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ABSTRACT

In last several years periodic reports indicating damages toward resident's homes due to ground movements in Barikan region, 120 km far from Tehran, have been issued. The earth movements are demonstrated by tension cracks and scarps on ground surfaces and walls of in site homes and gardens. Since the slow and continuous earth movements were observed in the site, a course of site investigation consisted of the monitoring of surface and deep earth movements has been considered to study the affecting factors and the extent of landslide. In addition to ground movement measurements, by using the geotechnical properties of different soil layers, stability analysis of the soil mass was performed. Results showed that the village would be stable at static conditions in all relative groundwater levels. However, in case of earthquake with the value of horizontal acceleration equal to 0.14g, analyses indicated total instability of the site. It seems that the movements, which apparently widen the cracks and damage the houses and walls of the gardens, are due to the mild in site earthquakes or accelerations of the farther occurred earthquakes of the area, which by reducing the F.S. of the slope, increase the severity of movements' rate in the village. In this paper the results of conducted researches, as well as possible remedial solutions for ground movements, with regard to known effective factors of landslide, are presented.

INTRODUCTION

Each year natural disasters impose human life and enforce financial charges on governments. Landslides are one of those disasters. Based on UN reports, destructions due to landslide occurrence in developed countries expense about 1 to 2 percents of their GNP. Regarding to this report before year 2000, the overall charges due to landslides occurrence in Japan, Italy, U.S.A., and India were about 4.5, 2.6, 2, and 1.5 billion dollars respectively [9].
In addition to financial damages, life damage is one of the parameters that indicates the significance of landslide. Discovering the mechanism in which a landslide occurs, and its effective factors can help us to recognize and prevent its occurrence. One of the factors, which lead to the occurrence of a landslide, is the existence of a previous shear surface in soil mass. In such cases, the secondary sliding will happen because of the factors such as increased groundwater level (GWL), earthquake or any other factor that leads to increase of applied load or decrease of soil resistance in the weakened zone. In this zone, soil elements won't let out a brittle behavior and no progressive failure will occur. Many investigations were performed on these lines e.g. the work which were done by Potts et al. (1990), Picarelli (1991) and Lupini et al. (1981).
Until present, several homes in Barikan region have been damaged and successive repairs have not been effective. In such condition the feeling of insecurity is quite ordinary. It can be estimated that if the rate of the movement continues in the same way and if it leads to a total instability in the village, the overall damage will impose $1,250,000 to people and government. Therefore the study of the movements in the village will be logical and economic.
This research was defined as the investigation of Barikan landslide in Talequan area. In this manner at the first stage, general conditions of the area and previous investigations have been reviewed and then in order to attain a better perception of the manner and the amount of movements in the area also to find the appropriate stability condition and the critical condition in which the region would become unstable, the stability of the site in different conditions was analyzed. At the end by studying various methods of stabilizing, the best one is proposed.

SITE RECOGNITION

Barikan village is located inside Alborz Mountains, in Talequan region, 110 km far from Tehran (See Fig. 1). The average height of the village, comparing with surface level of free seas, is 2100 m, the average annual rainfall is about 424.5 mm, and the average annual temperature is about $8^{\circ C}$[3]. Herbaceous covering the hills and farmlands are short grasses.

Fig.1. Geographical location of Talequan and Barikan village.

Total area of sliding zone was about 40 to 50 hectare, included the central area of the village, farmlands and other areas around the village. Whereas the sliding phenomenon in the village lasted more than 15 years it was considered as an old phenomenon. According to the information obtained from the villagers, there had also been slow movements in the area before Manjil & Roudbar earthquake in 1990, which had caused in ostensible cracks in houses. But significant site movement occurred at the time of Manjil & Roudbar earthquake, when 2-meter and higher scarps and deep cracks in houses' walls and roofs had been occurred and forced several villagers to leave their homes (See Fig. 2)

Fig. 2. Scarp above the well 6, has been caused at Manjil & Roudbar earthquake [5].

General geology investigations, e.g. investigations of tectonics, faults and seismicity of the site were been the first stage of the site studies, in this regard the accomplished studies by other researchers were used [3,4]. The next stage was specification of the DesignE arthquake Acceleration for the site, there would be two methods to specify that, determination method and probabilistic method. In determination method, maximum earthquake potentials in the faults next to the sightly region are computed separately and then the relevant acceleration that can be applied to the perspective site is calculated; finally by an engineering judgment a coefficient of calculated acceleration is chosen as Design Base Acceleration for the site, the maximum historical acceleration which has been applied there so far, is considered as well. In probabilistic method, earthquake contingency with various intensities that may occur during the design life of structures is determined and then the maximum applied earthquake acceleration to the site can be obtained. In this research at first, by using attenuation relationships, the maximum applied acceleration due to some earthquakes that had occurred near the site, was obtained. Based on the records, all of recent earthquakes in this region had horizontal acceleration less than 0.14g; in addition, according to presented attenuation relationships, that involved Alborz Mountains, the maximum credible acceleration due to vicinal faults was obtained about 0.5g. In this research, analysis of earthquake occurrence didn't accomplish by probabilistic method and just, by using the Gutenberg-Richter method, the return period of earthquake occurrence, with various intensities, was obtained. Regarding that in most of the engineering work in spite of all studies, which are done on earthquake contingency of the site, when semi-quasi method is used for earthquake analysis, the real applied earthquake force is not considered and there is just some percentage of maximum credible acceleration (MCE) supposed with an engineering judgment, this percentage is selected by considering importance of the structures in the site and experiments from the structures in site which had been exposed to earthquake before. In designing earth structures, semi-quasi analysis is usually done for two seismic levels with different allowable factor of safety; maximum design level (MDL) and design base level (DBL). In order to propose values of lateral acceleration for semi-quasi method Seed developed wide range of researches on low and medium height embankments (Table 1).

Table 1. Seed proposed values of K_h for embankments [4]

EQ.magnitude	Design criteria
6.5	F.S.=1.15, K_h=0.1
8.25	F.S.=1.15, K_h=0.15

In addition Table 2 shows the values of $K_{h,}$ which were used for some of dam construction projects in various countries.

Table 2- k_h and minimum factor of safety in dam designing projects in different countries (Based on ICOLD report) [3]

Dam	Country	K_h	$F.S._{min}$
Aviemore	New Zealand	0.1	1.5
Bersemisnoi	Canada	0.1	1.25
Digma	Chile	0.1	1.15
Globocica	Yugoslavia	0.1	1
Karamauri	Turkey	0.1	1.2
Kisenyama	Japan	0.12	1.15
Mica	Canada	0.1	1.25
Mikasobo	Japan	0.12	--
Netzahualcoyote	Mexico	0.15	1.36
Oroville	USA	0.1	1.2
Tercan	Turkey	0.15	1.2
Ramganga	India	0.12	1.2

In this study, 0.14 was chosen as the coefficient of lateral acceleration (K_h) for semi-quasi analysis; this is the maximum value which has applied to the perspective site since 100 years ago within a 250 km radius of that. This value has appropriate accordance with Seed purposed values and common values of dam construction projects. The earthquake recurrence interval for an intense magnitude of 7.2 Richter was obtained about 75 years.

SITE INVESTIGATION

The accomplished in situ investigations are as follows:

- Preparation of topography plan for the site (See Fig. 5).
- Monitoring which will be discussed at next section.
- Geotechnical investigations were performed by excavating 7 exploration wells. The maximum depth of them was 29m and the overall length of them was 130m (See W1-W7 in Fig. 5). In these wells the UGWTL was monitored, the results of monitoring the variation of UGWTL in these wells are brought in Table 3.

Table 3. Variations of UGWTL in monitoring wells during the investigation

Stage (Date)	Days after 1st reading	*W1*	*W2*	*W3*	*W4*	*W5*	*W6*
		Head Wells Level(m)					
		165	*131*	*149*	*152*	*133*	*119*
2: 6/14/02	0	-17.48	-15.12	-10.42	-----	-----	-6.73
3: 6/28/02	15	-18.13	-15.16	-10.48	-11.64	-4	-8.39
4: 7/19/02	37	-18.15	-15.63	-11.18	-23.28	-4.15	-9.48
5: 9/3/02	81	-18.24	-16.45	-12	-23.5	-5.19	-10.8
6:12/26/02	195	-18.3	-15.07	-10.07	-23.55	-3.45	-9.3

In addition following tests was performed in those wells:

- Particle size analysis.
- Determination of Atterberg limits.
- Determination of natural moisture content and in some of fine grain layers, undisturbed specific gravity.
- Determination of organic contents (just in one weak layer).
- Standard penetration test (SPT) in fine grain layers.

MONITORING

To have a better concept of site movement, two types of surface and deep monitoring was performed. Surface monitoring consists of surveying monitoring and sequential measurements of surface cracks. Surveying monitoring was performed by establishment of the main sign on the nearby heights of the village and outside of the landslide zone (point O) and monitoring of 15 pillars that were installed on the outskirts of the village, at certain intervals (See Fig. 5).

In each read, the main sign was situated at point O and was attached to X, then by aiming all of the pillars, the coordinates of them was directly obtained. Reading the situation of pillars was performed through 6 stages during 6 months, from June 2002 to December. Reading the increase of the cracks' width on ground surface, between two fixed symbols, was done by metal meter which was installed on two sides of each crack. In those cracks on the walls, that two sides were fixed along each other, the width was measured by metal meter, but on those cracks that two sides were not along each other, the opening of two sides was measured by two grading bevels (See Fig. 3)[5].

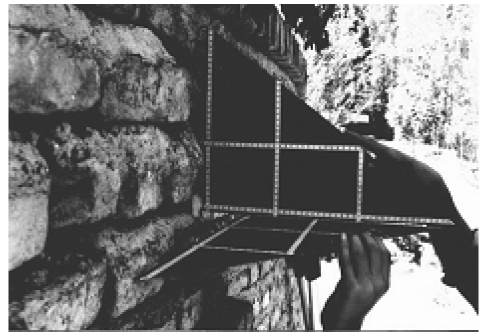

Fig. 3. Measurement of cracks width in two directions for those that have not been along each other.

In addition, underground monitoring was performed with simple methods like installing plaster plagues with dimensions $3 \times 5 \times 15$ cm between the joints of concrete frames. They were visited during monitoring period. From the rate of cracking and the relative movements of two sides, we could find out the relative movement of the soil mass in that depth (See Fig. 4) [5].

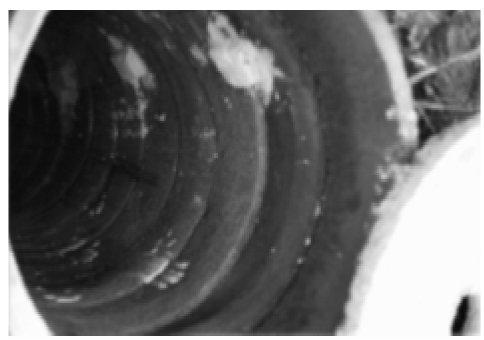

Fig.4. Plaster plagues between concrete frames inside the exploration wells.

Because of the limited period of monitoring and low speed of movements in the monitored region, the superficial cracks and underground investigations didn't show any sign of sliding. But surveying monitoring expressed a slow movement of the whole region toward the river. Directions of pillars' movements during the investigation period are showed in Fig. 5. Furthermore, some of the southern points in some stages sank into the soil mass. The extents of movements in monitoring points are illustrated in Fig. 6.

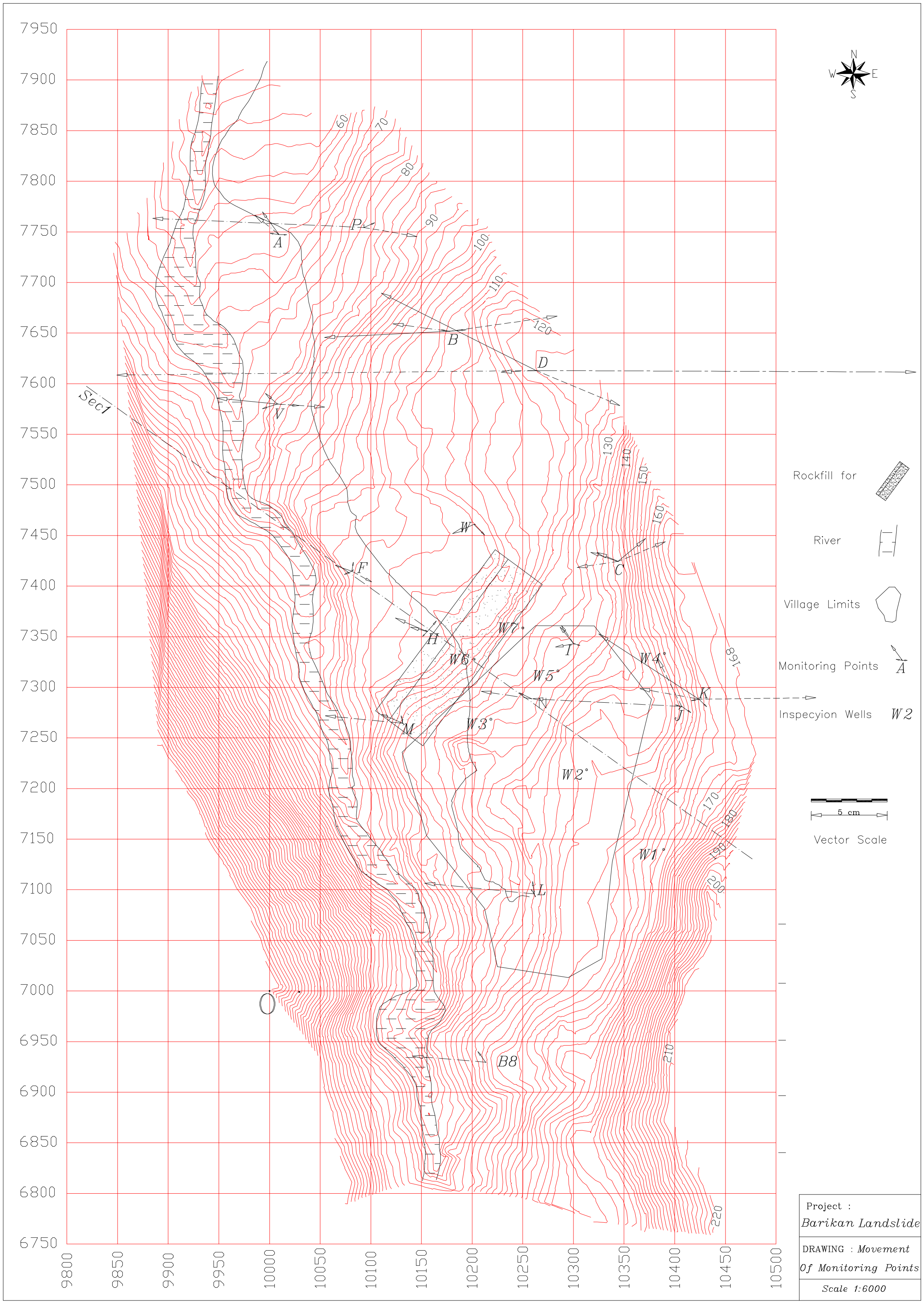

Fig. 5. Topography plan of the site, movement of pillars in sequential time stages, situation of exploration wells, village limits, and the section that the stability analyses were performed on it (Section 1).

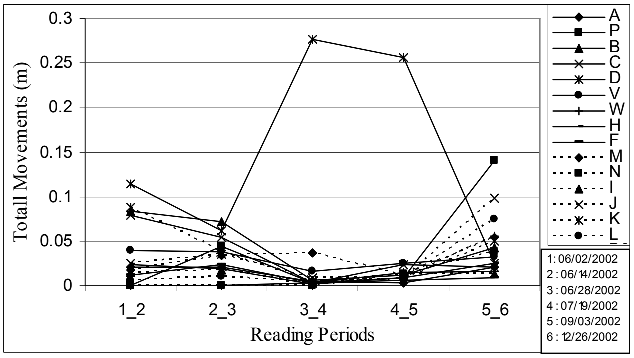

Fig. 6. Total movements of monitoring points during the investigation.

By comparing pillars' movements (Fig. 6) with the variations of UGWTL in the monitoring wells (Table 3), it can be inferred that decreasing the underground water table caused in reduction of the points' movements and increasing the underground water table led to further movements of the points.

STABILITY ANALYSIS

To perform a stability analysis of the region, a section was selected that passed from 3 monitoring points which were N, H and F, also the slope of this section was more than that of the other sections (Fig. 7 and Fig. 8). Considering the lack of data, the low depth of the exploration wells and the complexity of stratification of in situ soil; the most important stage of stability analysis was drawing the soil stratification and selecting their strength parameters. However, considering the unified classification method and the results of SPT tests, strength parameters were estimated in two consolidated and unconsolidated conditions (Table 4).

Table 4. Sample strength parameters of some of in situ soil layers

Layer No.	Unif. Classi.	γ_{wet} (kN/m3)		φ'_{Design} (Degree)		C'_{Design} (kPa)		$C_{uDesign}$ (kPa)	
		V.	S.D.	V.	S.D.	V.	S.D.	V.	S.D.
1	GC	20	0.5	36	2	27	2	---	---
2	CL	16	1	28	2	13	1.9	112	13
4	ML-CL	17	1	44	2	22	2	183	20
9	CL	16	1	28	2	13	1.9	112	13
10	CL-ML	17	1	34	2	22	2	183	20
17	CL	16	---	35	2	13	1.9	182	10
18	CL	18	---	28	2	13	1.9	32	2
19	---	18	---	(50<Bedrock)N_{SPT}					

V. value
S.D. standard deviation

For stability analyses, SLOPE/W program, from GEOSLOPE package ver.4, was used. This software can perform statistical analysis by Monte Carlo method. In this manner, for each of the resistance parameters and UGWTL conditions, a standard deviation is considered. The software draws the probabilistic distribution of factor of safety (F.S.) at critical sliding surface. Slope stability analyses were performed in two static and dynamic conditions. Stability analyses based on the assumption of earthquake occurrence were performed with three lateral accelerations, 0.05g (using EQ, this is the value that 95% of the earthquakes during past 100 years, within a 250 km radius of the site, has accelerated the site more than it), 0.9g (using EQ, this is the transmitted acceleration to the site during Manjil & Roudbar earthquake) and 0.14g (design base level). Regarding those values, the stability analyses were performed for each UGWTL condition which was monitored in exploration wells.
The results indicated that the slope is stable in static conditions. Although if UGWTL increases, part of the slope's toe will slide and will cause in surface and local sliding, but it can not cause in global instability of the site and F.S. will always be higher than 2. In earthquake conditions, at k_h=0.05, F.S. decreases to 1.3 but regarding to statistical analyses, probability of instability will be zero. At k_h=0.09, F.S. decreases to 1.15 and probability of the instability increases. Logically, stability analysis in this condition should indicate the instability of slope, which means that F.S. is less than 1 (in Manjil & Roudbar earthquake, instability was observed in village).

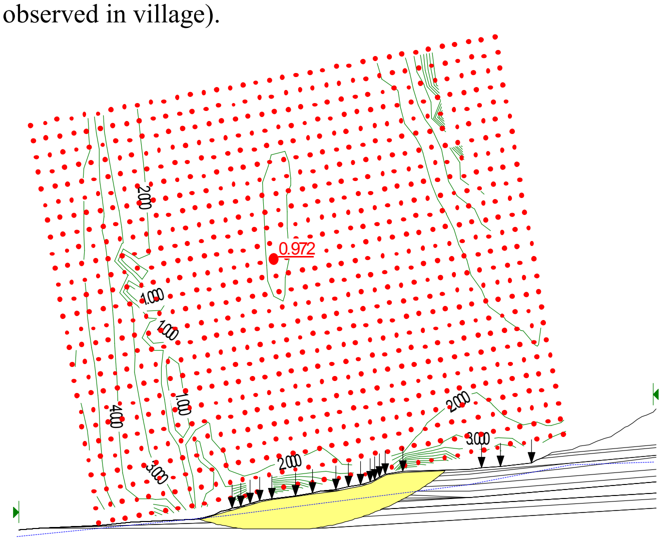

Fig. 7. A typical result of stability analyses in sec. 1.

One of the reasons of the fact that the F.S. is less than 1 is error in determining the in situ soil layers and/or natural error in stability analysis method. At k_h=0.14, F.S. in all UGWTL conditions decreases toward less than 1 and total instability occurs in the village. Variations of F.S. are in good conformity with the total movements of the points which means that, with decrease of the F.S., movements of the points increase and with increase of the F.S., movements decrease. Considering that in static conditions the F.S. of the village's slope is high (toward 2.3), we can not relate these invisible movements to instability of the village.

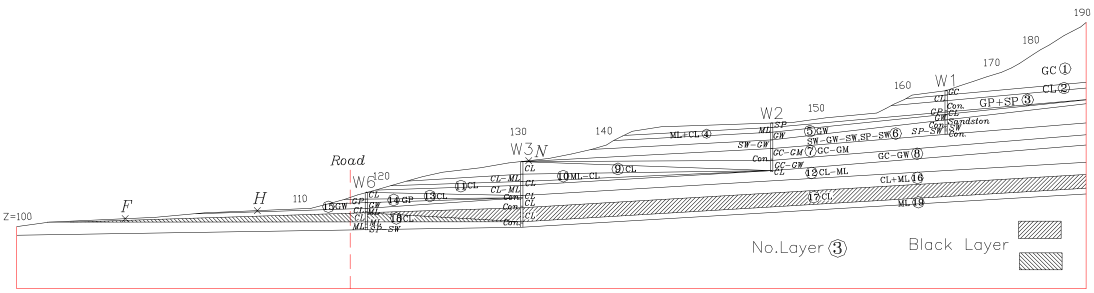

Fig.8. Ground stratification in section 1 (Section 1 in Fig. 5)

Table 5. Sample results of stability analysis in section 1

Water Level	F.S. (static)	F.S. (Semi-Quasi Analysis) k_h=0.05	k_h=0.09***	k_h=0.14****
IN(6/28/02)	0.31(100**)	1.29(0)	1.121(.037)	0.963(88.8)
dw1*=0.4 m	0.383(100)	1.211(0)	1.032(12.3)	0.908(99.7)
dw1=-1 m	2.506(0)	1.3(0)	-----	0.973(80.61)
dw1=-3 m	2.506(0)	2.224(0)	-----	1.829(0)

*Index of virtual variation of UGWTL based on variation of it in w1

**Probability of F.S.<1 based on Monte Carlo probability analyses.

***Mangil earthquake.

****Design earthquake.

The reasons that are mentioned below support the viewpoint that monitored movements can not demonstrate the instability of the village in static conditions and probably those are because of the creep phenomenon

A) The value of total movements of the points are in direct relationship with variations ofUGWTL, which means that with decrease of UGWTL, total movement of points decrease and with increase of that, total movements increase too (See Table 3 and Fig.11). By understanding the fact that when soil moisture increases the creep movement increases too, this assumption fortifies the thought that the monitored movements are the consequences of the creep phenomenon.

B) In farther distances from the points in higher levels, which are on thicker fine grain layers, the total extent of the points' movements decreases (See Fig. 5). Considering that the creep mechanism is relevant in fine materials, this also fortifies the thought that the monitored movements are due to creep phenomenon.

C) According to the classification made by Varens et al. the registered movements of the points are involved in the range of extremely slow movements (See table 6)[6].

Table 6. Landslide classification based on their sliding velocity

Old classification (Varens,1978) Velocity	Value in mm/sec	New classification (WP/WLI, 1994) Vel. Class	Description Of velocity	Examples (Table2)	Velocity limits	Value in mm/sec
		7	Extremely rapid	1-8[2)]		
3m/sec	3.10^{3}	------	--------------------	----------	5m/sec	5.10^{3}
600[1)]		6	Very rapid	8[2)]-9	100[1)]	
0.3m/min	5	------	--------------------	----------	3m/min	50
288		5	Rapid	10-11	100	
1.5m/day	17.10^{-3}	------	----------	----------	1.8m/hour	0.5
30		4	Moderate	12-14	100	
1.5m/month	$0.6.10^{-3}$	------	--------------------	----------	13m/month	5.10^{-3}
12		3	Slow	15-17	100	
1.5m/year	48.10^{-6}	------	--------------------	----------	1.6m/year	50.10^{-6}
25		2	Very Slow	18-22	100	
0.06m/year	$1.9.10^{-6}$	------	--------------------	----------	16mm/year	$0.5.10^{-6}$
		1	Extremely Slow	23-24		

1) Conversion factor between low and high velocity limits.
2) According to limits in Table 1.

STABLIZATION AND TREATMENT METHOD

First, a number of possible methods, that would be practical in case of earthquake occurrence, were investigated and then the best method, the most executable and economic method, was selected and discussed.

The methods are as follows:

- Geometrical modification of the slope
- Surface and under ground water drainage
- Mechanical stabilization methods like retaining walls and piling
- Loading on the slope's toe

Because of the residential utilization and slow slip of the village, geometrical modification of the slope is not possible. This method can be used to stabilize the non-residential areas like the slopes lying to the north of the village.

As we can understand from the stability analyses (Table 5) that the decrease in UGWTL won't contribute neither to increase the F.S. nor to stabilize the area while the water level has not reached the surface of the weak layer. Decreasing UGWTL to below the weak layer, needs advanced technology which is neither wise nor economic in comparison with the "best" approach. Besides, decreasing the water level to such a low level, will also dries the wells which are needed to obtain adequate water both for drink and agriculture, and that will ruin the lives of the villagers. We should not also forget that decreasing the water level to such a low level will cause a great change in the ecology of the region and hence will lead to further biological and environmental problems.
Utilizing the gravity retaining walls is not possible in case of a slide in such extension. This approach is usually used in small slopes with little height or in road constructions. Sewing two sides of the weak layer via a pile is not possible as well, therefore that is not accepted because of the following reasons:

- The high concentration of the houses will cause problems.
- If a pile gets broken, because of a sudden load, there is no way to fix the broken pile.
- There is no economic explanation to use this approach, compared with the "best" approach.

The "best" approach is loadingo n the toe of the slope by establishing an embankment with a height of approximately 8m, and a platform with about 30m length and a 2H: 1V slope at the toe of the residential region of the village with a length of about 200m. In this method, the F.S. of the slope will increase to 1.151 at most, in the worst situation which can be imagined for UGWTL.

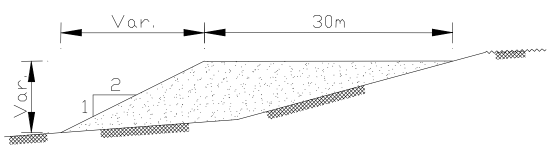

Fig. 9. Section of embankment (See location of embankment in Fig. 5)

The reasons, that demonstrate the cause of choosing this approach as the best method, are as follows:

- Existence of enough non-residential space for earth filling and the low cost of terrain in this area.
- Easy portage of materials from the river to the site in a distance which is only about 1.5km.
- The possibility of repairing, in case of earthquake occurrence with more intensity than the design earthquake.
- In case of more extended investigations, if the embankment should be identified as to be a weak one, it could easily be fortified.

CONCLUSIONS AND SUGGESTIONS

In spite of people's complaint about the movement of the earth and the damages that it has caused, the stability analyses demonstrate the complete stability of the village in the static situation. The monitoring carried out during 8 months doesn't show any significant movement related to a landslide. The variations in UGWTL cannot also cause any instability in the area. Thus, it seems that the reason of the movements of the village, which are occurring every once in a while, is the effect of the dynamic loads of either the mild in site earthquakes or the earthquake occurrence far away from the village, which cause in decrease of the F.S. of the village against the slides and makes the movements severe.
In order to site stabilization, the method of loading on the toe is suggested. Considering that the materials are available near the site and that the areas around the slope's toe are non-residential, this approach seems to be the most economic and the most applicable approach to stabilize the village.
Based on the experiences achieved in this study, the followings are suggested:

1- In the regions in which, the goal of the study is stabilizing the area, it is the most proper method to utilize monitoring wells, which are caved by automatic machines, to perform a geotechnical study. It is important to use precise caving machines, because by using these machineries it would be possible to obtain the intact and non-intact species to reach the precise characteristics of the in situ soil, they can also be used to determine the UGWTL and to utilize precise apparatus such as inclinometers so as to monitor the underground situations. Besides, by increasing the work speed, the working period will be reduced as well, and it can be an important factor to make the project economic.
2- In regions like Barikan, in which from the beginning, the evidence indicates that the earth has a slow movement, using methods with little precision has no result except wasting time, energy and money and thus they should be avoided. Also, using methods with little precision in monitoring of the superficial cracks are of the same sort.
Considering the low cost of the study, compared with the high cost of stabilizing, utilizing the most precise devices is suggested, for example, using the precise methods of geodesy in surveying monitoring or using accurate devices like inclinometers and extensometers can reduce the study period and increase the accuracy of the study. In addition, using inaccurate devices can make errors in conceiving the behavior of the slope and thus lead to wasting the time and money.

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