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Designing geometric specifications of main access road and its effect on pavement rutting

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ABSTRACT

The present study were done to assess the influence of geometric design of forest roads on the rate of pavement rutting. For this purpose, geometric specification of 2 kilometers of road in Pashakola forest in mountainous area were measured using the NIVO-C mapping camera. Then, forest road network were designed using ROADENG software. Results showed significant difference for rut depth between the longitudinal slope in classes of above and below 5% ($P>0.05$, $R^2= 0.42$). A significant difference was found for pavement rutting for horizontal radius curves between the classes of < 22 m and > 30 m. The rut area and depth decreased with increasing width on curve. The rut depth decreased with increasing super elevation up to 4 percent and then increased. To reduce damages, the plan details, operational tasks and the type of vehicles which will pass in later years must be considered when the roads are planned. Suitable materials must be used for pavement layer of road to increase stability of this layer. Also, the road surface must be graded before and after of timber harvesting. When the weather is unsuitable (rainy) and the road surface is wet it is better that the timber skidding was stopped.

Key words: Forest road, Rut, Longitudinal slope, Horizontal curve, width on curve, super elevation.

INTRODUCTION

Forest roads create economical, social and cultural benefits via wood, staff and equipment and providing traffic facilities for people and eco-tourists[1, 27, 32]. Trucks used in logging vary widely in size and load-carrying capabilities. Choosing a truck with different capacities depends on different variables such as topography, climate, size of operation, haul distance, volumes available, and the product to be hauled. Additionally local highway regulations restrict the gross vehicle weight, length, width, and height of loaded log trucks traveling on public roads [23-29].

Rutting occurs when soil strength is not sufficient to support the applied load from vehicle traffic. Rutting affects aesthetics, biology, hydrology, site productivity and vehicle safety [22]. The extent and degree of soil compaction and rutting depend on several factors including soil texture, soil moisture content at the time of trafficking, soil organic matter, slash and twigs content, soil structure, parent materials and pore size distribution, vehicle mass, machine type and size, , the number of loading cycles and duration of loading [2-9]. Design speed in main access roads is 25 to 30 km hr^{-1} and maximum longitudinal slope depends on several factors involving type of machine, type of travel, design speed which affecton the rate of rut. Hence, the longitudinal slope of forest roads along the horizontal curve should be reduced to 5 percent [29].

A mistake in planning of a road, like ignoring the effects of environmental and other parameters may lead not only to the waste of public investment but also to adverse environmental impacts and increase maintenance costs [11-12]. The minimum radius of horizontal curve in the forest road is 16 meter that depend to the design speed, topographic conditions, soil conditions, limits of super elevation, the length of timber and timber truck, the financial resources, the importance of forest and environmental conservation and the maximum of longitudinal slope [29]. The radius of horizontal curve is considered minimum to decrease the environmental damage [15]. In horizontal curves with low radius the cross section of road is sloped into the curve center to facilitate turning of vehicles. The value of this slope which is named super elevation is depended on design speed, horizontal curve radius and the friction coefficient of road surface [26-31]. in order to make economic efficiency and to avoid forest destruction the length of tangent and horizontal curve radius must be short [29].

In the developing countries, inappropriate ground skidding system for forest utilization [24] and unauthorized load (more than capacity) of trucks for timber transport cause stress on the road pavement [14] and consequently degraded forest soils as the main recipient of static and dynamic forces [13]. Several investigations have been done in order to find a way to minimize the damage and wear to the forest access roads and reducing the cost of entire logging operations. Those include; the establishment of safe axle load limits as the basis for designing an envirogentle trailer [20], establishment of optimal haulage vehicle combination [3], and the adaptation of trucks to impart lower ground contact pressures [21]. However, economic reasons require the maximization of payload, and forest access roads are often expected to cater to heavier traffic resulting in accelerated pavement distress.

Since 1974 many of computer software are made for designing road that including the software packages Autocad LD, Roadeng, Routes, Pegger, Tracer and FLRDS [28]. Enache [8] with carried out the study in the Trach forest of Austria using GIS and Roadeng software to design forest road network. He stated that ROADENG software able to design longitudinal and cross section, horizontal and vertical curve and makes facilitate the difficult activities of forest management implementation. Liu et al. [17] demonstrated that with decrease the horizontal curve radius in the roads with curve radius lower than 20 m , the rate of depth, the width and depth multiplied in width of wheels rejection increased.

The present study were done to assess the influence of geometric design of forest roads on the rate of pavement rutting.

MATERIALS AND METHODS

1. Description of the Study Area

The present investigation was carried out in Pashakola forest (Figure 1) with an area of 1826 ha in south of Savadkooh city north of Iran. The latitude, longitude and elevation ranges of this forest are 36° 23′ to 36° 26′ N, 52° 09′ to 52° 19 ″ E and 1040 -1720 meter at sea level, respectively.

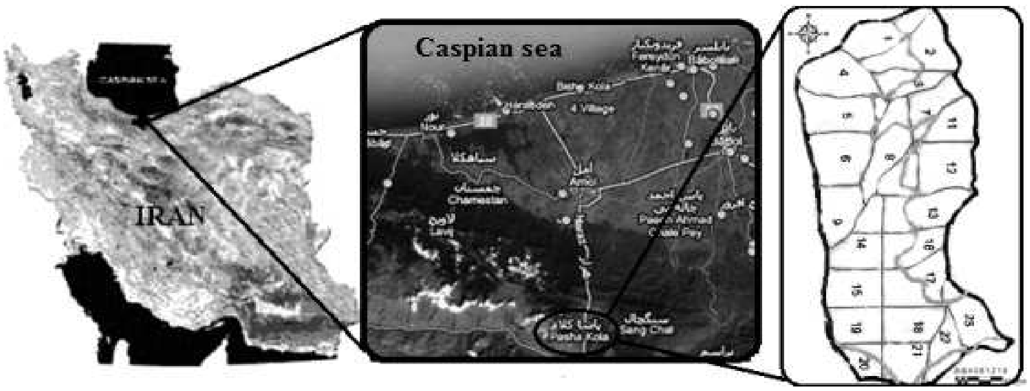


Figure 1. Map and geographical location of study area

2. Data collection

In order to study the effect of geometric specification of forest road on pavement rutting, geometric specification of 2 kilometers of road in Pashakola forest in mountainous area were measured . The longitudinal slope in direction carrying the load, cross slope, super elevation in location of horizontal curve, cut and fill slope were measured in the pavement surface by a clinometer as well as the width on curve and widening by means of the steel meter. The graduate metal ruler and mathematical equations of calculation of shape area was used to measure the depth and area of ruts.

Table 1. Geometric specifications of aligment and the rate of measured rut at the location of pavement rutting

station (Distance, m)	Cross slope.L(%)	Cross slope.R(%)	Longitudinal Slope (%)	Fill slope (%)	Cut slope (%)	Rut depth (cm)	Rut Area (m^2)
47.7	1	-1	4	-42	42	7.2	0.145
100	5	-5	3	-50	52	5.9	0.152
120	5	-5	3	-48	49	3.8	0.148
160	3	-3	-3	-50	52	7.6	0.21
180	1	-1	-3	-40	44	6.3	0.178
200	0	0	-3	-40	44	6.1	0.205
231	-1	1	-5	-43	45	4.6	0.154
300	-2	2	-5	-43	45	3.1	0.175
340	-3	3	-7	-43	45	8.2	0.148
431.4	2	-2	-3	-55	56	5.9	0.202
480	3	-3	3	52	53	8.7	0.164
500	4	-4	9	-36	38	8.3	0.095
539.3	-3	3	6	-35	34	8.4	0.136
580	-1	1	4	-35	36	1.5	0.148
680	0	0	3	-27	26	6.9	0.152
720	2	-2	3	-29	31	3.5	0.126
777.4	0	0	-3	-10	14	4.9	0.157
860	1	-1	-5	-11	18	9.6	0.136
1020	-1	1	-7	-25	25	9.3	0.145
1081.6	-4	4	-5	-25	25	9.7	0.116
1159.2	0	0	-6	-25	25	6.3	0.174
1286.6	2	-2	-3	-28	38	5.4	0.085
1360	1	-1	3	26	33	3.4	0.142
1443.5	-4	4	-5	19	31	7.2	0.118
1490.6	2	-2	-5	-45	48	7.9	0.154
1577.4	-3	3	7	-40	44	10.3	0.135
1641	0	0	8	-35	36	9.3	0.185
1704.3	2	-2	8	-32	33	8.3	0.132
1810	-3	3	5	-28	30	8.6	0.124
1880	2	-2	3	-35	34	7.5	0.13
1960	1	-1	-3	-26	28	3.1	0.156

Table 2. Geometric specifications of horizontal curve and the rate of measured rut at the location of pavement rutting

station (Distance, m)	Super elevation (%)	Longitudinal Slope (%)	Horizontal Curve radius (m)	Cut slope (%)	Width on curve (m)	widening (m)	Rut depth (cm)	Rut Area (m^2)
75	3	6	50	38	8.5	1.2	5.4	0.09
123.6	5	-3	32	52	7.7	0.8	5.2	0.08
322.1	4	-3	28	45	8.9	1	5.3	0.143
486.5	4	9	22	52	7.5	1.6	12.1	0.185
632.5	2	4	18	26	7.8	0.5	6.1	0.192
814	5	-5	16	13	9.1	0	8.4	0.36
902.1	0	-7	24	22	6.1	1.4	9.5	0.192
1094	1	-5	18	25	7	1.2	12.3	0.258
1193.4	2	-7	20	38	5.5	1.6	4.1	0.18
1311.7	0	-6	18	25	7.6	1.2	12.9	0.28
1388.6	3	5	22	33	8.3	0.9	5.2	0.178
1592.6	3	5	26	42	10.1	0.5	7.4	0.08
1735.8	0	8	18	36	5.5	0.5	13.4	0.48
1822.9	3	4	29	29	5.8	2.1	9.3	0.29
1905.2	5	3	55	34	6.1	3.5	4.1	0.28
1983.3	1	-4	19	28	7.8	0	11.7	0.18

3. Designing alignment and horizontal curve

To design the forest road, its geometric design andparameters were measured using NIVO C. The specification were entered to Survey_Map package of ROADENG software. Then, existing forest road network, cross section and horizontal curve were designed using LOCATION accessories package in location of pavement rutting.

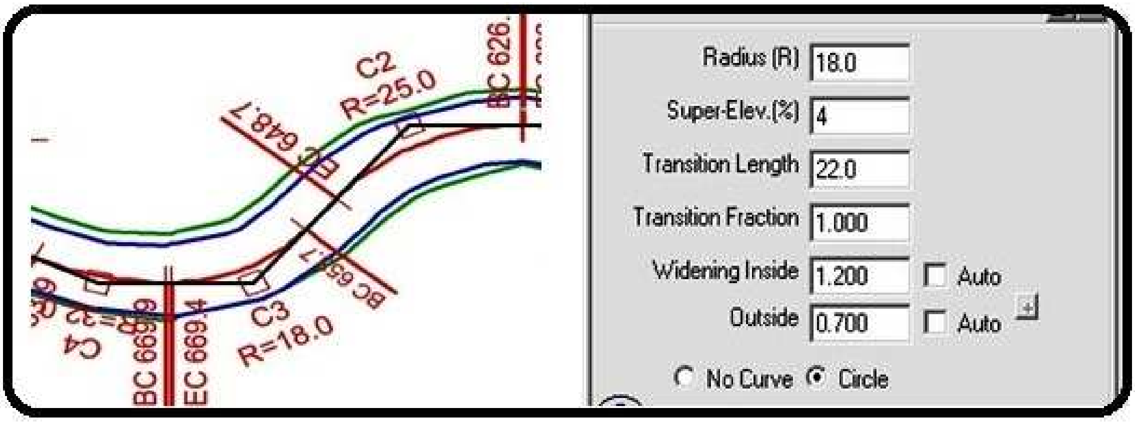


Figure 2. Designing horizontal curve using the LOCATION accessory package

4. Data Analysis

Data were analyzed based on Completely Randomized Block (CRB) Design using SAS software. The comparison of means were done using *Multivariate Linear Analysis* and *Tukey HSD* test.

RESULTS AND DISCUSSION

1. Designing forest road and horizontal curve

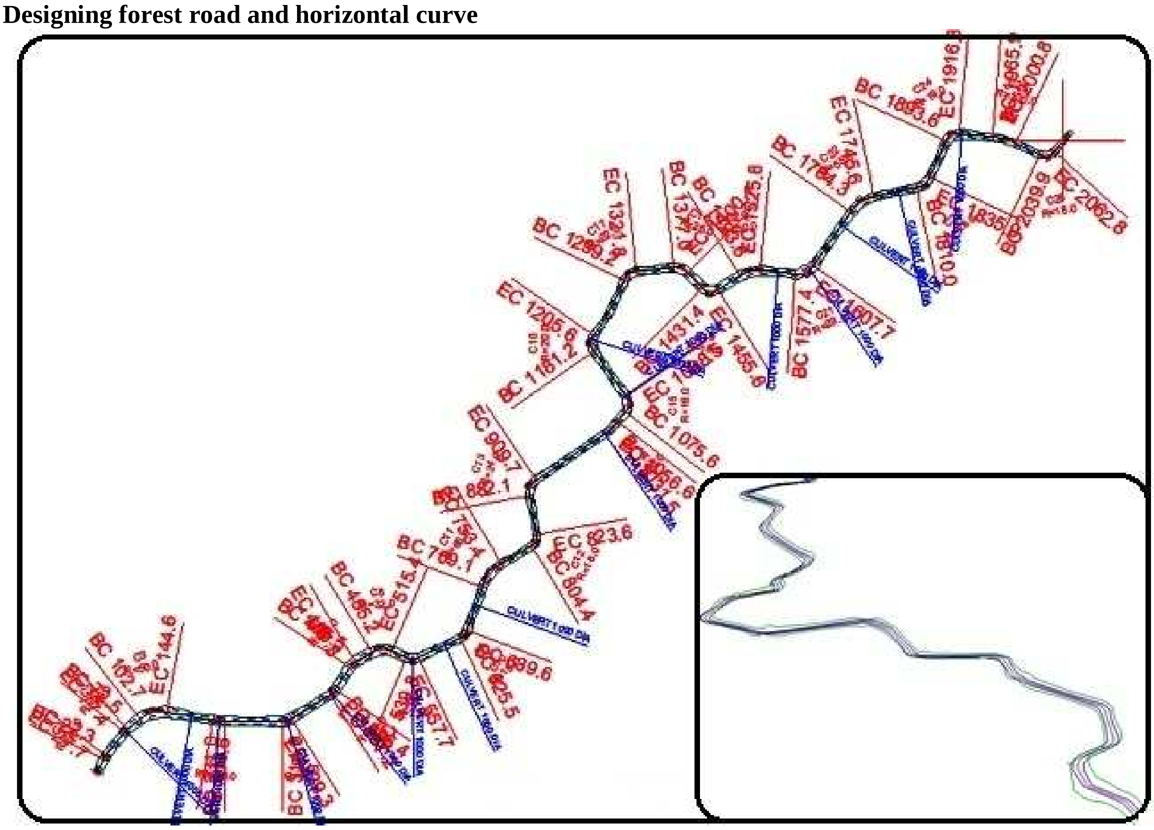


Figure 3. Designing two-dimensional and three-dimensional of forest road

2. Effect of geometric design of alignment on pavement rutting
Results of this study showed that rut area and depth increased with increasing longitudinal slope and there was significant linear relationship between the longitudinal slope and rut depth (P>0.05, R^2= 0.42). This increase, in positive longitudinal slope is higher than to negative ones. The longitudinal slope was inversely related to rut area. Significant difference was found between the slope classes higher and lower than 5 percent(P<0.05).

If the longitudinal slope of horizontal curve radius were above the threshold or range (X > 5), the rate of accidents increased. On the other hand, if the longitudinal slope be close to zero, damages increased as low-level pit on road surface [23]. Washing the fine-grained materials and therefore detachable the components of pavement materials is main factor leads to deep wheel rejection in the high slope of road [25]. Eliasson, [7] claimed that the depth of created rut by heavy machinery was positively correlated with increasing the machines travel not to the rate of tire pressure.

Table 3. Statistically comparison of rut area and depth among different longitudinal slope

Long.slope (m) / Rutting	(-8) - (-5)	(-5) - (-3)	3 - 5	X > 5
Rut depth (cm)	8.3 [a*]	5.2 [b]	5.4 [b]	8.7[a]
Rut area (m^2)	0.141 [a*]	0.169 [ab]	0.145 [ab]	0.134 [b]

*Note : * Significantly different at 0.05 probability level*

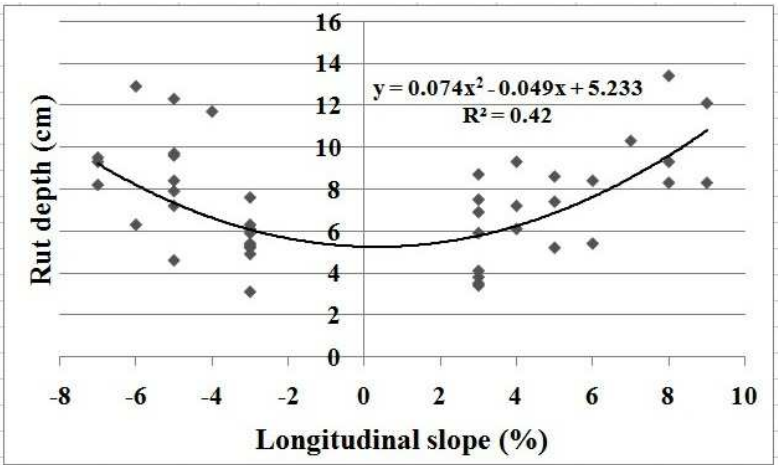


Figure 4. Relationship between longitudinal slope and the rate of rut depth

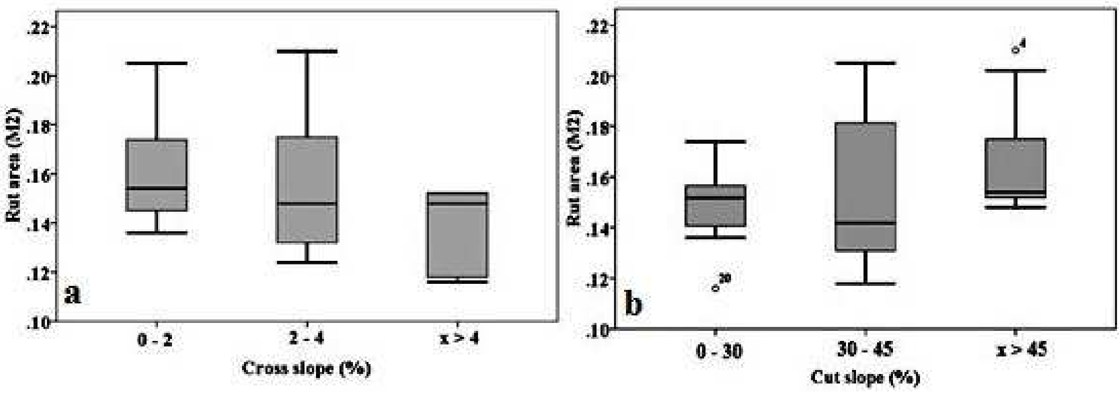


Figure 5. Comparison of rut area in different cross slope (a) and cut slope (b)

Norelationship was found between the cut slope and pavement rutting. Proportional angle of cut and fill slope with standard criteria because the part of these profiles is involved in hydrological connection, Soil stability and continuity of work [4]. Hence, in the steep terrain, increased ruts area may result in water flow and runoff on the roadbed and increases the soil erosion. Also, when the cross slope is less than 2 percent, the water accumulates on the road surface which lead to intensify soil erosion. In winter, vehicles movement on these soils increase the rut area . In our investigated site, the ruts area increased in locations with low cross slope (<2%).

Existence of cut slope at the both sides of the road causes to collect water on road surface (Figure 6, profile 480 and 1360). This can increase the surface erosion on road. Moreover, incorrect installation of culverts causes to subside pavement layer of road. The passage of vehicles from these points increases the depth and area of ruts on pavement layer (Figure 6, profile 180 and 680). The hillside with steep slope and road without super elevation causes to wash embankments and sedimentation. Sediment on road surface disturbs the materials gradation and destroys road surface (Figure 6. profile 160, 431.4 and 200).

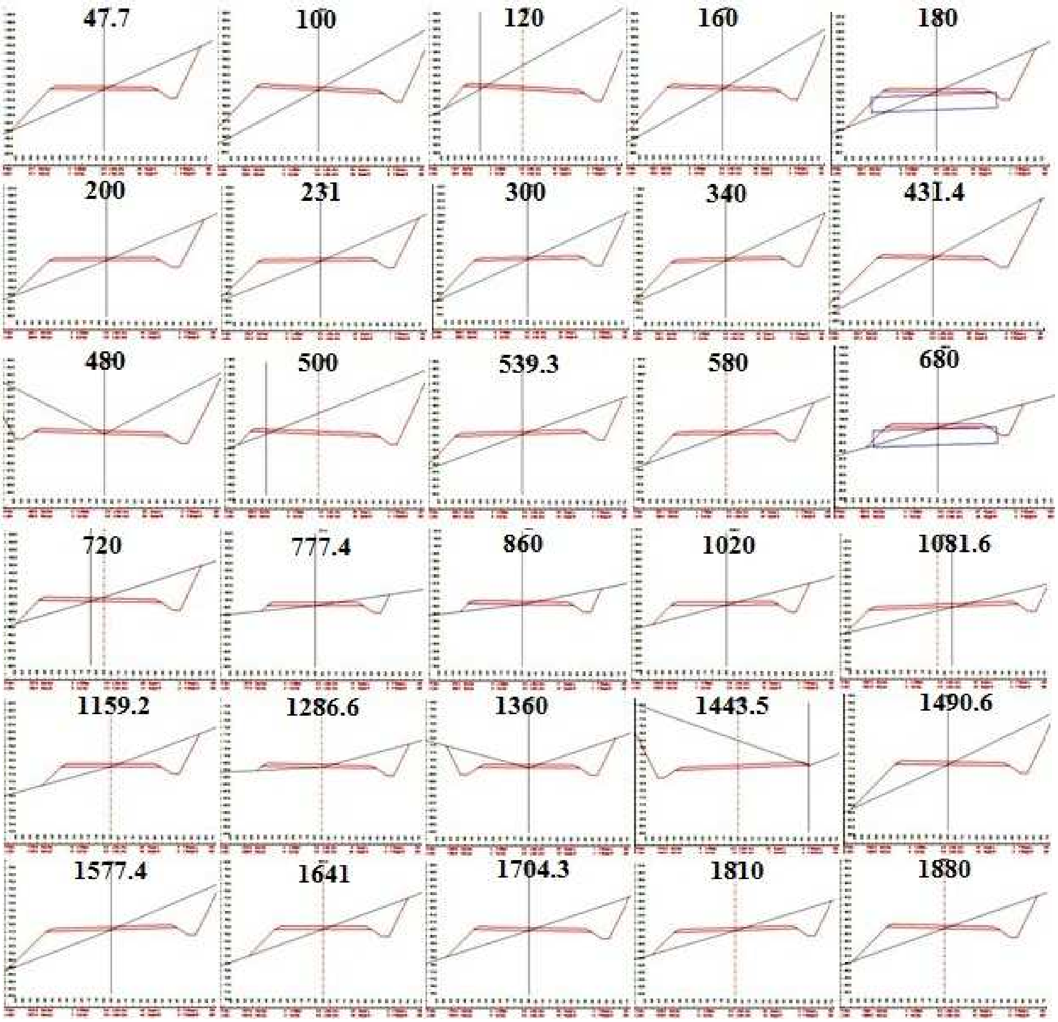


Figure 6. Geometric specification of cross-section in the location of pavement rutting

3. Effect of geometric design in horizontal curve on pavement rutting

The depth and area of ruts decreases with increasing curve radius. Results showed significantly difference between radius lower than 22 m and higher than 30 m ($P>0.05$). There was significant difference between rut depth in classes 16 -22 m and > 30 m (Table 4**)**. In forest roads that horizontal curve radius is less than standard criteria, the rate of destruction, erosion and compaction of soil in the outside of the widening limit is more than roads with standard curve radius [16]. The results of this study shows the rate of depth and area of ruts in curves with radius 16 - 22 m is about 2 folds more than curves with radius > 30 m. When the heavy vehicles pass from curves with low radius, the vertical forces on tires conduct the vehicle into the curve center and so the vehicle skids. When the heavy vehicles skid on curve the rut depth and area on pavement layer is increased [31].

Table 4. Statistically comparison of rut area and depth among different radius of curve

Curve radius (m) / Rutting	16 - 22	22 - 30	X > 30
Rut depth (cm)	9.84 [a*]	8.13 [ab]	4.9 [b]
Rut area (m^2)	0.276 [a*]	0.178 [ab]	0.15 [b]

*Note : * Significantly different at 0.05 probability level*

The rate of rut depth decreased with increasing super elevation up to 4 and then increased and in class 0-2% was significantly greater than other classes (Table 5**)**. The rate of rut area also followed the same trend but not significantly (Table 5**)**. If the super elevation is considered more than 3 percent, the friction force would against centrifugal force. This creates damage in central part of horizontal curve. In addition if the super elevation is considered more than 8 percent, the vector direction of centrifugal force and friction force would be similar and the damage to road cut slopes would increase [18]. The rate of super elevation in forest road for less than 16 m radius of horizontal curve should not be less than 2 percent [29]. The observations in study area showed that this phenomenon produced deep ruts. For curves with radius more than 30 m the super elevation is not necessary and the slope of the crown will suffice [29]. Our results showed that the rate of ruts area increased in slope classes with super elevation > 4 percent (Table 5).

Table 5. Effect of super elevation on rut depth and area

Super elevation (%)	Rut area (m^2)	Rut depth (CM)
0 - 2	0.27 [n.s]	11.96 [a*]
2 - 4	0.168 [n.s]	6.25 [b]
X > 4	0.2 [n.s]	7.02 [b]

*Note : * Significantly different at 0.05 probability level; n.s : Not significant*

The rut area and depth decreased with increasing width on curve (Figure 7). When the width of road and the radius of horizontal curve are suitable the braking of vehicle is less and the couple force (the force against the movement of machine wheels) will decrease [19]. So, the rutting decreased with decreasing couple force. Structural damage to road pavements is mainly attributed to the axle loads imposed by heavy trucks [10]. So, selecting the best secondary transportation machines is necessary for suitable and scientific management [30]. When the tire pressure on ground is high, the rutting and water erosion on road surface is occured [5]. Thus, the rate of ruts depth decreased with increasing the width on curve and passing the machinery on a repetitive path of the road will be less and.

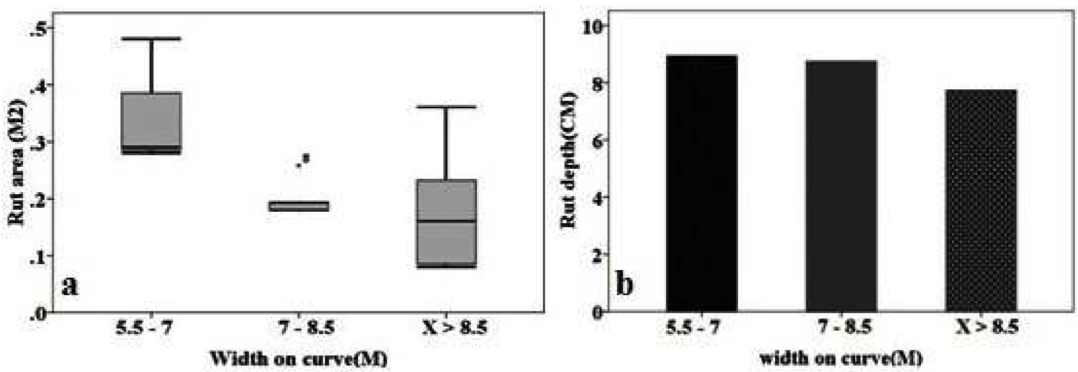
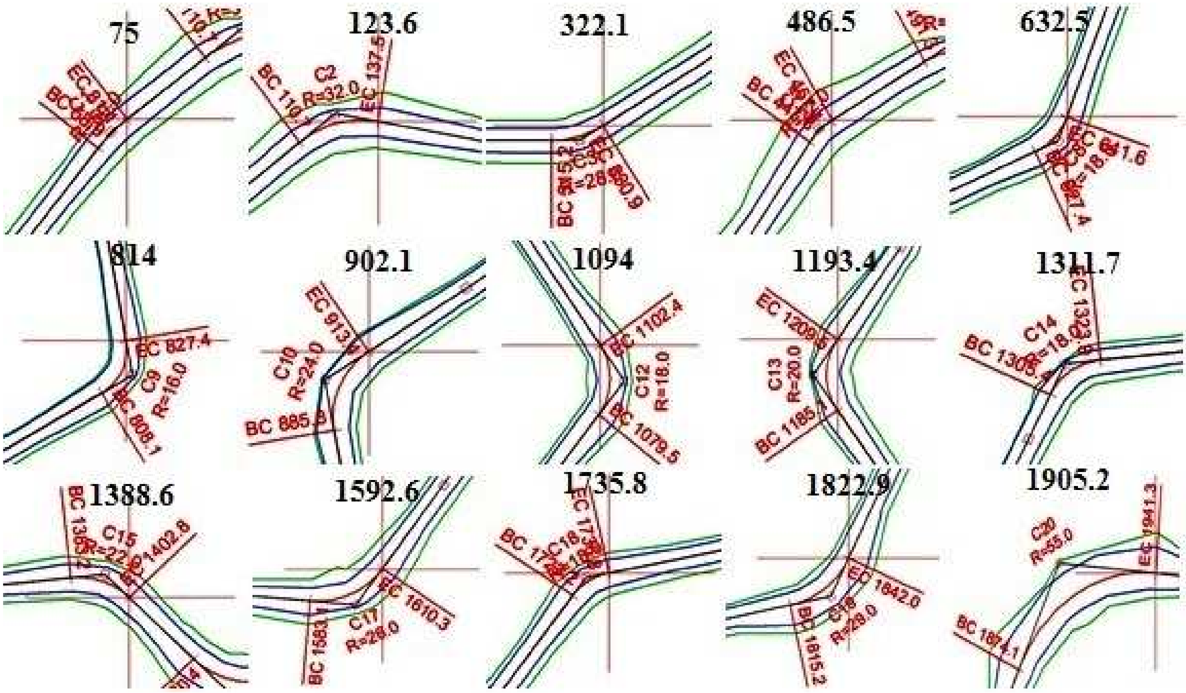


Figure 7. Comparision of rut area (a) and rut depth (b) in different width on curve

According to figure 8, especially for the horizontal curves without additional width of road, the truck must more brake to pass the horizontal curve. This causes to sever ruts on horizontal curve (Figure 8, curve 814 and 1735.8). Moreover, in places which the super elevation is not considered and the longitudinal slope of road is high, the ruts are often occurred frequently (Figure 8, curve 486.5, 1735.8 and 1311.7). For prevention of rutting the longitudinal slope of road must decreased to 5 percent at the beginning of horizontal curve [29]. The radius of horizontal curve must be selected according to transportation standards to decrease rutting (Figure 8, curve 632.5, 902.1, 1094 and 1311.7). Besides, if the width on curve is considered more than standard the vehicle speed on horizontal curve would increase and the rutting and the rate of road accident would increase after the induction of centrifugal force to vehicle (Figure 8, curve 1905.2).



Fiure 8. Geometric design of horizontal curve in location of pavement rutting

CONCLUSION

The planning and design decisions as the first phase of the forest road construction project ustbe carefully carried out in order to achieve a desired road standard efficiently and effectively with minimal environmental impact. Many forest roads in Iran are used as the rural roads, inappropriate implementation of the technical principals, particularly in the location of horizontal curve can causes the irreparable damage. To reduce damages, the selection of transportation machinery should be done with further studies and given bearing capacity of roads. Also, the selection of high gradients when designing a roads and low horizontal curve radius to minimize environmental damage can be caused the pavement rutting. Thus, the plan details, operational tasks and the type of vehicles which will pass in later years must be considered when the roads are planned. Suitable materials must be used for pavement layer of road to increase stability of this layer. The road surface must be graded before and after of timber harvesting. When the weather is unsuitable (rainy) and the road surface is wet it is better that the timber skidding was stopped.

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