Comparative study of slope stability of a highway constructed in hilly area using limit equilibrium and finite element methods

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Abstract. Slope stability analysis is one of the most challenging field in which the slope factor of safety is the main concern. Normally limit equilibrium and finite element methods are used to analyse such slopes. A variation in the result is also found in both these analysis methods. This analysis work is done using both limit and finite equilibrium methods. The variation in the factor of safety is investigated and a correlation is developed. These values can be used to know about the safe value for factor of safety in any homogenous slopes.

1. Introduction
Geotechnical engineering is concerned with the soil related studies and is a sub field of Civil engineering. For constructing any building, it is necessary to know about the compaction and strength of soil as soil will have to bear the load. If the soil strength is low then it must be treated such that the strength gets increased. Similarly if a highway is required to be constructed, it also needs a well graded soil and strength so that it must bear the load. An earth fill dam must have enough strength and compaction value to withstand against the applied load and maintain the seepage so that it should not increase from the allowable value. Along with all these issues, one important issue is slope stability analysis which is especially required if a road is required to be constructed in hills or an earthen dam is to be constructed. The slopes are normally studied and analysed by different ways such as limit equilibrium and finite element methods. This paper is also related with slope stability issues and a study is conducted to compare the results of both these methods in details.

Since long time, Limit equilibrium methods are in practice. Engineers must therefore carry out calculations to determine the stability and serviceability of any new construction project [1]. In many codes, limit equilibrium methods are recommended by researchers to evaluate the stability of a lateral support systems, such as soil-nails and anchors, to an acceptable defined factor of safety. For decades, limit equilibrium methods have been used successfully in providing an acceptable margin of safety against failure (movements, which can be significantly more complex, is not considered). However, due to the advances in software and computational technology which is offered by personal computers, finite element modelling has become one of the most usable method in the running century. Several codes of practice use the numerical quantity of ‘factor of safety’ to define the suitability of geotechnical design. Whether finite element- or limit equilibrium methods are used, the accurate calculation of the factor of safety remains paramount to quantifying the stability of a geotechnical structure.
2. Literature Survey
A lot of useful research has already been conducted on the concept of slope stability related issues [2]. Limit equilibrium and finite element methods are greatly explored by researchers from different aspects, however there is still a vacant space for more research. The reason is that most of the previous analysis methods whether limit equilibrium or finite element, they have variation in the results. Different codes have different definitions for the Factor of Safety [3, 4]. Normally limit equilibrium and finite element methods are used to analyze the slopes and find out the value for factor of safety. Limit equilibrium methods are most useful for non-complex slope models. In recent years, the use of finite element approach is increased especially in complex slope models. Griffiths and Lane [6] promoted the idea to use strength reduction factor in finite element analyses, therefore an increase in the use of this method is observed. Potgieter [7] also investigated the conditions under which finite element methods are conservative or not conservative compared to well established limit equilibrium methods.

Cheng et al. [8] after the research work concludes that the finite element strength reduction technique cannot be seen as superior to the method of slices and that each method must be viewed on their unique advantages and disadvantages and suggests to cross check the results of finite element with limit equilibrium to be on safe side.

Hence this paper is mainly focused on the difference of results achieved by finite element 2D analysis with limit equilibrium 2D analysis methods for a homogenous slope which is pre-defined in a hill with road.

3. Methodology
Figure 1 shows the slope model considered in this work. The angle of repose was changed from 30 degrees to 45 degrees with interval of 5 in each case.

![Slope model](image)

Figure 1. Slope model

Clay and clayey sand have investigated in this work by considering six different material properties for a predefined slope. All the material properties and factor of safety using limit and finite element method are shown in table 1.
Table 1. Factor of safety using finite element method

| Material Number (M) | Cohesion (kN/m²) | Angle of Repose (AOR) | Unit Weight (kN/m³) | Friction angle (ϕ) | Material Type | Road width (m) | Factor of Safety in Finite element case | Factor of Safety in Limit equilibrium case |
|---------------------|------------------|----------------------|---------------------|-------------------|---------------|---------------|----------------------------------------|------------------------------------------|
| 1                   | 10.5             | 30                   | 13.5                | 30                | Clay          | 6             | 1.464                                  | 1.645                                    |
| 1                   | 10.5             | 35                   | 13.5                | 30                | Clay          | 15            | 1.373                                  | 1.543                                    |
| 1                   | 10.5             | 40                   | 13.5                | 30                | Clay          | 22            | 1.238                                  | 1.391                                    |
| 1                   | 10.5             | 45                   | 13.5                | 30                | Clay          | 28            | 1.120                                  | 1.259                                    |
| 2                   | 14.5             | 30                   | 15.5                | 32                | Clay          | 6             | 1.619                                  | 1.819                                    |
| 2                   | 14.5             | 35                   | 15.5                | 32                | Clay          | 15            | 1.540                                  | 1.730                                    |
| 2                   | 14.5             | 40                   | 15.5                | 32                | Clay          | 22            | 1.397                                  | 1.570                                    |
| 2                   | 14.5             | 45                   | 15.5                | 32                | Clay          | 28            | 1.264                                  | 1.420                                    |
| 3                   | 18.5             | 30                   | 17.5                | 34                | Clay          | 6             | 1.765                                  | 1.983                                    |
| 3                   | 18.5             | 35                   | 17.5                | 34                | Clay          | 15            | 1.687                                  | 1.896                                    |
| 3                   | 18.5             | 40                   | 17.5                | 34                | Clay          | 22            | 1.532                                  | 1.721                                    |
| 3                   | 18.5             | 45                   | 17.5                | 34                | Clay          | 28            | 1.389                                  | 1.561                                    |
| 4                   | 1                | 30                   | 16.5                | 36                | Clayey Sand   | 6             | 1.245                                  | 1.399                                    |
| 4                   | 1                | 35                   | 16.5                | 36                | Clayey Sand   | 15            | 1.044                                  | 1.173                                    |
| 4                   | 1                | 40                   | 16.5                | 36                | Clayey Sand   | 22            | 0.888                                  | 0.998                                    |
| 4                   | 1                | 45                   | 16.5                | 36                | Clayey Sand   | 28            | 0.765                                  | 0.860                                    |
| 5                   | 5                | 30                   | 17                  | 38                | Clayey Sand   | 6             | 1.573                                  | 1.767                                    |
| 5                   | 5                | 35                   | 17                  | 38                | Clayey Sand   | 15            | 1.346                                  | 1.513                                    |
| 5                   | 5                | 40                   | 17                  | 38                | Clayey Sand   | 22            | 1.173                                  | 1.318                                    |
| 5                   | 5                | 45                   | 17                  | 38                | Clayey Sand   | 28            | 1.029                                  | 1.156                                    |
| 6                   | 10               | 30                   | 17.5                | 40                | Clayey Sand   | 6             | 1.887                                  | 2.121                                    |
| 6                   | 10               | 35                   | 17.5                | 40                | Clayey Sand   | 15            | 1.635                                  | 1.837                                    |
| 6                   | 10               | 40                   | 17.5                | 40                | Clayey Sand   | 22            | 1.454                                  | 1.634                                    |
| 6                   | 10               | 45                   | 17.5                | 40                | Clayey Sand   | 28            | 1.281                                  | 1.439                                    |

4. Results and Discussions
Figure 2, 3, 4, 5, 6 and 7 shows the variation of factor of safety for all the six material types in form of bar graph for both limit and finite element methods.
Figure 2. Variation of factor of safety between FE and LE methods for material 1

Figure 3. Variation of factor of safety between FE and LE methods for material 2

Figure 4. Variation of factor of safety between FE and LE methods for material 3
Figure 5. Variation of factor of safety between FE and LE methods for material 4

Figure 6. Variation of factor of safety between FE and LE methods for material 5

Figure 7. Variation of factor of safety between FE and LE methods for material 6
From these graphs a correlation between limit equilibrium and finite element methods came out to be;

$$FE = 0.88 \times LE$$  \hspace{1cm} (1)

### 5. Conclusion

Equation 1 can be used as a cross check to know about the value for factor of safety in both limit and finite element methods. It will give a comparison of both values. This equation is valid for homogenous slopes only. This equation has no influence of seismic loads and pore water pressure.

There is still vacant space to investigate both finite and limit equilibrium methods considering the seismic loads, rainfall effects and the effect of underground tunneling on slopes.

### Acknowledgments

This work was conducted with supports from the National Natural Science Foundation of China (Grant Nos. U1602232 and 51474050), Doctoral Scientific Research Foundation of Liaoning Province (Grant No. 20170540304 and 20170520341), China Scholarship Council (Grant No. 201806080103), Key Research and Development Program of Science and Technology in Liaoning Province, China (Grant No. 2019JH2/10100035), the Fundamental Research Funds for the Central Universities (Grant No. N170108029).

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