



Research Article

Use of geosynthetics to reduce the required right-of-way for roadways and railways

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ABSTRACT

Roadway and railway routes require a right-of-way (ROW) to provide the necessary width for the required travelled way, drainage and earthwork. Correct understanding of ROW along a route is necessary in order to establish a correct width for the intended transportation corridor. Availability of land becomes scarce and cost of land increases in urban zones. Therefore, the costs of establishing a ROW in rural areas and in urban areas are not the same. Earthworks are an important component of route establishment. The required excavations and fills necessitate the use of proper side slopes for the stability of the excavation or the fill. These side slopes directly relate to the mechanical properties of the soil and the depth of the earthwork. This study provides a quantitative and a qualitative understanding of the ROW requirements of roadways and railways and the influence of the earthworks on the determined values of the ROW. The study further investigates the benefits of using geogrids to reduce the necessary ROW for a transportation route through finite element analysis.

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1. Introduction

Establishment of roadway and railway routes necessitates the establishment of the required ROW for the placement of the requirements of a particular transportation corridor. Transportation engineers respond to the estimated transportation demand along a route by providing a capacity that produces a satisfactory level-of-service (LOS). A common representation of the transportation capacity is the number of units that can be transported per unit value time. The number of roadway lanes and railroad tracks of a route, along with the values of curvatures and profile slopes influence the capacity of a route.

The width required for the establishment of roadways and railways must be correctly estimated to facilitate sufficient space for the requirement of the route. On the other hand, the scarcity of land in urban grounds increase the construction costs per distance as opposed to route construction costs in rural grounds. Therefore, one must correctly estimate the required ROW and investigate means to reduce the required ROW in order to establish

an economic and an achievable transportation route. The following section offers simple parametric tools to estimate the required ROW for roadways and railways. The discussion included in the section that follows provides an analytical insight into how geogrid reinforcements can effectively reduce the required ROW.

2. Right-of-way Requirements for Railways and Roadways

Roadways and railways have unique requirements for their cross-sections. The following two subsections discuss these requirements and the necessary widths for their establishment.

2.1. Roadways

Roadways are built to provide a link between locations where there is a mutual traffic demand. Number of lanes and the geometric alignment requirements are

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based on the design LOS and the estimated volume of traffic. A roadway section includes the travelled way which is provided by the total number of lanes, shoulder lanes that provide refuge for disabled vehicles and emergency vehicles and a median that includes space for barriers, drainage and future space for possible lane additions. The lane widths typically vary from 3.3 m or 3.5 m

to 3.75 m and the shoulder widths vary up to 3 m. The median width is variable depending on the route conditions, the costs of providing the ROW and the projected traffic conditions. Fig. 1 shows a typical cross section for a 4-lane and 2-way roadway. The left part of the figure represents the roadway on a fill and the right side of the figure represents the roadway within a cut.

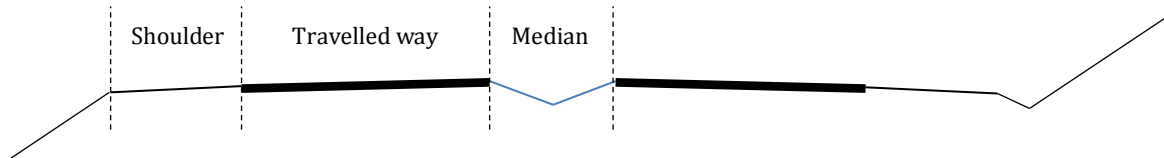


Fig. 1. Typical components of two-way and 4-lane roadway (TEM, 2002).

One needs to account for all the aspects of roadway construction in order to have an understanding of the required ROW to satisfy all the needs of the roadway. The geography along which the route is placed may require extensive earthwork to attain the design gradients. To this end, cuts and fills may take place along the route that requires an extended ROW for the route. The following list summarizes the necessary components of a roadway and Eq. (1) provides an equation to estimate the required ROW.

- A. Lane width.
- B. Shoulder lane width.
- C. Number of lanes.
- D. Number of shoulder lanes. 1 or 2.
- E. Median width.
- F. Total drainage width of the drainage channels.
- G. Depth of the cut.
- H. Depth of the fill.
- I. Side slope of the cut: vertical depth/lateral extent.

J. Side slope of the fill: vertical height/lateral extent.

K. Number of cut slope. 0, 1 or 2.

L. Number of fill slope. 0, 1 or 2.

Eq. (1), proposed by the author presents the required width of the ROW for a roadway. This is a general equation that can be modified to reflect the particular earthwork conditions. For instance, if the earthwork is completely on a fill then $L=2$ and $K=0$. If half of the earthwork is on a fill and half of it is on a cut then $L=1$ and $K=1$. If the earthwork is completely within a cut then $L=0$ and $K=2$.

$$\text{ROW} = A \times C + B \times D + E + F + (G/I) \times K + (H/J) \times L. \quad (1)$$

Table 1 is a summary of ROW requirements for a 4-lane and two-way roadway with the given properties with varying depths of cut and fills. The roadway cross sections presented in Table 1 is composed of either a total fill or a total cut. The requirements are determined based on the proposed Eq. (1).

Table 1. ROW requirements for a roadway.

Lane width (m)	Shoulder width (m)	Median width (m)	Number of lanes	Number of shoulders	Total width of drainage ditch (m)	Width of super-structure (m)	
3.6	2	1	2	2	2	14.2	
Depth of cut (m)	Depth of fill (m)	Slope of cut	Slope of fill	Total width of the cut (m)	Width of the fill (m)	Width of ROW in only cut (m)	Width of ROW on only fill (m)
2	2			4	8	18.2	22.2
4	4	1	1/2	8	16	22.2	30.2
6	6			12	24	26.2	38.2
2	2			8	12	22.2	26.2
4	4	1/2	1/3	16	24	30.2	38.2
6	6			24	36	38.2	50.2

The required side slopes for cuts and fills is partly a question of geotechnical engineering and partly a question of traffic safety engineering. The cuts and fills must take place under correct slope angles to provide long term stability and safety of the slope. On the other hand, the

slopes must be forgiving to vehicles that have gone astray and prevent them from over turning down a fill slope and crashing into a cut slope. The required side slope for a cut in a particular geotechnical material is typically higher than the required side slope of a fill consisted of the same

materials, since the angle of repose of the undisturbed material within the cut is typically higher than the angle of repose of the disturbed material that is excavated and compacted for the fill. With this understanding, Table 1 provides an insight into the variation of the need for a ROW for a roadway of a certain superstructure width. Table 1 indicates that the earthwork requirements are an important component of the required ROW of a roadway.

2.2. Railways

Trains provide transport of goods and people between locations along a guided way. Railways are a common form of guided ways that are mainly composed of ballasted superstructures. But contemporary guided ways are increasingly using slab tracks and more recently the electrified tracks that are a part of magnetic levitation superstructures. Experimental studies for an alternative land transport named the “Hyperloop” that rely on magnetic levitation within a vacuumed tube as a guide way is underway.

Design of the railway superstructure takes into account the expected wheel forces, the design speeds and

the design traffic. A ballasted railway superstructure consists of the rails, the ties supporting the rails, the ballast surrounding and underneath the ties and the sub-ballast layers. The number of tracks thus attained determines the superstructure width of the railway. Along with the drainage and earthwork slope requirements, the required ROW of railways is typically lower than roadways, which is beneficial from an environmental and civil engineering point of view. Nevertheless, the ROW required for a railway route is much greater than what is typically needed for the individual railway tracks.

Fig. 2 is a sketch of the components of a ballasted track. A ballasted railway superstructure consists of the sub-ballast layer, underlying a ballast layer within which the sleepers that support the rails are embedded. The sub-ballast provides frost protection, drainage and filtering to the ballast layer and together with the ballast layer they distribute the bearing stresses underneath the sleepers to acceptable levels on the sub-grade. The sub-grade may be a fill or natural ground in a cut. The width of a normal gauge track as measured from the centerlines of the rails is 1.5 m.

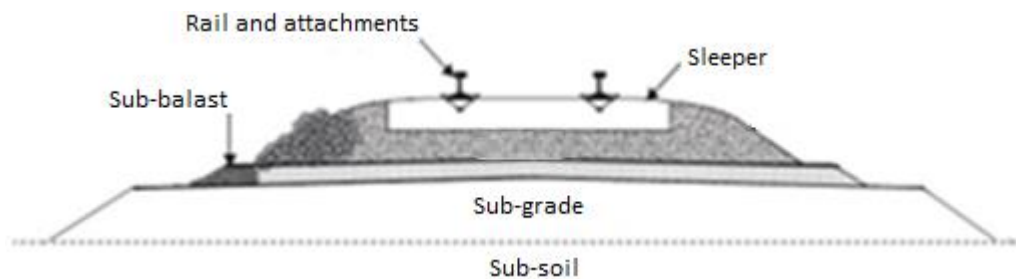


Fig. 2. Components of a ballasted railway track.

The following list provides the details of the components and their design values that determine the required ROW of a particular section along a railway route.

1. Sleeper width: 240 cm – 280 cm
2. Shoulder ballast width: Up to 50 cm.
3. Ballast depth: 30 cm minimum.
4. Sub-ballast depth: Variable. 20 cm minimum.
5. Sub-ballast slope: 1:2 typical.
6. Ballast side slope: 1:2 typical.
7. Safety walkway width: Variable. 1 m minimum preferred.
8. Number of tracks: Variable. Contemporary railways minimum 2 tracks.
9. Minimum centerline distance between tracks: Variable.
10. Drainage channel width: Variable
11. Depth of cut: Variable.
12. Depth of fill: Variable
13. Side slope of the cut: Variable.
14. Side slope of the fill: Variable.

The variables listed above are simplified for design and based on the simplification; the variables below become effective on the ROW requirement.

- A. Minimum distance between the centerline of the track and the edge of the superstructure.
- B. Minimum distance between the centerlines of the tracks.

- C. Number of tracks.

- D. Required total width of drainage channels.

- E. Depth of the cut.

- F. Depth of the fill.

- G. Side slope of the cut: vertical depth/lateral extent.

- H. Side slope of the fill: vertical height/lateral extent.

- I. Number of cut slope. 0, 1 or 2.

- J. Number of fill slope. 0, 1 or 2.

Eq. (2), proposed by the author, presents the required width of the ROW for a railway. Similar to Eq. (1), this is a general equation that can be modified to reflect the particular earthwork conditions. For instance, if the earthwork is completely on a fill then $I=0$ and $J=2$. If half of the earthwork is on a fill and half of it is on a cut then $I=1$ and $J=1$. If the earthwork is completely within a cut then $I=2$ and $J=0$.

$$\text{ROW} = A \times 2 + B \times (C-1) + D + (E/G) \times I + (F/H) \times J. \quad (2)$$

Fig. 3 is a sketch of a two-track ballasted railway showing the centerline spacing of the two tracks and the edge distances of a track centerline with respect to the boundary of the track superstructure. The variations in the specified dimensions occur according to the design train speeds for the tracks, with higher dimensions affiliated with higher speeds.

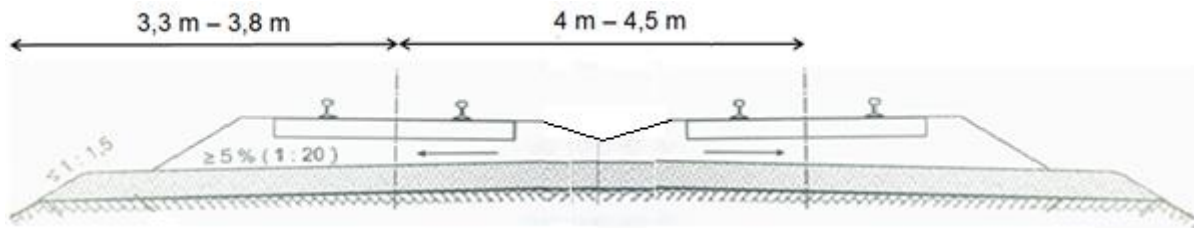


Fig. 3. Two track ballasted railway superstructure (Lichtberger, 2011).

Fig. 4 is a photograph showing the ROW required for a cut. Notice that the required width is directly proportional to the cut depth and the needed ROW is much greater than

the width required for only the railway superstructure. Table 2 presents the ROW requirements for a double track high speed railway route for varying cut and fill values.



Fig. 4. Perspective of a double track railway route through a cut (UDH, 2012).

Table 2. ROW requirements for a railway.

		Track centerline distance (m)		Track edge distance (m)	Number of tracks	Total width of drainage ditch (m)	Width of super-structure (m)	
		4.5		3.8	2	2	12.1	
Depth of cut (m)	Depth of fill (m)	Slope of cut	Slope of fill	Total width of the cut (m)	Width of the fill (m)	Width of ROW in only cut (m)	Width of ROW on only fill (m)	
2	2	1	1/2	4	8	16.1	20.1	
4	4			8	16	20.1	28.1	
6	6			12	24	24.1	36.1	
2	2	1/2	1/3	8	12	20.1	24.1	
4	4			16	24	28.1	36.1	
6	6			24	36	36.1	48.1	

3. Expropriation Costs for Transportation Routes

Previous discussions highlight the need and the necessity of sufficient ROW for roadways and railways. The required ROW becomes especially critical in urban grounds where the land costs are much higher compared to rural areas. Urban land values can be up to 20 times

more than rural land values (McCarthy, 2001). Recent studies indicate ROW acquisition costs up to 20% of the total projects costs in urban areas (Balci, 2010).

One must remember that although the transportation routes appear as curvilinear lines on a map, they do have a width. The fact that their widths are very low compared to the length of a route sometimes result in under-

estimating the needs for width that becomes problematic especially in urban grounds where the cost of land and the cost of acquisition is high. 1-m extra ROW width per kilometer of route amounts to an extra 1,000 m² land per km of route.

The following section provides a simple analytic explanation for the benefits of reinforcing the earth to reduce the required ROW, which has useful implications in the establishment of transportation routes.

4. Effects of Geogrids in Earthworks

Uses and benefits of geogrids in transportation applications is plenty. From a mechanical point of view, the interlocking and interaction between a geogrid layer embedded in soil with the surrounding soil domain is essential to the improvement of the soil resistance. Deformations within a soil domain under applied loads generate tensile stresses within the embedded geogrid layer interacting with the soil. The tension in the geogrid provides confinement on the soil. This confinement changes the positioning of the failure planes and delays their development via increasing the shear strength of the soil. Typical application of geogrids involve parallel placement at 30 cm–60 cm intervals up to a 70% height of the strengthened and stiffened soil mass (EBGEO, 2011).

A thorough numeric investigation of the stress states within a soil mass requires a sophisticated anal-

ysis program than can conduct a non-linear, discrete element contact stress variation analysis. In the absence of such a program, a simple linear continuous domain analysis yielded a limited but effective understanding of the influence of the side slopes of a fill on its stability and the benefits of geogrids in achieving slope stability.

Finite element models for a 1-m thick and 6-m high sand fill with a unit mass of 2,000 kg/m³ established for a 14-m wide roadway superstructure with variable side slopes provided some understanding of stress distribution within the supported soil mass. The modulus of elasticity of the soil is taken as $E=204$ MPa. The unit of the stresses presented in the finite element analysis results is kg-f/m² (kilogram-force per m²). The internal friction angle of the modeled soil is 30°. In order to shorten the run time of the models, only half of the soil mass is modeled. In other words, the left edges of the models are the centerlines of the modeled superstructure.

Fig. 5 shows the results obtained for the case of the absence of a side slope. In this case where the soil mass is vertical, it is a known fact that the soil mass fails and reaches stability at its natural angle of repose. Fig. 5(c) reveals the upper portion of the stress field that tends to “flow over” the bottom part of the soil. The maximum top displacement is 2 mm and the highest vertical stress developed at the bottom is 12,000 kg-f/m². The highest lateral shear stress at the bottom right corner of Fig. 5(c) is 2,040 kg-f/m².

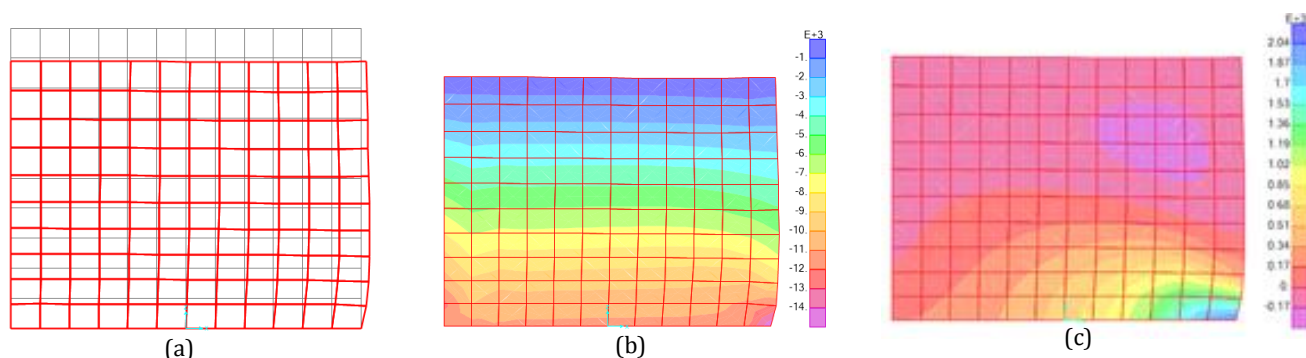


Fig. 5. FEM analysis results of a half model: (a) Deformed shape of a 14 m wide superstructure on a 6 m fill; (b) Vertical normal stress distribution; (c) Shear stress distribution.

Figs. 6 and 7 shows the FE analysis results of a similar soil mass, where the side slopes of the fill is lowered to 1:1 (vertical : lateral) with a slope angle of 45°. If one compares Fig. 7 with Fig. 5(c), the part of the soil mass that moves rightwards is resisted by the abutting soil at the toe of the slope. The provided support for the tendency to flow to the right is shown by the dashed arrow emanating from the toe region of the side slope. The maximum shear stress at the toe of the slope develops within the slope that is slightly to the left of the slope boundary and reduces to 1,300 kg-f/m² for the case of 1:1 slope. In other words, the side slope provides some form of an abutment to the lateral shearing deformation and provides confinement to the lateral spread of the vertical height of the fill.

Fig. 8 shows the FE model for the case where the side slope is further lowered to 1:2 with a slope angle of 26.5°.

Fig. 10 yields that the shear stresses at the toe are lower than the values shown at Fig. 7 for the case with a side slope of 1 to 1. The vertical displacement is about 1.5 mm. The maximum shear stresses at the toe of the slope further reduces to 960 kg-f/m² for the case of 1:2 slope and the region of maximum shear stress is further pushed inwards the fill thereby highlighting the effect of decreased side slopes on the developing shears and improved slope stability.

The stress distribution within the soil mass can be changed by introducing the horizontal stiffening action of geogrids. Fig. 11 shows a soil mass with a 1:1 slope stiffened by layers of geogrids placed at 60 cm intervals along the depth of the soil mass. The stiffness of the geogrids are 1,000 kg-f/mm per meter geogrid width. Compared to Fig. 7, the geogrids provides a second source of lateral confinement to the fill additionally to

the abutment effect of the side slope. The center of lateral tensile forces on the geogrids distribute the maximum areas of the shear stresses to approximately mid-height of the fill and the interior of the toe of the fill. The confinement due to geogrids

represented by the dotted arrow is added to the abutting support provided by the toe of the fill. Compared to the shear stresses presented in Fig. 7, the use of geogrids have reduced the shear stresses approximately 23%.

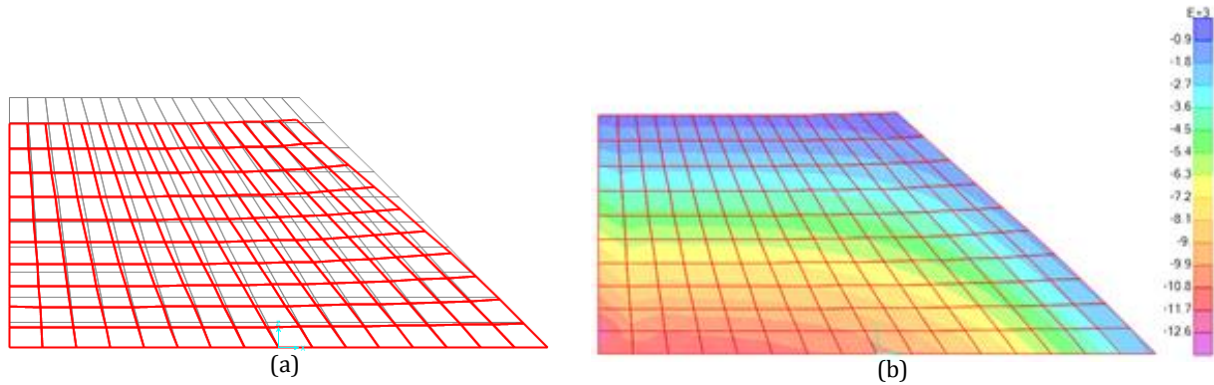


Fig. 6. FE model analysis results of a half model with a 1:1 side slope: (a) Deformed shape of a 14 m wide superstructure on a 6 m fill; (b) Vertical normal stress distribution.

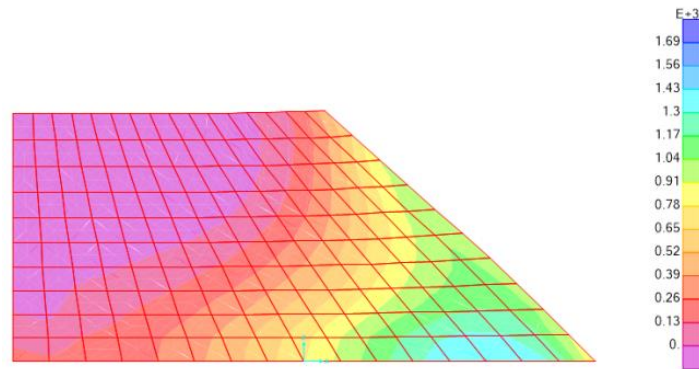


Fig. 7. FEM analysis result of a half model with a 1:1 side slope for shear stress distribution.

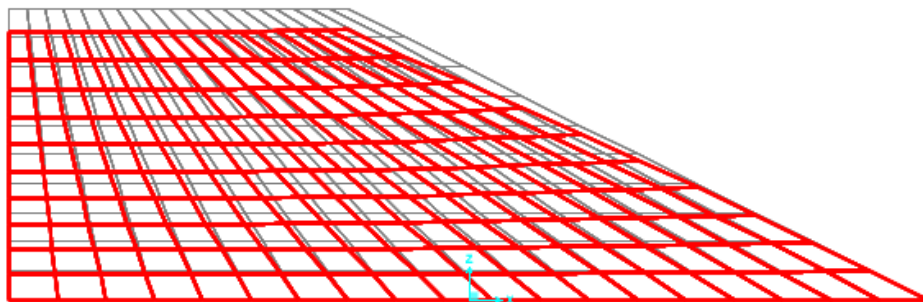


Fig. 8. FE model deformation results of a half model with 1:2 side slope.

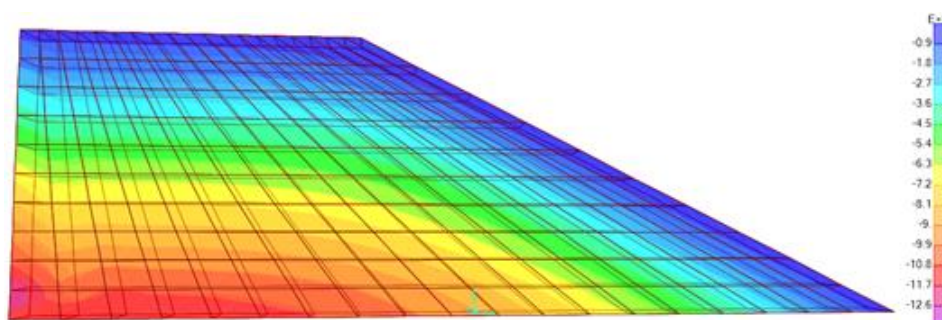


Fig. 9. FE model analysis results of vertical stress distribution of a half model.

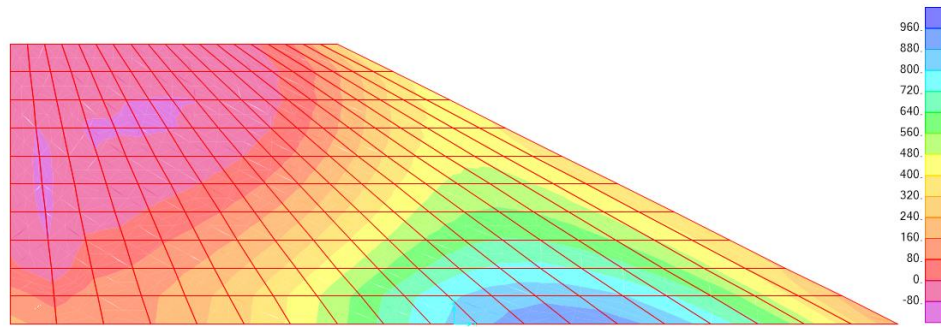


Fig. 10. FE model analysis results of shear stress distribution of a half model.

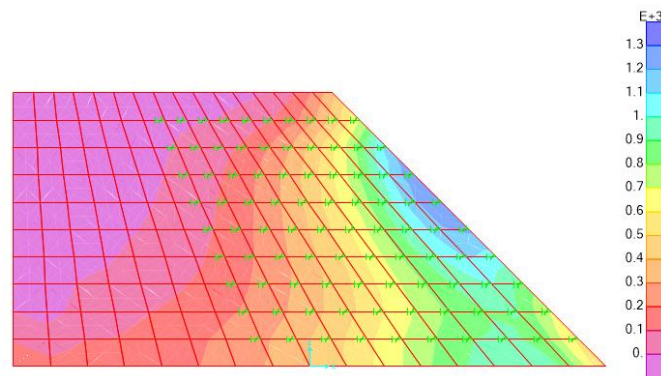


Fig. 11. FE model analysis results of shear stress distribution of a geogrid supported soil mass.

5. Conclusions

This paper qualitatively discussed the issue or ROW for roadways and railways. For the investigated cases, the ROW needs were shown to be able to reach up to 350% of the size of the transportation superstructure depending on the depth of the earthwork. The costs of land and expropriation in urban settings, which could be up to 20 times more than values in rural environments, require means and methods to limit the required ROW for a particular route. Simple qualitative and quantitative finite element analysis showed how the geogrids could change the stress distribution in soil masses thereby providing alternative earthwork designs which require lower ROW values. Inclusion of geogrids provides a lateral confinement to the soil masses thereby increasing the internal shear strength of the supported soil mass. Inclusion of the geogrids reduced and distributed the shear stresses within the soil mass such that a 1:1 slope became possible with respect to a 1:2 slope for a 6-m high fill, resulting in a total reduction of 12-m for the required ROW for a 14 m wide railway superstructure.

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