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**A CASE STUDY FOR CUTS IN SOFT SOILS**

by

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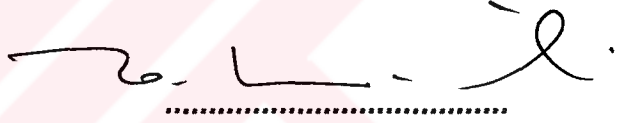
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1992**

**YÜKSEKÖĞRETİM KURULU  
DOKÜMANTASYON MERKEZİ**

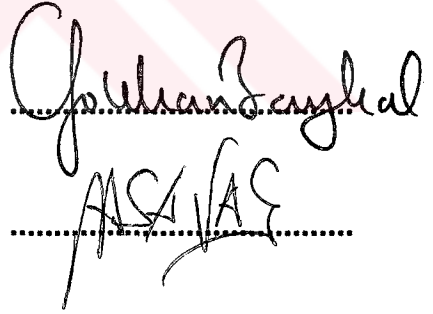
**A CASE STUDY FOR CUTS IN SOFT SOILS**

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.....

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.....

**to my family**



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**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 arasındaki yarmaların kazısı sırasında oluşan toprak kayması bir vaka analizi olarak incelenmiştir. Laboratuvar 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.

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### LIST OF SYMBOLS

$\phi$	Internal friction angle
$\phi_r$	Residual internal friction angle
$\phi_r'$	Effective residual internal friction angle
$\phi_p$	Peak internal friction angle
$\phi_p'$	Effective residual internal friction angle
$c$	Cohesion
$c_p'$	Effective Peak cohesion
$c_r'$	Effective residual cohesion
$\tau$	Shear Strength
$\tau'$	Effective shear strength
$\sigma$	Normal Strength
$\sigma'$	Effective normal strength
$Q$	External load
$\alpha$	Slope of failure surface
$W$	Weight of the soil
$T_1, T_2$	Shear force on the slice
$E_1, E_2$	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
$u$	Pore water pressure
X,Y	Coordinates of the circular slip surface
$F_r$	Resisting force
$F_d$	Driving force (force tending to slip)
$F_k$	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 m<sup>3</sup> mass of soil had slid. 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  $\phi$  ( $\phi'$ ) 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 strength 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.

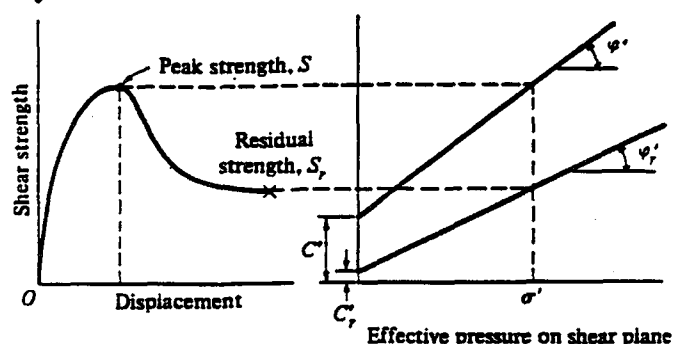


FIGURE 2.1. Shear Strength Characteristics Skempton 1964 (2)

### 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 ( $\phi'$ ) 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;

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

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

## 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.

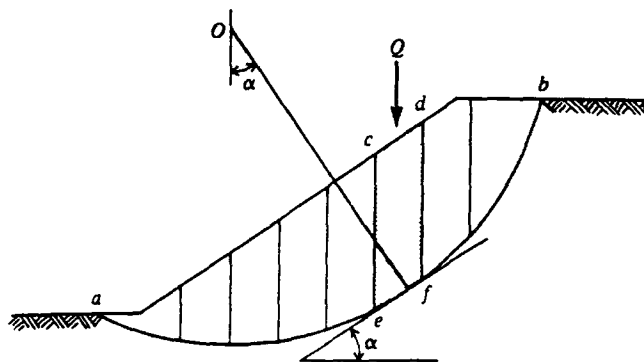


FIGURE 2.2 Modified Bishop Method

Bishop A.W. 1955 (14)

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

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

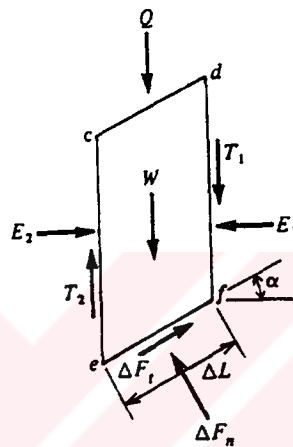


FIGURE 2.3. Method of Slices  
Bishop A.W. 1955 (14)

Substituting (eq.2) and solving for  $\tau$  and  $S$ , we obtain;

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

in general form;

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

## 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 character 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.

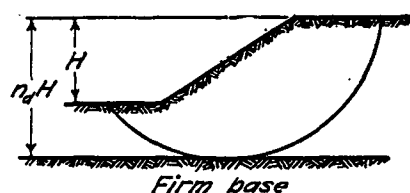


FIGURE 2.4. Firm Base  
K. Terzaghi and R. Peck 1967 (4)

## **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 - Pozanti 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 length : 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**

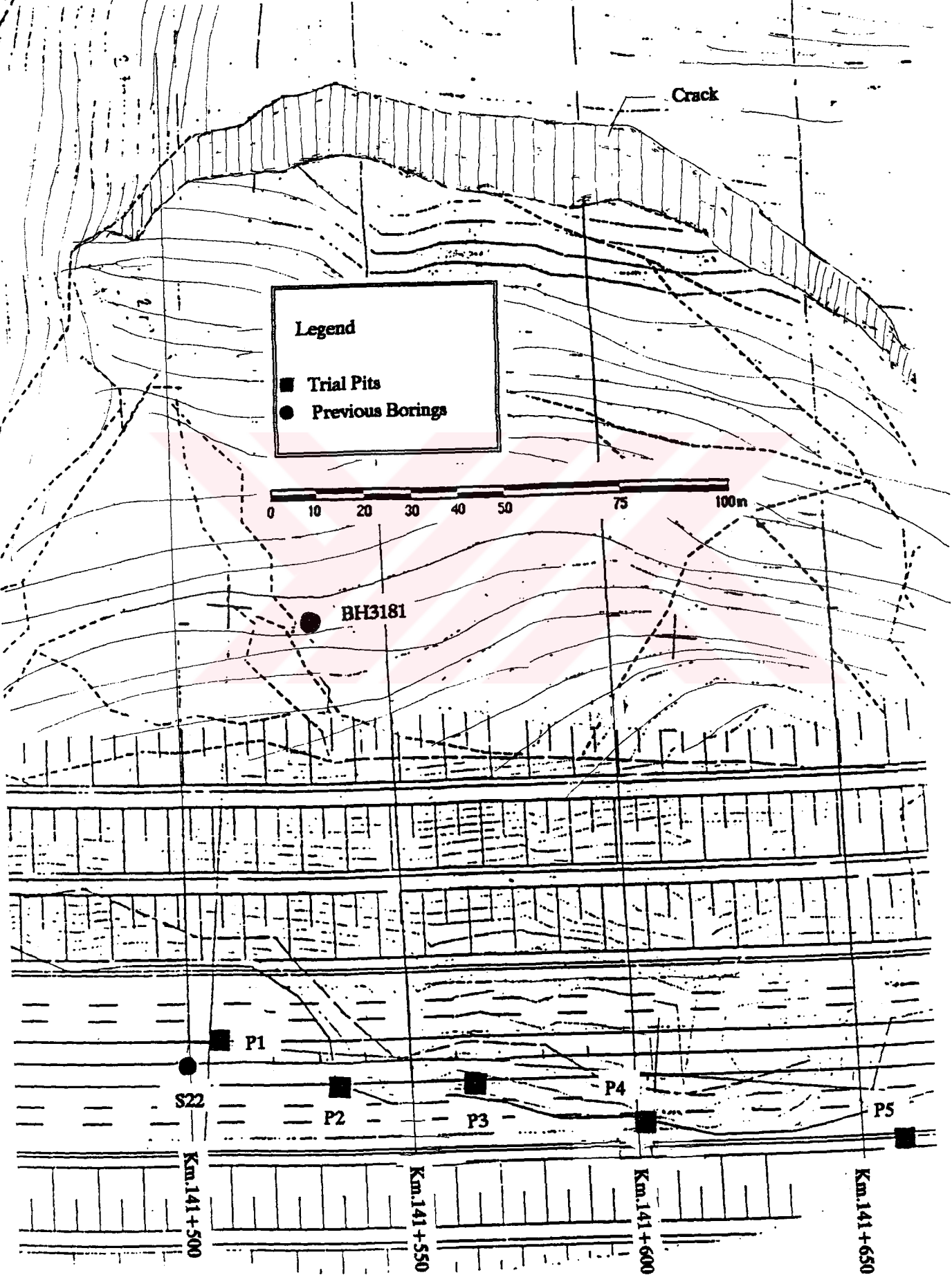
In 1990, a final design geotechnical report was prepared by A. Saglamer (5) for TAG motorway for the sections ranged between Km.139+000 and Km.153+400. In this report, the implemented design procedures are summarized. It was pointed out that the most critical sections were located between Km.141+200 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**

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

### **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

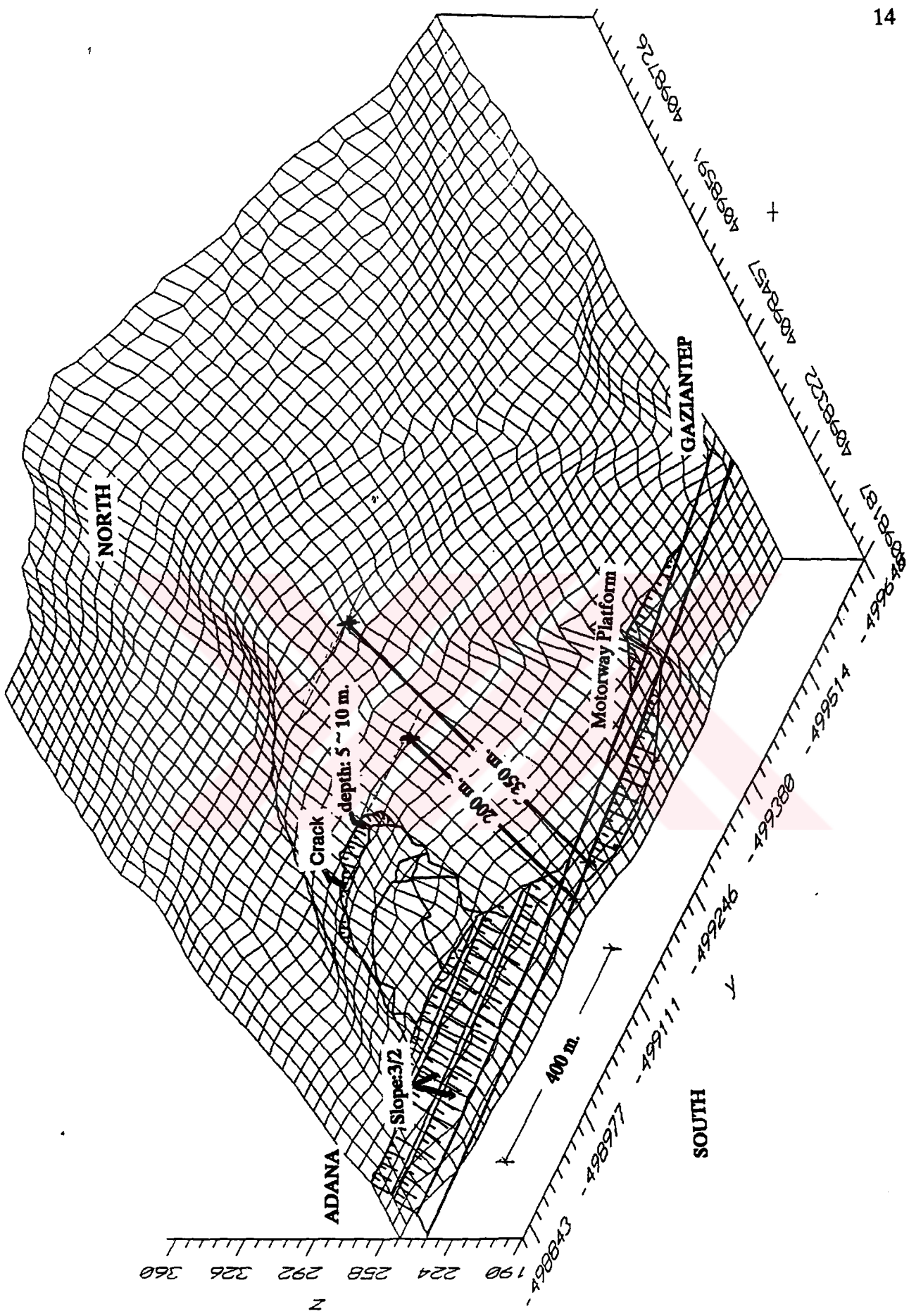


FIGURE 3.2. Slide Topography

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

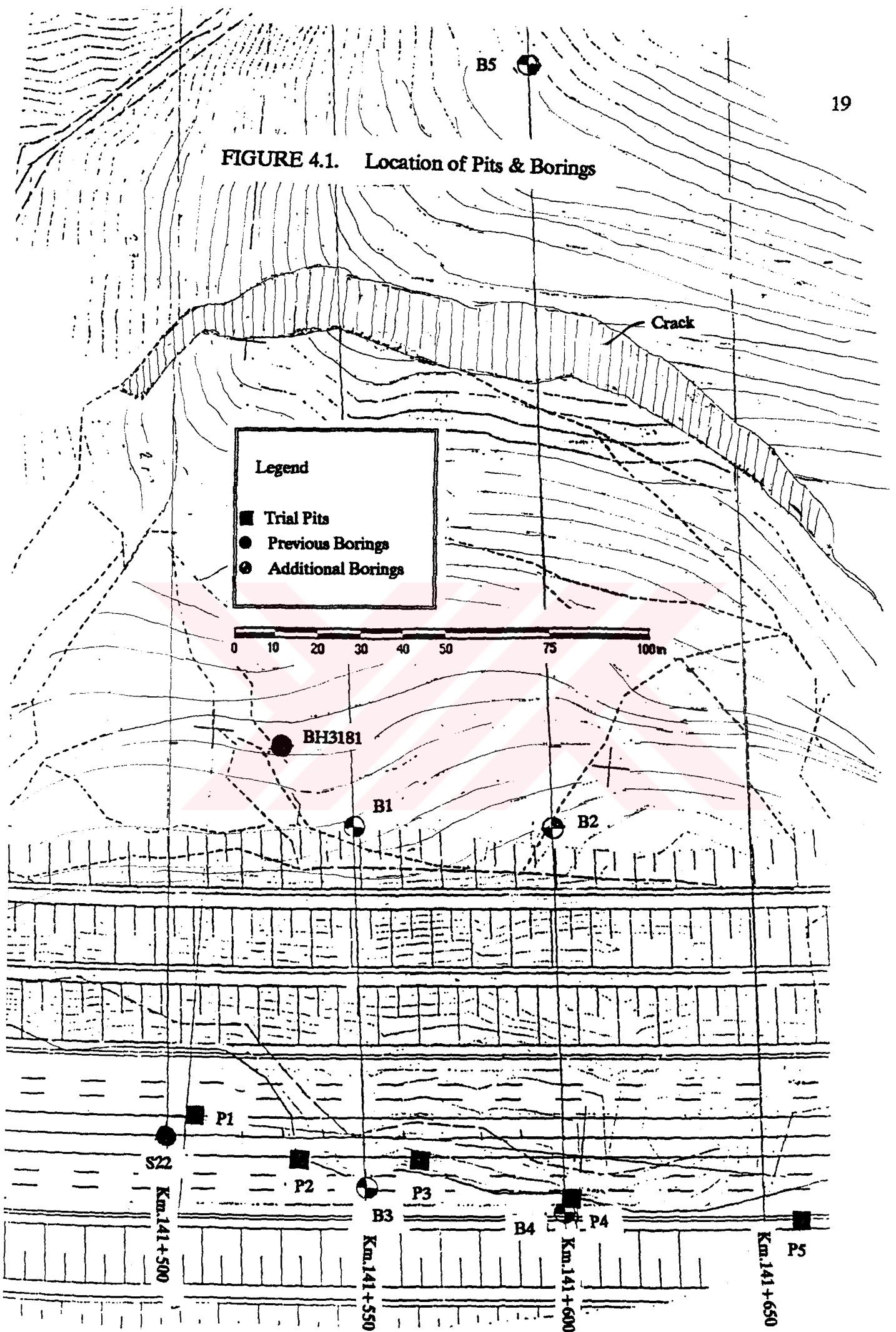


TABLE 4.1. Summary of Additional Boring Logs

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 Spillit
B2	Km.141+600	+260.86	-4.70 m -16.70 m -29.20 m -30.00 m	Slope Debris Slope Breccia Gravelly Clay Spillit
B3	Km.141+550	+260.00	-1.80 m -10.80 m -13.40 m	Slope Debris Silty Clay Spillit
B4	Km.141+600	+232.75	-9.30 m -14.40 m -19.30 m -20.00 m	Slope Debris Gravelly Clay Spillit Agglomerate Spillit
B5	Km.141+600	+295.94	-8.80 m -12.00 m -17.00 m	Gravelly Clay Gravelly Clay Spillit

### **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 ( $\phi'$ ) 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.

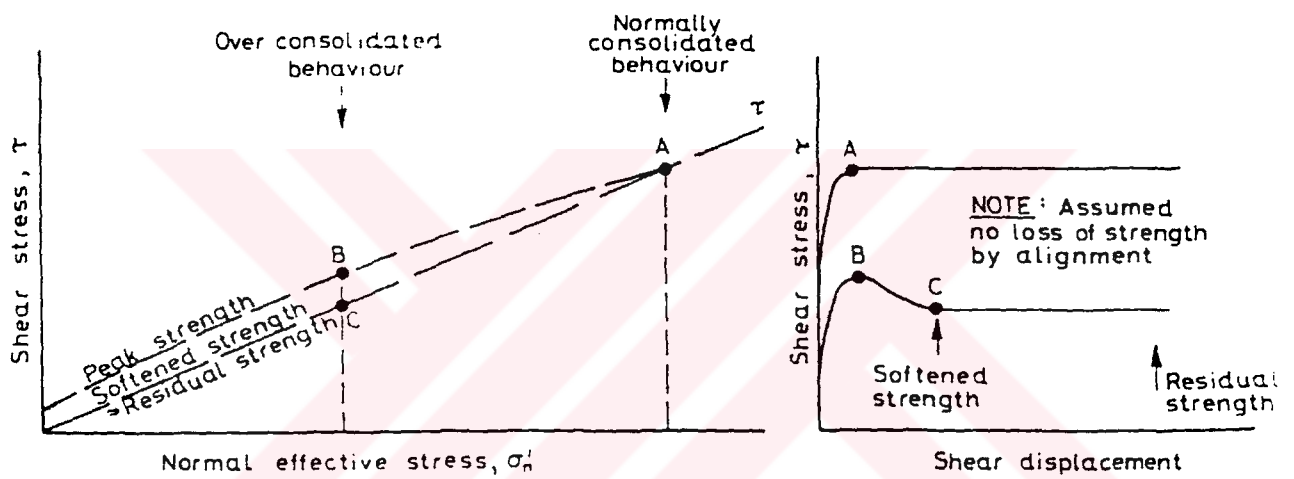
The test is usually saturated consolidated drained (CD) with the sample sheared at slow constant rate of displacement, so that pore pressures due to shearing are dissipated giving drained conditions. Typical load displacement curves for "turbulent" and "sliding" shear are shown in Figure 5.2.

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).

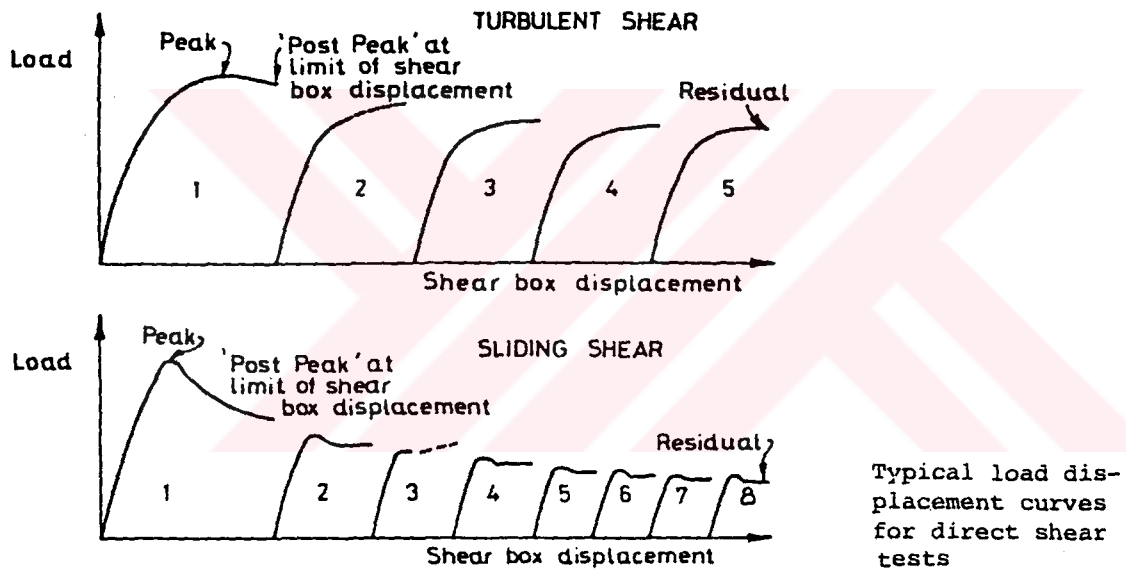
### **5.2.2. Test Procedure and Application**

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. Each time, 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	$\phi$ p deg	Cr kPa	$\phi$ r 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  
 **$\phi$  p** Peak internal friction angle  
**Cr** Residual cohesion  
 **$\phi$  r** 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	w <sub>n</sub> %	γ <sub>n</sub> kN/m <sup>3</sup>	ATTENBERG LIMITS			CF %
				LL %	PL %	PI %	
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.

w<sub>n</sub>      Natural water content  
γ<sub>n</sub>      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) :

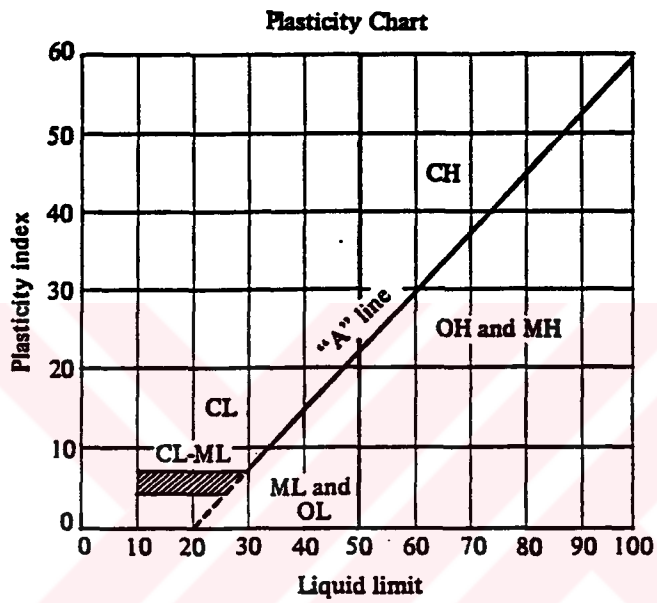
Natural water content (in percent)	= 35
Liquid limit (in percent)	= 74
Plastic Limit (in percent)	= 29.5
Plasticity Index (in percent)	= 43.5
Clay Fraction (in percent)	= 42.6

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 points should be clearly identified. These are the tension cracks, toe of the slid 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 ( $\phi'$ ) 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/m<sup>3</sup>

cohesion.....: 0 kN/m<sup>2</sup>

pore water pressure ...: 0 kN/m<sup>2</sup>

initial  $\phi'$  .....: varies 10 -13 degree

For Bedrock...;

Natural unit weight ...: 30 kN/m<sup>3</sup>

cohesion.....: 200 kN/m<sup>2</sup>

#### 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;

$$X = 67.00 \text{ m.}$$

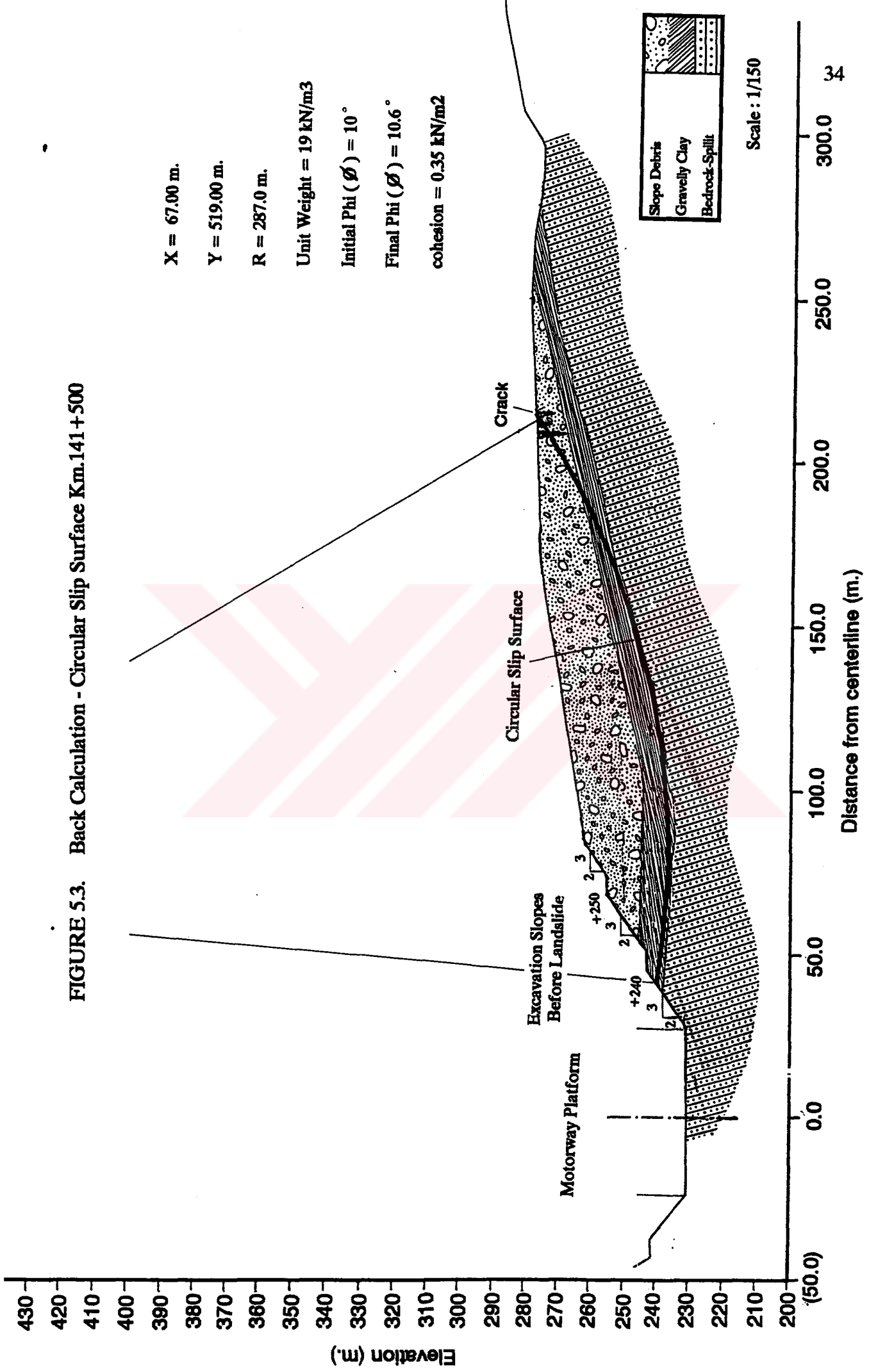
$$Y = 519.00 \text{ m.}$$

$$R = 287.00 \text{ m.}$$

$$\phi' = 10 \text{ ( initial value) degree}$$



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



X = 67.00 m.

Y = 519.00 m.

R = 287.0 m.

Unit Weight = 19 kN/m<sup>3</sup>

Initial Phi (ϕ) = 10°

Final Phi (ϕ) = 10.6°

cohesion = 0.35 kN/m<sup>2</sup>

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;

$$FS = 1.00$$

$$c' = 0.35 \text{ kN/m}^2$$

$$\phi' = 10.60 \text{ kN/m}^2$$

$$r_u = 0.10 \text{ kN/m}^2$$

#### 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;

$$X = 46.50 \text{ m.}$$

$$Y = 540.50 \text{ m.}$$

$$R = 339.00 \text{ m.}$$

$$\phi' = 12 \text{ ( initial value) degree}$$

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;

$$FS = 1.00$$

$$c' = 0.81 \text{ kN/m}^2$$

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

**X = 46.50 m.**  
**Y = 540.50 m.**  
**R = 339.0 m.**

**Unit Weight = 19 kN/m<sup>3</sup>**  
**Initial Phi (  $\phi$  ) = 12 °**  
**Final Phi (  $\phi$  ) = 12.2 °**  
**cohesion = 0.81 kN/m<sup>2</sup>**

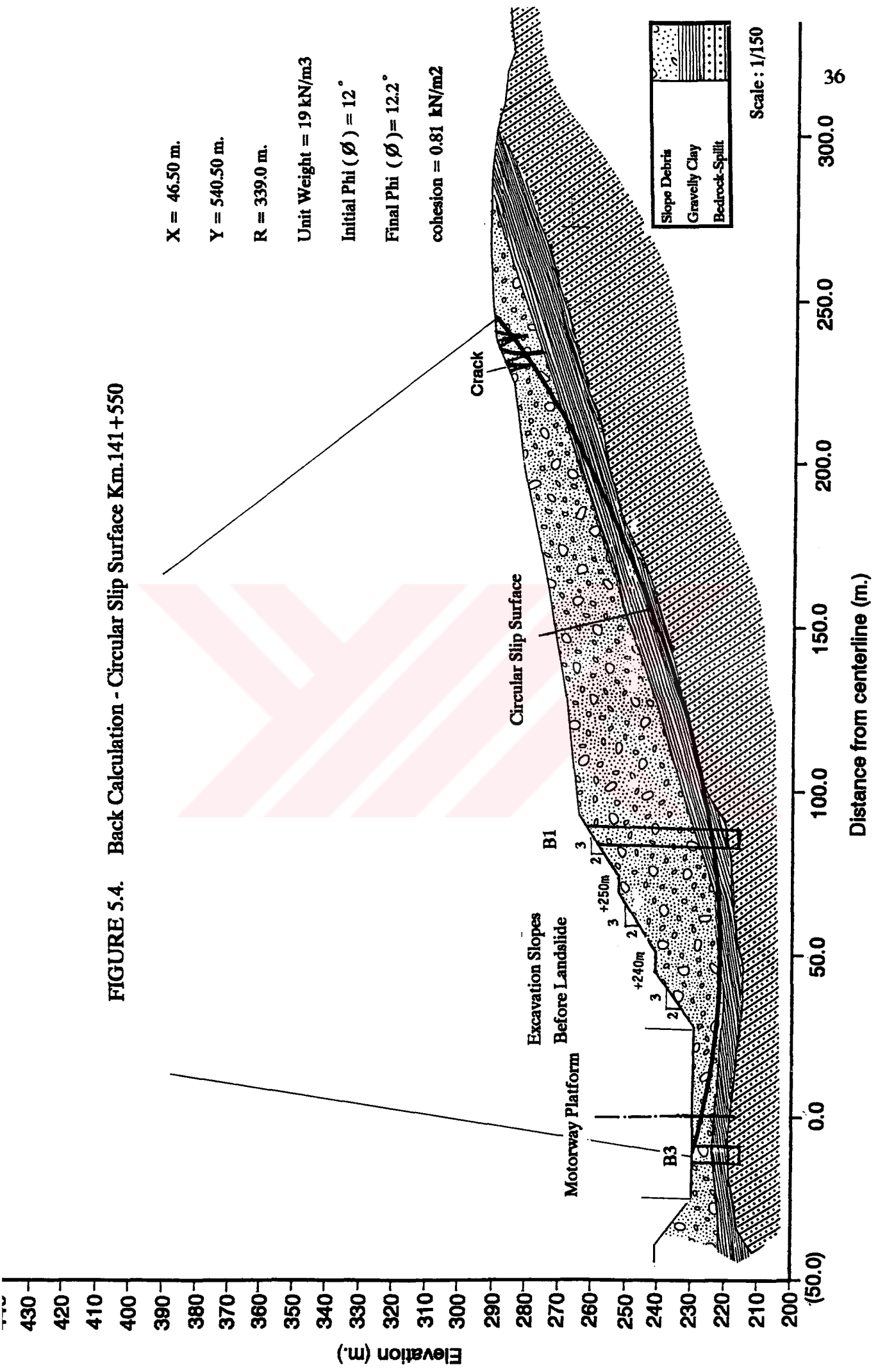
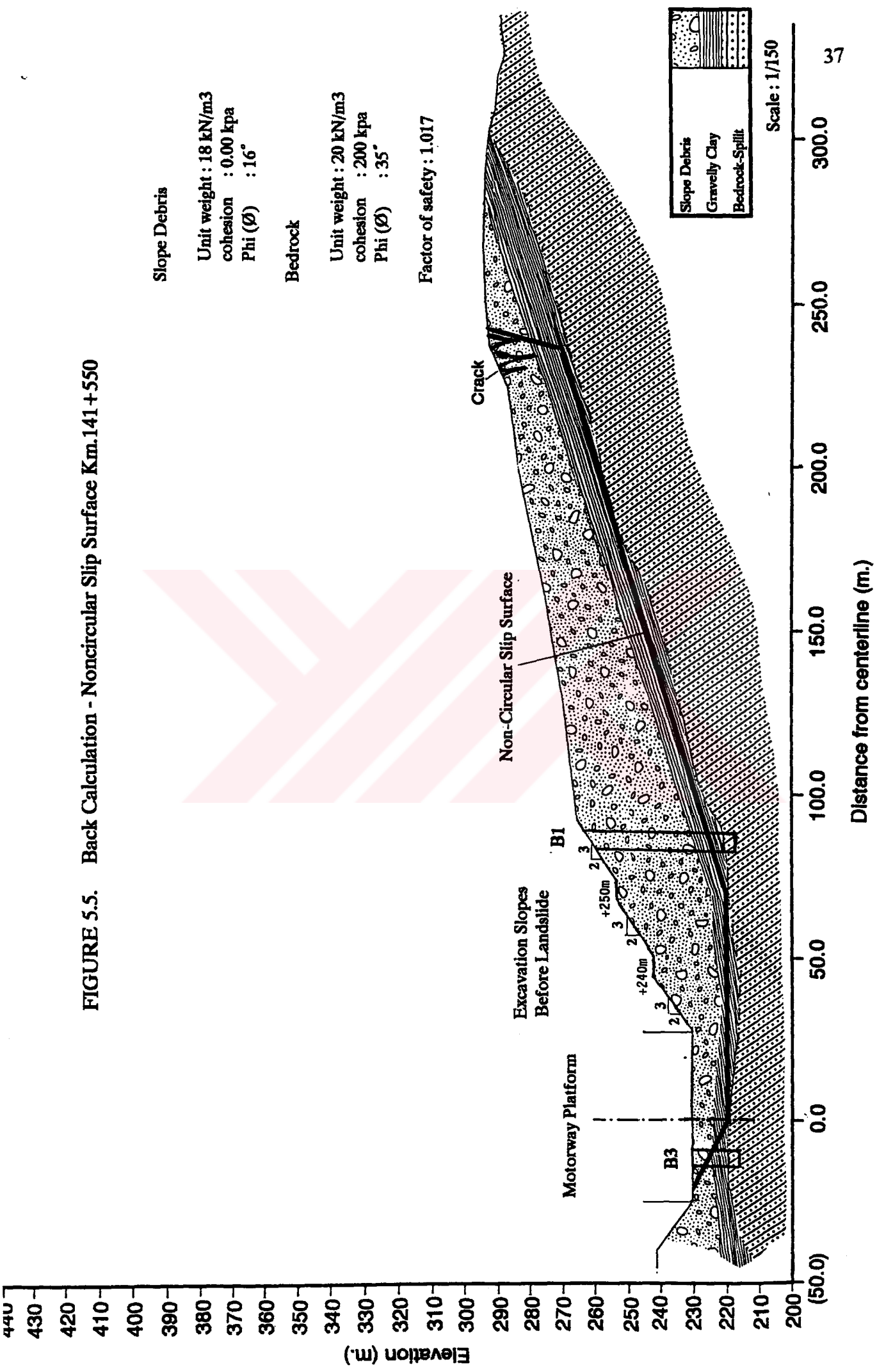


FIGURE 5.5. Back Calculation - Noncircular Slip Surface Km.141+550



**Slope Debris**

Unit weight : 18 kN/m<sup>3</sup>  
 cohesion : 0.00 kpa  
 Phi (Ø) : 16°

**Bedrock**

Unit weight : 20 kN/m<sup>3</sup>  
 cohesion : 200 kpa  
 Phi (Ø) : 35°

Factor of safety : 1.017

Scale : 1/150

$$\phi' = 12.20 \text{ degree}$$

$$r_u = 0.00 \text{ kN/m}^2$$

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

$$\phi' = 16.0 \text{ degree} \quad \text{and} \quad c' = 0.0 \text{ kN/m}^2$$

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;

$$X = 26.00 \text{ m.}$$

$$Y = 604.00 \text{ m.}$$

$$R = 384.00 \text{ m.}$$

$$\phi' = 11.5 \text{ ( initial value) degree}$$

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;

$$FS = 1.00$$

$$c' = 0.89 \text{ kN/m}^2$$

$$\phi' = 11.70 \text{ degree}$$

$$r_u = 0.00 \text{ kN/m}^2$$

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

X = 26.00 m.

Y = 604.00 m.

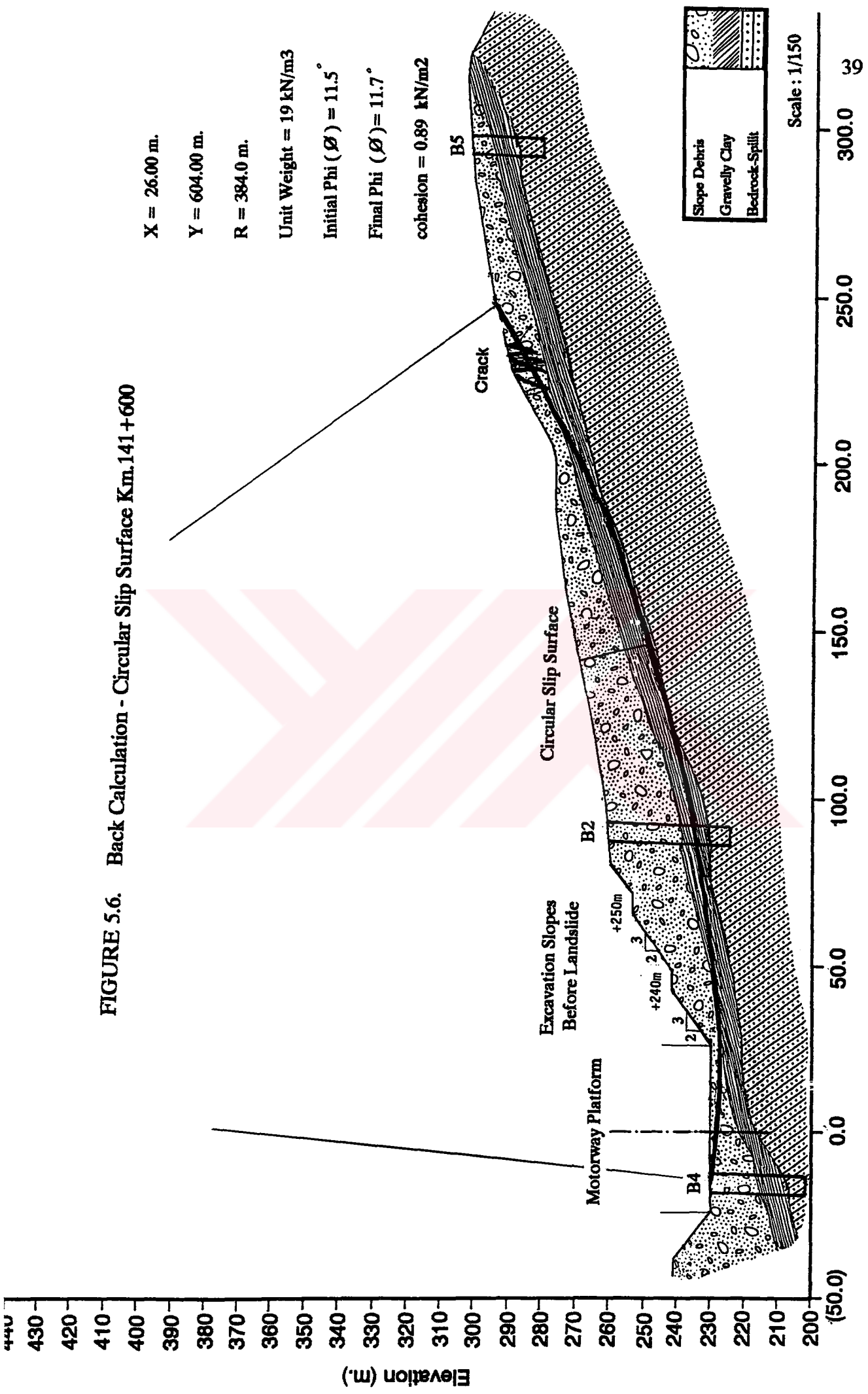
R = 384.0 m.

Unit Weight = 19 kN/m<sup>3</sup>

Initial Phi ( $\phi$ ) = 11.5°

Final Phi ( $\phi$ ) = 11.7°

cohesion = 0.89 kN/m<sup>2</sup>



Distance from centerline (m.)

Scale: 1/150

	Slope Debris
	Gravelly Clay
	Bedrock-Split

#### 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 analysis 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;

$$X = 65.00 \text{ m.}$$

$$Y = 434.00 \text{ m.}$$

$$R = 196.00 \text{ m.}$$

$$\phi' = 13 \text{ ( initial value) degree}$$

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;

$$FS = 1.00$$

$$c' = 0.00 \text{ kN/m}^2$$

$$\phi' = 14.00 \text{ degree}$$

$$ru = 0.00 \text{ kN/m}^2$$

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

$$\phi' = 13.0 \text{ degree and } c = 0.0 \text{ kN/m}^2$$

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.**

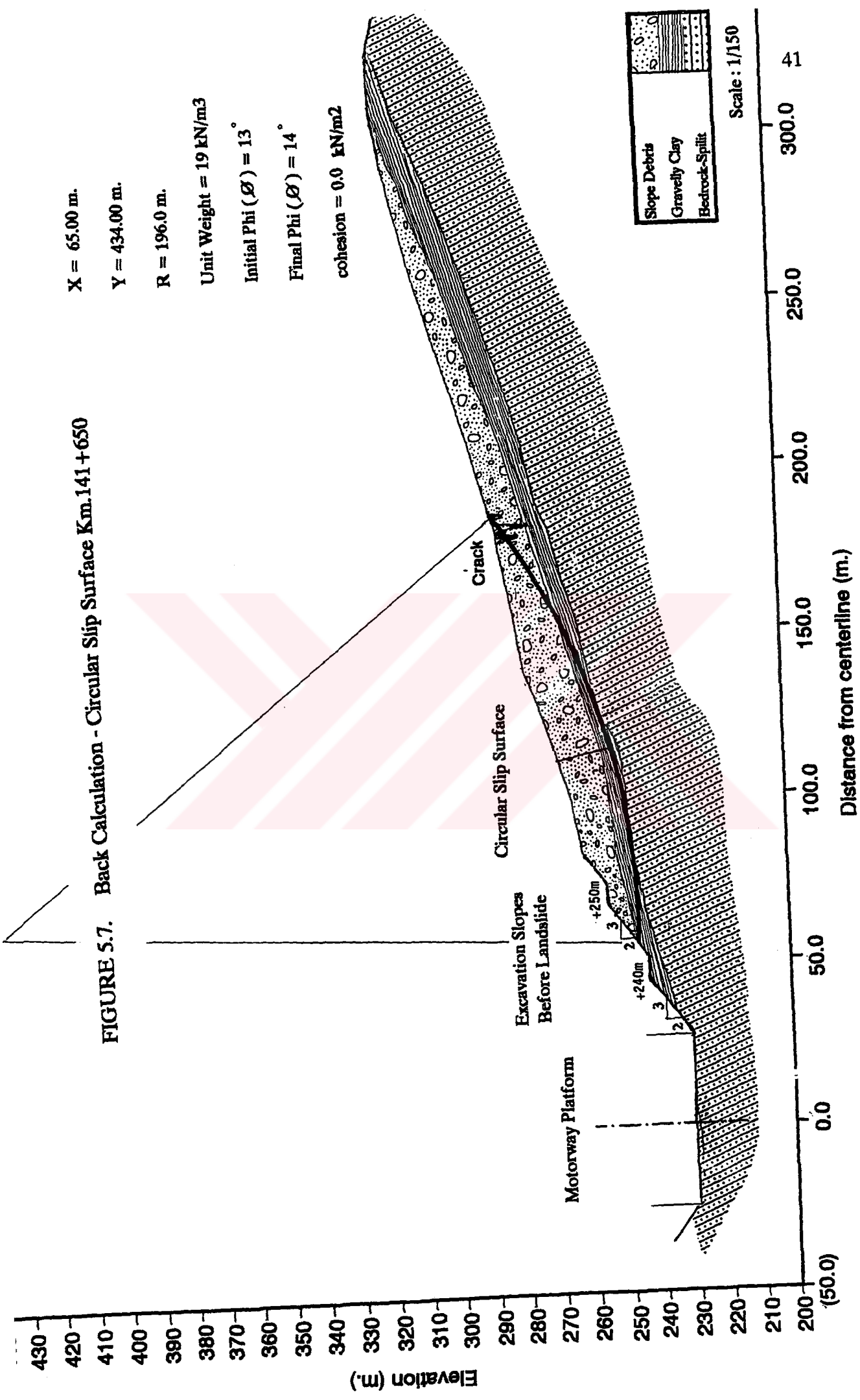
**R = 196.0 m.**

**Unit Weight = 19 kN/m<sup>3</sup>**

**Initial Phi ( $\phi$ ) = 13°**

**Final Phi ( $\phi$ ) = 14°**

**cohesion = 0.0 kN/m<sup>2</sup>**



Distance from centerline (m.)

Scale : 1/150



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

**Slope Debris**

Unit weight : 18 kN/m<sup>3</sup>  
 cohesion : 0.00 kpa  
 Phi (Ø) : 13°

**Bedrock**

Unit weight : 20 kN/m<sup>3</sup>  
 cohesion : 200 kpa  
 Phi (Ø) : 35°

**Factor of safety : 1.004**

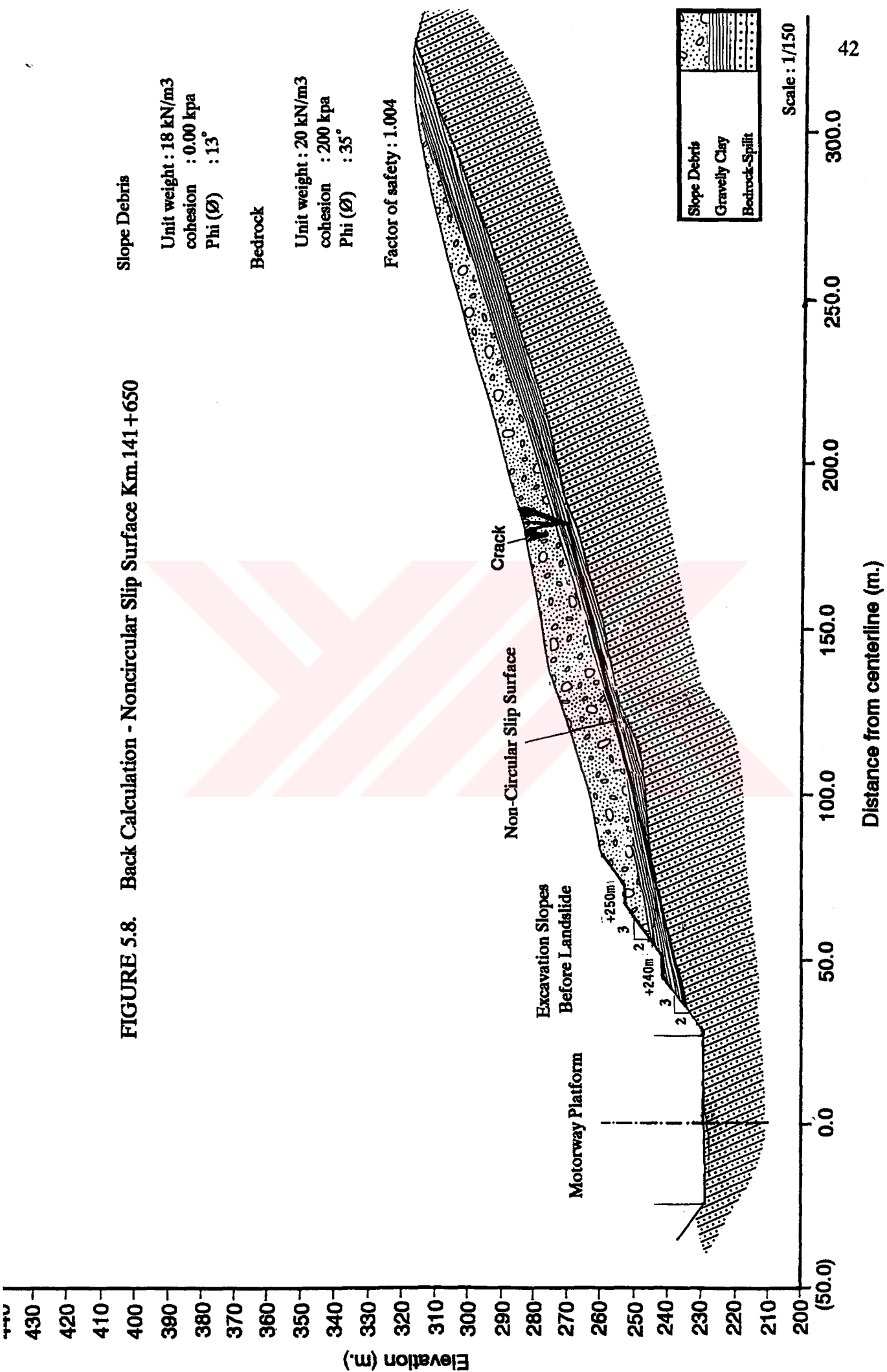


TABLE 5.5. Results of Back Calculation Method

<b>Slip Surface</b>	<b>Section</b>	<b>F.S.</b>	<b>Cr (kpa)</b>	<b><math>\phi_r</math> (deg)</b>
<b>Circular</b>	<b>Km.141+500</b>	<b>1.00</b>	<b>0.35</b>	<b>10.6°</b>
<b>Circular</b>	<b>Km.141+550</b>	<b>1.00</b>	<b>0.81</b>	<b>12.2°</b>
<b>Circular</b>	<b>Km.141+600</b>	<b>1.00</b>	<b>0.89</b>	<b>11.7°</b>
<b>Circular</b>	<b>Km.141+650</b>	<b>1.00</b>	<b>0.00</b>	<b>14.0°</b>
<b>Non-circular</b>	<b>Km.141+550</b>	<b>1.00</b>	<b>0.00</b>	<b>16.0°</b>
<b>Non-circular</b>	<b>Km.141+650</b>	<b>1.00</b>	<b>0.00</b>	<b>13.0°</b>

## 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;

$$\phi' = 14 \text{ degree}$$

$$c' = 0 \text{ kN/m}^2$$

### 5.5.1. Correlation Between $\phi'$ , Gradation and Index Properties

In the recent years, a new correlation between residual internal friction angle ( $\phi'$ ) 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,  $\phi_r$ , 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**

<b>TEST</b>	<b><math>C_r'</math></b> <b>(kpa)</b>	<b><math>\phi_r'</math></b> <b>(degree)</b>
<b>Back Calculation</b>	<b>0</b>	<b>varies <math>11^\circ - 16^\circ</math></b>
<b>Laboratory</b>	<b>0</b>	<b>varies <math>13^\circ - 14^\circ</math></b>

**$C_r$**   
 **$\phi_r$**

**Residual cohesion (kpa)**  
**Residual internal friction angle (deg.)**

Limit (LL) and Plasticity Index (PI). The proposed correlation relates  $\phi_r'$  to a parameter that combines CF, LL and PI in the following manner;

$$\phi_r' = f(CALIP) \quad (\text{eq.5})$$

where

$$CALIP = (\bar{CF})^2 \times LL \times PI \times 10^{-5} \quad (\text{eq.6})$$

CF : Clay fraction in percent passing N.40 ASTM sieve (0.42 mm. opening)

LL : Liquid limit in percent

PI : Plasticity index in percent

The relation between  $\phi_r'$  and CALIP are drawn in Figure 5.9. and as a comparison, the relation between  $\phi_r'$  and CF are given in Figure 5.10.

The soil properties are given at Table 5.7. and the implemented correlation result are given in Table 5.8.

It can be concluded that the correlation of CALIP- $\phi_r'$  can be regarded as a more reliable method than other correlations. If index properties of cohesive soil are clearly identified, the residual internal friction angle can be obtained not precisely but more satisfactorily.

### 5.5.2. Correlation between Liquid Limit and $\phi_r'$

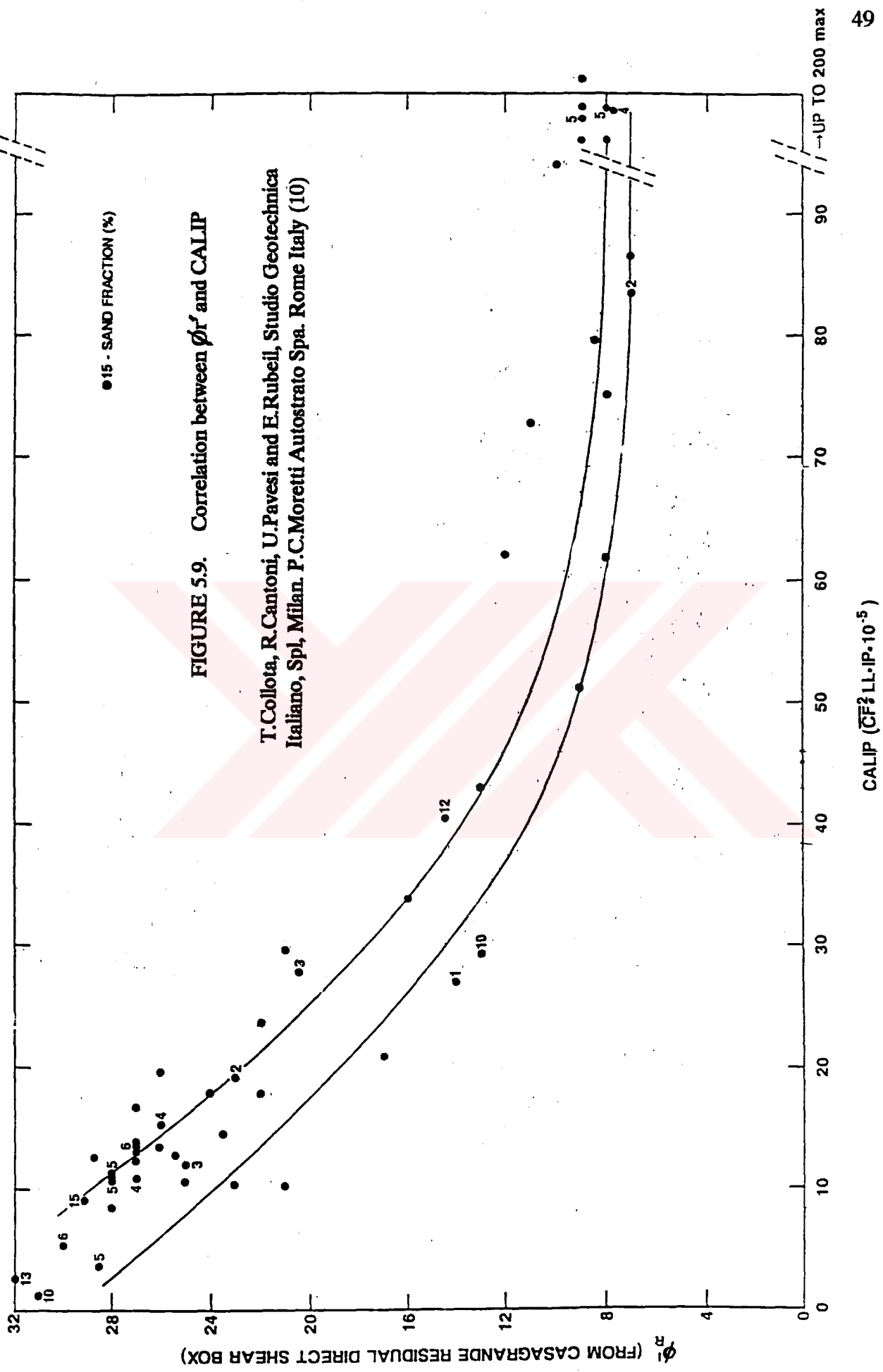
This correlation was made by Mesri-Cepeda Diaz 1986 (12) and the relevant relation is given in Figure 5.11. A comparison between the internal friction angles which were obtained from laboratory tests and from Figure 5.11., was made and given at the following;

**TABLE 5.7. Soil Properties for CALIP**

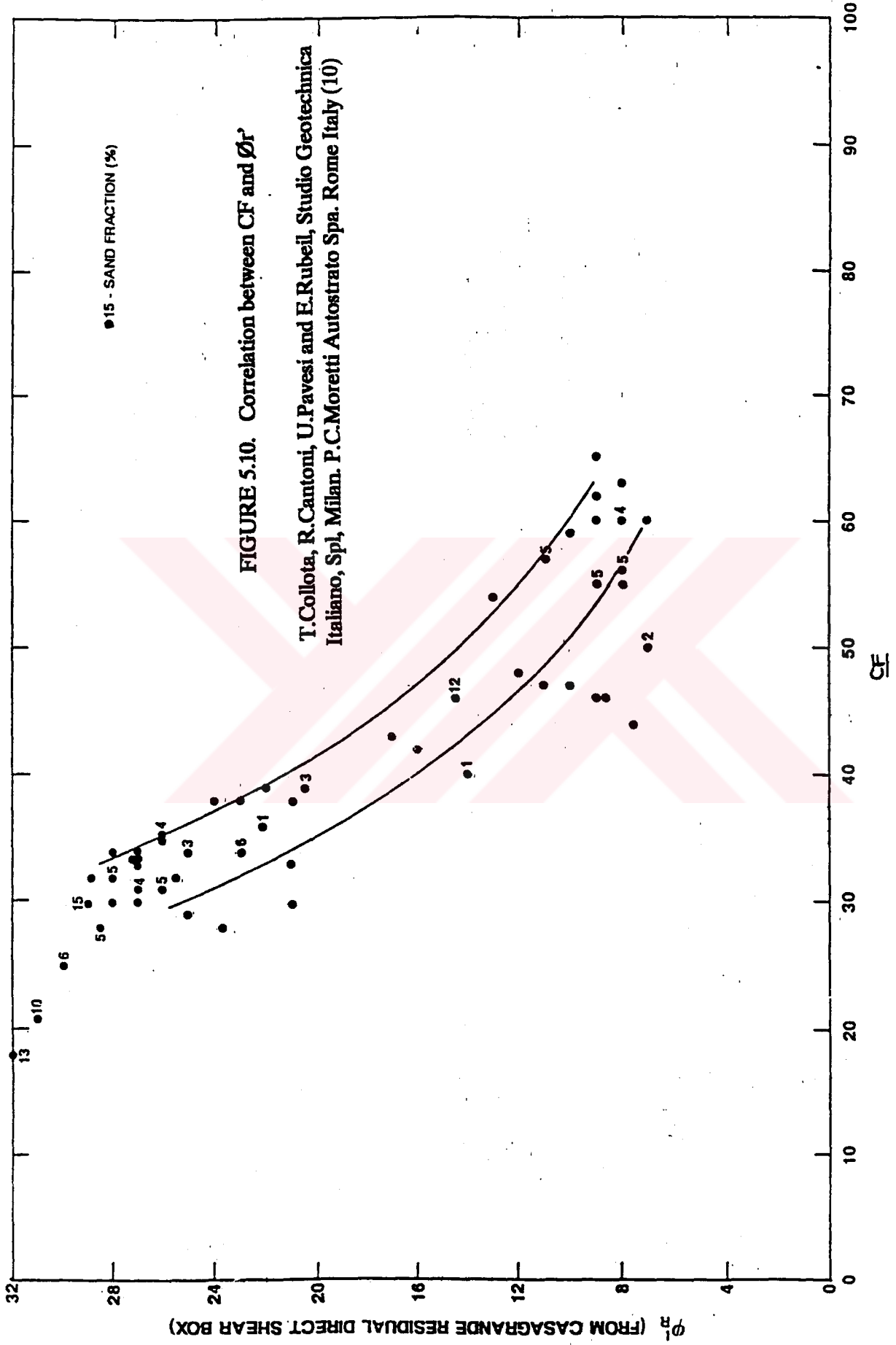
<b>Sample</b>	<b>Clay Fraction (%)</b>	<b>Liquid Limit (%)</b>	<b>Plasticity Index (%)</b>	<b><math>\phi</math> r (deg)</b>
<b>1A</b>	<b>16.6</b>	<b>44</b>	<b>17</b>	<b>38°</b>
<b>1B</b>	<b>10.7</b>	<b>42</b>	<b>12</b>	<b>48°</b>
<b>CBR1</b>	<b>46.9</b>	<b>76</b>	<b>44</b>	<b>15°</b>
<b>CBR2</b>	<b>38.2</b>	<b>72</b>	<b>43</b>	<b>13°</b>

TABLE 5.8. Results of CALIP -  $\phi_r'$  Correlation

Sample	CALIP	$\phi_r'$ from fig.18 (deg)	$\phi_r'$ from fig.19 (deg)	$\phi_r'$ 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°







<u>Sample</u>	<u>LL (percent)</u>	<u><math>\phi_r'</math>(degree) from Figure 5.1.</u>	<u><math>\phi_r'</math> (degree) from Figure 5.11.</u>
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 difference, and also it is observed that the results which has high liquid limit has low internal friction angle.



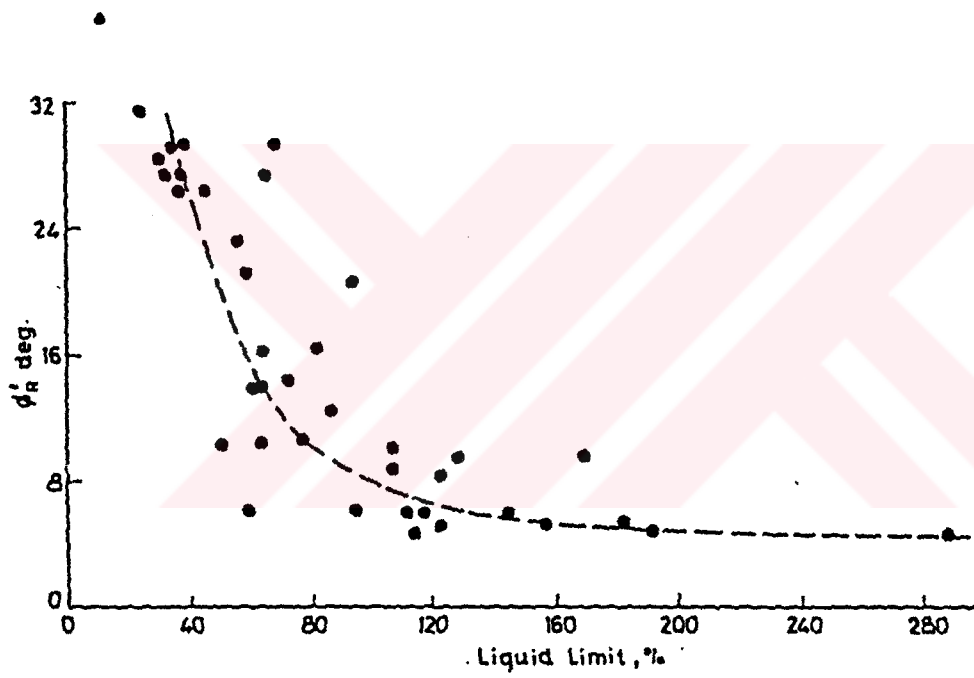


FIGURE 5.11. Relation between LL,  $\phi_R$

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 m<sup>3</sup>
- . approximate excavation within bedrock ..... 300,000 m<sup>3</sup>
- total excavation .....: 1,300,000 m<sup>3</sup>

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

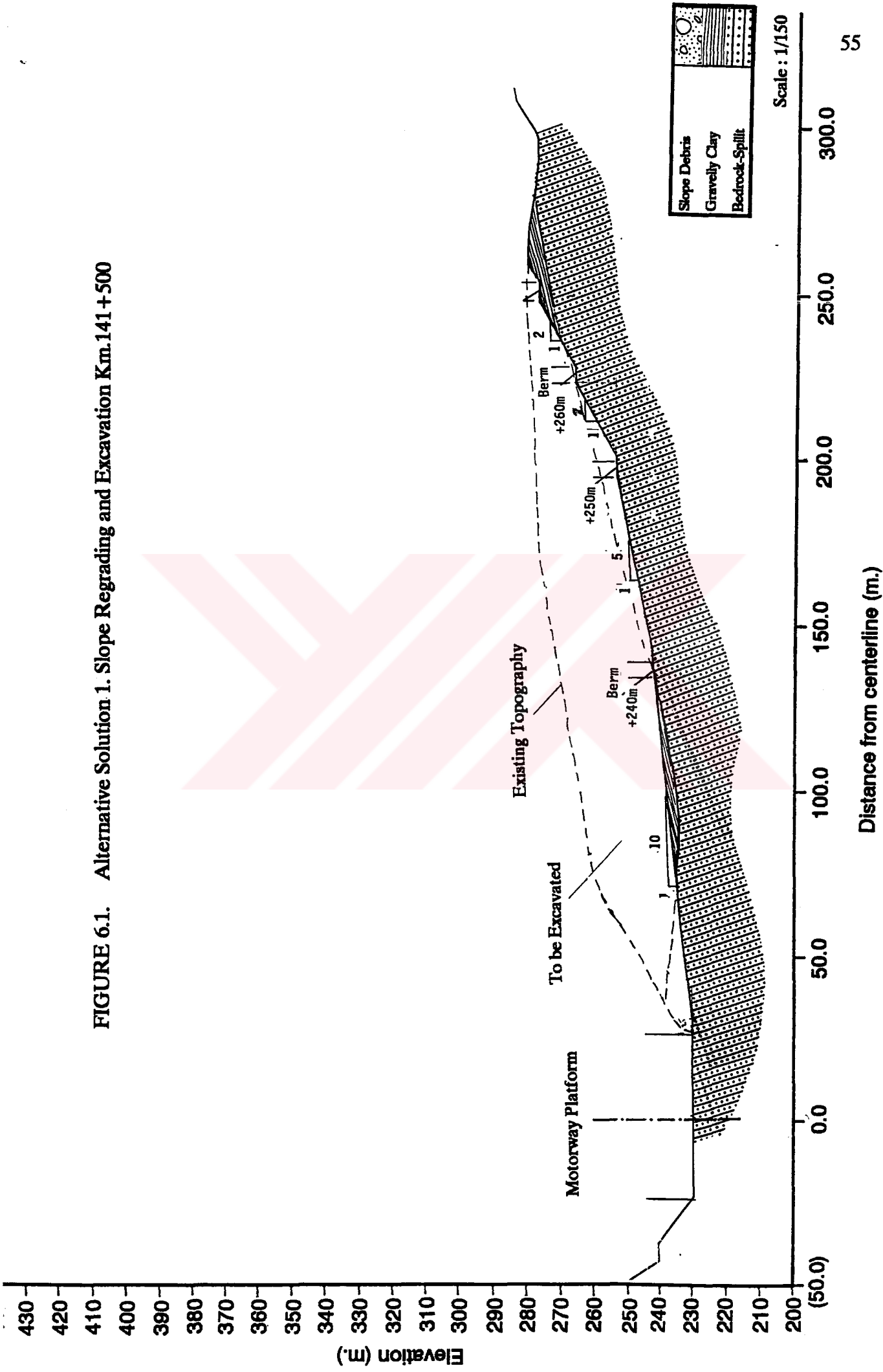


FIGURE 6.2. Alternative Solution 1. Slope Regrading and Excavation Km.141+550

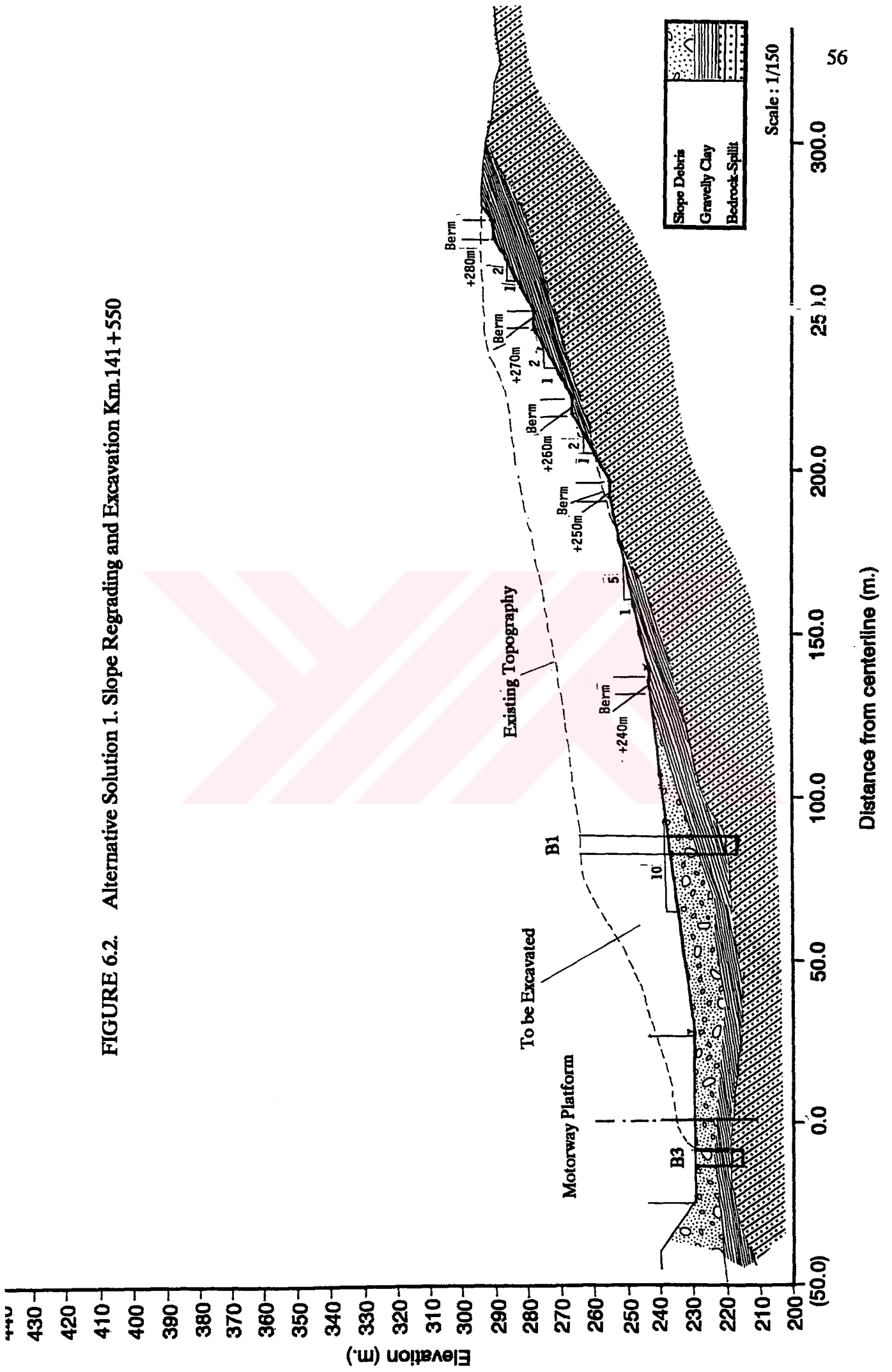


FIGURE 6.3. Alternative Solution 1. Slope Regrading and Excavation Km.141+600

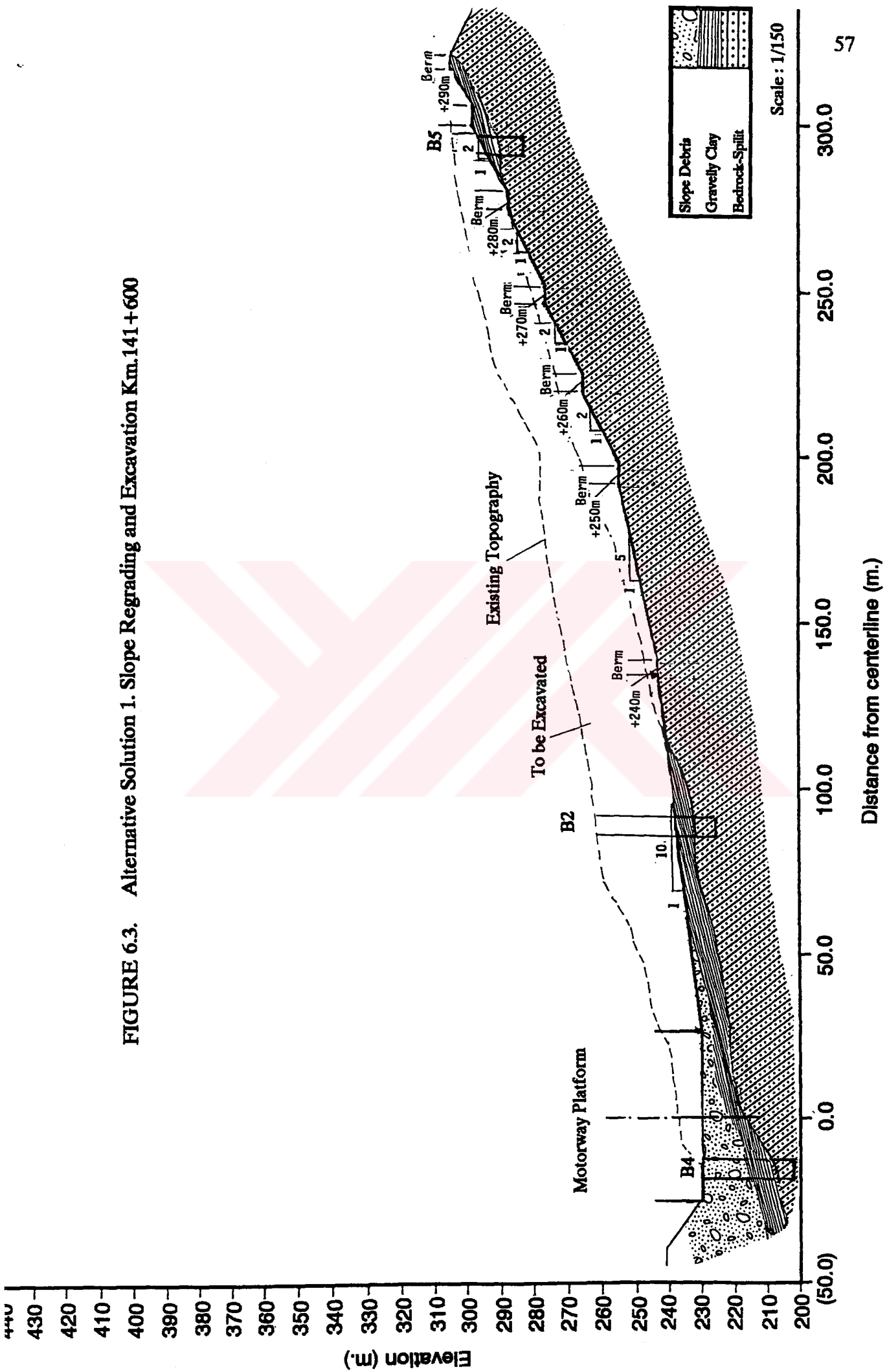
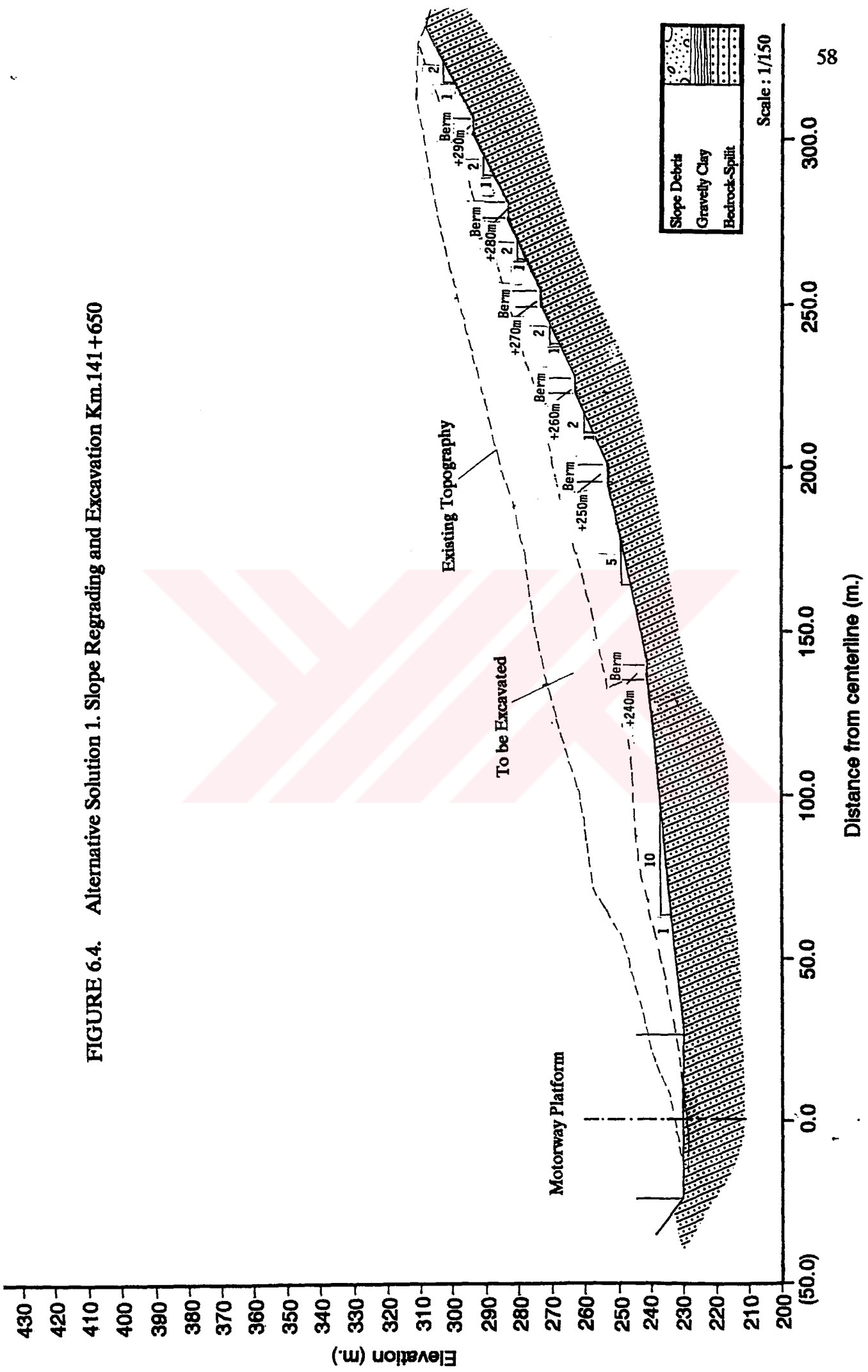




FIGURE 6.4. Alternative Solution 1. Slope Regrading and Excavation Km. 141 +650



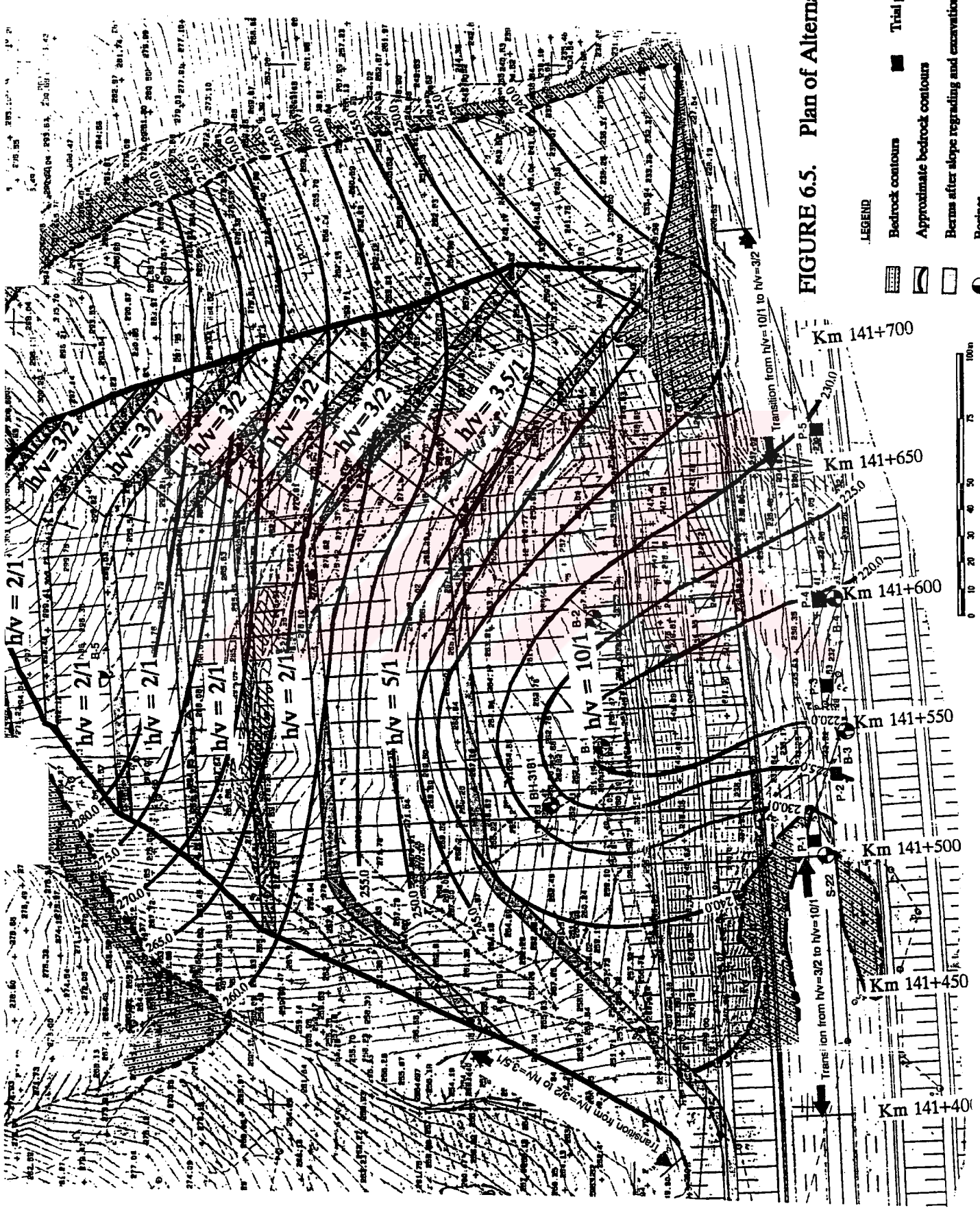


FIGURE 6.5. Plan of Alternative Solution 1.

- LEGEND
- Bedrock contours
  - Approximate bedrock contours
  - Berms after slope regrading and excavation
  - Borings
  - Trial pits

### 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 m<sup>3</sup>

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;

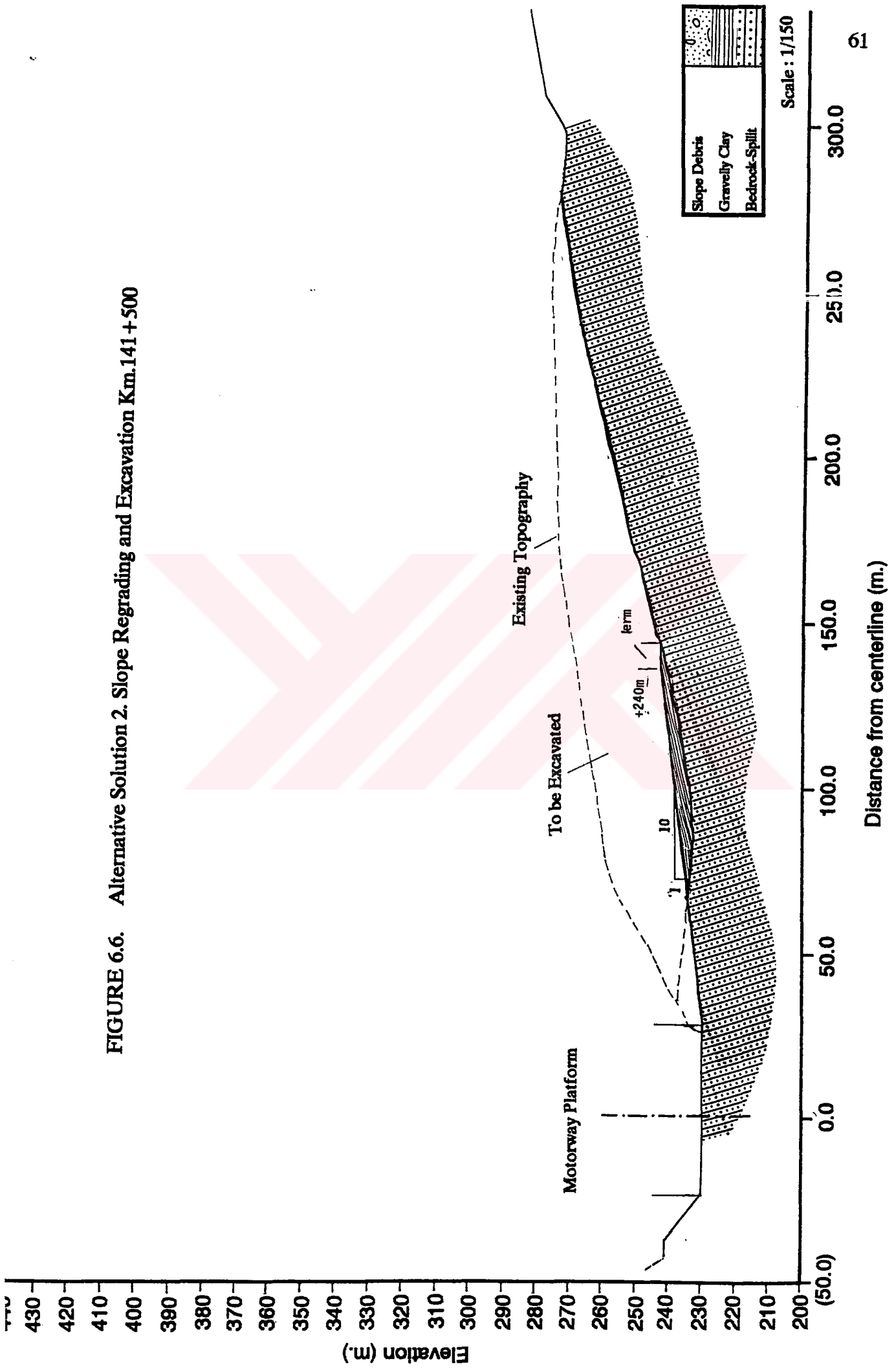
$$\phi_r' = 14 \text{ deg.} \quad \gamma = 19 \text{ kN/m}^3$$

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 no groundwater and earthquake case

F.S. = 1.78 in which groundwater conditions. ( $u = 145 \text{ kN/m}^2$ )

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



Distance from centerline (m.)

FIGURE 6.7. Alternative Solution 2. Slope Regrading and Excavation Km.141+550

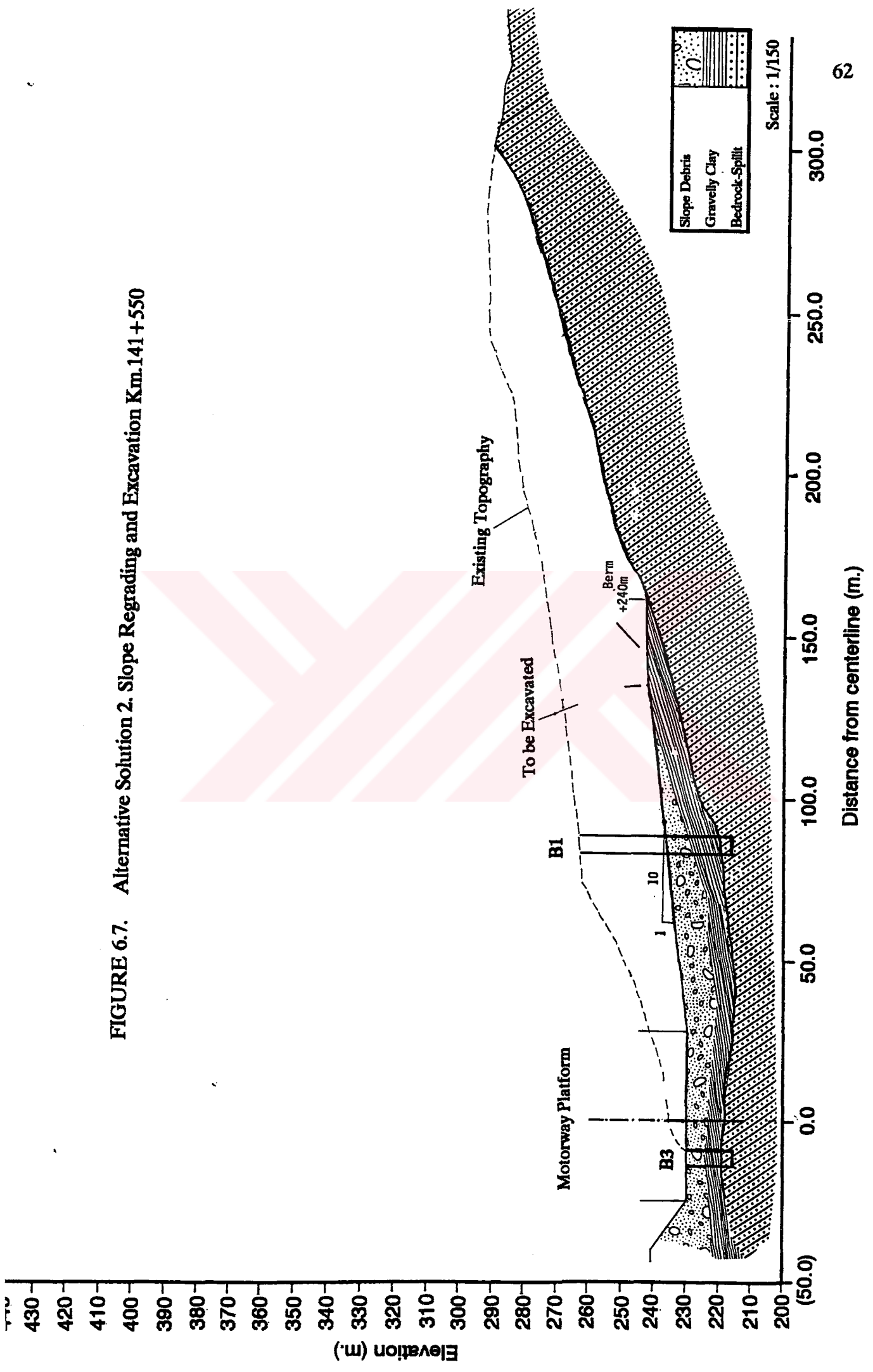


FIGURE 6.8. Alternative Solution 2. Slope Regrading and Excavation Km.141 + 600

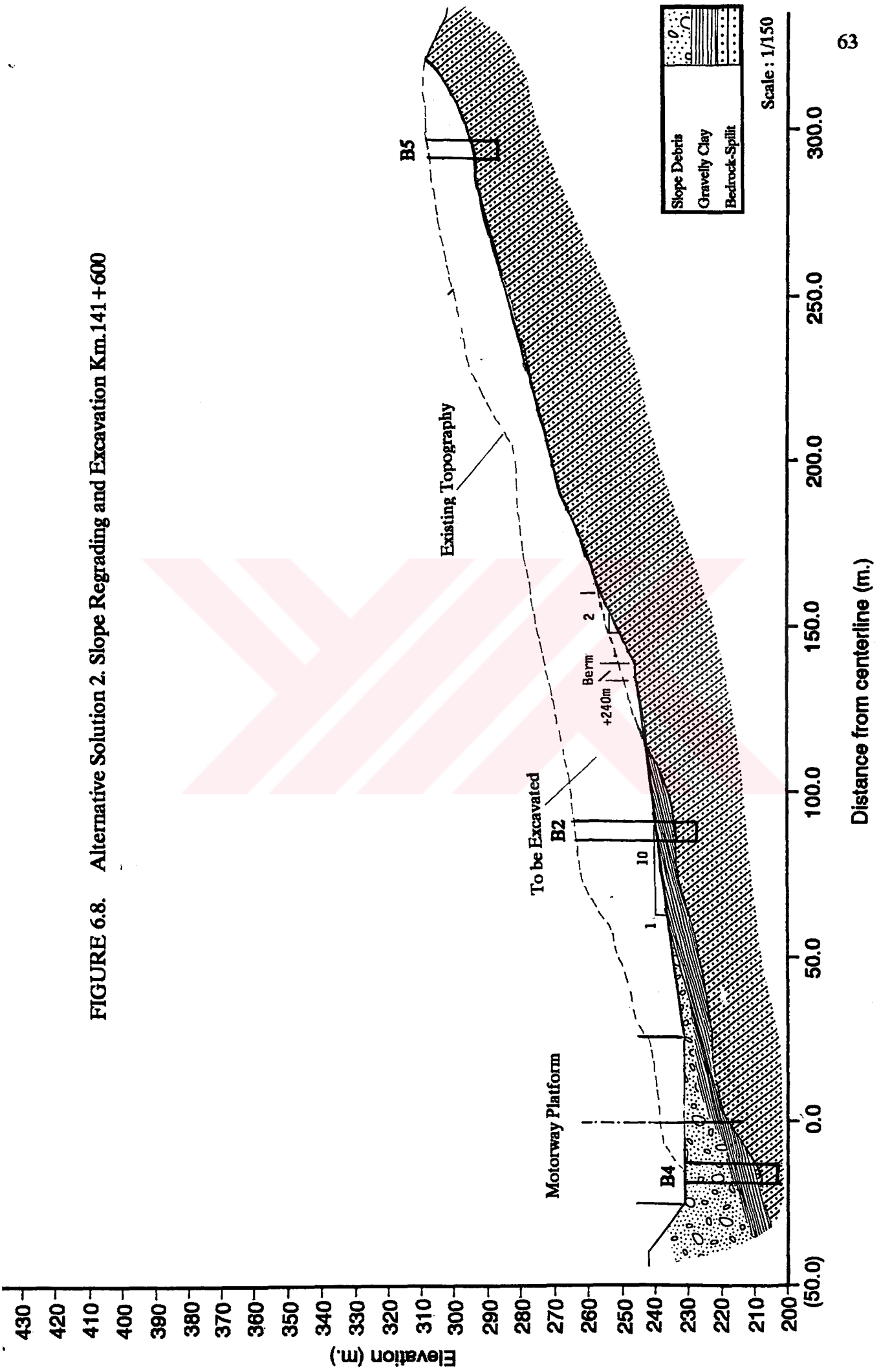
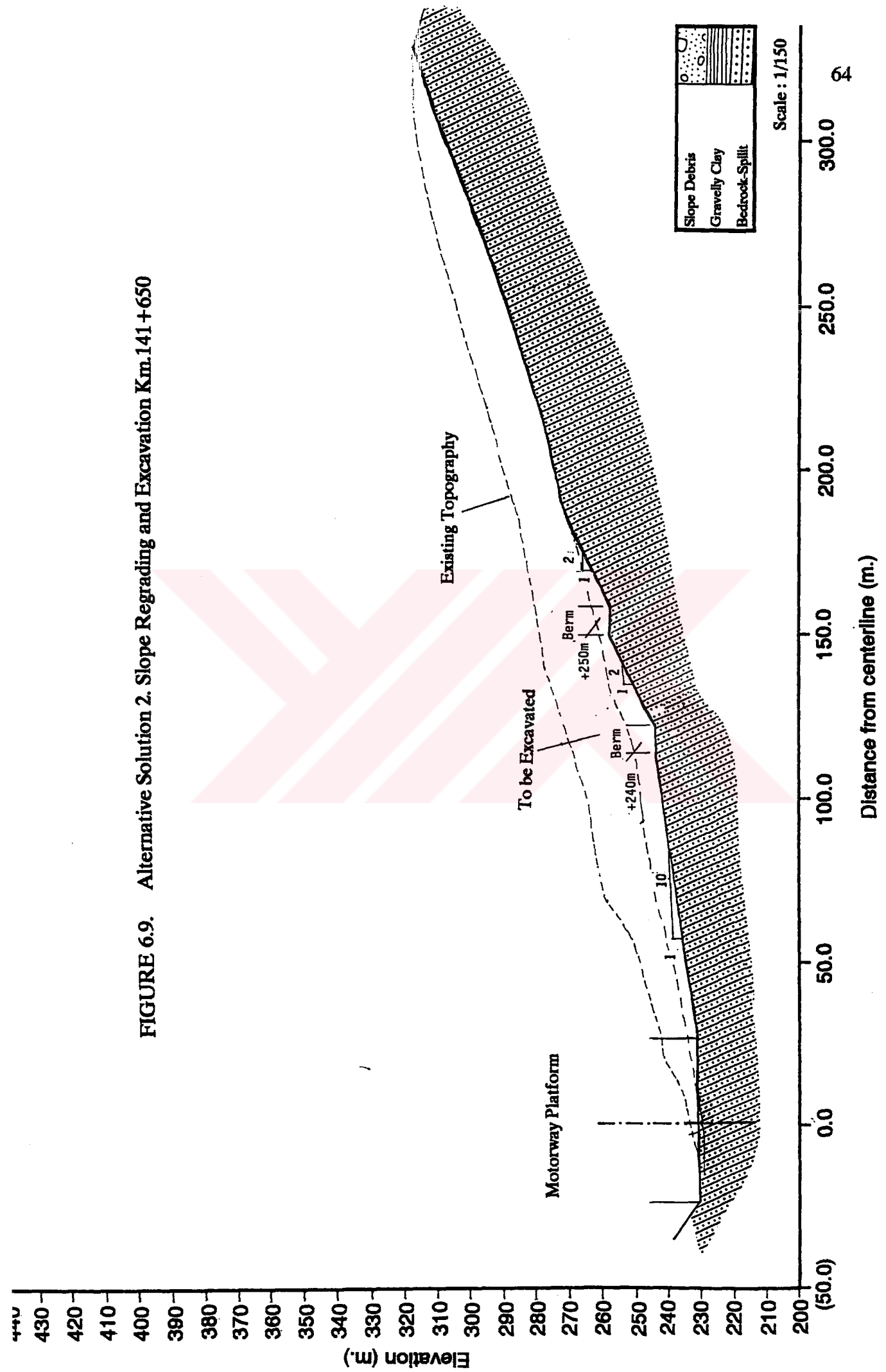
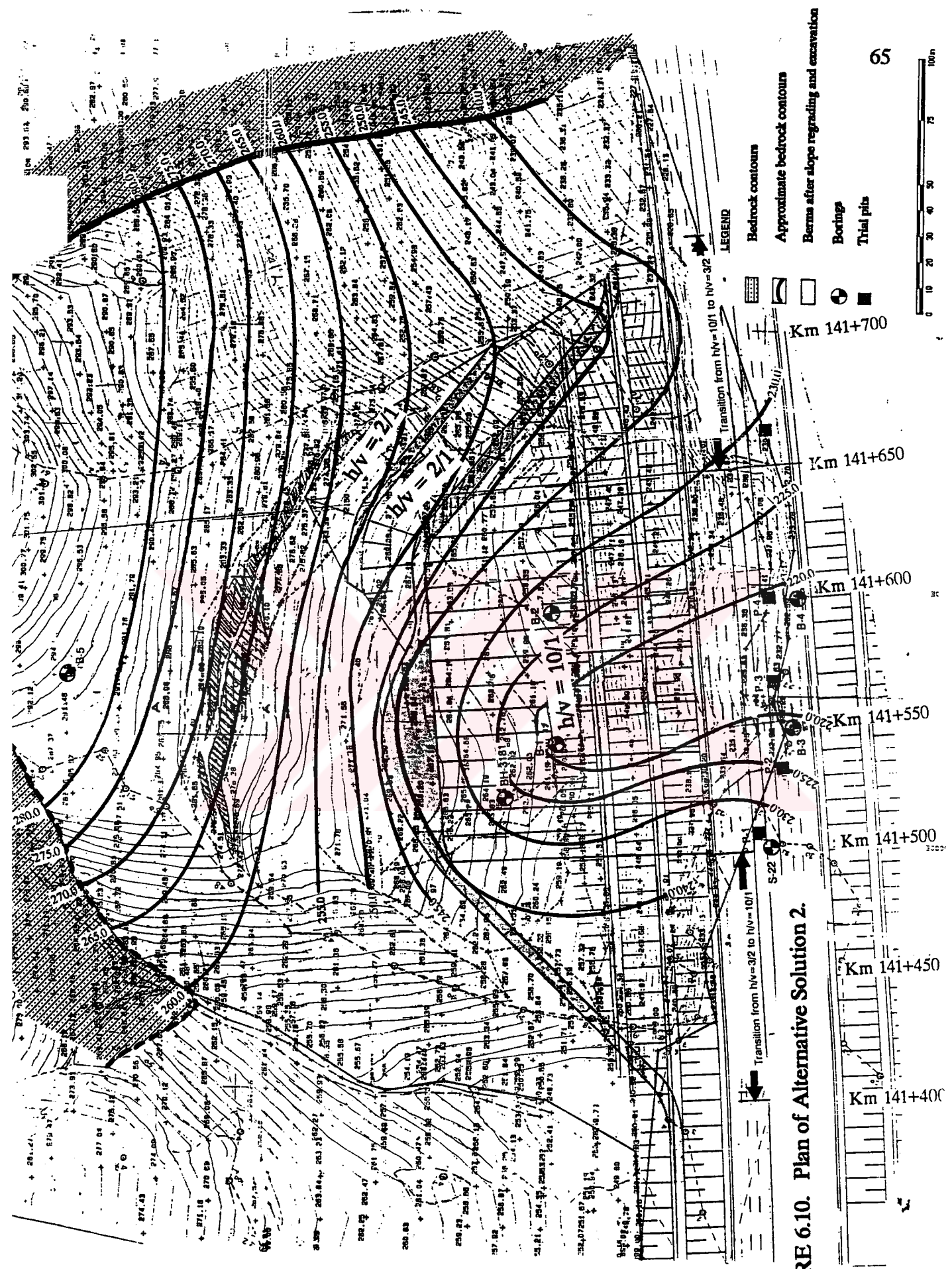


FIGURE 6.9. Alternative Solution 2. Slope Regrading and Excavation Km.141+650





**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 ( $\gamma$ ) =  $19$  kN/m<sup>3</sup>
- Internal Friction Angle ( $\phi'$ ) =  $14$  deg
- Lateral load for  $\phi$  165 single pile =  $1500$  kN.

and

$$F_z = m \cdot g \cdot \cos\alpha (\tan\phi') + F_k \quad (\text{eq.7})$$

$$F_d = m \cdot g \cdot \sin\alpha \quad (\text{eq.8})$$

$$F.S. = \frac{F_z}{F_d} \geq 2.0 \quad (\text{eq.9})$$

$$m = 8,000,000 \text{ kN}$$

$$2.0 = \frac{8,000,000 \cdot \cos 20 \cdot (\tan 14) + F_k}{8,000,000 \cdot \sin 20}$$

$$F_k = 3,598,000 \text{ kN.}$$

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

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**

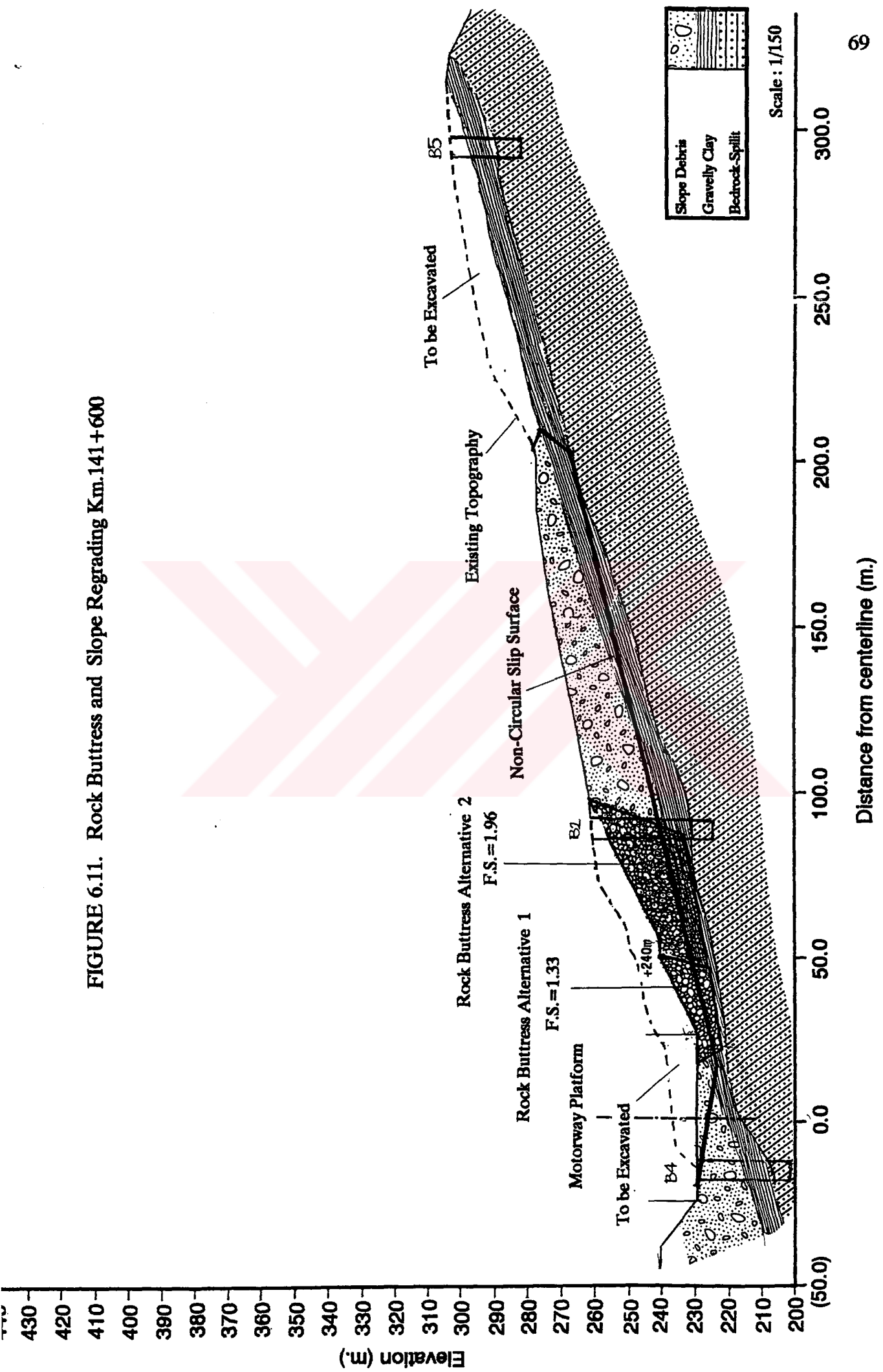
This alternative is composed of partial excavation and the formation of the rock buttress solution. The method is based on the principle of having enough length of the most critical failure surface through rock buttress, so that overall factor of safety along the length of failure surface is above the 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



Distance from centerline (m.)

a. For F.S. = 1.3

Approximate total excavation including rock buttress..... 300,000 m<sup>3</sup>

Approximate rockfill for rock buttress..... 50,000 m<sup>3</sup>

a. For F.S. = 2.0

Approximate total excavation including rock buttress..... 450,000 m<sup>3</sup>

Approximate rockfill for rock buttress..... 200,000 m<sup>3</sup>

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. Comparison of Alternatives

ALTERNATIVE	EVALUATIONS
1. Slope Regrading & Excavation	requires approximately 300,000 m <sup>3</sup> excavation in the bedrock. The slopes will be h/v=5/1 and 10/1 seems applicable but need excavation in bedrock. Drainage precausion requires.
2. Slope Regrading & Excavation	excavation down to the bedrock surface, the final regraded slope will be the bedrock surface after first berm, drainage precausion 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 m <sup>3</sup> 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 ( $\phi'$ ) and cohesion ( $c'$ ). 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  $\phi_r' = 14$  degree and  $c_r' = 0.0 \text{ kN/m}^2$

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 preliminary stage of the landslide problem is to determine 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  $\phi$  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  $\phi'$  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  $\phi'$ .

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 ( $\phi'$ ) and the cohesion  $c'$  are simultaneously determined by utilizing a main cross section only without assuming beforehand the value of  $c'$  and  $\phi'$ .

## 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

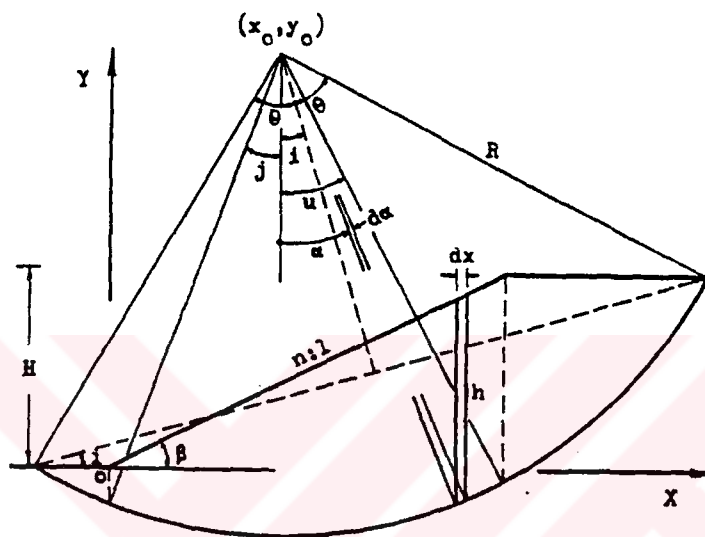


Figure A1.1 Typical geometry in slope stability analysis  
D.H.He (13)

The origin of the coordinates defines at the toe of the slope. The point  $(x_0, y_0)$  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.

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

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

$\phi'$ ..... 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;

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

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

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

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

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

where  $i$ ,  $\theta$  and  $j$  denotes the angles specifying the location of the slip circle

$$n = \cot\beta \dots \dots \dots \beta : \text{of slope inclination} \qquad \text{(eq.17)}$$

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

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

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

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

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

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

### 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  $\phi'$  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).

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

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

in which ;

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

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

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

and

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

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

in which ;

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

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

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

and

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

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

in which

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

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

It is found that the back calculation formulae for the angle of internal friction  $\phi$

can be written from the equ.(23).

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

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  $\phi'$  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).

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

## 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.

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

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

in which ;

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

$$\begin{aligned}
 A &= \theta - i + u \tan \phi' \ln \frac{\cos(u - \phi')}{\cos(\theta - i + \phi')} \\
 B &= \theta + i - u \tan \phi' \ln \frac{\cos(\theta + i - \phi')}{\cos(u - \phi')}
 \end{aligned}
 \tag{eq.40}$$

The angle of internal friction  $\phi'$  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		ARARTIRMA ÇUKURU LOGU PIT LOG				
PROJE: TAG OTOYOLU PROJECT: TAG MOTORWAY			ÇUKUR NO: 1 PIT NO : 1			
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 :		
D E E R P I T N H L I K(m)	Litoloji Lithology	Numune Sample		Cep Penetr.	Zemin Sınıfı	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation	Pocket Penetr.	Soil Clas.	
			234.15			Bitkisel Toprak/Top Soil
			230.83			Kahverengi kızıl KİL, tabana doğru aglomera sipilit kirintileri içermekte olup A ile kontaktı gevsek derine inildikçe sertleşmekte  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 yeşil renkte volkanik AGLOMERA, sipilit içerikli, üst yüzeyler kısmen altere olmuş.  Light brown - green volcanic AGGLOMERATE, with split, upper levels are altered

NOT / NOTE :

N4098190.612 E498027.612 ELEV232.974		ARARIRMA 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 derinlii: Depth of pit :		Y.A.S. Derinlii(m): Depth of GW (m) :		Kontrol eden: Checked by :		
D D E E R P I T N H L I K(m)	Litoloji Lithology	Numune Sample		Cep Penetr. Pocket Penetr.	Zemin Sınıfı Soil Clas.	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation			
			232.43			<p>Sari kirli beyaz renkte ust yuzeyler travertenlesme gosterir kirectasi (bloktan-cakila) kal-ker tufu icinde tabana dogru bloklarda azalma, kil-kirec yuzdesinde artis</p> <p>Yellow-white, traverten appearance at upper levels limestone (boulder to gravel) within calcareous tuff, decrease in boulders and increase in clay-lime percent at lower levels</p>
			227.41			<p>kahverenkli-kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup ust formasyon ile kontagi gevsek derine inildikce sertlesmekte (kiltasi)</p> <p>reddish brown CLAY, with agglomerate, spilit particles at lower levels, contact with upper formation is soft, harder at lower levels (claystone)</p>

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 :		Kazıcı cinsi: Type of rig :		
Çukur derinliği: Depth of pit :		Y.A.S. Derinliği(m): Depth of GWT (m) :		Kontrol eden: Checked by :		
D E E R P I T N H L I K(m)	Litoloji Lithology	Numune Sample		Cep Penetr.	Zemin Sınıfı	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation	Pocket Penetr.	Soil Clas.	
						<p>Sari kirli beyaz renkte ust yuzeyler travertenlesme gosterir kirectasi (bloktan-cakila) kal-ker tufu icinde tabana dogru bloklarda azalma, kil-kirec yuzdesinde artis</p> <p>Yellow-white, traverten appearance at upper levels limestone (boulder to gravel) within calcareous tuff, decrease in boulders and increase in clay-lime percent at lower levels</p>
		230.98				<p>kahverenkli-kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup ust formasyon ile kontagi gevsek derine inildikce sertlesmekte (kiltasi)</p> <p>reddish brown CLAY, with agglomerate,spilit particles at lower levels, contact with upper formation is soft, harder at lower levels (claystone)</p>
		226.91				

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 : ~Km 141 Location:		Tarih : Date :		Kazıcı cinsi: Type of rig :		
Çukur derinliği: Depth of pit :		Y.A.S. Derinliği(m): Depth of GW (m) :		Kontrol eden: Checked by :		
D E E R P I T N H L I K(m)	Litoloji Lithology	Numune Sample		Cep Penetr.	Zemin Sınıfı	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation	Pocket Penetr.	Soil Clas.	
			225.31			<p>Sari kirli beyaz renkte ust yuzeyler travertenlesme gosterir kirectasi (bloktan-cakila) kal-ker tufu icinde tabana dogru bloklarda azalma, kil-kirec yuzdesinde artis</p> <p>Yellow-white, traverten appearance at upper levels limestone (boulder to gravel) within calcareous tuff, decrease in boulders and increase in clay-lime percent at lower levels</p>
						<p>kahverenkli-kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup ust formasyon ile kontagi gevsek derine inildikce sertlesmekte (kiltasi)</p> <p>reddish brown CLAY, with agglomerate, spilit particles at lower levels, contact with upper formation is soft, harder at lower levels (claystone)</p>

NOT / NOTE :

N4098188.451 E499155.267 ELEV232.407		ARARTIRMA 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 derinlii: Depth of pit :		Y.A.S. Derinlii(m): Depth of GW (m) :		Kontrol eden: Checked by :		
D E E R P I T N H L I K(m)	Litoloji Lithology	Numune Sample		Cep Penetr.	Zemin Sınıfı	TANIMI IDENTIFICATION
		NO	Kot (m) Elevation	Pocket Penetr.	Soil Clas.	
			229.95			Bitkisel Toprak/Top Soil
			229.42			Kahverengi kizil KIL, tabana dogru aglomera sipilit kirintilari icermekte olup A ile kon-tagı 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
			228.53			Acik kahverengi yesil renkte volkanik AGLOMERA, sipilit icerikli, ust yuzeyler kismen altere olmus.  Light brown - green volcanic AGGLOMERATE, with split, upper levels are altered

NOT / NOTE :

SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B1

SAYFA NO/PAGE NO : 87

VEREN / OWNER:  
TEKFEN-IMPRESIT O.G.

PROJE / PROJECT:  
TAG OTOYOLU/MOTORWAY

Yerli/Locality: ADANA

Agiz kotu/Ground elevation : 260.99

Sondaj tipi/Boring type: ROTARY

Başlangıç tarihi/Begin date : 30/12/91

Sondaj derinliği/Boring depth: 43.90

Sondor/Driller: H.GOZCU

Tamamlanma tarihi/Completion date: 30/12/91

Su seviyesi/Water table :

Mühendis/Engineer:

Der. (m)	Litoloji Lithology	Orselemem'i's Undisturbed	Orselemem'i's Disturbed	S.P.T.					Zemin Sınıfı Soil Class	KAROT/CORE			Kaya Sınıfı Rock Class	AÇIKLAMALAR/EXPLANATIONS	
				Darbe:Blows			N <sub>30</sub>			TCR%	SCR%	RQD%			
				No	0-15	15-30	30-45	10							20
					GRAPHIC			GRAPHIC			GRAPHIC				
1				50/15	-	-								<p><b>YAMAC MOLOZU</b> 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) <b>SLOPE DEBRIS</b> material varying as clay, sand, gravel in size, the boulders are white, strong and originated from limestone, occasionally slope breccia, lime cemebed, occasionally with cavities (between 0.0-11.30m, high clay concentration with yellow color)</p>	
2				19	23	50/3									
3				50/10	-	-									
4				50/10	-	-									
5				0/15	-	-									
6				25	50/13	-									
7				32	28	35							<p><b>ÇAKILLI KIL</b> cakillar koseli - yuvarlak, sipilit ve kirectasi parcalari, ust seviyelerde kirectasi cakillari, alt seviyelerde sipilitik aglomeraya ait kirintilar <b>GRAVELLY CLAY</b> gravels are subangular and rounded, sipilit and limestone particles, limestone gravels at upper layers, and particles blonging to sipilit at lower levels</p>		
8				25	26	32									



## SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B2

SAYFA NO/PAGE NO : 89

SVEREN / OWNER:

PROJE / PROJECT:

TEKFEN-IMPRESIT O.G.

TAG OTOYOLU/MOTORWAY

Mekii/Locality: ADANA

Agiz kotu/Ground elevation : 260.86

Sondaj tipi/Boring type: ROTARY

Başlangıç tarihi/Begin date : 30/12/91

Sondaj derinliği/Boring depth: 31.00

Sondor/Driller: H.GOZCU

Bitiş tarihi/Completion date: 30/12/91

Su seviyesi/Water table :

Mühendis/Engineer:

Derinlik (m)	Litoloji Lithology	Orseleminin Undisturbed	Orseleminin Disturbed	S.P.T.				Zemin Sınıfı Soil Class	KAROT/CORE			Kaya Sınıfı Rock Class	ACIKLAMALAR/EXPLANATIONS
				Darbe:Blows			N <sub>30</sub>		TCR%	SCR%	ROD%		
				No	0-15	15-30							
									100	100	100		
													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)
					1	20	25	32					
					2	19	25	26					
					3	50/10							
					4	25	27	22					
					5	18	19	24					
					6	23	25	32					
													SIPILIT kahvemsii yesil, ince - orta







SONDAJ LOGU / BORING LOG

SONDAJ NO/BORING NO : B4

SAYFA NO/PAGE NO : 92

VEREN / OWNER:  
TEKFEN-IMPRESIT O.G.

PROJE / PROJECT:  
TAG OTOYOLU/MOTORWAY

Yer/Kil/Locality: ADANA

Agiz kotu/Ground elevation : 232.75

Sondaj tipi/Boring type: ROTARY

Çalışma başlangıç tarihi/Begin date : 10/12/91

Sondaj derinliği/Boring depth: 20.00

Sondor/Driller: H.GOZCU

Çalışma bitiş tarihi/Completion date: 10/12/91

Su seviyesi/Water table :

Mühendis/Engineer:

Der. (m)	Litoloji Lithology	Orseleminin Undisturbed	Orseleminin Disturbed	S.P.T.					Zemin Sinifi Soil Class	KAROT/CORE			Kaya Sinifi Rock Class	ACIKLAMALAR/EXPLANATIONS
				Darbe:Blows			N <sub>30</sub>			TCR%	SCR%	RQD%		
				No	0-15	15-30	30-45	10						
									100	100	100			
														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 breccia, 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
														SPLITIK AGLONERA 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 SIPILIT 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:

PROJE / PROJECT:

TEKFEN-IMPRESIT O.G.

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	Orsele nemi s Undisturbed	Orsele nemi s Disturbed	S.P.T.					Zemin Sınıfı Soil Class	KAROT/CORE			Kaya Sınıfı Rock Class	AÇIKLAMALAR/EXPLANATIONS
				Darbe:Blows			N <sub>30</sub>			TCR%	SCR%	RQD%		
				0-15	15-30	30-45	10	20						
				No	GRAPHIC			100		100	100			
														<p><b>ÇAKILLI KİL</b> çok kati-sert, beyaz - kahverengi, cakillar koseli, max. cakil boyutu 2.0cm (KALIS)  <b>GRAVELLY CLAY</b> very stiff-hard, white - brown, gravels are subangular, max. gravel size is 2.0cm (CALICHE)</p>
														<p><b>ÇAKILLI KİL</b> kızil kahverengi, cakillar yuvarlak-koseli, max. cakil boyutu 2.0cm, kirectasi ve sipilit parcalari  <b>GRAVELLY CLAY</b> reddish brown, gravels are round - subangular, max. gravel size is 2.0cm, limestone and sipilit particles</p>
														<p><b>SİPİLİT</b> kahvemi yesil renkli, ince-orta daneli, ayrismamis, kilcal ve yogun kalsit damarli, gelisiguzel duzensiz  <b>SİPİLİT</b> brownish green, fine-medium grained, not weathered, fine and dense calsite infillings, irregular</p>
														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	8.08	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	:	

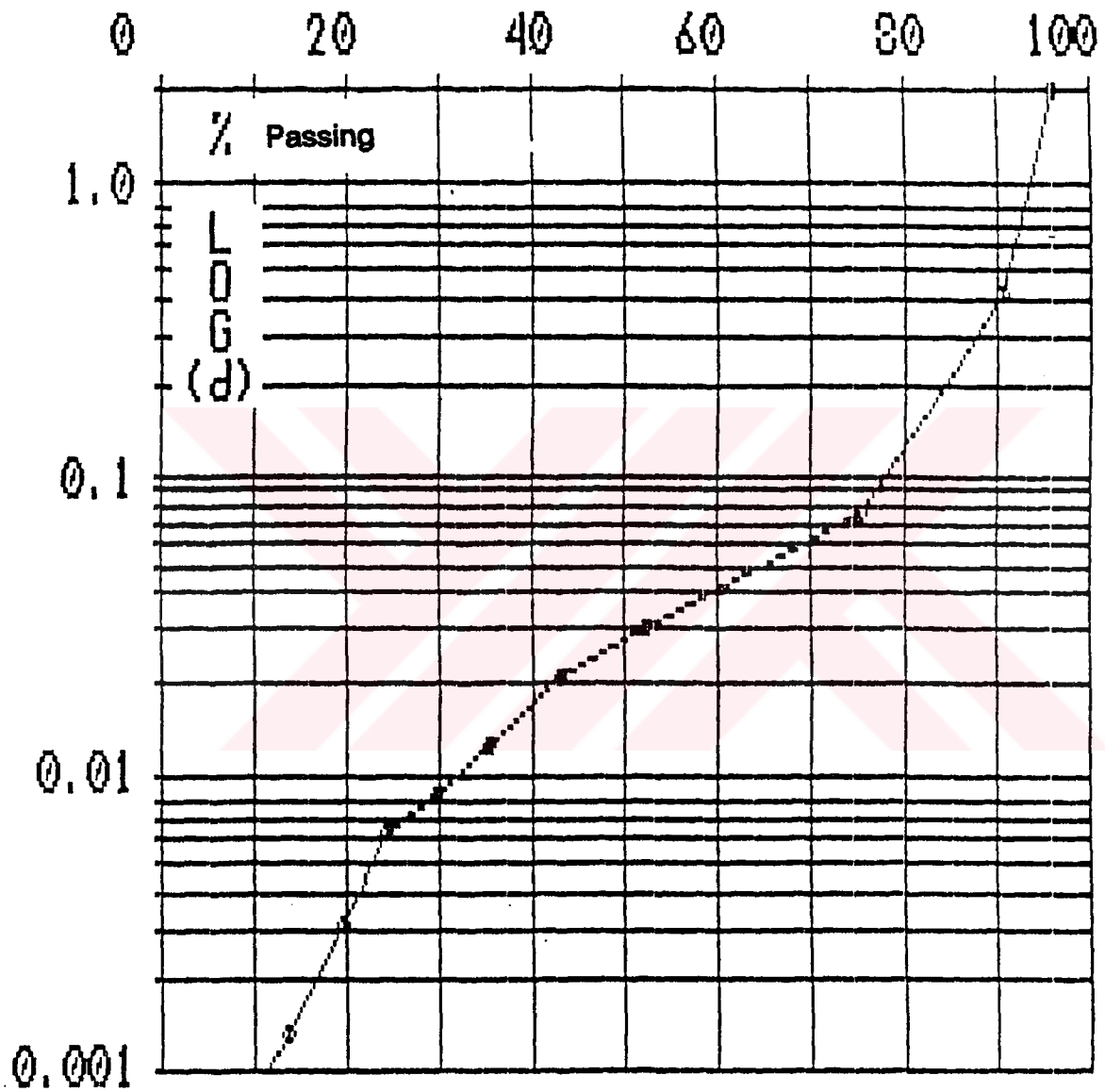


FIGURE A3.1.1 Sieve analysis on sample no.1A

**RESIDUAL DIRECT SHEAR TEST  
SAMPLE NO.1A 1st.SHEAR**

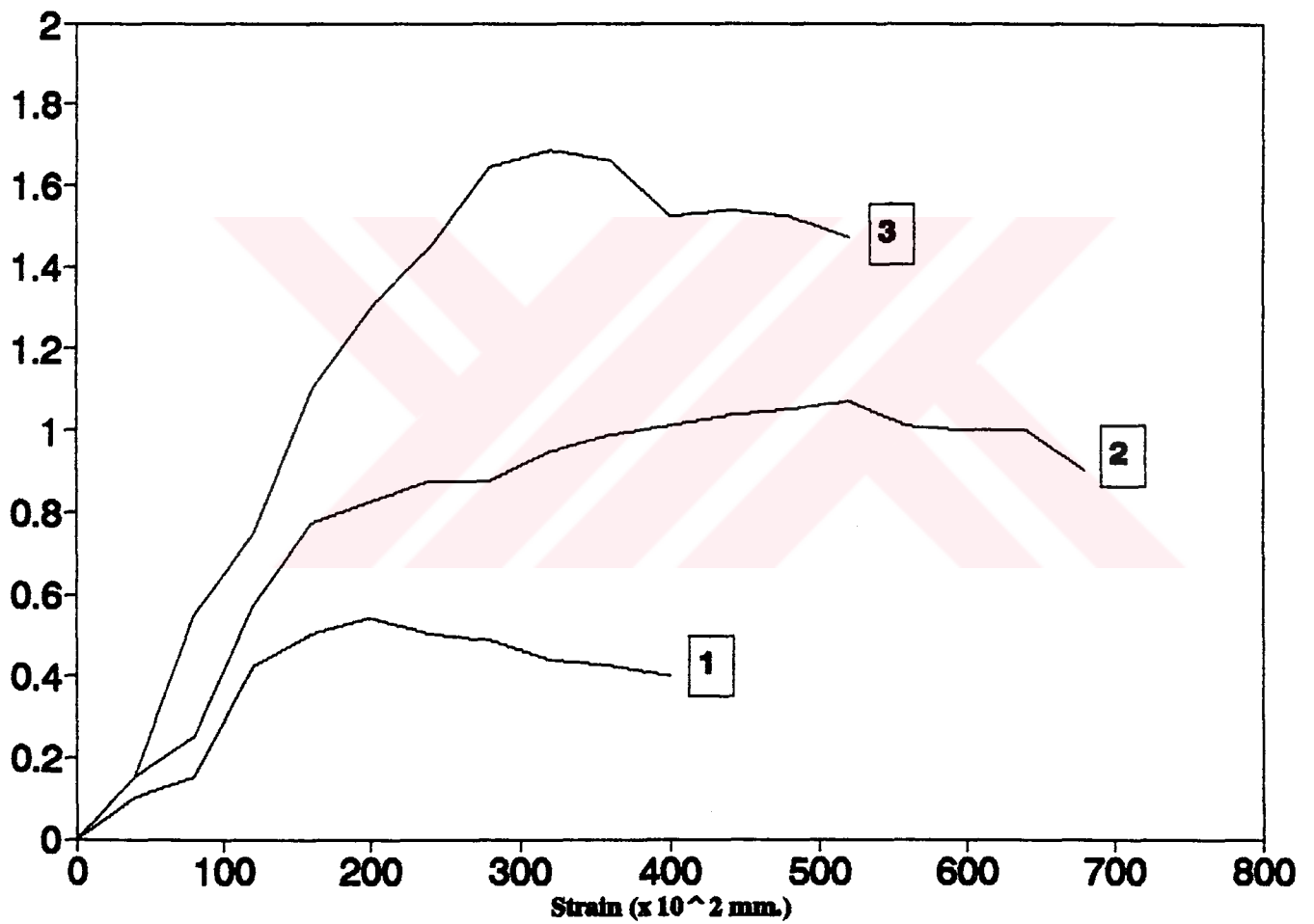


FIGURE A3.1.2 Residual direct shear test

Sample no.1A 1st. Shear



**RESIDUAL DIRECT SHEAR TEST  
SAMPLE No.1 A 2nd SHEAR**

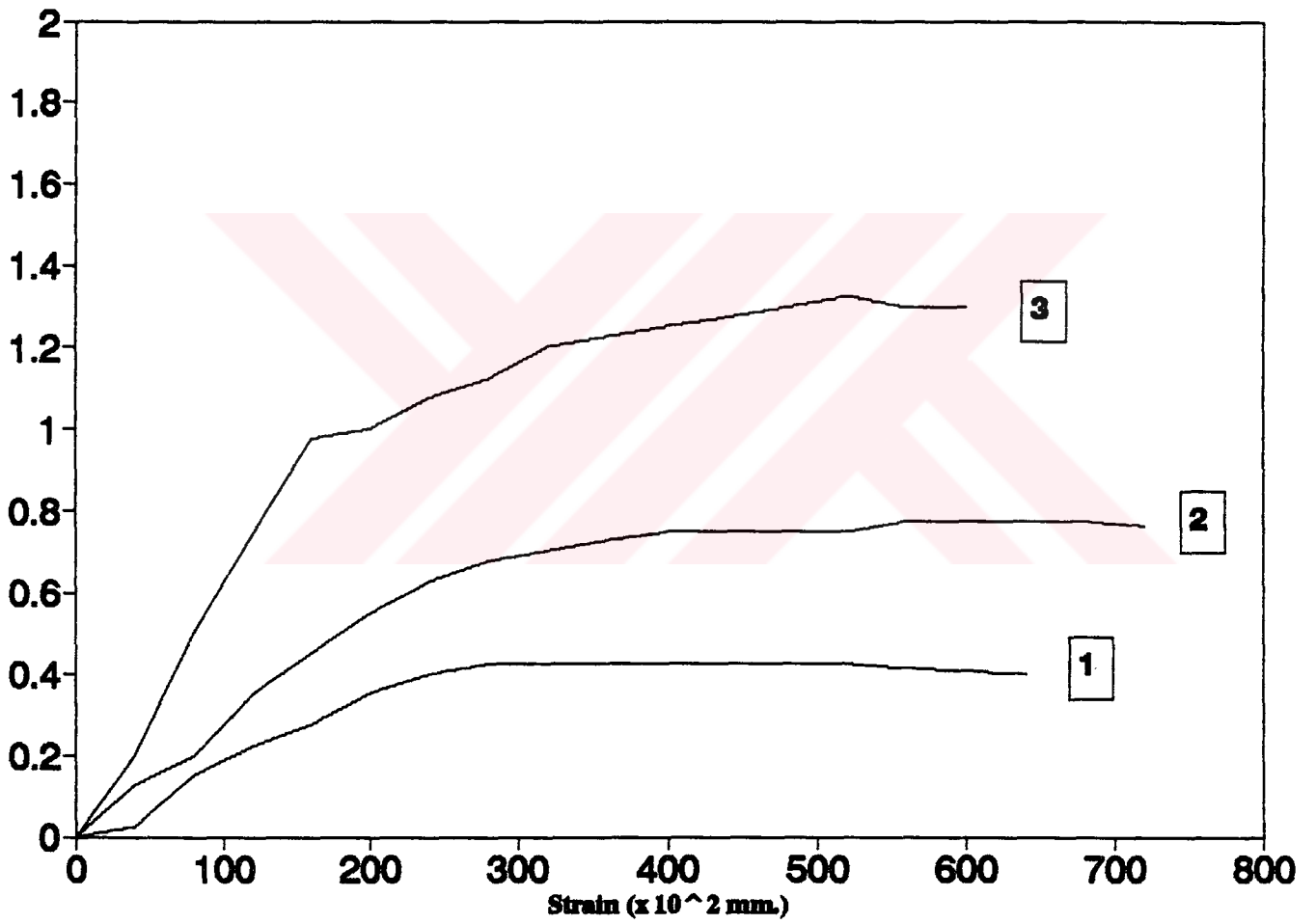


FIGURE A3.1.3 Residual direct shear test

Sample no.1A 2nd. Shear

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

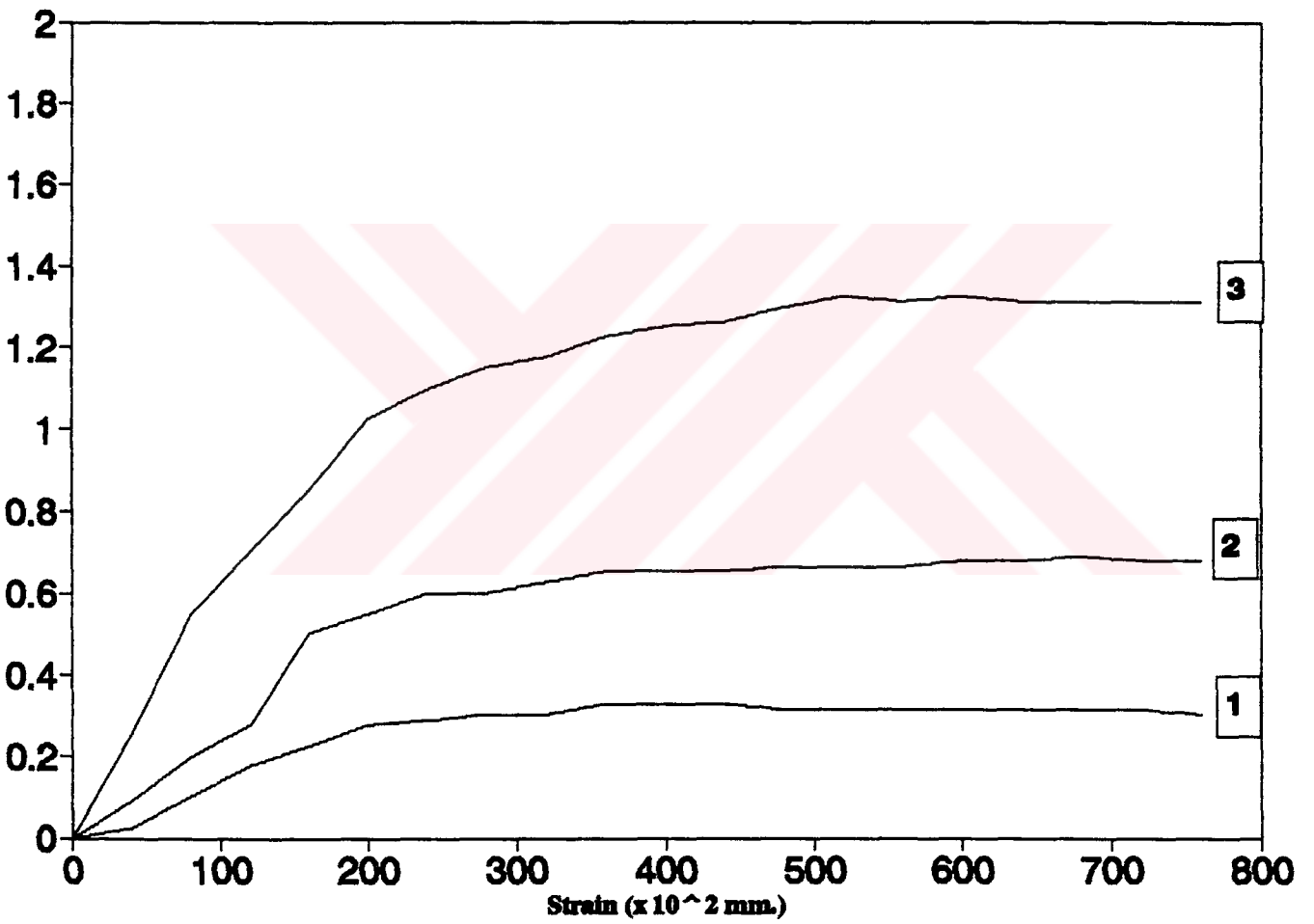
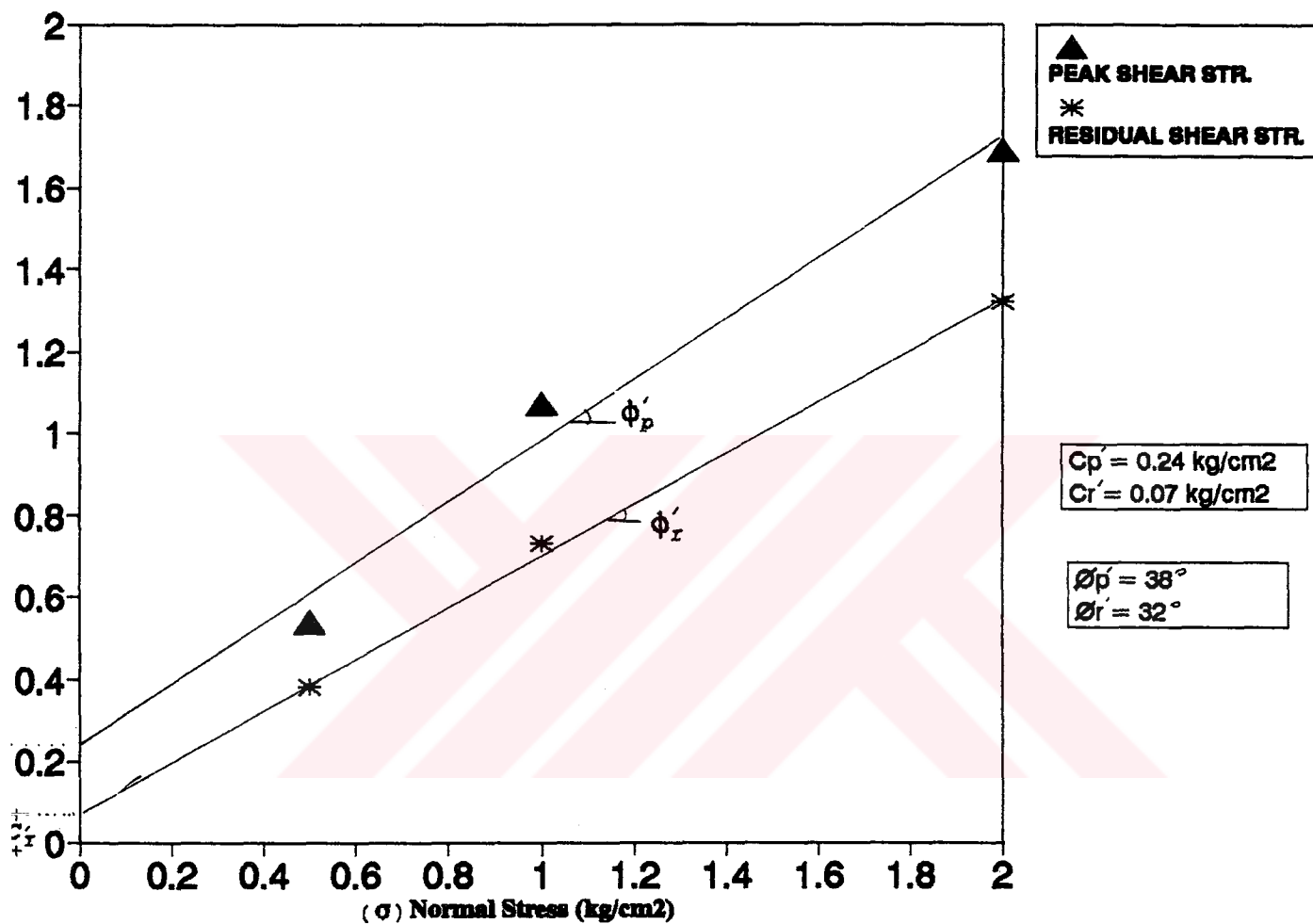


FIGURE A3.1.4 Residual direct shear test

Sample no.1A 3rd. Shear

**RESIDUAL DIRECT SHEAR TEST  
SAMPLE No.1 A**



**TEST:1A**

SAMPLE	$\sigma_n$ (Kg/cm <sup>2</sup> )	$\tau_p$ (Kg/cm <sup>2</sup> )	$\tau_r$ (Kg/cm <sup>2</sup> )
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

<u>Sieve No.</u>	<u>Sieve Size (mm)</u>	<u>Retained (gr)</u>	<u>Cum.Ret. (gr)</u>	<u>Cum.Ret. (%)</u>	<u>Cum.Pass. (%)</u>	<u>Total Pass Samp. %</u>
# 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.  
e : 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

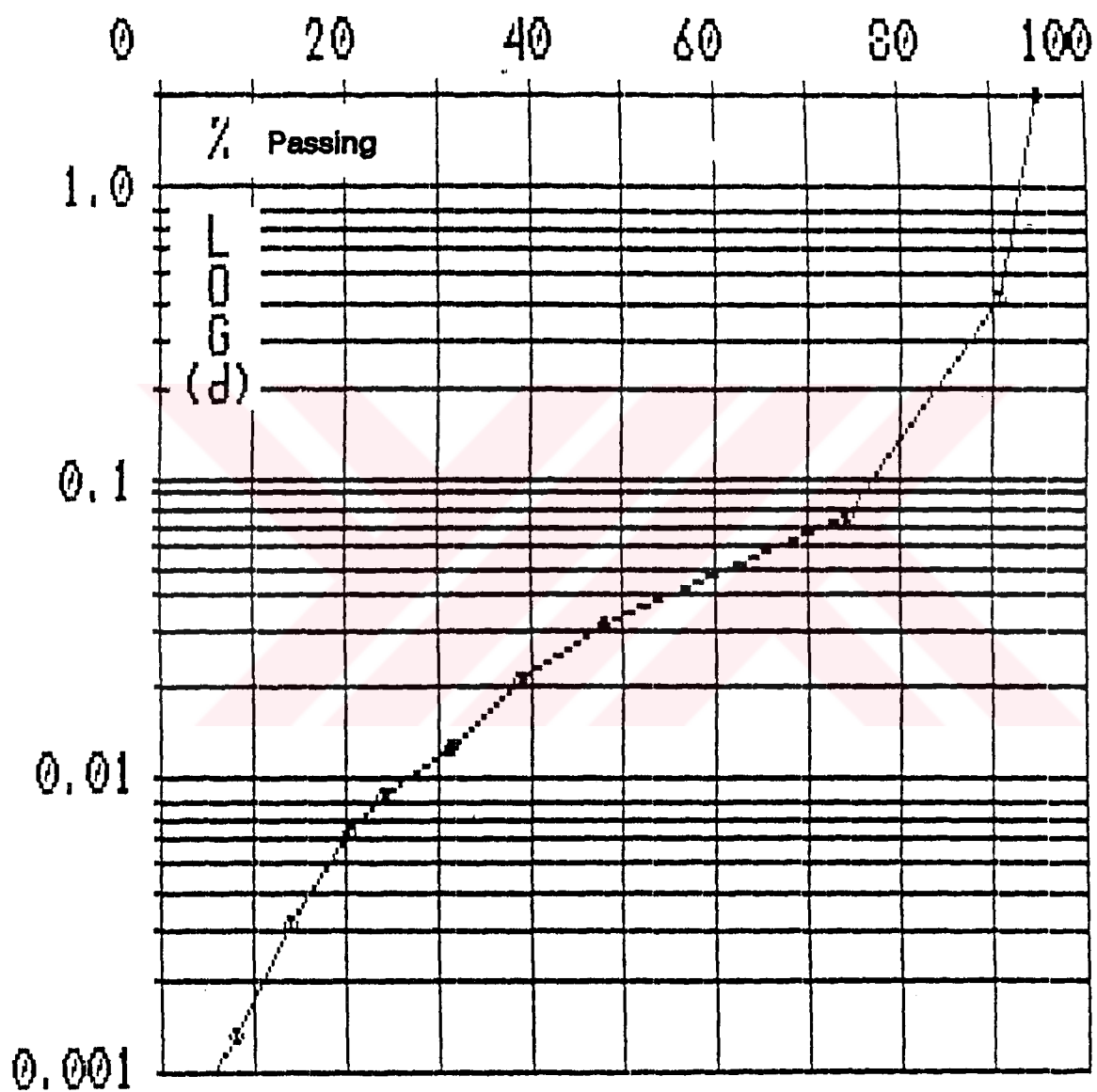


FIGURE A3.2.1 Sieve analysis on sample no.1B

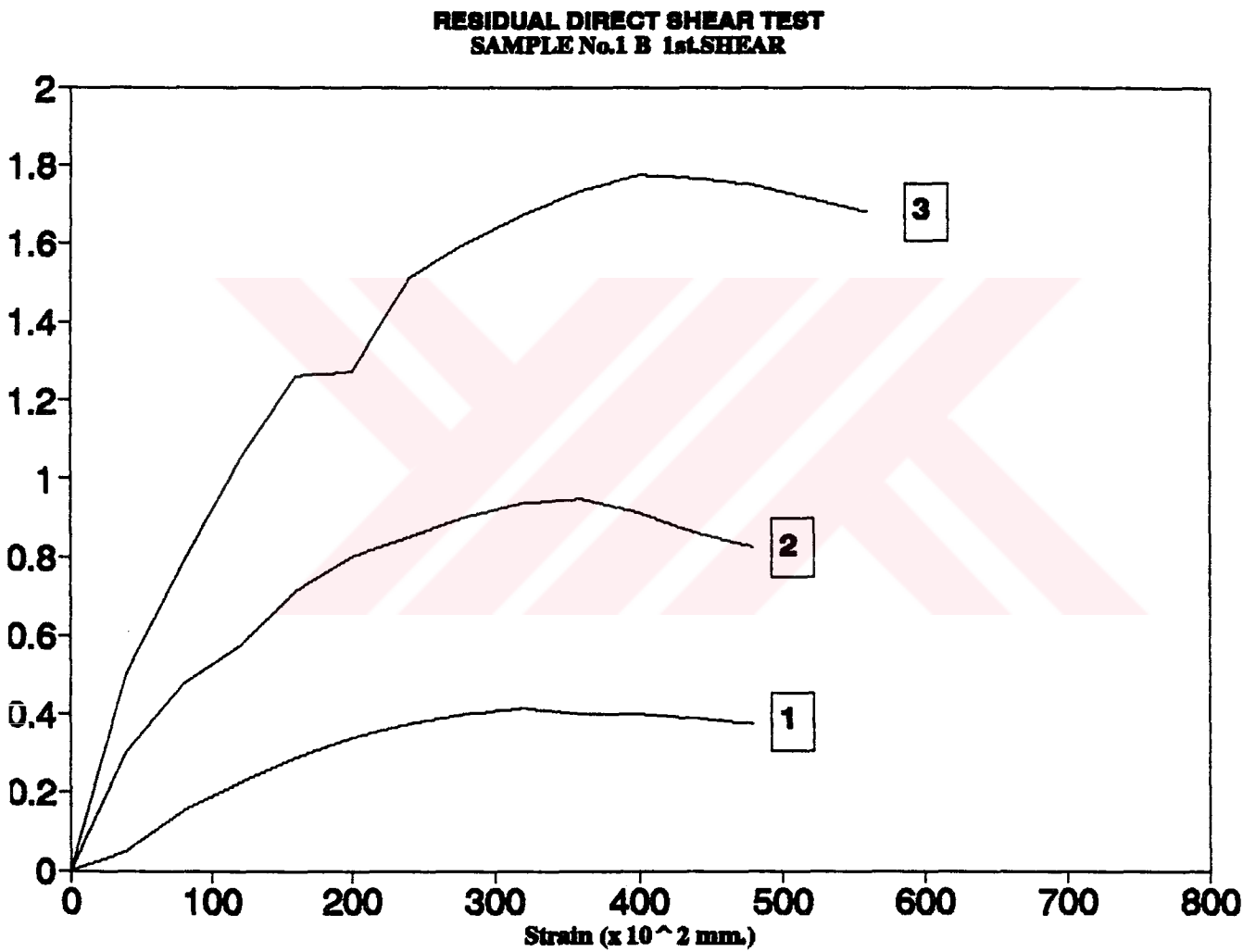


FIGURE A3.2.2 Residual direct shear test

Sample no.1B 1st. Shear

**RESIDUAL DIRECT SHEAR TEST**  
**SAMPLE No.1 B 2nd.SHEAR**

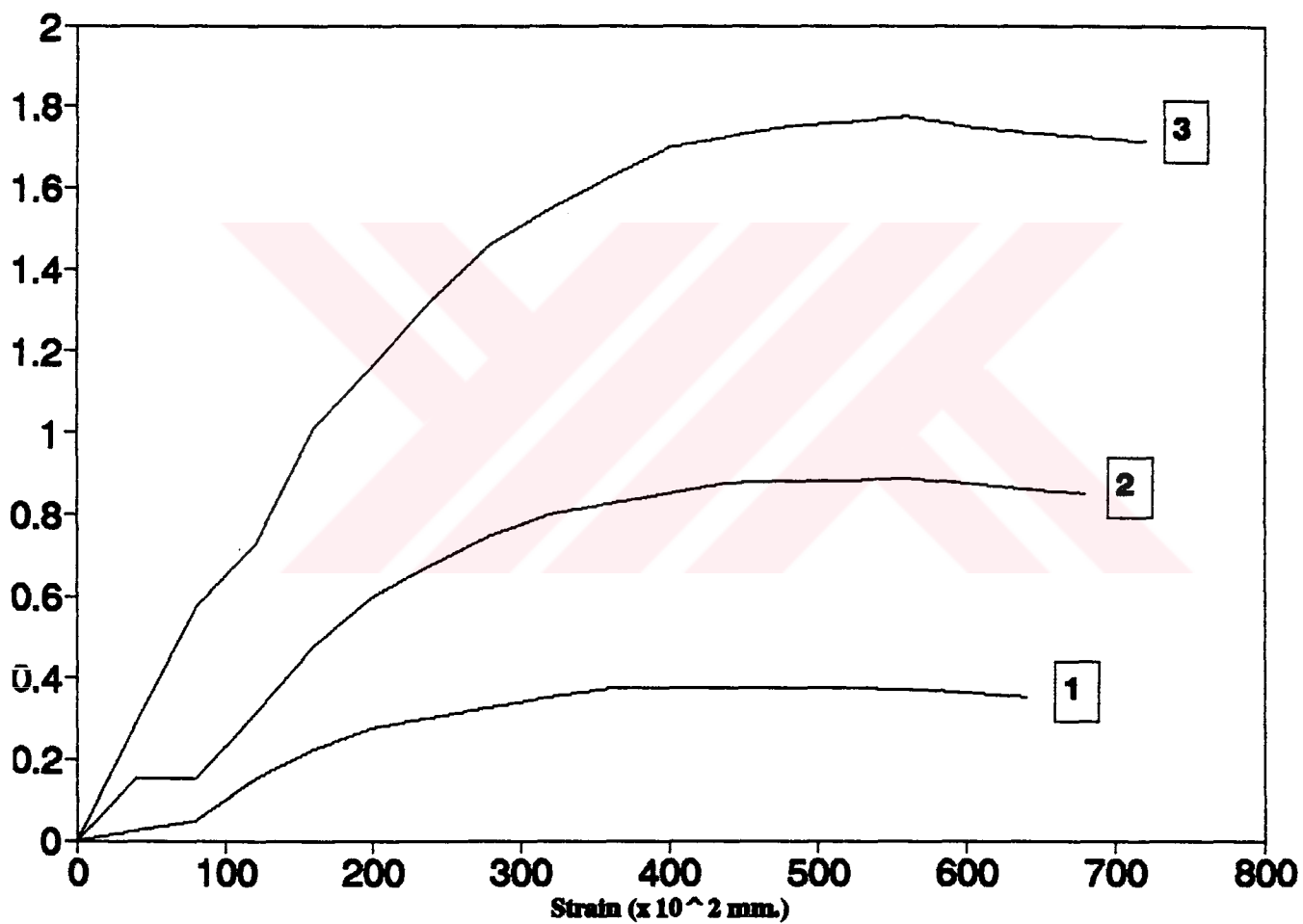


FIGURE A3.2.3 Residual direct shear test

Sample no.1B 2nd. Shear

**RESIDUAL DIRECT SHEAR TEST  
SAMPLE No.1 B 3rd.SHEAR**

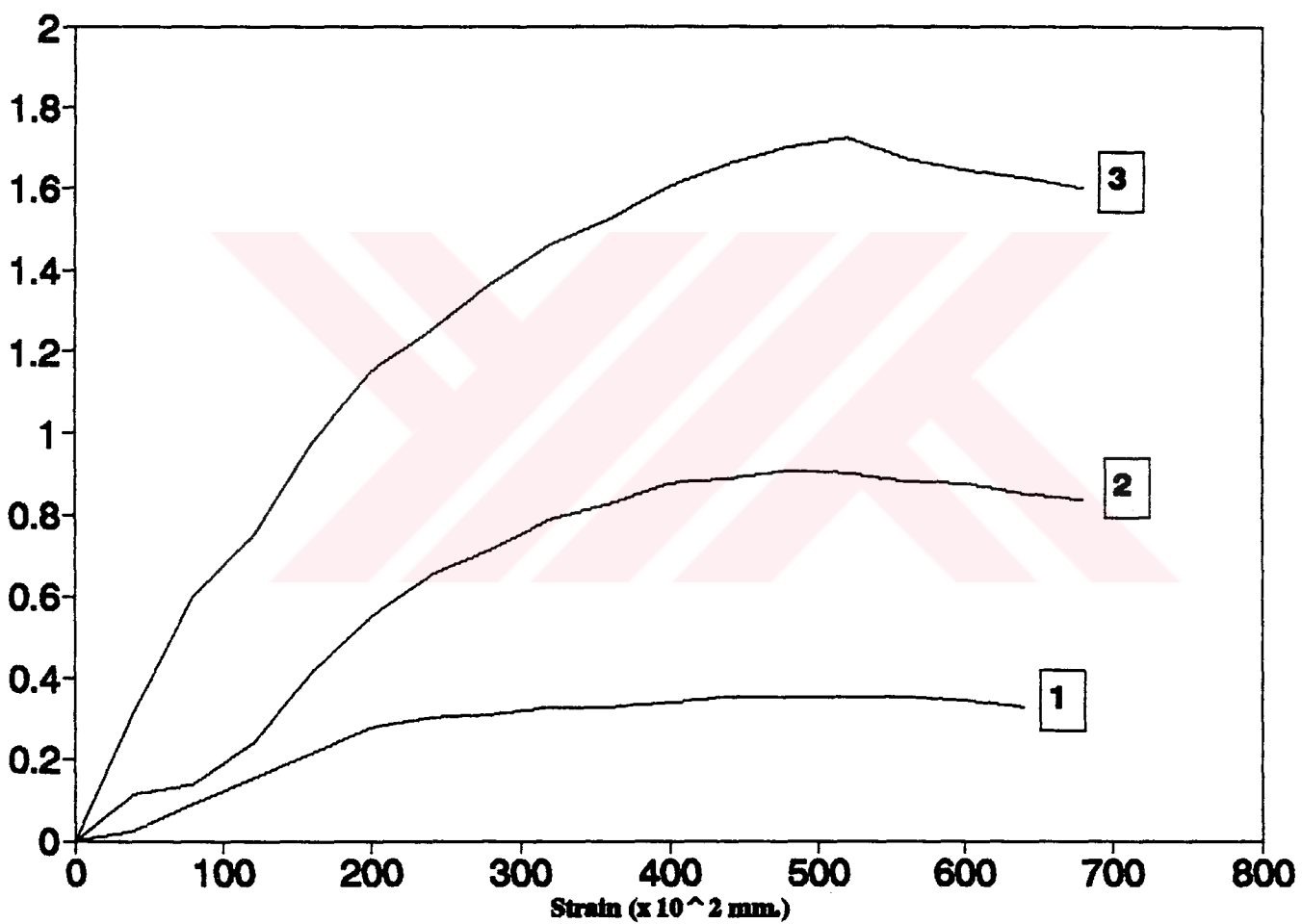
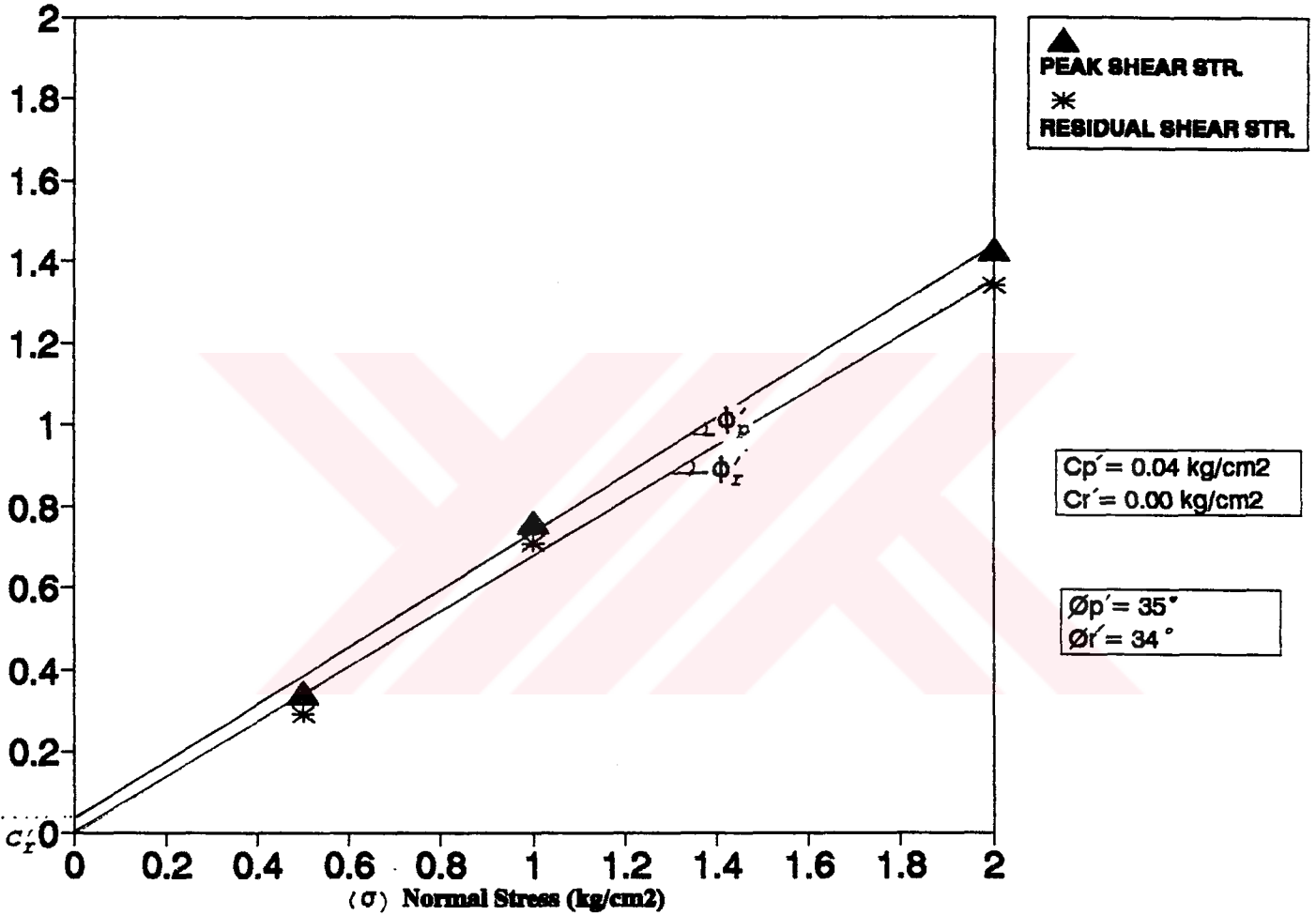


FIGURE A3.2.4 Residual direct shear test

Sample no.1B 3rd. Shear



**RESIDUAL DIRECT SHEAR TEST  
SAMPLE No.1 B**



**TEST:1B**

SAMPLE	$\sigma_H$ (Kg/cm <sup>2</sup> )	$\tau_p$ (Kg/cm <sup>2</sup> )	$\tau_r$ (Kg/cm <sup>2</sup> )
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 Pass 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 :

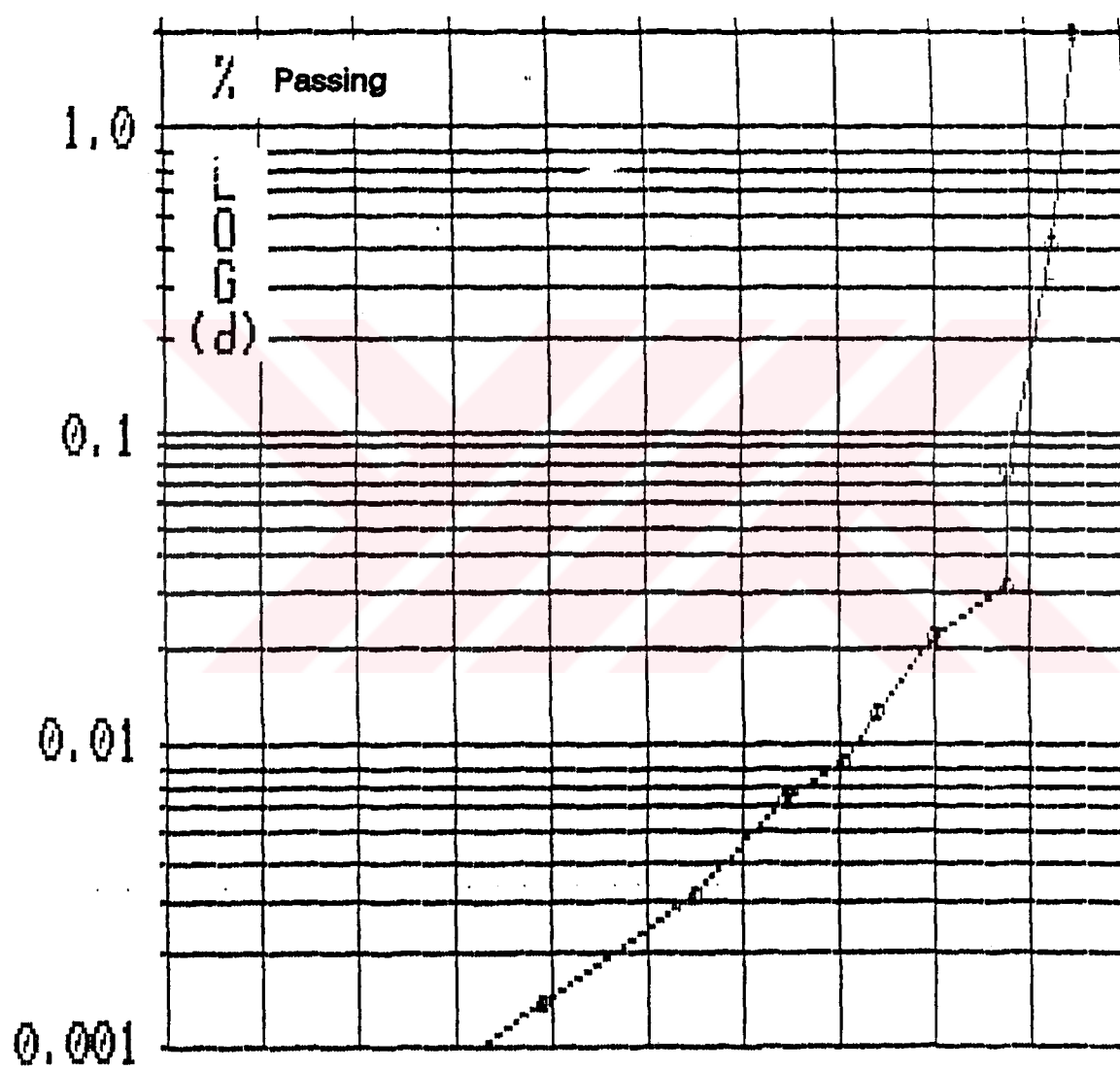


FIGURE A3.3.1 Sieve analysis on sample no.CBR1

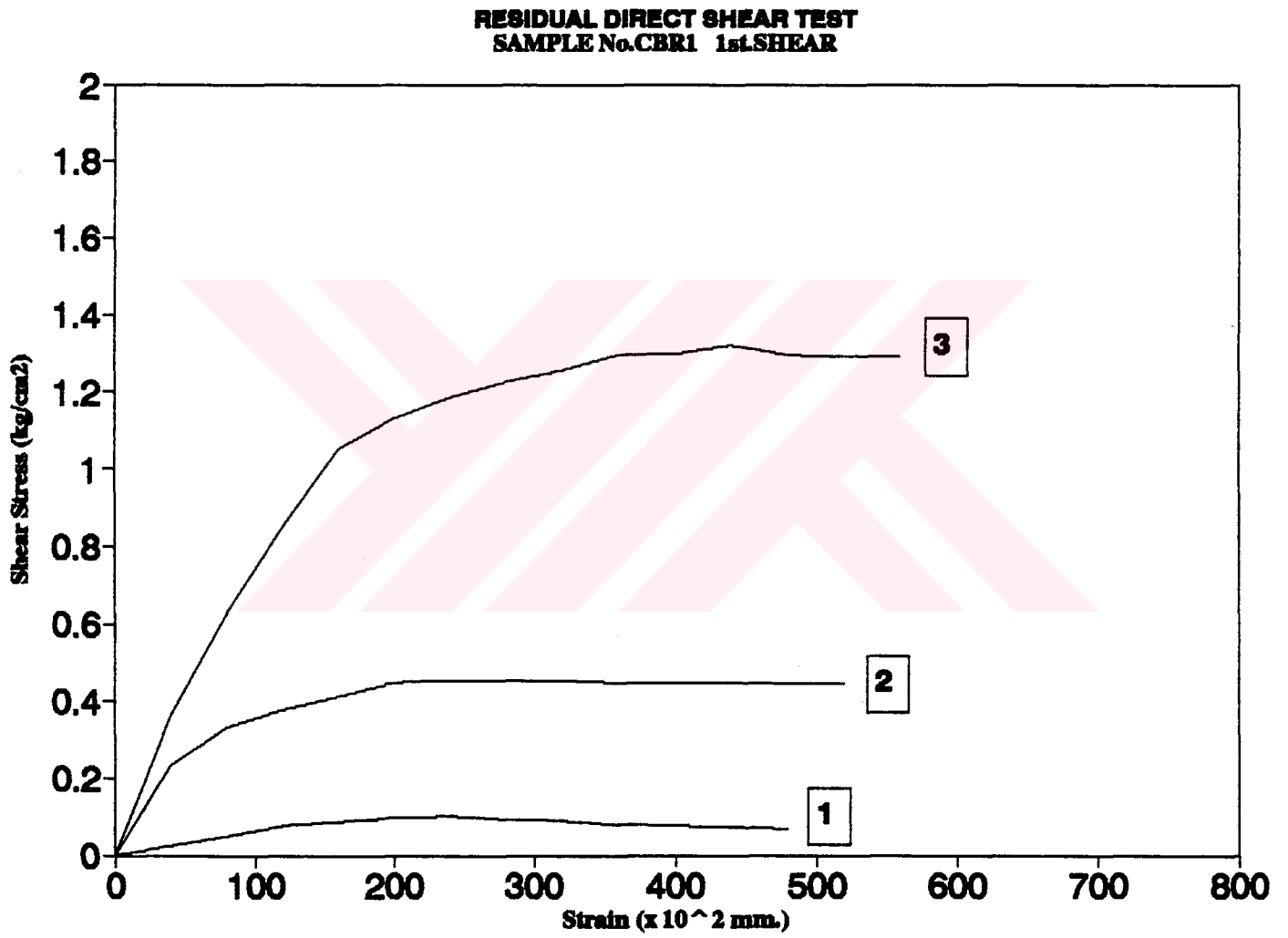


FIGURE A3.3.2 Residual direct shear test

Sample no.CBR1 1st. Shear

**RESIDUAL DIRECT SHEAR TEST  
SAMPLE No.CBR1 2nd.SHEAR**

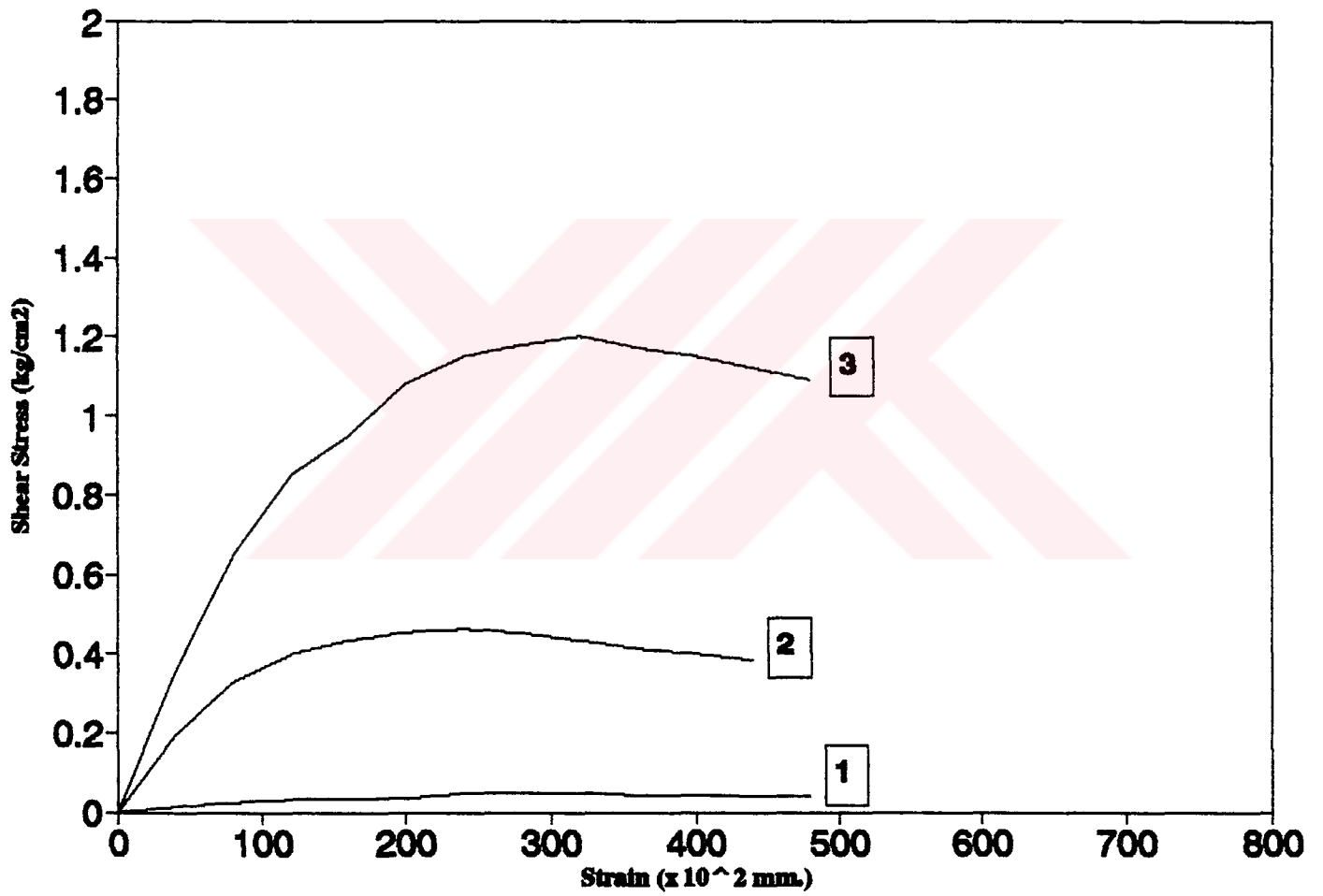


FIGURE A3.3.3 Residual direct shear test

Sample no.CBR1 2nd. Shear

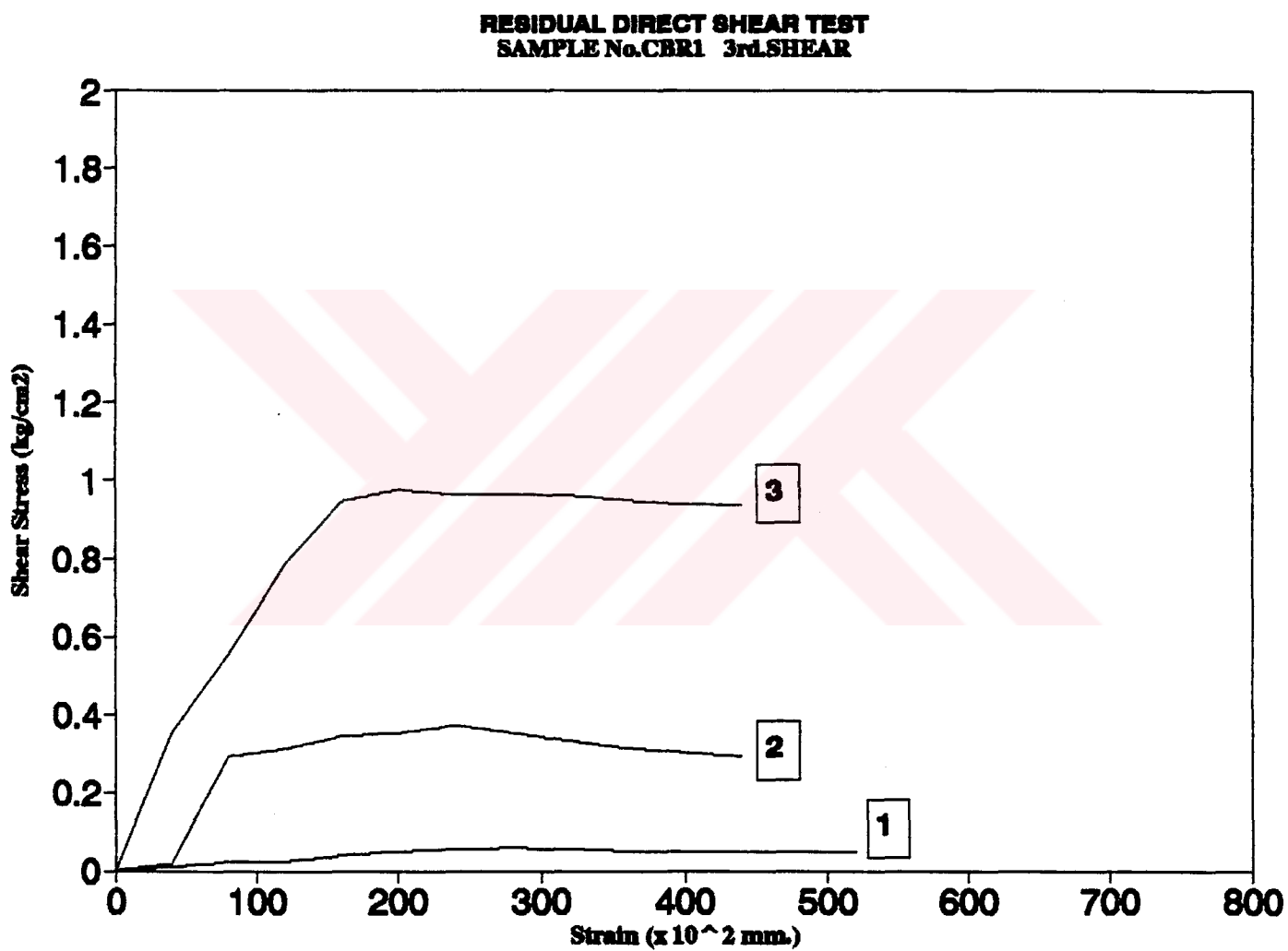


FIGURE A3.3.4 Residual direct shear test

Sample no.CBR1 3rd. Shear

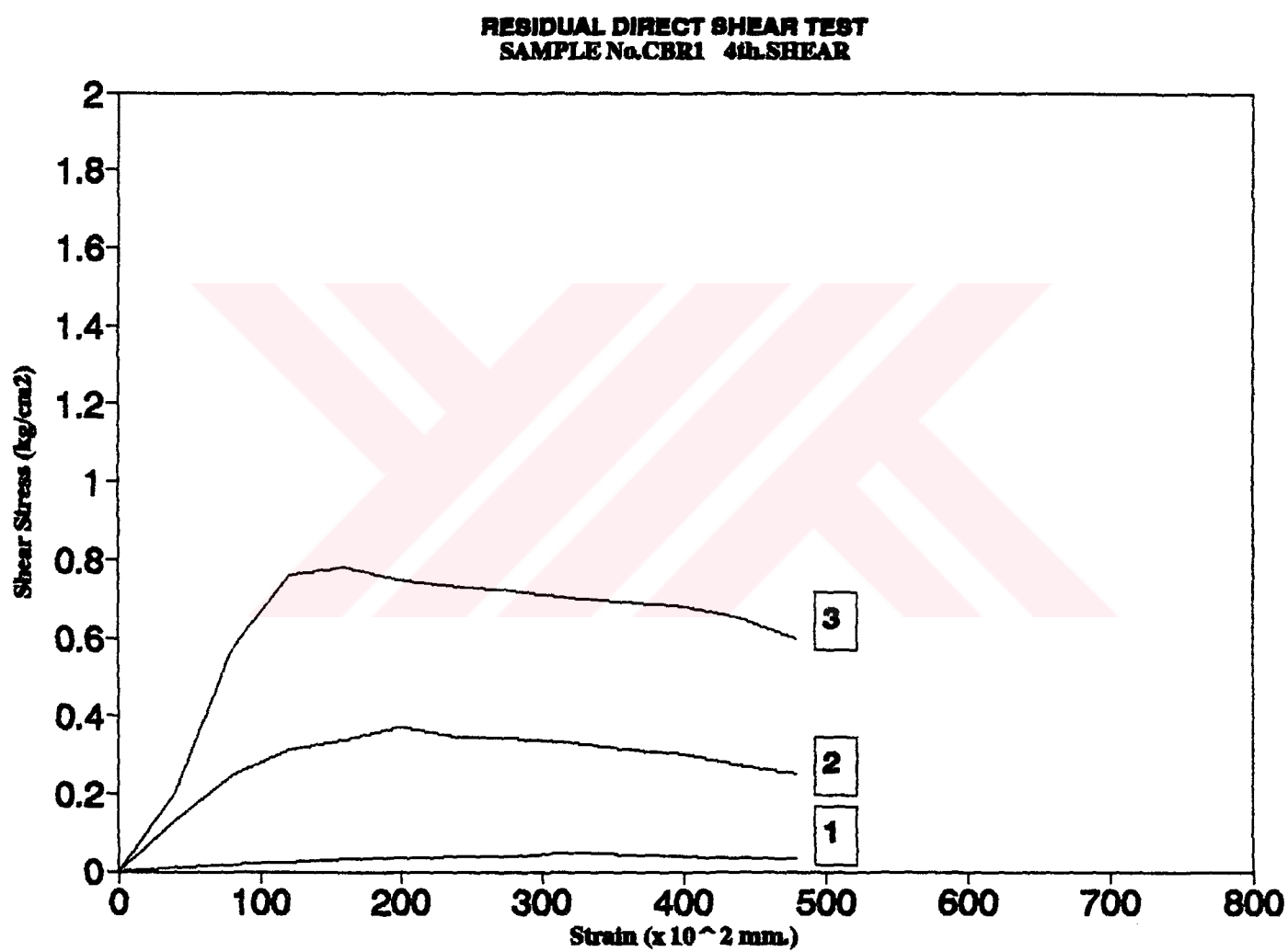
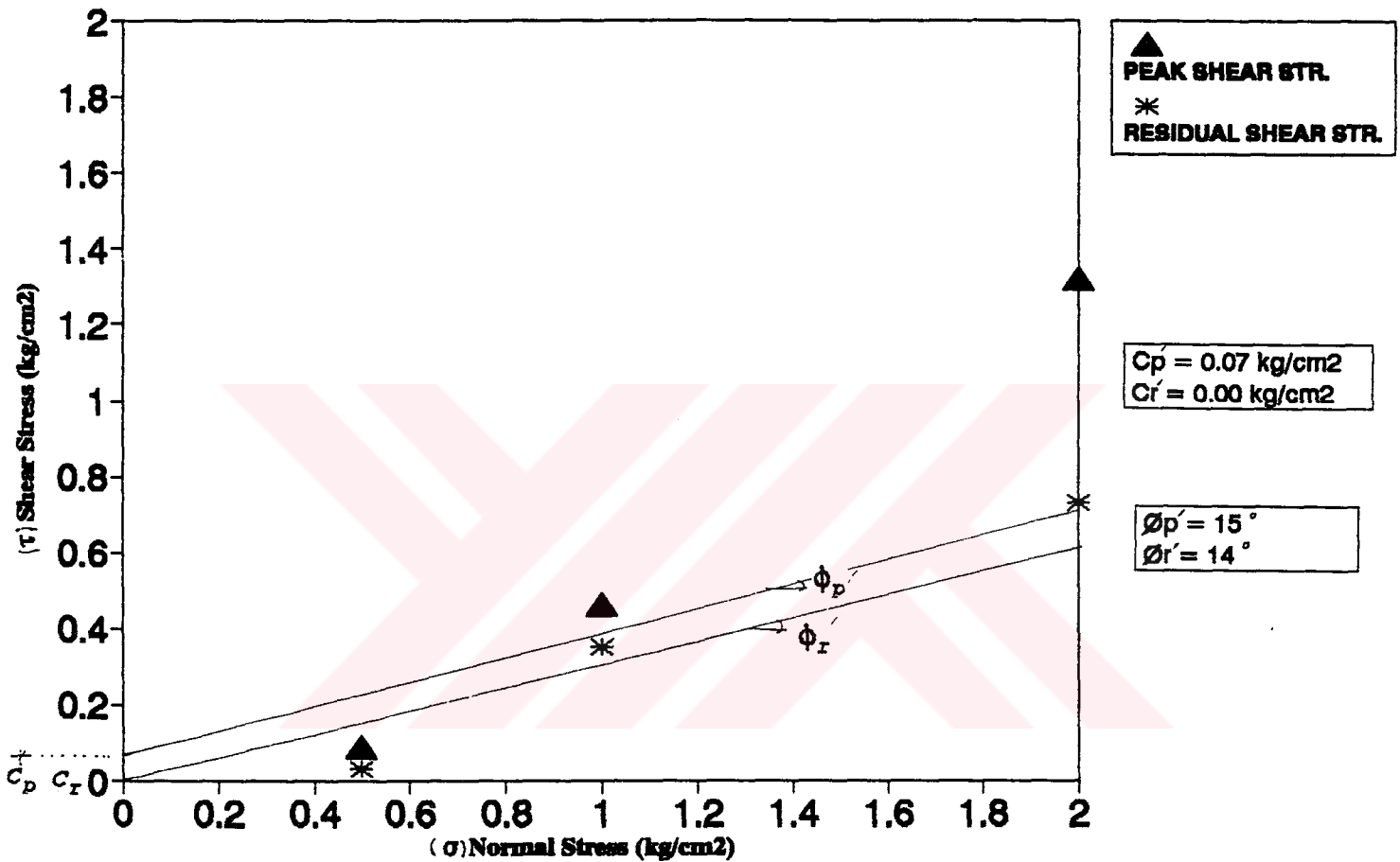


FIGURE A3.3.5 Residual direct shear test

Sample no.CBR1 4th. Shear

**RESIDUAL DIRECT SHEAR TEST  
SAMPLE CBR1**



**TEST: CBR1**

SAMPLE	$\sigma_n$ (Kg/cm <sup>2</sup> )	$\tau_p$ (Kg/cm <sup>2</sup> )	$\tau_r$ (Kg/cm <sup>2</sup> )
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 :

**RESIDUAL DIRECT SHEAR TEST**  
**SAMPLE No.CBR2 1st.SHEAR**

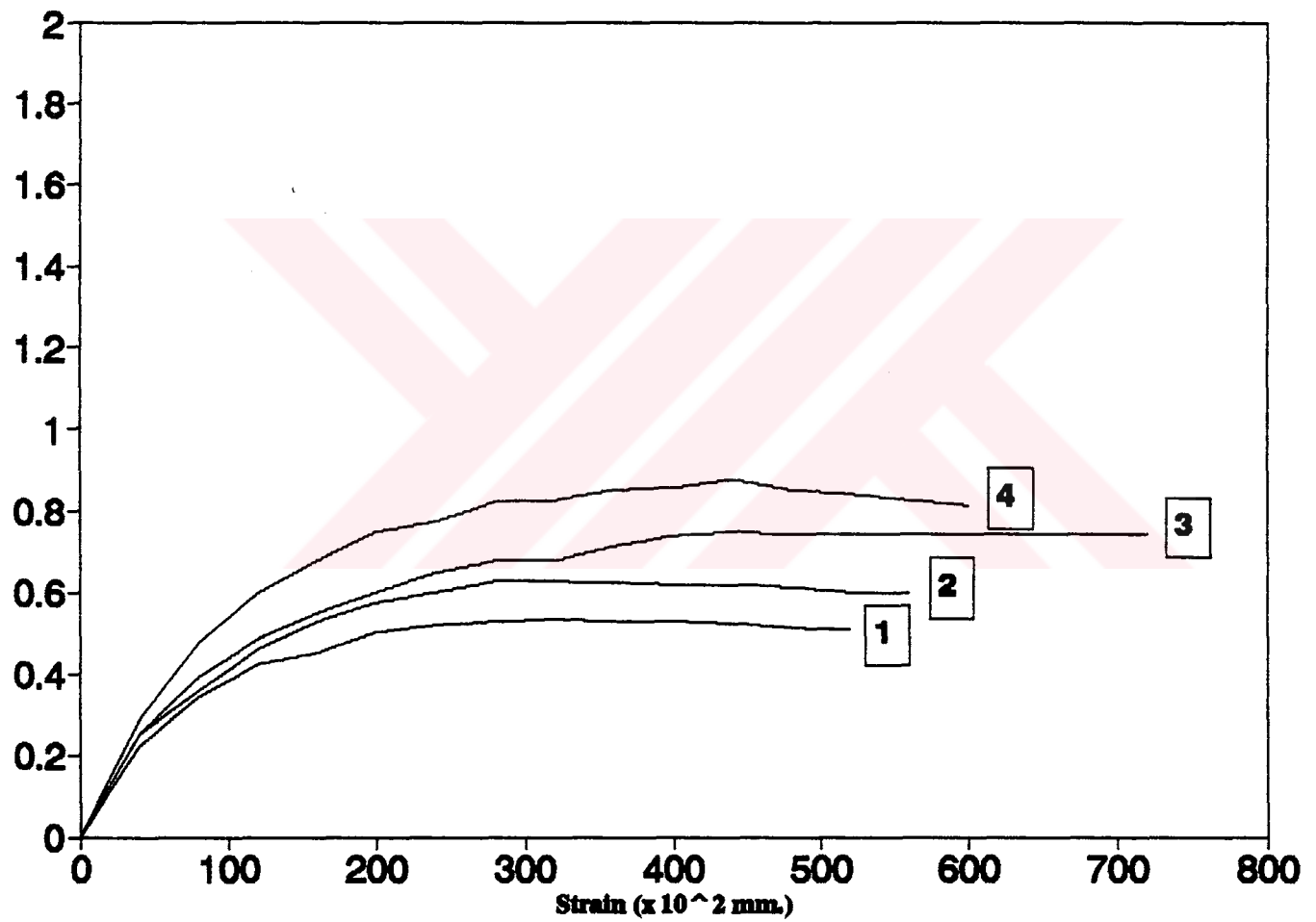


FIGURE A3.4.1 Residual direct shear test

Sample no.CBR2 1st. Shear

**RESIDUAL DIRECT SHEAR TEST**  
**SAMPLE No.CBR2 2nd.SHEAR**

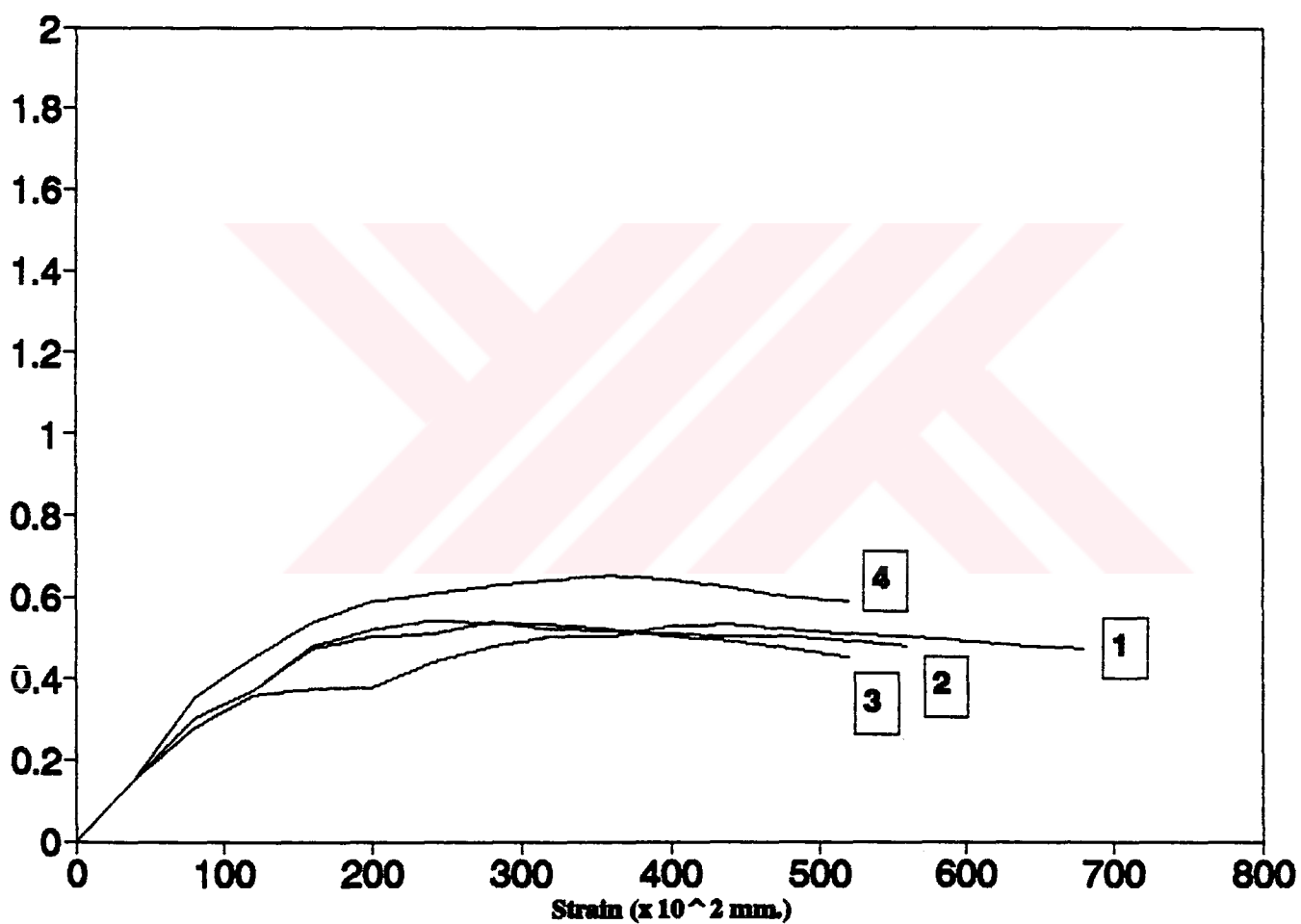


FIGURE A3.4.2 Residual direct shear test

Sample no.CBR2 2nd. Shear

**RESIDUAL DIRECT SHEAR TEST**  
**SAMPLE No.CBR2 3rd.SHEAR**

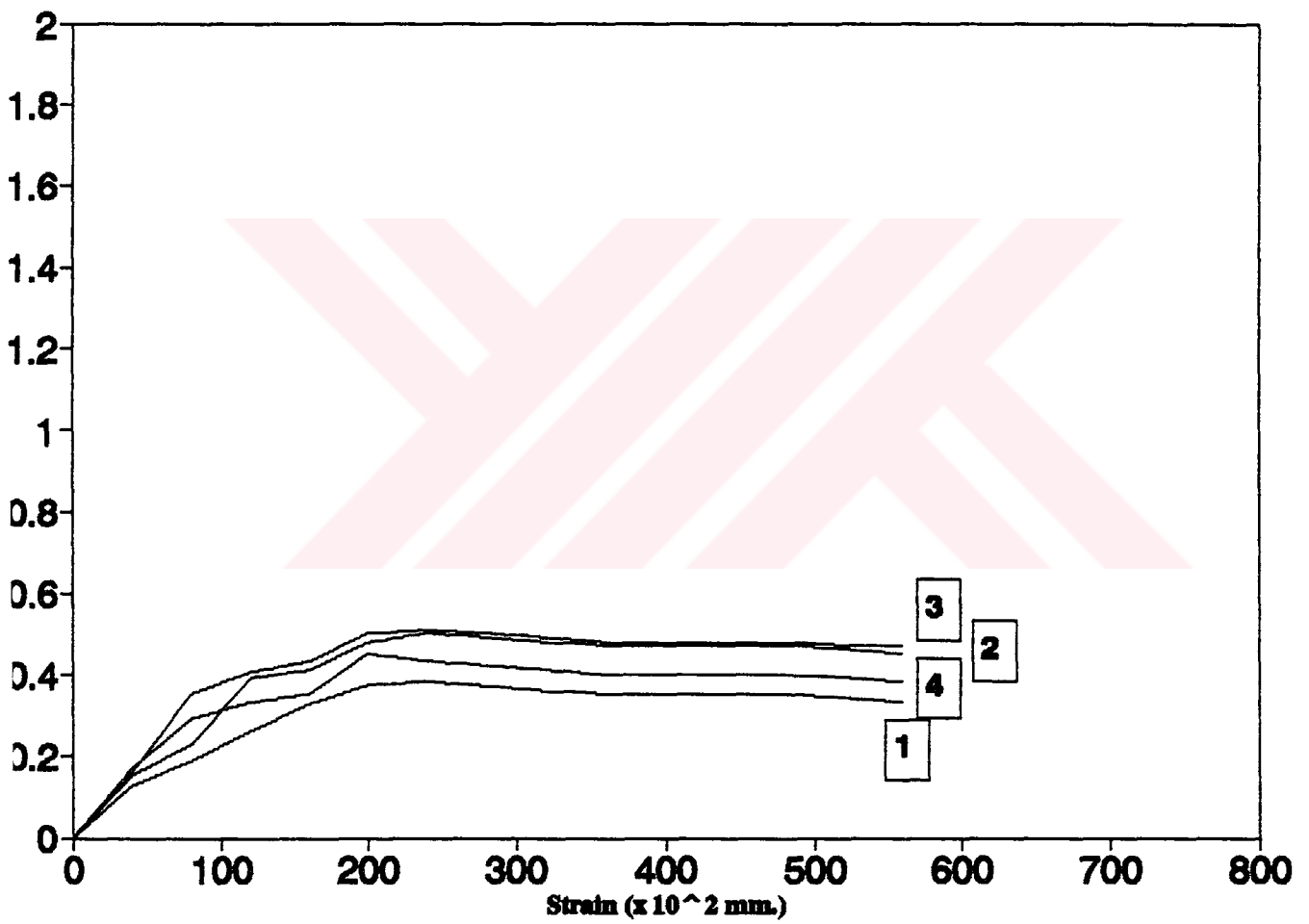
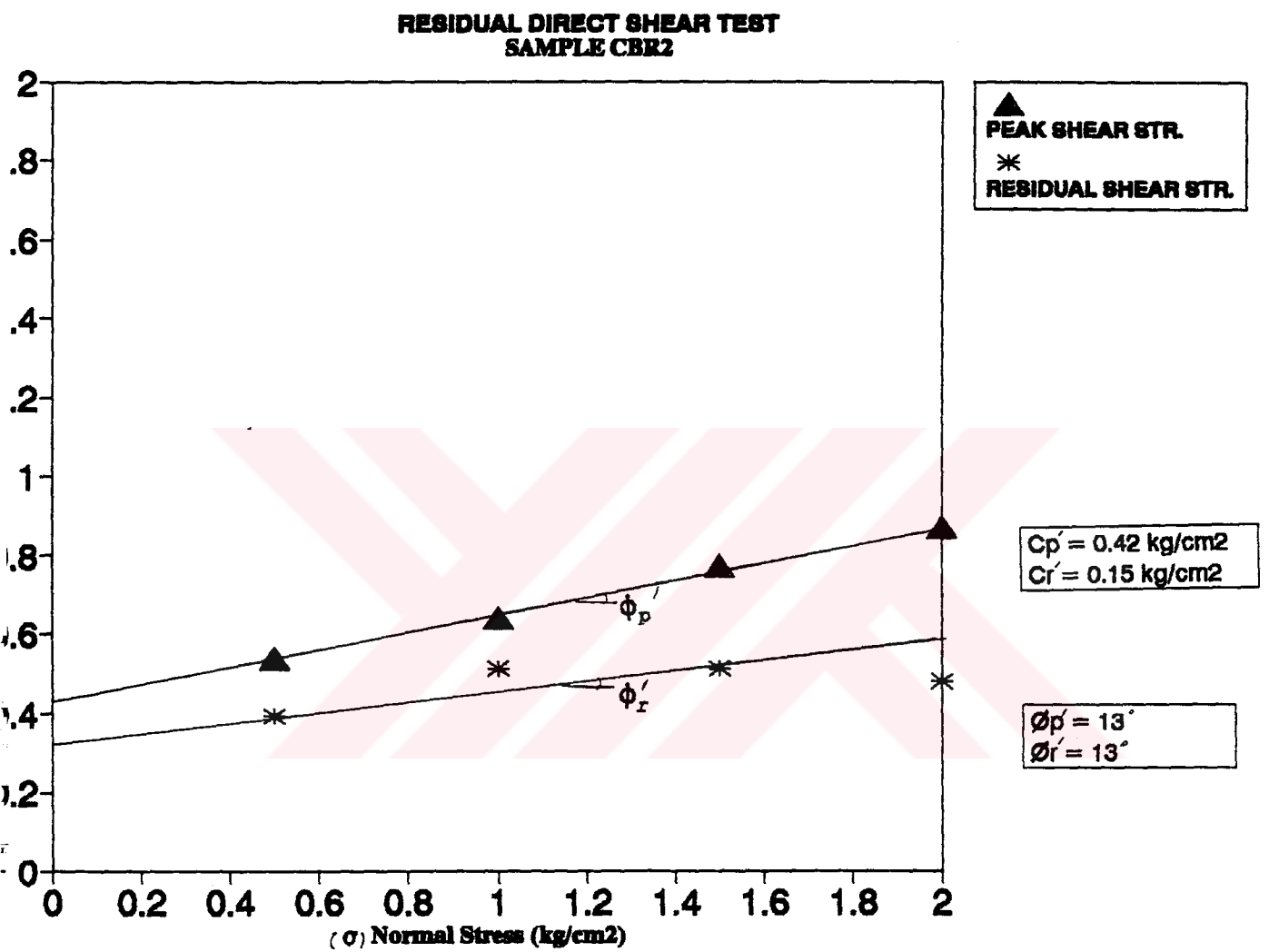


FIGURE A3.4.3 Residual direct shear test

Sample no.CBR2 3rd. Shear

**TEST : CBR2**

SAMPLE	$\sigma_n$ (Kg/cm <sup>2</sup> )	$\tau_p$ (Kg/cm <sup>2</sup> )	$\tau_r$ (Kg/cm <sup>2</sup> )
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 FD= 1.00000

0 THE SAFETY FACTOR FOR POINT 121S 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 ,KILDNEWTONS  
 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 FD= 1.00000

0 THE SAFETY FACTOR FOR POINT 10IS 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    FD= 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



TAG MOTORWAY KM 141+000 LANDSLIDE  
SECTION KM 141+550

Made by :  
Date:  
Checked : 128

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

Stratum No.	Description	Bulk densities		Strength parameters			Datum for C
		below GWL	above GWL	C	Phi (deg)	dC/dY	
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

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

TAG MOTORWAY KM 141+000 LANDSLIDE  
 SECTION KM 141+550

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 = 1.017  
 Slipped mass = 77746 Out of balance vertical force = 0  
 Delta = 14.5deg Out of balance horizontal force = 3  
 Moments taken about: X = 40.16 , Y = 386.25  
 Overturning moment = 3577459 Restoring moment = 3637708

Slip surface coordinates	Piezometric elevation	Interslice forces				
		horizontal		vertical		
No.	X	Y	Y(w)	E(total)	E'(effective)	Q
1	-20.00	230.00	0.00	0	0	0
2	0.00	220.00	0.00	2138	2138	549
3	12.50	220.00	0.00	2823	2823	726
4	25.00	220.00	0.00	3507	3507	902
5	40.00	220.00	0.00	4739	4739	1220
6	45.00	220.00	0.00	5286	5286	1361
7	60.00	220.00	0.00	7339	7339	1890
8	65.00	220.00	0.00	8160	8160	2102
9	76.50	224.93	0.00	7339	7339	1890
10	88.00	229.86	0.00	6446	6446	1660
11	108.50	238.64	0.00	4876	4876	1256
12	129.00	247.43	0.00	3474	3474	895
13	149.50	256.21	0.00	2241	2241	577
14	170.00	265.00	0.00	1176	1176	303
15	175.00	287.00	0.00	-3	-3	-0

Slice No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		
					normal P	P'	shear S
1	0.00	0.2867	0.00	1800	3057	3057	862
2	0.00	0.2867	0.00	2250	2427	2427	684
3	0.00	0.2867	0.00	2250	2427	2427	684
4	0.00	0.2867	0.00	4050	4368	4368	1232
5	0.00	0.2867	0.00	1800	1941	1941	547
6	0.00	0.2867	0.00	6750	7279	7279	2053
7	0.00	0.2867	0.00	2700	2912	2912	821
8	0.00	0.2867	0.00	6492	6096	6096	1719
9	0.00	0.2867	0.00	7055	6625	6625	1868
10	0.00	0.2867	0.00	12412	11655	11655	3287
11	0.00	0.2867	0.00	11080	10404	10404	2934
12	0.00	0.2867	0.00	9748	9153	9153	2581
13	0.00	0.2867	0.00	8415	7902	7902	2228
14	0.00	0.2867	0.00	945	1293	1293	365



TAG MOTORWAY KM 141+000 LANDSLIDE  
SECTION KM 141+650

Made by :

Date:

Checked :

130

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

--- S t r a t u m --- No.	Description	Bulk densities		-----Strength parameters-----			
		below GWL	above GWL	C	Phi (deg)	dC/dY	Datum 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

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

Units: kN-m

RESULTS

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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 elevation		Interslice forces			
			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 No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		
					normal P	shear 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**

TAG MOTORWAY KM 141+000 LANDSLIDE  
 SECTION KM 141+600 ROCK-BUTTRRESS

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

Stratum No.	Description	Bulk densities		Strength parameters			Datum for C
		below GWL	above GWL	C	Phi (deg)	dC/dY	
1	ROCK BUTTRRESS	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

TAG MOTORWAY KM 141+000 LANDSLIDE  
SECTION KM 141+600 ROCK-BUTTRRESS

Made by :  
Date: 134  
Checked :

Units: kN-m

RESULTS

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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 = 40024 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 elevation		Interslice forces			
			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 No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		
					normal P	P'	shear 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

TAG MOTORWAY KM 141+000 LANDSLIDE  
SECTION KM 141+600 ROCK-BUTTRESS

Made by :  
Date: 135  
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

Stratum No.	Description	Bulk densities		Strength parameters			Datum for C
		below GWL	above GWL	C	Phi (deg)	dC/dY	
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

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

Program: SLOPE version 6.00 licensed from GEOSOLVE

TAG MOTORWAY KM 141+000 LANDSLIDE  
SECTION KM 141+600 ROCK-BUTTRESS

Units: kN-m

RESULTS

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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 No.	Coordinates		Piezometric elevation Y(w)	Interslice forces		vertical Q
	X	Y		E(total)	E'(effective)	
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 No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		shear S
					--- normal --- P	--- P'	
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



**STABILITY ANALYSIS FOR ALTERNATIVE 2**



Program: SLOPE version 6.00 licensed from GEOSOLVE

Run No. 550ALT2  
Job No. 003  
Made by :  
Date: 138  
Checked :

TAG MOTORWAY KM.141+550 LANDSLIDE  
SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2

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	230.00	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

--- S t r a t u m --- No.	Description	Bulk densities		-----Strength parameters-----			Datum for C
		below GWL	above GWL	C	Phi (deg)	dC/dY	
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

TAG MOTORWAY KM. 141+550 LANDSLIDE  
 SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2

Units: kN-m

RESULTS

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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 ----- No.	X	Y	Piezometric elevation Y(w)	----- Interslice forces -----		vertical Q
				----- horizontal ----- E(total)	----- E'(effective)	
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 No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		
					--- normal --- P	--- P'	shear 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

TAG MOTORWAY KM.141+550 LANDSLIDE  
 SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2

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 (BL)	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 (BL)	275.00							
2	275.00							

SOIL PROPERTIES

Stratum No.	Description	Bulk densities		Strength parameters			
		below GWL	above GWL	C	Phi (deg)	dC/dY	Datum for C
1	SLOPE DEPRIS	8.00	18.00	0.00	16.00		
2	BEDROCK	10.00	20.00	300.00	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 intercalice forces  
 Factor of safety on Shear Strength  
 Minimum number of slices = 8

TAG MOTORWAY KM.141+550 LANDSLIDE  
 SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2

Units: kN-m

RESULTS

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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 = 14446 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 No.	X	Y	Piezometric elevation Y(w)	Interslice forces		vertical Q
				horizontal E(total)	vertical E'(effective)	
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	913	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 No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		shear S
					normal P	P'	
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 No.	Surface loads		Water pressure on submerged ground	
	vertical pressure	horizontal 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	0
9	0	0	1	0
10	0	0	0	0
11	0	0	0	0

TAG MOTORWAY KM.141+550 LANDSLIDE  
 SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2

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

--- Stratum --- No.	Description	Bulk densities		Strength parameters			Datum for C
		below GWL	above SWL	C	Phi (deg)	dC/dY	
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 = 5

Earthquake acceleration factors:  
 vertical = 0.000  
 horizontal = 0.200

TAG MOTORWAY KM.141+550 LANDSLIDE  
 SLOPE REGRADING AND EXCAVATION - ALTERNATIVE 2

Units: kN-m

RESULTS

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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

No.	Slip surface coordinates		Piezometric elevation Y(w)	Interslice forces		vertical Q
	X	Y		horizontal E(total)	horizontal E'(effective)	
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 No.	Cohesion (avge)	Tan(phi) (avge)	Pore pressure (avge)	Weight of slice W	Forces on base of slice		slice shear S
					normal P	shear P'	
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

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