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STABILITY ANALYSIS OF FINE SOILS FROM A ROAD PROJECT, M32 SAMARA - SHYMKENT (RUSSIA - KAZAKHSTAN)

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ABSTRACT: Generally, the soil is considered to be a material strong in compression but weak in tension, while the stability of fine soils is an essential prerequisite to ensure the safe operation of road transport. The stability of soils analysis is routinely performed by engineers to evaluate the stability of embankment dams, road embankments, river training works, excavations, and retaining walls. In frozen regions of Russia and Kazakhstan, roads may promote shallow landsliding, gully formation, or headward channel migration through interception of subsurface flow along with the road cut and concentration of flow on particular areas below the road, while shallow landslide hazards in soil slopes usually happen, which pose a serious threat to road safety operations. The research goal of this paper is to conduct field observations and numerical simulation tests and stability analysis to investigate the soil strength and stability of the geotechnical engineering system. The research object of this paper is the road engineering M32: Samara - Shymkent (Russia - Kazakhstan). The results show that under the same simulation conditions and an increase in surface roughness and inhomogeneity of soil particles, the dynamic stability of the slope increases. This article presents the basic engineering properties with an emphasis on design strength parameters of soil together with the stability analysis results considering the unsaturated condition.

Keywords: Road engineering; Soil stability; M32 Samara - Shymkent

1. INTRODUCTION

Accurate evaluation of the deformation and stability of soil structures is the main objective of many geotechnical analyses. Slope stability analysis is a branch of geotechnical engineering that is highly amenable to treatment, and it has received considerable attention in the literature. The earliest papers appeared in the 1970s - e.g., [1-4] and have continued steadily - e.g., [5-16]. El-Ramly et al. [17] produced a useful review of the literature on this topic and noted that the geotechnical profession was slow to adopt approaches to geotechnical design, especially for traditional problems such as slopes and foundations. Chowdhury and Tang [6] indicated that when subjected to monotonic shearing in a drained condition, different soils might exhibit distinctly different patterns of stress-strain behavior. In dense granular soils and highly over consolidated cohesive soils, the stress-strain response is generally associated with the emergence of peak shear strength at the relatively low shear strain. This peak strength is generally followed by a critical-state strength as the soil is sheared further. The ductile response is typical of loose granular soils and normally consolidated cohesive soils whose critical-state strength is only reached at high strain levels. Lacasse [10], Christian [11], and Lacasse and Nadim [12] showed that the volume change of the soil is a major factor contributing to its shear resistance and that dilatancy, which is the change of soil volume on shear loading, is the main reason for the emergence of the peak strength in dense sands and over consolidated clays. The peak and critical state strengths of soil are generally expressed in terms of the peak and critical state angle of friction.

The soil type in steppe forested regions of Samara - Shymkent is almost silty clay, and the permeable performance of soil is poor [18,19]. While freezing and thawing cycling, the capillary water migration takes place inside the soil slope [20]. Then it makes soil strength conditions further deteriorate. However, the national common method of evaluation criteria for soil slope stability is followed in the region. At the same time, the specific climatic conditions affecting the internal shear strength deterioration of soil stability are not considered. As a result, the representative regional slope stability criteria are deficient. Soil shear strength is the direct parameters to determine the slope stability, so consider the inner soil shear strength as the evaluation index of the slope. Considering the actual conditions of the shear strength deterioration between frozen soil and thawed soil under freezing and thawing cycles, it is necessary to study the evaluation methods of soil stability based on the special way and then establish the evaluating formulation of stability. The research goal of this paper is to conduct field observations and numerical simulations to investigate the soil strength and slope stability of the geotechnical engineering system. The research object of this paper is the road engineering "M32: Samara - Shymkent" (Russia – Kazakhstan). The results could present the basis for the analysis. Besides, it could present data that refers to the stability evaluation and numerical analysis of the seasonal frozen regions.

2. RESEARCH METHOD

Over the year various analysis tools and techniques like empirical, analytical, statistical, limit equilibrium, finite element, finite difference, distinct element methods, neural networks, GIS, and fuzzy logic have been applied to the problems about landslides and slope stability [21-38]. For example, Ward et al. [39] applied distributed, physically-based modeling to slope stability at the basin scale. In their research, soil strengths were assumed static and randomly assigned. They used a grid network for the model structure and applied the infinite slope equation to each grid cell to determine the safety factor of that cell. Shasko [40] discussed the possibility and feasibility of integrating sophisticated slope stability modeling with GIS. They concluded that it is possible and feasible to integrate sophisticated slope stability modeling in GIS using available digital inventories as input data at any scale.

The length of the motor roads of Kazakhstan is 128.3 thousand km, of which more than 96.4 thousand km of the public road, including 23.7 thousand km of the republican value and 72.7 thousand km of regional and regional significance. Transit traffic occurs mainly between the republics of Central Asia, Russia, and China. Currently, six international road routes pass through the territory of the Republic of Kazakhstan: (i) Tashkent - Shymkent - Taraz - Almaty – Khorgos; (ii) Samara - Uralsk - Aktobe - Kyzylorda – Shymkent; (iii) Almaty - Karaganda - Astana - Petropavlovsk; (iv) Astrakhan - Atyrau - Aktau - Turkmenistan; (v) Omsk - Pavlodar - Semey - Maikapshagai; (vi) Astana - Kostanay - Chelyabinsk – Ekaterinburg.

The transport corridor M32 Samara - Shymkent is approximately 2511 km along with the Samara, Uralsk, Aktobe, Kyzylorda, Shymkent. The intensity of traffic along the "Samara – Shymkent" varies between 1.5 and 3.5 thousand cars per day [41]. The volumes of transit are very low in comparison with the potential. The "Samara – Shymkent" transit potential is estimated at 0.5-0.7 billion US dollars per year. In the study area, cold winters and light summer rains are observed [42]. The maximum precipitation, mainly in the form of snow, maybe observed between November and February. Based on the meteorological data for the last 50 years, the average annual precipitation is 840.6 mm. The study area is located at topographic elevations between 960 and 840 m [43].

To clarify the role of the soil particle size distribution in the stable slope steepness the soils with different sizes and compositions were selected. Of these, soils No. 1, 2, and 3 were represented in the natural deposit, and the other two No. 4 and 5 were artificially formed by adding particles of different sizes, whose composition as noted above. Based on the previous studies about the positive role of form and particle size distribution in the dynamic stability of sand, a series of numerical simulation tests were conducted. These tests show the effect distributed on a slope to vertical or horizontal constant acceleration which will produce inertial force acting on the unstable slope. The inertial force, as a cause of the slide, is used for slope stability calculations. This method has been playing a major role in slope stability analysis and is widely used in dynamic slope stability analysis [25-30]. Field data were collected from five road cut slopes along with M32 Samara - Shymkent road. The soil slopes were selected in such a manner that they represent varied geological and slope stability conditions. The data includes physicomechanical characteristics of soils: soil density, soil type, internal friction angle, soil cohesion, joint condition, joint roughness, soil mass structure, and hydrological condition (Table 1).

Table 1 Physicomechanical characteristics of soils

Soil sample	Soil density, 104 kN/m^3	Internal friction angle, degree	Cohesion, 10^3Pa	Grading soil composition, mm		
				>0,05	0,05-0,005	<0,005
1	1.68	26	0.987	8.15	8.20	9.85
2	1.64	24	0.042	19.6	78.9	1.5
3	1.67	20	0.20	7.1	74.2	18.7
4	1.77	26	0.179	19.88	71.47	9.65
5	1.73	18	0.987	4.5	59.8	35.7

Table 2 Dependence of slope stability from internal friction angle

Porosity in clay mixtures, %	Internal friction angle, degree					
	34	36	38	40	42	44
41.7	0.34	0.36	0.38	0.40	0.42	0.46
46.4	0.22	0.28	0.30	0.31	0.33	0.36

Table 3 Compaction of various porosity soils under long-term oscillation

Soil porosity, %	Oscillation duration, seconds							
	10	20	30	40	50	60	70	80
45.8	-	-	-	44.4	43.9	43.0	42.3	42.1
50.2	-	-	46.2	45.7	45.1	44.0	43.7	43.2
51.6	-	49.1	47.1	45.0	44.6	44.5	43.3	42.6

3. RESEARCH FINDINGS

Since these soils had different genesis origin (e.g., soil No. 2 - alluvial, No. 3 - diluvial and No. 5 - pluvial) the roughness of their surface was different. Among them, soil No. 1 was characterized by the relatively smooth surface of particles and soil No. 3, the soil, on the contrary, by unevenness. Fig. 1 shows the dependence of slope stability on the shape of the ground particles surface. According to Fig. 1, under the same vibration condition tests, the dynamic slope stability increased with increasing roughness of the ground particles surface, which indicates a relatively long steep slope from the ground No. 1 in comparison with the slope from the ground No. 3. The role of internal friction in the dynamic stability of the slope was observed during the first test conducted with different soils (Table 2).

Fig. 2 shows the results of simulation tests on soils with different compositions. According to Fig. 2, it follows that slopes from natural soils (No. 2 and 3) of homogeneous composition are characterized by less dynamic stability in comparison with the slope from artificially prepared soils (No. 4 and 5) of heterogeneous composition. Summary results of simulation tests of change of stable angle of slope from soils No. 2 and 3 (homogeneous and heterogeneous composition) with different accelerations are shown in Fig. 2.

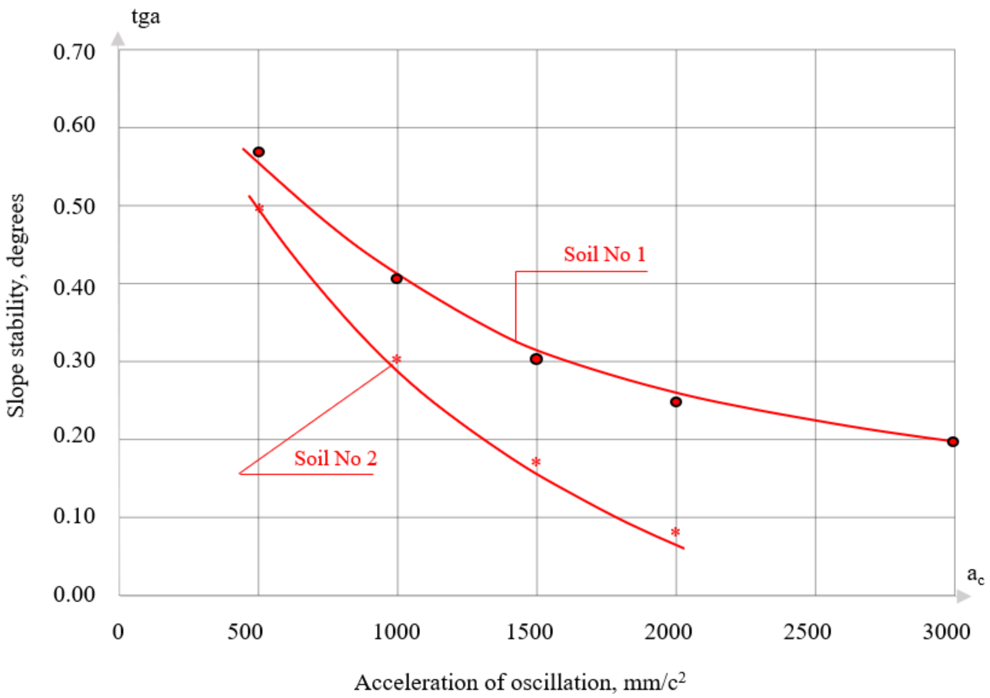

Fig. 1 Dependence of slope stability on the acceleration of oscillation

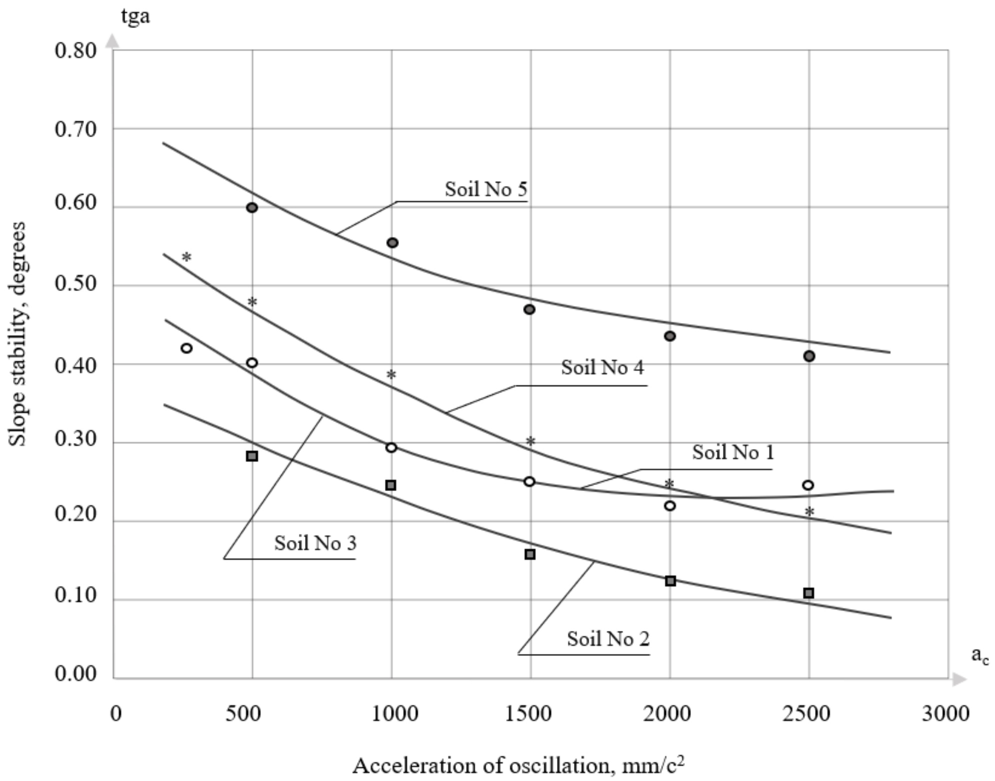

Fig. 2 Change of slope stability at vibrations with different accelerations

The vibration tests have also shown a comparatively smaller role of internal friction forces in the soil strength as compared to the clutch force (Fig. 3 and 4), which shows the advantage of the clutch force in providing dynamic angle stability of slopes.

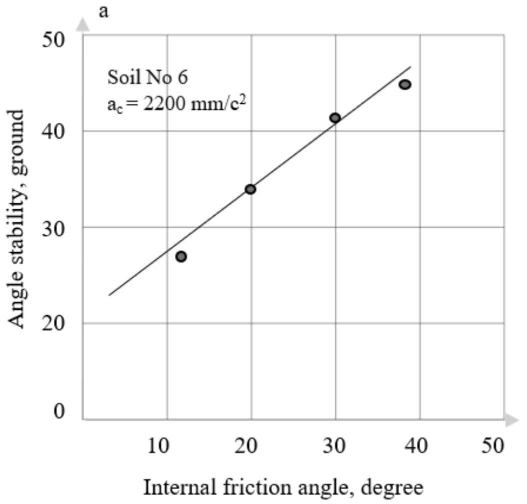

Fig. 3 The character of the dependency of slope on the dependency of the internal friction angle

The tests showed a long process of soil compaction. And the beginning of compaction did not occur immediately but appears after 20-30 seconds after the application of dynamic load to the soil. This nature of change in compaction over time is shown in the graph compiled on the basis of Table 3 “Compaction of various porosity soils under long-term oscillation” and corresponds to fluctuations within 3000-3200 mm/s^2 under long-term oscillation.

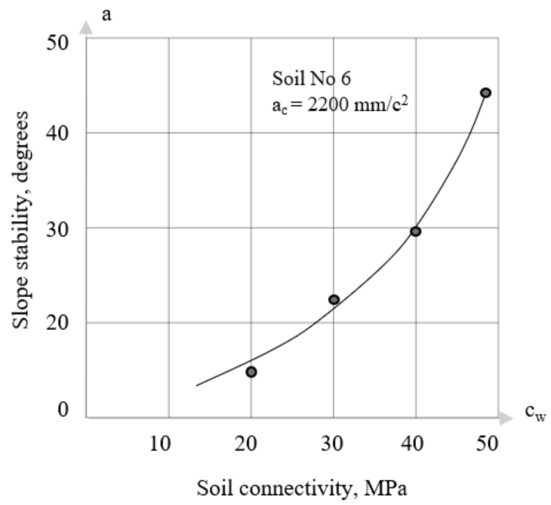

Fig. 4 Nature of change in stable slope from forest soil connectivity

The analysis of the results of the tests allowed concluding that the slope stability disturbance under dynamic influences occurs only after the disturbance of the general ground cohesion, and in wet forests - after the disturbance of the plastic cohesion. In such a case, it may be assumed that soil moisture has a significant impact on the structure of wet forests. The relationship between moisture and connectivity in wet forests is evident from the following considerations. It is known that changes in humidity in shaking conditions are usually due to water displacement during the compaction of ground particles. However, compaction can only occur once the soil structure has deteriorated. Finally, the strength of the structure, due to the forces of connectivity, depends on the moisture of the soil. The relationship of dependence of stable slope angle on ground adhesion is shown in Fig. 5. Generally, slope stability is one of the most important and complex issues for a road engineering project.

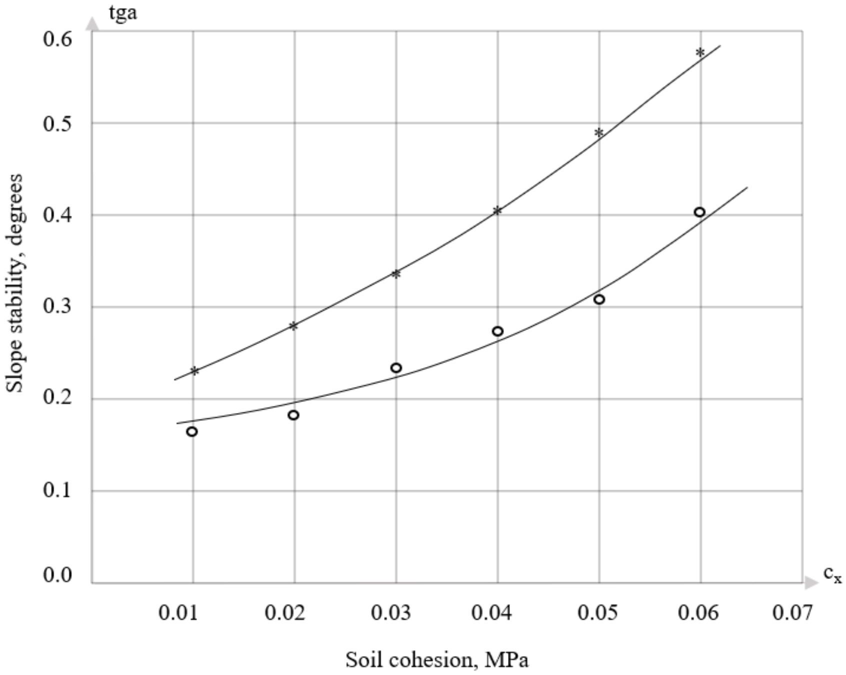

Fig. 5 Dependence of stable slope angle on ground adhesion

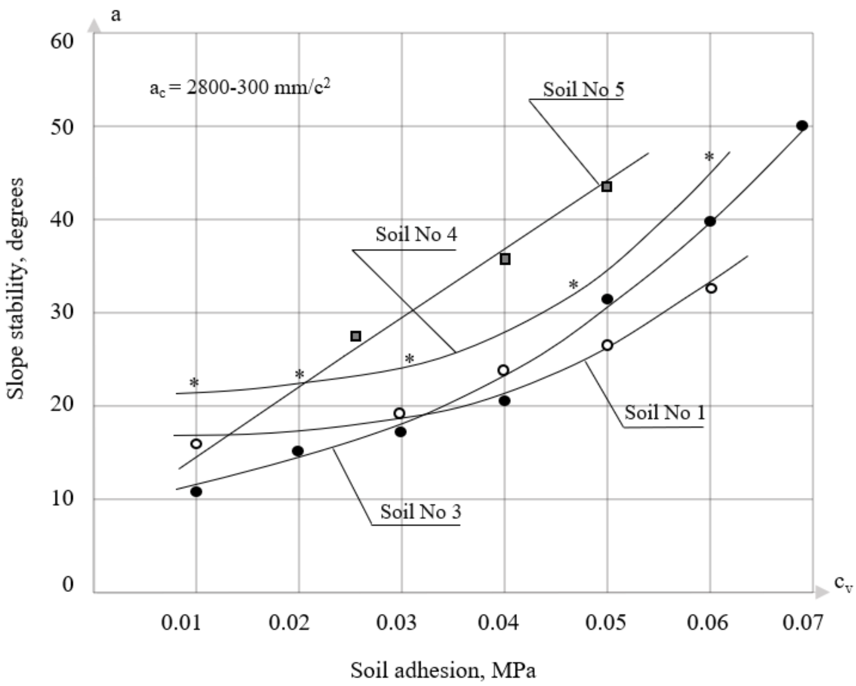

Fig. 6 Summary graph of the dependence of stable slope on soil adhesion

In Fig. 5 the reflections of the loess soil oscillations numbered 1, 2 at an acceleration of 3000 mm/s^2 were received. In this case, different values of clutches were obtained by increasing the soil density by preliminary vibrating the sample. Following Fig. 6, increasing soil adhesion will result in a reduction in slope steepness. This conclusion, which is of great practical importance, has been confirmed in many tests (Fig. 6).

It is necessary to notice, that any increase in adhesion of a ground promotes the reduction of slope steepness thanks to an increase in durability of ground in these conditions (Fig. 6). This graph also clearly shows the role of soil adhesion in the slope's stable steepness. The increase in slope steepness as clay particles in the soil has increased has been shown in many tests. This fact has been confirmed, in particular, by artificially created soils with different amounts of clayey particles.

Fig. 7 shows the results of tests on soils containing clayey particles in different amounts. For example, a slope containing 31.9% clayey particles is much steeper than a slope with clayey particles containing 15.08%.

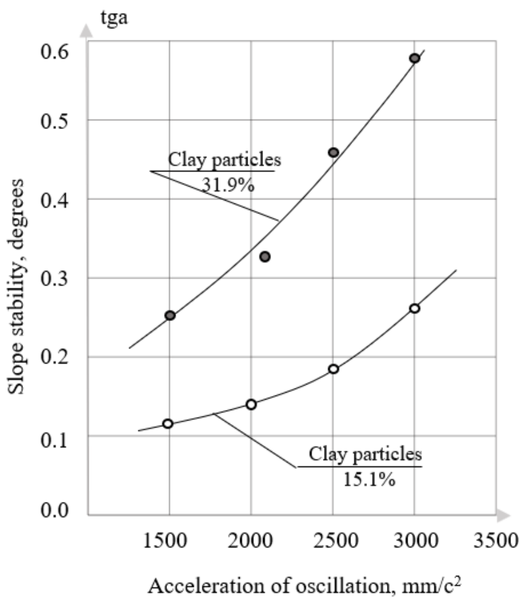

Fig. 7 Dependence of the type *tgα=f(w)* for soils by the contents of clay particles

4. CONCLUSION

Roads are considered significant structures and therefore it is needed to pay high attention to the design and assessment of these constructions. Because of their importance, security, and reliability throughout their lifetime remain the top priority. The stability of the slope is an essential prerequisite to ensure the safe operation of road transport. In frozen regions of Russia and Kazakhstan, shallow landslide hazards in soil slopes usually happen, which poses a serious threat to road safety operations. The research goal of this paper is to conduct field observations and numerical simulations to investigate the soil strength and slope stability of the geotechnical engineering system. The site studied is a non-homogeneous and unsaturated slope located in the road M32 Samara - Shymkent (Russia - Kazakhstan). Slope stability assessment based on numerical vibration tests shows that under the same vibration conditions, the dynamic stability of the slope increases with an increase in surface roughness and inhomogeneity of soil particles. This article presents the basic engineering properties with an emphasis on design strength parameters of soil together with the stability analysis results considering the unsaturated condition.

Further work is required to improve knowledge on soil strength and slope stability in the case of road engineering M32: Samara - Shymkent (Russia - Kazakhstan). Based on the information provided in this article, the back analysis might be used to improve knowledge on slope stability parameters (e.g., [46-47]). The back analysis method is used to perform back-analysis. The philosophies behind back analysis methods are different. While deterministic back-analysis methods intend to find a set of parameters that would result in the slope failure, back-analysis methods recognize that there might be numerous combinations of such parameters, but their relative likelihoods are different, which can be quantified by probability distributions. Major advantages of back analysis methods include: it provides a logical way to incorporate information from other sources in the back-analysis and it is capable of back-analyzing multiple sets of slope stability parameters simultaneously. One possible disadvantage of back-analysis methods is that they are usually not as easy to implement compared with deterministic back-analysis methods.

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