COST ANALYSIS IN REINFORCED CONCRETE CANTILEVER RETAINING WALLS

Atila DEMİRÖZ[1,] *, Erkan YILDIRIM[1]
[1]Konya Teknik Üniversitesi, İnşaat Mühendisliği Bölümü, Konya Türkiye
*ademiroz@ktun.edu.tr, erkan05@gmail.com

Abstract

Many factors are effective in the design of cantilever retaining walls. These factors are; factors such as wall height, soil internal friction angle, surcharge loads, groundwater level, seismic effects and frost effects. These factors directly affect the design of the retaining walls and therefore the cost of them. In this study, the effects of wall height, soil internal friction angle and surcharge loads, which are the factors affecting the design, were investigated. For this purpose, solutions of 64 different cantilever retaining wall designs were made separately at 4, 6, 8 and 10 m wall height, 24, 26, 28, 30° internal friction angles and under 10, 15, 20, 25 kN/m^2 surcharge loads and their costs were calculated. With these solutions, analysis of variance (ANOVA) was performed using the full factorial design method and the effects of wall height, internal friction angle and surcharge load variables on cost were investigated. Thus, cost changes of cantilever retaining walls at different wall heights, internal friction angles and surcharge loads were investigated. IdeCAD Static v10.09 software was used for solutions of cantilever retaining wall designs and Minitab v17 software was used for ANOVA.

Keywords: Reinforced concrete retaining walls, Cost Analysis, Full Factorial Design Analysis, ANOVA.

BETONARME KONSOL İSTİNAT DUVARLARINDA MALİYET ANALİZİ

Özet

Betonarme istinat duvarlarının tasarımında birçok faktör etkili olmaktadır. Bu faktörler; duvar yüksekliği, zemin içsel sürtünme açısı, sürşarj yükleri, yeraltı su seviyesi, sismik etkiler ve don tesirleri gibi faktörler olarak sıralanabilir. Bu faktörler istinat duvarlarının tasarımını ve dolayısıyla maliyetini doğrudan etkilemektedir. Bu çalışmada tasarıma etki eden faktörlerden olan duvar yüksekliği, zemin içsel sürtünme açısı ve sürşarj yüklerinin tasarımdaki etkileri araştırılmıştır. Bu amaçla 4, 6, 8 ve 10 m duvar yüksekliğinde, 24, 26, 28, 30° içsel sürtünme açılarında ve 10, 15, 20, 25 kN/m^2 sürşarj yükleri altında ayrı ayrı olarak 64 farklı betonarme konsol istinat duvarı tasarımının çözümleri yapılmış ve bunların maliyetleri hesaplanmıştır. Bu çözümler ile tam faktöriyel tasarım metodu kullanılarak varyans analizleri (ANOVA) yapılmış ve yükseklik, içsel sürtünme açısı ve sürşarj yükü değişkenlerinin maliyet üzerine etkileri araştırılmıştır. Böylelikle betonarme konsol istinat duvarlarının farklı duvar yüksekliğinde, içsel sürtünme açısında ve sürşarj yüklerinde maliyet değişimleri incelenmiştir. Betonarme konsol istinat duvarlarının çözümleri için ideCAD Statik v 10.09 yazılımı ve ANOVA için de Minitab v17 yazılımı kullanılmıştır.

Anahtar Kelimeler: Betonarme Konsol İstinat Duvarı, Maliyet Analizi, Tam Faktöriyel Tasarım Analizi, ANOVA

1. Introduction

Retaining walls are retaining structures constructed to prevent the subsidence of ground having sudden slope changes. Today, there are many fields of application for retaining walls. Having many areas of usage also make the correct selection and design of the retaining walls more important. Although there are many types of retaining walls, nowadays, the most preferred ones are reinforced concrete cantilever retaining walls and especially the reinforced earth retaining walls and those created by using metallic strip, geogrid, which have increased rapidly in recent years. Another commonly used type of retaining wall is stone walls. As the stone walls cannot deliver economical and feasible solutions after a certain height, it has made the use of reinforced concrete cantilever and reinforced concrete ribbed retaining wall widespread.

It is required to determine the factors affecting the retaining wall design accurately. It complicates the behavior of the retaining walls because there are so many variables in the factors affecting the design. For this, various assumptions are made. This complex situation affects the design and thus the cost of the retaining walls.

In the literature, Durukan and Tezcan (1992) calculated the of cost reinforced concrete cantilever retaining walls by analyzing on firm ground and pile foundation [1]. In the same study, reinforced retaining walls were analyzed and their costs were calculated by using metal strip, polymer strip and geogrid. In his study, Şahin (1994) investigated the effect of the internal friction angle and seismic coefficient, which are the factors affecting the factor of safety in earthquake design of cantilever retaining walls [2]. In their study, Sarıbaş and Erbatur (1996) defined 7 different design variables in which 4 of them are geometry variables and 3 of them are reinforcement variables, and provided solutions for minimum weight and minimum cost as objective function [3]. Khan and Sikder (2004), in their study, made separate cost analyzes for reinforced concrete cantilever retaining wall, reinforced concrete wall formed using metallic strip, retaining wall with geotextile reinforcement and retaining walls with bitumen or anchored with epoxy coated rebar for the heights of 2,1-3-4,2-5,1 and 6 m [4]. Çakır and Aytekin (2005) designed a 7m high reinforced concrete cantilever retaining wall and a geogrid reinforced retaining wall, taking into account the parameters affecting the cost factors and making a cost comparison [5]. In their study, Khajehzadeh, et al. (2014) performed an optimization study to minimize cost and CO_2 emissions in reinforced concrete retaining walls with Hybrid Gravitational Search Algorithm [6]. Kaveh and Soleimani (2015) employed colliding bodies optimization and democratic particle swarm optimization algorithms to design the optimum cost of reinforced concrete cantilever retaining walls [7]. In his study, Aydoğdu (2017), investigated the effects of optimum design parameters with the minimum cost of reinforced concrete cantilever retaining walls and CO_2 emission by meta-heuristic optimization method [8].

In this study, the effects of height, internal friction angle and surcharge loads on the design of reinforced concrete cantilever retaining walls in a non-earthquake state were investigated. Detailed information about the study is available in Yıldırım (2019) [9].

2. Determination of The Costs of Reinforced Concrete Retaining Walls and ANOVA Calculations

2.1. Full Factorial Design Method and Variance Analysis

It is a method that examines all combinations of multiple factors formed by the interaction with independent variables at a certain level in an experiment and performs optimization analysis in dependent variable depending on independent variables. For example, let factors A and B have 2 and 3 levels. If these levels are indicated by the symbols (a_1, a_2, a_3) and (b_1, b_2);

a_1b_1 a_1b_2 a_2b_1

a_2b_2 a_3b_1 a_3b_2

This design is called as 3×2 factorial design. In 2k factorial design, 2 levels indicate the number of k factors. A mathematical model for a×b×c factorial design, where A, B, and C factors have a, b, and c levels are given in equation (2.1).

$$y_{ijk} = \mu + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} + \varepsilon_{l(ijk)} \begin{cases} i = 1,2,\ldots,a \\ j = 1,2,\ldots,b \\ k = 1,2,\ldots,c \\ l = 1,2,\ldots,n \end{cases} \quad (2.1)$$

where;

y_{ij} : The i-th value of factor A, the j-th factor of B, the k-th observation value of factor C

μ : General Average

A_i : Impact value of factor A at i th level

B_j : Impact value of factor B at j th level

C_k : Impact value of factor C at k th level

AB_{ij} : Interaction effect of A and B factors

AC_{ik} : Interaction effect of A and C factors

BC_{jk} : Interaction effect of B and C factors

ABC_{ijk} : Interaction effect of A, B and C factors

ε : Random error component

Sum of squares for the factorial design, where the factors A, B and C are a, b, and c;

$$KT_{GENEL} = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}\sum_{l=1}^{n} y_{ijk}^{2} - \frac{y^2}{a.b.c.n} \quad (2.2)$$

$$KT_A = \frac{1}{b.c.n}\sum_{i=1}^{a} y_i^2 - \frac{y^2}{a.b.c.n} \quad (2.3)$$

$$KT_B = \frac{1}{a.c.n}\sum_{j=1}^{b} y_j^2 - \frac{y^2}{a.b.c.n} \quad (2.4)$$

$$KT_C = \frac{1}{a.b.n}\sum_{k=1}^{c} y_k^2 - \frac{y^2}{a.b.c.n} \quad (2.5)$$

$$KT_{AB} = \frac{1}{c.n}\sum_{i=1}^{a}\sum_{j=1}^{b} y_{ij}^{2} - \frac{y^2}{a.b.c.n} - KT_A - KT_B \quad (2.6)$$

$$KT_{AC} = \frac{1}{b.n}\sum_{i=1}^{a}\sum_{k=1}^{c} y_{ik}^2 - \frac{y^2}{a.b.c.n} - KT_A - KT_C \quad (2.7)$$

$$KT_{BC} = \frac{1}{a.n}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{jk}^2 - \frac{y^2}{a.b.c.n} - KT_B - KT_C \quad (2.8)$$

$$KT_{ABC} = \frac{1}{n}\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{ijk}^2 - \frac{y^2}{a.b.c.n} - KT_A - KT_B - KT_C - KT_{AB} - KT_{AC} - KT_{BC} \quad (2.9)$$

$$KT_{HATA} = KT_{GENEL} - KT_A - KT_B - KT_C - KT_{AB} - KT_{AC} - KT_{BC} - KT_{ABC} \quad (2.10)$$

Results of variance analysis for the three-factor fixed-effect order are given in Table 2.1 (Erbaş and Olmuş, 2006) [10], (Montgomery, 2001) [11].

Table 2.1 Result table of variance analysis

Source of Variability	**Sum of Squares**	**Degree of Freedom**	**Sum of Squares (Variance)**	**Test Statistics (F)**
A	KT_A	a-1	KO_A	KO_A / KO_{ERROR}
B	KT_B	b-1	KO_B	KO_B / KO_{ERROR}
C	KT_C	c-1	KO_C	KO_C / KO_{ERROR}
AB	KT_{AB}	(a-1)(b-1)	KO_{AB}	KO_{AB} / KO_{ERROR}
AC	KT_{AC}	(a-1)(c-1)	KO_{AC}	KO_{AC} / KO_{ERROR}
BC	KT_{BC}	(b-1)(c-1)	KO_{BC}	KO_{BC} / KO_{ERROR}
ABC	KT_{ABC}	(a-1)(b-1)(c-1)	KO_{ABC}	KO_{ABC} / KO_{ERROR}
ERROR	KT_{ERROR}	abc(n-1)	KO_{ERROR}	-
TOTAL	$KT_{GENERAL}$	abcn-1	-	-

Investigation of the validity of a hypothesis about the main population parameters at a certain level of significance (α=1-confidence level) based on sample statistics is called as Hypothesis tests. In performing hypothesis tests, the stages of writing the hypotheses, determining the level of significance, determining the F value based on the sample values and making decisions are followed [8].

To test these hypotheses, variance analysis is performed and F values are calculated. The F statistic is a term of the F sampling distribution and the F distribution, which is a two-parameter distribution, is shown by the initial letter of his surname since it is calculated by R.A. Fisher (Çömlekçi, 2005), [12].

In order to interpret the model created by full factorial analysis method, F and P values are calculated for each independent variable related to the dependent variable by variance analysis. With this method called F statistics, the closer the calculated P values to zero, the more significant the independent variable is for the dependent variable.

As the P value grows, it would not mean that the independent variable is significant for the dependent variable. In other words, a hypothesis is set up in such a manner that the independent variables do not have a correlation with the dependent variable, and the larger the P value, the hypothesis we have set up would be correct. If smaller the P value, the hypothesis which we set up would be incorrect and it is rejected. The smaller the P value, the hypothesis we set up is incorrect and rejected. Generally, P value is required to be less than 0.05. Then, Variance Inflation Factor VIF values are calculated for each independent variable. This value is used to determine whether or not there is a linear relationship between the variables. This value is used to determine whether or not there is a linear relationship between the independent variables. If this value is 1 or close to 1, it would mean that there is a linear relationship between the independent variables. Finally, "Multiple Coefficient of Determination" (R^2) value is calculated. With this coefficient, the result of how significant the independent variables are for the dependent variable is determined, because this value is required to be close to 1. Because the closer this value is to 1, the more significant the hypothesis we set up. If this value is small, it follows that it must be included in the hypothesis in other independent variables related to the dependent variable.

2.2. Numerical Application

Height H = 4-6-8-10 m, internal friction angle $\phi°$=24-26-28-30, and surcharge load q = 10-15-20-25 kN/m² of reinforced concrete cantilever retaining walls have been solved separately and their costs have been calculated. Solutions of reinforced concrete cantilever retaining walls were made with ideCAD Reinforced Concrete v10.09 program. Length of the retaining wall is considered as 1 m.

Regression equation and statistical analysis between these variables, including cost dependent variable and height, independent variables of internal friction angle and surcharge load, were performed with the Minitab v17 program.

As is seen in Figure 2.1, 2 different types of grounds are chosen: manmade soil and undisturbed soil. Geotechnical properties of these soils are shown in Table 2.2. The solutions of the retaining structures were calculated according to the non-earthquake state. It is assumed that there is no groundwater in the calculations.

Reinforced concrete cantilever retaining wall solutions were made in ideCAD v10.09 program. Calculations are made for the dimensions h, b, D, d, L and B shown in Figure 2.1. Depending on these values, iron, concrete, formwork, excavation and filling quantities, which are the factors determining the cost, have been calculated.

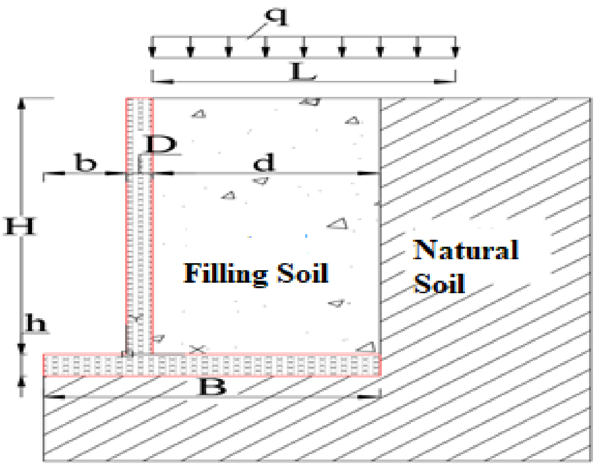

Figure 2.1 General view of the retaining wall

Table 2.2 Soil geotechnical values used in calculations

	Undisturbed Soil	Manmade Soil
Specific bulk density γ_n (kN/m³)	19	21
İnternal friction angle (ϕ°)	24-26-28-30	24-26-28-30
Wall friction angle (δ°=2/3ϕ)	16-17,33-18,66-20	16-17,33-18,66-20
Cohesion value c (kN/m²)	0	0
Allowable bearing value of soil σ_{em} (kN/m²)	150	-

3. Research Findings

When the chart in Figure 3.1 is examined, it indicates the average cost indicated by the dotted line. As is seen from the graphic, the slope between cost and height is much more than the internal friction angle and the surcharge load. From this graph, unit increases in height change the cost much more than the internal friction angle and the surcharge load. Although the slope between the internal friction angle and the surcharge load and the cost is close to each other, the slope of the internal friction angle is higher. Hence, the change in the unit of quantity in the internal friction angle changes the cost more than the surcharge load. When the graphic is examined, the slope dip direction of the height and the surcharge load is upwards and the slope dip direction of the internal friction angle is downwards. From here, we can conclude as follows: as the height and the surcharge load increase, the cost also increases, and as the internal friction angle increases, the cost decreases.

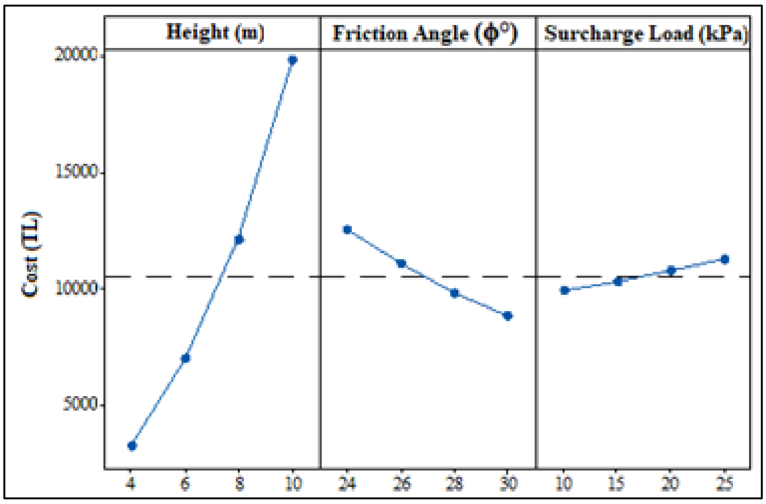

Figure 3.1 Correlation between reinforced concrete cantilever retaining walls cost and height, internal friction angle and surcharge load

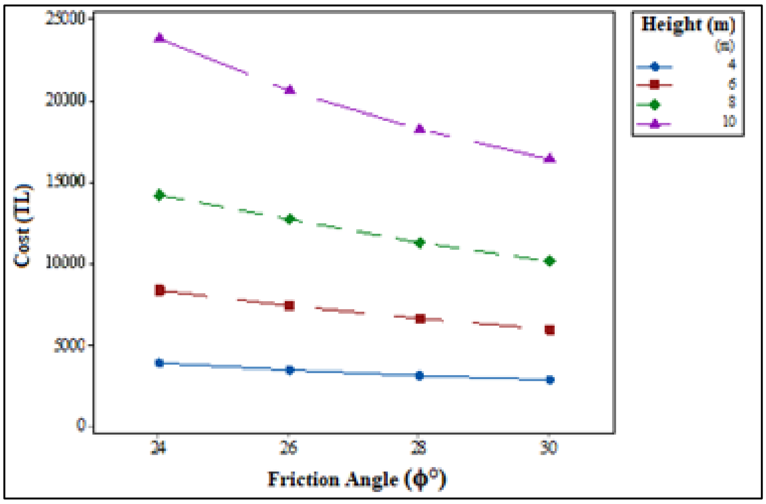

Figure 3.2 Change between internal friction angle, height and cost

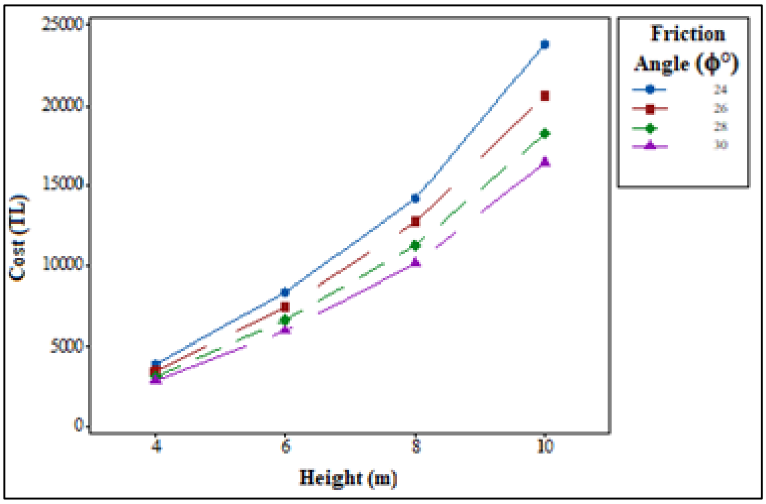

Figure 3.3 Change between internal friction angle, height and cost

As is seen in Figure 3.2 and Figure 3.3, the effect of the internal friction angle to change the cost also increases with the increase in the height of the retaining wall. With the increase in the height of the reinforced concrete cantilever retaining walls, the cost reduction rate for internal friction angle also increases.

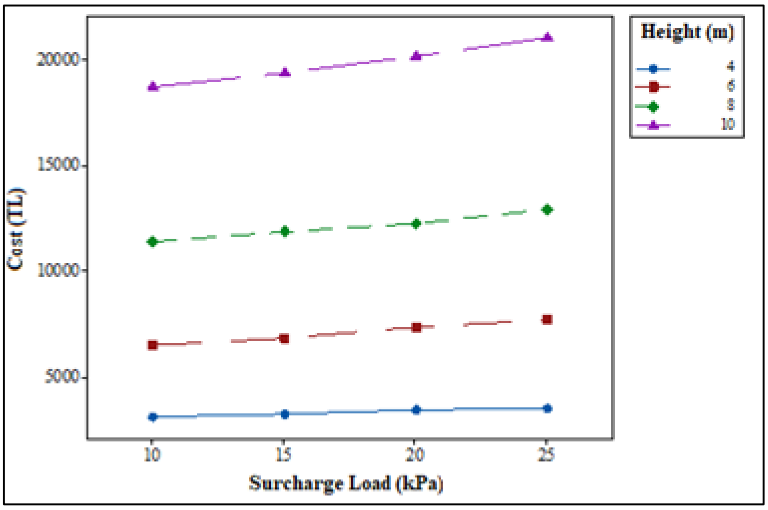

Figure 3.4 Change between surcharge load, height and cost

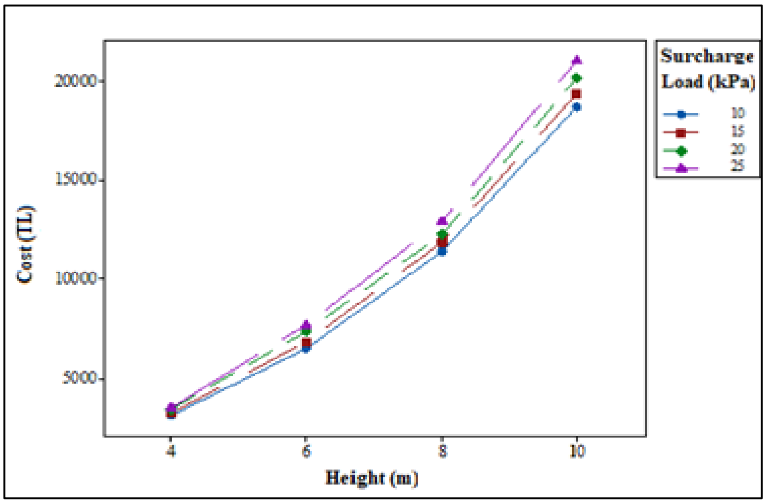

Figure 3.5 Change between height, surcharge load and cost

As is seen in Figure 3.4 and Figure 3.5, the effect of the surcharge load to change the cost also increases with the increase in the height of the retaining wall. With the increase in the height of the reinforced concrete cantilever retaining walls, the cost reduction rate for surcharge load also increases.

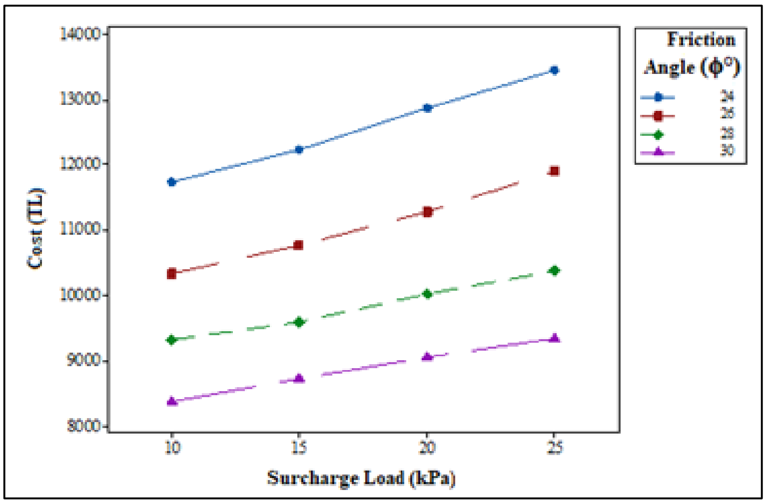

Figure 3.6 Change between surcharge load, internal friction angle and cost

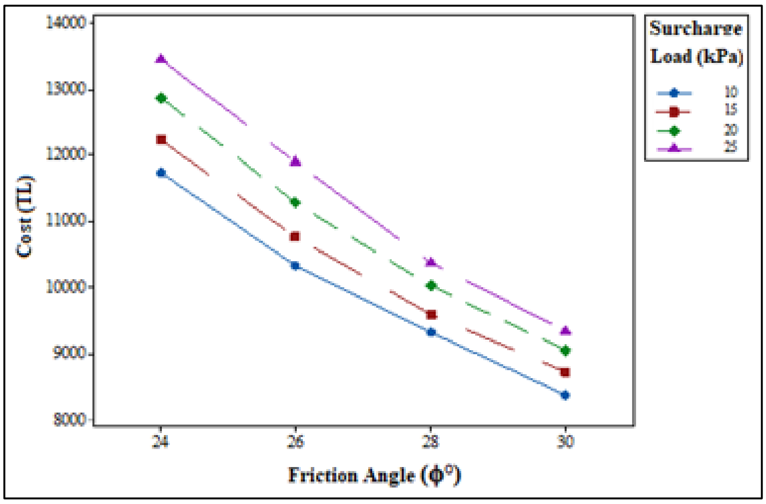

Figure 3.7 Change between internal friction angle, surcharge load and cost

As is seen in Figure 3.6 and Figure 3.7, the effect of the surcharge load to change the cost also increases with the increase in the height of the retaining wall. With the increase in the height of the reinforced concrete cantilever retaining walls, the cost reduction rate for surcharge load also increases. As the surcharge load increases in the retaining wall, the cost increases, and as the internal friction angle increases, the cost decreases. As seen from both graphs, the slopes are very close to each other. Together with the increase of the surcharge load in the reinforced concrete cantilever retaining walls, it was observed that the internal friction angle did not affect the cost change rate.

4. Conclusions

As a result of calculations and analyses performed, it is concluded as follows:

1. Rate of increase in cost increases depending on the height. As the height increases by %, the cost change decreases. It was determined that the cost change has increased by 109.9% when the retaining wall height increased from 4 m to 6 m, by 71.5% from 6 m to 8 m, and by 63.3% from 8 m to 10 m
2. As the internal friction angle increases in reinforced concrete cantilever retaining walls, the cost decreases. As the height of retaining wall increases, the cost reduction rate of the internal friction angle also increases. Cost decreases by 12.7% if the internal friction angle increases between the range of 24-26°, and by 11.5% if it increases between the range of 26-28°and by 10.8% if it increases between the range of 28-30°.

3. As the surcharge load increases in reinforced concrete cantilever retaining walls, the cost increases. As the height of retaining wall increases, the cost increase rate of surcharge load increases, and as the internal friction angle increases, the cost increase rate of surcharge load decreases. It was determined that the cost increased by 4.1% if the surcharge load increases between the range of 10-15 kPa, by 5.3% if it increases between the range of 15-20 kPa and by 4.8% if it increases between the range of 20-25 kPa.
4. It was determined that there was a linear relationship between the cost, height, internal friction angle and surcharge load in reinforced concrete cantilever retaining walls and that R^2 significance value of the model was 95.16%. It was calculated that the factor affecting the cost at maximum was height with 90.14% and that the effect of internal friction angle was 4.64% and the effect of surcharge load was 0.61%. Random error rate was determined to be 4.61%. Equation between cost and height, internal friction angle, and surcharge load is calculated as follows;

$$\text{Cost (TRY)} = 6641 + 2728{,}4 \times H\ (m) - 619{,}2 \times \phi + 89{,}8 \times q\ (kN/m^2)$$

In non-earthquake state, the equation above is valid for reinforced concrete cantilever retaining walls with no groundwater level where height is between the range of 4-10 m, internal friction angle is between the range of 24-30° and surcharge load is between the range of 10-25 kPa. Studies have been carried out in the specified ranges for height, internal friction angle and surcharge load. At values outside these ranges, it changes the cost in variables such as base width, base height, etc.

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