NUMERICAL ANALYSIS OF MSE WALL USING FINITE ELEMENT AND LIMIT EQUILIBRIUM METHODS

S. S. Konnur[1]
A. M. Hulagabali[2]
[1]PG Student, [2]Assistant Professor, Department of Civil Engineering, Basaveshwar Engineering College, Bagalkot, Karnataka
[1]konnursangamesh1991@gmail.com, [2]anandmhulagabali@gmail.com

C. H. Solanki
Professor and Head, Applied Mechanics Department, SVNIT Surat, Gujarat
chs@amd.svnit.ac.in

G. R. Dodagoudar
Professor, Department of Civil Engineering, IIT Madras, Chennai, Tamilnadu
goudar@iitm.ac.in

ABSTRACT: Mechanically stabilized earth (MSE) retaining walls are the most suitable design alternatives to the conventional retaining walls due to their simple, rapid and cost effective construction, reduced right-of-way acquisition etc; hence the MSE walls are used in many central, state and private sector projects. But the design and analysis is a challenging task for geotechnical engineers. This paper deals with the study of stability and wall movement of a existing MSE wall constructed on a major state highway in central Texas, using a finite element (FE) analysis and Limit Equilibrium (LE) slope stability analysis program GEO5 2016. The detailed analyses for both internal and external stabilities were obtained from the finite element and limit equilibrium analysis, with a critical failure surfaces and the wall movement of a MSE wall. The factors of safety obtained from both analyses were compared. The study shows that the factors of safety obtained from finite element and the limit equilibrium analysis, for a given problem, match in an acceptable range with a different critical failure surfaces. Also this paper deals with the effect of backfill soil and reinforcements on stability and excessive movements of MSE wall.

Keywords: MSE Retaining Wall, Reinforcements, Finite Element (FE) Analysis, Limit Equilibrium (LE) Analysis, Wall movement.

1 INTRODUCTION:

Soil is an most widely used construction material, which is strong in compression and very weak in tension and similarly the steel is widely used as reinforcing material in almost of all civil engineering infrastructure projects which is very strong in tensile strength. Hence the combination of both these soil and reinforcement will give very good engineering properties than properties of individual materials. Basically reinforced soil has two components which are soil and reinforcement with different properties but basic concept is that the embedded reinforcement in soil provides tensile strength to the soil it is because of higher stiffness of the reinforcement. The basic mechanism of MSE is, while reinforcement is in the soil system the friction is formed between them and due to this friction soil movement is hold on the surface of reinforcement and then the shear stress is developed which produces tension in reinforcement this leads to confinement to the soil and results in decrease in soil deformation and increase in shear strength of the soil.

The complete design analysis of a mechanically stabilized earth (MSE) retaining wall includes evaluation of internal, external and global stabilities as well as horizontal and vertical wall displacements [1]. In these three parameters, the internal stability of MSE wall by means of pullout resistance and tensile strength of the reinforcement is mainly depends on the type of reinforcement, spacing and length of the reinforcement and the external stabilities by means of failure modes such as sliding, overturning, wall bearing and global stability failure. Hence these both internal and external failure modes are considered as slope failure through sliding surfaces, and the overall stability of an MSE wall can be evaluated using slope stability analysis [2].

The two common and general methods of stability analysis are limit equilibrium and numerical methods in which limit equilibrium method considers the soil as a perfectly plastic and rigid material. The safety factor of limit equilibrium technique is calculated by Spencer method, Fellenius method, Morgenstern method, Janbu method, Bishop Method etc. As we know that numerical modeling involves the calculation of stresses/displacements by method of descritisation of continua and then assembling properties of each element and nodes by imposing boundary conditions to those elements and finally stresses/displacements are calculated by solving governing or system equations. But it is not possible to get exact safety factor by numerical method but it can be determined by shear strength reduction technique (SSR).

In this paper, the stability analysis of an existed MSE wall project using both limit equilibrium and numerical method is presented. The slope stability analysis and stress/deformation analysis programmes, GEO5 MSE (for LE) and GEO5 FEM (for numerical) are used in the present study. The calculated results from limit equilibrium method and numerical method are compared with each other.

2 LIMIT EQUILIBRIUM AND NUMERICAL ANALYSIS PROGRAMS

GEO-5 fine is a power full programme for solving geotechnical problems based on traditional and FE Method. It is mainly designed to solve most geotechnical tasks, from the basic one to highly specialized programmes. It works basically on the technique that, initially the structure is designed analytically and then it is transferred analytical model into FEM programme where the structure is verified by the FE method.GEO-5 fine contains two options one for analysis internal and external stabilities, slope stability using a variety of popular limit equilibrium methods including the Bishops method, Spencer Method, the Morgenstern-Price Method, Janbu Method and another one for analysis of stresses, displacements/deformations of wall. GEO-5 fine also provides explicit options for reinforcing elements including piers/piles, tiebacks (anchors), soil nails. In this study, the Spencer method is used in the analysis due its wide acceptance and the fact that it satisfies both force and moment equilibrium.

3 MECAHNICALLY STABILIZED EARTH WALL PROJECT

The MSE wall project selected in this study was constructed on a major state highway in central Texas. The wall was required to support a new bridge abutment for an overpass on a new roadway passing over an existing roadway. The project contained numerous walls of varying heights. The wall analyzed in this study was the tallest wall with the steepest back slope and was the most critical case. A minimum FS of 1.3 was required in the design. The retained fill was placed simultaneously with the reinforcement [1].

The proposed geometry of the MSE wall and the soil profile are presented in Fig. 1. Soil properties used in the limit equilibrium and numerical analyses are listed in Table 1. The reinforcement consisted of galvanized metal ribbed straps with a nominal width of 50 mm and a nominal thickness of 4 mm. The straps were 5.7 m in length with both horizontal and vertical spacing of 0.76 m. The allowable tendon strength of each metal strap was 89.6 kN. The allowable pullout strength of each metal strap was determined according to the FHWA design standard (Berg, et al. 2009). A surcharge load of 12 kPa was considered at the back of the wall (as shown in Fig. 1) to account for the traffic load [1].

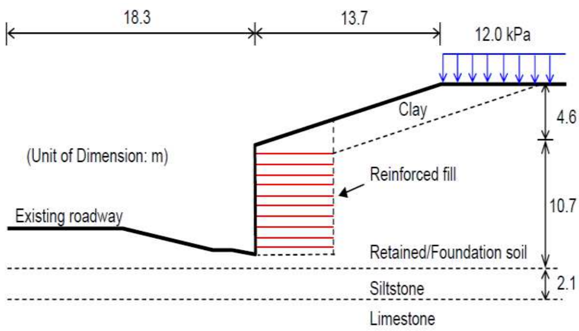

Fig.1. Soil profile and slope geometry [1]

Table 1. Soil properties [1]

Soil Description	Moist Unit weight (kN/m3)	Saturated Unit Weight (kN/m3)	Cohesion (kPa)	Friction Angle (degree)
Siltstone	20.4	20.4	0	28
Limestone	21.7	21.7	56	30
Reinforced Fill	19.6	20.1	0.05	34
Retained/Foundation Soil	19.6	20.1	4.8	28
Clay	19.6	20.1	4.1	26

4 STABILITY ANALYSIS

As mentioned earlier, the Spencer method was used in the limit equilibrium method in the GEO-5 MSE software. In the limit equilibrium analysis, trial failure surfaces were assumed to pass through the toe of the wall, since it is considered the most critical failure surface. A total of 232 circular failure surfaces were evaluated for the MSE wall, and the factor of safety for each failure surface was calculated. The most critical failure surface with a factor of safety of 1.5 is illustrated by the yellow line in Fig. 2.

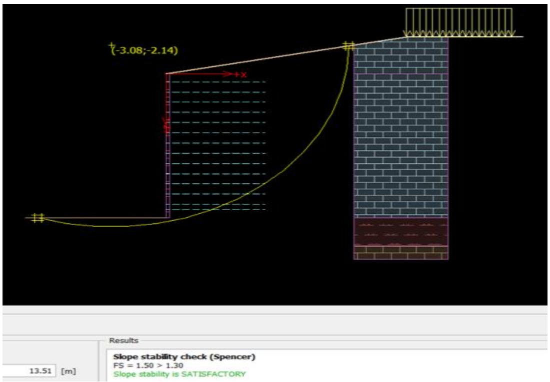

Fig.2. Critical failure surfaces and the factor of safeties

Table.2. FOS for each trial critical failure surfaces

Critical failure surfaces	1	2	3	4	5	6	7	8	9	10
Factor of safety	1.5	1.5	9.6	1.5	7.2	1.5	1.5	1.5	1.5	1.5

The numerical analysis of the MSE wall was performed using the finite element program, GEO5 FEM. The numerical model was built with the same dimensions of that shown in Fig.1. Horizontal displacement was fixed at the side boundaries, and the vertical displacement was fixed at the bottom boundary. In this study, the facing material of the wall was not physically modeled thus exclusion zone was set so that no failure surface passes through the facing of the wall.

Compared to the limit equilibrium method, the numerical analysis does not need a presumed failure surface. More information (stress, strain, displacement, etc.) can be extracted from a numerical model rather than a single factor of safety output. For example, the contour plot of shear strain increment is a good indicator of the critical failure surface of the MSE wall, as shown in Fig. 4. For comparison purposes, the critical failure surface determined by the GEO5 MSE software was also plotted. It is shown that in the numerical analysis the failure surface is similar to an active earth pressure failure case. The failure surface passed through the back toe of the reinforced zone, and the reinforced zone behaves as a coherent mass. The factor of safety determined by the shear strength reduction method is 1.56, which is close to that determined by the limit equilibrium method.

Fig.3 shows the discretized MSE wall with 3209 nodes and 1956 elements (1090 regions, 219 beams, 657 interfaces) in the numerical model and the fig.4 (displacement plot) indicated that entire reinforced zone is rotating around the front toe of wall, which confirmed that failure model of the wall is an active earth pressure failure. Fig.5 shows the comparison between the numerical solution and the limit equilibrium solutions, in which the factor of safety from numerical solution is 1.56 and factor of safety from limit equilibrium method is 1.5. The different predicted critical failure surfaces predicted from the two programs are due to the different underlying assumptions associated with the two different types of analyses.

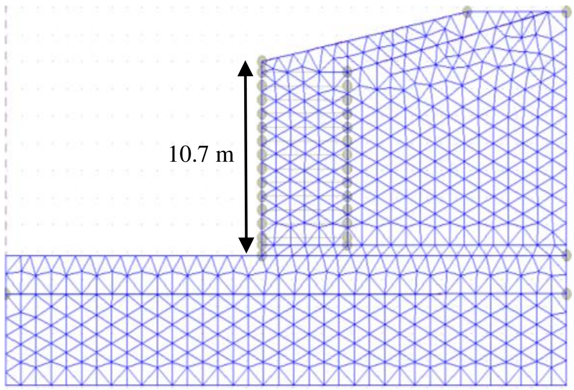

Fig.3. Discretized MSE wall (Meshing)

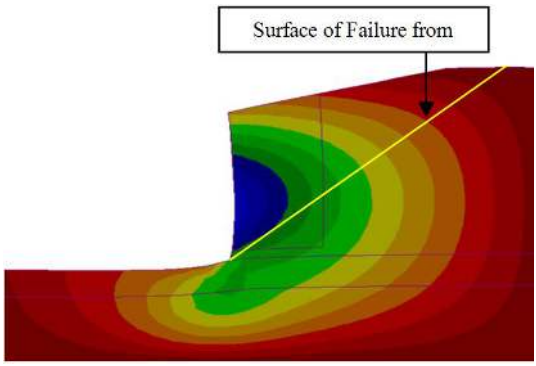

Fig. 4. Failure surface predicted by the numerical method

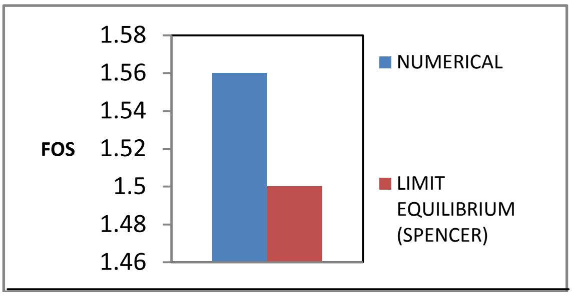

Fig. 5. FS of Numerical and Limit equilibrium (Spencer)

5 CONCLUSION

In this study, the stability of an MSE wall is analysed using both limit equilibrium and numerical methods. It was found that the two analysis programs give different factor of safety for the retaining wall. This type of difference in factor of safety is due to the different underlying assumptions made with the two different analysis methods. From FEM and Limit Equilibrium methods, FEM gives little higher factor of safety than LE method. This is because of descritisation of single structure in to number of nodes, element and regions. So it gives more convenient results than other methods. Analyzed values from both methods are in well acceptable ranges and are in good agreement. For the difficulties of many real-world projects, it is suggested that two or more different analysis methods should be considered in order to get a better analysis of the MSE retaining wall projects.

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