

Full Length Research Paper

Comparisons of environmental effects and productivity by road construction machines in forest areas in Turkey

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In this study, forest road construction techniques, environmental damages, cross sections and productivity by using hydraulic excavator and bulldozer were investigated in forested lands in Antalya and Eskisehir region in Turkey. Maximum length of fill slope for bulldozer and excavator were found 17 m on 80% slope gradient and 11 m on same slope gradient, respectively. The costs of forest roads for bulldozer and excavator were calculated to be 21.8 US dollars/m and 8.5 US dollars/m, respectively. Productivity of bulldozer and excavator were found to be 105.8 and 66.2 m³/h, respectively. The types of environmental damages on trees were determined and found to be wounded, bending and crushing. In this study, 23% of trees under the forest road construction by excavator are damaged and 40% of trees by bulldozer are damaged for 45 - 90% ground slope.

Key words: Hydraulic excavator, bulldozer, forest road, road construction, environmental damage, construction cost.

INTRODUCTION

Forest roads construction activities must be carefully executed by considering economical, environmental, and social requirements (Akay and Sessions, 2005). In locating forest roads, construction methods and equipment selection directly affects the economical, functional, and ecological efficiency of the forest roads. Southern and western parts of Turkey are influenced by Mediterranean climate, so there is always a great risk of occurring and spreading of forest fires (Ayberk et al., 2010). So we should take into consideration the ecological structure of the region where the forest roads intended to build in. In Turkey, various types of bulldozers have been generally used in traditional forest road construction activities (Acar and Eker, 2003). On the terrains with gentle to moderate hillside slope, bulldozers have been still commonly used in right-of-way, cut-and fill slope, and subgrade activities.

However, in steep and rocky terrain conditions, the efficiency of the bulldozers diminishes and excessive environmental damages may occur since it becomes troublesome to keep the excavated material along the day-light point of fill slopes. In order to reduce the environmental damages on forest ecosystem, especially in steep terrains, hydraulic excavators have replaced bulldozers in forest road construction activities (Stjemberg, 1982). Besides, using excavator improves the quality of the forest roads, which extends life of the roads, improves the driver's comfort, and reduces the frequency of maintenance activities. In fact, using excavators can be the only option to perform feasible road construction activities in steep mountainous terrains (FAO, 1998).

Using bulldozer reduces the road construction cost in terrains with moderate slope and deep cut-slopes; however, they store the excavated material on the roadside along the roadway and these material falls downhill, which results in landslide and erosion problems (Acar and Eker, 2003). The falling logs can also cause wounding of the trees and this situation set the stage for

coming of the bark beetles especially *Dendroctonus micans* (Kug.) and *Ips typographus* (L.) in Blacksea region of Turkey causing big environmental problems (Ozturk and Ayberk, 2005). The excavator has the advantages of performing excavation activity with better control and placing the material efficiently on fill slope. In a study conducted by Erdas (1986), it was indicated that excavator should be used in construction activities on steep terrains to reduce environmental impacts. Bayoglu (1986) suggested that bulldozers should be used in the forested areas with less than 40% ground slope, while excavators should be preferred when the slope is greater than 40%. According to Spaeth (1998), combination of bulldozers and excavators can be used in road construction activities on terrain with greater than 50%. Winkler (1999) evaluated the productivity of excavators by considering various types of road lengths and terrain conditions. The results indicated that production rate of excavators were satisfactory in forest road construction. However, the study conducted by Bayoglu (1986) reported that road construction cost of the excavator was 12% greater than that of the bulldozer even though purchase price of the excavator was 10% less than that of the bulldozer. The excavator has high operation cost due to lower travel speed (≈ 5 km/h) comparing with bulldozers (≈ 10 km/h). The performance of a skilled excavator operator can play important role in reducing operation cost. The excavators perform road construction activities in stationary position with limited movements between work sites. Thus, excavators cannot move further distances to collect material from outside of the work zone (Stjemberg, 1982).

The studies indicated that road construction activities using excavator have advantages in long run due to reducing damages on forest ecosystem, biodiversity, and forest soil (Haanshus, 1998; Winkler 1999). Heinrich (2001) indicated that excavators have been commonly used in environmentally sensitive areas to reduce impact on forest vegetation, provide adequate drainage system, protect stream crossings, and improve stabilization of cut-and-fill slopes.

Excavators work with narrow right-of-way to reduce disturbance of the forest cover and diminish open lands for erosion risk. Besides, the ground pressure of the excavators on forest soil is less than that of bulldozer (Stjemberg, 1982). Due to lower ground pressure, excavators can carry out the operation in wet areas, while bulldozers are most likely stuck in mud. In order to take advantages of using excavator in forest road construction, the performances of the excavator should be evaluated considering economical and environmental requirements. In this study, forest road construction techniques by using hydraulic excavator and bulldozer were investigated based on sample roads constructions activities conducted in forest lands in Antalya region and Eskisehir region of Turkey. The environmental damages,

cross sections, productivities and construction costs and the hydraulic excavator and bulldozer were evaluated and some suggestions were provided.

MATERIALS AND METHODS

Study areas

The study areas are selected from the management zone of Aykircay Forest Enterprise in Antalya region and Seyitgazi Forest Enterprise in Eskisehir region (Figure 1). Firstly, in Aykircay Forest Enterprise area, commercial tree species include *Pinus brutia*, *Cedrus libani*, *Juniperus* sp. and *Quercus* sp. The elevation ranges from 700 to 900 m with the ground slopes of 20 to 90%. Total length of the sample road examined in this study was about 1650 m with the average road width of 5 m. The study area is consisting of type B forest roads with the density of 14 m/ha. Secondly, in the Seyitgazi Forest Enterprise area, commercial tree species include *Quercus* sp. and *Pinus sylvestris* L. The elevation ranges from 1200 to 1300 m with the ground slopes of 10 - 80%. Total length of this sample road examined in this study was about 3000 m and the average road width was 5 m. The road density of this area is 15 m/ha. The soil type of every study areas resembles each other. The amount of rocky areas in Aykircay region is further than Seyitgazi. The structure of rocky areas in Aykircay region is karst circulation system and the structure of rocky areas in Seyitgazi region is block rock system (Boydak, 2003).

The equipment specifications

In the Aykircay region, Daewoo Solar-220 LC-V type excavator was used in forest road construction and Caterpillar D7G type bulldozer was used in the Seyitgazi region. The undercarriage of the excavator was equipped with full-length track guards and had a protective plate. The technical specifications of the excavator and bulldozer are shown in Tables 1 and 2, respectively.

Field study

The whole construction activity of the sample forest road was observed in the field and data collection was performed during and after the road construction. The construction activity in Aykircay and Seyitgazi regions took place in August 2006 and May 2008, respectively. To characterize the forest road sections, nine decision variables were measured from each cross section along the roadway. These variables include cut-slope height (Ch), cut-slope width (Cw), ditch width (Dw), road width (Rw), fill-slope width (Fw), fill-slope length (Fl), road construction zone width (L), length of the impact zone beyond the fill-slope (P), and ground slope (S) (Figure 2). The surveying instruments such as clinometers, steel tape, measuring batten, altimeter, and compass were used in the field studies. Along the 1650 m of sample road section, decision variables were collected from 40 cross sections and along the 3000 m of road section, decision variables were collected from 100 cross sections, which were different distances. Then, the data were entered into a spread-sheet program (Microsoft Excel) to compute simple statistics such as arithmetic average and standard deviation. The average excavating speeds and productivities of every machine were found in these forest roads constructions. For every machines, every cross section as percent of slope were showed different on cut-slope and fill-slope. The shape of cross section of bulldozer and excavator were measured and difference between

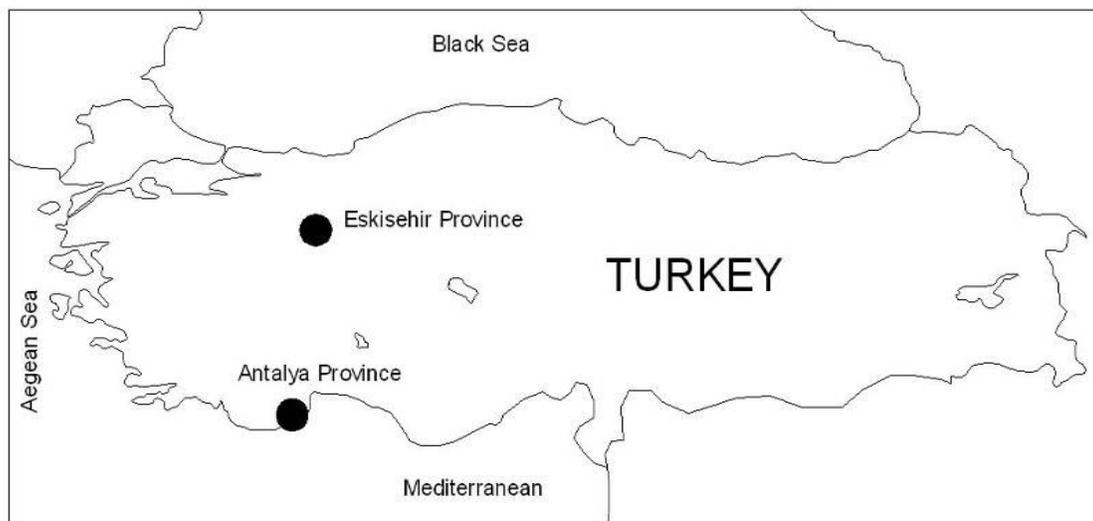


Figure 1. Study areas.

Table 1. Technical features of the Daewoo Solar 220-LC-V and hydraulic Hammer (Anonymous, 2007).

Specifications	Values	Specifications	Values
Weighth	21500 kg	Hydraulic hammer	Soosan SB81TS
Capacity of bucket	0.93-1.17 m ³	Working weigth	1721 kg
Engine type	DB58TIS	Working pressure	160-180 kg/cm ²
Engine power	148 - 1950 PS/rpm	Number of stroke	400 - 490 bpm
Speed	5 km/h	Hammer diameter	140 mm
Max. force	13100 kgf	Excavator types	18 - 34 ton
Max. Excavation depth	6630 mm		
Max. unloading height	6810 mm		
Boom turn speed	10.9 d/min		
Fuel tank	370 liters		

Table 2. Technical features of the Caterpillar D7G (Anonymous, 2008).

Specifications	Values	Specifications	Values
Weigth	20600 kg	Fuel tank	435 L
Engine type	Cat 3306 turbo	Hydraulic tank	50 L
Engine power	200 hp	Blade capacity	4.2 m ³
Max. travel speed		Height	1270 mm
i. Forward	10 km/h	Width	3660 mm
ii. Reverse	11.9 km/h	Digging depth	447 mm
Relief valve settings		Grand clearance	1170 mm
i. Blade	15516 kPa	Max.tilt	720 mm
ii. Ripper	15513 kPa	Balde weigth	3475 kg

length of cut-slope and length of fill-slope was showed. Besides, environmental damages of forest road constructions were investigated. For each study area, the shapes of damages under constructing roads were investigated.

RESULTS

In the first stage of road construction, either Aykiricay or

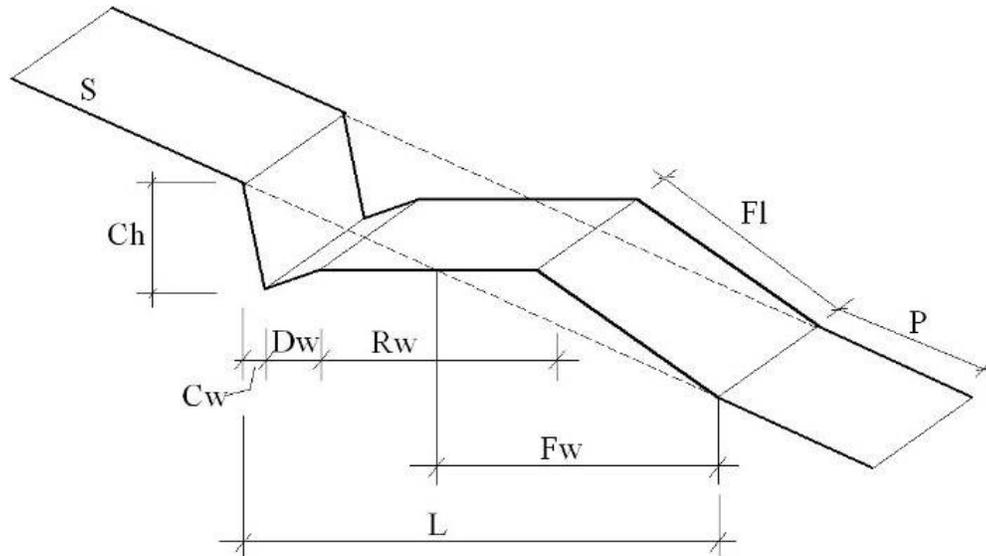


Figure 2. The decision variables measured from each cross section along the sample road.

Seyitgazi forest road construction areas were cut to trees on alignments. The numbers of trees in Aykircay and Seyitgazi areas are 345 and 654, respectively. The trees fallen were mostly *P. brutia* and *C. libani* in Aykircay region and *Quercus* sp. and *P. sylvestris* in Seyitgazi region. In Aykircay region, the results indicated that total materials excavated along the roadway was 12480 m³ in which the percentages of soil, loose rock and rock were 25, 25 and 50%, respectively. In Seyitgazi region, the total material excavated along the roadway was 6110 m³ in which the percentages of soil, loose rock and rock were 57, 13 and 30%. In road construction activities, explosives were not used for crushing rocks in two regions. The average operation time of the hydraulic excavator and bulldozer were 8 h per day.

Cross sections

Data of cross sections were collected for each road alignments. The values of the specific variables measured on the cross sections were listed on Tables 3 and 4. In Aykircay region, the average construction zone width was 6.22 m, therefore sample road section impacted approximately 1.00 ha of forested area (6.22 x 1650 m road length) during the road construction activity. In Seyitgazi region, average zone width was 7.47 m and sample road section impacted 2.24 ha of forested area (7.47 x 3000 m). The differences of cut-slope and fill-slope areas between excavator and bulldozer were measured. In this study, cut-slope rate of excavator and bulldozer were estimated 3/1 and 5/1 accordingly to ensure slope stability in terrains with step hillside gradient. For same gradient area, amount of excavated materials by excavator was found smaller than bulldozer. On the other hand, fill amount of excavator was found

higher than bulldozer. As a result, excavators were carefully placed on the fill-slope that circumvented materials using the bucket. Thus, in road construction activity, the optimum excavator operating techniques were implemented to minimize residual stand damage and overall environmental impacts. The logging residual is placed on the fill-slope with excavator as a barrier that keeps material falling down to fill-slope. Excated materials are scattered down than roadway by bulldozer. The rolling distance of excated materials were measured. For a bulldozer, the rolling distance of excated materials are average 10 m along the roadway and the distance of fill-slope were changed between 2 and 17 m according to slope gradient. However, when an excavator was used, this distance were measured average 7 m while the distance of fill-slopes were changed between 2 - 11 m according to slope gradient. Besides, excavators are placed on the fill slope by using the bucket to rocks in excavated materials. Especially, in the areas above 50% of slope gradient, all excated materials by bulldozer are thowed down than roadway. On the other hand, parting of all excavated materials were underlay of road by excavator.

Productivity and cost

The total road construction cost of Aykircay and Seyitgazi regions were found to be 35800 and 25500 US dollars, with the unit cost of 21.8 and 8.5 US dollars/m, respectively. Although the road length of Aykircay region is less, road construction cost was found higher than Seyitgazi region. Because the amount of rocks were found further in Aykircay region and this situation, cost of road was increased. In this study, the average productivities of the excavator to soil, loose rock and rock (35 -

Table 3. The values of decision variables measured on the cross sections (For excavator).

Variables	Symbol	Average	Standard deviation	Maximum values	Minimum values
Ground slope (%)	S	59.38	28.39	110.0	5.0
Cut-slope height (m)	Ch	3.46	2.15	7.2	0.5
Cut-slope width (m)	Cw	1.14	0.75	2.5	0.2
Ditch width (m)	Dw	0.78	0.08	1.0	0.7
Road width (m)	Rw	4.10	0.09	4.3	4.0
Fill-slope width (m)	Fw	4.94	2.70	10.8	1.2
Fill-slope length (m)	Fl	3.67	3.47	12.0	0.2
Impact zone length (m)	P	4.29	3.13	10.0	0.5
Construction zone width (m)	L	6.22	0.36	6.8	5.7

Table 4. The values of decision variables measured on the cross sections (For bulldozer).

Variables	Symbol	Average	Standard Deviation	Maximum Values	Minimum Values
Ground slope (%)	S	35	19.47	65	5
Cut-slope height (m)	Ch	2.15	1.19	4.5	0.7
Cut-slope width (m)	Cw	0.9	0.44	1.7	0.3
Ditch width (m)	Dw	1	0.11	1.2	0.7
Road width (m)	Rw	4	0.21	4.5	3.8
Fill-slope width (m)	Fw	3.1	0.5	4.28	2.59
Fill-slope length (m)	Fl	3.87	1.17	6.52	2.64
Impact zone length (m)	P	2.01	0.5	2.52	0.83
Construction zone width (m)	L	7.47	2.31	14.0	5.0

Table 5. Productivities of bulldozer and excavator at different excavated materials.

Slope (%)	Excavated materials type	Distance of cross sections	Productivity	
			Bulldozer (m ³ /h)	Excavator (m ³ /h)
35 - 45	Soil	15 m	189.0	102.3
35 - 45	Loose rock	15 m	83.7	56.2
35 - 45	Rock	15 m	44.8	40.0

45% slope) were found to be 102.3, 56.2 and 40 m³/h, respectively (Table 5). Besides, the average productivities of the bulldozer to soil, loose rock and rock (35 - 45% slope) were found to be 189.0, 83.7 and 44.8 m³/h, respectively. The average productivity on all constructed roads for bulldozer and excavator were found 105.8 and 66.2 m³/h, respectively.

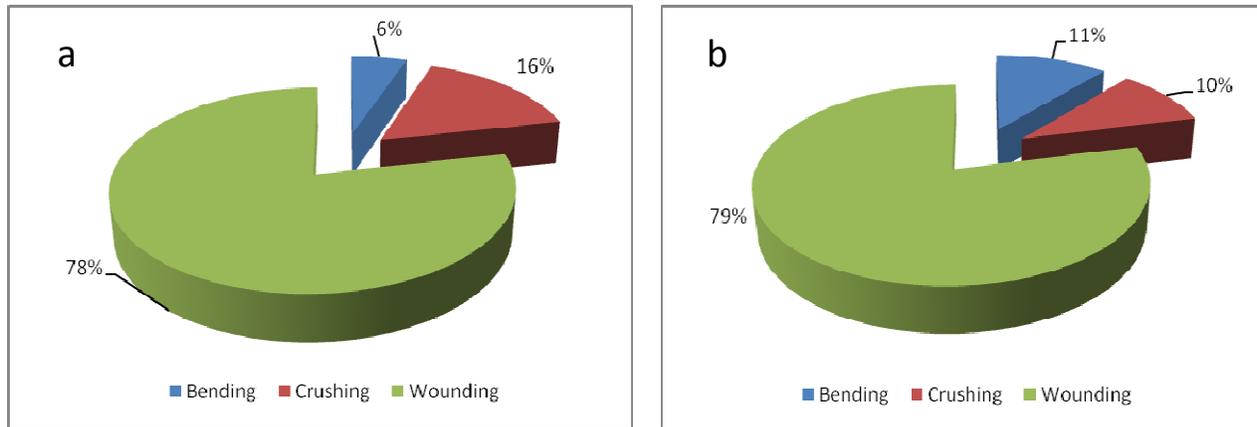
Environmental damages

The trail areas were designated between appointed cross sections for every road. The numbers of damaged trees and non damaged trees in every cross section were

counted to every road alignment. The resultant damages at trees are three types. These types are bending of tree, crushing of tree and wounding of tree stem. The number and rate of damaged trees in study areas are shown in Table 6. Another damage of road construction is staying under the soil material of trees and seedlings. The bark beetles are there to damage trees during road construction. Therefore, environmental damages are increased in these regions. Also, direct economic loss is increased for timber quality. The amount of damaged trees on steep terrain are found further to forest road constructing by bulldozer. In the 46 - 90% slope areas, the total number of damaged tree on forest roads constructing by using excavator and bulldozer were counted to be 20 and 53,

Table 6. Number and rate of damaged trees in study areas.

Machine type	Average terrain slope (%)	Number of damage trees	Number of non damage trees	Types of damages			Number of total trees	Damage rate (%)
				Bending	Crushing	Wounding		
Excavator	20 - 45	12	90	1	2	9	102	12
	46 - 90	20	68	1	4	20	88	23
Bulldozer	10 - 45	18	105	3	2	13	123	15
	46 - 80	53	88	5	5	43	131	40

**Figure 3.** The percent of damages in (a) Aykırıcay and (b) Seyitgazi.

respectively. The damage rate of excavator is 23% and the damage rate of bulldozer is 40%. In the forested areas with greater than 55% ground slope, all excavated materials are scattered down than roadway by bulldozer. This situation of the roads is causing increase of damages. The percent of damages as wounding, crushing and bending for trees in Aykırıcay and Seyitgazi are 78, 16, 6% and 70, 10, 11%, respectively (Figure 3). In every study areas, the bark beetles can occur to damage trees after road constructions. These bark beetles caused big damages in these forest regions. Also, direct economic loss is increased for timber quality. The damages of road construction are shown in Figure 4.

DISCUSSION

In this study, the average construction zone width in Aykırıcay and Seyitgazi were found as 6.22 and 7.47 m, respectively. The impacted 'forested' area by using the bulldozer was approximately 20.1% greater than that of using the excavator. A study conducted in Antalya region (Tunay and Melemez, 2004) reported that a road construction activity on a terrain with 36 - 50% ground slope resulted in 9.40 and 12.18 m wide road construction zones by using excavator and bulldozer, respectively. This suggested that the impacted forested

area by using the bulldozer was approximately 29.58% greater than that of using the excavator. Tunay and Melemez (2004) also revealed that the bulldozer results are about 26.16% of more impacted forested area than the excavator in road construction activity.

In this study, the total road construction cost of Aykırıcay and Seyitgazi regions were found to be 35800 and 25500 US dollars, with the unit cost of 21.8 and 8.5 US dollars/m, respectively. Besides, the average product rate of the excavator and bulldozer were found to be 8 and 12.5 m/h, respectively. In a study conducted by Winkler (1999) in Himalaya (Bhutan), the unit cost of construction by excavator was 9.38 US dollars/m with the production rate of 6.91 m/h. Acar and Eker (2001) conducted a similar study in Eastern Black Sea Region of Turkey where 4341 m of forest road was constructed by an excavator on a steep terrain with 70% ground slope. In that study, the unit cost of road construction and average production rate was 5.87 US dollars/m and 8.67 m/h, respectively. Another study conducted by Filipsson and Eriksson (1989) in Sweden indicated that the average productivity of using excavator in road construction was 12.7 m/h.

In this study, the unit cost of road construction (21.8 US dollars/m) was greater than the unit costs reported by the previous studies. This was because the study area



Figure 4. Environmental damages during forest road construction.

was located on a karstic region with rough terrain characteristics and large amount of rocks (6232 m³) to be excavated along the roadway. Besides, ground slope, soil characteristics, and operator factor might affect the cost of road construction. Cut slope rate for karstic steep terrains in this study was determined 5/1. Another study conducted by Kramer (2001) indicated that cut slope rate of 5/1 is the most appropriate rate for especially for steep terrains (Kramer, 2001).

In this study, environmental damages of the forest roads constructed by the excavator are less than that constructed by the bulldozer. The previous studies indicated that impacted forested area due to road construction by using the bulldozer is much more than that of using the hydraulic excavator. Besides, visual quality of the forest roads constructed by the hydraulic excavator is much better than that of constructed by the bulldozer, considering technical and environmental aspects (Bayoglu, 1989).

CONCLUSION

In this study, the forest road construction techniques by using hydraulic excavator and bulldozer were evaluated by considering economical and environmental requirements and the following suggestions are made:

1. The use of excavator in forest road construction activities should be encouraged and even mandatory in mountainous regions with steep terrains.
2. Bulldozers should be used in the forested areas with less than 45% ground slope, while excavators should be preferred when the slope is greater than 45%.
3. The use of hydraulic hammer of excavator on the rocks areas is very effective and it is not environmental damages as explosive materials.
4. The excavator operators should be well trained to improve the efficiency of construction activity, regarding economical and environmental aspects.
5. In the planning phase of the forest roads, the methods and equipment selection should be predetermined not only considering by economical issues but also environmental requirement.

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