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Determination of Influencing Factors for Slope Stability Using Grey Relational Analysis (GRA) Technique

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ABSTRACT

This study aims to analyze and investigate the influencing factors for factor of safety (FOS) in slope stability analysis. The study proposes the grey relational analysis (GRA) method to analyze the influencing factors to the slope stability based on previous case studies reported in the literature. The six influencing factors including unit weight (γ), cohesion, (c), internal friction angle (ϕ), slope angle (β), slope height (H), and pore water pressure ratio (r_u) with FOS were analyzed based on grey relational grade (GRG) value to determine the relationships between these factors. From the study, it was found that slope height (H) is the most influencing factor to the slope stability by giving the mean GRG value of 0. 704, while slope angle (β), and pore water pressure (r_u) are the less influencing factors by giving the lowest mean GRG with 0.628 and 0.629, respectively. The analysis results play an important role in slope stability analysis as well as slope design and reinforcement.

Index Terms: Grey Relational Analysis (GRA), Factor of Safety (FOS), Slope Stability.

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INTRODUCTION

Determination of accurate factor of safety (FOS) is important in slope stability analysis. The accurate FOS can be obtained by finding the accurate critical failure surface. The stability of a slope is a primary concern in order to identify the potential landslide and to mitigate the landslide damage [1]. Generally, it is a challenging task to predict the stability of slope due to it facts that the slope stability depends on various factors including physical and geotechnical factors. Furthermore, the relationships between these factors are complex and difficult to describe mathematically. There are many factors that influence the slope stability including complex, uncertainty, and interactive factors. According to Hang et al [2], different slopes may have different effects on slope stability based on their landform and topography. The most influencing factors should be investigated in order to achieve the effective, safe and economic slope treatment.

The studies of influencing factors of slope stability are studied by previous researchers. Hoang and Pham [3] analyzed the influencing factors of earth slope based on mutual information technique. The larger mutual information value indicates that the factor contributes stronger relationship between influencing factors and output factors. Each of the factors were ranked based on their mutual information value, and it was found that pore pressure ratio, unit weight, and soil cohesion were the most influencing factors by giving the comparatively high values of mutual information with 0.54, 0.23, and 0.16, respectively. Hang et al [2] investigates the influencing factors for the earth slope based on the variance analysis of orthogonal array. The orthogonal analysis method distinguishes the influencing factors sensitivity using finite different software. Five factors were investigates, and it was found that slope height and unit weight have significant influence to the slope stability compared to friction angle, cohesive force and slope rate.

The current study investigates the influence of slope factors for four case studies, which was collected by Manouchehrian et al [4], Zhao and Chen, [5], Samui and Kothari, [6] and Jun et al, [7] using grey relational analysis (GRA). The data from all case studies covers different slopes area with same factors namely unit weight (γ), cohesion (c), internal friction angle (φ), slope angle (β), slope height (H), and pore water pressure ratio (ru). Unit weight (γ) refers to the total weight divided by total volume of the soil. Unit weight can be calculated as follows:\

$$\gamma = \frac{W}{V} \quad (1)$$

$$= \frac{W_s + W_w}{V_s + V_w + V_a} \quad (2)$$

Where γ is the unit weight, W_S is the soil weight, W_W is the pore water, V_S is the soil volume, V_W is the water volume, and V_a is the air volume. Cohesion (c) is the shear strength component of a soil or rock that is independent of inter-particle friction. Internal friction angle (φ) refers to the angle of Mohr's Circle of the shear stress and normal effective stresses at which shear failure occurs for a given soil. Internal friction angle can be determined using Direct Shear test or the Trixial Stress Test in the laboratory. The slope angle (β) is the inverse-tangent of the rise divided by the run. The tangent of a given angle in degrees is equal to the rise divided by the run. The slope angle can be calculated as follows:

$$\beta = \tan^{-1}\left(\frac{y}{x}\right) \quad (3)$$

Where y is the vertical rise (m, ft), x is the horizontal run (m, ft). Slope height refers to the vertical distance of the slope from the slope base to the crest of the slope. Pore water pressure refers to the pressure of the groundwater held within a soil or rock, in gaps between the particles. Pore water pressure ratio is a crude way to describe the pore-water condition in a slope stability analysis. The ratio for pore water pressure is calculated as:

$$\mathrm{Ru} = \frac{\Delta\mu}{\Delta\sigma_1} \tag{4}$$

Where $\Delta\mu$ is the change for pore water pressure, $\Delta\sigma_1$ is the change in the major principal stress, which is often assumed as, the equal value to the change in vertical stress (σ_v).

METHODS AND PROCEDURES

Case Study 1

A data consists of 121 sample was collected by Manouchehrian et al [4], which are abstracted from Sah et al [8] and Dong and Li [9]. Based on the data, six slope parameters were selected as the factors to characterize the factor of safety (FOS). Table 1 lists all the influencing factors with their statistical descriptions.

Case Study 2

The data samples collected from the study by Zhao and Chen [5], which consists of 40 sample data. Table 2 lists all the influencing factors with their statistical descriptions.

Case Study 3

The data samples collected by Samui and Kothari, [6], which consists of 21 samples from [10-13]. Table 3 lists all the influencing factors with their statistical descriptions.

Case Study 4

The data collected by Jun et al [7] which consists of 34 samples. Table 4 lists all the influencing factors with their statistical descriptions.

Grey Relational Analysis (GRA)

To demonstrate the influencing of each of the factors to the FOS, GRA is employed. It should be noted that the factor with greater grey relational grade (GRG) value indicates a stronger relationship between the influencing factors and FOS, while the factor with lesser GRG value indicates a weaker relationship between the influencing factor and FOS. GRA is basically an analysis technique that was proposed in Grey system theory by Professor Deng Julong [14]. According to Tosun [15], black means having no information and white means having all the information. Hence, a grey system has a level of information in the middle of black and white system. It means that, some of the information is known and some of the information is unknown. The grade of correlation value of two sequences, namely, reference and the comparability sequence can be represented using grey analysis to measure the distance of two factors discretely. Reference sequence refers to the output value (FOS) while the comparability sequence refers to the input values (influencing factors).

The first step in GRA process is data pre- processing. The slope influencing factors data series (*X*) is represented as reference (x0) and comparative series (xi). The original data is normalized based on the characteristic of the sequence data. There are three approaches of data normalization in GRA [15]. Firstly, if the target value of original sequence is infinite, the characteristic is the "higher is better". Data normalization can be calculated based on this formula:

$$x_i{}^*(k) = \frac{x_i{}^*(k) - \min x_i{}^*(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{5}$$

Second, if the target value is the "lower the better" characteristic, then the data can be normalized as follow:

$$x_i{}^*(k) = \frac{\max x_i{}^0(k) - x_i{}^*(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{6}$$

And the third approach, if the target has the desired value, the data can be normalized as follows:

$$x_i{}^*(k) = 1 - \frac{|x_i{}^*(k) - x^0|}{\max x_i^0(k) - x^0} \tag{7}$$

Table 1: Statistical Description of Slope Factors for Case Study 1

	Unit weight (γ)	Cohesion (c)	Internal friction (φ)	Slope angle(β)	Slope height (*H*)	Pore water pressure ratio (ru)	Factor of safety (FOS)
Min	12	0	0	16	3.6	0	0.63
Max	28.44	50	45	53	214	0.5	2.31
Average	19.928	10.454	25.835	33.049	41.762	0.201	1.284
Standard deviation	3.659	10.032	11.016	9.382	44.655	0.174	0.399
Variance	13.388	100.64	121.35	88.027	1994.07	0.030	0.159
Median	19.97	8.35	30	30	21	0.25	1.2

Table 2: Statistical Description of Slope Factors for Case Study 2

	Unit weight (γ)	Cohesion (c)	Internal friction (φ)	Slope angle(β)	Slope height (H)	Pore water pressure ratio (ru)	Factor of safety (FOS)
Min	12	0	0	20	4	0.25	0.67

Max	31.3	150	45	50	511	0.5	2.05
Average	23.523	25.820	32.964	40.810	183.4	0.274	1.254
Standard deviation	4.745	28.094	8.580	7.592	176.797	0.062	0.3
Variance	22.515	789.252	73.62	57.635	31257.16	0.004	0.09
Median	25	20	35	43.5	101	0.25	1.2475

Table 3: Statistical Description of Slope Factors for Case Study 3

	Unit weight (γ)	Cohesion (c)	Internal friction (φ)	Slope angle(β)	Slope height (H)	Pore water pressure ratio (ru)	Factor of safety (FOS)
Min	18	10	10	20	6	0	0.65
Max	22	45	40	49	180	0.5	2.3
Average	19.7	25.721	23.505	31.248	44.667	0.257	1.372
Standard deviation	1.184	11.077	9.215	7.453	48.422	0.143	0.446
Variance	1.400	122.702	84.921	55.548	2344.733	0.021	0.199
Median	19.1	25	22	30	37	0.3	1.34

Table 4: Statistical Description of Slope Factors for Case Study

	Unit weight (γ)	Cohesion(c)	Internal friction angle (φ)	Slope angle (β)	Slope height (H)	Pore water pressure ratio (ru)	actor of safety (FOS)
Min	18	0	0	20	6	0.25	0.67
Max	31.3	150	45	50	511	0.5	2.05
Average	19.7	25.721	23.505	31.248	44.667	0.257	1.372
Standard deviation	3.474	28.066	10.739	7.865	177.33	0.067	0.308
Variance	12.067	787.688	115.337	61.865	31446.03	0.0044	0.095
Median	25	20	35	42.1	122.5	0.25	1.246

RESULT

This section discusses the result and analysis of GRA values for the identified case studies. Table 5 shows the GRG value for case study 1. Based on Table 5, it shows that slope height is the most influencing parameter with the first ranked of GRG value, 0.8116,while slope angle is the least influencing parameters with the last ranked of GRG value, 0.6027. The order of the influencing factor to the FOS for case study 1 is slope height > internal friction angle> cohesion> pore water pressure > slope angle.

Table 6 shows the GRG value for case study 2.Based on Table 6, it shows that cohesion is the most influencing parameter with the first ranked of GRG value, 0.6812 while internal friction angle is the least influencing parameters with the last ranked of GRG value, 0.6119. The order of the influencing factor to the FOS for case study 2 is cohesion> slope height> pore water pressure> slope angle> unit weight> internal friction angle

Table 5: Grg Value for Case Study 1

Parameter	GRG	Rank
Unit weight (γ)	0.6060	5
Cohesion (c)	0.6614	3
Internal friction angle (φ)	0.6712	2
Slope angle (β)	0.6027	6
Slope height (H)	0.8116	1
Pore water pressure ratio (ru)	0.6244	4

Table 6: Grg Value for Case Study 2

Parameter	GRG	Rank
Unit weight (γ)	0.6119	5
Cohesion (c)	0.6812	1
Internal friction angle (φ)	0.6119	6
Slope angle (β)	0.6153	4
Slope height (H)	0.6780	2
Pore water pressure ratio (ru)	0.6481	3

Table 7 shows the GRG value for case study 3. Based on Table 7, it shows that slope angle is the most influencing parameter with the first ranked of GRG value, 0.6738 while pore water pressure is the least influencing parameters with the last ranked of GRG value, 0.5941. The order of the influencing factor to the FOS for case study 3 is slope angle> unit weight> internal friction angle> cohesion> slope height > pore water pressure.

Table 7: Grg Value for Case Study 3

Parameter	GRG	Rank
Unit weight (γ)	0.6713	2
Cohesion (c)	0.6518	4
Internal friction angle (φ)	0.6522	3
Slope angle (β)	0.6738	1
Slope height (H)	0.6498	5
Pore water pressure ratio (ru)	0.5941	6

Table 8 shows the GRG value for case study 4. Based on Table 8, it shows that unit weight is the most influencing parameter with the first ranked of GRG value, 0.7350 while Internal friction angle is the least influencing parameters with the last ranked of GRG value, 0.5965. The order of the influencing factor to the FOS for case study 4 is unit weight> cohesion> slope height > pore water pressure > slope angle> internal friction angle.

Table 8: Grg Value for Case Study 4

Parameter	GRG	Rank
Unit weight (γ)	0.7350	1
Cohesion, (c)	0.6942	2
Internal friction angle (φ)	0.5965	6
Slope angle (β)	0.6182	5
Slope height (H)	0.6769	3
Pore water pressure ratio (ru)	0.6497	4

CONCLUSION

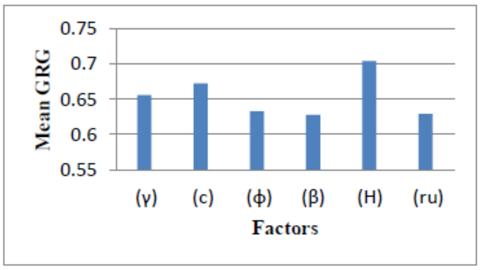

Figure 1: Mean GRG for each influencing factor

Fig 1 shows the mean GRG value of each of the influencing factors for all the case studies. The figures show that all the factors have GRG value more than 0.6. According to Sallehuddin et al [16], the factor that gave GRG higher than 0.6 can be considered as significant factor and the factor that gave GRG value less than 0.6 is considered as less influencing factors to the sequence reference or output value. The figures also show that slope height gives the highest mean GRG with 0. 704, while slope angle, and pore water pressure give the lowest mean GRG with 0.628 and 0.629, respectively. These suggest that slope height is the most significant factor to the slope stability, and slope angle and pore water pressure are the less significant factors to the slope stability.

The grey analysis is able to reduce the test data sample information of slope stability analysis by considering the GRG value for each of the influencing factors. For example, for the prediction of slope failure, the factor that have GRG value less than 0.6 can be eliminated from the input values to reduce the size of the datasets. Eliminating the less influencing factor will improve the prediction result as well as reduce the computing time. Normally, GRA will act as a feature selection method prior to the prediction process to investigate the influencing factors to the output feature. The analysis results presented in this paper play an important role in slope stability analysis as well as slope design and reinforcement.

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