A CASE STUDY FOR CUTS IN SOFT SOILS

by

M. ERHAN KÖSELİ

B.S. in CE. ISTANBUL TECHNICAL UNIVERSITY ,1988

Submitted to Institute for Graduate Studies in
Science and Engineering in Partial Fulfillment of
the Requirements for the Degree of
Master of Science
in
Civil Engineering

Boğaziçi University
1992

to my family

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Prof.Dr.Turan Durgunoğlu who introduced and motivated me throughout my graduate study in geotechnical engineering for his valuable remarks and his encouragements.

I would like to express my appreciation to Doç.Dr.Gökhan Baykal who provided me his full support and motivation during the preparation of my thesis, and Doç.Dr.Mahmut Savaş for their valuable remarks and recommendations.

I would also like to express my gratitude to all personells of Zetaş Earth Technology Corporation for their delicate and friendly cooperation and also provided me valuable data during the study.

I'm greatly thankful to İntes Construction Trade and Industry Co.Inc. who had been always so kind, patient and a great help during the preparation of my thesis.

A CASE STUDY FOR CUTS IN SOFT SOILS LANDSLIDE AT TAG MOTORWAY BETWEEN KM.141+400 AND KM.141+700

ABSTRACT

The slope stability problems resulting from soft subsoil conditions on the unbraced excavated cuts are usually observed as rapid and sudden landslides. This is even more evident in the case of inappropriate slope application on this kind of soil conditions. The approaches for the remedial solutions of such problems generally concentrate on the regrading of the inappropriate material and flattening the applied slopes. However, in such cases, it is more important to identify the subsoil conditions properly and to perform the detailed analyses accordingly.

In this respect, the landslide which had occurred at TAG motorway during the excavation of cut slopes between Km.141+400 and Km.141+700 is investigated as a case study. The required analyses are performed in order to determine the residual strength parameters by both laboratory tests and back calculation method. In the light of these analyses, it is determined that the real cause to slip is the inadequate slope application on the soft soil conditions.

During the analyses, it is also observed that there is a logical relationship between soil properties and residual strength parameters which can give profitable data for designers where the remedial solutions are urgent. The residual internal friction angle of slipped soil is obtained as 14 degree.

YUMUŞAK ZEMİNLERDEKİ YARMALAR İÇİN VAKA İNCELEMESİ TAG OTOYOLU KM.141+400 KM.141+700 ARASI HEYELANI

ÖZET

Istinatsız yarma kazılarında, yumuşak zemin durumundan doğan şev stabilitesi problemleri genellikle hızlı ve ani toprak kayması şeklinde olmaktadır. Bu durum, uygun olmayan şev kriterlerinin bu gibi zemin koşullarında uygulanması durumunda dahada belirli olmaktadır. Bu konu ile ilgili toprak kaymaları için iyileştirme çalışmaları genellikle uygun olmayan zeminin temizlenmesi ve şevin yatırılması üzerinde yoğunlaştırılmıştır. Ancak, yinede bu gibi durumlarda, zemin koşullarının doğru olarak tanımlanması, ve ona göre detaylı analizlerin yapılması önem kazanmaktadır.

Bu açıdan, TAG (Tarsus - Adana - Gaziantep) otoyolundaki, Km.141+400 ile Km.141+700 arasindaki yarmaların kazısı sırasında oluşan toprak kayması bir vaka analizi olarak incelenmiştir. Laboratuar deneyleri ve geri hesap metodu ile gerekli analizler yapılmıştır. Bu analizlerin sonucu altında , kaymayı oluşturan gerçek nedenin yumuşak zemin koşullarında yetersiz şev uygulaması olarak tesbit edilmiştir.

Analizler esnasında, zemin özellikleri ile kalıcı mukavemet parametreleri arasında, iyileştirme çalışmaları aşamasında kullanılmak üzere yararlı datalar veren bir mantıksal ilişkinin olduğu gözlenmiştir. Hesaplarda kayan zeminin kalıcı içsel sürtünme açısı 14 derece olarak bulunmuştur.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF SYMBOLS

Ø	Internal friction angle
Ør	Residual internal friction angle
Ør’	Effective residual internal friction angle
Øp	Peak internal friction angle
Øp’	Effective residual internal friction angle
c	Cohesion
cp’	Effective Peak cohesion
cr’	Effective residual cohesion
τ	Shear Strength
τ'	Effective shear strength
σ	Normal Strength
σ'	Effective normal strength
Q	External load
α	Slope of failure surface
W	Weight of the soil
T1,T2	Shear force on the slice
E1,E2	Normal force on the slice
F.S.	Factor of safety
LL	Liquid Limit
PL	Plastic Limit

LIST OF SYMBOLS (Continued)

PI	Plasticity Index
w	Water content
CF	Clay fraction
ru	Pore water pressure
X,Y	Coordinates of the circular slip surface
Fr	Resisting force
Fd	Driving force (force tending to slip)
Fk	Resisting force from retaining structure
m	Mass of the sliding material
g	Gravitational acceleration

CHAPTER 1. INTRODUCTION

In many engineering projects, especially in the construction of motorway projects, the stability of cut slopes have been always considered as primary importance and often attracted the attention of many engineering authorities in the history. The importance of the cut stabilities are more pronounced when they cause great problems and economic losses. In our country, with the increasing of motorway projects in recent years, these problems have been more encountered and subjected to the new researches.

For this purpose, a case study is presented for the stabilities of the cuts which are located at the Tarsus - Adana - Gaziantep (TAG) motorway construction between Km.141+400 and Km.141+700. A landslide had occurred at the relevant sections of the motorway on October 17th, 1991 and it was reported that approximately 1 million m3 mass of soil had slided. After the slide event, the required analyses were performed under the cooperation of Zetas Earth Technology Corporation.

In order to assist the better understanding of the problem, the general considerations and theoretical method of the stability analysis are first presented in Chapter II.

At the previous stage of the design, two borings were performed to identify the subsoil conditions. According to these borings, the cut slopes were arranged based on the K.Terzaghi's (1) recommended cut slope criteria.The slide event and previous studies are reported at the Chapter III.

In Chapter IV. the subsoil conditions are summarized as a result of performed trial pits and additional borings.

An important stage of the stability analysis is to determine the shear strength characteristics such as internal friction angle phi (ϕ') and cohesion (c'). Therefore, mathematical analyses are performed based on the data from the borings and tests are performed on the block samples, obtained from the slide area, in the laboratory. The evaluation on the slide mechanism is presented in Chapter V.

In Chapter VI. the remedial solutions are briefly discussed on account of the performed tests and back calculation analyses results . The required alternative solutions were evaluated by Zetas Earth Technology Corporation.

In Chapter VII. the conclusions are given. Based on the compared solutions, it was determined that the most optimum and feasible solution is the regrading of the slope areas.

CHAPTER II. SLOPE STABILITY PROBLEMS

2.1. Introduction

Most of the problem involving the stability of slopes are associated with the design and construction of unbraced cuts for highways, railways and canals . The excavations of the deep cuts have been started after the construction of the first railways at the early 19th century.

According to Terzaghi 1967 (1) ; every mass of soil located beneath a sloping sides of an open cut, has a tendency to move downward and outward under the influence of gravity. If this tendency is counteracted by the shearing resistance of the soil, the slope is stable. Otherwise a slide occurs. Slides may occur in every conceivable manner, slowly or suddenly, with or without any apparent provocation. Basically, they are caused by excavation, by undercutting the foot of an existing soil, by an increase of the pore water pressure in a few exceptionally permeable layers, or by a shock force that liquifies the soil.

There are numerous methods proposed for stability computations assuming homogeneous or nonhomogeneous soil conditions. In this chapter, first, the theoretical methods are summarized, and then the cut stabilities based on the soil conditions are discussed.

2.2. Types of the Problems

There are two types of slope stability problems that occur in clays; short-term stability (end-of-construction case) and long-term stability (steady seepage case). The short term case is a temporary case in which the stability is designed to secure the structure until the end of construction. However the stability in the long-term case should be maintained permanently.

In short-term stability, during the excavating for a cut, shear stresses are induced which may cause failure in undrained state. Theoretically, it is possible to analyze the stability of a newly cut slope on the basis of either total or effective stresses, however, since it is difficult to ascertain the distribution of pore pressure under these conditions, it has been proved that total stresses have given much more satisfactory results.

However, in the long-term stability, pore pressures may be assumed to be in equilibrium and are determined from the considerations of steady seepage, thus , no excess pore pressure are included. This case is the analogous to that of the drained shear test, therefore effective shear stress parameters should be used.

Stability analysis depends on an accurate assessment of the strength of the soil along the potential sliding surfaces. In the majority of cases, the correct value of strengt for stability analysis will be close to the residual strength of the soil. Skempton 1964 (2) for overconsolidated clays, suggested to use of residual shear strength concept for long-term slope analysis. In Figure 2.1 , it is shown the shear strength characteristics of an overconsolidated clay in terms of effective stress.

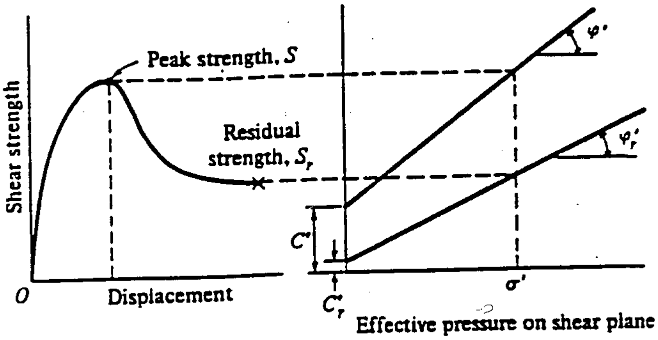


FIGURE 2.1. Shear Strength Characteristics Skempton 1964 (2)

2.3. Method of Analysis and Design

The method of analysis of slope stability problems is mostly depended on the accuracy degree of determination of the many factors; failure plane geometry, nonhomogeneity of soil layers, tension cracks, dynamic loading or earthquakes and seepage flow. By determining these factors, field observations, test borings, laboratory tests and slope stability calculations are performed to construct the design method.

The first step in evaluating a slope stability is based on the determination of the failure geometry. By doing this, firstly existing data is reviewed and checked. Soil stratification should be clearly identified from the data of performed boring logs. After the identification of the subsoil profile, the required evaluations can be proceed.

At the calculation stage, all data should be already available in order to perform the analysis. All methods of analyses are based on the correct determination of the shear parameters such as internal friction angle (ϕ') and cohesion (c'), and by utilizing these parameters, factor of safety against sliding is checked. Factor of safety is indicated that whether or not an earth structure will fail under the worst service conditions for which it was designed. The present concept for determining the factor of safety for a slope is based on Coulomb's Law;

$$\tau = c + \sigma \tan\phi \qquad \text{(eg.1)}$$

Generally, the factor of safety is described as the sum of resisting moments (Mr) divided by the sum of the moments tending to cause failure (Mo).

2.4. Theoretical Method of Slope Stability

There are numerous methods currently available for performing slope stability analysis in the literature. The majority of these may be categorized as limit equilibrium methods. The basic assumption of the limit equilibrium approach is that Coulomb's failure criterion is satisfied along the assumed failure surface which may be a straight line, circular arc, logarithmic spiral, or other irregular surface. Basically the methods are divided into two category;

a. Methods utilizing circular slip surface

a. Methods utilizing non-circular slip surface

In the case of circular slip surface, Bishop's modified method is widely used. Formulation of the factor of safety based on this method is summarized below;

In Bishop modified method, the mass of soil as illustrated at Figure 2.2. is divided into many vertical slices. The forces acting on each slice are evaluated from the limit equilibrium of the slices. The equilibrium of the entire mass is determined by the summation of the forces on all the slices. A typical slice (cdfe) is shown in Figure 2.3.

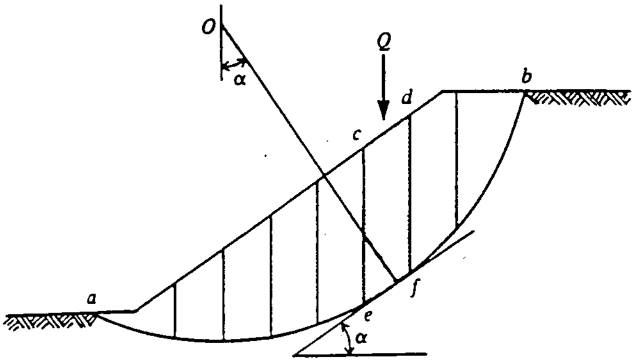


FIGURE 2.2 Modified Bishop Method

Bishop A.W. 1955 (14)

After required statical equilibrium, the factor of safety is determined from the ratio of required shear strength (τ) to the available shear strength (S).

$$F=\frac{\tau}{S} \qquad \text{(eq.2)}$$

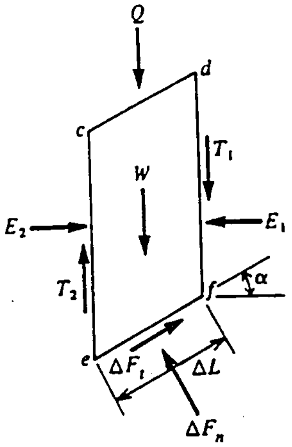


FIGURE 2.3. Method of Slices
Bishop A.W. 1955 (14)

Substituting (eq.2) and solving for τ and S, we obtain;

$$F=\frac{\sum (c'\Delta L+[(W+Q)\cos\alpha-u\Delta L]\tan\phi')}{\sum (W+Q)\sin\alpha} \qquad \text{(eq.3)}$$

in general form;

$$F=\frac{\sum (c'\Delta L\cos\alpha+[(W+Q-u\Delta L\cos\alpha)+(T_1-T_2)]\tan\phi')\,[\cos\alpha+(\tan\phi'\frac{\sin\alpha}{F})]^{-1}}{\sum (W+Q)\sin\alpha} \qquad \text{(eq.4}$$

2.5. Cut stabilities

The slope stabilities of open cuts in practice is mostly ensured by the a definite criterion. In experience, this criterion is defined as 1 1/2 (horizontal) to 1 (vertical). It is shown that this slope is commonly stable and considered as a standard value for the construction of highway cut stabilities. As a matter of fact, it is clear that the slope of cuts are mostly depended on the subsoil conditions. According to Terzaghi (3) the standard slopes are only stable at cohesionless or cohesive sandy or gravelly soil in a moist or dry state. However in soft clay or in stiff fissured clay, the excavation of even a very shallow cut with standard slopes may cause the soil to move toward the cut, and the movement may spread to a distance from the cut equal to many times the depth. Clay soils containing layers or pockets of water-bearing sand may react to a disturbance of their equilibrium in a similar manner. Deposits with properties of this type constitute troublesome ground.

2.5.1. Slides in Homogeneous Soft Clays

Terzaghi (4) stated that if the standard criterion is applied at the soft clay slopes, a slide is likely to occur before the cut reaches a depth of 10 ft. The movement has a charter of base failure as illustrated in Figure 2.4.

There is no significant cut criteria in the clayey soils. The cuts should be determined according to the performed analysis and subsoil conditions. However, it is evident that stability calculation on soft soil conditions should be performed with great care.

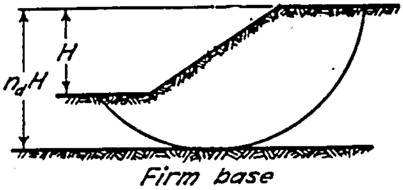


FIGURE 2.4. Firm Base
K.Terzaghi and R. Peck 1967 (4)

CHAPTER III. IDENTIFICATION OF THE PROBLEM

3.1. Description of the Project

The project of TAG (Tarsus - Adana - Gaziantep) motorway is designed as totally 258 Km. long, starting from Tarsus - Pozantı Interchange (Km.44) and passing from Adana bypass (Km.70) and ends up at Gaziantep (Km.302) by following the alignment of Ceyhan, Toprakkale and Nur mountains respectively. The first part of the project with 70 Km. had opened to service last year.

Some specific characteristics of the motorway are summarized at the following ;

Total lenght : 258 Km.

No. of lane : 2 x 4 (between Tarsus - Pozanti Interchange and Adana)

2 x 3 (at the remaining sections)

Width of the Lane : 3.75 m.

Design Speed : 120 Km/hr.

Min. Curb Diameter : 550 m.

Max. Slope : %4, %4.5 at mountainous sections

Structures : 13 each Bridge and Viaduct .. total 16 Km.

6 special Viaduct ....total 2.5 Km.

4 tunnel..................................... total 2684 m.

In this study, the cuts of the relevant motorway between Km.141+400 and Km.141+700 are investigated and stability analyses are evaluated.

3.2. Previous Studies

In 1990, a final design geotechnical report was prepared by A. Saglamer (5) for TAG motorway for the sections ranged between Km.139+000 and Km.153+400. In this report, the implemented design procedures are summarized. It was pointed out that the most critical sections were located between Km.141+200 and Km.141+750, and a slope as 3(horizontal) to 2 (vertical) was recommended based on the Terzaghi and Peck (3) criterion for the excavations on the slope debris formation. According to this slope criterion, it was reported that the excavation was reached 32 m. height at Km.141+530 on the left side of the motorway.

In order to determine the subsoil profile, two borings at the relevant section of the motorway are performed before the excavation of the cuts. Among these, boring with no S22 was performed on the motorway axis at Km.141+500 and it was observed a clay-claystone layer underneath a 6.0 m. thick slope debris material down to 20.0 m. depth. The surface elevation of this boring log was +252.50 m.

An other boring with no.BH3181 was performed from the 100 m. to the left of the motorway axis at Km.141+530 and it is encountered a talus breccia material down to 25.0 m. depth. The surface elevation of this boring was +261.20 m. The performed boring logs are given in Figure 3.1.

The required analyses and tests were carried out on the samples, which were taken from these borings, and it was determined that the TCR and RQD values in the samples of the S22 and BH3181 borings were below the acceptable limits. Also the standard penetration test was performed on the claystone and slope debris. It was concluded from all these results that slope debris material was in a weakly cemented

FIGURE 3.1. Location of Trial Pits and Previous Borings

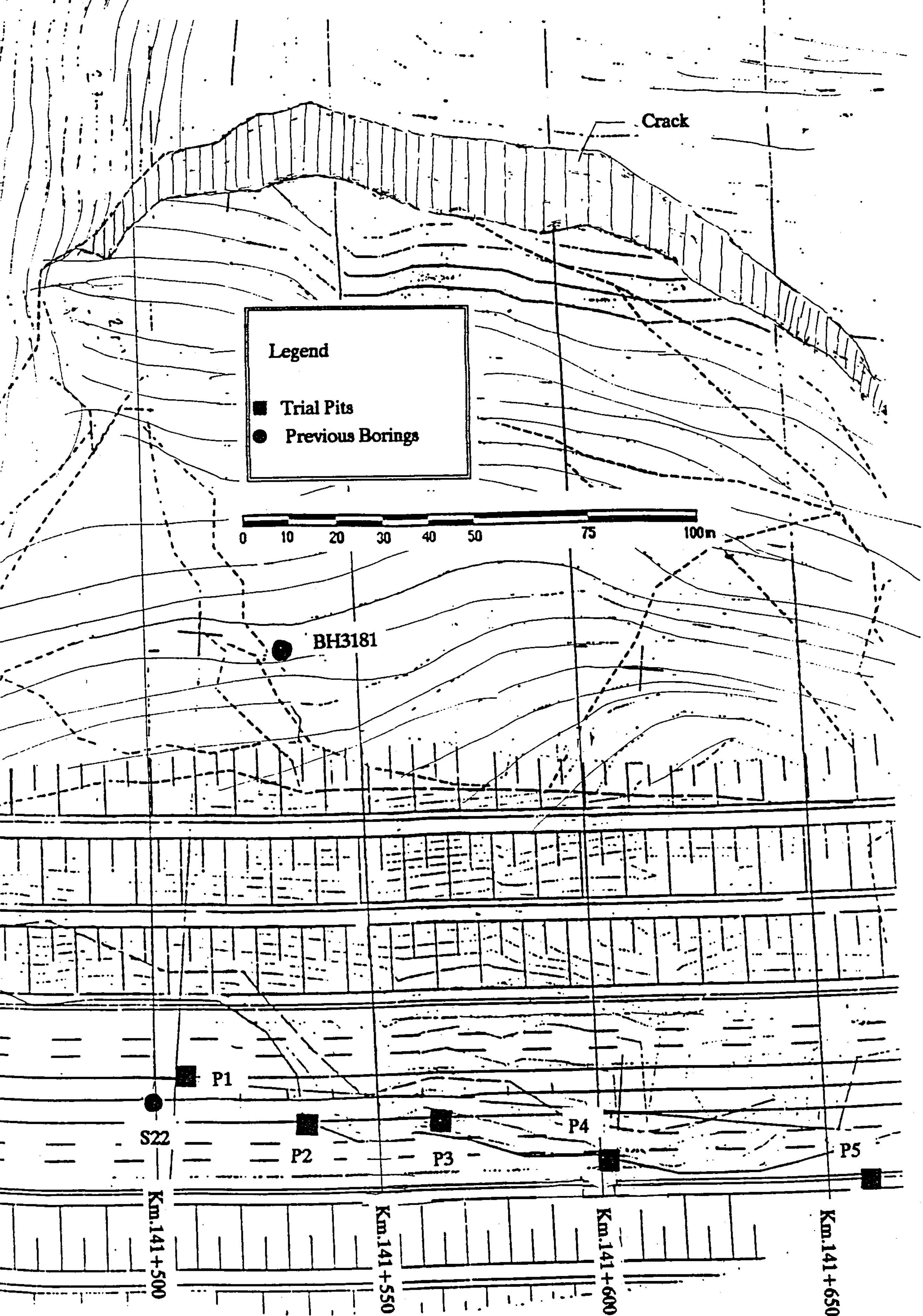


TABLE 3.1. Soil Conditions from the Previous Boring Logs

LEVEL (m.)	**S22 BORING Elevation :252.50**	**BH 3181 BORING Elevation :269.20**
-1.	TALUS	CLAY
-2.	(Clayey Gravelly)	Dirty white lime 267.80 m.
-3.	249.50 m.	
-4.		CLAY
-5.	TALUS BRECCIA	with calcarous gravel
-6.		263.00 m.
-7.	Lime cemented	
-8.	vesicular	CLAY with claystone
-9.	closely	
-10.	fractures	
-11.		258.20 m.
-12.		CLAYSTONE

3.3. Slide Event

A slide event had occurred between the sections Km.141+400 and Km.141+700 of the motorway on the left edge in the direction of N/S (North to South) as rapid and sudden action on October 17th,1991 during the excavating for relevant cuts. Based on the first estimation it was reported that the slide mass was 400m. in the N/S direction and 300 - 350 m. in the E/W (East to West) direction. The slide material had a 25 or 30 degree angle on the slope.

The area where the slide took place is a hilly to almost mountainous zone. The origin is rocky and spilit formations. However, in the course of time, slope debris material was accumulated by weathering and erosion of the rock formations. This was formed as a coverage on the rock formation at the end. The slide has occurred as a result of sliding this slope debris material. The depth of the slide material was 10 ~ 20 m. During the slide, tension cracks were formed approximately 200 m. away from the motorway platform. The width and depth of these cracks were 5 ~ 10 m. The slide topography is illustrated at Figure 3.2.

According to Bength B. Broms (6), this kind of slides are categorized as Rotational slides. Rotational slides are relatively common in soft soils and occur when the inclination of the slope exceeds the angle of internal friction of soil along the bedding plane.

After the slide, the required evaluations and developments have been started in order to analyze the slide mechanism and proposed remedial measures. At the first stage, a 1/1000 scaled map of landslide region including the nearby surroundings has

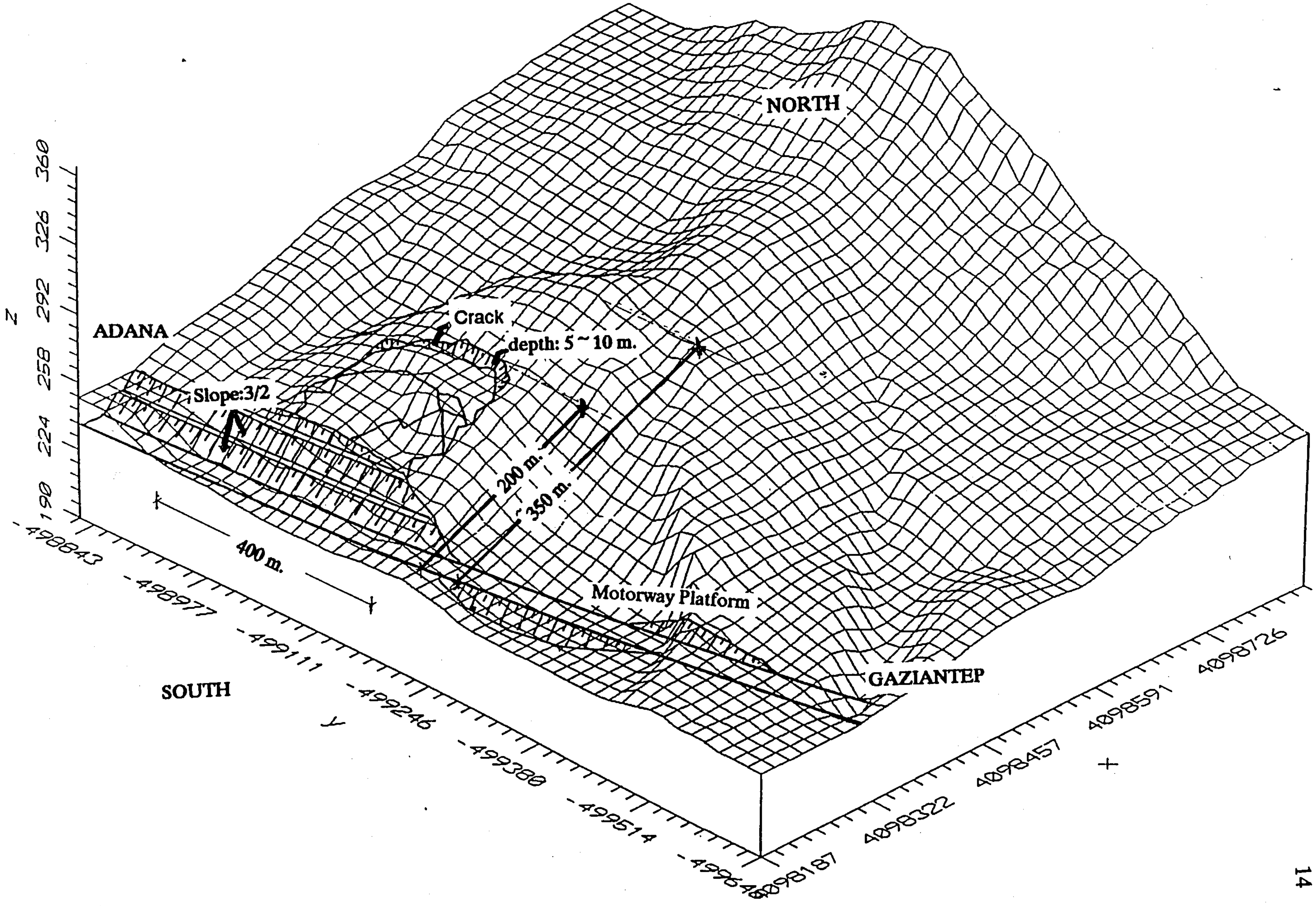


FIGURE 3.2. Slide Topography

been prepared in order to determine after-slide topography. Following this,five (5) trial pits reaching down to max. 7.0 m. from motorway platform are excavated at the toe of the slide. Location of these pits are shown in Figure 3.1. and the pits logs are given in the appendix(2). In order to determine the shear strength parameters two samples are obtained and sent to KGM (General Directorate of Highways) laboratories The evaluations on the slide mechanism are discussed in Chapter V.

The views from the slide area are given at Figures 3.3. and 3.4.

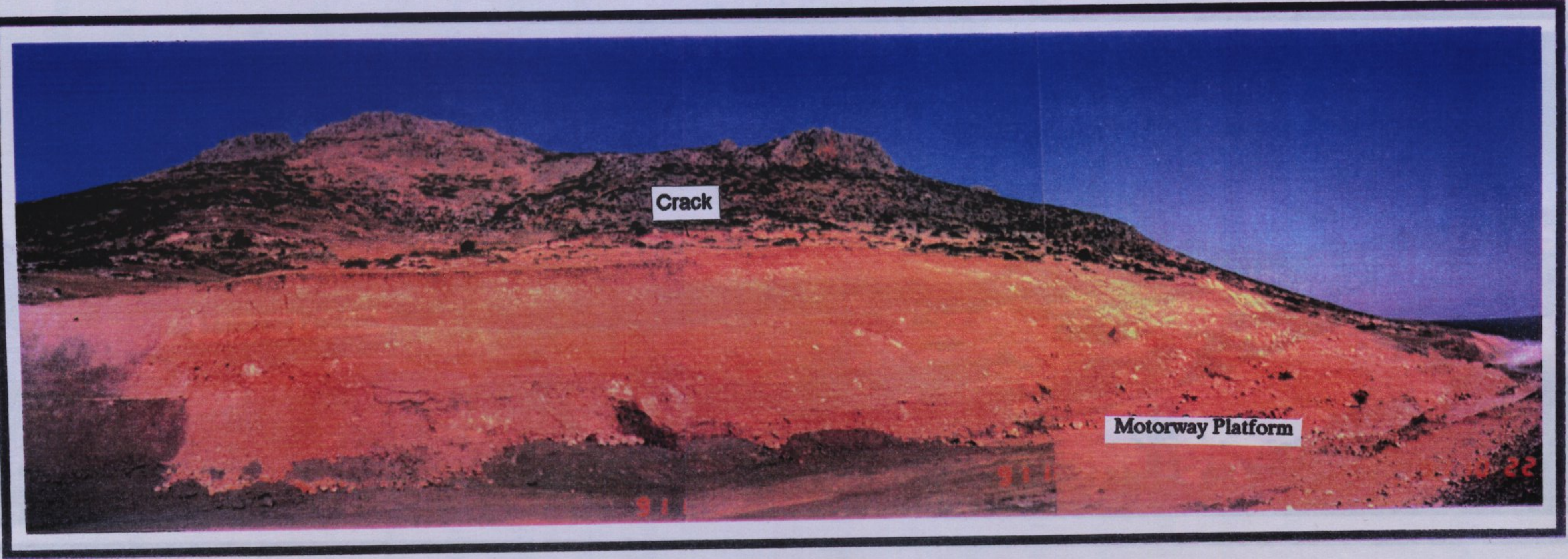


FIGURE 3.3. View from Slide Photo 1.

FIGURE 3.4. View from Slide Photo 2.

CHAPTER IV. SUBSOIL CONDITIONS

4.1. Introduction

As it was stated in Chapter III., two borings with S22 and BH3181 were performed on the motorway platform before the excavation. However, the depths of these borings were not sufficient to identify the real subsoil conditions of the slide area. Although the relevant sections of this area were reported, in previous design (5) as critical, the slide had occurred. It was evident that the subsoil conditions prevailing underneath the slopes of the cuts exhibit an important role, since no other effect such as earthquake or rainfall etc. are reported.

This chapter mainly summarizes the effect of the subsoil conditions on the slide event.

4.2. Subsoil Investigations

For the purpose of determining the geological properties of slide area, at the first stage, 5 (five) trial pits were excavated along the toe of the slide on the present motorway elevation in order to verify the bedrock profile. However, the bedrock was encountered only in 2 (two) of them; at the pits with no.P1 and no.P5 which were at Km.141+500 and Km.141+650 respectively. The locations of these trial pits are shown at Figure 4.1 and relevant logs results are given at Appendix (2).

Since the bedrock location was not sufficiently determined between the sections Km.141+500 and Km.141+650, five (5) additional borings basically at the Km.141+550 and Km.141+600 were performed until the bedrock was reached. The locations of these borings are also given at Figure 4.1. and the boring logs are given at Appendix (2).

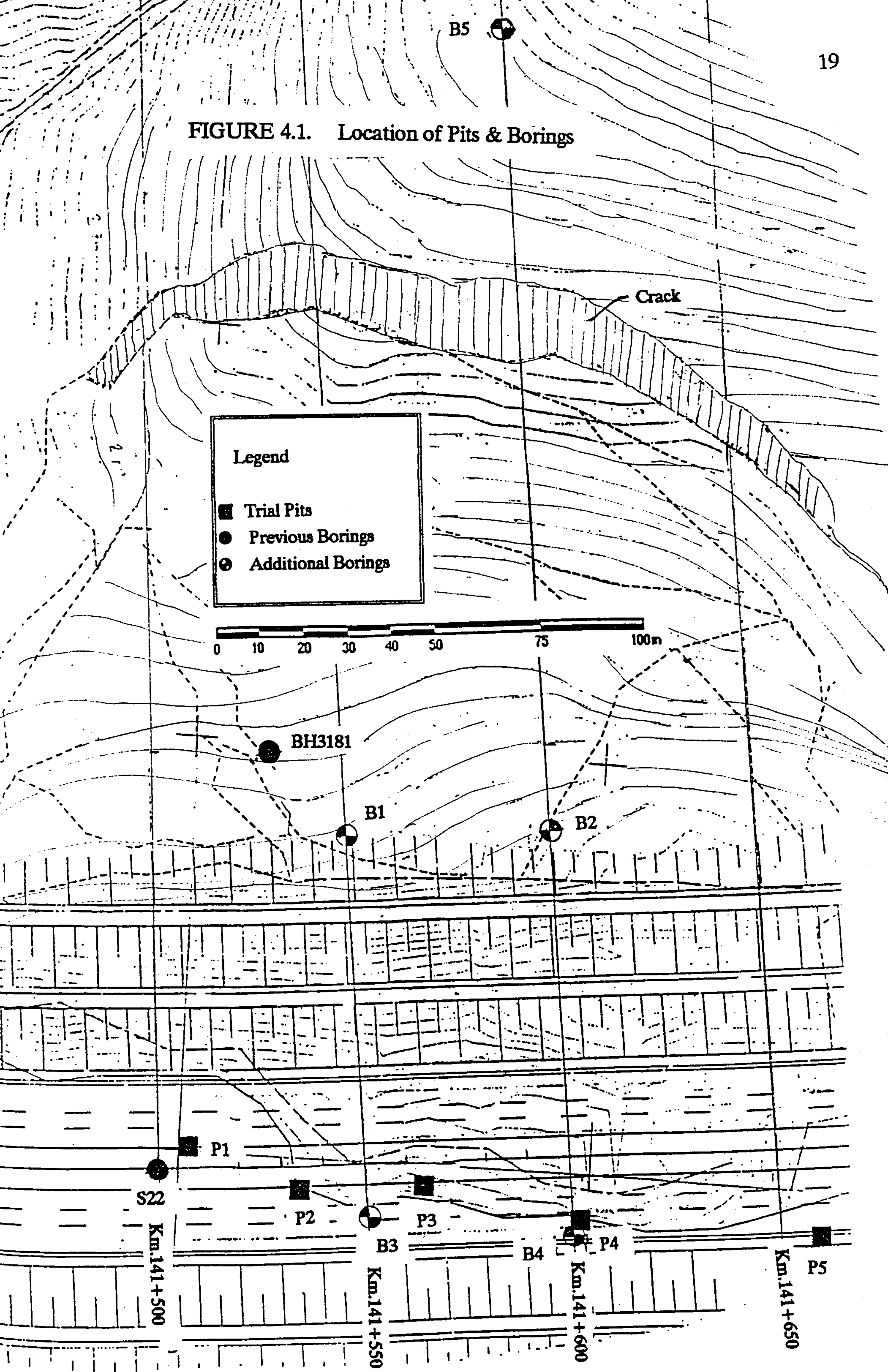


FIGURE 4.1. Location of Pits & Borings

TABLE 4.1. Summary of Additional Boring Logs

Boring No.	Location	Elevation	Level	Soil Profile
B1	Km.141+550	+260.99	-25.00 m -40.30 m -43.20 m	Slope Debris Gravelly Clay Spilit
B2	Km.141+600	+260.86	-4.70 m -16.70 m -29.20 m -30.00 m	Slope Debris Slope Breccia Gravelly Clay Spilit
B3	Km.141+550	+260.00	-1.80 m -10.80 m -13.40 m	Slope Debris Silty Clay Spilit
B4	Km.141+600	+232.75	-9.30 m -14.40 m -19.30 m -20.00 m	Slope Debris Gravelly Clay Spilit Agglomerate Spilit
B5	Km.141+600	+295.94	-8.80 m -12.00 m -17.00 m	Gravelly Clay Gravelly Clay Spilit

4.3. Subsoil Profile

During the subsoil investigations, a clay layer just underlaying the slope debris material was encountered. The encountered layer is formed by gravelly material in dense and hard condition.

Based on the performed borings and trial pits, the subsoil profile is categorized as three (3) different layer as follows;

1 - Slope debris
2 - Gravelly Clay
3 - Spilit

In Table 4.1. ,additional boring logs are summarized.

Although a thin gravelly clay layer is encountered between slope debris and bedrock, the slope debris layer played an important role in order to trigger the slide event. This layer was formed from the weathered rock fragments , gravel particles ,silt and clay. Since it is formed in loose and weak state, it affected the slide mechanism by increasing the gravitational forces and caused to slip.

CHAPTER V. EVALUATIONS ON THE SLIDE MECHANISM

5.1. Introduction

For the proper identification of the slide mechanism, it is needed to determine the residual shear strength parameters such as (Ø') and (c') and soil properties. The residual shear strength parameters were obtained by both laboratory tests and back calculation analysis, whereas the soil properties are determined by laboratory tests.

The stability analyses for determining the residual shear strength parameters, are performed on the excavated slopes before the slide topography. These analyses are evaluated by utilizing circular and non-circular slip surfaces. In this chapter, the implemented evaluations on slide mechanism are summarized.

5.2. Laboratory Tests

After the landslide, block samples were obtained from the slide area in order to determine the residual shear strength parameters and soil properties. The importance of the determination of the residual strength parameters was explained in Chapter II. The purpose of determining the soil properties is to make some correlations which is useful in the preliminary design of remedial measures.

The residual direct shear test was performed on the first series of block samples. However, it was shown that the test results indicated more gravelly material such that it cannot represent the similar properties of the real slip surface. Therefore, the second group of the block samples was obtained by using special mould in the slide area and tests are performed on these samples. The results from the second group of samples are found to be satisfactory, since its index properties might reflect the properties of the real slip surface. Consequently, the test's results from second group of samples are utilized during the evaluations.

5.2.1. Residual Direct Shear Test

Because of the giving rapid results and low cost, the direct shear tests are the most common method of obtaining the residual strength and the peak strength of the soils. The illustrated peak and residual shear strengths are given in the Figure 5.1.

The test is usually saturated consolidated drained (CD) with the sample sheared at slow constant rate of displacement, so that pore pressures due to shearing are dissipated giving drained conditions. Typical load displacement curves for "turbulent" and "sliding" shear are shown in Figure 5.2.

In literature, test has been investigated by many researches such as Bishop et al (1971), Bromhead (1979), Saada and Townsend (1981) and Bromhead and Curtis (1983).

5.2.2. Test Procedure and Application

In 1964, Skempton (2) has pointed out that the strength remaining in the laboratory samples after large shearing displacements was corresponded closely with the computed strength from slide. This concept is brought the idea of using residual strength parameters in determining the slide analysis.

The residual shear test which is summarized herein is described by Kenny (7). Kenny has applied this technique to very fine grained soils and technique is described as a modification of direct shear test.

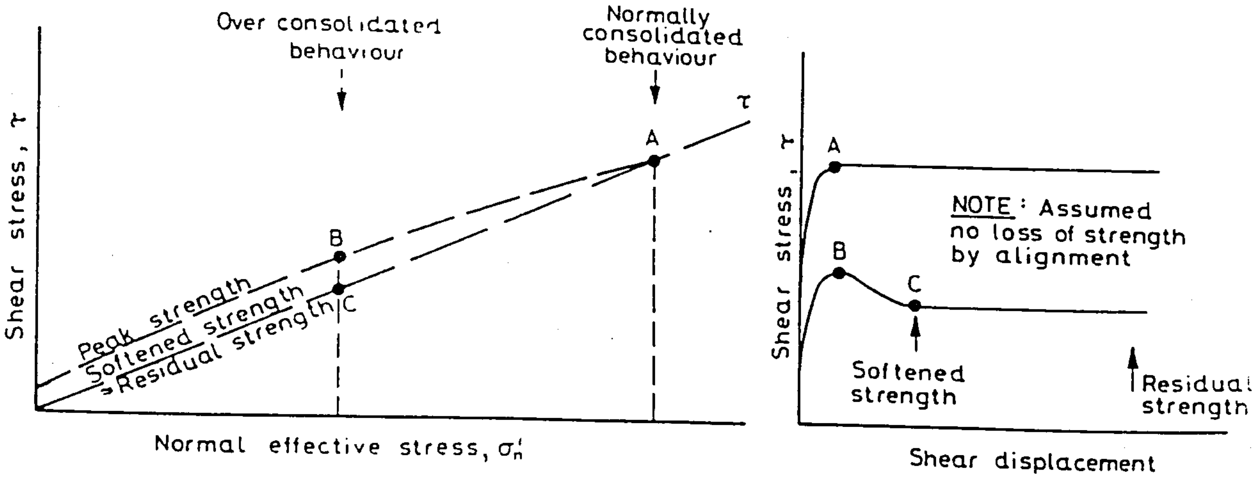
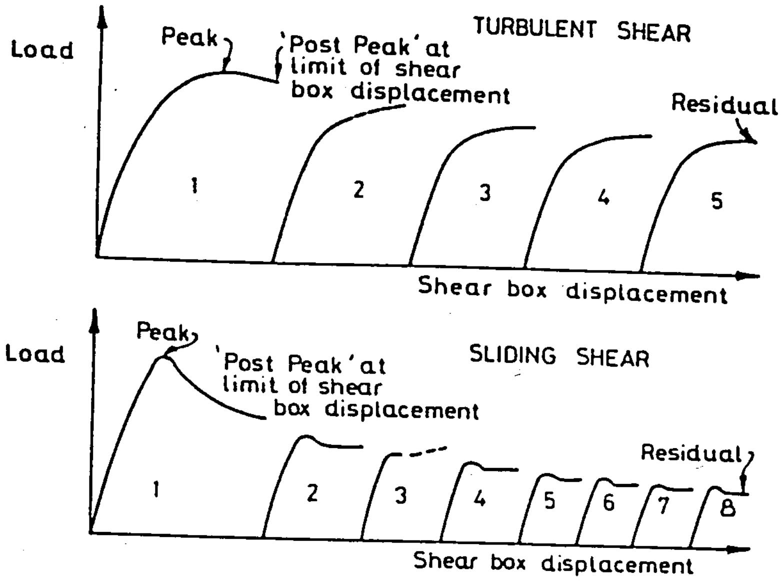


FIGURE 5.1. Residual Shear Strength and Peak Shear Strength (12)



Typical load displacement curves for direct shear tests

FIGURE 5.2. Turbulent and Sliding Shear (12)

In this test, a slurry of remolded clay or shale is smeared on a porous stone in a layer about 0.25 in. (6.4 mm.) thick and then consolidated under a vertical load for 18hr to 24 hr. Following consolidation, a shearing displacement is applied at the rate of about 0.1 in. (0.25 mm.) per hr. After about 0.1 in. (0.25 mm.) displacement, the shearing load is reversed in direction. About 10 to 15 reversals of shear are required before the shearing load to a constant value. This constant value is the residual shear strength of the soil. Eachtime, the tests are repeated for different consolidated forces and the residual shear strengths are determined for each reversals. At the end, the normal forces and obtained residual shear strengths are plotted in a coordinate system. The required shear parameters are obtained from these plotted graphs. The cohesion (c) is the point where the graph cuts the ordinate. The slope of this graph gives the internal friction angle.

The residual direct shear test results are given in the Table 5.1 and the graphical solutions are presented in Appendix (3).

5.2.3. Determination of Soil Properties

In order to determine the geotechnical properties of the slide area, laboratory laboratory tests such as sieve analysis, hydrometer test and determination of index properties are performed on the both sets of samples. As stated previously, the results obtained from first block of samples have not been found to be satisfactory whereas the other block sample indicated much satisfactory results. Tests results are given in Table 5.2 and Table 5.3 . The hydrometer test results are given in Appendix (2). Based on these tests, the average geotechnical properties could be summarized as follow

TABLE 5.1. Laboratory Test Results - Shear Strength Parameters

GROUP	Sample	Test Method	Cp kPa	Øp deg	Cr kPa	Ør deg
1 (*)	Samp.1A	CD	24	38	7	32
	Samp.1B	CD	32	48	-	-
	Artificial	CD	4	35	0	34
2	Samp.CBR1	CD	7	15	0	14
	Samp.CBR2	CD	42	13	15	13
	Samp.CBR3	CD	-	-	-	-

(*) Gravelly material therefore does not represent the shear strength on the slip surface.

CD	Consolidated - Drained test
Cp	Peak Cohesion
Øp	Peak internal friction angle
Cr	Residual cohesion
Ør	Residual internal friction angle

TABLE 5.2. Laboratory Test Results - Soil Properties

GROUP	Sample	+No.4 %	-No.200 %	USCS
1 (*)	**Samp.1A**	1	81	CL
	Samp.1B	2	74	CL
	Artificial	-	-	-
2	**Samp.CBR1**	3	84	CH
	Samp.CBR2	-	96	CH
	Samp.CBR3	4	84	CH

(*) Gravelly material therefore does not represent the shear strength on the slip surface.

+No.4	Percent Passing No.4 Sieve
-No.200	Percent Retained on No.200 Sieve
USCS	Unified Soil Classification

TABLE 5.3. Laboratory Test Results - Soil Properties

GROUP	**Sample**	**wn** **%**	**γn** kN/m3	**ATTENBERG LIMITS** **LL** **%**	 **PL** **%**	 **PI** **%**	**CF** **%**
1 **(*)**	**Samp.1A**	23	20.03	44	27	17	16.6
	Samp.1B	23	18.82	42	30	12	10.7
	Artificial	-	18.69	-	-	-	
2	**Samp.CBR1**	35	17.12	76	32	44	46.9
	Samp.CBR2	35	17.64	72	27	43	38.2
	Samp.CBR3	26	-	57	17	40	

(*) Gravelly material therefore does not represent the shear strength on the slip surface.

wn	**Natural water content**
γn	**natural unit weight**
LL	**Liquid Limit**
PL	**Plastic Limit**
PI	**Plastic Index**
CF	**Clay Fraction**

For Group(1) :

Natural water content (in percent) = 23
Liquid limit (in percent) = 43
Plastic Limit (in percent) = 28.5
Plasticity Index (in percent) = 14.5
Clay Fraction (in percent) = 13.7

Obviously, this cannot represent the real slip surface because of low plasticity.

For Group(2) :

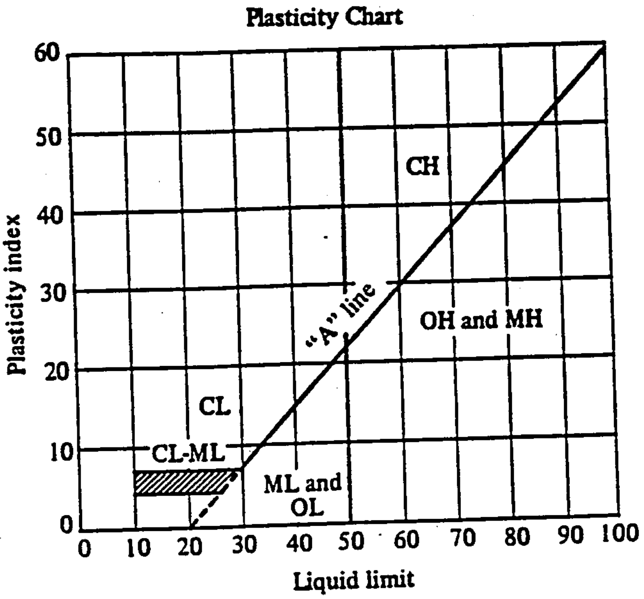
Natural water content (in percent) = 35
Liquid limit (in percent) = 74
Plastic Limit (in percent) = 29.5
Plasticity Index (in percent) = 43.5
Clay Fraction (in percent) = 42.6

The index properties were plotted on the plasticity chart of the Unified Soil Classification System (USCS) according to (ASTM D-2487) and presented in Table 5.4. According to USCS, the subsoil is classified as CH.

5.3. Slip Surface

The geology of the subject area is complex and indicates variations within short distances. Therefore, bedrock agglomerate could be encountered in only two of the trial pits performed along the toe of slide area. The other five(5) borings also supported this concept so that geology has a three dimensional shape. During borings, no ground water was reported.

TABLE 5.4. Unified Soil Classification System



For the determination of the position of the slip surface, basically three point should be clearly identified. These are the tension cracks, toe of the slided material and the bedrock position. On the light of the performed borings, the bedrock position had been determined.

Based on the performed borings, it is determined that slip surface passes through gravelly clay layer (II.layer). However, the real factor that cause to slip is the slope debris layer (I.layer). This layer is contained bedrock particles; such as boulders gravel , silt or clay. Therefore, it is also evident that the slide was triggered during the excavation of the cut slopes. Furthermore it can be concluded that the equilibrium between resisting forces and sliding forces are broken down and slide had occurred.

5.4. Back Calculation Analysis

One other way of the determination of the residual shear strength parameters is to utilize the back calculation method on the slipped surface. In this method, the required shear parameters are determined based on the just-before slide topography of the cut slopes. The theory and method are summarized at Appendix (1).

The slide event is investigated basically on 4(four) different sections; Km.141+500 Km.141+550, Km.141+600 and Km.141+650 respectively. Therefore the back calculation method is performed on these sections by assuming two different slip surfaces; circular and non-circular slip surface.

During the evaluation of the parameters (ϕ') and (c'), a computer program (8), which utilizes the modified Bishop's method for circular slip surface and other program (9), which utilizes the Janbu's inclined method of slices are used. Also following values are taken into account;

For Clay layer ...;

Natural unit weight ..: 19 kN/m3

cohesion......................: 0 kN/m2

pore water pressure ..: 0 kN/m2

initial Ø' ....: varies 10 -13 degree

For Bedrock...;

Natural unit weigth ..: 30 kN/m3

cohesion......................: 200 kN/m2

5.4.1. Back Calculation Analysis on Km.141+500

The first case study is performed on the Km.141+500 section. The subsoil conditions had been determined previously during the trial pits excavation. In figure 5.3 the section is illustrated and the back calculation method is performed based on this section. As stated before, a computer program (8) has been used, the data and the results of the computer calculations are given in the Appendix (4).

Based on the before landslide topography and factor of safety equals to unity, the slip circle coordinates are obtained as follows;

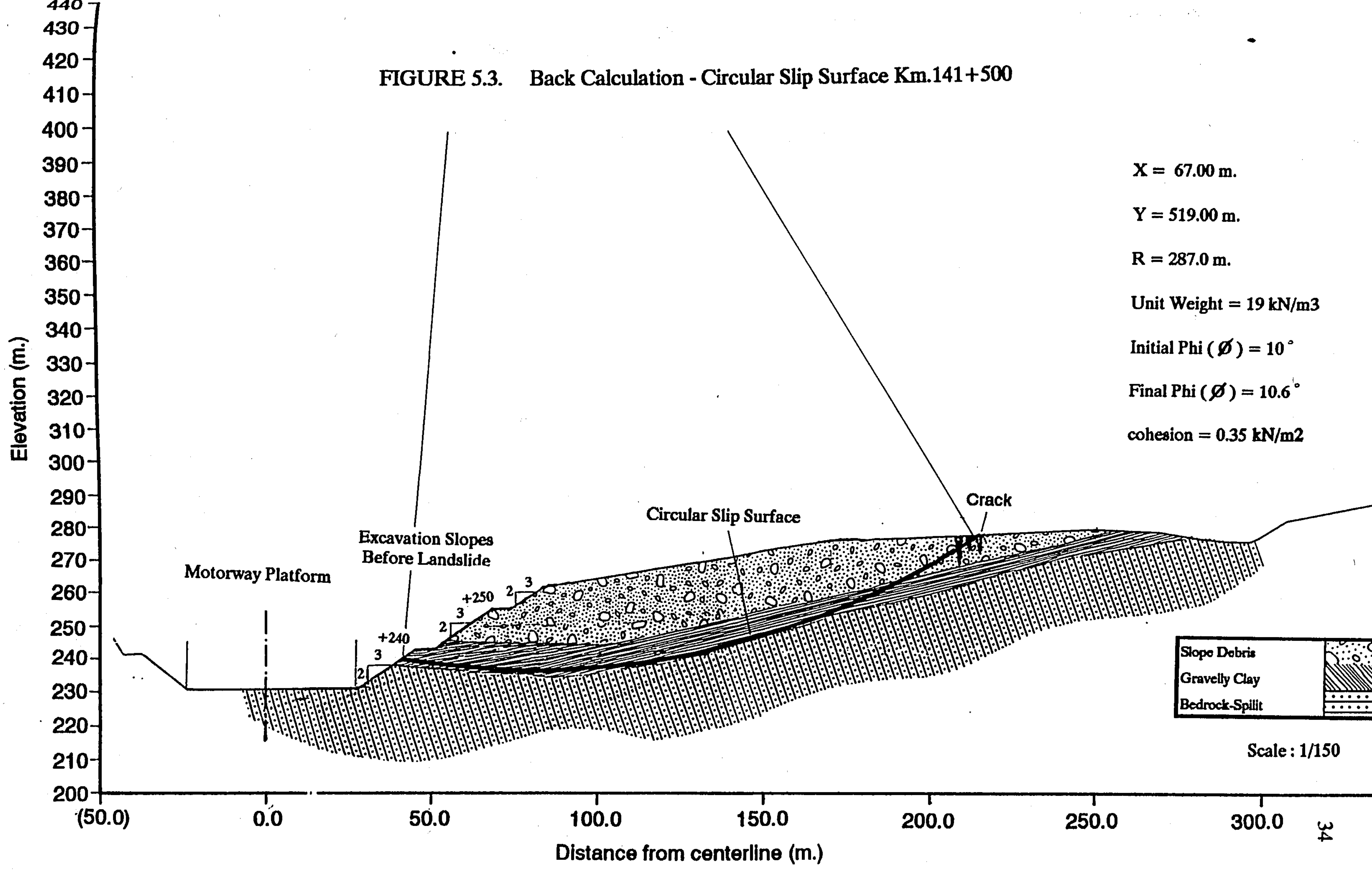
X = 67.00 m.

Y = 519.00 m.

R = 287.00 m.

Ø' = 10 (initial value) degree

FIGURE 5.3. Back Calculation - Circular Slip Surface Km.141+500



In the case of factor of safety equals to 1.00 (unity) (FS=1.00), the shear strength parameters are obtained by utilizing a computer program (8), and found as follows;

FS = 1.00

c ' = 0.35 kN/m2

Ø ' = 10.60 kN/m2

ru = 0.10 kN/m2

5.4.2. Back Calculation Analysis on Km.141+550

The subsoil profile on this section was prevailed by the borings with no.B1 and B3. According to these borings, the position of the slip surface which passing from tension crack and bedrock formation was determined. In this section, two analyses are performed by considering circular slip surface and non-circular slip surface. These are shown at Figure 5.4. and Figure 5.5. respectively.

Based on the before landslide topography and the factor of safety equals to unity, the slip circle coordinates are obtained as follows;

X = 46.50 m.

Y = 540.50 m.

R = 339.00 m.

Ø'= 12 (initial value) degree

In the case of factor of safety equals to 1.00 (unity) (FS=1.00), the shear strength parameters are obtained by utilizing a computer program (8) and found as follows;

FS = 1.00

c ' = 0.81 kN/m2

FIGURE 5.4. Back Calculation - Circular Slip Surface Km.141+550

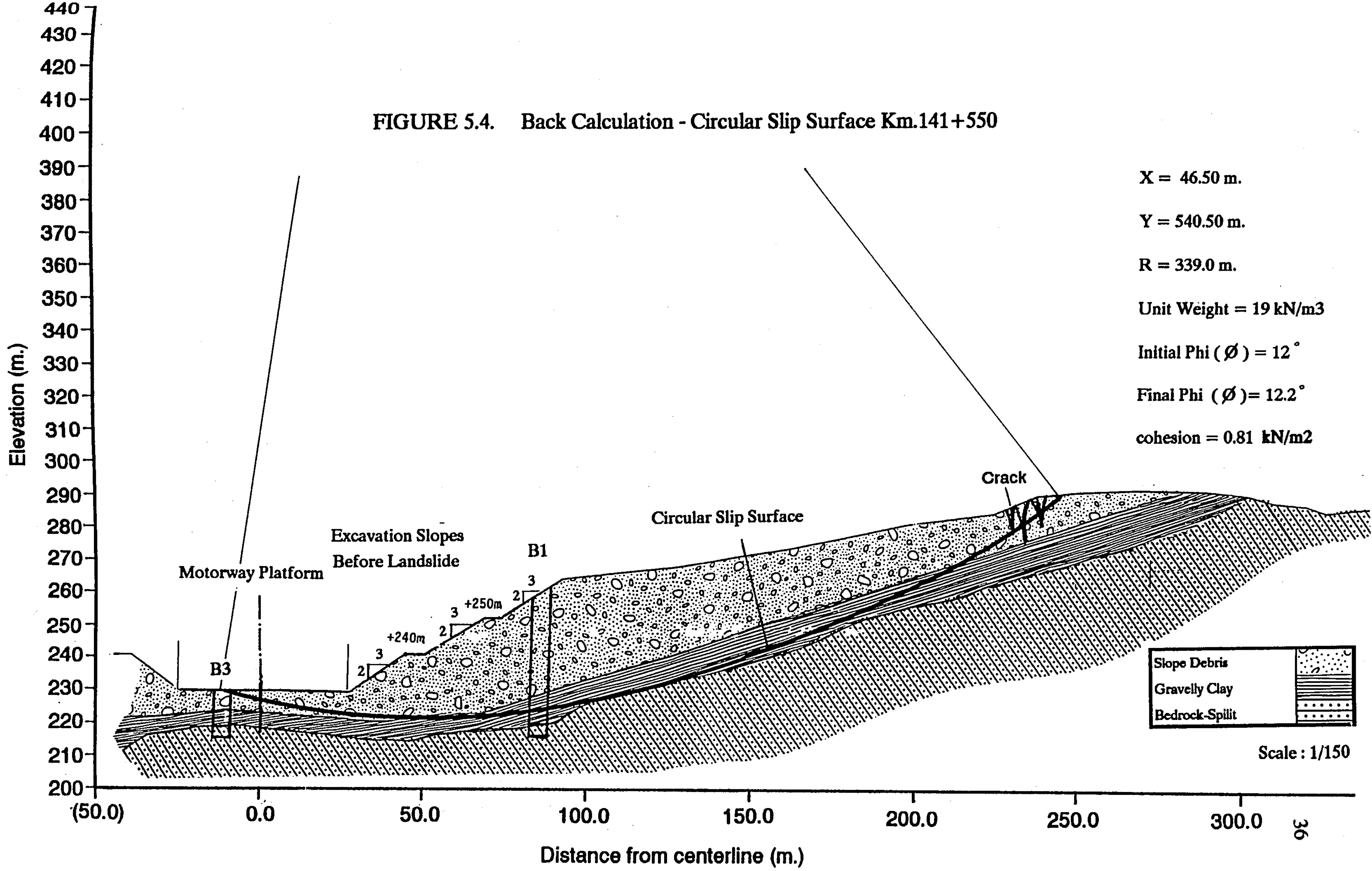
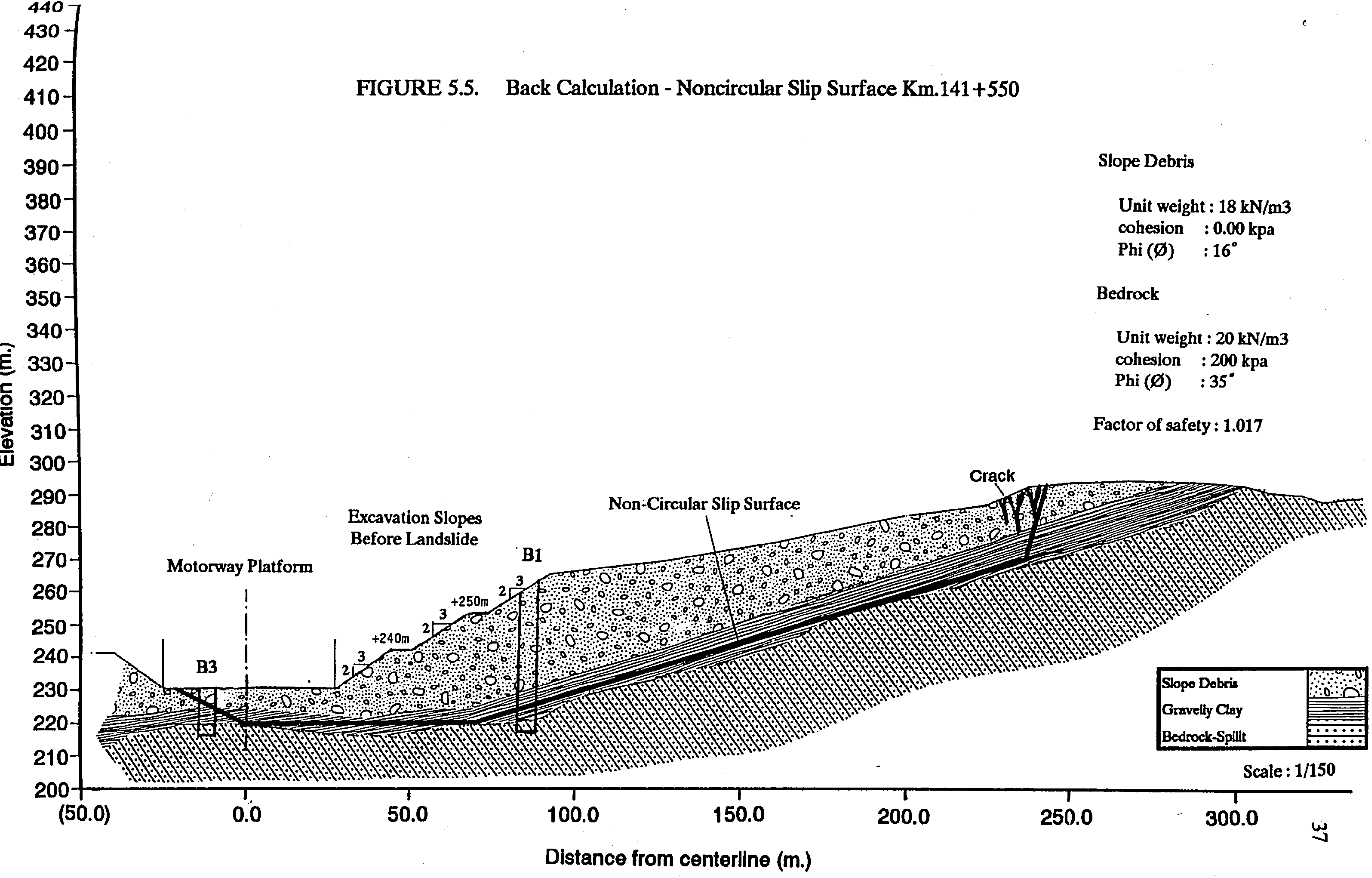


FIGURE 5.5. Back Calculation - Noncircular Slip Surface Km.141+550



$\phi' = 12.20$ degree

ru = 0.00 kN/m2

In the non-circular slip surface analysis, for the following assumed shear parameters

$\phi' = 16.0$ degree and $c' = 0.0$ kN/m2

the factor of safety is obtained by utilizing a computer program (9) as equal to 1.017.

5.4.3. Back Calculation Analysis on Km.141+600

The subsoil profile on this section was prevailed by the borings with no.B4 and B2 and B5. According to these borings, the position of the slip surface which passing from tension crack and bedrock formation was determined. The section is presented at the Figure 5.6.

Based on the before landslide topography and the factor of safety equals to unity, the slip circle coordinates are obtained as follows;

X = 26.00 m.

Y = 604.00 m.

R = 384.00 m.

$\phi' = 11.5$ (initial value) degree

In the case of factor of safety equals to 1.00 (unity) (FS=1.00), the shear strength parameters are obtained by utilizing a computer program (8) and found as follows;

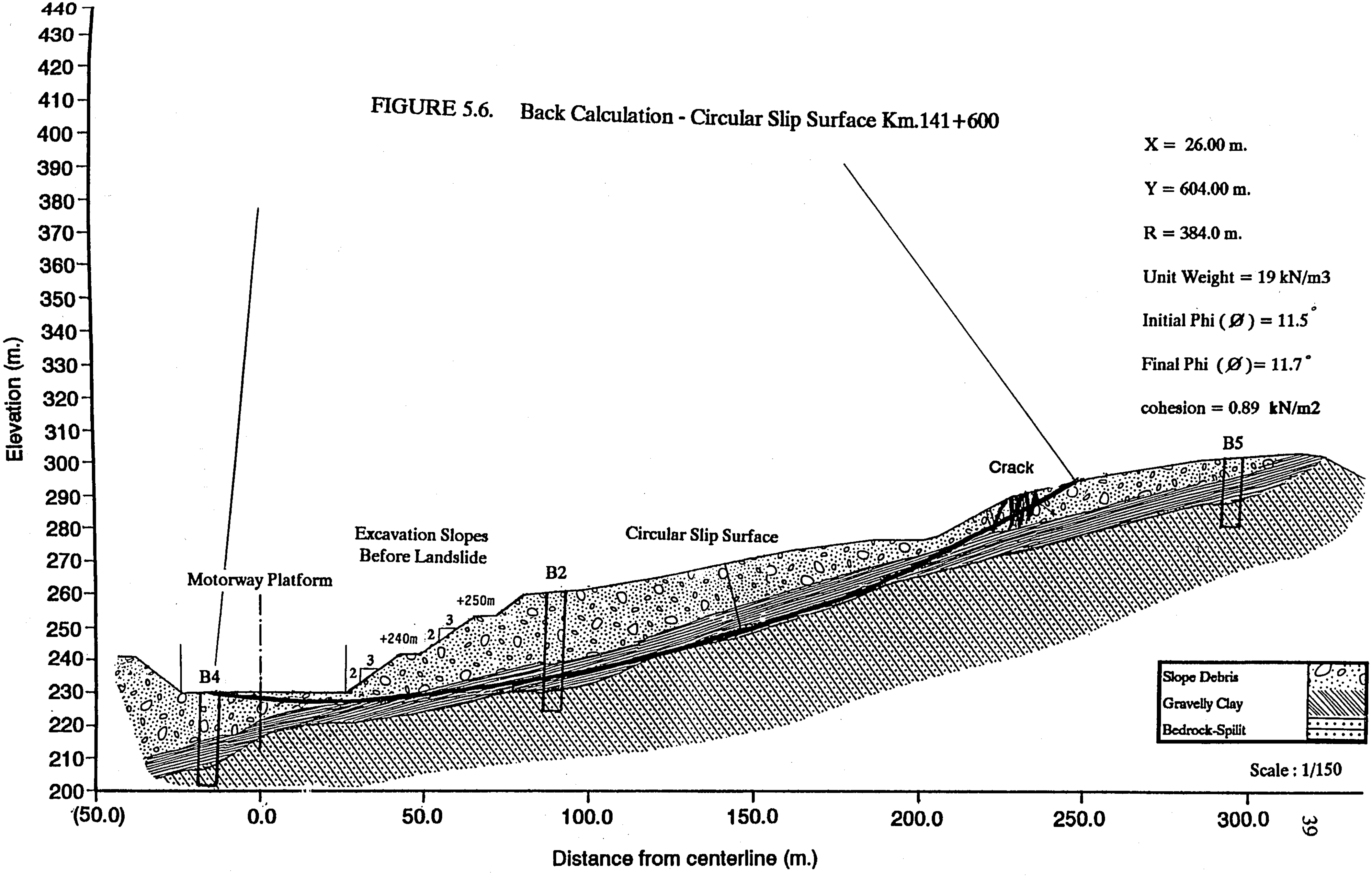
FS = 1.00

c' = 0.89 kN/m2

$\phi' = 11.70$ degree

ru = 0.00 kN/m2

FIGURE 5.6. Back Calculation - Circular Slip Surface Km.141+600



5.4.4. Back Calculation Analysis on Km.141+650

In this section, the subsoil profile had been determined by the trial pits excavation. Two type of analyses as being circular and non-circular anlysis are performed on this case. In Figure 5.7., the circular analysis and in Figure 5.8.,noncircular analysis are give As it was stated previously, two computer programs,which one of them (8) for circular slip surface in Figure 5.7 and the other one(9) for non-circular slip surface in Figure 5.8 have been used and the relevant computer results are given in Appendix (4).

In the circular slip surface analysis, based on the before landslide topography and factor of safety equals to unity, the slip circle coordinates are found as follows;

X = 65.00 m.

Y = 434.00 m.

R = 196.00 m.

Ø′= 13 (initial value) degree

In the case of factor of safety equals to 1.00 (unity) (FS=1.00), the shear strength parameters are obtained by utilizing a computer program (8) and shown at the following;

FS = 1.00

c ' = 0.00 kN/m2

Ø ' = 14.00 degree

ru = 0.00 kN/m2

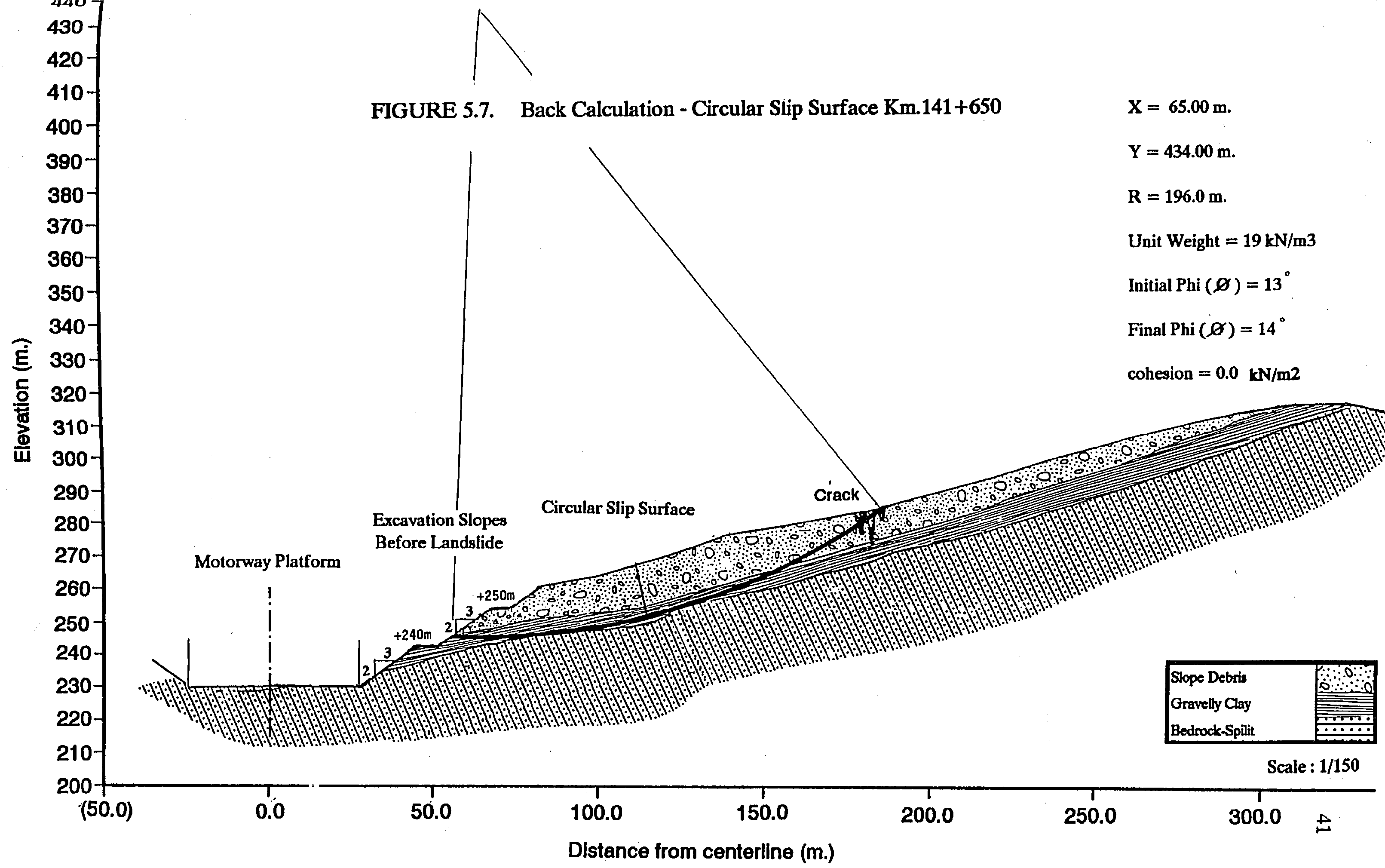
In the non-circular slip surface analysis for the shear parameters ;

Ø′= 13.0 degree and c = 0.0 kN/m2

the factor of safety is obtained as equal to 1.004

Consequently , all results are summarized at Table 5.5.

FIGURE 5.7. Back Calculation - Circular Slip Surface Km.141+650



X = 65.00 m.

Y = 434.00 m.

R = 196.0 m.

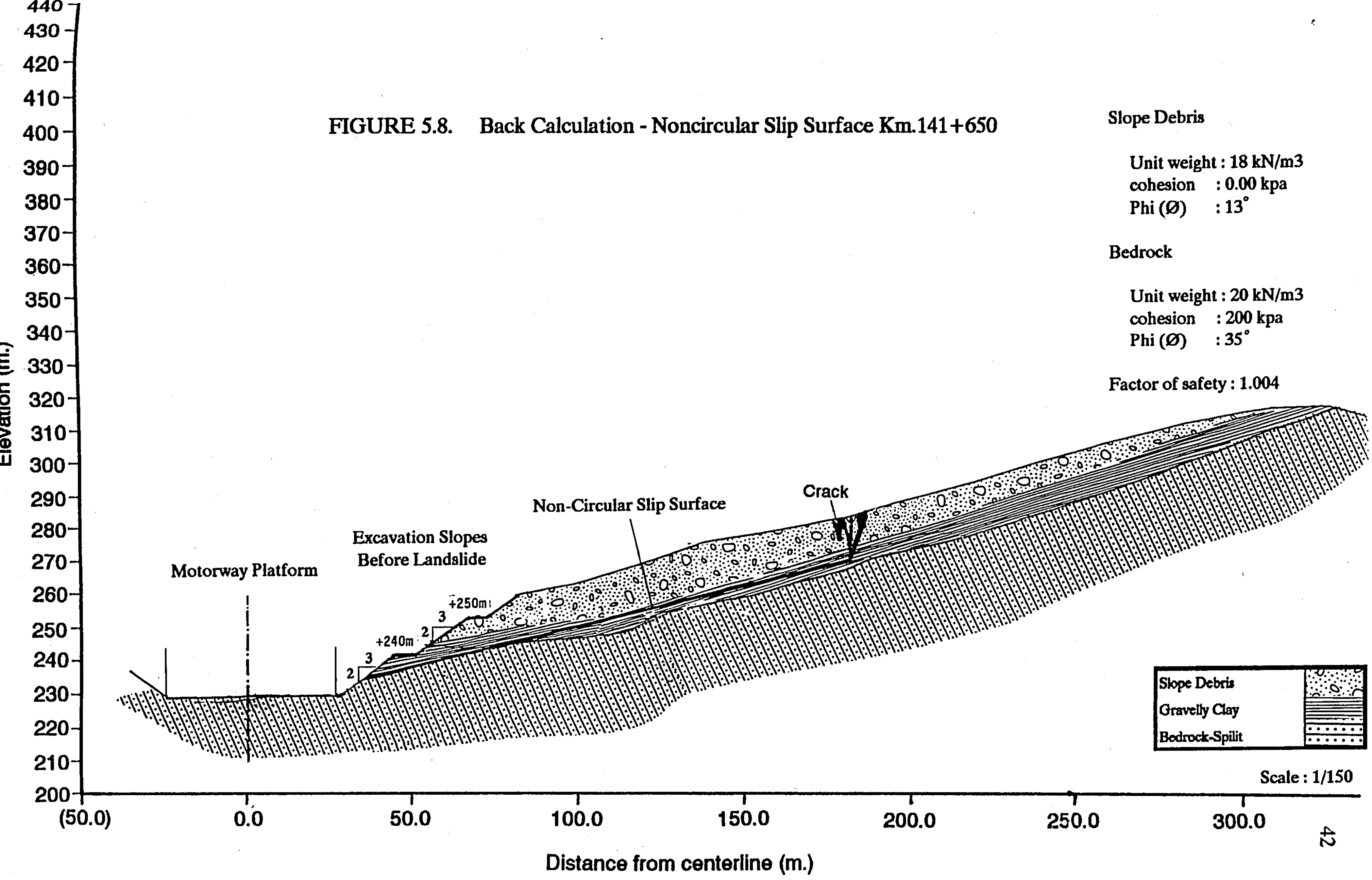
Unit Weight = 19 kN/m3

Initial Phi (Ø) = 13°

Final Phi (Ø) = 14°

cohesion = 0.0 kN/m2

FIGURE 5.8. Back Calculation - Noncircular Slip Surface Km.141+650



5.5. Shear Strength Parameters

The results from back calculation analyses and laboratory tests are compared with each others and as a result of this comparison, it was shown that both results are in good agreement with each others. The implemented correlation is given in the Table 5.6.

As a conclusion, the shear strength parameters are obtained as follows;

$$Ø' = 14 \text{ degree}$$

$$c' = 0 \text{ kN/m2}$$

5.5.1. Correlation Between Ø' ,Gradation and Index Properties

In the recent years, a new correlation between residual internal friction angle (Ø') gradation and index properties of cohesive soils has been carried out by some Italian researchers (10). The proposed correlation was obtained on the basis of the results of laboratory analyses carried out on more than 150 samples at 20 Italian sites along the "Autostrade Spa" motorway network.

The aim of this correlation is to give a profitable and practical data as a guideline for designers where the remedial works are very urgent. It can give reliable qualitative indications when the input data for design cannot be obtained from an extensive laboratory test program.

The correlation makes reference to the comprehensive study by Lupini et al (1981) (11) on the drained residual strength of cohesive soils.

It was confirmed after several tests that the residual friction angle, Ør, is influence by both the clay fraction (CF) and the consistency index properties of the clay as Liquid

TABLE 5.6. Summary of Laboratory Test and Back Calculation Analysis

TEST	Cr´ (kpa)	Ør´ (degree)
Back Calculation	0	varies 11° - 16°
Laboratory	0	varies 13° - 14°

Cr	Residual cohesion (kpa)
Ør	Residual internal friction angle (deg.)

TABLE 5.7. Soil Properties for CALIP

Sample	**Clay Fraction (%)**	**Liquid Limit (%)**	**Plasticity Index (%)**	**ϕ_r' (deg)**
1A	16.6	44	17	38°
1B	10.7	42	12	48°
CBR1	46.9	76	44	15°
CBR2	38.2	72	43	13°

TABLE 5.8. Results of CALIP - Ør' Correlation

Sample	CALIP	Ør' from fig.18 (deg)	Ør' from fig.19 (deg)	Ø r' from lab.test (deg)
1A	2.06	32°	>32°	32°
1B	0.58	>32°	>32°	34°
CBR1	73.55	10°	14°	14°
CBR2	45.18	13°	22°	13°

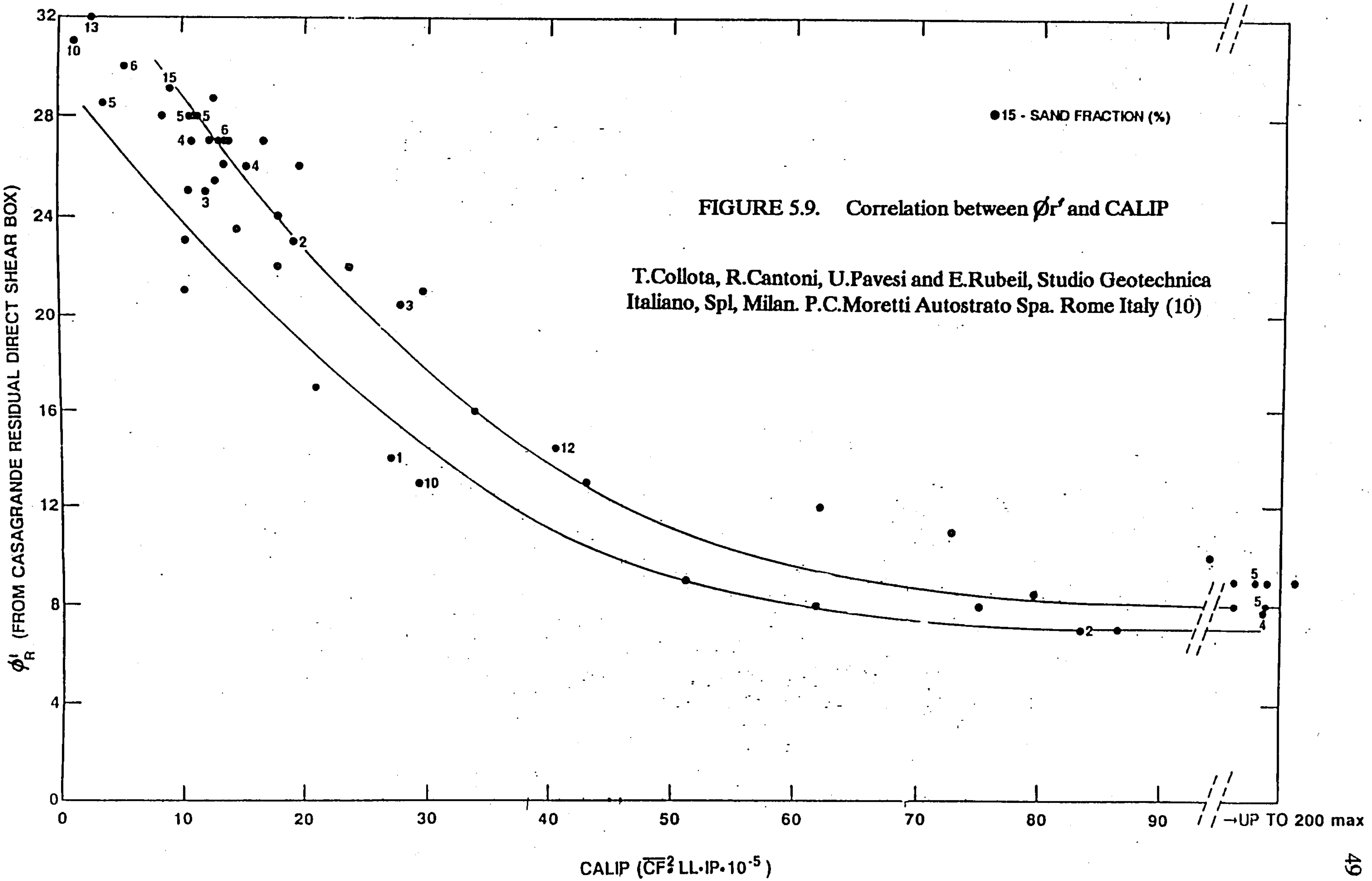


FIGURE 5.9. Correlation between Ør′ and CALIP

T.Collota, R.Cantoni, U.Pavesi and E.Rubeil, Studio Geotechnica Italiano, Spl, Milan. P.C.Moretti Autostrato Spa. Rome Italy (10)

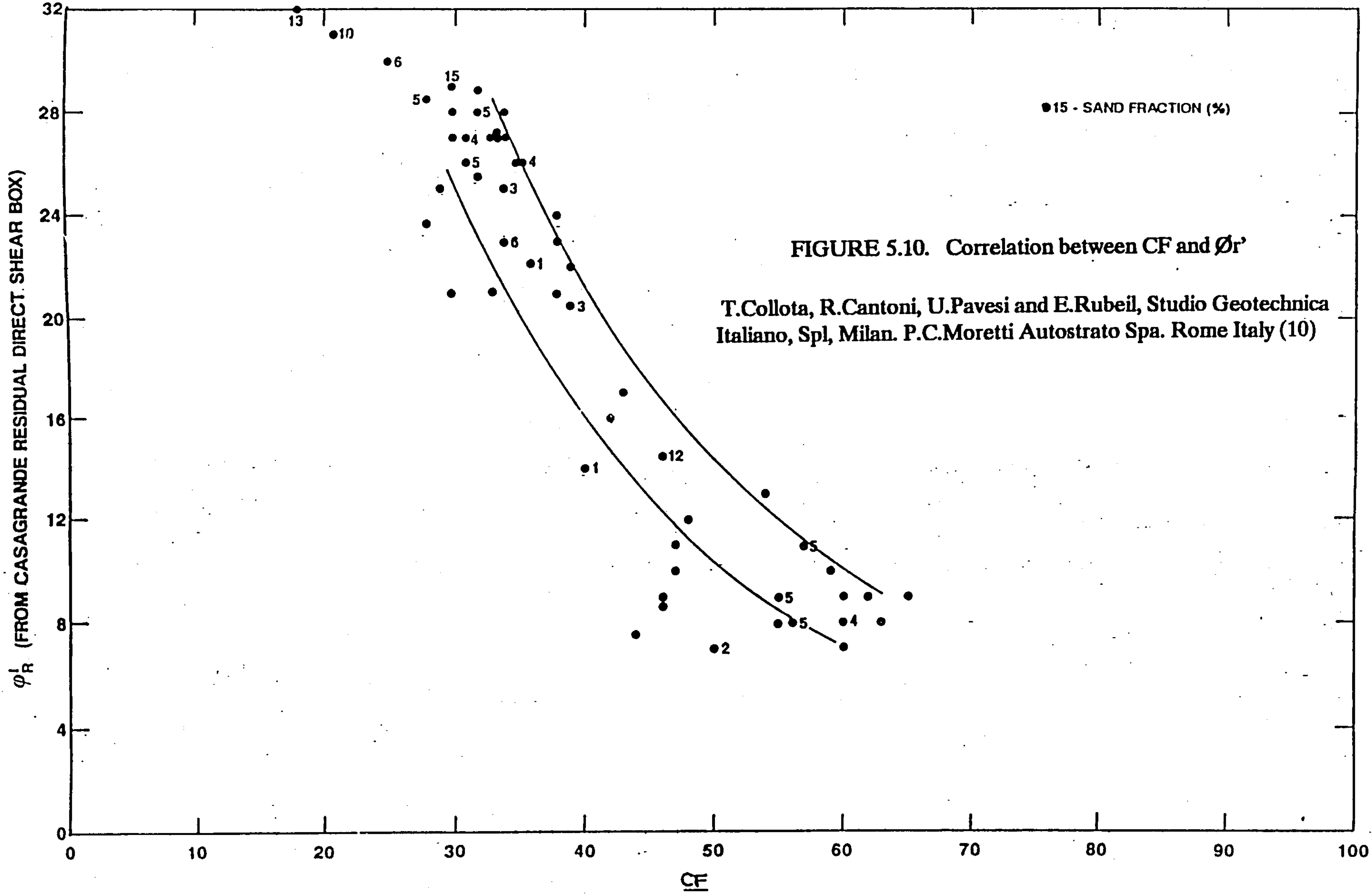


FIGURE 5.10. Correlation between CF and Ør'

T.Collota, R.Cantoni, U.Pavesi and E.Rubeil, Studio Geotechnica Italiano, Spl, Milan. P.C.Moretti Autostrato Spa. Rome Italy (10)

Sample	LL (percent)	Ør'(degree) from Figure 5.1.	Ør' (degree) from Figure 5.11.
1A	44	32	>24
1B	42	34	>24
CBR1	76	14	11.5
CBR2	72	13	12

It can be concluded that the results from laboratory tests and Figure 5.11. indicate no diffrence, and also it is observed that the results which has high liquid limit has low internal friction angle.

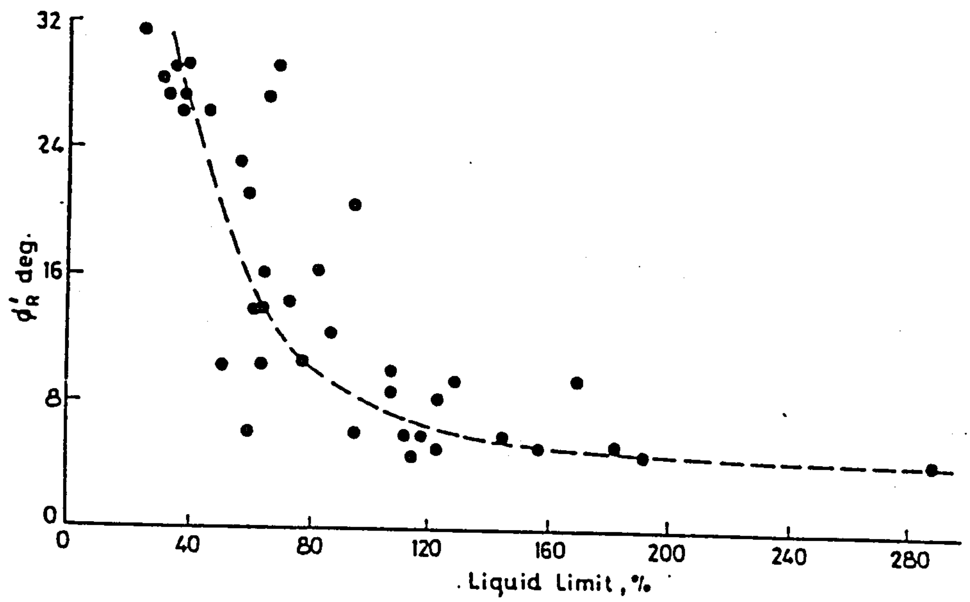


FIGURE 5.11. Relation between LL, $\phi r'$

Mesri-Cepeda Diaz 1986 (13)

CHAPTER VI. REMEDIAL DESIGN MEASURES

6.1. Introduction

In this section of the analysis, remedial design measures that are recommended to stabilize the area are presented as alternative solutions and at the final section of this chapter , these alternatives are compared with each others.

Many methods can be proposed to correct the landslide problem; such as flattening of slopes, pressure berms, lowering of the groundwater table, erosion protection etc. But it is a fact that the most important one is to find the most safe and economical one.

In the remedial stage of the landslide area , the solutions are studied under the title of two main groups;

- Geometrical methods
- Mechanical methods

In each group, the alternative solutions are summarized and discussed as comparing their feasibilities.

6.2. Geometrical Methods

The stability of a slipped slope can be increased by some arrangement on the deformed shape by flattening of the slope, by removal of the soil or other loads at the top of the slope, by placing pressure berms at certain level of the slope, or by relocation of the motorway alignment.

Among these methods, the removal of major part of the sliding material is considered as a most proper solution. For this purpose, an excavation proceeding from the top of the slide down to grade elevation is necessary. Two alternative solutions are studied within the content of this solution.

6.2.1. Alternative solution 1. Slope Regrading and Excavation

This alternative solution is recommended the removal of the major part of the sliding mass together with a slope arrangement. Slope arrangement is consisted of pressure berms with 5.0 m. at 10.0 m. height intervals from the platform. During the excavation, a composition of various slopes is proposed based on the approximate location of the bedrock.

In principle, the slope will be shaped to a flatter slope i.e. h/v (horizontal over vertical) of 10/1 followed by a slope of h/v=5/1 after the first berm beginning from the motorway platform until the bedrock is encountered. A steeper slope i.e. h/v=2/1 and h/v=3/2 will be applied within the bedrock. This slope regrading work will be carried out along a 350m. section between Km.141+400 and Km.141+750. However, since the topography has a concave shape the major part of the excavation will be performed between Km.141+550 and Km.141+650.

All required works are shown in Figures 6.1. thru 6.5.

Based on this solution the estimated earthwork can be summarized as follows;

. approximate excavation within slope debris and clay 1,000,000 m3

. approximate excavation within bedrock 300,000 m3

total excavation ....: 1,300,000 m3

After excavation, ultimate importance should be given to the drainage precautions by constructing drainage ditches on the berms. Since slope is towards Gaziantep side the flow speed within head ditches at steep areas should be regulated.

FIGURE 6.1. Alternative Solution 1. Slope Regrading and Excavation Km.141+500

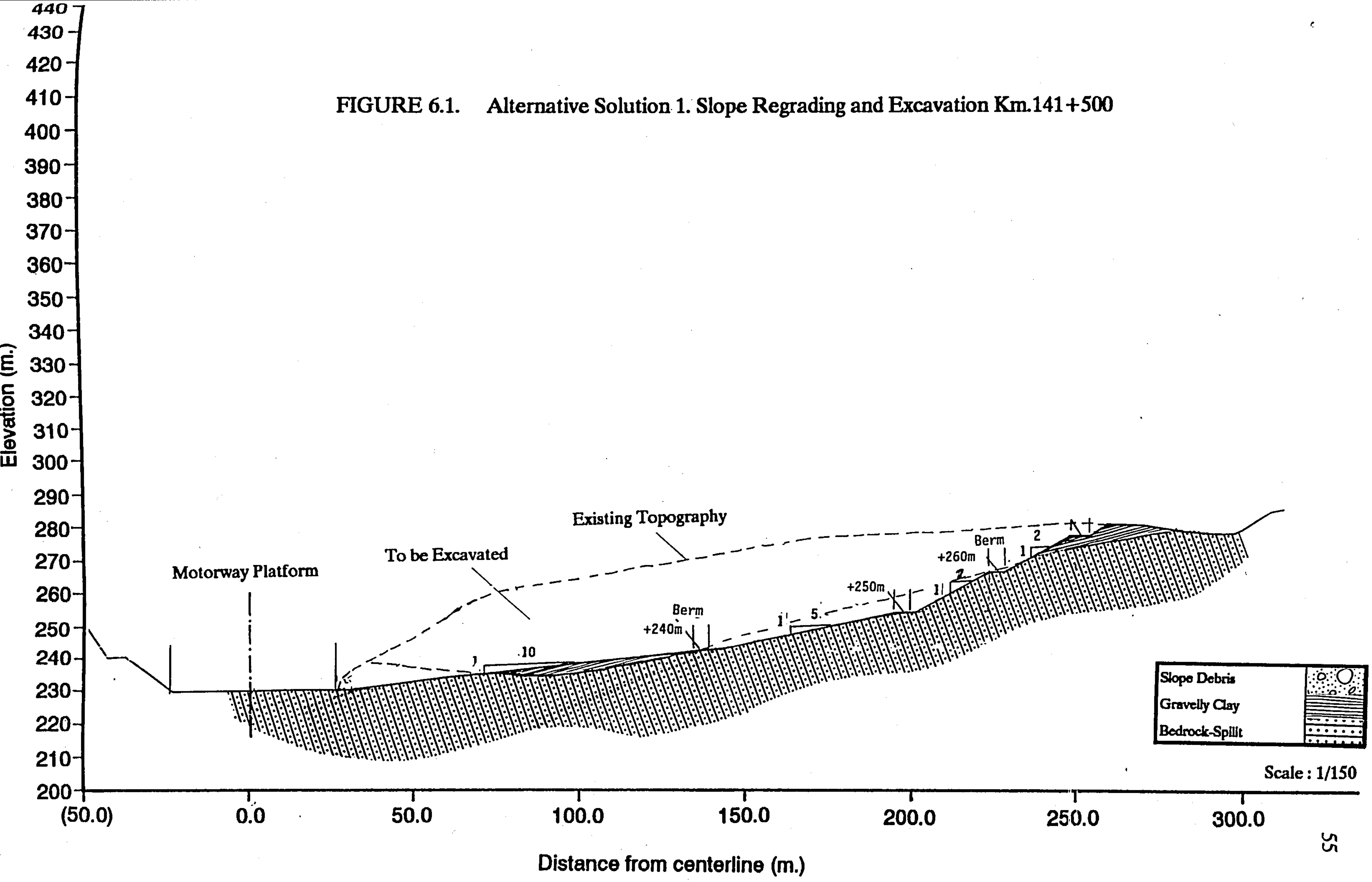


FIGURE 6.2. Alternative Solution 1. Slope Regrading and Excavation Km.141+550

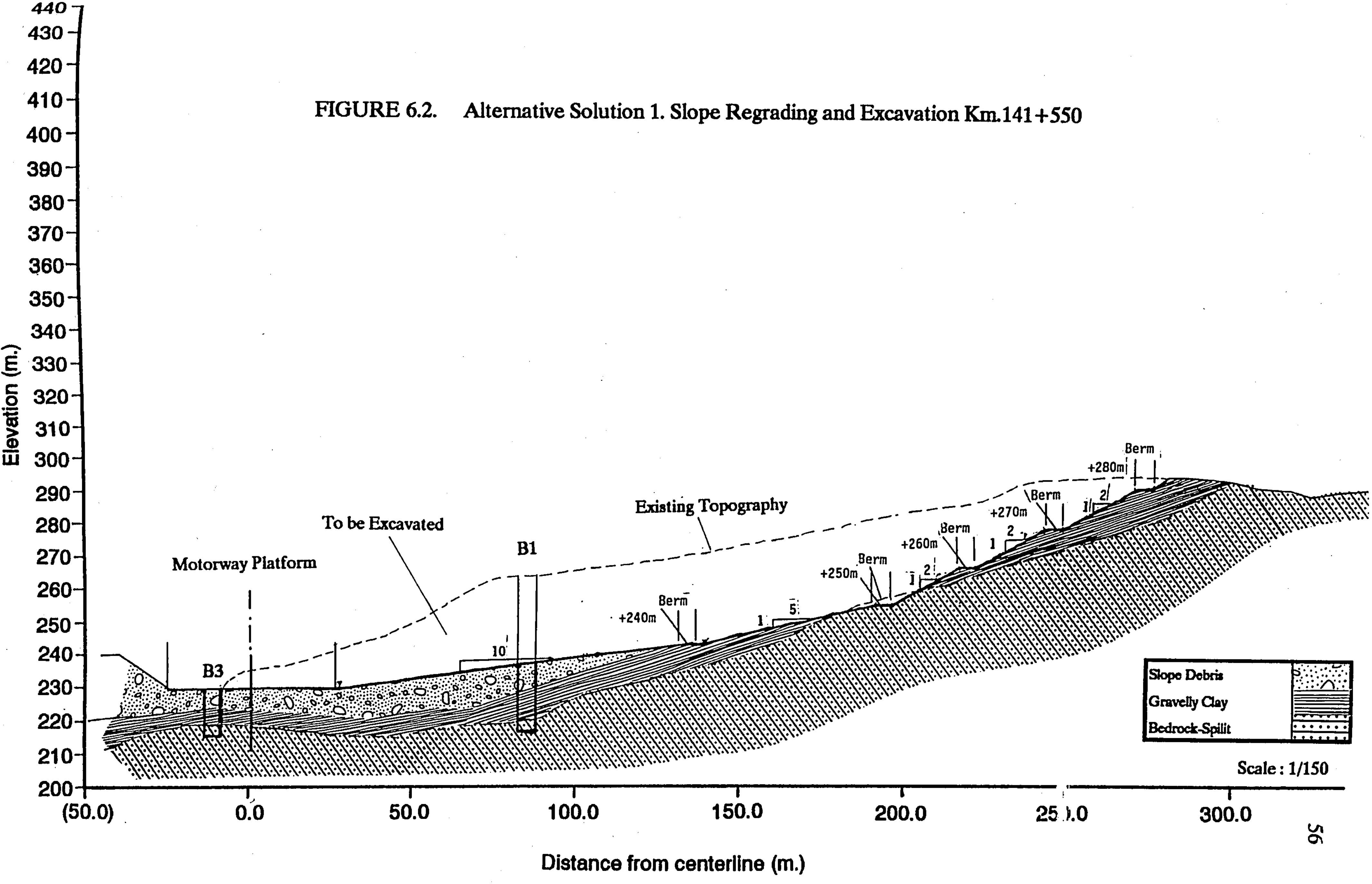


FIGURE 6.3. Alternative Solution 1. Slope Regrading and Excavation Km.141+600

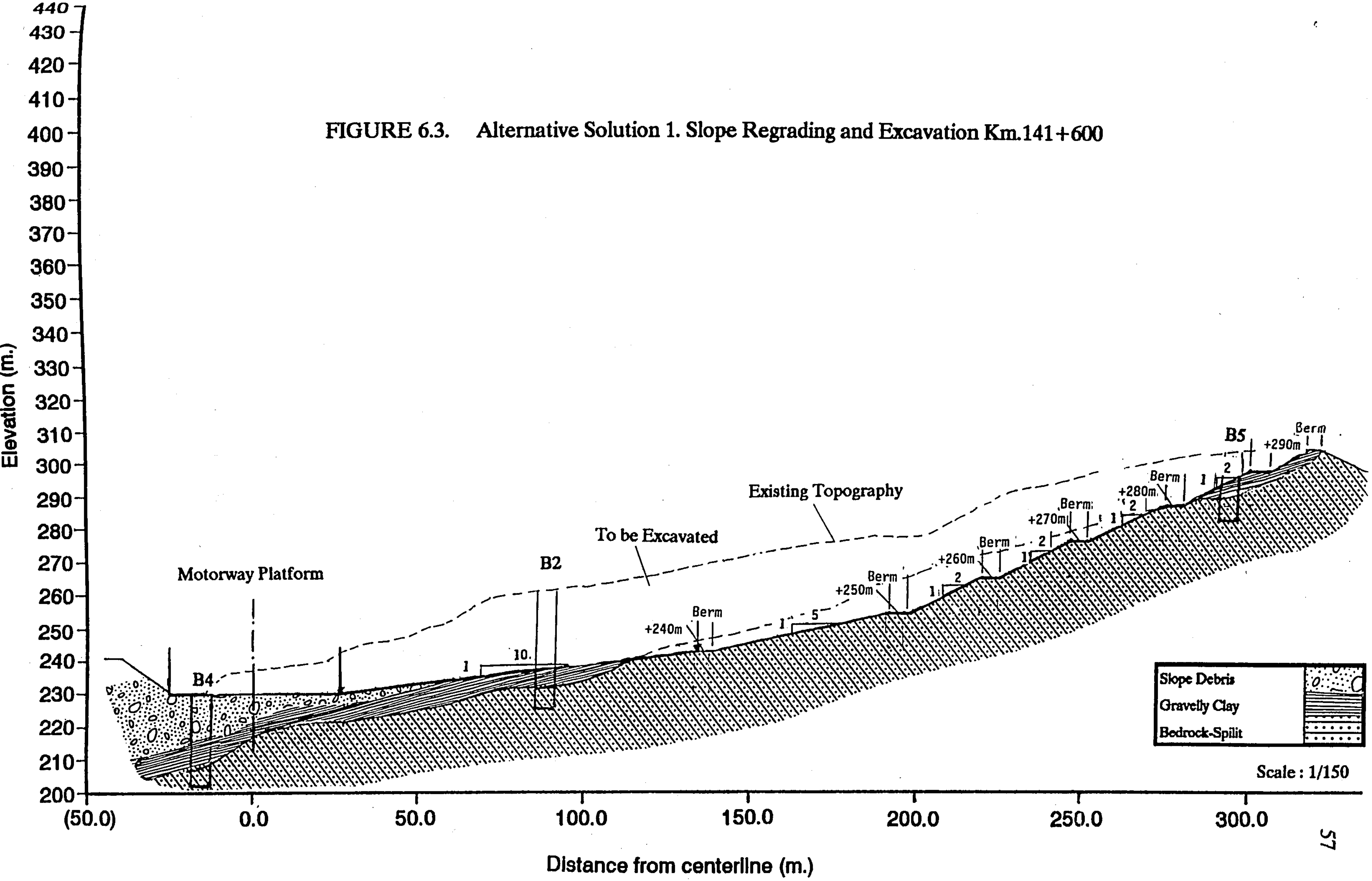
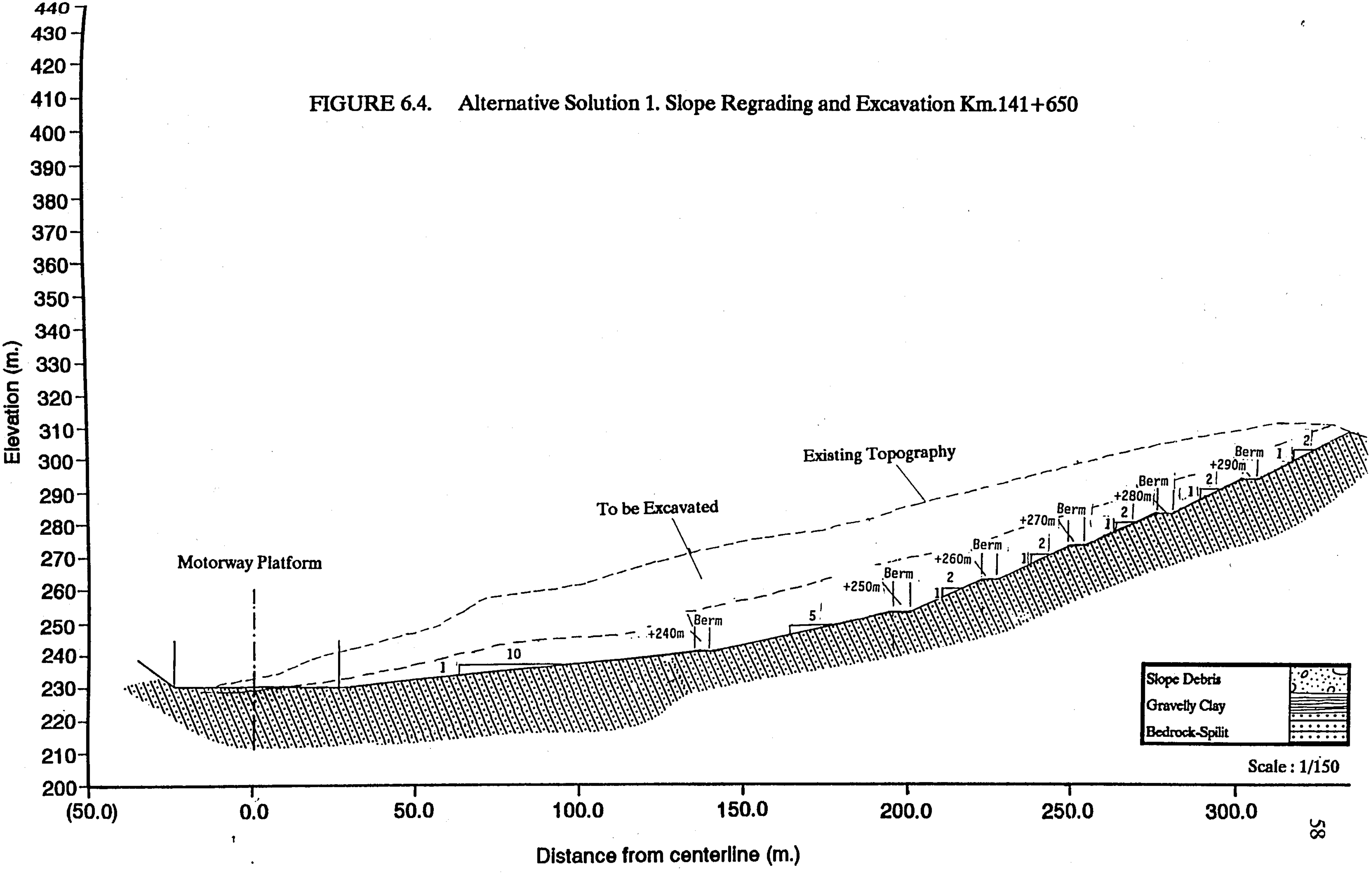


FIGURE 6.4. Alternative Solution 1. Slope Regrading and Excavation Km.141+650



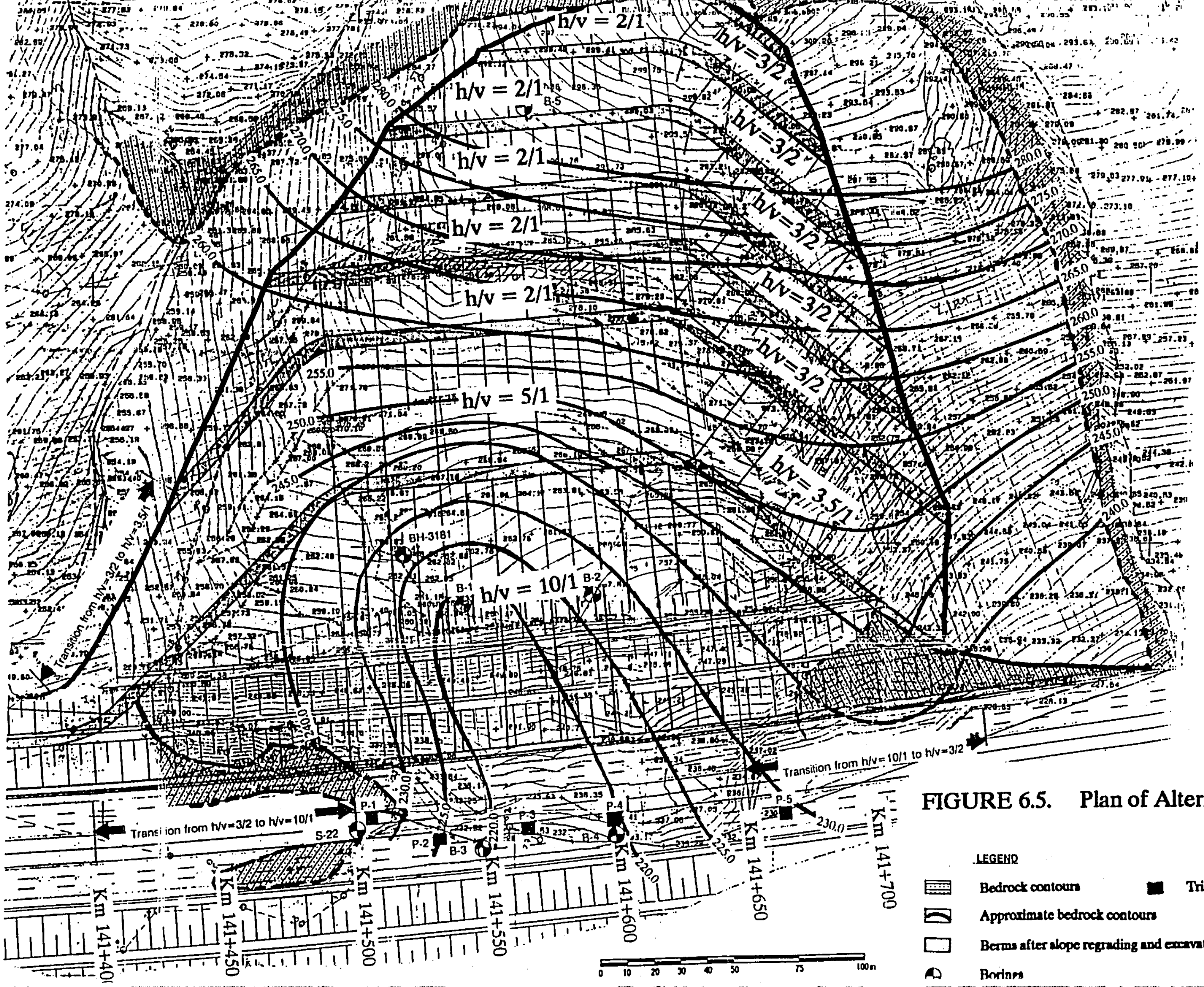


FIGURE 6.5. Plan of Alternative Solution 1.

LEGEND

▨	Bedrock contours	■	Trial pits
◠	Approximate bedrock contours		
☐	Berms after slope regrading and excavation		
◒	Borings		

6.2.2. Alternative Solution 2. Slope Regrading and Excavation

The difference of this alternative from alternative 1, is mainly in the proposed slope arrangement. This proposed slope arrangement is contained a single flat slope with h/v = 10/1 beginning from the edge of the motorway platform until the first berm located at 10.0 m. height. The berm width is variable at this elevation and will be determined in accordance with the location of bedrock. However, practically the slope debris material should be excavated above this level until the bedrock is reached. Only a small excavation will be implemented within the bedrock. This slope will be in range of 400 m. between Km.141+400 and Km.141+800. However, the major portion of the excavation will be carried out for a 100m. section between Km.141+550 and Km.141+650

Based on the proposed slope regrading pattern shown in Figures 6.6. thru 6.10. the estimated earthwork could be summarized as follows;

total excavation ....: 1,000,000 m3

As stated in alternative 1., a drainage work should be applied on this slope by constructing the concrete lined drainage ditches.

Based on this proposed slope, a stability analysis is performed by utilizing a computer program (9) on this alternative and during the calculations following properties are considered;

Ør' = 14 deg.   Y = 19 kN/m3

The relevant computer results are given in Appendix(4) and the factor of safety are checked on three different cases. The results are summarized at the following;

F.S. = 3.86 in which nogroundwater and earthquake case

F.S. = 1.78 in which groundwater conditions. (ru= 145 kN/m2)

FIGURE 6.6. Alternative Solution 2. Slope Regrading and Excavation Km.141+500

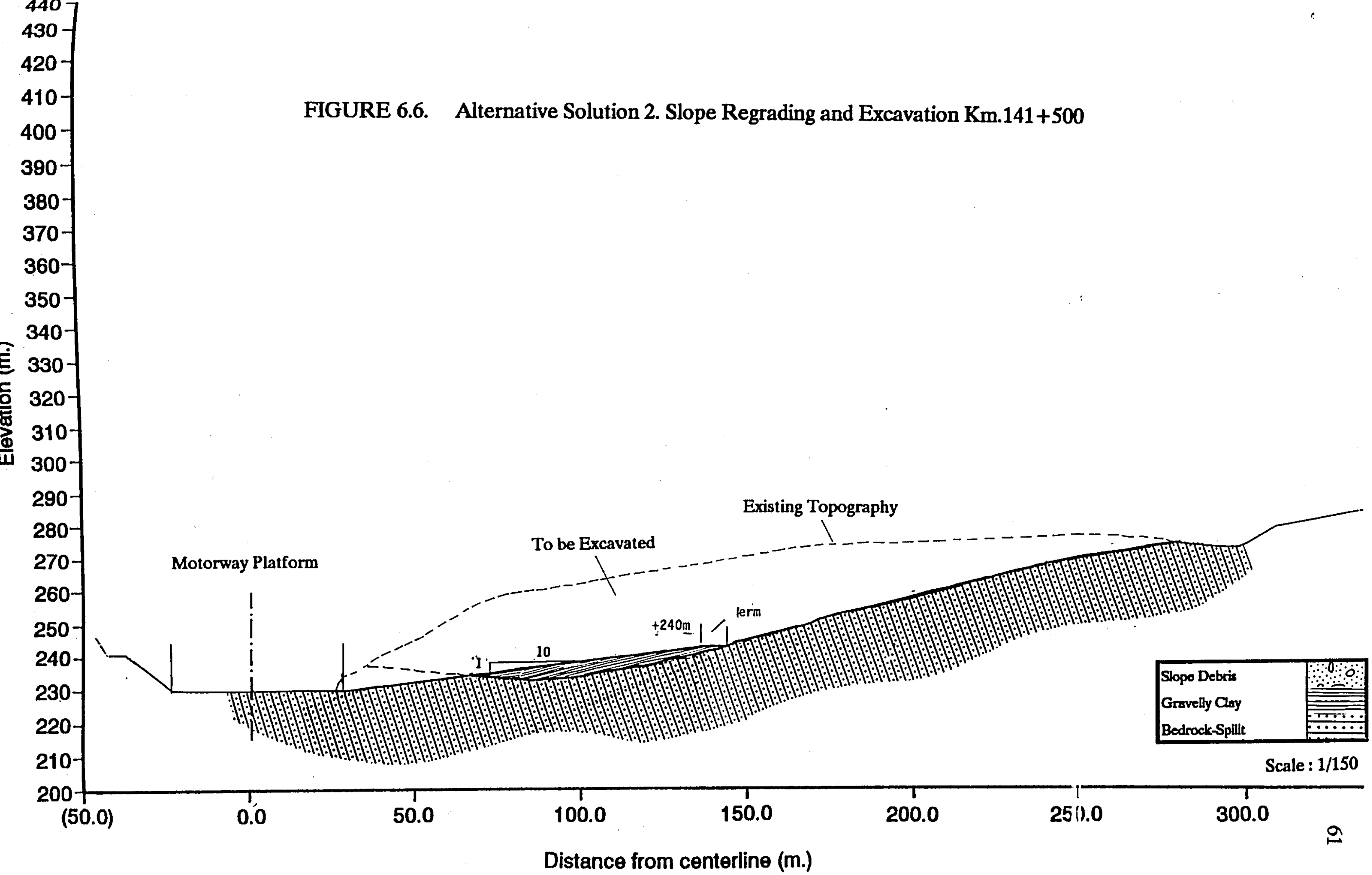
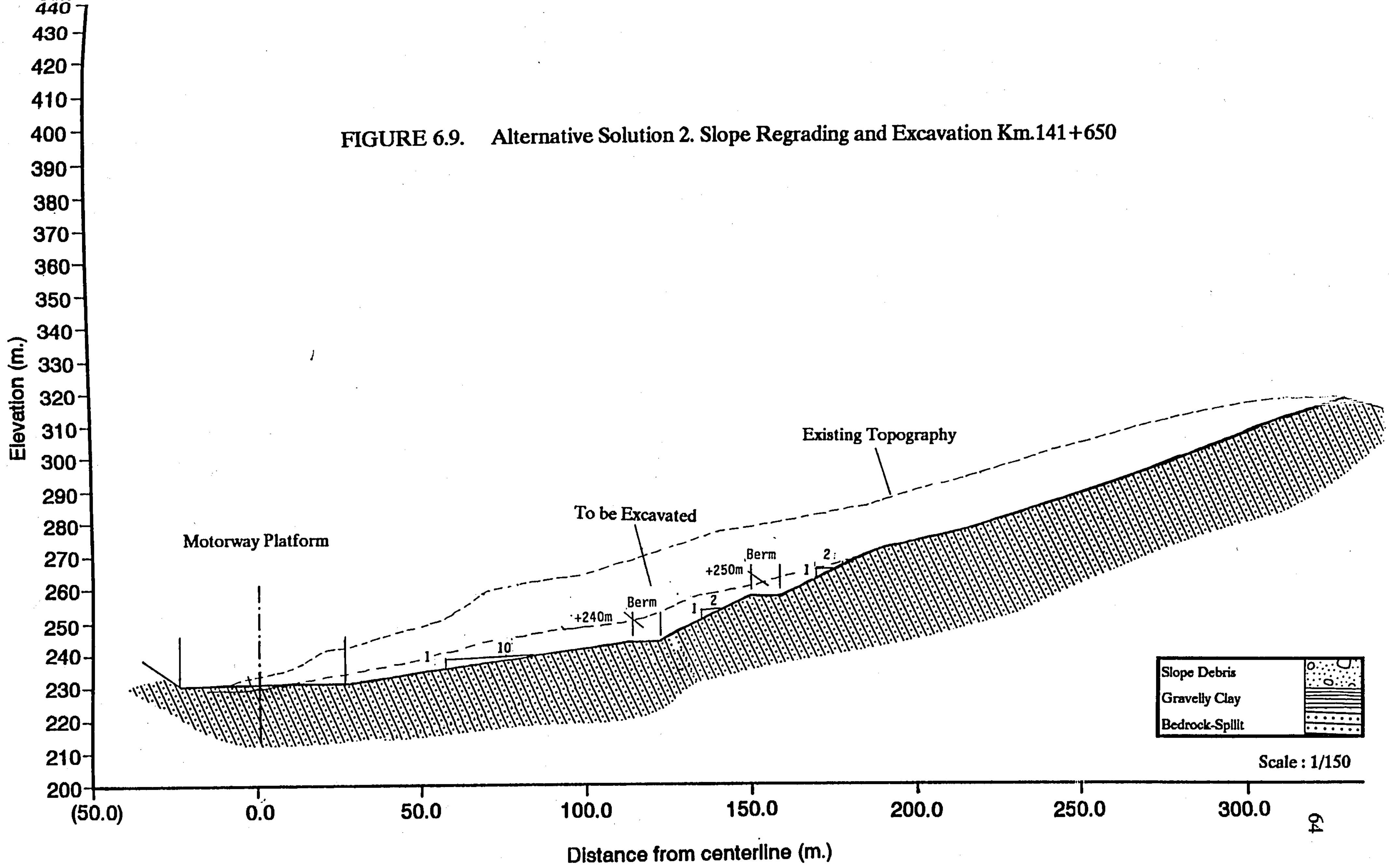


FIGURE 6.9. Alternative Solution 2. Slope Regrading and Excavation Km.141+650



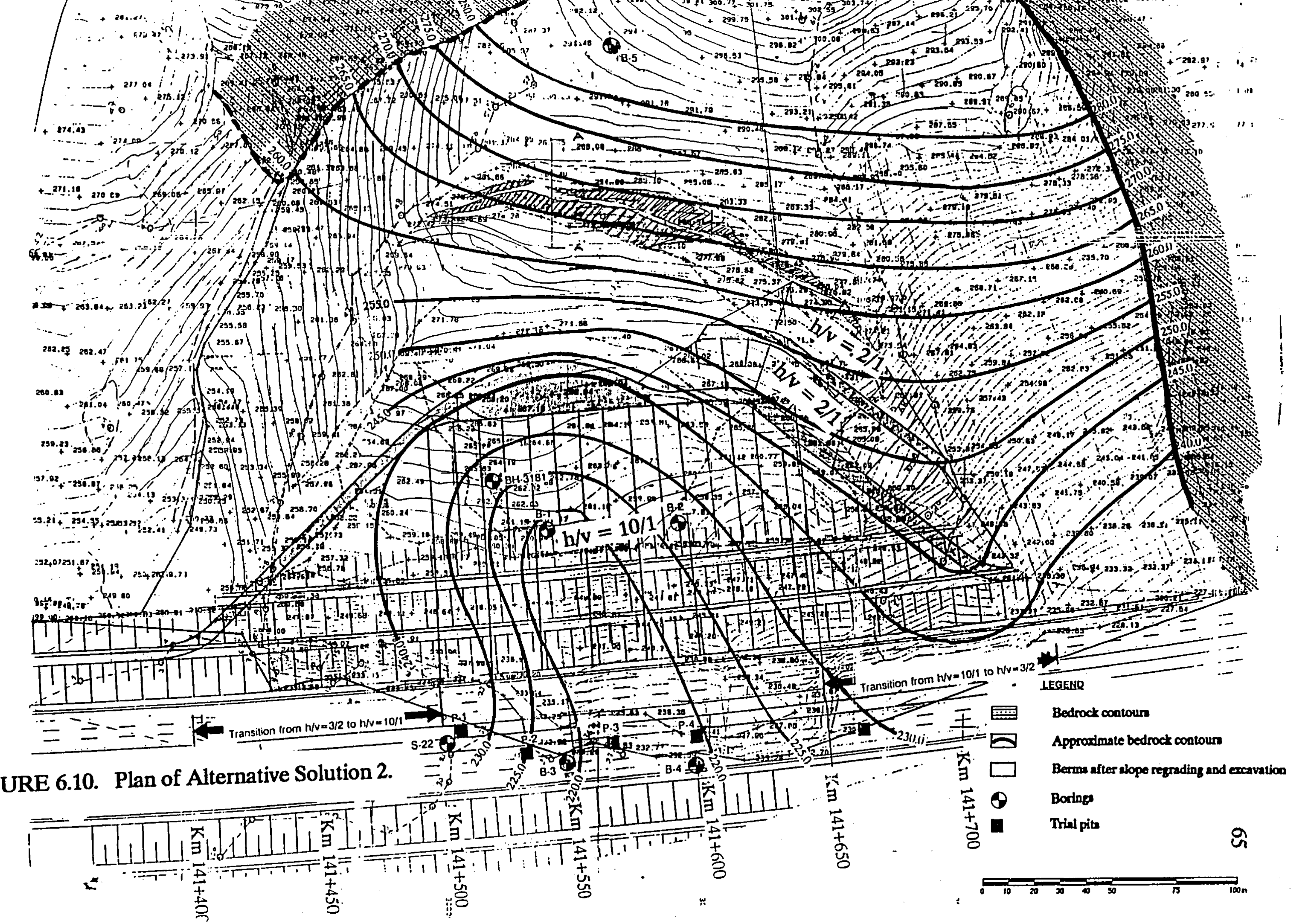


FIGURE 6.10. Plan of Alternative Solution 2.

F.S. = 1.11 in which earthquake exists. (k=0.2)

6.2.3. Alternative Solution 3. Realignment of the Motorway

An optimization study should be carried out for the realignment of the motorway route for a possible solution to the landslide problem. It was shown that 3(three) criteria should be considered;

i) Shifting the motorway route to a safe distance from the landslide area.

ii) The completed works in the existing motorway should be affected in minimum level.

iii) Following the motorway geometric design standards.

However, it was shown that the realignment design, which fulfills the above criteria could not be a feasible solution due to its high cost and requirement of the long construction time.

6.3. Mechanical Methods

This solution is covered the implemented geotechnical design and remedial measures for the landslide area with the motorway alignment being unchanged. This method could be subdivided into two categories based on the evaluations of various remedial measures. At the following, these alternative solutions are summarized.

6.3.1. Alternative solution 4. Retaining Structure

Construction of a retaining structure in front of the slide is proposed in this solution. For this purpose, retaining structure composed of the piles with 165 cm. diameter is considered. The required calculations are shown below. During the analysis, following considerations are taken into account.

- length of slip surface : L=200 m.
- Required factor of safety : F.S.=2.0
- Force due to estimated mass = 8,000,000 kN.
- Inclination of the slip surface : = 20 deg.
- Natural unit weight (γ) = 19 kN/m3
- Internal Friction Angle (Ør') = 14 deg
- Lateral load for Φ 165 single pile = 1500 kN.

and

$$F_r = m.g.Cos\alpha\,(TAN\phi') + F_k \qquad \textbf{(eq.7)}$$

$$F_d = m.g.cos\alpha \qquad \textbf{(eq.8)}$$

$$F.S. = \frac{F_r}{F_d} \geq 2.0 \qquad \textbf{(eq.9)}$$

$$m = 8,000,000kN$$

$$2.0 = \frac{8,000,000.Cos20.(tan14) + F_k}{8,000,000.Sin20}$$

$$F_k = 3,598,000kN.$$

$$N(no.of\ piles) = \frac{3,598,000kN}{1500kN} = 2400\ piles$$

As a conclusion, it was shown that an approximate estimate of number of piles with 165 cm. diameter that required for this solution is about 2400 piles which makes this solution unfeasible.

6.3.2. Alternative Solution 5. Rock Buttress and Slope Regrading

This alternative is composed of partial excavation and the formation of the rock buttress solution. The method is based on the principle of having enough length of the most critical failure surface through rock buttress, so that overall factor of safety along the length of failure surface is above the critical value. The procedure of this alternative can be summarized as follows;

i. removal of the sliding material above the present crack.

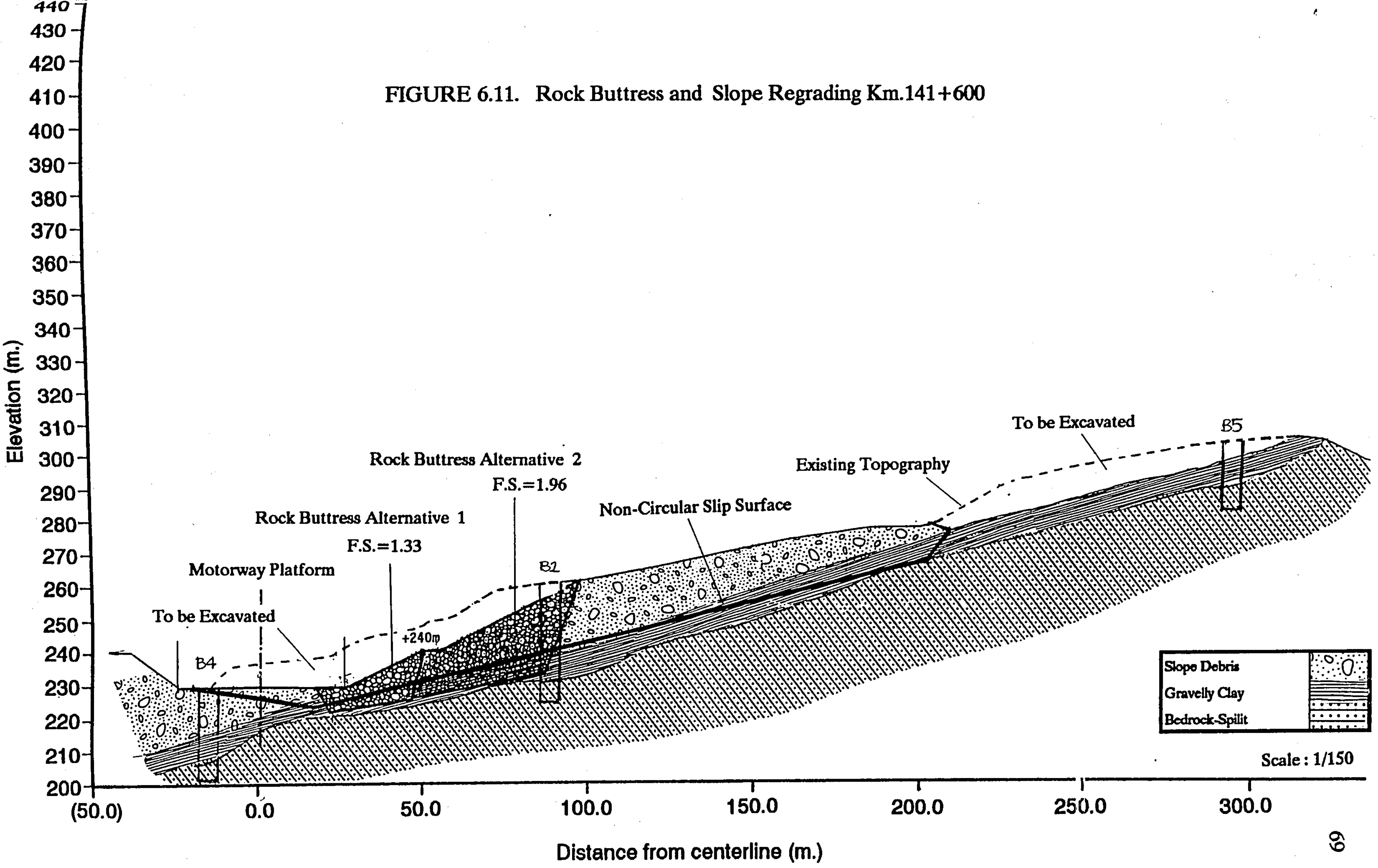
ii. removal of the material that has covered the motorway and slope arrangement

iii. and, forming a rock buttress shifted into the gravelly clay layer for an appropriate depth.

Two sub-alternatives are discussed on this solution based on the size of the rock buttress formation. The stabilities of each case are checked by utilizing a computer program (9). and proposed solutions are presented at Figure 6.11. Also the computer results are given at Appendix 4.

As a most critical section, Km.141+600 is selected and based on the size of the rock buttress to be implemented, the factor of safeties would be in order of FS=1.3 and FS = 2.0 . Consequently, the approximate amount of earthwork necessary for the above given factor of safeties could be summarized as follows;

FIGURE 6.11. Rock Buttress and Slope Regrading Km.141+600



a. For F.S.= 1.3

Approximate total excavation including rock buttress....... 300,000 m3

Approximate rockfill for rock buttress.................................. 50,000 m3

a. For F.S.= 2.0

Approximate total excavation including rock buttress....... 450,000 m3

Approximate rockfill for rock buttress.................................. 200,000 m3

It should be emphasized that this alternative assumes that the construction will be proceed from both sides of the slipped mass towards the centerline of the landslide area. However, in such cases, that the rock buttress does not extend down to bedrock interface, there is the risk of reslide along the surface remaining within the clay layer in the long-term, after the rock buttress is formed. In addition, this alternative requires relatively steep excavations and this might led to cause additional earth movements during the construction.

Because of all these risky conclusions, this alternative could not be feasible and safe.

6.4. Comparision of the Results

Basically, two main alternative solutions were proposed in this Chapter;

i) Improvement of the geometrical measures of the slide area

ii) Construction of additional structures along the motorway platform

In order to able to compare these two main alternative, the subdivisions on each item should be evaluated. For this reason, Geometrical solutions are divided into 3(three) subitems and mechanical solutions are divided into 2 (two) subitems. Based on the above evaluations and analyses, the implemented alternatives are compared at Table 6.1.

TABLE 6.1. Comparision of Alternatives

ALTERNATIVE	EVALUATIONS
1. Slope Regrading & Excavation	requires approximately 300,000 m3 excavation in the bedrock. The slopes will be h/v=5/1 and 10/1 seems applicable but need excavation in bedrock. Drainage precausition requires.
2. Slope Regrading & Excavation	excavation down to the bedrock surface, the final regraded slope will be the bedrock surface after first berm, drainage precausition requires. The slopes varies. obtained most proper solution.
3. Realignment of the motorway	requires high cost and long construction time. Also need design studies. Not feasible.
4.Retaining wall	Requires construction of structure in deep foundation and 2400 piles with 165 cm. diameter to stabilize the area. Not feasible.
5. Rock Buttress and Slope Regrading	requires 450,00 m3 earthwork for F.S.2.0. there are difficulties during construction and long-term stability. Not feasible.

CHAPTER VII. CONCLUSIONS

The cuts of TAG motorway between Km.141+400 and Km.141+700, constitute a typical example of a case where the landslide had occurred as a result of deficiencies of the implemented slopes in soft soils. Most of the time, the remedial solutions for such cases are very much dependent on the subsoil conditions and require high cost and long construction time. In this respect, the substantial results of the evaluations on the landslide are presented in this study.

The problem has been identified as the slide of the slope debris formation during the excavation of relevant cut slopes. During the performed borings, it was stated that this slope debris layer was formed in loose and weak state by weathering of the rock formation. The implemented slope criterion for the relevant sections of the motorway had been proposed as being 3(horizontal) to 2(vertical) in the previous stage of the design. However, it was realized that the subsoil conditions, especially the bedrock location was not determined sufficiently so that the proposed slope application had led to slide in these soil conditions. Hence, it is important to generalize the cause in terms of applicable slopes in soft soils for the purpose of presenting an example for similar cases that might be encountered. Therefore the required evaluations are performed in order to construct the remedial design measures.

The important stage of the slope stability analysis is to determine the residual strength parameters such as internal friction angle ($\phi r'$) and cohesion (cr'). For the purpose of determining these parameters, basically two methods are performed during the evaluations of the slide mechanism. The back calculation method was performed on

4(four) different sections of the motorway based on the after slide topography. The results from back calculation analyses are compared with the results of laboratory test. The residual direct shear test is performed on two block of samples, which are obtained from the slip surface of the slide. Also a new method, which makes a correlation between residual strength parameters and soil properties is introduced and verified. The results from this correlation are found satisfactory. Consequently, the residual strength parameters of the slipped soil are found as $Ør'$ = 14 degree and cr' = 0.0 kN/m2

For the rehabilitation of the slide area, 5(five) alternative solutions are proposed in the remedial design measures. These alternatives are compared with each other by considering their feasibilities. As a result of the evaluation and comparison of the alternatives, it is shown that the most proper solution is to regrade the slide area and to rearrange the slopes as being h/v=10/1 and h/v=5/1.

TAG motorway is one of the remarkable and major projects of our country. The stability problems that are encountered during the construction of the motorway, constitute typical examples for the further problems. Therefore the aim of presented case study is to form a preliminary approach for such cases that might be encountered in the future.

APPENDIX 1. BACK DETERMINATION METHOD

A. INTRODUCTION

An important and preminary stage of the landslide problem is to determination the residual strength parameters of the failed slopes. For this purpose, the technique of the Back Analysis has been served in the stability problems for several decades. The technique described herein is the same technique that cited by D.H.HE (13). The shear strength parameters of the failed slopes have been backcalculated in the following procedures;

1. Assuming the value of the angle of internal friction angle Ø or the cohesion c' to calculate another
2. Or utilizing a main cross section of a failed slope and another cross section near the main one in the same failed slope to establish two equations from which the value of c' and Ø' can be evaluated.
3. Or utilizing two cross sections in two failed slopes which have similarly geological and hydrological conditions to establish two equations and the evaluate the values of the c' and Ø '.

The results obtained by all of these procedures can not be independent of the will of the engineers. However, there is a logical relation between the shear strength and the location of the slip surface. In this procedure, the shear strength parameters such as internal friction angle (Ø ') and the cohesion c' are simultaneously determined by utilizing a main cross section only without assuming beforehand the value of c' and Ø '.

B. FACTOR OF SAFETY

Before start to derive the back calculation formulas, it is needed to obtain the factor of safety with great precision by direct integration over the whole slip surface. It will be assumed that the potential slip surface passing from the beneath the toe of the slope is a circular arc. A section of a slide is illustrated at Figure A1.1

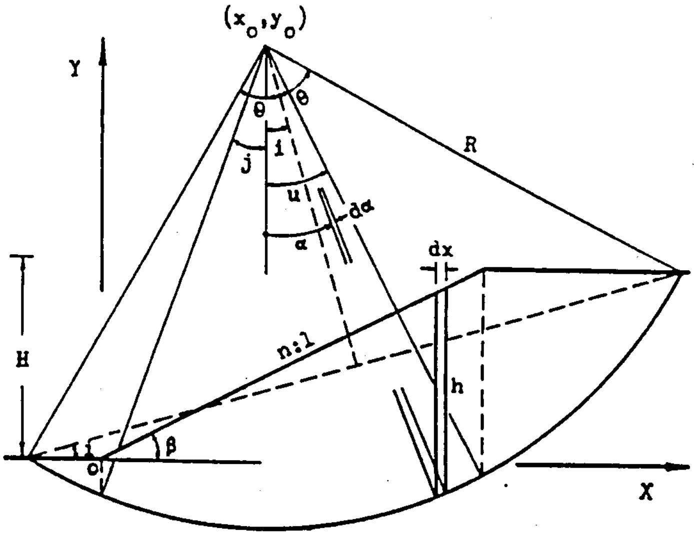


Figure A1.1 Typical geometry in slope stability analysis
D.H.He (13)

The origin of the coordinates defines at the toe of the slope. The point (xo,yo) is the center of the failure circle. The factor of safety F, is defined as that by which available shear strength should be reduced so as to bring it into equilibrium with mobilized shear stress. The available shear strength is calculated on the basis of Mohr's Coloumb failure criterion. The sliding mass is divided into slices inwhich its width is dx. Therefore the factor of safety of the Bishop's modified methodis expressed in the form of integrations as stated in the chapter I.

$$F=\frac{c'\int_{i-\theta}^{i+\theta}\frac{\cos\alpha}{m_\alpha}d\alpha+\gamma\,(1-r_u)\,\tan\phi'\int_{i-\theta}^{i+\theta}h\frac{\cos\alpha}{m_\alpha}d\alpha}{\gamma\int_{j-\theta}^{j+\theta}h\sin\alpha\cos\alpha\,d\alpha} \qquad \text{(eq.10)}$$

in which ;

$$m_\alpha = \cos\alpha + \sin\alpha \frac{\tan\theta'}{F} \qquad m_\alpha = \frac{\cos(\alpha - \phi_m)}{\cos\phi_m} \qquad \text{(eq.11)}$$

$$\tan\phi_m = \frac{\tan\phi'}{F} \qquad \text{(eq.12)}$$

c'........... denotes effective cohesion
Ø '......... denotes effective angle of internal friction angle
ru........... denotes pore water pressure

after integration and simplification the factor of safety of the slope can be finally expressed as a function of a set of variables comprising the location of slip circle and the shear strength parameters in the following ;

$$F = \frac{\frac{c'}{\gamma H} K_c + (1 - r_u) \tan\phi' K_f}{K_d} \qquad \text{(eq.13)}$$

in which;

$$K_d = \frac{1}{3} \sin^2 i \sin^2\theta \left(1 - 2\frac{n}{2} + 3\eta\left(n - \frac{1}{2}\eta\right) + \frac{3}{2}(\cot^2 i + \cot^2\theta)\right) \qquad \text{(eq.14)}$$

$$K_c = \cos^2\phi_m \left(2\theta + \tan_m \ln \frac{\cos(\theta + i - \phi_m)}{\cos(\theta - i + \phi_m)}\right) \qquad \text{(eq.15)}$$

$$K_f = -\frac{1}{2}(1 + \cot i \cot\theta) K_c + \cos^2\phi_m \left(\theta + i - u + \tan\phi_m \ln \frac{\cos(\theta + i - \phi_m)}{\cos(u - \phi_m)}\right) \qquad \text{(eq.16)}$$

$$+ \frac{\cos\phi_m}{2 \sin i \sin\theta} + \sin^2\phi_m \ln \frac{\tan\left(45 + \frac{1}{2}(\theta + i - \phi_m)\right)}{\tan\left(45 - \frac{1}{2}(\theta - i + \phi_m)\right)} + \frac{1}{n}\left(\cos(j - \phi_m) - \cos(u + \phi_m)\right.$$

$$\left. - \frac{1}{2} \sin 2\phi_m \ln \frac{\tan\left(45 + \frac{1}{2}(u - \phi_m)\right)}{\tan\left(45 - \frac{1}{2}(j + \phi_m)\right)} + \sin j \cos\phi_m \left(u + j + \tan\phi_m \ln \frac{\cos(u - \phi_m)}{\cos(j + \phi_m)}\right)\right))$$

where i, Ø and j denotes the angles specifying the location of the slip circle

$n = \cot\beta$ .... β : ∠ofslopeinclination (eq.17)

$$\sin u = 2n \sin i \sin\theta - \sin j \qquad \text{(eq.18)}$$

$$\eta = \frac{\sin j}{\sin i \sin\theta} \qquad \text{(eq.19)}$$

The factor of safety for the slip circle should have minimum value when the angle of i, Ø and j satisfy the necessary conditions of the gradient;

$$\frac{\partial F}{\partial i} = 0 \qquad \frac{\partial F}{\partial \theta} = 0 \qquad \frac{\partial F}{\partial j} = 0 \qquad \text{(eq.20)}$$

If j= Ø - i that means slip surface passing through the toe of the circle then;

$$\frac{\partial F}{\partial i} = 0 \qquad \frac{\partial F}{\partial \theta} = 0 \qquad \text{(eq.21)}$$

C. FORMULAE OF BACK ANALYSIS

It is evident that slide mass moves along the most critical surface and factor of safety is equal to unity when the displacement just begins. By this concept,the formula of back calculation of the shear strength parameters c' and Ø' of slip zone soils can be derived from the conditional equations which provide the relationship between the parameters of the shear strength and the location of critical slip circle.

1. Below the toe circle

Let the factor of safety of slope F equal to 1.00 . The equations for the below the toe circle can be obtained from the conditional equations (20).

$$\frac{\partial F}{\partial i} = 0 \qquad \text{(eq.22)}$$

$$\frac{c'}{\gamma H}\frac{\partial K_c}{\partial i} + (1 - r_u)\tan\phi'\frac{\partial K_f}{\partial i} - \frac{\partial K_d}{\partial i} = 0 \qquad \text{(eq.23)}$$

in which ;

$$\frac{\partial K_c}{\partial i}=-\frac{\sin 2\phi'\sin 2\theta}{2\cos(\theta+i-\phi')\cos(\theta-i+\phi')} \qquad \text{(eq.24)}$$

$$\frac{\partial K_d}{\partial i}=2\cot i K_d-\cos i\sin\theta((n-\eta)\sin j+\frac{\sin\theta}{\sin i} \qquad \text{(eq.25)}$$

$$\frac{\partial K_f}{\partial i}=-\cot i K_f-\frac{1}{2}(\cot i-\cot\theta)K_c+\cot i\cos^2\phi'(\theta+i-u+\tan\phi'\ln\frac{\cos(\theta+i-\phi')}{\cos(u-\phi')}) \qquad \text{(eq.26)}$$

and

$$\frac{\partial F}{\partial\theta}=0 \qquad \text{(eq.27)}$$

$$\frac{c'}{\gamma H}\frac{\partial K_c}{\partial\theta}+(1-r_u)\tan\phi'\frac{\partial K_f}{\partial\theta}-\frac{\partial K_d}{\partial\theta}=0 \qquad \text{(eq.28)}$$

in which ;

$$\frac{\partial K_c}{\partial\theta}=\cos^2\phi'(2-\frac{\tan\phi'\sin 2(i-\phi')}{\cos(\theta+i-\phi')\cos(\theta-i+\phi')}) \qquad \text{(eq.29)}$$

$$\frac{\partial K_d}{\partial\theta}=2\cot\theta K_d-\cos\theta\sin i((n-\eta)\sin j+\frac{\sin i}{\sin\theta}) \qquad \text{(eq.30)}$$

$$\frac{\partial K_f}{\partial\theta}=-\cot\theta K_f+\frac{1}{2}(\cot i-\cot\theta)K_c+\cot\theta\cos^2\phi'(\theta+i-u+\tan\phi'\ln\frac{\cos(\theta+i-\phi')}{\cos(u-\phi')}) \qquad \text{(eq.31)}$$

and

$$\frac{\partial F}{\partial j}=0 \qquad \text{(eq.32)}$$

$$(1-r_u)\tan\phi'\frac{\partial K_f}{\partial j}-\frac{\partial K_d}{\partial j}=0 \qquad \text{(eq.33)}$$

in which

$$\frac{\partial K_d}{\partial j}=\sin i\sin\theta\cos j(n-\eta) \qquad \text{(eq.34)}$$

$$\frac{\partial K_f}{\partial j}=\frac{\cos j\cos^2\phi'}{2n\sin i\sin\theta}(u+j+\tan\phi'\ln\frac{\cos(u-\phi')}{\cos(j+\phi')}) \qquad \text{(eq.35)}$$

It is found that the back calculation formulae for the angle of internal friction ϕ

can be written from the equ.(23).

$$\sin 2\phi' = \frac{4n\sin i\sin\theta(n\sin i\sin\theta-\sin j)}{(1-r_u)(u+j+\tan\phi'\ln\frac{\cos(u-\phi')}{\cos(j+\phi')}}) \qquad \text{(eq.36)}$$

If the location of the slip surface of a failed slope and the geometrical form of the original slope and the pore pressure ratio of the slope are known, the angle of internal friction of slip zone soils ∅' can be calculated from equ.(36)by utilizing Newton-Raphson iterative procedure. Furthermore the cohesion of slip-zone c' can be calculated from the rearranged formulae of equ. (23).

$$c'=\gamma H\frac{K_d-(1-r_u)\tan\phi' K_f}{K_c} \qquad \text{(eq.37)}$$

2. Toe circle

For the case of slip surface passing through the toe of the slope , the equation can be derived from the conditional equations(21)with letting the factor of safety equal to 1.

Elimating some terms and doing some simplification , the back determination formula of the internal friction angle ∅ 'for the toe circle may be written as follows ;

$$\sin 2\theta' = \frac{\sin^2 u-\sin^2(\theta-i)-(\sin^2(\theta+i)-\sin^2 u)N}{(1-r_u)(A-BN)} \qquad \text{(eq.38)}$$

in which ;

$$N=\frac{n\sin(\theta+i)\dfrac{2}{1-\tan\phi'\tan(\theta-i)}+(\cot\theta-\cot i)K_c}{\cos(\theta-i)+n\sin(\theta-i)\dfrac{2}{1+\tan\phi'\tan(\theta+i)}+(\cot\theta+\cot i)K_c} \qquad \text{(eq.39)}$$

$$A=\theta-i+u\tan\phi'\ln\frac{\cos(u-\phi')}{\cos(\theta-i+\phi')}$$

$$B=\theta+i-u+\tan\phi'\ln\frac{\cos(\theta+i-\phi')}{\cos(u-\phi')} \qquad \textbf{(eq.40)}$$

The angle of internal friction Ø ' for the toe circle can be computed from equ. (38) using newton- raphson iterative method if the location of the failure surface and pore pressure ratio and the geometrical form of the slope are described.

APPENDIX 2.

BORING LOGS

N4098200.592 E499003.314 ELEV234.315	ARAŖTIRMA ÇUKURU LOGU PIT LOG	
PROJE: TAG OTOYOLU PROJECT: TAG MOTORWAY		ÇUKUR NO: 1 PIT NO : 1
Yeri : ˜Km 141 Location:	Tarih : Date :	Kazìcì cinsi: Type of rig :
Çukur derinliºi: / Depth of pit :	Y.A.S. Derinliºi(m): Depth of GWT (m) :	Kontrol eden: Checked by :

DERINLIK(m) DEPTH	Litoloji Lithology	Numune Sample		Cep Penetr. Pocket Penetr.	Zemin Sìnìfì Soil Clas.	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation			
			234.15			Bitkisel Toprak/Top Soil
			230.83			Kahverengi kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup A ile kontagi gevsek derine inildikce sertlesmekte Reddish brown CLAY, with agglomerate, split particles at deeper levels, the contact with top formation is loose, harder at the bottom
			229.75			Acik kahverengi yesil renkte volkanik AGLOMERA, sipilit icerikli, ust yuzeyler kismen altere olmus. Light brown - green volcanic AGGLOMERATE, with spilit, upper levels are altered

NOT / NOTE :

N4098190.612 E498027.612 ELEV232.974	ARARTIRMA ÇUKURU LOGU PIT LOG	
PROJE: TAG OTOYOLU PROJECT: TAG MOTORWAY		ÇUKUR NO: 2 PIT NO : 2
Yeri : Km 141 Location:	Tarih : Date :	Kazıcı cinsi: Type of rig :
Çukur derinliği: Depth of pit :	Y.A.S. Derinliği(m): Depth of GWT (m) :	Kontrol eden: Checked by :

DERINLIK DEPTH (m)	Litoloji Lithology	Numune Sample NO	Numune Sample Kot (m) Elevation	Cep Penetr. Pocket Penetr.	Zemin Sınıfı Soil Clas.	TANIMI IDENTIFICATION
						Sari kirli beyaz renkte ust yuzeyler travertenlesme gosterir kirectasi (bloktan-cakila) kalker tufu icinde tabana dogru bloklarda azalma, kil-kirec yuzdesinde artis Yellow-white, traverten appearance at upper levels limestone (boulder to gravel) within calcareouus tuff, decrease in boulders and increase in clay-lime percent at lower levels
			232.43			
						kahverenkli-kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup ust formasyon ile kontagi gevsek derine inildikce sertlesmekte (kiltasi) reddish brown CLAY, with agglomerate,spilit particles at lower levels, contact with upper formation is soft, harder at lower levels (claystone)
			227.41			

NOT / NOTE :

N4098153.677
E498057.193
ELEV232.397

ARARTIRMA
ÇUKURU LOGU
PIT LOG

PROJE: TAG OTOYOLU
PROJECT: TAG MOTORWAY

ÇUKUR NO: 3
PIT NO : 3

Yeri : ¯Km 141
Location:

Tarih :
Date :

Kazìcì cinsi:
Type of rig :

Çukur derinli²i:
Depth of pit :

Y.A.S. Derinli²i(m):
Depth of GWT (m) :

Kontrol eden:
Checked by :

DERİNLİK(m) DEPTH	Litoloji Lithology	Numune Sample		Cep Penetr. Pocket Penetr.	Zemin Sìnìfì Soil Clas.	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation			
			230.98			Sari kirli beyaz renkte ust yuzeyler travertenlesme gosterir kirectasi (bloktan-cakila) kalker tufu icinde tabana dogru bloklarda azalma, kil-kirec yuzdesinde artis Yellow-white, traverten appearance at upper levels limestone (boulder to gravel) within calcareouus tuff, decrease in boulders and increase in clay-lime percent at lower levels
			226.91			kahverenkli-kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup ust formasyon ile kontagi gevsek derine inildikce sertlesmekte (kiltasi) reddish brown CLAY, with agglomerate,spilit particles at lower levels, contact with upper formation is soft, harder at lower levels (claystone)

NOT / NOTE :

N4098188.804 E499098.140 ELEV232.770	ARARTIRMA ÇUKURU LOGU PIT LOG	
PROJE: TAG OTOYOLU PROJECT: TAG MOTORWAY		ÇUKUR NO: 4 PIT NO : 4
Yeri : ˉKm 141 Location:	Tarih : Date :	Kazìcì cinsi: Type of rig :
Çukur derinliºi: Depth of pit :	Y.A.S. Derinliºi(m): Depth of GWT (m) :	Kontrol eden: Checked by :

DER!NL!K(m) DEPTH	Litoloji Lithology	Numune Sample		Cep Penetr. Pocket Penetr.	Zemin Sìnìfì Soil Clas.	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation			
			225.31			Sari kirli beyaz renkte ust yuzeyler travertenlesme gosterir kirectasi (bloktan-cakila) kalker tufu icinde tabana dogru bloklarda azalma, kil-kirec yuzdesinde artis Yellow-white, traverten appearance at upper levels limestone (boulder to gravel) within calcareouus tuff, decrease in boulders and increase in clay-lime percent at lower levels
						kahverenkli-kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup ust formasyon ile kontagi gevsek derine inildikce sertlesmekte (kiltasi) reddish brown CLAY, with agglomerate,spilit particles at lower levels, contact with upper formation is soft, harder at lower levels (claystone)

NOT / NOTE :

N4098188.451 E499155.267 ELEV232.407	ARAŞTIRMA ÇUKURU LOGU PIT LOG	
PROJE: TAG OTOYOLU PROJECT: TAG MOTORWAY		ÇUKUR NO: 5 PIT NO : 5
Yeri : ˜Km 141 Location:	Tarih : Date :	Kazıcı cinsi: Type of rig :
Çukur derinliği: Depth of pit :	Y.A.S. Derinliği(m): Depth of GWT (m) :	Kontrol eden: Checked by :

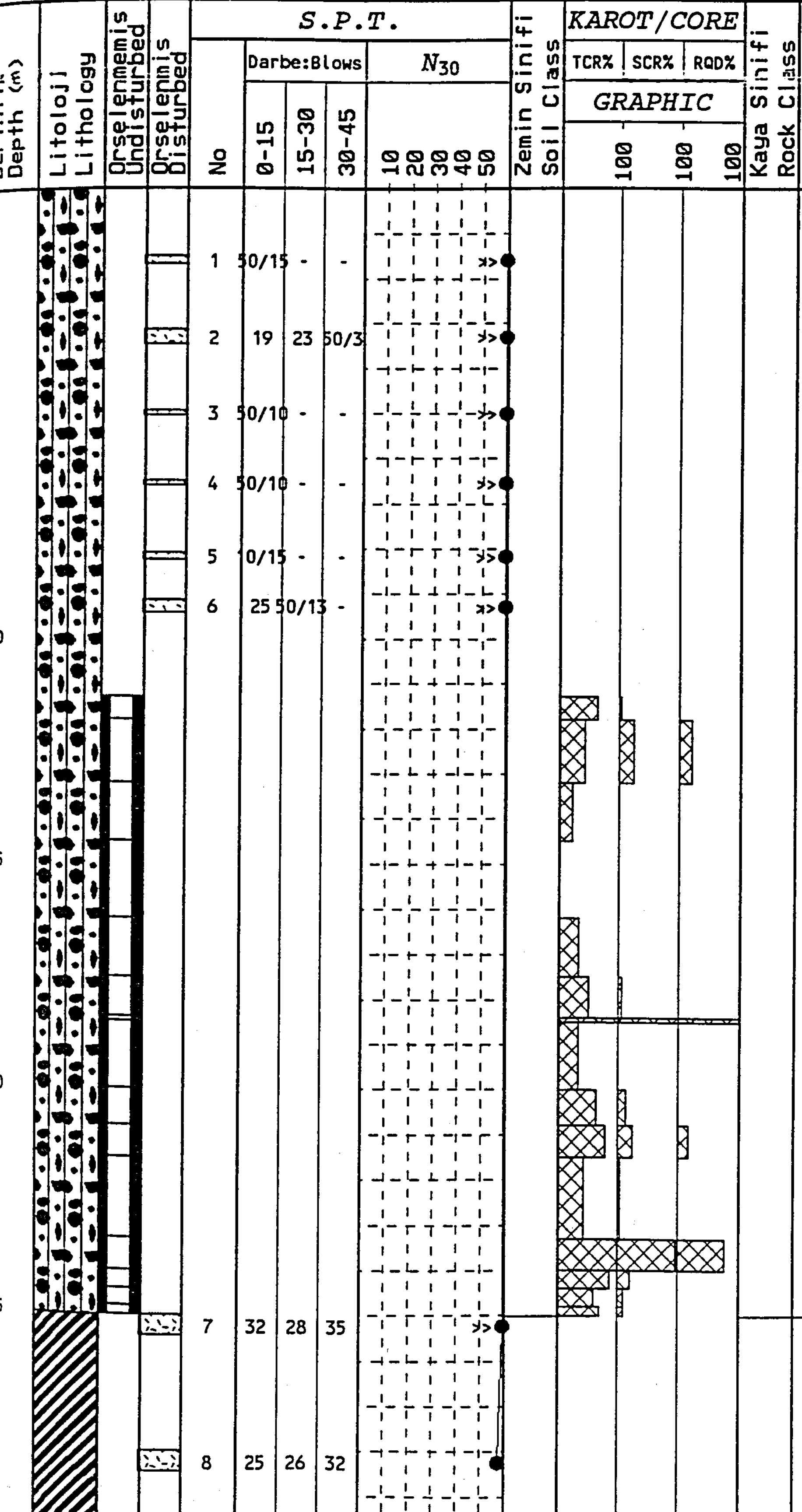
DERİNLİK DEPTH (m)	Litoloji Lithology	Numune Sample NO	Numune Sample Kot (m) Elevation	Cep Penetr. Pocket Penetr.	Zemin Sınıfı Soil Clas.	TANIMI IDENTIFICATION
						Bitkisel Toprak/Top Soil
			229.95			Kahverengi kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup A ile kontagi gevsek derine inildikce sertlesmekte Reddish brown CLAY, with agglomerate, split particles at deeper levels, the contact with top formation is loose, harder at the bottom
			229.42			Acik kahverengi yesil renkte volkanik AGLOMERA, sipilit icerikli, ust yuzeyler kismen altere olmus. Light brown - green volcanic AGGLOMERATE, with spilit, upper levels are altered
			228.53			

NOT / NOTE :

SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B1
SAYFA NO/PAGE NO : 87

SVEREN / OWNER: *TEKFEN-IMPRESIT O.G.*	*PROJE / PROJECT:* *TAG OTOYOLU/MOTORWAY*	
ykii/Locality: ADANA	Agiz kotu/Ground elevation : 260.99	Sondaj tipi/Boring type: ROTARY
slangic tarihi/Begin date : 30/12/91	Sondaj derinligi/Boring depth: 43.90	Sondor/Driller: H.GOZCU
tis tarihi/Completion date: 30/12/91	Su seviyesi/Water table :	Muhendis/Engineer:



No	Darbe:Blows 0-15	15-30	30-45
1	50/15	-	-
2	19	23	50/3
3	50/10	-	-
4	50/10	-	-
5	50/15	-	-
6	25	50/13	-
7	32	28	35
8	25	26	32

ACIKLAMALAR/EXPLANATIONS

YAMAC MOLOZU kil, kum, cakil boyutunda malzeme, bloklar beyaz renkli, saglam, kirectasi orijinli, yer yer yamac bresleri, kirec cimentolu, kirectaslari yer yer erimeli ve bosluklu (0.0-11.30m arasi cok killi sari renkli) **SLOPE DEBRIS** material varying as clay, sand, gravel in size, the boulders are white, strong and originated from limestone, occasionally slope breccia, lime cemebted, occasionally with cavities (between 0.0-11.30m, high clay concentration with yellow color)

CAKILLI KIL cakillar koseli - yuvarlak, sipilit ve kirectasi parcalari, ust seviyelerde kirectasi cakillari, alt seviyelerde spilitik aglomeraya ait kirintilar **GRAVELLY CLAY** gravels are subangular and rounded, spilit and limestone particles, limestone gravels at upper layers,and particles blonging to

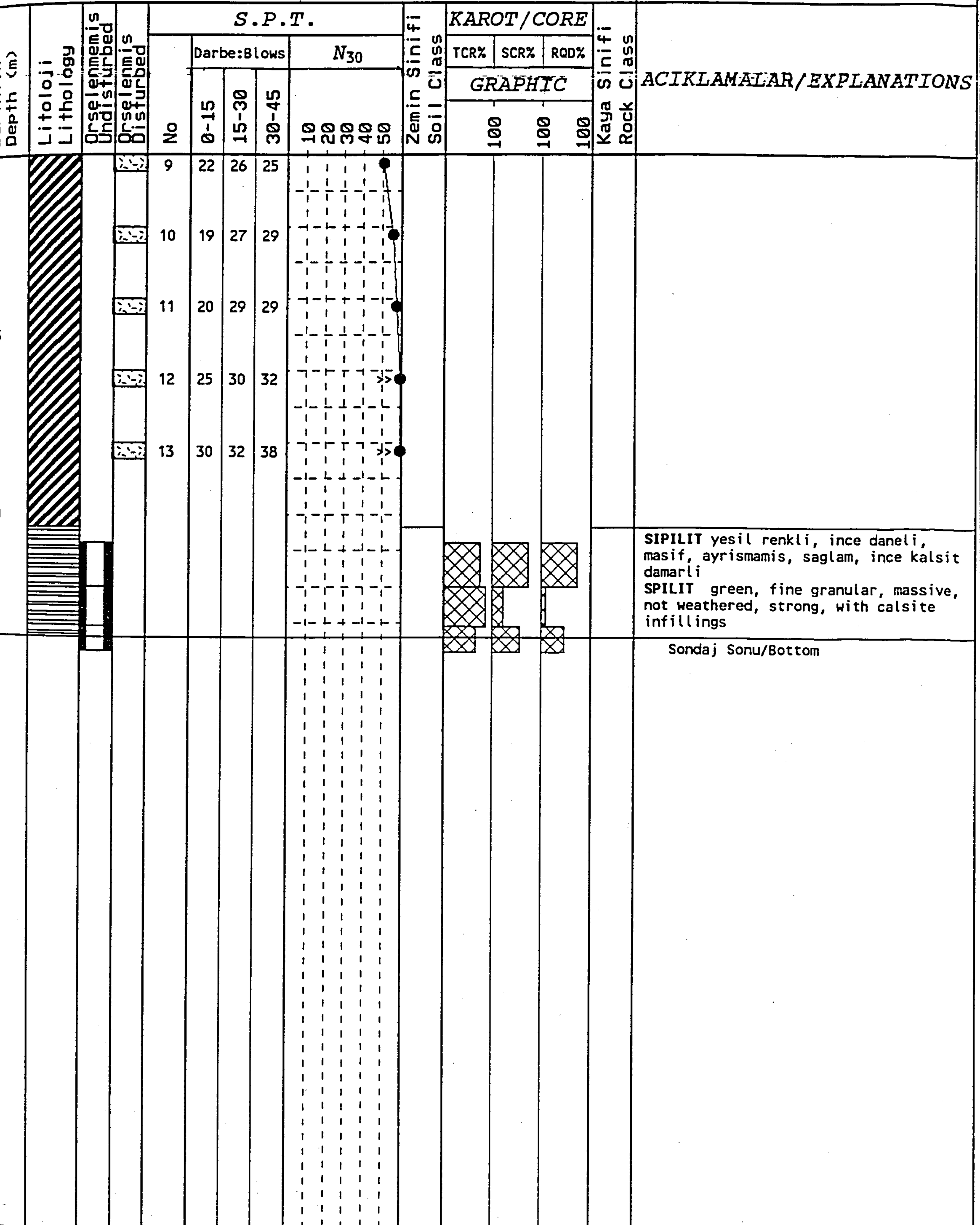
SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : *B1*
SAYFA NO/PAGE NO : 88

SVEREN / OWNER:
TEKFEN-IMPRESIT O.G.

PROJE / PROJECT:
TAG OTOYOLU/MOTORWAY

vkii/Locality: ADANA
Agiz kotu/Ground elevation : 260.99
Sondaj tipi/Boring type: ROTARY
slangic tarihi/Begin date : 30/12/91
Sondaj derinligi/Boring depth: 43.90
Sondor/Driller: H.GOZCU
tis tarihi/Completion date: 30/12/91
Su seviyesi/Water table :
Muhendis/Engineer:



No	0-15	15-30	30-45
9	22	26	25
10	19	27	29
11	20	29	29
12	25	30	32
13	30	32	38

SIPILIT yesil renkli, ince daneli, masif, ayrismamis, saglam, ince kalsit damarli
SPILIT green, fine granular, massive, not weathered, strong, with calsite infillings

Sondaj Sonu/Bottom

SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B2
SAYFA NO/PAGE NO : 89

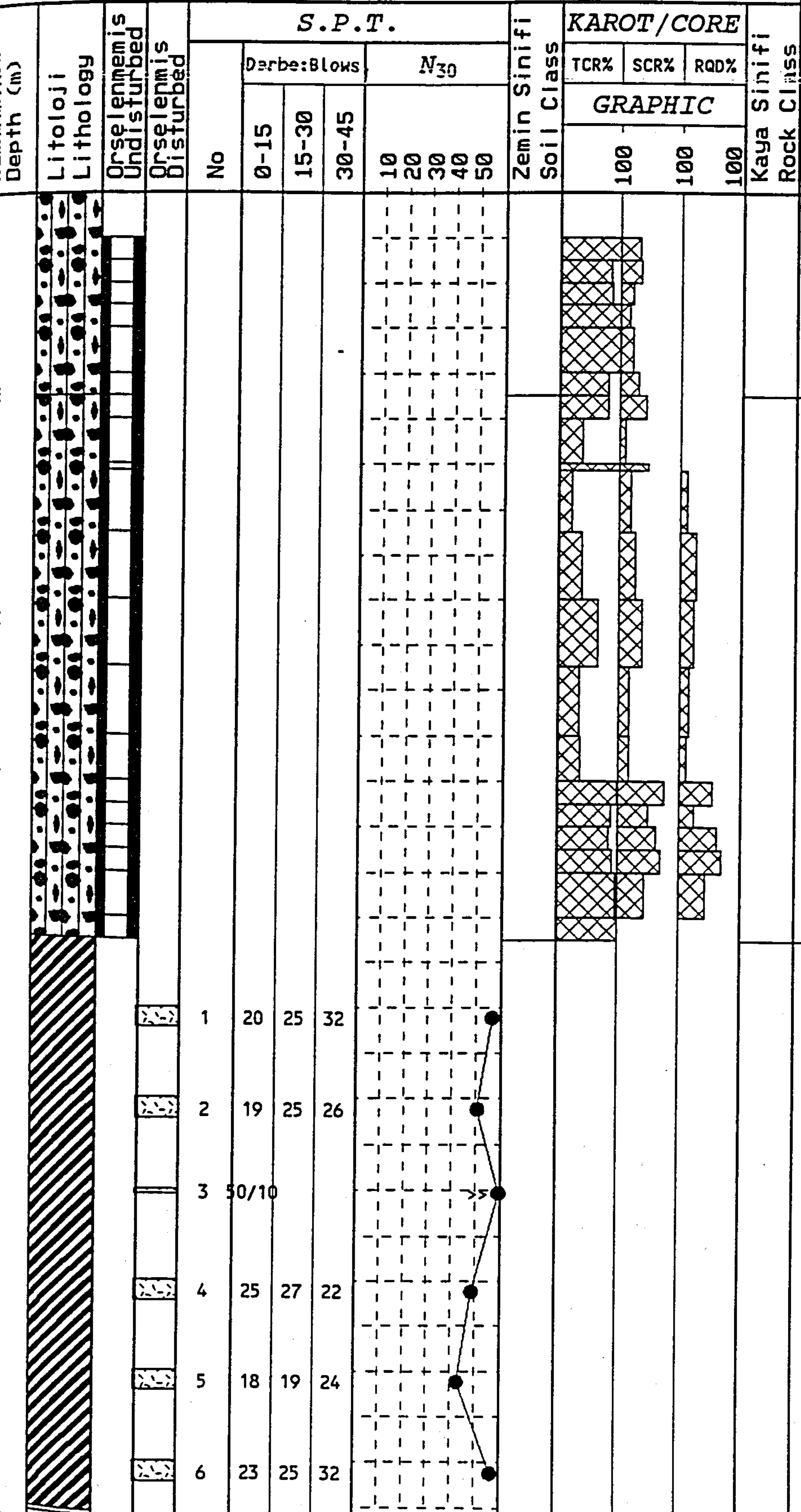
SVEREN / OWNER:
TEKFEN-IMPRESIT O.G.

PROJE / PROJECT:
TAG OTOYOLU/MOTORWAY

vkii/Locality: ADANA
slangic tarihi/Begin date : 30/12/91
tis tarihi/Completion date: 30/12/91

Agiz kotu/Ground elevation : 260.86
Sondaj derinligi/Boring depth: 31.00
Su seviyesi/Water table :

Sondaj tipi/Boring type: ROTARY
Sondor/Driller: H.GOZCU
Muhendis/Engineer:



No	Darbe:Blows 0-15	15-30	30-45
1	20	25	32
2	19	25	26
3	50/10		
4	25	27	22
5	18	19	24
6	23	25	32

ACIKLAMALAR/EXPLANATIONS

YAMAC MOLOZU blok, cakil, kil, bloklar beyaz renkli, kirectasi orjinli, orta saglam
SLOPE DEBRIS with blocks, gravel, clay, blocks are white and originated from limestone, medium strong

YAMAC BRESI beyaz renkli, kirec cimentolu, erime bosluklu, kirectasi bloklari
SLOPE BRECCIA white, lime cemented, with cavities, limestone blocks

CAKILLI KIL sert, kahverenkli, cakillar kirectasi ve spilit aglomera parcalari (28.60m'den sonra cok kirikli ana kaya parcalari, ust seviyelerde kirectasi cakillari, alt seviyelerde ise spilitik aglomeraya ait kirintilar)
GRAVELLY CLAY hard, brown, gravels are from limestone and spilit (below 28.60m, very fractured bedrock particles, limestone gravels at upper layers, spilit particles at lower levels)

	SONDAJ LOGU / BORING LOG	SONDAJ NO/BORING NO : *B2* SAYFA NO/PAGE NO : 90

SVEREN / OWNER:

TEKFEN-IMPRESIT O.G.

PROJE / PROJECT:

TAG OTOYOLU/MOTORWAY

vkii/Locality: ADANA

Agiz kotu/Ground elevation : 260.86

Sondaj tipi/Boring type: ROTARY

slangic tarihi/Begin date : 30/12/91

Sondaj derinligi/Boring depth: 31.00

Sondor/Driller: H.GOZCU

tis tarihi/Completion date: 30/12/91

Su seviyesi/Water table :

Muhendis/Engineer:

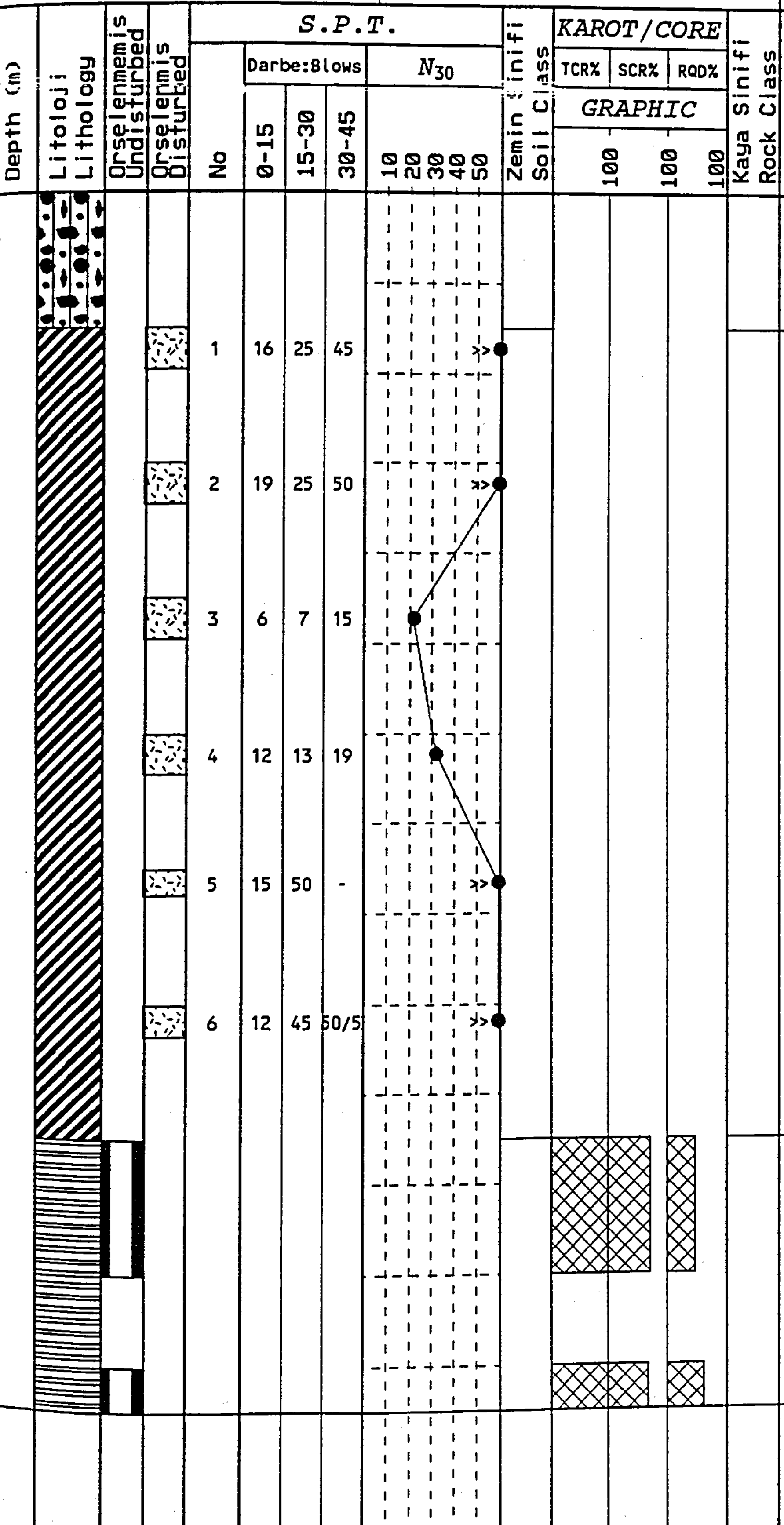
Depth (m)	Litoloji Lithology	Orselenmemis Undisturbed	Orselenmis Disturbed	*S.P.T.*					Zemin Sinifi Soil Class	*KAROT/CORE*			Kaya Sinifi Rock Class	*ACIKLAMALAR/EXPLANATIONS*
				No	Darbe:Blows 0-15	15-30	30-45	N_{30} 10 20 30 40 50		TCR% *GRAPHIC* 100	SCR% 100	RQD% 100		
														saglam, kilcal ince kalsit damarli **SPILIT** brownish green, fine - coarse grained, low weathered, medium weak - medium strong, fine calsite infillings
														Sondaj Sonu/Bottom

SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B3
SAYFA NO/PAGE NO : 91

VEREN / OWNER: TEKFEN-IMPRESIT O.G.
PROJE / PROJECT: TAG OTOYOLU/MOTORWAY

kii/Locality: ADANA
slangic tarihi/Begin date : 3/12/91
tis tarihi/Completion date: 3/12/91
Agiz kotu/Ground elevation : 260.00
Sondaj derinligi/Boring depth: 13.50
Su seviyesi/Water table :
Sondaj tipi/Boring type: ROTARY
Sondor/Driller: H.GOZCU
Muhendis/Engineer:



S.P.T. No	Darbe:Blows 0-15	15-30	30-45
1	16	25	45
2	19	25	50
3	6	7	15
4	12	13	19
5	15	50	-
6	12	45	50/5

ACIKLAMALAR/EXPLANATIONS

YAMAC MOLOZU kil, kum, cakil boyutunda malzeme, bloklar kirectasi orijinli
SLOPE DEBRIS material varying as clay, sand, gravel in size, the boulders are originated from limestone

SILTLI KIL cok kati-sert, kahverengi, cakilli, dusuk plastisiteli, cakillar koseli, yer yer kirectasi ve sipilit parcalari, max. cakil boyu 2cm , (9.0m - 10.5m) arasi cok ayrismis SIPILIT
SILTY CLAY very stiff-hard, brown, gravelly, low plasticity, gravels are subangular, occasionally with limestone and spilit, max. gravel size 2cm, very weathered SPILIT between (9.0m - 10.5m)

SIPILIT koyu yesil renkli, orta daneli, masif, saglam-orta saglam ayrismamis, az kirikli, kalsit dolgulu, yer yer kilcal kalsit dolgulu ve duzensiz
SPILIT dark green, medium granular, massive, strong - medium strong, not weathered, low fractured, calsite infillings, occasionally, calsite infillings and irregularities

Sondaj Sonu/Bottom of B3 at 13.5m

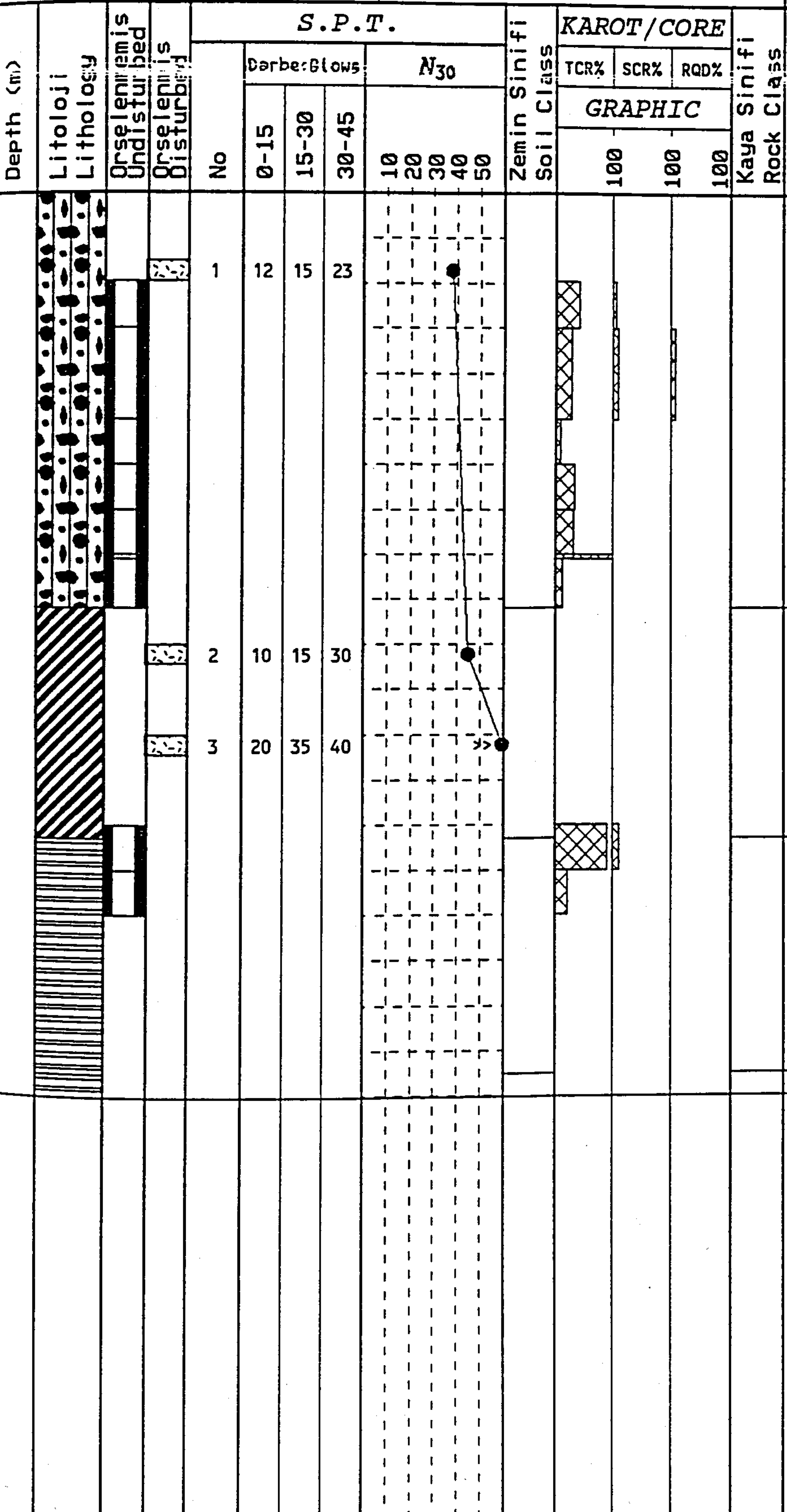
SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B4
SAYFA NO/PAGE NO : 92

SVEREN / OWNER:
TEKFEN-IMPRESIT O.G.

PROJE / PROJECT:
TAG OTOYOLU/MOTORWAY

vkii/Locality: ADANA
slangic tarihi/Begin date : 10/12/91
tis tarihi/Completion date: 10/12/91
Agiz kotu/Ground elevation : 232.75
Sondaj derinligi/Boring depth: 20.00
Su seviyesi/Water table :
Sondaj tipi/Boring type: ROTARY
Sondor/Driller: H.GOZCU
Muhendis/Engineer:



No	Darbe:Blows 0-15	15-30	30-45
1	12	15	23
2	10	15	30
3	20	35	40

ACIKLAMALAR/EXPLANATIONS

YAMAC MOLOZU blok, cakil, kum kil boyutunda malzeme, bloklar beyaz renkli, saglam, erime bosluklu kirectasi, yer yer bres, 8.2-9.2 m arasi kahverengi kirectasi cakillari
SLOPE DEBRIS material with varying sizes as boulders, gravel, sand, clay, boulders are white, strong limestone, occasionally brecia, limestone gravels between 8.2-9.2m depths

CAKILLI KIL sert, sari-kahverenkli, dusuk plastisiteli, cakillar kirectasi orijinli, yer yer sipilit parcalari, max. cakil boyutu 2.5 cm, cakillar koseli
GRAVELLY CLAY hard, yellow-brown, low plasticity, gravels are originated from limestone, occasionally split particles, max. gravel size is 2.5cm, gravels are subangular

SPILITIK AGLOMERA kahverenkli, ince daneli, kirikli, orta derecede ayrismis, yer yer cok ayrismis, orta zayif-orta saglam, ince kalsit damarli
SPLITIC AGLOMERATE brown, fine grained, fractured, medium - occasionally heavily weathered, medium weak - medium strong, fine calsite infillings.

SIPILIT yesil renkli, ince daneli masif, ayrismamis
SPILIT green, fine grained, massive, not weathered,

Sondaj Sonu/Bottom

SONDAJ LOGU / BORING LOG

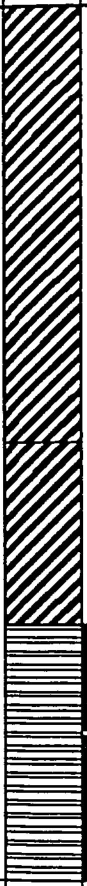
SONDAJ NO/BORING NO : *B5*
SAYFA NO/PAGE NO : 93

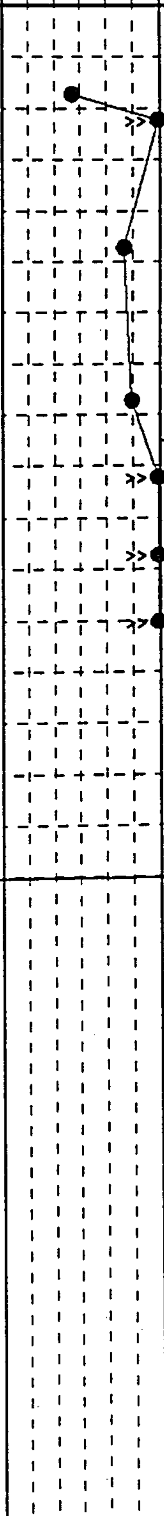
SVEREN / OWNER:
TEKFEN-IMPRESIT O.G.

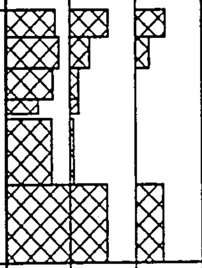
PROJE / PROJECT:
TAG OTOYOLU/MOTORWAY

vkii/Locality: ADANA
Agiz kotu/Ground elevation : 295.94
Sondaj tipi/Boring type: ROTARY
slangic tarihi/Begin date : 18/12/91
Sondaj derinligi/Boring depth: 17.00
Sondor/Driller: H.GOZCU
tis tarihi/Completion date: 18/12/91
Su seviyesi/Water table :
Muhendis/Engineer:

Depth (m)	Litoloji Lithology	Orselenmemis Undisturbed	Orselenmis Disturbed	No	S.P.T. Darbe:Blows 0-15	15-30	30-45	N30 10 20 30 40 50	Zemin Sinifi Soil Class	KAROT/CORE TCR% 100	SCR% 100	RQD% 100	Kaya Sinifi Rock Class
			▨	1	10	12	15						
			▨	2	35	37	40						
			▨	3	16	22	25						
			▨	4	15	20	30						
			▨	5	35	50/10							
0													
			▨	6	30	40	50						
				50/5	-	-							
5													







ACIKLAMALAR/EXPLANATIONS

CAKILLI KIL cok kati-sert, beyaz - kahverengi, cakillar koseli, max. cakil boyutu 2.0cm (KALIS)
GRAVELLY CLAY very stiff-hard, white - brown, gravels are subangular, max. gravel size is 2.0cm (CALICHE)

CAKILLI KIL kizil kahverengi, cakillar yuvarlak-koseli, max. cakil boyutu 2.0cm, kirectasi ve sipilit parcalari
GRAVELLY CLAY reddish brown, gravels are round - subangular, max. gravel size is 2.0cm, limestone and spilit particles

SIPILIT kahvemsi yesil renkli, ince-orta daneli, ayrismamis, kilcal ve yogun kalsit damarli, gelisiguzel duzensiz
SPILIT brownish green, fine-medium grained, not weathered, fine and dense calsite infillings, irregular

Sondaj Sonu/Bottom

APPENDIX 3.

LABORATORY TEST RESULTS

HYDROMETER TEST RESULTS

Sample : 1A
Location : Km.141

Sieve No.	Sieve Size (mm)	Retained (gr)	Cum.Ret. (gr)	Cum.Ret. (%)	Cum.Pass. (%)	Total Pass Samp. %
# 10	2.00	0.00	0.00	0.00	100.00	96
#40	0.42	2.71	2.71	5.42	94.58	91
# 200	0.08	8.06	10.77	21.54	78.46	75

Gs : 2.769
W : 50.00 gr.
a : 0.975

% GRAVEL (Larger than 2 mm) : 4
% COARSE SAND (2mm - 0.42 mm) : 5.2
% FINE SAND (0.42 mm - 0.0075 mm) : 15.5
% SILT (0.075 mm - 0.002 mm) : 58.7
% CLAY (0.002 mm - 0.001 mm) : 5.1
% COLLOIDAL CALY (Less than 0.001 m : 11.5

d60 : 0.0420
d30 : 0.0086
d10 :

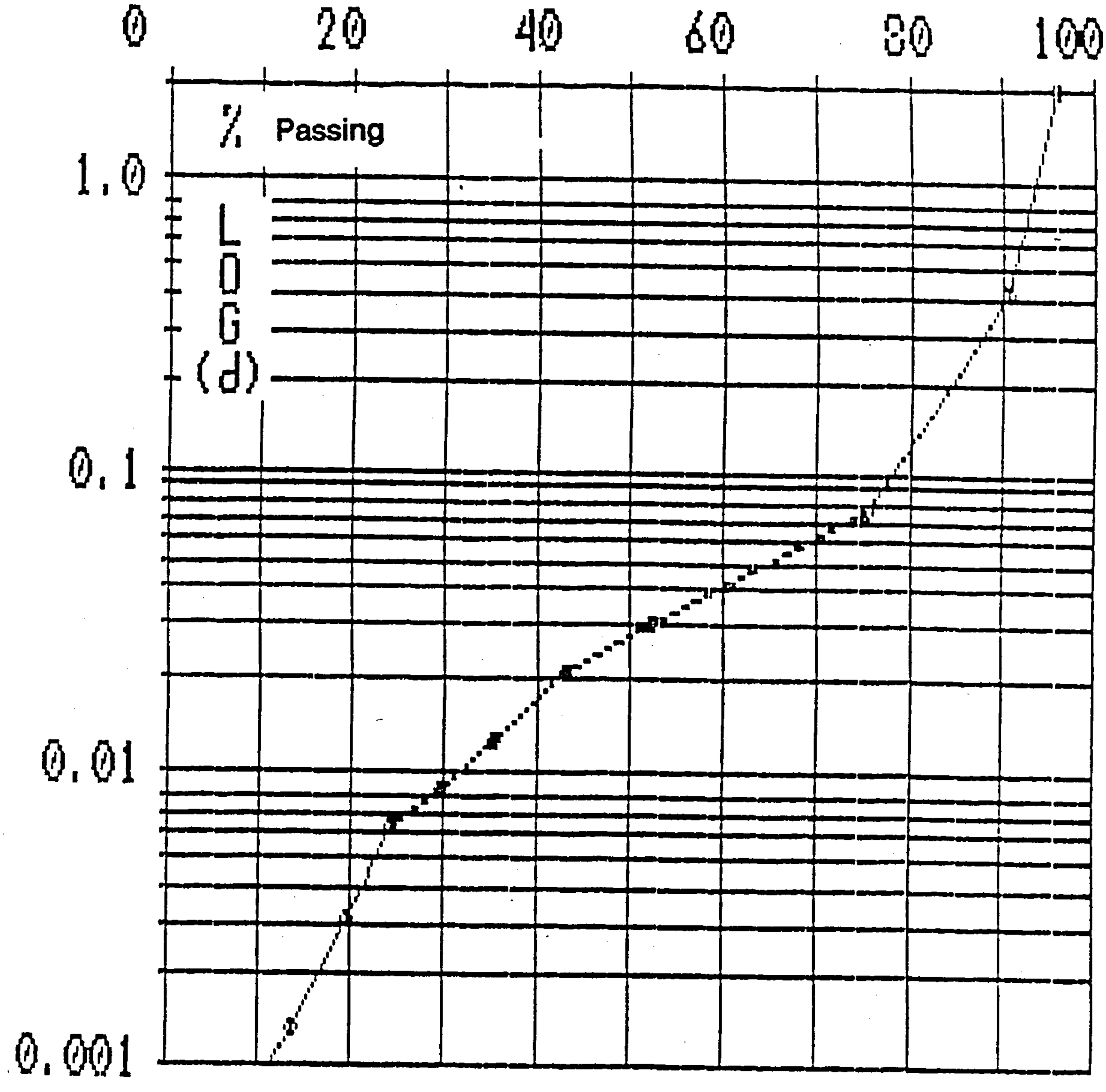


FIGURE A3.1.1 Sieve analysis on sample no.1A

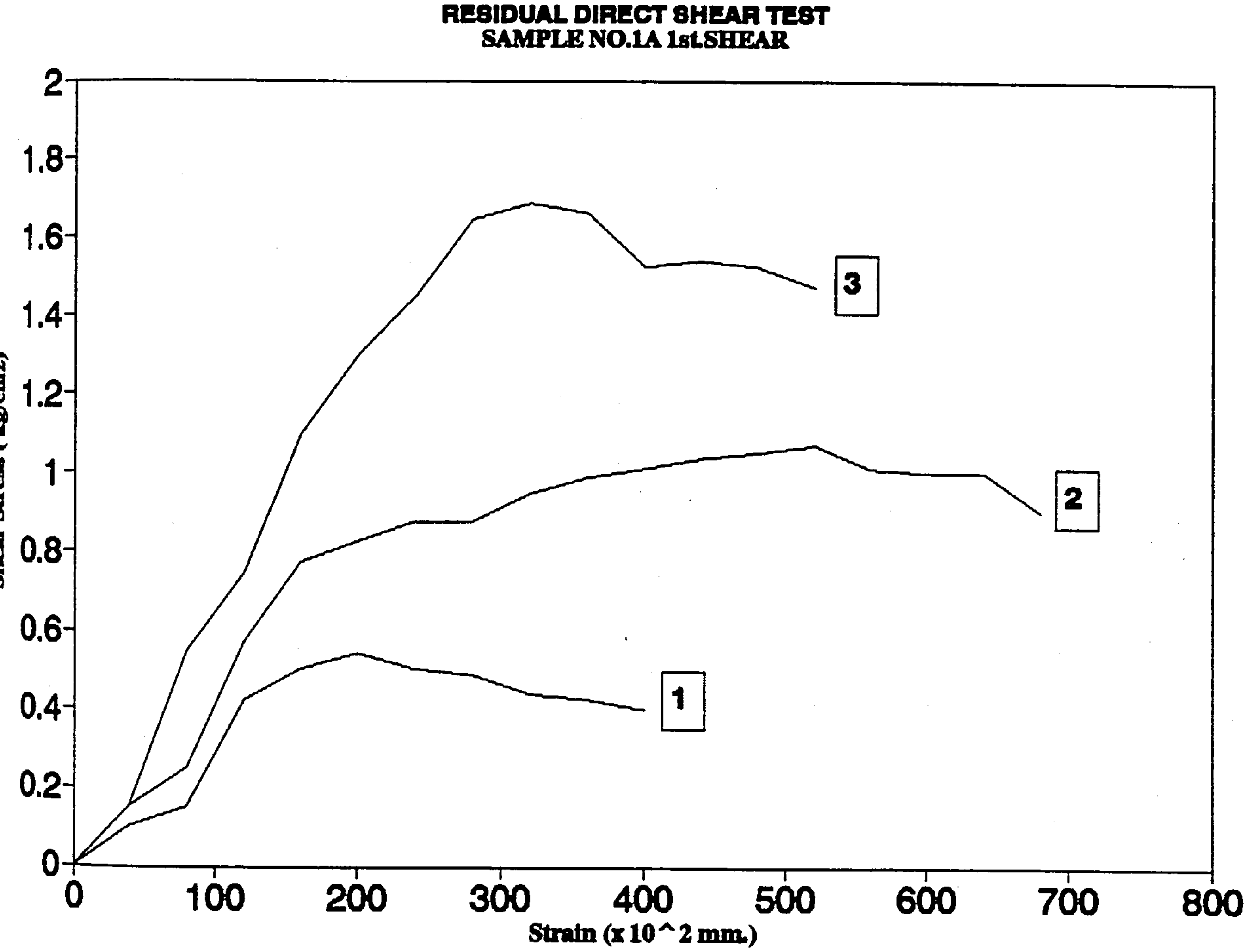


FIGURE A3.1.2 Residual direct shear test

Sample no.1A 1st. Shear

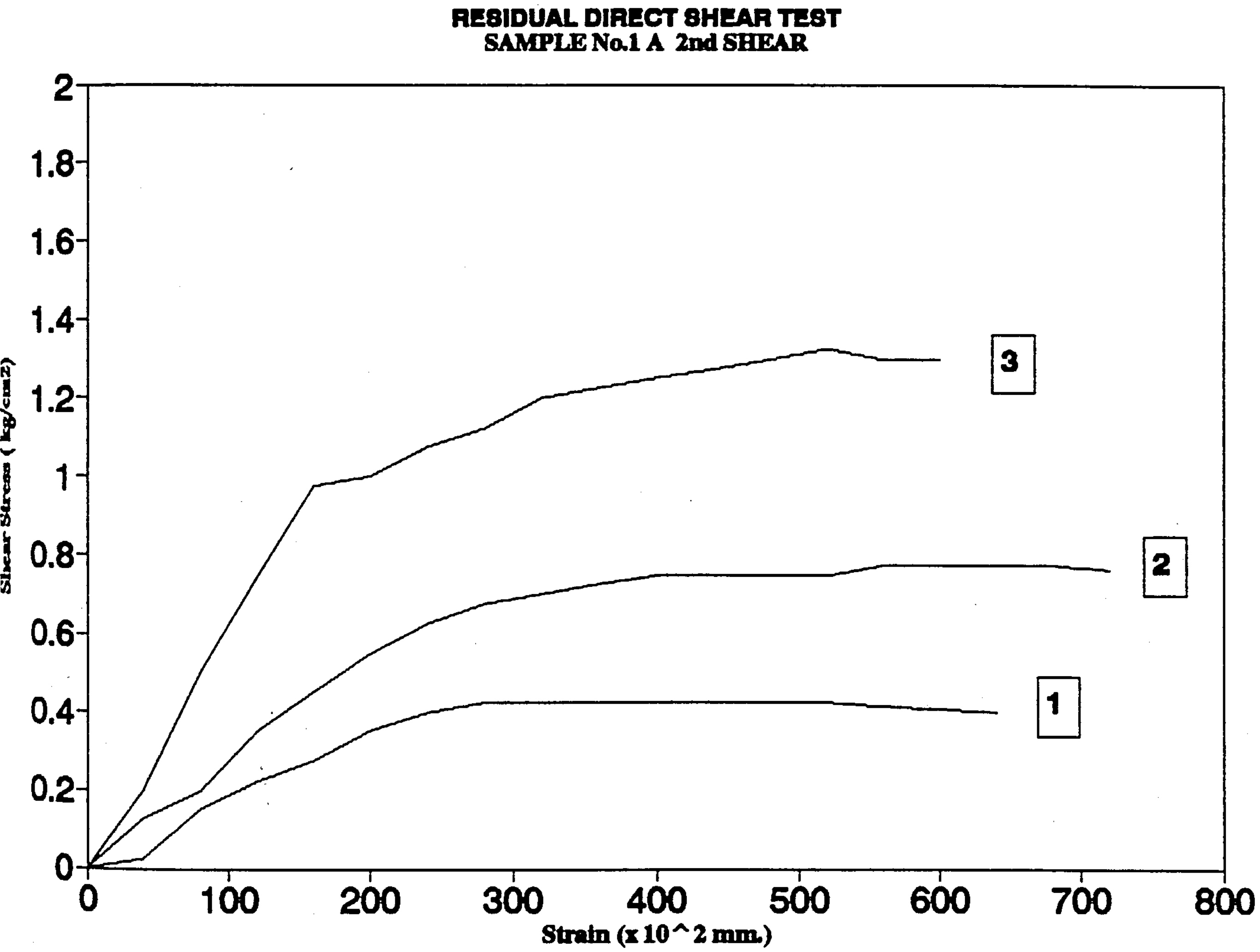
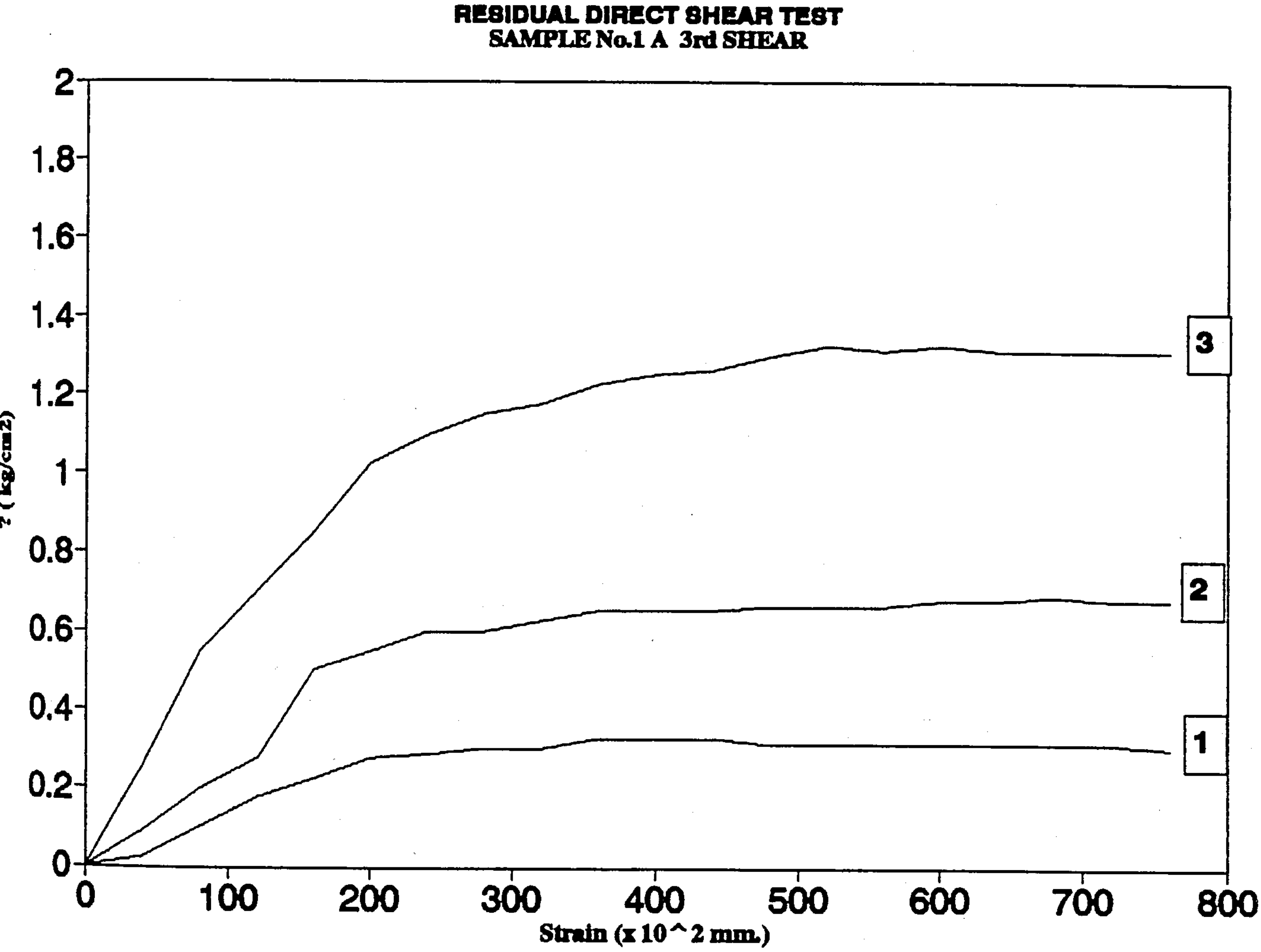


FIGURE A3.1.3 Residual direct shear test

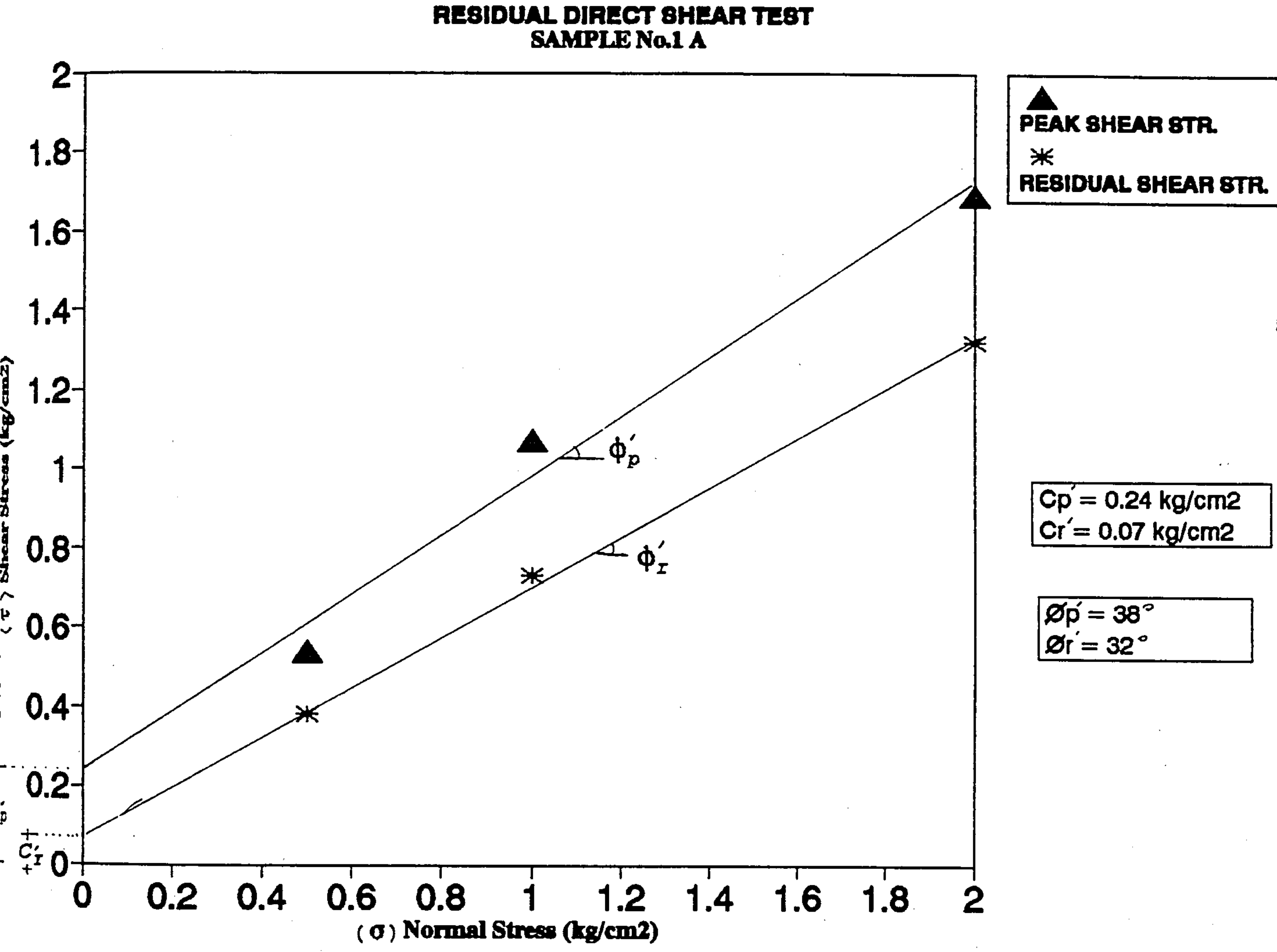
Sample no.1A 2nd. Shear



RESIDUAL DIRECT SHEAR TEST
SAMPLE No.1 A 3rd SHEAR

FIGURE A3.1.4 Residual direct shear test

Sample no.1A 3rd. Shear



TEST:1A

SAMPLE	σ_n (Kg/cm2)	τ_p(Kg/cm2)	τ_r(Kg/cm
1	0.5000	0.5400	0.38
2	1.0000	1.0700	0.73
3	2.0000	1.6900	1.32

FIGURE A3.1.5 Residual direct shear test results

Sample no.1A

HYDROMETER TEST RESULTS

Sample : 1B
Location : Km.141

Sieve No.	Sieve Size (mm)	Retained (gr)	Cum.Ret. (gr)	Cum.Ret. (%)	Cum.Pass. (%)	Total Pas Samp. %
# 10	2.00	0.00	0.00	0.00	100.00	95
#40	0.42	2.21	2.21	4.42	95.58	91
# 200	0.08	8.61	10.82	21.64	78.36	74

Gs : 2.779
W : 50.00 gr.
a : 0.973

% GRAVEL (Larger than 2 mm) : 5.0
% COARSE SAND (2mm - 0.42 mm) : 4.2
% FINE SAND (0.42 mm - 0.0075 mm) : 16.4
% SILT (0.075 mm - 0.002 mm) : 63.7
% CLAY (0.002 mm - 0.001 mm) : 5.0
% COLLOIDAL CALY (Less than 0.001 m : 5.7

d60 : 0.0469
d30 : 0.0118
d10 : 0.0018

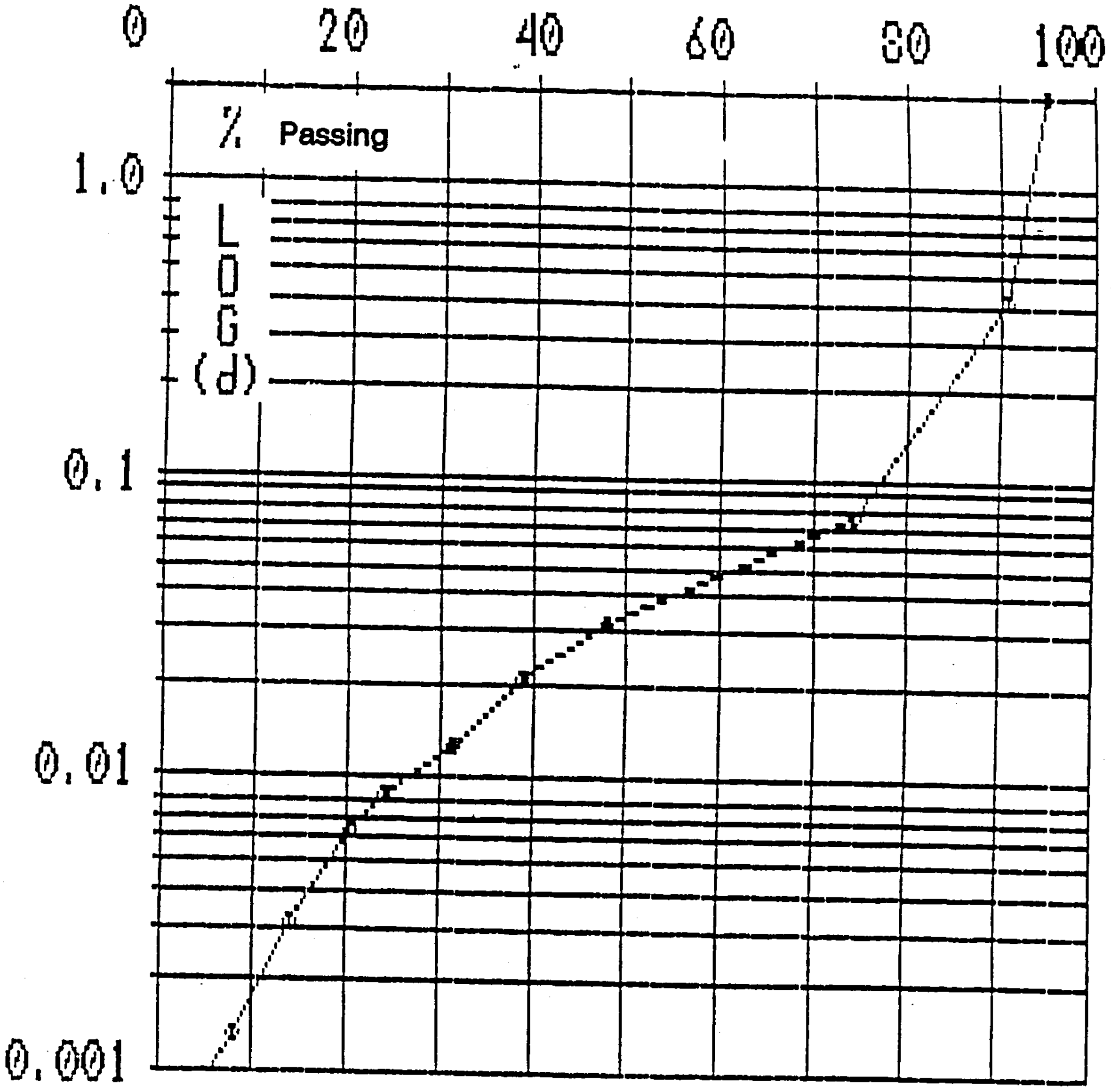


FIGURE A3.2.1 Sieve analysis on sample no.1B

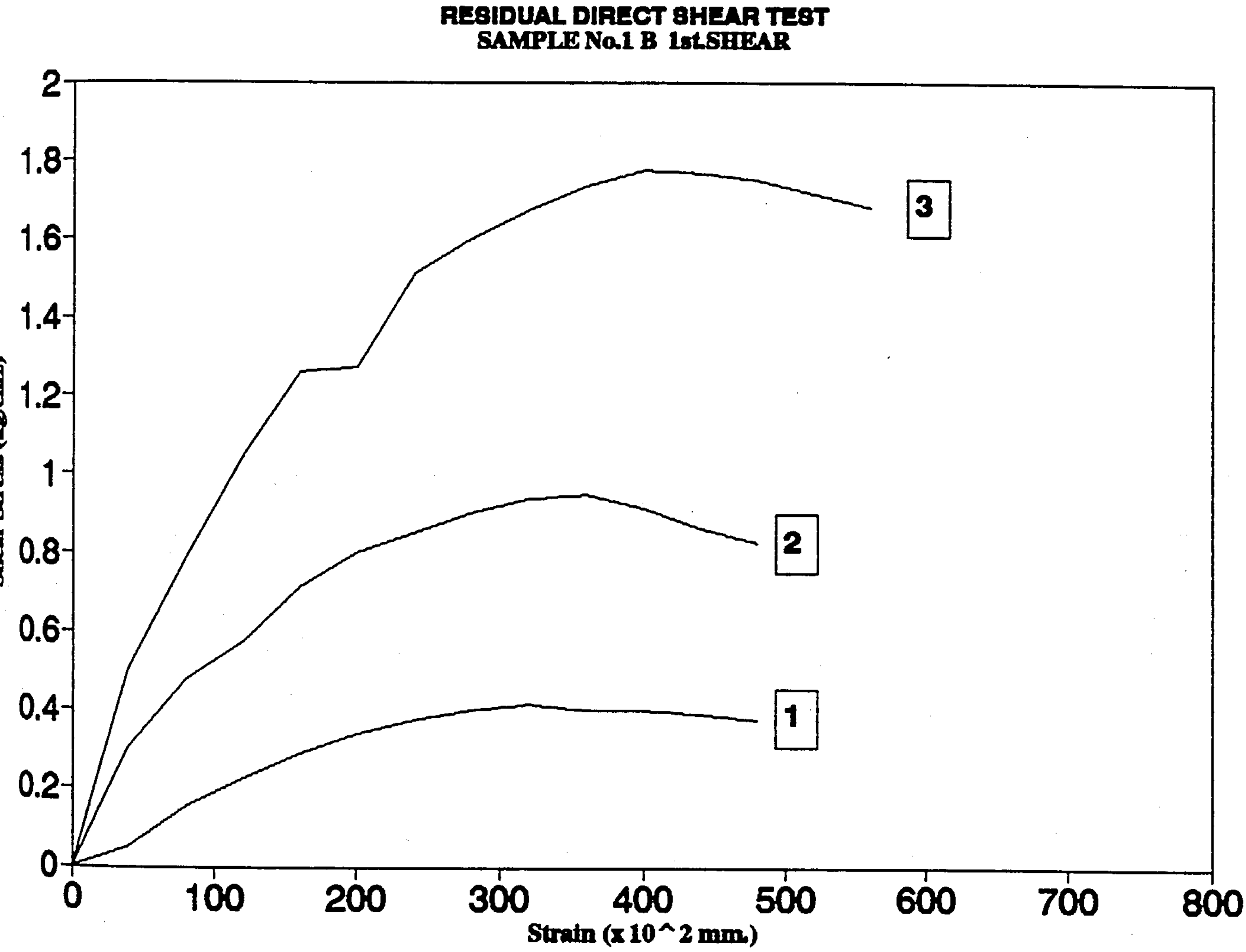


FIGURE A3.2.2 Residual direct shear test

Sample no.1B 1st. Shear

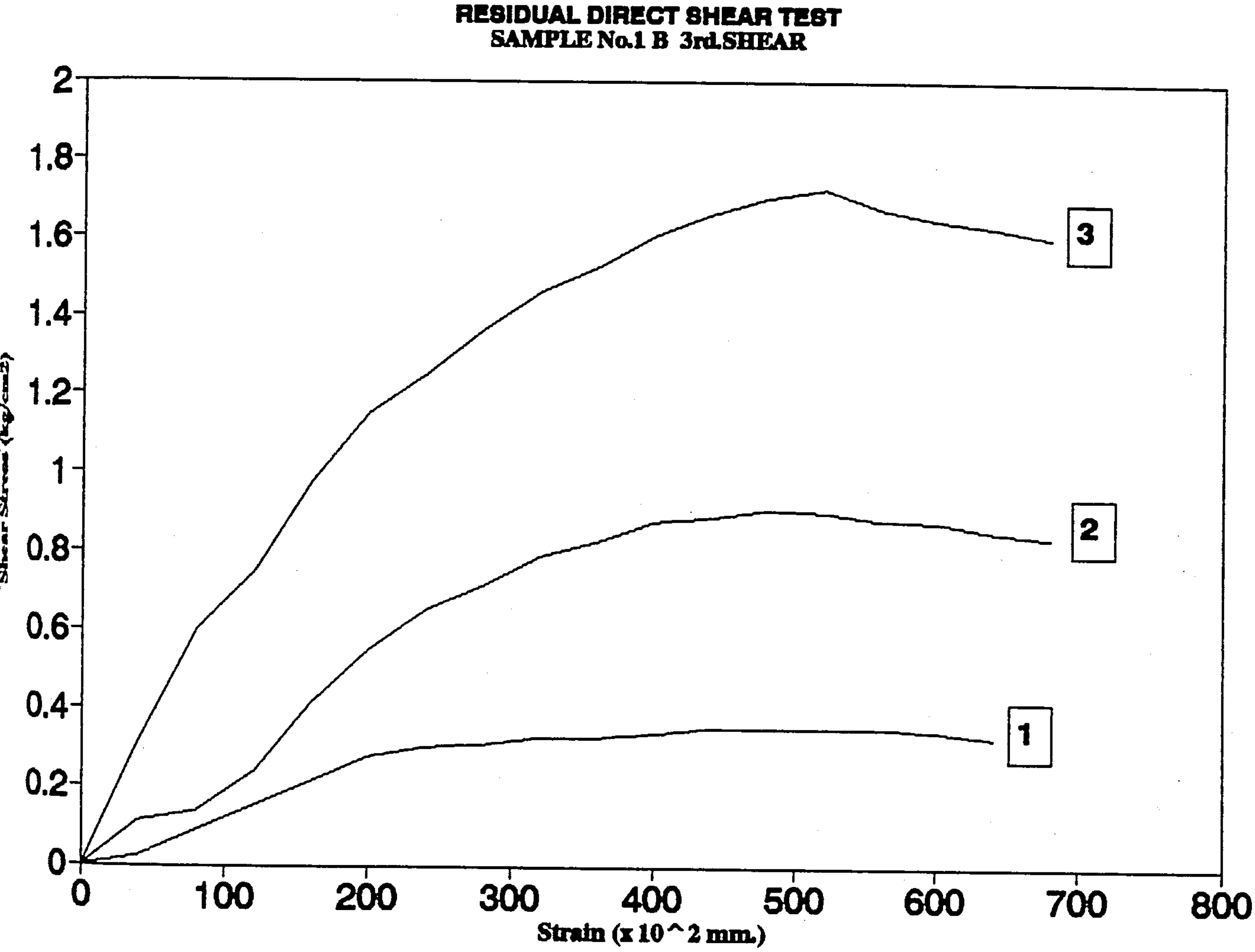
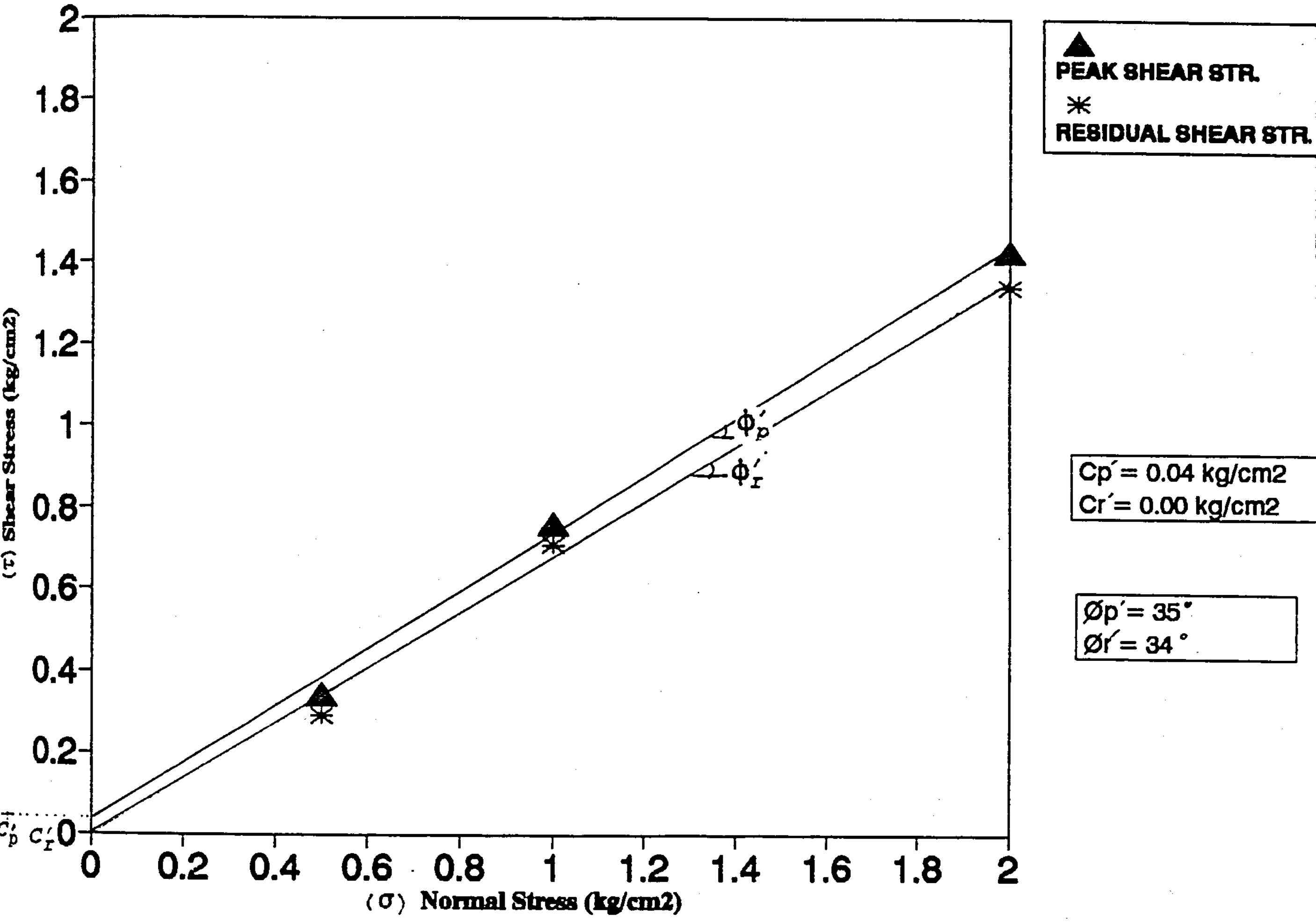


FIGURE A3.2.4 Residual direct shear test

Sample no.1B 3rd. Shear

RESIDUAL DIRECT SHEAR TEST
SAMPLE No.1 B



TEST:1B

SAMPLE	σ_n (Kg/cm2)	τ_p (Kg/cm2)	τ_r(Kg/cm
1	0.5000	0.3400	0.29
2	1.0000	0.7600	0.71
3	2.0000	1.4300	1.34

FIGURE A3.2.5 Residual direct shear test results

Sample no.1B

HYDROMETER TEST RESULTS

Sample : CBR1
Location : Km.141

Sieve No.	Sieve Size (mm)	Retained (gr)	Cum.Ret. (gr)	Cum.Ret. (%)	Cum.Pass. (%)	Total Pas Samp. %
# 10	2.00	0.00	0.00	0.00	100.00	95
#40	0.42	1.43	1.43	2.86	97.14	92
# 200	0.075	2.49	3.92	7.84	92.16	88

Gs : 2.438
W : 50.00 gr.
a : 1.056

% GRAVEL (Larger than 2 mm) : 5.0
% COARSE SAND (2mm - 0.42 mm) : 2.7
% FINE SAND (0.42 mm - 0.0075 mm) : 4.7
% SILT (0.075 mm - 0.002 mm) : 41.7
% CLAY (0.002 mm - 0.001 mm) : 13.7
% COLLOIDAL CALY (Less than 0.001 m : 32.2

d60 : 0.0046
d30 :
d10 :

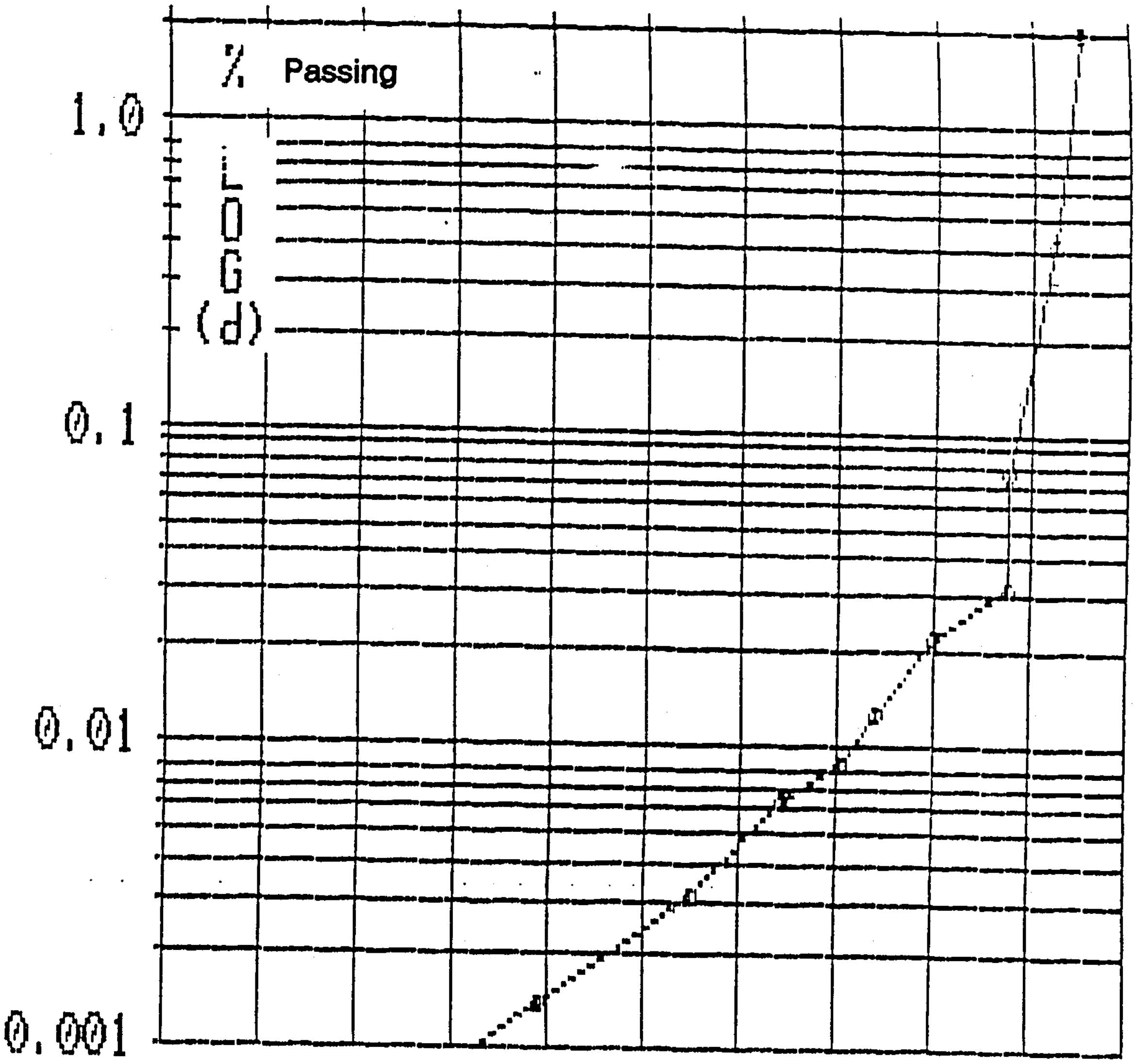


FIGURE A3.3.1 Sieve analysis on sample no.CBR1

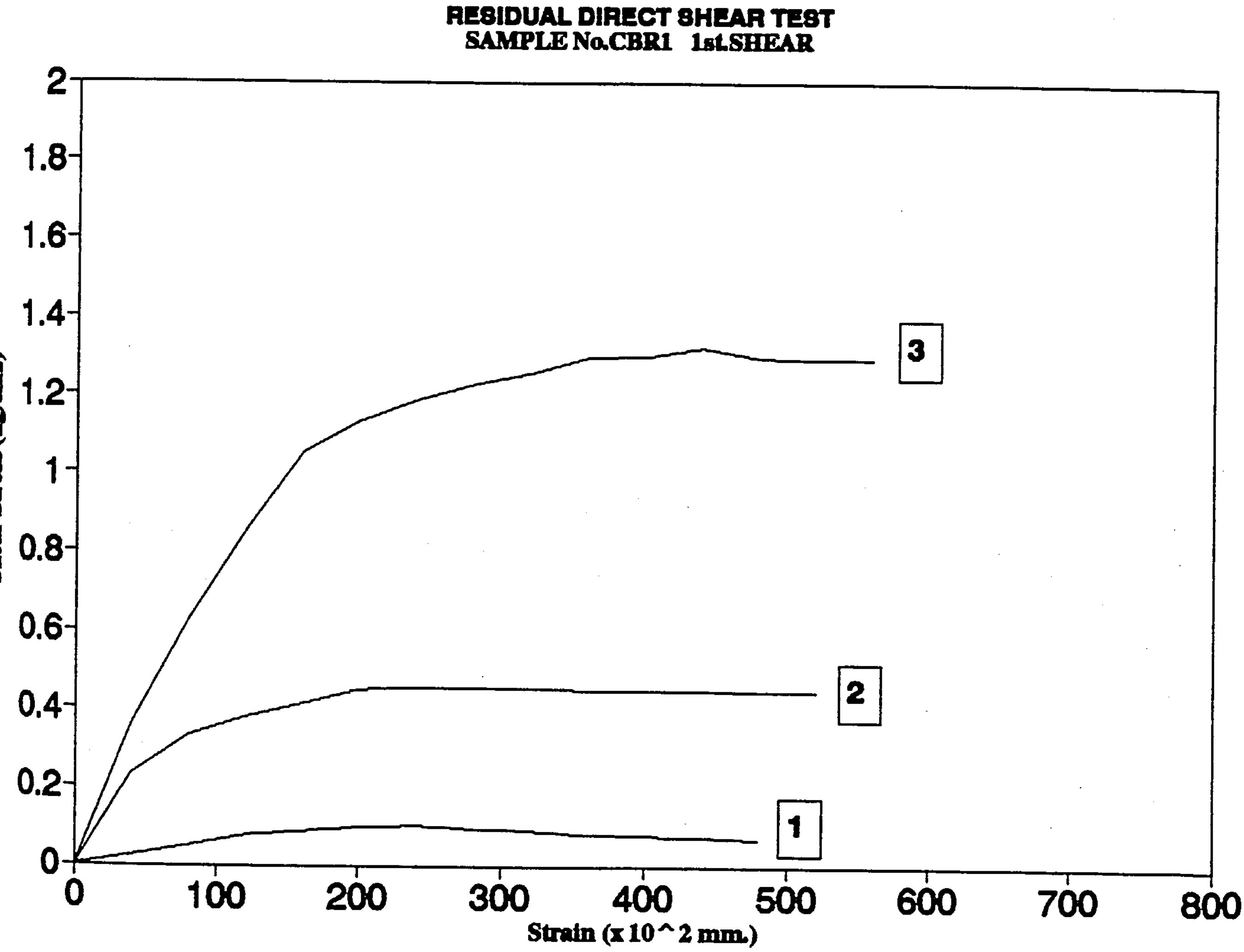


FIGURE A3.3.2 Residual direct shear test

Sample no.CBR1 1st. Shear

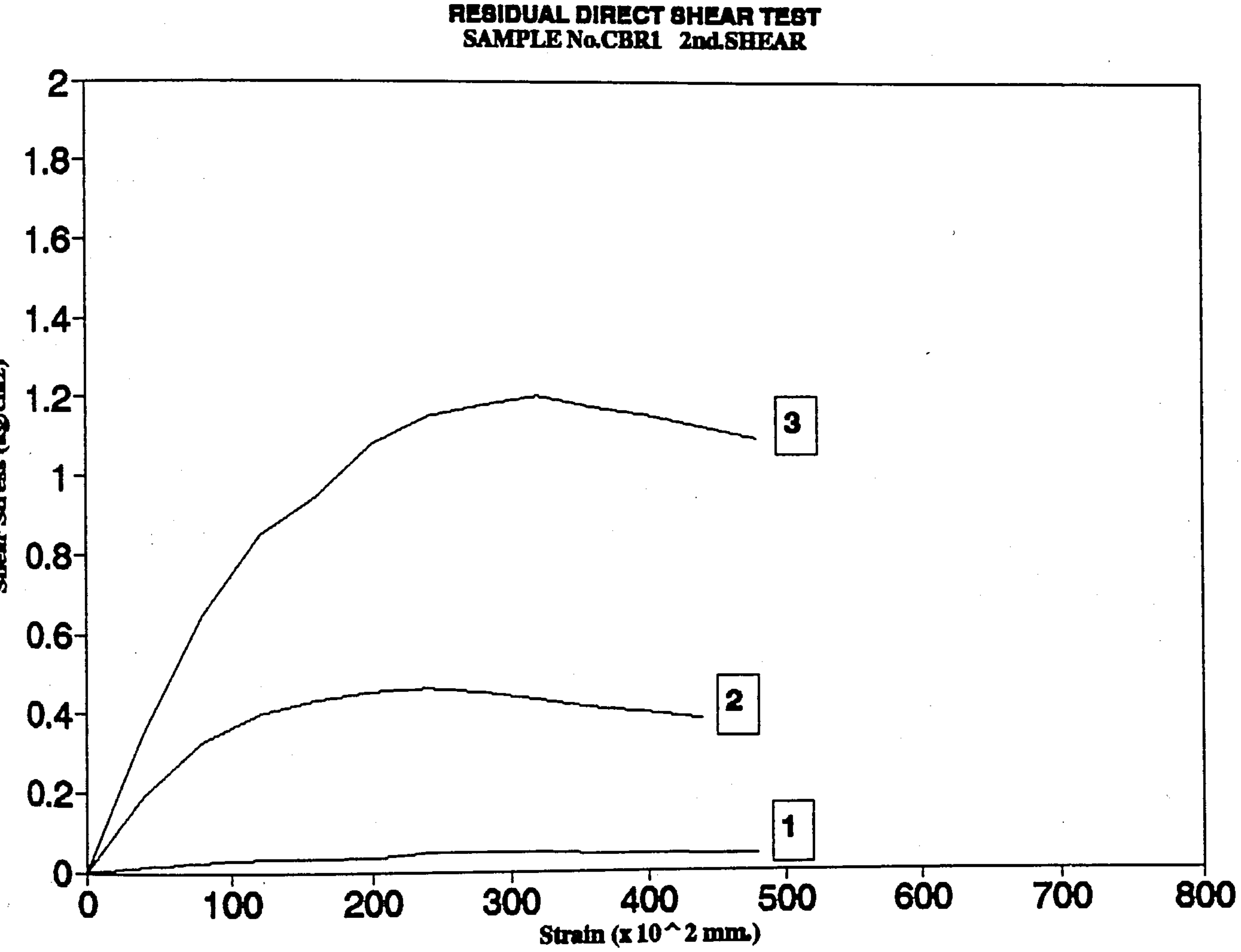


FIGURE A3.3.3 Residual direct shear test

Sample no.CBR1 2nd. Shear

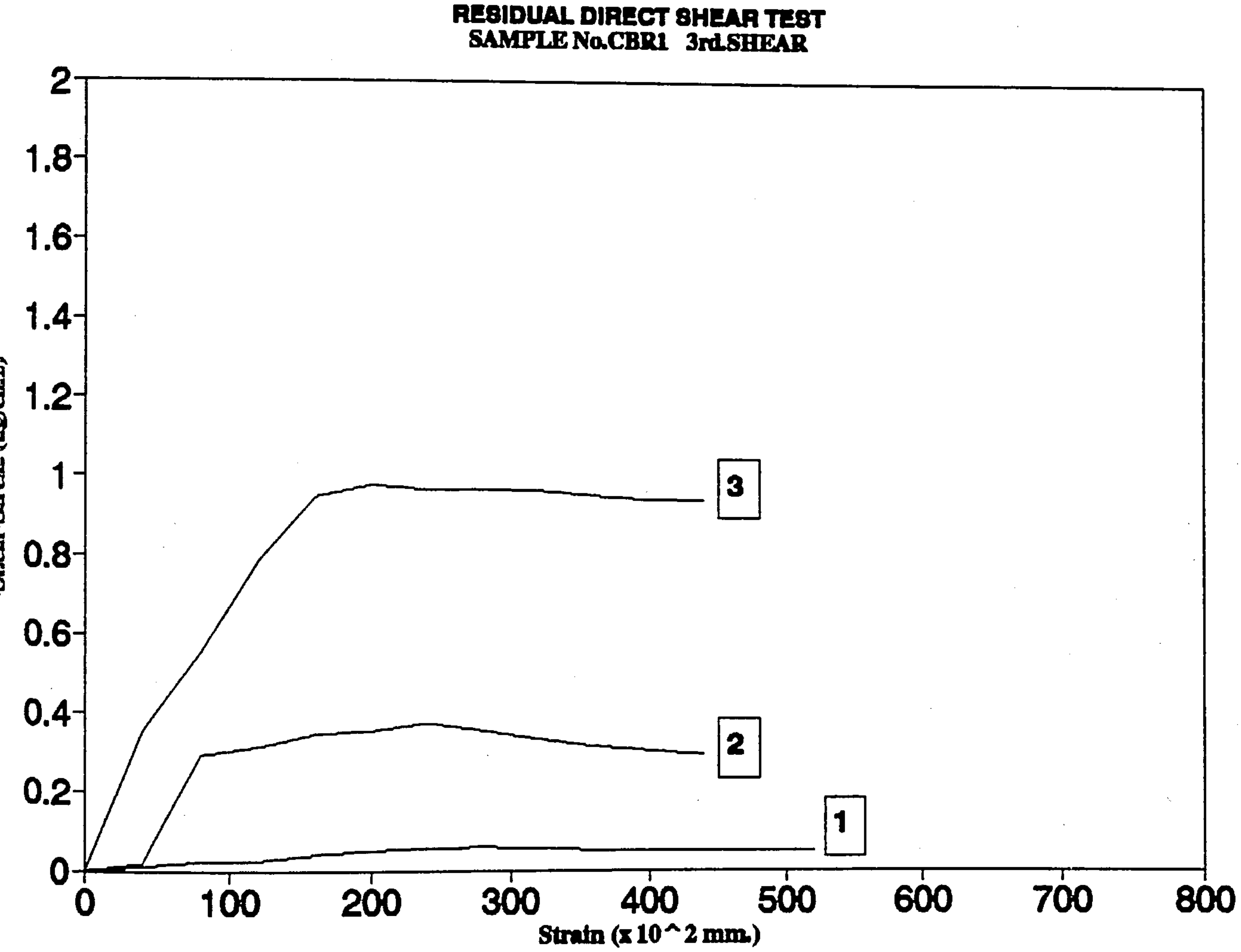


FIGURE A3.3.4 Residual direct shear test

Sample no.CBR1 3rd. Shear

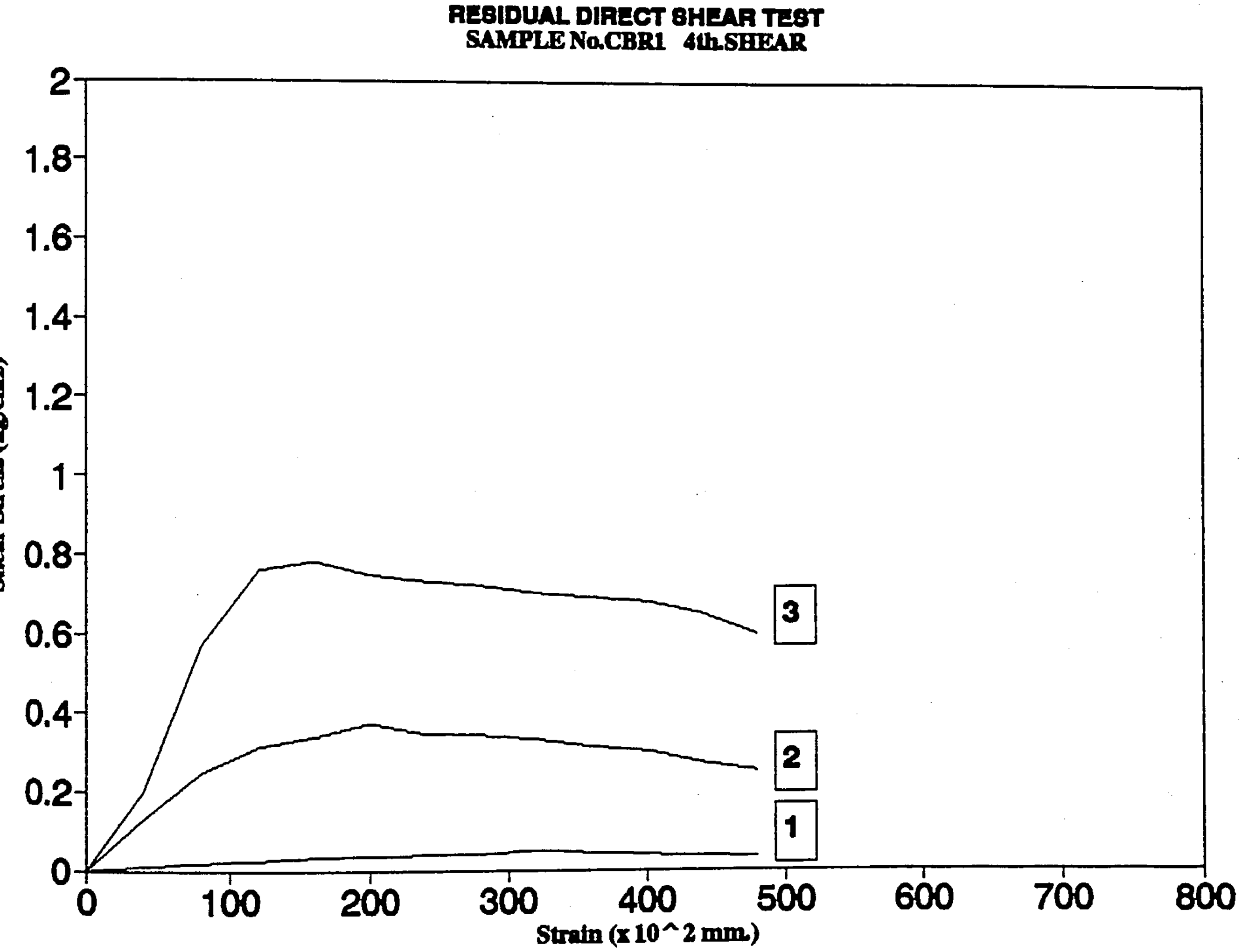
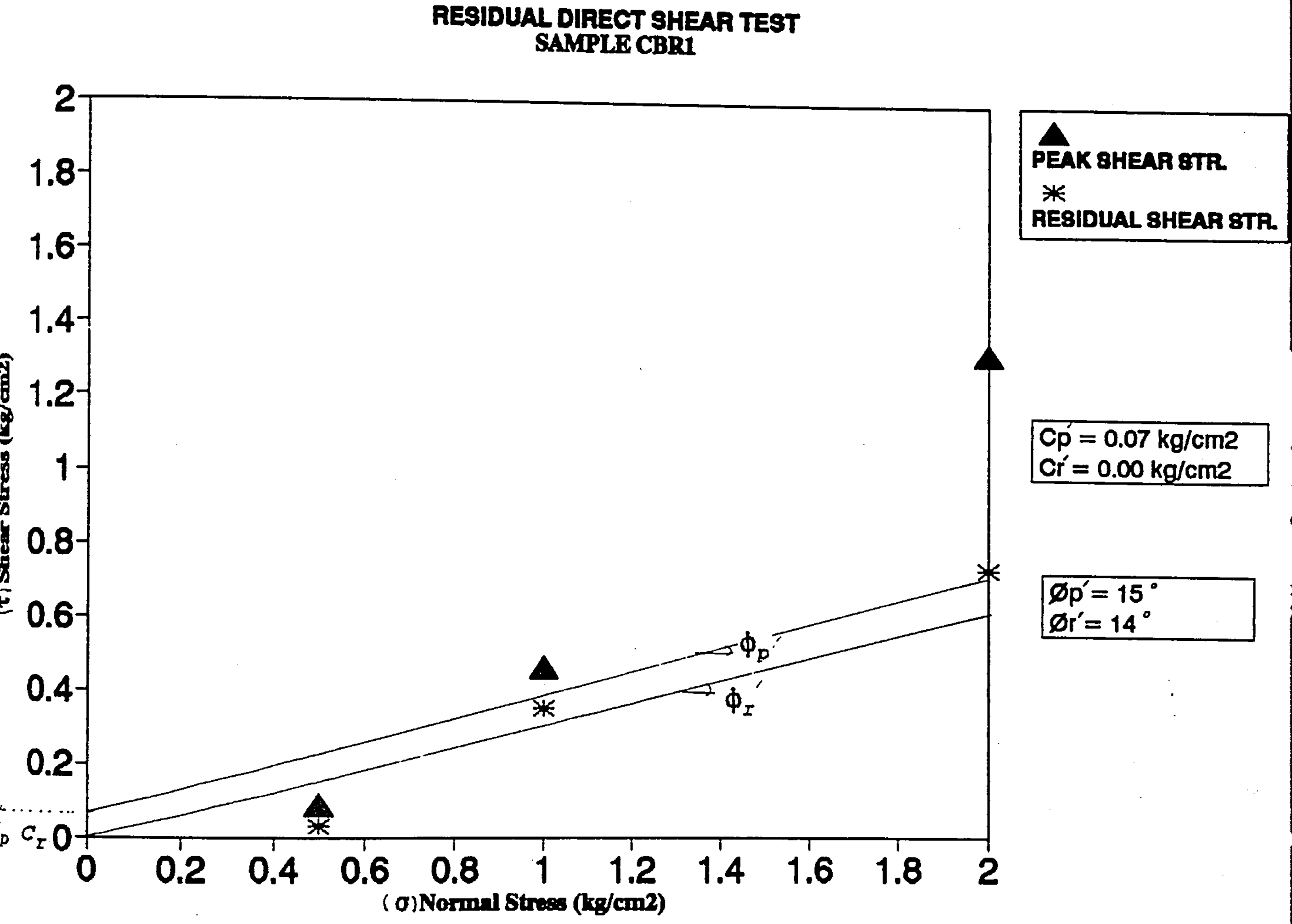


FIGURE A3.3.5 Residual direct shear test

Sample no.CBR1 4th. Shear



TEST: CBR1

SAMPLE	σ_n (Kg/cm2)	τ_p (Kg/cm2)	τ_r (Kg/cm2)
1	0.50	0.09	0.03
2	1.00	0.46	0.35
3	2.00	1.32	0.73

FIGURE A3.3.6 Residual direct shear test results

Sample no.CBR1

HYDROMETER TEST RESULTS

Sample : CBR2
Location : Km.141

Sieve No.	Sieve Size (mm)	Retained (gr)	Cum.Ret. (gr)	Cum.Ret. (%)	Cum.Pass. (%)	Total Pass Samp. %
# 10	2.00	0.00	0.00	0.00	100.00	97
#40	0.42	1.73	1.73	3.46	96.54	94
# 200	0.075	5.27	7.00	14.00	86.00	83

Gs : 2.466
W : 50.00 gr.
a : 1.047

% GRAVEL (Larger than 2 mm) : 3.0
% COARSE SAND (2mm - 0.42 mm) : 3.4
% FINE SAND (0.42 mm - 0.0075 mm) : 10.2
% SILT (0.075 mm - 0.002 mm) : 45.2
% CLAY (0.002 mm - 0.001 mm) : 12.6
% COLLOIDAL CALY (Less than 0.001 m : 25.6

d60 : 0.0079
d30 :
d10 :

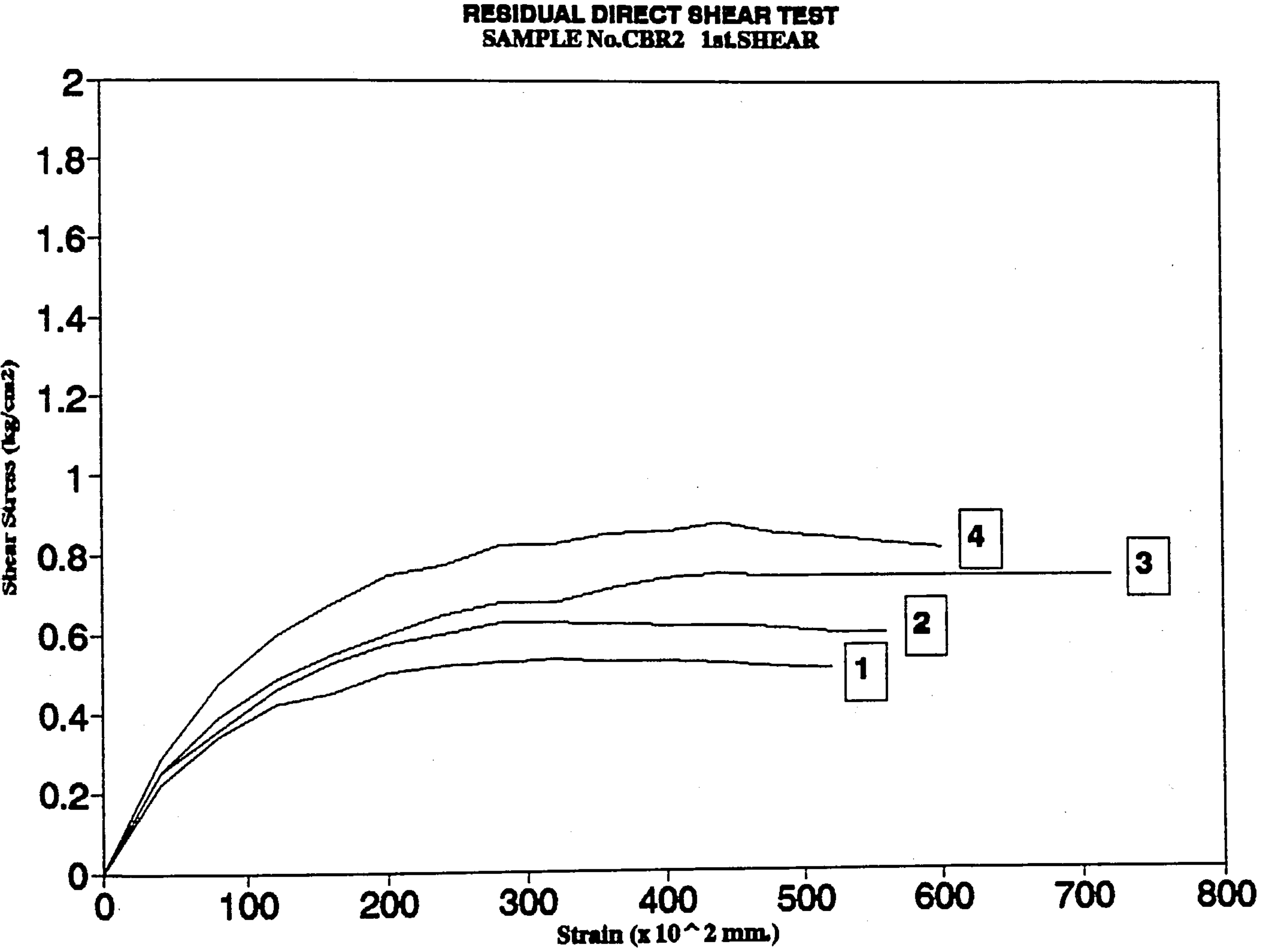


FIGURE A3.4.1 Residual direct shear test

Sample no.CBR2 1st. Shear

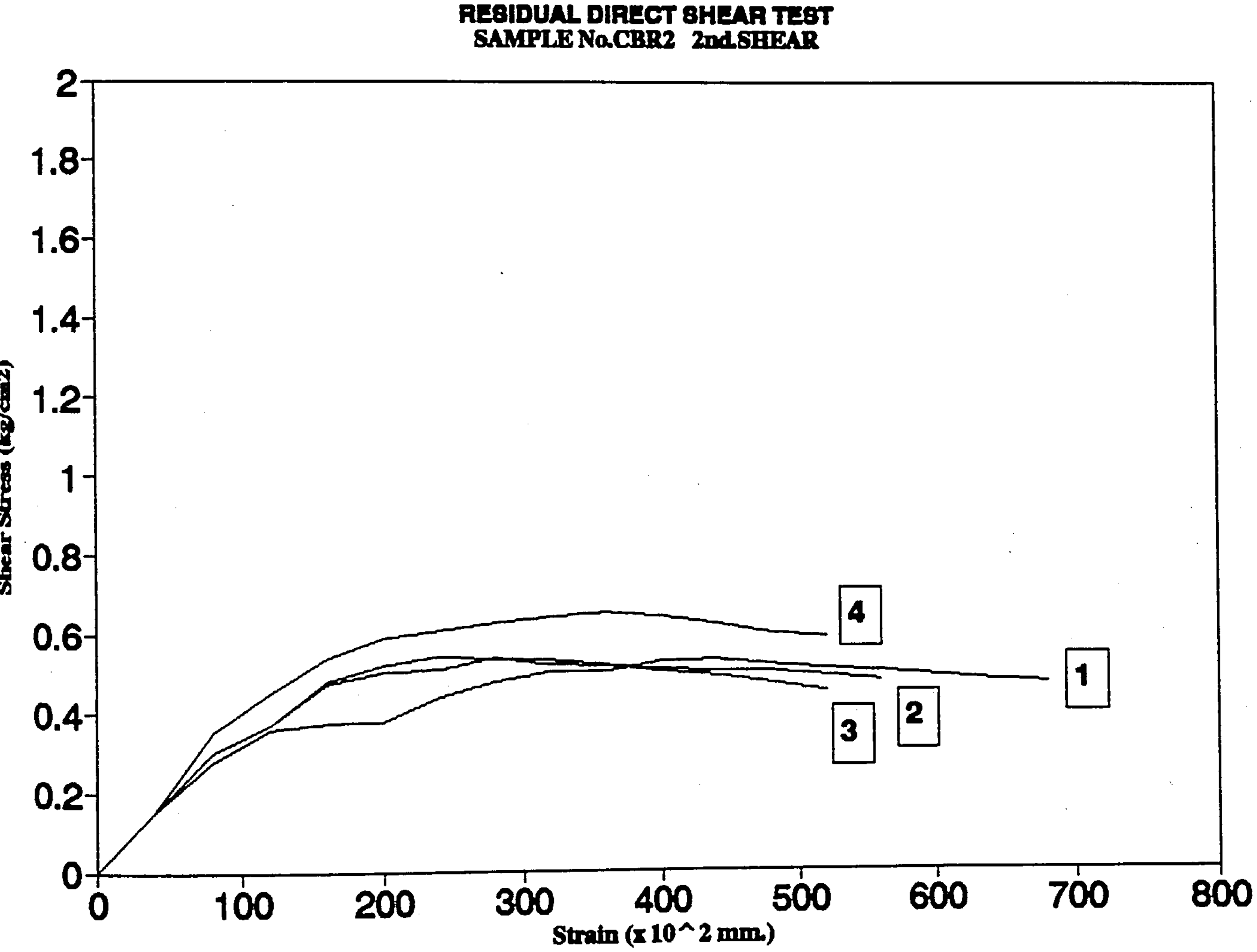


FIGURE A3.4.2 Residual direct shear test

Sample no.CBR2 2nd. Shear

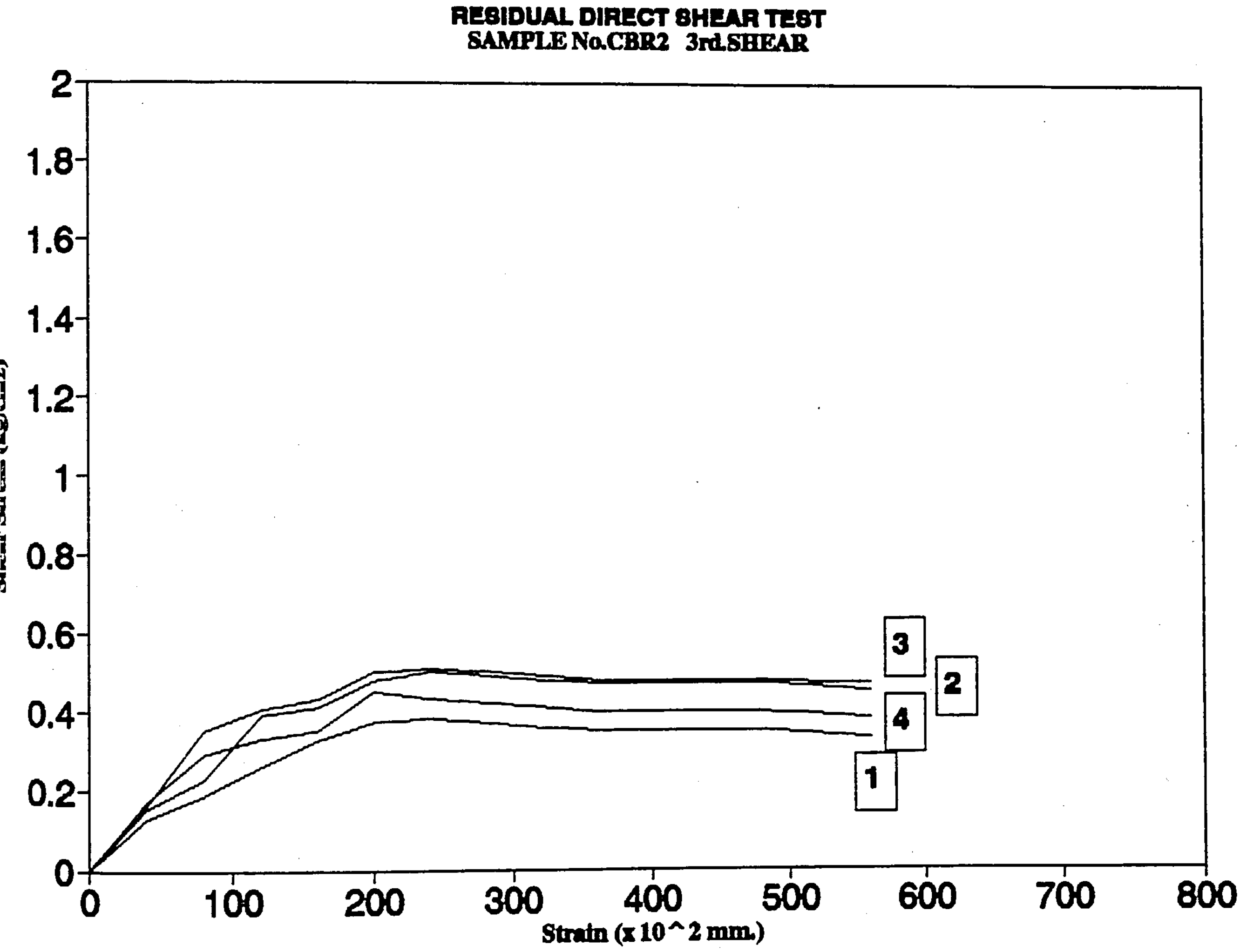
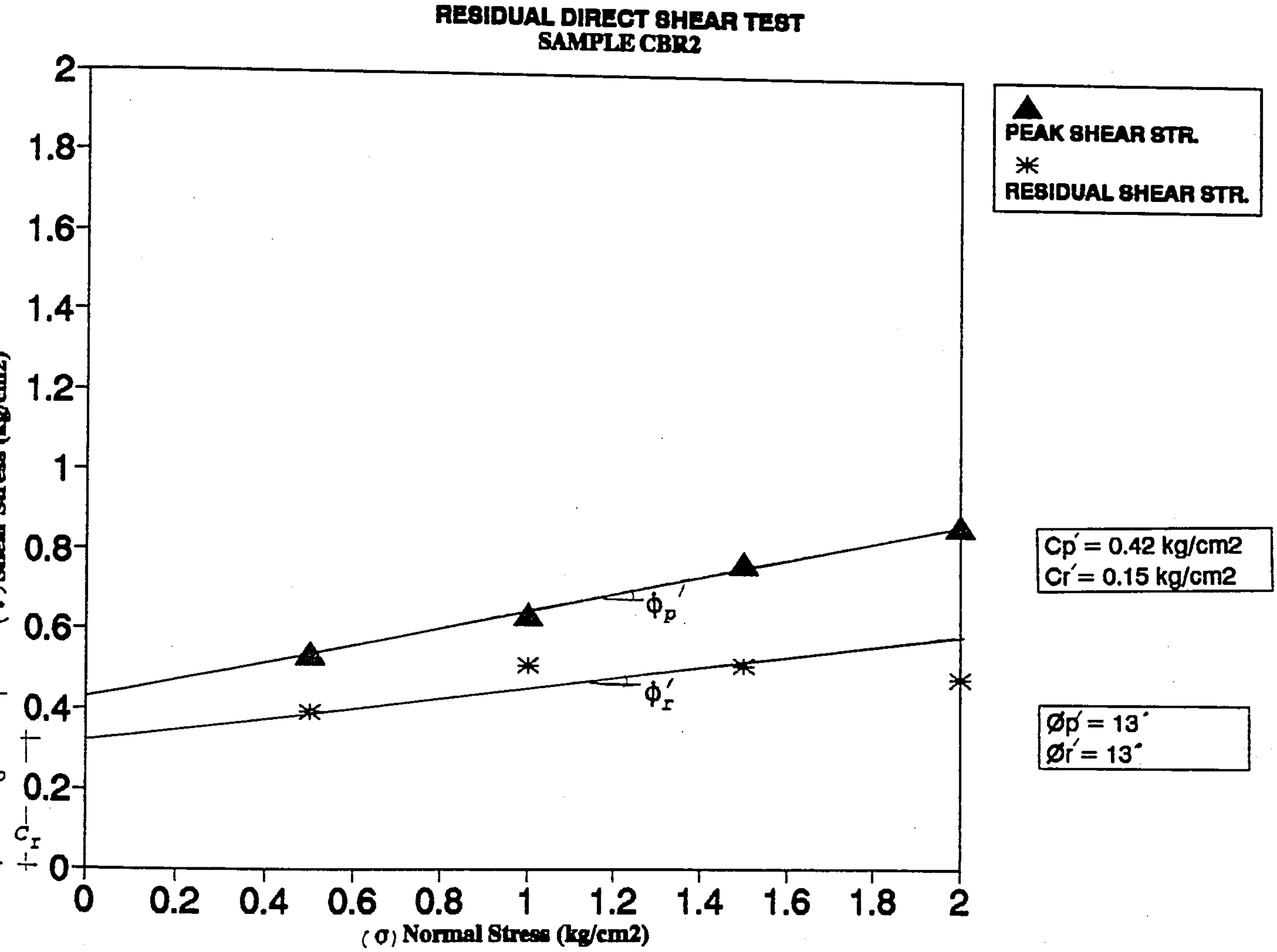


FIGURE A3.4.3 Residual direct shear test

Sample no.CBR2 3rd. Shear



TEST :CBR2

SAMPLE	σ_n (Kg/cm2)	τ_p (Kg/cm2)	τ_r (Kg/cm2)
1	0.5	0.54	0.39
2	1	0.64	0.51
3	1.5	0.77	0.51
4	2	0.87	0.48

FIGURE A3.4.4 Residual direct shear test results

Sample no.CBR2

APPENDIX 4.

COMPUTER OUTPUTS

```
          SLOPE STABILITY CALCULATIONS
1   BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+500

     UNITS IN METERS      ,KILONEWTONS
    NO OF LINES=  8     NO OF LINE INTERSECT=  9
    NO OF SOILS=  1     NO OF EXTERNAL SOIL LINES=  8
    NO OF X INCREMENTS=  4     NO OF Y INCREMENTS=  1
    INITIAL SLICE WIDTH=   .5 METERS
    UNI. DIST. LOAD =     .0000    BETWEEN  92.5000 -  150.0000

    LINE END COORD MATRIX
  LINE NO NO INT    X1        Y1        X2        Y2      SLOPE      LINE INTER NO
    1.    2.        .00     30.00     95.00     30.00  .000000        1    2
    2.    2.      95.00     30.00    110.00     40.00  .666667        2    3
    3.    2.     110.00     40.00    115.00     40.00  .000000        3    4
    4.    2.     115.00     40.00    130.00     50.00  .666667        4    5
    5.    2.     130.00     50.00    135.00     50.00  .000000        5    6
    6.    2.     135.00     50.00    144.00     56.00  .666667        6    7
    7.    2.     144.00     56.00    226.00     67.00  .134146        7    8
    8.    2.     226.00     67.00    301.00     68.00  .133333E-01    8    9


   LINE INTERSECT ARRAY
  INT NO      X          Y
     1         .00      30.00
     2       95.00      30.00
     3      110.00      40.00
     4      115.00      40.00
     5      130.00      50.00
     6      135.00      50.00
     7      144.00      56.00
     8      226.00      67.00
     9      301.00      68.00
    RU =     .10
   EARTHQUAKE COEFF. =      .00

    SOIL DATA ARRAY
  SOIL NO  LINE NO LEFT INT   RT. INT   SAT   UNIT WT   PHI   COHESION
     1       1.         1.       2.      0.      19.0   10.0        .0
     1       2.         2.       3.      0.      19.0   10.0        .0
     1       3.         3.       4.      0.      19.0   10.0        .0
     1       4.         4.       5.      0.      19.0   10.0        .0
     1       5.         5.       6.      0.      19.0   10.0        .0
     1       6.         6.       7.      0.      19.0   10.0        .0
     1       7.         7.       8.      0.      19.0   10.0        .0
     1       8.         8.       9.      0.      19.0   10.0        .0

   NOTE:THE COHES. , PHI AND RU  WRITTEN ABOVE
   ARE THE INITIAL VALUES USED IN BACK CALCULATION

                  FI=   1.00000   FO=   1.00000
0 THE SAFETY FACTOR FOR POINT  12IS   1.00000
```

```
SLOPE STABILITY CALCULATIONS
BACK CALCULATION FOR LANDSLIDES AT SECTION  / Km 141+500 /


 PHI        RU      COHES
 10.00       .10     3.16
 10.20       .10     2.22
 10.40       .10     1.29
 10.60       .10      .35
```

```
   SLOPE STABILITY CALCULATIONS
1  BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+550

    UNITS IN METERS      ,KILONEWTONS
    NO OF LINES=  7     NO OF LINE INTERSECT=  8
    NO OF SOILS=  1     NO OF EXTERNAL SOIL LINES=  7
    NO OF X INCREMENTS=  3     NO OF Y INCREMENTS=  1
    INITIAL SLICE WIDTH=   .5 METERS
    UNI. DIST. LOAD =     .0000    BETWEEN  92.5000 -  150.0000

   LINE END COORD MATRIX
  LINE NO NO INT   X1        Y1        X2        Y2     SLOPE     LINE INTER NO
     1.    2.       .00     30.00     95.00     30.00  .000000       1    2
     2.    2.     95.00     30.00    110.00     40.00  .666667       2    3
     3.    2.    110.00     40.00    115.00     40.00  .000000       3    4
     4.    2.    115.00     40.00    130.00     50.00  .666667       4    5
     5.    2.    130.00     50.00    135.00     50.00  .000000       5    6
     6.    2.    135.00     50.00    150.00     60.00  .666667       6    7
     7.    2.    150.00     60.00    320.00     83.00  .135294       7    8


   LINE INTERSECT ARRAY
  INT NO      X          Y
     1          .00      30.00
     2        95.00      30.00
     3       110.00      40.00
     4       115.00      40.00
     5       130.00      50.00
     6       135.00      50.00
     7       150.00      60.00
     8       320.00      83.00
    RU =     .00
   EARTHQUAKE COEFF. =     .00

    SOIL DATA ARRAY
  SOIL NO  LINE NO LEFT INT   RT. INT   SAT   UNIT WT   PHI   COHESION
     1       1.        1.        2.      0.      19.0   12.0       .0
     1       2.        2.        3.      0.      19.0   12.0       .0
     1       3.        3.        4.      0.      19.0   12.0       .0
     1       4.        4.        5.      0.      19.0   12.0       .0
     1       5.        5.        6.      0.      19.0   12.0       .0
     1       6.        6.        7.      0.      19.0   12.0       .0
     1       7.        7.        8.      0.      19.0   12.0       .0

    NOTE:THE COHES. , PHI AND RU  WRITTEN ABOVE
    ARE THE INITIAL VALUES USED IN BACK CALCULATION

                       FI=   1.00000   FO=   1.00000
 0 THE SAFETY FACTOR FOR POINT  1OIS   1.00000
```

```
SLOPE STABILITY CALCULATIONS
BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+550


 PHI       RU      COHES
 12.00      .00     2.02
 12.10      .00     1.41
 12.20      .00      .81
```

```
   SLOPE STABILITY CALCULATIONS
1  BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+600

    UNITS IN METERS      ,KILONEWTONS
    NO OF LINES=  8     NO OF LINE INTERSECT=  9
    NO OF SOILS=  1     NO OF EXTERNAL SOIL LINES=  8
    NO OF X INCREMENTS=  3     NO OF Y INCREMENTS=  1
    INITIAL SLICE WIDTH=   .5 METERS
    UNI. DIST. LOAD =     .0000    BETWEEN  92.5000 -  150.0000

    LINE END COORD MATRIX
  LINE NO NO INT   X1         Y1        X2        Y2      SLOPE     LINE INTER NO
     1.     2.       .00     30.00     95.00     30.00  .000000        1    2
     2.     2.     95.00     30.00    110.00     40.00  .666667        2    3
     3.     2.    110.00     40.00    115.00     40.00  .000000        3    4
     4.     2.    115.00     40.00    130.00     50.00  .666667        4    5
     5.     2.    130.00     50.00    135.00     50.00  .000000        5    6
     6.     2.    135.00     50.00    144.00     56.00  .666667        6    7
     7.     2.    144.00     56.00    259.00     70.00  .121739        7    8
     8.     2.    259.00     70.00    339.00     92.00  .275000        8    9


   LINE INTERSECT ARRAY
  INT NO       X          Y
     1          .00      30.00
     2        95.00      30.00
     3       110.00      40.00
     4       115.00      40.00
     5       130.00      50.00
     6       135.00      50.00
     7       144.00      56.00
     8       259.00      70.00
     9       339.00      92.00
    RU =     .00
   EARTHQUAKE COEFF. =     .00

    SOIL DATA ARRAY
  SOIL NO  LINE NO LEFT INT   RT. INT   SAT   UNIT WT   PHI   COHESION
     1       1.        1.        2.      0.      19.0   11.5        .0
     1       2.        2.        3.      0.      19.0   11.5        .0
     1       3.        3.        4.      0.      19.0   11.5        .0
     1       4.        4.        5.      0.      19.0   11.5        .0
     1       5.        5.        6.      0.      19.0   11.5        .0
     1       6.        6.        7.      0.      19.0   11.5        .0
     1       7.        7.        8.      0.      19.0   11.5        .0
     1       8.        8.        9.      0.      19.0   11.5        .0

    NOTE:THE COHES. , PHI AND RU  WRITTEN ABOVE
    ARE THE INITIAL VALUES USED IN BACK CALCULATION

                    FI=   1.00000   FO=   1.00000
0 THE SAFETY FACTOR FOR POINT   9IS   1.00000
```

```
SLOPE STABILITY CALCULATIONS
BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+600


 PHI        RU      COHES
 11.50      .00     1.73
 11.60      .00     1.31
 11.70      .00      .89
```

```
  SLOPE STABILITY CALCULATIONS
1  BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+650

    UNITS IN METERS      ,KILONEWTONS
    NO OF LINES=  8     NO OF LINE INTERSECT=  9
    NO OF SOILS=  1     NO OF EXTERNAL SOIL LINES=  8
    NO OF X INCREMENTS=  3     NO OF Y INCREMENTS=  1
    INITIAL SLICE WIDTH=   .5 METERS
    UNI. DIST. LOAD =     .0000    BETWEEN  92.5000 -  150.0000

   LINE END COORD MATRIX
  LINE NO NO INT    X1         Y1         X2          Y2      SLOPE       LINE INTER NO
     1.    2.        .00      30.00      95.00       30.00  .000000         1     2
     2.    2.      95.00      30.00     110.00       40.00  .666667         2     3
     3.    2.     110.00      40.00     115.00       40.00  .000000         3     4
     4.    2.     115.00      40.00     130.00       50.00  .666667         4     5
     5.    2.     130.00      50.00     135.00       50.00  .000000         5     6
     6.    2.     135.00      50.00     144.00       56.00  .666667         6     7
     7.    2.     144.00      56.00     198.00       69.00  .240741         7     8
     8.    2.     198.00      69.00     310.00       93.00  .214286         8     9


   LINE INTERSECT ARRAY
  INT NO       X            Y
      1          .00       30.00
      2        95.00       30.00
      3       110.00       40.00
      4       115.00       40.00
      5       130.00       50.00
      6       135.00       50.00
      7       144.00       56.00
      8       198.00       69.00
      9       310.00       93.00
    RU =      .00
   EARTHQUAKE COEFF. =     .00

     SOIL DATA ARRAY
  SOIL NO  LINE NO LEFT INT   RT. INT   SAT   UNIT WT   PHI   COHESION
     1        1.        1.        2.      0.      19.0   13.0       .0
     1        2.        2.        3.      0.      19.0   13.0       .0
     1        3.        3.        4.      0.      19.0   13.0       .0
     1        4.        4.        5.      0.      19.0   13.0       .0
     1        5.        5.        6.      0.      19.0   13.0       .0
     1        6.        6.        7.      0.      19.0   13.0       .0
     1        7.        7.        8.      0.      19.0   13.0       .0
     1        8.        8.        9.      0.      19.0   13.0       .0

     NOTE:THE COHES. , PHI AND RU  WRITTEN ABOVE
    ARE THE INITIAL VALUES USED IN BACK CALCULATION

                      FI=   1.00000   FO=   1.00070
0 THE SAFETY FACTOR FOR POINT   9IS  1.00070
```

```
SLOPE STABILITY CALCULATIONS
BACK CALCULATION FOR LANDSLIDES AT SECTION / KM.141+650


 PHI        RU       COHES
 13.00       .00      3.56
 13.50       .00      1.77
 14.00       .00       .00
```

```
                                                                    ! Run No.     550
Program: SLOPE  version 6.00  licensed from GEOSOLVE                ! Job No.     002
                                                                    ! Made by :
TAG MOTORWAY KM 141+000 LANDSLIDE                                   ! Date:
SECTION KM 141+550                                                  ! Checked :
                                                                    !
--------------------------------------------------------------------!-----------------

                                                        Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line    1          2          3          4          5          6          7          8
 X-Coord  -20.00       0.00      25.00      40.00      45.00      60.00      65.00      88.00
 ----------------------------------------------------------------------------------------
 Stratum     Y-Coordinates
  1(GL)    230.00     230.00     230.00     240.00     240.00     250.00     250.00     265.30
  2        220.00     220.00     217.00     217.00     218.00     220.00     220.00     225.00

 Grid line    9         10         11
 X-Coord  170.00     175.00     285.00
 -------------------------------------
 Stratum     Y-Coordinates
  1(GL)    286.00     287.00     285.00
  2        264.00     265.00     285.00

SOIL PROPERTIES
                               Bulk densities    -------Strength parameters-------
 --- S t r a t u m ---        below    above       C       Phi        dC/dY    Datum
 No.       Description         GWL      GWL               (deg)               for C
 1    slope debris          .  8.00    18.00     0.00     16.00
 2    bedrock                 10.00    20.00   200.00     35.00

GROUND WATER CONDITIONS
 Density of water = 10.00
 Grid line    1          2          3          4          5          6          7          8
 X-Coord   -20.00      0.00      25.00      40.00      45.00      60.00      65.00      88.00
 ----------------------------------------------------------------------------------------
             Ground water level
             0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00

 Grid line    9         10         11
 X-Coord  170.00     175.00     285.00
 -------------------------------------
             Ground water level
             0.00       0.00       0.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.      X Coord      Y Coord
     1          -20.00       230.00
     2            0.00       220.00
     3           65.00       220.00
     4          170.00       265.00
     5          175.00       287.00

METHOD OF ANALYSIS
 JANBU  - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  8
```

```
                                                            ! Run No.      650
Program: SLOPE  version 6.00  licensed from GEOSOLVE        ! Job No.      001
                                                            ! Made by :
TAG MOTORWAY KM 141+000 LANDSLIDE                           ! Date:
SECTION KM 141+650                                          ! Checked :
------------------------------------------------------------!-------------

                                                     Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line    1        2        3        4        5        6        7        8
 X-Coord     0.00    25.00    35.00    40.00    45.00    60.00    65.00    78.00
 ------------------------------------------------------------------------------
 Stratum     Y-Coordinates
  1(GL)     230.00   230.00   236.67   240.00   240.00   250.00   250.00   258.00
  2         230.00   230.00   233.33   235.00   237.00   241.00   242.00   244.00

 Grid line    9       10       11       12
 X-Coord   170.00   171.00   308.00   310.00
 ------------------------------------------
 Stratum     Y-Coordinates
  1(GL)     280.00   280.14   300.00   290.00
  2         265.00   265.25   300.00   290.00

SOIL PROPERTIES
                               Bulk densities   -------Strength parameters-------
 --- S t r a t u m ---         below   above      C      Phi       dC/dY    Datum
 No.       Description          GWL     GWL              (deg)              for C
 1    slope debris              8.00   18.00     0.00   13.00
 2    bedrock                  10.00   20.00   200.00   35.00

GROUND WATER CONDITIONS
 Density of water =   1.00
 Grid line    1        2        3        4        5        6        7        8
 X-Coord     0.00    25.00    35.00    40.00    45.00    60.00    65.00    78.00
 ------------------------------------------------------------------------------
             Ground water level
         -100.00  -100.00  -100.00  -100.00  -100.00  -100.00  -100.00  -100.00

 Grid line    9       10       11       12
 X-Coord   170.00   171.00   308.00   310.00
 ------------------------------------------
             Ground water level
         -100.00  -100.00  -100.00  -100.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.     X Coord     Y Coord
     1          35.00      236.67
     2         170.00      266.00
     3         171.00      280.14

METHOD OF ANALYSIS
 JANBU  - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  8
```

```
                                                            ! Run No.    650
Program: SLOPE  version 6.00  licensed from GEOSOLVE        ! Job No.    001
                                                            ! Made by :
TAG MOTORWAY KM 141+000 LANDSLIDE                           ! Date:
SECTION KM 141+650                                          ! Checked :
------------------------------------------------------------!--------------

                                                     Units: kN-m
RESULTS
*******
Method of analysis: JANBU  - Parallel inclined interslice forces
                    Factor of safety on Shear Strength
                    Minimum number of slices =  8

 Factor of safety =    1.004
 Slipped mass     =     2599     Out of balance  vertical   force =      0
 Delta =  5.0deg                 Out of balance horizontal  force =      1
 Moments taken about: X =   -53.74 , Y =   748.68
 Overturning moment  =     303011      Restoring moment =     304348

  Slip surface coordinates  Piezometric  ------- Interslice forces --------
  ------------------------   elevation   ----- horizontal ------   vertical
   No.       X        Y        Y(w)     E(total)  E'(effective)      Q
    1      35.00   236.67   -100.00        0            0            0
    2      40.00   237.75   -100.00        0            0            0
    3      45.00   238.84   -100.00        0            0            0
    4      60.00   242.10   -100.00        2            2            0
    5      65.00   243.19   -100.00        3            3            0
    6      78.00   246.01   -100.00        5            5            0
    7      93.33   249.34   -100.00        9            9            1
    8     108.67   252.67   -100.00       13           13            1
    9     124.00   256.00   -100.00       18           18            2
   10     139.33   259.34   -100.00       22           22            2
   11     154.67   262.67   -100.00       26           26            2
   12     170.00   266.00   -100.00       31           31            3
   13     171.00   280.14   -100.00       -1           -1            0

  Slice   Cohesion   Tan(phi)    Pore     Weight   Forces on base of slice
   No.                         pressure  of slice  --- normal ---    shear
          (avge)     (avge)    (avge)      W        P        P'        S
    1      0.00     0.2309      0.00       10       10       10        2
    2      0.00     0.2309      0.00       15       15       15        3
    3      0.00     0.2309      0.00      122      119      119       27
    4      0.00     0.2309      0.00       66       65       65       15
    5      0.00     0.2309      0.00      220      215      215       49
    6      0.00     0.2309      0.00      336      327      327       75
    7      0.00     0.2309      0.00      345      336      336       77
    8      0.00     0.2309      0.00      354      345      345       79
    9      0.00     0.2309      0.00      363      354      354       81
   10      0.00     0.2309      0.00      373      363      363       84
   11      0.00     0.2309      0.00      382      372      372       86
   12      0.00     0.2309      0.00       13       32       32        7
```

SLOPE STABILITY ANALYSIS FOR ROCK BUTTRESS ALTERNATIVE

```
                                                           ! Run No.   600RB
Program: SLOPE  version 6.00  licensed from GEOSOLVE       ! Job No.    003
                                                           ! Made by :
TAG MOTORWAY KM 141+000 LANDSLIDE                          ! Date:
SECTION KM 141+600 ROCK-BUTTRESS                           ! Checked :
                                                           !
-----------------------------------------------------------!--------------

                                                    Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line   1        2        3        4        5        6        7        8
 X-Coord  -20.00    15.00    20.00    25.00    40.00    45.00    50.00    90.00
 ------------------------------------------------------------------------------
 Stratum     Y-Coordinates
  1(GL)    230.00   230.00   230.00   230.00   237.50   240.00   240.00   260.00
  2        230.00   230.00   220.00   222.00   228.00   240.00   240.00   260.00
  3        210.00   216.00   218.00   219.00   223.00   224.00   225.00   226.00

 Grid line   9       10       11
 X-Coord  190.00   200.00   300.00
 ----------------------------------
 Stratum     Y-Coordinates
  1(GL)    275.00   270.00   295.00
  2        275.00   270.00   295.00
  3        260.00   262.00   295.00

SOIL PROPERTIES
                           Bulk densities   -------Strength parameters-------
 --- S t r a t u m ---     below   above       C      Phi      dC/dY   Datum
 No.      Description       GWL     GWL              (deg)             for C
 1    ROCK BUTTRESS        10.00   20.00     0.00   45.00
 2    SLOPE DEBRIS          8.00   18.00     0.00   14.00
 3    BEDROCK              10.00   20.00   200.00   35.00

GROUND WATER CONDITIONS
 Density of water = 10.00
 Grid line   1        2        3        4        5        6        7        8
 X-Coord  -20.00    15.00    20.00    25.00    40.00    45.00    50.00    90.00
 ------------------------------------------------------------------------------
            Ground water level
            0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 Grid line   9       10       11
 X-Coord  190.00   200.00   300.00
 ----------------------------------
            Ground water level
            0.00     0.00     0.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.      X Coord     Y Coord
     1          -20.00      230.00
     2           15.00      225.00
     3          190.00      265.00
     4          200.00      270.00


METHOD OF ANALYSIS
 JANBU  - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  8
```

```
                                                           ! Sheet No.
Program: SLOPE  version 6.00  licensed from GEOSOLVE       ! Run No.  600RB
                                                           ! Job No.    003
TAG MOTORWAY KM 141+000 LANDSLIDE                          ! Made by :
SECTION KM 141+600 ROCK-BUTTRESS                           ! Date:
                                                           ! Checked :
-----------------------------------------------------------!-------------

                                                     Units: kN-m
RESULTS
*******
Method of analysis: JANBU  - Parallel inclined interslice forces
                    Factor of safety on Shear Strength
                    Minimum number of slices =  8

 Factor of safety =    1.332
 Slipped mass     =    40054    Out of balance  vertical  force =     0
 Delta = 11.7deg                Out of balance horizontal force =     2
 Moments taken about: X =    -2.60 , Y =   759.28
 Overturning moment  =    4474366     Restoring moment =    5961222

  Slip surface coordinates  Piezometric  ------- Interslice forces --------
  ------------------------   elevation   ----- horizontal ------   vertical
   No.       X        Y        Y(w)      E(total)  E'(effective)     Q
    1     -20.00   230.00      0.00          0           0           0
    2      -2.50   227.50      0.00        144         144          30
    3      15.00   225.00      0.00        575         575         119
    4      20.00   226.14      0.00        681         681         141
    5      25.00   227.29      0.00        842         842         175
    6      40.00   230.71      0.00       1542        1542         319
    7      45.00   231.86      0.00       1608        1608         333
    8      50.00   233.00      0.00       1581        1581         328
    9      70.00   237.57      0.00       1443        1443         299
   10      90.00   242.14      0.00       1229        1229         255
   11     115.00   247.86      0.00        929         929         193
   12     140.00   253.57      0.00        665         665         138
   13     165.00   259.29      0.00        435         435          91
   14     190.00   265.00      0.00        241         241          50
   15     200.00   270.00      0.00         -2          -2           0

  Slice   Cohesion   Tan(phi)     Pore      Weight   Forces on base of slice
   No.                          pressure   of slice  --- normal ---    shear
           (avge)     (avge)     (avge)       W        P        P'       S
    1       0.00     0.2496      0.00       394      440      440       82
    2       0.00     0.2493      0.00      1181     1319     1319      247
    3       0.00     0.6632      0.00       418      405      405      202
    4       0.00     1.0000      0.00       329      317      317      238
    5       0.00     1.0000      0.00      1425     1374     1374     1032
    6       0.00     0.4370      0.00       706      687      687      225
    7       0.00     0.2493      0.00       681      665      665      124
    8       0.00     0.2493      0.00      3497     3412     3412      639
    9       0.00     0.2493      0.00      5451     5319     5319      995
   10       0.00     0.2493      0.00      7594     7409     7409     1387
   11       0.00     0.2493      0.00      6710     6547     6547     1225
   12       0.00     0.2493      0.00      5826     5684     5684     1064
   13       0.00     0.2493      0.00      4942     4822     4822      902
   14       0.00     0.2494      0.00       900      869      869      163
```

```
                                                                    ¦ Sheet No.
Program: SLOPE  version 6.00  licensed from GEOSOLVE               ¦ Run No. 600rb1
                                                                    ¦ Job No.    003
                                                                    ¦ Made by :
TAG MOTORWAY KM 141+000 LANDSLIDE                                   ¦ Date:
SECTION KM 141+600 ROCK-BUTTRESS                                    ¦ Checked :
-------------------------------------------------------------------¦-------------

                                                           Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line    1         2         3         4         5         6         7         8
 X-Coord   -20.00     15.00     20.00     25.00     40.00     45.00     50.00     80.00
 -----------------------------------------------------------------------------------------
 Stratum     Y-Coordinates
  1(GL)    230.00    230.00    230.00    230.00    237.50    240.00    240.00    255.00
  2        230.00    230.00    220.00    222.00    228.00    229.00    230.00    240.00
  3        210.00    216.00    218.00    219.00    223.00    224.00    225.00    225.75

 Grid line    9        10        11        12
 X-Coord    90.00    190.00    200.00    300.00
 ---------------------------------------------
 Stratum     Y-Coordinates
  1(GL)    260.00    275.00    270.00    295.00
  2        260.00    275.00    270.00    295.00
  3        226.00    260.00    262.00    295.00

SOIL PROPERTIES
                                Bulk densities    -------Strength parameters-------
 --- S t r a t u m ---          below   above       C      Phi         dC/dY    Datum
 No.        Description          GWL     GWL              (deg)                 for C
 1    SLOPE DEBRIS              10.00   20.00      0.00   45.00
 2    ROCK-BUTTRESS              8.00   18.00      0.00   14.00
 3    BEDROCK                   10.00   20.00    200.00   35.00

GROUND WATER CONDITIONS
 Density of water = 10.00
 Grid line    1         2         3         4         5         6         7         8
 X-Coord   -20.00     15.00     20.00     25.00     40.00     45.00     50.00     80.00
 -----------------------------------------------------------------------------------------
             Ground water level
             0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 Grid line    9        10        11        12
 X-Coord    90.00    190.00    200.00    300.00
 ---------------------------------------------
             Ground water level
             0.00      0.00      0.00      0.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.      X Coord      Y Coord
     1          -20.00       230.00
     2           15.00       225.00
     3          190.00       265.00
     4          200.00       270.00


METHOD OF ANALYSIS
 JANBU  - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  8
```

```
SOIL STRUCTURES INTERNATIONAL LTD.                          ! Sheet No.
                                                            ! Run No. 600rb1
Program: SLOPE  version 6.00  licensed from GEOSOLVE        ! Job No.    003
                                                            ! Made by :
TAG MOTORWAY KM 141+000 LANDSLIDE                           ! Date:
SECTION KM 141+600 ROCK-BUTTRESS                            ! Checked :
------------------------------------------------------------!-------------

                                                     Units: kN-m
RESULTS
*******
Method of analysis: JANBU  - Parallel inclined interslice forces
                    Factor of safety on Shear Strength
                    Minimum number of slices =  8

 Factor of safety =    1.961
 Slipped mass     =    40982     Out of balance  vertical  force =      0
 Delta = 12.1deg                 Out of balance horizontal force =      4
 Moments taken about: X =    -9.17 , Y =   795.43
 Overturning moment  =    4905660      Restoring moment =    9619576

  Slip surface coordinates  Piezometric  ------- Interslice forces --------
  ------------------------   elevation   ----- horizontal ------   vertical
   No.        X        Y        Y(w)     E(total)  E'(effective)    Q
    1      -20.00   230.00      0.00          0           0          0
    2       -2.50   227.50      0.00        115         115         25
    3       15.00   225.00      0.00        460         460         98
    4       20.00   226.14      0.00        504         504        108
    5       25.00   227.29      0.00        591         591        126
    6       40.00   230.71      0.00        971         971        207
    7       45.00   231.86      0.00       1170        1170        250
    8       50.00   233.00      0.00       1371        1371        293
    9       65.00   236.43      0.00       2093        2093        447
   10       80.00   239.86      0.00       3011        3011        643
   11       90.00   242.14      0.00       2710        2710        579
   12      115.00   247.86      0.00       1977        1977        423
   13      140.00   253.57      0.00       1329        1329        284
   14      165.00   259.29      0.00        767         767        164
   15      190.00   265.00      0.00        290         290         63
   16      200.00   270.00      0.00         -4          -4         -0

  Slice   Cohesion   Tan(phi)    Pore      Weight   Forces on base of slice
   No.                         pressure   of slice  --- normal ---    shear
           (avge)     (avge)    (avge)       W         P        P'       S
    1       0.00     0.2496      0.00       394       431      431      55
    2       0.00     0.2493      0.00      1181      1291     1291     164
    3       0.00     0.6632      0.00       418       407      407     138
    4       0.00     1.0000      0.00       329       319      319     163
    5       0.00     1.0000      0.00      1425      1384     1384     706
    6       0.00     1.0000      0.00       746       725      725     370
    7       0.00     1.0000      0.00       757       735      735     375
    8       0.00     1.0000      0.00      2711      2632     2632    1342
    9       0.00     0.9318      0.00      3930      3818     3818    1814
   10       0.00     0.2493      0.00      3120      3046     3046     387
   11       0.00     0.2493      0.00      7594      7414     7414     943
   12       0.00     0.2493      0.00      6710      6551     6551     833
   13       0.00     0.2493      0.00      5826      5688     5688     723
   14       0.00     0.2493      0.00      4942      4825     4825     613

   15       0.00     0.2494      0.00       900       880      880     112
```

STABİLİTY ANALYSIS FOR ALTERNATIVE 2

```
                                                           : Sheet No.
                                                           : Run No.550ALT2
Program: SLOPE  version 6.00  licensed from GEOSOLVE        : Job No.     003
                                                           : Made by :
TAG MOTORWAY KM.141+550 LANDSLIDE                          : Date:         138
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2             : Checked :
___________________________________________________________:_____________

                                                      Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line   1        2        3        4        5        6        7        8
 X-Coord  -20.00     0.00    25.00    75.00   126.00   141.00   152.00   167.00
 ------------------------------------------------------------------------------
 Stratum     Y-Coordinates
  1(GL)    230.00   230.00   230.00   235.00   241.00   242.00   242.50   248.00
  2        220.00   220.00   217.00   220.00   234.00   238.00   242.50   248.00

 Grid line   9
 X-Coord  267.00
 ---------------
 Stratum     Y-Coordinates
  1(GL)    275.00
  2        275.00

SOIL PROPERTIES
                                   Bulk densities   -------Strength parameters-------
 --- S t r a t u m ---             below   above      C      Phi        dC/dY   Datum
 No.      Description               GWL     GWL              (deg)              for C
 1     SLOPE DEPRIS                8.00   18.00     0.00   16.00
 2     BEDROCK                    10.00   20.00   200.00   35.00

GROUND WATER CONDITIONS
 Density of water = 10.00
 Grid line   1        2        3        4        5        6        7        8
 X-Coord  -20.00     0.00    25.00    75.00   126.00   141.00   152.00   167.00
 ------------------------------------------------------------------------------
            Ground water level
            0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 Grid line   9
 X-Coord  267.00
 ---------------
            Ground water level
            0.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.     X Coord     Y Coord
     1          -20.00      230.00
     2            0.00      220.00
     3           75.00      220.00
     4          141.00      242.00

METHOD OF ANALYSIS
 JANBU  - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  8
```

```
                                                              No.
                                                            ! Run No.550ALT2
Program: SLOPE  version 6.00  licensed from GEOSOLVE        ! Job No.    003
                                                            ! Made by :
TAG MOTORWAY KM.141+550 LANDSLIDE                           ! Date:
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2              ! Checked :
-------------------------------------------------------------------------------

                                                     Units: kN-m
RESULTS
*******

Method of analysis: JANBU  - Parallel inclined interslice forces
                    Factor of safety on Shear Strength
                    Minimum number of slices =  8

 Factor of safety =     3.859
 Slipped mass     =     26811     Out of balance vertical  force =      0
 Delta =  4.1deg                  Out of balance horizontal force =      1
 Moments taken about: X =    45.42 , Y =   438.30
 Overturning moment  =     442261      Restoring moment =    1706839

  Slip surface coordinates  Piezometric  ------- Interslice forces --------
  ------------------------   elevation   ----- horizontal ------   vertical
  No.       X        Y         Y(w)      E(total)  E'(effective)     Q
   1     -20.00   230.00       0.00          0          0            0
   2     -10.00   225.00       0.00        280        280           20
   3       0.00   220.00       0.00       1122       1122           80
   4      12.50   220.00       0.00       1290       1290           93
   5      25.00   220.00       0.00       1458       1458          105
   6      41.67   220.00       0.00       1701       1701          122
   7      58.33   220.00       0.00       1981       1981          142
   8      75.00   220.00       0.00       2298       2298          165
   9      92.00   225.67       0.00       1298       1298           93
  10     109.00   231.33       0.00        576        576           41
  11     126.00   237.00       0.00        133        133           10
  12     141.00   242.00       0.00         -1         -1           -0

  Slice   Cohesion  Tan(phi)    Pore      Weight   Forces on base of slice
  No.                         pressure   of slice  --- normal ---     shear
          (avge)    (avge)    (avge)       W         P        P'        S
   1       0.00    0.2867      0.00       450      546       546       41
   2       0.00    0.2867      0.00      1350     1638      1638      122
   3       0.00    0.2867      0.00      2250     2262      2262      168
   4       0.00    0.2867      0.00      2250     2262      2262      168
   5       0.00    0.2867      0.00      3250     3267      3267      243
   6       0.00    0.2867      0.00      3750     3770      3770      280
   7       0.00    0.2867      0.00      4250     4273      4273      317
   8       0.00    0.2867      0.00      4029     4070      4070      302
   9       0.00    0.2867      0.00      2907     2937      2937      218
  10       0.00    0.2867      0.00      1785     1803      1803      134
  11       0.00    0.2867      0.00       540      546       546       41

 Program SLOPE -
```

```
                                                                    ! Sheet No.
Program: SLOPE  version 6.00  licensed from GEOSOLVE               ! Run No.550alt2
-----------------------------------------------------------------  ! Job No.    003
                                                                    ! Made by :
TAG MOTORWAY KM.141+550 LANDSLIDE                                   ! Date:          140
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2                      ! Checked :
--------------------------------------------------------------------!----------------
                                                          Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line   1          2         3         4         5         6         7         8
 X-Coord  -20.00     0.00     25.00     75.00    126.00    141.00    152.00    167.00
---------------------------------------------------------------------------------------
 Stratum      Y-Coordinates
  1(GL)    230.00   230.00    230.00    235.00    241.00    242.00    242.50    248.00
  2        220.00   220.00    217.00    220.00    234.00    238.00    242.50    248.00

 Grid line    9
 X-Coord   267.00
 ---------------
 Stratum      Y-Coordinates
  1(GL)    275.00
  2        275.00

SOIL PROPERTIES
                              Bulk densities    -------Strength parameters-------
 --- S t r a t u m ---        below  above       C      Phi        dC/dY    Datum
 No.      Description          GWL    GWL              (deg)                for C
 1   SLOPE DEPRIS             8.00  18.00      0.00   16.00
 2   BEDROCK                 10.00  20.00    200.00   35.00

GROUND WATER CONDITIONS
 Density of water = 10.00
 Grid line   1          2         3         4         5         6         7         8
 X-Coord  -20.00     0.00     25.00     75.00    126.00    141.00    152.00    167.00
---------------------------------------------------------------------------------------
               Ground water level
           225.00   225.00    227.00    236.00    240.00    240.00    240.00    246.00

 Grid line    9
 X-Coord   267.00
 ---------------
               Ground water level
           273.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.      X Coord      Y Coord
     1          -20.00       230.00
     2            0.00       220.00
     3           75.00       220.00
     4          141.00       242.00

METHOD OF ANALYSIS
 JANBU   - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  9
```

```
                                                            ! Sheet No.
Program: SLOPE  version 6.00  licensed from GEOSOLVE         ! Run No.550alt2
                                                            ! Job No.    003
                                                            ! Made by :
TAG MOTORWAY KM.141+550 LANDSLIDE                           ! Date:
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2              ! Checked :
------------------------------------------------------------!-----------------------

                                                     Units: kN-m

RESULTS
*******
Method of analysis: JANBU  - Parallel inclined interslice forces
                    Factor of safety on Shear Strength
                    Minimum number of slices =  8

 Factor of safety =        1.779
 Slipped mass      =       14466      Out of balance  vertical  force =        0
 Delta =  4.7deg                      Out of balance horizontal force =        0
 Moments taken about: X =    45.42 , Y =   438.30
 Overturning moment   =        132635      Restoring moment =        235919

  Slip surface coordinates  Piezometric  ------- Interslice forces --------
  ------------------------   elevation   ----- horizontal ------   vertical
   No.        X        Y       Y(w)      E(total)  E'(effective)      Q
    1     -20.00   230.00     225.00           0             0        0
    2     -10.00   225.00     225.00         344           344       28
    3       0.00   220.00     225.00        1119           994       82
    4      12.50   220.00     226.00        1261          1081       89
    5      25.00   220.00     227.00        1362          1117       92
    6      41.67   220.00     230.00        1427           927       76
    7      58.33   220.00     233.00        1427           582       48
    8      75.00   220.00     236.00        1433           158       13
    9      92.00   225.67     237.33         813           133       11
   10     109.00   231.33     238.67         370           101        8
   11     126.00   237.00     240.00          74            29        2
   12     141.00   242.00     240.00          -0            -0        0

  Slice   Cohesion  Tan(phi)     Pore     Weight   Forces on base of slice
   No.                         pressure  of slice  --- normal ---      shear
          (avge)     (avge)     (avge)       W        P         P'        S
    1      0.00     0.2867       0.00       450      582       582       94
    2      0.00     0.2867      25.00      1100     1378      1099      177
    3      0.00     0.2867      55.00      1563     1570       882      142
    4      0.00     0.2867      65.00      1438     1440       628      101
    5      0.00     0.2867      85.00      1833     1818       401       65
    6      0.00     0.2867     115.00      1833     1805      -112       -0
    7      0.00     0.2867     145.00      1917     1944      -472       -0
    8      0.00     0.2867     138.33      1791     2005      -474       -0
    9      0.00     0.2867      95.00      1320     1404      -298       -0
   10      0.00     0.2867      51.67       907      948        22        4
   11      0.00     0.2867       9.00       315      320       178       29

  Slice    --- Surface loads ---           Water pressure on
   No.    vertical   horizontal           submerged  ground
          pressure    pressure          vertical   horizontal
    1         0          0                  0           0
    2         0          0                  0           0
    3         0          0                  0           0
    4         0          0                  0           0
    5         0          0                  0           0
    6         0          0                  0           0
    7         0          0                  4           0
    8         0          0                  7           1
    9         0          0                  1           0
   10         0          0                  0           0
   11         0          0                  0           0
```

```
                                                              ! Sheet No.
                                                              ! Run No.550alt2
Program: SLOPE  version 6.00  licensed from GEOSOLVE          ! Job No.    003
                                                              ! Made by :
TAG MOTORWAY KM.141+550 LANDSLIDE                             ! Date:
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2                ! Checked :
                                                              !
--------------------------------------------------------------!--------------

                                                        Units: kN-m
INPUT DATA

PROFILE DATA
 Grid line    1         2         3         4         5         6         7         8
 X-Coord  -20.00      0.00     25.00     75.00    126.00    141.00    152.00    167.00
 ----------------------------------------------------------------------------------
 Stratum     Y-Coordinates
  1(GL)   230.00    230.00    230.00    235.00    241.00    242.00    242.50    248.00
  2       220.00    220.00   217.00     220.00    234.00    238.00    242.50    248.00

 Grid line    9
 X-Coord  267.00
 --------------
 Stratum     Y-Coordinates
  1(GL)   275.00
  2       275.00

SOIL PROPERTIES
                              Bulk densities    -------Strength parameters-------
 --- S t r a t u m ---      below    above        C      Phi       dC/dY    Datum
 No.      Description        GWL      GWL               (deg)               for C
 1   SLOPE DEBRIS            8.00    18.00      0.00    16.00
 2   BEDROCK                10.00    20.00    200.00    35.00

GROUND WATER CONDITIONS
 Density of water = 10.00
 Grid line    1         2         3         4         5         6         7         8
 X-Coord  -20.00      0.00     25.00     75.00    126.00    141.00    152.00    167.00
 ----------------------------------------------------------------------------------
           Ground water level
           0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

 Grid line    9
 X-Coord  267.00
 --------------
           Ground water level
           0.00

SLIP SURFACE DATA
 Non-circular slip surface

 Point no.     X Coord      Y Coord
     1          -20.00      230.00
     2            0.00      220.00
     3           75.00      220.00
     4          141.00      242.00


METHOD OF ANALYSIS
 JANBU  - Parallel inclined interslice forces
 Factor of safety on Shear Strength
 Minimum number of slices =  8

 Earthquake acceleration factors:
                         vertical =  0.000
                       horizontal =  0.200
```

```
                                                                | Sheet No.
                                                                | Run No.550alt2
Program: SLOPE  version 6.00  licensed from GEOSOLVE            | Job No.     003
                                                                | Made by :
TAG MOTORWAY KM.141+550 LANDSLIDE                               | Date:
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2                  | Checked :
                                                                |
----------------------------------------------------------------|--------------

                                                       Units: kN-m
RESULTS
*******
Method of analysis: JANBU  - Parallel inclined interslice forces
                    Factor of safety on Shear Strength
                    Minimum number of slices =  8
Earthquake acceleration factors:   Vertical =  0.000g
                                 Horizontal =  0.200g
                                                --
 Factor of safety =     1.106
 Slipped mass     =     26811     Out of balance  vertical force =       0
 Delta = 11.2deg                  Out of balance horizontal force =      3
 Moments taken about: X =    45.42 , Y =   438.30
 Overturning moment  =    1530420      Restoring moment =    1692494

  Slip surface coordinates Piezometric  ------- Interslice forces --------
  ------------------------  elevation   ----- horizontal ------   vertical
   No.      X         Y        Y(w)      E(total)  E'(effective)     Q
    1    -20.00    230.00      0.00          0           0           0
    2    -10.00    225.00      0.00        366         366          72
    3      0.00    220.00      0.00       1463        1463         289
    4     12.50    220.00      0.00       1604        1604         317
    5     25.00    220.00      0.00       1744        1744         345
    6     41.67    220.00      0.00       1947        1947         386
    7     58.33    220.00      0.00       2182        2182         433
    8     75.00    220.00      0.00       2447        2447         486
    9     92.00    225.67      0.00       1381        1381         274
   10    109.00    231.33      0.00        612         612         122
   11    126.00    237.00      0.00        140         140          28
   12    141.00    242.00      0.00         -3          -3          -0

  Slice   Cohesion   Tan(phi)     Pore      Weight   Forces on base of slice
   No.                          pressure  of slice   --- normal ---     shear
           (avge)     (avge)     (avge)       W        P        P'        S
    1       0.00      0.2867      0.00       450      671      671      174
    2       0.00      0.2867      0.00      1350     2013     2013      522
    3       0.00      0.2867      0.00      2250     2278     2278      591
    4       0.00      0.2867      0.00      2250     2278     2278      591
    5       0.00      0.2867      0.00      3250     3290     3290      853
    6       0.00      0.2867      0.00      3750     3797     3797      984
    7       0.00      0.2867      0.00      4250     4303     4303     1116
    8       0.00      0.2867      0.00      4029     3704     3704      960
    9       0.00      0.2867      0.00      2907     2672     2672      693
   10       0.00      0.2867      0.00      1785     1641     1641      426
   11       0.00      0.2867      0.00       540      497      497      129


 Program SLOPE - Copyright (C) 1982 by D.L.Borin
```

REFERENCES

1. K.Terzaghi and R.Peck. ," Soil Mechanics in Engineering Practice ",4 th ed. NewYork : John Wiley & Sons , 1967, pp.232.

2. Skempton A.W.," Long Term Stability of Clay Slopes ",Geotechnique XIV., No.2, 1964, pp.77-101.

3. K.Terzaghi and R.Peck. ," Soil Mechanics in Engineering Practice ",4 th ed. NewYork : John Wiley & Sons , 1967, pp.415.

4. K.Terzaghi and R.Peck. ," Soil Mechanics in Engineering Practice ",4 th ed. NewYork : John Wiley & Sons , 1967, pp.418.

5. A.Sağlamer Prof.Dr. İTÜ " A final design geotechnical report for TAG Motorway " Karayolları Genel Müdürlüğü ,1990.

6. Bength B.Broms, " Stability of natural slopes and embankment foundations " , Proc. 7 th.Conf. Soil Mech. Found. Eng. 3 , pp. 385-394.

7. Kenney T.C.," The influence of Mineral Composition on Residual Strenght of Natural Soils " , Geotechnical Conference Norway,1967

8. Slope Stability Computer Programme utilizing Bishop Modified Method " BI3 ", Zetaş Earth Technology Co.

9. Slope Stability Computer Programme utilizing Janbu inclined slice's Method " Slope ", Zetaş Earth Technology Co.

10. T.Collotta,R.Cantoni,U.Pavesi and E.Rubeil,P.C.Moretti ,Scientific Paper," A new correlation between residual friction angle,gradation,index properties of cohesive soils ",Studio Geotechnica Italiano,Srl,Milan,and Autostrato Spa.Rome,Italy,1991

11. Lupini,J.F.et al, " The drained residual strength of cohesive soils ", Geotechnique 31, no.2, 1981

12. B.Walker,R.Fell " Soil Slope Instability and Stabilization ",A.A.Balkema,1987.,pp.68-75.

13. D.H.He,Scientific Paper," Back Determination of the Shear Strength Parameters in failed slopes ",Xi'an Institute of Highway. ,1990

14. Bishop A.W.,"The Use of the Slip Circle in the Stability Analysis of Slopes", Geot.X No.1,pp.7-17.