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SLOPE STABILITY ANALYSIS USING SLOPEEX PROGRAM IN COMPARISON WITH COMMERCIAL SOFTWARE

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Abstract

Slope stability analysis is routinely performed to assess the safe design of man-made soil slopes such as embankments, road cuts, open-pit mining, excavations, dams, landfills, etc. The design of a soil slope requires geological information such as soil layers, soil properties, slope geometry, groundwater conditions and natural or man-made forces acting on the slope. The objectives of slope stability analysis are to investigate potential failure mechanisms, to design an optimal slope with safety, reliability and economics considerations and to design possible remedial measures in slope reinstatement works. SlopeEX is a slope stability analysis programme. It is an EXCEL® spreadsheet programmed based on the simplified Bishop's method. This paper exploit SlopeEX programme in comparison with one of the most used commercial software namely Slope/W. A few cases of slope condition have been analyzed using both programmes to find the consistency of the results obtained. The results of the SlopeEX analysis have been compared with the results obtained from SLOPE/W and it shows that the different percentage in safety factors obtained by both programmes are very nominal ranges between 1 % to 8 % and are found to be consistent. From the results obtained from the analysis, it can be concluded that SlopeEX programme is comparable with the commercial software for slope stability analysis. It is affordable, simple and easy to use for students, researchers or engineers.

Keywords: SlopeEX; Slope Stability Analysis; EXCEL workbook.

1.0 INTRODUCTION

There are many methods of slope stability analysis depending on the nature of the slopes, the slope materials, potential mode of failure and whether the analysis is for a short-term or for a long-term stability (undrained or drained analysis). The most common methods of stability analysis of slopes in soils are based on limiting plastic equilibrium [1]. The condition of limiting plastic equilibrium exists when the shear stress developed on a potential failure surface equal to the available shear strength of the soil and the soil mass above the failure surface starts sliding down the slope. The most common limit equilibrium techniques are methods of slices, such as the ordinary method of slices (Fellenius) and the Bishop simplified, Spencer, and Morgenstern-Price methods [2].

In the stability analysis of slopes, many design parameters cannot be determined with certainty. Therefore, a degree of risk should be assessed in an adopted design. In all slope stability analysis, the use of factor of safety can fulfill this requirement. The factor of safety defined as the ratio of the shear strength at failure to the shear stress required for equilibrium of the slope. The factor of safety adopted should consider not only the uncertainties in design parameters but also the consequences of failure with acceptable level of failure; slight, greater or a lower [3]. The acceptable value of factor of safety should be more than 1.0 depends on the failure state. If it is less than 1.0, the slope is assumed to be unstable. Table 1 shows some typical factors of safety in slope design for shear slip surface in the form of plane, cylindrical or log-spiral.

Table 1. Typical Factors of Safety in Geotechnical Design of slope (Whitlow, 2004)

Failure state		Typical range of factor of safety (FOS)
(i)	Temporary cuttings and embankments: using undrained shear strength (c_u) and Total stresses.	1.10 to 1.30
(ii)	Permanent cuttings: using critical strength (ϕ'_c) and effective stresses.	1.20 to 1.40
(iii)	Embankment – foundation soil : undrained (c_u) or drained (ϕ') analysis	1.20 to 1.50
(iv)	Embankment – Fill : drained (ϕ') of compacted soil and effective stresses	1.20 to 1.40
(v)	Reactivated Landslip : residual strength (ϕ'_r)	(natural value)

There are many commercially available computer programs for soil slope stability analysis from simple to more complicated slope failure mechanisms and requires sophisticated numerical modeling techniques such as using finite element method [4][5][6]. However, the major drawbacks for the conventional programs involve complex analysis and expensive.

An inexpensive and simple workbook namely SlopeEX is developed in EXCEL® spreadsheet program to perform stability analysis of soil slopes based on the simplified Bishop's method. The calculation routines designed in EXCEL is simple to use with user-friendly data input and useful graphical visualization and the results of the calculations can be observed almost instantaneously.

Slope/W is one of the leading slope stability analysis software for computing the factor of safety of soil and rock slope [7]. With this software, the analysis of simple and complex slope stability can be executed with variety of slip surface geometry, soil properties, loading condition and groundwater table. Besides that, it is also capable to execute various methods of analysis including simplified Bishop's method.

2.0 LITERATURE REVIEW

Slope stability analysis can be carried out using various methods. Each of the methods possesses its own advantages and criteria. One of the methods is using limit equilibrium analysis that relies on the concept of the slip surface. Most of the slope stability analysis computer programs are based on the limit equilibrium concept for two or three-dimensional model. Two dimensional sections are analyzed assuming plane strain conditions and provide important insights into the initial design and risk assessment of slopes. This method investigates the equilibrium of a soil mass tending to slide down under the influence of gravity.

Comparison between general limit equilibrium methods with other method also has been studied in previous research. M.W.Agam in his paper has studied the comparison between Spencer's Method and general limit equilibrium method. He found out the percentage differences in safety factors obtained by both methods are very nominal and showed good agreement to each other. [8]

Method of slices is particularly the most suitable method for computer programs due to repetitive nature of the calculations and the need to select the most critical failure surface [9]. To perform effective and efficient analysis, the potential failure slip is divided into few slices and forces acting on every slice will be calculated to determine the factor of safety of the slope. Several versions of the method are in use such as Bishop simplified, Ordinary method of slices (Swedish, Petterson, Fellinius), Spencer and Sarma method. These methods satisfy all or some of the three conditions of equilibrium; force equilibrium in horizontal and vertical direction and moment equilibrium condition. However, this paper focuses on slope stability analysis using computer programs by using simplified Bishop's method of slice theory. Bishop's method satisfies vertical force, moment equilibrium and circular shape of slip surface. This method also commonly being used in most of the commercial computer programs.

3.0 METHODOLOGY

SlopeEX is a slope stability analysis programme developed using EXCEL spreadsheet. The programme workbook consists of various sheets that include Interactive input area (Figure 1), input data storage, graph manipulation and calculation sheet and the slope stability analysis sheet.

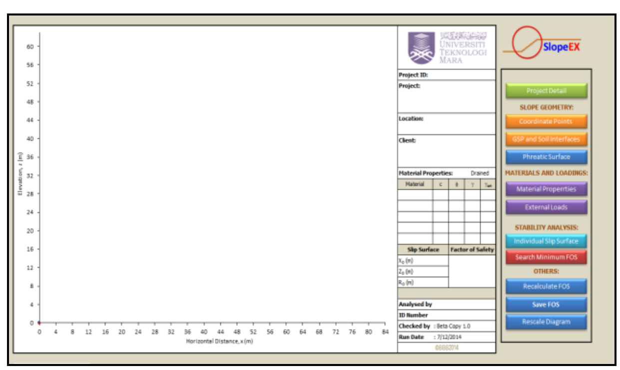

Figure 1. Interactive data input area and visualization of slope geometry in SlopeEX

The analysis requires six input data; project information, coordinate points, ground surface profile (GSP) and soil lines, ground water level, material properties and external loads. There are two search methods, the grid method and the random search method developed to search for the most critical slip surface. Figure 2 shows the flowchart of the program.

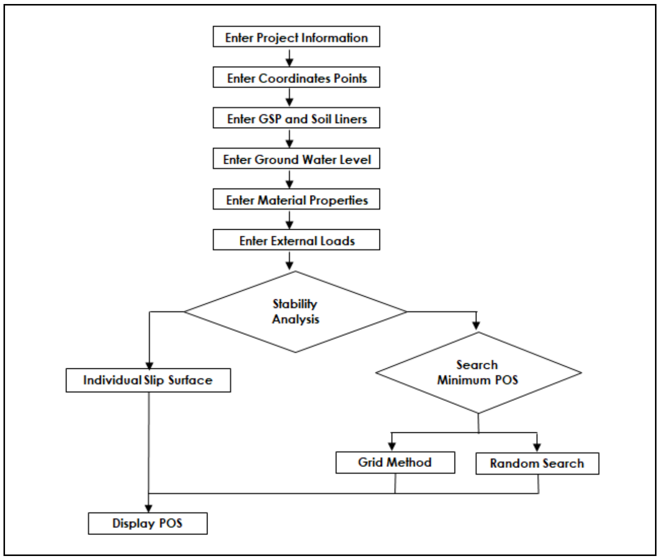

Figure 2. Flowchart of SlopeEX Program

Few cases of slope condition have been analyzed using SlopeEX and Slope/W program to find the consistency of the results obtained. There are 4 cases of different slope condition has been considered in the analysis. Case 1 is a basic condition of fill embankment without ground water table and surcharge load. The soil boundary has been identified by inserting the coordinate points, ground surface profile and soil interfaces. There are three layers of soil for this condition and the soil properties for each of the soil layer has been inserted in the both programmes. For case 2, water table has been added into the programme. Water surface was inserted to define the pore pressure conditions for the soil. When there is groundwater flow within a slope, it is necessary to consider its effect on the slope stability. For case 3, surcharge load has been added into the analysis. External loads that will be imposed on the slope is either strip loads or line loads. For SlopeEX, analysis can be done by individual slip surface or search for minimum factor of safety by using grid search or random search. The factor of safety obtained with this program has been compared with the FOS obtained from Slope/W for similar condition of each case.

For cases 1, 2 and 3, the slope embankment consists of three layers of soil with the soil properties as shown in Table 2. For case 4, back analysis of real case of slope failure has been executed. The slope has undergone rainfall induced slope failure which causes medium to high risk to the people and vehicles parked at the car park. The plan view, cross-section and photographs of the slope failure are shown in Figure 3.

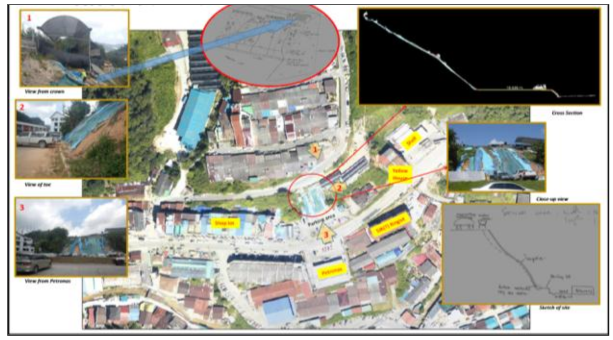

Figure 3. Plan view and cross-section for critical slope condition

Table 2. Soil properties for slope embankment

Soil Layer	**Unit weight (kN/m³)**	**Cohesion, c (kPa)**	**Friction angle, ϕ^o**
1	20	5	30
2	18	3	28
3	18.5	4	30

According to the proforma and incident reports provided, it is a cut developed slope at a width of 34 m, slope height of 24 m and at an angle of 54°. The slope is planar and straight with the distress location seen at the crest of the slope. The parking area is situated at the toe of the slope where the buffer zone is at least 1 m away from the structure. The vegetation cover is poor and the slope consists of predominantly grade VI (residual soil). The soil properties of the failed slope are shown in Table 3.

Table 3. Soil properties for the failed slope

Soil Layer	**Unit weight (kN/m³)**	**Cohesion, c (kPa)**	**Friction angle, ϕ^o**
Loose silty SAND	18	5	30
Dense silty SAND	19	8	36

4.0 RESULTS AND DISCUSSION

Factor of safety obtained from SlopeEX analysis has been compared with the FOS obtained from SLOPE/W and it shows that the different percentage in safety factors obtained from both programs are very nominal and found to be consistent as shown in Table 4. Results of analysis from both programs are shown in Figures 6 to 9 for all the above-mentioned cases.

Table 4. Results of analysis from SlopeEX and Slope/W

Case	Factor of Safety (FOS)	
	SlopeEX	Slope/W
1	1.556	1.602
2	1.139	1.229
3	1.114	1.187
4	0.835	0.888

For Case 1, Factor of safety (FOS) for slope stability analysis using SlopeEX program is 1.556 whilst FOS for slope stability analysis using Slope/W is 1.602 as shown in Figure 4. The discrepancy between both programs is very low which is 2.9%.

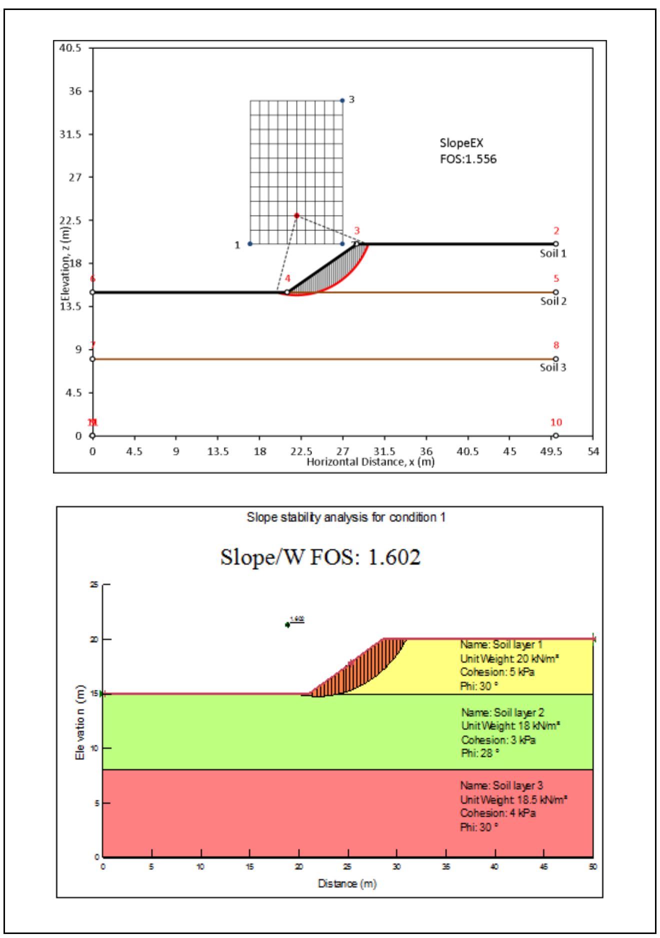

Figure 4. Stability analysis from both SlopeEX and Slope/W analysis for Case 1

For Case 2, slope stability analysis with Factor of Safety (FOS) of 1.139 and 1.229 are adopted for both programs of SlopeEX and Slope/W respectively as shown in Figure 5. The discrepancy between both programs is 7.3%.

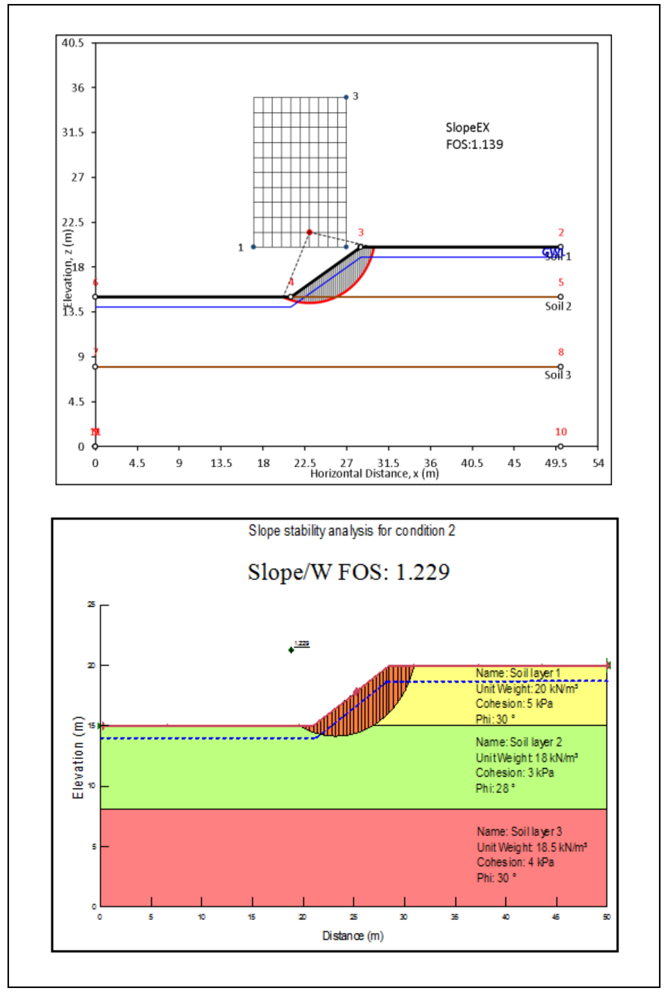

Figure 5. Stability analysis from both SlopeEX and Slope/W analysis for Case 2

For Case 3, Factor of safety (FOS) for slope stability analysis using SlopeEX program is 1.114 whilst FOS for slope stability analysis using SlopeW is 1.187 as shown in Figure 6. The discrepancy between both programs is 6.2%.

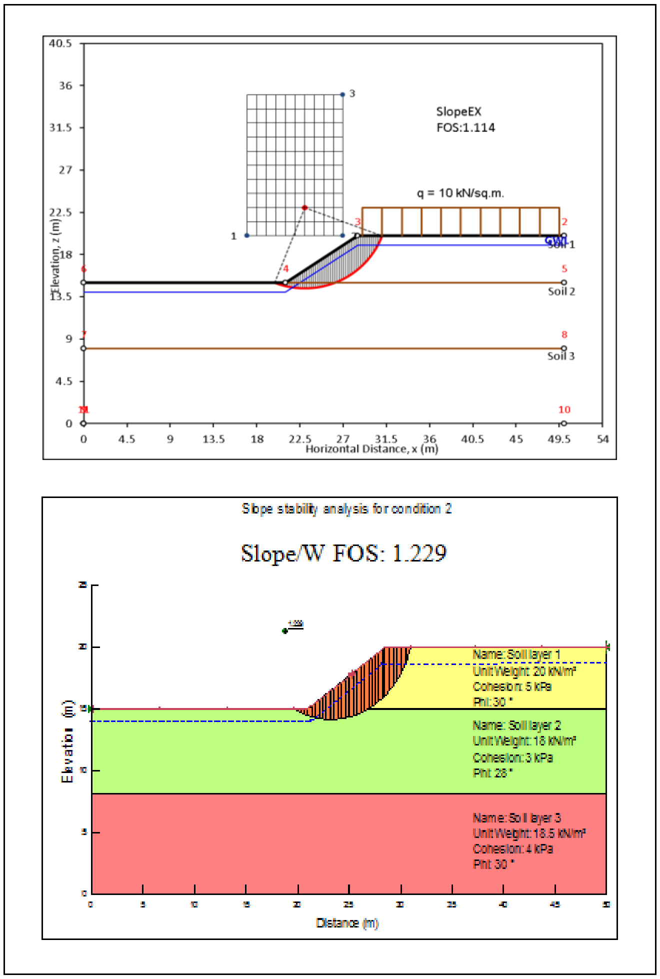

Figure 6. Stability analysis from both SlopeEX and Slope/W analysis for Case 3

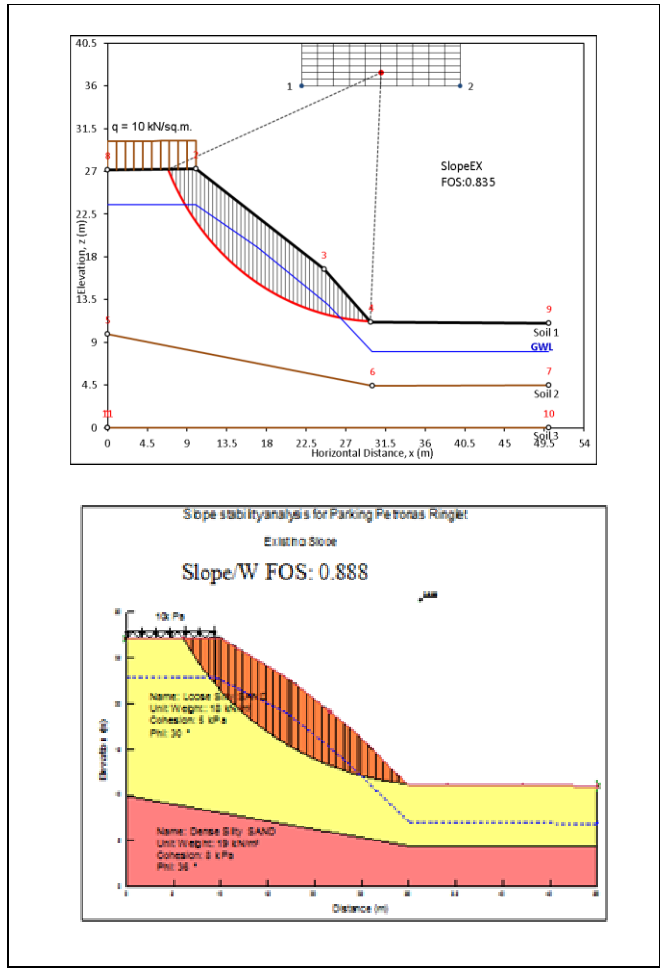

Figure 7. Stability analysis from both SlopeEX and Slope/W analysis for Case 4

For real case of slope failure as shown in Figure 7, factor of safety (FOS) adopted for slope stability analysis using SlopeEX program and Slope/W are 0.835 and 0.888 respectively. The discrepancy between both programs is 5.9%.

5.0 CONCLUSION

The results of slope stability analysis using SlopeEX have been compared with the results obtained from more sophisticated commercially available software namely SLOPE/W and found to be consistent. The discrepancy of factor of safety between analysis using SLOPE/W and SlopeEX program were lesser than 8%. It can be concluded that, SlopeEX program is comparable with the commercial software for slope stability analysis and this workbook can be used in classroom setting to enhance the student's understanding towards slope stability analysis and various failure mechanisms since it is cheap and user friendly. The workbook can also be used by geotechnical engineers for routine and practical stability analysis in the design of safe, reliable and economical soil slopes. SlopeEX can also be used by researchers for stability analysis of different slope geometry, conditions and material properties in their respective investigative research works.

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