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Analysis of Soil Slope Stability in Heterogeneous and Homogeneous Soil under Leakage Based on Numerical and Limit Equilibrium Methods

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Abstract

Any natural or artificial surfaces are called slope which can be made of soil, stone, and sometimes a combination of both. The Effects of instability and landslides in the soil slopes under leakage get clearer when slip and movement of the earth including soil and rock have devastating effects on the roads, tunnels, water and sewer lines and even buildings and so on. The slip and instabilities can cause blockage of the arteries and reduce the level of their performance and in general reduce the public safety of roads which lead to imposing enormous cost of inspection, maintenance, repair and renovating to the authorities. In critical cases, the occurrence of this instability may cause loss of life for the users of the roads in the downstream slope. The two main methods for slope stability analysis are the limit equilibrium and the numerical methods. Studying the natural and artificial slope stability and determining and assessing their reliability and stability are the common goals in the two methods. This article compares the reliability coefficients in heterogeneous soils of clay and sand with the homogeneous soils of clay obtained through the limit equilibrium and numerical methods expressions are under leakage and dryness.

Keywords: soil slope, numerical method, limit equilibrium method, under leakage, heterogeneous soil, homogeneous soil

Introduction

Rupture occurrence in soil slope under leakage and also embankments may occur with limited shift or change of large areas that either cause problems or failures and irreparable damage to lives and property. Slope rupturemay occur under Natural conditions and only under the weight of unsustainable or may be due to factors such as earthquakes, severe and prolonged rains or floods. However, in normal circumstances, there are other factors such as soil erosion in some parts of the slope by flowing water or wind, a gradual rise in groundwater level or even human activities, including loading and unloading on the slope can intensify their instability. Various methods are offered to evaluate the stability of slopes and gables Among which limit equilibrium methods such as Fliniyus method , Bishop and Morgenstern and numerical methods can be indicated. The common goal of all these methods is determining the minimum reliability coefficient of stability and the corresponding surface rupture along which the slope will be slided and disrupted. In this study, the trench of a certain profile is assumed and its modeling and reliability coefficient are identified by using numerical methods (Polksis) then that trench will be studied and analyzed by limit equilibrium methods(Geo Studio).

Previous studies and general features of the project

To evaluate soil slope stability there are different methods such as those based on the limit equilibrium method , finite element method , finite difference method, etc (Farhadi & Mojezi, 2008). In this study, using Geo Studio and Polksis methods, and based on the mentioned methods, slope stability has been analyzed and the results were compared. In the non- reinforcement slope stability, reliability coefficient is approximately indicating the needs for reinforcing theslope. The results of numerical method of finite elements confirmed good agreement between displacement changes of

this method and displacement changes resulted in the instrument. The level of reliability coefficient in the limit equilibrium method is higher than the values obtained from the finite element method which could be due to the impossibility of considering the actual tension conditions of the soil mass in the limit equilibrium method. Despite the difference between reliability coefficient in the limit equilibrium method and finite element method , the difference is not only very high but also acceptable. Despite major weakness in the limit equilibrium method in real functions of tension conditions, using this method for slope stability analysis with accuracy is acceptable. In the limit equilibrium method in a certain layer, resisting and destructive forces or their torque on a trial rupturesurface are studied in order to determine the conceptual level relating to the minimum of reliability coefficient in the finite element method consisting of two common definitions used to identify safety factors including additional loading and resistance decrease (Elaheh Moghadami Kahi). In this article, the previous methods were reviewed and then based on the the case study, it can be seen that the results of the finite element method in most of the loadings are higher than that of the limit equilibrium method. According to Sharafi Safa and Delshad (2010), two main methods used to analyze slope stability are limit equilibrium and numerical methods. In the limit equilibrium method, forces affecting the environment of the study and safety factors are the basis of the study. However, the stability analysis using numerical method is based on the tension and strain on the environment with high accuracy. The results of this study show that in the stability analysis of limit equilibrium and numerical methods , the plastic zones can be created in the slope. By combining these points, the surface of circle rupture is formed which also be formed in smaller scale in stairs. The shift from numerical method represents uplift in the bottom of the stairs (0.11 meter) and wall motion of the stairs (0.04 meter) in horizontal direction. Charts from the limit equilibrium method of analysis indicated that the rupture surface involves more surface of the slope and analyzes slope stability with high safety factors which is not economically a proper design. Based on these results, it is clear that the numerical method is more accurate and more economical than limit equilibrium method to analyze the slope stability. Jamshidijam and Tofigh (2010) stated since the slope instability can cause many damages, this paper proposes a new method to find reliabilty coefficient and critical rupture surface of three-dimensional soil slopes applicable to different behavioral models and in different complicated conditions (complex geometry conditions , pore water pressure , etc.).

Table 1: Geometric characteristics of the project

The tilt angle (β, in degree)	Lateral side of the left (m)	Longitudinal side of the left (m)	Lateral side of the lower (m)	Lateral side of the right (m)	Longitudinal side of the right
30.60	40	25	120	50	40

Table 2. Soil type

specific weight of unsaturation KN/m^3	specific weight of saturation KN/m^3	Adherence (Kpa, C)	Angle of internal friction) (Φ, in degree)	soil type
17	20	100	zero	Homogeneous soil (clay)
17	20	zero	30	Heterogeneous soil (the top layer of sand)
17	20	100	zero	Heterogeneous soil (bottom layer, clay)

In the current method, the analysis of tension – strain was first done by numerical method of finite difference using Ferris software with special ability to solve Geotechnical Engineering problems with large deformations. Then, by using the data and considering the circular slip surfaces and equilibrium relationships , reliabilty coefficient and critical rupture surface are calculated. To evaluate the accuracy of this method in the static mode, a comparison is done by reducing the resistance , indicating good compliance between reliabilty coefficient and rupture surface . Agha Amini Lavasani, Hasanloo Rad, and Hasanloo (2013) investigated the impact of water flow on the rupture mechanism of soil slope by limit equilibrium and numerical methods.

Analysis and comparison of the data of numerical method

In this section, the reliability coefficients in the numerical method for the both types of the soil are studied and analyzed.

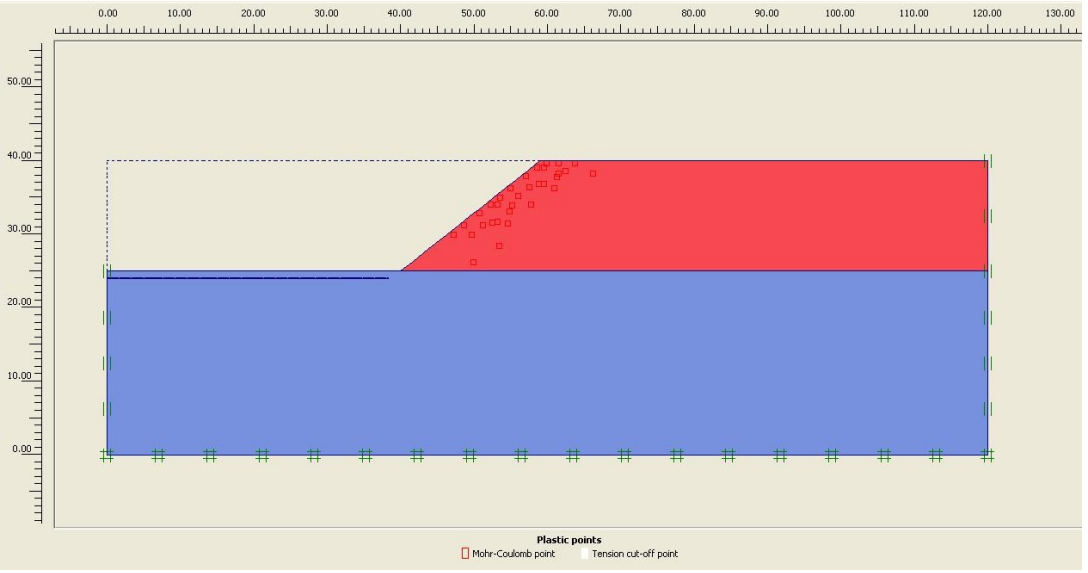

Figure 1 : Model of the tilt angle of thirty degrees in the numerical method

Figure 2 : Model of the tilt angle of sixty degrees in the numerical method

The above figures clearly reveal that blue color represents clay (lower layer) and the red color represents the sandy soil (upper layer).

Table 3: Reliability coefficent of both types of the soil in the numerical method

Reliability coefficients in the form of homogeneous soil dryness in the numerical method	Reliability coefficients in the form of heterogeneous soil dryness in the numerical method	Reliability coefficients in the form of homogeneous soil under leakage in the numerical method	Reliability coefficients in the form of heterogeneous soil under leakage in the numerical method	The water level in the right side of the Model (in meters)	The water level in the Left side of the Model (in meters)	The tilt angle (In degrees)
2.099	Collapses	2.099	Collapses	22	24	30
2.099	Collapses	2.047	Collapses	28	24	30
2.099	Collapses	1.938	Collapses	36	24	30
2.099	Collapses	2.073	Collapses	26	25	30
2.099	Collapses	1.999	Collapses	32	25	30
2.099	Collapses	1.862	Collapses	39	25	30
1.638	Collapses	1.638	Collapses	22	24	60
1.638	Collapses	1.637	Collapses	28	24	60
1.638	Collapses	1.626	Collapses	36	24	60
1.638	Collapses	1.638	Collapses	26	25	60
1.638	Collapses	1.634	Collapses	32	25	60
1.638	Collapses	1.606	Collapses	39	25	60

1. In the heterogeneous soil in the tilt angle of thirty and sixty degrees in the forms of under leakage and dryness of the numerical method, the model gets rupture.
2. In the heterogeneous soil in the tilt angle of thirty degrees, the reliability coefficient of the numerical method in the form of dryness is more than the reliability coefficient in the form of under leakage.
3. In the heterogeneous soil in the form of dryness in the tilt angle of thirty degrees in numerical method is 2.099 and in the tilt angle of sixty degrees is 1.683. Therefore the reliability coefficeint in the heterogeneous soil of numerical method in the tilt angle of thirty degrees is more than the reliability coefficeint in the tilt angle of sixty degrees.
4. The reliability coefficeint in the heterogeneous soil of numerical method in the tilt angle of thirty degrees in the form of under leakage is lessened by increasing the water level.
5. In the heterogeneous soil in the tilt angle of sixty degrees in the numerical method, the reliability coefficeint in the form of under leakage is less than the reliability coefficeint in the form of dryness.
6. The reliability coefficeint in the heterogeneous soil of numerical method in the tilt angle of sixty degrees in the form of under leakage is lessened by increasing the water level.

Analysis and comparison of the data of limit equilibrium method

In this section, the reliability coefficients in the limit equilibrium method for the both types of the soil are studied and analyzed.

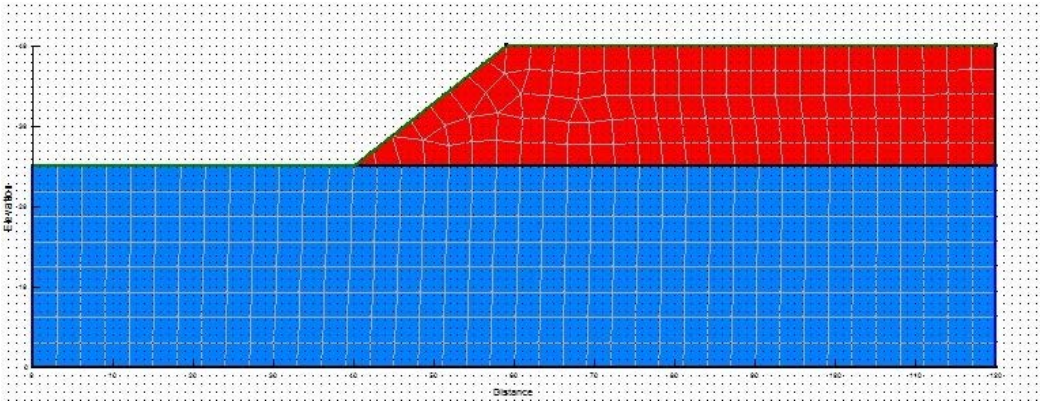

Figure 3 : Model of the tilt angle of thirty degrees in the limit equilibrium method

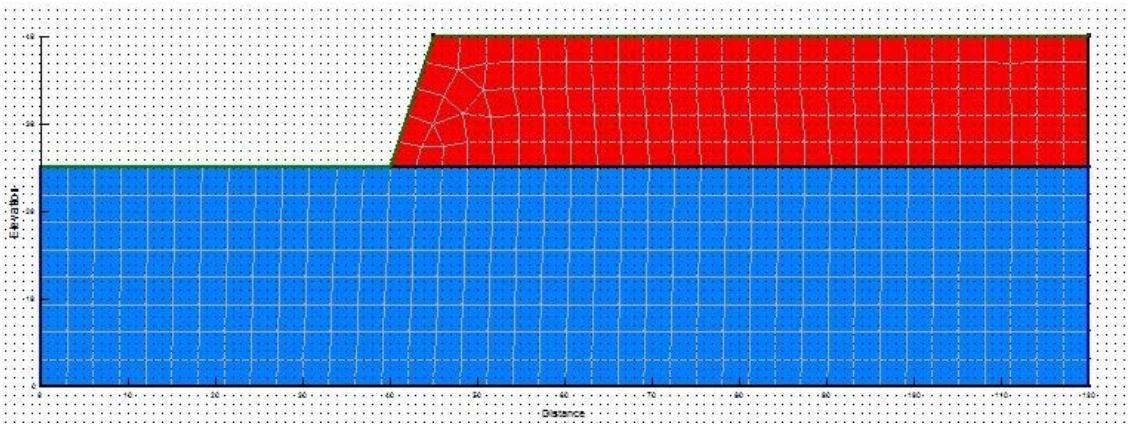

Figure 4 : Model of the tilt angle of thirty degrees in the limit equilibrium method

1. In the homogeneous soil in the tilt angle of thirty and sixty degrees in the forms of under leakage and dryness of the limit equilibrium method, the reliability coefficient is less than 1(the term “rupture” was used in the numerical method but the reliability coefficient is not offered for the rupture example) but this method offers the number to compare and strengthen the reliability coefficient.
2. In the homogeneous soil in the tilt angle of thirty degrees, the reliability coefficient of the limit equilibrium method in the form of dryness is more than the reliability coefficient in the form of under leakage.
3. In the homogeneous soil in the form of dryness in the tilt angle of thirty degrees in limit equilibrium method is 1.955 and in the tilt angle of sixty degrees is 1.631. Therefore the reliability coefficeint in the homogeneous soil of limit equilibrium method in the tilt angle of thirty degrees is more than the reliability coefficeint in the tilt angle of sixty degrees.
4. In the homogeneous soil in the form of dryness in the tilt angle of thirty degrees in limit equilibrium method in the form of under leakage is more and sometimes less than the form of dryness by increasing the water level (Because of the ability and inability to pass the flow line through the rupture).
5. In the tilt angle of thirty degrees in limit equilibrium method, the reliability coefficient in the two forms are less than heterogeneous soil due to the presence of sand in the upper layers and water in this layer and also hitting the flow line to the slope.

6. In the tilt angle of thirty degrees in limit equilibrium method, the reliability coefficient in the two forms are less than heterogeneous soil due to the presence of sand in the upper layers of the structures and water in this layer and also hitting the flow line to the slope.
7. In the tilt angle of sixty degrees in limit equilibrium method the reliability coefficient in the form of dryness is more than the reliability coefficient in the form of under leakage while it is less in heterogeneous soil.
8. The reason for number 7 is that sand in the heterogeneous soil in limit equilibrium method decreases the reliability coefficient and clay in the homogeneous soil increases the reliability coefficient.

Table 4: Reliability coefficent of both types of the soil in the limit equilibrium method

Reliability coefficients in the form of homogeneous soil dryness in the limit equilibrium method	Reliability coefficients in the form of heterogeneous soil dryness in the limit equilibrium method	Reliability coefficients in the form of homogeneous soil under leakage in the limit equilibrium method	Reliability coefficients in the form of heterogeneous soil under leakage in the limit equilibrium method	The water level in the right side of the Model (in meters)	The water level in the Left side of the Model (in meters)	The tilt angle (In degrees)
1.955	0.735	1.955	0.735	22	24	30
1.955	0.735	1.955	0.735	28	24	30
1.955	0.735	2.215	0.558	36	24	30
1.955	0.735	1.972	0.729	26	25	30
1.955	0.735	2.163	0.593	32	25	30
1.955	0.735	2.355	0.553	39	25	30
1.631	0.205	1.631	0.205	22	24	60
1.631	0.205	1.657	0.19	28	24	60
1.631	0.205	1.867	0.139	36	24	60
1.631	0.205	1.636	0.205	26	25	60
1.631	0.205	1.761	0.164	32	25	60
1.631	0.205	2	0.169	39	25	60

9. In the tilt angle of sixty degrees in the heterogeneous soil in limit equilibrium method the reliability coefficient in the form of under leakage is added or some times lessened by increasing the water level and in general the reliability coefficient is under 1.
10. In the tilt angle of sixty degrees in the heterogeneous soil in limit equilibrium method the reliability coefficient in the form of under leakage is added by increasing the water level due to water in clay.

Analysis and comparison of the data of limit equilibrium and numerical methods

In this section the reliability coefficients in the limit equilibrium and numerical methods for the both types of the soil are studied and analyzed by diagrams.

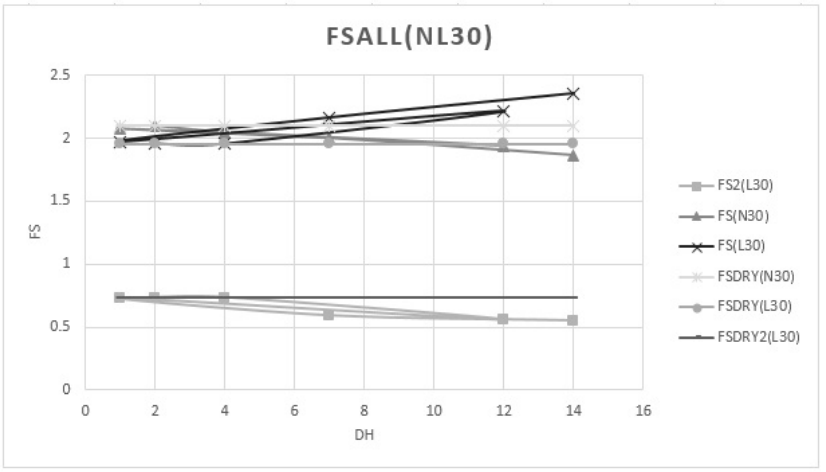

Figure 5: Changing process of reliability coefficients in all forms with the tilt angle of thirty degrees in the both methods

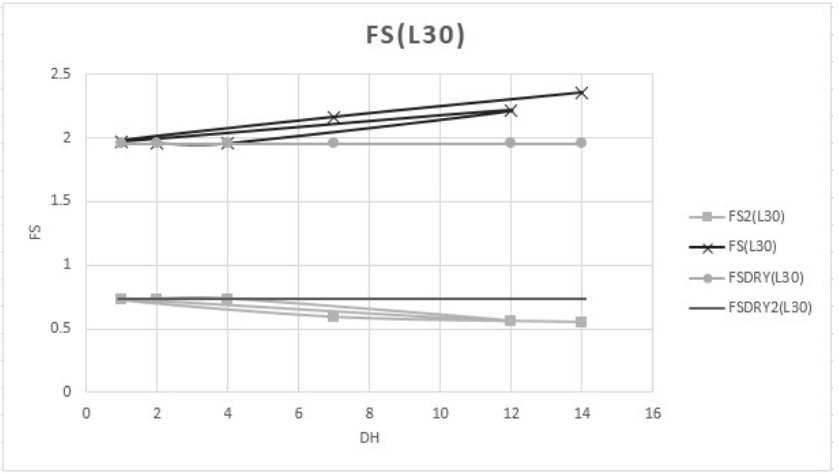

Figure 6: Changing process of reliability coefficients in all forms with the tilt angle of thirty degrees in limit equilibrium method

The horizontal axis of the diagram includes the difference in water levels on both sides of the model in meter, while the vertical axis includes the reliability coefficient.

In figure 1 and 2:

FS(N30) = the reliability coefficient in the homogeneous soil of numerical method in the tilt angle of thirty degrees and in the form of under leakage;

FSDRY(N30) = the reliability coefficient in the homogeneous soil of numerical method in the tilt angle of thirty degrees and in the form of dryness;

FS(L30) = the reliability coefficient in the homogeneous soil of limit equilibrium method in the tilt angle of thirty degrees and in the form of under leakage;

FSDRY (L30) = the reliability coefficient in the homogeneous soil of limit equilibrium method in the tilt angle of thirty degrees and in the form of dryness;

FS2(L30) = the reliability coefficient in the heterogeneous soil of limit equilibrium method in the tilt angle of thirty degrees and in the form of under leakage;

FSDRY2(L30) = the reliability coefficient in the heterogeneous soil of limit equilibrium method in the tilt angle of thirty degrees and in the form of dryness;

FSALL(NL30) = the reliability coefficient in the two types of the soil of limit equilibrium and umerical methods in the tilt angle of thirty degrees and in the two forms.

1. The reliability coefficient in the heterogeneous soil of numerical method in the tilt angle of thirty degrees and in the forms of under leakage and dryness get rupture due to the way to calculate reliability coefficient (The model is divided into nodes and its extension).
2. The reliability coefficient of numerical method is not less than 1, so this method does not offer numbers for rupture models, while in the limit equilibrium, the reliability coefficient is offered to compare and strengthen the previous form.
3. Homogeneous soil in the numerical method in the tilt angle of thirty degrees gets dried by increasing the water level of the reliability coefficient line in the form of under leakage due to the flow line hitting to the bottom of the slope lower than the reliability coefficient line in the form of dryness.
4. Homogeneous soil in the numerical method in the tilt angle of thirty degrees gets dried by increasing the water level of the reliability coefficient line some times higher or lower than the reliability coefficient line in the form of dryness. This is due to the ability and inability to pass the flow line through the wedge rupture and the flow line hitting to the bottom of the slope.
5. Heterogeneous soil in the limit equilibrium method in the tilt angle of thirty degrees are less than 1 in the two forms by increasing the water level of the reliability coefficient line in the form of under leakage due to the flow line hitting to the bottom of the slope and its presense in the sand lower than the reliability coefficient line in the form of dryness.
6. In the numerical method and in the homogeneous soil with tilt angle of thirty degrees, the reliability coefficient line in the form of dryness is more than the reliability coefficient line in the same form in the limit equilibrium method.
7. In the numerical method and in the homogeneous soil with tilt angle of thirty degrees, the reliability coefficient line in the form of under leakage except in two forms in which the water level on the left of the model is 24 meters and the water level on the right of the model is 36 meters and on the left of the model is 25 meters and the water level on the right of the model is 39 meters, is more than the reliability coefficient line in the same form in the limit equilibrium method.
8. The reason for number 7 is the calculation way of the the reliability coefficient in the limit equilibrium method which is to create several circles in the model and to choose a wedge with the lowest reliability coefficient as a possible wedge rupture.

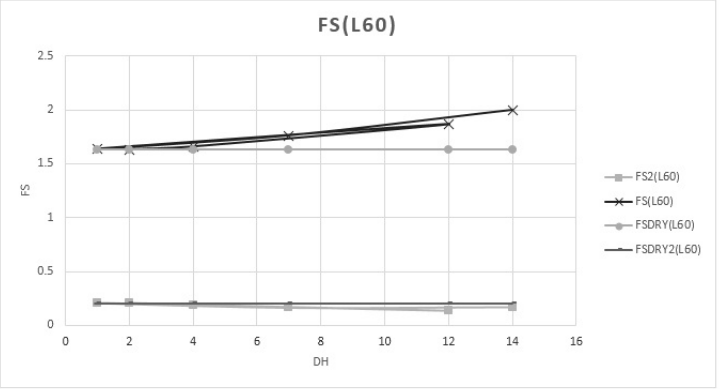

Figure 7: Changing process of reliability coefficients in all states with the tilt angle of sixty degrees in limit equilibrium method

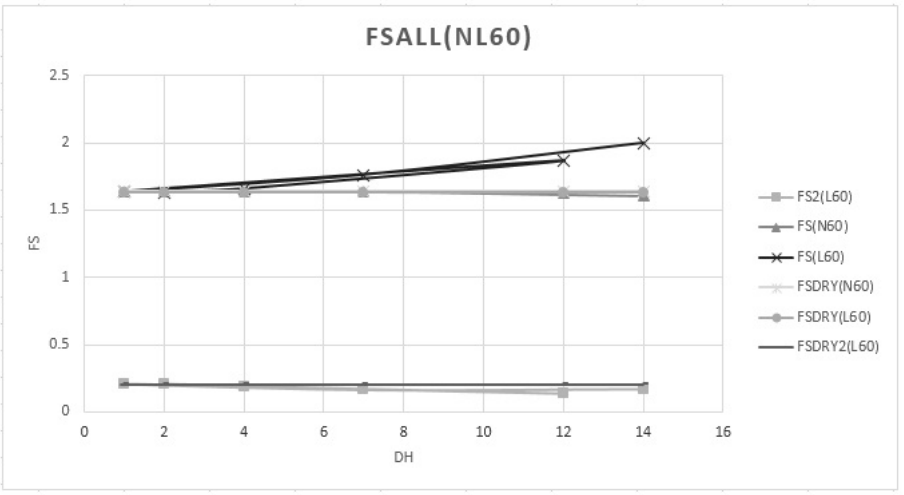

Figure 8: Changing process of reliability coefficients in all states with the tilt angle of sixty degrees in the both methods

In figure 7 and 8:

FS(N60) = the reliability coefficient in the homogeneous soil of numerical method in the tilt angle of sixty degrees and in the form of under leakage;

FSDRY(N60) = the reliability coefficient in the homogeneous soil of numerical method in the tilt angle of sixty degrees and in the form of dryness;

FS(L60) = the reliability coefficient in the homogeneous soil of limit equilibrium method in the tilt angle of sixty degrees and in the form of under leakage;

FSDRY (L60) = the reliability coefficient in the homogeneous soil of limit equilibrium method in the tilt angle of sixty degrees and in the form of dryness;

FS2(L60) = the reliability coefficient in the heterogeneous soil of limit equilibrium method in the tilt angle of sixty degrees and in the form of under leakage;

FSDRY2(L60) = the reliability coefficient in the heterogeneous soil of limit equilibrium method in the tilt angle of sixty degrees and in the form of dryness;

FSALL(NL60) = the reliability coefficient in the two types of the soil of limit equilibrium and umerical methods in the tilt angle of sixty degrees and in the two forms.

1. The reliability coefficient in the heterogeneous soil of numerical method in the tilt angle of sixty degrees and in the forms of under leakage and dryness get rupture due to the way to calculate reliability coefficient (The model is divided into nodes and its extension).
2. The reliability coefficient of numerical method is not less than 1, so this method does not offer numbers for rupture models, while in the limit equilibrium method, the reliability coefficient is offered to compare and strengthen the previous form.
3. Homogeneous soil in the numerical method in the tilt angle of sixty degrees gets dried by increasing the water level of the reliability coefficient line in the form of under leakage due to the flow line hitting to the bottom of the slope lower than the reliability coefficient line in the form of dryness.
4. Homogeneous soil in the limit equilibrium method in the tilt angle of sixty degrees gets dried by increasing the water level of the reliability coefficient line some times higher or lower than the reliability coefficient line in the form of dryness. This is due to the ability and inability to pass the flow line through the wedge rupture and the flow line hitting to the bottom of the slope.

5. Heterogeneous soil in the limit equilibrium method in the tilt angle of sixty degrees are less than 1 in the two forms by increasing the water level of the reliability coefficient line in the form of under leakage due to the flow line hitting to the bottom of the slope and its presense in the sand lower than the reliability coefficient line in the form of dryness.
6. In the numerical method and in the homogeneous soil with tilt angle of sixty degrees, the reliability coefficient line in the form of dryness is more than the reliability coefficient line in the same form in the limit equilibrium method.
7. In the numerical method and in the homogeneous soil with tilt angle of sixty degrees, the reliability coefficient line in the form of under leakage except in two forms in which the water level on the left of the model is 24 meters and the water level on the right of the model is 22 meters and on the left of the model is 25 meters and the water level on the right of the model is 26 meters, is less than the reliability coefficient line in the same form in the limit equilibrium method.
8. The reason for number 7 is the calculation way of the the reliability coefficient in the two methods and the tilt angle of the bottom of the slope.

Conclusion

- In the homogeneous soil with tilt angle of sixty degrees, the reliability coefficient line in the form of under leakage is less than the reliability coefficient line in the same form in the limit equilibrium method in the tilt angle of thirty degrees.
- The reliability coefficient in the heterogeneous soil of numerical method in the tilt angle of thirty and sixty degrees and in the forms of under leakage and dryness get rupture due to the way to calculate reliability coefficient (The model is divided into nodes and its extension).
- The reliability coefficient of numerical method is not less than 1, so this method does not offer numbers for rupture models, while in the limit equilibrium method, the reliability coefficient is offered to compare and strengthen the previous form.
- Homogeneous soil in the numerical method in the tilt angle of thirty and sixty degrees gets dried by increasing the water level of the reliability coefficient line in the form of under leakage due to the flow line hitting to the bottom of the slope lower than the reliability coefficient line in the form of dryness.
- Heterogeneous soil in the limit equilibrium method in the tilt angle of thirty and sixty degrees are less than 1 in the two forms by increasing the water level of the reliability coefficient line in the form of under leakage due to the flow line hitting to the bottom of the slope and its presense in the sand lower than the reliability coefficient line in the form of dryness.
- In the numerical method and in the homogeneous soil with tilt angle of thirty and sixty degrees, the reliability coefficient line in the form of dryness is more than the reliability coefficient line in the same form in the limit equilibrium method.
- The reliability coefficient in the homogeneous soil with tilt angle of sixty degrees in the numerical method in the form of under leakage is leessened by increasing the water level and in the limit equilibrium is added.
- In the tilt angle of sixty degrees in the heterogeneous soil in limit equilibrium method, the reliability coefficient in the form of under leakage is added or some times lessened by increasing the water level and in general the reliability coefficient is under 1.
- In the homogeneous soil in the tilt angle of thirty degrees in the numerical method, the reliability coefficeint in the form of dryness is more than the reliability coefficeint in the

form of under leakage and in limit equilibrium method, it is sometimes more and sometimes less than in the form of dryness.

- The reliability coefficeint in the two forms and the two methods in the tilt angle of thirty degrees is more than in the tilt angle of sixty degrees.
- There are rupture mechanism in the two methods and local rupture in the numerical method.

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