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THE EFFECT OF THE SETBACK ANGLE ON OVERTURNING STABILITY OF THE RETAINING WALL

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Abstract. A retaining wall is a relatively common type of protective structure in construction to hold soil behind them. The form of the retaining wall is also relatively diverse with changing setback angle. Design cross-selection of retaining wall virtually ensures the stability of the retaining wall depends on many aspects. It is essential to consider these to bring a overall factor. For this reason, in this work, a study on the influence of the setback angle on the overturning stability of the retaining wall is presented. To evaluate the behavior stability of retaining wall with some key factors having different levels such as setback angle, internal friction angle of the soil, the slope of the backfill is based on the design of the experiment with useful statistical analysis tools. In addition, we have proposed a necessary technical requirements in choosing significant cross-sections of retaining structure to suit natural terrain and save construction costs, ensure safety for the project.

Keywords: retaining wall, setback angle, overturning stability.

1. INTRODUCTION

Retaining wall is a type of protective structure for roadbed, which is relatively common in construction, transport, and irrigation, to provide lateral resistance for a mass of earth or other material to accommodate a transportation facility. Several types of retaining wall systems are available to maintain the land and satisfy specific project requirements. The structure of the retaining wall is also relatively diverse, with different setback angle. When designing the earth retaining wall, it is necessary to carefully and accurately calculate the retaining wall's full load, especially the active earth pressure on the retaining to avoid some geotechnical failures like sliding, overturning, bearing, stability, and settlement [1]. Structure selection is mainly based on the designer's perception without any comparison when to choose which one. Therefore, the designer often designs retaining walls with a trapezoidal cross-section, so there are still some disadvantages, such as positive talus reinforcement on the slope. Besides, after the construction is completed, backfilling must be carried out; the backfilled soil cannot be seamless and homogeneous with the natural soil layer, thus breaking the natural soil's stability behind the wall. Moreover, the earth excavated during the wall's construction back is easy to drop, causing danger to the construction operator, especially when the ground is wet. The issues mentioned above reflect the need to study setback angle is necessary.

2. DESIGN CRITERIA

2.1. Design model of retaining wall

In the retaining wall design, the calculation of the earth pressure acting on the retaining wall is relatively complicated. Once the soil pressure has been calculated, solving the retaining wall design. However, to design a reasonable retaining wall, it is necessary to base on many factors. One of the factors affecting the safety of the retaining wall is the angle of the wall back. So, the retaining wall's setback angle is chosen to vary from -20^o to 20^o to assess its effect, while the remaining dimension parameters are by the structure of the gravity retaining wall [1,2,3,4]. The selection of dimensions must still ensure that the cross-sectional area (A) of the retaining wall does not change. To determine the cross-sectional area of the retaining wall in all cases, divide the retaining wall's cross-section into four parts, denoted I, II, III, IV, as shown in Fig. 1.

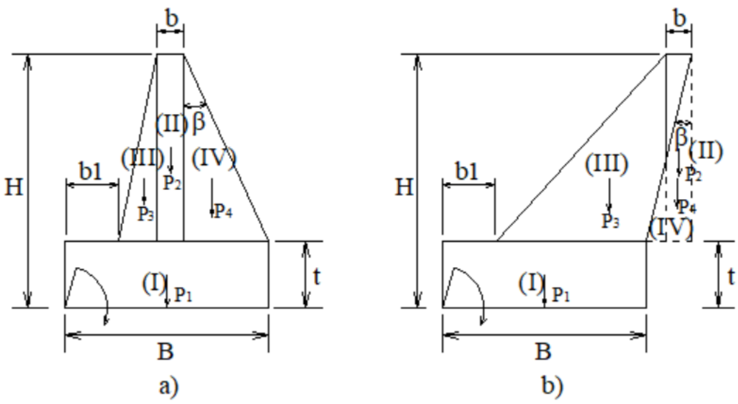

Figure 1. Diagram for determining the cross-sectional area in the cases.

While: φ is the internal friction angle of the soil, α is the slope of the backfill (Ground Inclination Angle), β is the setback angle, δ is the friction angle between soil and back of retaining wall. With the retaining wall structure, choose values for parameters: H, t, B, b, b1, γ_{bt} is the unit weight of the concrete retaining wall, and γ' is the unit weight of backfill soil. From an angle β select combined with the values selected above, each part's remaining dimensions and area are as follows.

$$A_I = B.t(m^2); \tag{1}$$

$$A_{II} = b.(H-t)(m^2); \tag{2}$$

$$A_{III} = \frac{1}{2}.(H-t).\left[B-(H-t).\tan\beta - b1 - b\right](m^2); \tag{3}$$

$$A_{IV} = \frac{1}{2}.(H-t).\left[B-(H-t).\tan\beta\right](m^2). \tag{4}$$

Calculation for 1m length of retaining wall, overturning moment of each part as follows:

$$M_{E(I)} = A_I.\gamma_{bt}.\frac{B}{2}; \tag{5}$$

$$M_{E(II)} = A_{II}.\gamma_{bt}.\left\{b1+\left[B-(H-t).\tan\beta-b1-b\right]+\frac{b}{2}\right\}; \tag{6}$$

$$M_{E(III)} = A_{III}.\gamma_{bt}.\left\{b1+\frac{\left[B-(H-t).\tan\beta-b1-b\right]}{3}\right\}; \tag{7}$$

$$M_{E(IV)} = A_{IV}.\gamma_{bt}.\left[B-\frac{(H-t).\tan\beta}{3}\right]; \tag{8}$$

$$M_G = M_{E(I)} + M_{E(II)} + M_{E(III)} + M_{E(IV)}. \tag{9}$$

The Coulomb's active earth pressure coefficient Ka [1,2] is given by:

$$K_a = \frac{\cos^2(\varphi-\beta)}{\cos^2\beta\cos(\beta+\delta)\left[1+\sqrt{\frac{\sin(\delta+\varphi)\sin(\varphi-\alpha)}{\cos(\beta+\delta)\cos(\alpha-\beta)}}\right]^2} \tag{10}$$

Active Earth Force Resultant:

$$E_a = \frac{1}{2}\gamma'.H_1^2K_a(kN/m) \tag{11}$$

The active horizontal soil pressure components Ex and vertical Ey are calculated as follows:

$$E_x = E_a * \cos(\beta+\delta) \quad (kN/m) \tag{12}$$

$$E_y = E_a * \sin(\beta+\delta) \quad (kN/m) \tag{13}$$

Determine the point to place the force at a distance from the foundation of the retaining wall *h'=1/3H + h*. Then overturning safety factor coefficient is calculated as follows:

$$K_0 = \frac{G.z_G + E_y z_x}{E_x Z_y} \text{ or } K_0 = \frac{M_G + M_{Ey}}{M_x} \quad (14)$$

With M_G, M_x, M_y, respectively the moment caused by the self-weight of the wall, active earth pressure components Ex, Ey.

$$M_{Ex} = E_x * Z_y \quad (kNm) \quad (15)$$

$$M_{Ey} = E_y * Z_x \quad (kNm) \quad (16)$$

2.2. Design of experiment

Experimental Design mathematical methodology is a branch of applied statistics used to plan and conduct experiments and analyze and interpret data obtained from experiments. Over the past two decades, the experiment (DOE) design has expanded across a wide range of industries. It is a handy tool often that is used to improve product quality and reliability [5, 6].

Suppose there are two factors A, B affect the output variable Y, then the relational equation is as follows:

$$Y_{ijk} = \xi + a_i + b_j + (ab)_{ij} + \epsilon_{ijk} \quad (17)$$

where:

ξ represents the overall mean effect;

a_i is the effect of the i_{th} level of factor A (i= 1, 2, …, n_a);

b_j is the effect of the j_{th} level of factor B (j= 1, 2, …, n_b);

$(ab)_{ij}$ represents the interaction effect between A and B;

ϵ_{ijk} represents the random error terms (which are assumed to be normally distributed with a mean of zero and variance of σ^2) and the subscript k denotes the m replicates (k = 1,2,…,m).

Since the effects a_i, b_j and $(ab)_{ij}$ represent deviations from the overall mean, the following constraints exist:

$$\sum_{i=1}^{n_a} a_i = 0; \ \sum_{j=1}^{n_b} b_j = 0; \ \sum_{i=1}^{n_a} (ab)_{ij} = 0; \ \sum_{i=1}^{n_b} (ab)_{ij} = 0; \quad (18)$$

Hypothesis Tests in General Factorial Experiments

Furthermore, in addition to the two factors A, B, and the interaction between them AB, after building the relationship model eq. (17), it is necessary to check the hypotheses to evaluate their significance in the following aspects.

1. H0: $a_1 = a_2 = \ldots = a_{na} = 0$ (Main effect of A is absent)

H1: $a_I \neq 0$ for at least one i

2. H0: $b_1 = b_2 = \ldots = b_{nb} = 0$ (Main effect of B is absent)
H1: $b_j \neq 0$ for at least one j

3. H0: $(ab)_{11} = (ab)_{12} = \ldots = (ab)_{nanb} = 0$ (Main effect of AB is absent)
H1: $(ab)_{Ij} \neq 0$ for at least one ij

The sum of squares of the factors is as follows:

$$SS_{TR} = SS_A + SS_B + SS_{AB} \tag{19}$$

where SS is the mean sum of squares like SS_A represents the sequential sum of squares due to factor A. MS is the mean square obtained by dividing the sum of squares by the associated degrees of freedom.

Once the mean squares are known the test statistics can be calculated. For example, the test statistic to test the significance of factor A (or the hypothesis H0: $\tau_I = 0$) can then be obtained as:

$$(F_0)_A = \frac{MS_A}{MS_E} = \frac{SS_A/dof(SS_A)}{SS_E/dof(SS_E)} \tag{20}$$

$$(F_0)_B = \frac{MS_B}{MS_E} = \frac{SS_B/dof(SS_B)}{SS_E/dof(SS_E)} \tag{21}$$

$$(F_0)_{AB} = \frac{MS_{AB}}{MS_E} = \frac{SS_{AB}/dof(SS_{AB})}{SS_E/dof(SS_E)} \tag{22}$$

3. RESULTS AND DISCUSSION

3.1. Input parameters

Cross-section of retaining wall and backfill behind retaining wall detailed in Table 1.

Table 1. Input parameters.

H (m)	**B** (m)	γ_{bt} (kN/m^3)	**t** (m)	**b** (m)	**b1** (m)	γ’ (kN/m^3)	δ	**f**
6	3	22	1	0.5	0.75	15	0,67φ	0.4

The retaining wall's cross-sectional area has an area of A constant (here A = 9.875m2).

3.2. Result and discussion

Input variables of experimental design: 3 variables, with specific information as follows:

- Ground Inclination Angle (α) with four value levels: 0, 10, 20, 30;
- Internal Friction Angle (φ) with four value levels: 30, 32, 34, 36;
- Setback Angle (β) with 21 value levels: -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

Note that the unit of angle is degrees. The total number of computations 4 * 4 * 21 = 336 times for all cases, calculated with variables made into Excel calculation file, get the aggregated results in Table 2.

Table 2. Coefficient K.

φ	β	K , α=0	K , α=10	K , α=20	K , α=30
30	-20	4.2531	3.8065	3.18	1.5849
30	-18	4.0587	3.6296	3.0354	1.5482
30	-16	3.8905	3.4767	2.9112	1.5182
30	-14	3.7442	3.3441	2.8039	1.4937
30	-12	3.6167	3.2286	2.7109	1.4739
30	-10	3.5052	3.1278	2.6302	1.458
30	-8	3.4076	3.0396	2.5599	1.4456
30	-6	3.3221	2.9623	2.4987	1.436
30	-4	3.2471	2.8945	2.4452	1.429
30	-2	3.1814	2.8351	2.3987	1.4241
30	0	3.124	2.7831	2.3581	1.4212
30	2	3.0741	2.7377	2.3229	1.42
30	4	3.0308	2.6982	2.2925	1.4204
30	6	2.9935	2.664	2.2663	1.422
30	8	2.9617	2.6345	2.2438	1.4248
30	10	2.935	2.6094	2.2249	1.4287
30	12	2.913	2.5883	2.209	1.4336
30	14	2.8953	2.5708	2.1959	1.4393
30	16	2.8817	2.5566	2.1854	1.4457
30	18	2.8719	2.5456	2.1772	1.4528
30	20	2.8657	2.5374	2.1711	1.4604
32	-20	4.8631	4.3926	3.7464	2.5549
32	-18	4.6095	4.1585	3.5473	2.4388
32	-16	4.3909	3.957	3.3765	2.3402
32	-14	4.2014	3.7826	3.2294	2.2563
32	-12	4.0366	3.6311	3.102	2.1845
32	-10	3.8927	3.499	2.9913	2.1229
32	-8	3.7667	3.3835	2.8948	2.0701
32	-6	3.6563	3.2822	2.8105	2.0247
32	-4	3.5595	3.1932	2.7367	1.9857
32	-2	3.4745	3.1152	2.6722	1.9524
32	0	3.3999	3.0466	2.6157	1.9239
32	2	3.3347	2.9864	2.5663	1.8997
32	4	3.2779	2.9338	2.5231	1.8792
32	6	3.2286	2.8878	2.4856	1.8622
32	8	3.1862	2.848	2.4531	1.8481
32	10	3.15	2.8136	2.4251	1.8368
32	12	3.1196	2.7842	2.4012	1.8279
32	14	3.0946	2.7595	2.3811	1.8211
32	16	3.0746	2.739	2.3643	1.8164
32	18	3.0593	2.7225	2.3507	1.8134
32	20	3.0485	2.7096	2.3399	1.812
34	-20	5.5738	5.0767	4.4055	3.2714
34	-18	5.2456	4.7704	4.1373	3.0854

34	-16	4.9642	4.5081	3.9085	2.9277
34	-14	4.7214	4.2822	3.712	2.7932
34	-12	4.511	4.0866	3.5423	2.6779
34	-10	4.3278	3.9165	3.3952	2.5786
34	-8	4.1678	3.768	3.2671	2.4929
34	-6	4.0277	3.638	3.1553	2.4188
34	-4	3.9049	3.524	3.0574	2.3544
34	-2	3.7971	3.4238	2.9716	2.2986
34	0	3.7025	3.3357	2.8963	2.2503
34	2	3.6195	3.2583	2.8303	2.2083
34	4	3.547	3.1904	2.7725	2.1722
34	6	3.4838	3.131	2.7219	2.141
34	8	3.4291	3.0791	2.6778	2.1144
34	10	3.3821	3.0342	2.6395	2.0919
34	12	3.3422	2.9955	2.6065	2.0729
34	14	3.3088	2.9625	2.5783	2.0573
34	16	3.2816	2.9349	2.5545	2.0447
34	18	3.2601	2.9121	2.5348	2.0348
34	20	3.2441	2.894	2.5187	2.0274
36	-20	6.4094	5.8828	4.4055	4.0565
36	-18	5.9863	5.4844	4.1373	3.7849
36	-16	5.626	5.1456	3.9085	3.5558
36	-14	5.317	4.8555	3.712	3.3612
36	-12	5.0504	4.6054	3.5423	3.1947
36	-10	4.8193	4.3888	3.3952	3.0517
36	-8	4.6181	4.2004	3.2671	2.9281
36	-6	4.4424	4.0359	3.1553	2.8211
36	-4	4.2886	3.8918	3.0574	2.7281
36	-2	4.1538	3.7654	2.9716	2.6472
36	0	4.0355	3.6544	2.8963	2.5767
36	2	3.9318	3.5568	2.8303	2.5152
36	4	3.841	3.4711	2.7725	2.4618
36	6	3.7617	3.396	2.7219	2.4153
36	8	3.6928	3.3303	2.6778	2.3751
36	10	3.6334	3.2732	2.6395	2.3405
36	12	3.5826	3.2238	2.6065	2.3109
36	14	3.5397	3.1815	2.5783	2.2859
36	16	3.5043	3.1457	2.5545	2.265
36	18	3.4759	3.116	2.5348	2.2479
36	20	3.4541	3.0919	2.5187	2.2342

Display the results in Table 2 in Figure 2 as follows.

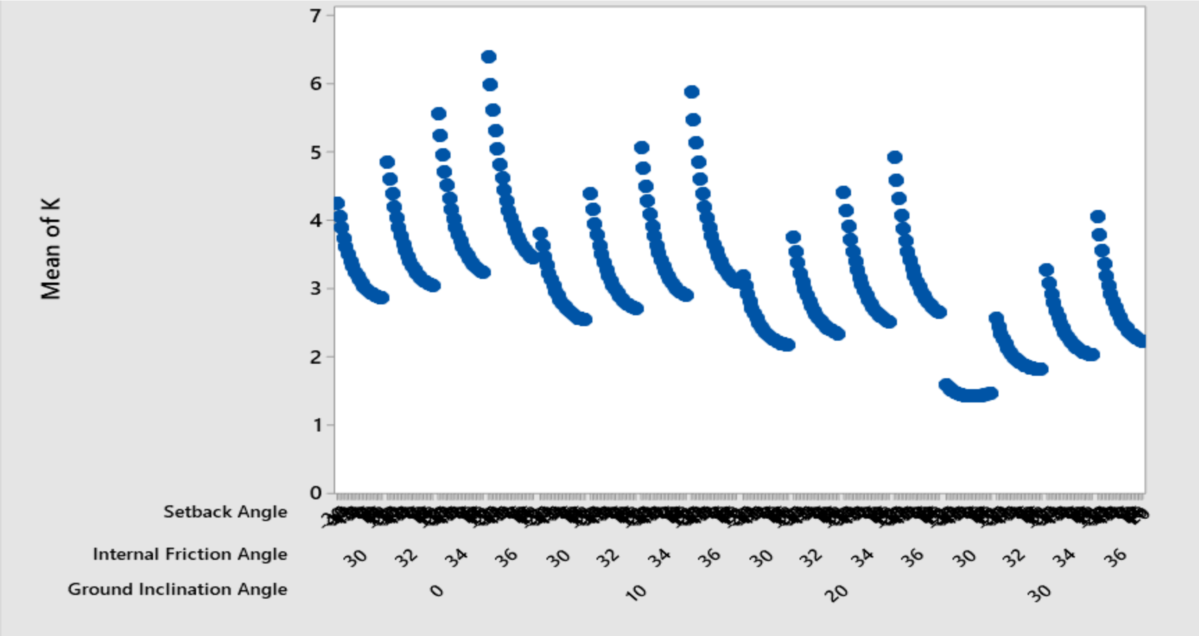

Figure 2. Chart of K.

Based on factor evaluation, using Minitab19 software to design a general experiment and analyze the coefficient K. Analysis results of the factors' variance are detailed in Table 3.

Table 3. Analysis of Variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	8	815.137	101.892	7414.80	0.000
Ground Inclination Angle	1	1.685	1.685	122.62	0.000
Internal Friction Angle	1	48.289	48.289	3514.07	0.000
Setback Angle	1	12.413	12.413	903.33	0.000
Ground Inclination Angle*Ground Inclination Angle	1	8.982	8.982	653.63	0.000
Setback Angle*Setback Angle	1	28.091	28.091	2044.22	0.000
Ground Inclination Angle*Internal Friction Angle	1	0.516	0.516	37.58	0.000
Ground Inclination Angle*Setback Angle	1	14.016	14.016	1019.97	0.000
Internal Friction Angle*Setback Angle	1	23.812	23.812	1732.79	0.000
Error	999	13.728	0.014		
Lack-of-Fit	327	11.506	0.035	10.64	0.000
Pure Error	672	2.222	0.003		
Total	1007	828.865			

Table 3 shows the analysis results with all variances have a significant level with P-value <0.05. So that, regression equation of K will be built as follows:

$$K = -1.8156 - 0.05547*\alpha + 0.16379*\varphi + 0.13610*\beta - 0.000944*\alpha^2$$
$$+ 0.001277*\beta^2 + 0.000905*\alpha*\varphi + 0.000871*\alpha*\beta - 0.005676*\varphi*\beta \quad (23)$$

Table 4. Model Summary of K.

S	R-sq	R-sq(adj)	R-sq(pred)
0.117225	98.34%	98.33%	98.30%

As can be seen from Table 4 that the model summary of K has adjusted determination coefficient R-sp(adj) = 98.33%. So, eq. (23) is formulated perfectly accordingly. Based on eq. (23), the coefficient K can be estimated together with the input values.

Figure 3. Main Effects Plot for K

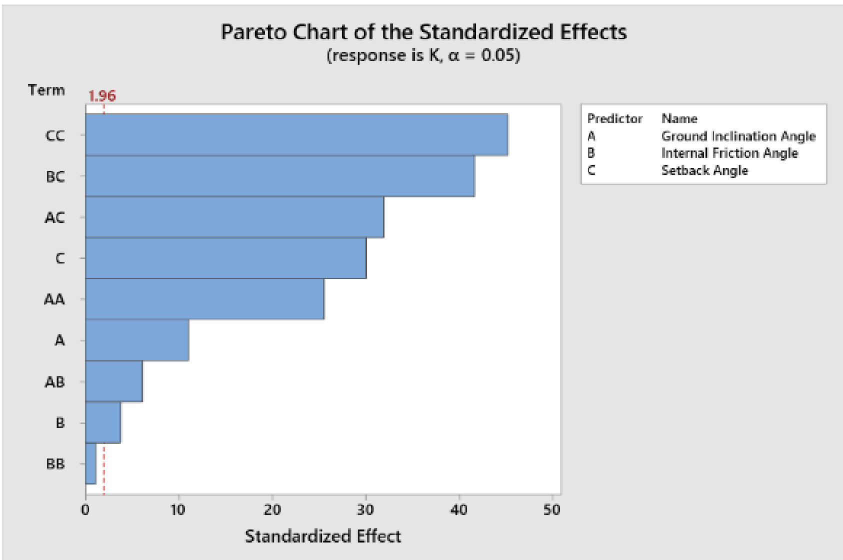

Figure 4. Pareto Chart for K.

Figure 3 plots the main effects for K. The most significant influence on the K coefficient is the angle behind the wall. Moreover, it also shows that the steeper the slope angle of the ground roof, the lower the tipping resistance coefficient decreases, which contrasts to the soil's internal friction angle, where the internal friction angle is large, the coefficient K is increased. Meanwhile, the back-inclination angle used to have a nonlinear effect on the K. When the smaller of the setback angle, the bigger of the K, significantly the negative the back slope angle, the higher the safety factor of the overturning resistance. This is also clearly seen from Table 2, where K has the most considerable value in the cases with $\beta = -20^o$, where the retaining wall stability coefficient is high. Furthermore, the Pareto chart in Fig.4 shows that all variables and interactions between variables (the product of variables) affect K statistically. Like previous theory, the setback of a retaining wall increases, the leverage from course to course rises [7, 8, 9,10].

4. CONCLUSIONS

The research results show that the retaining wall's design with the "negative" setback angle is of great significance. It increases the safety factor and ensures that the natural ground remains unchanged and safe to the operator and safe when exploiting. Although there are various factors to consider, selecting the appropriate angle of the setback is always vital to ensure the retaining wall's stability.

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