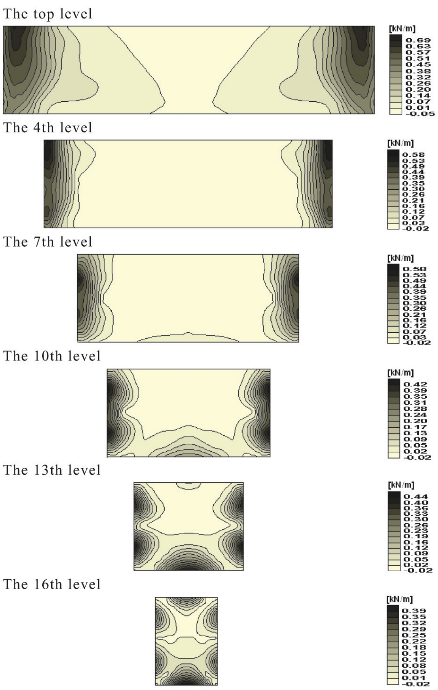

Figure 10. Contour plots of reinforcement stress in minor direction at the end of the backfilling stage.

lateral bent deformation in the reinforcement if reinforced earth retaining structures are constructed on a V-shaped valley.

(4) After completion of the structure, the maximum reinforcement stress ($F_{x\text{-}max}$) at upper level, middle level, and lower level of the structure takes place at the area near one-quarter reinforcement length from the valley sides, near the central part, and close to its front and back faces, respectively. The reinforcement stress in the principal direction is mostly mobilized during the construction stage of the structure.

(5) Reinforcement stresses (F_z) in the minor direction at its central front area and at the end of the structure by the valley sides are noticably mobilized at the end of the backfilling stage.

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REFERENCES

Belyakov A.A. (1989). Three-dimensional behavior of an earth dam at a wide site. *Hydrotechnical Constrution*, 22(12), pp. 718-725.

Fan C.C. and Chou N.S. (2002). A new failure mechanism of reinforced retaining structures induced by long beam effect. *Proceedings of the 7th International Conference on Geosynthetics*, Nice, France, pp. 65-78.

Huang C.C., Tsai C.C. and Chen Y.H. (2002). Generalized method for three-dimensional slope stability analysis. *J. of Geotechnical and Geoenvironmental Engineering*, ASCE, 128(10), pp. 836-848.

Lee K., Jones C.J.F.P., Sullivan, W.R. and Trolinger, W. (1994). Failure and deformation of four reinforced soil walls in eastern Tennessee. *Geotechnique*, 44(3), pp. 397-426.

Leshchinsky D. and Baker R. (1986). Three-dimensional slope stability: end effects. Soils and Foundations, 26(4), pp. 98-110.

Mejia L.H. (1989). Three-dimensional stability of an old dam. *Proceedings of the 12th international conference on soil mechanics and foundation engineering*, Rio de Janeiro, Brazil, pp. 1579-1582.

PLAXIS BV. 2002. *PLAXIS 3DT V. 1.2*.

Stark T.D. and Eid H.T. (1998). Performance of three-dimensional slope stability analysis method in practice. *J. Geotechnical Engineering*, ASCE, 124(11), pp. 1049-1060.

Yu Yuzhen, Xie Liquan, and Zhang Bingyin. (2005). Stability of earth–*rockfill* dams: Influence of geometry on the three-dimensional effect. *Computers and Geotechnics*, 32(5), pp. 326-339.