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Vertical Alignment of Forest Road Longitudinal Profile by Excavation Machines

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Abstract: To avoid heavy forest road maintenance costs, vertical alignment of longitudinal section must be developed according to road gradient standards and different kinds of excavation machines. In this study, bulldozer and hydraulic excavator ability to construct the forest road with standard longitudinal section has been examined using nivelman method. Data were collected by Niveau and mire from 2 km secondary road in Lat Talar forest, Hyrcanian zone. Results indicated that the standard longitudinal section for constructed road by bulldozer and hydraulic excavator were 92.73% and 83.67%, respectively. Although the difference between project numbers in excavation area and standard plan wasn't significant ($p>0.05$), soil material was less excavated by hydraulic excavator as compared with bulldozer. The positive significant correlation was observed between the natural ground, standard plan and constructed road elevation ($p<0.001$). In conclude the ability of bulldozer in vertical alignment of the forest road longitudinal section is better than hydraulic excavator.

Key words: Longitudinal section, vertical alignment, forest road, project number, excavation machine

INTRODUCTION

The forest road grade should be carefully selected, not only to minimize the total road cost but also to reduce the environmental impact and to improve driver safety. Vertical alignment should be properly coordinated with environmental impacts (e.g., encroachment onto wetlands). The vertical alignment of a road consists of straight segments (leveled or inclined) connected by sag or crest vertical curves. Combinations of these elements create various shapes of road profiles. The vertical alignment of a road includes sections with constant gradient and the related transition curves[2,9,11,12].

The perception of the driver of the road features ahead is an important human factor that can considerably affect traffic safety and design consistency, and should be addressed in road design. An erroneous perception of the road can lead to actions that may compromise traffic safety. Previous studies have shown that combined horizontal and vertical alignments can cause a wrong perception of the horizontal curvature [10].

On sections with high gradient, safety problems may occur from speed differentials between passenger cars and heavy vehicles (e.g., heavy vehicles idling on upgrade sections), as well as vehicles braking on downhill sections (e.g., increases in braking distances and possibility of heavy vehicle brake overheating). It should be noted that road sections with gradients higher than 4% tend to present an increased road accident risk[4,15]. As gradient increases, the water runoff speed and consequently its eroding power also increases. Speeding vehicles brake prior to negotiating curves and then wheels brake and scuff the road surface, resulting into the development of ruts and washboards on the road surface[3,8,20].

The total length of Hyrcanian forest roads at the end of year 2000 was about 6000 km. Roads network planning and standard methods for their construction are performed in accordance with the principle of the bulletin No. 131 and 148, published by Plan and Budget Organization of Iran (PBOI)[18,19]. In recent years, hydraulic excavator usage has become current in Hyrcanian forests due to its environmental aspects. Furthermore, the crawler bulldozers are the other machines that use in earth working operations. Approximately 80% of forest roads are constructed by bulldozer. One major factor preventing the more usage of excavators is their low productivity[16]. Excavator ability for excavating the large area such as road surface isn't suitable. Therefore it seems that the

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vertical alignments of road in the excavator operational area aren't coinciding with planned grade line compared with bulldozer.

The optimal road grade and curve radii which minimized road maintenance cost in Tanzania logging Roads were grades less than 6% and radii above 100 m respectively. Statistical analysis however showed that there was no significant difference between straight sections of the road and the curve sections in terms of loss of surface layer materials[1]. Recently, genetic algorithms and Tabu search are used to search for the best vertical alignment among the different placements of grade change points[6,13].

In this study specifically the bulldozer and hydraulic excavator performance in constructing the forest road longitudinal sections is compared. Use this study approach as a case study and check results between standards plans and constructed road segments according to number of grade change and project number in vertical alignment.

MATERIALS AND METHODS

Study Area: Field data were collected in the spring of 2008. Study was conducted on a loamy soil at the Lat Talar site in the northern forest of Iran (36°12 55″-36°15 45″ N, 53°9 40″-53°13 55″ E and elevation 1000 m). The area has a mid moist and cold climate and its bedrock is typically marl, marl lime and limestone. The observed overburden consisted of well drained, gravely and a natural soil moisture content ranging from 16-20%. The soil depth is greater than 0.45 m; with a rooting depth of approximately 0.6 m (Fig. 1).

Roads in Lat Talar were not paved and their density was 10 m ha^{-1}. Two kilometers of these roads excavated by Komatsu PC_{220} crawler hydraulic excavator and other were constructed by Komatsu D_{60} crawler bulldozer. In this study, the maximum longitudinal gradient of secondary forest roads for design speed of 24-32 km h^{-1} is limited to-12-14% and + 5-+ 7% considering truck performance (3 axles, 10 m^3 box capacities). The gradient must also be more than ±5% to provide adequate water drainage (Table 1). According to Forest and Rangeland Organization of Iran (FROI), the width of secondary forest roads and their vertical curves should be 5.5 and 500 meter, respectively (Table 2).

Nivellement of Road Sections: Geometrical height measure is called "nivelman". The main principle is to measure the vertical distances from a horizontal level which is constituted on the survey area. In this study, two constructed roads with the length of 1 km which were constructed by bulldozer and hydraulic excavator were leveled. Longitudinal profile and grade change of these roads in each of 20m was measured by nivellement method. The working principle of Niveau is like this; after the device was leveled in each of stations, the observed number on the mire was read. Then the height of each point was obtained by difference of first number from subsequent number. The profiles planning were done in Excel software. Constructed longitudinal sections were compared to standard plans which were developed by forest engineers. Also, the LSD comparison test was used for data treatment. The basic equation for controlling the nivellement method as follows Eq. 1:

$$H = \sum hi + a - c \qquad (1)$$

Where H is the elevation of last point from first point (m), hi is the sum of elevation difference for all stations (m), a is the first reading in first point and *c* is the last reading in last point.

RESULTS AND DISCUSSIONS

Results: 59 grade changes were observed on longitudinal section of forest road which was constructed by bulldozer, whereas 55 grade changes had been predicted on standard plans (Fig. 2, Table 3). In hydraulic excavator construction area, the grade change frequency was 57. For this section of road 49 grade changes had been predicted on standard plans (Fig. 3, Table 3). Thus, the standard longitudinal section for constructed roads by bulldozer and hydraulic excavator were 92.73% and 83.67%, respectively.

Results indicated that there wasn't significant difference ($p > 0.05$) between the project numbers in excavation areas and standard plans of forest road, but the soil material was less excavated by hydraulic excavator as compared with bulldozer (Fig. 4).

The positive significant correlation ($p < 0.0001$) was observed between the natural ground, constructed roads and standard plans (Table 4). Regression analyses indicated that each stake altitude on center line of constructed road was affected by standard plan ($p < 0.0001$). The R^2 value which indicates the degree of explanation of the model showed very high value of 0.999 indicating that the model should be appropriate in expressing the importance of constructed road as a dependent variable (Table 5, Fig. 5a). Also, each stake altitude on standard plans of road was affected by natural ground elevation ($p < 0.0001$). The R^2 value that explains the explanation of the model was 0.998 which could be judged to be appropriate in the performance test of natural ground elevation (Table 5, Fig. 5b).

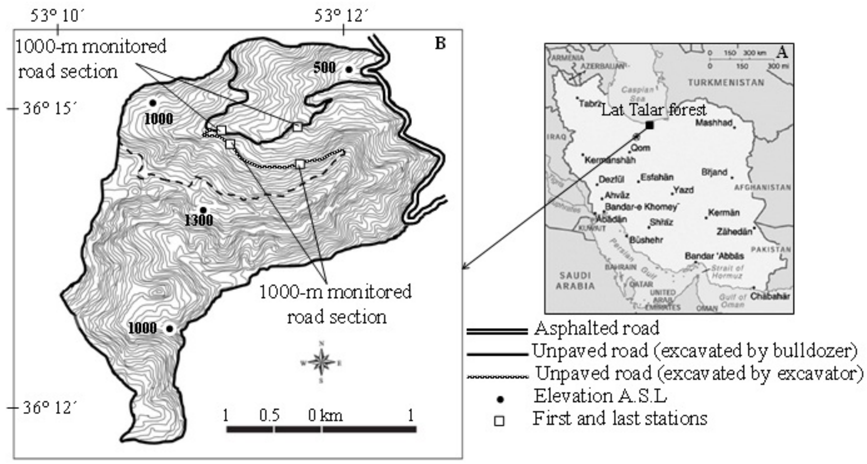


Fig. 1: Geographical position of the study area and road

Table 1: Standard gradients for different type of forest roads [18]

Gradient / Road type	Maximum negative gradient (%)	Maximum positive gradient (%)	Minimum gradient (%)
Main sideway	- 7 to - 8	+ 5 to + 7	± 2
Main mutual	- 8 to - 9	+ 5 to + 7	± 3
Secondary road	- 12 to - 14	+ 5 to + 7	± 5
Skid road	- 15 to - 20	+ 10 to + 12	± 5

Table 2: Standard gradients for design speed and truck axles [18]

design speed (km h^{-1})	Forest roads gradient (%)		
	Two axles truck	Three axles truck	Five axles truck
16	15.0	11.0	6.0
24	12.5	8.0	4.5
32	10.0	6.0	3.0
40	7.8	4.2	2.2
48	6.3	3.3	1.6

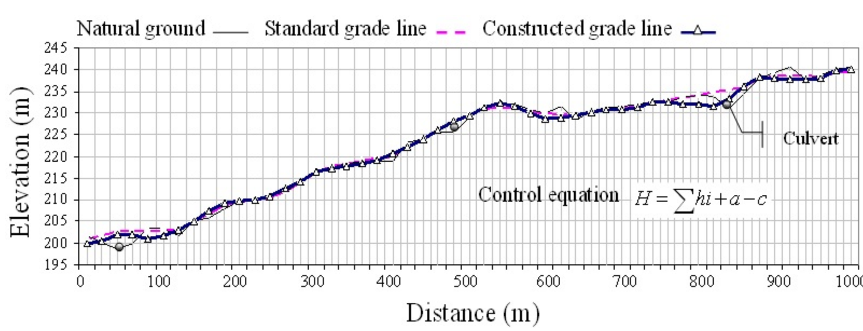


Fig. 2: Vertical alignment of forest road for bulldozer

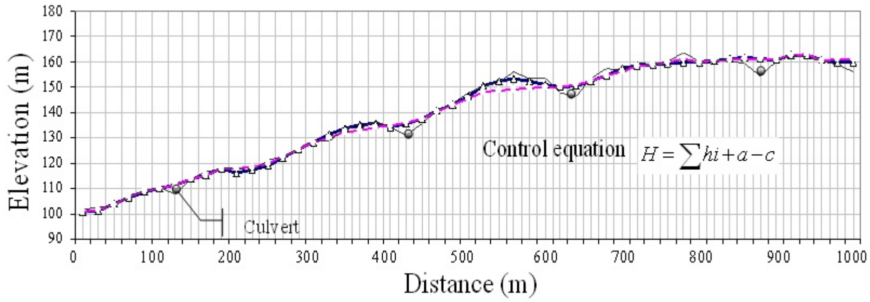


Fig. 3: Vertical alignment of forest road for excavator

Table 3: Number of grade change on longitudinal section of forest roads

Machine		Number of grade change (%)					
	Grade change	0 to ± 2	± 2 to ± 4	± 4 to ± 6	± 6 to ± 8	± 8 to ± 10	± 8 to ± 10
Bulldozer	Standard plan	25	13	10	4	3	-
	Constructed	26	15	11	4	3	-
Excavator	Standard plan	16	10	8	5	5	5
	Constructed	17	14	13	5	5	3

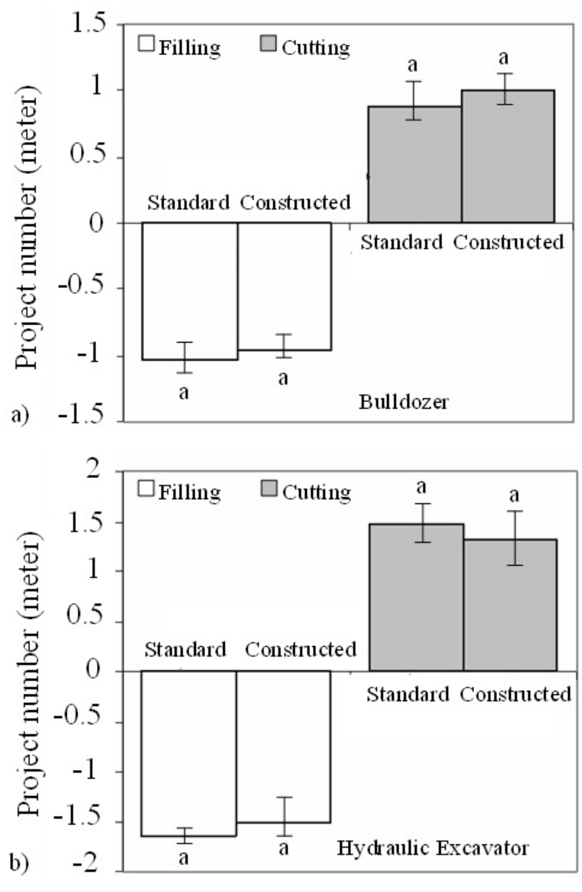


Fig. 4: Comparing the project number of longitudinal sections for bulldozer and hydraulic excavator

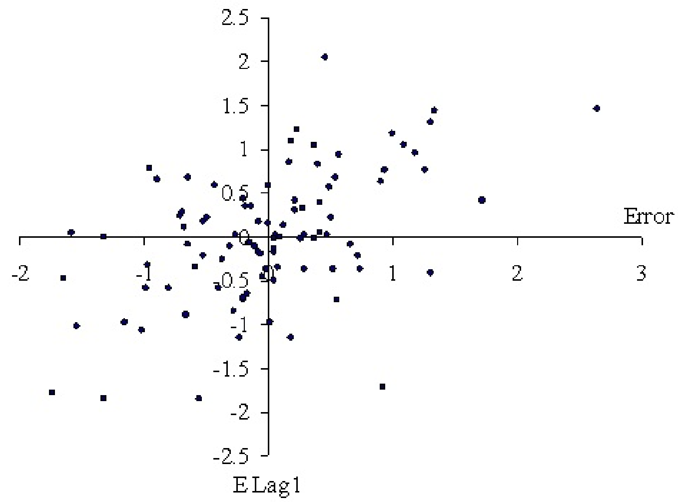
Table 4: Pearson correlation coefficients for various parameters

no	Parameter	1	2	3	4
1	Machine	1			
2	Constructed road	0.93***	1		
3	Standard plan	0.93***	0.99***	1	
4	Natural ground	0.93***	0.99***	0.99***	1

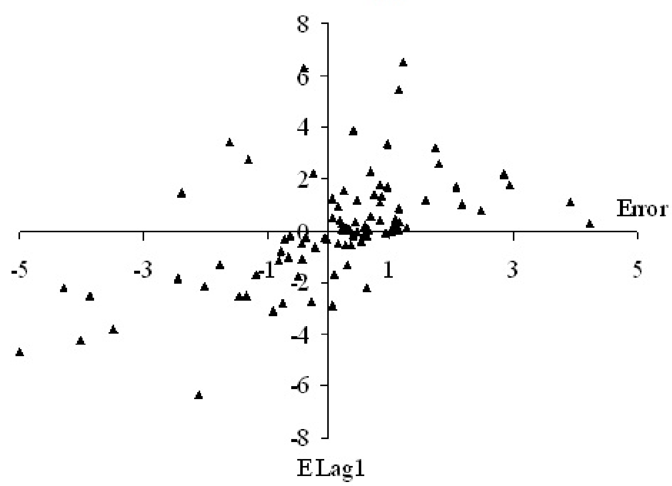
***: Significant at probability of 0.1%

Table 5: Regression analysis for depended (natural ground and constructed road) and independed variable (standard plan)

Variable	b_0	b_1	aR^2	CV
Constructed road	0.421	0.997***	0.999	0.419
Natural ground	- 0.187	0.999***	0.998	0.995



(a)



(b)

Fig. 5: (a) Regression model for constructed road and standard plan (b) regression model for natural ground and standard plan of forest road

Disscution: Geometric standards for forest roads designing and building have a direct effect on maintenance cost and frequency, wood transportation cost, environmental and ecological disturbances, level of risk for drivers and other road users. The geometric elements that are critical to road safety are comprised of horizontal alignment, vertical alignment, cross section (pavement width, shoulder width and type, lane width) and roadside design such as width, slopes and condition[2,9,4].

Forest road surface in excavator operational area ragged and its grade changes frequently. This problem increases the maintenance cost, because forest roads longitudinal gradient and its surface compaction is considered to be one of the most important factors which influence the frequency of road erosion, consequently road maintenance cost[3,5,14, 17,20].

The key areas of geometric road design that require improved information involve determining the effect of various standards of horizontal curvature for roads including variables such as length of curve and tangent conditions (e.g., alignment or approach speed), combinations of horizontal and vertical alignment, different combinations of lane width and shoulder width for rural roads, shoulder type at various traffic levels, downhill gradient particularly for grades above 6%, narrow lane widths and horizontal alignment for typical situations in urban and outer urban areas[5].

On steeper grades vertical alignment has a greater effect on travel speed than horizontal alignment. Therefore, surfacing and horizontal alignment should not be improved to increase speed where the road gradient is the controlling element[7]. Vertical alignment, or grade, is of critical concern because of its potential for environmental damage and becomes increasingly important for grades exceeding 10%. Erosion potential increases as a function of the square of the slope and the cube of water velocity. The most desirable combination of grade and other design elements should be determined early in the road location phase with additional caution exercised when grades exceed 8%. Vertical alignment normally governs the speed of light vehicles for grades exceeding 15% favorable and 11% adverse and of loaded trucks for grades exceeding 8% favorable and 3% adverse. The ability of a vehicle to traverse a particular grade is dependent on vehicle weight and horsepower and on the traction coefficient of the driving surface[14,17].

Table 3 showed that the excavation equipments could perfectly built the macro grade change according to standard grade line, whereas forest roads with longitudinal gradient less than ±6%, had more grade changes as compared with predicted amount (Standard) in hydraulic excavator construction area. In contrary, the road gradient in bulldozer construction area was approximately coincided to standard plans. Also, the positive significant correlation ($p<0.0001$) was observed between the machines, natural ground, constructed and planned roads Table 4.

Maximum allowable gradient in forest road planning depends on machine type, traffic and design speed. Also, topographic conditions, soil type, pavement type, safety, sill of water erosion are other characteristics which are determining the optimum longitudinal gradient. In public roads, the traffic and repair cost are increased by increase road slope gradient[3]. Therefore, ability of bulldozer in construct the forest roads vertical alignment was better than hydraulic excavator.

Based upon the regression analysis results, each stakes altitude on center line of constructed road was affected by engineer's planned road. Also, each stakes altitude on engineer's planned road was affected by natural ground conditions. The R^2 value that explains the explanation of the model was 0.99 which could be judged to be appropriate in the performance test of constructed road and natural ground elevation Table 5.

Regression model between constructed vertical alignment and planned project by engineers was the best model with the concurrent distribution (Fig. 5a). This topic was also observed for regression model between natural ground and engineers planned forest road, but the concurrent distribution of residual values in this model was less than previous model Fig 5b.

Conclusion: In order to determine the most economical alignment, standard, and density of the road system, it is necessary to be able to calculate the cost of the vehicles which use the roads and the cost of the roads themselves. The optimal design is one that minimizes the combination of logging, transport, construction, and maintenance costs while providing for safe operation and controlling environmental impacts.

Forest road construction project or site preparation requires excavation machines for grading the vertical alignment and the machines used depend on the precision specified. In this study bulldozer reduced uneven ground to levels that are flat or sloped correctly for building. Therefore, bulldozer ability for grading the forest road vertical alignment was better than excavator. But it seems that if the small blade to be attached in front of the hydraulic excavator, its ability for grading forest roads longitudinal section would improve.

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