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Numerical Analysis for Tectonic Activity and Landslide Stability Evaluation in Baneh, Kurdistan, Iran

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ABSTRACT

Landslides are present on all continents playing important role in the continual evolution of this type of similar geohazard. They constitute a serious hazard in many areas of the world. Most of Iran's land is covered by mountainous areas. One of The dangers that always threaten these areas is the instabilities of the slopes. The occurrence of this phenomenon causes a lot of damage to the cultivated lands every year Human enters. Among these, one of the most dangerous domain instabilities Landslide is phenomenon. Kurdistan province and within the study area (Bane city) as a part of the province, is one of the areas that due to the conditions geological, topographical, and climatic specifics along with the human factor, in some places, is prone to landslides. The most important of these landslides can be found in Gardaneh Khan, Savan, Sabdlo, and Dar. Finally, an ALUT is pointed out as an indicator. Therefore, identifying the process of landslides is necessary to identify, investigate and determine the causes of landslides at the level of the regions of the country it arrives in this study, the paper also discussed the manifestation, causes, and effect of landslides. For geotechnical analysis, samples were collected from the landslide site and subjected to the following tests: natural soil moisture content, specific gravity, relative density, shear strength, and compaction permeability. Adjacent slopes of still intact slides were also analyzed using Plaxis 2D to determine their safety factor. Both the geotechnical laboratory results and the Plaxis 2D results show that without the improvement of the infinite slope condition using the method recommended in this paper, another landslide will inevitably occur. Several of the methods recommended include cutting back of slope to reduce its gradient, reinforcements, soil nailing as well as anchors and retaining structures.

1. Introduction

A landslide can be defined as the movement of rocks, detritus, or soil caused by the action of gravity (Pourghasemi et al., 2018). It also includes the rapid movement of rock mass, residual soil, or sediment close to the slope (Zhao and Lu, 2019; Lee, 2019). Landslides are classified according to the type of movement (topples, slumps, subside, flow, slides, falls), material mixture (silt, rock, loose sediment), and speed (slow, medium, fast). Landslides are major categories of natural disasters that can lead to huge casualties and economic losses in the affected areas (Azarafza et al., 2018). For a better understanding of the issue, we can refer to the landslide in Yungayperu, which buried several villages and killed about 25,000

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people, as well as the landslide in Rosenberg, Switzerland, in the year 1806 killed more than 475 people (Shariat Jafari, 1996). The reason, it is important in geotechnical practice to analyze the stability of the slope. Gravity would tend to flatten out slopes. However, stability conditions may change due to time adjustments of the equilibrium position or external disturbances. Water is one of the effective factors for instability. It reduces the soil's internal cohesion, increases the weight of the slope, and the pore water and the driving force (Pradhan and Kim, 2015; Davis and Blesius, 2015).

A high seepage rate may lead to instability. Landslides may be triggered by heavy storms, earthquakes, volcanic eruptions, geological factors, climatic change, erosion by glaciers or rivers, and human activities (Azarafza et al., 2021; Nanehkaran et al., 2021). Climate change affects the stability of slopes, especially infinite slopes. However, it is less clear the extent, magnitude, and direction of the impact of the climatic changes on slopes (Rabonza et al., 2016; Reichenbach et al., 2018). The most important cause of landslide can be linked to geology, failure generally occurs on weak planes in rock, including stratification, foliation, joints, or faults, and poorly lithified rocks and non-lithified sediments are more susceptible to failure than lithified materials. Water also permeates joints, fractures, and permeable strata elevating pore pressures to the threshold of collapse. In the presence of human activities, erecting structures on top of unstable slopes or excavating their foundations may lead to landslides as it increases the driving force of the slopes (Lazzari and Gioia, 2016; Batar and Watanabe, 2021). The use of landslide prediction models has increased recently, as almost complete landslide analysis requires reliable landslide hazard maps with strong temporal predictability, and many models have been used for landslide hazard analysis and prediction (Yong et al., 2022). The major factor that controls the prediction capabilities of the model predictions is the detailed geotechnical properties of the constituent soil and rock. Understanding the spatial distribution of geotechnical and geological input parameters facilitates the application of the model on a large scale (Wang et al., 2021; Lin et al., 2021). That is why the geotechnical analysis of the ALUT (bane city) landslide is needed since it is a prerequisite to the landslide prediction models and instrumentations.

2. Material and Methods

2.1. Studied Case

Kurdistan province with an area of 28235 km^2 covers about 1.7% of the whole country. This province is located in the west of Iran and adjacent to Iraq between 34°44" N to 36°30"N and 45°31"E to 48°16"E. The area of forests in the province is estimated to be 242,158 hectares, which is mostly concentrated in Baneh and Marivan cities and to some extent in Kamiyaran and Sanandaj cities. Meanwhile, Baneh city is one of its cities, which is located in its northwestern part. Its geographical range corresponds to the geographical latitude of 35 degrees and 8 minutes to 36 degrees and 23 minutes of north latitude and the geographical longitude of 45 degrees and 55 minutes to 46 degrees and 19 minutes of east longitude. The area of Baneh city is over 1450 square kilometers and its population is 116,733 people according to the latest results of the country's census. In the meantime, landslides in the northwestern part of the province, including Baneh city, have been investigated.

In the Baneh region, in terms of weather conditions (rainfall, humidity, and temperature changes) and lithological diversity and resulting weathering and the upper slopes covered with deposits and their instability and proximity to the Piranshahr fault, as a system and about each other which have become the basis for raising its sliding potential. In general, among the most important landslides in Bane, we can mention the Gardaneh Khan Pass in the communication axis of Bane-Saqez, Kokhan in the direction of Bane-Sardasht, and the landslides in the villages of Savan, Sabadlu in the vicinity of Bane, Siyuch and Soto and ALUT as part of Rukh landslides. Given in the last few years pointed out. Meanwhile, the landslide in ALUT village is the most important in the city and region that has occurred in the past few years, and on this basis, it has been emphasized as an indicator of the process vision.

ALUT landslide happened in March of 1366 in the village of ALUT, which is located in the west of Baneh city and on the border of Iran and Iraq. The studied area is also located exactly on the border line of the two Kurdistan-West Azerbaijan provinces (bane-Sardasht) and the upstream side of the Zab Saghir River. The villages of Gole Sepi and Morgan, which are located within the boundaries of Sardasht city, are located in front of the studied village (ALUT) and the village with a continuous history of Ziveh (affected by the same landslide) is also downstream of these two villages and on the edge of Zab river within the city limits. Sardasht was located. Its movement was slow and intermittent for about two days and nights, and in the end, a large part of the lands, especially the existing gardens, and some of the residential houses in the lower and southern part of ALUT village were moved. The importance of investigating this landslide is due to its broad and slow flow and consequently its geomorphic effects, after several years, its effects are still found, and on the other hand, it has been investigated and identified less.

2.2. Physical characteristics of the ALUT landslide

The lower limit of ALUT village is limited from the south by the fine-grained deposits of the alluvial fan formed in the fault valley in the northeastern part of the village. After heavy rains on the 8th and 9th of April 2016, with the infiltration of rainwater and the rapid saturation of the sliding mass, the increased pore pressure and its weight increase activated a part of the old landslide, and a new landslide formed.

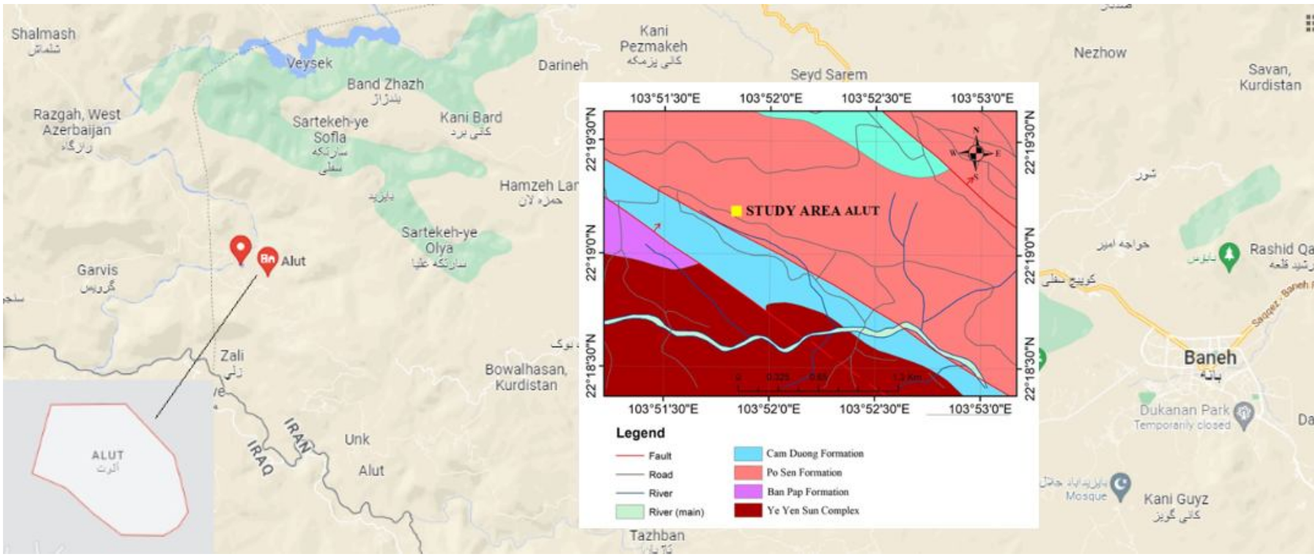

Figure 1. Location and geological map ALUT landslide in Baneh, Iran

Figure 2. A view of tension cracks on the ALUT landslide

The creation of vertical and horizontal movement and tensile cracks on the upstream slope on the one hand, and the displacement of the village land in the middle part and the landslide on the other hand, which caused damage to village houses, are signs of this incident. The damages caused to the buildings of the village often include cracks in the roofs, floors, and walls of the buildings, collapsing of the slope of the roofs, broken glass and raised floors, as well as water leakage from the floors of some houses and the release of a large amount of water from the drains. And it has been the wall of many buildings that have been revealed after the rain and has expanded over time. By controlling and collecting the runoff caused by the rain and controlling the underground water, the recurrence of the landslide can be largely prevented or its severity reduced which was analyzed for stability using Plaxis 8.6.

3. Results and Discussions

3.1. Geotechnical Test Results

Samples were collected from 10 different points around the slope and subjected to the following tests: natural moisture, specific gravity, relative density, Altberg limit, sieve analysis, density, permeability, shear strength, and specific gravity as shown in Table 1.

Table 1. Results of the technical test

Parameter	Unit	Value
Moisture content	%	10.7 – 14.4
Specific gravity	%	3.0 – 3.06
Relative density	%	30.0 – 39.6
Liquid limit	%	38.4 – 42
Plastic limit	%	24 – 30
Plasticity index	%	12 – 15.6
Passing (#200)	%	57.6 – 62.4
Compaction	kg/m^3	2520 – 2556
OMC	%	15.12 – 16.08
Permeability	cm/s	1.2×10^{-4}
Cohesion	kN/m^2	4.8 – 12
Internal friction	Degree	20.4 – 21.6
Unit weight	kN/m^3	19.2 – 22.8

Table 2. Typical values of specific gravity

Type of Soil	Unit	Specific Gravity
Sand	-	2.61 – 2.65
Silty sand	-	2.65 – 2.68
Inorganic clay	-	2.68 – 2.75
Soil with mica-iron	-	2.75 – 3.00
Organic soil	-	1.00 – 2.55

Table 3. Characteristics of soils based on relative density and porosity

Description	Relative Density (%)	Porosity (%)
Very loose	0 – 20	80 – 100
Loose	20 – 40	60 – 80
Medium dense	40 – 70	30 – 60
Dense	70 – 85	15 – 30
Very dense	85 - 100	<45

Specific gravity is the ratio of the mass of soil solids to the mass of an equal volume of water content. Typical values of specific gravity are given in Table 2. According to the results, an increase in specific gravity can increase the shear strength. The specific gravity obtained indicates that the soil contain same of inorganic soil encouraging instability in the soil. Relative density is an index that quantifies the degree of packing between the loosest and density possible state of coarse-grained soils. The description of soil based on relative density and porosity is given in Table3. The values of 76% and 34% obtain for the relative density and porosity respectively point to the fact that the soil is loose and prone to collapse on little agitation or external forces.

Consistency limits of plastic soil are significantly affected by soil moisture content. The gradual increase in humidity causes the soil to change from liquid to plastic, from plastic to semi-solid, and finally to solid. The water content at which the soil changes from a semi-solid to a plastic state is called the plastic limit (PL), while the water content at which the soil changes from a plastic state to a liquid state is called the liquid limit (LL) which known as the Plasticity Index (PI):

$$PI = LL - PL \tag{1}$$

The values of liquid limits, plastic limits, and plasticity indices obtain show that the soil mass is predominantly silt. This means that the soil lacks sufficient plasticity to ensure shear strength and stability. Soil compaction is the compaction of soil by using mechanical means to release air. Soil compaction increases the shear strength per unit weight and the carrying capacity of the soil. It reduces porosity, permeability, and settlements. Typical values for optimum moisture content (OMC) and maximum dry density (MDD) are shown in Table 5. Although, compaction results are used mostly in highway analysis, the results of MDD and OMC indicate that compaction can give the soils of the slope the needed stability.

Permeability is the ease with which water flows in porous soils is called permeability. Soil engineers are interested in the speed of water flow in the soil because in their work they sometimes use soils that inhibit water flow and sometimes they must use soils that promote water flow. Soil permeability has a decisive influence on the stability of geotechnical structures, especially slopes. According to tests, soil less than 10^{-6} m/s is permeable soil, the soil between 10^{-6} to 10^{-4} cm/s is semi-permeable, and soil greater than 10^{-4} cm is in second's rank. The obtained value of 1.2×10^{-4} cm/s is slightly higher than that determined as a half pass. Slope soil can be classified as intrusive soil, but enough to encourage instability, especially during prolonged periods of precipitation.

The shear strength of a soil is its maximum span resistance to an applied shear force. This is the highest stress the soil can withstand before it fails. The shear strength parameters of soil are cohesion and friction angle. The ability of soil to withstand structural loads to maintain slopes depends on its shear strength. Soil shear resistance is very important in the design of foundations, dams, roads, and lateral earth pressure problems, especially the stability of slopes and cuttings. According to results, the friction angle of sand is higher compared to its adhesion, while the opposite is true for clay. Internal friction angle from 14 to 18 degree and cohesion 4 $kN/m^2$to 10 kN/m^2 means the soil is mainly silt. The shear strength results not only show that the soil is permeable but also has low shear strength and is prone to instability. This instability is exacerbated if the pore water becomes saturated and the pressure increases.

Table 4. Atterberg limits for soils

Soil Type	LL (%)	PL (%)	PI (%)
Sand	-	-	-
Silt	30 – 40	20 – 25	10 - 15
Clay	40 - 150	25 - 50	15 – 100

Table 5. Typical values of soil standard proctor compaction

Material	MDD (kg/m^3)	OMC (%)
Clayey soil	1555	28
Silty soil	1670	21
Sandy clay	1840	14
Sand	1940	11
Gravel, sand & clay	2070	9

Table 6. Strength properties of the slope

Properties	Unit	Slope A	Slope B
Slope consolidation line	-	0.09	0.1
Slope swelling line	-	0.012	0.013
Slope critical state line	-	0.57	0.54
Dry unit weight	kN/m^2	16.1	16.1
Saturated unit weight	kN/m^2	20.14	20.14
Internal friction	Degree	19	18
Cohesion	kN/m^2	4.24	10.6
Dilactancy	Degree	47.7	54
Void ratio	-	0.9	0.79

Plaxis 2D was used for numerical analysis in this study. Modified Clay Model (CCM) is a critical state-based soil model used to assess the capacity of slopes. This soil model explains the behavior of the subsoil as strength, dilatancy, and criticality. The Slope boundary condition enables full fixation to apply to the vertical axis and bottom of the model, but the top or slope of the model is not constrained. The permeable zone is the area where the applied stress on the slope is negligible until the size of the model domain is determined. The engineering properties used for the analysis are shown in Table 4. As shown in Figs. 3 and 2, the analysis using Plaxis 2D version 8.6 shows that the safety factors for slopes A and B are 0.7 and 0.9, respectively, well below the recommended value of 1.5. The obtained safety factor results are not surprising since their resistance properties, especially adhesion, are between 4 and 10 kN/m^2. Another effective factor is that their inclination angles (47.7 and 54 degree) are greater than their internal friction angles (19 and 18 degree).

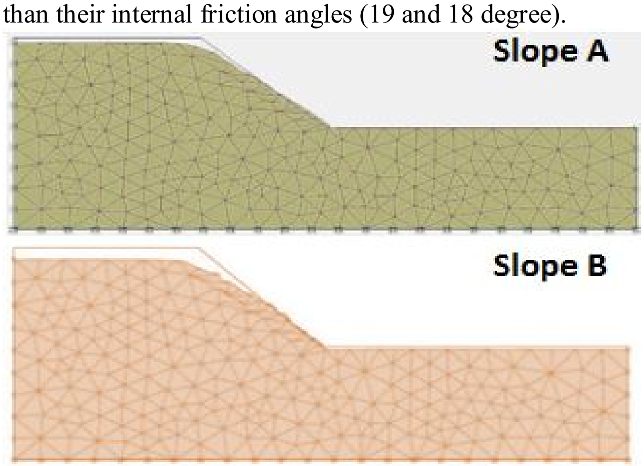

Figure 3. Slope A and B deformation meshes

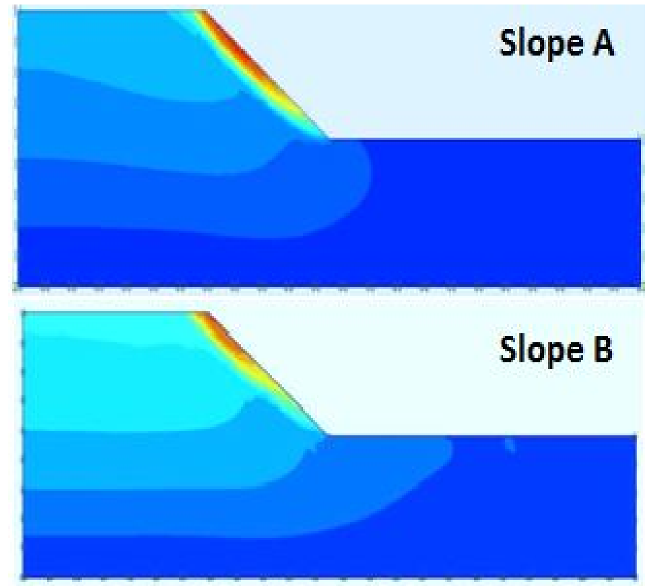

Figure 4. Slope A and B displacement esimations

4. Conclusion

Evidence and research indicate that the province of Kurdistan and the city of Bane, due to their geographical location and natural parameters such as topography and morphology, are mainly mountainous and young structures and faults in the region, including Zagros and Piranshahr, and High rainfall and various formations with varying permeability and porosity have a high potential for landslides, a typical example being the ALUT landslide. Therefore, site identification, including landslide risk, should be prioritized in all construction activities and mapping in the city, especially in the construction of civil structures such as dams and cities in the province.

Typically, in most of the construction work done in Iran, miners have been unsuccessful in restoring the land or replanting the area. These activities led to the formation of aquifers in the area, which eventually led to landslides. Vegetation is applied to slopes up to 55 degrees. For steep slopes, a hard surface such as shotcrete should be used for stabilization. However, appropriate landscaping measures, such as masonry fencing and grate holes in slopes for planting, should be taken to promote aesthetics.

The slope should be reduced so that, where possible, the angle of inclination is at least less than or close to the angle of internal friction. During this process, existing vegetation, especially trees and shrubs, should be protected as much as possible. Slope stabilization works such as slope reduction to reduce slope, reinforcement (using reinforced concrete), soil nailing, and anchoring and retaining structures are highly recommended. The beam should be placed below the toe of the slope to resist movement due to possible foundation failure. Strengthened drainage systems are also necessary to reduce seepage forces and instabilities caused by pore water pressure.

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References

Azarafza M., Azarafza M., Akgün H., Atkinson P.M., Derakhshani R., 2021. Deep learning-based landslide susceptibility mapping. *Scientific Reports*, 11(1): 1-16.

Azarafza M., Ghazifard A., Akgün H., Asghari-Kaljahi E., 2018. Landslide susceptibility assessment of South Pars Special Zone, southwest Iran. *Environmental Earth Sciences*, 77(24): 805.

Batar A.K., Watanabe T., 2021. Landslide susceptibility mapping and assessment using geospatial platforms and weights of evidence (WoE) method in the Indian Himalayan region: Recent developments, gaps, and future directions. *ISPRS International Journal of Geo-Information*, 10(3): 114.

Davis J., Blesius L., 2015. A hybrid physical and maximum-entropy landslide susceptibility model. *Entropy*, 17(6): 4271-4292.

Lazzari M., Gioia D., 2016. Regional-scale landslide inventory, central-western sector of the Basilicata region (Southern Apennines, Italy). *Journal of Maps*, 12(5): 852-859.

Lee S., 2019. Current and Future Status of GIS-based Landslide Susceptibility Mapping: A Literature Review. *Korean Journal of Remote Sensing*, 35(1): 179-193.

Lin Q., Lima P., Steger S., Glade T., Jiang T., Zhang J., Wang Y., 2021. National-scale data-driven rainfall induced landslide susceptibility mapping for China by accounting for incomplete landslide data. *Geoscience Frontiers*, 12(6): 101248.

Nanehkaran Y.A., Mao Y., Azarafza M., Kockar M.K., Zhu H.H., 2021. Fuzzy-based multiple decision method for landslide susceptibility and hazard assessment: A case study of Tabriz, Iran. *Geomechanics and Engineering*, 24(5): 407-418.

Pourghasemi H.R. Teimoori Yansari Z., Panagos P., Pradhan B., 2018. Analysis and evaluation of landslide susceptibility: a review on articles published during 2005–2016 (periods of 2005–2012 and 2013–2016). *Arabian Journal of Geosciences*, 11(9): 193.

Pradhan A.M.S., Kim Y.T., 2015. Application and comparison of shallow landslide susceptibility models in weathered granite soil under extreme rainfall events. *Environmental Earth Sciences*, 73(9): 5761-5771.

Rabonza M.L., Felix R.P., Lagmay A.M.F.A., Eco R.N.C., Ortiz I.J.G., Aquino D.T., 2016. Shallow landslide susceptibility mapping using high-resolution topography for areas devastated by super typhoon Haiyan. *Landslides*, 13(1): 201-210.

Reichenbach P., Rossi M., Malamud B.D., Mihir M., Guzzetti F., 2018. A review of statistically-based landslide susceptibility models. *Earth-Science Reviews*, 180: 60-91.

Shariat Jafari M., 1996. *Landslide, Basics, and Principles of Stability of Slopes Natural*. Sazeh Publications, Tehran, Iran. [In Persian]

Wang H., Zhang L., Luo H., He J., Cheung R.W.M., 2021. AI-powered landslide susceptibility assessment in Hong Kong. *Engineering Geology*, 288: 106103.

Yong C., Jinlong D., Fei G., Bin T., Tao Z., Hao F., Qinghua Z., 2022. Review of landslide susceptibility assessment based on knowledge mapping. *Stochastic Environmental Research and Risk Assessment*, 2022: 1-19.

Zhao C., Lu Z., 2018. Remote sensing of landslides-A review. *Remote Sensing*, 10(2): 8-13.