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Reliability of Geotechnical Parameters in the Analysis of Ancient Landslides

Hamid Pedram

Independent Consultant Geotechnical and Engineering Geology, Tehran, Iran

Email address:
pedram.hamid@yahoo.com

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Abstract: More than 850 large scale landslides in the two main active seismic zones (Alborz and Zagros) in Iran have been studied over the past nearly four decades. Of these, remedial designs made by the author for major engineering works in the 180 or so landslides encountered in the projects have, to the present, been successful. This work has led me to the conclusion that, regardless of their geotechnical parameters measured on intact samples in the laboratory, the main cause of forming of these landslides has been occurrence of high magnitude recent and historical earthquakes, combined with micro/mega discontinuities existing within the soil/rock masses. In this study, according to the results of geotechnical studies, the stability analysis of ancient landslides in the area of gas transmission lines (IGAT) in Iran, is discussed. Three samples, taken from slip surfaces of ancient landslides of the two main active zones are discussed. The samples were taken from apparently weak soils, but, unexpectedly, they showed good stability strength. The major occurrences of landslides were in the two mentioned active zones (Zagros and Alborz). In the sampling process of the three landslides, samples representative of apparently geotechnically weak rock or poor soil type were the only ones selected for testing and were taken from slip surface/zones with well-defined natural deformation, remolding and slicken siding. Geotechnical and soil shear parameters measured on samples taken from the slip surface showed apparent good results indicating that a landslide should not occur. However this assumption proved to be misleading, for despite these measurements, land sliding did occur. This was especially so in the case of rockslides.

Keywords: Ancient Landslide, Slip Surface, Geotechnical Parameters

1. Introduction

The stability analysis of natural and engineering slopes is a complex problem, especially when the ancient landslide has to be taken into account. The stability analysis of an ancient landslide is so complicated.

It is distinctive that an ancient landslide, generally characterized by existing slip zones, that can ba instable by excavation with in the slide zone [1]. In recent decades, multiple, many quantitative studies have been carried out to estimate the progressive failure. Potts [2, 3] suggested an approach to simulate the strain-softening properties of brittle soils by reducing the strength. Troncone [4] offered the results of a numerical study on a landslide in deep excavations at the slope toe and further extended this analysis into a three dimensional problem [5]. Many countries are facing increasing pressure to ensure the safe transport of energy, especially by pipelines, as global economic development results in greater energy demand. So great attention is placed on the safety assessment [6, 7], and design of pipelines [8]. landslides are gaining much attention because of their potentially devastating effects on the integrity of gas pipelines. Deng et al. [9] simplified pipelines inside and outside a slope to determine internal stresses and deformations.

In this study, according to the results of geotechnical studies, the stability analysis of ancient landslides in the area of gas transmission lines (IGAT) in Iran, is discussed.

2. Tectonic and Seismology of the Iranian Plateau

The occurrence of large scale landslide as the result of earthquake and tectonic activity is a common phenomenon in Iran and has been occurring over many centuries.

The Iranian plateau is situated on the Himalayan earthquake belt, where destructive earthquakes are frequent and repeated events. In addition, countless low-magnitude earthquakes are common and being recorded daily. Although no part of the plateau is safe from earthquakes, the two major active fold belts, namely Zagros and Alborz, are the most affected zones (Figure 1). In a broader study than presented here some other zones with varying seismicity and geological conditions can be recognized in Iran. Where an ancient landslide is present, but which has not been recognized as such, problems will arise when excavations and building operations have been carried out or are in progress. This is because one or more slip surfaces have been formed, so any excavation can upset the balance and equilibrium state.

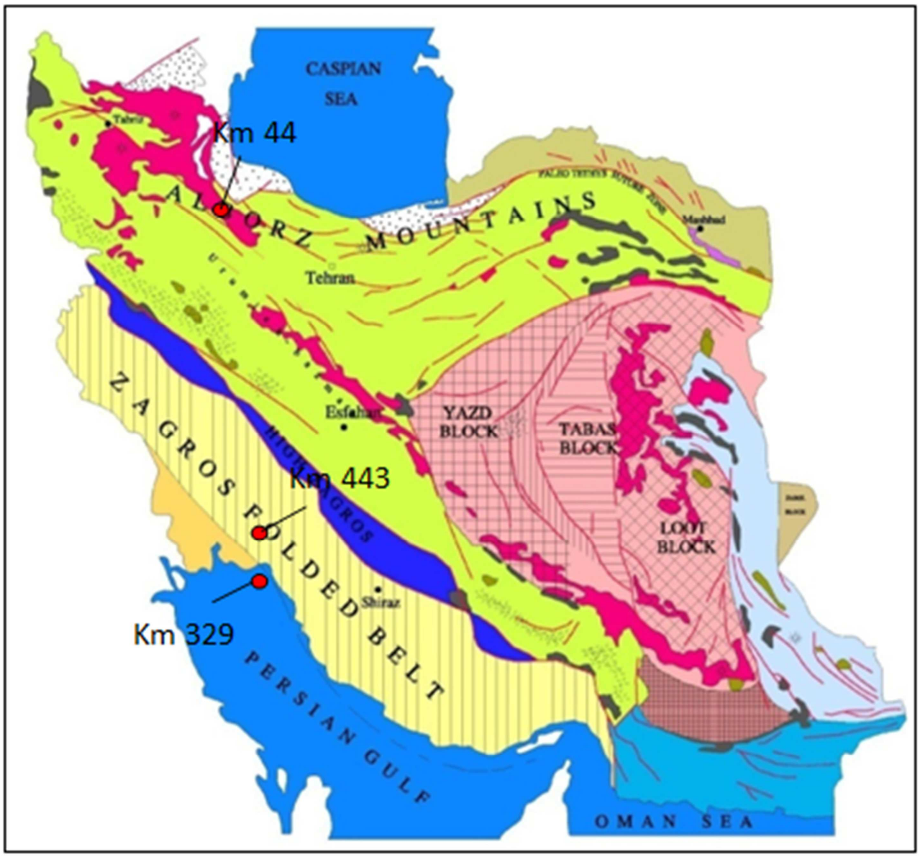

Figure 1. *Structural Map of Iran showing the two major active folded belts, namely Zagros and Alborz [10].*

The development of a suitable design to mitigate or eliminate the hazard of slope failure in an unrecognized ancient landslide, and thus secure the planned structure, requires time and investment.

On the other hand, it should be noted that minor slope failures due to excavations and collapse of excavation walls can be managed and should not be mistaken for major complications.

Ancient landslides can have occurred in any rock or soil type. In this paper three samples, taken from slip surfaces of ancient landslides of the two main active zones are discussed. Sampling of slip surfaces is a difficult and dangerous process, but it is necessary to obtain a good and undisturbed sample. Any sort of machinery drilling which is frequently used to obtain samples for laboratory testing can produce misleading results, because it is almost impossible to identify and locate the slip surface/zone correctly in such a small recovered sample, especially when the slip surface has been formed as a zone and not a simple surface. Thus the term “slip surface” may rightly be either a plane or a thin zone. No zones more than 80cm thick have yet been observed. The author reiterates this point: the term slip SURFACE can be misleading because it might be a thin zone.

The samples which are discussed below were taken from apparently weak soils, but, unexpectedly, they showed good stability strength. Other slip surface samples, with much better geotechnical characters, are not discussed here.

After the 1990 Manjil earthquake (Ms=7.4) Pedram [11] indicated that although more than 110 landslides were induced in many rock/soil types none of the ancient landslides present in the affected area was reactivated. This is still my firm opinion and only interference by man or river undercutting reactivates them. This is a fact to be considered in any analyses or designs.

The first distribution map of landslides, based on 250 examples in Iran, was published by the author [12] after the Manjil 1990 earthquake. Later, in a broader collection of data (2050 cases), despite the difference in the numbers noted in the two lists, the outcome was similar [13]. The major occurrences of landslides were in the two mentioned active zones (Zagros and Alborz). In Figure 2 position studded area has shown in the map of Iran.

3. Location and Sampling

In the sampling process of the three landslides discussed below samples representative of apparently geotechnically weak rock or poor soil type were the only ones selected for testing and were taken from slip surface/zones with well-defined natural deformation, remolding and slicken siding.

3.1. Km.329, IGAT II landslide

Km.329, IGAT II (Iranian Gas Trunkline) landslide (Figure 3) is located in the Zagros region (Figure 2). It has a downslope length of nearly 400m. And width of 250m. A hand-bored pit about 1m. in diameter was excavated (Figure3, point A) so that the slip surface/zone could be examined and identified visually. The sample taken was a block 60x70x30cm. The depth of sampling was 12m from the excavated service road and 19m deep from the natural ground level. In this case the slip appeared as a zone almost 50cm thick. landslide occurred in fine grain soils.

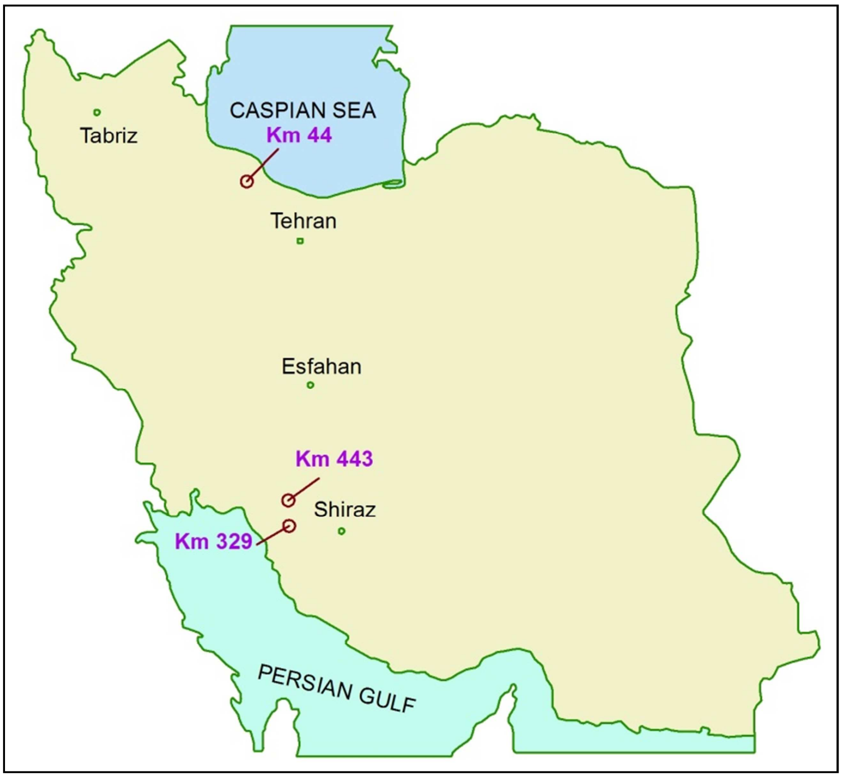

Figure 2. *Study Area on Map of Iran.*

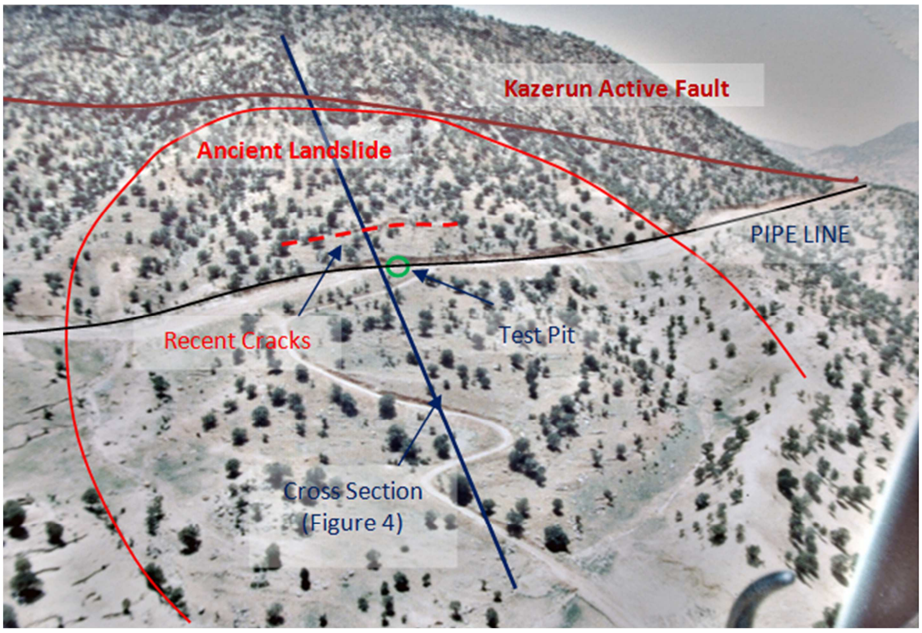

Figure 3. *Km. 329 IGAT II landslide (Zagros).*

The undisturbed samples were recovered from the samped blocks and were tested in the laboratory. The test results are shown in table 1. A geological cross section of Km. 329 IGAT II landslide shown in figure 4.

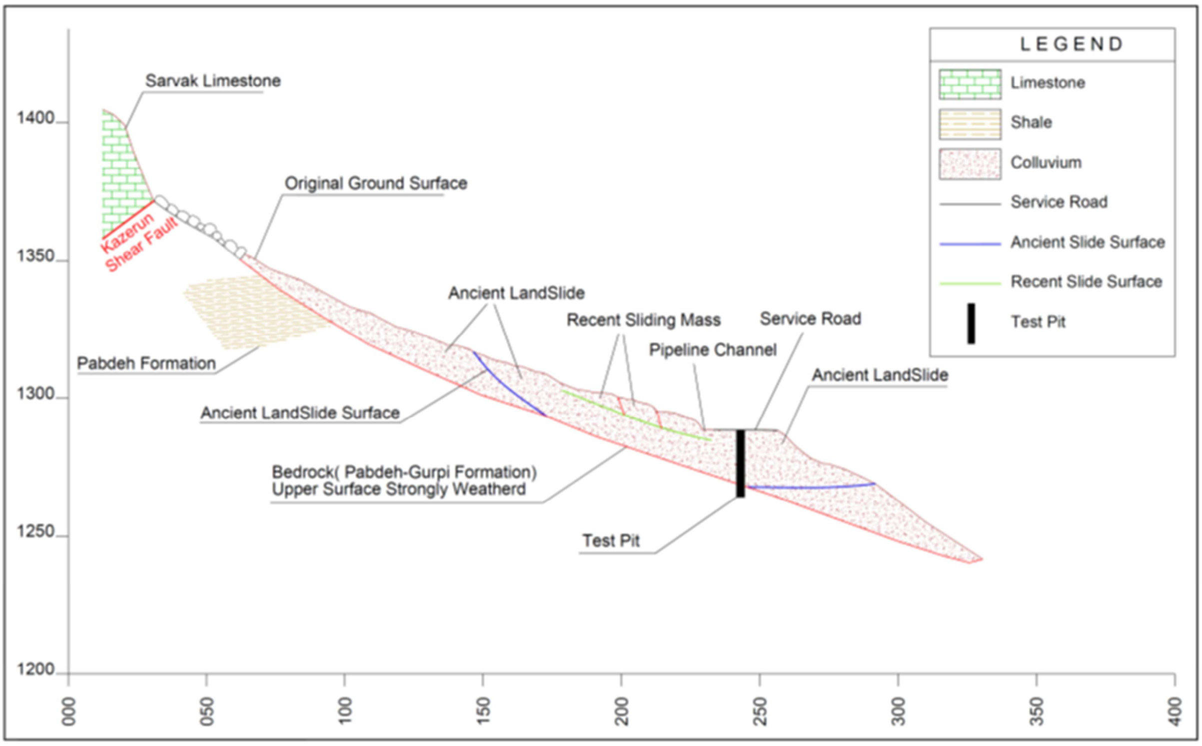

Figure 4. *Geological cross section, Km. 329 IGAT II (Zagros).*

Based on the geotechnical parameters obtained from laboratory testing (Table 1), back analyses were performed using the Geo Studio /2007 program. To obtain the safety factor the Morgenstern-Price procedure was used. In this procedure forces equilibrium and moment equilibrium controlled together. It is worthwhile mentioning here that using any other widely -used programs will lead more or less to the same results; only small differences will be observed. In no analysis has the slip surface been considered as a hazardous element; so the calculated safety factor from any analysis is going to be under question.

Table 1. *Km.329 sample Test results.*

Identification				Classification							
Sample		Depth From	Description	Particle Size distribution Passing %				Atterberg Lmit			Moisture %
No.	Type	(m)		76 mm	4.8 mm	76µ	2µ	LL	PL	PI	W
1	Km 329+000 Pipeline	10 (Slip Surface)	L.Br. Very Stiff Lean CLAY (CL)		100	86	24	34	22	12	16.9

Table 1. *Continue.*

Dencity			Strength						Consolidation		
Bulk Dencity (g/cm³)	Dry Dencity (g/cm³)	Specific Gravity	S.P.T Blow Per 30 cm		Triaxial Tests		Effective Stress Tests		Pressure Range (kg/cm2)	$cm^2/kg\times10^2$	$cm^2/sec\times10^{-3}$
γ_{wet}	γ_d	γ_s	N	N_{70}	φ(Degree)	C (Kpa)	φ'(Degree)	C' (Kpa)	σ_1	m_v	c_v
2.11	1.8	2.684	-	-	3	0.98	31	0.06	0.5-1 1-2 2-4 4-8	0.09 1.16 0.87 0.56	7.56 5.47 3.41 4.26

The results of the analysis for the landslide at Km.329 IGAT II (Table 1) for both total stress (UU) and effective stress (CD) are presented below:

A-Considering total stress (UU) parameters of the soil mass (Table 1)

$$C = 98 \text{ kPa}$$

$$\varnothing = 3^{\circ}$$

In this condition FS = 1.669 (figure 5) thus confirming the soil stability

By introducing an earthquake with horizontal ground acceleration of 0.22g (Based on seismological studies), the safety factor drops to less than 1. At this stage the soil mass is on the verge of failure. In pseudo- static analysis this coefficient of earthquake, corresponds to an earthquake with horizontal ground acceleration of 0.45 – 0.65g.

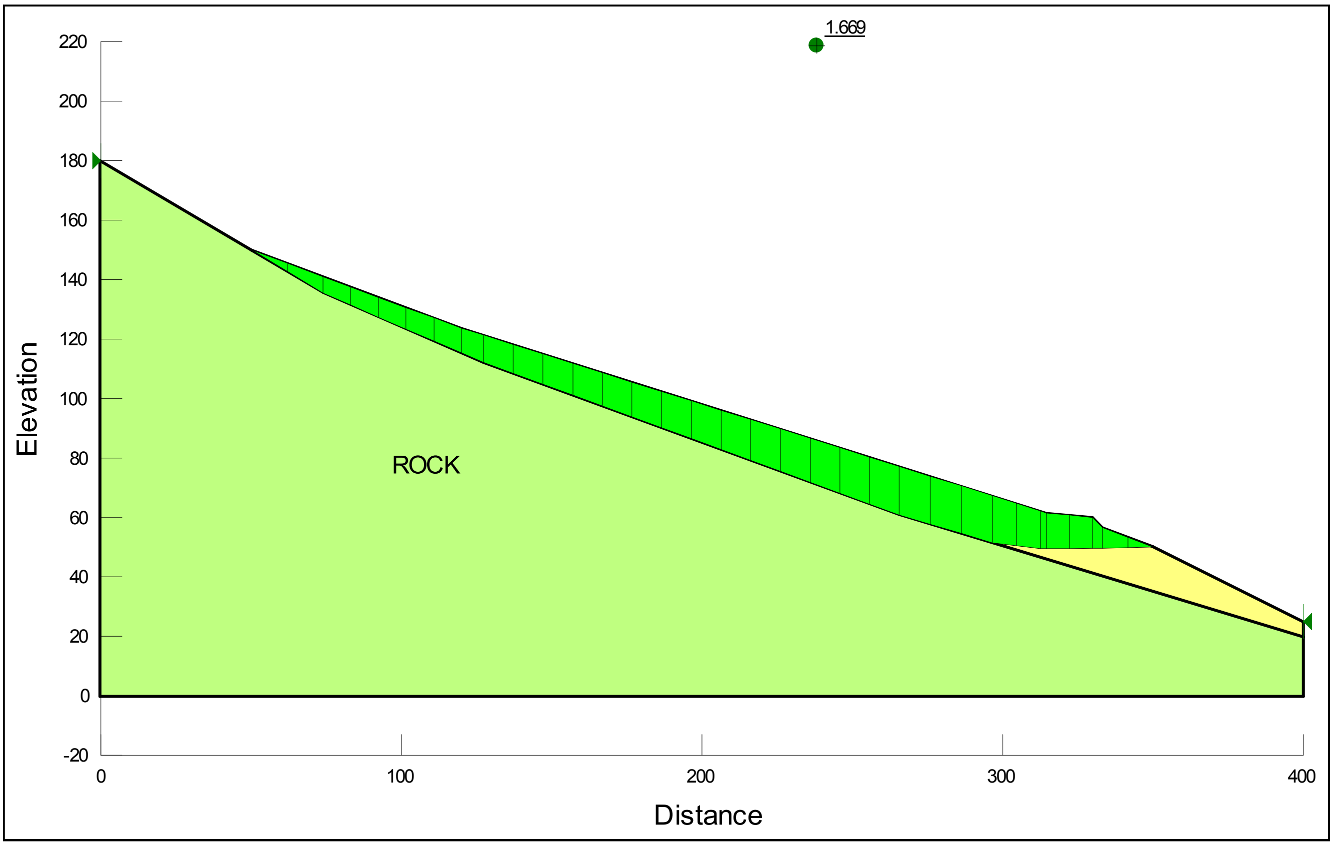

Figure 5. *Factor of safety in slope stability analysis, Km. 329 IGAT II.*

In a trial and error procedure, to bring the soil mass into the failure threshold, the values of the geotechnical parameters have to be reduced so that the safety factor drops to less than 1. Which is:

$$C_{slide} = 58.7 \text{ KPa}$$

$$Ø_{slide} = 1.8^o$$

In this state soil failure begins.

B-Considering effective stress (CD) parameters of the soil mass (Table 1)

$$C = 6 \text{ KPa}$$

$$Ø = 31^o$$

In this condition Fs = 2.019 which confirms the soil stability

By introducing an earthquake with horizontal ground acceleration of 0.275g, the safety factor drops to less than 1. At this stage the soil mass is on the verge of failure. This coefficient of an earthquake in pseudo- static analysis corresponds to an earthquake with horizontal ground acceleration of 0.55 – 0.825g.

In a trial and error procedure, to bring the soil mass into the failure threshold, the values of the geotechnical parameters have to be reduced so that the safety factor drops to less than 1. Which is:

$$C_{slide} = 3 \text{ KPa}$$

$$Ø_{slide} = 16.57^o$$

At this state soil failure begins.

3.2. Km. 44 IGAT IV landslide

Km. 44 IGAT IV landslide (Figure 6) is located in Alborz (Figure1). It has an average of 2km length, nearly 1km width, and depth of sampling 23m from the natural ground level. A sample 70x70x30cm was taken from an excavation hole by using a hydraulic excavator. Here the slip appeared as a zone 80cm thick. The slip zone is well defined by remolding, deformation and conspicuous slicken siding.

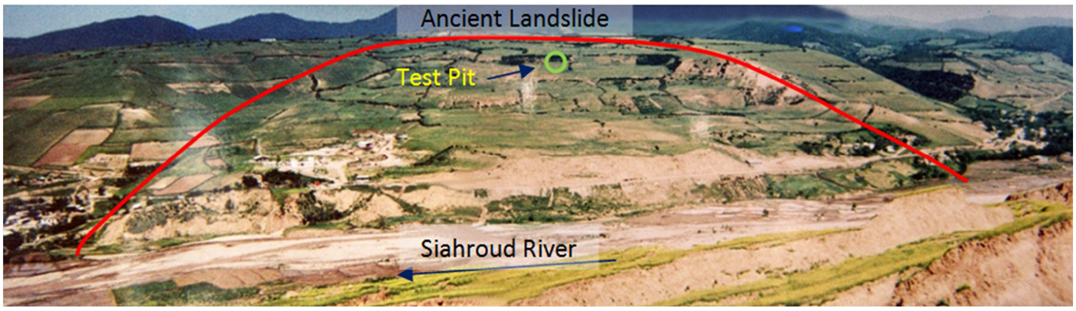

Figure 6. *Schematic of Km. 44 IGAT IV landslide (W. Alborz).*

The undisturbed samples were recovered from the sampled blocks and were tested in the laboratory. Samples Composed of fine grain soils named loess. The test results are shown in table 2.

Based on the same procedure as mentioned above, back analyses were performed. The results of the analysis for the landslide at Km.44 IGAT IV (Table 2) for both total stress (UU) and effective stress (CD) are presented below:

A-Considering total stress (UU) parameters of the soil mass (Table 2)

$$C = 75 \text{ KPa}$$

$$Ø = 2^{o}$$

Table 2. *Km.44 sample Test results.*

Identification				**Classification**							
Sample		**Depth From (m)**	**Description**	**Particle Size distribution Passing %**				**Atterberg Lmit**			**Moisture %**
No.	**Type**			**76 mm**	**4.8 mm**	**76µ**	**2µ**	**LL**	**PL**	**PI**	**W**
1	Km 44+000 Pipeline	20 (Slip Surface)	L.Br.Stiff Lean CLAY (CL)		100	87	28	46	26	21	20.3

Table 2. *Continue.*

Density			**Strength**						**Consolidation**		
Bulk Dencity (g/cm³)	**Dry Dencity (g/cm³)**	**Specific Gravity**	**S.P.T Blow Per 30 cm**		**Triaxial Tests**		**Effective Stress Tests**		**Pressure Range (kg/cm2)**	**cm²/kg×10⁻²**	**cm²/sec×10⁻³**
γ_{wet}	γ_d	γ_s	N	N_{70}	φ(Degree)	C (Kpa)	φ'(Degree)	C' (Kpa)	σ_1	m_v	c_v
2.06	1.71	2.773	-	-	2	0.76	30	0.09	0.5-1	1.37	5.00
									1-2	1.44	6.81
									2-4	0.99	3.43
									4-8	0.70	4.67

In this condition FS = 1.996 (figure 7) thus confirming the soil stability

By introducing an earthquake with horizontal ground acceleration of 0.118g (based on seismological studies), the safety factor drops to less than 1. At this stage the soil mass is on the verge of failure. In pseudo- static analysis this coefficient of earthquake, corresponds to an earthquake with horizontal ground acceleration of 0.24 – 0.36g.

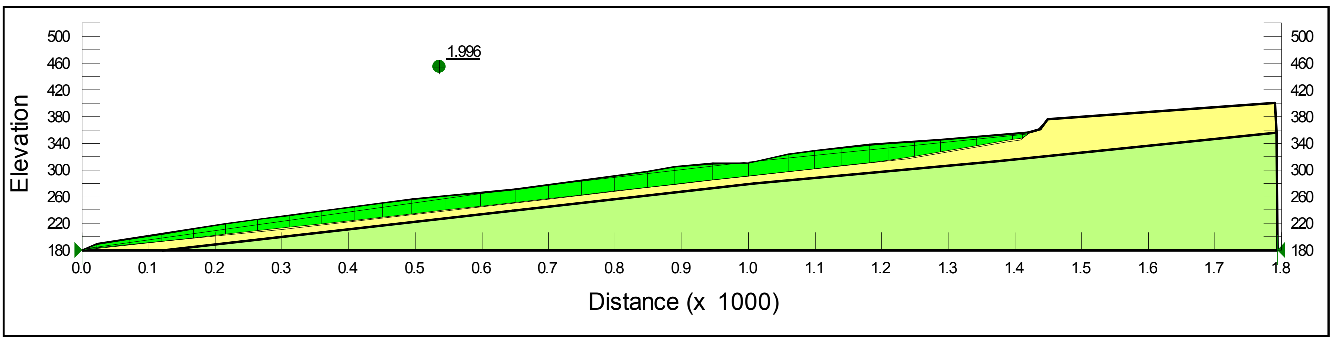

Figure 7. *Factor of safety in slope stability analysis, Km. 44 IGAT IV.*

In a trial and error procedure, to bring the soil mass to the failure threshold, the values of the geotechnical parameters have to be reduced so that the safety factor drops to less than 1.Which is:

$$C_{slide} = 37.5 \text{ KPa}$$

$$Ø_{slide} = 1^{o}$$

In this state soil failure begins.

A-Considering effective stress (CD) parameters of the soil mass (Table 2)

$$C = 9 \text{ KPa}$$

$$Ø = 30^o$$

In this condition Fs = 4.775 which confirms the soil stability

By introducing an earthquake with horizontal ground acceleration of 0.44g(based on seismological studies), the safety factor drops to less than 1.At this stage the soil mass is on the verge of failure. This coefficient of earthquake in pseudo- static analysis corresponds to an earthquake with horizontal ground acceleration of 0.9 – 1.2g.

In a trial and error procedure, to bring the soil mass into the failure threshold, the values of the geotechnical parameters have to be reduced so that the safety factor drops to less than 1.Which is:

$$C_{slide} = 1.8 \text{ KPa}$$

$$Ø_{slide} = 6.5^o$$

At this state soil failure begins.

3.3. Km.443, IGAT II landslide

Km.443, IGAT II landslide (Figure8) is situated in Zagros almost 300m. In length, about 100 m. width and 12 m. deep from the original natural ground level. The sample was taken after excavation for construction of the service road, i.e. 5.5 m. deep using a hydraulic excavator. The slip surface was sharply defined as a plane and developed in a weak and weathered rock of marl.

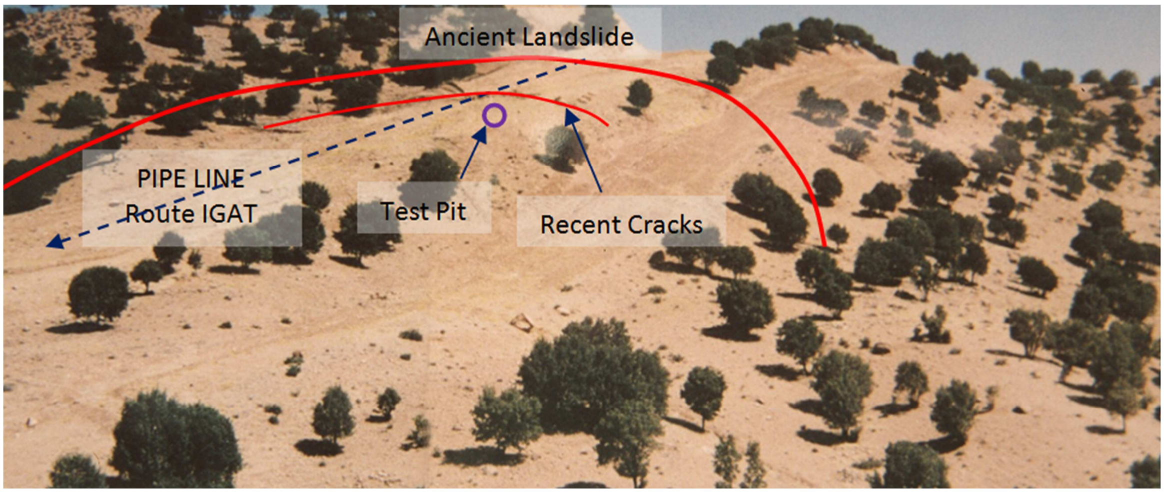

Figure 8. *Km.443 IGAT II landslide (Zagros).*

The undisturbed samples were recovered from the obtained blocks and were tested in the laboratory. The test results are shown in table 3.

Table 3. *Km.443 sample Test results.*

Laboratory Soil Test (IIEES*)							
Direct Shear Test							
Project: Km P. 443 IGAT II							
Diameter: 6 cm Width: 2 cm Area: 28.26 cm2 Depth: 5 m (from Slip Surface)							
Coefficient of ring: 0.4 Velocity: 0.05 mm/min							
No. test	**W% Before test**	**Dry Dencity gr/cm^3**	**W% After Test**	**Normal Load Kgf/cm2**	**Shear Load Kgf/cm2**	**C Kgf/cm^2**	**Phi Degree**
1	17	1.82	18	1	2.3354565		
2	17	1.82	17	2	2.6185421	2	18
3	17	1.82	16.2	3	2.9723992		
*: International Institute of Earthquake Engineering and Seismology							

Slope stability analysis of the cross section for Km.443 IGAT II landslide was performed by the same software considering geotechnical parameters in table 3 (see Figure 9). The factor of safety value is so great that it leaves no expectation of any instability.

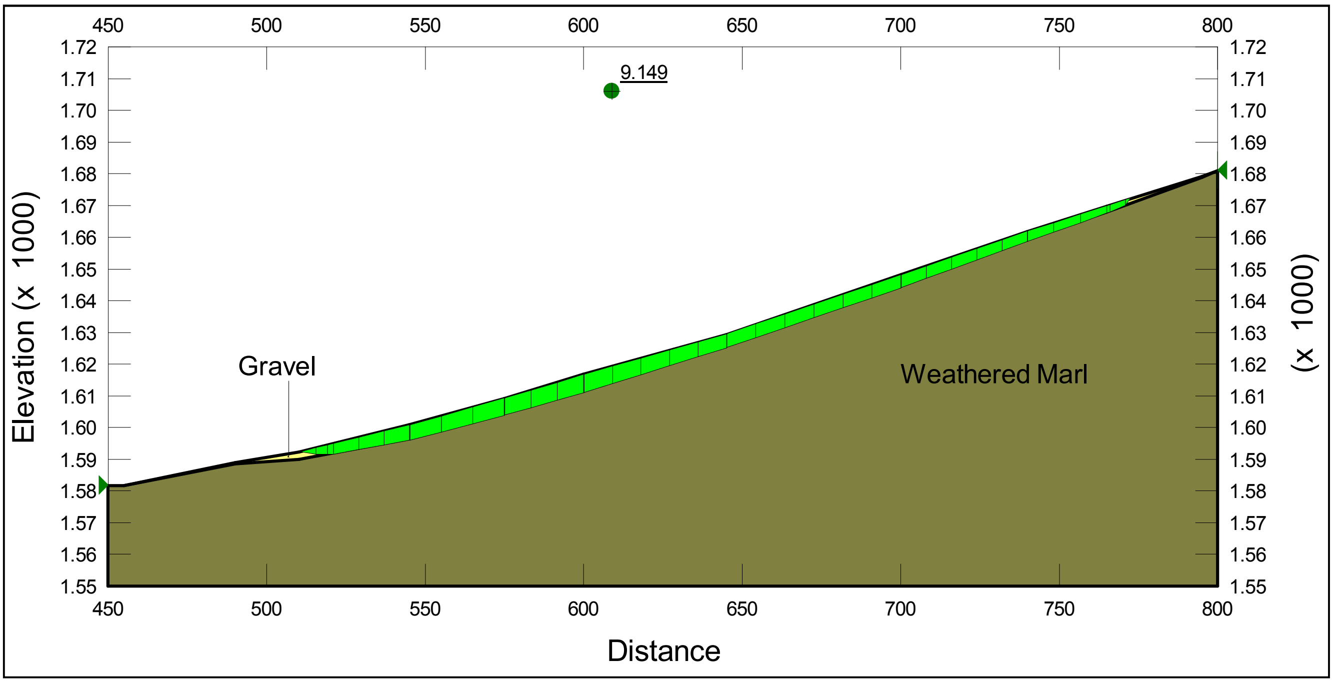

Figure 9. *Factor of safety in slope stability analysis, Km. 443 IGAT II.*

4. Conclusions

In this study, geotechnical properties of three samples, taken from slip surfaces of ancient landslides of the two main active zones are investigated. However, the samples were taken from apparently weak soils, but, unexpectedly, they showed good stability strengthIn the sampling process of the three landslides, samples representative of apparently geotechnically weak rock or poor soil type were the only ones selected for testing and were taken from slip surface/zones with well-defined natural deformation, remolding and slicken siding. Geotechnical and soil shear parameters measured on samples taken from the slip surface showed apparent good results indicating that a landslide should not occur. However this assumption proved to be misleading, for despite these measurements, land sliding did occur. This was especially so in the case of rockslides.

The investigation indicated that the presence of slip surfaces controls the behavior of ancient landslides. Reliance on the geotechnical parameters and the subsequent analyses is misleading. However, geotechnical parameters are of great value for stability analysis when no slip surface or ancient landside exists. The abundance of large-scale ancient landslides in active fold belts is the result of historical earthquakes. Human interference and river undercutting can reactivate ancient landslides but later earthquakes do not. In development projects; the best way is to avoid ancient landslides, but if avoidance is not possible, the main slip surface/zone has to be determined and considered in any design for remedial work. Since no numerical value can be assigned to the slip surface in analyzing an ancient landslide therefore we are left with the enigma that the acceptance of soil test values as essentially the sole reason for determining stability is totally misleading for design purposes.

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In this regard; a wide range of people has to be acknowledged, from simple workers, operators of excavators to highly experienced experts of whom are Professor D. F. Branagan for his enthusiasm and his encouragement, A. Fathi for assisting in Analysis, A. Mina for preparation of profiles and data and Khakvaran geotechnical consulting engineers for performing the laboratory tests.

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