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Evaluating the effects of physiographic parameters on the road cross section in mountain forests (Case study: northern forests of Iran)

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ABSTRACT: Road cross section, as one the main effective factors in relation to fill and cut volume, was effective in costs and disturbance of forest road constructions. In this research, the effect of a few physiographic parameters on forest road cross section was evaluated. For this purpose, 192 cross sections on forest roads were delineated selectively in mountain forests in the north of Iran. The physiographic factors including elevation, hillside slope, slope aspect, rock base, and soil texture as well as cross section width were measured. After evaluating the data in terms of normality and homogeneity, it was analysed by Spearman's and Pearson's correlation tests using SPSS20. One-way ANOVA, two-way ANOVA, and Duncan grouping tests were used to determine the effect of the above-mentioned factors both separately and simultaneously. Results showed that the parameters including hillside slope, rock base, and soil texture had a significant effect. Elevation was recognized as a regional parameter due to the lack of any relationship with cross section. There was no significant relation between slope aspect and cross section. The hillside slope was defined as the most effective parameter on the cross section.

Keywords: hillside slope; rock base; soil texture

Among the indicators of development in each country are the quantity and quality of the road network, especially in the areas of road and rail transportations (Ariel, Gucinski 2000). Construction and maintenance of roads in the forest as an economic renewable source and as an influencing factor on other activities as well as human life are obviously rational and clear. The forest road network provides accessibility to different parts of forest to conduct forest management activities such as fire protection, managing pest invasions and illegal logging as well as marking, forest planting and logging (Majnounian et al. 2010). Forest roads are also used to transport raw materials, personnel and equipment as well as to communicate between villages and cities, thus forest roads are of high importance from the point of view of social, economic and cultural perspectives (Erdas et al. 1995). Meanwhile, due to the huge costs associated with the construction and maintenance as well as negative effects on forest soil because of soil degradation and displacement, constructing forest roads is of high sensitivity in terms of economic, environmental aspects and also public opinion (Tan 1992). The most effective parameter in relation to the volume of cut and fill operations and the cost of forest roads is cross section which represents the horizontal field width perpendicular to the road direction comprising the area beginning at the upper point of cut-slope and ending at the lowest point of fill-slope (Sarikhani, Majnounian 1994; Ryan et al. 2004) (Fig. 1). Road cross section may be affected by different conditions of physiographic parameters including hillside slope (Sedlak 1983; Potocnik 2003), rock base (Hay 1996; Potocnik 2003), slope aspect, elevation, and the soil texture (Hosseini et al. 2010). Increasing the cut and fill slope length had a significant influence on the earthwork width. The earthwork width increased with an increase in the hillside gradient. The road bed width decreased with increasing hillside gradient because of soil instability in steeper slopes (Parsakhoo et al. 2009). Elevation may also affect cross section, as precipitation amount and type at different heights vary depending on different properties such as humidity and soil moisture regime, and hillside stability, and these changes, in turn, cause changes in the angle of cut-slope and fill-slope. The slope aspect likely causes the angle of the cut-slope to decrease or increase by influencing the moisture content and the stability of hillsides. The amount of rock and soil stones as a hardness index of construction exerts a direct effect on road cross section so that by increasing soil hardness and rockiness the angle of cutting and filling trenches will increase relative to the road surface, consequently the horizontal distance of trenches will change (Anonymous 1998). In soft and moist soil, this angle and the distance increase, in turn causing the cross section to increase.

In this regard some researches have been carried out as follows:

Gorton (1985) found in German forests that the length of the fill slope was about 3.5, 12 and 22 m for hillside gradients of 45, 60 and 70%. Also, an angle of repose for side-cast material was about 37° and on slopes of over 75% the fill cannot be established at all. Fill slope plays an important role in the overall aesthetic value of road templates.

In evaluating the effect of topography on forest road construction in Finland, Hay (1996) assessed factors such as hillside slope; bedrock and soil rupture strength are concluded that the hillside slope is the most important factor in designing the forest roads.

Sedlak (1983) stated that increasing the hillside slope, the width of right-of-way increases and he suggested the standard right-of-way width of 11, 13, 15 and 19 m for slope classes of 30–40, 40–50, 50–60 and 60–70%, respectively. In a study Potocnik (2003) assessed rock base and hillside natural slope as some factors influencing the road formation width, and results showed that the road formation width could increase up 80% more on a steeper terrain (compared to a gentle terrain slope) and 20% less on a solid rock base regardless of the terrain slope. It varies between 5.4 m (solid rock base, gentle slope) and 11.4 m (soft rock base, steep slope).

Hosseini et al. (2010) showed that by decreasing the hillside slope and aggregate diameter, the cutting becomes easier and where the soil is soft and the hillside has a gentle slope, compared to rocky areas, the damage caused by cutting is greater. A review of the literature shows that the effect of these parameters on the cross section has been studied separately but the effect of a few probably effective parameters has not received enough attention. The aim of this study was to evaluate the effect of the above-mentioned parameters on cross section on forest roads.

MATERIAL AND METHODS

Study area. This investigation was carried out in districts 1 and 2 of Mountain forests, watershed 50, Mazandaran province of Iran. The research area is located at 36°30'N and 52°10'E, this region is situated in the central part of the northern margin of the Alborz Mountains and is a part of the Hyrcanian forests. Mean annual precipitation in the region is 818.8 mm and soils in the study area, based on experimental results and percentage of minerals, which have originated from calcareous bedrock materials mainly limestone marl, are sandy silt, and predominantly are deep to moderately deep soils. The study area totally has approximately 20 km of forest roads of grades 2 and 3. The newest roads were constructed 2 years ago, while the oldest roads have over 20 years of lifetime.

Collecting information. In order to conduct this research, the road cross section and physiographic factors, including hillside natural slope, slope aspect, elevation, rock base and soil texture were measured in one-way and grade 2 forest roads. This information was measured in 192 profiles. Natural hillside slope was measured in terms of percentage and was classified in classes, namely 0–15, 15–30, 30–45, 45 to 60 and > 60%. To evaluate the role of elevation and slope aspect, the study area was classified to four elevation classes, namely 150–400, 400–600, 600–800, and 1,000–1,200 m in terms of elevation, and it was divided into four aspect classes as northern, southern, eastern and western aspects. Also the amount of rockiness in each profile was determined as soft, medium and hard classes (Ghajar et al. 2012). To study the soil in each profile, 2–3 soil samples were taken from a depth from 0 to 20 cm using an auger outside of the construction boundaries where the soil was undisturbed. These samples were classifieds in sandy loam, loam, clayey loam and clayey classes (Shahoei 2007).

Data preparation and statistical analysis. After data collection, SPSS 20 (SPSS, Tulsa, USA) was used for statistical analysis and the Kolmogorov-Smirnov and Leuven tests were used to check the normality and homogeneity of data, respectively. The correlations between the parameters with each other were assessed, then the correlations between the cross section with parameters including the hillside slope, elevation, slope aspect, rock base and soil texture were evaluated. Correlations in quantitative and qualitative data were determined using Pearson's and Spearman's correlation tests, respectively. Since each of these parameters has different roles, so their influences on the cross section will be different. One-way ANOVA was

Table 1. Correlation between the studied parameters

Parameter	Hillside slope		Rock base		Soil texture	
	R	Sig.	R	Sig.	R	Sig.
Elevation	0.423**	0.000	0.319**	0.000	0.423**	0.000
Hillside slope	–	–	0.478**	0.000	0.006	0.935
Rock base	–	–	–	–	–0.181*	0.020

used to determine the effect of each of these factors, while two-way ANOVA was used to assess the means of cross section by two variables simultaneously. Duncan's test was employed to evaluate the change in the average of cross section in different classes of parameters as well as different composition groups.

RESULTS

Correlation and analysis of variance

Results showed that there was a significant positive correlation between the elevation and hillside slope at a significance level of 1%. Also there is a significant correlation between hillside slope and rock base at a significance level of 1% so that the area becomes rockier by increasing the slope (Table 1).

The results revealed that the parameters hillside slope and elevation had significant positive correlations with the cross section operations ($P < 0.01$). Also, rock base had a significant negative correlation with cross section so that by increasing the rock base the cross section decreased. Also, there was a significant negative correlation between soil texture and cross section ($P < 0.01$), so by decreasing the soil particle, the size of cross section increased. No significant correlation was found between slope aspect and cross section (Table 2). ANOVA and Duncan grouping tests were used to better assess this correlation.

Results of ANOVA showed that the road cross section was significantly different between different classes of slope, elevation and rock base ($P < 0.01$), whereas between different classes of soil texture it was significantly different ($P < 0.05$). No significant difference was found between cross section and aspect classes (Table 3). According to the results of Duncan grouping test, the slope classes of 45–60% and > 60% had the highest cross section and the slope class of 0–15% had the lowest cross section, and the remaining classes occurred between these two extremes (Fig. 1a). In grouping the parameter elevation, the class 600–800 m showed the highest cross section while the classes 150–400 m and 1,000–1,200 m indicated the lowest cross section, and the class 400–600 m had the intermediate condition (Fig. 1b). In the case of slope aspect, all the classes were classified in the same class (Fig. 1c). The results of grouping in rock base showed that soft class had the highest cross section and hard class had the lowest cross section, and the medium rock base exhibited the intermediate condition (Fig. 1d). In the case of soil texture parameter, it was found that soil texture classes of clayey and clayey loam had the highest cross section but loam and sandy loam classes showed the lowest cross section (Fig. 1e).

Table 2. Correlation between the studied parameters and the road cross section

Parameter	Road cross section	
	R	Sig.
Hillside slope	0.491**	0.000
Elevation	0.292**	0.001
Rock base	–0.385**	0.006
Slope aspect	–0.148	0.212
Soil texture	–0.258*	0.015

Table 3. Result of the analysis of variance for parameters in road cross section

Parameter	Road cross section	
	F	Sig.
Hillside slope	7.910	0.004
Elevation	4.069	0.008
Rock base	4.530	0.039
Slope aspect	1.255	0.291
Soil texture	2.950	0.040

Interaction

The two-way ANOVA test showed that the interaction of two parameters slope aspect and rock base with cross section is significant (Table 4). The interaction of these two parameters showed that by increasing the rock base, the average cross section increased in all slope classes. In areas with soft

Table 4. Result of the analysis of variance (two-way ANOVA) for hillside slope and rock base parameters in road cross section

Parameter	Road cross section	
	F	Sig.
Hillside slope	5.650	0.000
Rock base	2.917	0.005
Hillside slope (rock base)	2.650	0.034

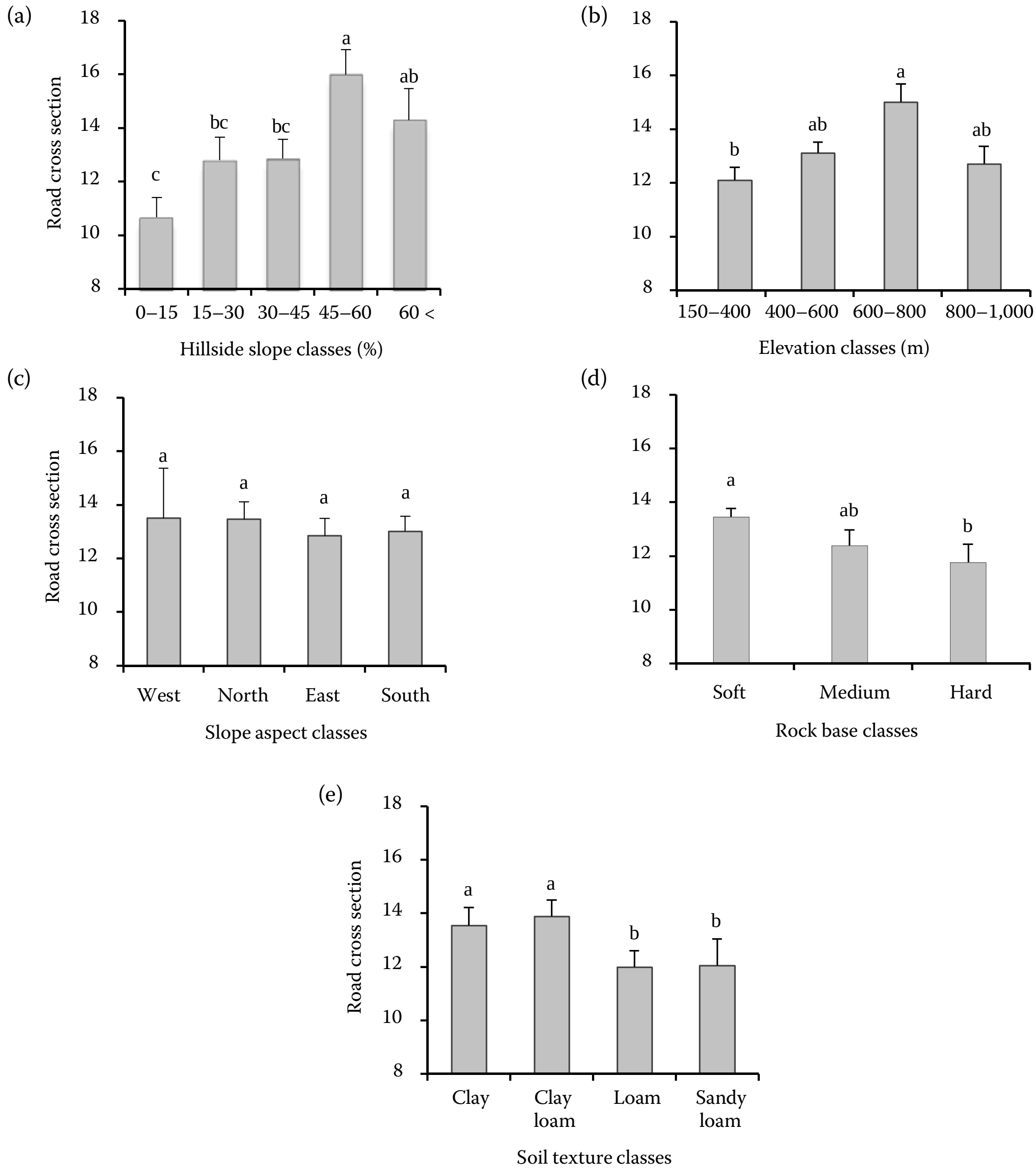

Fig. 1. Average road cross sections according to classes

and medium rock bases it was observed that by increasing the hillside slope to 60% the cross section increases while above this value (60%) the width decreases. In rocky areas, by increasing the slope to 45%, the cross section increases, then above this value the cross section decreases (Fig. 2). Results of Duncan's test in different composition groups of the two parameters of hillside slope and rock base classes showed that in soft and medium classes of the rock base there is a significant difference between the average widths of construction operations in different slope classes, so that the classes 45–60 and 0–15% had the highest and the lowest road cross section, respectively, with other classes as intermediate. In the study area, there was no significant difference between the averages of cross section in different slope classes (Fig. 3).

The two-way ANOVA test showed no significant interaction between slope and soil texture at a significance level of 5% (Table 5). The diagram of in-

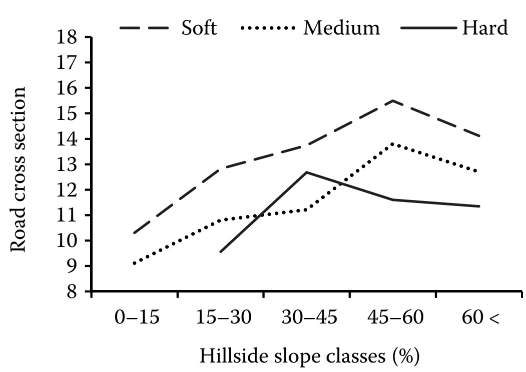

Fig. 2 Interaction of two parameters slope aspect and rock base with road cross section

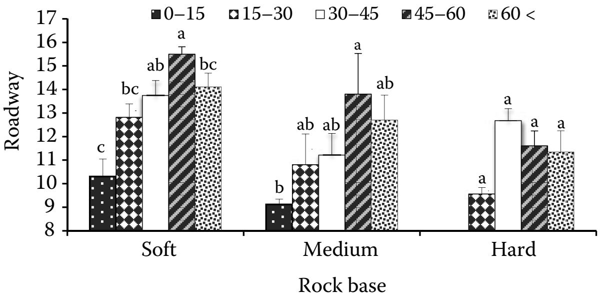

Fig. 3. Average road cross sections according to hillside slope and rock base in various classes of forest roads

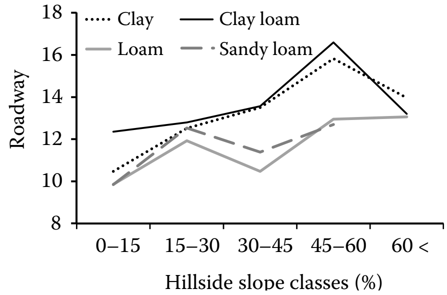

Fig. 4. Interaction of two parameters slope aspect and rock base with road cross section

teraction, however, showed that by decreasing the soil particle size in slopes ranging from 15 to 60% and when the soil texture becomes more clayey, the cross section changes more quickly compared to slope variations (Fig. 4). Results of Duncan's test in different composition groups of the two parameters of hillside slope and soil texture classes showed that in clay texture there is a significant difference between the average cross sections in different slope classes, so that the classes 45–60% and 0–15% had the highest and the lowest road cross section, respectively. Also in the clay loam class the slope class of 60–45% had the highest road cross section and the remaining classes represented the lowest road cross section. In loam and sandy loam classes there was no significant difference between the averages of cross section (Fig. 5).

DISCUSSION AND CONCLUSIONS

The results showed that the road cross sections in slope classes of 0–15, 15–30, 30–45, 45–60, and > 60% were measured to be 10.62, 12.70, 12.85, 15.96 and 14.28 m, respectively (Fig. 1a). The road cross section increased by increasing the slope percentage up to 60%, after passing this range, the road cross section decreased due to the increased rock base. Most scientists have reported that among the

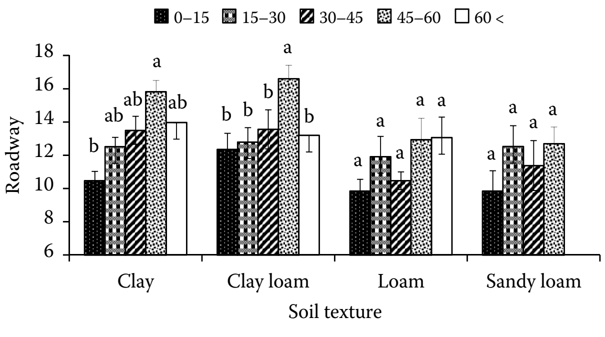

Fig. 5. Average road cross sections according to hillside slope and soil texture in various classes of forest roads

effective parameters in relation to the road cross section slope angle is the most important. Soil aggregate stability against displacement in gentle slopes is greater than in steep slopes. The steeper the slope, the higher the soil instability and the soil is more likely to slip and move downhill. It should be noted that in very steep slopes the soil depth is very low due to the lack of stability. For this reason, the road cross section will be lower in very steep slopes if this slope is instable how can you road cross section could be decreased. Thus, the medium slopes, due to the thick layer of soil, are more exposed to instability and have the maximum road cross section (Sedlak 1983; Gorton 1985; Hay 1996; Potocnik 2003; Parsakhoo et al. 2009). In the case of elevation, the results showed that the class of 600–800 m had the highest road cross section (15 m) and the classes of 150–400 and 1,000 to 1,200 m with the road cross section 12.68 and 12.7 m, respectively, had the lowest road cross section. The elevation class of 400–600 m with the road cross section 13.20 m represented the intermediate condition (Fig. 1b). Due to the irregular trend of the average road cross section, different elevation classes, i.e. it increases to 800 m, then it decreases at higher elevations, it could be concluded that the elevation is a regional parameter and it is not recognizably correlated with the road cross section. No significant difference was found between different slope aspect classes and the road cross section (Fig. 1c). In the case of rock base, it was observed that the soft class and hard class had the highest (13.60 m) and the lowest (11.50 m) road cross section, respectively, and the medium class showed the intermediate condition (Fig. 1d). The amount of rock base in soil is considered as a decisive factor for determining the road cross section and road construction project, so that by decreasing the rock base the road cross section increases while by increasing the rock base the operation of cutting the trenches is more difficult, which in turn decreases the road cross section. These findings confirm the results of Potocnik (2003). The results showed that clay and clay loam classes with 13.90 and 14 m, respectively, had the highest road cross section while loam and sandy loam classes, with 11.95 and 12.03 m, respectively, had the lowest road cross section (Fig. 1e) Thus, clayey soils with plastic properties resulted in wider road cross section compared to sandy loam soils because by decreasing the aggregate size and increasing plasticity the slope of cut-slope will increase and the slope of fill-slope will decrease, which in turn causes the increased horizontal width of the cut-slope and fill-slope, and consequently increased road cross section (Haarlaa 1973; Hosseini et al. 2012). The simultaneous effects of the two factors, namely hillside slope and rock base, on the road cross section showed that the average road cross section will decrease in all slope classes by increasing the rock base. Also in both soft and medium classes of rock base, the road cross section increases to a 60% slope, and then the road cross section decreases above 60%. But in hard rock base areas with increasing the slope percentage to 45% the road cross section increases and beyond this value the road cross section decreases. There were no data for the hard rock base area in slope classes of 0–15% and 15–30% (Fig. 2).

Results of Duncan's test in different groups of the two parameters for hillside slope and rock base showed that in the soft class there is a significant difference between the average road cross section in different slope classes so that slope classes of 45 to 60% and 0–15% had the highest and the lowest road cross section. Again, in the medium class there is a significant difference between the average road cross section operations in different slope classes so that slope classes of 45–60% and 0–15% similarly had the highest and the lowest road cross section, and the remaining classes represent the intermediate condition. In rocky areas there was no significant difference between average road cross sections in different classes of slope and it could be concluded that in rocky areas changes in road cross section vary more intensely compared to changes in slope (Fig. 3).

The interaction graph of soil texture and hillside slope showed that by decreasing the particle size and increasing the percentage of clay in the slope steeper than 30% the road cross section changes more rapidly relative to changes in the slope and also in slopes steeper than 30% the road cross section in hillsides containing soils with more clayey textures is higher than in soils with loam and sandy textures. Totally the highest road cross section was found in clayey textures and moderately steep slopes (45–60%). This could be due to the higher thickness of soils in these slopes and the higher soil instability in clayey soils compared to loam ones (Fig. 4) (Anonymous 1998; Nunnally 2000; Narimani 2002). Results of Duncan's test in different composition groups of the two parameters hillside and soil texture showed that in the fine texture class there was a significant difference between the average road cross sections in different slope classes so that the slope classes of 45–60% and 0–15% had the highest and the lowest road cross section, respectively. In the loam clayey texture class there was no significant difference between the average widths of construction operations in different slope classes (Fig. 5). Therefore, the road cross section shows a more sensitive response to changes in clayey soils but in more loamy and sandy soils the sensitivity of road cross section to changes in slopes decreases. Finally, with regard to various conditions and mountainous areas at risk the road should not pass through areas with high sensitivity such as hillsides with clayey soils and medium slope to avoid an increase in the road cross section and its subsequent destruction as well as to decrease the environmental and economic costs.

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