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**REVIEW OF THE FACULTY OF FORESTRY, UNIVERSITY OF ISTANBUL**

**ZEITSCHRIFT DER FORSTLICHEN FAKULTÄT DER UNIVERSITÄT ISTANBUL**

**REVUE DE LA FACULTÉ FORESTIÈRE DEL 'UNIVERSITÉ D'ISTANBUL**

F-1

# The Use of Excavator in Forest Road Construction in Karst Region of Turkey

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## Abstract

**In this study, forest road construction techniques, environmental damages, cross sections and productivity by using hydraulic excavator were investigated in forested lands in Antalya region of Turkey. Besides, cross sections of excavator were compared according to gradient. Differences of fill-slope and cut-slope in the cross sections were determined. Maximum length of fill slope for excavator was found to be 17 m on 80% slope gradient. The cost of excavator was calculated as $21.8 per meter. Productivity of excavator was found as 105.8 $m^3$/h.**

**Keywords:** Hydraulic excavator, forest road, road construction, environmental damage

## 1. 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). Besides, planning forest road networks depends on social requirements since they provide access to forest villages, rural settlements, and

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recreational areas (Acar and Eker, 2005). Therefore, 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. 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 (Stjernback, 1982). Besides, using excavator improves the quality of the forest roads, which extends life of the roads, improves the driver comforts, 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).

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 Erdaş (1986), it was indicated that excavator should be used in construction activities on steep terrains to reduce environmental impacts. Bayoğlu (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 was satisfactory in forest road construction. 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 can not move further distances to collect material from outside of the work zone (Stjernback, 1982).

The studies indicated that road construction activities using excavator has advantages in long run due to reducing damages on forest ecosystem, biodiversity, and forest soil (Haanshus, 1998 and 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 (Stjernback, 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 were investigated based on a sample road construction activity conducted in forested lands in Antalya region of Turkey. The construction costs and the environmental damages of hydraulic excavator were evaluated and some suggestions were provided.

## 2. Hydraulic Excavator

### 2.1. Hydraulic excavator operating techniques

In recent decades, there has been an increasing interest in using the hydraulic excavators in forest road construction activities. In North America, excavators have been used as a complement to the bulldozers and in most cases they successfully replaced the bulldozers. Excavators can be used to construct roads, upgrade old roads, load gravel and woods, extract hard cut material, break rocks, shape high-sided cut slopes, build the sub-grade and side ditches, and place culverts (FAO, 1998). They have advantages of working on smaller sections in the slopes from 20-50% (Figure 1). There are many excavator operating techniques related mainly to terrain types and environmental sensitivity (Stjernback, 1982).

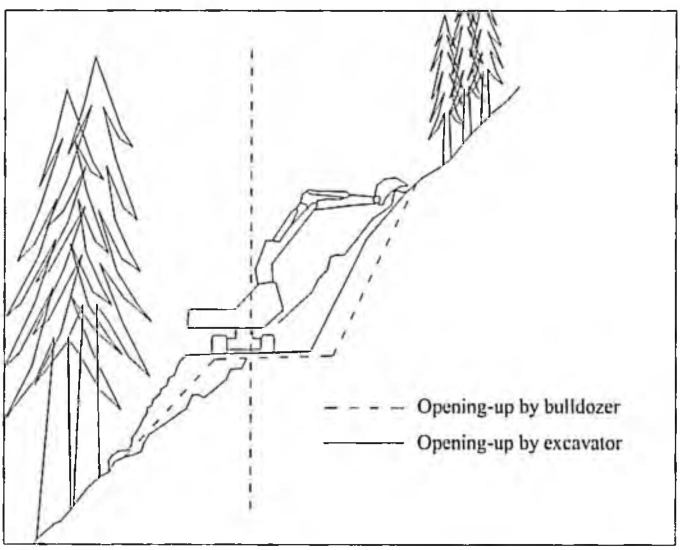


Figure 1. Forest road construction by excavator vs. bulldozer (Kararizos, 2001).
Şekil 1. Buldozer ve ekskavatör ile orman yol yapımı.

The excavators generally take place in follows activities in the forest road construction: (1) removing logs and waste material, (2) constructing, leveling, and compacting subgrade, (3) constructing ditches and installing culverts.

## 2.2. Removing logs and waste material

The excavators carry the logs by moving backward and pile them at one side of the road, leaving other side free to obtain fill material and access to the forest (Stjernback, 1982). It is rather difficult and inefficient to carry out the logs all the way to landing area due to lower travel speed of the excavators (FAO, 1999). Then, the waste material such as unmerchantable trees, stumps, branches, and topsoil is removed from the roadbase. In wet areas, excavator can easily remove the topsoil without disturbing the roots or mixing it with fill material.

## 2.3. Constructing, leveling, and compacting subgrade

The hydraulic excavators are the most suitable for subgrade function in forest road construction since sufficient fill material is generally available within the reach of the excavators (i.e. 8 m to 10 m) in most terrain conditions (Stjernback, 1982). There are three different techniques in implementing roadbase excavation, based on location of the excavators (Stjernback, 1982);

- The excavator operates in the ditchline by digging over the front of the undercarriage In this case, the excavator can reach further distances from the roadbase to obtain extra fill material.
- The excavator operates between the ditchline and the roadbase by digging over the side of the undercarriage. This provides a shoulder wider than the undercarriage, which is an advantage from aspect of road safety.
- The excavator operates from the roadbase by digging over the side of the carriage. However, this position provides the operator with the best view of the road alignment. If the fill material is available at both sides of the road, working from the roadbase has advantages of obtaining extra fill material from both sides.

The bucket of the excavator can be also efficiently used in smoothing and compacting activities. The material spread by the excavator is to be compacted after several passes to build about 30 to 50 cm layer with coarse material (FAO, 1999).

## 2.4. Constructing ditches and installing culverts

In order to reduce the potential soil disturbance due to subgrade construction, an adequate drainage system should be established by constructing ditches and installing culverts. Using excavator in establishing drainage system provides clean and well-groomed ditches, which reduces surface flow and sub-surface flow (Stjernback, 1982). The hydraulic hammer can be used in constructing ditches and then bucket of the excavator performs cleaning up the ditches (FAO, 1999).

## 3. Forest Roads in Turkey

In the forested lands of Turkey, there are three common forest road types; Type A, Type B, and Skid Roads. The main factor that distinguishes these road types is road gradient which is reflected by the performance of logging trucks and water drainage. The road standards are listed in Table 1. In order to adequately carry out sustainable management of forest resources, about 202000 km of forest road network is required and about 68000 km of forest road is yet to be constructed (Demir, 2007).

Table 1. The technical standards of forest road types in Turkey
Tablo 1. Türkiyedeki orman yol tiplerinin teknik özellikleri

| Technical specifications Teknik Özellikler | Road Types (Yol Tipleri) | | |
|---|---|---|---|
| | Type A | Type B | Skid Roads |
| Road width (m) Yol Genişliği (m) | 6.0 | 4.0 | 3.5 |
| Max. Road Grade (%) Mak. Yol Eğimi (%) | 10.0 | 9.0-12.0 | 18.0 |
| Min. Curve radius (m) Min. Kurp Yarıçapı (m) | 35.0 | 10.0-12.0 | 8.0 |
| Number of Lines Şerit Sayısı | 1.0 | 1.0 | 1.0 |
| Travelway width (m) Platform Genişliği (m) | 5.0 | 3.0 | 3.0 |
| Shoulder width (m) Banket Genişliği (m) | 0.5 | 0.5 | – |
| Ditch width (m) Hendek Genişliği (m) | 1.0 | 1.0 | – |

The various types of bulldozers had been traditionally used by private contractors in forest road construction activities till last decade in Turkey. After the Eight Five-year National Development Plan of Turkey in 2001, General Directorate of Forestry has encouraged the use of excavators in construction of new forest roads, due to excessive damage of bulldozers on forest ecosystem (Acar and Eker, 2003).

## 4. Material and Methods

### 4.1. Study area

The study area is selected from the management zone of Aykırıçay Forest Enterprise in Finike Forest Management (Figure 2).

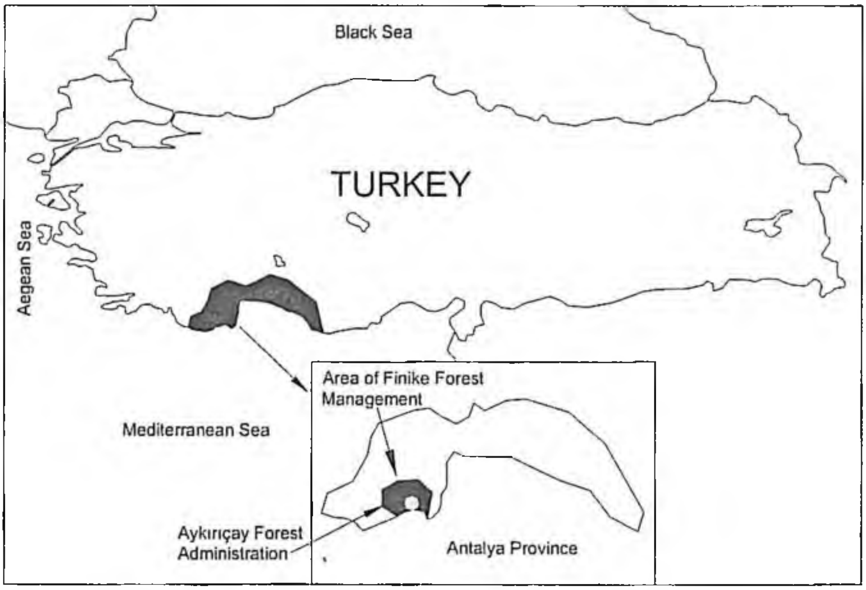


Figure 2. The location of the study area in Antalya region
Şekil 2. Antalya bölgesindeki çalışma alanının konumu

In this enterprise, dominant commercial tree species include *Pinus brutia* Ten., *Cedrus libani* A.Rich., *Juniperus* sp. and *Quercus* sp. The elevation ranges from 700 m to 900 m with the ground slopes of 20% to 100%. The study area consists of Type B forest roads with the density of 14 m/ha. Total length of the sample road examined in this study was about 1640 m with the average road width of 5 m. The study area is located on the Taurus Mountains, which is the largest and most important karst region in Turkey. According to Boydak (2003), this region has one of the most complex karst circulation system and rough terrain characteristics such as sharp peaks, deep valleys, and narrow gorges. Due to immediate penetration of rainfall and snow melt into the rock crack system, surface soil formation very slowly occurs along the cracks and stratification surfaces of the limestone (Boydak, 2003).

## 4.2. The equipment specifications

Daewoo Solar 220 LC-V type hydraulic excavator and Soosan SB 81 TS type hydraulic hammer were used in forest road construction activity. The undercarriage of the excavator was equipped with full-length track guards and had a protective plate. The technical specifications of the excavator and hammer are shown in Table 2.

Table 2. Technical features of the Daewoo Solar 220-LC-V and hydraulic hammer (Anonymous, 2007)
Tablo 2. Daewoo Solar 220-LC-V ve hidrolik kırıcının teknik özellikleri

| Specifications Özellikler | Values Değerler | Specifications Özellikler | Values Değerler |
|---|---|---|---|
| Weigth - Ağırlık | 21500 kg | Boom turn speed Kule dönüş hızı | 10.9 d/min |
| Capacity of bucket Kepçe kapasitesi | 0.93-1.17 $m^3$ | Fuel tank Yakıt deposu | 370 liters |
| Engine type Motor tipi | DB58TIS | Hydraulic hammer Hidrolik kırıcı | Soosan SB81TS |
| Engine power Motor gücü | 148-1950 PS/rpm | Working weigth Çalışma ağırlığı | 1721 kg |
| Speed - Hız | 5 km/hr | Working pressure Çalışma basıncı | 160-180 $kg/cm^2$ |
| Max. force Mak. güç | 13100 kgf | Number of stroke Piston sayısı | 400-490 bpm |
| Max. Excavation depth – Mak. Kazma derinliği | 6630 mm | Hammer diameter Kırıcı çapı | 140 mm |
| Max.unloading height – Mak. boşalma yüksekliği | 6810 mm | Excavator types Ekskavatör tipleri | 18-34 ton |

## 4.3. 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 took place in August 2006. 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 3).

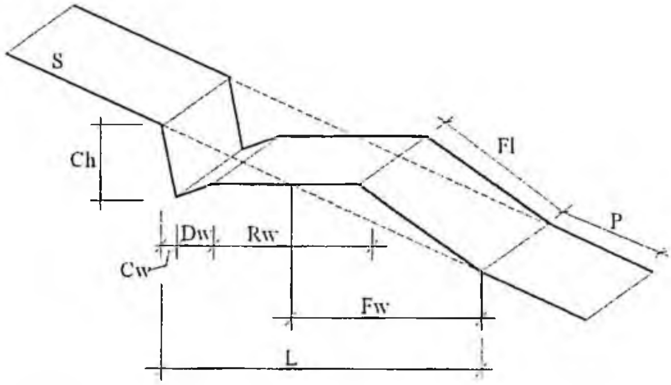


Figure 3. The decision variables measured from each cross section along the road
Şekil 3. Yol boyunca her enkesit için ölçülen değerler

The surveying instruments such as clinometers, steel tape, measuring batten, altimeter, and compass were used in the field study. Along the 1640 m of sample road section, decision variables were collected from 32 cross sections, which were 50 m apart. Then, the data were entered into a spread-sheet program (Microsoft Excel) to compute simple statistics such as arithmetic average and standard deviation.

## 5. Results

In the first stage of road construction, 354 $m^3$ of logs were extracted by felling 345 trees along the road construction zone of sample road. The trees fallen were mostly *Pinus brutia* and *Cedrus libani*. The logging residuals were placed on the fill-slope as a barrier that keeps material falling down to fill-slope. The results indicated that total material excavated along the roadway was 12480 $m^3$ in which the percentages of soil, loose rock, and rock were 24.88%, 25.19%, and 49.93%, respectively. In road construction activities, explosives were not used for crushing rocks. The average operation time of the hydraulic excavator was 8 hours per day (Figure 4).

Since it is very hot in Antalya in summer season, the excavator operated from 7:00 to 11:00 AM in the morning, and from 14:00 to 18:00 PM in the afternoon. The values of the specific variables measured on the cross sections were listed on Table 3. The average construction zone width was 7.47 m, therefore, sample road section impacted approximately 1.23 ha of forested area (7.47 m x 1640 m) during the road construction activity.

Figure 4. Constructing the subgrade by an excavator (Photo: T.Ozturk)
Şekil 4. Bir ekskavatör ile yol temelinin yapılması

Table 3. The values of decision variables measured on the cross sections
Tablo 3. Enkesitlerde ölçülmüş değişkenlerin değerleri

| Variables Değişkenler | Symbol Sembol | Average Ortalama | Standard Deviation Std. Sapma | Maximum Values Mak. Değer | Minimum Values Min.değer |
|---|---|---|---|---|---|
| Ground slope (%) Arazi eğimi | S | 59.38 | 28.39 | 110.0 | 5.0 |
| Cut-slope height (m) Kazı şevi yüksekliği | Ch | 3.46 | 2.15 | 7.2 | 0.5 |
| Cut-slope width (m) Kazı şevi genişliği | Cw | 1.14 | 0.75 | 2.5 | 0.2 |
| Ditch width (m) Hendek genişliği | Dw | 0.78 | 0.08 | 1.0 | 0.7 |
| Road width (m) Yol genişliği | Rw | 4.10 | 0.09 | 4.3 | 4.0 |
| Fill-slope width (m) Dolgu şevi genişliği | Fw | 4.94 | 2.70 | 10.8 | 1.2 |
| Fill-slope lenght (m) Dolgu şevi uzunluğu | Fl | 3.67 | 3.47 | 12.0 | 0.2 |
| Impact zone length (m) Etkilenen alan uzunluğu | P | 4.29 | 3.13 | 10.0 | 0.5 |
| Construction zone width (m) İnşaat alanı genişliği | L | 7.47 | 2.31 | 14.0 | 5.0 |

The total road construction cost was found to be $35800, with the unit cost of $ 21.8 per meter. The production rate of the excavator is generally computed as the length of constructed road per hour. In this study, the average production rate of the excavator was found to be 8.0 m hr. The excavator excavated 36 $m^3$ of material per hour and cleared them away from the roadway. This high productivity indicated that hydraulic excavators combined with hydraulic hammers can perform excavation operations quickly and effectively in karstic regions.

In road construction activity, the optimum excavator operating techniques were tried to be implemented to minimize residual stand damage and overall environmental impacts. For example, after rocks were crushed by the hydraulic hammer and then they are carefully placed on the fill slope by using the bucket. Besides, cut slope rate of 5/1 was maintained along the roadway to ensure slope-stability in terrains with steep hillside gradient. In fact, cut slope rate of 5/1 is the most appropriate rate for karstic areas, especially for steep terrains. 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 aligment. 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 showed Table 4.

Table 4. Number and rate of damaged trees in study areas
Tablo 4. Çalışma alanında zarar görmüş ağaçların sayısı ve oranı

| Average terrain slope (%) Ort.arazi eğimi | Number of damage trees Zarar gören ağaç sayısı | Number of non damage trees Zarar görmeyen ağaç sayısı | Types of damages Zarar tipleri | | | Number of total trees Toplam ağaç sayısı | Damage rate (%) Zarar oranı |
|---|---|---|---|---|---|---|---|
| | | | **Bending Eğilme** | **Crushing Kırılma** | **Wounding Yaralanma** | | |
| 20-45 | 12 | 90 | 1 | 2 | 9 | 102 | 12 |
| 46-90 | 20 | 68 | 1 | 4 | 20 | 88 | 23 |

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 is counted 25. The damage rate of excavator is 23%. On the terrain less than 45%, number of total damages is 9. Wounding damages are prevail among in this area.

## 6. Discussion

In road constructions activities, environmental damages were not showed in this study. 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 that of constructed by the bulldozer, considering technical and environmental aspects (Bayoglu, 1989).

The average construction zone width was found as 7.47 m in this study. 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 m 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 indicated that the bulldozer results in about 26.16% of more impacted forested area than the excavator in road construction activity.

In this study, the total road construction cost was found to be $35800, with the unit cost of $21.8 per meter. Besides, the average product rate of the excavator was found to be 8 m $hr^{-1}$. In a study conducted by Winkler (1999) in Himalaya (Bhutan), the unit cost of construction by excavator was $ 9.38 per meter with the production rate of 6.91 m/hr. 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 per meter and 8.67 m $hr^{-1}$, respectively. Another study conducted by Filipsson and Eriksson (2004) in Sweden indicated that the average productivity of using excavator in road construction was 12.7 metres per hour.

In this study, the unit cost of road construction ($ 21.8 per meter) was greater than the unit costs reported by the previous studies. This was because the study area was located on a karstic region with rough terrain characteristics and large amount of rocks (6232 $m^3$) 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).

## 7. Conclusions

In this study, the forest road construction techniques by using hydraulic excavator were evaluated by considering economical, technical and environmental requirements. The following suggestions are made in the light of the previous studies and the results derived from the sample road construction activity:

The use of excavator in forest road construction activities should be encouraged and even mandatory in mountainous regions with steep terrains.

In order to reduce road construction costs and environmental impacts, the excavators should replace bulldozers, especially in Antalya region where explosives are used in karstic lands with great danger to forest ecosystem.

The excavator operators should be well trained to improve the efficiency of construction activity, regarding economical and environmental aspects.

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.

The drainage ditches should be adequately located by using excavators and should be maintained properly, especially at Southern Mediterranean Region.

The culverts with adequate size and lengths should be installed by using the excavators. Besides, crowned slopes, pipes, and drain dips should be constructed along the roadway where they are necessary.

# Türkiye'nin Karstik Bölgelerinde Orman Yol Yapımında Ekskavatörün Kullanımı

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## Özet

**Bu çalışmada, Türkiye'nin Akdeniz bölgesinde kullanılan bir hidrolik ekskavatörün orman yol yapım teknikleri, çevresel zararları, enkesitleri ve verimliliği incelenmiştir. Çalışmanın sonuçlarında, ekskavatörün arazi eğimine göre yol enkesitleri karşılaştırılmıştır. Enkesitlerde dolgu ve kazı şevi farklılıkları belirlenmiştir. Ekskavatör için dolgu şevinin maksimum uzunluğu %80 eğimde 17 m olarak hesaplanmıştır. Ekskavatörün maliyeti 21.8 $/m ve verimi 105.8 $m^3$/sa olarak bulunmuştur.**

**Anahtar Kelimeler:** Hidrolik ekskavatör, orman yolu, yol yapımı, çevresel zararlar

## 1. Giriş

Orman yolları bölmeden çıkarma, ağaçlandırma, koruma ve rekreasyonel aktiviteler gibi ormancılık çalışmalarının yerine getirilebilmesi için orman alanına girişi sağlayan temel yapılardır. Orman yollarının yapımı ekonomik, çevresel ve sosyal ihtiyaçlara cevap verebilecek şekilde olmalıdır. Yolların yapım çalışmalarında en önemli husus makina seçimidir. Özellikle dağlık alanlarda ekskavatörlerin kullanımı çevresel açıdan daha uygundur. Bu tip alanlarda dozerlerin kullanımı çevreye ve özellikle yol altında kalan meşçerelere büyük zararlar verebilmektedir. Aynı zamanda, bu alanlarda ileride doğabilecek erozyon riskini de arttırmaktadır. Bu çalışmada, Antalya bölgesindeki karstik alanlarda ekskavatörle yol yapım çalışmaları takip

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edilmiştir. Ekskavatörlerin değişen eğimlerde enkesit şekilleri, verimlilikleri, kazı hızları, maliyetleri ve çevreye verdikleri zararlar incelenmiştir.

## 2. Materyal ve Metod

Çalışma alanı olarak, Antalya Orman Bölge Müdürlüğü bünyesinde bulunan Finike Orman İşletme Müdürlüğü'ne bağlı Aykırıçay Orman İşletme Şefliği'nde bir orman yol yapım alanı seçilmiştir. Alanın seçilmesinde göz önünde bulundurulan en önemli özellik alanın karstik bir yapıya sahip olmasıdır. Orman alanı içerisinde 1640 m uzunluğunda, B tipi tali orman yolu inşa edilmiştir. Yolun genişliği 4 m ve hendek genişliği 1 m olarak projelendirilmiştir. Alanın eğimi %20-100 arasında değişiklikler göstermektedir. Yol yapımında kullanılan makine Daewoo Solar 220 LC-V tipi hidrolik ekskavatördür.

Yapılan bu çalışmada, öncelikle yol güzergahı boyunca belirli aralıklarla enkesitler alınmıştır. Bu enkesitler göz önüne alınarak, kazı ve dolgu miktarları, makinenin kazı hızı ve verimliliği hesaplanmıştır. Ayrıca, yol yapımı esnasında yolun altında kalan meşçerlerdeki zararlar ölçülmüştür. Belirli aralıklardaki enkesitlerden, yine belirli sayıdaki enkesit deneme alanı olarak seçilmiş ve bu enkesitler arasında kalan alanlardaki zarar gören ağaçlar tesbit edilmiştir. Çevresel zararları tespit etmek için toplam 10 adet deneme alanı seçilmiştir. Alanda bulunan ağaç sayısına göre zarar oranı hesaplanmaya çalışılmıştır. Bunların yanında, ekskavatörün yol yapım maliyeti bulunmuştur.

## 3. Sonuçlar

Yol güzergahı boyunca toplam 354 $m^3$ ağaç kesilerek güzergah oluşturulmuştur. Yol güzergahı boyunca toplam 12480 $m^3$ kazı yapılmıştır. Bu kazının %24.88'ini toprak, %25.19'unu küskülük ve %49.93'ünü kaya oluşturmuştur. Enkesitlerden alınan değerlerin MS Excel Programında değerlendirilmesi ile, ortalama yolun kazı genişliği 7.47 m olarak bulunmuştur. Bu yolun 7.47 m kazı genişliği ve 1640 m yol uzunluğu ile toplam 1.23 ha orman alanının kayba uğradığı hesap edilmiştir. Yolun toplam maliyeti 35800 $ olup, yolun metre olarak yapım maliyeti 21.8 $/m olarak bulunmuştur. Ekskavatörün ortalama kazı hızı 8 m/saat olarak hesaplanmıştır. Makine küskülük bir alanda ortalama 36 $m^3$ kazı materyalini yol üzerinden uzaklaştırmaktadır. Alınan enkesitler, ekskavatörün yol yapım tekniği ve alanın eğimi göz önüne alındığında, özellikle %50'nin üzerindeki eğimli alanlarda kazı şevi eğiminin 5/1 olarak alınması uygun bulunmuştur. Daha düşük eğimlerde kazı şevi eğimi 3/1 olarak da alınabilmektedir.

Bu çalışmada, ekskavatörle yol yapımı sırasında %20-45 arası eğimli alanlarda çevreye verilen zarar düşüktür. Çevresel zararları tespit ederken ağaçlar üzerinde meydana gelen zararlar ölçülmüştür. Bu zararlar, kabuğun yaralanması, eğilme ve kırılma şeklinde sınıflandırılmıştır. Alınan enkesit alanlarında toplam 9 ağaçta zarar görülmüştür. Eğimin %46-90 arasında olduğu alanlarda ise zarar 25'e yükselmiştir. Zararlar içerisinde en fazla görüleni ağaç gövdelerinin yaralanmasıdır. Toplam zarar görme oranı %45'e kadar eğimli olan arazilerde %12, eğimin daha yüksek olduğu arazilerde ise %23 olarak belirlenmiştir.

## 4. Öneriler

Bu çalışmanın sonuçlarından yola çıkılarak aşağıdaki öneriler getirilmiştir:

- Ekskavatörler özellikle dağlık alanlarda ve eğimin %50'yi aşması durumda yol yapım çalışmalarında tercih edilmelidir.
- Ekskavatörlerin orman yolu yapımında tercih edilmesi ile patlayıcı maddelerin kullanılması en aza indirilebilecek ve bu durumda çevreye verilecek zararlar minimumda tutulabilecektir.
- Ekskavatör operatörlerinin orman yolu yapımı hakkında mutlaka deneyimli olması gerekmektedir. Yol yapım ihalelerinde idare tarafından mutlaka bu şart aranmalı ve kontrol edilmelidir.
- Ekskavatörlerin kazı materyalini kontrollü bir şekilde yamaca yerleştirmesi veya dağıtması nedeniyle çevresel zararlar az olmakta ve bu alanlarda meydana gelecek erozyon riski de ortadan kalkabilmektedir.

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