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Evaluating the effect of biological stabilization on landslide control at the edge of forest road

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Abstract

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Landslide is one of the negative sides of building non-standard roads in forest areas. The aim of the present study was to assess the effect of biological stabilization on landslide at the edge of forest roads in south and north aspects. For this purpose, in Neka forest (Mazandaran province) three treatments including control, sliding and stabilized areas covered by 35-years-old even-aged alder trees were selected. Benchmarking and soil sampling were conducted during three periods including July, November after rainfall events and March after rainfall events. The results showed that the mean movement of landslide in north direction was 9 cm, while this value was 6 cm in south direction. Sliding in north direction was 32% more than that in south direction. Biological stabilization by alder in north and south direction caused a 33 and 66% reduction in landslide movement, respectively. The characteristics of soil mechanics were different between stabilized and sliding areas. Besides, the soil texture in north direction for control and stabilized areas was clay with high liquid limit (CH) and for sliding area it was clay with low liquid limit, while this value in south direction was CH for three treatments of control, stabilized and sliding areas. To plan biological stabilization, the mechanical characteristics of soil, site features, and appropriate plant species should be considered as important factors.

Keywords: sliding area; stabilized area; alder trees; soil mechanics; benchmarking

Forest roads are the most eminent means of access to forest (Leung et al. 2015). Besides, these roads are constructed in order to provide sustainability and access to forest lands for managing activities, utilization, wood transportation, forest conservation and forest planning (Hasmadi et al. 2008). Landslide in various aspects of forest roads causes direct and indirect damage such as restrictions on forest management and utilization, and habitat destruction and degradation (Ashish Kumar 2010). Roads increase landslides 25 to 350 times on steep and unstable lands in comparison with undisturbed forest lands (Allison et al. 2004; Eker, Aydin 2014). In general, land movements and especially landslides are an integral part of any deformation of land in steep slopes (Ashish Kumar 2010). Scientific and comprehensive study of landslide phenomena is the most important issue in the world due to its environmental, safety and economic reasons (Indraratna et al. 2006;

Pollen 2007). Main and detour roads of mountainous regions are among the most sensitive factors in all projects and lack of attention to this issue will result in irreversible damage (Preti et al. 2010; Rees, Ali 2012). Therefore, bioengineering is one of the most effective ways to stabilize the long and steep slopes which is affordable (Lewis et al. 2001). The mechanism of this method is the use of vegetation to reduce instability and erosion.

Vegetation can improve the strength of slopes prone to instability through root reinforcement (de Brito Galvão et al. 2010). Voottipruex et al. (2008) reported that Vetiver grass roots increased the soil strength 1.5 times and Acacia tree roots increased the soil shear strength 3 times. Plant roots reinforce the soil by increasing the soil-root friction and cohesion and consequently improving the soil shear strength (Operstein, Frydman 2000; Schmidt et al. 2001; Reubens et al. 2007; Stokes et al. 2009; Abdi et al. 2010). Various studies have been conducted in different parts of Iran (Ahmadi, Talebi-Esfandarani 2002; Abedi et al. 2010; Hosseini et al. 2011; Nazari et al. 2011). These studies have shown the significant factors such as liquid and plastic limits in sliding areas. Lako and Marko (2012) showed that slope and human interference are the important factors in soil degradation; Saiful Iskandar et al. (2012) indicated that moisture had a direct impact on the physical properties of soil; Leung et al. (2015) concluded that shrubs had more appropriate root systems than trees for soil sustainability in steep slopes. In northern forests of Iran, alder species are naturally established on landslide areas because of their environmental adaptability and ability of nitrogen fixation. It was reported that the root density in *Alnus subcordata* C.A. Meyer decreased with the increasing depth. Tensile strength is decreased with the diameter of roots following the power function with an average of 16.29 MPa (Maleki et al. 2014). In biological stabilization of soil it is necessary to know the changes in soil mechanics, landslide movement and ability of trees to enhance the mechanical reinforcement of soils. Studying the soil mechanics in the north of Iran due to its mountainous features is an economically and environmentally significant factor. Hence considering this value can help the managers to construct the most appropriate road based on land capability. The aim of the present study was to assess the effect of biological stabilization on landslide control at the edge of forest roads in south and north geographical directions.

MATERIAL AND METHODS

Study area. The present study was conducted in a forestry plan in the Hyrcanian zone of Iran (Neka Forestry Management). Neka forest is very susceptible to landslide and areas with signs of creep can be frequently detected. The northern part of Neka forest is located from 36°25'N to 36°30'N and from 53°30'E to 53°45'E. Mean annual rainfall in this region is 96 mm, ranging from 39 to 154 mm. Three parcels with areas of 74.61 and 51 ha were selected as control, sliding area and stabilized area in the northern part, respectively. The southern part is located from 36°26'N to 36°29'N and from 53°30'E to 53°45'E with similar rainfall properties to the northern part. Elevation of the study area is 500–600 m a.s.l. Other factors such as geology, physiography, soil, etc. were the same in both northern and southern aspects. Three parcels with areas of 61.44, and 39 ha were used as control, sliding and stabilized area, respectively. Alder (*A. subcordata*) trees were naturally established on the landslide area 35 years ago. So, both stabilized areas were even-aged with the mean density of 190 trees per hectare and volume of 300 $m^3 \cdot ha^{-1}$.

Landslide analysis. A sliding area was selected at the edge of forest road. Then, the movement points were benchmarked on a straight line to determine the displacement. In addition, a stabilized area by alder trees was selected and the movement points from a line with given distance and angle perpendicular to the longitudinal axis were determined. The points of 5 m distance were selected on lines and their elevation was recorded (Ahmadi, Talebi-Esfandarani 2002; Abedi et al. 2010). The longitudinal variations of landslide were studied at three periods based on dry and wet seasons using the elevation and slope. The benchmarking was conducted to determine the type of movement based on Amberg climograph during three periods including July, November after rainfall events and March after rainfall events. After measuring and recording the point data at three studied periods, the horizontal movements of benchmarks were determined (Fig. 1). Some soil mechanic properties including liquid limit, liquid index, plastic limit and plastic index were analysed in stabilized and landslide areas by collecting 10 samples based on a systematic randomized sampling method.

Measurements of soil mechanics. Soil moisture content, Atterberg limits and hydrometer analysis were done. The liquid and plastic limits were determined using Casagrande method. To determine the particle size distribution, sieve and hydrometer

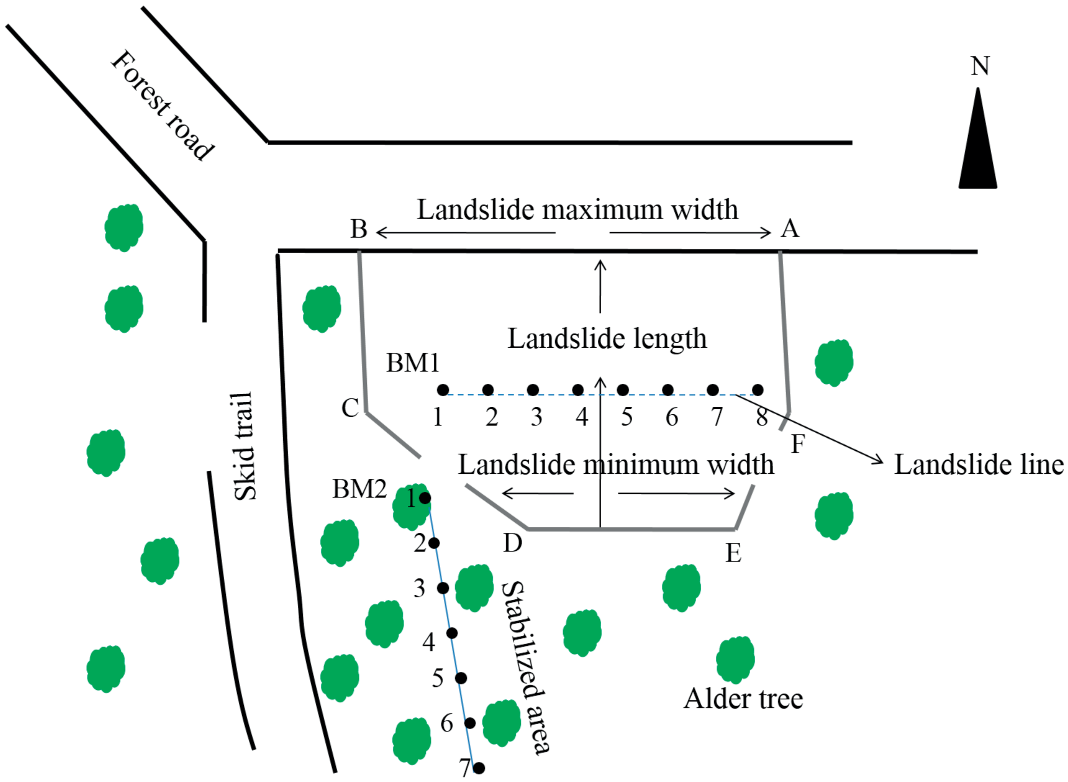

Fig. 1. Schematics of the sampling design in stabilized and landslide areas

BM1, BM2 – benchmark 1, 2

analyses were conducted; sieve for large granules and hydrometer for small granules. SPSS software (Version 21, 2016) was applied to statistical analyses, and the Kolmogorov-Smirnov test was used to evaluate the normalization. After that, the movement in sliding and stabilized areas was studied using the *t*-test.

RESULTS AND DISCUSSION

The horizontal movement during the measuring periods in sliding areas is presented in Table 1. In north direction, 6 points were marked so that the maximum movement belonged to bench mark 5 (16 cm) and the mean movement of benchmark was 9 cm. This value in south direction in the second and third sampling was higher than in the first one. The total mean of point movement was 6 cm. The results showed that the movement in north direction is 32% higher than in south direction.

The horizontal movement based on differences in measuring periods in the stabilized area is shown in Table 1. The mean movement of benchmark was 6 cm. Among 7 benchmarks in the southern stabilized area, benchmark 2 showed the maximum movement (8 cm). The mean movement of all

Table 1. The horizontal movement of points in three periods of benchmarking (cm)

No.	North			South		
	AB	BC	AC	AB	BC	AC
Sliding areas						
1	4	4	8	4	4	8
2	0	4	8	0	4	4
3	4	4	8	0	4	4
4	4	4	8	0	4	4
5	8	8	16	0	8	8
6	4	4	8	4	4	8
7	–	–	–	0	8	8
Mean	4.0	4.7	9.3	1.1	5.1	6.3
Stabilized area						
1	0	0	0	4	0	4
2	4	4	4	4	4	8
3	4	4	8	4	0	4
4	0	4	4	0	0	0
5	0	8	8	0	0	0
6	4	4	8	4	0	4
7	4	4	8	0	0	0
8	0	4	4	–	–	–
Mean	2.0	4.0	5.5	2.3	0.6	2.8

AB – horizontal movement in the first and second sampling, BC – horizontal movement in the second and third sampling, AC – horizontal movement in the first and third sampling

Table 2. Comparison of the movement in sliding and stabilized areas according to the *t*-test

Variable	Mean	SD	*t*-Value	*df*	Significance
Movement in sliding area (cm)	14.83	8.83	1.68	11	0.12
Movement in stabilized area (cm)	22.92	2.15	10	13	0.00

SD – standard deviation, significant difference at a 95% level

benchmarks was 2 cm. The results indicated that the movement in south direction is 95% less than in north direction. The area, length and width of the case study region have differences that are not effective in outputs. The mean movement in the northern sliding area is 9 cm and in the southern sliding area it is 6 cm. The sliding movement in similar areas in north direction is higher than that in south direction (32%). Hence, the geographical direction is effective in landslide, which is similar to results obtained by Moradi et al. (2007).

The results showed that there was no significant difference in the amount of movement between south and north for the sliding area at a 95% confidence level, while a significant difference was found for the stabilized area (Table 2).

The features of soil mechanics and its texture and grading in north direction are presented in Tables 3 and 4. The results indicated that soil moisture increased with the increasing depth. The soil texture in control, stabilized and sliding areas is clay with high liquid limit (CH), CH and clay with low liquid limit (CL), respectively. North direction due to its higher moisture has a higher volume of clay minerals, which is consistent with results obtained by Pourghasemi et al. (2007) and Hosseini et al. (2011). In addition, the movement of benchmarks between the second and third sampling is higher than in the other samplings due to the rainfall in the months of November and March. Although both south and north directions were covered by alder for biological stabilization, alder was more affected by south direction. It can be so because this is a light-demanding species which is more success-

Table 4. The characteristics of soil grading and texture in north direction

Area	Depth (cm)	Small particles (%)	Large particles (%)	Texture
Control	20–30	98.1	1.9	CH
	70–80	78.8	21.2	CH
Sliding	20–30	85.7	14.3	CL
	60–70	84.0	16.0	CL
Stabilized	20–30	98.0	2.0	CH
	60–70	96.0	4.0	CH

CH – clay with high liquid limit, CL – clay with low liquid limit

Table 3. The characteristics of soil mechanics in north direction

Area	Period	Depth (cm)	LL (%)	PL (%)	LI	PI	Moisture (%)
Control	1	20–30	55	29	0.15	26	24.9
		70–80	44	18	0.02	26	18.5
	2	20–30	51	27	0.11	24	29.7
		70–80	44	22	0.11	22	21.7
	3	20–30	35	15	0.23	20	39.7
		70–80	29	10	0.17	19	23.3
Sliding	1	20–30	38	17	0.01	21	27.4
		60–70	34	14	0.11	20	23.2
	2	20–30	38	17	0.08	21	28.8
		60–70	38	17	0.15	21	24.2
	3	20–30	37	16	0.29	21	34.2
		60–70	38	17	0.28	21	26
Stabilized	1	20–30	50	26	0.22	24	20.7
		60–70	36	16	0.03	20	15.3
	2	20–30	60	33	0.09	27	23.4
		60–70	50	26	–0.1	24	21.5
	3	20–30	64	37	0.1	27	35.6
		60–70	45	23	0.08	22	24.9

LL – liquid limit, PL – plastic limit, LI – liquid index, PI – plastic index

Table 5. The characteristics of soil mechanics in south direction

Area	Period	Depth (cm)	LL (%)	PL (%)	LI (%)	PI (%)	Moisture (%)
Control	1	20–30	53	28	–0.31	25	20.23
		70–80	44	22	–0.19	22	18.38
	2	20–30	62	35	–0.24	27	28.30
		70–80	65	38	–0.40	27	24.60
	3	20–30	56	30	0.10	26	34.10
		70–80	48	25	0.07	23	26.80
Sliding	1	20–30	58	30	–0.31	28	21.11
		60–70	52	27	–0.28	25	19.97
	2	20–30	66	39	–0.38	27	28.70
		60–70	54	29	–0.22	25	23.50
	3	20–30	55	30	0.19	25	34.90
		60–70	50	26	–0.05	24	24.60
Stabilized	1	20–30	63	35	–0.28	28	27.13
		60–70	60	32	–0.23	28	25.38
	2	20–30	75	46	–0.28	29	37.70
		60–70	67	39	–0.22	28	32.70
	3	20–30	66	38	0.10	28	40.90
		60–70	59	33	0.08	26	35.20

LL – liquid limit, PL – plastic limit, LI – liquid index, PI – plastic index

ful in the southern areas. There is a difference between control and stabilized areas between south and north directions. In addition, the southern stabilized area has more moisture than the northern stabilized area because alder is a light-demanding species (Marvie Mohadjer 2006).

The results of soil mechanics in south direction showed that moisture increased with the increasing depth (Table 5). Besides, the soil grading and texture analyses indicated that the soil texture in three control, sliding and stabilized areas (treatments) is CH (Table 6). The small particle percent in the studied soil is high. Small particles absorb a large amount of water and reach a higher volume which will be significantly reduced in the course of drying. The high quantity of small particles has adverse impacts on the road in a long time. It increases the soil volume and compaction and decreases the pores which will be more vulnerable to vehicles. This finding is similar to that of Feiznia et al. (2001) and Coe et al. (2003). The liquid index and plastic index and soil moisture have proved the reasons of soil movement and changes from plastic to liquid phase. The analyses of soil mechanics show that soil moisture decreased with the increasing depth. This value in the control area documents that surface soil has clay with high liquid limit (LL) and deep soil has clay with low plastic limit (PL). Hence, the LL and PL have higher values on the surface, and also the moisture increased from first to third sampling.

Table 6. The features of soil grading and texture in south direction

Area	Depth (cm)	Small particles (%)	Large particles (%)	Texture
Control	20–30	97.6	2.4	CH
	70–80	98.4	1.6	CH
Sliding	20–30	86.3	13.7	CH
	60–70	95.9	4.1	CH
Stabilized	20–30	96.3	3.7	CH
	60–70	98.2	1.8	CH

CH – clay with high liquid limit

CONCLUSIONS

The measurements of mean horizontal movement in stabilized area, sliding area and control area have been carried out in northern and southern aspects. When the alder trees grow in the sliding area, they tend to prevent the landslide due to the wide ground coverage of their crowns and root depth. They create a dense land cover and a network of root systems that significantly reduce the landslide movement. 35 years after natural establishment, soil mechanics changed from CL to CH. Since the efficient and practical researches in forests especially forest engineering have a large range, doing such researches needs more attention and consideration. The sliding value in north direction of forests in the north of Iran is higher than that in south direction. Hence planning and constructing the forest roads need more attention technically. Bioengineering is a reasonable and economic way to decrease the cost of road maintenance and ensure the appropriate characteristics of roads based on a close-to-nature approach. Due to its use of local materials, bioengineering is one of the most appropriate methods for reinforcing the slope regions as protection from erosion.

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