IMPLEMENTATION OF A HAZARD RATING SYSTEM TO THE CUT SLOPES ALONG KIZILCAHAMAM-GEREDE SEGMENT OF D750 HIGHWAY

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IMPLEMENTATION OF A HAZARD RATING SYSTEM TO THE CUT SLOPES ALONG KIZILCAHAMAM-GEREDE SEGMENT OF D750 HIGHWAY

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ABSTRACT

IMPLEMENTATION OF A HAZARD RATING SYSTEM TO THE CUT SLOPES ALONG KIZILCAHAMAM-GEREDE SEGMENT OF D750 HIGHWAY

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The purpose of this study is to implement a rock fall hazard rating system to the cut slopes along Kızılcahamam-Gerede segment of D750 (Ankara-İstanbul) Highway. The rating system developed by the Tennessee Department of Transportation was assessed for thirty six cut slopes which were selected based on a reconnaissance survey along D750 highway, between Kurtboğazı Dam (50 km northwest of Ankara) and Aktaş village (15 km to Gerede town of Bolu province).

The stages of the investigation consist of project conception, field investigations and application of this system, assessment and presentation of data. The cut slopes were classified by implementing this method which requires a scoring on an exponential scale assigned to various parameters related to the site and roadway geometry and geologic characteristics. The rating process was completed at two stages: Preliminary and Detailed Rating. Based on the Tennessee RHRS, nineteen cutslopes were assessed according to these two stages while the other seventeen cut slopes were able to be classified only with the preliminary rating stage. Different modes of slope failure (planar, wedge, toppling, rock fall with differential weathering, raveling) throughout the selected segments of the highway were investigated and the slope and highway related parameters such as slope height, ditch effectiveness, average vehicle risk, road width, percent desicion site distance and rockfall history were identified for these nineteen cut slopes. After the scoring process was completed all cut slopes were classified based on their hazard ratings from the point of the problems that they may cause in transportation.

According to the rules of Tennessee RHRS, a total of thirty five cut slopes were rated. Among these slopes, nineteen of them are rated as "A" slopes which are considered to be potentially hazardous, while a total of seven are rated as "C" slopes which pose no danger. In placing a slope into a "B" category, it is considered that they are not as prone as A slopes to create a danger and a total of nine B slopes are detected. The detailed rating is accomplished for these nineteen "A" slopes and as a result of the scorings, it has been seen that the final RHRS scores range from 164 to 591. The slopes with scores over 300 (both additive and multiplicative) can be counted as more hazardous slopes since they get very high scores both from site and roadway geometry and geologic hazard part.

Keywords: Rock fall Hazard Rating System, Highway, Scoring, Cut slopes, Classification.

ÖZ

D750 KARAYOLU KIZILCAHAMAM-GEREDE KESİMİ ARASINDAKİ YOL YARMALARINDA TEHLİKE SINIFLANDIRMA SİSTEMİ UYGULAMASI

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Bu çalışmanın amacı, D750 (Ankara-İstanbul) Karayolu'nun Kızılcahamam-Gerede arasında kalan kesimindeki yol yarmalarında bir kaya düşmesi tehlike sınıflandırma sistemi uygulamaktır.Yapılan incelemeler sonucu D750 karayolunun Kurtboğazı Barajı (Ankara'nın 50 km KB'sı) ve Aktaş Köyü (Bolu ilinin Gerede ilçesine 15 km uzaklıktaki) arasındaki otuz altı adet yol yarmasında Tennessee Ulaşım Dairesi tarafından geliştirilen tehlike sınıflandırma sistemi (RHRS) değerlendirilmiştir.

Bu araştırma; büro çalışmaları, saha çalışmaları sırasında sistemin uygulanması, verilerin değerlendirilmesi ve sunumu aşamalarından oluşmaktadır. Seçilen yol yarmaları, saha ve yol geometrisi ile jeolojik özelliklere bağlı çeşitli parametrelere atanan üstel bir puanlama sistemi ile sınıflandırılmıştır. Bu sınıflandırma süreci, İlksel ve Ayrıntılı Sınıflandırma olmak üzere iki aşamada gerçekleştirilmiştir. Tennessee RHRS'e dayanarak yol yarmalarından on dokuz tanesi her iki aşamada değerlendirmeye tabi tutulurken, diğer on yedi yol yarması için ilksel sınıflandırma yeterli olmuştur. Karayolunun seçilen kesimi boyunca farklı türde şev duraysızlıkları (düzlemsel, kama, devrilme, farklı bozunmaya bağlı kaya düşmesi, döküntüler) saptanmış ve şev yüksekliği, şev önü hendek etkinliği, ortalama araç riski, yol genişliği, düşen bloğun algılanma mesafesi, kaya düşme tarihçesi gibi şeve ve karayoluna ilişkin özellikler bu on dokuz şev için belirlenmiştir. Puanlama aşaması tamamlandıktan sonra tüm yol yarmaları karayolu ulaşımında yaratabilecekleri tehlikelere göre sınıflandırılmışlardır.

Tennessee RHRS'ın kurallarına dayanarak otuz beş adet yol yarması sınıflandırılmıştır. Bu şevler arasında, tehlikeli olmadığı düşünülen yedi adet "C" sınıfında şev tespit edilmişken ondokuz adet şevin potansiyel olarak tehlike oluşturduğu ve "A" sınıfında olduğuna karar verilmiştir. "B" sınıfında yer alan şevlere karar verilirken ise, "A" sınıfı kadar tehlike yaratmayacağı düşünülen dokuz adet "B" sınıfı şev tespit edilmiştir. Ayrıntılı sınıflandırma çalışmaları için bu ondokuz şev kullanılmış olup, puanlamaların 164 ve 591 arasında değiştiği görülmüştür. 300 ve üzeri puan alan şevlerin hem saha ve yol geometrisi, hem de jeolojik karakter aşamalarından diğerlerine göre daha yüksek puanlar alarak en tehlikeli şevleri oluşturdukları görülmüştür.

Anahtar Kelimeler: Kaya Düşmesi Tehlike Sınıflandırma Sistemi, Karayolu, Puanlama, Yol Yarmaları, Sınıflandırma.

To My Mother

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ABBREVIATIONS

AASHTO .... American Association of State Highway and Transportation Officials
ADT .... Average Daily Traffic
AVR .... Average Vehicle Risk
DSD .... Decision Site Distance
FHWA .... Federal Highway Administration
GF .... Geologic Factor
GIS .... Geographical Information System
GPS .... Global Positioning System
HEF .... Human Exposure Factor
JRC .... Joint Roughness Coefficient
MTO .... Ontario's Ministry of Transportation
NAF .... North Anatolian Fault
NHI .... National Highway Institute
NYSDOT .... New York State Department of Transportation
ODOT.. Oregon Department of Transportation
ODOT .... Ohio Department of Transportation
PDA .... Personal Digital Assistant
Q .... Rock Mass Quality
RHRS .... Rockfall Hazard Rating System
RHRON .... Ontario Rockfall Hazard Rating System
RIMS .... Roadway Information Management System
RMR .... Rock Mass Rating
RMS .... Rockfall Management System
RQD .... Rock Quality Designation
SF .... Section Factor
SMR .... Slope Mass Rating
TDOT .... Tennessee Department of Transportation
TRIMS .... Tennessee Roadway Information Management System
USMS .... Unstable Slope Management System
WASHDOT .... Washington State Department of Transportation

CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

Highways are differentiated from other engineering structures since they pass through terrain with various geological units from the point of lithological and engineering characteristics. Besides, the topography continuously changes along the transportation corridors. Geometric standards of highways are maintained with structures such as retaining walls, tunnels, viaducts and cut slopes. In this study a new method, which has been developed by Tennessee Department of Transportation (Cain, 2004) for classifying the cut slopes along the highways according to their hazard ratings, is utilized.

Rock and soil slopes cause various instabilities due to the vibrations associated with earthquakes or high traffic intensities. Besides, the climatic conditions, which can be counted as the reasons of weathering or freze-thaw actions, play roles in these instabilities. The major slope instabilities which are used in the content of this new method and this study are planar, wedge and toppling failures and rockfall with differential weathering and raveling. Drivers are warned by warning signs against these instabilities, which constitute major hazard for traffic and public safety, when the conditions are not satisfied from the point of remediation methods for hazardous slopes.

In this study, it is aimed to implement a method named as “Rockfall Hazard Rating System” (Cain, 2004) which requires a scoring assigned to various parameters related to slope instabilities, site and traffic conditions on an exponential scale. The highway between the Kurtboğazı Dam and the Gerede segment of D750 is selected to implement this system since a majority of cut slopes along this route are susceptible to slope instabilities which may affect traffic and public safety. This area is also convenient from the point of accessing to the site and it is safe to work along this route. The system is not only limited with identifying the locations of slope instabilities and classifying them according to their hazard ratings. Besides, it is a new tool for road risk assessment and it helps to create the database necessary for Risk in Rockfall Management Studies (Budetta, 2003). The database is also considered to provide necessary groundwork for future projects regarding road risk assessment studies and it may aid in efficient remediation desicions for the future projects which can be developed on the basis of remedial approach. During the process of implementing the system, especially on rock slopes, realistic informations are gained about which rock blocks may fall and reach to the road. Thus, the transportation agencies will be able to minimize the problems due to the slope instabilities which affect the public safety and economics of the country. In addition, as a result of assessing the system in Turkey for the first time, the study is expected to be a guide for future projects which may be performed along the highways by General Directorate of Highways (TCK) or various other corporations.

1.2. Location of the Study Area

The study area is located between Kızılcahamam-Gerede segment of D750 (TEM E-89) Highway (Figure 1.1). More specifically, the cut slopes are between the Kurtboğazı Dam which is located 50 km northwest of Ankara province and Aktaş village at 15 km to Gerede town of Bolu province. The study area is covered by four 1:25.000 scale topographical map quadrangles of Bolu- H29a2, H29a3, G29d4 and G28c1.

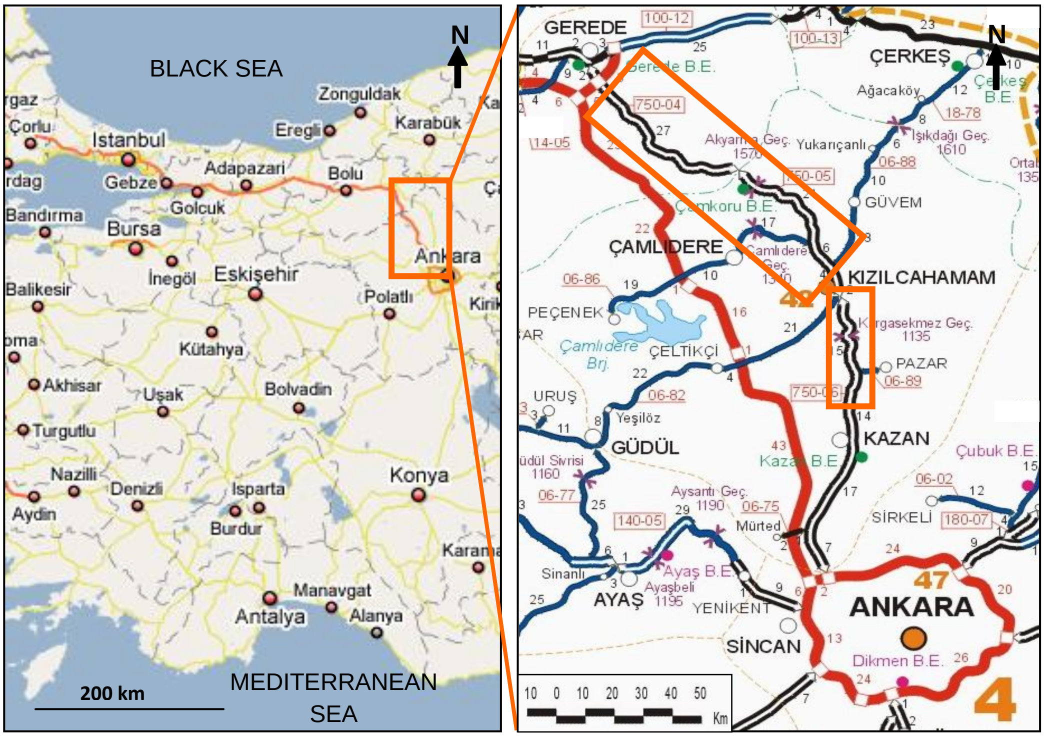


Figure 1.1. Location map of the study area (General Directorate of Highways, 2008).

1.3. Geology

The geological map of the study area is compiled from 1:100.000 scale geological maps of the Bolu- H29- G29- G28 quadrangles and available reports which are obtained from General Directorate of Mineral Research and Exploration (MTA). Geological map prepared is scanned and digitized by using a software named CorelDRAW (Figure 1.2).

In the study area, nine lithological units have been identified. In the Sakarya zone south of the North Anatolian Fault Zone (NAFZ) Lower-Middle Jurassic Mudurnu formation, which is characterized by clastics and volcanics, is the oldest rock unit. This unit is conformably overlain by the Soğukçam formation (Callovian-Aptian) comprising cherty, clayey hemipelagic limestones and grades upward into turbiditic Yenipazar formation of Albian-Maastrichtian age. Early-Middle Miocene terrestrial Hançili formation and volcanics unconformably overly all these units (Sevin and Aksay, 2002).

The volcanics of Lower-Middle Miocene age, known as Galatia massif and are interfingering with each other, are described considering their compositions and times of eruptions. These are, from bottom to top, the Karasivri, Kirazdağı, Ilıcadere, Deveören and Bakacaktepe volcanics. The Örencik formation of Pliocene age of the terrestrial deposits and the Quarternary deposits are the younger units (Duru and Aksay, 2002). The study area is composed of volcanic and sedimentary rocks formed between Jurassic and Quaternary. The lithologies are grouped in Table 1.1 and descriptions of various units are given below.

1.3.1. Mudurnu Formation

The formation, which comprises volcanogenic sandstone, mudstone, shale, tuff, agglomerate, andesite, basalt and limestone alternation, is firstly named as Jurassic naphta colored fylsch by Abdüsselamoğlu (1959). Later it is named as Mudurnu formation by Gözübol (1978). In the upper levels of the formation, the lithology consists of sandstone shale alternation with an increasing content of limestone. Due to the increase of limestone content in the upper most levels, the unit is gradually passes into the Soğukçam formation. There is no characteristic fossil found in the unit, thus the age of the formation is accepted as Lias-Dogger (Sevin and Aksay, 2002).

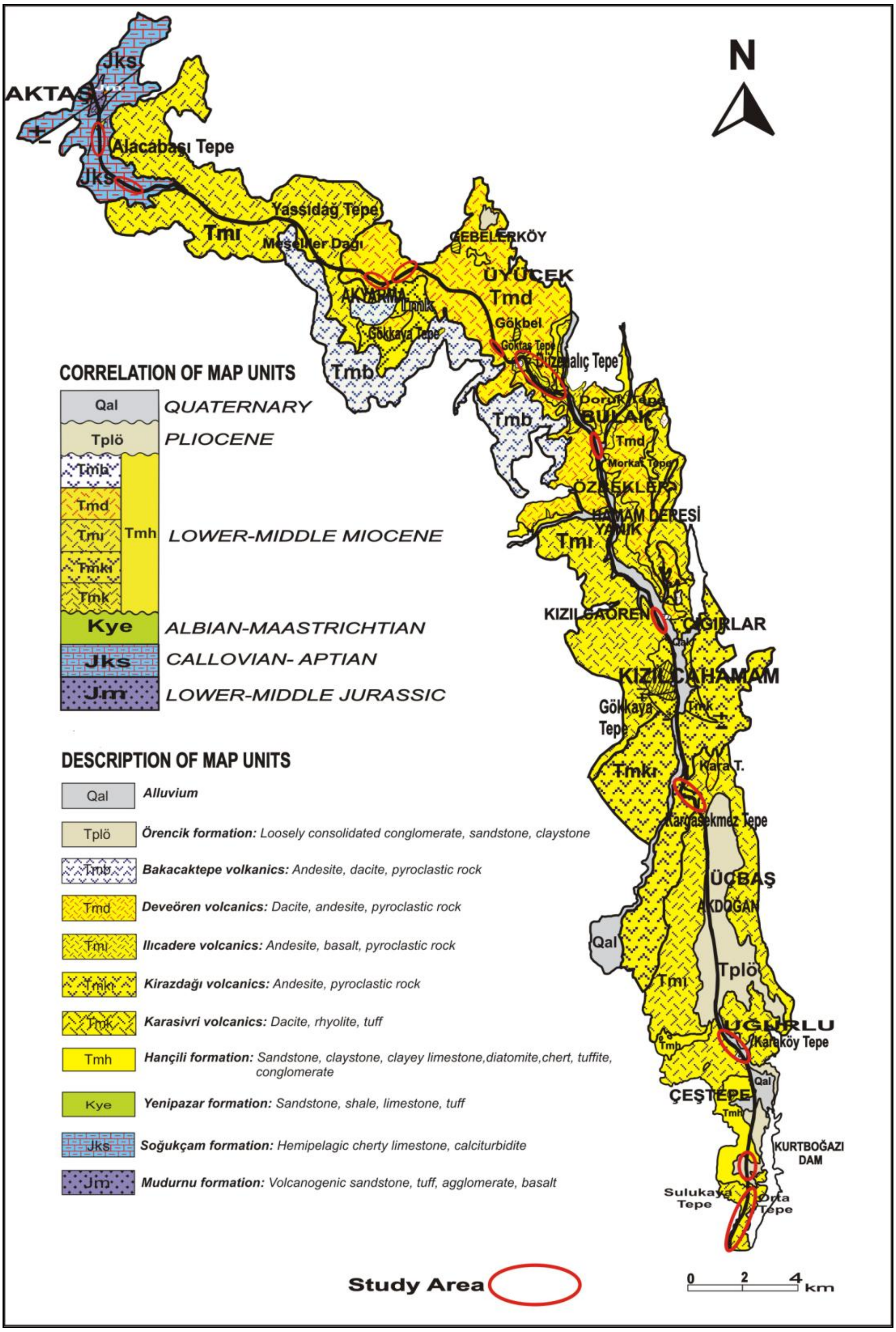


Figure 1.2. The geological map of the study area along the Kızılcahamam-Gerede segment of D750 Highway (after Sevin and Aksay, 2002; Bilginer, et.al., 2002; Duru and Aksay, 2002.)

1.3.2. Soğukçam Formation

The unit is first defined by Altınlı (1973a and 1973b) as Soğukçam limestone. The Soğukçam formation comprises white-cream, pinkish, porcelain appearance, cherty, thin-to-medium bedded and intensely folded clayey hemipelagic limestones.

The boundary of the Mudurnu formation in this unit comprises limestones with alternation of volcanogenic sandstone, tuff and agglomerate. In the upper levels of the formation, the clay content increases and it is represented by clayey limestone and marl alternation. This formation is transitional with the Mudurnu formation at the bottom levels and conformable with Yenipazar formation at the top. The thickness of the unit is over 350m (Sevin and Aksay, 2002). According to Altıner et al. (1991), age of the Soğukçam formation is in Callovian-Aptian age.

1.3.3. Yenipazar Formation

The Yenipazar formation is firstly named by Saner (1980). This formation comprises greyish green, thin-to-medium bedded sandstone-shale alternation, and green and brown volcanics, green marl and white, red and pink colored, thin bedded micritic (pelagic-hemipelagic) limestone and conglomerates. The age of the formation is accepted as Albian-Paleocene (Sevin and Aksay, 2002).

1.3.4. Hançili Formation

This formation is composed of sandstone, claystone, shale, tuff and limestone and it was first defined by Akyürek et al. (1980). It unconformably overlies older units and unconformably underlies the Örencik formation. The products of this formation is deposited in the lakes in a terrestrial environment. The age of Hançili Formation is Early-Middle Miocene (Akyürek et al., 1996).

1.3.5. Karasivri Volcanics

The Karasivri volcanics are firstly named by Türkecan et al. (1991). The unit comprises dacite, rhyolite lava, tuff and agglomerates. Lava is seen in white, grey and pink colores and shows flow banded structure. Tuff is white and pink and locally exhibits perlitic texture. The age of the unit is Early Miocene.

1.3.6. Kirazdağı Volcanics

The Kirazdağı Volcanics are firstly named by Türkecan et al. (1991). The unit is composed of andesite and pyroclastic rocks. Pink, black, grey and greyish green lavas represent thin-to-thick bedded, flow banded structure and porphyritic texture. It is also fractured and they are filled with silica. The unit overlies the agglomerate level of Karasivri Volcanics. The age of Kirazdağı Volcanics is reported as Early Miocene based on the K/Ar radiometric dating. It is formed within the terrestrial environment.

1.3.7. Ilıcadere Volcanics

The Ilıcadere Volcanics are firstly named in Ilıcadere, in the west of Kıbrısçık town of Bolu province, by Türkecan et al. (1991). It is composed of basaltic and andesitic lavas and agglomerates. The lavas are seen in grey, black, red and brown colores and they represent massive and blocky structure. They comprise basalt and basaltic andesite. Agglomerates are yellow, red, grey and brown. The unit underlies Deveören lavas and pyroclastics. The age of the Ilıcadere Volcanics is relatively Middle Miocene (Sevin and Aksay, 2002).

1.3.8. Deveören Volcanics

The Deveören Volcanics are firstly named in the vicinity of Deveören village in Kıbrısçık town of Bolu province by Türkecan et al. (1991). The unit comprises dacite, andesite lavas, tuffs and agglomerates and crops out in the east of Üyücek and in the vicinity of Gökbel. In the study area it is seen as grey, black, green and brown colored rocks and represents a dacitic volcanic character according to the chemical analysis. Tuffs are white, pink and agglomerates are red colored. Deveören Volcanics overlie the Ilıcadere Volcanics and underlies Bakacaktepe lavas. The age of the unit is Middle Miocene (Sevin and Aksay, 2002).

1.3.9. Bakacaktepe Volcanics

The Bakacaktepe Volcanics are firstly named by Türkecan et al. (1991) and comprises andesite, tuff and agglomerates. It is distinguished from Deveören Volcanics with the presence of white and coarse feldspars. Agglomerates are grey, black, pink and brown. Bakacaktepe Volcanics overlie the Deveören Volcanics and underlies unconformably Örencik formation. It is formed within terrestrial environment. The age of the unit is Middle Miocen (Sevin and Aksay, 2002).

1.3.10. Örencik Formation

The formation comprises the youngest deposits of the study area. It crops out along Kurtboğazı Dam, Çeştepe, Uğurlu and it is widespread till the Kargasekmez Passage along the study area. The formation is named by Aydın et al. (1987). It is represented by terrestrial conglomerate, sandstone and mudstone. Similar rock types are defined by Kipman (1974) as Kırmacıdere formation.

The Örencik formation is represented by red, yellowish red, brown colored conglomerate, sandstone, mudstone and limestone alternation. It is medium-to-thick bedded. Conglomerates are poorly sorted. It grades upward into sandstones and mudstones. Parallel and cross lamination is commonly seen in the sandstones. Its thickness ranges between 50 to 100 m and it consists of terrestrial-lacustrine deposits of Pliocene age. The formation overlies the older units unconformably (Duru and Aksay, 2002).

1.3.11. Alluvium

The alluviums are composed of sand, silt, clay and gravel deposited within the channels of the main streams.

Table 1.1. Lithological units of the study area and their descriptions (Compiled from Sevin and Aksay, 2002; Bilginer et al., 2002; Duru and Aksay, 2002).

Symbol	Lithology	Description	Age
Qal	Alluvium	Sand, silt, gravel	Quaternary
Tplö	Örencik Formation	Loosely consolidated conglomerate, sandstone, claystone	Pliocene
Tmb	Bakacaktepe Volcanics	Andesite, dacite, tuff, agglomerate	Middle Miocene
Tmd	Deveören Volcanics	Dacite, andesite, lava, tuff, agglomerate	Middle Miocene
Tmı	Ilıcadere Volcanics	Andesite, basalt, pyroclastik rock	Middle Miocene
Tmkı	Kirazdağı Volcanics	Andesite, pyroclastic rock	Early Miocene
Tmk	Karasivri Volcanics	Dacite, rhyolite, tuff, agglomerate	Early Miocene
Tmh	Hançili Formation	Sandstone, claystone, clayey limestone, diatomite, chert, tuffite, conglomerate	Early-Middle Miocene
Kye	Yenipazar Formation	Sandstone, shale, limestone, tuff	Albian-Maastrichtian
Jks	Soğukçam Formation	Hemipelagic cherty limestone, calciturbidite	Callovian-Aptian
Jm	Mudurnu Formation	Volcanogenic sandstone, tuff, agglomerate, basalt	Early-Middle Jurassic

CHAPTER 2

BACKGROUND INFORMATION ON VARIOUS ROCKFALL HAZARD RATING SYSTEMS

This study is concerned with an assessment of a Rockfall Hazard Rating System (RHRS) which is a part of the Rockfall Hazard Management System (Rose, 2005) that was developed by the Tennessee Department of Transportation (TDOT) in the USA. A detailed literature review together with the descriptions of evolution of various hazard system paradigms for rock fall will be presented in this chapter, since the Rockfall Hazard Rating Systems are increasingly being implemented by transportation agencies worldwide.

Rock slope failures along highways constitute hazards to the public that close roads and cost money. These failures cause significant loss of convenience, property or life. Considering the difficulties that are faced in highway and railway construction projects in mountainous terrains inspired the engineering geologists and geotechnical engineers to do special studies. In addition, obtaining adequate information to permit stability assessments for each of the slopes along a route is difficult due to the extended length of this kind of projects. Consequently, a system is needed which would provide a highway department to determine the slopes that pose the highest threat to safety, and then work accordingly. Numerous slope hazard-rating systems have been introduced in order to provide the highway engineers with a useful evaluating and highway maintenance toll (Szwilski, 2002). Many of these systems, however, are technically demanding and too time-consuming to be practical for a largescale project. The Rock Quality Designation (RQD) and Rock Mass Quality (Q) are examples where boring and technical study of the slope are required (Waltham, 1994). The nation of Jordan has used an evaluation system based on Q (Barton et al., 1974), seismic risk, slope geometry, precipitation, and drainage that has worked well for them (Al-Homoud and Tubeileh, 1997). Although these evaluation systems are quite useful, they are generally impractical. Due to the seriousness of rock fall hazards, various departments of transportation in the U.S., Canada, Australia and elsewhere have worked on classification schemes which can be provided by visual inspection and simple calculations. As a result of these studies, the Rock Hazard Rating System (RHRS) was developed that can rate slope hazards with a minimum of time and expense (Szwilski, 2002).

The researchers have made considerable progresses by modificating the system according to the conditions which are faced along various highway systems. It is expected that the system should prove to be a valuable tool for the proactive management of rock slopes. Rose (2005), has stated that the most important use of a system is to identify and prioritizing rock slopes with the greatest potential for rock fall so that the researchers can provide all the necessary information they need to plan remediation efforts. Over time, the RHRS can be used to track costs and effectiveness of different remediation methods used on problematic rock slopes.

Rockfall is the natural downward motion of a detached block or series of blocks by free falling, bouncing, rolling, or sliding (Ritchie, 1963). Rock falls along highways occur where natural slopes or rock slope excavations exist, and when rock falls reach the roadway they constitute a hazard to roadway users. Transportation systems such as highways and rail lines are vulnerable to rock fall wherever they cut across or skirt along mountains, ridges and similar topographic features (Bunce et al., 1997; Brawner and Wyllie, 1976; Hungr et al., 1999). New demands to develop civil infrastructure across difficult terrain as population centers expand in coming decades will increase the number of rock cuts along transportation systems (Dai et al., 2002). Highway systems may experience rock falls on a daily basis, but these may not be considered hazardous unless rocks enter the roadway (Chau et al., 2003 and 2004).

Rock fall is best viewed within the larger context of landslides and slope failure with respect to which Varnes (1978) made a significant contribution by proposing a rational system of landslide classification that has since found wide usage. Varnes' nomenclature was subsequently refined by Cruden and Varnes (1996). Rock fall and rock slide are forms of landslide in both the original (Varnes, 1978) and updated (Cruden and Varnes, 1996) classification systems, the first term (rock) indicating type of material and the second term (fall or slide) indicating type of movement. For operational reasons, however, state transportation agencies and the Federal Highways Administration (FHWA) have adopted simpler nomenclature for rock slope failures impacting highways, referring to all such failures as rock fall. This usage is consistent with that of the rock fall hazard rating systems that have been implemented by several states, including Oregon (Pierson, 1992); Utah (Pack and Boie, 2002); New Hampshire (Fish and Lane, 2002); New York (Hadjin, 2002); Washington (Ho and Norton, 1991); Tennessee (Bateman, 2002; Bellamy et al., 2003; Vandewater et al., 2005), and Missouri (Maerz et al., 2005).

Most of the studies include solving the local slope problems and remediating them. However, the slope movements, which occur along transportation lines such as highways and rail lines, are mostly perceived as a second priority problem and it is considered that the most economical solutions with the short term precautions will be enough for this kind of problems. Instead of permanent solutions, the drivers' attention is paid with warning signs against the dangers during transportation.

Transportation agencies in states or regions with mountainous terrain have, in the past, tended to remediate rock slopes only after failure, making it difficult to plan and budget for remediation expenditures, and resulting in unknown levels of safety for most rock slopes impacting transportation routes. The approach of remediating slopes only after failure also leaves transportation agencies unnecessarily exposed to legal action if slope failure results, directly or indirectly, in damage to property, injury or death and a planned, sustainable approach to the maintenance of transportation infrastructure requires an objective, reliable, coherent system for prioritizing remediation of potential rock slope hazards (Rose, 2005).

The priority in the highway transportation is road safety. It is known that the rock blocks reaching to the roadway are how dangerous for the vehicles even travelling in the speed limits. In this sense, also the broad usage of Geographical Information Systems (GIS) technology has paid most of the researchers' attention to the subjects about "sensitivity, hazard and risk mapping" related to rock and soil slopes. And some of the pioneer studies regarding analysis of rockfall hazards were accomplished by Ritchie (1963), Brawner and Wyllie (1976), Goodman and Bray (1976), Hoek and Bray (1981), Wyllie (1987), Hungr and Evans (1989), Badger and Lowell (1992).

Today, the Rockfall Hazard Rating System has found an important place in the international literature. This system has evolved in the last two decades (Wyllie, 1987; Pierson, 1992; Pack and Boie, 2002; Fish and Lane, 2002; Hadjin, 2002; Ho and Norton, 1991; Bellamy, et al., 2003; Bateman, 2002; Franklin and Senior, 1987; Budetta, 2004; McMillan and Matheson, 1998, Ko-Ko et al., 2004). Most of the researchers use the principles of the widely accepted RHRS which is originated in 1993 by the Oregon Department of Transportation with input from the Federal Highway Administration. The Oregon RHRS is a modification of a study done by Brawner and Wyllie (1984) and later work by Wyllie (after Pierson and Van Vickle, 1993). To have a better understanding about the system, several applications of RHRS accomplished in different states are given below.

(1) Oregon Department of Transportation (ODOT) decided that there is a need to develop a quantitative rating system to evaluate and prioritize potential rockfall sites in the late 1980's. Following a literature survey on the subject, a study by Brawner and Wyllie (1984) was reviewed. This study included a rating criteria and a scoring method that grouped rock fall sections into either A, B, C, D or E categories based on the potential and expected effect of a rock fall event. By using this approach, Oregon Department of Transportation engineers used a similar method in the RHRS from the point of preliminary rating for rock fall sections. In a following study, Wyllie (1987) accomplished a more detailed rating phenomenon for prioritizing rock fall sites. It contained specific categories for evaluation and scoring based on an exponential scoring system. So, this became the prototype for Oregon's RHRS (Pierson, 1992). Based on these studies, a rating sheet format and an exponential scoring system including some changes with the categories were adopted.

Rockfall Hazard Rating System (RHRS) developed by the Oregon State Highway Division (Pierson et al., 1990); National Highway Institute (NHI, 1993); Scesi, et al., (2001) has become the most widely accepted system. Oregon's System provided significant innovation with respect to how potential rock fall sites are identified, assessed and remediated, and has resulted in the emergence of a proactive rock fall management paradigm focused on rapid assessment, prioritization and pre-event intervention (Rose, 2005). To accomplish the RHRS, there are three major steps to be carried out during the studies. These steps explained below include Slope Survey, Preliminary Rating and Detailed Rating System.

Slope Survey: The slope survey is a fundamental part of the RHRS since it allows the desicion makers to accurately identify the number and location of rock fall sites. According to the Oregon RHRS, precise description of the rock fall section is important. A rock fall section is defined as any uninterupted slope along a highway where the level and occurrence mode of rock fall are the same. Grouping separate cut slopes into one long section will diminish the value and the flexibility of the resulting data base (Pierson, 1992). The maintenance person who has a knowledge about a section's rock fall history helps the rater since the past rock fall activity is an important indicator of what to expect in the future.

Preliminary Rating: According to the Oregon RHRS, the purpose of the preliminary rating, which is a second step, is to group the rock fall sections inspected during the observations into three part (Table 2.1.). This rating is a subjective evaluation of the rock fall potential and requires judgements by experienced personnel. Kliche (1999) has claimed that the key factor in preliminary ratings is the concept of "risk", which refers to the likelihood of rock fall material reaching the roadway.

Table 2.1. Preliminary Oregon Rating System (Pierson,1992).

CRITERIA \ CLASS	A	B	C
ESTIMATED POTENTIAL FOR ROCK ON ROADWAY	HIGH	MODERATE	LOW
HISTORICAL ROCKFALL ACTIVITY	HIGH	MODERATE	LOW

A-C rating is achieved by site inspections in an effort to assign the criteria from high to low to the rock fall sites according to their hazardous situations. During this rating process, the situation whether the rock fall site constitutes blocks that will reach the roadway or not is taken as the most important criterion. If one should fall and reach the roadway, the rock fall section is assigned as A-class. As the rock fall site gets less hazardous, the class will change from A to B with a change in range from high to moderate. And the sections which do not constitute any risk are assigned as C class with a low range.

The preliminary step is very critical if there are a large number of slopes to consider. Initially, only the A-rated sections are evaluated with the detailed rating system since this will economize the effort while directing it toward the most critical areas. The B-rated sections should be evaluated as time and funding allow. The C-rated sections receive no further attention and therefore are not included in the RHRS data base (Pierson, 1992).

Detailed Rating System: Detailed rating is the third step in the RHRS which takes into consideration ten categories such as slope height, ditch effectiveness, average vehicle risk, percent of decision sight distance, geologic character, block size or quantity of rock fall per event, climate and presence of water on slope and rock fall history (Table 2.2.). These parameters are evaluated, scored and totaled to permit an agency for numerically differentiating rock slopes from the least to the most hazardous. According to this rating system, as the risk for occurence of a rock fall hazard gets higher, the slope is assigned to higher scores.

The categories mentioned above comprise the important elements of a rock fall section that contributes to an overall hazard. As it can be seen in Table 2.2. the four columns under the headline “RATING CRITERIA AND SCORE” on the right correspond to logical breaks in the increasing risk associated with each category. The scores above each column increase from left to right exponentially from 3 to 81 points. An exponential system provides a rapid increase in score that seperates the more hazardous sites (Pierson, 1992).

Table 2.2. Summary of the scoring sheet of the Oregon Rockfall Hazard Rating System (after Pierson, 1992)

<table>
<tr><th colspan="3" rowspan="2">CATEGORY</th><th colspan="4">RATING CRITERIA AND SCORE</th></tr>
<tr><th>POINTS 3</th><th>POINTS 9</th><th>POINTS 27</th><th>POINTS 81</th></tr>
<tr><td colspan="3">SLOPE HEIGHT</td><td>25 ft</td><td>50 ft</td><td>75 ft</td><td>100 ft</td></tr>
<tr><td colspan="3">DITCH EFFECTIVENESS</td><td>Good catchment</td><td>Moderate catchment</td><td>Limited catchment</td><td>No catchment</td></tr>
<tr><td colspan="3">AVERAGE VEHICLE RISK</td><td>25 % of the time</td><td>50% of the time</td><td>75% of the time</td><td>100% of the time</td></tr>
<tr><td colspan="3">PERCENT OF DECISION SIGHT DISTANCE</td><td>Adequate site distance, 100% of low design</td><td>Moderate site distance, 80% of low design value</td><td>Limited site distance, 80% of low design value</td><td>Very limited site distance, 40% of low design value</td></tr>
<tr><td colspan="3">ROADWAY WIDTH INCLUDING PAVED SHOULDERS</td><td>44 ft</td><td>36 ft</td><td>28 ft</td><td>20 ft</td></tr>
<tr><td rowspan="4">GEOLOGIC CHARACTER</td><td rowspan="2">CASE 1</td><td>STRUCTURAL CONDITION</td><td>Discontinuous joints, favorable orientation</td><td>Discontinuous joints, random orientation</td><td>Discontinuous joints, adverse orientation</td><td>Continuous joints, adverse orientation</td></tr>
<tr><td>ROCK FRICTION</td><td>Rough, irregular</td><td>Undulating</td><td>Planar</td><td>Clay infilling or slickensided</td></tr>
<tr><td rowspan="2">CASE 2</td><td>STRUCTURAL CONDITION</td><td>Few differential erosion features</td><td>Occasional erosion features</td><td>Many erosion features</td><td>Major erosion features</td></tr>
<tr><td>DIFFERENCE IN EROSION RATES</td><td>Small difference</td><td>Moderate difference</td><td>Large difference</td><td>Extreme difference</td></tr>
<tr><td colspan="3">BLOCK SIZE
———
QUANTITY OF ROCKFALL / EVENT</td><td>1 ft
———
3 yd^3</td><td>2 ft
———
6 yd^3</td><td>3 ft
———
9 yd^3</td><td>4 ft
———
12 yd^3</td></tr>
<tr><td colspan="3">CLIMATE AND PRESENCE OF WATER ON SLOPE</td><td>Low to moderate precipitation; no freezing periods, no water on slope</td><td>Moderate precipitation or short freezing periods or intermittent water on slope</td><td>High precipitation or long freezing periods or continual water on slope</td><td>High precipitation and long freezing periods or continual water on slope and long freezing periods</td></tr>
<tr><td colspan="3">ROCK FALL HISTORY</td><td>Few falls</td><td>Occasional falls</td><td>Many falls</td><td>Constant falls</td></tr>
</table>

To assist with scoring, the RHRS includes a scoring graph for each category. According to Pierson (1992); the curve on the graph (Figure 2.1.) is formed as the plot of the function $y=3^x$, which defines the exponential scoring system used for all categories. Similar curves for other category scores can be calculated from the following values (Table 2.3.) of the exponent *x.* The graph relates the category evaluation to an appropriate score. Even with subjective categories such as ditch effectiveness, the graph is quite useful in assigning a score to a condition that falls somewhere between the described benchmarks. Exact scores can be tabulated for the measurable categories by calculating the value of the exponent *x* of the function $y=3^x$. Table 2.3 presents the formulas that yield the exponent values.

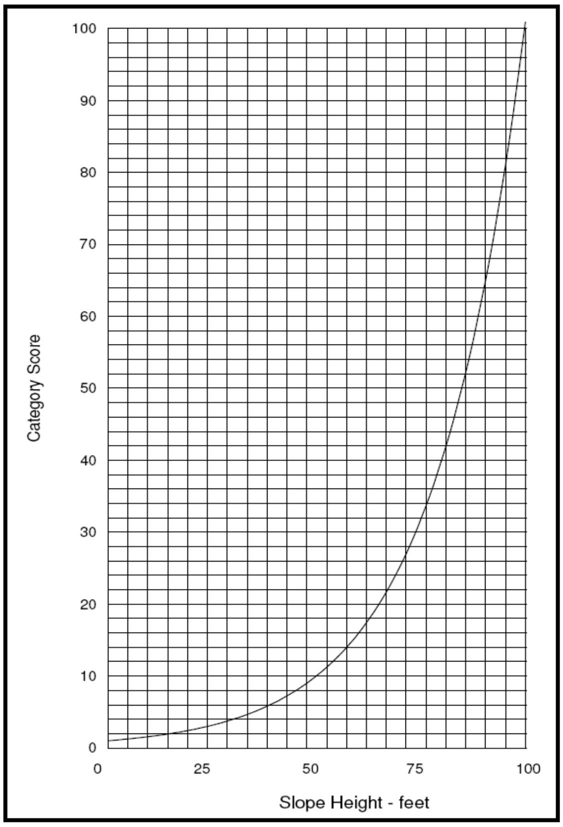


Figure 2.1. Sample scoring graph (Pierson, 1992)

Table 2.3. Exponent Formulas (Pierson, 1992)

Slope height	x= slope height (ft) / 25
Average vehicle risk	x= % time / 25
Sight distance	x= (120- % Decision sight distance) / 20
Roadway width	x= (52- Roadway width (ft)) / 8
Block size	x= Block size (ft)
Volume	x= Volume (ft^3) / 3

The categories defined in this detailed rating system (Pierson et al., 1990) are briefly explained below since the categories in other rating systems have mainly similar features with those of the Oregon RHRS.

Slope Height: It presents the vertical height of the slope not the slope distance. Rocks on high slopes have more potential energy than rocks on lower slopes, thus they present a greater hazard and receive a higher rating. Measurement is to the highest point from which rock fall is expected.

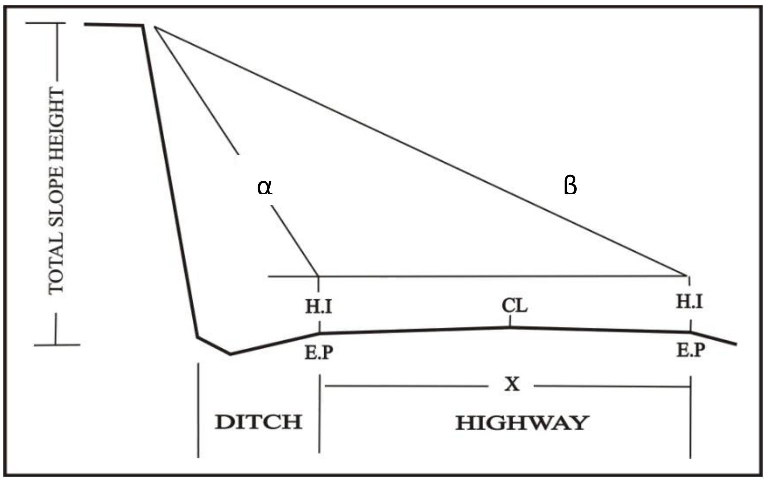


Figure 2.2. Measurement of slope height (after Pierson,1992)

If rock blocks are coming from the natural slope above the cut, the cut height plus the additional slope height (vertical distance) are used. A good approximation of vertical slope height can be obtained using the relationships given below (Pierson and Van Vickle, 1993).

$$\text{Total Slope Height: } [((X)\sin\alpha \sin\beta) / \sin(\alpha-\beta)] + H.I \quad (2.1)$$

where X: distance between the edge of pavements (E.P)

H.I: height of the instrument

α: angle from the near side of the road

β: angle from the far side of the road

The measurement can be carried out by using an inclinometer to determine the angles in degrees at eye level at the top of the section from both the far and near sides of the road.

Ditch Effectiveness: The effectiveness of a ditch is measured by its capability to prevent falling rock from reaching the roadway. To estimate this parameter, there are several factors to consider. These are a) slope height and angle; b) ditch width, depth and shape; c) predicted volume of rockfall per event; d) slope irregularities (launching features) which may trigger rock fall reaching to roadway. The definitions of rating criteria for ditch effectiveness are as follows (Table 2.4.).

Table 2.4. Scores and rating criterias for ditch effectiveness (Pierson, 1992)

3 points	***Good catchment*.** All or nearly all of falling rocks are retained in the catch ditch.
9 points	***Moderate Catchment*.** Falling rocks occasionally reach the roadway.
27 points	***Limited Catchment*.** Falling rocks frequently reach the roadway.
81 points	***No Catchment*.** No ditch or ditch is totally ineffective. All or nearly all falling rocks reach the roadway.

Average Vehicle Risk: It measures the percentage of time that a vehicle will be present in the rock fall hazard zone. A rating of 100% means that on average a car can be expected to be within the hazard section 100% of the time. AVR is calculated by using the formula below (Pierson, 1992).

$$AVR = \frac{\text{ADT (cars/hour)} \times \text{Slope Length (miles)} \times 100\%}{\text{Posted Speed Limit (miles per hour)}} \quad (2.2)$$

Percent of Decision Sight Distance: The Decision Sight Distance (DSD) is a measurement of the length of roadway (in feet) that a driver must have to make a complex or instantaneous decision.

When it is diffucult to perceive obstacles on the road, the DSD gets critical. The American Association of State Highway and Transportation Officials (AASHTO) proposed a relationship between DSD and the posted speed limit in Table 2.5. Sight distance is the shortest distance along a roadway for which a 6-in. object is continuously visible to the driver and it is calculated as a percentage by using the formula below (Pierson et al., 1990) and AASHTO (1984) norms. DSD compares the distance that a driver needs to react to stop or swerve his car at a given speed (West, 1995).

$$\% \text{ DSD} = 100\% \times (\text{Actual sight distance} / \text{Decision sight distance}) \qquad (2.3)$$

Table 2.5. Decision Sight Distance (AASHTO, 1984)

Posted Speed limit (miles/h)	DSD (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1000
65	1050

Roadway width: It is measured perpendicular to the highway centreline from edge of pavement to edge of pavement (EP to EP) as it is shown with X in Figure 2.2. It indicates the available manoeuvring room to avoid a rock fall. This measurement should be the minimum width when the roadway width is not consistent. On divided roadways only the paved portion available to the driver should be measured.

Geologic Character: The geological conditions of a slope are assessed with this category. It is investigated according to two cases which are briefly mentioned below.

Case1: It is the case which structural features of a rock slope are examined and it is divided into two phases.
Structural Condition: The scoring due to the structural conditions of a rock slope are given in Table 2.6.

Table 2.6. Structural Condition (Pierson, 1992)

3 points	**Discontinuous Joints, Favourable Orientation:** Jointed rock with no adversely oriented joints, bedding planes, etc.
9 points	**Discontinuous Joints, Random Orientation:** Rock slope contains randomly oriented joints creating a variable pattern. The slope is likely to have some scattered blocks with adversely oriented joints but no dominant adverse pattern is present.
27 points	**Discontinuous Joints, Adverse Orientation:** Rock slope exhibits a prominent joint pattern, bedding plane, or other discontinuity with an adverse orientation. These features have less than 10 ft of continuous length.
81 points	**Continuous Joints, Adverse Orientation:** Rock slopes exhibit a dominant joint pattern, bedding plane, or other discontinuity with an adverse orientation and more than 10 ft long.

Rock Friction: This parameter directly affects the potential for a block to move relative to another. The scoring due to the features to be considered are given in Table 2.7.

Table 2.7. Rock Friction (Pierson, 1992)

3 points	**Rough, irregular:** The surfaces of the joints are rough and the joint planes are irregular enough to cause interlocking. This macro and micro roughness provides an optimal friction situation.
9 points	**Undulating:** Also macro and micro rough but without the interlocking ability.
27 points	**Planar:** Macro smooth and micro rough joint surfaces. Surface contains no undulations. Friction is derived strictly from the roughness of the rock surface.
81 points	**Clay Infilling or Slickensided**: Low friction materials, such as clay and weathered rock, separate the rock surfaces negating any micro or macro roughness of the joint planes. These infilling materials have much lower friction angles than a rock on rock contact. Slickensided joints also have a very low friction angle and belong in this category.

Case 2: It is the case which examined under two conditions. These are given in Table 2.8 and Table 2.9.

Table 2.8. Structural Condition (Pierson, 1992)

3 points	**Few Differential Erosion Features:** Minor differential erosion features that are not distributed throughout the slope.
9 points	**Occasional Erosion Features:** Minor differential erosion features that are widely distributed throughout the slope.
27 points	**Many Erosion Features:** Differential erosion features are large and numerous throughout the slope.
81 points	**Major Erosion Features:** Severe cases such as dangerous erosion-created overhangs; or significantly oversteepened soil/rock slopes or talus slopes.

Table 2.9. Difference in Erosion Rates (Pierson,1992).

3 points	**Small Difference:** The difference in erosion rates is such that erosion features develop over many years. Slopes that are near equilibrium with their environment are covered by this category.
9 points	**Moderate Difference:** The difference in erosion rates is such that erosion features develop over a few years.
27 points	**Large Difference:** The difference in erosion rates is such that erosion features develop annually.
81 points	**Extreme Difference:** The difference in erosion rates is such that erosion features develop rapidly.

Block Size or Quantity of Rockfall Per Event: This category represents the type of rock fall event which is most likely to occur. If individual blocks are formed due to a rock fall event, the block size should be used for scoring. In case of a mass of blocks are formed, the quantity per event should be used. These are obtained from maintenance history or estimated from observed conditions if there is no history available.

Climate and Presence of Water on Slope: Water and freeze/thaw cycles are controlling factors of rock fall event and they contribute to the weathering and movement of rock materials. Considering the area's condition from the point of precipitation and thus the water on slope, the rater gives 27 points for sites with long freezing periods or water problems such as high precipitation or continually flowing water. The 81-point category is reserved for sites that have both long freezing periods and one of the two extreme water conditions.

Rockfall History: It directly represents the known rockfall activity at the site. The scoring is made according to Table 2.10.

Table 2.10. Rockfall History (Pierson,1992).

3 points	**Few Falls:** Rock falls have occurred several times according to historical information but it is not a persistent problem. If rock fall only occurs a few times a year or less, or only during severe storms this category should be used. This category is also used if no rock fall history data is available.
9 points	**Occasional Falls:** Rock fall occurs regularly. Rock fall can be expected several times per year and during most storms.
27 points	**Many Falls:** Typically rock fall occurs frequently during a certain season, such as the winter or spring wet period, or the winter freeze-thaw, etc. This category is for sites where frequent rock falls occur during a certain season and is not a significant problem during the rest of the year. This category may also be used where severe rockfall events have occurred.
81 points	**Constant Falls:** Rock falls occur frequently throughout the year. This category is also for sites where severe rock fall events are common.

In this study, the method which will be assessed and similar approaches regarding RHRS are part of the studies carried out by National Highway Institute (NHI) in 1993. Various states of America such as Oregon, Arizona, California, Idaho, Massachusetts, New Hampshire, New Mexico, Ohio, Washington and Wyoming have revised their own rating systems since 1993.

(2) New York State Department of Transportation (NYSDOT, 1996) developed their system to include a hazard rating that identifies the backslope angle as part of the risk the rock slope presents and the New York State Slope Rating Procedure uses geological, cross-sectional, and traffic related factors to create a number representing the total relative risk of a rock fall causing a vehicular accident. In this procedure, the categories are divided into three factors as the geologic factor (GF), section factor (SF), and human exposure factor (HEF) (NYSDOT, 1996). The GF takes into account a series of geological parameters that influence the hazard potential. The section factor (SF) represents the risk that the fallen rocks would actually reach the pavement by comparing actual ditch geometry and with the widely accepted "Ritchie Ditch Criteria" (Ritchie, 1963). The human exposure factor (HEF) represents the risk to the vehicle if a rock falls and reaches the roadway. It considers traffic-related parameters. The total relative risk value is obtained by multiplying the scores of three factor categories, i.e., GF*SF*HEF.

(3) Washington State Department of Transportation (WASHDOT) developed an Unstable Slope Management System (USMS) in 1993 as part of a proactive approach to address unstable slopes (Ho and Norton, 1991). The system is designed to evaluate all unstable slopes with the cost-benefit analyses of them, and prioritize the mitigation of known unstable slopes according to the expected benefits.

The USMS comprises 11 contributing factors including: soil/rock type, average daily traffic, decision sight distance, failure impact on roadway, roadway impedance, average vehicle risk, pavement damage, failure frequency, annual maintenance costs, economic factor (dealing with detours), and number of accidents in the last 10 years (Lowell and Morin, 2000). Like the Oregon RHRS, the USMS assigns exponentially increasing scores of 3, 9, 27, and 81 for the 11 risk factors.

(4) New Hampshire has increased their rating systems and databases to include structural data of the rock cuts (Fish and Lane, 2002). Additionally, the province of Ontario, Canada (Senior,1999) has also implemented a rock fall hazard rating system based on a similar rating system developed by the Oregon Department of Transportation. The Ontario perspective is briefly explained below since it brings new approaches to RHRS.

(5) While applying the Oregon RHRS to Ontario's highway rock cuts, five new parameters are added and the existing ones have been redefined by combining them into four factors based on magnitude, instability, reach and consequences (Franklin and Senior, 1997). Ontario's Ministry of Transportation (MTO) proposed a modified version of the RHRS developed during 1985-1990 by the Oregon Department of Transportation (Pierson et al, 1990).

Although it was just intended to metricate RHRS and incorporate it into an expert system by clarifying some of the definitions and providing a continuous quantitative scale for each parameter, some modifications were made as a result of further study of RHRS which revealed some problems resulting from its exponential (3^x) weighting system. According to Franklin and Senior (1997); while making the Ontario version of RHRS (termed as RHRON), a compatibility problem of RHRS arised with exponential weighting which results in observer errors being magnified more than three-fold at the high-risk end of the measuring range, whereas at mid-range. So, the researchers decided not to use (3^x) weighting system in the Ontario version of RHRS. RHRON is carried out in two stages as it is illustrated in Figure 2.3.

Preliminary Screening is obtained by answering four major questions which refer to the four "factors" of RHRON based on magnitude, instability, reach and consequences. The factors are rated on a scale from 0 (good) to 9 (bad) and the ratings are averaged and converted to a percentage as it is shown in the last line of Table 2.11. (Franklin and Senior, 1997). It is used to determine the "Class A" sites which require detailed rating.

"F1 Magnitude" asks the rater how much rock is unstable,

“F2 Instability” asks the rater how soon or often it is likely to come down,
“F3 Reach” asks the rater the chances of a rock reaching the highway and how much of the highway will be blocked by this rock,
“F4 Consequences” asks the rater how serious the consequences of the blockage are.

RHRON

Preliminary Screening

<u>Detailed Inspection</u>

- Identification of potential instability mechanisms,
- A detailed RHRON hazard rating,
- Preliminary recommendations on remedial treatments,
- Preliminary cost estimates for preferred treatments,
- Photo or video tape documentation of the hazards.

Figure 2.3. The stages of RHRON (compiled from Franklin and Senior, 1997).

The changes with new measures due to The Ontario Rock Hazard Rating (RHRON) can be seen in Figure 2.4. New parameters which are developed for RHRON comprise the total quantity of unstable rock, face looseness, crest angle (ratio of slope height to width of ditch plus shoulder), and “overspill”, an estimate of how much of the road will get blocked by the rockfall (Figure 2.4.). Most of the original parameters are redefined. For instance, “difference in erosion rates” (durability) has been defined in terms of slake-durability index which permits a forecast of rates of erosion (Franklin, 1983; Shakoor and Rodgers, 1992).

The most important phenomenon which distinguishes RHRS and RHRON is instability mechanisms since the RHRON system gives equal and seperate attention to the three main categories namely ravelling, sliding and erosion types while the RHRS system evaluates ravelling in the same manner as sliding. The RHRS approach to this is inappropriate hence ravelling and sliding depend on quite different rock mass characteristics (Franklin and Senior, 1997). Although RHRON is a modification of RHRS, it has also limitations from some points as well as the existing systems have. According to Youssef et al., (2003); the limitation of existing systems are as in the following.

a. The systems that apply easily to analyses of planar, wedge and toppling failure types are not useful for other types of failures.

b. Some of them consider geological factors only and essentially classifying risk only without considering the consequence of failure.

c. It is hard to distinguish between stable slopes from unstable slopes by using a field inspection as the rock engineering system.

d. The rock hazard rating system developed in Oregon is not very sensitive to low rock cuts. It is not a universal system.

e. The Ontario RHRON is somewhat arbitrary. There is no actual separation between risk factors and consequence factors. It is time consuming to measure such a large number of factors. Some factors need laboratory analysis and this adds time and cost.

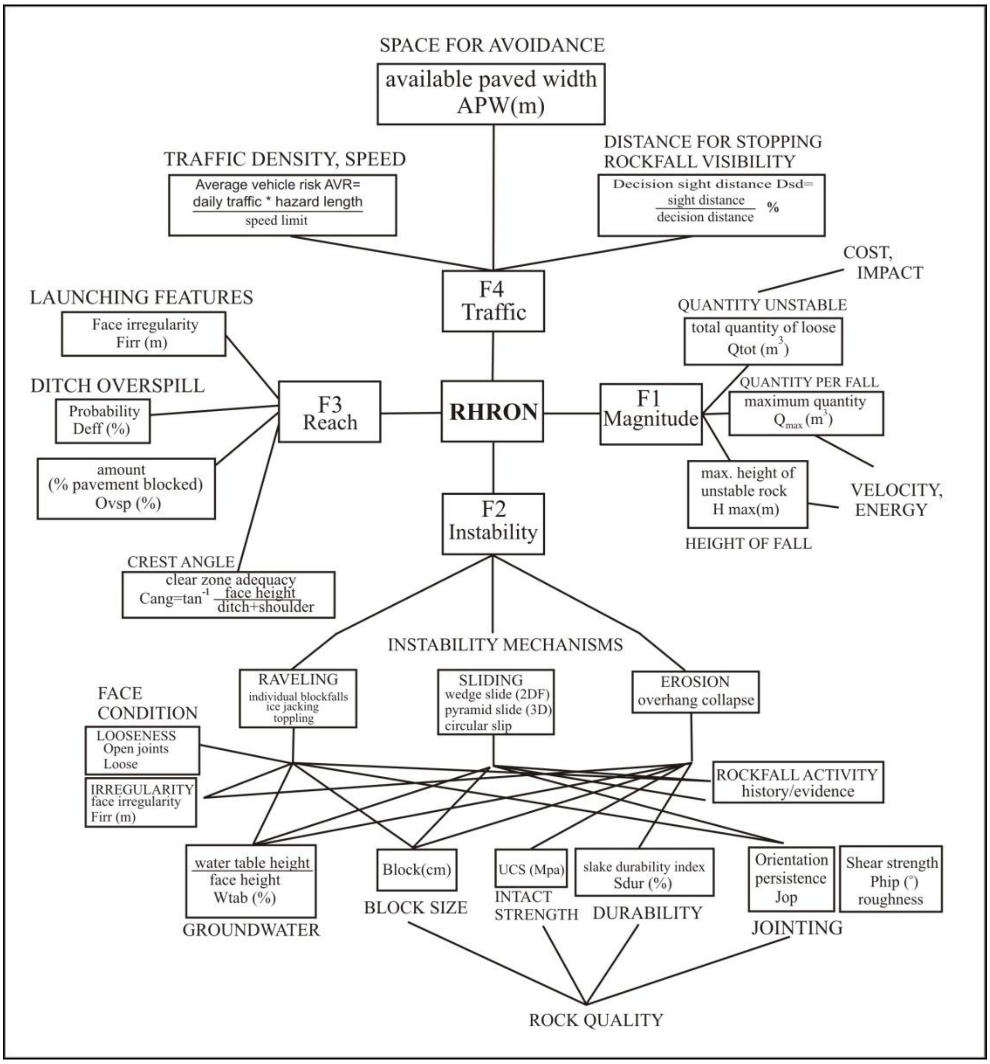


Figure 2.4. Composition of RHRON (Franklin and Senior, 1997).

Table 2.11. RHRON Preliminary Rating and Route Log (Franklin and Senior,1997)

FACTOR F1 MAGNITUDE: "How much rock is potentially unstable?"											
m^3 in place	1	1.7	2.8	4.7	7.8	13	21	36	61	100	m^3 in place
F1 rating	0 B	1 B	2	3	4	5	6	7	8	9	F1 rating
FACTOR F2 INSTABILITY: "How long before the next fall? " (or interval between falls)											
Interval Designation	> 100 yr unlikely		> 10 yr infrequent		1 yr occasional		1 month frequent		Weeks Imminent	Days	Interval Designation
F2 rating	0 B	1 B	2	3	4	5	6	7	8	9	F2 rating
FACTOR F3 REACH: "What are the chances of this fall reaching/blocking the road?"											
Crest angle°	<20°	30°		40°	50°		60°	70°		>80°	Crest angle°
Overspill % hwy blocked	Fragments in ditch	shldr		%15	25%	35%	50%		100%		Overspill % hwy blocked
F3 rating	0 C	1 C	2 B	3	4	5	6	7	8	9	F3 rating
FACTOR F4 CONSEQUENCES: "What damage will it do when it gets there?"											
traffic veh/min	0	1	5	10	15	20	25	30	35	40	Traffic v/min
Visibility	excl	good	good	good	mod	mod	mod	poor	poor	bad	Visibility
F4 rating	0 C	1 B	2	3	4	5	6	7	8	9	F4 rating

Hwy	Site #	Side NSEW	Offset km NSEW	From jn hwy — & —	Remarks (instability mode & treatment)	**Prelim. RHRON**

Rated by__________ Date______ Affiliation __________ Preliminary RHRON%=(R1+R2+R3+R4)100/36

RHRON also considers the treatment alternatives such as stabilization, hazard removal, catch systems for Class A sites. Different remedial treatments are appropriate depending on the instability mechanisms. The stabilization methods are proposed to reduce the F2 Instability Factor, catch methods are designed to reduce the F3 Reach Factor, and warning and monitoring systems are used to reduce the F4 Consequences Factor (Franklin and Senior,1997).

Table 2.12. RHRON Detailed Rating (Franklin and Senior,1997).

RHRON	**ROCK HAZARD RATING**	Hwy: Side:	SITE#:
Location:	km (EWNS) of Junction Hwy &		
Identification	**PARAMETER P**	**VALUE V**	**RATING R** **Good Bad**
P1 Hist	History/evidence of falls	______________	0 1 2 3 4 5 6 7 8 9
P2 Qmax	Quantity of largest potential fall	m^3	0 1 2 3 4 5 6 7 8 9
P3 Qtot	Total quantity of potential rockfall	m^3	0 1 2 3 4 5 6 7 8 9
P4 Firr	Face irregularity	m	0 1 2 3 4 5 6 7 8 9
P5 Hbr	Overbreak(% half-barrels)	%	0 1 2 3 4 5 6 7 8 9
P6 Loose	Face looseness (open joints)	______________	0 1 2 3 4 5 6 7 8 9
P7 Jop	Joint orientation-persistence	______________	0 1 2 3 4 5 6 7 8 9
P8 Phip	Joint shear strength	^{o}	0 1 2 3 4 5 6 7 8 9
P8a Fill	Filling type and thickness		0 1 2 3 4 5 6 7 8 9
P8b Ruff	Roughness/waviness		0 1 2 3 4 5 6 7 8 9
P9 Block	Block size	cm	0 1 2 3 4 5 6 7 8 9
P10 UCS	Intact strength(uniaxial compressive)	MPa	0 1 2 3 4 5 6 7 8 9
P11 Sdur	Slake-durability index	%	0 1 2 3 4 5 6 7 8 9
P12 Wtab	Water table(%height of face)	%	0 1 2 3 4 5 6 7 8 9
P13 Seep	Water seepage	______________	0 1 2 3 4 5 6 7 8 9
P14 Height	Slope height (to highest hazard)	m	0 1 2 3 4 5 6 7 8 9
P15 Cang	Crest angle=$\tan^{-1}$(V14/V16)	^{o}	0 1 2 3 4 5 6 7 8 9
P16 Czw	Clear zone width(ditch+shoulder)	m	0 1 2 3 4 5 6 7 8 9
P17 Din	Ditch ineffectiveness	%	0 1 2 3 4 5 6 7 8 9
P18 Ovsp	Ditch overspill	%	0 1 2 3 4 5 6 7 8 9
P19 Avr	Average vehicle risk V20*V21/[240*V22]	veh	0 1 2 3 4 5 6 7 8 9
V20 SADT veh/dy	V21 Lhaz m	V22 Psl km/h	______________
P23 Dsd	Decision sight distance	100*P24/P25 %	0 1 2 3 4 5 6 7 8 9
P24Sdist m	P25 DD Decision distance	m	______________
P26 Apw	Available paved width	m	0 1 2 3 4 5 6 7 8 9
F1 Magnitude= (R2+R3+R14)/3			
F2 Instability= max(R27, R28, R29)			
F3 Reach= [R4+R15+R17+R18]/4			
F4 Traffic= (R19+R22+R26)/3			
RHRON= (F1+F2+F3+F4)*100/36			
Rating by:			Date:

(6) In southern Italy, various studies presented some critical aspects from the point of applicability of RHRS (Budetta and Panico, 2002). According to these researchers, qualitative descriptions of some categories may cause appraisals too much subjective and rough, therefore, not sensitive enough. It is especially true for some categories such as ditch effectiveness, geologic character, climate and presence of water on slope and rockfall history. So, it is thought that this method can provide advantage for very expert personnel's studies. Otherwise, it is easy to use for land planning before studies of greater detail are performed. Hence, ratings for mentioned categories above were modified to render them easier and more objective (Budetta, 2004).

In order to see the differences between the original RHRS and the modified one, Table 2.2 and Table 2.13. should be compared. One of these modifications were made for ditch effectiveness. In the modified method Ritchie's ditch design chart (Ritchie,1963) is updated, as in Figure 2.5, with the proposal by Fookes and Sweeny (1976) and Whiteside (1986). For the geologic character, as can be seen from Table 2.2, the original method shows two cases of conditions that cause rockfalls. In the modified method, the Romana's Slope Mass Rating (*SMR*-Romana, 1985, 1988, 1991) for slope instability hazard evaluation is introduced. *SMR* is obtained from *RMR* (Rock Mass Rating by Bieniawski, 1989) by subtracting a factorial adjustment factor depending on the joint as it can been in the following equation (Budetta,2004).

$$SMR = RMR - (F1*F2*F3)*F4 \tag{2.4}$$

F1; a factorial depending on parallelism between joints and slope face strikes,
F2; joint dip angle in the planar mode of failure, measuring the probability of joint shear strength,
F3; reflects the relationship between the slope face and joint dip,
F4; an adjustment factor for the method of excavation.

According to the modified method of RHRS, from the point of climate and presence of water on slope, the groundwater circulation is already considered in the Romana's Slope Mass Rating and the slopes are rated according to mean values of annual rainfalls (Budetta, 2004). A careful database of historical information is necessary for rating while assessing the rock fall history category in the modified RHRS.

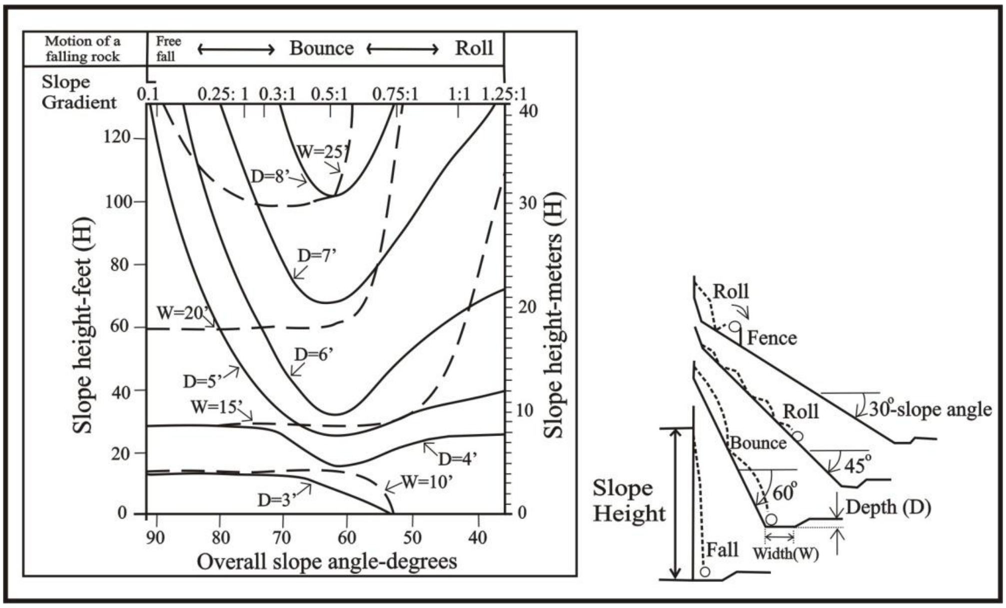


Figure 2.5. Modified Ritchie's design chart to determine required width (W) and depth (D) of rock catch ditches in relation to height (H) and slope angle of hillslope (after Whiteside, 1986).

Table 2.13. Summary sheet of modified Rockfall Hazard System (Budetta, 2004).

CATEGORY	POINTS 3	POINTS 9	POINTS 27	POINTS 81
Slope Height	7.5 m	15 m	22.5 m	> 30 m
Ditch effectiveness	Good catchment: properly designed according to updates of Ritchie's ditch design chart +barriers	Moderatecatchment: properly designed according to updates of Ritchie's ditch design chart	Limited catchment: wrongly designed	No catchment
Average vehicle risk (% of time)	25 %	50 %	75 %	100 %
Decision sight distance	Adequate (100%)	Moderate (80%)	Limited (60%)	Very Limited (40 %)
Roadway width	21,5 m	15,50 m	9,50 m	3,50 m
Slope Mass Rating	80	40	27	20
Block size	30 cm	60 cm	90 cm	120 cm
Boulder volume	26 dm^3	0,21 m^3	0,73 m^3	1,74 m^3
Volume of rock fall per event	2,3 m^3	4,6 m^3	6,9 m^3	9,2 m^3
Annual rainfall and freezing periods	*h*= 300 mm or no freezing periods	*h*= 600 mm or short freezing periods	*h*=900 mm or long freezing periods	*h*=1200mm or long freezing periods
Rockfall frequency	1 per 10 years	3 per years	6 per years	9 per years

Table 2.13 shows the expressions for detailed rating that best fits the data which have been found by means of several attempts for the exponents of the equation $y=3^{f(x)}$. Table 2.14 represents the mathematical descriptions of the functions used to obtain the categories' scores (except ditch effectiveness).

Table 2.14. Exponential functions for the score computations in the modified RHRS method (after Budetta, 2004).

Category	Equation
Slope height (*H*)	$y= 3^{H/7.5}$
Average vehicle risk (AVR)	$y= 3^{AVR/25}$
Decision sight distance (%D_a)	$y= 3^{(120\text{-}\%D_a)/20}$
Roadway width (L_c)	$y= 3^{(27.5\text{-}L_c)/6}$
Slope mass rating (SMR)	$y= 3^{80/SMR}$
Block size (D_b)	$y= 3^{D_b/0.3}$
Volume of rock fall per event (V_{fall})	$Y= 3^{V_{fall}/2.3}$
Annual rainfall (*h*)	$Y= 3^{h/300}$
Rockfall frequency (*f*)	$Y=3^{1+(0.334 \cdot f)}$

This modified Rockfall Hazard Rating System requires immediate stabilization measures for the slopes with scores higher than 500 whereas those lower than 300 are classified for remedial works with low urgency in the original RHRS method. The modified RHRS is a preliminary tool for mapping the road risk assessment and then to allow more detailed investigations with geotechnical and geomechanical stability analyses in dangerous areas (Budetta, 2004).

(7) As mentioned before, mountainous terrains are more prone to rock fall incidents. Apart from rock fall rating approaches above which are generally developed considering the states' mountainous terrains, Ohio Department of Transportation (ODOT) created a rock fall hazard rating matrix although it is not considered a "mountainous state". It has been well documented that rock falls constitute a major hazard along Ohio highways (Young and Shakoor, 1987; Shakoor and Weber, 1988; Shakoor and Rodgers, 1992; Geiger et al., 1991, and Shakoor, 1995).

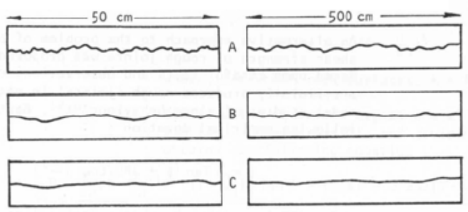
The geology in Ohio represents gently dipping, harder, more competent strata (siltstones, sandstones, limestones) alternating with softer, less competent strata (claystones, mudstones, shales) that this stratigraphy is highly susceptible to differential weathering which results in undercutting of the competent layers by erosion of the incompetent layers. According to site investigations accomplished by these researchers, many of the slope failures in Ohio initiate as plane and wedge failures in competent strata at higher elevations and descend as rock falls. When the subject is differential weathering, not only important the amount of undercutting, but also its rate should be taken into consideration while evaluating stability of slopes. In the study, a second-cycle slake durability index, which was developed by Shakoor and Rodgers (1992), can be used to predict the approximate rate of undercutting along roadways and hence, the time of initiation of rock falls from the date of excavation of a road cut (Woodard et al., 2005).

Table 2.15. shows the proposed rock fall hazard rating matrix for Ohio. In this table, the parameters which are found statistically important as well as some of them included in the existing systems can be seen. This matrix uses continual scales in addition to exponential scales which are used in the other systems (Woodard et al., 2005). Table 2.16. represents the accompanying scoring sheet for application of this rating matrix. The matrix comprises four types of parameters and the overall score for a rock slope is determined by adding scores together which are given separately to each of these parameters. These parameters are listed as: (i) geologic parameters, (ii) geometric parameters, (iii) traffic parameters, and (iv) rock fall history.

Table 2.15. The rockfall hazard rating matrix for Ohio (after Woodard et al., 2005)

EVALUATION PARAMETERS			RATING SCORES FOR DIFFERENT CATEGORIES OF EVALUATION CRITERIA			
			3 Point/(1)	9 Points/(2)	27 Points/(3)	81 Points/(4)
GEOLOGIC PARAMETERS						
Geologic Character	Differential Weathering	Slake Durability Index	90-100%	75-90%	50-75%	<50%
		Max. Amount of Undercutting	0-1 ft	1-2 ft	2-4 ft	>4 ft
	Discontinuity Role	Discontinuity Extent/Orient.	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		Discontinuity Surface Features	Very rough JRC=20	Rough JRC=15	Undulating JRC=10	Smooth JRC=5
Block Size/Volume of Rock Fall			1 ft/ 3 yd^3	2 ft/ 6 yd^3	3 ft/ 9 yd^3	4 ft/ 12 yd^3
Hydrologic Conditions			No water seeps on slope	A few water seeps on slope	Many water seeps on slope	Numerous water seeps on slope
GEOMETRIC PARAMETERS						
Ritchie Score			<1	1-1.5	1.5-2.5	>2.5
TRAFFIC PARAMETERS						
$\frac{\text{ADT x Slope Length / 24 hrs}}{\text{Posted Speed Limit}}$ x100%			25% of time (very low)	50% of time (low)	75% of time (medium)	100% of time (high)
% Decision Sight Distance			Adequate sight distance, ≥100%	Moderate sight distance, 75%	Limited sight distance, 50%	Very limited sight distance, <50%
Pavement Width			50 feet	40 feet	30 feet	20 feet
ROCKFALL HISTORY			No falls	A few falls	Many falls	Numerous falls

EXAMPLES OF ROUGHNESS



Joint Roughness Coefficient

A. Rough undulating- tension joints, rough sheeting, rough bedding. JRC= 20

B. Smooth undulating-smooth sheeting, non-planar foliation, undulating bedding. JRC= 10

C. Smooth nearly planar-planar shear joints, planar foliation, planar bedding. JRC= 5

Table 2.16. Scoring sheet for the rock fall hazard rating matrix (Woodard et al., 2005).

GEOLOGIC PARAMETERS					
Differential Erosion					
SDI	______	(a)	Greater Value (c or f)*	______	(g)
Maximum Amount of Undercutting	______	(b)			
Total (a + b)	______	(c)*	Block size	______	(h)
Discontinuities Role			Hydrologic	______	(i)
Discontinuity Extent/Orientation	______	(d)			
Discontinuity Surface Features	______	(e)	Total (g+h+i)/4	______	(j)
Total (d + e)	______	(f)*			
GEOMETRIC PARAMETER					
Ritchie's Score	______	(n)			
TRAFFIC PARAMETERS					
AVR	______	(o)			
% DSD	______	(p)			
Pavement Width	______	(q)			
Total (o+ p+q)/3	______	(r)			
ROCK FALL HISTORY					
History	______	(s)			
OVERALL SCORE					
Lines (j+n+r+s)	______	(t)			

(8) Apart from the rating methods which are mentioned above, Tennessee Rockfall Hazard Rating System is explained in the following chapter in detail. The differences which distinguishes Tennessee's system from the others are also be explained in order to present the reasons why this system has been chosen for the study.

CHAPTER 3

METHODOLOGY

3.1. INTRODUCTION

In this chapter, the application of Tennessee Rockfall Hazard Rating System (Cain, 2004) is explained, since this system is used as the method of the study. In addition to this, the advantages of Tennessee RHRS and a brief evaluation of this method are presented in order to explain why it is considered as suitable to implement in the study area.

The state of Tennessee has implemented the Tennessee Rockfall Management System (RMS) as a means of reducing the liabilities associated with rock fall hazard. The Tennessee Department of Transportation (TDOT) began to implement Phase I of its Rockfall Hazard Rating System (RHRS) in an effort to rate the hazard of all hazardous rock slopes on state roads and interstate highways in five counties within the state of Tennessee in 2001. In October of 2002, Phase II, involving the remaining 72 counties with rock slopes, was mostly complete with a majority of the counties complete and many more in progress. The Tennessee Rockfall Hazard Rating System (RHRS) is part of a larger Rockfall Management System (RMS), which uses digital data acquisition via PDAs (Bellamy et al, 2003) coupled with distribution via an expandable web-based GIS database (Rose et al, 2003). This system assigns a numerical hazard rating according to relative hazard for all slopes identified as having a high potential for delivering rock blocks onto Tennessee Department of Transportation maintained roadways (Cain, 2004).

The Tennessee Rockfall Hazard Rating System was designed to provide information for the Tennessee Rockfall Management System (RMS), a geospatial-database that contains all the information collected on hazardous slopes located on TDOT maintained roads (Bateman, 2001). TDOT began funding research in 2000 into development and implementation of a proactive management tool to inventory, assess and prioritize the remediation of rock fall hazards and risks along Tennessee highways (Bateman, 2002; Bellamy et al., 2003; Rose et al., 2003). Effectiveness of the catchment emerged as a key factor in preventing rocks from entering the roadway (Ritchie, 1963).

Other significant factors include slope height, roadway width, catchment width, average vehicle speed, line of sight and number of vehicles per day (NHI, 1993).

The Tennessee RHRS is a modified form of the National Highway Institute's RHRS (NHI, 1993). This system aids to rate rock slopes along a roadway in a consistent and repeatable manner with respect to rock fall hazard (Cain, 2004). The Tennessee RHRS is implemented by considering two major components: 1) Site and roadway geometry and 2) Geologic characterization.

The primary differences between NHI (1993) system and the Tennessee RHRS are in the area of geologic characterization (Vandewater, 2002). Some changes were also made to the site and roadway geometry section, particularly with respect to ditch effectiveness and how it is defined (Cain, 2004). The overall geologic character may also govern the failure mode that is likely to occur at a given rock slope. In contrast to rockfall hazard rating systems such as the NHI (1993), Tennessee's system identifies a potential failure mode. Modes defined in the Tennessee system include the structural modes of plane slide, wedge slide and topple, and the nonstructural modes of differential weathering and raveling (Bateman, 2002; Vandewater et al., 2005). Apart from the geologic assessment of the NHI (1993) system, the geologic character of the Tennessee RHRS allows multiple modes of failure to be assigned to an individual slope, where in the NHI (1993) only the worst case is rated.

As mentioned before, the safety is a very important issue to deal with in the roadway transportation. However, transportation agencies do not have sufficient available funds to deal with all safety issues at one time. It is becoming increasingly clear, however, that liabilities with respect to rock fall hazard are reduced if agencies have systems in place that identify potentially hazardous rock cuts and prioritize their remediation, as funds become available (NHI, 1993). Therefore, Federal Highway Administration (1999) developed a philosophy called Asset Management which is a systems-based approach to rockfall management.

Implementation of this approach improves public safety by helping engineers and geologists to locate all potentially hazardous slopes in order to remain cognizant of slopes that may present a hazard, and it can also aid in remediation decisions by providing key geotechnical information about slopes before a full site investigation is carried out. This approach is consistent with the Asset Management which also promotes preventative maintenance and long-term planning rather than reactive, short-term patches.

Tennessee RMS also utilizes a statewide database which reduces the likelihood that a transportation agency will spend limited financial resources investigating a slope, only to find that the hazard is not sufficient to warrant remediation. Also, the feature that the fieldwork can be performed by employees with minimal geological or geotechnical experience makes the Tennessee RHRS attractive since it cuts down on the labor cost of a statewide survey (Cain, 2004).

Apart from the other rock fall hazard rating systems, the feature regarding geologic assesment which includes more thorough descriptions of the geologic character of a slope can be counted as an important advantage of the Tennessee RHRS (Vandewater, 2002). The research teams performing the hazard rating throughout the state of Tennessee observed that the study areas offered a diverse geology and hence, it gave the opportunity to examine a variety of slopes with different lithologies and structural geology, allowing the researcher to inspect all the failure modes in many different settings (Cain, 2004).

Therefore, it has been decided to assess Tennessee's system in this study, since the cutslopes along the selected highway route presents variety of failure modes as considered in Tennessee RHRS. This system also requires to take digital images of each rated slope in order to enter them into the database. According to Cain (2004), an engineer has opportunity to infer the required remediation type from their desk and get a rough estimate of cost without going into the field by using Tennessee RHRS. More detailed information about this system's application and its advantages can be found in the following sections.

3.1.1. Tennessee Roadway Information Management System (TRIMS)

TDOT engineers or geologists utilize TRIMS to collect four to five pieces of information, Average Daily Traffic (ADT), beginning log mile of the slope, side of the road on which the cut is located, and road width, for Tennessee RHRS. It also provides a digital image log of the entire network of state-maintained roadways and hence, manages the state maintained roadway network with maintenance decisions (Cain, 2004).

As explained by Cain (2004), for each state route and interstate highway, TRIMS contains a sequence of wideangle digital images taken from the front of a vehicle at 0.016-kilometer (0.01 mile) intervals (Figure 3.1). The images, which are also taken from either side of the vehicle on some roads, allow a user to identify potentially hazardous rock slopes while sitting at their desktop, prior to going to the field.

Figure 3.1. Screen-capture of TRIMS digital image log showing rock cut (Cain, 2004; Note the narrow catchment next to wide paved shoulder).

3.2. Tennessee Rockfall Hazard Rating System

3.2.1. Preliminary Ratings

The first step in Tennessee RHRS is collecting the initial roadway data and locating all rock slopes in the study area by using TRIMS. Once this step is completed, a preliminary site investigation is accomplished by a walk-over survey and given the preliminary ratings to all identified slopes. Standard safety protocols are essential for this fieldwork; safety can be a particular concern because the majority of the hazardous slopes tend to be older cuts with narrow ditches and no shoulders (Cain, 2004). Tennessee RHRS suggested to use the preliminary rating criteria developed by NHI (1993). It is divided into three categories to assess the general hazard of a rock slope, as high (A), moderate (B), or low (C). The definitions made in NHI (1993) are given in Table 3.1.

Table 3.1. Preliminary rating definitions (NHI, 1993).

A-slopes:	Moderate-to-high potential to deliver rock to the roadway and/or high historical rock fall activity.
B- slopes:	Low-to-moderate potential to deliver rock to the roadway and/or moderate historical rock fall activity.
C- slopes:	Negligible-to-low potential to deliver rock to the roadway and/or low historical rock fall activity.

According to Cain (2004), C-slopes are the easiest of the three to recognize. Most C-slopes are less than 3 m (10 ft) in height with no significant slope behind, in flat-lying strata, and have catchment or ditch width of at least 1.5 m (5 ft). Wyllie and Norrish (1996), have defined also an R-slope (remediated slopes) class which means "slopes constructed with features that exclude them from the A and B categories". Terraced slopes, or slopes isolated from the roadway by means of an engineered rockfall barrier can be counted as R-slopes.

a) In case a slope is given a preliminary rating of A or B, the rater records the following in the preliminary data set: TDOT region number, county name and number, state route number, beginning log mile, centerline reference, speed limit, ADT, and GPS coordinates (Cain, 2004).
b) If a slope is given the preliminary designation of A, the crew can either choose to do a detailed rating immediately or to come back later to do the detailed rating (Cain, 2004).
c) Slopes classified as B are entered into the RMS database, but no numeric hazard score is given to the slope (Cain, 2004).

3.2.1.1. Distinguishing A and B Slopes

It is more important to decide which slopes are given A or B ratings at the preliminary rating stage in comparison with identifying C slopes since it is usually straightforward and unambiguous to give the C-rating to a slope. If the slope is called an A-slope, detailed rating is performed on this slope. In case it is called a B-slope, there is no need to do a detailed rating. As explained by Cain (2004), the conservative course of action is to designate all borderline cases as A-slopes, but this will distort the database if the slopes are in fact B-slopes. Typical examples for A, B and C slopes from the study area (Kurtboğazı Dam-Gerede segment of D750 Highway) are shown in Figures 3.2 to 3.4.

Figure 3.2. Example of an A-slope through the Azaphane Pass along D750 Highway. (Note the narrow catchment and the blocks are likely to reach the roadway).

Figure 3.3. Example of a B-slope in the vicinity of Aktaş village along D750 Highway. (Note the wide enough catchment that is able to contain the rockfall event).

Figure 3.4. Example of a C slope with wide catchment and shoulder, a view looking toward Kurtboğazı Dam along D750 Highway.

The Tennessee RHRS tries to answer the following questions while distinguishing the A and B preliminary hazard categories. As explained by Cain (2004), the questions are:

1. Is the catchment insufficient to contain the likely range of rock fall events?

2. Is there evidence of past rock fall events reaching the roadway? Such evidence might include impact marks on the road or identification of the slope in maintenance records as a problem area.

Answering YES to either (1) or (2) is indicative of an A-slope. Based on the researchers' experience it has been shown useful to also consider the following two questions as aids for answering question (1).

3. Does the slope have characteristics that increase the likelihood of rock fall reaching the roadway? Examples are launching features and a tendency to fill its catchment with talus, creating a ramp that promotes rolling.

4. What is the likely range in size of individual blocks, and volume of potential rock fall events?

In addition to the questions above, the Tennessee RHRS also considers some site-specific variables such as the ADT and the Decision Site Distance (DSD) in order to make the best decision about the slopes' preliminary rating. Cain (2004) has suggested the raters to be more inclined to call a rock slope on a major highway or interstate as an A-slope since ADT and hence the public safety risk, is higher. If the slope is on a blind curve where a driver is unlikely to see an obstruction in the roadway with adequate time to react, as reflected in a low DSD, then a rater should be more inclined to call the slope an A-slope. In case a rater is still suspicious about the preliminary assessment of the slope, the conservative approach should be adopted and the slope should be given an A designation and a detailed rating is performed (Cain, 2004).

3.2.2. Detailed ratings

After the preliminary rating stage of Tennessee RHRS is completed, the detailed ratings for only A-slopes are performed. The detailed rating part of the Tennessee RHRS is completed at two stages by searching the parameters: 1) site and roadway geometry and, 2) geologic character. Cain (2004) indicated that the site and roadway geometry is defined and scored in the Tennessee RHRS much as it is in the NHI (1993) with the exception of the ditch effectiveness, and major difference between the two systems lies in how the geologic hazard of the slope is characterized.

At the detailed rating stage of Tennessee RHRS, the scoring for each category or parameter is accomplished by using an exponentially increasing scale as well as in the NHI system, meaning that as a category becomes more hazardous, the score for that category increases exponentially. This is done so that the slopes with a high degree of hazard have a much higher score than the less hazardous slopes (NHI, 1993). The scoring sheet for detailed rating (Table 3.2a&b) is used to enter the rating data manually or the rating data are entered in a digital format on a PDA that exactly mimics the paper form input structure.

The data entry forms for the PDA were constructed using Pendragon software (Bellamy et al, 2003). If the paper form is used, numeric hazard scores for individual categories are determined either from lookup tables or using equations as provided in the NHI (1993) system. The PDA, which is not recommended for training, is separated from the paper forms with its tremendous advantages for data entry and calculation of hazard for trained personnel while the paper forms are suggested to be used for training of field personnel so that the hazard determination is transparent and explicit. The PDA also allows for the use of SI or traditional British system of units while the paper form was developed traditional British units (Cain, 2004).

Table 3.2. a) Example of the Tennessee RHRS scoring sheet (front side). **b)** Tennessee RHRS scoring sheet lookup tables (back side) (after Cain, 2004)

TDOT RHRS FIELD SHEET v 1.0

I. TRIMS/Preliminary Data

Date ________

File No ________

County No. ______ Rater ______

Route No. ______ Speed Limit ______

Beg.L.M. ______ District ______

Ref C/L ______ ADT ______

County ______ Latitude ______

Region ______ Longitude ______

SCORING

1. Slope Height ______
2. AVR ______
3. %DSD ______
4. Road Width ______
5. Ditch Effectiveness ______
6. Rockfall History ______
7. Water ______
8. Geologic Character ______

TOTAL ☐ SCORE ______

II. Site and Roadway Geometry

1. Slope Height (ft)

☐ Estimated ______

alpha (a) ___ beta (b) ___

width (x) ___ ft

Instrument height (H.I) ___ ft

$$\text{Slope height} = \frac{\sin a * \sin b * X}{\sin (a-b)} + H.I.$$

2. Average Vehicle Risk (AVR)

$$AVR = \frac{\text{ADT (cars/day)*(Rock Slope Length/5280)}}{\text{((24 hpd)*Speed Limit (mph))}}$$

Slope Length ____ ft Speed Limit ____ mph AVR= ____ %

3. %Decision Site Distance (%DSD)

choose one: adequate, 3 moderate, 9 limited, 27 very limited 81

OR

calculate ______ / ______ X 100 = ______ %

(observed DSD) / (AASHTO DSD)

4. Road width(ft) ______

5. Ditch Effectiveness

Design Catchment Width (feet)

Slope Height (ft)	Recommended width for vertical slope	Recommended width for non-vertical slope
0-40	18	18
40-50	18	24
50-60	24	30
60-70	28	34
70-80	32	38
80-100	36	42
100-125	36	42
125-175	40	48
>175	52	60

Effective catchment width (ft) ______ Launching Features? (Yes or no) ______

6:1 catchment shape? (yes or no) ______

Percent of Design Catchment Width from Table	>90%	70%-90%	50%-70%	<50%
Score with 6:1 or greater catchment slope	3	9	27	81
Score w/ Poor Catchment Slope OR Launch Features	9	27	81	81
Score w/ Poor Catchment Slope AND Launch Features	27	81	81	81

6. Rockfall History

Benchmark	Frequency	Field judgment	Score
Few	1 or less per year	No impact marks in the road, no rocks in the road, few rocks in the ditch	3
Several	2 per year	No impact marks in the road, no rocks in the road, many rocks in the ditch	9
Many	3-4 per year	Few impact marks or few rocks in the road	27
Constant	5 or more per year	Many impact marks and/or many rocks in the road	81

7. Presence of Water on Slope

(choose one) none 3 seeping 9 flowing 27 gushing 81 ______

NOTES:

III. Geologic Characteristics (circle all that apply; modes are additive)

	Planar				Wedge				Topple			
Abundance score	<10% 3	10-20% 9	20-30% 27	>30% 81	<10% 3	10-20% 9	20-30% 27	>30% 81	<10% 5	10-20% 14	20-30% 41	>30% 122
Block size score	< 1ft 3	1-3 ft 9	3-6 ft 27	> 6 ft 81	< 1ft 3	1-3 ft 9	3-6 ft 27	> 6 ft 81	< 1ft 5	1-3 ft 14	3-6 ft 41	> 6 ft 122
Steepness (degrees) score	0-20 2	20-40 5	40-60 14	> 60 41	0-20 2	20-40 5	40-60 14	> 60 41				
Friction (Micro/macro) score	rough/undulating 2	smooth/undulating 5	rough/planar 14	Smooth/planar 41	rough/undulating 2	smooth/undulating 5	rough/planar 14	smooth/planar 41				

8. Geology Score= ______

	Differential Weathering					Raveling			
Abundance score	<10% 3	10-20% 9	20-30% 27	>30% 81	Abundance score	<10% 3	10-20% 9	20-30% 27	>30% 81
Block size score	< 1ft 3	1-3 ft 9	3-6 ft 27	> 6 ft 81	Block size score	< 1ft 3	1-3 ft 9	3-6 ft 27	> 6 ft 81
Relief score	< 1ft 3	1-3 ft 9	3-6 ft 27	> 6 ft 81	Block Shape score	tabular 3	blocky 9	round 27	

Slope Height / AVR Scoring Table

Height / %AVR	Score	Height / %AVR		Score
9	1	77	29	1
10-20	2	78	31	2
21-28	3	79	32	3
29-34	4	80	34	4
35-38	5	81	35	5
39-42	6	82	37	6
43-45	7	83	38	7
46-48	8	84	40	8
46-51	9	85	42	9
52-53	10	86	44	10
54-55	11	87	46	11
56-57	12	88	48	12
58-59	13	89	50	13
60	14	90	52	14
61-62	15	91	55	15
63	16	92	57	16
64-65	17	93-94	60	17
66	18	95	62	18
67	19	96	65	19
68	20	97	71	20
69	21	98	74	21
70	22	99	78	22
71	23	100	81	23
72	24	101	85	24
73	25	102	88	25
74	26	103	92	26
75	27	104	97	27
76	28	105	100	28

Road Width Scoring Table

Width / Score		Width / Score	
18	100	35	10
19	93	36	9
20	81	37	8
21	71	38	7
22	62	39	6
23	54	40	5
24	47	41	5
25	41	42	4
26	36	43	3
27	31	44	3
28	27	45	3
29	24	46	2
30	21	47	2
31	18	48	2
32	16	49	2
33	14	50	1
34	12		

AASHTO Recommended DSD

Decision Site Distance	MPH
300 ft	20
375	25
450	30
525	35
600	40
675	45
750	50
875	55
1000	60
1015	65

%DSD Scoring Table

%DSD	Score	%DSD	Score
36	100	61	26
37	96	62	24
38	90	63	23
39	86	64	22
40	81	65	21
41	77	66	19
42	73	67	18
43	69	68	17
44	65	69-70	16
45	62	71	15
46	58	72	14
47	55	73-74	13
48	52	75	12
49	49	76-77	11
50	47	80-81	9
51	44	82-83	8
52	42	84-85	7
53	40	86-88	6
54	38	89-92	5
55	36	93-97	4
56	34	98-103	3
57	32	104-112	2
58	30	113	1
59	29		
60	27		

(b)

In this study, after the Tennessee's requirements for preliminary rating (NHI, 1993) is completed along the selected route, the detailed rating stage of Tennessee RHRS is adopted for the A-slopes along the route. As mentioned before, the detailed rating is performed at two stages by rating some parameters regarding these stages. The detailed information about these parameters is given in the following sections.

3.2.2.1. Site and Roadway Geometry

It is the first stage in detailed rating portion of Tennessee RHRS and it is divided into five categories (Figure 3.5). The categories which are also the hazard scoring parameters and their effects on scoring are briefly explained below.

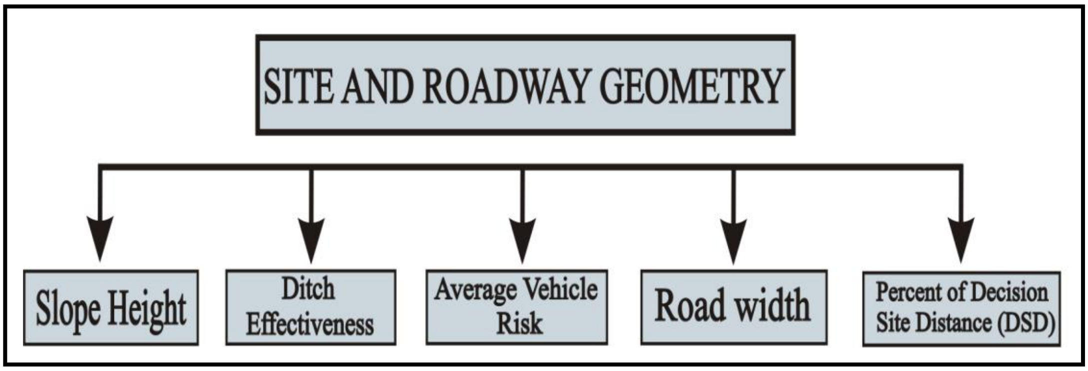


Figure 3.5. Site and Roadway Geometry Factors (after Cain, 2004)

3.2.2.1.1. Slope Height

A rock that falls from high up on a slope will have a greater kinetic energy when it reaches road level than a rock that falls from a lesser height, and therefore, taller slopes present a greater hazard (Cain, 2004). In Tennessee RHRS, the height of a slope is measured at the highest point along the hazardous portion of the slope being rated. A-slopes are generally taller than the B and C slopes and this important step of the detail rating requires to measure the A-slopes' heights. However, these kind of slopes can constitute some risks for the rater from the point of work-safety in case of climbing onto the slopes for height measurements. In Tennessee RHRS, a handheld hypsometer, a combined laser range finder and inclinometer, was found to be the most convenient tool for height measurements.

Using the hypsometer is quick and efficient because it requires only one measurement and reduces the uncertainty associated with estimation. After the height is measured, its hazard value can be obtained by using a lookup table provided on the back of the paper form (Table 3.2b) or it is calculated from the following equation (NHI, 1993):

$$\textit{Height Score} = 3^{x}\text{, where } x = \textit{Slope Height} / H_o \tag{3.1}$$

where the reference height H_o equals 7.6 m (25 ft) (Cain, 2004).

3.2.2.1.2. Ditch Effectiveness

Patton and Deere (1970), have stated that the experience shows that all rock slopes shed rock blocks or slabs to some degree, and it would be nearly impossible and extremely costly to design rock slopes so they did not shed any rock. However, the probability of rock debris reaching the roadway can be reduced by designing slopes with sufficiently wide catchments (Cain, 2004). Ditch effectiveness is also a deciding factor in identifying whether a slope is A or B. For instance, slopes with wide catchments are more inclined to contain the rock fall event and it plays a major role to call these kind of slopes as B or C slopes.

TDOT's requirements for catchment design are as follows (Cain, 2004):

a) A minimum catchment width of 5.5 m (18ft) for all slopes up to 12.2 m (40 ft) high.
b) Wider catchments are required for taller slopes and for slopes that are nonvertical.
c) As part of the catchment design, TDOT also requires a minimum 6:1 (H:V) roadway approach slope.

The scoring for ditch effectiveness which compares the actual catchment width and slope to TDOT design requirements can be seen in Table 3.2a. The overall ditch effectiveness score is based on the percentage of design width, the slope of the catchment, and the presence or absence of launching features (Table 3.2b). The presence or absence of launching features is also another factor that is considered in ditch effectiveness' scoring stage.

Cain (2004), has explained that the launching features are "topographical protrusions" in the slope profile that can change the trajectory of rock fall debris increasing the likelihood that rocks will reach the roadway. Hence, in case of launching features are present on a slope, the catchment width needed to contain a rock fall event is larger than for a slope without launching features.

3.2.2.1.3. Average Vehicle Risk (AVR)

It is an important parameter from the point of defining the traffic load along the highway corridors since the rock fall events affect the traffic safety. In Tennessee RHRS, AVR is defined as a measure of public exposure to the slope being rated. Cain (2004) has stated that the contribution of AVR to hazard is understandable because the more time vehicles spend adjacent to a hazardous rock slope, the more likely there will be an incident. The AVR is calculated as a percentage and the equation for this calculation is shown below (NHI, 1993):

$$AVR = \frac{ADT(cars/day) * Slope\ Length\ (km)}{24(hours/day) * Speed\ Limit\ (kph)} \times 100\% \qquad (3.2)$$

After the AVR is found by the formula above, the hazard score regarding this parameter is determined by using the lookup tables (Table 3.2a&b) or automatically using the PDA. In this study, ADT (Annual Daily Traffic is determined according to the data that were obtained from the counter devices which were built on certain stations by General Directorate of Highways (TCK) for defining the traffic load along the highway. The detailed information about how the AVR can be found for this study is explained in the following chapter by using the data and maps provided from TCK.

3.2.2.1.4. Roadway Width

Roadway width in the neighbourhood of a hazardous rock slope should be measured in order to see whether the road width increases the risk to the motoring public or not. This increasement occurs where the road is narrow since it will limit the time and space in which a driver can react.

Roadway width is measured at the narrowest portion of the road adjacent to the slope and perpendicular to the longitudinal axis of the road. There is also another criterion to be considered when the road includes a shoulder. In this case, roadway width includes all of the paved right-of-way, including the shoulder and also if the slope is on a divided highway then only the side of the highway adjacent to the slope is measured (Cain, 2004). In this study, these requirements for measuring the roadway width have been considered and data were obtained by using a tape measure as a tool.

3.2.2.1.5. Percent Decision Site Distance (%DSD)

Cain (2004) has stated that Decision Site Distance (DSD) is the maximum distance at which a driver can identify a 15 cm (6 in) diameter obstacle in the road with sufficient time to respond appropriately and it was standardized by AASHTO (1984), and is dependent on the posted speed limit. If a driver's time to react is reduced against a rock fall event, the rock fall hazard is increased.

The Tennessee RHRS gives the rater two options when scoring the DSD: 1) estimate the DSD as adequate, moderate, limited, or very limited; 2) measure the DSD and calculate the percent DSD as defined by:

$$\%\ DSD = DSD_{(measured)} / DSD_{(AASHTO)} \tag{3.3}$$

After calculating % DSD value, the percent DSD hazard score can be obtained from lookup tables (Table 3.2a&b) or using equations provided by NHI (1993). The PDA uses the same NHI (1993) equations to automatically calculate the hazard score for Percent DSD (Cain, 2004). In this study, DSD scoring is obtained by estimating based on the existence of highway curves.

3.2.2.2. Geologic Characterization

There are a number of changes between the origin of all other rock fall hazard rating systems (NHI, 1993) and the Tennessee RHRS from the point of defining the geologic character hazard score.

These changes improve the repeatability, ease of use, and amount of information provided by the rock fall survey (Cain, 2004). Due to these reasons, Tennessee RHRS is more adventageous in comparison with previous rock fall hazard rating systems. Cain (2004) has explained the changes as follows:

a) Basing the geological character rating score on conventional rock slope failure modes,
b) Allowing for the inclusion of multiple failure modes,
c) Reducing ambiguity in verbal descriptions.

In order to get more detailed information about the differences between NHI (1993) and Tennessee RHRS, Figure 3.6 can be checked.

Cain (2004) has stated that the geologic character assessment in the Tennessee system begins by asking the rater to identify pertinent failure modes (Table 3.3).

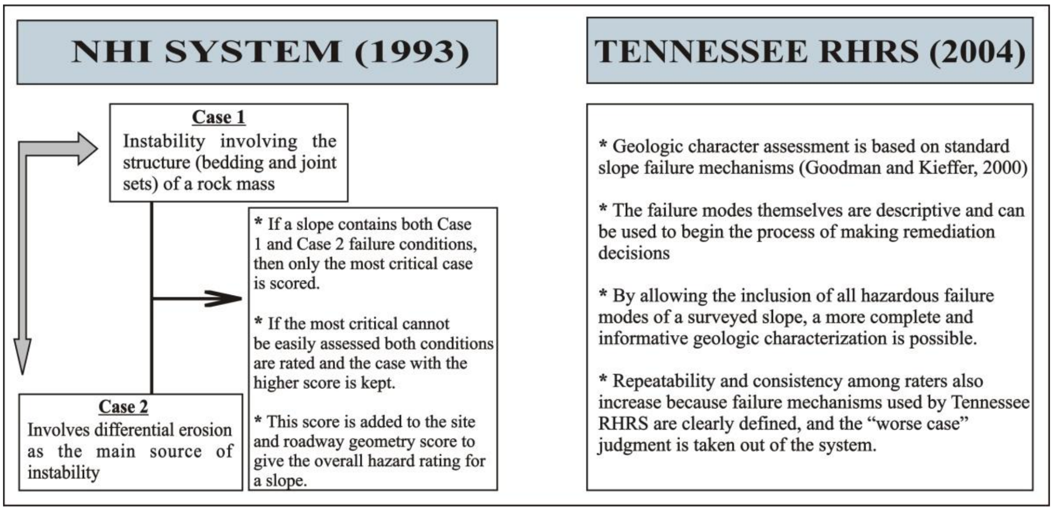


Figure 3.6. Differences between NHI (1993) and Tennessee RHRS (2004) (compiled from Cain, 2004)

Identifying the pertinent failure modes is logical and unambiguous and it is based on slope and geologic characteristics that are readily apparent to a rater with minimal training. The geologic characterization continues as follows (Cain, 2004):

a) The rater enters binned parameter values describing abundance, block size, steepness, friction, block shape or relief depending on the identified failure modes (Table 3.3).

b) The parameters are binned in such a way that the assignment of bin values is also consistent and repeatable.

c) By improving repeatability and decreasing ambiguity of rock fall hazard rating, the Tennessee RHRS increases the reliability and quality of information contained in the Tennessee RMS.

Table 3.3. Failure modes and parameters included in the Tennessee RHRS (after Cain, 2004)

Failure Mode	Geological Failure Attributes					
	Abundance	Block Size	Steepness	Friction	Relief	Block Shape
Planar	XXX	XXX	XXX	XXX	N/A	N/A
Wedge	XXX	XXX	XXX	XXX	N/A	N/A
Topple	XXX	XXX	N/A	N/A	N/A	N/A
Differential Weathering	XXX	XXX	N/A	N/A	XXX	N/A
Raveling	XXX	XXX	N/A	N/A	N/A	XXX

3.2.2.2.1. Scoring Geologic Character Parameters

In Tennessee RHRS, after the failure mode for a given slope has been identified, the hazard score is assigned to the individual failure mode by depending on its attributes (Table 3.4). Cain (2004) has expressed that assigning attributes to a failure mechanism lets the kinetics of a failure mechanism and mobility to be considered, and gives an idea of the impact of a failure event.

3.2.2.3. Other Scoring Criteria

3.2.2.3.1. Water

Water is another criteria (Table 3.2a) to consider while scoring the hazard since water on slope plays a significant role in decreasing the stability of structural failure modes (wedge, planar and also toppling). The effects of water on a slope are as follows (Cain, 2004):

a) Decreases the effective stress acting on the slip surface and thereby decreases the frictional resistance.
b) Water increases the rate of erosion, and loosens material on the slope, via freeze thaw and other mechanisms, which aid raveling and differential weathering.

3.2.2.3.2. Rock fall History

The information about the rock fall history is obtained in order to understand whether a given slope can be hazardous or not. This is accomplished in two ways, through maintenance records, if available, or via observation.

The availability of maintenance records is very difficult and hence the field observation is seen as the most convenient and commonly used technique. Cain (2004) has stated that the key factors to look for in the field are impact marks in the road and the amount of rock, if any, in the ditch (Table 3.2a).

Table 3.4. Parameters used in the Tennessee RHRS with applicable failure modes (after Cain, 2004)

Parameter	Applicable Failure Modes	Description
Abundance	All Modes	The abundance of a failure mode is defined as the ratio of the total surface area slope that is covered by that failure mode. The sum of individual abundances cannot exceed 100%, except in the cases where raveling is superimposed onto the structural modes planar or wedge failure.
Block Size	All Modes	The block size is determined by the longest dimension of the rock blocks associated with the typical range of rock fall events. It is best to characterize the size of rock blocks that have not yet fallen from the slope, but if the blocks are high up on the slope and estimation is not feasible, then similar size blocks in the ditch can be used to estimate the size.
Steepness	Planar &Wedge	The steepness component of the two structurally controlled failure mechanisms is the same as the dip of the slip surface for planar failure, and the plunge of the line of intersection for wedge failures. The steepness should be estimated based on the characteristic steepness of the planes or wedges that meet the kinematic requirements for failure.
Friction	Planar &Wedge	The friction score deals with shape of the failure surface on both the micro and macro scales. The macro scale is either planar or undulating. The micro is rough or smooth. Macro friction is more important than the micro friction because the smaller asperities accounting for the roughness are more easily broken through when sheared.
Relief	Differential Weathering	Relief is the measure of the amount of overhanging produced by the differing rates of erosion. As the overhang increases, the destabilizing moment also increases, thereby increasing the hazard of the slope.
Shape	Raveling	Since raveling is just blocks falling from the slope, the mobility a block is a function of the height of release and block shape. Block shape has increasing hazard as a block becomes cubic and rounded.

CHAPTER 4

ASSESSMENT OF TENNESSEE ROCKFALL HAZARD RATING SYSTEM IN THE STUDY AREA

4.1. Data Evaluation for Preliminary Ratings

In this section, the initial data regarding the cut slopes through the selected highway route are given in detail. The data are collected by using the rules of preliminary rating phase of Tennessee RHRS which are explained in detail in the previous chapter. In this study, locating the rock slopes in the study area is accomplished by walk-over survey at the site, since there is not a Roadway Information Management System (RIMS) as such in the Tennessee RHRS (TRIMS).

After completing the first walk-over survey through the study route, the preliminary ratings are given to the identified slopes by combining the site-observations and photos taken by a high resolution digital camera. In order to present the exact locations of the cut slopes, the GPS coordinates are recorded at each location and the kilometers are identified by starting from the first location. The location map (Figure 4.1), which is modified from the geological map in Figure 1.2, is used for illustrating the distibutions of the exact locations of the A-B-C slopes between the Kurtboğazı Dam located at 50 km northwest of Ankara province and Aktaş village located at 15 km to Gerede town of Bolu province. In this section, the typical photographs of A-B-C slopes are also illustrated in order to distinguish them from each other. In this sense, the Phase I of the RHRS for this study will provide to make an inventory to point out the cut slopes in a region which is susceptible to rock fall hazards.

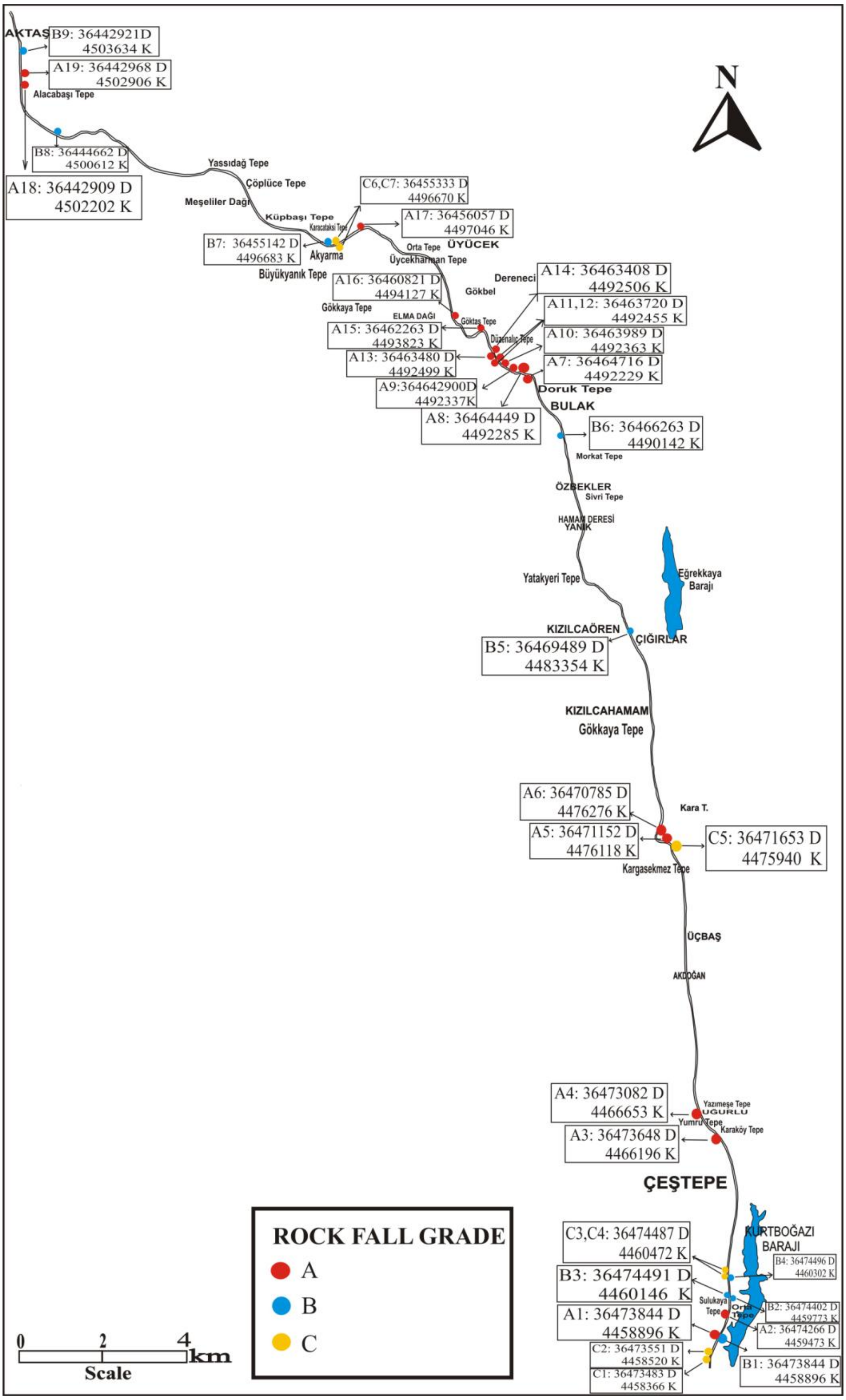


Figure 4.1. Location map showing the distribution of “A-B-C” rated slopes.

4.1.1. C-slopes

In accordance with the Tennessee RHRS requirements for preliminary rating, some of the cut slopes along the study route are given C-ratings. This route has a length of about 70 km which includes many cut slopes. Among these slopes, the easist ones to define are C-slopes. During a route reconnaissance survey, a total of 7 C-slope categories are identified. The locations of the C-slopes are illustrated with the yellow dots in Figure 4.1. The location map (Figure 4.1.), which is prepared for illustrating the types of cut slopes along the selected portion of D-750 Ankara-Bolu Highway, makes it easy to follow where the cut slopes localize. In this sense, this study carries a feature of inventory for these slopes along the route. A few examples for the typical C-slopes along the study route are given in Figures 4.2 and 4.3 in an effort to exhibit the differences which distinguish the C-slopes from the A and B slopes.

In the study area, the identified typical C-slopes are unlikely to produce any rock fall event and it is observed that even if a fall occurs, the rocks cannot reach the roadway since they stay in the roadway ditches. In this study, the C-slopes are not high and the slope angles and the roadside ditches are another deciding factors for C-rating. In other words, the Tennessee criteria for defining the C-slopes, "negligible-to-low potential to deliver rock to the roadway and/or low historical rock fall activity" (Cain, 2004), is valid during the rating process. Pierson and Van Vickle (1993) suggests that "it is not worthwhile to clutter a database with information on slopes of this nature" . However, a few characteristic C-slopes are explained in detail to get a feel for their nature and how they are distinguished from the "A" and "B" rated sites.

The C-slope in Figure 4.2, which is shown as C2 with the yellow dot in the location map (Figure 4.1), is located in the neighbourhood of the Kurtboğazı Dam, on the left side of the roadway in the direction to Bolu. The slope angle for this site is relatively low and cut within andesite and pyroclastic rocks. The small rock fragments in the slope pose no risk to the roadway since they stay in the ditch as it can be seen in Figure 4.2. Accordingly, this slope has been given "C" rating.

Another example for C-slope is given in Figure 4.3, shown as C5 with the yellow dot in the location map (Figure 4.1), is located at the Kargasekmez Pass at KM: 19.5 from the starting point designated as KM: 0 point (C1 in Figure 4.1). The slope is not high and is formed within andesite and pyroclastic rocks (agglomerates). It has a ditch and a wall providing the material to be captured within the ditch. There is no evidence of any rock fall event and hence the slope has been given "C" rating.

Figure 4.2. “C” rated slope near Kurtboğazı Dam, Ankara.

Figure 4.3. “C” rated slope through Kargasekmez Pass, Ankara.

4.1.2. B-slopes

During the preliminary rating phase, nine B-slopes along the study route have been identified. Their locations and GPS coordinates are given in Figure 4.1. Two characteristic “B” rated slopes have been included as examples in the Figures 4.4 and 4.5 in order to exhibit the features of B-slopes. These two examples have been chosen since they present two different features of B-slopes. As mentioned in the Tennessee RHRS, distinguishing the distinctions between A and B slopes can be more subjective while it is very easy to decide whether a slope should be rated as “C” or not. Accordingly, these two examples can pay the attentions to the points which help the rater to decide the slope should be designated as “B” rather than designating it as “A”.

The B-slope in Figure 4.4a, (B9 in Figure 4.1) is located near Aktaş village (15 km to Gerede town of Bolu province) at KM: 70. The slope is on the right side of the roadway in the direction to Bolu. The site can be envisioned as a typical B-slope. This cut is surrounded by abundant plant cover. It is formed in thin-to-medium bedded clayey limestones. In addition to the figures above, Figure 3.3 in Chapter 3 can also be checked in order to see the rock blocks which stay in the ditch. The thin-to-medium layered rock mass dips away from the road and the rock face is highly fractured and likely to shed rock blocks. The rock slabs above the dashed lines, which are shown on the slope face in Figure 4.4b have potential to fail by forward rotation into the ditch due to the lack of support resulting from the less resistant layers between the bedding planes. It is apparent that the ditch is wide enough to catch the failed rock blocks. This slope has been given “B” rating because of accumulation of many rock blocks within the ditch.

Figure 4.5a also shows a “B” rated slope. The slope, shown as B1 with the blue dot on the location map (Figure 4.1), is located near Kurtboğazı Dam at KM: 1.2. The slope is on the right side of the roadway in the direction to Bolu. The bedrock is andesite. On first glance, this slope seems to get an “A” rating since it is a high slope and also due to the launching features which can be seen above the rock face. But on closer inspection, the presence of the wall with an effective ditch which contains the rock debris shedding from the rock face due to the weathering makes this cut a “B” slope. According to the inspections, it is considered that the ditch is cleaned from the rock debris by the highway maintenance personels.

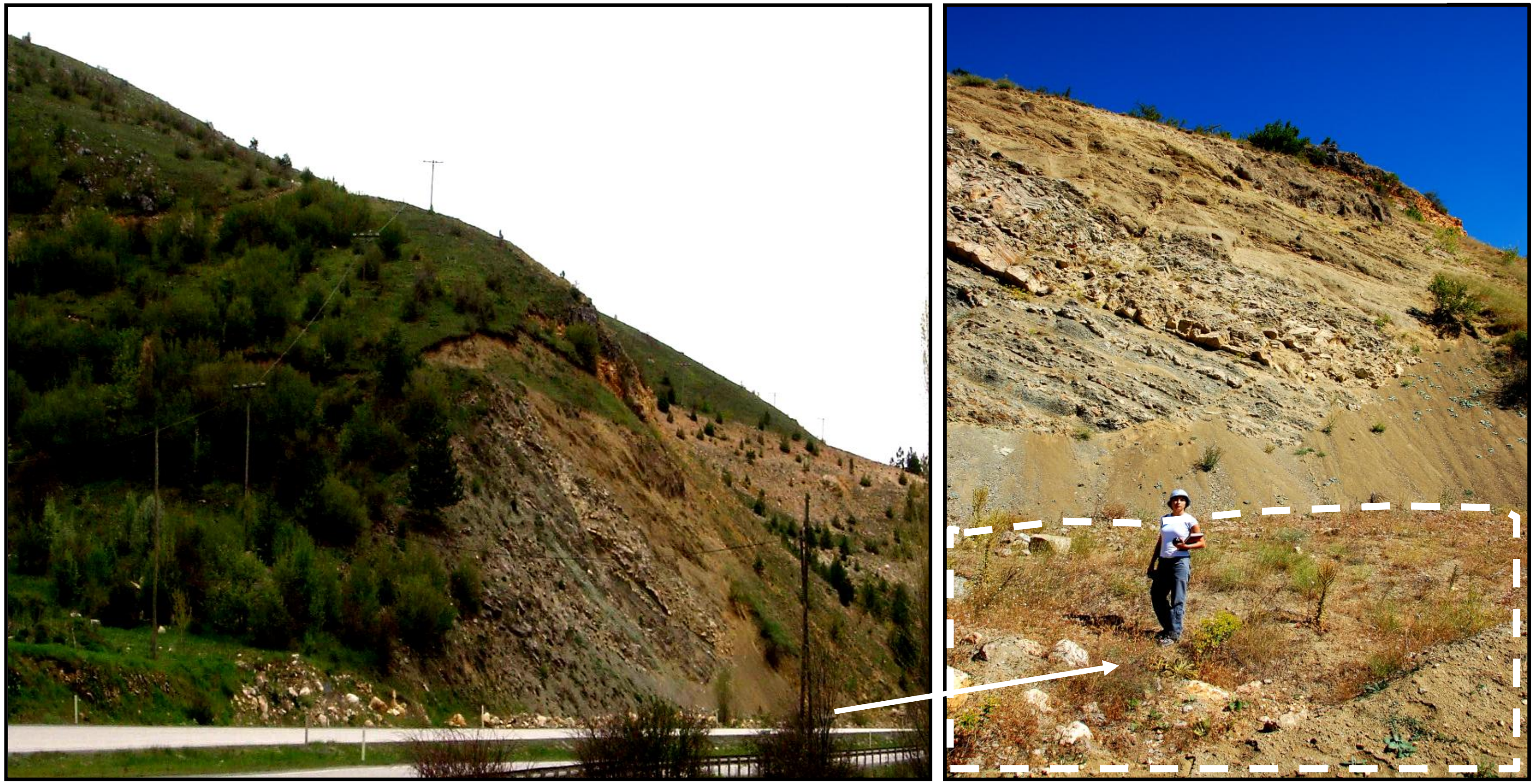


Figure 4.4. a) “B” rated slope near Aktaş village, Gerede-Bolu. **b)** A view showing the ditch of the “B” rated slope in (a).

Figure 4.5a. “B” rated slope near Kurtboğazı Dam, Ankara.

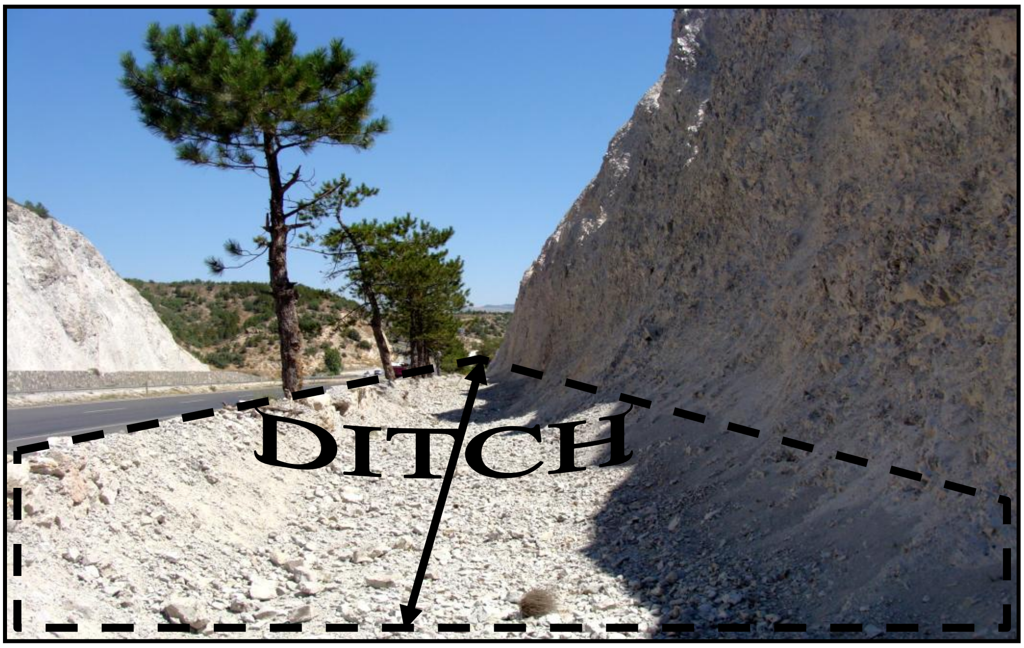


Figure 4.5b. A side view showing the ditch of the “B” slope in Figure 4.5a.

4.1.3. A-slopes

During the preliminary rating phase, a total of 19 A-slopes have been identified. Their locations (red dots) and GPS coordinates are given in Figure 4.1. In order to give a slope "A" rating during the preliminary rating phase, the criteria developed by NHI (1993) and also Tennessee RHRS (2004) have been considered. Accordingly, the slopes which are considered to have a moderate-to-high potential to deliver the rock blocks to the roadway have been rated as "A" slopes. In this sense, the observations regarding the factors such as the height of slopes and the condition of ditches have been taken into consideration in this phase of the study.

A typical "A" rated slope is shown in Figure 4.6b. The cut slope designated as A7 and with the red dot in the location map (Figure 4.1), is located in the beginning of the Azaphane Pass at KM: 40. The slope is located at the left side of the roadway as shown in Figure 4.6a. The unit which forms the slope is heavily jointed basalt. The cut can be counted as a representative "A" rated slope for several reasons.

As it can be seen from Figure 4.6b, the catchment ditch area is ineffective in both width and depth to catch the blocks falling from the rock face. At this locality the road is curved and this may create a danger for the drivers in identifying any obstacle behind the curve in the direction of arrow. The rock blocks marked with the arrows above the blue dashed lines are likely to shed from the rock face and reach to the roadway. The potential effects of saturation due to rainfall and also freeze-thaw action during spring thaw can be considered as contributing factors to instability. An accumulation of rock aggregates which were separated from the exposed sliding planes from past failures can be seen above the dashed lines shown in Figure 4.6b. Accordingly, it is decided to assign this slope "A" rating in the preliminary rating phase. After the preliminary ratings, the "A" rated slopes are assessed in the detailed rating phase of this study.

Figure 4.6a. The warning sign showing that the area is susceptible to rock fall events.

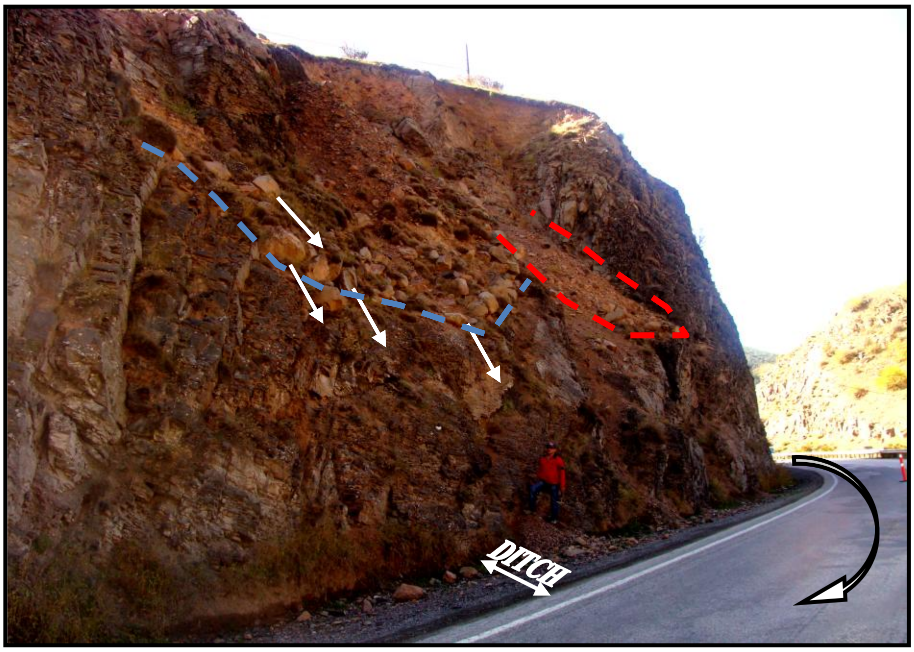


Figure 4.6b. Near-vertical "A" rated rock cut at the beginning of the Azaphane Pass.

4.2. Data Evaluation for Detailed Ratings of "A" Category Slopes in the Study Area

In this section, data regarding the cut slopes defined as "A-class" during the preliminary rating phase and detailed ratings accomplished based on the rules of Tennessee RHRS (2004) are given in detail. In this sense, the data collected for a total of 19 A-slopes are interpreted and photos are given in order to exhibit the features of each cut slope. The data collected from the field through field observations and direct measurements of some parameters and scorings regarding the data are given with tables for each cut slope in the following sections. Also, some of the measurements are illustrated on the figures and important points are emphasized. In order to see the exact locations (GPS coordinates) of each cut slope, which are illustrated in this section, can be seen from the Figure 4.1 in Chapter 4.1.

Detailed numerical ratings of cut slopes are based on some categories, or attributes which were defined at two stages: 1) Site and Roadway Geometry, 2) Geologic Characterization. Site and Roadway Geometry is the first stage of detailed ratings. The detailed information about the parameters regarding this stage and how to identify them based on the Tennessee RHRS was given in the Chapter 3.2. Table 3.2a&b (also, equations) given in Chapter 3.2. should be checked in order to assign values and corresponding parameters.

Some of the parameters like DSD is estimated in the field by site observations considering highway's relationship with the cut slopes. It is interpreted with the figures in the following sections, too. It should also be noted that the AVR assesment requires a continous measurement of daily traffic throughout a year which can only be provided by vehicle counter devices. The data regarding these measurements are provided by the General Directorate of Highways every year. A map showing the annual daily traffic (ADT parameter) results are given in Figure 4.7, in order to exhibit the locations of counter devices which are placed at some points along D750 Highway by Directorate of Fourth Region (Ankara is named as the fourth region by the General Directorate of Highways).

In addition to the site and roadway geometry, two more parameters, rock fall history and water, should also be considered in scoring. Rock fall history is provided for all failure modes by observations throughout the year since there is no available records regarding it. Also, the water parameter is assessed according to climatic conditions, freze-thaw and other mechanisms. The presence of water on slope title in Table 3.2a in the Chapter 3.2 should be checked to see the scorings for this part. The water conditions of the rock faces are decided by the observations which show that the failures generally occur during winter and spring seasons. Considering the site observations, it can be said that the rock faces generally get the seeping scores.

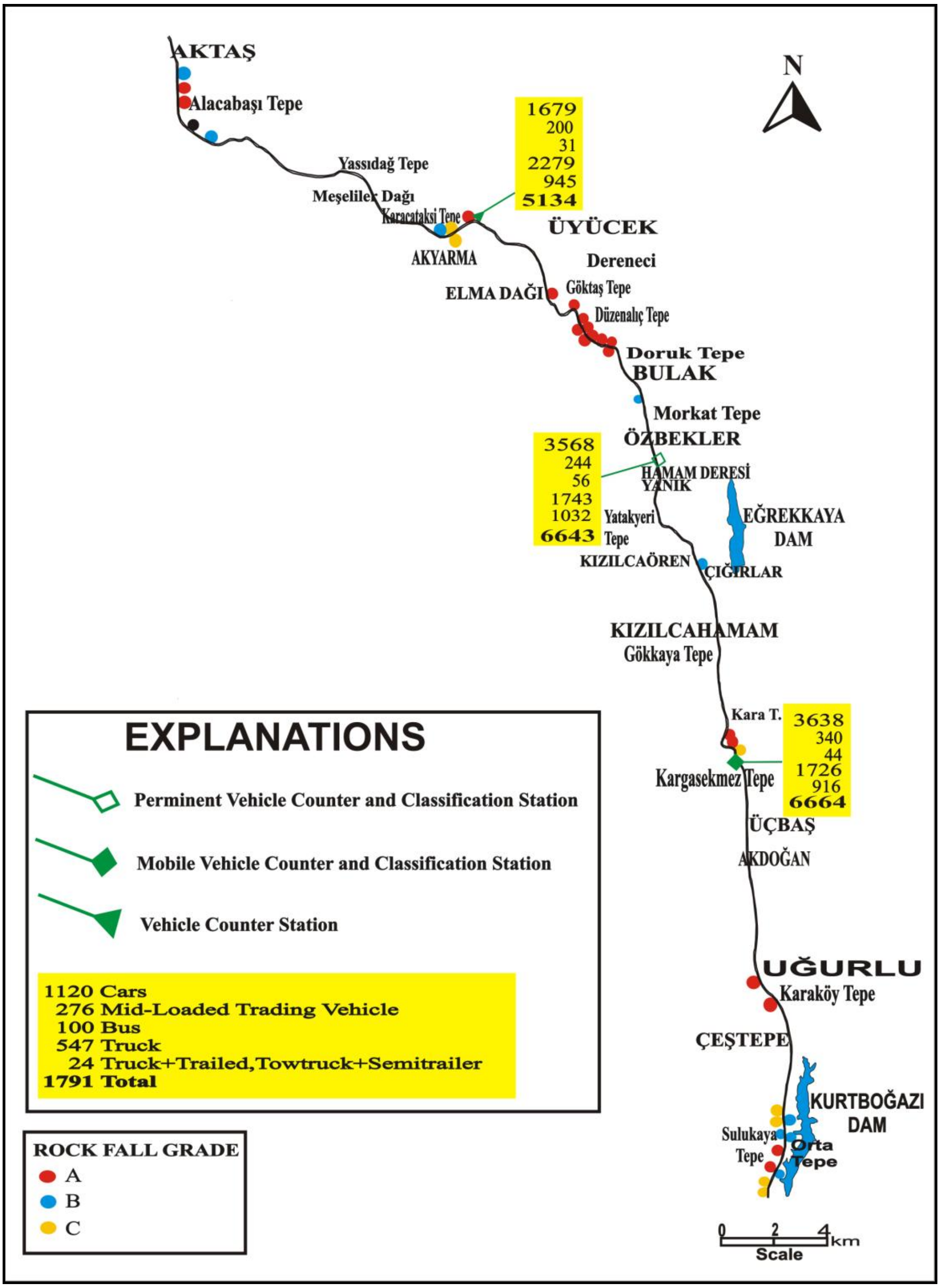


Figure 4.7. The map showing the locations of counter devices and ADT results along the study area.

In geological characterization phase, after deciding the failure mechanism on a slope surface, a geologic failure mode abundance assessment is accomplished.

Example pictures of rock faces with potential failure modes and estimated abundance of each identified mode are given in the following sections. Abundance in the Tennessee RHRS is defined as the aerial extent of a slope face that exhibits a given failure mode (planar, wedge, topple, differential weathering, and raveling) expressed as a percent of the total area (Cain, 2004). It is visually estimated and decided by using the slope lengths accordingly. So, the abundances for any failure mode are obtained as the percantage of the area which is covered by the existing failure mode. The results for the abundance scorings can be seen in tables in the following sections. Also, the length of the rock cuts captured in following figures are assumed to be the total length of the cut. The figures generally represent a portion of the longer cut slopes but the abundance scores given in tables are accomplished by considering the entire rock cut.

Each identified failure mode is indicated with dashed lines and labeled accordingly using the following abbreviations: P = Planar, W = Wedge, T = Topple, DW = Differential Weathering, R = Raveling. The abundance scorings and also parameters which are used for each failure mode are given in Tables 3.2a&b and 3.4. Abundance percentages which are carried out in the first step of geologic characterization are called additive abundance and they are scored using an additive exponential score the same as other contributors to hazard such as steepness or slope height. According to Tennessee RHRS using an additive abundance has potential to inflate the hazard rating of slopes that have a high abundance of low consequence failure mechanisms. To prevent this situations it was found helpful to think in terms of a unit geological hazard, which represents a combination of stability, block size, and block mobility for a given failure mode. In terms of unit geological hazard, it is possible to consider two ways of scoring abundance:

Additive Score: Total Hazard = Unit hazard + Abundance Score

Multiplicative Score: Total Hazard = Unit Hazard * Abundance Score.

By using a multiplicative abundance, the contribution of a given failure mode to the overall hazard is proportional to the hazard of the individual failure mode rather than the score being independent of the rest of the geologic assessment. The multiplicative abundance effectively and retroactively solves the problem associated with inflated scores of low consequence failure mechanisms. The multiplicative abundance also raise the relative hazard of high consequence failure with low abundance. The benefit of using a multiplicative abundance is realized by comparing the RHRS hazard rating of slopes that have approximately the same score when an additive abundance is used. Overall effect of the multiplicative abundance does little to the rating of most slopes, but is realized through a slope to slope comparison.

The use of a multiplicative abundance also makes the more hazardous slope have a much higher relative hazard (Cain, 2004). So, the multiplicative hazard should be applied in order to compare two different slopes. When it is applied, the abundance ratings drop or raise and it helps to realize which one of the compared slopes is more hazardous. Total RHRS scores including multiplicative scorings are given in Appendix A and an example for a slope to slope comparison is given in Appendix B.

a) A1 rated slope: This slope is located at KM:1.0 from the starting point designated as KM: 0 point (C1 in Figure 4.1). The slope is on the left side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figures 4.8 to 4.10.

Figure 4.8a. "A1" rated slope near the Kurtboğazı Dam, showing the slope length and road width measurements. Note that the DSD is high due to the linear alignment of the road. Looking NW.

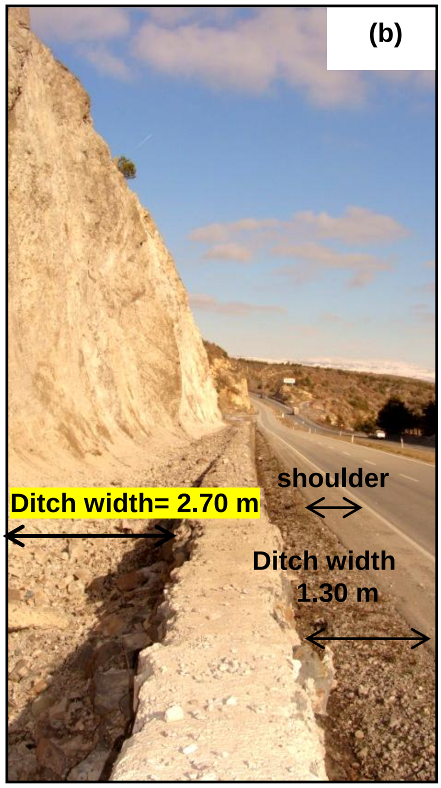


Figure 4.8b. A side view showing the ditch design of the A1 rated slope. For the ditch effectiveness, the width of the catchment on and bottom of the wall is considered. Note that the photo is taken from the top of the wall in front of the cut slope. Looking NW.

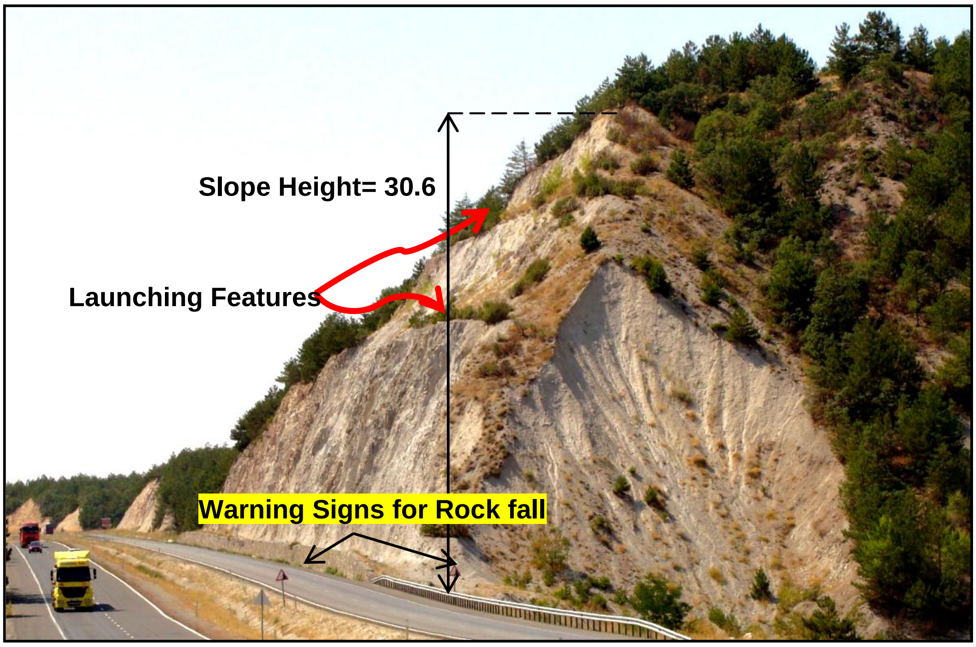


Figure 4.9. A view showing the launching features and warning signs for rock fall. Looking South.

The scoring results for the site and roadway geometry and other scoring criteria (rock fall history and water) and estimated abundances with scorings regarding the failure modes identified in the "A1" rated slope are given in Table 4.1 and 4.2. For each cut slopes, the similar scoring tables are given below or above the related figures.

Table 4.1. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A1" rated slope. (See Chapter 3.2, Table 3.2a&b and Eq.3.1 and 3.2. for scorings.)

Site and Roadway Geometry	**Data Collected**	**Score**	**Site and Roadway Geometry and Other Scoring Criteria**	**Data Collected**	**Score**
SlopeHeight (m)	30.6	81	Ditch Effectiveness	< 50	81
% AVR	82	37	Rock fall History	Several	9
DSD	Adequate	3	Water	Seeping	9
Road Width (m)	4.40	100		**TOTAL**	**320**

Table 4.2. Estimated abundance (additive) scorings for the failure modes which are identified in the "A1" rated slope. (See Chapter 3.2, Geologic Characteristics part in Table 3.2a for the abundance scorings).

Failure Mode	**Abundance (%)**	**Score**
Planar Failure	≈40% (>30%)	81
Toppling	≈6% (<10%)	5
Raveling	≈55%(>30%)	81

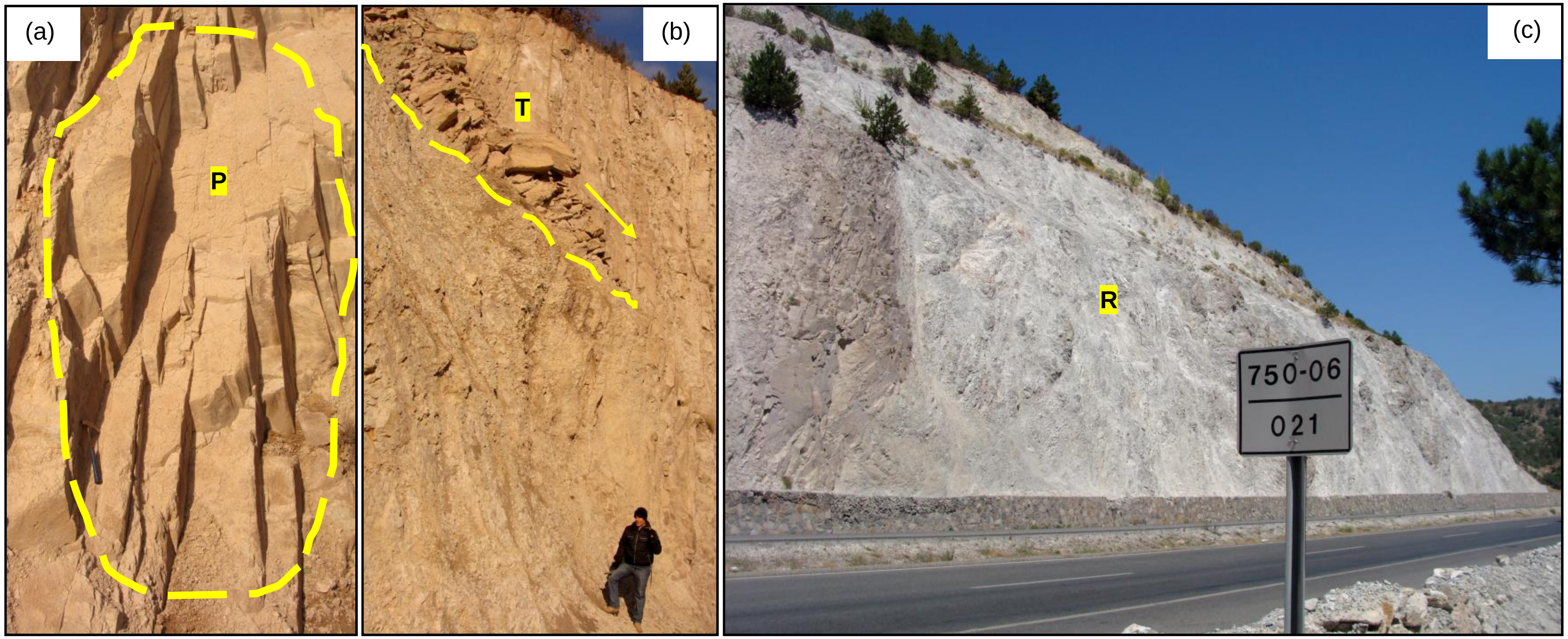


Figure 4.10. Close-up views of the failure modes identified in the “A1” rated slope. This rock cut exhibits characteristics of planar failure, toppling and raveling. **a)** A view of the planar failure from a portion of the rockcut. For the length of cut shown in Figure 4.8a., approximately 40% of the rock face has the potential to fail by planar failure, which correlates to the abundance score of 81.**b)** The rock slabs over the dotted line show potential to fail and rotate forward onto the road (toppling). **c)** Rock face shows highly weathered surface and evidence of gradual shedding of loose small rock blocks. The most important mechanism in this portion of the rock cut is detachment of rock blocks by a continuous bouncing movement and reaching onto the roadway (note that the launching features also promote the bouncing).

b) A2 rated slope: This slope is located at KM:1.6, on the left side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figures 4.11 to 4.14.

Figure 4.11. A view of a portion of the longer rock cut which shows some of the site and roadway geometry parameters. Looking NW. The following figures can also be checked to have an idea about the measurements of the parameters listed in Table 4.3.

Table 4.3. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A2" rated slope.

Slope Height(m)	19	Score: 16	Road Width (m)	4.70	Score: 100	Water	None	Score: 3
% AVR	74	Score: 26	Ditch Effectiveness	< 50	Score: 81			
DSD	Adequate	Score: 3	Rock fall History	Several	Score: 9		TOTAL	SCORE: **238**

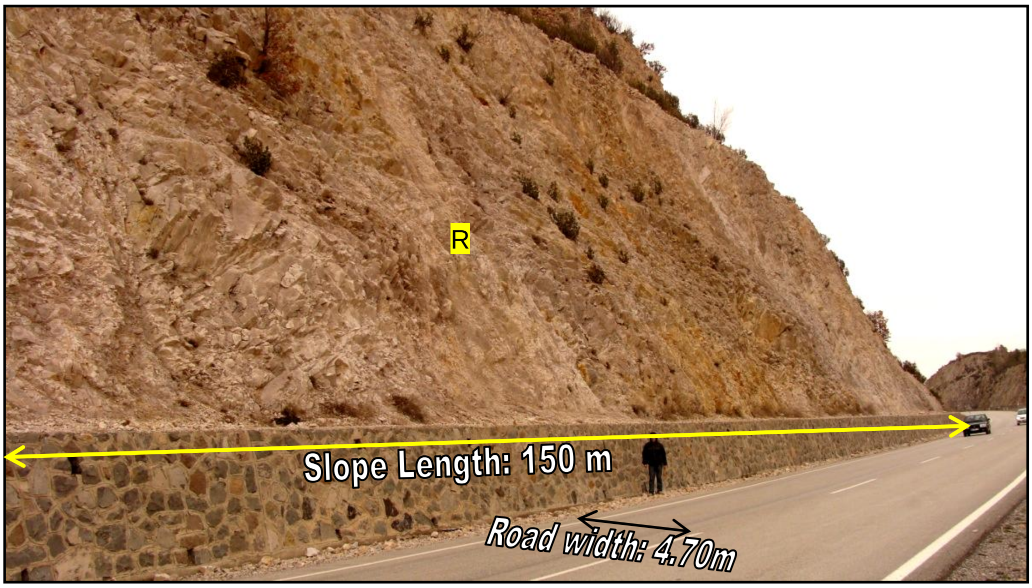


Figure 4.12. A view showing the rest of the cut slope, including slope length, road width and DSD parameters. Looking NW. (Note that this slope length and the previous one in the Figure 4.11 are added to each other while calculating the AVR. The reason for that is the observation of detached rock blocks in the ditch and on the roadway along this whole length. Also, the coming way of the vehicles in the entrance to the rock cut are placed on a linear alignment which makes the DSD is adequate for the drivers)

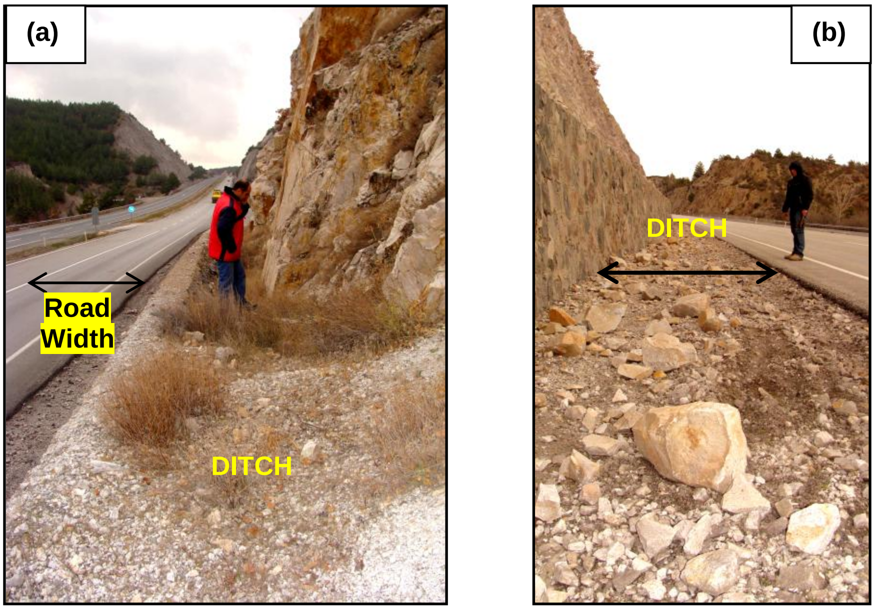


Figure 4.13. The figures showing the road width and ditch features. **a**) The arrow on the highway lane shows that the road width is measured perpendicular to the longitudinal axis of the roadway and it includes all of the paved right-of-way, including the shoulder. Note that the ditch effectiveness is decided also considering the catchment in the narrowest part on the wall. If the ditch is filled with rock blocks, it should be noted that it looses its effectiveness. Looking SE. **b)** A side view showing the ditch design which contains rock blocks. Looking NW.

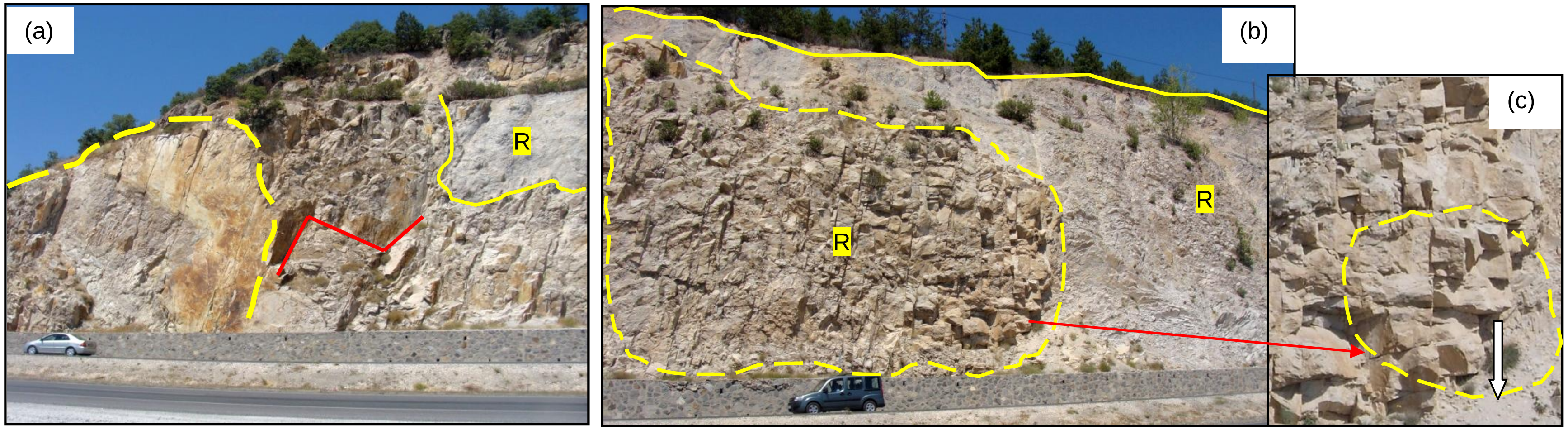


Figure 4.14. Figures showing the failure modes identified in the “A2” rated slope. **a)** Sliding planes below the dashed and red lines are exposed from past rock slides. An example for raveling can also be seen above the yellow line. **b)** The letter “R” shows the rock faces which have no distinct failure mechanisms and promotes shedding of small rock blocks onto the roadway due to weathering. Rock mass enclosed with dashed lines, is bedded with near horizontal layers. The fracture set produces columns of rock susceptible to fail with no distinct failure mechanism. So, the failure mode is considered as raveling. **c)** A close-up view of the rock slabs circled with dotted lines, have potential to fail by block release.

Table 4.4. Abundance scoring results for geologic characterization for the “A2” rated slope.

Failure Mode	Abundance (%)	Score
Raveling	80 (>30%)	81

c) A3 rated slope: This slope is located at kM: 9.0 on the left side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figures 4.15 and 4.16.

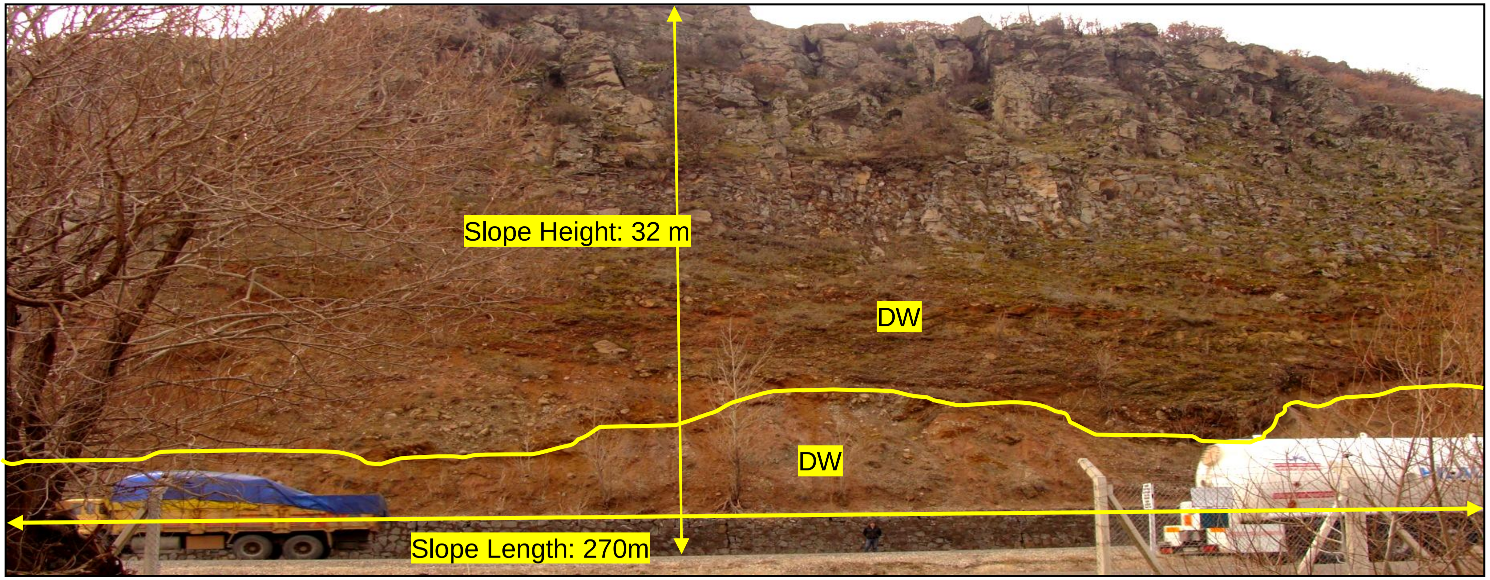


Figure 4.15. The view showing some of the features regarding site and roadway geometry and geologic characteristic of the "A3" rated slope. Looking NW. Note that this rock cut shows two lithologies with the lower unit eroding faster than the upper unit. Length of the rock cut captured in this figure is assumed to be the total length of the cut. An overhang is created along the boundary shown with the yellow line. Note that the boundary continues along the total length. Progression of the differential erosion may lead to loss of support of the more resistant unit above the rock cut.

Table 4.5. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A3" rated slope.

Slope Height(m)	32	Score: 100	Road Width (m)	6.40	Score: 71	Water	Seeping	Score: 9
% AVR	83	Score: 38	Ditch Effectiveness	50-70	Score: 27			
DSD	Adequate	Score: 3	Rock fall History	Several	Score: 9		TOTAL	SCORE: **257**

Figure 4.16. A close-up view to the top of the units of the rock cut. Looking NW. It can be seen that the rock blocks have potential to fail by wedge sliding. The gap which can be seen in the figure has been explained as the consequence of a failure occurred in the previous spring season by the local people.

Table 4.6. Abundance scoring results for geologic characterization for the “A3” rated slope.

Failure Mode	Abundance (%)	Score
Differential Weathering	50 (>30%)	81
Wedge Failure	5 (<10%)	3

d) “A4” rated slope

This slope is located at kM: 9.7, on the left side of the roadway in the direction to Bolu. The features regarding the cut slope’s site and roadway geometry and geologic characteristics are illustrated in Figures 4.17a&b and 4.18a&b.

Table 4.7. Scoring results for the site and roadway geometry factors and other scoring criteria for the “A4” rated slope.

SlopeHeight (m)	23	Score: 28	Ditch Effectiveness	<50	Score: 81
% AVR	37	Score: 5	Rock fall History	Many	Score: 27
DSD	Adequate	Score: 3	Water	Seeping	Score: 9
Road Width (m)	6.10	Score: 81		**TOTAL**	Score: **228**

Table 4.8. Abundance scoring results for geologic characterization for the “A4” rated slope.

Failure Mode	Abundance (%)	Score
Raveling	95 (>30%)	81
Toppling	5 (<10%)	5

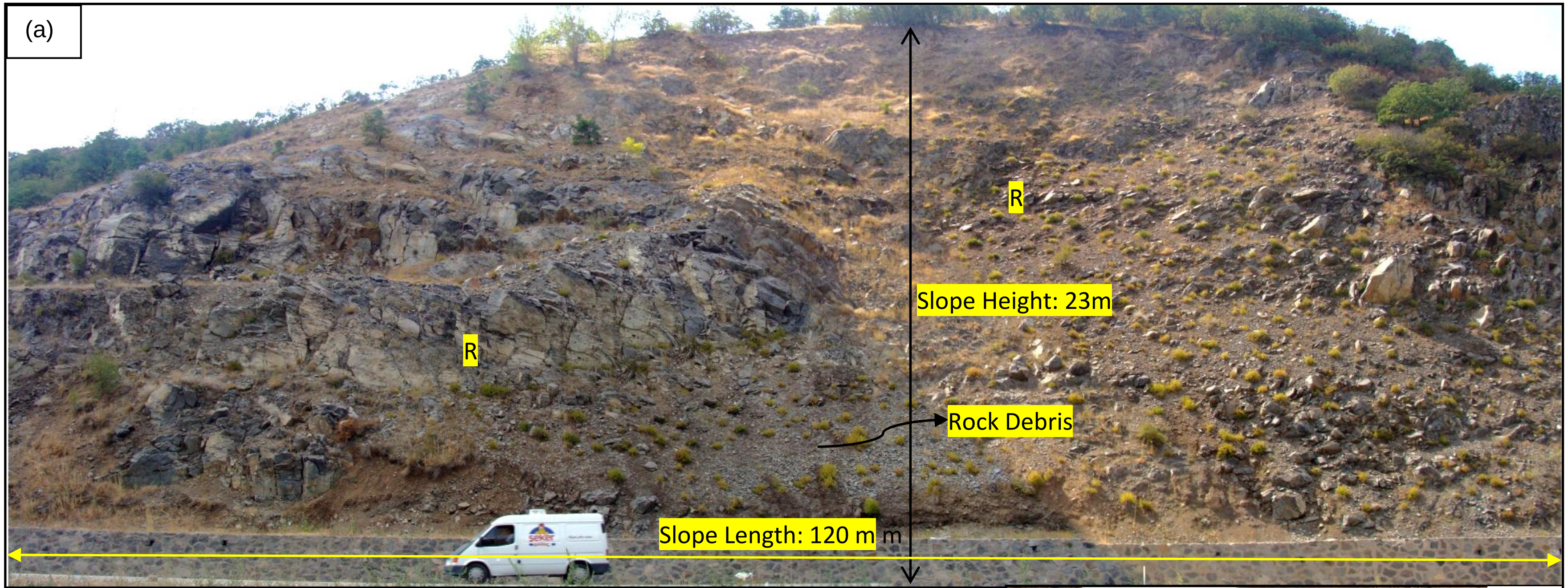


Figure 4.17. The figures showing the features regarding the site and roadway geometry and geologic characteristics of the “A4” rated slope. **a)** Almost the entire rock cut exhibits potential for raveling. Shedding of rock blocks due to the erosion and non-specific failure mechanisms can be seen and accumulation of rock debris at the bottom parts of the slope also presents the characteristics for raveling. As in the other examples, the slope length captured in the figure is assumed as the total length of the cut slope (includes the following figures’ length). Looking W. **b)** The ditch on the wall along this part of the cut seems insufficient since the rock blocks are observed in the ditch below the wall. Few tracking marks of the vehicles which is considered as a sign of the cleaning the roadway from the rock blocks and dragging them into the ditch. Looking S.

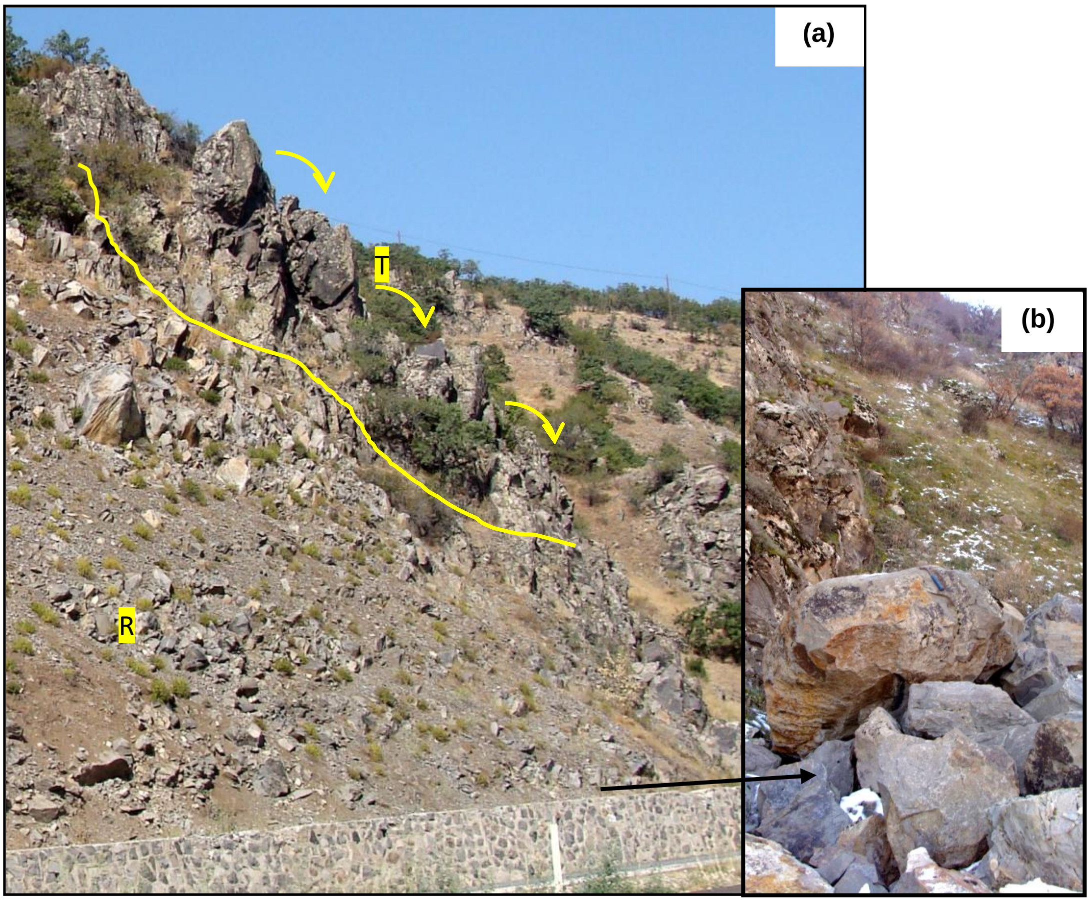


Figure 4.18. The close-up views regarding the ditch and the failure modes identified in the "A4" rated slopes. Looking NW. **a)** The rock mass above the line has wide tension cracks with the boulders which are prone to detached from the rock face by the water pressure effect that may fill these cracks. Although this is not a classic example of toppling, the boulders are considered as susceptible to toppling failure by outward rotation. Note that the height and the inclined surface will let the boulders reach to the roadway. **b)** Condition of the ditch which are filled with the fallen blocks**.**

e) A5 rated slope: This slope is located at kM: 20, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figures 4.19a,b&c.

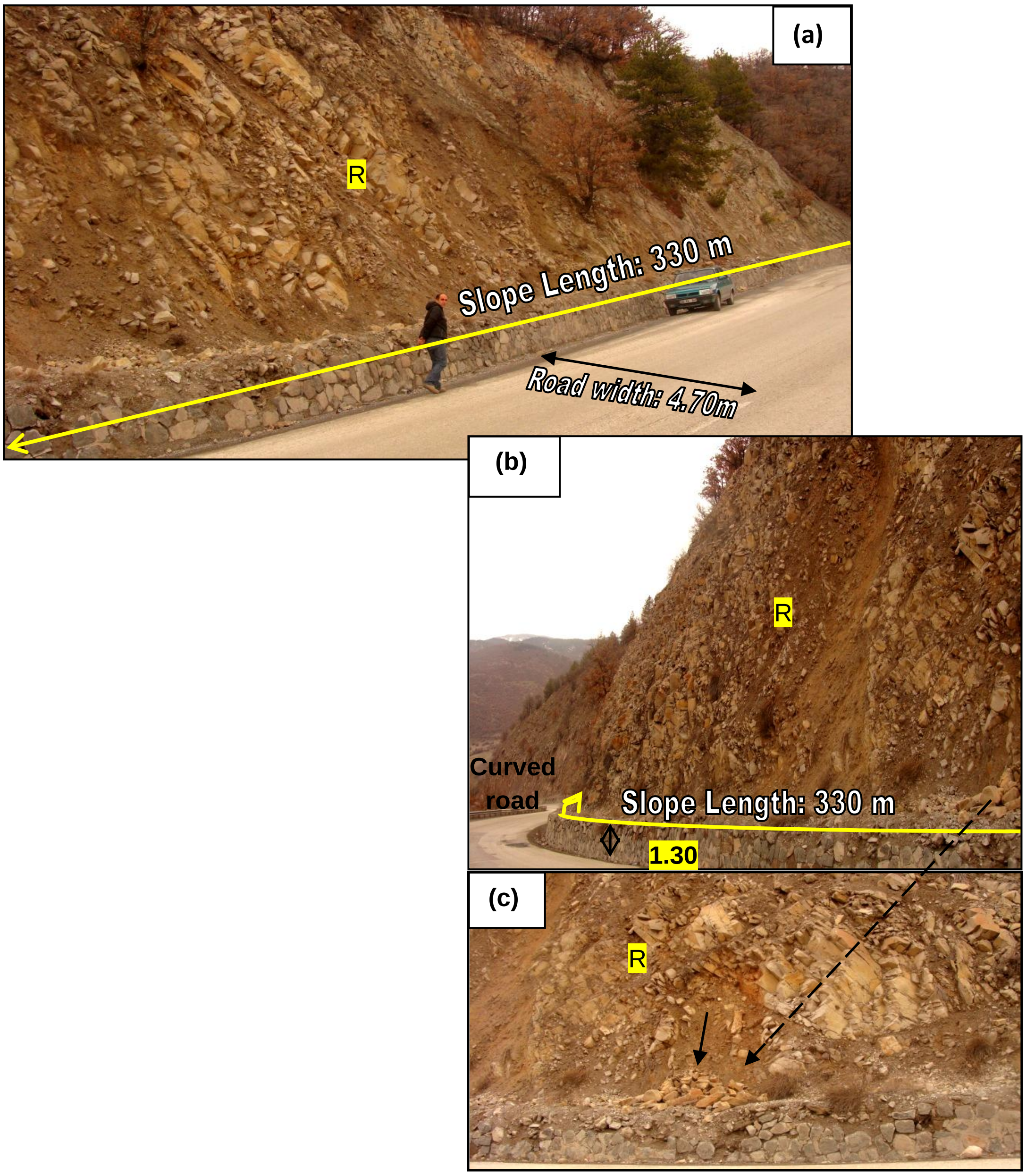


Figure 4.19. The figures showing some features regarding the site and roadway geometry and geologic characteristics of the "A5" rated slope. Looking E. **a)** The slope length is assumed to be the total length of the cut as it can be understood from the figure b showing a part of the rest of the slope. The rockcut has the potential for raveling. **b)** The rest of the slope, which has the same features with the shown parts in the figures, remains behind the curved road and it makes DSD limited. **c)** A close-up view from a part of the Figure (b) showing the rock face with the detached rock blocks from it.

Table 4.9. Scoring results for the site and roadway geometry factors and other scoring criteria for the “A5” rated slope

Slope Height(m)	10	Score: 4	Ditch Effectiveness	<50	Score: 81
% AVR	183	Score: 100	Rock fall History	Many	Score: 27
DSD	Limited	Score: 27	Water	Seeping	Score: 9
Road Width (m)	5.80	Score: 93		TOTAL	Score:**341**

Table 4.10. Abundance scoring results for geologic characterization for the “A5” rated slope.

Failure Mode	Abundance (%)	Score
Raveling	≈90 (>30%)	81

f) “A6” rated slope

This slope is located at kM: 22, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope’s site and roadway geometry and geologic characteristics are illustrated in Figures 4.20a&b and 4.21a&b.

Table 4.11. Scoring results for the site and roadway geometry factors and other scoring criteria for the “A6” rated slope.

Slope Height(m)	12.2	Score: 6	Ditch Effectiveness	<50	Score: 81
% AVR	99	Score: 78	Rock fall History	Constant	Score: 81
DSD	Very Limited	Score: 81	Water	Seeping	Score: 9
Road Width (m)	6.60	Score: 62		TOTAL	Score: 398

Table 4.12. Abundance scoring results for geologic characterization for the “A6” rated slope.

Failure Mode	Abundance (%)	Score
Raveling	≈90 (>30%)	81

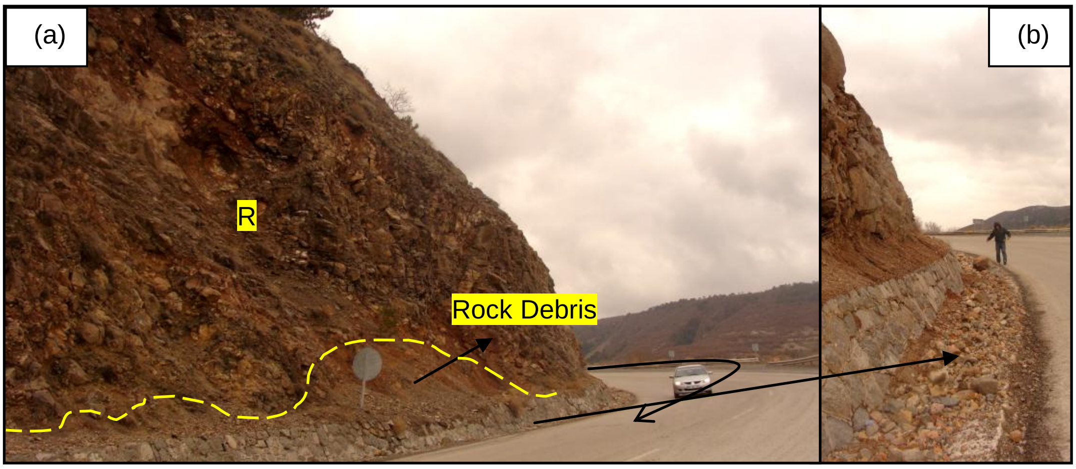


Figure 4.20. The figures showing the views behind a curved road. Looking SW. **a)** The curve shown by the arrow on the road is the reason why DSD is very limited. Under the dashed lines, the rock debris which is produced by shedding of rock blocks detached from the rock face (raveling). **b)** A close-up view to the ditch filled with rock blocks.

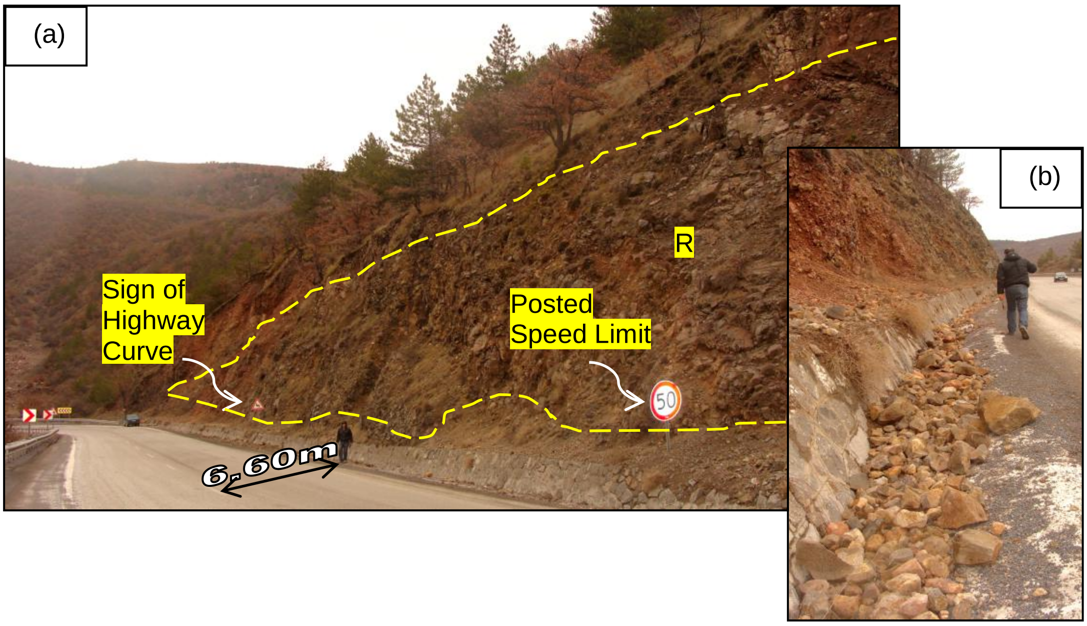


Figure 4.21. The figures showing the views from the rest of the “A6” rated slope. **a)** Almost the entire rock cut has the potential for raveling. The posted speed limit which is used in AVR calculations can be seen with a sign in the figure. Looking NE. **b)** The entire ditch is filled with the products of detached rock blocks from the rock face. The blocks are likely to reach onto the roadway. Looking SW.

g) “A7” rated slope

This slope is located at kM: 40, on the left side of the roadway in the direction to Bolu. The features regarding the cut slope’s site and roadway geometry and geologic characteristics are illustrated in Figure 4.22.

Table 4.13. Scoring results for the site and roadway geometry factors and other scoring criteria for the “A7” rated slope.

Slope Height(m)	13.5 m	Score: 7	Ditch Effectiveness	50-70	Score: 81
% AVR	17	Score: 2	Rock fall History	Few	Score: 3
DSD	Limited	Score: 27	Water	Flowing	Score: 27
Road Width (m)	4.50 m	Score: 100		TOTAL	Score: 247

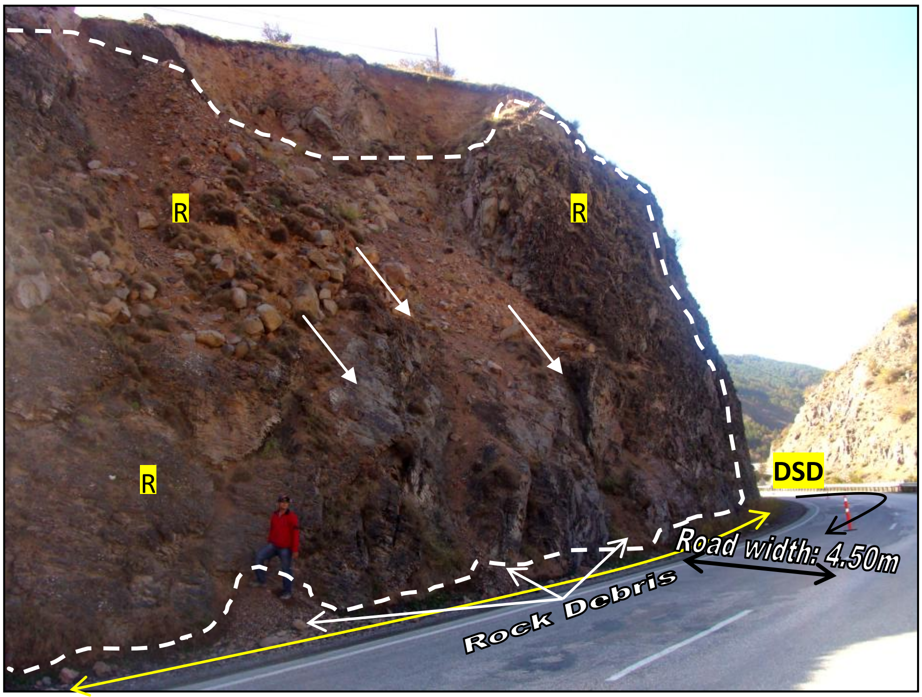


Figure 4.22. The figure showing the features of the “A7” rated slope. The rock face outlined with white dashed line shows potential for further loosening of small blocks due to weathering. Shedding of small rock blocks are shown in the figure (rock debris). Accumulation of rock blocks on the slope face which might have been produced by past failures shows that they are prone to reach to the roadway following heavy rainfall. The curve in the entrance of the cut slope shown with the black arrow makes DSD limited and the insufficient road width makes the cut slope risky for the drivers. Slope length is measured for the failed portion as shown with the yellow arrow. Looking W.

Table 4.14. Abundance scoring results for geologic characterization for the "A7" rated slope.

Failure Mode	Abundance (%)	Score
Raveling	≈90 (>30%)	81

h) "A8" rated slope

This slope is located at kM: 40.2, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.23a,b&c.

Table 4.15. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A8" rated slope.

Slope Height(m)	31.5	Score: 95	Ditch Effectiveness	<50	Score: 81
% AVR	40	Score: 6	Rock fall History	Many	Score: 27
DSD	Moderate	Score: 9	Water	Flowing	Score: 27
Road Width (m)	5.90 m	Score: 89		TOTAL	Score: 334

Table 4.16. Abundance scoring results for geologic characterization for the "A8" rated slope.

Failure Mode	Abundance (%)	Score
Planar Failure	≈90 (>30%)	81

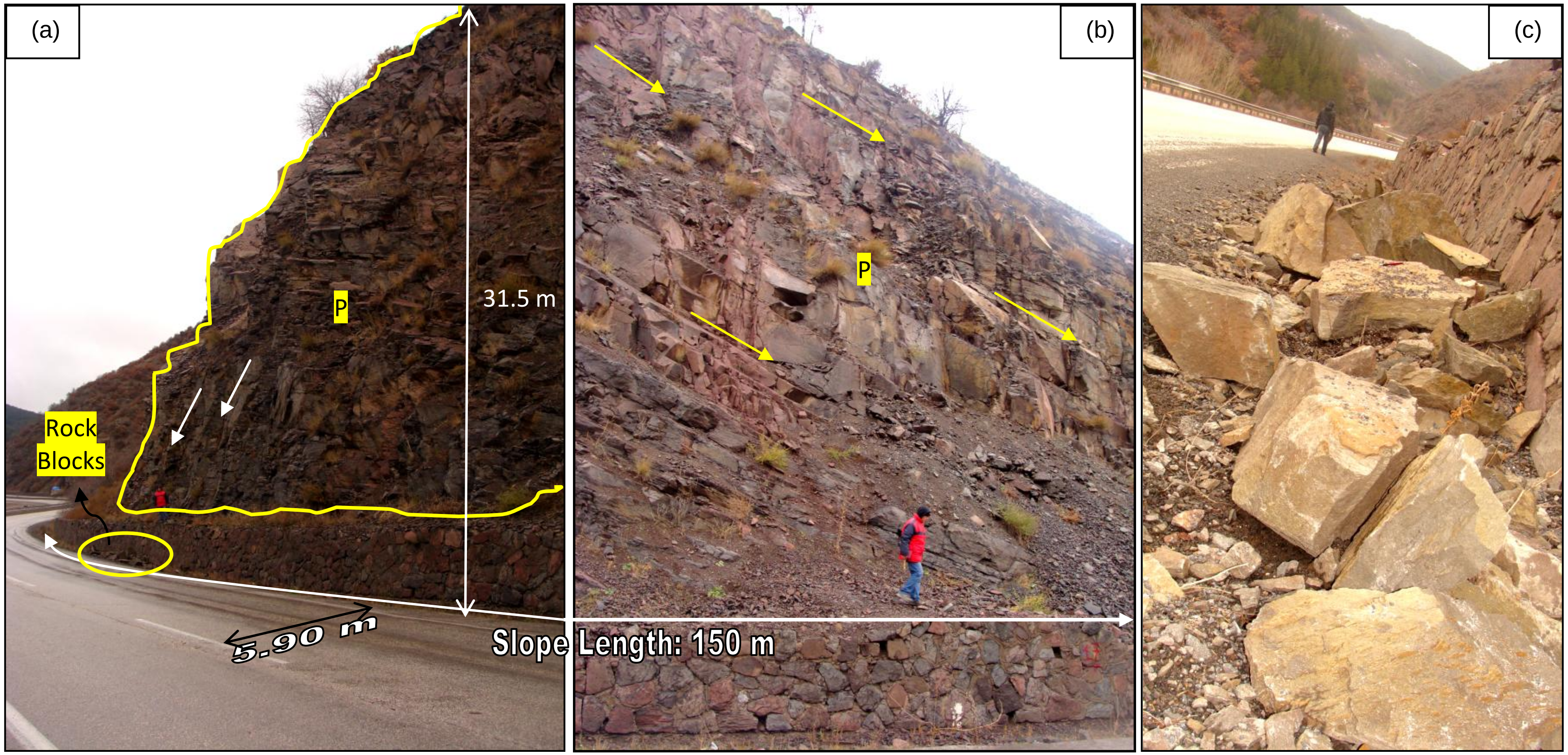


Figure 4.23. The figures showing the views from the rest of the "A8" rated slope. **a)** The bedrock is highly fractured basalt and consists of parallel sliding planes. The rock blocks have potential to slide along these planes by planar sliding onto the roadway. Slope height and road width can also be seen. Slope length is assumed to be the total length of the slope and note that the figures (a-b) don't show the whole slope view (looking NW). **b)** A view from the slope creating the zone of accumulation by planar failure (looking NE). **c)** A close-up view of the rock blocks in the ditch which are shown with yellow circle in (a). The catchment on the wall seems insufficient from the point of catching the rock blocks fallen from the slope face since it's so narrow along the whole slope (looking W).

i) "A9" rated slope

This slope is located at kM: 40.4, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.24.

Table 4.17. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A9" rated slope.

Slope Height(m)	12.5m	Score: 6	Ditch Effectiveness	50-70	Score: 81
% AVR	50	Score: 9	Rock fall History	Few	Score: 3
DSD	Adequate	Score: 3	Water	Seeping	Score: 9
Road Width (m)	5.90 m	Score: 89		TOTAL	Score: **200**

Figure 4.24. The figure showing the raveling mechanism in the "A9" rated slope Looking SE.

Table 4.18. Abundance scoring results for geologic characterization for the "A9" rated slope.

Failure Mode	**Abundance (%)**	**Score**
Raveling	≈100 (>30%)	81

j) "A10" rated slope

This slope is located at kM: 40.6, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figures 4.25 and 4.26.

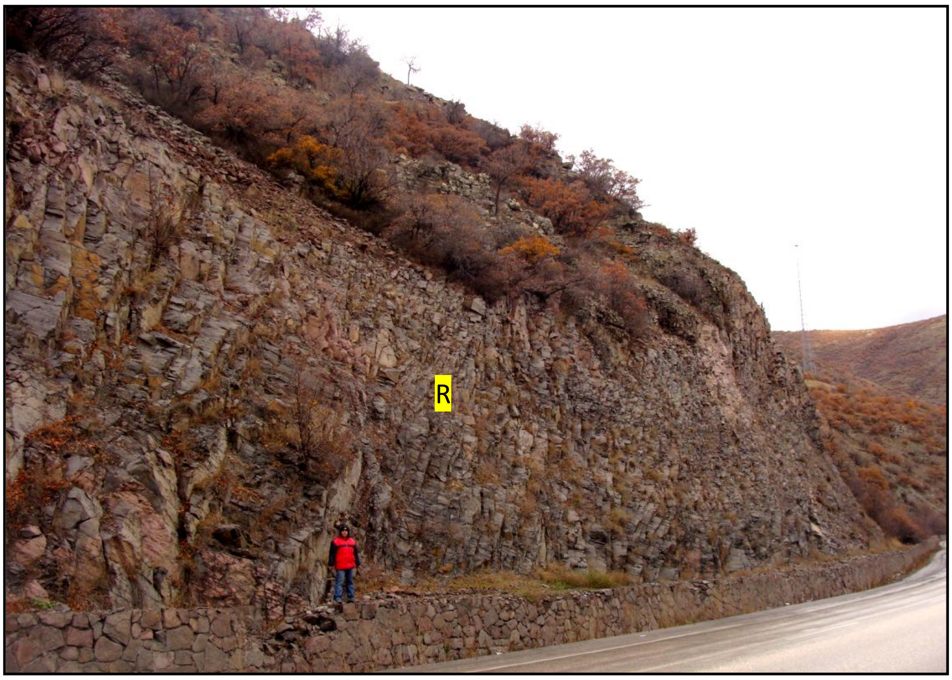


Figure 4.25. The figure showing an example for raveling and topple failure. Llooking SE.

Table 4.19. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A10" rated slope.

Site and Roadway Geometry	Data Collected	Score
Slope Height	14.7	8
% AVR	66	18
DSD	Adequate	3
Road Width	6.40	71
Ditch Effectiveness	<50	81
Rock fall History	Several	9
Water	Seeping	9
TOTAL		**199**

Figure 4.26. A view from the widest part of the catchment on the wall. It is filled with the rock blocks and the rest of the catchment is much more narrower than this part. The ditch down the wall is also insufficient and the wall is deformed in some places along the cut. Looking NW.

Table 4.20. Abundance scoring results for geologic characterization for the "A10" rated slope.

Failure Mode	Abundance (%)	Score
Raveling	≈70 (>30%)	81

k) "A11" rated slope

This slope is located at kM: 41.2, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.27.

Table 4.21. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A11" rated slope.

Slope Height(m)	9.5	Score: 4	Ditch Effectiveness	50-70	Score: 81
% AVR	30	Score: 4	Rock fall History	Few	Score: 3
DSD	Adequate	Score: 3	Water	Seeping	Score: 9
Road Width (m)	5.05m	Score: 100		TOTAL	Score: 204

Figure 4.27. The figure shows the features of the rock face of the “A11” rated slope. Looking NE. It can be seen that the rock face under the dashed line is prone to raveling. The rock blocks at the crown part of the slope are prone to reach the roadway following heavy rainfall. The ditch is so narrow that it is hard to catch the rock blocks that may fall from the crown part.

Table 4.22. Abundance scoring results for geologic characterization for the “A11” rated slope.

Failure Mode	Abundance (%)	Score
Raveling Failure	≈80 (>30%)	81

l) A12 rated slope: This slope is located at kM: 41.2, on the left side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.28.

Figure 4.28. The figure showing the cut slope ("A12" rated slope") which is opposite the A11 rated slope. Looking SW. The similar features are observed in this slope, too. The warning sign for rock fall is another indicator that these rock slopes may present hazard to the driving public. Note that the wall in front of the slope is demolished in some places.

Table 4.23. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A12" rated slope.

Slope Height (m)	12	Score: **6**	Road Width (m)	4.30	Score: **100**	Water	Seeping	Score: **9**
%AVR	65	Score: **17**	Ditch Effectiveness	50-70	Score: **81**			
DSD	Moderate	Score: **9**	Rock fall History	Several	Score: **9**		TOTAL	SCORE: **231**

Table 4.24. Abundance scoring results for geologic characterization for the “A12” rated slope.

Failure Mode	Abundance (%)	Score
Raveling Failure	≈60 (>30%)	81

m) “A13” rated slope

This slope is located at kM: 41.4, on the left side of the roadway in the direction to Bolu. The features regarding the cut slope’s site and roadway geometry and geologic characteristics are illustrated in Figures 4.29a&b and 4.30a&b.

Table 4.25. Scoring results for the site and roadway geometry factors and other scoring criteria for the “A13” rated slope.

Slope Height(m)	18.3	Score:	14
%AVR	83	Score:	38
DSD	Adequate	Score:	3
Road Width (m)	3.9	Score:	100
Ditch Effectiveness	<50	Score:	81
Rock fall History	Many	Score:	27
Water	Flowing	Score:	27
	TOTAL	Score:	**290**

Table 4.26. Abundance scoring results for geologic characterization for the “A13” rated slope.

Failure Mode	Abundance (%)	Score
Wedge Failure	20 (10-20%)	9
Differential Weathering	80 (>30%)	81

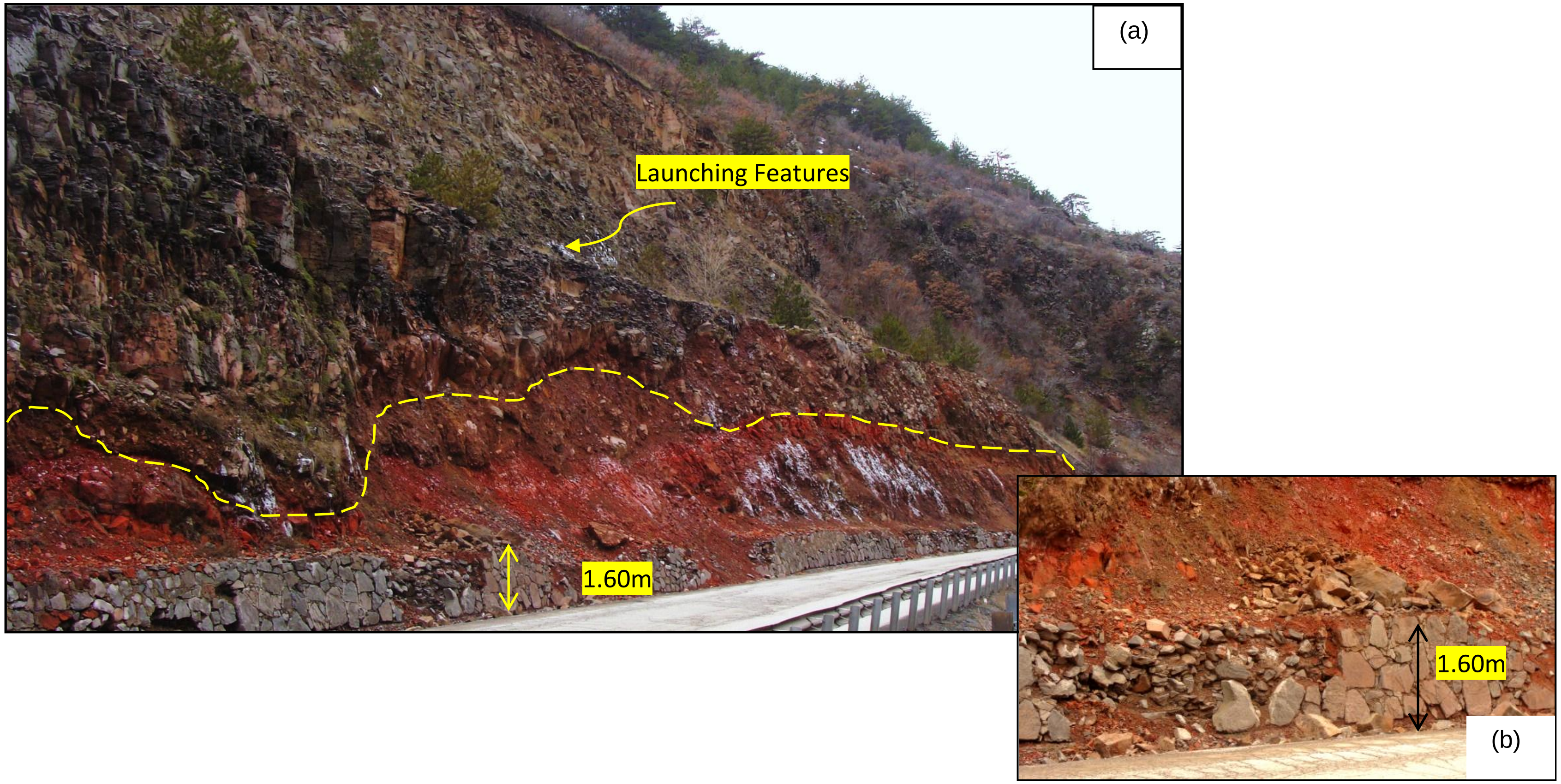


Figure 4.29. The figures showing the features of the “A13” rated slope. Looking NW. **a)** The view showing the differential weathering along the cut slope. The boundary between the units which have different erosion rates is illustrated with the dashed line. **b)** A close-up view to the catchment of the slope which is continuos in the same way along the slope. See the ditch is insufficient to catch the rock blocks and deformation of the wall should be noted.

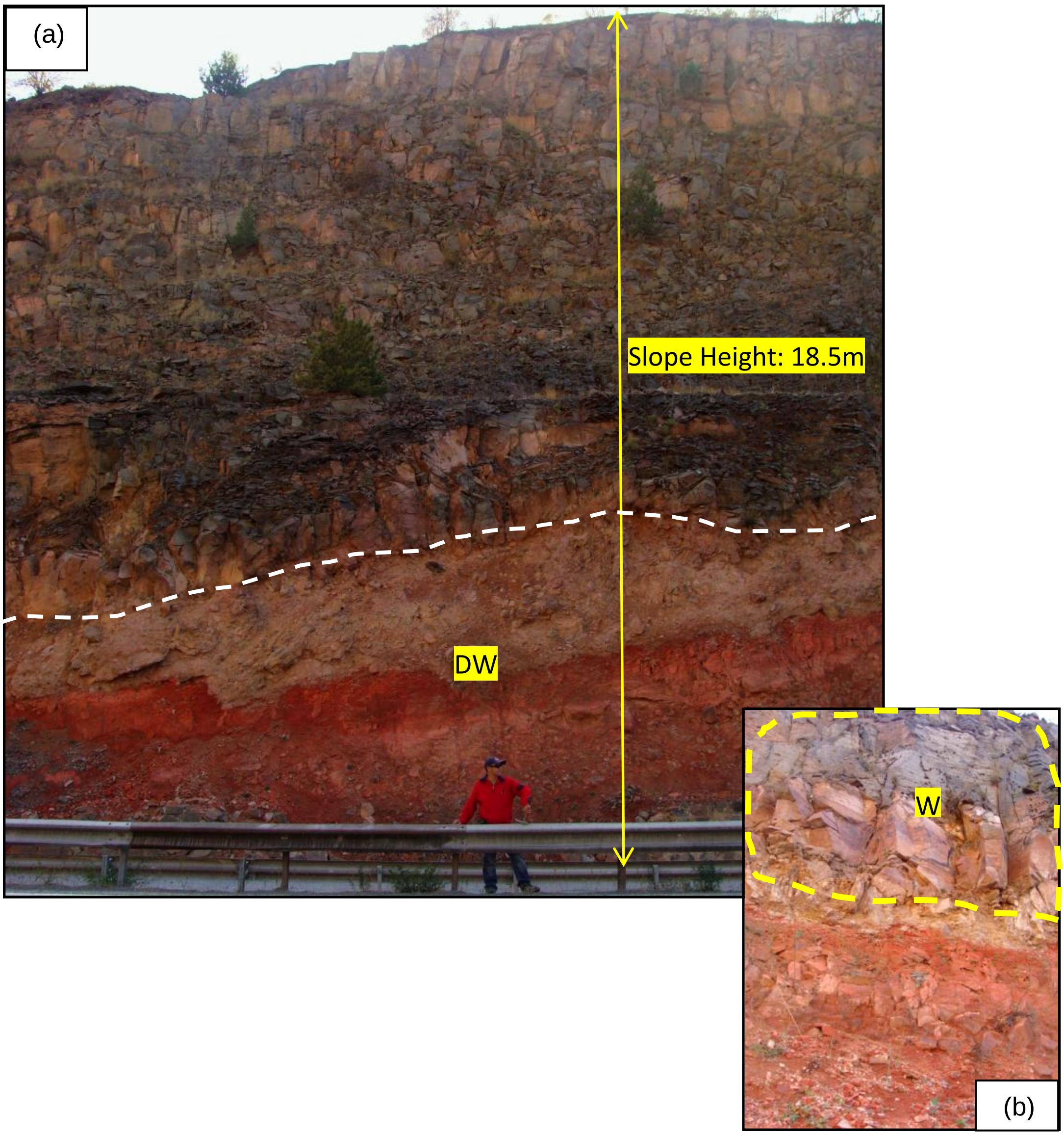
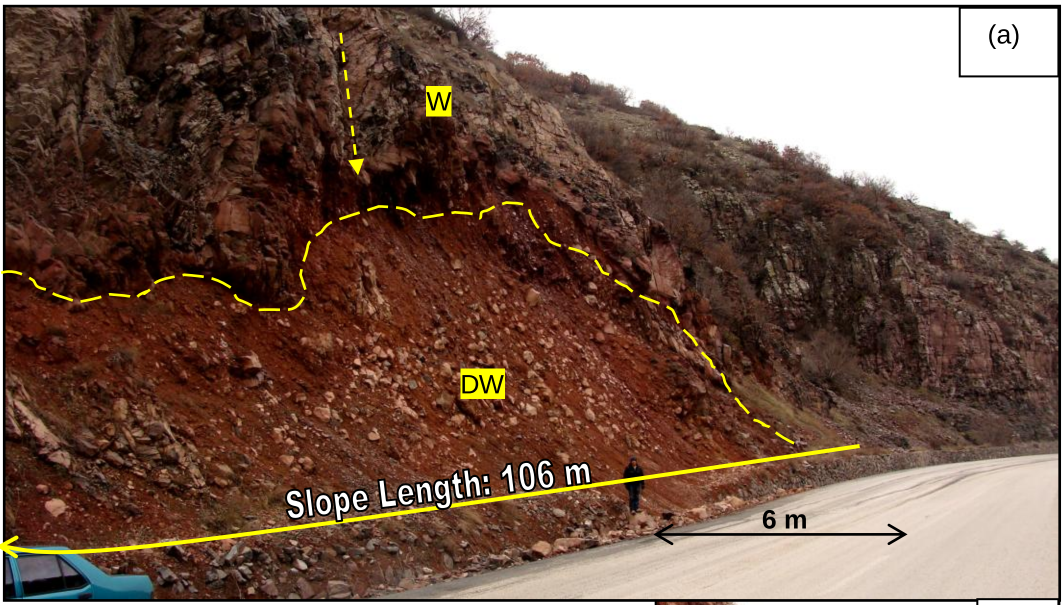


Figure 4.30. The close-up views to the “A13” rated slope. Looking SW. **a)** A close up view to the cut slope. **b)** The close-up view can be counted as a wedge failure example (dashed line). But the important mechanism in this cut slope is considered as differential weathering.

n) “A14” rated slope

This slope is located at kM: 41.8, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope’s site and roadway geometry and geologic characteristics are illustrated in Figure 4.31a&b.



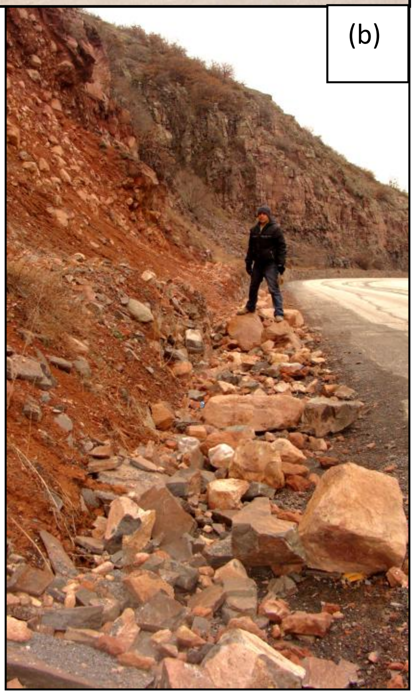


Figure 4.31. The figures showing the features of "A14" rated slope. Looking SE. **a)** Rock slope presents differential weathering and wedge failure. It can be seen that the wall in front of the slope doesn't exist anymore due to the rock blocks' impact fallen from the slope face. An example to the line of intersection which causes wedge failure is shown with the dashed arrow. The boundary for the differential weathering is also shown with the dashed line. Note that the slope length is assumed to be the total length of the cut slope. **b)** The rock blocks in the ditch can be seen along the whole length.

Table 4.27. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A14" rated slope.

Slope Height(m)	18	Score: 13	Ditch Effectiveness	<50	Score: 81
% AVR	59	Score: 13	Rock fall History	Many	Score: 27
DSD	Adequate	Score: 3	Water	Flowing	Score: 27
Road Width (m)	6	Score: 85		TOTAL	Score: 249

Table 4.28. Abundance scoring results for geologic characterization for the “A14” rated slope.

Failure Mode	**Abundance (%)**	**Score**
Wedge Failure	≈30 (20-30%)	27
Differential Weathering	≈70 (>30%)	81

o) “A15” rated slope

This slope is located at kM: 43.3, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope’s site and roadway geometry and geologic characteristics are illustrated in Figures 4.32 and 4.33.

Table 4.29. Scoring results for the site and roadway geometry factors and other scoring criteria for the “A15” rated slope.

Slope Height(m)	10.7	Score: **5**	Ditch Effectiveness	50-70	Score: **27**
% AVR	66	Score: **18**	Rock fall History	Several	Score: **9**
DSD	Adequate	Score: **3**	Water	Seeping	Score: **9**
Road Width (m)	6.10	Score: **81**		TOTAL	Score:**152**

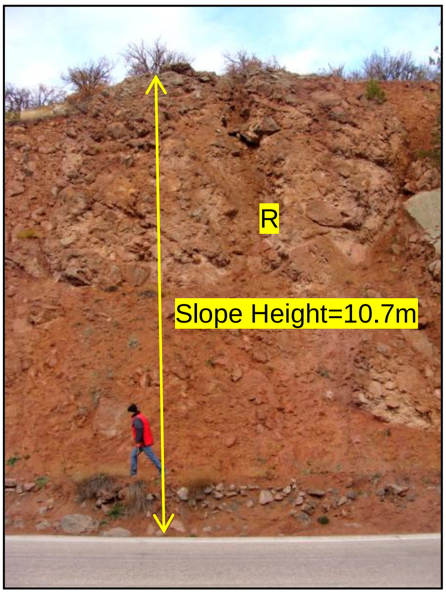


Figure 4.32. A view showing the raveling mechanism in the “A15” rated slope. Looking N. The entire rock face is highly weathered and has potential to shed rock blocks onto the road (ravelling). It can also be seen that the wall is ineffective for this cut slope.

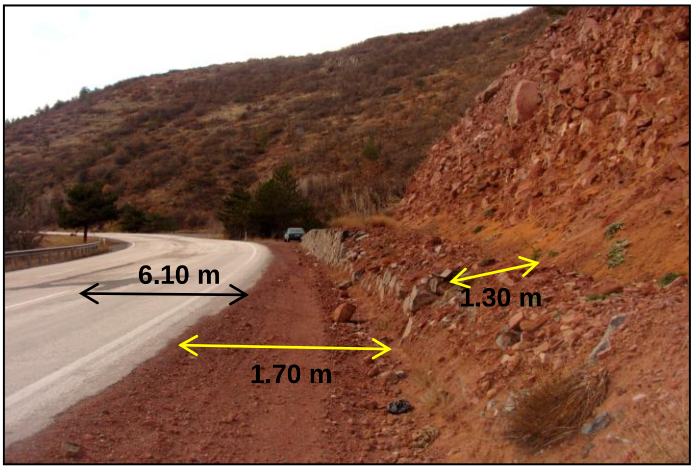


Figure 4.33. The figure regarding the features of ditch and the wall in front of the "A15" rated slope. Looking W. Note that the wall in front of the cut slope is mostly demolished. In case there is a wall as in the other examples and this one, the ditch effectiveness is scored by considering the width of each catchment which is on and down the wall.

Table 4.30. Abundance scoring results for geologic characterization for the "A15" rated slope.

Failure Mode	Abundance (%)	Score
Raveling	≈100 (>30%)	81

p) "A16" rated slope

This slope is located at kM: 45, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.34a&b.

Table 4.31. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A16" rated slope.

Slope Height(m)	10	Score: **4**	Ditch Effectiveness	<50	Score: **81**
% AVR	66	Score: **18**	Rock fall History	Few	Score: **3**
DSD	Moderate	Score: **9**	Water	Seeping	Score: **9**
Road Width (m)	6.10	Score: **81**		TOTAL	Score:**205**

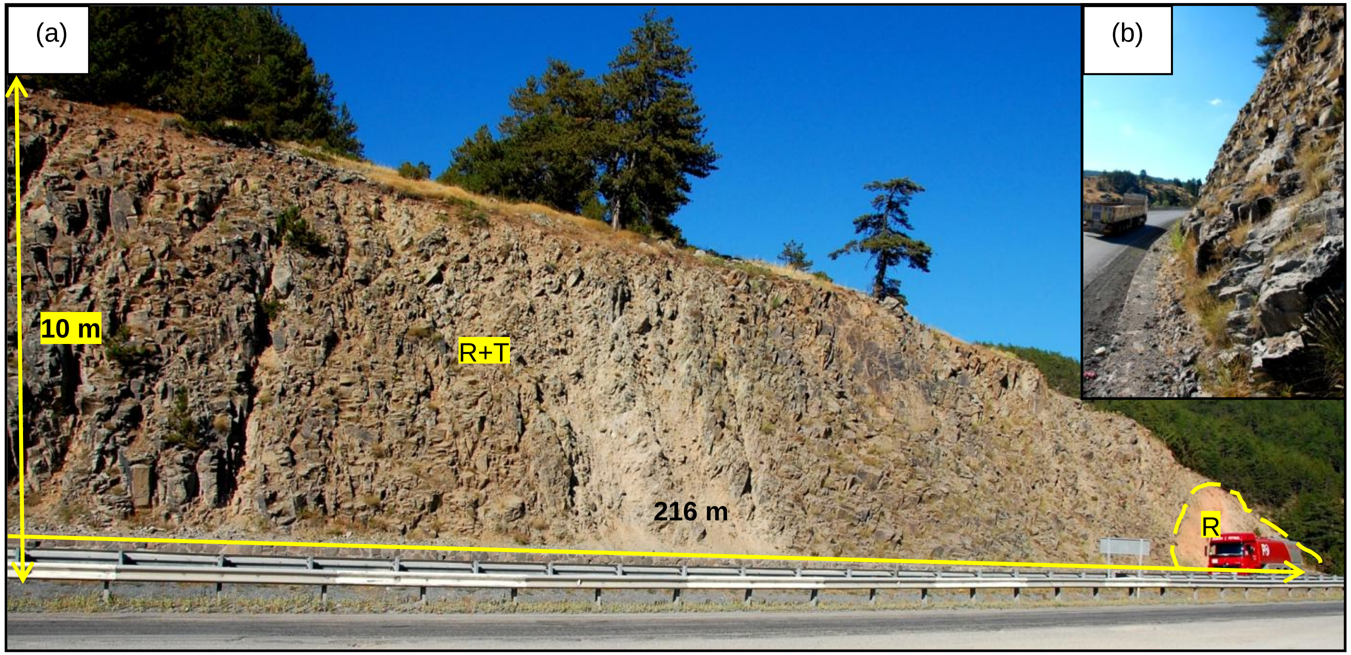


Figure 4.34. The figures regarding the features of the “A16” rated slope. **a)** The rock slope presents raveling and toppling. Assuming that what is shown here is the total length of the rock cut, roughly 40% of the slope has the potential for topple failure. This rockcut should be rated as having the potential for raveling failure with an abundance over 30%, which correlates to the abundance score of 81. Looking NE. **b)** It can be seen that the ditch (especially on the wall) is so narrow for a slope which is nearly steep and higly jointed. Looking NW.

Table 4.32. Abundance scoring results for geologic characterization for the “A16” rated slope.

Failure Mode	Abundance (%)	Score	Failure Mode	Abundance (%)	Score
Toppling	40 (>30%)	81	Raveling	60 (>30%)	81

r) "A17" rated slope

This slope is located at KM: 51.6, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.35a&b.

Table 4.33. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A17" rated slope.

Slope Height (m)	11	Score: **5**	DitchEffectiveness	50-70	Score: **27**
% AVR	19	Score: **2**	Rock fall History	Several	Score: **9**
DSD	Adequate	Score: **3**	Water	Flowing	Score: **27**
Road Width (m)	5.2	Score: **100**		TOTAL	Score: **173**

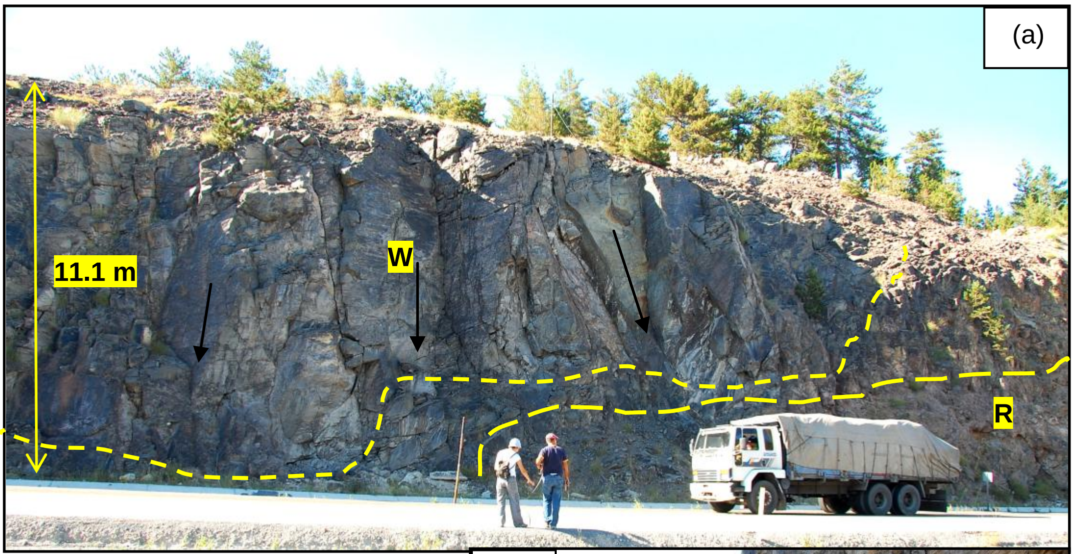


Figure 4.35. The figures regarding the features of the "A17" rated slope. **a)** Rock slope has mostly wedge failure potential and raveling along the highly weathered part of it (below the dashed line). The figure is a part of this longer cut slope just to show the failure examples. Looking N. **b)** The ditch is likely to catch rock blocks in it since it has also a depth. But the width of the ditch seems insufficient at some points along the slope length section.

Table 4.34. Abundance scoring results for geologic characterization for the "A17" rated slope.

Failure Mode	Abundance (%)	Score
Wedge Failure	≈80 (>30%)	81
Raveling	10-20	9

s) "A18" rated slope

This slope is located at kM: 67.7, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.36a&b.

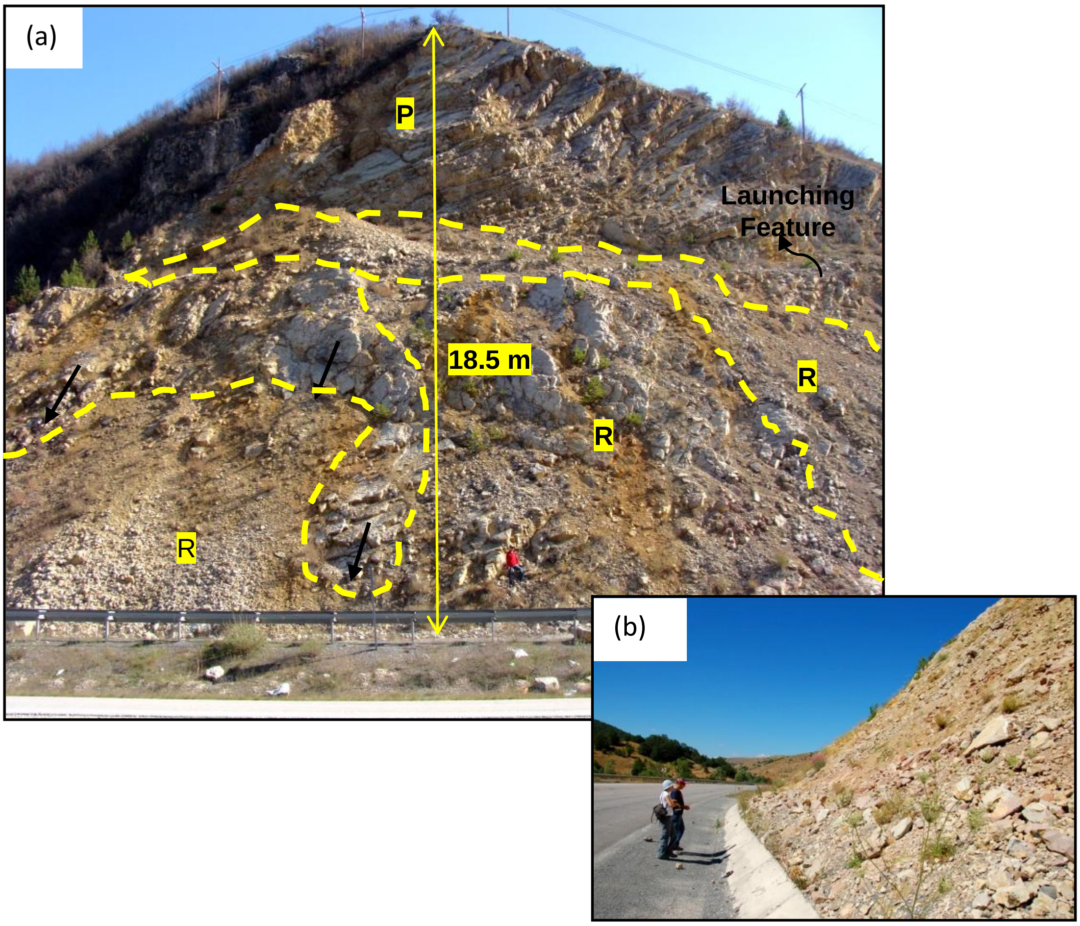


Figure 4.36. The features regarding the "A18" rated slope. **a)** Thin slab of rock blocks (limestone) from crown to the nearly toe of the slope has potential to fail by planar slide in the direction of the arrows. Also, the highly weathered rock face has likely to shed small blocks without any distinct failure mechanism (ravelling). Looking E. **b)** Note that the accumulation in the ditch may let the rock blocks reach onto the road. Looking N.

Table 4.35. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A18" rated slope.

Slope Height (m)	18.5	Score: **15**	DitchEffectiveness	<50	Score: **81**
% AVR	9	Score: **1**	Rock fall History	Few	Score: **3**
DSD	Adequate	Score: **3**	Water	Seeping	Score: **9**
Road Width (m)	3.55	Score: **100**		TOTAL	Score: **209**

Table 4.36. Abundance scoring results for geologic characterization for the "A18" rated slope.

Failure Mode	**Abundance (%)**	**Score**
Planar Failure	≈70 (>30%)	81
Raveling	≈30 (20-30%)	27

t) "A19" rated slope

This slope is located at kM: 70, on the right side of the roadway in the direction to Bolu. The features regarding the cut slope's site and roadway geometry and geologic characteristics are illustrated in Figure 4.37.

Table 4.37. Scoring results for the site and roadway geometry factors and other scoring criteria for the "A19" rated slope.

Slope Height(m)	11.3	Score: **5**	Ditch Effectiveness	> 90	Score: **3**
%AVR	38	Score: **5**	Rock fall History	Several	Score: **9**
DSD	Adequate	Score: **3**	Water	Seeping	Score: **9**
Road Width (m)	3.55	Score: **100**		TOTAL	Score: 134

Table 4.38. Abundance scoring results for geologic characterization for the "A19" rated slope.

Failure Mode	**Abundance (%)**	**Score**
Planar Failure	80 (>30%)	81

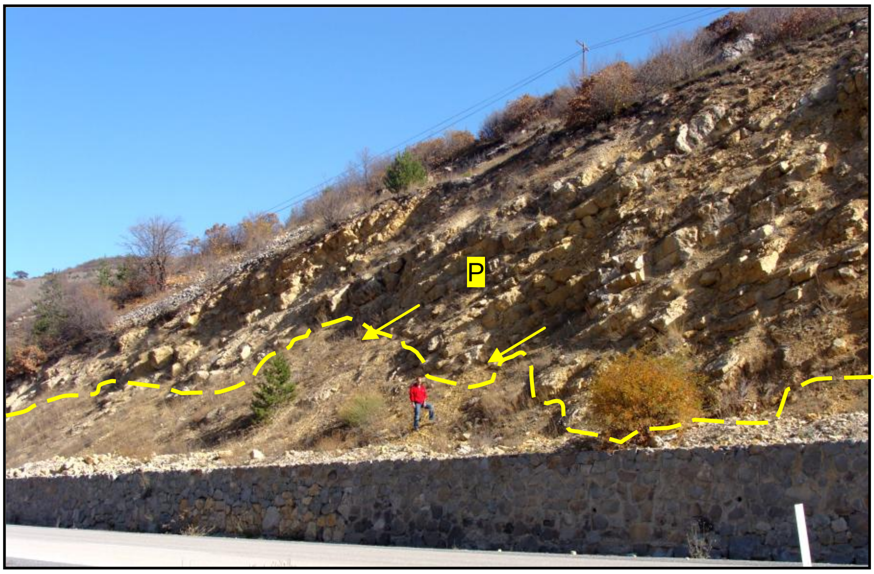


Figure 4.37. The limestone formation (Soğukçam formation, Aktaş region) which presents potential for planar slide in the direction of arrows. Looking NE.

CHAPTER 5

DISCUSSION

Rock fall hazard rating systems have drawn attention of many researchers since it helps to identify rock slopes with greatest potential for rock fall and prioritize remediation efforts, also allocate funds in an efficient and consistent manner for cut slopes along highways which may create a danger for public transportation. Various hazard rating systems have been developed by using an exponential scoring system which helps to rate parameters regarding some characteristics of a cut slope. According to the literature review of this study, it can be seen that new parameters may be added and modified for rock fall hazard rating systems. This study is not a modification of any system but it is an adoption of one of the most important rock fall hazard rating systems (Tennessee RHRS).

In this study, the basic principles of Tennessee RHRS for the study area is focused on and the rules of this RHRS which offers guidance for assessing rock fall hazard, particularly those aspects regarding geologic character of rock slope is followed. The study is accomplished at two stages: Preliminary Rating and Detailed Rating. A slope's preliminary rating is the most subjective part of the system while detailed ratings present numeric scorings which allow the slope to be prioritized according to hazard. If this step is not assessed properly, it can lead to skew some cut slopes which may be hazardous. In such a case, the rating will yield a wrong answer. The proper identification of failure modes after a careful consideration of preliminary rating stage and repeatability of the system make Tennessee RHRS advantageous. For these reason, the personnel or researchers, who may be responsible for applying this rating system along a highway, must be adequately trained to recognize failure mechanisms and to correctly score binned geologic parameters. Although it is important to complete this kind of study with adequately trained personnels, it should be paid attention that the kinematic analysis for some of the failure modes may be necessary to apply. In this sense, the observation results can be supported with analysis results or new parameters can be developed based on more quantitative data which may be obtained by more detailed rock slope stability applications.

The scoring results, which may be obtained from both the Tennessee RHRS and various other systems, show that they don't present a specific range or limitation for the scores. As long as a parameter and a score regarding it is added into a system, the scoring results can also raise. Slope with the highest score is the most hazardous one.

The term "hazard" has various definitions and specific comments in the geotechnical and landslide literature from the last decade. Although it is defined commonly by researchers as a probability that a given event of given size will occur within a fix time interval, just a definition of a potentially dangerous event or condition is considered in this study. So, it can be said that this study is far from defining the exact time of a rock fall event. It can also be seen that the name of the system (Rockfall Hazard Rating System) does not represent its content since it does not include only rock falls. Also, it should be considered, for some cut slopes which have heavily jointed rocks, that the expected rock failure can turn into circular failure and it may be necessary to assess the system in the sense of these kind of possibilities.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In the preliminary rating stage, a total of thirty five cut slopes are rated. Among these slopes, nineteen of them are rated as “A” slopes which are considered to be potentially hazardous, while a total of seven are rated as “C” slopes which pose no danger. In placing a slope into a “B” category, it is considered that they are not as prone as A slopes to create a danger and a total of nine B slopes are detected. The detailed rating is accomplished for these nineteen “A” slopes and as a result of the scorings, it has been seen that the final RHRS scores range from 164 to 591. The slopes with scores over 300 (both additive and multiplicative scores) can be counted as more hazardous slopes since they get very high scores both from site and roadway geometry and geologic hazard part. A total of nine cut slopes (A1, A3, A4, A5, A6, A8, A13, A14 and A17 rated slopes), which have got the highest scores from both additive and multiplicative ratings, can be counted as the most hazardous slopes.

As a general aspect of this study, as the height of slope increased, the RHRS score increased. As the height of slope increases, the mitigation or repear costs increases. It should also be noted that the field features and cut slope designs in Turkey may be different from Tennessee or any other region. So, the parameters, which are defined in various rockfall hazard rating systems according to their regions’ features, can be modified or new parameters can be added in order to produce a rock fall hazard rating system for highways in Turkey, too. In this study, these differences can be seen easily from some points. For instance, the walls in front of the slopes may cause the rock blocks which fall from the rock faces to hit onto them and reach onto the roadway easier. It can also be understood from the deformed walls at some places. In addition to this, the catchments designed on the wall are inadequate for “A” slopes since they generally don’t have an adequate depth and width behind the wall to contain all rock blocks that fall from rock faces. So, they fill the catchments down the wall which also don’t have the ability to contain these rock blocks which may fall continuously during winter and spring seasons. That’s why the ditch effectiveness score gets generally the highest value (81) of the RHRS scoring range. It is strongly recommended that it should be worked on maintanence of walls and ditches, rock fall protection fences or wire mesh installations for each cut slopes by considering the cost of repairing or applying these mitigation measures.

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APPENDIX A

SCORING RESULTS

Table A.1. Scorings of attributes regarding the geologic characterization of each cut slope.

Rated Slopes	Date	County	Road	Km	Planar Failure						
					Block Size	Steepness	Friction	Abundance		Total Score	
								Additive	Multiplicative	Additive	Multiplicative
A1	06/08/2008	Kızılcahamam	D750	1.0	9	14	14	81	1.9	118	70
A2	06/08/2008	Kızılcahamam	D750	1.6	-	-	-	-	-	-	-
A3	04/09/2008	Kızılcahamam	D750	9.0	-	-	-	-	-	-	-
A4	04/09/2008	Kızılcahamam	D750	9.7	-	-	-	-	-	-	-
A5	28/08/2008	Kızılcahamam	D750	21	-	-	-	-	-	-	-
A6	28/08/2008	Kızılcahamam	D750	24.3	-	-	-	-	-	-	-
A7	27/11/2008	Kızılcahamam	D750	40.0	-	-	-	-	-	-	-
A8	27/11/2008	Kızılcahamam	D750	40.2	9	41	14	81	1.9	145	122
A9	27/11/2008	Kızılcahamam	D750	40.4	-	-	-	-	-	-	-
A10	27/11/2008	Kızılcahamam	D750	40.6	-	-	-	-	-	-	-
A11	27/11/2008	Kızılcahamam	D750	41.2	-	-	-	-	-	-	-
A12	27/11/2008	Kızılcahamam	D750	41.2	-	-	-	-	-	-	-
A13	31/01/2009	Kızılcahamam	D750	41.4	-	-	-	-	-	-	-
A14	31/01/2009	Kızılcahamam	D750	41.8	-	-	-	-	-	-	-
A15	31/01/2009	Kızılcahamam	D750	43.3	-	-	-	-	-	-	-
A16	31/01/2009	Kızılcahamam	D750	45.0	-	-	-	-	-	-	-
A17	30/03/2009	Kızılcahamam	D750	51.6	-	-	-	-	-	-	-
A18	30/03/2009	Gerede	D750	67.7	9	5	2	81	1.9	97	30
A19	30/03/2009	Gerede	D750	68.5	9	5	2	81	1.9	97	30

Table 1 continued

Rated Slopes	Wedge Failure							Toppling Failure				
	Block Size	Steepness	Friction	Abundance		Total Score		Block Size	Abundance		Total Score	
				Additive	Multiplicative	Additive	Multiplicative		Additive	Multiplicative	Additive	Multiplicative
A1	-	-	-	-	-	-	-	41	5	1.2	46	49
A2	-	-	-	-	-	-	-	-	-	-	-	-
A3	81	41	2	3	1.15	127	163	-	-	-	-	-
A4	-	-	-	-	-	-	-	122	5	1.2	127	146
A5	-	-	-	-	-	-	-	-	-	-	-	-
A6	-	-	-	-	-	-	-	-	-	-	-	-
A7	-	-	-	-	-	-	-	-	-	-	-	-
A8	-	-	-	-	-	-	-	-	-	-	-	-
A9	-	-	-	-	-	-	-	-	-	-	-	-
A10	-	-	-	-	-	-	-	-	-	-	-	-
A11	-	-	-	-	-	-	-	-	-	-	-	-
A12	-	-	-	-	-	-	-	-	-	-	-	-
A13	9	14	14	9	1.3	46	48	-	-	-	-	-
A14	9	41	2	27	1.6	79	83	-	-	-	-	-
A15	-	-	-	-	-	-	-	-	-	-	-	-
A16	-	-	-	-	-	-	-	14	81	1.9	95	27
A17	27	41	14	81	1.9	163	156	-	-	-	-	-
A18	-	-	-	-	-	-	-	-	-	-	-	-
A19	-	-	-	-	-	-	-	-	-	-	-	-

Table 1 continued

Rated Slopes	Differential Weathering						Raveling					
	Block Size	Relief	Abundance		Total Score		Block Size	Block Shape	Abundance		Total Score	
			Additive	Multiplicative	Additive	Multiplicative			Additive	Multiplicative	Additive	Multiplicative
A1	-	-	-	-	-	-	3	3	81	1.9	87	11
A2	-	-	-	-	-	-	9	3	81	1.9	93	23
A3	81	9	81	1.9	171	171	-	-	-	-	-	-
A4	-	-	-	-	-	-	9	3	81	1.9	93	23
A5	-	-	-	-	-	-	9	9	81	1.9	99	34
A6	-	-	-	-	-	-	9	9	81	1.9	99	34
A7	-	-	-	-	-	-	9	9	81	1.9	99	34
A8	-	-	-	-	-	-	-	-	-	-	-	-
A9	-	-	-	-	-	-	9	9	81	1.9	99	34
A10	-	-	-	-	-	-	9	9	81	1.9	99	34
A11	-	-	-	-	-	-	9	9	81	1.9	99	34
A12	-	-	-	-	-	-	9	9	81	1.9	99	34
A13	9	3	81	1.9	93	23	-	-	-	-	-	-
A14	9	9	81	1.9	99	34	-	-	-	-	-	-
A15	-	-	-	-	-	-	9	9	81	1.9	99	34
A16	-	-	-	-	-	-	3	9	81	1.9	93	23
A17	-	-	-	-	-	-	9	3	9	1.3	21	16
A18	-	-	-	-	-	-	9	3	27	1.6	39	19
A19	-	-	-	-	-	-	-	-	-	-	-	-

Table A.2. Final scores regarding all stages of RHRS (RHRS Total Score)

Rated Slopes	Site & Roadway	RHRS TOTAL SCORE			
		Geologic Hazard		RHRS Hazard	
		Additive	Multiplicative	Additive	Multiplicative
A1	320	251	130	571	450
A2	238	93	23	331	261
A3	257	298	334	555	591
A4	228	220	169	448	397
A5	341	99	34	440	375
A6	398	99	34	497	432
A7	247	99	34	346	281
A8	334	145	122	479	456
A9	200	99	34	299	234
A10	199	99	34	298	233
A11	204	99	34	303	238
A12	231	99	34	330	265
A13	290	139	71	429	361
A14	249	178	117	427	366
A15	152	99	34	251	186
A16	205	188	50	393	255
A17	173	184	172	357	345
A18	209	136	49	345	258
A19	134	97	30	231	164

APPENDIX B

COMPARING ADDITIVE AND MULTIPLICATIVE ABUNDANCE

Comparative Example

Using a multiplicative abundance is emphasized by an example which compares the “A6” and “A7” rated slopes. The figures of these cut slopes are given in Chapter 4.2. Both slope score over 300, regardless of the abundance scoring method. “A6” rated slope has a RHRS rating of 497 with an additive abundance and 432 with the multiplicative, while “A7” rated slope has an additive and multiplicative rating of 346 and 281, respectively. Both slopes presents raveling with a difference which makes one of these slopes more hazardous than the other. “A6” rated slope presents large scale raveling, block size less than 90 cm (3ft) while “A7” rated slope presents small scale raveling, block size less than 40 cm. Also, A6 additive abundance is higher than the other. In case assessing the site and roadway geometry conditions, it can also be clearly seen from the related figures in Chapter 4.2, A6 presents higher risk for transportation as it can also be understood from the score, 398. Both slopes pose a relatively high hazard to the public, but A6 is more hazardous than A7 and the multiplicative abundance makes this point more apparent since it is less in “A7” rated slope.

APPENDIX C

GEOLOGICAL MAP OF THE STUDY AREA

The geological map of the study area is illustrated in Figure C1.

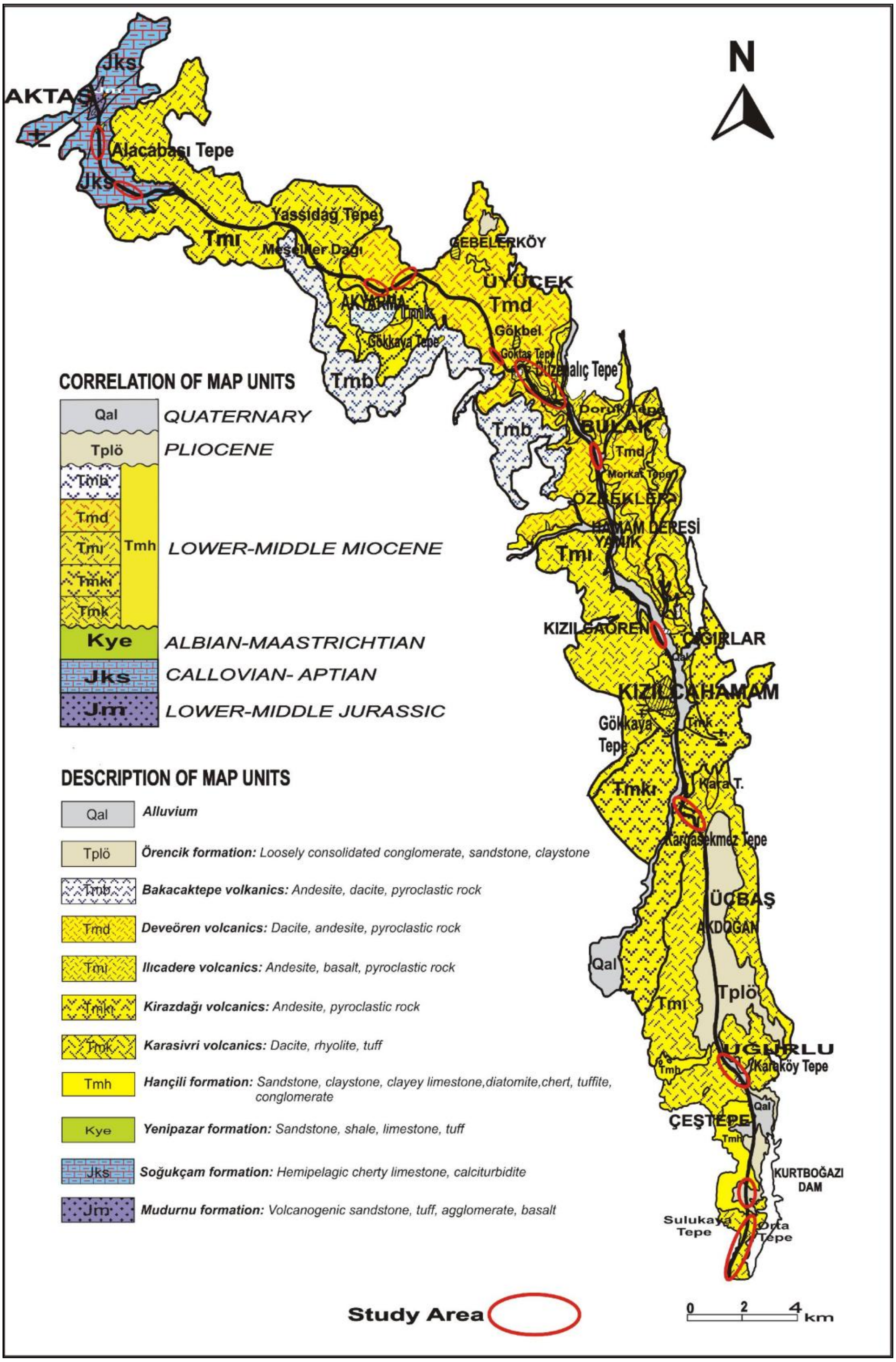

Figure C1. The geological map of the study area along the Kızılcahamam-Gerede segment of D750 Highway (after Sevin and Aksay, 2002; Bilginer, et.al., 2002; Duru and Aksay, 2002).