Geotechnical Asset Management for the Highway Route Between Değirmenlik and Kyrenia, North Cyprus

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ABSTRACT

The highway route between Nicosia and Kyrenia via Değirmenlik is studied in this thesis. This route is vital as it links important facilities such as, Ercan airport in Nicosia and touristic hotels in Kyernia. The serviceability of the highway route relies on the performance of the geotechnical assets along the route, which can be effectively maintained by applying geotechnical asset management. The geotechnical assets along the route are comprised of three types of assets; natural earth slopes, rock slopes and earth retaining walls.

In this thesis, a geotechnical asset management framework is developed to be applied on the selected highway route. Condition appraisals of the selected assets are carried out by collecting data on the geotechnical assets and a database for the selected assets are formed. A risk assessment study is carried out in order to evaluate the effect of failure of the assets on the highway performance. In parallel to these studies, slope stability assessments for the natural earth slopes and retaining wall assets are carried out to evaluate the stability of the assets. Decisions on maintenance and improvement options are made for the selected assets by combining the results from the above studies. Life cycle cost analyses are also carried out to help compare the maintenance and improvement options available for the assets. The proposed methodology for the geotechnical asset management is presented in a flowchart with details of stages to be followed in managing the selected assets along the highway route.

Within the studied geotechnical assets; five of the seven natural earth slopes studied are found to be in need of only minor maintenance, whereas five of the six rockfall sites studied are found to have major maintenance needs. In the assessments for the earth retaining walls, two of the three assets studied are found to be in need of minor maintenance such as slope regrading and wall strengthening.

As a result of all analyses, Time Line Plans and Budgeting Plans are developed for all of the assets for the next thirty years. From these plans, rockfall sites seem to require relatively the most expensive maintenance options to be applied. For all assets, provision of rigid barriers or net fences in the ditch areas are considered to be the most effective solutions to retain the slope materials.

Keywords: Asset management, decision making, life cycle cost, slope stability, condition survey.

ÖZ

Bu tezde, Lefkoşa ile Girne arasında Değirmenlik üzeri güzergahı içeren otoyol çalışılmıştır. Bu güzergah, Lefkoşa'daki Ercan havaalanı ve Girne'deki turistik oteller gibi önemli tesisleri bağladığı için hayati önem taşımaktadır. Otoyol güzergahının kullanılabilirliği, güzergah boyunca jeoteknik varlık yönetimini uygulayarak etkin bir şekilde sürdürülebilen jeoteknik varlıkların performansına dayanır. Güzergah boyunca bulunan jeoteknik varlıklar üç çeşit varlıktan oluşur: Doğal toprak şevleri, kaya şevleri ve toprak istinad duvarları.

Bu tezde, seçilen otoyol güzergahına uygulanacak jeoteknik bir varlık yönetimi çerçevesi geliştirilmiştir. Seçilen varlıkların durum değerlendirmeleri, jeoteknik varlıklarla ilgili veriler toplanarak gerçekleştirilir ve seçilen varlıkların bir veri tabanı oluşturulur. Varlıkların çöküşün otoyol performansı üzerindeki etkisini değerlendirmek için bir risk değerlendirmesi çalışması yapılmıştır. Bu çalışmalara paralel olarak, doğal toprak şevleri ve istinat duvarı varlıkları için şev stabilite değerlendirmeleri varlıkların stabilitesini değerlendirmek için gerçekleştirilmektedir. Yukarıdaki çalışmaların sonuçlarını birleştirerek seçilen varlıklar için bakım ve iyileştirme seçenekleri üzerine kararlar alınır. Yaşam döngüsü maliyet analizi, varlıklarla ilgili mevcut bakım ve iyileştirme seçeneklerinin karşılaştırılmasına yardımcı olmak için de yapılmaktadır. Jeoteknik varlık yönetimi için önerilen metodoloji, otoyol güzergahında seçilen varlıkların yönetiminde takip edilecek aşamaların detaylarını içeren bir akış şemasında sunulmaktadır.

Çalışılan jeoteknik varlıklarda, incelenen yedi doğal toprak şevinden beşinde yalnızca küçük bakıma ihtiyaç duyulduğu görülürken, incelenen altı kaya düşme bölgesinin beşinde önemli bakım ihtiyacı bulunduğu tespit edilmiştir. Toprak istinat duvarları için yapılan değerlendirmelerde, incelenen üç varlıktan ikisinde şev düzeltme ve duvar güçlendirme gibi küçük bakıma ihtiyaç duyulduğu bulunmuştur.

Tüm analizlerin sonucunda, gelecek 30 yıl boyunca tüm varlıkların Zaman Çizelgesi Planları ve Bütçeleme Planları geliştirilmiştir. Bu planlardan, kaya düşme yerleri nispeten en pahalı bakım seçeneklerinin uygulanmasını gerektiriyor gibi görünmektedir. Tüm varlıklar için, hendek alanlarında sert bariyerler veya file çitler sağlanması, şev malzemelerini korumak için en etkili çözümler olarak kabul edilmektedir.

Anahtar Kelimeler: Varlık yönetimi, karar verme, yaşam döngüsü maliyeti, şev stabilitesi, durum incelemesi.

I want to dedicate my research to my parents, who helped me and supported me with all meanings during my study.

To my brothers and sister Osama, Eyad and Alice.

To my lovely fiancée Nour who supported me and motivated me through the research years.

To my friends.

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LIST OF ABBREVIATIONS

CDOT	Colorado Department of Transportation
US	United States of America
RHRS	Rockfall Hazard Rating System
FHWA	Federal Highway Administration
WIP	Wall Inventory and Condition Assessment Program
AMS	Asset Management System
RCAD	Rockfall Catchment Area Design Guide
CRSP	Colorado Rockfall Simulation Program
LEA	Limit Equilibrium Analysis
GDP	Gross Domestic Production
ERS	Earth Retaining Wall
AASHTO	American Association of State Highway and Transportation
GEO5	Geotechnical Software, “fine” engineering software company
EN1997	Eurocode 7: Geotechnical design
ASD	Allowable Stress Design
FoS	Factor of Safety
DA1	Designing Approach 1
EC6	Eurocode 6
AVR	Average Vehicle Risk
DSD	Decision Sight Distance
eq	Equation
ID	Identification
NA	Not applicable

MTA	Maden Tetkik Arama

LIST OF SYMBOLS

\$	United States Dollars
M	Million
S_i	Shear forces between slices
E_i	Normal forces between slices
W	Weight of the slice
T	Shear force at the bottom of the slice
N	Normal force at the bottom of the slice
R	Radius of the circular slip surface
O	The origin
km/hr	Kilometre per hour
m	Metre
cm	Centimetre
γ	Unit weight of the wall
kN/m^3	Kilo Newton per cubic metre
ϕ'	Effective angle of internal friction
$(^o)$	Degree
kPa	Kilo Pascal
δ	Angle of friction between the wall and the backfill soil
f_k	Compressive strength
f_{vko}	Shear strength
B	Approximate width of the foundation of the wall
q_u	Ultimate bearing capacity
$\gamma_{concrete}$	Unit weight of foundation material

$d_{foundation}$	Foundation thickness
c'	Effective cohesion
q	Effective stress at foundation level
N_c, N_q and N_γ	Bearing capacity factors
TL/m^2	Turkish Lira per metre square
TL/day	Turkish Lira per day
C	Cycle
S	Swing factor
V	Heaped bucket volume
B'	Bucket fill factor
E	Job efficiency
L	Loose

Chapter 1

INTRODUCTION

1.1 General

In this thesis, a geotechnical asset management study is carried out for the highway route between Nicosia and Kyrenia (via Değirmenlik) in Cyprus. The thesis presents; a methodology for condition appraisal of the selected geotechnical assets, geotechnical stability assessments for the assets, and a methodology developed for management of the assets.

Geotechnical asset management is a process that helps to produce new technologies and procedures in order to reduce the damages that could follow any type of failures of the geotechnical assets. Beyond the reduction of the damages, development of the geotechnical asset management could also help to arrange the efforts of the involved agencies to draw a course of actions in the early stages of the failure of geotechnical asset. When the geotechnical asset management control the way to analyze and protect the geotechnical assets, the efforts of the involved agencies could be directed in a way that the failure could be treated in the optimal time, cost and with less hazards (Cottrell et al., 2009).

1.2 Problem statement

The Nicosia-Kyrenia (via Değirmenlik) route is a very critical route in the heart of Kyrenia Mountain Range with a number of links to rock quarry sites, which produce most of the aggregate supply for the production of concrete needed for the construction industry in North Cyprus. The route also acts as a shortcut between the Ercan Airport and the hotels and holiday villages in the east of Kyrenia. All assets on this route are very crucial to maintain a reasonable service performance and safety for the highway. A geographical view of the route is presented in Figure 1.1 (Google Earth © 2016).

The selected highway route suffers from a heavy traffic load as it is busy all the time with heavy trucks and other industrial vehicles servicing the quarries located along the route.

In addition, the highway route also has a touristic importance used for access to touristic attractions such as Buffavento Castle, the Five Fingers (Beş Parmak) Mountain.

Figure 1.1. Nicosia-Kyrenia highway route (Google Earth © 2016).

Along the highway route, there are a lot of geotechnical assets which need to be maintained professionally. Accessibility of the highway route depends on these geotechnical assets and their performance. The geotechnical assets chosen to be studied are; the natural earth slopes, rockfall sites and earth retaining walls. Hence, it is considered that a number of these assets, which are critical for the serviceability of the route can be selected for assessment of their current condition and stability, so that a plan for their management can be produced to ensure they perform at a reasonable and safe level of service.

1.3 Objective

The objective of this thesis is to develop a methodology for the management of regular maintenance and improvement of the selected critical geotechnical assets along the highway route. With an asset management plan, the required works can be arranged to avoid adverse impact on the service performance of the highway, also providing value engineering.

1.4 Research questions

In this thesis, the following research questions about geotechnical asset management, are be answered;

- What are geotechnical assets?
- How existing geotechnical assets are technically assessed?
- How existing geotechnical assets are managed with respect to their maintenance and improvement requirements?
- What is the importance of the geotechnical asset management?
- How could asset management improve the transportation infrastructure services?

Condition appraisal, stability assessment and management methodology for geotechnical assets are the main topics that the research goes through. The selected highway route is used to apply a geotechnical asset management procedure, which is developed as part of this thesis.

1.5 Methodology

In this research, a generic plan for the geotechnical asset management of selected assets along the Nicosia-Kyrenia Highway route (via Değirmenlik) is developed.

Two main principles are followed:

• a risk assessment based approach taking consideration of; the types of hazards affecting the geotechnical assets, consequences of these hazards, and, an assessment on the probability of occurrence of the hazards in terms of a risk rating.

• Provision of a linkage between the geotechnical assets and the highway; interactions between the geotechnical assets, other assets and the surrounding environment.

Condition appraisals are carried out for all geotechnical assets. Geotechnical stability analyses are carried out for natural earth slopes and earth retaining walls. Geotechnical risk assessments are carried out for all geotechnical assets. Decision making process is developed to produce assessment criteria to choose the best option (do nothing, maintenance or improvement) for the assets. Time line plan is developed for the geotechnical assets.

1.6 Thesis contents

In the second chapter, a historical review of the previous efforts on geotechnical asset management are discussed. Some important concepts regarding the geotechnical management are introduced. The classification of the geotechnical assets is discussed and information on stability assessment of the geotechnical assets are presented.

In the third chapter, the methodology followed for condition appraisal and stability assessment of natural earth slopes, rockfall sites and earth retaining walls are discussed. Detailed information on the methodology used for the evaluation of the asset performance is presented. A ranking system is developed to assess the selected geotechnical assets to ease the evaluation and to help choosing the best option for maintenance and improvement.

In the fourth chapter, the results of the evaluations carried out are presented. The preferable maintenance or improvement options are presented. The analysis results on slope stability, which are obtained by using the software GEO5 2016 are summarized. A methodology for decision making process is developed.

A detailed timeline plan and life cycle cost analysis are presented, which also include calculations on budgeting throughout the lifespan of the assets. Conclusion and recommendations for further studies are presented in the fifth chapter. The limitations of the current study are also discussed briefly.

Chapter 2

LITERATURE REVIEW

2.1 General

In this chapter, a brief background information on the geotechnical asset management is presented. Some definitions about basic terms are included and importance of geotechnical asset management and historical failures of some assets and their impacts on the highway performance are discussed. Geotechnical categorization and features to be managed according to their impact on risks regarding asset performance are also discussed. A historical review of the development of asset management methods are presented.

Types of geotechnical assets and their interaction with other civil engineering assets and the nearby environment are discussed to define types of geotechnical assets.

2.2 Geotechnical asset management

An asset is the physical transportation infrastructure (e.g., travel way, structures, other features and appurtenances, operations systems, and major elements thereof); more generally, can include the full range of resources capable of producing value-added for an agency: e.g., human resources, financial capacity, real estate, corporate information, equipment and materials, etc.; an individual, separately-managed component of the infrastructure, e.g., bridge deck, road section, streetlight (Anderson et al., 2016).

Geotechnical assets are any structures related to earth works directly or indirectly. These assets can be already formed natural slopes, which may produce uncertainties such as landslide, events if they are not stable, or manmade cut slopes, both of which may also comprise a structure for stability. Geotechnical assets may also be manmade earth works such as subgrade or embankment. Geotechnical assets can be part of civil engineering structures, performance of which may be effected by geotechnical properties such as foundation. They may also be in the form of buried structures to maintain the required performance of other assets (e.g.: tunnels, earth retaining walls...etc.). Performance of geotechnical components may significantly affect performance of other transportation assets such as culverts, drainage pipes, pavement, bridge etc (Anderson et al., 2016).

Any type of failure along highway routes could be a very risk producing source, where the damages can vary from functional loss of a geotechnical asset to a significant failure causing fatalities. In order to avoid any catastrophic scenario, a geotechnical asset management strategy should be developed.

A highway route may comprise a number of uncertainties relocated with the geotechnical assets depending on the terrain characteristics.

Geotechnical assets all over the world are designed according to various standards and codes (BS 8002:1994, 2001). The most effective method of managing geotechnical assets is by observation of their conditions and performance with regular periods. The observation of geotechnical assets may take different forms based on the purpose of the data to be obtained. Geotechnical asset management involves formation of an asset inventory and data base followed by collection of sufficient data to enable carrying out condition appraisal for the assets. In addition to this, geotechnical modeling and analysis of stability of the assets may be required. In parallel with the above a risk assessment study and cost estimation of maintenance and improvement works will be required to help the decision making process (Holt, & Gramling, 1991).

Nonetheless, geotechnical asset management should be progressed by considering planning of budgets and maintenance and improvement strategies. These result to prioritization of the works required as output of an effective geotechnical asset management.

It is obvious that following an effective geotechnical asset management approach, considering performance and periodical maintenance and improvement (as and when needed for geotechnical assets) is much cost effective than trying to manage the reinstatement of their functions in urgent conditions.

In the following case studies, there will be examples for the economic impact of the failures of different types of geotechnical assets are predicted;

Ferguson slide, California

In April 2006, a rock slide happened in Ferguson, California, which closed the main roadway to the Yosemite National Park. Because of the 92-day closure period, the economic loss was about 4.8 million dollars. The economic impact was still managed even after opening of a detour, after four months (Vessely, 2013).

Tennessee and North Carolina Rockslides

In 2009, six months of highway route closures had to be in place as a result of two main rockslides in North Carolina and Tennessee. The closures had a significant negative impact on the local economy, such as: loss of revenue for the lodging operators, restaurant businesses, gasoline sales and hospitals. The failure also made a negative impact to the emissions and congestion, due to the use of alternative assets. Other costs included costs due to delays from longer travel distance (Vessely, 2013).

Vail Pass Culvert Failure, Colorado

In 2003, after a substantial rain event in Colorado, a major culvert failure occurred. A depression was formed on a highway continued for a period of 12 hours which failure by the collapse of the highway. The failure was due to water leakage from a 66 inch diameter culvert carrying piping failure in embankment carrying to highway.

After the failure, both directions of the highway were closed for approximately three days until the embankment is stabilized and a road is constructed in single lane each direction. These lanes could only be doubled both directions 16 days after the failure, and the highway was opened in its original configuration 22 days from the event. During this event, also the on street drainage systems were contaminated with sediment. The total repair cost for the highway and infrastructure was $4.2M, and the transportation user costs were estimated to be over $4M. After this event, the Colorado Department of Transportation (CDOT) statewide inspections of 6,273 culverts and identified 205 critical structures that require maintenance or replacement (Molinas & Mommandi, 2011).

Bear tooth Pass Closure, Montana

During seasonal snow clearing operations, the runoff due to the storm water could not be contained, which triggered debris flows moving over 100,000 cubic yards of soil and rock damaging the highways in 13 locations (Vessely, 2013).

As a result of this event, there were a number of closures, which led to 19M maintenance and improvement work.

2.3 Historical review of asset management

2.3.1 Natural earth slopes

Natural earth slopes management systems have common features. These features are: inventory, methods to collect data, procedures for condition appraisal and rating systems. Risk assessment method is an alternative way to detect various types of uncertainties for natural earth slopes.

In 1984 Ang and Tang developed a framework for decision making process and analysis for natural slopes. The developed framework model depends on deterministic and probabilistic aspects (Ang, & Tang, 1984).

In 1992, New York Department of Transportation developed a rating system for landslides. The rating system was developed to check many features such as slope height, ground water and surface water (Collin et al., 2008).

In 1993, Washington Department of Transportation developed a management rating system which concentrating mainly on risks coming from highway traffic.

In 2001, Oregon Department of Transportation developed a system for natural slope management including all types of slope uncertainties (Collin, et al 2008).

2.3.2 Rockfall sites

In early 1960's the need of asset management was on the rise to avoid the mismanagement cost in assets in general in the United States of America (US). At the 1970, many departments of transportation in different states in the US tried to develop systems to manage the data coming from transportation assets in association with civil engineering department in those states.

Pierson & Van Vickle (1992) developed the system of rock fall hazard rating system. Rockfall hazard rating system (RHRS) was developed in 1970s, which includes ranking procedures and maintenance program for rockfall sites (Pierson & Van Vickle, 1992).

2.3.3 Earth retaining walls

The need of asset management for earth retaining walls started with the systems of data inventory, which were developed by various organizations. Federal Highway Administration (FHWA) in the US was one of the first organizations to develop data inventory for transportation assets. The geotechnical assets were included in the same system with all other transportation asset (Pierson et al., 1990).

The Central Federal Lands Highway Division of the FHWA developed the WIP, Wall Inventory and Condition Assessment Program. WIP is an extensive wall inventory program, which includes the information about 3500 walls in the US. This program were designed to provide wall data, assess the current condition and give estimated costs for the improvements (DeMarco et al., 2010).

In 1990, the City of Cincinnati started to use their own retaining wall database and program to inspect and prioritize the improvement processes through their city. For this purpose, about 7000 walls were surveyed (Anderson et al., 2008).

Brutus, & Tauber (2009) have developed a guidance program for inventory and inspection of the earth retaining walls. They used the developed system for the inventory of 2000 retaining walls in the New York City Department of Transportation (Brutus, & Tauber, 2009).

The North Carolina Department of Transportation currently implements an integrated asset management system (AMS). This system comprises pavement and bridge management systems and has asset trade-off analysis as well (Bhargava et al., 2012). The system is accessible throughout the state, which includes various types of information such as; historical data, condition rankings and performance rates and analyses (Bhargava et al., 2012).

In 2013 Syrachrani et al. developed a tree based decision model which can provide prioritization study of periodically maintenance and rehabilitations (Syachrani et al., 2012).

2.4 Categorization of geotechnical assets

For categorization of geotechnical assets, the interaction with other assets should be identified. In general, all geotechnical assets may be classified into three groups: primary geotechnical assets, secondary geotechnical assets and minimal geotechnical assets. In addition, each group may further be divided into subgroups according to their physical location, whether they are visible or buried as shown in Figure2.1.

Primary geotechnical assets are comprised of assets such as natural earth slopes, earth retaining walls and embankments, which play a significant role in providing support or suitable space for other assets. They also protect other structures from potential dangers or failures.

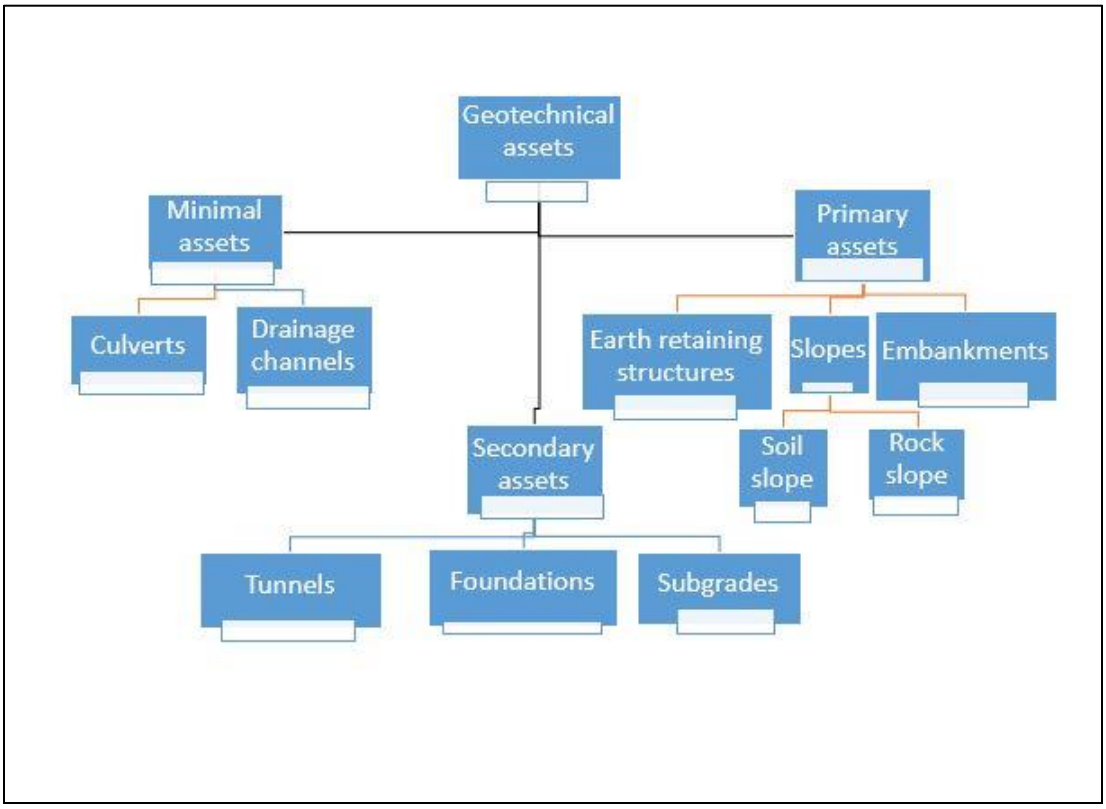

Figure 2.1. Categorization of geotechnical assets.

Secondary geotechnical assets are comprised of buried assets that are largely or partially affected by other assets. They may also be part of other structures. Foundations of which main purpose is to transmit loads coming from structures to ground are clarified as secondary geotechnical assets. Tunnels, for example, which retain earthen material so that transportation structures and routes could serve better, are also clarified as secondary geotechnical assets. Subgrade, subbase and base which function as the foundation of pavement structures in general, are examples of secondary geotechnical assets (Anderson et al., 2016).

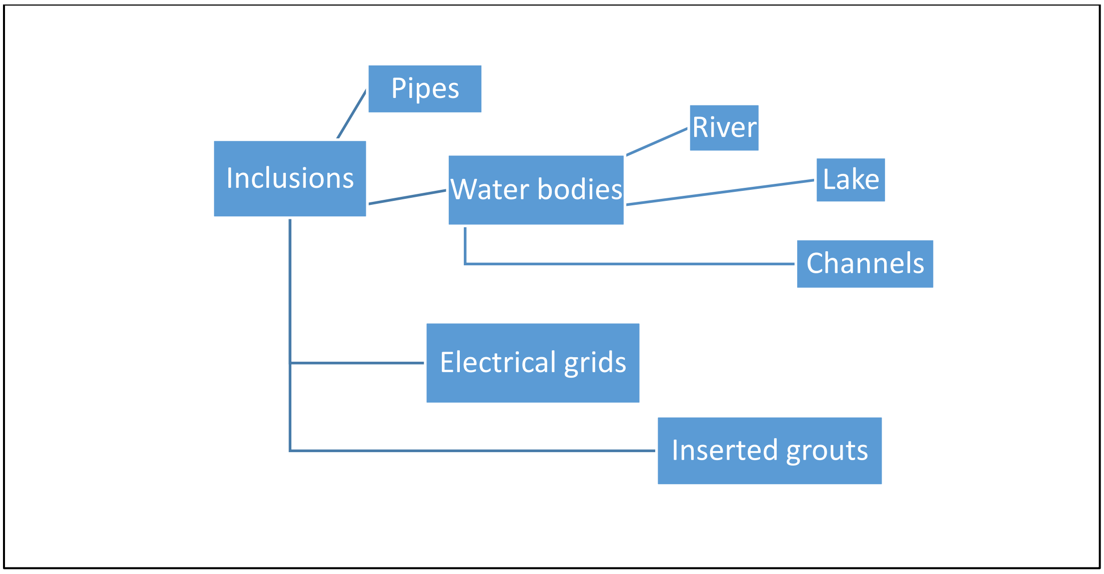

Figure 2.2. Geotechnical inclusions.

Minimal geotechnical assets group, which is comprised of water transmitting facilities, in general, culverts and drainage systems, can be visible or buried assets. These assets have a common objective of controlling water flows, either on the surface or inside other assets (Vessely, 2013).

In Figure 2.2, some examples of the environmental inclusions related to the geotechnical assets are shown. These can potentially affect performance of the geotechnical assets, and they can be listed as; water bodies alongside the route such as rivers, reservoirs, lakes or oceans. The interactions between the water bodies and the ground may affect the performance of the geotechnical assets.

Other types of inclusions may be the non-earth modifications: pipes, electrical grids and inserted grouts which are not geotechnical assets, however their performance may be significantly affected by geotechnical assets.

Other geotechnical assets could be included in this classification are the non-physical assets like the geotechnical knowledge, equipment, laboratory tests and site investigation (Perry et al., 2003).

2.5 Features of geotechnical assets that require management

Features require management are any geotechnical features of the geotechnical asset which are important for the functionality and stability of the asset. Those features may suffer from a low level of serviceability through the lifespan of the asset and require management and maintenance (Whitman, 2000).

Natural earth slopes features that require management are the degree of inclination of the slope, drainage system on or upslope, vegetation cover, the ditch along the slope and barriers that retaining the slope or improving its stability (Stanley, & Pierson, 2013).

Rockfall sites features that require management are the ditch along the site, the shape of the rockfall site and any reinforcements used to increase the stability of the rockfall site.

Earth retaining walls features that require management are the backfill materials, weep holes or drainage system, the ditch and other geotechnical assets along the wall such as culverts (Duncan, 2000).

2.6 Stability assessment of the slopes

Many scientists and engineers studied the topic of ‘Slope Stability’ analysis in the last few centuries and this is still a current research topic. William Rankine was the first to develop a practicable calculation on lateral earth pressure theory following

Coulomb's earlier efforts on lateral earth pressure theory. More recently, in 1954, Alan Bishop produced an article called 'The use of the slip circle in the stability analysis of slopes' which is nowadays still one of the best methodologies to follow in the stability assessment studies (Das, 2015). In 1955, Petterson was the first engineer who applied the circle method to analysis of soil failure. In 1967, Hutchinson produced a system of classification for slope instability (Das, 2015).

In SoilVision report (2007), a summary of common methods of slope stability analysis was given. Ordinary method of slices was developed by Fellinius in 1927, the limitations of this method were low factors of safety and it was only for circular slip surfaces.

In 1955, Bishop developed his own modified method which was accurate only for circular slip surfaces. In the simplified Bishop's method, the method tried to satisfy the moment equation of equilibrium and the vertical force equilibrium. The factor of safety obtained through successive iterations (Bishop, 1955).

A simple sketch of circular slip surface is shown in Figure 2.3, where method of slices is used to show the forces between the slices. The shear forces between the slices are ignored in the simplified Bishop method; where:

S_i: Shear forces between slices, E_i: Normal forces between slices, W: Weight of the slice, T: shear force at the bottom of the slice and N: Normal force at the bottom of the slice.

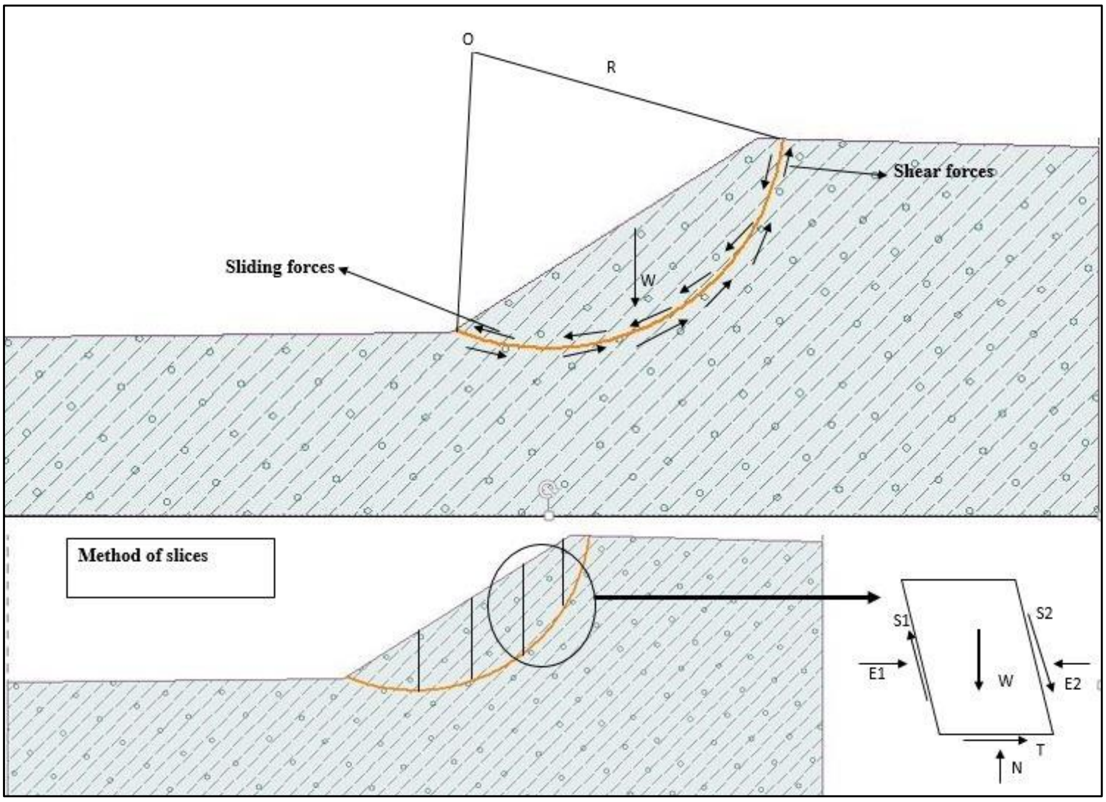

Figure 2.3.Circular slip surface.

Janbu's simplified method was developed in 1968. The method based on the force equilibrium method and it was applicable to any shape of slip surfaces (TRB special report, 1996).

Some of the other researchers and engineers who developed methods on stability assessment can be listed as; Gilboy (1934), Taylor (1937), Terzagi (1943), Fellenius (1947).

In this thesis, slope stability assessment is carried out by using the software GEO5 (2016) © fine.

2.7 Methods used for asset management

Long term solutions may be obtained by a good designed plan of maintenance and improvements. The infrastructures asset management is the plan that help to more useful methods to manage all the risks may be produced by the asset. Asset management may help to maintain the asset for long time by elongating its lifespan with many significant solutions (Shah et al., 2014).

The following diagram is presenting the framework element system developed by (Shah et al., 2014).

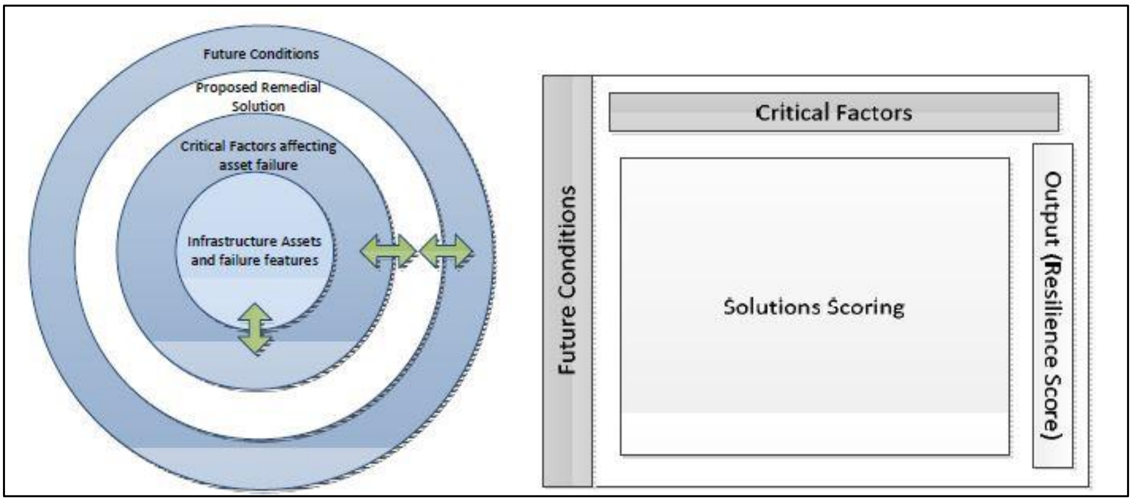

Figure 2.4. Diagrammatic representation of proposed framework elements (Shah et al., 2014).

Categorization of geotechnical assets is very important to understand the behaviour and interactions of those assets. In Figure2.5, various types of geotechnical assets are shown (Vessely, 2013).

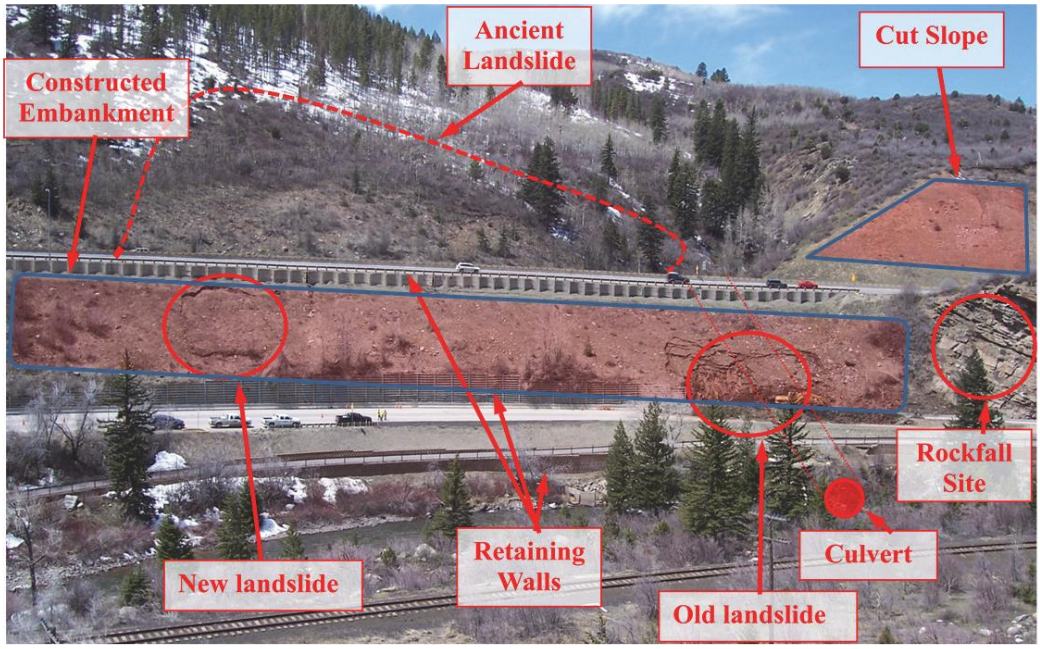

Figure 2.5. Geotechnical assets (Vessely, 2013).

Data inventory and collection were discussed earlier in this chapter. Some existing methods of asset management for rockfall site is the Rockfall Hazard Rating System (RHRS) which used in the thesis. RHRS was developed in the 1980s by the Oregon Department of Transportation with support from FHWA and other states. The RHRS is one of the first systematically programs for inventory and to rank and classify the geotechnical assets along highways. The evaluation of the risk through the geotechnical analysis process is important. Risk analysis should be obtained from the developed analysis methods, and the next step is to define the consequences. The following Figure 2.6 shows the rockfall hazard rating system steps to check the consequence of risk (Anderson, & DeMarco, 2012).

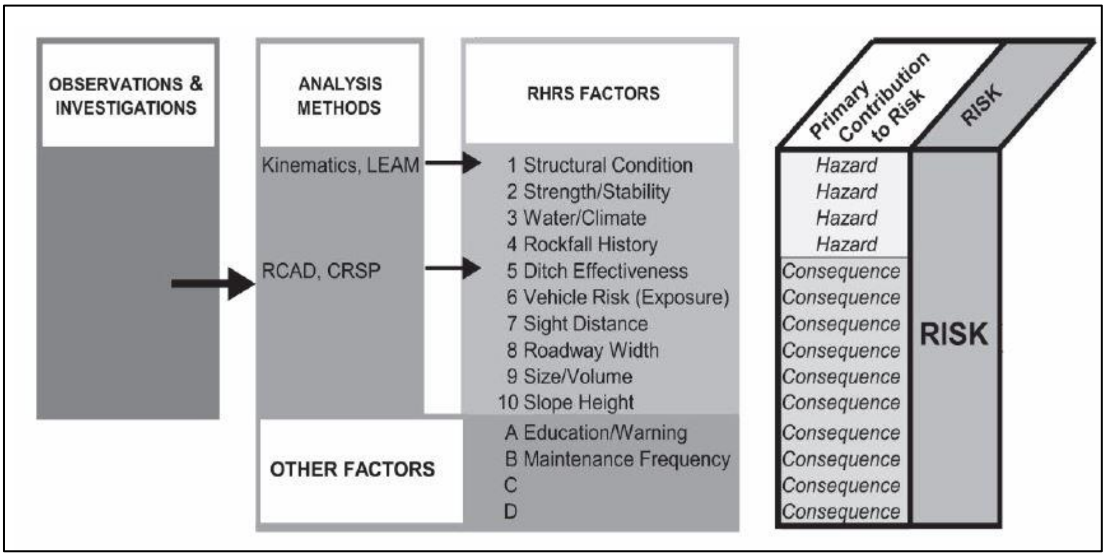

Figure 2.6. Consequences-risk analysis (Anderson, & DeMarco, 2012).

Geotechnical asset management can start from asset inventory and develops a condition assessment in order to understand the current situation of the asset. Then the process could be developed to long and short term plans with interactions with risk assessment and budgeting plan (Sanford Bernhardt et al., 2003). The asset management components are shown in the Figure 2.7.

Asset management could reduce the life cycle cost for the assets. In 1960, the United States federal public spending on infrastructure was about 5% of the gross domestic production (GDP). Today, by using the asset management techniques and concepts, U.S. spends about 2% of its GDP which is 50% less than what it used to spend 50 years ago (Farrukh, & Bayraktar, 2012).

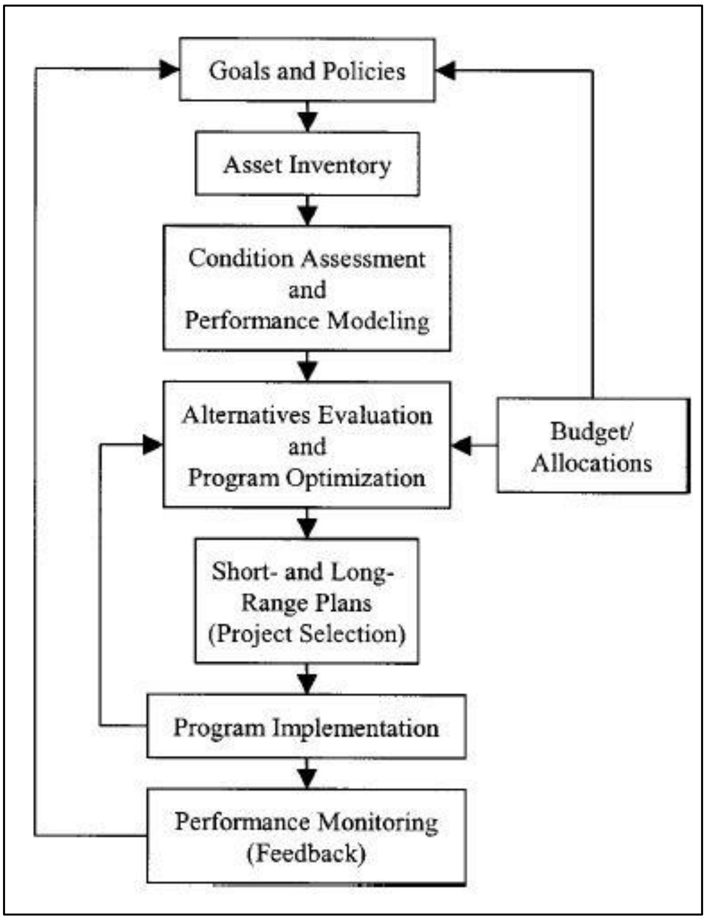

Figure 2.7. Asset management components (Sanford Bernhardt et al., 2003).

Advanced study was developed in 1997 by Markov and Alfelor. They check many former studies about economic benefits of maintenance. They review the benefits, listed them. Preservation of the infrastructure using frequently maintenance may help to reduce the life cycle cost of the asset. Various aspects of maintenance were developed such as, maintenance of traffic volume on the highways to control safety regulations, maintenance for aesthetic appearances for the assets, maintenance for different types of barriers and maintenance for rest stops along the highways (Markow, & Alfelor, 1997).

The activities of the asset management could be subdivided in a particular way to assign all the needed stages for asset management. Data collection stage comprises of several information about the costs, performance, values, inventory and other data. Next step is to obtain data base including all the collected data. Analysis tools will take place whenever data are ready to be analysed and assessment study could start at this level. Finally, decision making process and implementation procedures could be followed (Sanford Bernhardt et al., 2003). The diagram of the asset management steps is shown in Figure2.8.

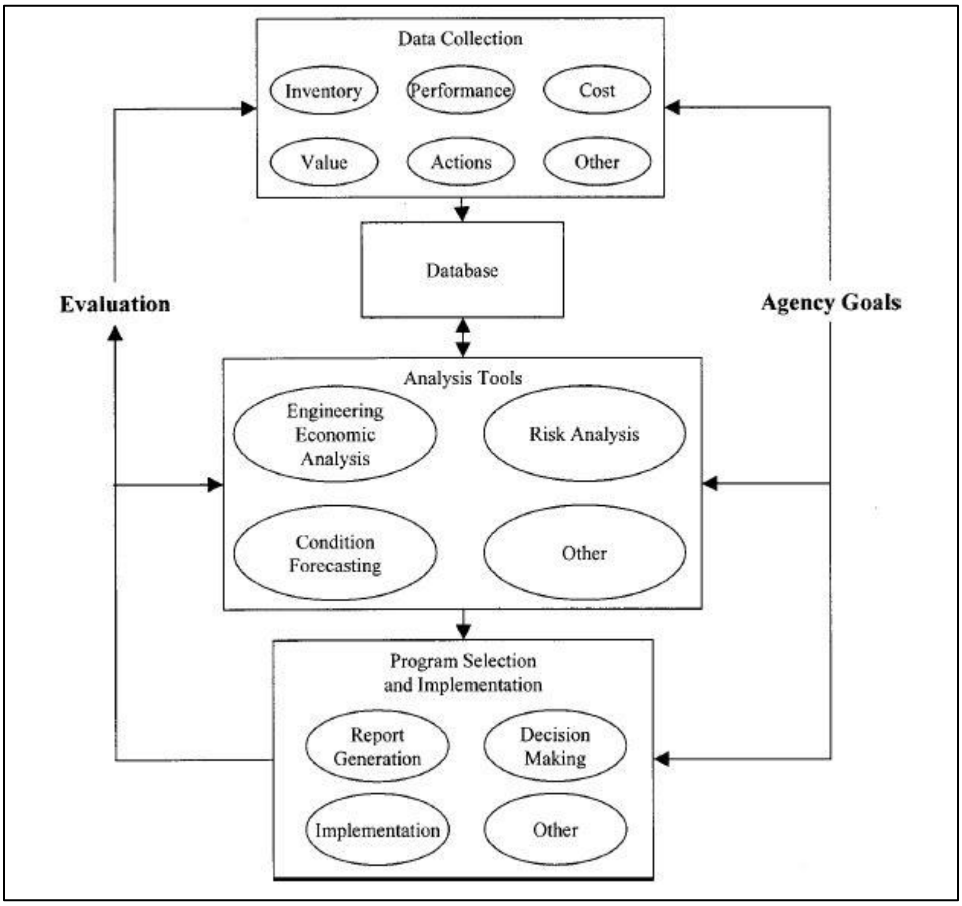

Figure 2.8. Asset management levels.

Chapter 3

METHODOLOGY

3.1 General

In this chapter, the methods used in the collection of data for condition appraisals, analysis methods and asset management methods adopted as part of the geotechnical asset management process are presented in detail. For all design related geotechnical assessment calculation, global factor of safety method and Eurocodes7 are used.

3.2 Desk study

In this section, all the data collection process prior to condition appraisal of the assets and stability analyses is carried out. In general, the data collection process included; studying maps of the related route, site visit and identification of the geotechnical assets.

3.2.1 Studying maps of the selected route

The approximate locations of the geotechnical assets are marked on the selected highway route between Nicosia and Kyrenia on the road map of Northern Cyprus [Appendix A]. After several site visits on dates 02.01.2016, 27.03.2016, 21.07.2016 and 14.08.2016, the "critical" geotechnical assets are selected and their positions are also marked on the same map.

The 'critical' geotechnical assets are assumed to be the ones, which by visual inspection, clarified as 'in need of more attention' due to their function being more important for the performance and stability of the highway.

The geological maps of superficial deposits and bedrocks outcrops for the area of the selected highway are also obtained from the Department of Geology and Mining [Appendix F]. The geological maps were used to study the geological characteristics of the site of the selected geotechnical assets. This study helped to form corresponding ground mode and estimate the ground parameters to be used in the stability analysis for the geotechnical assets (Hakyemz et al., 2002). Due to the absence of insitu testing and any laboratory test results, the geotechnical parameters are estimated based on the visual observations and geological interpretation and with the help of the published data in the literature for similar geological materials (Bowles, 1988).

3.2.2 Site visit of the selected assets

Several site visits have been carried out to observe the current condition of the geotechnical assets and the route in general. In the first few visits, coordination of all the geotechnical assets are mapped using GPS and they are accurately measured on the road map. In addition, brief notes about observations on the locality of the assets are recorded such as their location with respect to the highway, their proximity to the pavement and their setting according to the highway layout.

In the following visits, the critical assets are selected and more detailed observations are recorded such as; presence of drainage systems, approximate measurements (dimensions) [Appendices B, C and D], existing defects on the assets, observation on fallen materials from upslope and erosion, vegetation and trees on or at the proximity of the asset.

3.2.3 Identification of the geotechnical assets

The highway route between Nicosia and Kyrenia contains various types of geotechnical assets. The selected geotechnical assets are all categorized as primary assets. Natural earth slopes and rockfall sites are categorized to be primary geotechnical assets. According to the interaction between both types of natural earth slopes and rock slopes as geotechnical assets and the pavement (highway route) as transportation asset, both geotechnical assets play a role in providing a suitable space for the pavement to do its function. The natural earth slopes and rockfall sites protect also the transportation assets from damages. And this is a reason to do asset management study for those assets.

On the other hand, earth retaining walls are categorized as primary geotechnical assets. Earth retaining walls along the route are retained the slopes and provided supports to other types of assets. This type of geotechnical assets comprised of two stability analyses, for natural earth slope and for the earth retaining wall.

Subgrades of the pavement could be included in any asset management study as secondary asset. There are a lot of minimal assets along the highway route including; culverts and drainage systems. These types of assets are not included in the geotechnical asset management in this thesis. Geological maps and reports are categorized to be non-physical assets.

3.3 Condition appraisal for the assets

3.3.1 Introduction

Condition appraisal is an observational method that allow the inspector to collect various factors, parameters or properties of any type of asset. The collection of these data is an ongoing process carried out periodically, which helps evaluation of the performance of an asset. The condition appraisal is a simple way to assess the asset by checking its current condition. It needs to be carried out by experts or a committee of specialist engineers about the particular type of asset being evaluated.

The condition appraisal is not only a system for data collection, but it is also a methodology to carry out a preliminary assessment of the asset in the site. Condition appraisal methodology gives the inspector the main role of assessing the condition of the asset according to the technical observations and notes taken at the time of visits to the assets (Hearn, 2003).

3.3.2 Importance of condition appraisal

Condition appraisal is a key stage, which life-cycle condition and performance are directly assessed for effective management. With successful completion of condition appraisal for geotechnical assets, safety, mobility, preservation, economics, and environmental parameters and sustainability can be provided. The fair evaluation of condition appraisals of assets can also provide a cost effective maintenance and improvement plan.

Condition appraisals may lead to a technical evaluation of the stability and/or performance of an asset by analysis or monitoring or both. At the end of evaluation process, depending on the result of the evaluation the asset may be observed for a further period or minor maintenance an urgent improvement works may be required. However, the result of the evaluation process needs to be considered in parallel with other features prior to decision making process, which are discussed in proceeding sections of this chapter.

3.3.3 Data inventory

The data required to be collected for condition appraisal differs for each type of asset. For each type of asset, there is a typical initial procedure to record the data. The generic data collected for all assets considered in this thesis is comprised of the coordination of the asset, the serial number of the asset on the map, the date and time of data collection, weather, dimensions and particular structural features.

Other observations on the performance of each asset to enable evaluation of its durability and maintenance and/or improvement needs are also recorded, which are in sections 3.3.4, 3.3.5 and 3.3.6.

3.3.4 Condition appraisal form for earth retaining walls

The form of condition appraisal of earth retaining walls is divided into four sections. Each section is designed to concentrate on various aspects of condition appraisal such as; generic data, general information, wall properties, soil properties and drainage. The form used to collect data is presented in Table 3.1 where ERS stands for earth retaining structures.

In the wall properties section, observational data on any type of distortions or deformations that could appear on the wall affecting the wall performance is investigated. The defects to be recorded are listed as the following: visual deflection, bulges, settlement of wall or parts of it, any cracking, and some checks for the joints through the wall and the missing blocks. Root penetration and presence of graffiti are also observed. In the soil properties and drainage sections, observations on retained soil and the backfill are recorded. Any evidence of settlement, tension cracks, landslide, earth movement, erosion, excessive moisture or movement of any material from upslope adding loads to the wall are recorded. The performance of the drainage system through the retaining wall, or any top or toe drainages are recorded.

Table 3.1. ERS condition appraisal data collector system.

ERS condition appraisal form	
Number of wall on map:	
Coordinates: Longitude Latitude	
Date:	
Time:	
Name of inspector:	
General information	
Slope height:	
Slope length:	
Ditch width:	
Daily traffic:	
Speed limit:	
Roadway width (from paved edge to another edge):	
Wall	
Visual deflection:(horizontal or vertical)	
Bulges or distortions:	
Settlement of wall or parts of it:	
Joints between panels or bricks are misaligned:	
Joints between facing units(panels or bricks) are too narrow or too wide:	
Joints between adjacent sections of wall are misaligned:	
Cracks or spalls in concrete or bricks:	
Missing blocks or any part of wall:	
Staining (water, rust or any evidence of corrosion):	
Root penetration of wall faces:	
Displacement of top wall features (coping, parapet or barrier rail):	
Presence of graffiti:	
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall:	
Evidence of landslide or earth moving:	
Settlement or heaving in front of the wall:	
Evidence of erosion or scour:	

Table 3.1 (cont.)

Evidence of excessive moisture in backfill:	
Material from upslope adding load to wall like rocks or new soils:	
Drainage	
Drainage outlets are clogged:	
Drainage channels along top of wall are not working properly:	

The completed condition appraisal forms for Earth Retaining Walls within the selected assets are presented in Appendix B.

3.3.5 Condition appraisal form for the rockfall sites

For the sites of assets comprising rock slopes, a rockfall condition appraisal is carried out. In this particular type of condition appraisal the structural formation and rock fracturing is recorded. The approximate block sizes and volume of the fallen rocks in the proximity of the sites are observed and recorded.

The condition appraisal form used to record data for the rockfall sites is presented in Table3.2. A completed set of condition appraisal form for rockfall sites is presented in Appendix C.

Table 3.2. Rockfall site condition appraisal form.

Rockfall site condition appraisal form	
Number of site on map	
Coordinates:	
Longitudinal	
Latitudinal	
Date:	
Time:	
Name of inspector:	
Slope height:	
Ditch width:	
Slope length:	
Daily traffic:	
Speed limit:	
Actual sight distance:	

Table 3.2. (cont.)

Decision sight distance:	
Roadway width (from paved edge to another):	
Structural condition for rocks:	
Rock friction:	
Block size (from peak to peak):	
Present water on slope:	

3.3.6 Condition appraisal form for the natural earth slopes

For natural earth slopes the evidences for the following are observed: ground cracks, soil pulling away in front of the slope, offset fence lines on the slopes, unusual bulges, and sunken paths along the slopes or broken water lines, cleanliness of ditches or drainage systems.

The following Table3.3 is the condition appraisal form used for the natural earth slopes.

Table 3.3. Condition appraisal form for the natural slopes.

Natural slopes condition appraisal form	
Number of asset on the map:	
Coordinates:	
Longitude	
latitude	
Date:	
Name of inspector:	
Slope height:	
Ditch distance:	
Slope length:	
Daily traffic:	
Speed limit:	
Roadway width (from paved edge to another edge):	
Presence of any spring, seep or saturated soil:	
Ground cracks at the head of slope:	
Soil pulling away from foundation of structures or retaining walls:	

Table 3.3 (cont.)

Offset fence lines appearing on the slope:	
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	
Tilting of telephone poles , trees, fences or retaining walls:	
Broken water lines or other underground utilities inside the slopes:	
Sunken or down dropped paths or roads:	
Additional comments	

The condition appraisals for natural earth slopes are presented in Appendix D.

3.4 Data collected from governmental offices

The condition appraisal cannot depend only on the observations and the records that obtained by one inspector or a committee of expert engineers. The historical records and the geological and transportation data and statistics could be useful also in the frame of assessing the performance of the geotechnical assets. Two local organizations cooperated with the author and provide highly valuable data about the sites and the traffic information.

The first organization was the Transportation Department (Karayolları Dairesi), which provided data about the history of the highway route and the history of the facilities along the route are presented in Appendix E. The Transportation Department also provided traffic information about the frequency and the types of vehicles using the route and records of the previous maintenance carried out. The following is a summary of the data that provided by the Transportation Department;

- Traffic volume is about 9416 vehicle/day (Değirmenlik rounabout to Çatalköy).
- Speed limit as a maximum speed limit is 80 km/hr.

- Roadway designing width is (1m*2 for shoulders, 3m*2 for platform), the roadway is second class road.
- The highway route between Nicosia and Kyrenia was constructed on 1963.

The second organization was the Geological Department (Jeoloji ve Maden Dairesi), which provided geological maps and records for boreholes in different points near the sites of the selected assets presented in Appendix F.

3.5 Geotechnical assessment of the stability of the assets

3.5.1 Assessment of earth retaining walls

Earth retaining structures are one of the most expensive and important structures which can retain different types of soil. The earth retaining structures generally function to isolate various hazards such as landslides from the highway route, railways etc.

Following (DeMarco et al., 2010) ‘’FHWA’’ for National Parks Services is used for evaluating the earth retaining walls located on the highway route between Nicosia and Kyrenia. In this method of evaluation for earth retaining walls, there is a rating system which involves observational assessments, giving scores at the end to show that the asset is in a good, fair or poor condition. The combined numerical-statistical method involves a check list for which data is collected during condition appraisals.

The scoring system used in this evaluation method is based on the 1–4 rating system outlined in AASHTO’s Manual for Bridge Element Inspection for its bridge element ratings (AASHTO, 2013). The scoring assessment is implemented as description in the following:

- In order to evaluate and score the elements of the earth retaining wall, each of the element is scored according to the inspector observation from (1=good) to (4=worst) then an average is taken for all of the elements and the final rating score of the asset is determined.

- Any asset that receives an average score about 1.5 or less is considered as in ‘’good’’ condition, while assets with a composite score between 1.5 and 2.4 will be considered as in “fair” condition, and the assets with a composite score between 2.5 and 3.4 will be considered as in “poor” condition. Finally the assets with a composite score greater than 3.4 will be considered as in “severe” condition.

Hence, the scoring system is four levels, varying from good condition to severe condition. The following Table3.4 shows the condition rating and the scoring criteria at the same time (Butler et al., 2015).

Table 3.4. Rating criteria for earth retaining walls.

Average score	Condition rating	Rating criteria
≤1.5	Good	The distress does not obviously affect the function of the element.
1.5-2.4	Fair	The distress does not affect the function of the element, but lack of maintenance and treatment could lead to serious problems and produce uncertainty, which can lead to risks of failure in the long term.
2.5-3.4	Poor	The distress obviously affect the elements function. There is no immediate risk but strength and stability of the asset are in danger.
>3.4	Severe	The element is functionless and no longer in service anymore.

In addition to the above a second method is also used to evaluate the current stability of the earth retaining walls. The computer programme GEO5 is used to study the stability of the slopes retained by the earth retaining structures and check with the current design codes and standards.

The design standards used in the analyses are; Global factor of safety method and Eurocode 7, namely EN1997. Using the computer programme GEO5, analysis methods such as Bishop, Janbu, Fellenius/Petterson, Morgenstern/ Price or Spencer can be used to generate circular slip planes for slope stability and obtain factors of safety. In this thesis, Bishop Method is chosen for implementation in the slope stability analyses. Bishop's method and the circular slip surface discussed in details in literature review chapter, section 2.6.

A strip foundation was used beneath the wall, the foundation made of concrete with thickness of 0.5m. The bearing capacity for the foundation soil was calculated using Terzagi's ultimate bearing capacity (Das, 2015) for strip foundation shown in equation (3.1).

$$q_u=c`*Nc + q*Nq + 0.5*\Upsilon*B*N\gamma. \qquad (3.1)$$

Where;

c′: cohesion of the soil.

Υ_{bulk}: unit weight of soil.

Nc, Nq and Nγ: Bearing capacity factors for the soil.

q: effective stress at foundation level (base).

B: width of foundation.

3.5.1.1 Standards and codes

Global factor of safety

Analysis according to the factor of safety (ASD) as referred in GEO5 2016 is used.

Factors of safety are differentiated according to the type of the used parameters. For effective stress state, factors of safety for circular slip plane and non-circular surface was FoS= 1.35 and this approach was implemented on all the studied sites. For total stress state, factor of safety was FoS = 1.5 and this approach implemented on sites with clayey silty sand. For sand and gravel sites, total stress state was not used because there is no undrained condition for cohesionless soils.

EN1997 DA1

The gravity wall analysis was done using GEO5 software, using Eurocode 1997 with DA1 designing approach by automatically reducing the parameters of soils by the corresponding partial factors. The design situation used in analyzing the walls was for permanent design.

In wall analysis, Coulomb method was used for active earth pressure calculation. Standard for masonry (stone) wall analysis was EN1996-1-1(EC6). In slope stability and wall analysis two combinations were used to reduce actions and soil parameters by partial factors. Utilization was used to check resisting moment to sliding moment.

3.5.1.2 Analysis strategies

Inspections of slip surface type and restrictions for slip surface analysis will be discussed for face stability and global stability.

Free setting strategy is used as well beyond the face and global strategies. The free setting stability gave the freedom for slip surface to occur through a slope with no restrictions, to check the possibility of any failure could happen that not considered in face or global stability strategies. In addition, consequences of any failure will be discussed.

Face stability

Using the GEO5-slope stability package, the face stability is used to check the possibilities of failures for the superficial soil layers located on the slopes. This failure could happen for many reasons but the consequences of this failure will be minor comparing with the global failure.

Checking the face stability using restrictions to the slope model with a depth of 1m and checking the factor of safety according to this type of failure are needed. The face stability restrictions will take place on the face of the slope to check the possibility of any future slip surfaces. If the stability ratio is less than the factor of safety, some minor improvements could take place like vegetating the slope, on-slope or upslope drainage system or regarding the slope.

Global stability

The global stability strategy checked any major failure could happen through the wall and the slope including the superficial and partial failures. Restrictions for this strategy used to check the slip surfaces deeper than 1m from upslope to the toe of the wall. If the stability analysis indicate any failures, major consequences could happen including catastrophic failures which will surpass the minor consequences to major noes over the ditch like failures in the wall or closures to the high way route.

Major improvements could place in case of problems in global stability which could differ according to the type of the caused consequences and the possibility of occurring.

3.5.2 Assessment of rockfall sites

Rockfall events can happen along any highway route cuts, which produce significant risks for both humans and properties. These events may result to various types starting from damages to the pavement and the assets nearby to road closures and damages to the vehicles and even injuries to passengers or facilities.

Rockfall may occur when the type of rock present at upslope is vulnerable to uncertainty and has a cracked or fractured structure. This could pose significant risk to the users of a highway, especially if these are no protection measures around the highway.

Evaluation of the geometry of the rock slope, geological characteristics of the type of rock present, climatic features and historical records of rockfall are the key features studied in this thesis.

Particularly the following features are investigated for the rockfall sites identified along the highway route studied in this thesis;

- Slope height,
- Highway width,
- ditch effectiveness,
- volume of traffic,
- decision sight distance,
- ground condition,
- ground water or surface water,
- climate,
- historical records of rockfall or observations on the block size and distribution on site.

In this context Rockfall hazards Rating System (RHRS) implemented in this thesis is based on (Pierson, 1991) with some of the factors used modified considering local conditions along the selected highway route.

The RHRS is a system to evaluate the rock slopes in a way to manage and provide a rational method of how to make decisions about these slopes.

RHRS is comprised of the following stages;

- Slope survey,
- preliminary study,
- detailed rating.

Upon completion of the rock slope surveys the preliminary rating is carried out in accordance with the following Table3.5;

Table 3.5. Preliminary rating for rockfall slopes (Pierson, 1991).

Criteria\Class	A	B	C
Estimated potential for rock on roadway	High	Moderate	Low
Historical rockfall activity	High	Moderate	Low

According to this rating, when a slope is rated as ‘A’ class, that means the slope need to be evaluated, while ‘B’ class means that the slope could be evaluated when the time and funding allows. Class ‘C’ means there is a low potential of hazard coming from this slope, hence there is no need for evaluation.

The detailed rating comprises 10 categories that helps to differentiate the hazards associated with rock slopes according to their potential of occurrence. The slopes with highest score are the most hazardous ones. The rating scores each slope hazard in an exponential system to highly and quickly modify and differ the highest and lowest hazardous slopes. The scores increase according to the increase in risk, exponentially from 3 to 81, and then a continuum score is calculated out of 100. The 10 categories of the detailed rating are:

1- Slope height:

This relates to the vertical height of the slope. If rocks exist at high level, they have more potential energy to fall than the ones at a lower level, and this principle rates the former as higher risk composed to the latter.

2- Ditch effectiveness:

The effectiveness of the existing ditch depends on the ability of this ditch to prevent and retain all the fallen materials from reaching the highway. The concurrency of reaching the fallen rocks to the roadway controls the level of risk of the existing ditch and its function. There are several factors that affect the effectiveness of the ditch such as: slope height and angle of inclination, dimensions of the ditch (width, depth and shape), quantity of rocks per event, Types of the rocks, size of boulders, slope irregularities. According to the RHRS there are 4 rating classes that explain the level of each hazard: good catchment means that no rocks reach the highway, moderate catchment means that some of the fallen rocks reach the highway, low catchment means that rocks frequently reach the highway and no catchment means no caught rocks by the ditch at all.

3- Average vehicle risk:

This category measures the possibility of presence of a vehicle during a rockfall event. According to an equation considering the slope length, the average of daily traffic (ADT) and the speed limits in that section of the highway, a rating is calculated; 100% rating means that one car may exist at that section during a rockfall event, whereas more than 100% rating means more than one car on average may exist during a rockfall event;

$$\frac{ADT\left(\frac{cars}{day}\right) * Slope\ length \frac{km}{24\left(\frac{hours}{dy}\right)}}{Speed\ limit\ \left(\frac{km}{hour}\right)} * 100\% = AVR \quad (3.2)$$

4- Percent of decision sight distance:

This category measures the percentage of the distance that the driver may notice prior to acting to stop in the event of a rockfall. The decision sight distance recommended by "Policy on geometric design of highways and streets" will be used in this research (AASHTO, 2001), which is presented in Table3.6.

Table 3.6. Decision site distance per speed limit (AASHTO, 2001).

Posted speed limit (km/hr)	Decision sight distance (m)
48	137
64	183
80	229
97	305
113	335

In order to determine the percent of decision sight distance, the following equation can be used (AASHTO, 2001);

$$\frac{Actual\ sight\ distance}{Decision\ sight\ distance} * 100\% = DSD(decision\ sight\ distance)\ \% \qquad (3.3)$$

5- Roadway width:

This category relates to the area of manoeuvring that the driver may have to avoid rock on the road. The width can be measured for the paving section of the roadway only from the edge of the pavement to the other edge several times along the section affected, and the minimum is taken, take on the safe side in case the roadway width is not constant.

6- Geological character.

Geological conditions can affect factors such as block size and weathering. Block size can be affected by the construction method that the highway route were constructed, rock types and the structural conditions like joints in the asset specially length and spacing of these joints (Vandewater et al., 2005).

Table 3.7. Rating criteria and score for rock fall slopes (Pierson, 1991).

Category			Rating criteria and score			
			3 points	9 points	27 points	81 points
Slope height			7.6m	15.2m	22.9m	30.5m
Ditch effectiveness			Good catchment	Moderate catchment	Low catchment	No catchment
Average vehicle risk			25% of the time	50% of the time	75% of the time	100% of the time
Percent of decision sight distance			Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value
Roadway width			13.4m	11m	8.5m	6m
Geological character	Case 1	Structural condition	Discontinuous joints, favourable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		Rock friction	Rough, irregular	Undulating	planar	Clay infilling, or slicken sided
	Case 2	Structural condition	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
		Difference in erosion rates	Small difference	Moderate difference	Large difference	Extreme difference
Block size / Volume of rockfall event			30.48 cm/ 2.29 cubic metre	60.9cm/ 4.59 cubic metre	91.44cm/ 6.88 cubic metre	121.92cm/ 9.17 cubic metre
Climate and presence of water on slope			Low to moderate precipitation, no freezing periods, no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
Rockfall history			Few falls	Occasional falls	Many falls	Constant falls

7-Block size or quantity of rocks per event. The following Table3.7 is used for this rating. The geological character rating scheme used in this study is presented in Table 3.8;

Table 3.8. Hazards according to geological characteristic (Vandewater et al., 2005).

Geological characteristic	Low hazard			High hazard
Case 1				
Structural Condition	Discontinuous joints, favourable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
Rock Friction	Rough, irregular	Undulating	Planar	Clay infilling or slickensides
Case 2				
Structural Condition	Few differential erosion features	Occasional differential erosion features	Many differential erosion features	Major differential erosion features
Difference in Erosion Rates	Small difference	Moderate difference	Large difference	Extreme difference

In case 1 the rockfall structurally depends and affected by discontinuity size, orientation and the rock friction. While case 2 is for differential erosion features. For structural condition in case 1, discontinuous joints can be determined as less than 3.3m in length, while continuous joints can be determined as greater than 3.3m. For the rock friction, the smoothness of the surface of the joints are integrated.

For case 2, structural condition describes the surficial weathering features of the rock slope and the difference in the erosion rates describes the formation of these features based on weathering at the slope’s face.

The rockfall modes

Three of the most important rock slide failures will be discussed as following:

1-Plane failure:

This type of failure mode could happen when a single or two discontinuities intersect together to create a free movement of the blocks or wedges of the rock mass. The combination of the discontinuities may link with other existing combination at the same rock slope and the rock slide will take place.

2-Wedge Failure:

In this type of failure the rock mass slides along two intersecting discontinuities. This failure requires two line of intersection, with angles of dip for one combination of joints greater than the angle of friction of the rock and the lines of the intersection can be perpendicular to the slope face and dip towards the slope.

3-Toppling failure

The toppling failure can happen when columns or slabs of rock are rotated about the base of the slope away from the slope face. The columns of the rock can be formed by steeply dipping discontinuities in the rock slope and the centre of gravity for these moving columns falls outside the geometrical dimensions of the rock slope.

The following Table 3.9 is implemented in the assessment of rockfall sites. The term abundance in the following table means expression as a percentage of the total slope face surface area containing the mode.

Table 3.9. Scoring schemes for the Tennessee RHRS Geological Character (Vandewater et al., 2005).

Planar Rockfall Mode				
Abundance	<10%	10–20%	20–30%	>30%
Score	3	9	27	81
Block size	<0.3 m	0.3–0.9 m	0.9–1.8 m	>1.8m
Score	3	9	27	81
Steepness(degree)	0–20	20–40	40–60	>60
Score	2	5	14	41
Friction (micro/macro)	Rough/ undulating	Smooth/ undulating	Rough/planar	Smooth/planar
Score	2	5	14	41
Wedge Rockfall Mode				
Abundance	<10%	10–20%	20–30%	>30%
Score	3	9	27	81
Block size	<0.3 m	0.3–0.9 m	0.9–1.8 m	>1.8 m
Score	3	9	27	81
Steepness(degree)	0–20	20–40	40–60	>60
Score	2	5	14	41
Friction (micro/macro)	Rough /undulating	Smooth/ undulating	Rough/planar	Smooth/planar
Score	2	5	14	41
Topple Rockfall Mode				
Abundance	<10%	10–20%	20–30%	>30%
Score	5	4	41	122
Block size	<0.3 m	0.3–0.9 m	0.9–1.8 m	>1.8 m
Score	5	14	41	122
Differential Weathering Rockfall Mode				
Abundance	<10%	10–20%	20–30%	>30%
Score	3	9	27	81

Table 3.9 (cont.)

Block size	<0.3 m	0.3–0.9 m	0.9–1.8 m	>1.8 m
Score	3	9	27	81
Relief	<0.3 m	0.3–0.9 m	0.9–1.8 m	>1.8 m
Score	3	9	27	81
Raveling Rockfall Mode				
Abundance	<10%	10–20%	20–30%	>30%
Score	3	9	27	81
Block size	<0.3 m	0.3–0.9 m	0.9–1.8 m	>1.8 m
Score	3	9	27	81
Shape	Tabular	Blocky	Round	—
Score	3	9	27	—

3.5.3 Assessment of natural earth slopes

The natural soil slopes may provide various types of landslides. The hazards that come from these geotechnical assets may produce many risks to the surrounding environment, they may occur gradually or suddenly without any alarm.

The methodology used to assess natural earth slopes involves observation of the changes on the original geometry of the existing natural soil slopes. Then a slope stability assessment is implemented for these assets using the computer programme GEO5 2016, slope stability package, to check the factor of safety of the geometry of these slopes against formation of critical slip planes.

The evaluation methodology for natural earth slopes considered various factors that can be used as an evidence that the slope is in a critical situation.

The following features are that included in condition appraisals for natural earth slopes, which can be indicators for potential landslide movements:

-Any springs, seeps or different levels of saturated soils on previously dry slopes.

-Evidence of ground cracks on the slope, or any type of cracking on rocks located at the head of the slope or on structures built next to the slope.

-Any tilting or tension cracking on sidewalks or culverts that are built at the bottom of the slopes.

-Offset fence lines that occurred on the slope starting from the upslope.

-Unusual bulges that occur to the structures built near or in the proximity of the slopes, or distortion or any differential settlements or changes in elevation of the pavement alongside the slopes (Highland, & Bobrowsky, 2008).

3.6 Developed methodology for geotechnical asset management

Geotechnical asset management is a method to manage all risks developed by the failures or partial failures of the geotechnical assets. Geotechnical asset management can develop a way to face risks, predict or analyze the most critical assets along a highway route, so that steps can be taken on time to minimize the risks. In order to manage risk, eliminate the uncertainties of the critical geotechnical assets and reduce the damage that may arise from potential failures, periodic data collection, and assessment is required. Geotechnical asset management is a methodology of arranging all these to be carried out in accordance with the relevant methods of condition appraisals and technical codes and standards. In addition, it also involves a decision making process about the maintenance or improvement options to prevent failures and/or increase the service performance and life of the geotechnical assets.

Geotechnical asset management should also include reporting on budgeting required on a time-based plan.

3.6.1 Data management

Collecting data for the geotechnical assets is carried out on 02.01.2016, 27.03.2016, 21.07.2016 and 14.08.2016 by different visits to provide any observable changes as much as possible with the duration of this study.

The data collected in the early stages is used to make a selection within the existing geotechnical assets for detailed studies. The data collected can be divided into two main classifications as summarized in the following;

- Desk study: Maps, preliminary site visits for asset selection, photos and observations.

- On-site data collection: visits to geotechnical offices for collection of data on geology of along the route, traffic and route geometry data and maintenance records of the assets. Site visits following on the preliminary visits for condition appraisals of the selected assets.

The general features observed in the data collection process are presented in Figure 3.1.

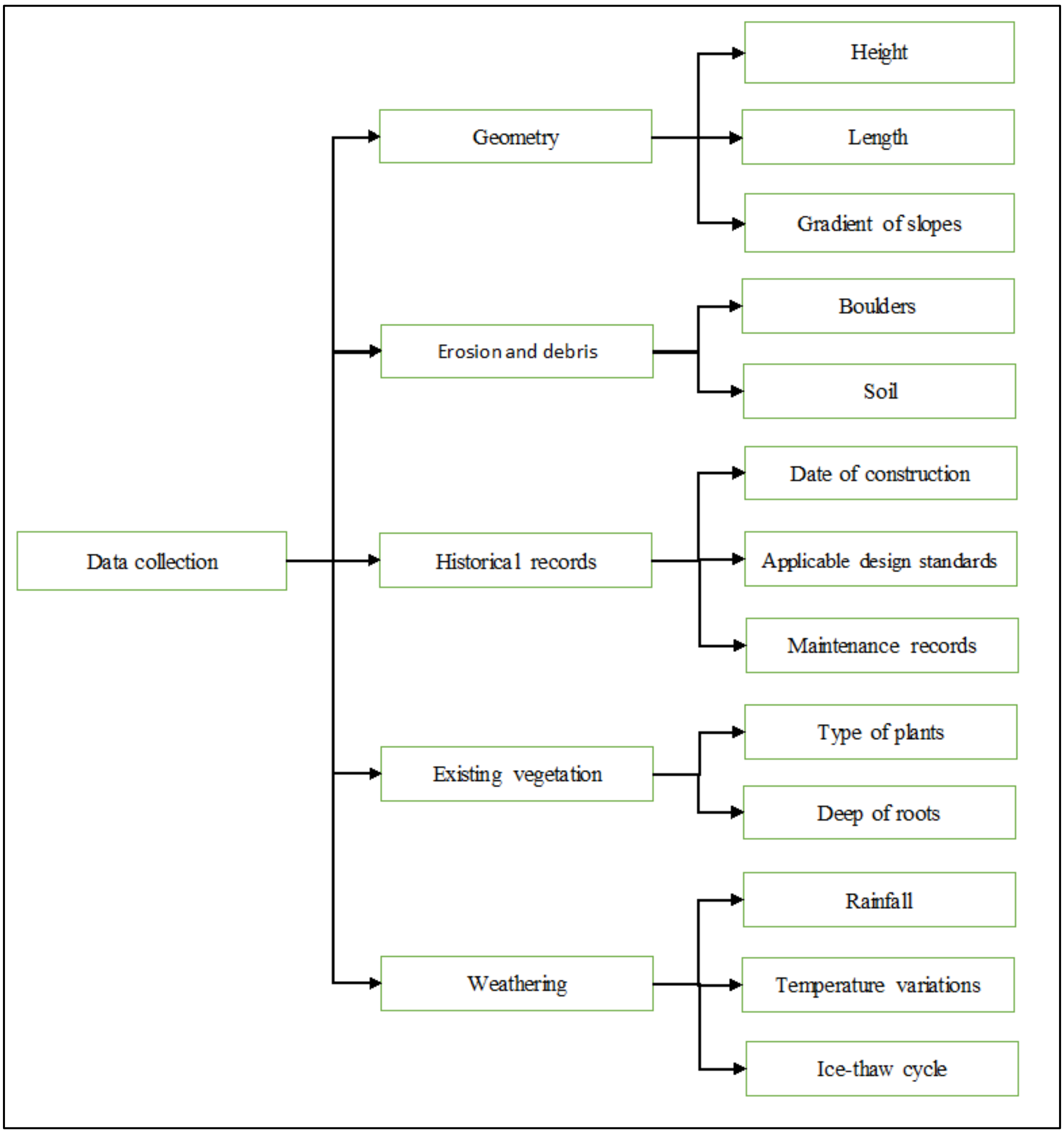

Figure 3.1. The general feature observed in the data collection process.

3.6.2 Decision making process

Geotechnical asset management provide two inter linked strategies that help to maintain the geotechnical assets:

1. Periodic/regular data collection in the form of observations fed into condition appraisals and,

2. Analysis of data and assessment of maintenance and/or improvement needs of assets.

When the above two strategies are implemented routinely, the service life of the assets and catastrophic events due to their sudden failure can be avoided.

In this section, the procedure developed from data collection to analysis and interpretation of the results is presented. In the developed asset management procedure, there are these main stages;

1. Preliminary study and reconnaissance.
2. Data interpretation and surveys.
3. Decision making process and plan.

The first stage is generally related to data collection and functionality with the route, the details of which are discussed in the previous section. It contributes largely to the formation of a background data set, within which observation recorded in various periodic visits help identification of worst critical assets that may need urgent attention.

In the second stage, detailed condition appraisals are carried out and the assets are categorized based on their functional use. The preliminary observations are supported with data collected in additional visits and trends, if any, in asset performance are studied.

The second stage is followed by the decision making process and development of plan for “do nothing”, “maintenance”, or “improvement” options. At this stage, a qualitative methodology is required to convey the results of the condition appraisals and hence, where possible, engineering stability analysis are used to support the scoring system adopted for the geotechnical assessment.

The results of the scoring lead to the three option selected above and there is an iterative analysis added in the end to help with obtaining an approximate estimate of the risks versus costs on the basis of the intervention planned to be implemented. In order to achieve this, a life cycle cost analysis and a risk assessment are run in parallel. Finally, a decision is reached and the recommended budget planning can be presented for each asset or for the whole route.

In the final process the key stages affecting the decision made are the geotechnical assessment for the assets and the results of the engineering stability analyses. The whole process of asset management is presented in the form of a flowchart in Figure 3.3.

The asset management process is a continuous or in other words “never-ending” process, decision requires routine periodic data collection, analysis, and assessments. The results should be continuously fed into risk analyses and life cycle cost analyses to update decisions. So that, the planed budgets can be checked and corrected if there is an urgent need. Figure 3.2 shows the global stability analysis for site eastern side according to EN1997DA1.

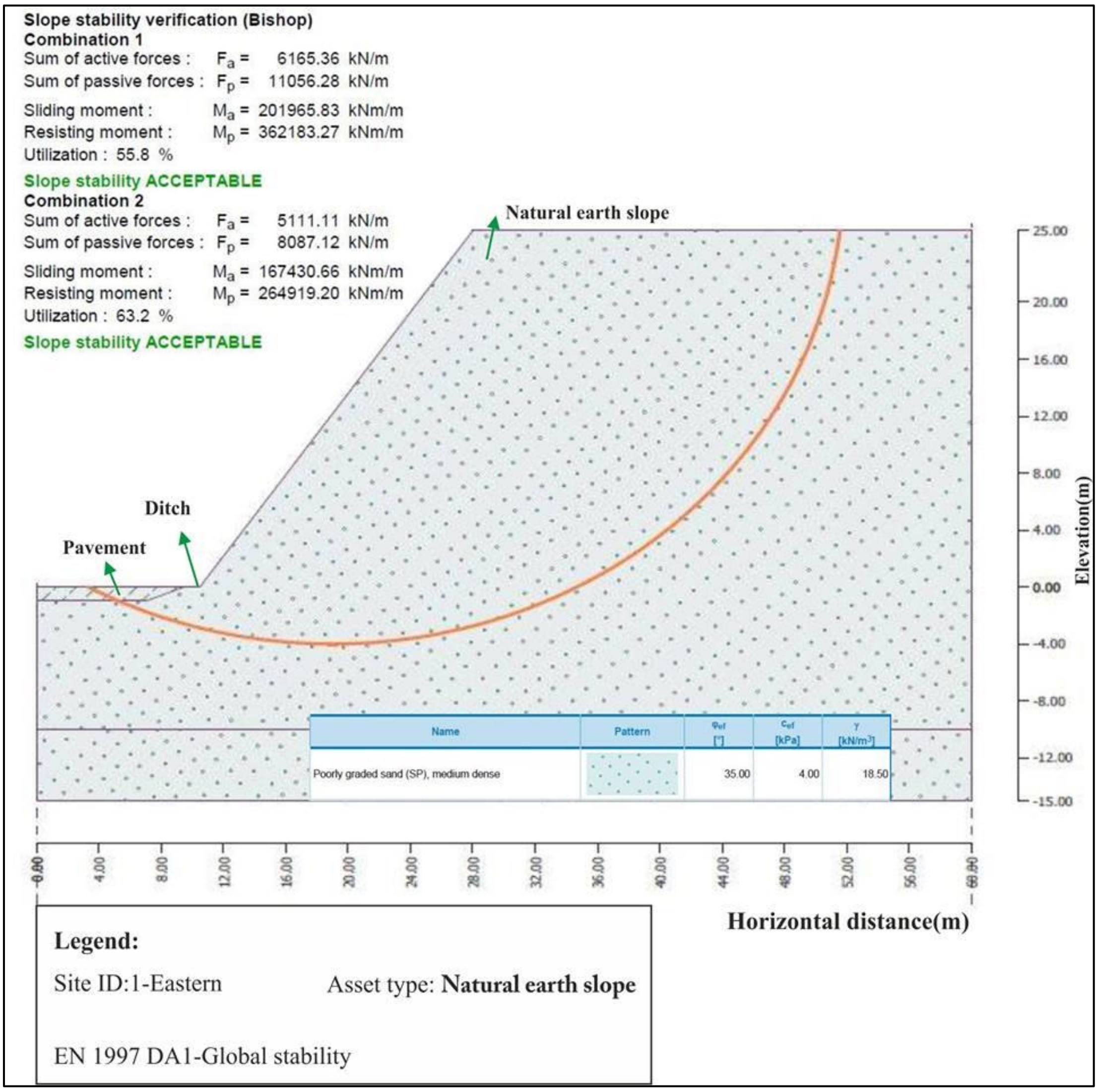

Figure 3.2. Site1-Eastern-EN1997-Global stability.

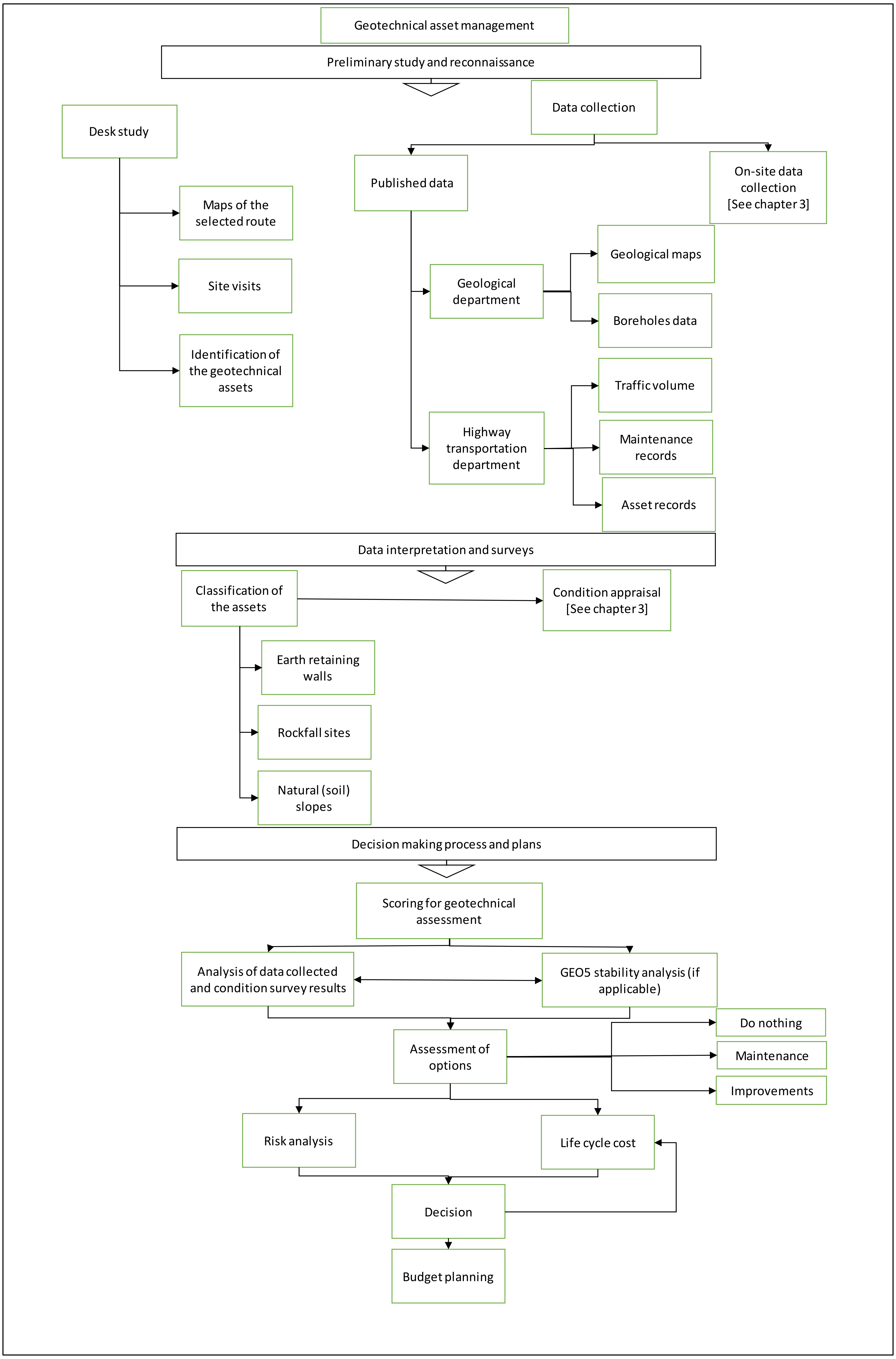

Figure 3.3. Geotechnical asset management stages.

For the selected highway route in this study, there were no records or historical review for the geotechnical assets to determine the frequency of condition appraisals. The frequency of the condition appraisals can be assumed to be once every five years for all the geotechnical assets according to various standards (Collin et al., 2008).

3.6.3 Assessment of Life cycle cost

3.6.3.1 General

In this research, a sensitivity analysis is used in order to assess the life cycle cost for the options decided for the selected assets. Sensitivity analysis helps to quantity uncertainties in the life cycle cost assessment based on the assumption made, the methodologies used indicate collection and the analysis methods used. Therefore, as the decisions made are affected by the life cycle cost analysis, it is critical to optimize the analysis results with a sensitivity analysis.

3.6.3.2 Sensitivity analysis

The sensitivity analysis may be the method to use in the economic risk assessment for the life cycle cost analysis. The sensitivity analysis method may give an approximated judgement for two alternatives. This method uses values of the input parameters, which they are affected by the variation of other input parameters, in other words "how sensitive is this alternative to the variation in the relevant parameters". The input parameters are all the costs involved in the life cycle cost analyses such as; the initial costs, energy costs, associated costs etc.

The determination of the 90% high and low estimates for the input costs was difficult according to the local market, so that, sensitivity analysis is used instead of the confidence index approach.

Although, no calculations are carried out for the sensitivity analyses, the concepts of the sensitivity analysis is involved in the decision making process. The selected improvements for the geotechnical assets were less sensitive to input costs than the other alternatives.

3.6.4 Options for decision making process

3.6.4.1 Do nothing option

For some of the assets there is no need for improving the asset or any preventative maintenance. This option is then assigned where the geotechnical assessment results are showing that the asset does not need any intervention. In this research, this option does not add any costs to the life cycle cost for the asset it is assigned.

3.6.4.2 Maintenance for earth retaining wall

The following procedure is the suggested routine maintenance plan for earth retaining walls, which include routine maintenance for the following features: surface drainage and catch pits, weep holes and drainage pipes, wall face, wall's topping, pavement and the backfill. The detailed information about these features maintenance are presented in the following Table3.10.

Table 3.10. Maintenance for the features of earth retaining walls.

Feature	Maintenance
Surface drainage or catch pits	Routine maintenance should include clearing for debris, undesirable vegetation and other obstructions inside the surface drainage which clog the surface drainage. This method could be used for the culverts along the earth retaining walls as well.
Weep holes or drainage pipes	All debris and weeds inside the weep holes should be cleared. There should be double checking for deeper unseen obstructions. In case of a clogged weep hole, the weep hole should be replaced.
Wall face	The cracked and spalled joints should be repaired. The missing blocks in joints should be filled also.
Wall's topping	The preventative maintenance for wall's topping contain repairing and refilling for all missing parts of the topping of the earth retaining walls.

Table 3.10. (cont.)

Pavement	Repair all cracked or deteriorated pavements along the earth retaining walls.
Backfill	Apply minor regrading to backfill soils with potential of forming a slip surface behind the earth retaining wall.

3.6.4.3 Maintenance for rockfall sites

The recommended maintenance for the rockfall sites is presented in Table3.11. The routine maintenance plan for rockfall sites is straighter forward than the plans for earth retaining walls or the soil slopes. The maintenance procedure may cause rockfall hence, it is recommended to use barriers around the maintenance site during any maintenance works. The routine maintenance plan for surface drainage of the rockfall sites is the same as the earth retaining walls, if any drainage systems exist at these sites.

Table 3.11. Maintenance for the features of rockfall sites.

Feature	Maintenance
Rockslope	Remove all debris on the up slope. Remove unstable (dead) trees, where roots are observed to have caused cracks. This is a minor intervention and any kind of stability problems should be avoided.
Ditch or catchment sides	Clear the ditches from debris.

3.6.4.4 Maintenance of natural earth slopes

A summary of the recommended slope maintenance is presented in the following table, Table3.12.

Table 3.12. Natural earth slope maintenance.

Feature	Maintenance
Erosion	Control surface flow and erosion by controlling the velocity of the surface water flow through the slope by using retention basins or ditches. Increase soil resistance to flow by using geotextiles mesh or control blankets or by maintaining closely spaced shallow vegetation.
Top or toe drainage	Clear debris, undesirable vegetation and other obstructions which discussed in previously. Check the gradient and reinstate if needed. Any major cracks to be repaired in drainage systems.
Slope face	Minor regrading of all eroded areas on the face of the slope. For upslope maintenance, remove all rocks and other materials which can cause debris flow.

3.6.5 Improvement options

3.6.5.1 Natural earth slopes and earth retaining walls

Improvement methods are needed where the routine preventative maintenance cannot resist or prevent future failure. Improvement methods can be in different ways according to the current condition and the expected failure mode of the geotechnical asset. The asset type controls the type of improvement method that can be applied.

In this thesis, there are four improvement methods considered. These improvement methods are categorized according to the slope hazard that they are targeting to treatment;

1-Wall modification.

2-Drainage provision.

3- Backfill soil stabilization.

4-Major regrading.

Wall modification involves increasing the wall site or application of strengthening option for the walls or backfill slope. These are briefly predicted in the following Figures3.4, 3.5, 3.6 and 3.7.

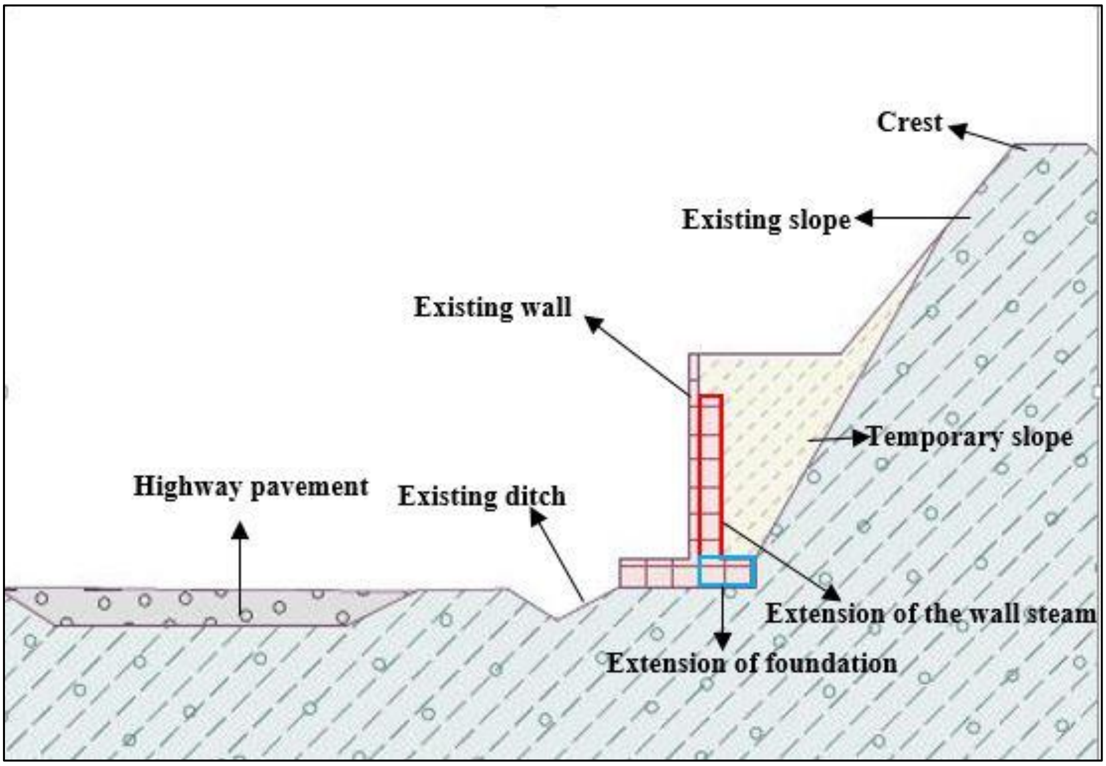

Figure 3.4. Increasing wall site (Wall modification).

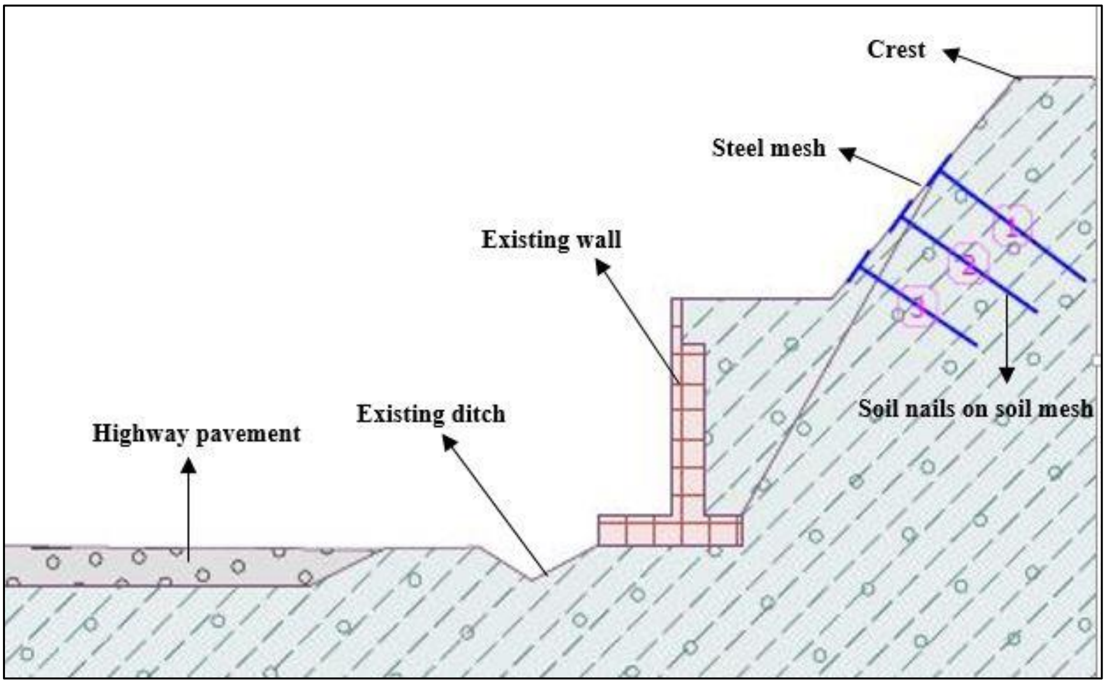

Figure 3.5. Reinforcement of backfill slope (Soil stabilization).

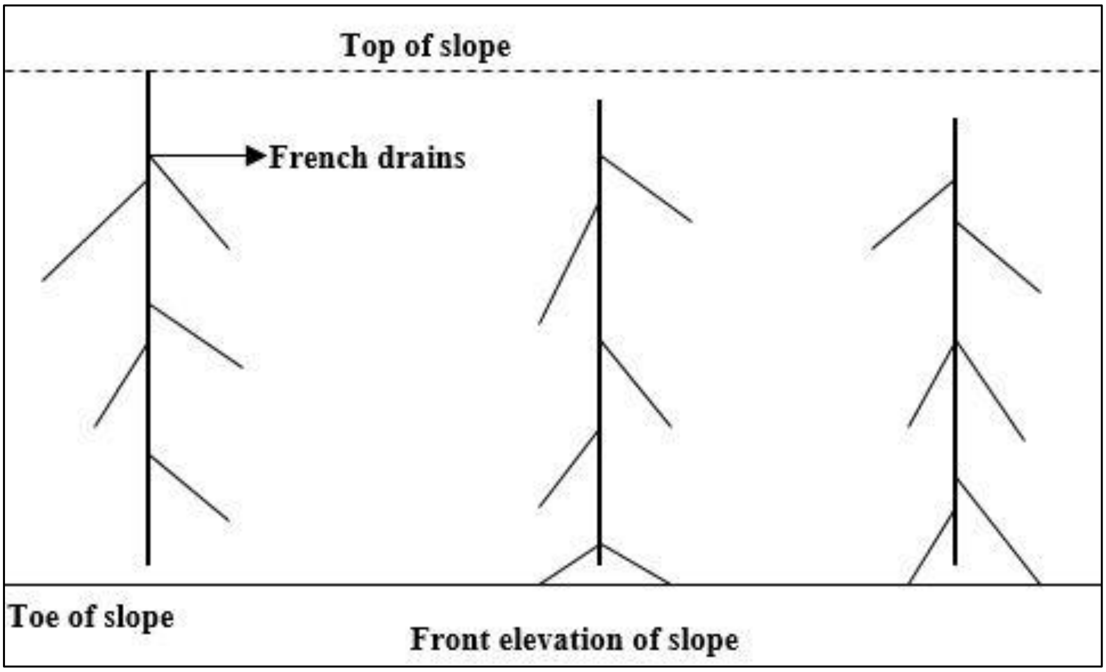

Figure 3.6. On-slope drainage.

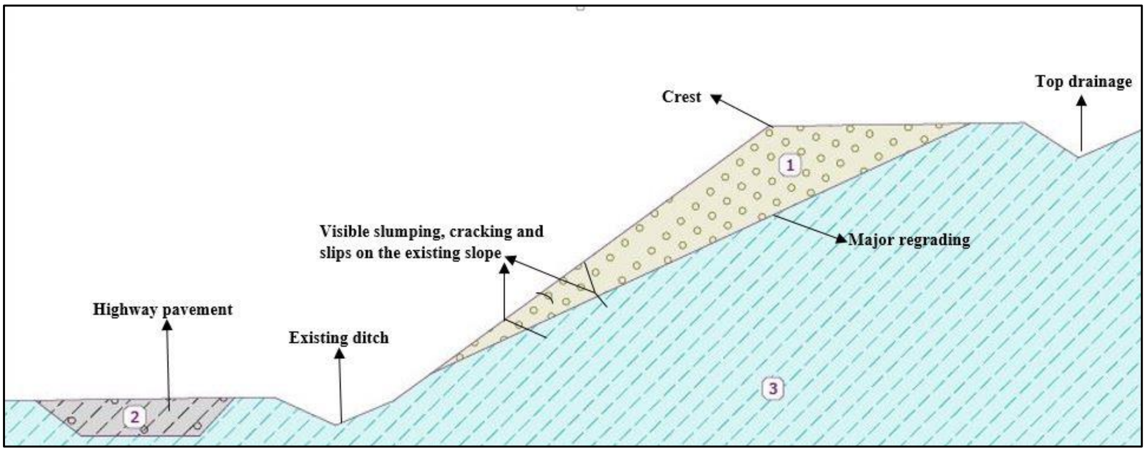

Figure 3.7. Major regrading.

Preventing surface flow of water from removing the soil particles is very important for the stability of the slopes. Distortions on slopes can be developed due to erosion, which can generally develop cracks, reducing the stability of the slope.

Hence, effective surface drainage is critical especially when fine grained soils are present on slopes (clay, silt and fine sand). Also routine maintenance of existing drainage system is necessary.

Vegetation can help to hold soil particles together, and also mechanically restrain major crack formation. Various types of vegetation can be used based on the slope angle. Telford (1995) discussed the difficulty of using vegetation cover for stabilization and protection purposes for slopes. He classified marls, chalk, mudstones and fine sands as the worst classes of slope strata to be stabilized by vegetation (Telford, 1995).

The usage of vegetation can be friendly to the environment, but the type of soil should be considered. Inclination of the slope can control the type of the vegetation, where on very flatten slopes deep rooted vegetation may be used such as trees and bushes. For steep slopes, shallow rooted vegetation may be used such as, grass or climber plants.

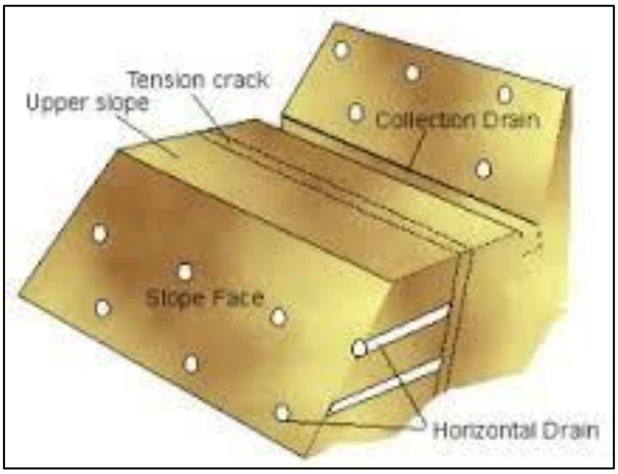

Figure 3.8. Horizontal drains.

Regarding is one of the best options to stabilize natural slopes or for retained slopes. The new slope after regarding will have a reduced angle of inclination, which increases the stability of the site. For the assets considered relatively small site excavators can apply regrading or terracing over the slopes. Geotextiles mesh or reinforcement can also be used for stabilizing slopes.

3.6.5.2 Rockfall sites improvement and stabilization methods

Various techniques can be used for the rockfall sites, the following are the techniques categorized according to their function, presented in Table3.14.

Table 3.13. Rockfall sites improvement techniques.

Improvement technique	Function
Scaling and rock removal	Removal of loose rocks from the slope by mechanical equipment. If needed, this method can be repeated every two years.
Blasting	If significant risks exist, removing loose boulders can be performed by blasting. This method requires skilled labour.
Resloping	The rock slope can be cut to a flatter angle to enhance the stability, or if the type of rock allows, the slope can be benched into steps, which reduce the velocity of the fallen rocks and can act as catchment.
Dowels and rock bolts	Rock bolts or dowels can be used to provide face stability. Rock bolts can be in the form of tensioned bars, dowels are untensioned steel bars.
Shotcrete	Erosion and spalling can increase the loss of supporting blocks on the rock slope. Applying shotcrete on the rock slope can help to stop losing rock blocks and ongoing loss of supports. Shotcrete is a special concrete designed without the use of coarse aggregates and it has the ability to be sprayed on slopes using special equipment.
Barriers on rock slope	Draped mesh can be used which require ditch areas to collect the fallen debris. Wire mesh and slope nets can control the fallen rocks on the slope to the ditches.
Ditch barriers	Rock fall barriers can vary from flexible to rigid barriers which can use to stop fallen rocks from reaching the highway route by including the ditch areas which used as safe side distances to prevent movements of rocks.
Other methods	Other methods such as buttresses, cable lashing and anchored wires can be used to strengthen stability of the rock slope and hold the boulders in place.

Figure 3.9. Rigid barrier (Fred Gullixson, & Peltz, 2013).

Figure 3.10. Net fence barrier (Fred Gullixson, & Peltz, 2013).

3.6.6 Frequency, time line analysis and time line plan

The frequency for routine preventative maintenance for all of the geotechnical assets along the highway route between Nicosia and Kyrenia is suggested to be once in a year. The routine preventative maintenance works are discussed in sections 3.6.4.2, 3.6.4.3 and 3.6.4.4. It is also recommended that the drainage systems are checked after significant climatic events.

The budget plan can be obtained by checking the time line plan for the assets. The time line plan for all the assets developed to obtain the suggested and necessary works (maintenance or improvement) related to each asset. The time line plan set to be flexible for any changes to the time line for all the assets. The sequences in the time line plan set to be every 5 years. The suggested lifespan in the timeline plan is 30 years for every asset. The budget plan can be discussed further with the local departments.

3.6.7 Risk assessment

Geotechnical asset management is a way to reduce and eliminate the hazards coming from the geotechnical assets. All hazards coming from the sites can be considered as geodynamic processes such as landslides, slope movements and the deflections of earth retaining structures.

These hazards develop risks, which can be result to dangerous failures affecting the local environment surrounding the assets. The geotechnical asset management methodology developed in this thesis is to prevent these hazards developing risks for the selected geotechnical assets. It is also important to identify risks associated with the assets when they are not treated to help develop a reasonable budget and time line plan. Hence, it is very important to include all data inventory to produce a sufficient risk assessment study (Fredlund, 2007).

In this thesis produced an estimated risk assessment is produced due to insufficient data related to historical records for the selected assets. Although some ground parameters and geological information are collected, the data needed to produce risk assessments could not be obtained simply because a data set as such does not exist. Therefore, this thesis forms an important benchmark for a data set to be generated by related geotechnical bodies. The risk assessment plays an important role in the sensitivity analyses, as absence of significant risk means that a particular asset may be delayed for application of important works, or only intervention might be needed to bring the risk level of an asset to an applicable level so that the expenditure for the lifetime of the asset can be optimized to provide a sustainable timeline plan.

The consequence level of the analysis for the earth retaining walls will be checked considering the stability analysis and the geotechnical risk assessment in order to assess the level of resultant consequences if they are low, moderate or high consequences that will affect the functionality and the stability of the earth retaining wall.

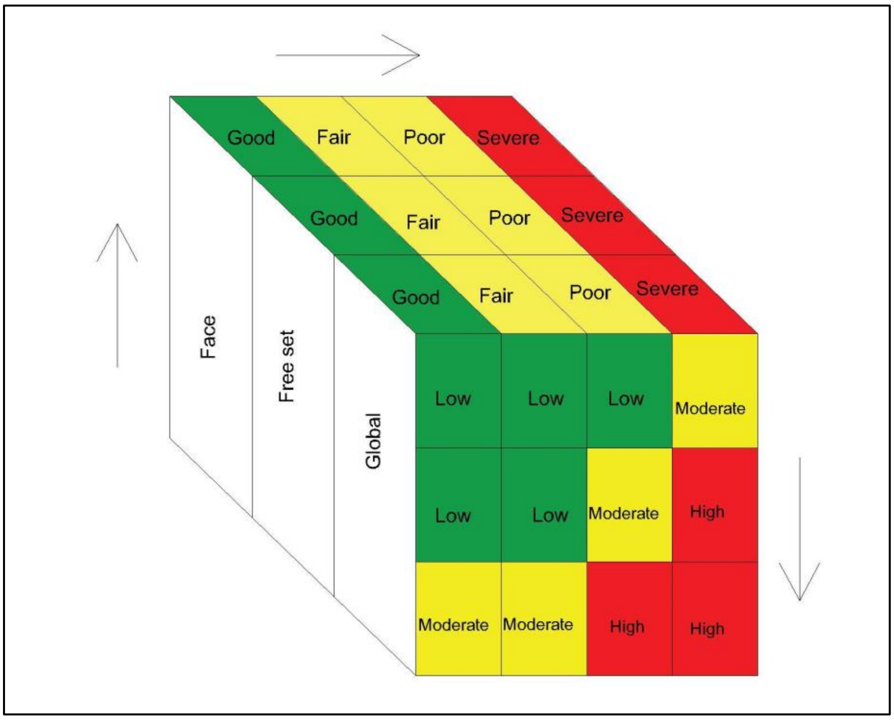

Figure 3.11. Consequence cube.

The consequence assessment for the natural slopes depends directly on the analysis results of the visual observations and the geotechnical analysis by GEO5. The consequence assessment will be classified as low, moderate or high consequence according to the risk level that indicated by the geotechnical analysis.

The consequence assessment for rockfall site will depends on the geotechnical risk assessment scoring which shown in the following Table3.15:

Table 3.14. Level of consequence according to the risk score.

Risk score	Level of consequence
<135	Low
<513	Moderate
>513	High

Chapter 4

RESULTS, ANALYSIS AND DISCUSSION

4.1 General

The selected assets are categorized based on their geometry and formation characteristics as discussed in Chapter 3. The results of the classification are presented in Table4.1 and Table4.2.

4.2 Interpretation of ground conditions

The geological formation of the soil strata along the highway route differs from site to site between Değirmenlik and Kyrenia. The assets located along the part of the route from Değirmenlik to Beşparmak Mountains are underlain by marine terrace deposits formed in the (Late Quaternary Period). The assets located along the route between Beşparmak Mountains and Kyrenia are generally underlain by various rock formations. The most common formation being sandstone according to the Geological Survey Maps (Hakyemz et al., 2002) also presented in Appendix F.

4.2.1 Ground Model for sites

As a result of the generic interpretation of the published geological records (Hakyemz et al., 2002), the available borehole records (MTA- mta-2 Değirmenlik, 1996), and the site observations, the following Table 4.1 is formed, which summarizes the rock outcrops in the local area of the selected assets.

Table 4.1. General classification of rock outcrops (based on geological maps, Hakyemez et al., 2002).

General classification of superficial strata				
SiteID(asreffered inChapter3)	Symbol	Formation	Age	Lithology
5	Ttk	Kanakkoy formation	Late traiassic	Dolomotic limestone
6,7,8,9 and 13	Q1bt	Flood sediments	Late quaternary	Tuff chalk, red earth(terra rosa)
11 and 14	Tdb	Buyuktepe formation	Early oligecene	Observed on site as various types of mixed soil deposits
4 and 10	Tdbe	Beylerbeyi formation	Late oligecene	Sandstone
12	Q3a	Marine terraces	Late quaternary	Sandstone and Marl
1,2 and 3	Q3b	Karasal seki	Late quaternary	Observed on site as various types of mixed soil deposits

Table 4.2. Collected data by site inspection.

Site ID	Number of included assets	Types of included assets	Location	
			Latitudinal	Longitudinal
1	2	Cut slope east/ Cut slope west	35.251198	33.461521
2	2	Cut slope east/ Cut slope west	35.25634	33.458351
3	1	Rock slope	35.264612	33.462093
4	1	Rock slope	35.273422	33.490111
5	2	Rock slope+culvert	35.274696	33.484505
6	1	Rock slope	35.278458	33.473293
7	1	Rock slope	35.27309	33.470406
8	1	Cut slope	35.286411	33.460434
9	2	Cut slope+Earth retaining wall	35.294315	33.442043
10	2	Cut slope+Earth retaining wall	35.296902	33.440979
11	2	Cut slope+Earth retaining wall	35.30949	33.423275
12	1	Rock slope	35.315132	33.423023
13	1	Cut slope	35.284242	33.462258
14	1	Cut slope	35.29	33.448436

Table 4.3. Collected data for earth retaining walls.

Site ID	Length(m)	Height(m)	Width(m)	Type of retained material
9	250	3	0.5	Soil
10	170	1.9	0.5	Soil
11	250	2.8	0.6	Soil

Table 4.4. Collected data for natural earth slopes.

Site ID	Length (m)	Height (m)	Type of materials	Diameter of boulders (cm)
1-Eastern	84	25	Rock+soil	26
1-Western	56	10	Rock+soil	26
2-Eastern	87	10	Rock+soil	
2-Western	110	30	Rock+soil	
8	46	10	Rock+soil	
13	100	10	Rock+soil	
14	110	12	Rock+soil	

Table 4.5. Collected data for rockfall sites.

Site ID	Length(m)	Height(m)	Type of materials	Diameter of boulders (cm)
3	130	36	Rock	
4	180	40	Rock	
5	100	10	Rock	80
6	150	20	Rock	40
7	250	30	Rock	35
12	300	6	Rock	

The bedrock geology interpreted from the available borehole records as summarized in the following Table4.6.

Table 4.6. Data on bedrock geology from available borehole records (MTA - 2 Değirmenlik, 1996, MTA-1975/37 Değirmenlik, 1976).

<table>
<tr><th colspan="5">Boreholes data</th></tr>
<tr><th rowspan="2">Borehole</th><th colspan="2">Approximate borehole coordinations</th><th rowspan="2">Depth (m)</th><th rowspan="2">Lithology</th></tr>
<tr><th>Latitude</th><th>Longitude</th></tr>
<tr><td rowspan="2">1975/37 Degirmenlik borehole</td><td rowspan="2">35.273469</td><td rowspan="2">33.479666</td><td>0-73</td><td>Hillarion Limestone</td></tr>
<tr><td>73-91</td><td>Dolomotic limestone</td></tr>
<tr><td>Mta-2 Degirmenlik borehole</td><td>35.273548</td><td>33.479842</td><td>0-18</td><td>White crystaline limestone</td></tr>
</table>

Although, for most of the sites rock outcrops can be interpreted for geological maps, when observed on site some of these sites are seen to have a superficial cover of soil deposits with unknown thickness. It is interpreted that some of these are brought to site on backfill materials for walls or gained from sites during post regrading works (earthen works). The geological assessment for these strata is mostly based on visual observations and therefore a convention approach is used to obtain parameters for site or materials from literature. Further back analysis is also performed for these sites to obtain shear strength parameters for a factor of safety against failure of the slopes.

4.3 Analysis parameters

4.3.1 Geotechnical parameters for slope stability

Slope stability analyses for natural soil slopes and slopes retained by the existing earth retaining walls are performed using the computer programme GEO5 2016. Natural slopes at sites 1, 2, 8, 13 and 14 are analysed by the Slope Stability package, whereas for sites 9. 10 and 11 which have earth retaining walls, Gravity Wall and Slope Stability analysis packages are employed consecutively.

The following Table4.7 and Table4.8 present summary of the geotechnical parameters used for slope stability analyses for these sites.

Table 4.7. Geotechnical parameters of Natural soil slopes (Bowles, 1988).

Site ID	Type of soil	Bulk unit weight, γ_b (kN/m^3)	Effective angle of internal friction, ϕ', (^{o})	Effective cohesion, c', (kPa)*
1-Eastern part-	Poorly graded sand-Medium dense	18.5	35	4
1-Western part-	Poorly graded sand-Medium dense	18.5	35	4

Table 4.7 (cont.)

2-Eastern part-	Poorly graded sand-Medium dense	18.5	35	3
2-Western part-	Poorly graded sand-Medium dense	18.5	35	3
8	Poorly graded gravel-dense	20	40	2
13	Poorly graded gravel-Medium dense	20	40	2
14	Clayey sand	18	26	10

*From back analysis.

Specific correlation are used to obtain the geotechnical parameters. For effective cohesion, the back analysis strategy is used while for effective angle of internal friction and bulk unit weight, shear strength correlations are used to obtain the values.The geotechnical parameters are “Assumed Parameters” interpreted from the ground model assessment study as described in the previous section. After assessment of the ground type and representative formation description, the data published in the literature for similar materials are adopted to enable analysis for the slope stability for the assets in the absence of any engineering data for the route. The generic interpretation only included effective internal angle of friction and bulk unit weight of the ground. The effective cohesion is interpreted based on back analyses. In the back analyses, considering the field observations, it is interpreted that there is no sign of catastrophic failures observable at the sites. Hence, from a conservative point of view, an imaginary failure plane of 1m deep from the face of the slope is assumed and, the effective cohesion corresponding to such a failure plane is back calculated. Long term behavior, effective stress analyses, are performed in the slope stability analyses. The slope materials are considered to be well drained for all of the sites.

Table 4.8. Geotechnical parameters of slopes with earth retaining walls.

Site ID	Type of soil	Bulk unit weight, γ_b (kN/m^3)	Effective angle of internal friction, ϕ', (°)	Effective cohesion, c′, (kPa)*
9	Poorly graded gravel-Medium dense	20	40	3
10	Silty clayey sand	18	26	10
11	Silty clayey sand	18	26	10

*From Back analysis.

The Gravity Wall package in GEO5 is used to model the existing earth retaining walls for sites 9, 10 and 11. The material used for the earth retaining walls is stone masonry Category I.

The angle of friction between the wall and the backfill soil is calculated according to the British Standard (BS 8002:1994, 2001), as presents in Equation 4.1;

$$\delta = 2/3 * \phi' \quad (4.1)$$

Where,

δ: angle of friction between the wall and the backfill soil.

ϕ' : effective angle of internal friction of backfill soil.

The following Table4.9 shows the parameters used in the calculation of the wall stability for sites 9, 10 and 11.

Table 4.9. Geotechnical parameters used in the analysis of earth retaining walls.

<table>
<tr><td>Wall properties</td><td>Unit weight of wall, γ, (kN/m^3)</td><td>f_k (MPa)</td><td colspan="2">f_{vko} (MPa)</td></tr>
<tr><td>Used to check internal stability</td><td>22</td><td>1.11</td><td colspan="2">0.1</td></tr>
<tr><td colspan="2" rowspan="5">Backfill properties in the calculation of stability forces</td><td colspan="3">Angle of friction between the wall and the backfill material</td></tr>
<tr><td>Site ID</td><td colspan="2">δ</td></tr>
<tr><td>9</td><td colspan="2">26</td></tr>
<tr><td>10</td><td colspan="2">17</td></tr>
<tr><td>11</td><td colspan="2">17</td></tr>
<tr><td colspan="2" rowspan="2">Foundation material properties</td><td>Unit weight of foundation material, $\gamma_{concrete}$, (kN/m^3)</td><td colspan="2">Foundation thickness, $d_{foundation}$ (m)</td></tr>
<tr><td>25</td><td colspan="2">1</td></tr>
<tr><td colspan="2" rowspan="4">Ultimate bearing capacity</td><td>Site</td><td>q_u (kPa)</td><td>B (m)</td></tr>
<tr><td>9</td><td>5371</td><td>3</td></tr>
<tr><td>10</td><td>783</td><td>2.9</td></tr>
<tr><td>11</td><td>859</td><td>3.76</td></tr>
<tr><td colspan="5">Notes:
Where,
B : is the approximate width of foundation.
q_u : is the ultimate bearing capacity.
fk : Compressive strength of wall material.
f_{vko} : Shear strength of wall material.</td></tr>
</table>

The backfill material with thickness of approximately 2m is presented in Table4.10. Those materials are observed to be formed of similar origin as the stones used in wall construction. Pavement materials used as compacted layers beneath the highway route as base and sub-base layers were modeled with the following parameters.

Table 4.10. Pavement foundation parameters.

Depth (m)	Unit weight (kN/m^3)	Angle of internal friction(^{o})	Cohesion (kPa)
1	20	38	0

4.4 Results of slope stability analysis

4.4.1 The most critical slip planes for earth retaining walls

Three types of stability was applied on the slopes retained by the earth retaining walls. Some partial failures and minor stability problems was obtained through the site visits and the stability ratios for those analyses indicate that. EN1997 DA1 used for those stability analyses and the modification results was shown in percentages as utilization out of 100.The results of these analyses are shown in Table4.11 classified according to the type of stability analysis. More details are presented in Appendix H.

Table 4.11. Slope stability analyses for earth retaining walls.

Site ID	Global stability		Face stability	
	EN1997 DA1	ASD FoS	EN1997 DA1	ASD FoS
9	56%	2.21	156%	0.8
10	67%	1.84	117%	1.14
11	113%	1.1	105%	0.86

Notes:

- ASD FoS represents the result of the global factor of safety approach.
- EN1997 DA1 represents the result of the Eurocode7 approach, where the results are indicated as percent utilization.

4.4.2. The most critical slip planes for natural slopes

For ASD global factor of safety approach it is considered that a factor of safety of less than 1.35 is not applicable. For EN1997 DA1 approach, it is considered that a percent utilization greater than 100% is not applicable. Hence, it is considered that the global stability of the walls are adequate, whereas problems may arise regarding the face stability of the backfill especially for site 9.

According to the global factor of safety and the EN1997DA1, analyses carried out for the natural earth slopes, all of the sites indicated exceedance of the acceptable limits as presented in Table4.11. At some of the sites such as site 1 and site 2, deposits of sandstones/siltstones with alternating layers of sand/silty sand, have made it difficult to model the actual conditions on site in the computer analyses. At these sites, those layers of rock may act like reinforcement perpendicular to the plane of slip.

Photos of the front elevation of the slopes at site 1 and 2 are presented in Figure4.1, which shows the rock layers in the slope. The shear strength properties of the soil between the rock layers are considered in the stability analyses, hence the reason for low factors of safety in the analyses results. The reinforcement effect from those interbedded rock layers are considered to affect the overall (mass) shear strength and the stability of the slopes.

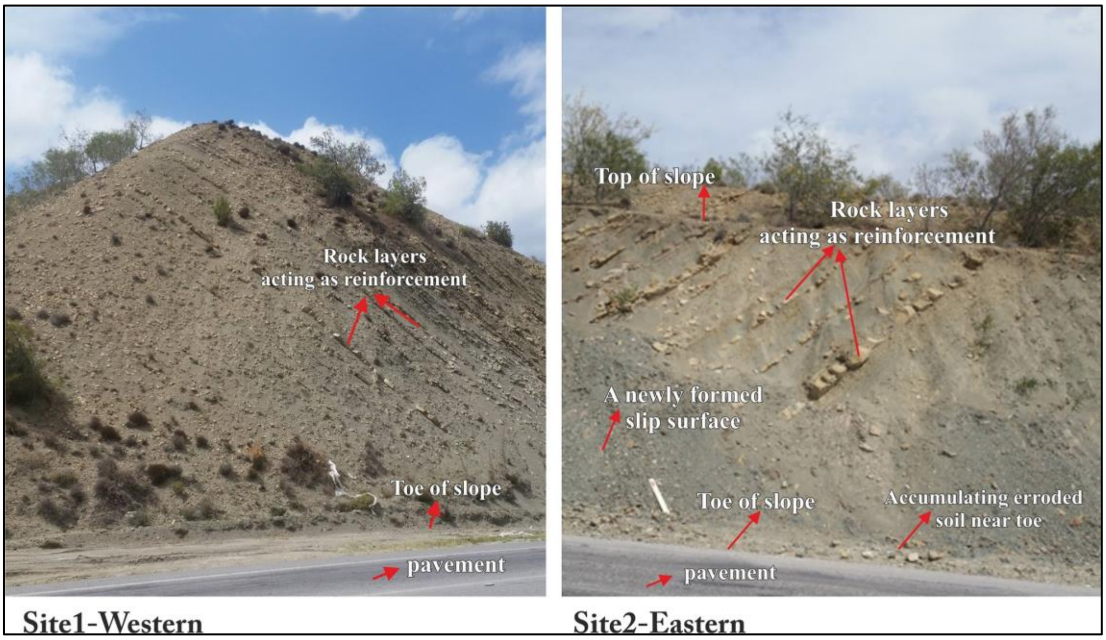

Figure 4.1. Front elevation of site1-western and site2-eastern with rock layers.

Sites such as 8, 13 and 14 are considered to be reinforced by a rock face which reinforcing the face slope against any failures. Sketches for natural earth slopes with analyses are presented in Appendix H.

Table 4.12. Slope stability results of the natural earth slopes.

Site ID	Global stability		Face stability	
	EN1997DA1	ASD FoS	EN1997DA1	ASD FoS
1-Eastern part-	63%	1.98	180%	0.69
1-Western part-	48%	2.56	279%	0.45
2-Estern part-	38%	3.29	180%	0.69
2-Western part-	66%	1.89	363%	0.34
8	37%	3.3	234%	0.53
13	24%	5.11	195%	0.64
14	63%	1.97	212%	0.59

Notes: Analyses did not model the rock layers in slope. It is considered that the rock layers act as reinforcement in the plane vertical to the potential slip planes. The rock layers inclination is according to the tectonic movements through the geological formation of the slopes. The inclined rock layers can provide additional frictional surface at the slopes.

4.5 Geotechnical risk assessment results

4.5.1 Earth retaining walls

All condition appraisal data for the sites are analysed in this section. Generally, similar observations are obtained for all these sites, site9, site10 and site11. Some vertical deflections are observed through investigating the masonry walls. There were some evidence for bulges or distortions, however these could not be differentiated whether they were due to construction or happened afterwards. Joints between adjacent sections of walls were misaligned, as a result of settlement of some parts of the wall, other joints in the wall between stones were in a good condition. The joints between stones were not misaligned, the sections of the wall reused to be integral as one unit. Due to the general misalignment at some locations, there were some cracks and spalls in joints stones and the concrete and in some places stones were also cracked due to overstrening. Root penetration is observed at the toe of the wall at site 10 along the joint between the wall and the culvert. The root penetration was not major and did not seem to cause a significant issue to the function of the wall. In all of the sites, no evidence of slippage is observed with the backfill soil, however rain channels were frequently observed. This is not considered to be a significant problem for the function of the asset directly. However, lack of maintenance may produce some instability issues for the face of backfill slope. In site 11, some earth movement was observable on the backfill slope, which require minor regrading as a maintenance action.

For all of the sites, the drainage outlets were observed to be clogged such that the function of these systems was in danger if no maintenance applied in the near future. The risk assessment data and results for the assets are presented in the following Table4.13, Table4.14 and Table4.15.

Table 4.13. Site-9- Scoring table.

Site-9- Scoring table	
Number of wall on map	9
Rated item	**Rating score**
Wall	
Visual deflection	2
Bulges or distortions	NA
Settlement of wall or parts of it	1
Joints between panels or bricks are misaligned	NA
Joints between facing units(panels or bricks) are too narrow or too wide	NA
Joints between adjacent sections of wall are misaligned	2
Cracks or spalls in concrete or bricks	2
Missing blocks or bricks or any part of wall	NA
Staining (water, rust or any evidence of corrosion)	NA
Root penetration of wall faces	1
Displacement of top wall features (coping, parapet or barrier rail)	NA
Presence of graffiti	NA
Average section score	1.6
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall	2
Evidence of landslide or earth moving	1
Settlement or heaving in front of the wall	NA
Evidence of erosion or scour	NA
Evidence of excessive moisture in backfill	1
Material from upslope adding load to wall like rocks or new soils	1
Average section score	1.25
Drainage	
Drainage outlets are clogged	2
Drainage channels along top of wall are not working properly	1
Average section score	1.5
Total average wall score	1.45

Table 4.14. Site-10- Scoring table.

Site-10- Scoring table	
Number of wall on map	10
Rated item	**Rating score**
Wall	
Visual deflection	1
Bulges or distortions	2
Settlement of wall or parts of it	NA
Joints between panels or bricks are misaligned	2
Joints between facing units(panels or bricks) are too narrow or too wide	2
Joints between adjacent sections of wall are misaligned	1
Cracks or spalls in concrete or bricks	2
Missing blocks or bricks or any part of wall	2
Staining (water, rust or any evidence of corrosion)	NA
Root penetration of wall faces	1
Displacement of top wall features (coping, parapet or barrier rail)	NA
Presence of graffiti	NA
Average section score	1.63
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall	2
Evidence of landslide or earth moving	1
Settlement or heaving in front of the wall	2
Evidence of erosion or scour	NA
Evidence of excessive moisture in backfill	1
Material from upslope adding load to wall like rocks or new soils	1
Average section score	1.4
Drainage	
Drainage outlets are clogged	3
Drainage channels along top of wall are not working properly	1
Average section score	3
Total average wall score	2

Table 4.15. Site-11- Scoring table.

Site-11- Scoring table	
Number of wall on map	11
Rated item	**Rating score**
Wall	
Visual deflection	1
Bulges or distortions	2
Settlement of wall or parts of it	1
Joints between panels or bricks are misaligned	2
Joints between facing units(panels or bricks) are too narrow or too wide	2
Joints between adjacent sections of wall are misaligned	1
Cracks or spalls in concrete or bricks	1
Missing blocks or bricks or any part of wall	2
Staining (water, rust or any evidence of corrosion)	1

Table 4.15 (cont.)

Root penetration of wall faces	1
Displacement of top wall features (coping, parapet or barrier rail)	2
Presence of graffiti	NA
Average section score	1.45
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall	1
Evidence of landslide or earth moving	2
Settlement or heaving in front of the wall	2
Evidence of erosion or scour	NA
Evidence of excessive moisture in backfill	1
Material from upslope adding load to wall like rocks or new soils	2
Average section score	1.6
Drainage	
Drainage outlets are clogged	1
Drainage channels along top of wall are not working properly	1
Average section score	1
Total average wall score	1.35

4.5.2 Natural slopes

Some ground cracks at the upslope were existed. These ground cracks could be tension cracks located at the upslope, where some failures or minor landslides happened along the slope in the past. There are clear cracks in the pavement along the slope. These pavement cracks differ from alligator cracks to transverse cracks. As these cracks developed next to the slope, tilting trees affected by developed earth movement along the slope.

4.5.3 Rockfall sites

Preliminary rating

All rockfall sites included in the research are categorized as a high potential for rockfall occurrence. Although there were no historical records for the previous rockfall at the sites, but observations during the site investigations and condition appraisal studies shows a high potential risk of rockfall event to occur comparing with the volume of fallen rocks and boulders onto the ditches along the sites.

High potential risk categorization for the rockfall sites means that all of the sites need to be evaluated in order to determine the accurate procedure for future preventative maintenance and repair methods if necessary. The risk assessment evaluations for all of the rockfall sites are presented in details in the following text:

Site-3-

-Slope height

Site-3- has a height of 36m, which gives the rocks on the slope a high potential energy in the event of a fall and a high risk for producing damage. The rating system score is 81 points as a high risk slope.

-Ditch effectiveness

No barriers exist along the ditch area. Ditch width is 1m. The ditch is constructed on the same depth of the shoulders of the pavement. The rating system score is 27 points as a risk slope and the catchment effectiveness is categorized as a low.

-Average vehicle risk, AVR

Slope length is 130m. The maximum speed limit is 80 km/hr. Average daily traffic is 9416 vehicle/day.

According to Equation 3.2

AVR = $\frac{9416 * \frac{0.13}{24}}{80} * 100 = 64\%$

AVR = 64%, so the rating system score is 9 points.

-Percent of decision sight distance, DSD

Actual sight distance is 101m. Decision sight distance related to speed limit is 229m. According to Equation 3.3

$$DSD = \frac{101}{229} * 100 = 44\%$$

DSD = 44%, so the rating system score is 27 points.

-Roadway width

Edge to edge paved width was 6m. The rating system score is 81 points.

-Geological character

Case 1: The structural condition is discontinuous joints because the joints are less than 3.3m length with a random orientation. The rating system score is 9 points. The rock friction is slickensides and the rating system score is 81 points.

-Block size

The fallen boulders are small and the block size is less than 30 cm. The rating system score is 3 points.

-Climate and presence of water

This item will be similar for all assets because they are in the same region –Kyrenia Terrain-, where there is a moderate precipitation demonstrated with 550mm. The rating system score is 9 points.

-Rockfall history

This item will be similar for all assets because according to the transportation department, there were no historical records, however, the department stated that according to their observations occasional falls used to happen in the Kyrenia Terrain. The rating system score is 9 points.

Table 4.16. Site-3- Scoring table.

Site-3- Scoring table	
Category	**Score**
Slope height	81
Ditch effectiveness	27
Average vehicle risk	9
Percent of decision sight distance	27
Roadway width	81
Geological character	9
Rock friction	81
Block size	3
Climate and presence of water	9
Rockfall history	9
Total score	336

Site-5-

-Slope height

Site-5- is a 10 m < 15.2m height, so according to the rating criteria site-5- is not high enough to produce a high potential energy for the fallen rocks. The rating system score is 9 points.

-Ditch effectiveness

No barriers exist along the ditch area to hold the fallen rocks. Ditch width is 1m. There is a culvert with 30 m length along the asset. Rock slope height is 10 m. Size of fallen boulders is <1m –peak to peak length-. The ditch effectiveness can be assessed as a low catchment. The rating system score is 27 points.

-Average vehicle risk, AVR

Slope length is 100m. The maximum speed limit is 80 km/hr. Average daily traffic is 9416 vehicle/day

According to Equation 3.2

AVR = $\frac{9416*\frac{0.1}{24}}{80} * 100 = 49\%$

AVR = 49% < 50%, so it is assessed as 50% of the rockfall occurrence time, a presence of a vehicle is possible. The rating system score is 9 points.

-Percent of decision sight distance, DSD

Actual sight distance is 179m. Decision sight distance related to speed limit is 229m. According to Equation 3.3

$$DSD = \frac{179}{229} * 100 = 78\%$$

DSD = 78%, it is assessed as a moderate sight decision to the driver can make a decision about a failure. The rating system score is 9 points.

-Roadway width

Edge to edge paved width was 5.5 m. The rating system score is 81 points.

-Geological character

Case 2: The structural condition is major erosion feature and the rating score is 81 points. The erosion happened occasionally, so the rating score is 9 points.

-Block size

The fallen boulders size is 80 cm. The rating system score is 27 points.

Table 4.17. Site-5- Scoring table.

Site-5- Scoring table	
Category	**Score**
Slope height	9
Ditch effectiveness	27
Average vehicle risk	9
Percent of decision sight distance	9
Roadway width	81
Geological character	81
Rock friction	9
Block size	27
Climate and presence of water	9
Rockfall history	9
Total score	264

Site-6-

-Slope height

Site-6- is 25 m < 30.5m height so according to the rating criteria site-6- is high enough to produce a moderate potential energy for the fallen rocks. The rating system score is 27 points.

-Ditch effectiveness

No barriers were existed along the ditch area to hold the fallen rocks. Ditch width is 0.75 m. Rock slope height is 25 m. Size of fallen boulders-peak to peak length- is 40 cm. The ditch effectiveness can be assessed as no catchment will hold the fallen boulders. The rating system score is 81 points.

-Average vehicle risk, AVR

Slope length is 150m. The maximum speed limit is 80 km/hr. Average daily traffic is 9416 vehicle/day.

According to Equation 3.2

AVR = $\frac{9416 * \frac{0.15}{24}}{80} * 100 = 73.6\%$

AVR = 73.6% < 75%, so the rating system score is 27 points.

-Percent of decision sight distance, DSD

Actual sight distance is 432 m. Decision sight distance related to speed limit is 229m. According to Equation 3.3

$$DSD = \frac{432}{229} * 100 = 188\%$$

DSD = 188%, so the rating system score is 3 points.

-Roadway width

Edge to edge paved width was 6 m. The rating system score is 81 points.

-Geological character

Case 1: The structural condition is continuous joints because the joints are longer than 3.3 m. The rating system score is 81 points. The rock friction is undulating. The rating system score is 9 points.

-Block size

The fallen boulders size is 40 cm> 30.48 cm. The rating system score is 9 points.

Table 4.18. Site-6- Scoring table.

Site-6- Scoring table	
Category	**Score**
Slope height	27
Ditch effectiveness	81
Average vehicle risk	27
Percent of decision sight distance	3
Roadway width	81
Geological character	81
Rock friction	9
Block size	9
Climate and presence of water	9
Rockfall history	9
Total score	336

Site-7-

-Slope height

Site-6- is 30 m < 30.5m height so according to the rating criteria site-7- is high enough to produce a high potential energy for the fallen rocks. The rating system score is 81 points.

-Ditch effectiveness

No barriers were existed along the ditch area to hold the fallen rocks. Ditch width is 1 m. Rock slope height is 30 m. Size of fallen boulders-peak to peak length- is 35 cm. The ditch effectiveness can be assessed as no catchment will hold the fallen boulders. The rating system score is 81 points.

-Average vehicle risk, AVR

Slope length is 250m. The maximum speed limit is 80 km/hr. Average daily traffic is 9416 vehicle/day.

According to Equation 3.2

AVR = $\frac{9416 * \frac{0.25}{24}}{80} * 100 = 122.6\%$

AVR = 122.6%, so the rating system score is 81 points.

-Percent of decision sight distance, DSD

Actual sight distance is 208 m. Decision sight distance related to speed limit is 229m. According to Equation 3.3

$$DSD = \frac{208}{229} * 100 = 90.8\%$$

DSD = 90.8%, so the rating system score is 3 points.

-Roadway width

Edge to edge paved width was 6 m. The rating system score is 81 points.

-Geological character

Case 1: The structural condition is continuous joints because the joints are longer than 3.3 m. The rating system score is 81 points. The rock friction is planar. The rating system score is 27 points.

-Block size

The fallen boulders size is 35 cm> 30.48 cm. The rating system score is 9 points.

Table 4.19. Site-7- Scoring table.

Site-7- Scoring table	
Category	**Score**
Slope height	81
Ditch effectiveness	81
Average vehicle risk	81
Percent of decision sight distance	3
Roadway width	81
Geological character	81
Rock friction	27
Block size	9
Climate and presence of water	9
Rockfall history	9
Total score	462

Site-12-

-Slope height

Site-6- is 6 m < 7.6 m height so according to the rating criteria site-12- is not high enough to produce a high potential energy for the fallen rocks. The rating system score is 3 points.

-Ditch effectiveness

No barriers were existed along the ditch area to hold the fallen rocks. Ditch width is 5 m. Rock slope height is 6 m. Size of fallen boulders is small. The ditch effectiveness can be assessed as a good catchment so that no boulders will reach the roadway. The rating system score is 3 points.

-Average vehicle risk, AVR

Slope length is 300 m. The maximum speed limit is 80 km/hr. Average daily traffic is 9416 vehicle/day.

According to Equation 3.2

AVR = $\frac{9416 * \frac{0.3}{24}}{80} * 100 = 147\%$

AVR = 147%, so the rating system score is 81 points.

-Percent of decision sight distance, DSD

Actual sight distance is 526 m. Decision sight distance related to speed limit is 229m. According to Equation 3.3

$$DSD = \frac{526}{229} * 100 = 229.7\%$$

DSD = 229.7%, so the rating system score is 3 points.

-Roadway width

Edge to edge paved width was 6 m. The rating system score is 81 points.

-Geological character

Case 1: The structural condition is major erosion features with extreme differences in erosion rates. The rating system score is 81 points for both items.

-Block size

The fallen boulders size is smaller than 30.48 cm. The rating system score is 3 points.

Table 4.20. Site-12- Scoring table.

Site-12- Scoring table	
Category	**Score**
Slope height	3
Ditch effectiveness	3
Average vehicle risk	81
Percent of decision sight distance	3
Roadway width	81
Geological character	81
Rock friction	81
Block size	3
Climate and presence of water	9
Rockfall history	9
Total score	354

4.6 Summary of stability analyses and risk assessment-Results

The following Table4.21 is a summary of the analysis results including the geotechnical risk assessment, consequence level and the recommended solution.

Table 4.21. Summary table of analysis results.

Earth retaining wall				
Site ID	Analysis	Risk	Consequence	Result
9	-From the visual observations, some vertical deflections appeared on some parts of the wall. There is an evidence of landslide. Some of the drainage outlets are clogged. -Geotechnical analysis: Face stability = Not adequate Global stability = Adequate	1.45 (Good)	Low	1. Replacing drainage outlets. 2. Minor regrading. 3. Apply vegetation cover.

Table 4.21 (cont.)

10	-Some bricks were misaligned. The joints between sections were misaligned and rain channels located on the slope. -Geotechnical analysis: Face stability = Adequate Global stability = Adequate	2 (Fair)	Moderate	1. Applying vegetation cover with drainage system on the slope. 2. Filling the misaligned joints.
11	-Landslides happened along the slope. -Geotechnical analysis: Face stability = Adequate Global stability = Adequate	1.35 (Good)	Low	1. Resurfacing the slope and minor regrading of backfill soil. 2. Change the drainage outlets.
Natural earth slopes				
Site ID	Analysis		Consequence	Results
1	-There were ground cracks at the upslope. Pavement next to the site suffered from elevation changes. -Stability ratio against global failure was less than factor of safety (1.35), but yet the site reinforced by the rock layers.		Eastern part: Low	Apply vegetation cover on the slope.
			Western part: Moderate	-On slope drainage system with vegetation cover. -Net fence or rigid barrier at the ditch.
2	Stability analysis shows stability factor of 0.34 for western part and 0.69 for eastern part, but the rock layers prevent the site from failure. The sufficient width of the ditch in western part reduce the resultant risk.		Eastern part: Moderate	-Apply net fence at the ditch with vegetation cover. -Drainage system up slope and on the slope. Rigid barrier along the ditch and vegetation.

Table 4.21 (cont.)

8	Stability factor less than 1.35, but the rock face of the slope act as a natural barrier. The ditch distance is too narrow.	Moderate	Rigid barrier is needed because the ditch distance is too narrow.
13	Elevation changes occurred to the pavement next to the site and some ground cracks observed upslope.	Low	Applying frequent maintenance.
14	Some cracks and offset lines occurred on the slope.	Low	Applying frequent maintenance.
Rockfall sites			
Site ID	Risk	Consequence	Results
3	336	Moderate	Applying net fence at the ditch.
5	264	Moderate	Applying net fence at the ditch.
6	336	Moderate	Applying net fence at upslope.
7	462	Moderate	Applying net fence at upslope.
12	354	Moderate	Do nothing

4.7 Life cycle cost analysis

Maintenance cost

For all sites, maintenance cost will be the same. Although the maintenance cost will not affect the making decision but it will affect the budgeting plan. The suggested maintenance cost will be the following: Asphalt maintenance will be according to the length of the site and the width of the lane. According to the transportation department the cost of asphalt maintenance is 33TL/m$^{2.}$ According to the transportation department also, the cleaning debris cost is 8TL/m$^{2.}$ The cost from transportation department including the labour and operation costs for ay used machines or trucks. Other costs could be included later according to the suggested plan for the engineering inspections. Road closure will be estimated to be 30TL/day.

All information are presented in Appendix H.

Life cycle costs

The costs have been used in order to calculate the life cycle cost for the improvements of the sites were conducted to be the following:

Initial cost

Wage of labour, cost of materials and cost of equipment were included as initial costs.

Energy costs

Energy cost will not be associated with the ongoing consumption of the facility, because there is no energy cost could be estimated for any of the suggested improvements neither gas nor electrical costs.

Operation costs

Any operation cost for equipment will be considered and calculated in the total initial cost.

Alteration, maintenance and replacement costs

The main reason of the project is maintenance and improvement, but yet some improvements need maintenance or replacement which will be considered.

Terminal and salvage costs

No salvage cost will be considered in the project, although sustainable materials will be used in accordance to their availability in Cyprus. Demolition cost will be part of the study and will be included in the costs of activities and wage of the labours.

Associated costs

Costs of traffic problems that could be occurred while a closure of one lane of the high way route happened as a result of maintenance or improvement will be considered.

Suggested interest rate will be used according to the central bank in Cyprus to be as 3% per year. The analysis period will be considered to be 30 years as an average of the facility life and it will be used in the life cycle cost analysis.

For used interest formula, present worth of annuity was used to calculate the present worth of the annual maintenance costs. Single present worth was used to calculate the present worth of the replacement costs for some improvements.

Materials costs

The materials costs and wages were been taking according to (İnşaat Türlerine Göre MZ Birim Fiyatlar, 2015). The materials costs used in the life cycle cost analysis shown in the following table:

Table 4.22. Materials costs.

Name of materials, activity or labour	Cost (TL)
Unskilled labour	20/hr
Concrete C20	149TL/m^3
Form wok	23TL/m^2
Asphalt	33TL/m^2
Galvanized wire (net fence)	145TL/m
Drainage pipes(Box PVC)	22TL/m
Rigid barrier (50cm*50cm*50cm)	209TL/m

On slope drainage cost

The on slope drainage improvement cost was calculated in terms of the length of every site improved by this option and according to the costs which shown in

Table4.22. The unit volume for on slope drainage calculated in terms of length as following:

Box 1. Example calculation for an on slope drainage.

1 unit with two sides with dimensions of 30cm*100cm*10cm
Volume = 2*0.3*0.1*Length = 0.06*Length m^3
Area of frame work = 0.3*2* Length of site = 0.6*Length m^2
The on slope drainage will be constructed as 3 lines so,
Area of frame work in terms of Length for a site = 0.6*L*3 = 1.8L m^2
Volume of concrete for three lines = 0.06L *3 = 0.18L m^3

Small excavator productivity for regrading

The best choice to do the regrading for the slopes retained by the earth retaining walls is small hydraulic operated shovel with bottom dump. The production of the hydraulic shovel will be discussed in the following method (Nunnally, 2004).

Production = C*S*V*B*E (4.2)

C: Cycles /hr

The machine size is small and the material is gravel or sand. Using the following Table 4.23 C = 190.

S: Swing factor, angle of swing estimated to be 45^o. Using Table 4.23 adjustment factor = 1.16.

V: Heaped bucket volume assumed to be 1Lm^3.

B′: Bucket fill factor, material is gravel or sand. Using Table 4.24 bucket factor = 0.9.

E: Job efficiency, management condition assumed to be good and job condition assumed to be poor. Using Table 4.25 E = 0.61.

Table 4.23. Cycles and swing factor (Nunnally, 2004).

Material	Machine Size					
	Small Under 3.8m^3		Medium 3.8m^3 – 7.6m^3		Large Over 7.6m^3	
	Bottom dump	Front dump	Bottom dump	Front dump	Bottom dump	Front dump
Soft(Sand, Gravel)	190	170	180	160	150	135
Average(Common Earth, Soft Clay)	170	150	160	145	145	130
Hard (Tough Clay)	150	135	140	130	135	125
Adjustment for swing angle						
	Angle of swing (deg)					
	45	60	75	90	120	180
Adjustment factor	1.16	1.1	1.05	1	0.94	0.83

Table 4.24. Bucket fill factor (Nunnally, 2004).

Material	Bucket fill factor
Common earth, loam	0.8 – 1.1
Sand and gravel	0.9 – 1
Hard clay	0.65 – 0.95
Wet clay	0.5 – 0.9
Rock, well blasted	0.7 – 0.9
Rock, poorly blasted	0.4 – 0.7

Table 4.25. Job efficiency (Nunnally, 2004).

	Management Conditions			
Job Conditions	Excellent	Good	Fair	Poor
Excellent	0.84	0.81	0.76	0.7
Good	0.78	0.75	0.71	0.65
Fair	0.72	0.69	0.65	0.6
Poor	0.63	0.61	0.57	0.52

Decision making process

The making decision process will take in consideration the difference between life cycle costs. The making decision process took in consideration the risk assessment results in previous steps to the life cycle cost analysis. The following table showing selected improvement and maintenance options for the sites and the costs for each of them and the chosen option.

Table 4.26. Decision making.

Site ID	Life cycle cost of option1 (TL)	Life cycle cost of option2 (TL)	Decision	Comments
1-Eastern part-	Net fence (161933)	On slope drainage (164126)	Net fence	
2-Eastern part-	Net fence (151067)	Upslope drainage (148314)	Upslope drainage	
8	Net fence (73332)	Rigid barrier (93936)	Net fence	
2-Western part-	Net fence (111688)	Rigid barrier (130564)	Net fence	
1-Western part-	Net fence (94991)	Rigid barrier (113699)	Net fence	
12	Net fence (619739)	Rigid barrier (596699)	Options costs are too close to each other, so decision could be changed according to other factors like availability.	

Table 4.26 (cont.)

7	Net fence (470292)	Rigid barrier (455847)	Rigid barrier	Options costs are too close to each other, so decision could be changed according to other factors like availability.
6	Net fence (249241)	Rigid barrier (251986)	Net fence	Options costs are too close to each other, so decision could be changed according to other factors like availability.
5	Net fence (158847)	Rigid barrier (170187)	Net fence	
3	Net fence (174534)	Rigid barrier (225415)	Net fence	
11	Regarding (400035)	Drainage outlets (413755)	Regrading	
9	Regarding (371886)	Drainage outlets (385606)	Regrading	

The following table is an example about calculation for drainage system and regrading life cycle cost for site9.

Table 4.27. Drainage system and regrading calculation.

Life cycle cost analysis						
Present worth method (PW) computation						
Project: Site9						
Location: Nicosia – Kyrenia highway route.						
Project life cycle = 30 years.			Regarding (Alternative 1)		Drainage outlets (Alternative 2)	
Discount rate = 3%						
Present time: Construction date.						
Initial costs	Quantity	Unit price	Est.	PW	Est.	PW
1.Labour for regrading(TL/day)	20	160	3200	3200		
2.Labour for drainage (TL/day)	5	160	0	0	800	800
3.Operation cost	250	20	5000	5000	5000	5000
4.Drainage outlet	20	22	0	0	440	440
5.Demolition cost	0	0	0	0	0	0
Road closure (TL/day)	1	30	30	30	30	30
Total initial cost				8230		6270
Initial cost PW savings (compared to Alternative 1)						1960
Annual costs	Escl. %	PWA				
Maintenance	7	57.14	0	0	800	15680
Total life cycle cost				8230		21950
Site maintenance		11.93	30482	363656		363656
Total life cycle cost of site				371886		385606

The following table shows an example of maintenance calculations of site5.

Table 4.28. Maintenance calculation of site5.

Maintenance			Area (m^2)	Cost (TL)
Asphalt	33	TL/m^2	275	9075
Cleaning debris	8	TL/m^2	100	800
Road closure	30	TL/day		30
			Total	9905

The following table shows the total initial cost for net fence improvement of site5.

Table 4.29. Net fence total initial cost calculations of site5.

Net fence			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	2	320	
Road closure	30	TL/day		30	
Operation cost	22	TL/m		2200	
material cost	145	TL/m		14500	
			Total initial cost	17050	TL

The following table shows the total initial cost for rigid barrier of site5.

Table 4.30. Rigid barrier total initial cost calculations of site5.

Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	2	320	
Road closure	30	TL/day	30	30	
material cost	209	TL/m		20900	
Operation cost	22	TL/m		2200	
			Total initial cost	23450	TL

The following table shows the life cycle cost analysis for site5.

Table 4.31. Life cycle cost analysis of site 5.

Life cycle cost analysis			Net fence		Rigid barrier	
Present worth method (pw) computation						
Project:	Site 5					
Initial costs (TL)			Est.	PW	Est.	Pw
1.Initial cost of net fence			17050	17050		
2.Initial cost of rigid barrier			0	0	23450	23450
Total initial cost				17050		23450
Initial cost PW savings(compared to Alt.1)						-6400
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.14196	0	0	500	28570.98
Total maintenance cost				0		28570.98
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	17050	12686.905		

Table 4.31 (cont.)

Net fence replacement	20	0.6419	17050	10944.395		
Total replacement cost				23631.3		0
Total life cycle cost				40681.3		52020.98
Site maintenance		11.93	9905	118166.65		118166.65
Total life cycle cost of site				158847.95		170187.63

Timeline and budgeting plan will be shown in the following table. Maintenance costs in the table mean that the money will be spent till the specified period in present worth. Maintenance costs shown in the table are the cumulative costs of maintenance till that period. For replacement costs, the shown amount of needed fund is the value of money will be spent at that specific period in present worth. Engineering inspection activity costs will be determined by the authorized department.

Table 4.32. Results of decision making process and timeline for budget between now and later.

Site	5 years	10 years	16 years	20 years	26 years	30 years
Earth retaining walls						
9	Slope regrading and wall strengthen-ing (8230 TL)	Engineering inspection	Maintenance for site (213978TL)	Engineering inspection.	Maintenance for site (213978TL)	Engineering inspection.
11	Slope regrading and wall strengthen-ing (18630 TL)	Engineering inspection	Maintenance for site (230540TL)	Engineering inspection	Maintenance for site (349274TL)	Engineering inspection
Rockfall sites						
5	Net fence cost (17050 TL)	Engineering inspection and replacement (12686TL)	Maintenance for site (69530TL)	Engineering inspection and replacement (10944TL)	Maintenance for site (105339TL)	Engineering inspection.
6	Net fence cost (25560TL)	Engineering inspection and replacement (19019TL)	Maintenance for site (110770TL)	Engineering inspection and replacement (16406TL)	Maintenance for site (167820TL)	Engineering inspection.

Table 4.32 (cont.)

7	Rigid barrier cost (58580TL)	Engineering inspection.	Maintenance for site (216943TL)	Engineering inspection.	Maintenance for site (328674TL)	Engineering inspection and maintenance of barrier (28570TL)
12	Rigid barrier cost (70290TL)	Engineering inspection.	Maintenance for site (292932TL)	Engineering inspection.	Maintenance for site (443798TL)	Engineering inspection and maintenance of barrier (28570TL)
Natural slopes						
1-Western-	Net fence cost (9702TL)	Engineering inspection and replacement (7219TL)	Maintenance for site (42273TL)	Engineering inspection and replacement (6227TL)	Maintenance for site (64043TL)	Engineering inspection.
2-Western-	Net fence cost (9535TL)	Engineering inspection and replacement (7094TL)	Maintenance for site (52331TL)	Engineering inspection and replacement (6120TL)	Maintenance for site (79283TL)	Engineering inspection.
8	Net fence cost (7872TL)	Engineering inspection and replacement (5857TL)	Maintenance for site (32097TL)	Engineering inspection and replacement (5053TL)	Maintenance for site (48268TL)	Engineering inspection.
1-Eastern-	Net fence cost (14378TL)	Engineering inspection and replacement (10698TL)	Maintenance for site (75096TL)	Engineering inspection and replacement (9229TL)	Maintenance for site (113773TL)	Engineering inspection.
2-Eastern-	Rigid barrier cost (10701TL)	Engineering inspection.	Maintenance for site (67999TL)	Engineering inspection.	Maintenance for site (103021TL)	Engineering inspection and maintenance of barrier (28570TL)

Chapter 5

CONCLUSION

The highway route between Nicosia and Kyrenia is a very vital route in Cyprus. Assessing and evaluating the condition of the geotechnical assets along this route is important to keep the route in serviceable condition.

Geological assessment is developed for the route using reports and geological maps of geological department. The assessment shows that most slopes are carried out of silty sand and gravel. Rockfall sites are comprised of various types of limestones and sandstones. Engineering and geotechnical properties are interpreted for backfill soils of earth retaining walls and natural earth slopes using results of the desk study, geotechnical maps for Cyprus and the condition appraisals.

Within the route, three of the geotechnical assets were retaining walls. Assessment and stability analysis have been conducted for both the retaining walls and the retained slopes. Five of the selected geotechnical assets were rockfall sites. Geotechnical risk assessment have been carried out for assets in detail. Seven of the selected assets were natural slopes with various types of soils. Slope stability analyses and risk assessments have been carried out for these sites. Condition appraisals have been carried out for all sites with observational data obtained during various visits to the sites of the assets.

Different standards applied in this research for the slop stability. Different factors of safety used for different types of stress states. The general purpose was to assure that the observations that done during the condition appraisal study will be assessed and evaluated by a geotechnical mean for the assets to make a good decision about their current condition. Most of the natural slopes failed to reach the factor of safety, but on site those slopes have been reinforced by different types of rock layers which acted as reinforcement layers in different orientations against the predicted slip surface.

All rockfall sites risk consequence considered to be a moderate level of consequence. One rockfall site has not been included in the study because it considered to be safe and stable according to the primary assessment. The research concluded that one rockfall site will take no improvement (do nothing option). Reasons for getting moderate risk consequences for most rockfall sites could be summarized in accordance to the ditch width which should be wider in many cases and no existing barriers could hold any fallen materials in case of failure.

The slope stability analysis for retained slopes by walls was improved in this research. Three major possible slip surfaces have been checked. The different modes of failure will give the most critical slip surfaces could occur to the slope. However, studying the asset from a geotechnical point of view is not sufficient for asset management. All stability checks for the retaining walls were obtained to be close to the facto of safety. So that regrading and drainage system construction were been chosen to be improvements for this type of geotechnical assets.

Risk analysis have been applied on the three types of the selected geotechnical assets. The geotechnical risk assessment aims to obtain the most critical sections on the highway route. Checking the uncertainties that could cause risks and evaluate the situation. In the risk analysis not only deflections and deformations was been assessed, but also the availability of any passengers or vehicles in order to know the possibility of any damages if any failure occurred.

For slope stability strategies, sites of 9, 10 and 11 which are comprised of soil slopes retained by earth retaining walls, the global stability was more suitable than the face stability. For sites 1, 2, 8, 13 and 14, which are comprised of natural earth slopes, both global and face stability strategies are important to determine the maintenance and improvement options.

Recommendations for further researches

Research on geotechnical asset management in Cyprus could be improved by creating data base of this type of assets. Lack of historical information about the assets reduces the accuracy of the predictions obtained for the geotechnical assets.

Inventory could help to preserve the serviceability of geotechnical assets. A wide data base could help for further advanced studies in geotechnical reliability. Uncertainties could be managed by more information and categorized data base.

Improving rating systems could help in predicting the level of the asset life. Modifications of rating systems to be convenient for Cyprus could elongate the life cycle of the geotechnical assets and get the most benefits of them.

Creating a computer application to manage the geotechnical assets could be helpful. This application could be created by a computer programming language and help the governmental departments to organize engineering inspections, maintenance and improvement for the geotechnical assets.

In the slope stability analyses, geotechnical assets have not been accurately analyzed, due to existing rock layers in the slopes. Rock stability analyses is also needed to be carried out for the geotechnical assets in the rockfall sites. In Table 5.1, final results are shown in summary.

Table 5.1. Table of results.

Site ID	Number of included assets	Types of included assets	Consequence level	Improvement	Expenditure (TL)
1	2	Cut slope east/ Cut slope west	Low	Net fence	161933
			Moderate	Net fence	94991
2	2	Cut slope east/ Cut slope west	Moderate	Upslope drainage	148314
			Moderate	Net fence	111688
3	1	Rock slope	Moderate	Net fence	174534
4	1	Rock slope	-	Do nothing	0
5	2	Rock slope+culvert	Moderate	Net fence	158847
6	1	Rock slope	Moderate	Net fence	249241
7	1	Rock slope	Moderate	Rigid barrier	455847
8	1	Cut slope	Moderate	Net fence	73332
9	2	Cut slope+Earth retaining wall	Low	Regrading	371886
10	2	Cut slope+Earth retaining wall	Moderate	Do nothing	0
11	2	Cut slope+Earth retaining wall	Low	Regrading	371886
12	1	Rock slope	Moderate	Rigid barrier	596699
13	1	Cut slope	Low	Do nothing	0
14	1	Cut slope	Low	Do nothing	0

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APPENDICES

Appendix A: Mapped geotechnical assets along Nicosia-Kyrenia highway route

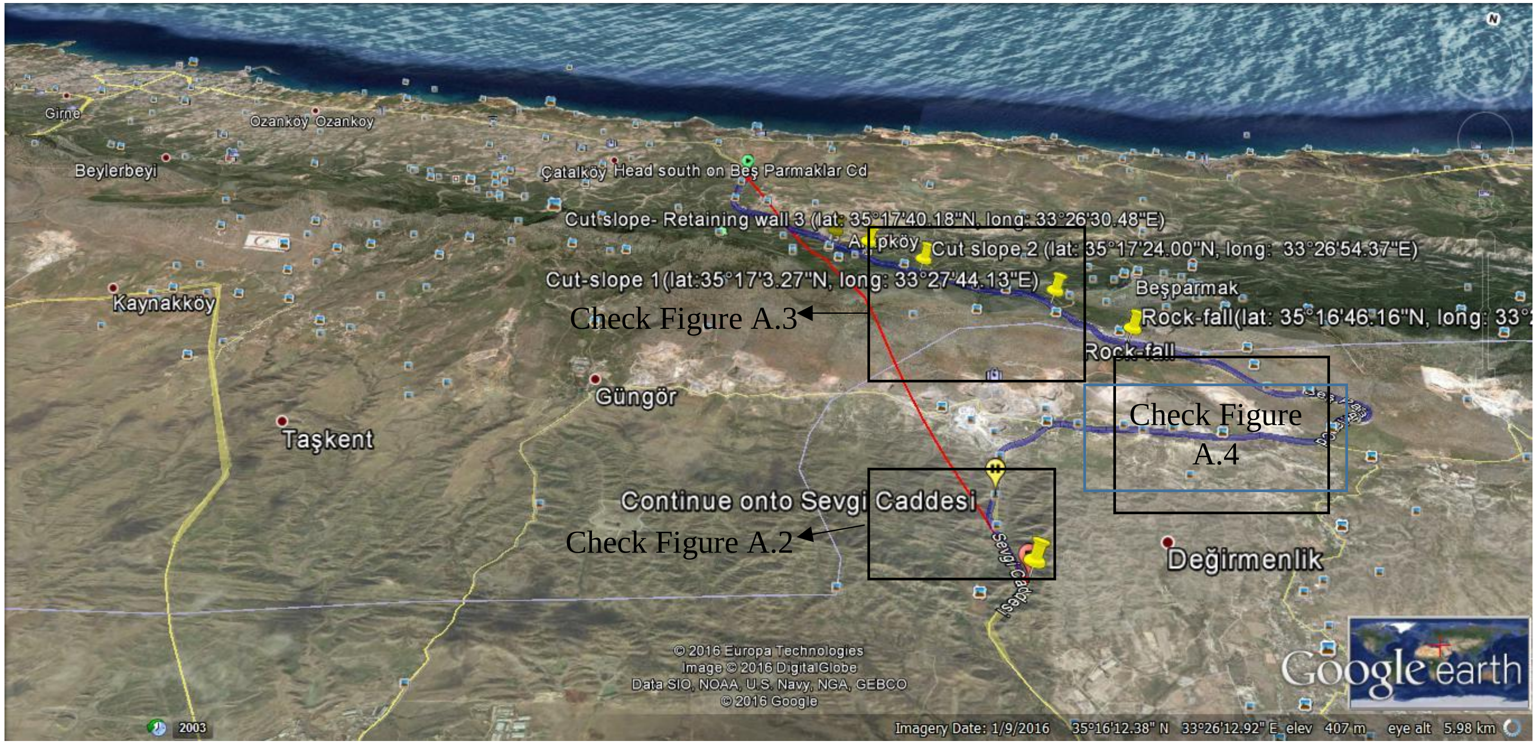

Figure A.1. Straight length along all the geotechnical assets (Areas in boxes are enlarged up in the pointed figures) (with the courtesy of Google Earth ©).

Figure A.2. Geotechnical assets along Kyrenia mountains range (with the courtesy of Google Earth ©).

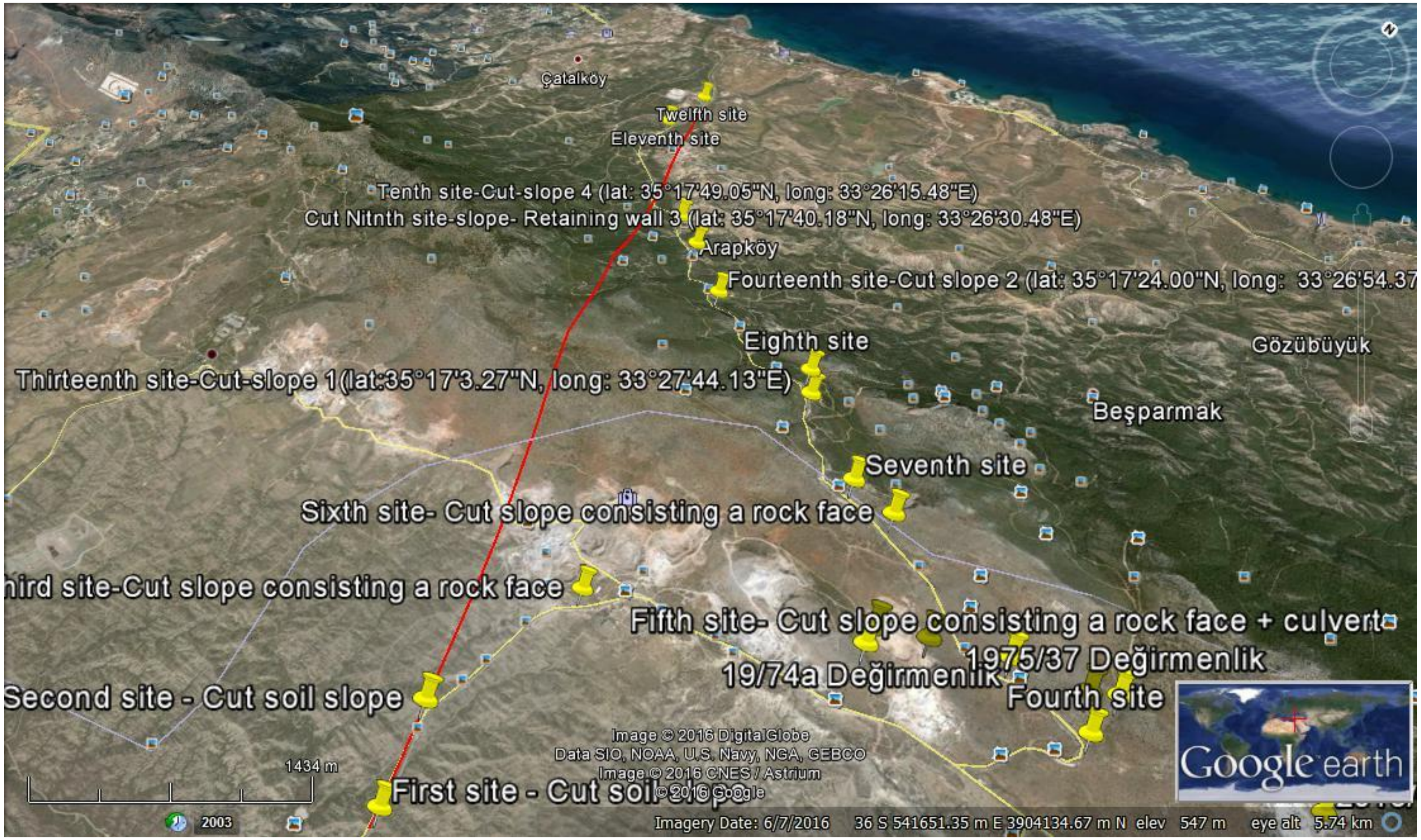

Figure A.3. All geotechnical assets (with the courtesy of Google Earth ©).

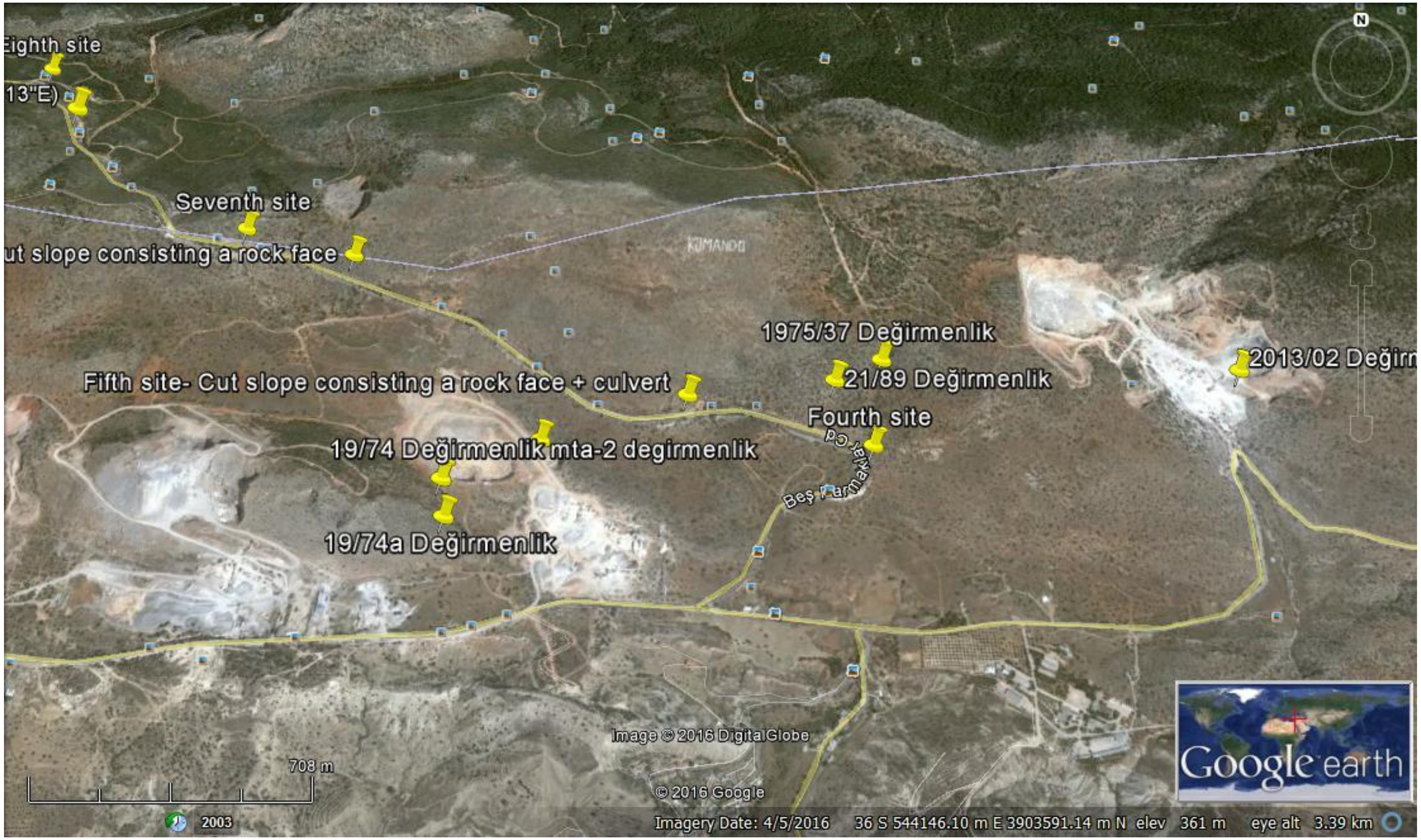

Figure A.4. The boreholes (with the courtesy of Google Earth ©).

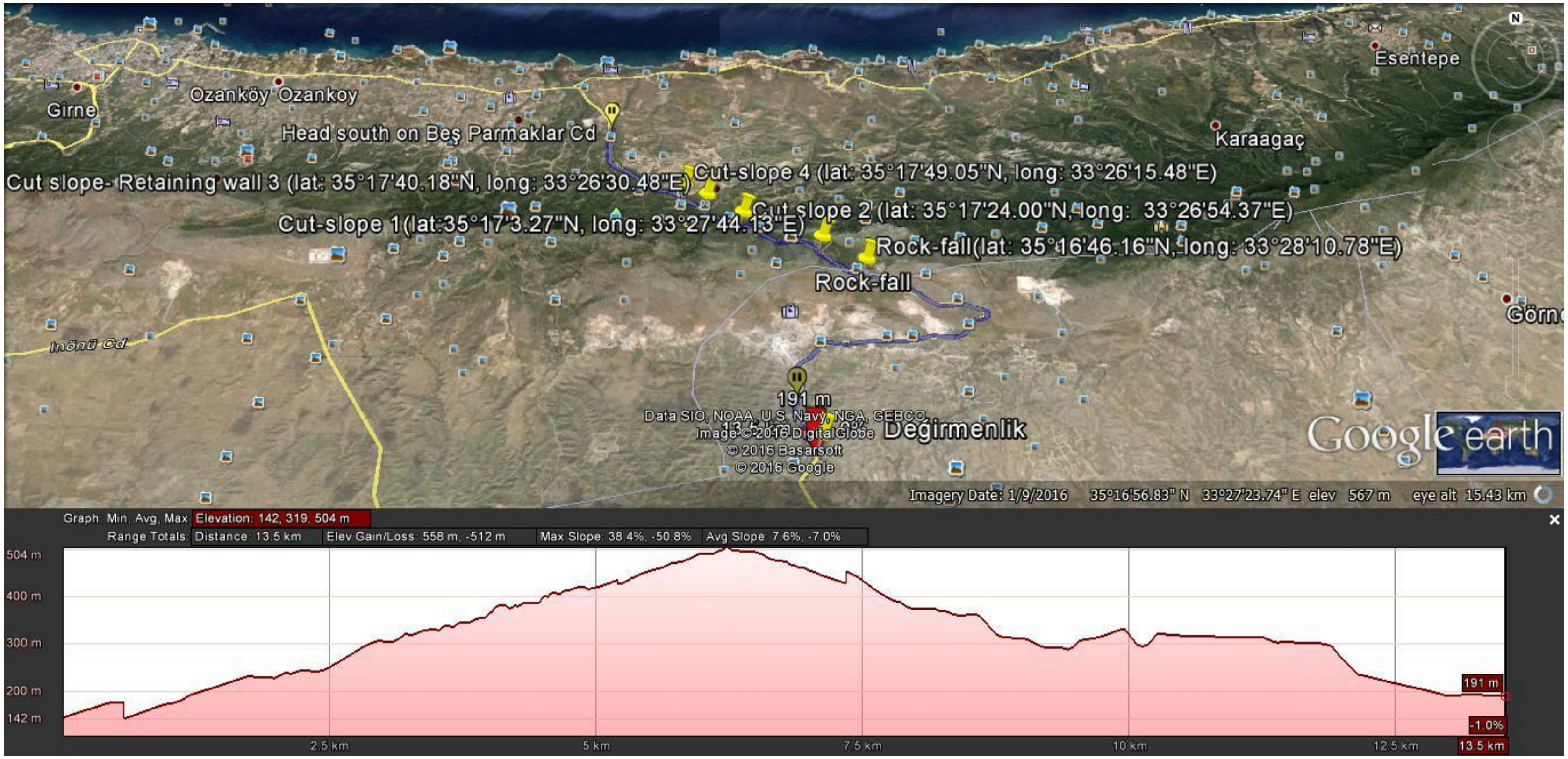

Figure A.5. Elevation profile (with the courtesy of Google Earth ©).

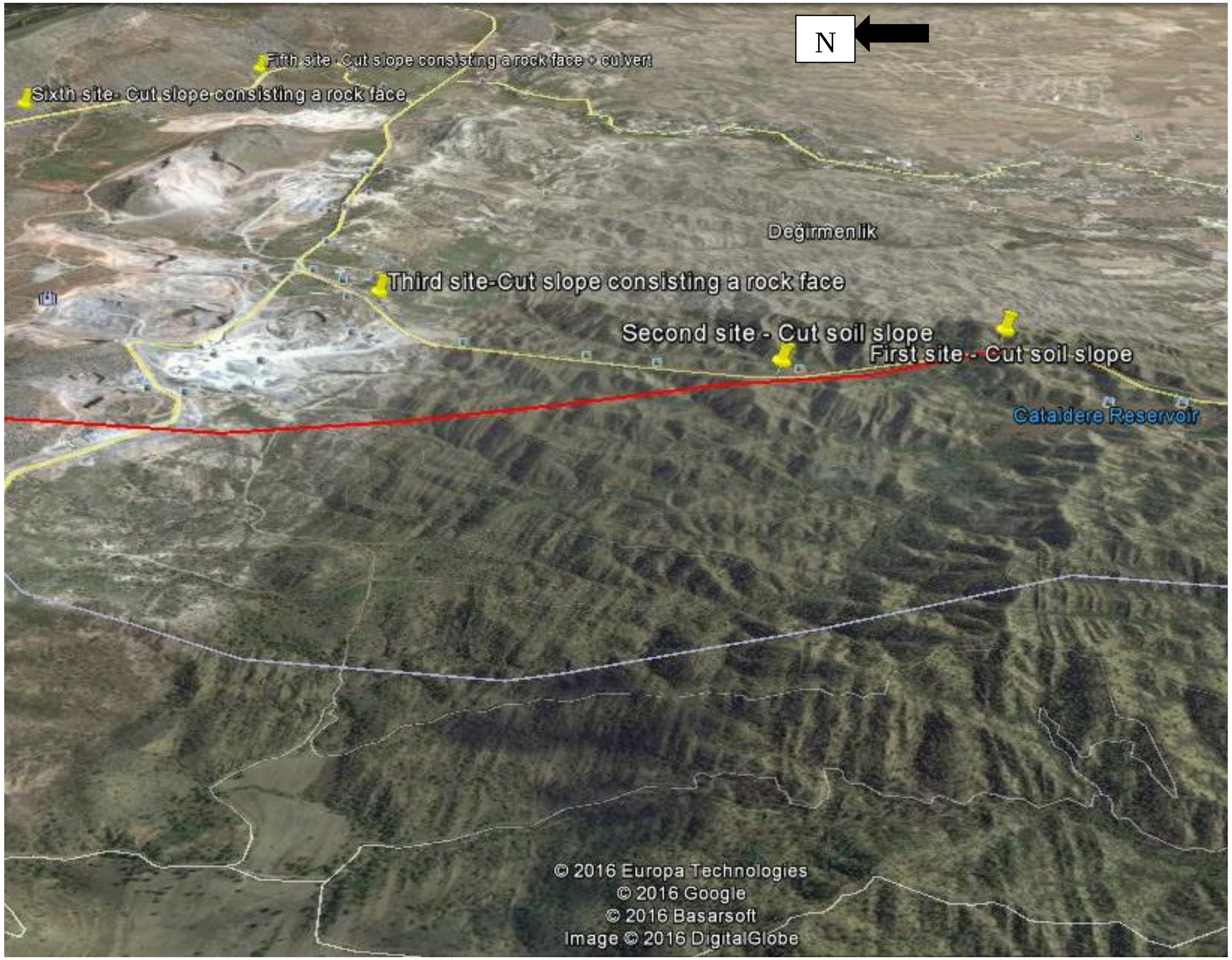

Figure A.6. Assets near Değirmenlik village (with the courtesy of Google Earth ©).

Appendix B: Condition appraisals for earth retaining structures

Table B.1. Site-9- condition appraisal.

ERS condition appraisal form	
General information	
Number of wall on map:	9
Coordinates: Longitude Latitude	 33.442043 35.294315
Date of inspection:	27.03.16
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	8m, 3m(wall)
Approximate slope length:	250m
Approximate ditch width:	1.5m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Approximate roadway width (from paved edge to another edge):	6.5m
Notes of visual observation of wall	
Visual deflection:(horizontal or vertical)	Yes, there are some vertical deflections.
Bulges or distortions:	No, there is not any evidence for bilges or distortions.
Settlement of wall or parts of it:	Yes, there is settlement in some parts of the wall.
Joints between panels or bricks are misaligned:	No, there is not any joints between the panels or misaligned bricks.
Joints between facing units(panels or bricks) are too narrow or too wide:	No.
Joints between adjacent sections of wall are misaligned:	Yes, there are some joints are misaligned.
Cracks or spalls in concrete or bricks:	Yes, there are cracks and spalls in the concrete between the bricks and the bricks themselves.
Missing blocks or any part of wall:	No, there is no evidence for missing blocks or bricks or any part of the wall.
Staining (water, rust or any evidence of corrosion):	No, there is no staining.
Root penetration of wall faces:	Yes, there are some root penetration through the wall.
Displacement of top wall features (coping, parapet or barrier rail):	No, there is not any displacement of top of the wall features.
Presence of graffiti:	No, there is not any presence of graffiti.
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall:	Yes, there are some tension cracks behind the wall.
Evidence of landslide or earth moving:	Yes, there is a massive amount of soils that moves to the top of the wall.

Table B.1. (cont.)

Settlement or heaving in front of the wall:	No, there is not any evidence for settlement or heaving in front of the wall.
ERS condition appraisal form	
Evidence of erosion or scour:	No, there is not any type of erosion or scour.
Evidence of excessive moisture in backfill:	There is an evidence of moisture in backfill as plants are there but not excessive.
Material from upslope adding load to wall like rocks or new soils:	Yes, as there is some landslide and earth moving. These moves will lead to adding load to the wall.
Drainage	
Drainage outlets are clogged:	Some of them are clogged.
Drainage channels along top of wall are not working properly:	Yes, according to the bulges that found on the top of the wall.

Figure B.1. Site 9.

Table B.2. Site-10- condition appraisal.

ERS condition appraisal form	
General information	
Number of wall on map:	10
Coordinates:	
Longitude	33.440979
Latitude	35.296902
Date of inspection:	21.07.16
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	10m, 1.9m(wall)
Approximate slope length:	170m
Approximate ditch width:	3m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Approximate roadway width (from paved edge to another edge):	6.5m
Notes of visual observation of wall	
Visual deflection:(horizontal or vertical)	Yes, there are some vertical and horizontal deflections.
Bulges or distortions:	Yes, there are some bulges in some parts of the wall.
Settlement of wall or parts of it:	No, there is not any type of settlement through the wall.
Joints between panels or bricks are misaligned:	Yes, there are some bricks misaligned.
Joints between facing units(panels or bricks) are too narrow or too wide:	The joints are look like that they move according to some deflections happened in the past.
Joints between adjacent sections of wall are misaligned:	Yes, the joints between the adjacent sections are misaligned (see figure 3).
Cracks or spalls in concrete or bricks:	Yes, there are some cracks in both concrete between bricks and the bricks (see figure 1).
ERS condition appraisal form	
Missing blocks or any part of wall:	Yes, there some blocks are missing in some parts of the wall.
Staining (water, rust or any evidence of corrosion):	No, there is not any staining.
Root penetration of wall faces:	Yes, there is some root penetration.
Displacement of top wall features (coping, parapet or barrier rail):	No, there is no displacement of top of the wall.
Presence of graffiti:	No, there is no presence of graffiti.
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall:	Yes. There are evidences that there are some settlement happened to the soil and tension cracks behind the wall (see figure 4).

Table B.2. (cont.)

Evidence of landslide or earth moving:	Yes, there is landslide happened to the soil.
Settlement or heaving in front of the wall:	Yes, there is some settlements happened in front of the wall.
Evidence of erosion or scour:	No, there is no evidence for erosion or scour.
Evidence of excessive moisture in backfill:	Yes, there is.
Material from upslope adding load to wall like rocks or new soils:	Yes, according to the landslide there are some upslope soil that added load to the wall (see figure 2).
Drainage	
Drainage outlets are clogged:	Yes, some of the drainage outlets are clogged by new culverts placed in front of them (see figure.2.).
Drainage channels along top of wall are not working properly:	Yes, they are not working properly.

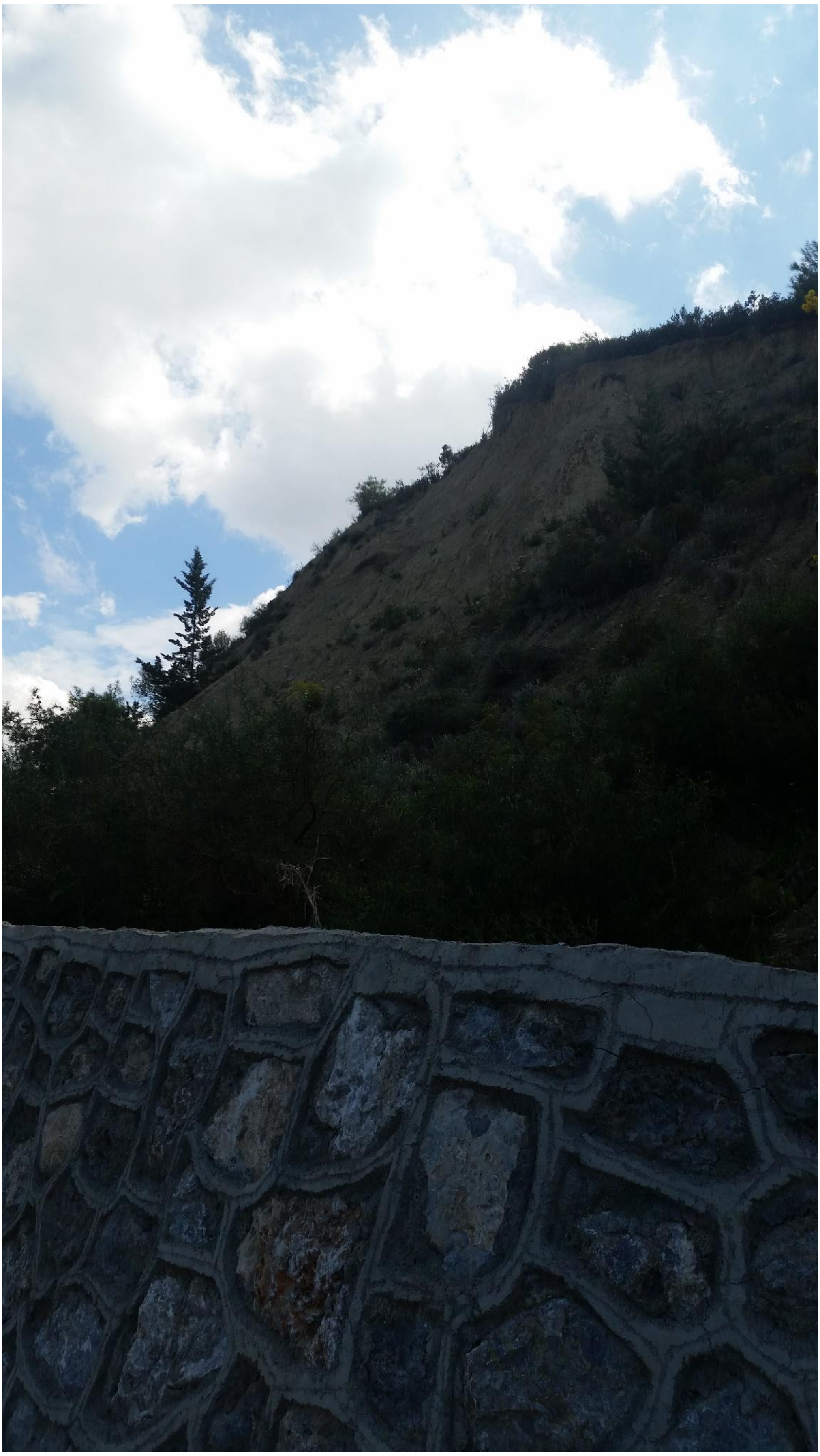

Figure B.2. Site 10.

Figure B.3. Site 10-cracks along the wall.

Figure B.4. Clogged drainage outlets.

Figure B.5. Erosion channels in the backfill soil.

Table B.3. Site-11- condition appraisal.

ERS condition appraisal form	
General information	
Number of wall on map:	11
Coordinates:	
Longitude	33.423275
Latitude	35.30949
Date of inspection:	27.03.16
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	23m, 2.8m(wall)
Approximate slope length:	250m
Approximate ditch width:	3m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Approximate roadway width (from paved edge to another edge):	6.5m
Notes of visual observation of wall	
Visual deflection:(horizontal or vertical)	Yes, there is a vertical deflection.
Bulges or distortions:	Yes, there are some distortions but no evidence for bulges.
Settlement of wall or parts of it:	Yes, there is settlement at the both ends of the wall.
Joints between panels or bricks are misaligned:	Yes, they are.
Joints between facing units(panels or bricks) are too narrow or too wide:	Yes, the joints are not the same width.
Joints between adjacent sections of wall are misaligned:	Yes, they are (see figure 1).
Cracks or spalls in concrete or bricks:	Yes, there ae missing parts of the concrete and bricks in the joints and some parts at the bottom of the wall.
Missing blocks or any part of wall:	Yes, there are.
Staining (water, rust or any evidence of corrosion):	Yes, there are evidences of water presence in front of the wall.
Root penetration of wall faces:	Yes, there is a root penetration of the wall faces.
Displacement of top wall features (coping, parapet or barrier rail):	Yes. There are some copping missed at the both ends of the wall (see figure 2).
Presence of graffiti:	No, there is not any presence of graffiti.
Soil (backfill and front heave)	
Settlement or tension cracks behind the wall:	Yes, there is settlement behind the wall.
Evidence of landslide or earth moving:	Yes, there are some evidences of earth moving along the top of wall (see figure 1).
Settlement or heaving in front of the wall:	Yes. There some settlement in front of the wall.
Settlement of wall or parts of it:	Yes, there is settlement at the both ends of the wall.

Table B.3. (cont.)

Evidence of erosion or scour:	No, there is no evidence for scour or erosion.
Evidence of excessive moisture in backfill:	Yes, there is evidence for existing moisture behind the wall.
Material from upslope adding load to wall like rocks or new soils:	Yes, some soil added load to the wall.
Drainage	
Drainage outlets are clogged:	Yes, some of the drainage outlets are clogged.
Drainage channels along top of wall are not working properly:	Yes, they are not.

Figure B.6. Site 11.

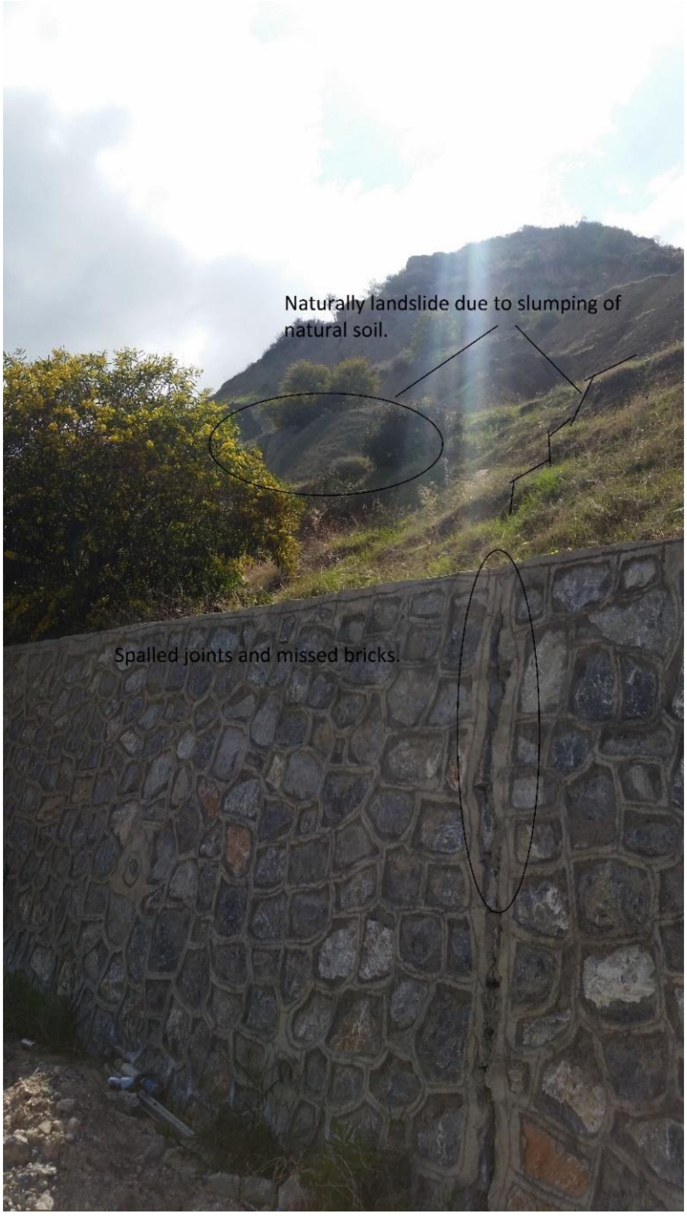

Figure B.7. Spalled joints and earth moving.

Figure B.8. Copping of the wall.

Appendix C: Condition appraisals for Rockfall sites

Table C.1. Site-3- condition appraisal.

Current condition data collector system for rockfall sites	
Number of site on map	3
Coordinates: Longitudinal Latitudinal	 33.462093 35.264612
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	36m
Ditch width:	1m
Approximate slope length:	130m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Actual sight distance:	101m
Decision sight distance:	
Approximate roadway width (from paved edge to another):	6m
Structural condition for rocks:	Discontinuous joints, random orientation
Rock friction:	slickensided
Block size (from peak to peak):	30cm
Presence of water on slope:	No water on the slope.

Table C.2. Site-5- condition appraisal.

Current condition data collector system for rockfall sites	
Number of site on map	5
Coordinates: Longitudinal Latitudinal	 33.484505 35.274696
Date:	21.07.16
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	10m
Ditch width:	1m
Approximate slope length:	100m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Actual sight distance:	179m
Decision sight distance:	
Approximate roadway width (from paved edge to another):	5.5m
Structural condition for rocks:	Discontinuous joints, favourable orientation
Rock friction:	planar
Block size (from peak to peak):	80cm
Presence of water on slope:	No water on the slope.

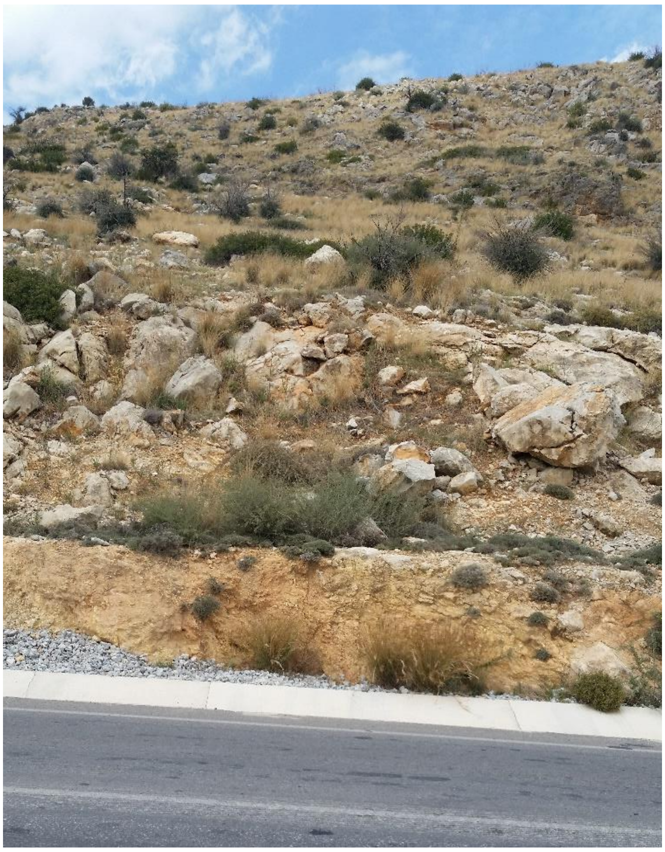

Figure C.1. Site 5.

Table C.3. Site-6-condition appraisal.

Current condition data collector system for rockfall sites	
Number of site on map	6
Coordinates:	
Longitudinal	33.473293
Latitudinal	35.278458
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	20m
Ditch width:	0.75m
Approximate slope length:	150m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Actual sight distance:	432m
Decision sight distance:	
Approximate roadway width (from paved edge to another):	6m
Structural condition for rocks:	continuous joints, adverse orientation
Rock friction:	undulating
Block size (from peak to peak):	40cm
Presence of water on slope:	Unable to observe.

Figure C.2. Site 6.

Table C.4. Site-7- condition appraisal.

Current condition data collector system for rockfall sites	
Number of site on map	7
Coordinates:	
Longitudinal	33.470406
Latitudinal	35.27309
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	30m
Ditch width:	1m
Approximate slope length:	250m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Actual sight distance:	208m
Decision sight distance:	
Approximate roadway width (from paved edge to another):	7m
Structural condition for rocks:	continuous joints, adverse orientation
Rock friction:	planar
Block size (from peak to peak):	35cm
Presence of water on slope:	Unable to observe.

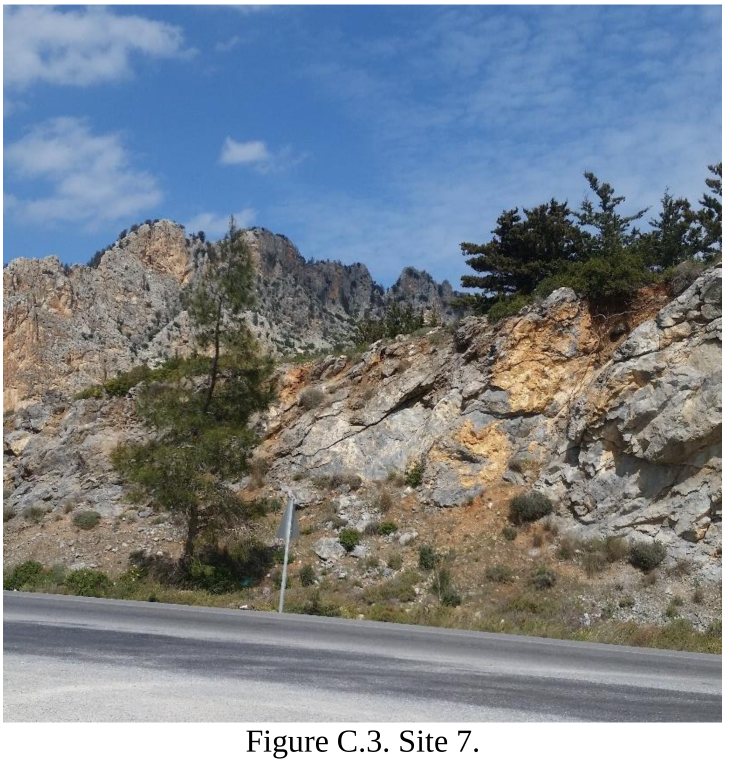

Figure C.3. Site 7.

Table C.5. Site-12- condition appraisal.

Current condition data collector system for rockfall sites	
Number of site on map	12
Coordinates: Longitudinal Latitudinal	 33.423023 35.315132
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height:	6m
Ditch width:	5m
Approximate slope length:	300m
Daily traffic (vehicle/day):	9416
Speed limit:	80km/hr
Actual sight distance:	526m
Decision sight distance:	
Approximate roadway width (from paved edge to another):	6m
Structural condition for rocks:	continuous joints, adverse orientation
Rock friction:	slickensided
Block size (from peak to peak):	Small boulders
Presence of water on slope:	No presence of water.
Additional comments:	Large amount of boulder could fail in any moment


Figure C.4. Site 12.

Appendix D: Condition appraisals for natural earth slopes

Table D.1. Site-1 western side- condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	1(Western slope)
Coordinates:	
Longitude	33.461521
latitude	35.251198
Date:	21.07.16
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	10
Ditch distance (m):	1
Approximate slope length (m):	56
Daily traffic (vehicle/day):	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	6m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	No, some lines appear which could be as a result from the geological structure formation of the slope itself.
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes, there are elevation changes at the edges of the pavement and at the ditch as well.
Tilting of telephone poles , trees, fences or retaining walls:	Yes, there are no fences, retaining walls or telephone poles next to the site but there are tilting in the trees.
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Figure D.1. Site 1-Western.


Figure D.2. Site 1-Western-Rain channels.

Table D.2. Site1 eastern side-condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	1(Eastern side)
Coordinates: Longitude latitude	 33.461521 35.251198
Date:	21.07.16
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	25
Ditch distance (m):	3.5
Approximate slope length (m):	84
Daily traffic (vehicle/day):	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	6m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	No, there were no offset fence lines on the slope.
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes
Tilting of telephone poles , trees, fences or retaining walls:	Yes
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Figure D.3. Site 1-Eastern.

Figure D.4. Site 1-Eastern-Fallen materials.

Table D.3. Site-2 western side- condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	2(Western side)
Coordinates: Longitude latitude	 33.458351 35.25634
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	30
Ditch distance (m):	4.5
Approximate slope length (m):	110
Daily traffic (vehicle/day)	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	6m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	No, there were no offset fence lines on the slope.
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes
Tilting of telephone poles , trees, fences or retaining walls:	No
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Figure D.5. Site 2-Western.

Table D.4. Site-2 eastern side-condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	2(Eastern side)
Coordinates:	
Longitude	33.458351
latitude	35.25634
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	10
Ditch distance (m):	1.5
Approximate slope length (m):	87
Daily traffic (vehicle/day)	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	6m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	yes
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes
Tilting of telephone poles , trees, fences or retaining walls:	Yes
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Figure D.6. Site 2-Eastern.

Figure D.7. Site 2-Eastern-the rock layers.

Table D.5. Site-8-condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	8
Coordinates: Longitude latitude	 33.460434 35.286411
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	10
Ditch distance (m):	1
Approximate slope length (m):	46
Daily traffic (vehicle/day)	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	5.5m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	Yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	Yes
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes
Tilting of telephone poles , trees, fences or retaining walls:	No
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Figure D.8. Site 8.

Table D.6. Site-13-condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	13
Coordinates: Longitude latitude	 33°27'44.13"E 35°17'3.27"N
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	10
Ditch distance (m):	1.5
Approximate slope length (m):	100
Daily traffic (vehicle/day)	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	6.5m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	Yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	No, there were no offset fence lines on the slope.
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes
Tilting of telephone poles , trees, fences or retaining walls:	yes
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Table D.7. Site-14-condition appraisal.

Condition appraisal for slopes	
Number of asset on the map:	14
Coordinates: Longitude latitude	 33°26'54.37"E 35°17'24.00"N
Date:	21.07.16
Time:	
Name of inspector:	Ahmad Alkhouzei
Approximate slope height (m):	12
Ditch distance (m):	2.5
Approximate slope length (m):	100
Daily traffic (vehicle/day)	9416
Speed limit (km/hr):	80
Approximate Roadway width (from paved edge to another edge):	6m
Presence of any spring, seep or saturated soil:	No, there is no spring or saturated soil as the inspector saw.
Ground cracks at the head of slope:	Yes
Soil pulling away from foundation of structures or retaining walls:	No, there were no structures near the site.
Offset fence lines appearing on the slope:	yes
Unusual bulges or elevation changes in pavement or sidewalk next to slope:	Yes
Tilting of telephone poles , trees, fences or retaining walls:	yes
Broken water lines or other underground utilities inside the slopes:	No
Sunken or down dropped paths or roads:	No
Additional comments	

Appendix E: Data collected from the transportation department in Nicosia

Data collected from the transportation department in Lefkoşa (Karayolları Dairesi)

Inspector: Ahmad Alkhouzei.

The meeting was held on 04.08.2016

- The traffic volume of the highway route from Değirmenlik rounabout to Çatalköy was about 9416 vehicle/day.
- The maximum speed limit of the highway route between Nicosia and Kyrenia was about 80 km/hr.
- No failures in the soil or rock slopes were recorded in the previous years on the highway route from Nicosia to Kyrenia.
- There were no historical records about the amount of fallen boulders and rocks per event.
- The roadway designing width was as following: the road was designed as class (2) with 3m for each side, the platform of the road contains 2 sides. The shoulders on both sides of the pavement were designed as 1m width.
- No maintenance were implemented for the slopes located along the highway route as regrading or resurfacing. Although maintenance for pavement were applied in a frequency of 2 to 5 years for each. The asphalt cost for rehabilitation was about 130tl/ton according to the newest records.
- The cost for removing and cleaning ditches from debris was about 8 TL per metre squre.

- According to the transportation department the highway route was constructed in 1963 and the retaining walls were constructed in the early 90s.

Accomplished by the help of: Mr.Hakan Korsan

Civil Engineer

05338647080

Appendix F: Data and maps collected from the geological department in Nicosia

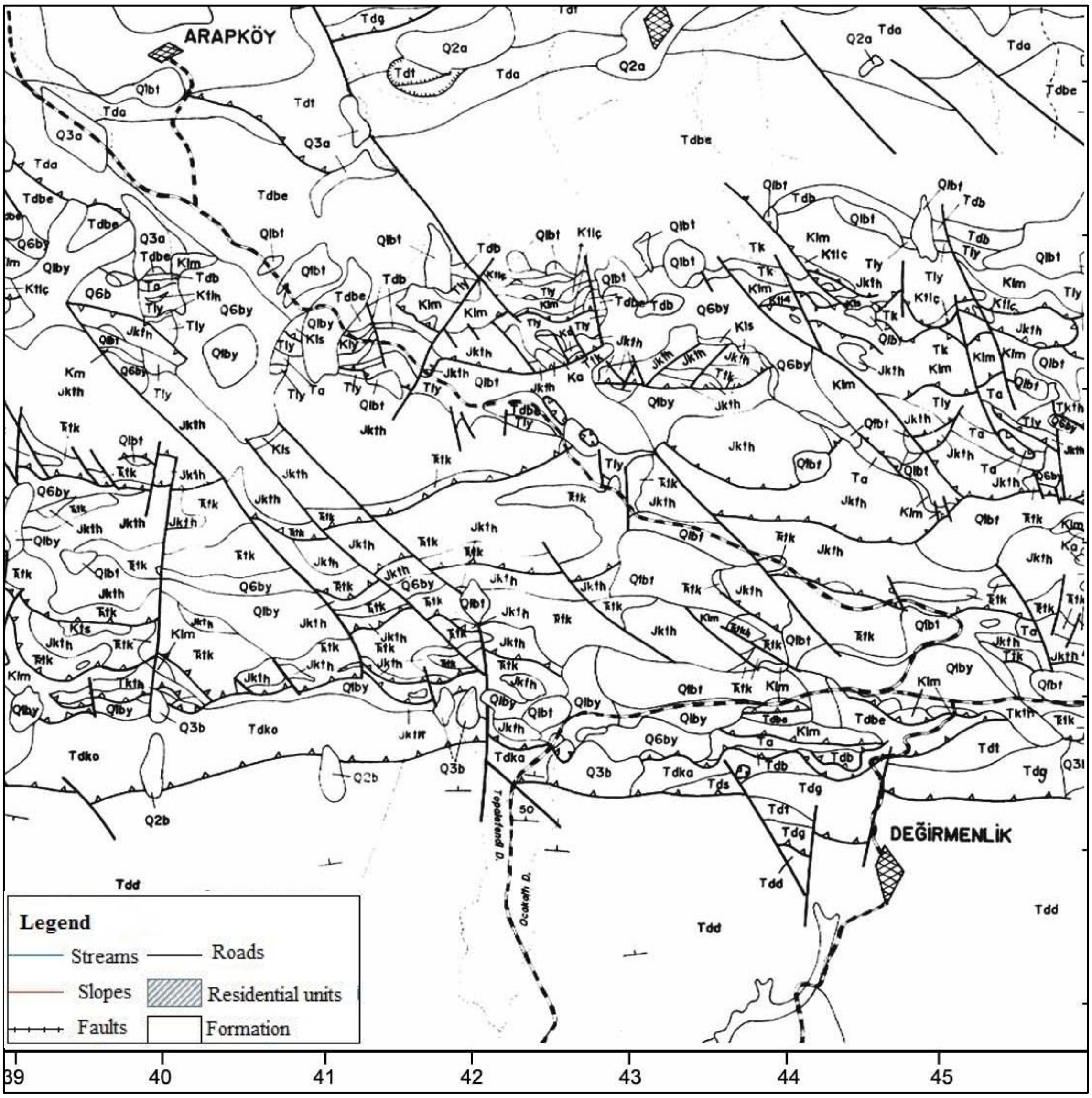

Figure F.1. Geological map of the selected highway route.

mta-2 değirmenlik

SITE INFORMATION

DISTRICT/VILLAGE: Girne Dağı District-değirmenlik

SERIAL NUMBER: mta-2 **HYDROLOGIC NUMBER:** na **FILE NUMBER:** na

MAP SHEET: No Data **MAP SCALE:** 0 **EAST:** 543641 **NORTH:** 3903484 **ELEVATION:** 310 a.m.s.l.

BOREHOLE OWNER: water works department **BOREHOLE PURPOSE:** Water Supply **DEPTH:** 220 m **DIAMETER:** 381.0 (15")

SITING METHOD: Geological **GEOLOGIST:** No data **CONSTRUCTION START:** No data **CONSTRUCTION END:** No data

CONSTRUCTION EVENTS

CONS #	START	END	GEOLOGIST	COMMENT
1	11.11.1996	23.11.1996	No data	

DRILLING EVENTS

CONS #	START	END	TOP	BOT TOM	DIA	ROCK	DRILLER	METHOD	RIG	BIT	HAMMER
1	11.11.1996	22.11.1996	0	220	381	ısolidated sediment	No data	rotary	No data	No data	

Figure F.2. mta-2 Değirmenlik borehole general information.

HOLE DIAMETER

CONS #	TOP	BOTTOM	DIAMETER
1	0	220	381

LITHOLOGY

TOP	BOTTOM	LITHOLOGY	GEOLOGIST
0,00	18,00	beyaz renkli kristalize kireçtaşı	
18,00	220,00	devridaimsiz/sirkülasyonsuz ilerleme kuyu temizliği sır	

PUMP TESTS

TEST	START	END	PUMP TYPE	TEST DURATION	STATIC WAT.LEV.	PUMPING WAT.LEV.	PUMP SUCTION	SAFE YIELD	COMMENT
1	26.03.1997	27.03.1997	No data	24	52,45	53,42	72	72	No data

Figure F.3. mta-2 Değirmenlik borehole lithology.

WATER LEVELS

DATE	DEPTH	SOURCE	METHOD	STATUS	MEASURED BY
26.03.1997	52,5	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
21.01.1998	54,0	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
04.03.1998	54,5	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
24.04.1998	56,7	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
02.06.1998	56,7	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
01.07.1998	55,1	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
01.11.1998	57,9	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
01.12.1998	58,1	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
10.01.2000	61,5	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
05.01.2001	64,1	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
01.05.2004	62,0	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
01.11.2004	61,4	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
22.05.2006	62,8	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe
02.05.2007	65,9	GDD	Steel-tape measurement	site was being pumı	Özhür Ayşe

Figure F.4. mta-2 Değirmenlik borehole water levels.

1975/37 değirmenlik

SITE INFORMATION				
DISTRICT/VILLAGE: Girne Dağı District-değirmenlik				
SERIAL NUMBER: 1975/37	HYDROLOGIC NUMBER: na	FILE NUMBER: na		
MAP SHEET: No Data	MAP SCALE: 0	EAST: 544632	NORTH: 3903704	ELEVATION: 324 a.m.s.l.
BOREHOLE OWNER: unknown	BOREHOLE PURPOSE: Water Supply	DEPTH: 162 m	DIAMETER: 228,3 (9")	
SITING METHOD: Geological	GEOLOGIST: Özhür Ayşe	CONSTRUCTION START: No data	CONSTRUCTION END: No data	

LITHOLOGY

TOP	BOTTOM	LITHOLOGY	GEOLOGIST
0,00	1,00	yamaç molozu	Hilmi B.
1,00	73,00	hilarion kireçtaşı	Hilmi B.
73,00	91,00	dolomitik kireçtaşı	Hilmi B.
91,00	99,00	ezik zon çatlaklı kırıntılı dolomitik kireçtaşı	Hilmi B.
99,00	165,00	dolomitik kireçtaşı	Hilmi B.

Figure F.5. 1975/37 Değirmenlik general information.

WATER LEVELS

DATE	DEPTH	SOURCE	METHOD	STATUS	MEASURED BY
12.07.1976	65,5	GDD	Steel-tape measurement	Static water level.	No data
02.06.1998	75,4	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
01.07.1998	75,4	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
01.11.1998	76,8	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
01.05.2004	81,0	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
01.11.2004	80,4	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
29.05.2006	82,0	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
02.05.2007	84,7	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
27.11.2013	103,0	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
23.10.2014	106,0	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
01.06.2015	107,9	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
11.01.2016	113,6	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe
14.06.2016	112,5	GDD	Steel-tape measurement	site was being pump	Özhür Ayşe

Figure F.6. 1975/37 Değirmenlik water levels.

19/74 değirmenlik

SITE INFORMATION				
DISTRICT/VILLAGE: Girne Dağı District-değirmenlik				
SERIAL NUMBER: 19/74	HYDROLOGIC NUMBER: na	FILE NUMBER: na		
MAP SHEET: No Data	MAP SCALE: 0	EAST: 543379	NORTH: 3903333	ELEVATION: No data
BOREHOLE OWNER: değirmenlik municipality	BOREHOLE PURPOSE: Water Supply	DEPTH: No data	DIAMETER: unknown	
SITING METHOD: Geological	GEOLOGIST: Özhür Ayşe	CONSTRUCTION START: No data	CONSTRUCTION END: No data	

Figure F.7. 19/74 Değirmenlik.

19/74a değirmenlik

SITE INFORMATION

DISTRICT/VILLAGE: Girne Dağı District-değirmenlik

SERIAL NUMBER: 19/74a **HYDROLOGIC NUMBER:** na **FILE NUMBER:** na

MAP SHEET: No Data **MAP SCALE:** 0 **EAST:** 543395 **NORTH:** 3903225 **ELEVATION:** No data

BOREHOLE OWNER: water works department **BOREHOLE PURPOSE:** Water Supply **DEPTH:** 115 m **DIAMETER:** 311.0 (12 1/

SITING METHOD: Geological **GEOLOGIST:** Batıhanlı Hilmi **CONSTRUCTION START:** No data **CONSTRUCTION END:** No data

PUMP TESTS

TEST	START	END	PUMP TYPE	TEST DURATION	STATIC WAT.LEV.	PUMPING WAT.LEV.	PUMP SUCTION	SAFE YIELD	COMMENT
1	19.01.2004	20.01.2004	No data	28	75	No data	45	30	No data

WATER LEVELS

DATE	DEPTH	SOURCE	METHOD	STATUS	MEASURED BY
20.01.2004	75,0	GDD	Steel-tape measurement	Static water level.	Batıhanlı Hilmi

Figure F.8. 19/74a Değirmenlik.

21/89 değirmenlik

SITE INFORMATION

DISTRICT/VILLAGE: Girne Dağı District-değirmenlik

SERIAL NUMBER: 21/89 **HYDROLOGIC NUMBER:** na **FILE NUMBER:** na

MAP SHEET: No Data **MAP SCALE:** 0 **EAST:** 544495 **NORTH:** 3903651 **ELEVATION:** 310 a.m.s.l.

BOREHOLE OWNER: village headmen of değirmenl **BOREHOLE PURPOSE:** Water Supply **DEPTH:** 152 m **DIAMETER:** unknown

SITING METHOD: Geological **GEOLOGIST:** Özhür Ayşe **CONSTRUCTION START:** No data **CONSTRUCTION END:** No data

Figure F.9. 21/89 Değirmenlik.

2013/02 değirmenlik

SITE INFORMATION

DISTRICT/VILLAGE: Girne Dağı District-değirmenlik

SERIAL NUMBER: 2013/02 **HYDROLOGIC NUMBER:** na **FILE NUMBER:** na

MAP SHEET: No Data **MAP SCALE:** No data **EAST:** 545675 **NORTH:** 3903674 **ELEVATION:** 389 a.m.s.l.

BOREHOLE OWNER: değirmenlik municipality **BOREHOLE PURPOSE:** Water Supply **DEPTH:** 244 m **DIAMETER:** 254.0 (10")

SITING METHOD: Geological **GEOLOGIST:** Özhür Ayşe **CONSTRUCTION START:** No data **CONSTRUCTION END:** No data

PUMP TESTS

TEST	START	END	PUMP TYPE	TEST DURATION	STATIC WAT.LEV.	PUMPING WAT.LEV.	PUMP SUCTION	SAFE YIELD	COMMENT
1	02.05.2013	04.05.2013	No data	48	144,08	144,92	59	45	No data

WATER LEVELS

DATE	DEPTH	SOURCE	METHOD	STATUS	MEASURED BY
02.05.2013	144,1	GDD	Steel-tape measurement	site was being pump	No data
07.05.2013	145,0	GDD	Steel-tape measurement	site was being pump	salih ersangil
21.05.2013	145,0	WDD	Steel-tape measurement	site was being pump	No data

Figure F.10. 2013/02 Değirmenlik.

Appendix G: Slope stability analysis

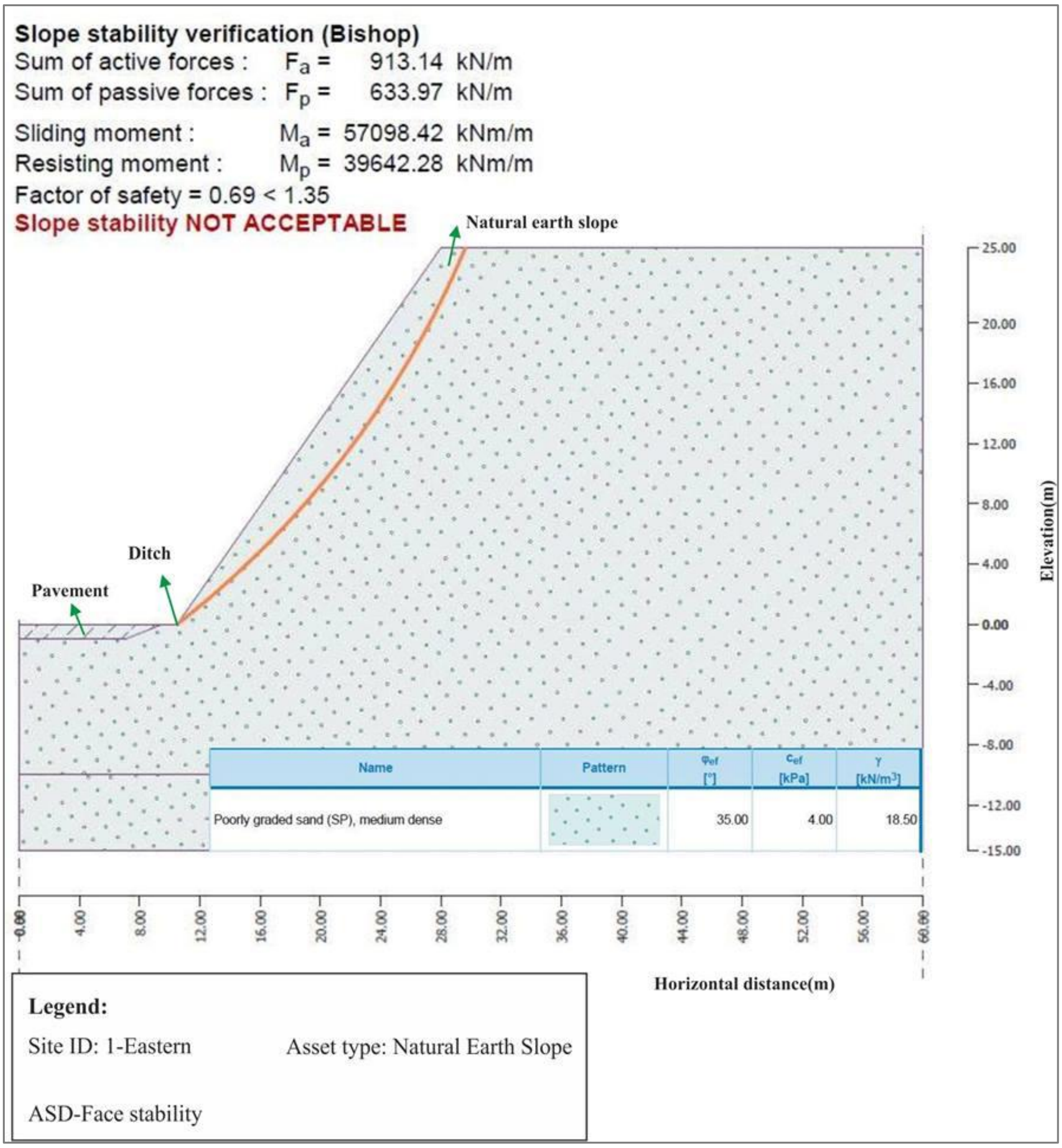

Figure G.1. Site 1-Eastern-ASD-Face stability.

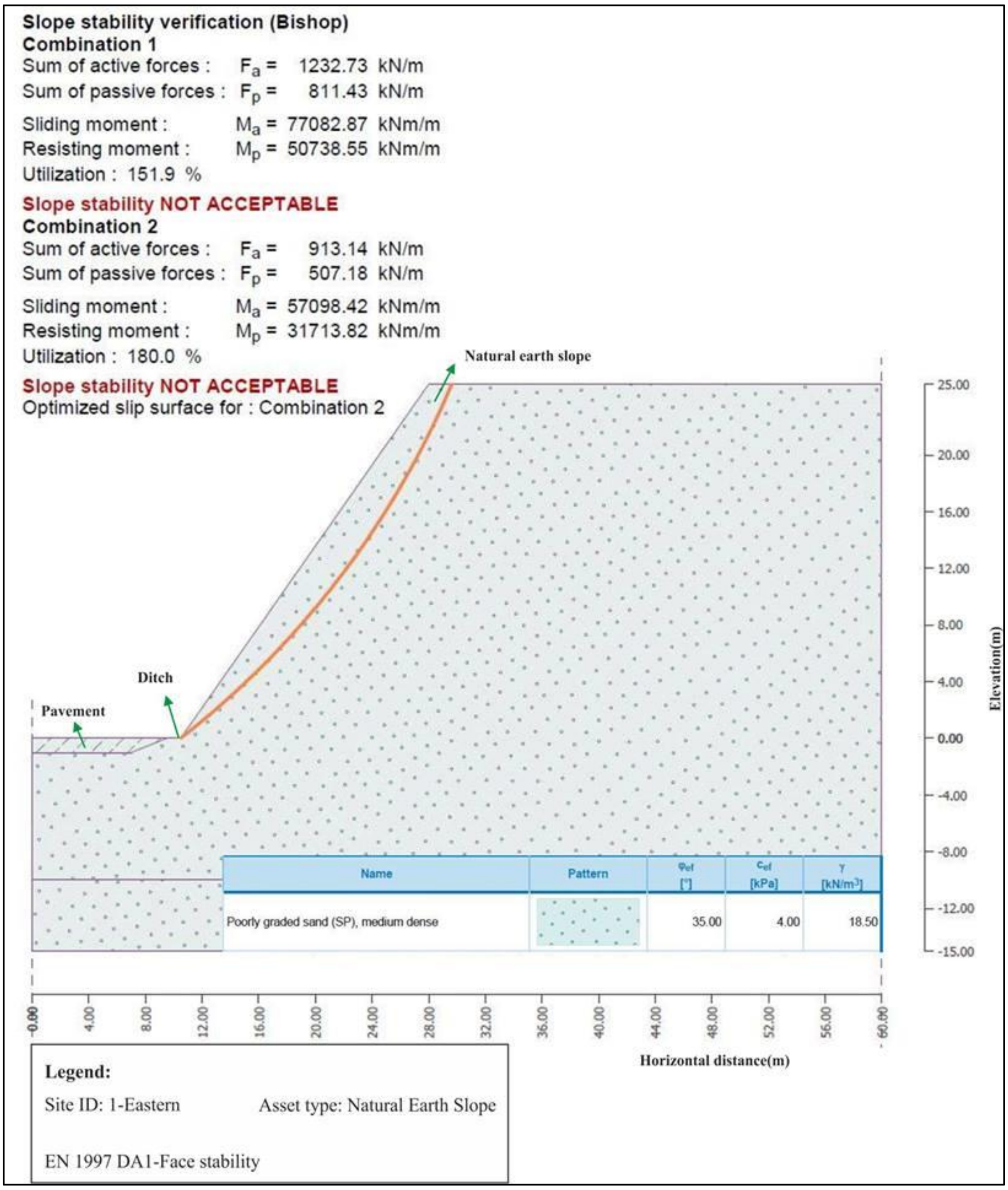

Figure G.2. Site1-Easter-EN1997-Face stability.

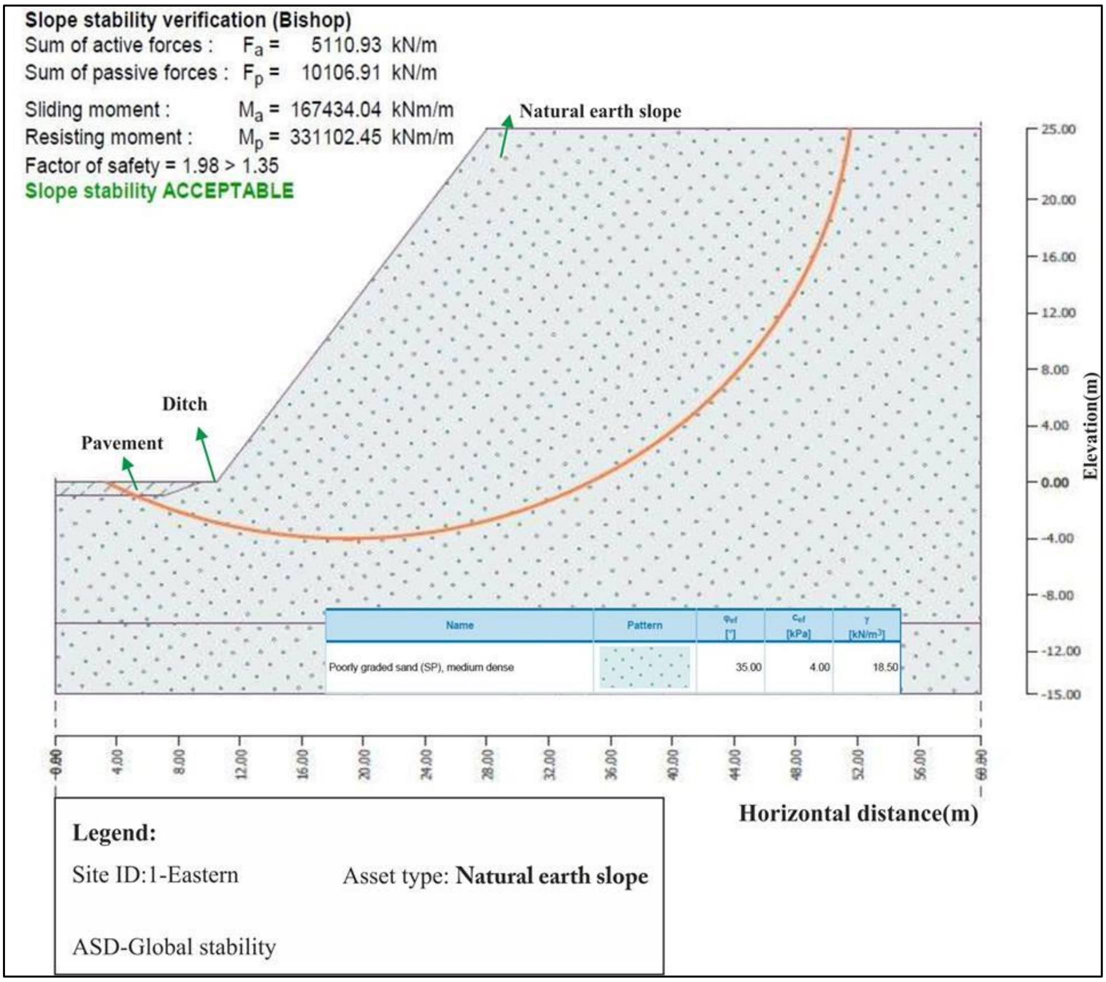

Figure G.3. Site 1-Eastern-ASD-Global stability.

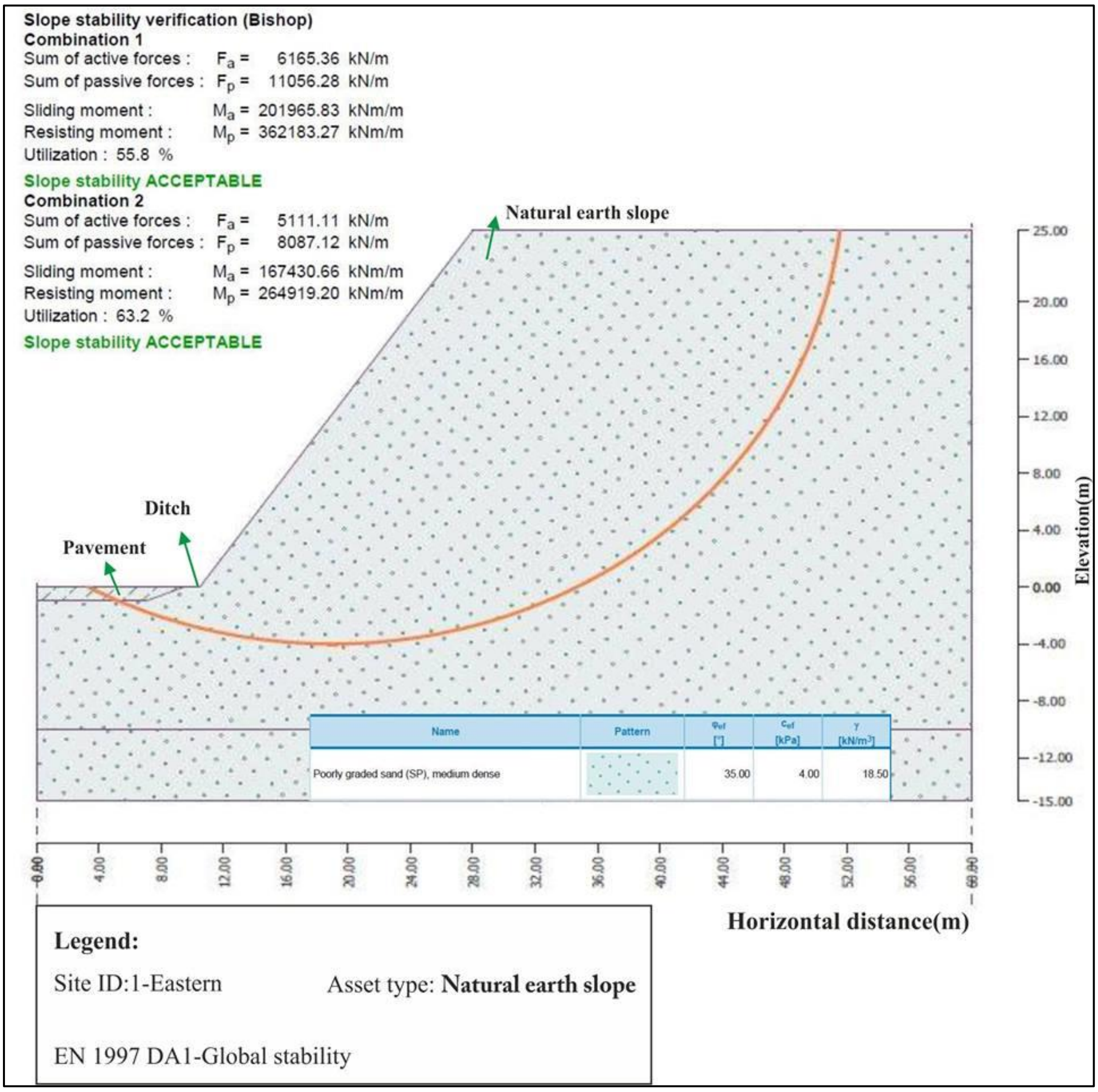

Figure G.4. Site1-Eastern-EN1997-Global stability.

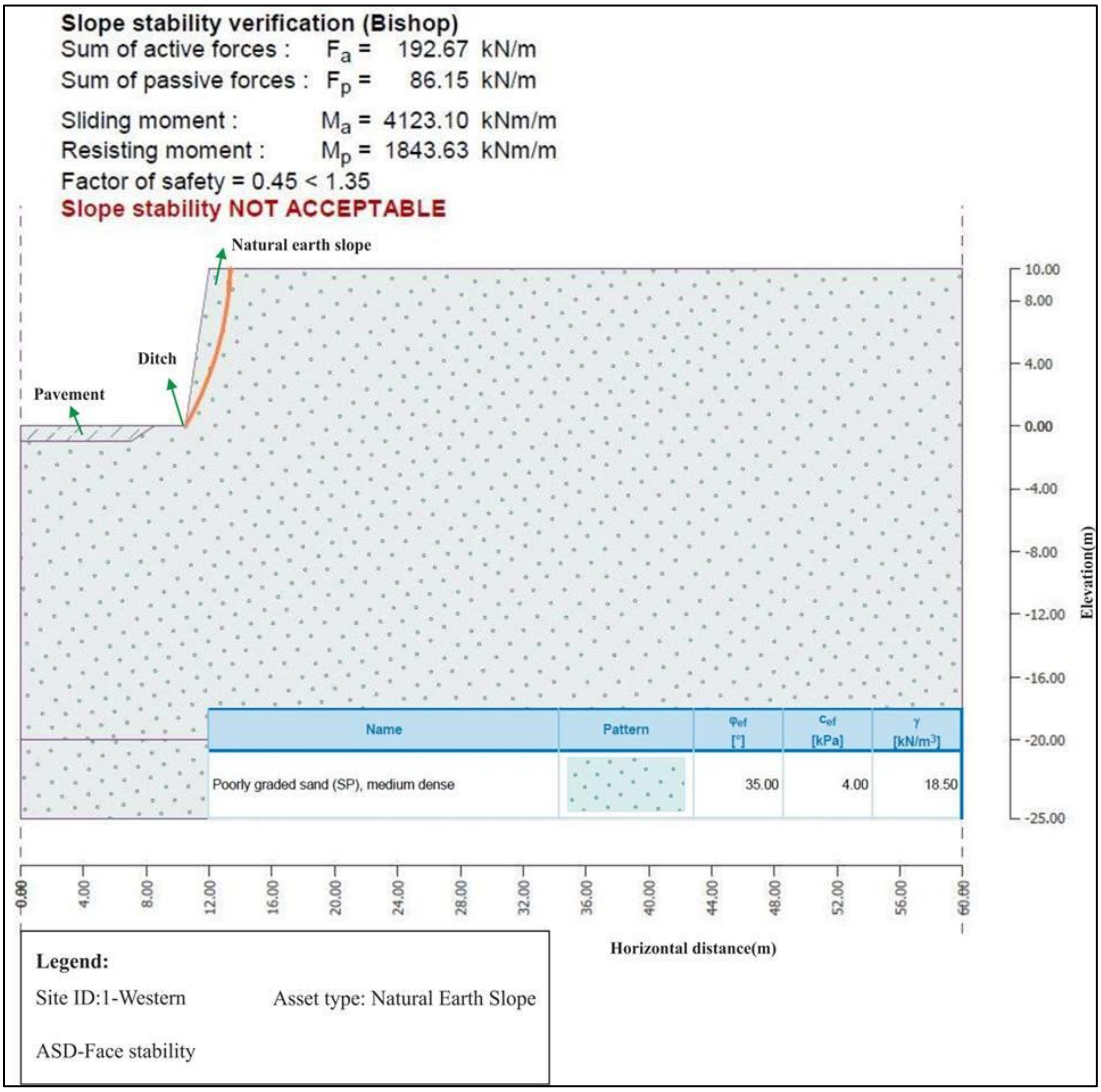

Figure G.5. Site 1-Western-ASD-Face stability.

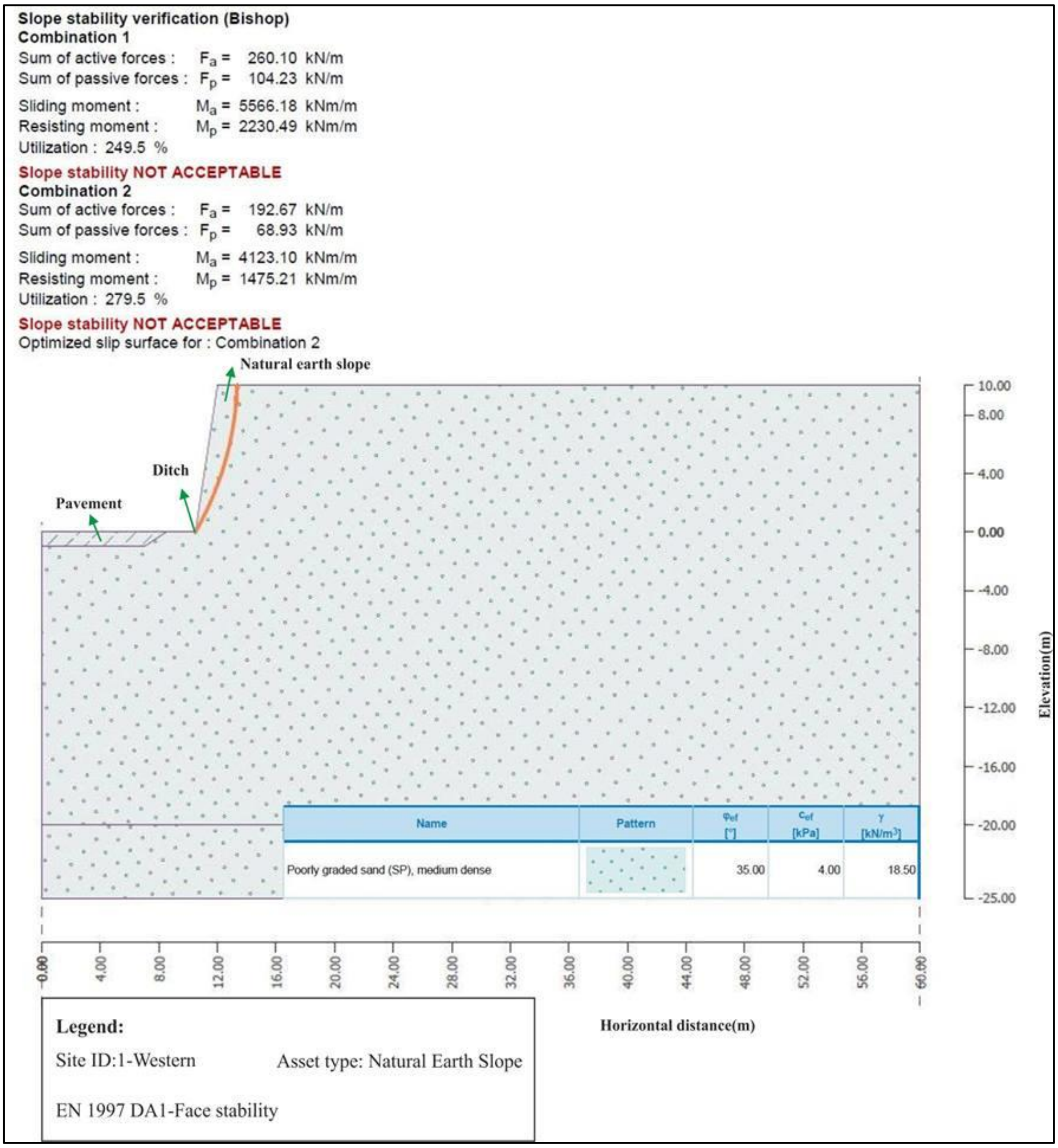

Figure G.6. Site 1-Western-EN1997-Face stability.

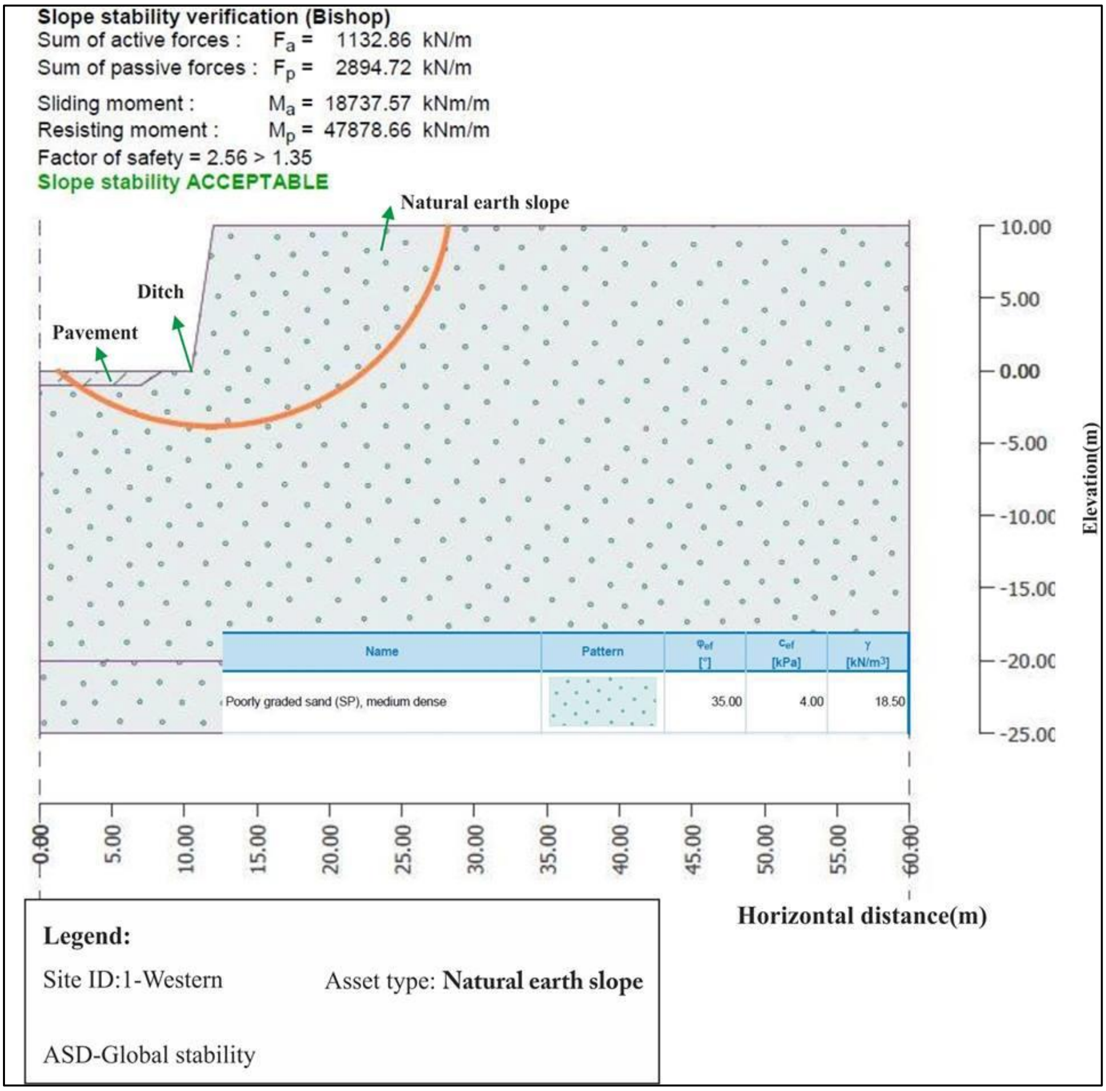

Figure G.7. Site 1-Western-ASD-Global stability.

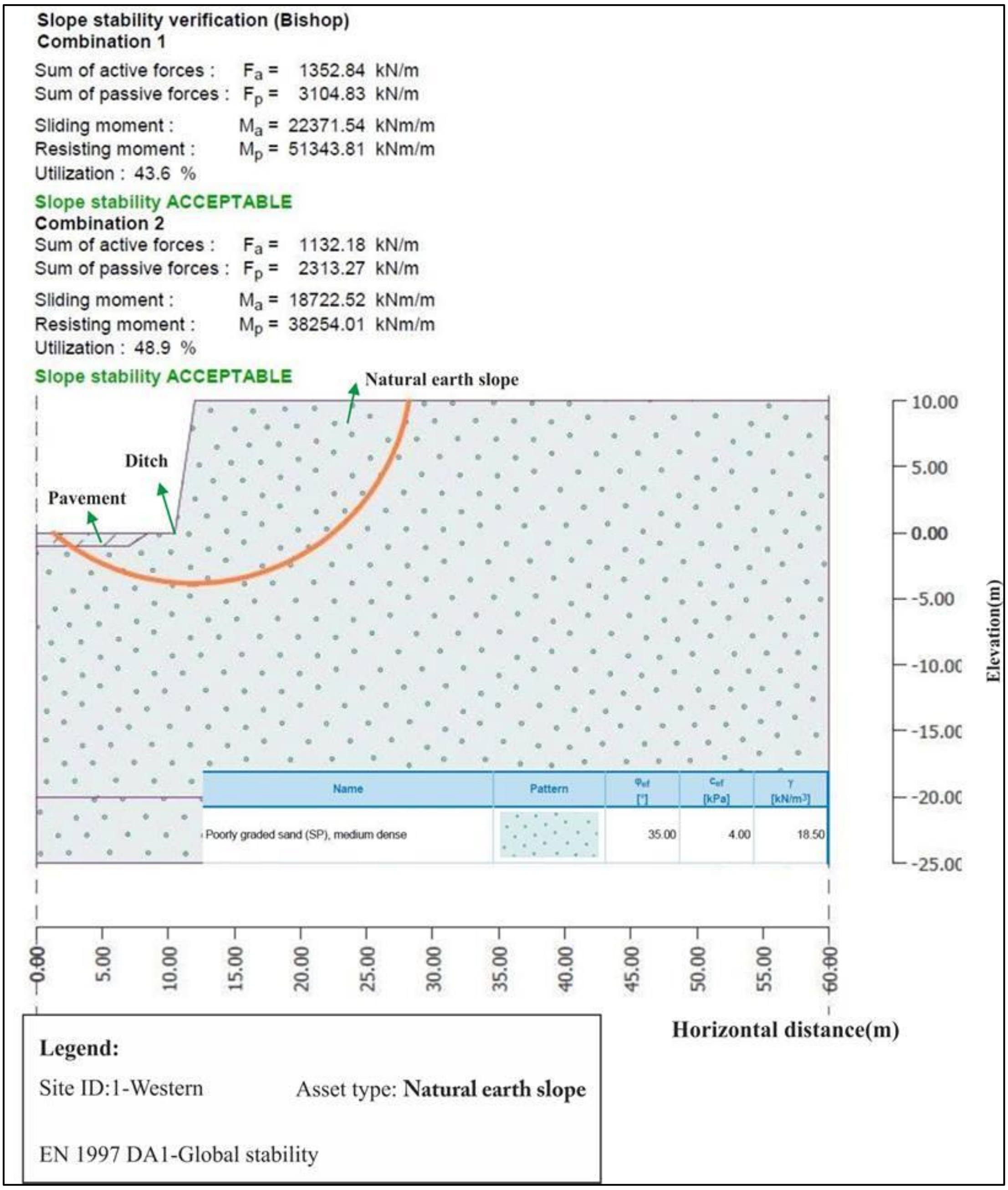

Figure G.8. Site 1-Western-EN1997-Global stability.

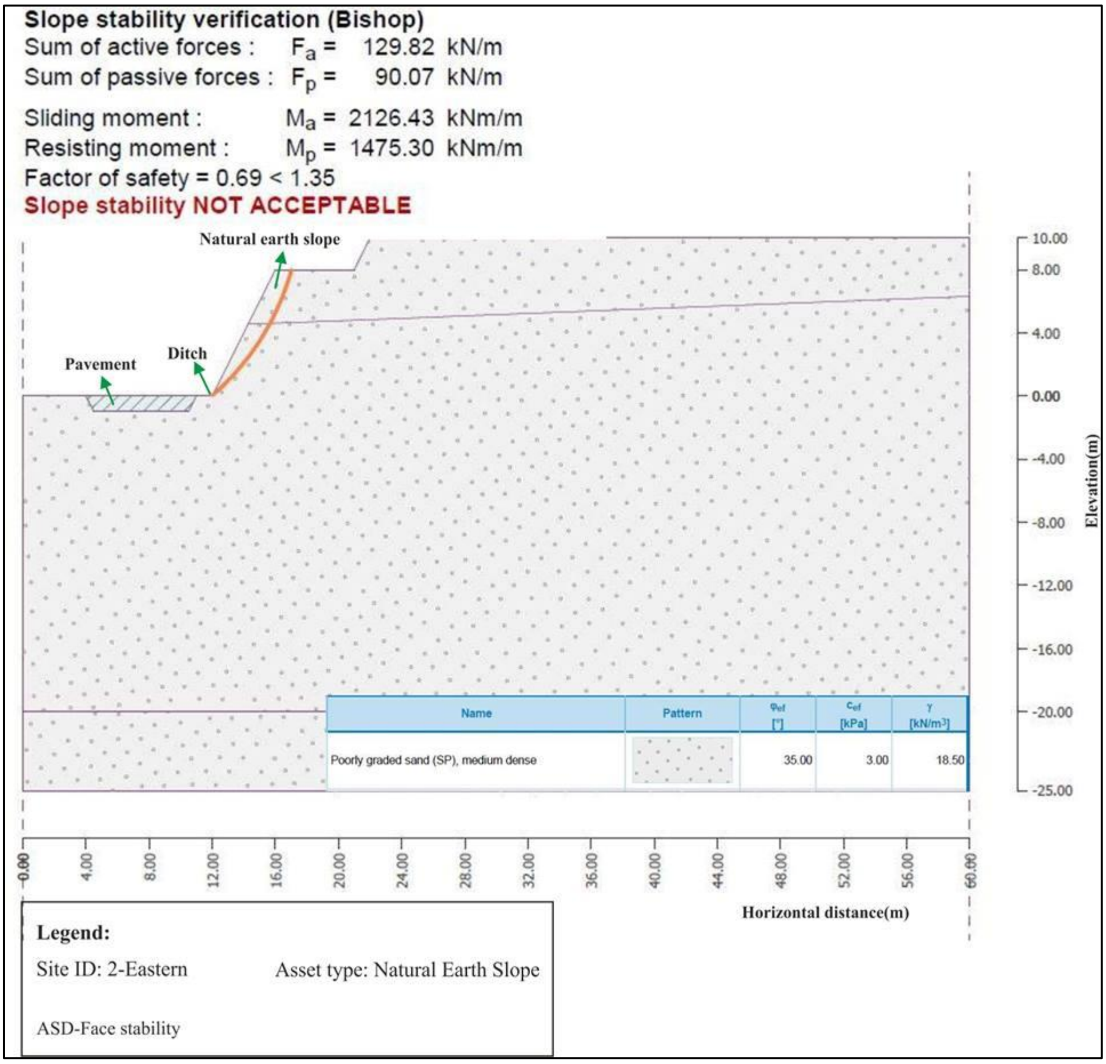

Figure G.9. Site2-Eastern-ASD-Face stability.

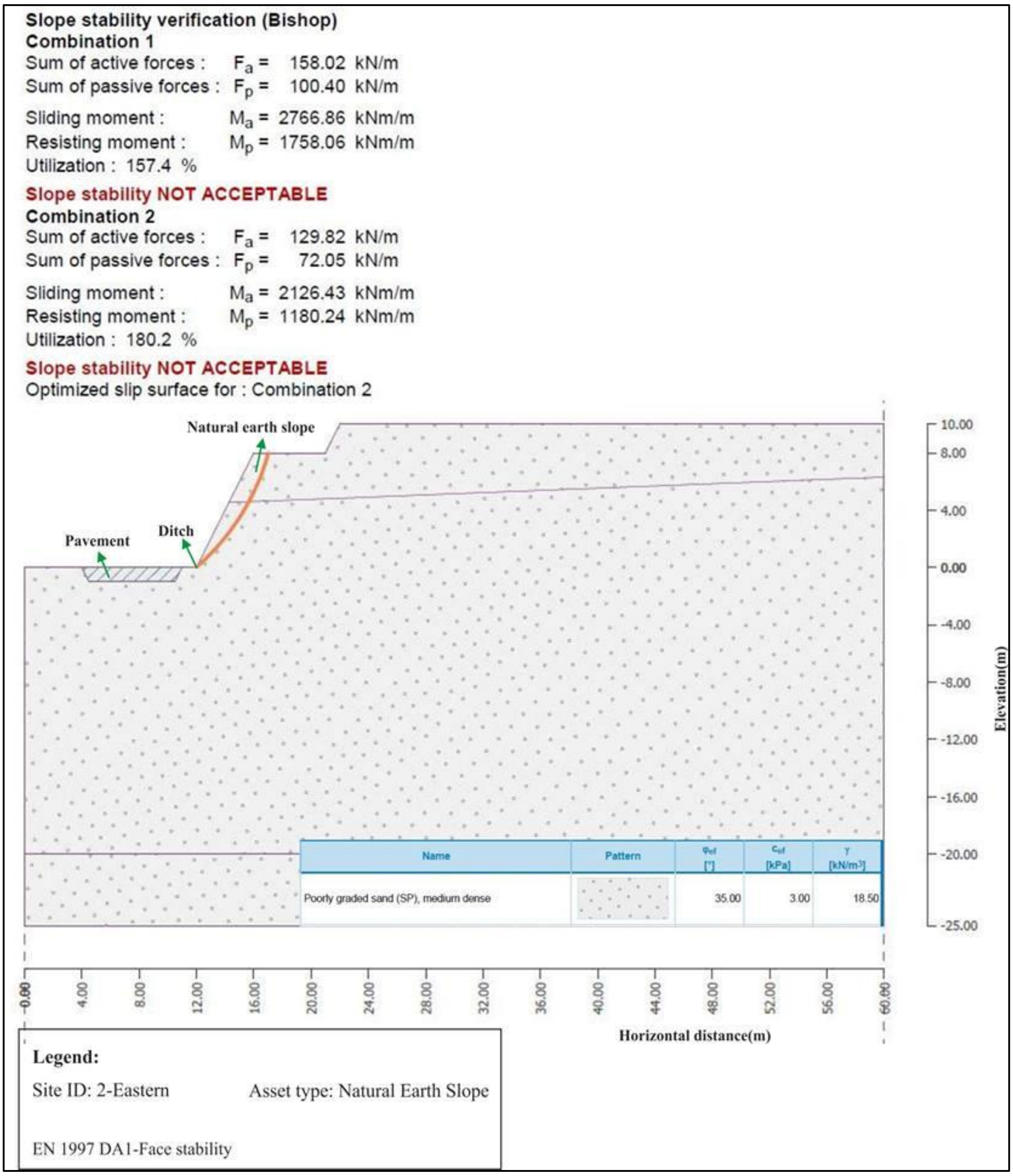

Figure G.10. Site 2-Eastern-EN1997-Face stability.

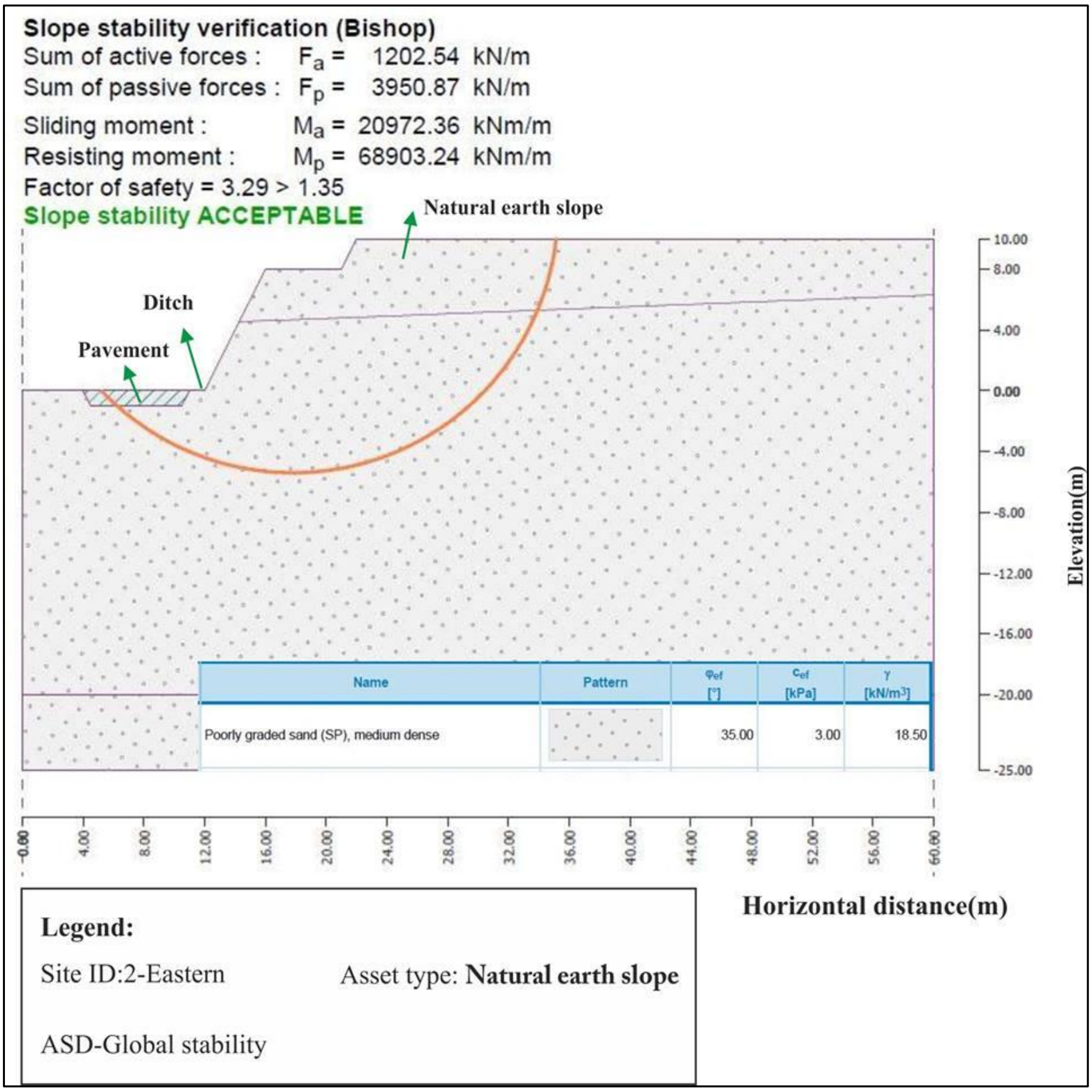

Figure G.11. Site 2-Eastern-ASD-Global stability.

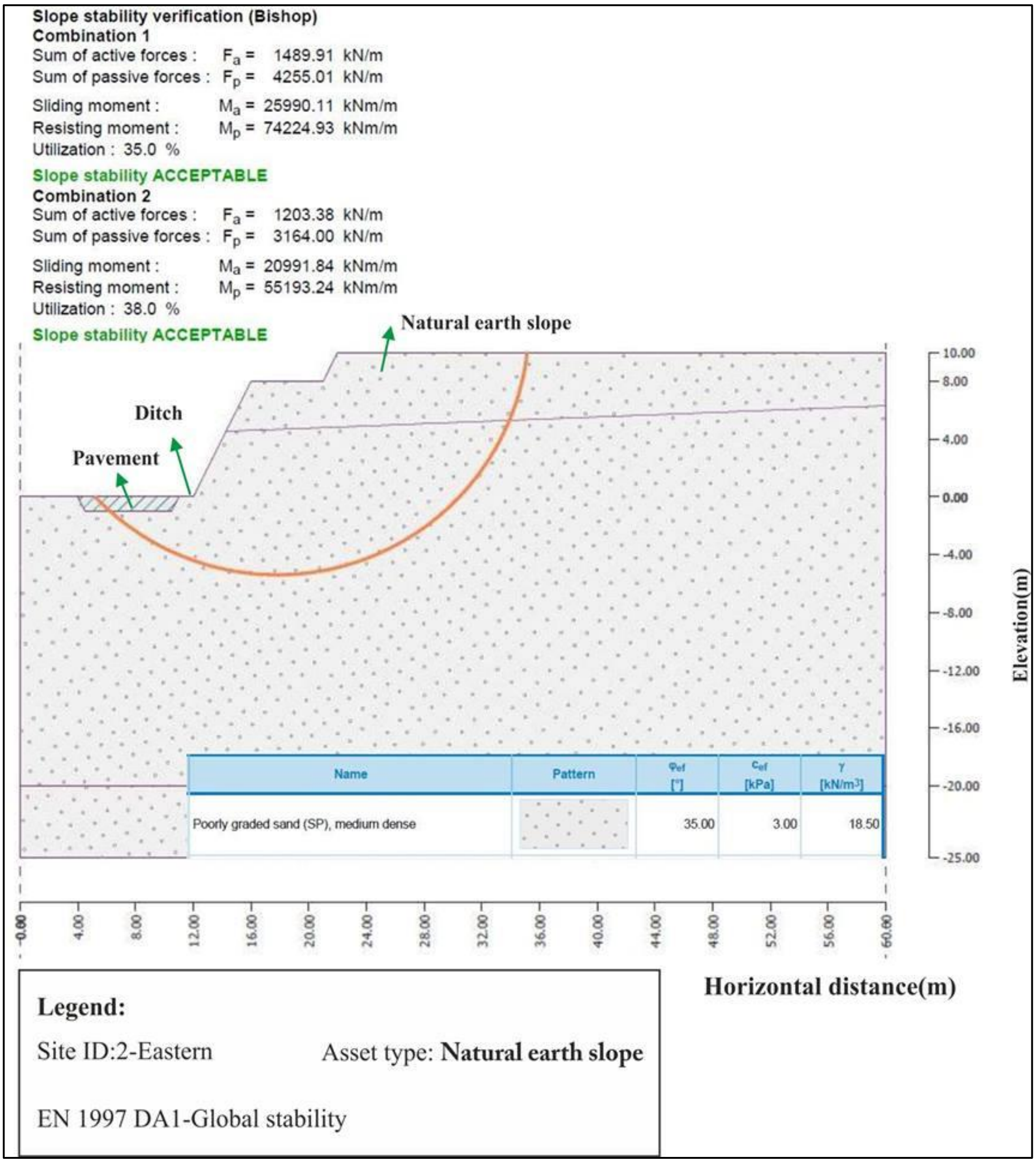

Figure G.12. Site 2-Eastern-EN1997-Global stability.

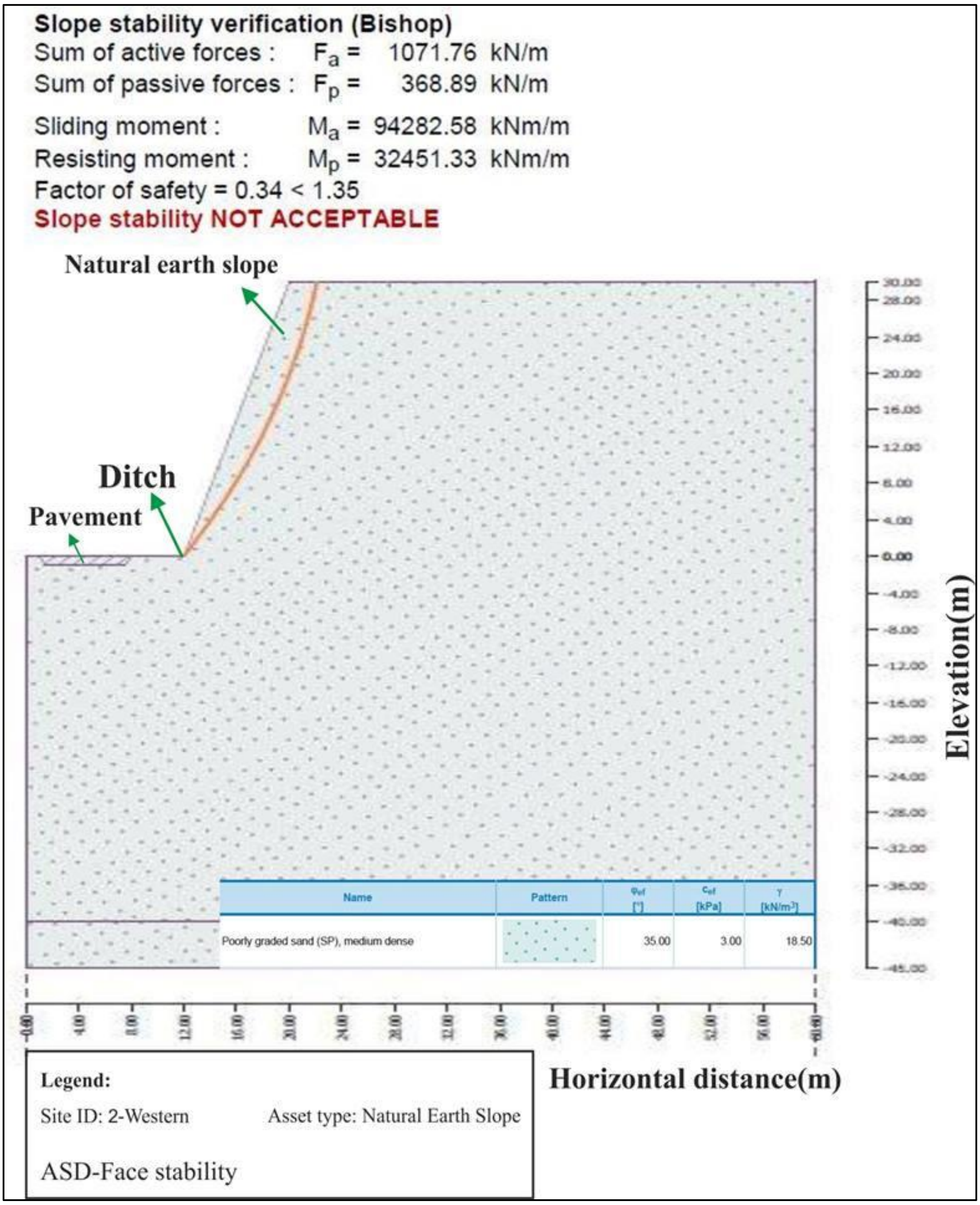

Figure G.13. Site 2-Western-ASD-Face stability.

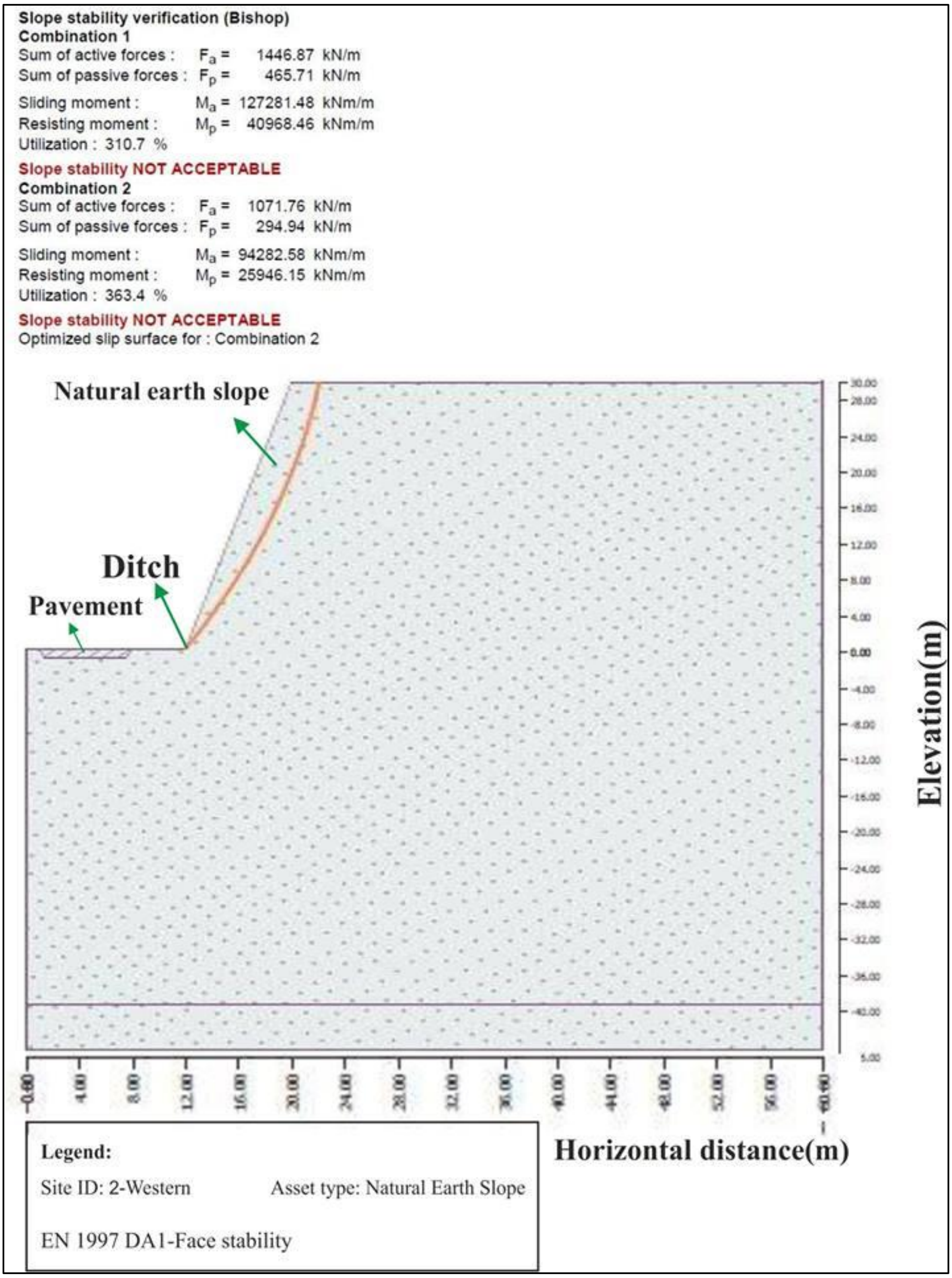

Figure G.14. Site 2-Western-EN1997-Face stability.

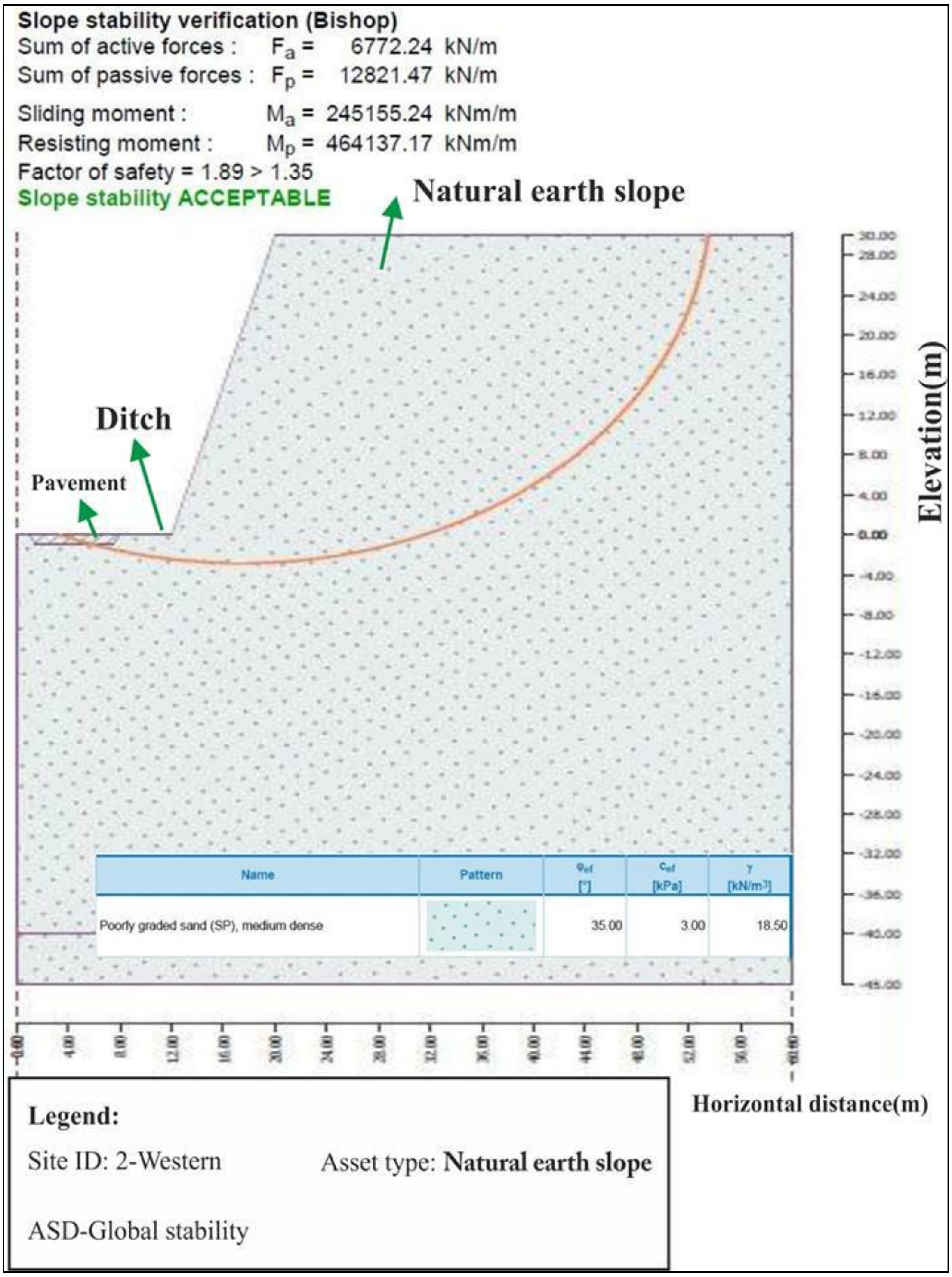

Figure G.15. Site 2-Western-ASD-Global stability.

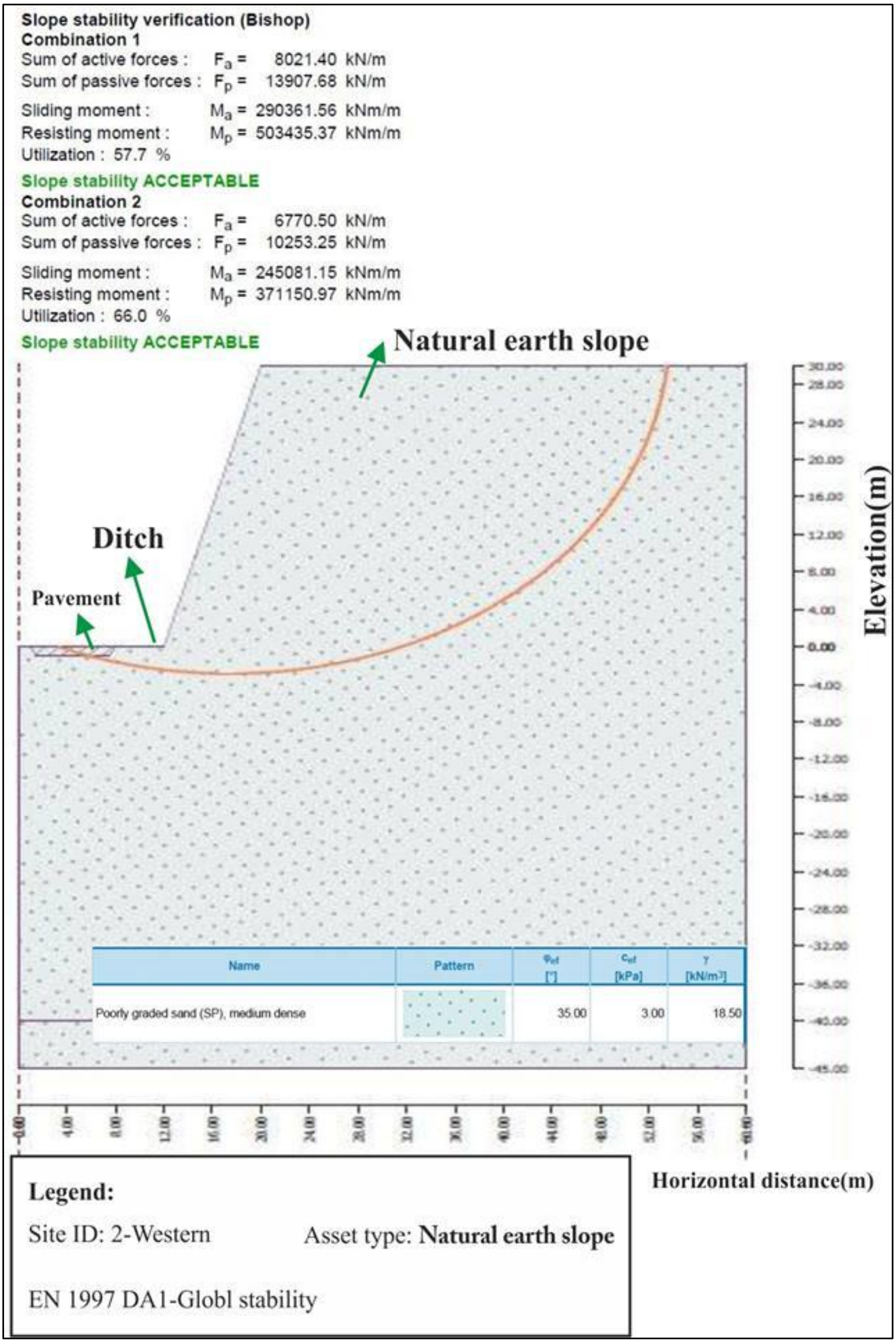

Figure G.16. Site 2-Western-EN1997-Global stability.

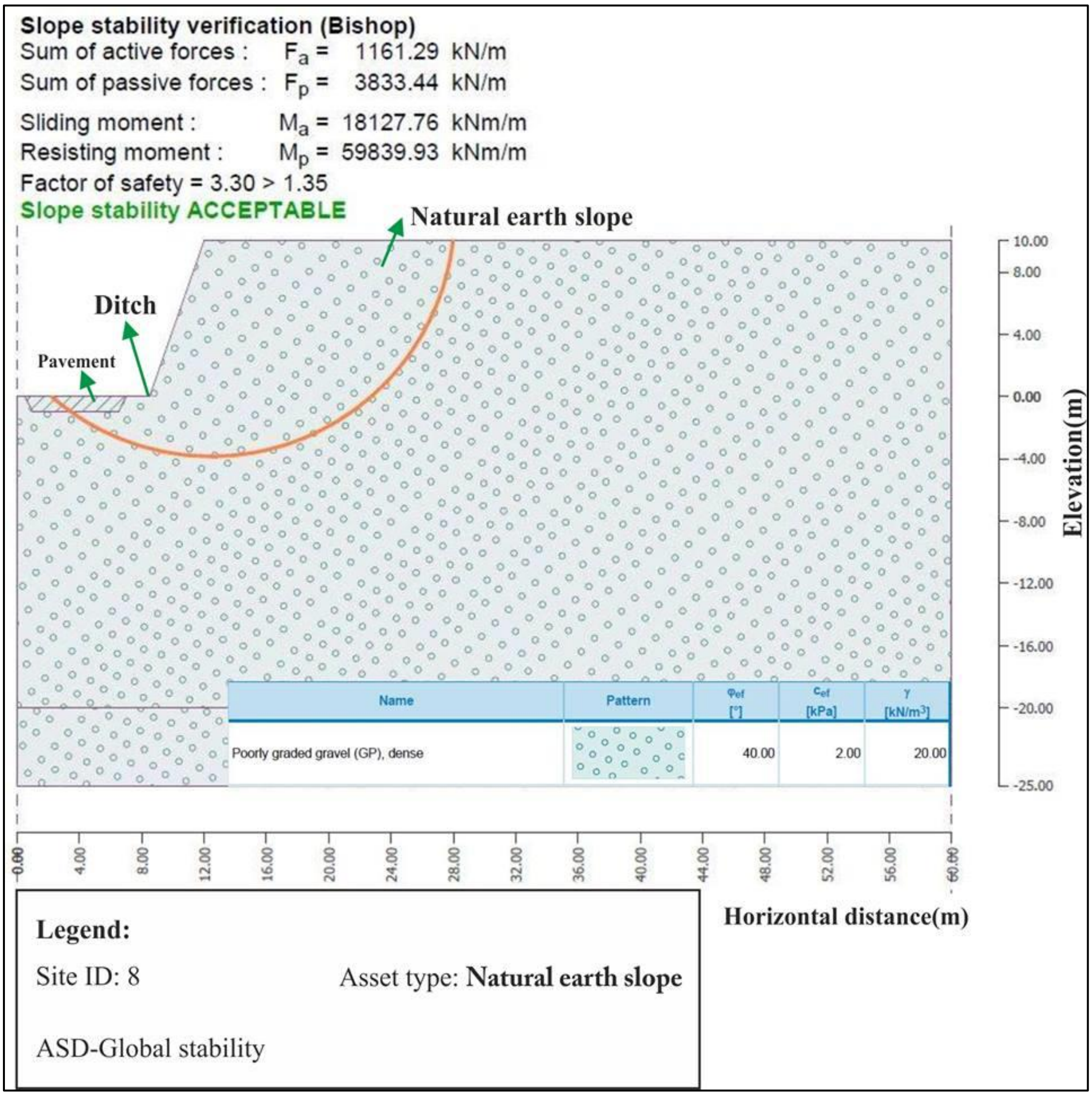

Figure G.17. Site 8-ASD-Global stability.

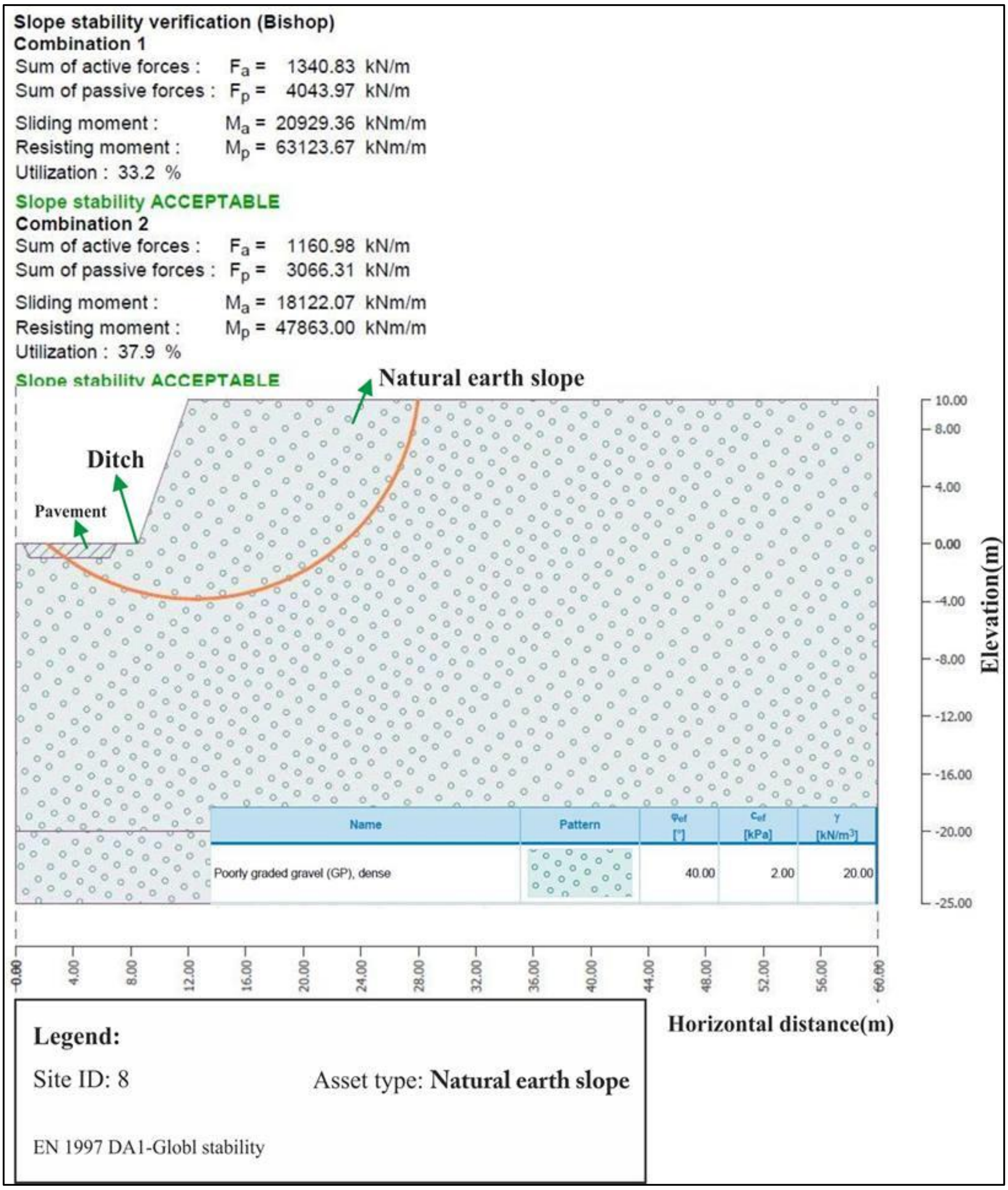

Figure G.18. Site 8-EN1997-Global stability.

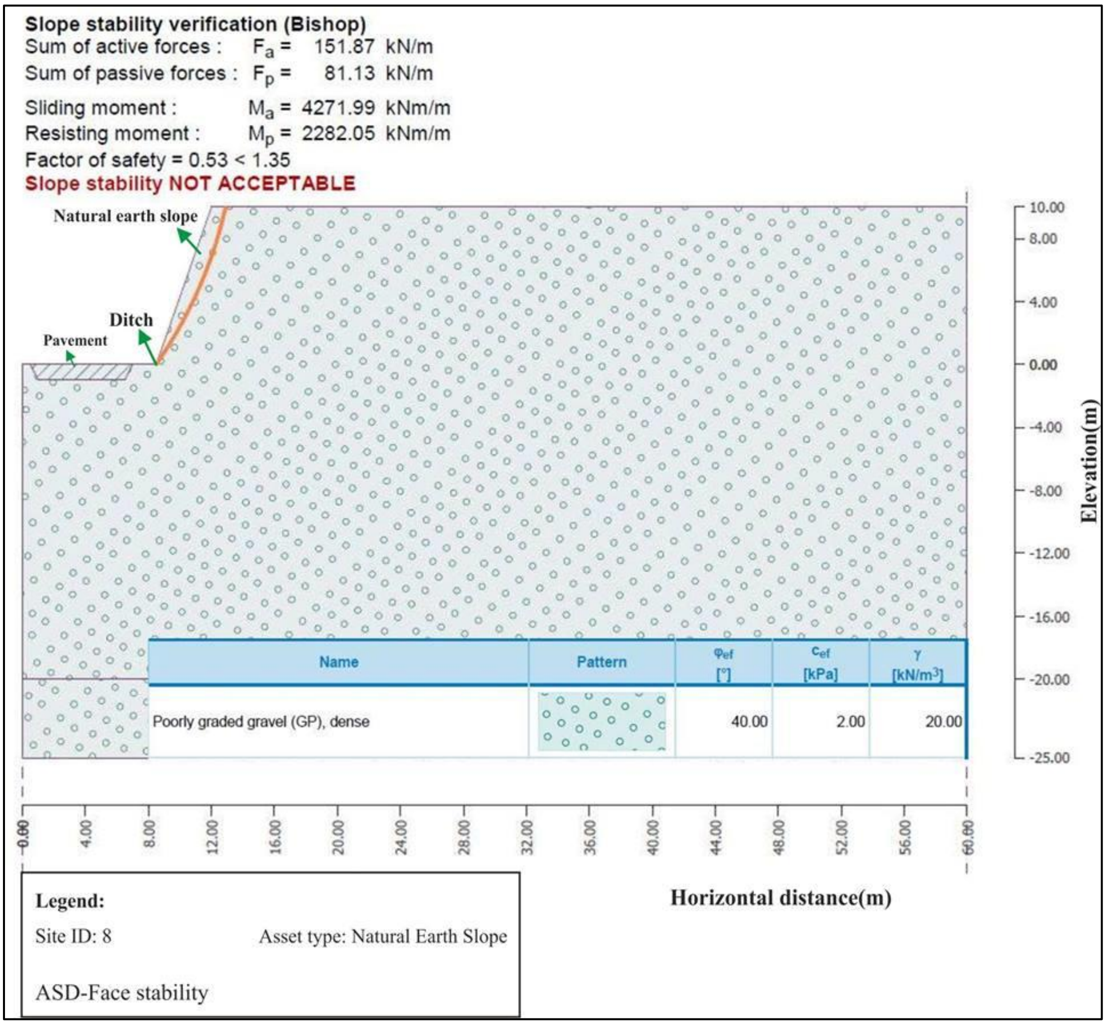

Figure G.19. Site 8-ASD-Face stability.

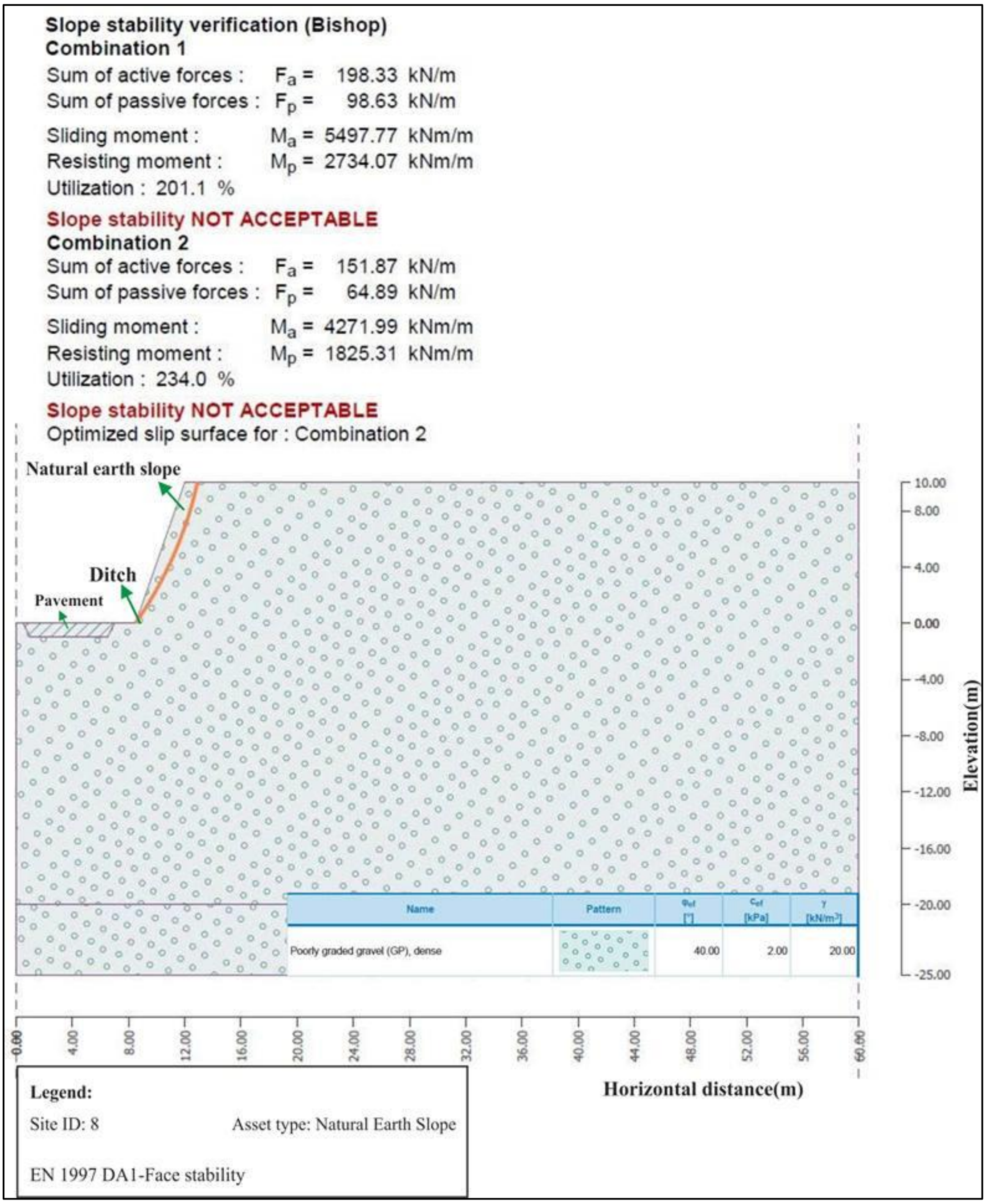

Figure G.20. Site 8-EN1997-Face stability.

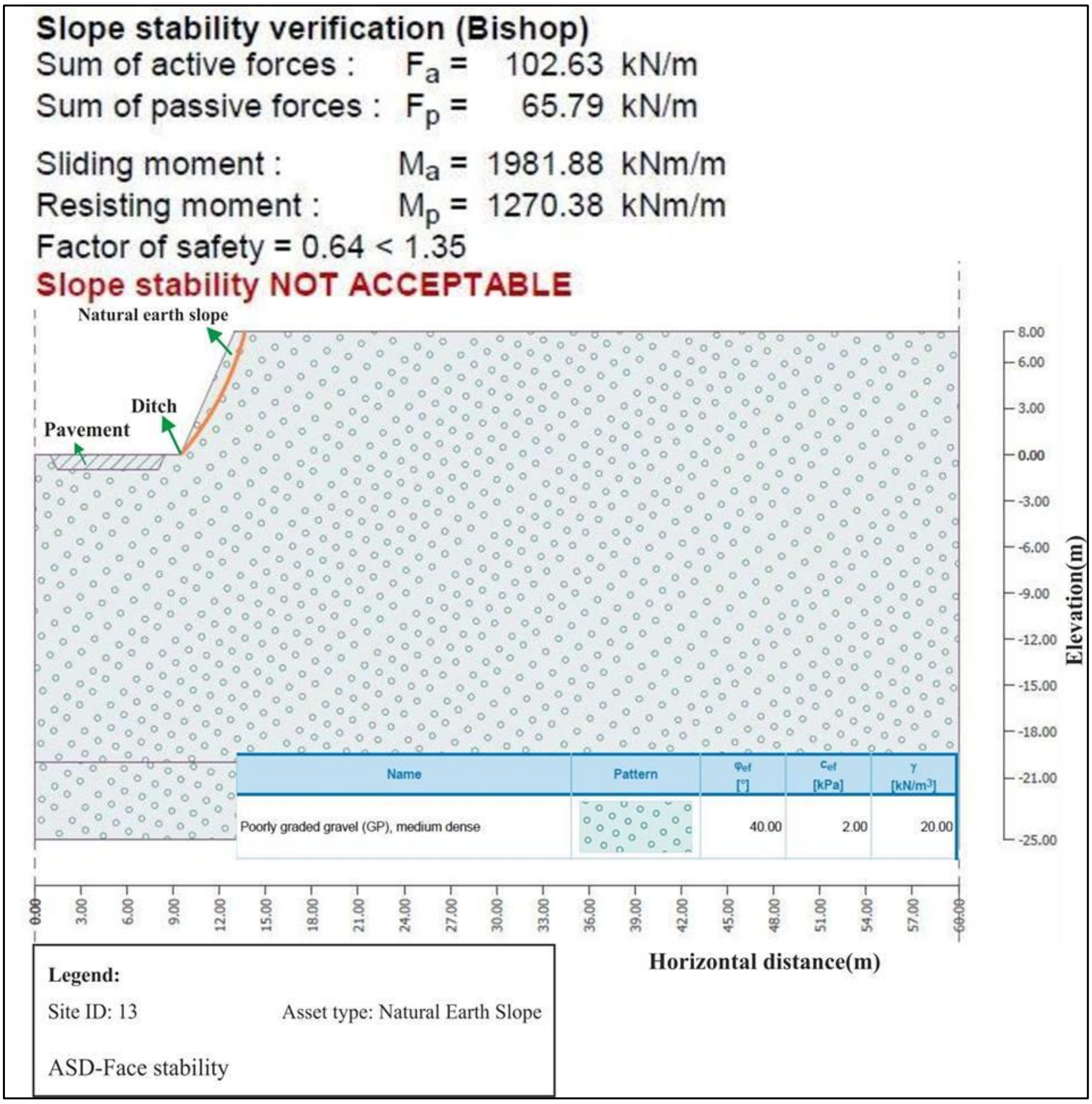

Figure G.21. Site 13-ASD-Face stability.

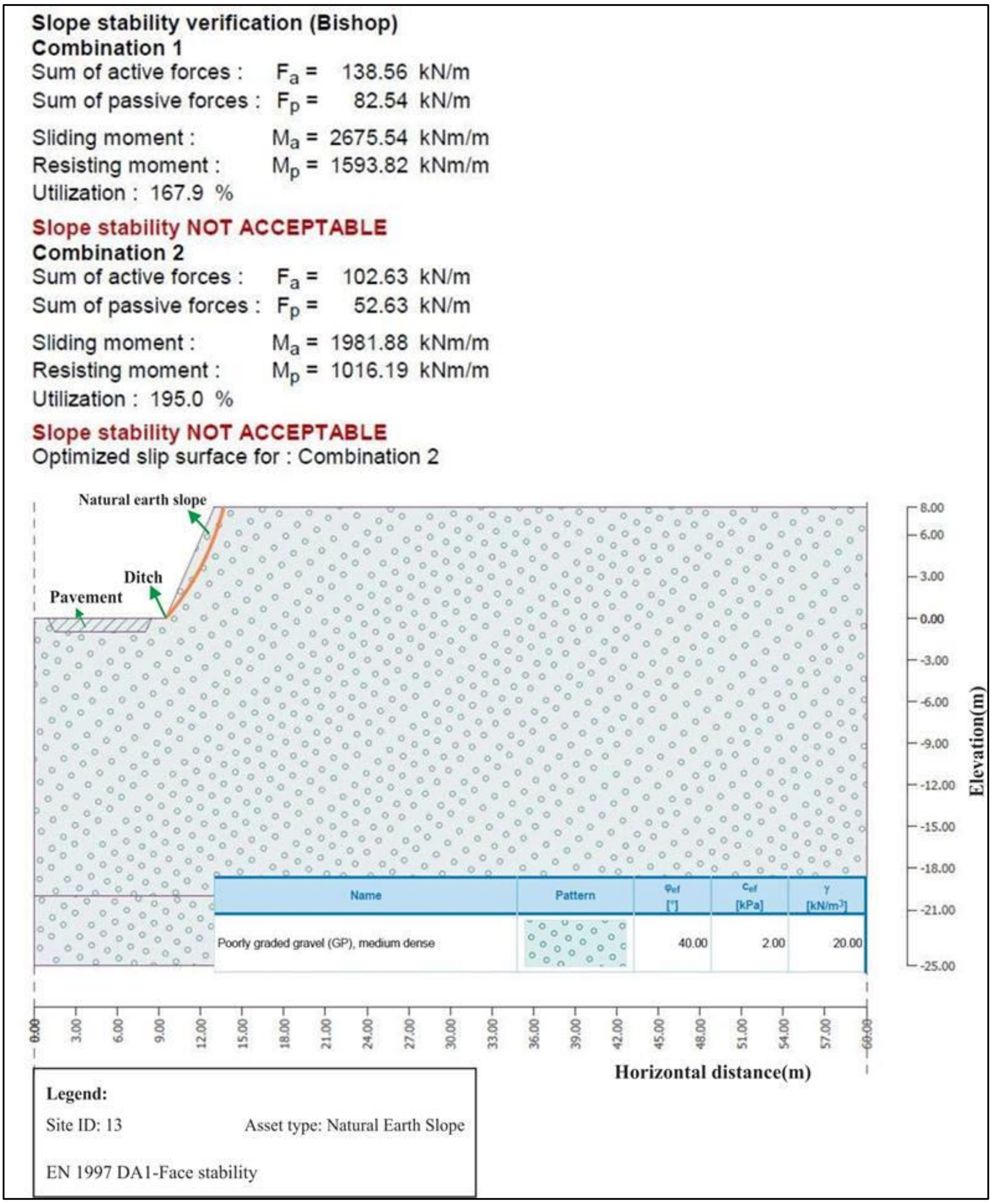

Figure G.22. Site 13-EN1997-Face stability.

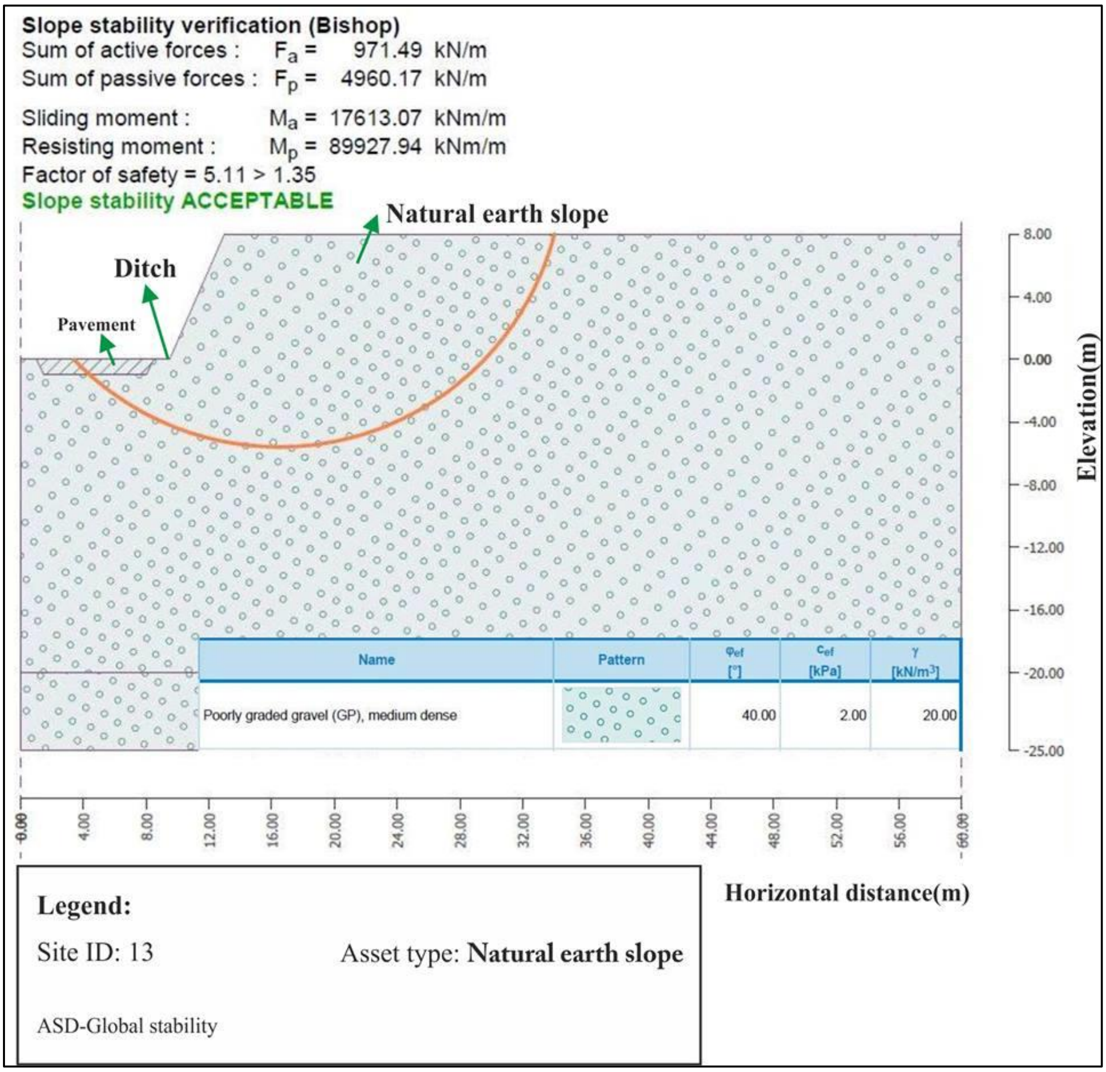

Figure G.23. Site 13-ASD-Global stability.

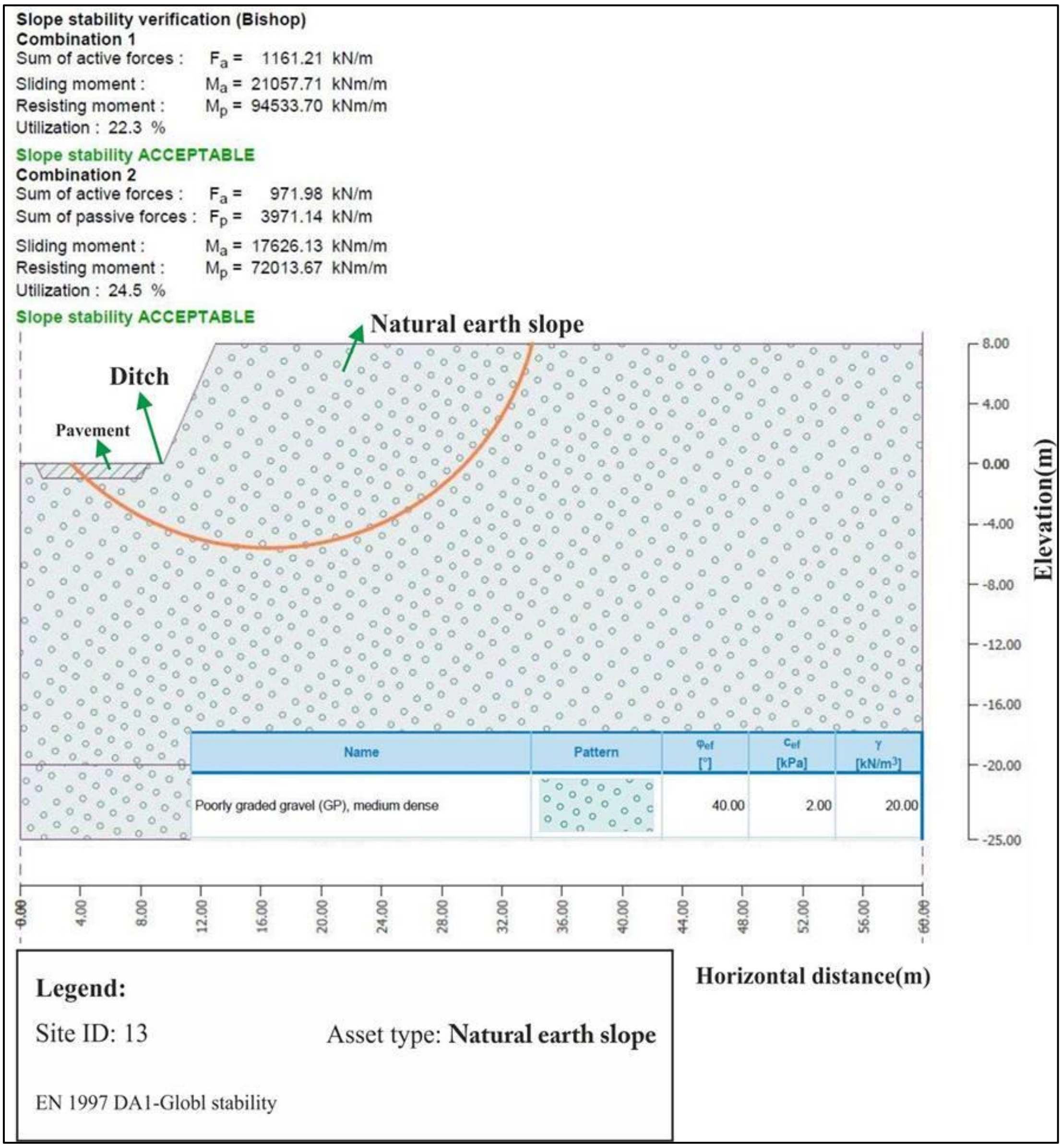

Figure G.24. Site 13-EN1997-Global stability.

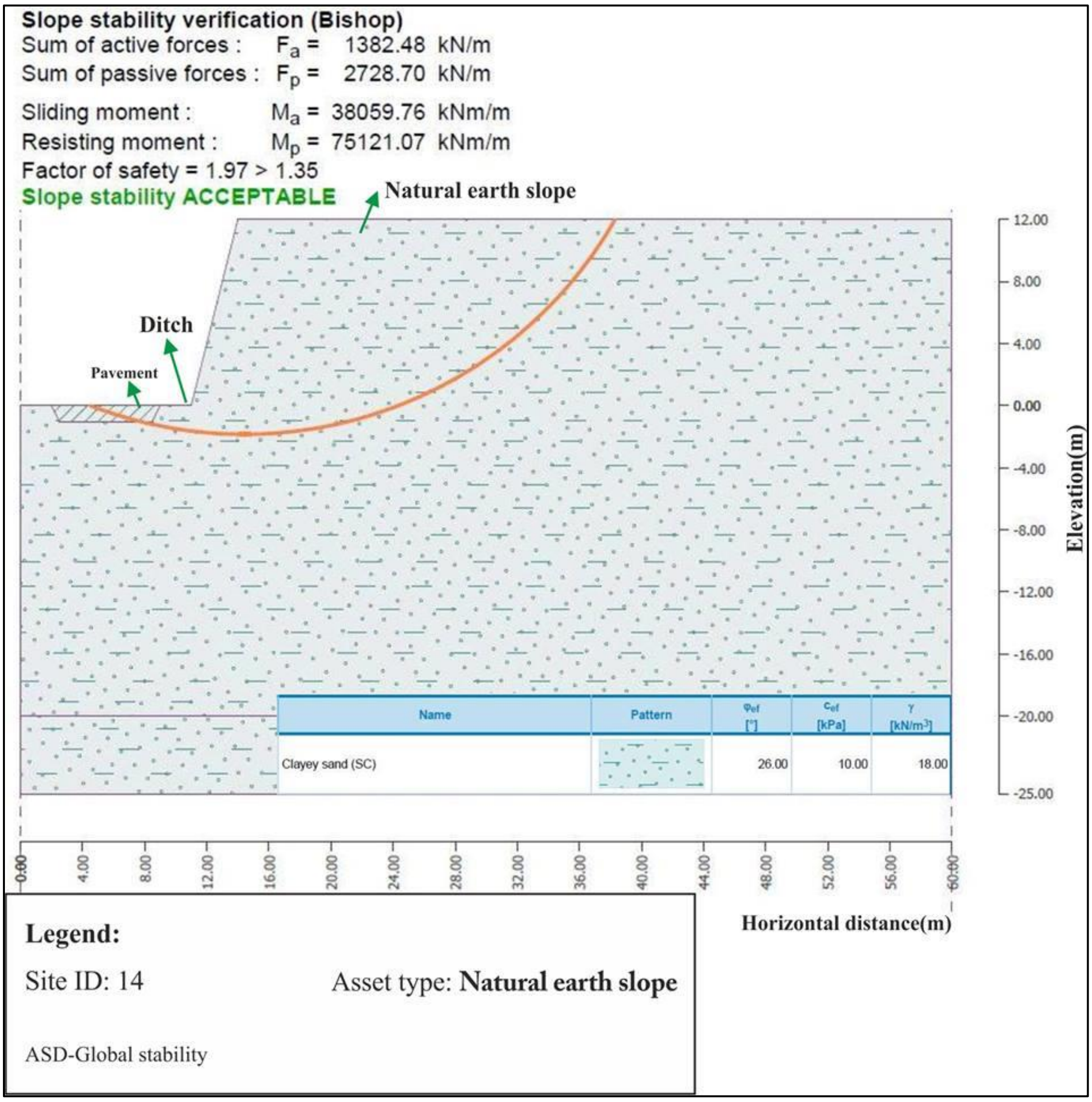

Figure G.25. Site 14-ASD-Global stability.

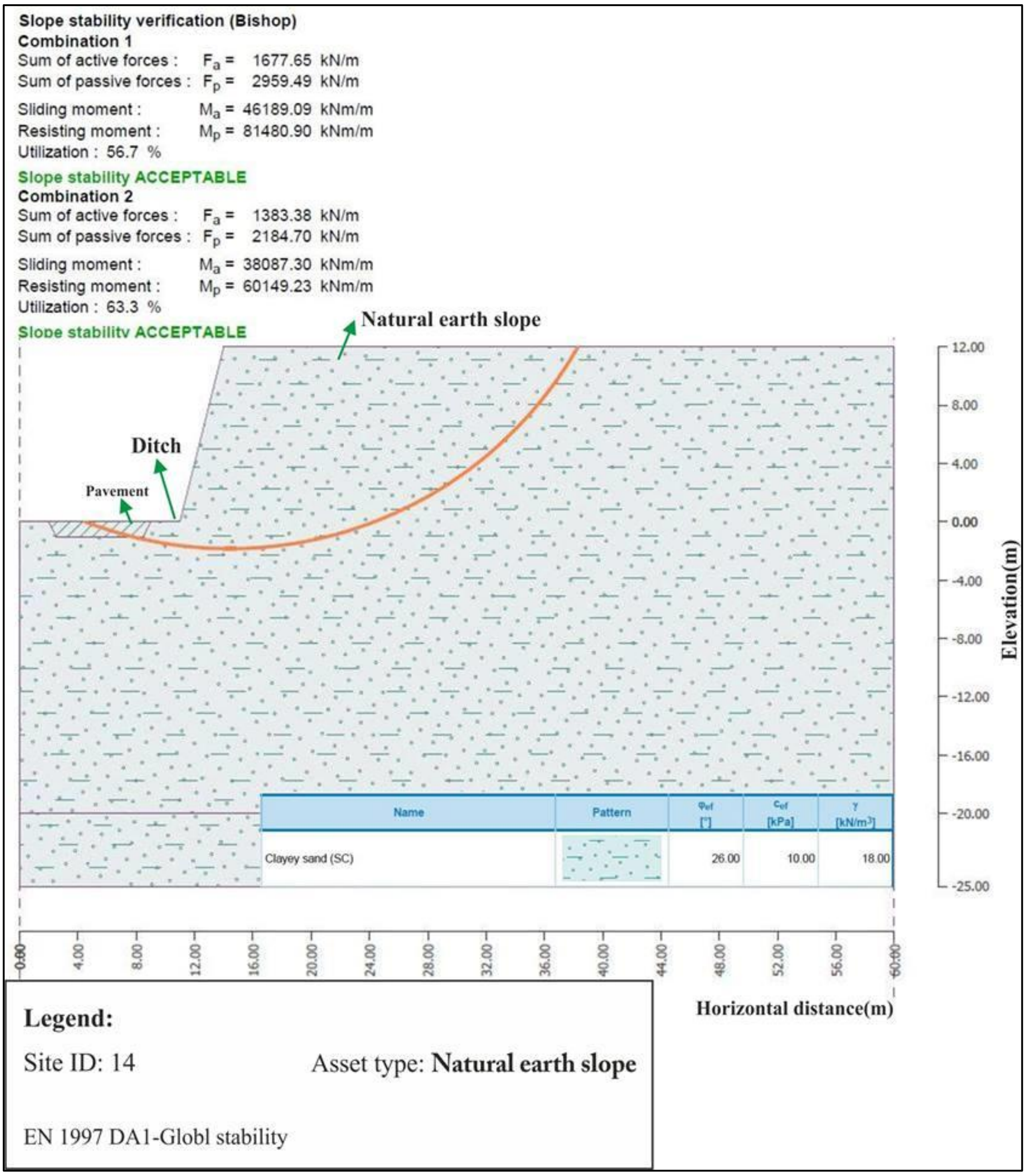

Figure G.26. Site 14-EN1997-Global stability.

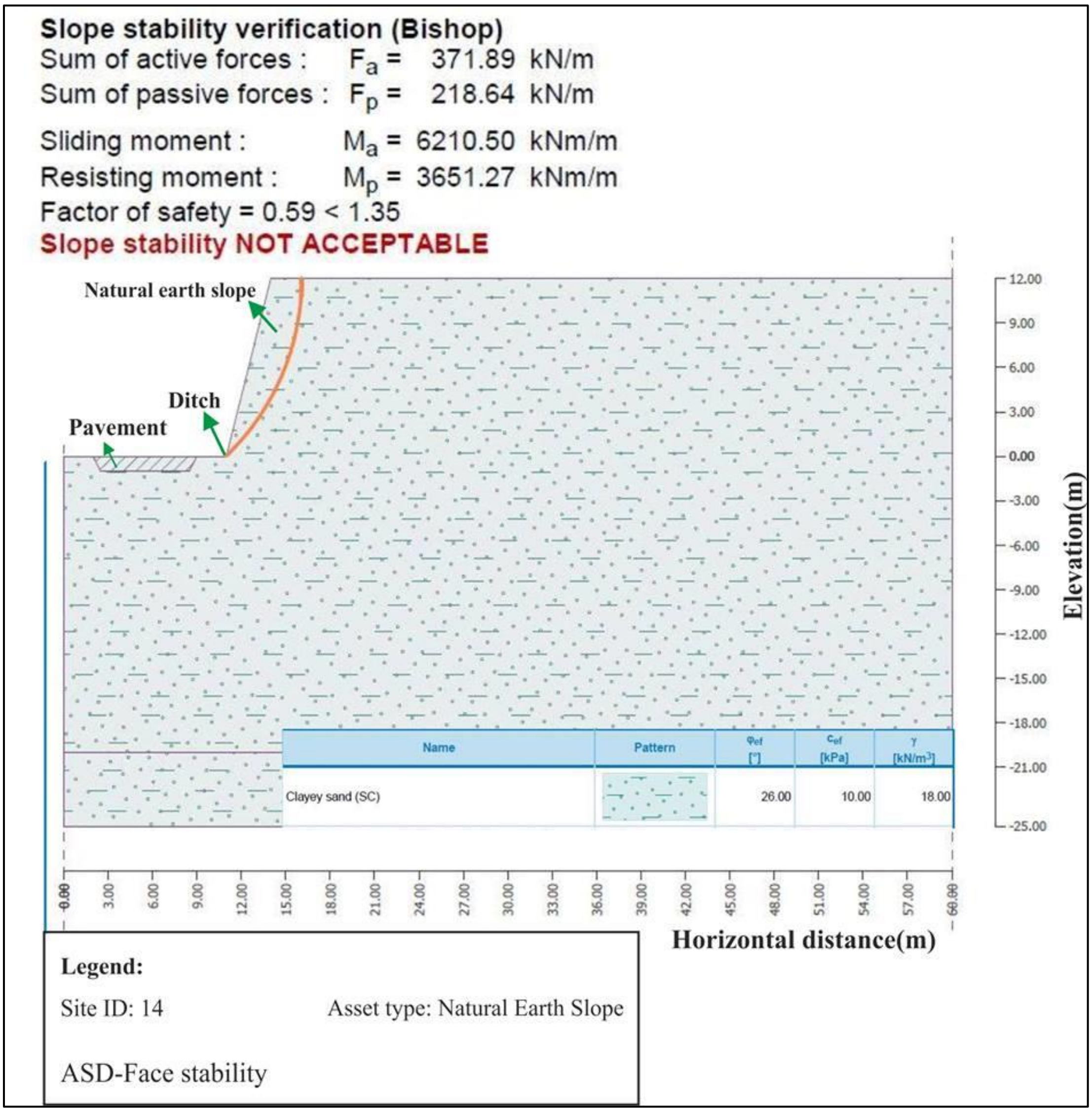

Figure G.27. Site 14-ASD-Face stability.

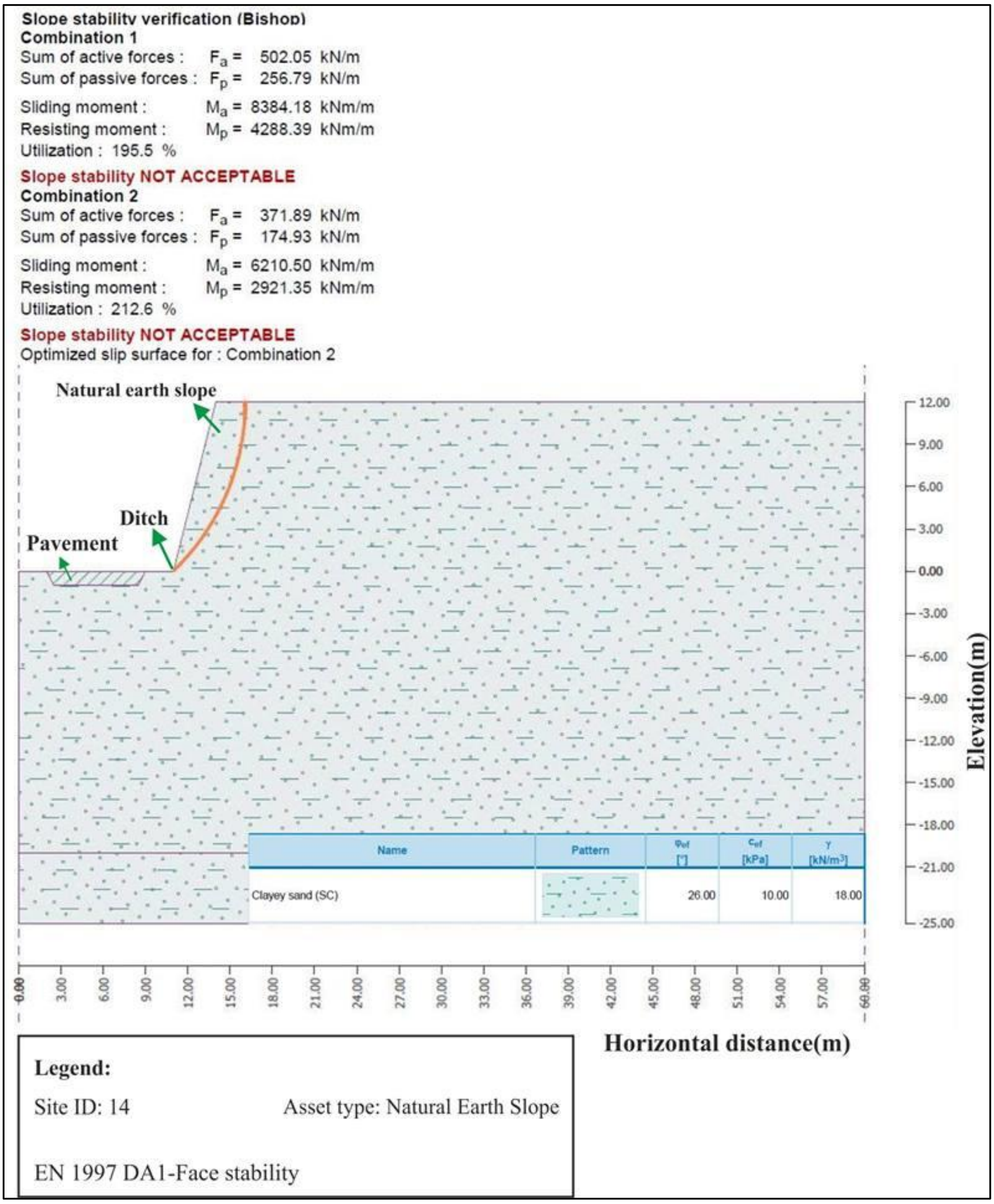

Figure G.28. Site 14-EN1997-Face stability.

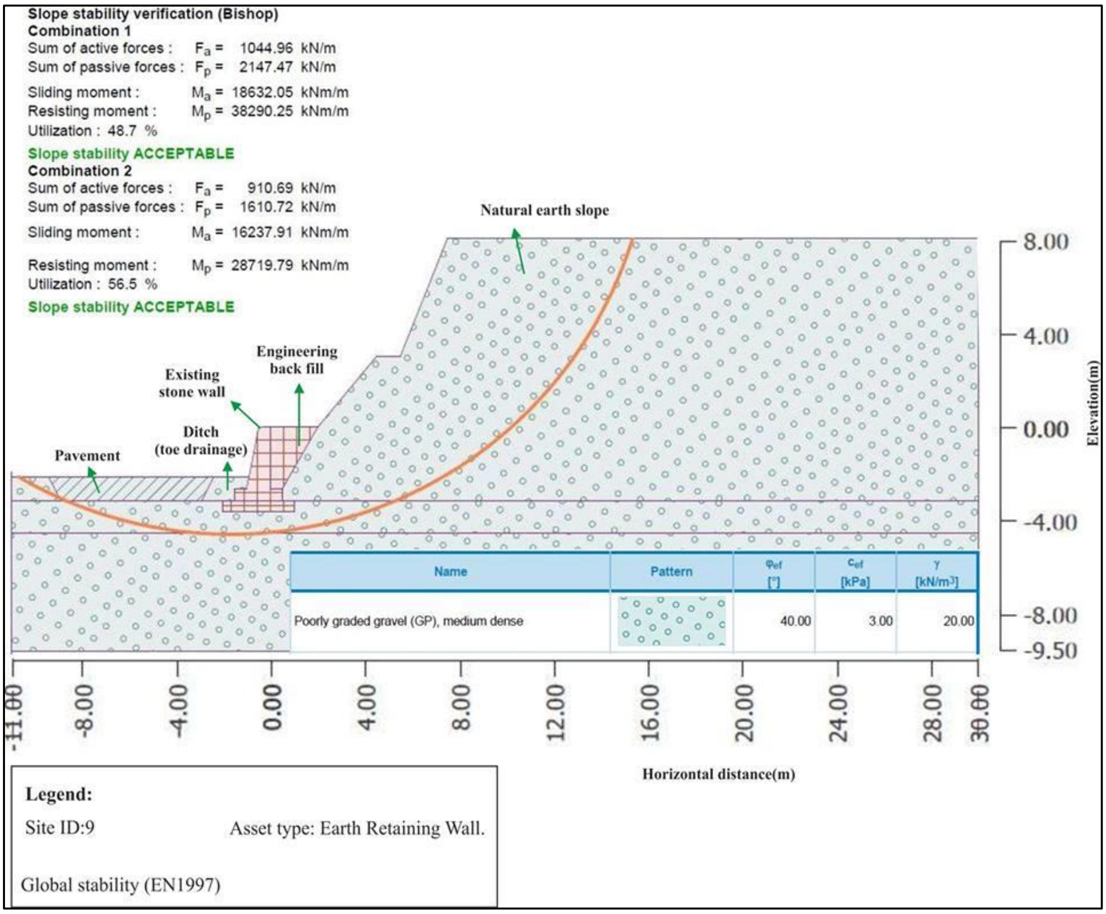

Figure G.29. Site 9-EN1997-Global stability.

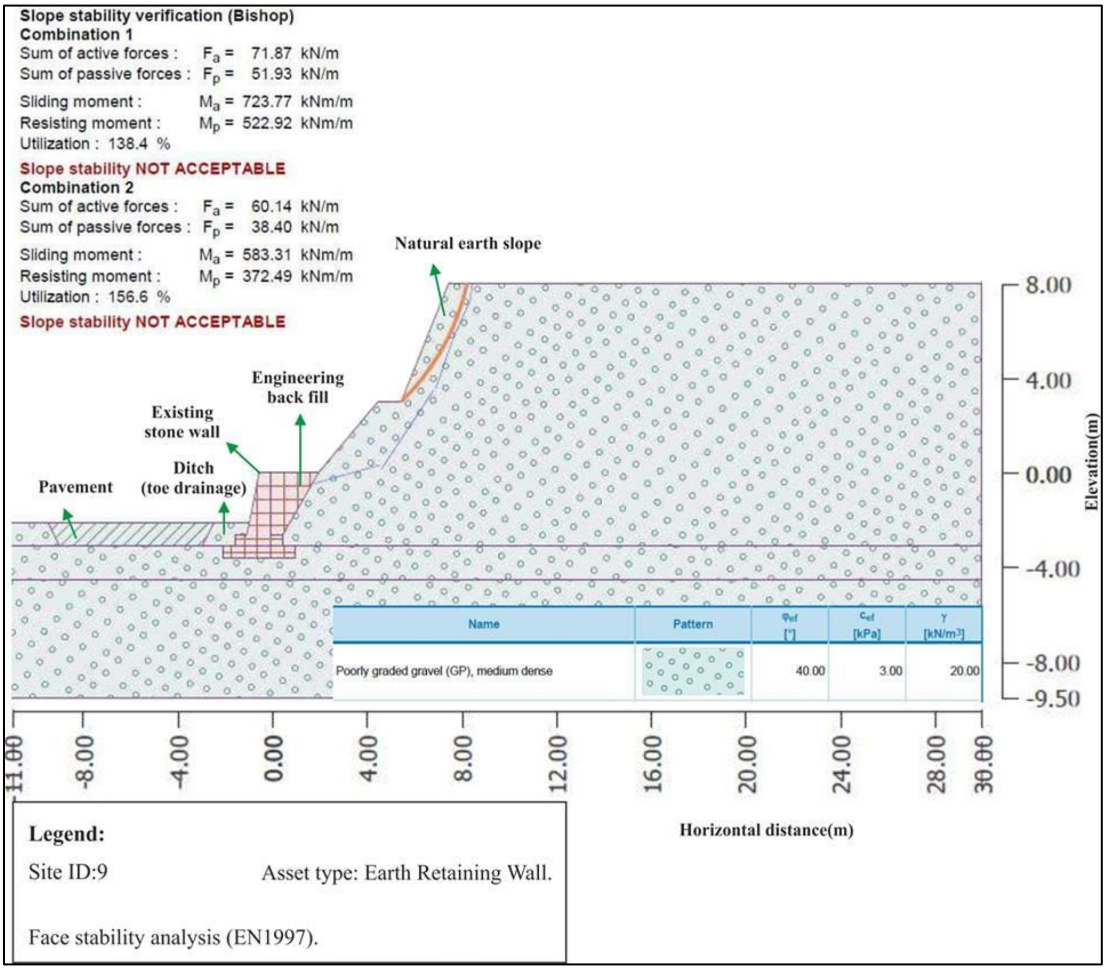

Figure G.30. Site 9-EN1997-Face stability.

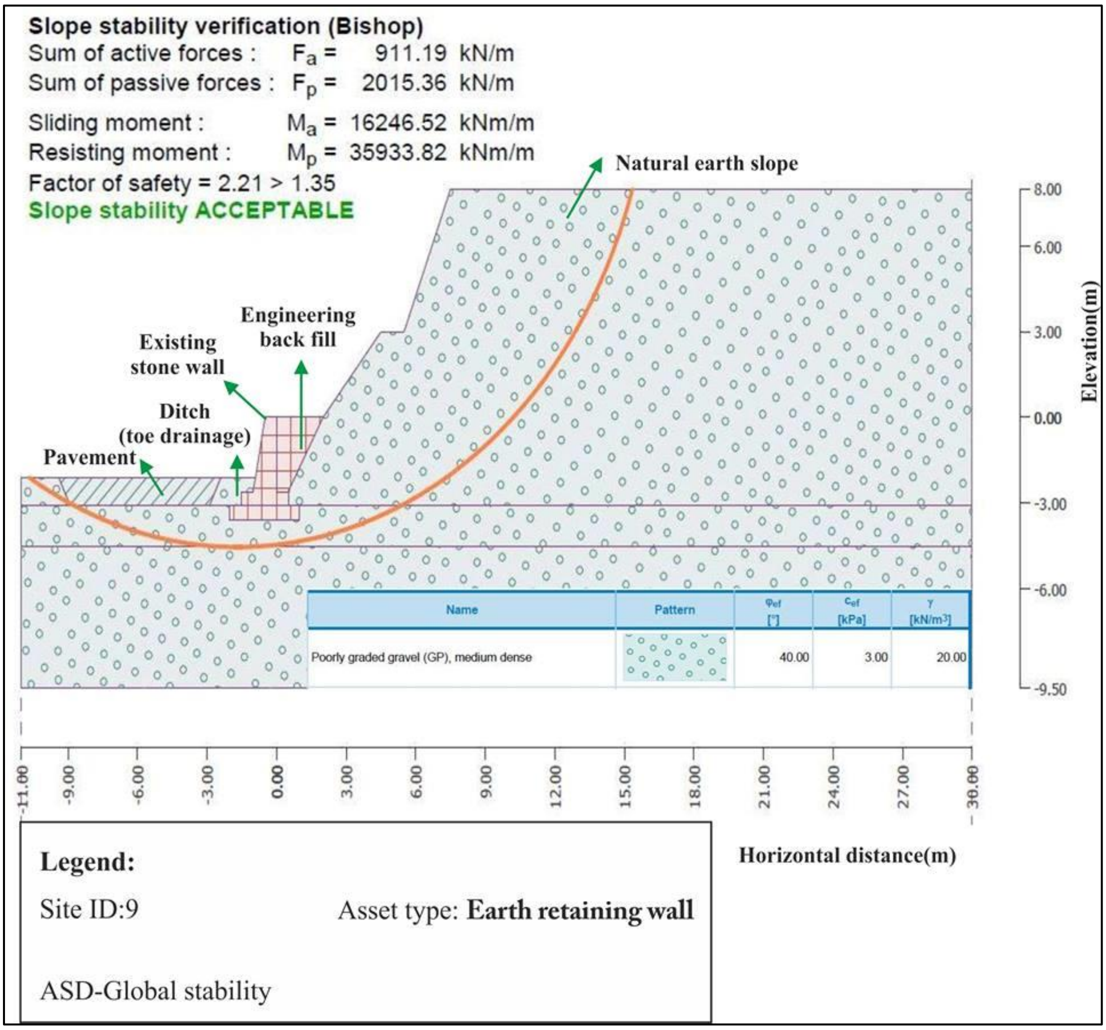

Figure G.31. Site 9-ASD-Global stability.

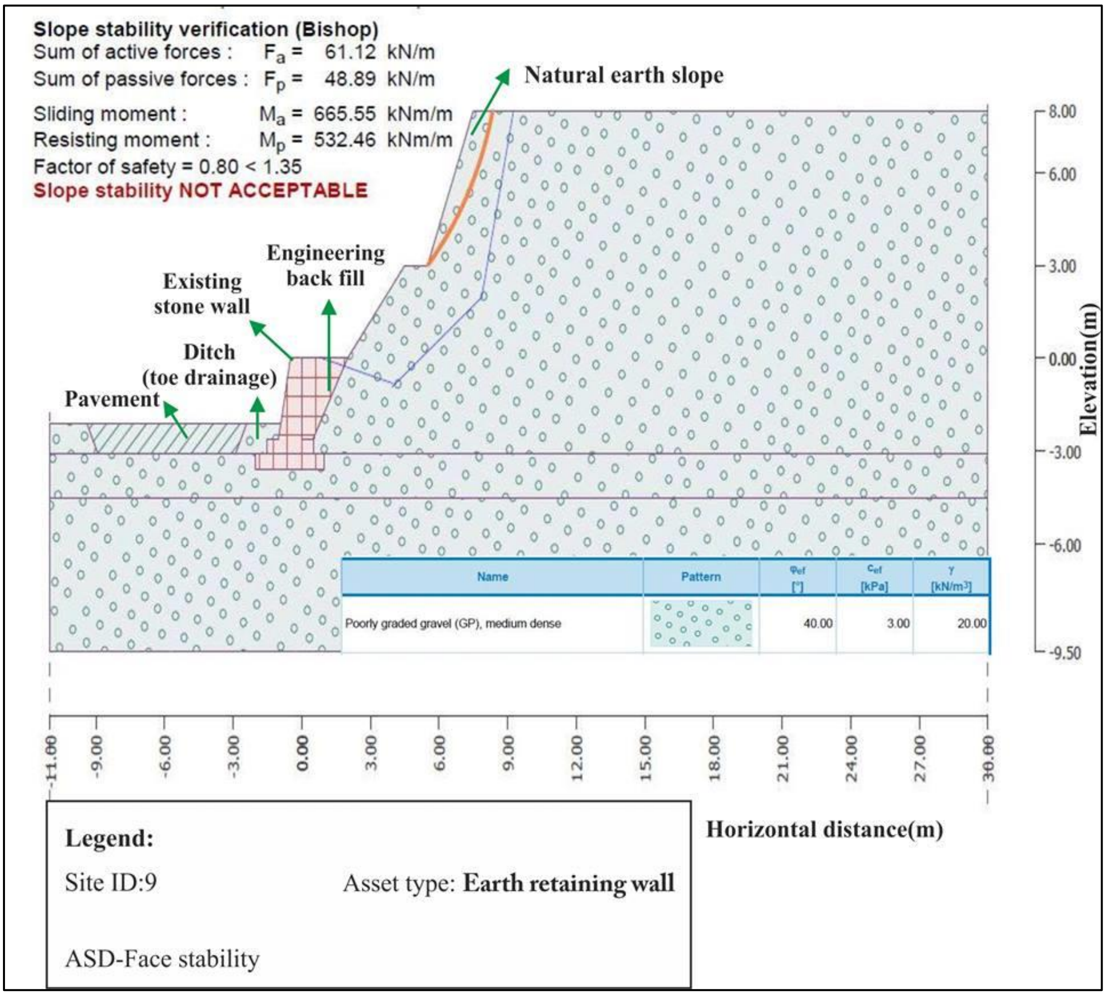

Figure G.32. Site 9-ASD-Face stability.

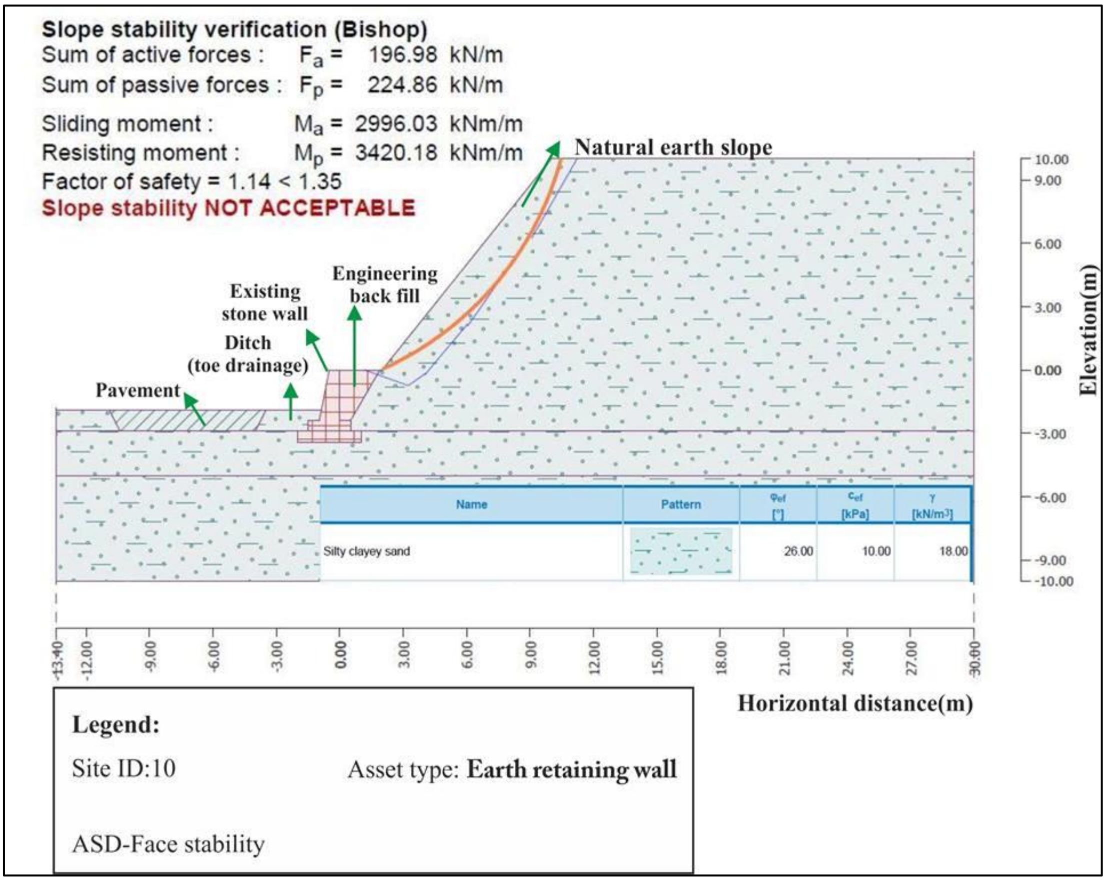

Figure G.33. Site 10-ASD-Face stability.

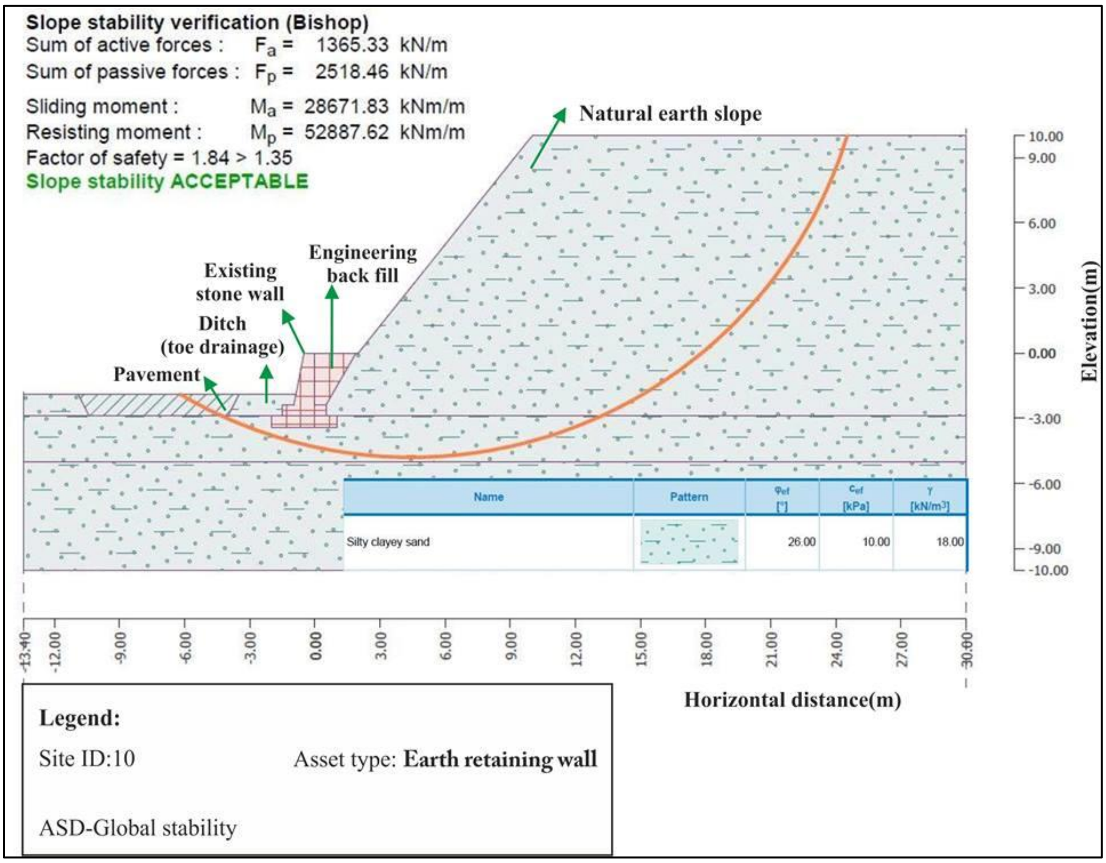

Figure G.34. Site 10-ASD-Global stability.

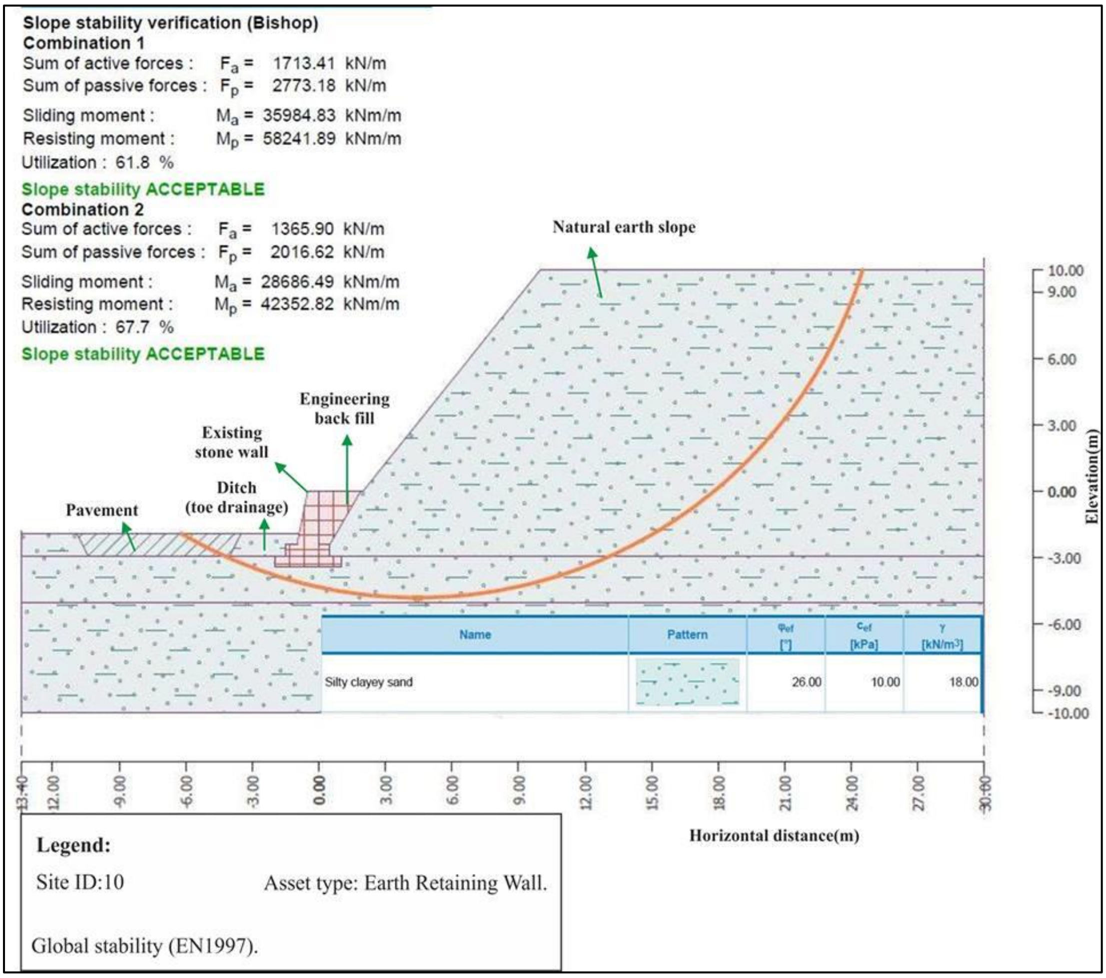

Figure G.35. Site 10-EN1997-Global stability.

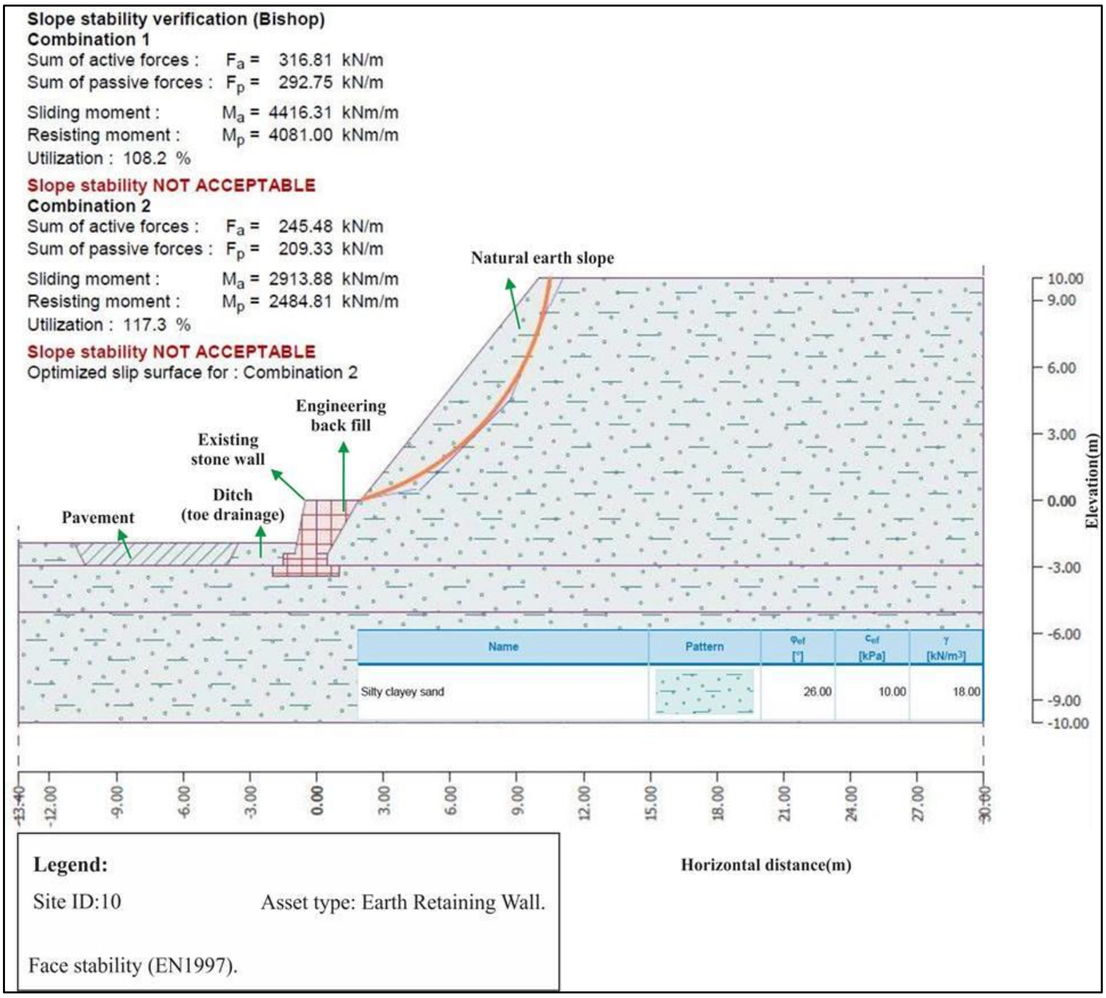

Figure G.36. Site 10-EN1997-Face stability.

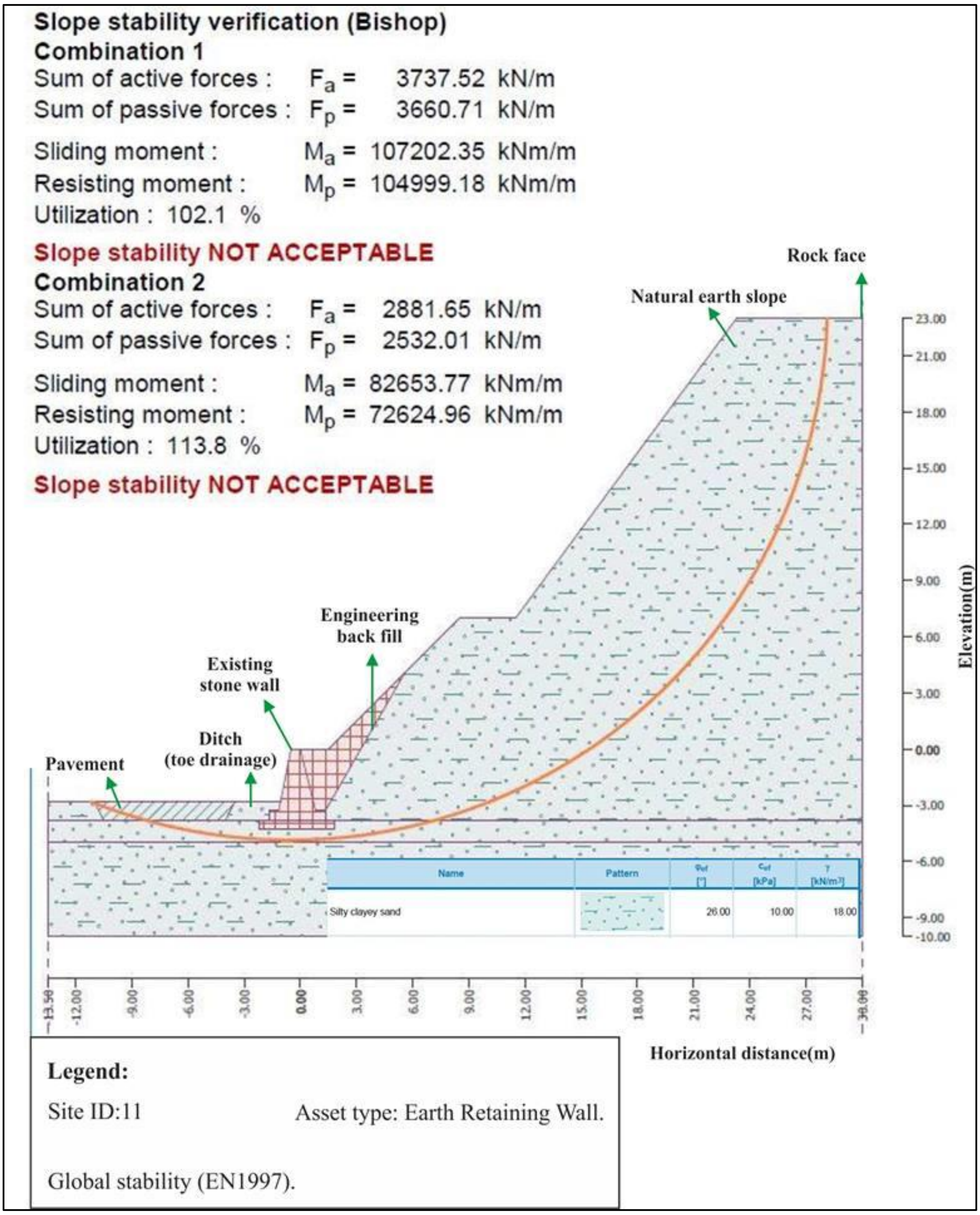

Figure G.37. Site 11-EN1997-Global stability.

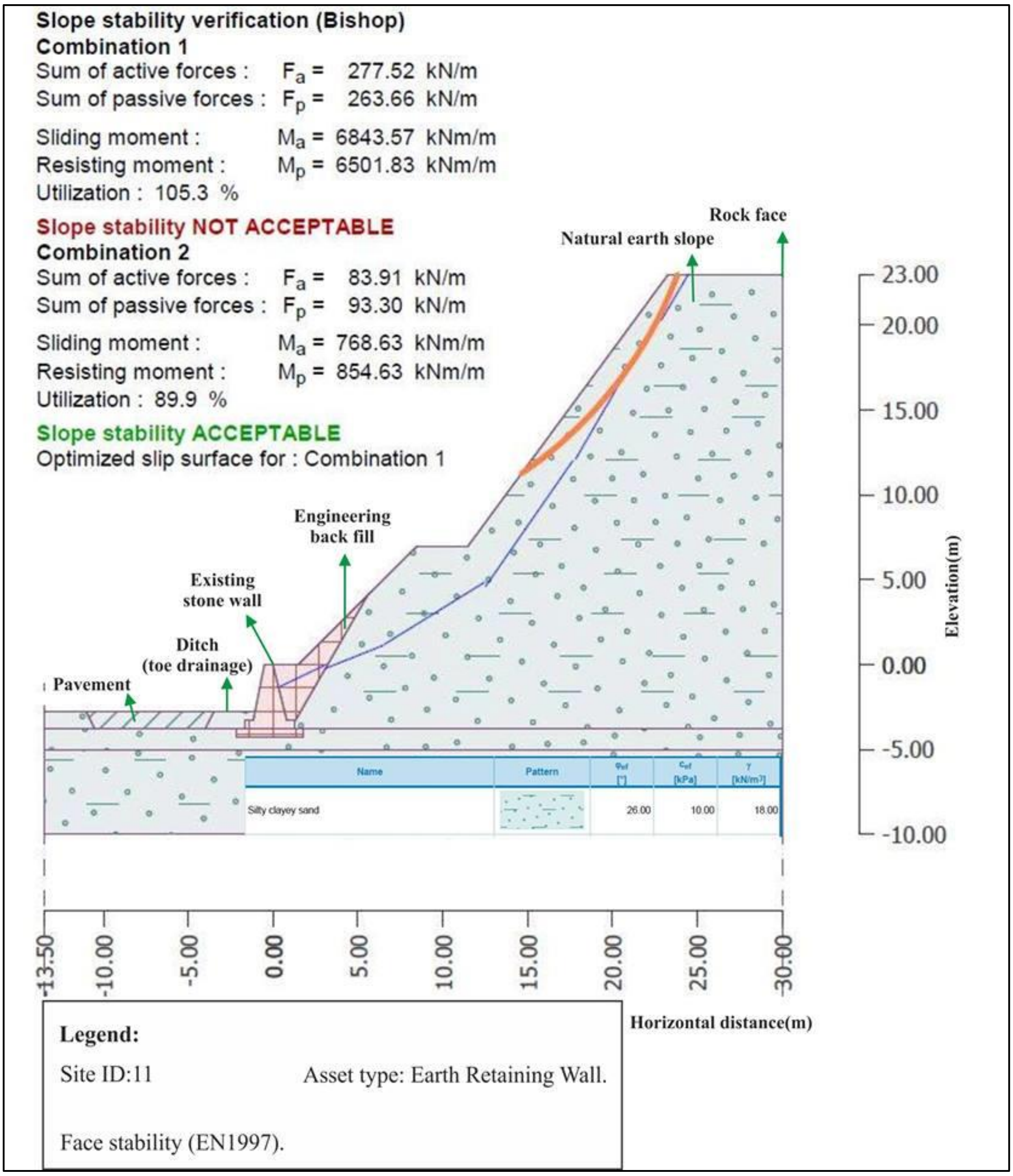

Figure G.38. Site 11-EN1997-Face stability.

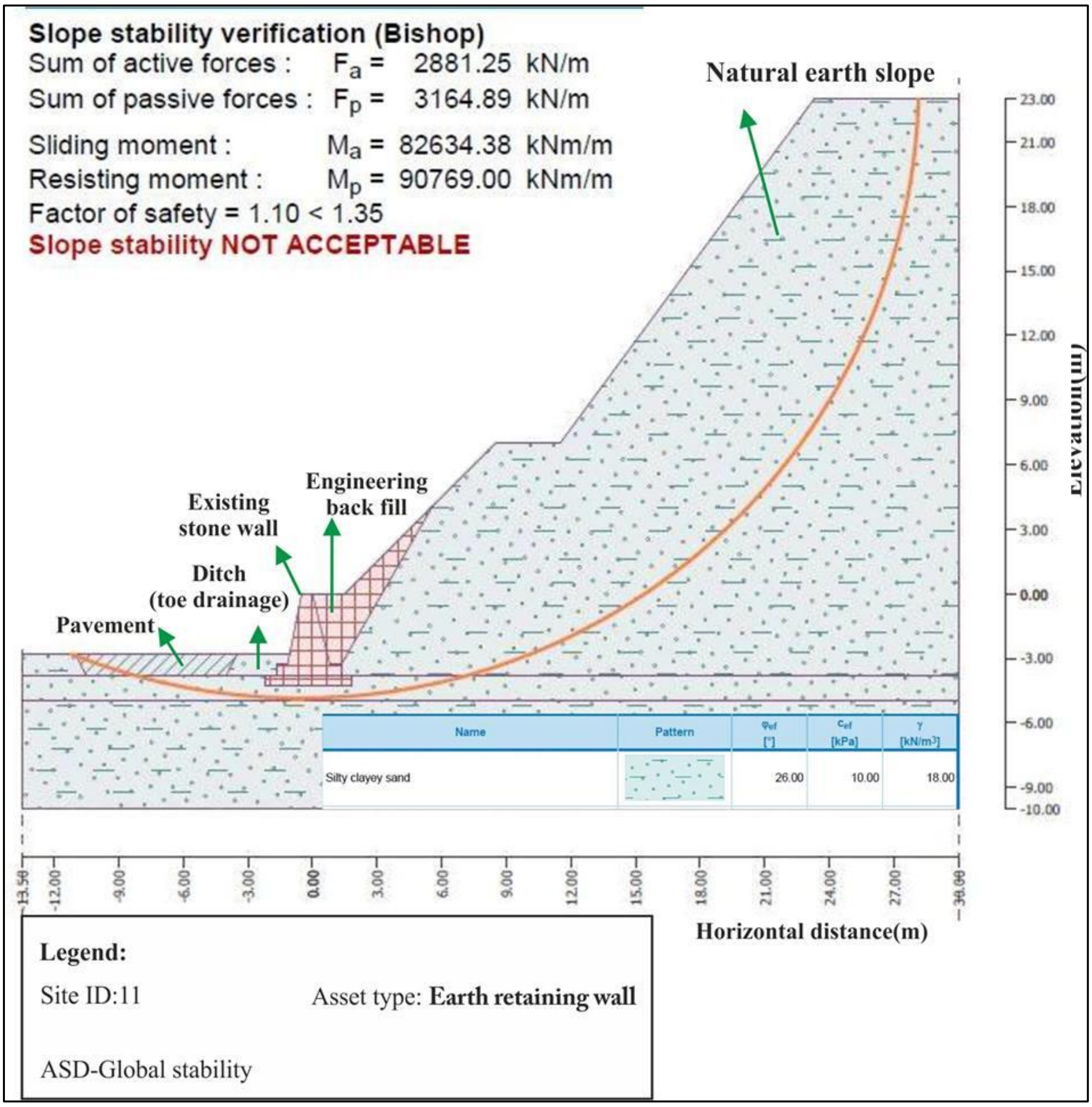

Figure G.39. Site 11-ASD-Global stability.

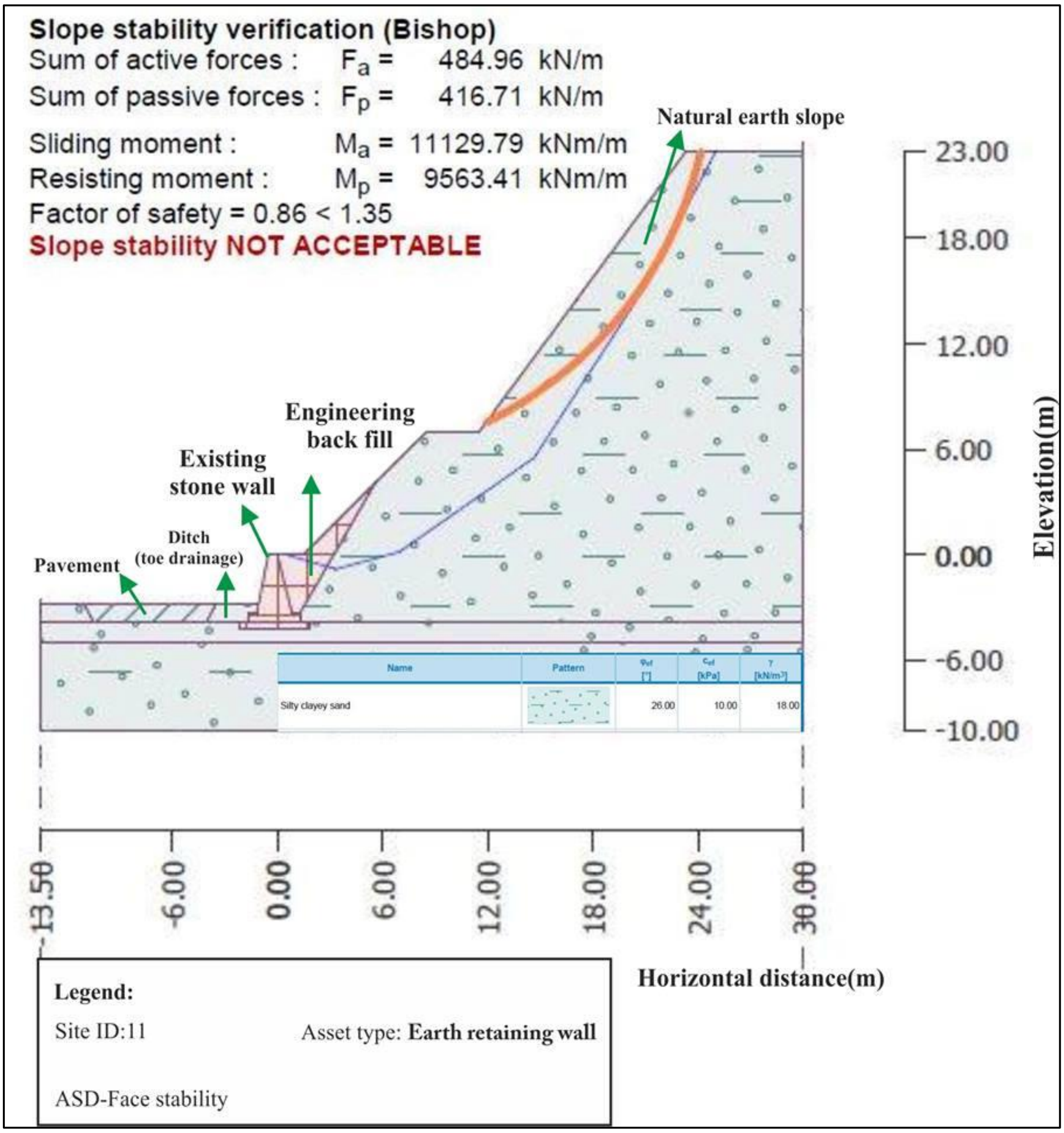

Figure G.40. Site 11-ASD-Face stability.

Appendix H: Life cycle cost analysis calculations.

Table H.1. Site 9.

Life cycle cost analysis						
Present worth method (pw) computation						
Project:Site 9						
Location:Nicosia-Kyrenia highway route						
Project life cycle = 30 years			Regrading		Drainage outlets	
Discount rate = 3%						
Present time: Construction date						
Initial costs	Quantity	Unit price	Est.	PW	Est.	Pw
1.Labour for regrading(tl/day)	20	160	3200	3200		
1.Labour for drainage(tl/day)	5	160	0	0	800	800
2.Operation cost(tl/m)	250	20	5000	5000	5000	5000
3.Drainage outlet (tl/m)	20	22	0	0	440	440
4.Demolition cost.	0	0	0	0	0	0
5.Road closure cost(TL/day)	1	30	30	30	30	30
Total initial cost				8230		6270
Initial cost PW savings(compared to Alt.1)						1960
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	800	15680
Total life cycle cost				8230		21950
Site maintenance		11.93	30482.5	363656.225		363656.225
Total life cycle cost of site				371886.225		385606.225

Table H.2. Site 11.

Life cycle cost analysis						
Present worth method (pw) computation						
Project:	Site 11					
Location:Nicosia-Kyrenia highway route						
Project life cycle = 30 years			Regrading		Drainage outlets	
Discount rate = 3%						
Present time: Construction date						
Initial costs	Quantity	Unit price	Est.	PW	Est.	Pw
1.Labour for resurfacing(tl/day)	85	160	13600	13600		
1.Labour for drainage(tl/day)	5	160	0	0	800	800
2.Operation cost(tl/m)	250	20	5000	5000	5000	5000
3.Drainage outlet (tl/m)	20	22	0	0	440	440
4.Demolition cost.	0	0	0	0	0	0
5.Road closure cost(TL/day)	1	30	30	30	30	30
Total initial cost				18630		6270
Initial cost PW savings(compared to Alt.1)						12360
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	800	15680
Total life cycle cost				8230		21950
Site maintenance		11.93	32842	391805.06		391805.06
Total life cycle cost of site				400035.06		413755.06

Table H.3. Site 3.

Life cycle cost analysis											
Present worth method (pw) computation											
Project:	Site 3										
Location: Nicosia-Kyrenia highway route			Length of site	130	m						
Project life cycle = 30 years			Height ofsite	36	m						
Discount rate = 3%			Labour effeciency	50	m/day						
Present time: Construction date			Duration	1	day						
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	3	480		labour cost	160	TL/day	3	480	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		2860		material cost	209	TL/m		27170	
material cost	145	TL/m		18850		Operation cost	22	TL/m		2860	
Total initial cost				22220	TL	Total initial cost				30540	TL
			Net fence		Rigid barrier						
Initial costs			Est.	PW	Est.	Pw					
1.Initial cost of net fence			22220	22220							
2.Initial cost of rigid barrier			0	0	30540	30540					
Total initial cost				22220		30540					
Initial cost PW savings(compared to Alt.1)						-8320					
Annual costs	Escl.%	PWA Factor									
Maintenance	7	57.1419667	0	0	500	28570.98335					
Total life cycle cost				8230		59110.98335					
Site maintenance		11.93	13940	166304.2		166304.2					
Total life cycle cost of site				174534.2		225415.1833					

Table H.4. Site 5.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	1	m						
Project:Site5			Length of site	100	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	10	m	Asphalt	33	tl/m2	275	9075	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	100	800	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	2.75	m				Total	9905	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	2	320		labour cost	160	TL/day	2	320	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		2200		material cost	209	TL/m		20900	
material cost	145	TL/m		14500		Operation cost	22	TL/m		2200	
			Total initial cost	17050	TL				Total initial cost	23450	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			17050	17050		
2.Initial cost of rigid barrier			0	0	23450	23450
Total initial cost				17050		23450
Initial cost PW savings(compared to Alt.1)						-6400
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	17050	12686.905		
Net fence replacement	20	0.6419	17050	10944.395		
Totl replacement cost				23631.3		0
Total life cycle cost				40681.3		52020.98335
Site maintenance		11.93	9905	118166.65		118166.65
Total life cycle cost of site				158847.95		170187.6333

Table H.5. Site 6.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	0.75	m						
Project:Site6			Length of site	150	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	20	m	Asphalt	33	tl/m2	450	14850	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	112.5	900	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	3	m				Total	15780	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	3	480		labour cost	160	TL/day	3	480	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		3300		material cost	209	TL/m		31350	
material cost	145	TL/m		21750		Operation cost	22	TL/m		3300	
			Total initial cost	25560	TL				Total initial cost	35160	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			25560	25560		
2.Initial cost of rigid barrier			0	0	35160	35160
Total initial cost				25560		35160
Initial cost PW savings(compared to Alt.1)						-9600
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	25560	19019.196		
Net fence replacement	20	0.6419	25560	16406.964		
Totl replacement cost				35426.16		0
Total life cycle cost				60986.16		63730.98335
Site maintenance		11.93	15780	188255.4		188255.4
Total life cycle cost of site				249241.56		251986.3833

Table H.6. Site 7.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	1	m						
Project:Site7			Length of site	250	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	30	m	Asphalt	33	tl/m2	875	28875	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	250	2000	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	3.5	m				Total	30905	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	5	800		labour cost	160	TL/day	5	800	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		5500		material cost	209	TL/m		52250	
material cost	145	TL/m		36250		Operation cost	22	TL/m		5500	
			Total initial cost	42580	TL				Total initial cost	58580	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			42580	42580		
2.Initial cost of rigid barrier			0	0	58580	58580
Total initial cost				42580		58580
Initial cost PW savings(compared to Alt.1)						-16000
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	42580	31683.778		
Net fence replacement	20	0.6419	42580	27332.102		
Totl replacement cost				59015.88		0
Total life cycle cost				101595.88		87150.98335
Site maintenance		11.93	30905	368696.65		368696.65
Total life cycle cost of site				470292.53		455847.6333

Table H.7. Site 12.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	5	m						
Project:Site12			Length of site	300	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	6	m	Asphalt	33	tl/m2	900	29700	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	1500	12000	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	3	m				Total	41730	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	6	960		labour cost	160	TL/day	6	960	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		6600		material cost	209	TL/m		62700	
material cost	145	TL/m		43500		Operation cost	22	TL/m		6600	
			Total initial cost	51090	TL				Total initial cost	70290	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			51090	51090		
2.Initial cost of rigid barrier			0	0	70290	70290
Total initial cost				51090		70290
Initial cost PW savings(compared to Alt.1)						-19200
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	51090	38016.069		
Net fence replacement	20	0.6419	51090	32794.671		
Totl replacement cost				70810.74		0
Total life cycle cost				121900.74		98860.98335
Site maintenance		11.93	41730	497838.9		497838.9
Total life cycle cost of site				619739.64		596699.8833

Table H.8. Site 1-Western.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	1	m						
Project:Site1-Western-			Length of site	56	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	10	m	Asphalt	33	tl/m2	168	5544	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	56	448	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	3	m				Total	6022	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	2	320		labour cost	160	TL/day	2	320	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		1232		material cost	209	TL/m		11704	
material cost	145	TL/m		8120		Operation cost	22	TL/m		1232	
			Total initial cost	9702	TL				Total initial cost	13286	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			9702	9702		
2.Initial cost of rigid barrier			0	0	13286	13286
Total initial cost				9702		13286
Initial cost PW savings(compared to Alt.1)						-3584
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	9702	7219.2582		
Net fence replacement	20	0.6419	9702	6227.7138		
Totl replacement cost				13446.972		0
Total life cycle cost				23148.972		41856.98335
Site maintenance		11.93	6022	71842.46		71842.46
Total life cycle cost of site				94991.432		113699.4433

Table H.9. Site 2-Western.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	4.5	m						
Project:Site2-Western-			Length of site	55	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	30	m	Asphalt	33	tl/m2	165	5445	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	247.5	1980	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	3	m				Total	7455	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	2	320		labour cost	160	TL/day	2	320	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		1210		material cost	209	TL/m		11495	
material cost	145	TL/m		7975		Operation cost	22	TL/m		1210	
			Total initial cost	9535	TL				Total initial cost	13055	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			9535	9535		
2.Initial cost of rigid barrier			0	0	13055	13055
Total initial cost				9535		13055
Initial cost PW savings(compared to Alt.1)						-3520
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	9535	7094.9935		
Net fence replacement	20	0.6419	9535	6120.5165		
Totl replacement cost				13215.51		0
Total life cycle cost				22750.51		41625.98335
Site maintenance		11.93	7455	88938.15		88938.15
Total life cycle cost of site				111688.66		130564.1333

Table H.10. Site 8.

Life cycle cost analysis											
Present worth method (pw) computation			Ditch width	1	m						
Project:Site8			Length of site	46	m	Maintenance			Area (m^2)	Cost (TL)	
Location:Nicosia-Kyrenia highway route			Height ofsite	10	m	Asphalt	33	tl/m2	126.5	4174.5	
Project life cycle = 30 years			Labour effeciency	50	m/day	cleaning debris	8	tl/m2	46	368	
Discount rate = 3%			Duration	1	day	Road closure	30	TL/day		30	
Present time: Construction date			Pavement width	2.75	m				Total	4572.5	
Net fence			Quantity (labour)	Cost (TL)		Rigid barrier			Quantity (labour)	Cost (TL)	
labour cost	160	TL/day	1	160		labour cost	160	TL/day	1	160	
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30	
Operation cost	22	TL/m		1012		material cost	209	TL/m		9614	
material cost	145	TL/m		6670		Operation cost	22	TL/m		1012	
			Total initial cost	7872	TL				Total initial cost	10816	TL

			Net fence		Rigid barrier	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			7872	7872		
2.Initial cost of rigid barrier			0	0	10816	10816
Total initial cost				7872		10816
Initial cost PW savings(compared to Alt.1)						-2944
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	7872	5857.5552		
Net fence replacement	20	0.6419	7872	5053.0368		
Totl replacement cost				10910.592		0
Total life cycle cost				18782.592		39386.98335
Site maintenance		11.93	4572.5	54549.925		54549.925
Total life cycle cost of site				73332.517		93936.90835

Table H.11. Site 2-Eastern.

Life cycle cost analysis			Duration	1	day					
Present worth method (pw) computation			Ditch width	1.5	m					
Project:Site2-Eastern-			Length of site	87	m	Maintenance			Area (m^2)	Cost (TL)
Location:Nicosia-Kyrenia highway route			Height ofsite	10	m	Asphalt	33	tl/m2	261	8613
Project life cycle = 30 years			Labour effeciency(Net fence)	50	m/day	cleaning debris	8	tl/m2	130.5	1044
Discount rate = 3%			Labour efficiency(Drainage)	250	m/day	Road closure	30	TL/day		30
Present time: Construction date			Pavement width	3	m				Total	9687
Net fence			Quantity (labour)	Cost (TL)		Drainage upslope			Quantity (labour)	Cost (TL)
labour cost	160	TL/day	2	320		labour cost	160	TL/day	2	320
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30
Operation cost	22	TL/m		1914		material cost	22	TL/m		1914
material cost	145	TL/m		12615		Operation cost	22	TL/m		1914
			Total initial cost	14879	TL				Total initial cost	4178

			Net fence		Upslope drainage	
Initial costs			Est.	PW	Est.	Pw
1.Initial cost of net fence			14879	14879		
2.Initial cost of upslope drainage			0	0	4178	4178
Total initial cost				14879		4178
Initial cost PW savings(compared to Alt.1)						10701
Annual costs	Escl.%	PWA Factor				
Maintenance	7	57.1419667	0	0	500	28570.98335
Total maintenance cost				0		28570.98335
Replacement costs	Year	PW Factor				
Net fence replacement	10	0.7441	14879	11071.4639		
Net fence replacement	20	0.6419	14879	9550.8301		
Totl replacement cost				20622.294		0
Total life cycle cost				35501.294		32748.98335
Site maintenance		11.93	9687	115565.91		115565.91
Total life cycle cost of site				151067.204		148314.8933

Table H.12. Site 1-Eastern.

Life cycle cost analysis			Duration	1	day							
Present worth method (pw) computation			Ditch width	3.5	m							
Project:Site1-Eastern-			Length of site	84	m	Maintenance			Area (m^2)	Cost (TL)	Onslope drainage	
Location:Nicosia-Kyrenia highway route			Height ofsite	25	m	Asphalt	33	tl/m2	252	8316	Area of form work	151.2
Project life cycle = 30 years			Labour effeciency(Net fence)	50	m/day	cleaning debris	8	tl/m2	294	2352	Concrete volume	15.12
Discount rate = 3%			Labour efficiency(Onslope dra	100	m/day	Road closure	30	TL/day		30		
Present time: Construction date			Pavement width	3	m				Total	10698		
Net fence			Quantity (labour)	Cost (TL)		Onslope drainage			Quantity (labour)	Cost (TL)		
labour cost	160	TL/day	2	320		labour cost	160	TL/day	2	320		
Road closure	30	TL/day		30		Road closure	30	TL/day	30	30		
Operation cost	22	TL/m		1848		Concrete cost	149	TL/m^3		2252.88		
material cost	145	TL/m		12180		Operation cost	22	TL/m		1848		
			Total initial cost	14378	TL	Form work cost	23	TL/m^2		3477.6		
									Total initial cost	7928.48		
			Net fence		Onslope drainage							
Initial costs			Est.	PW	Est.	Pw						
1.Initial cost of net fence			14378	14378								
2.Initial cost of onslope drainage			0	0	7928.48	7928.48						
Total initial cost				14378		7928.48						
Initial cost PW savings(compared to Alt.1)						6449.52						
Annual costs	Escl.%	PWA Factor										
Maintenance	7	57.1419667	0	0	500	28570.98335						
Total maintenance cost				0		28570.98335						
Replacement costs	Year	PW Factor										
Net fence replacement	10	0.7441	14378	10698.6698								
Net fence replacement	20	0.6419	14378	9229.2382								
Totl replacement cost				19927.908		0						
Total life cycle cost				34305.908		36499.46335						
Site maintenance		11.93	10698	127627.14		127627.14						
Total life cycle cost of site				161933.048		164126.6033						