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Full Length Research Paper

Environmental damages of forest road construction by bulldozer on steep terrain

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In this study, forest road construction technique by using bulldozer was investigated in forested lands in Bolu region in Turkey. The objective of the study was to evaluate cross sections constructed by bulldozer along the forest road alignment and to determine the differences between the fill-slope and cut-slope formations in the cross sections in terms of environmental damages. Maximum length and minimum length of fill slope was found to be 2 and 50 m on 10 and 80% slope gradient, respectively. The number of damaged trees and seedlings regarding with various gradient classes were also determined in study area. The results indicated that the 36% of trees under the forest road construction were wounded and 43% of seedlings stayed under the soil for 56-80% ground slope. The rate of wounding in three types specified damages (bending of tree, crushing of tree and wounding of tree stem) was 64%. The rate of staying under the soil was 81%.

Key words: Bulldozer, forest road, road construction, environmental damage.

INTRODUCTION

The forest roads are the base infrastructure foundations which provide access to forest lands for extraction, regeneration, protection, and recreation activities (Demir and Hasdemir, 2005). However, designing low-volume forest roads is a complex engineering problem involving economic, environmental and social requirements. Construction and maintenance costs are the largest components in the total cost of producing timber for industrial uses (Akay, 2006). Besides, road construction activities remove the forest vegetation and disturb soil structure, which may lead to number of environmental damages in forest ecosystem (Grace, 2002). For example, sediment yield delivered from forest roads to the streams result in dramatic effects on water quality and aquatic life (Akay et al., 2008). Moreover, planning forest road networks depends on social requirements since they provide access to forest villages, rural settlements, and recreational areas (Acar and Eker, 2001). Therefore, forest roads construction activities must be carefully executed by considering economical, environmental, and social requirements (Akay and Sessions, 2005).

Planning of multi-functional forest road networks is one essential for meeting the aims of the sustainable forest concept (Gumus et al., 2008). The main function of the forest road network is to open-up forest areas internally. The open-up of forest areas is doing with different road types such as A type roads, B type roads and skidding roads. Opening up networks can be accomplished with roads according to the national geographical and managing circumstances. However, forest road construction gets into the cross-firing of nature and environment protection. In locating forest roads, construction techniques and equipments selection directly affect the economical, functional, and ecological efficiency of the forest roads (Haanshus, 1998).

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

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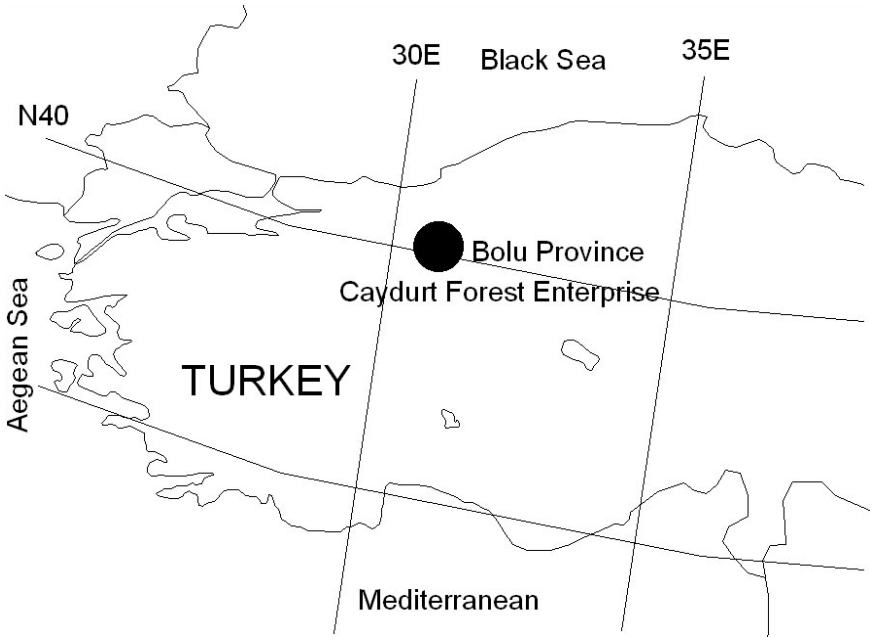

Figure 1. Study area.

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 (Stjernberg, 1982; Filipson et al., 1989). According to Spaeth (1998), combination of bulldozers and excavators can be used in road construction activities on terrain with greater than 50%.

Using bulldozers reduce 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). Forest roads construction should be both economical and protective for the landscape. Careful attention has to be paid when planning and locating roads, especially in steep terrain, to avoid or minimize the erosional impact of roads on the environment (Heinrich, 1979; Heinrich, 2001).

In this study, forest road construction techniques by using bulldozer were investigated based on sample roads constructions activities conducted in forested lands in Bolu region of Turkey. The environmental damages, productivities and construction cost of bulldozer were evaluated and some suggestions were provided.

MATERIALS AND METHODS

Materials

The study areas are selected from the management zone of Caydurt Forest Enterprise in Bolu region (Figure 1). The study area is selected from the management zone of Caydurt Forest Enterprise that lies in the Central Anatolia Region between the coordinates 31°45' - 31°60' East and 40°37'- 40°47' North. In the Caydurt Forest Enterprise area includes commercial tree species which *Pinus sylvestris*, *Pinus nigra*, *Abies bornmulleriana*, *Fagus orientalis* and *Quercus* sp. The elevation of this region ranges from 750 to 1850 m with the ground slopes of 10 to 100%. Total area of Caydurt Forest Enterprise is 19281 ha. The amount of forest area of this region is 12621 ha. The annual growing stock is 12625 m^3 with an annual increment of about 1.18 m^3/ha.

Total length of the sample road examined in this study was about 3670 m with the average road width of 5 m. The width of ditch is one meter. The elevation of road start point is 1550 m and finish point of road is 1370 m. The road density of region is 15 m/ha.

The equipment specifications

In the study area, Caterpillar D8T type bulldozer was used for forest road construction. The technical specifications of the bulldozer are shown in Table 1. The model of bulldozer used for road construction is 1986.

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 Caydurt region took place in July 2008. The surveying instruments such as clinometers, steel tape, measuring batten, altimeter, and compass were used in the field studies. Along the 3670 m of sample road section, decision variables were collected from 90 cross sections which have different distances.

The average excavating speeds and productivities of bulldozer was found in this forest road construction. Environmentally damages of forest road constructions were investigated for every cross section. The shapes of damages under constructing road were investigated.

Table 1. Technical features of the Caterpillar D7G Bulldozer (Anonymous, 2008).

Specifications	Values	Specifications	Values
Weigth	33075 kg	Fuel tank	625 liters
Engine type	Cat 3406 turbo	Hydraulic tank	72 litres
Engine power	305 hp	Blade capacity	8.7 m^3
Max. travel speed		Height	1690 mm
Forward	10.8 km/hr	Width	3937 mm
Reverse	13.9 km/hr	Digging depth	582 mm
Relief valve settings		Grand clearence	1231 mm
Blade	24100 kPa	Max.tilt	951 mm
Ripper	24100 kPa	Balde weigth	4570 kg

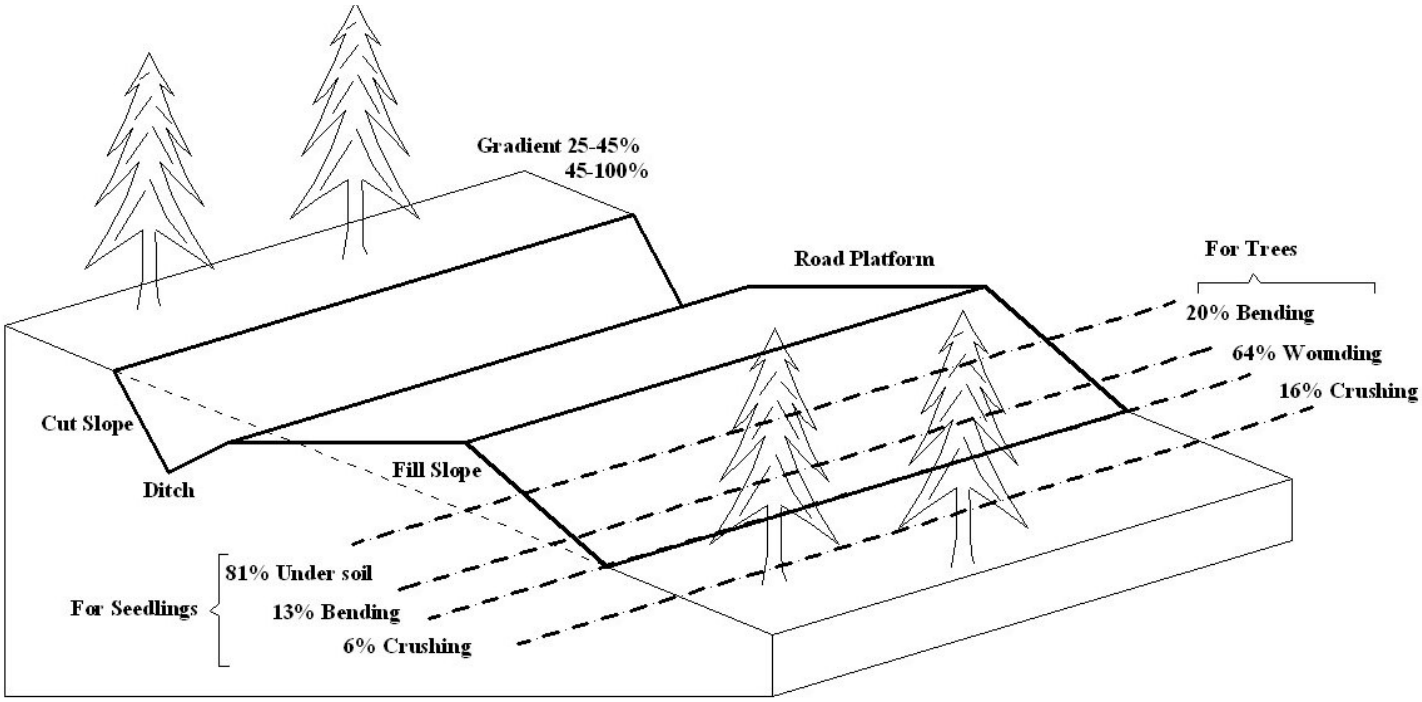

Figure 2. Proportion of environmental damages on road cross section.

RESULTS AND DISCUSSION

In the first stage of road construction, the trees on the forest road construction areas in Caydurt were removed from the road routes. The numbers of cutting trees removed were 560. The trees fallen were mostly *P. sylvestris* and *A. bornmulleriana* in Caydurt region.

In Caydurt region, the results indicated that total materials excavated along the roadway was 12964 m^3 in which the percentages of soil, loose rock and rock were 68.2, 21.2 and 10.6%, respectively. In road construction activities, explosive was not used for crushing rocks in regions. The average operation time of the bulldozer was 8 hours per day.

In Caydurt region, the average construction zone width was 7.27 m, therefore sample road section impacted approximately 2.67 ha of forested area (7.27 x 3670 m road length) during the road construction activity. The cut-slope and fill-slope areas were measured. In this study, cut-slope rate and fill slope rate of cross section were estimated 3:1 and 2:3 according to ensure slope stability in terrains with step hillside gradient.

Excated materials are scattered to down than roadway by bulldozer. The rolling distance of excated materials were measured for ever cross section. The rolling distance of excated materials are average 13.5 m along the roadway. The distance of fill-slope were changed

Table 2. Productivity of bulldozer at different excavated materials.

Slope (%)	Excavated materials type	Distance of cross sections	Productivity Bulldozer (m^3/hr)
15	Soil	15 m	176.4
35	Soil	20 m	284.2
55	Loose rock	20 m	136.0
70	Rock	25 m	83.3

Table 3. Average number and rate of damaged trees in study areas by bulldozer.

Average slope (%)	Number of trial areas	Number of damage trees	Number of non damage trees	Types of damages			Number of total trees	Damaged rate in area (%)
				Bending	Crushing	Wounding		
10-35	15	33	90	8	5	20	123	27
36-55	15	57	122	10	8	39	179	32
56-80	20	86	152	18	15	53	238	36

Table 4. Average number and rate of damaged seedings in study areas by bulldozer.

Average slope (%)	Number of trial areas	Number of damage seeding	Number of non damage seeding	Types of damages			Number of total seeding	Damaged rate in area (%)
				Bending	Crushing	Under the soil		
10-35	15	10	55	2	1	7	65	15
36-55	15	25	53	3	5	17	78	32
56-80	20	68	90	8	6	54	158	43

between 2 and 50 m according to ground slope. Especially, in the areas above 50% of ground slope all excated materials by bulldozer are throwed to down than roadway. More and more gradient of terrain, excavated materials is rolling towards down. The proportion of environmental damages on road cross section is shown Figure 2.

Productivity and cost

The total cost of road construction in Caydurt region was found as 32020 $ with the unit cost of $ 8.72 per meter. In this study, the average productivity of the bulldozer to soil, loose rock and rock was found to be 230.3 , 136.0 and 83.3 m^3/ hr, respectively (Table 2).

Environmental damages

The numbers of damaged trees and non damaged trees in every cross section were counted to across road aligment. The resultant damages at trees were three types namely bending of tree, crushing of tree and wounding of tree stem. The resultant damages at seedlings were three types. These types are bending of seedling, crushing of seedling and stay under soil of seedling. The number and rate of damaged trees and seedlings in study areas are showed Tables 3 and 4. The percent of damages as wounding, bending and crushing for trees are 64, 20 and 16%, respectively. Besides, the percent of damages as under soil, bending and crushing for seedlings are 81, 13 and 6%, respectively (Figure 3). The bark beetles can occur to damaged trees during road construction. The species of showing bark beetle in this region is *Pityokteines curvidens* (Germ). These beetles were composed to big damaged in this forest region. Thus, direct economic loss was increased on timber quality. The damages of road construction is showed Figure 4.

In this study, conifer trees in stands under road during forest road construction were damaged further than hardwood. Besides, wounding of trees bark is observed to thick diameter trees. Bending and crushing were observed to thin diameter trees. Environmental damages were affected by following factors; gradient of terrain, tree

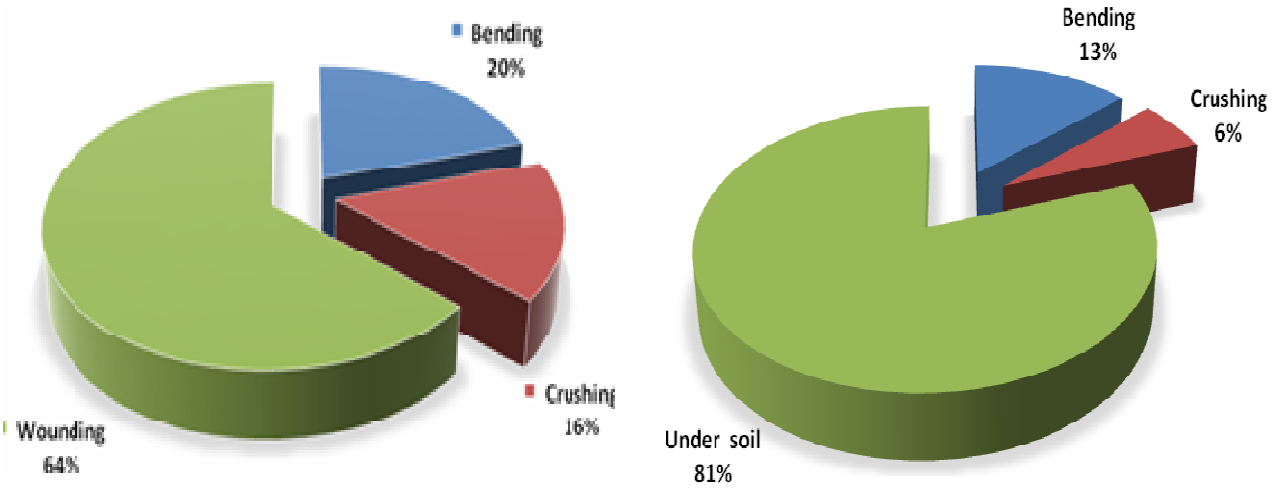

Figure 3. The rate of damages on trees and seedlings.

Figure 4. Environmental damages.

species, plant cover, diameter of rock and volume of excavated material.

In this study, 36% of trees under the forest road construction were wounded and 43% of seedlings stayed under the soil for 56-80% ground slope. The portion of wounding in three type damages was 64%. The portion of stay under the soil was 81%. In a similar study conducted by Tunay and Melemez (2004) in Antalya, 55% of trees under the forest road construction in terrain further than 51% of ground slope were damaged.

In this study, the average construction zone width in Caydurt was found as 7.27 meter on a terrain with 30-80% ground slope. 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 12.18 m wide road construction zones by using bulldozer. The total road construction cost of Caydurt region was found to be $32020, with the unit cost of $ 8.7 per meter. Besides, the average product rate of the bulldozer was found to be 8.5 m/hr. In a study conducted by Winkler (1999) in Himalaya (Bhutan), the unit cost of construction by bulldozer was $ 6.07 per meter with the production rate of 15.19 m/hr. In another research, approximate cost per lines meters of road are $15-25 on area greater than 50% slopes and $8-15 on area 30 to 50% slopes (Anonymous, 2005). In a study conducted by Blaha (1979), with a construction output of 80-200 m per working day (10 h) the cost would amount to averaging $ 6.7 per meter.

In this study, the unit cost of road construction ($ 8.7 per meter) was greater than the unit costs reported by the previous studies. The reason of this situation was due such factors that ground slope, soil characteristics and operator factor might affect the cost of road construction.

Cut slope rate for steep terrains in this study was determined 3/1. Another study conducted by Kramer (2001) indicated that cut slope rate of 3/1 is the most appropriate rate for especially for steep terrains (Kramer, 2001).

Environmental damages of the forest roads constructed by the bulldozer are generally bigger. Damages are especially observed in steep terrain. The previous studies indicated that impacted forested area due to road construction by using the bulldozer was much more than that of using the hydraulic excavator (Erdas, 1986; Bayoglu, 1989).

Conclusion

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

i) 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%.
ii) Especially, forest roads constructions in steep terrain may use together bulldozer and excavator. The use of hydraulic hammer of excavator on the rocks areas is very effective and it does not environmental damages as explosive materials.
iii) The bulldozer operators should be well trained to improve the efficiency of construction activity, regarding economical and environmental aspects.
iv) In the planning phase of the forest roads, the methods and equipment selection should be predetermined not only considering economical issues but also environmental requirement.

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