İSTANBUL TEKNİK ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ

BİR TAM CEPHE TÜNEL AÇMA MAKİNASININ KAZI PERFORMANSINA JEOTEKNİK ÖZELLİKLERİN ETKİSİ

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EFFECT OF GEOTECHNICAL PROPERTIES ON THE CUTTING PERFORMANCE OF A FULL-FACE TUNNEL BORING MACHINE

M.Sc. THESIS

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CONTENT

SUMMARY

In this research, the relationship between rock properties and the performance of a full-face tunnel boring machine were investigated. Research was carried out in both site and laboratory. Site investigation was made in Baltalimanı Tunnel which is a part of Istanbul Sewerage Project being constructed by STFA Cons. Co in Istanbul. Laboratory tests were carried out in the mechanical excavation research laboratory of Mining Department of Istanbul Technical University.

In the first chapter, Istanbul Sewerage Project, Geology along the tunnel line, and TBM being used in Baltalımanı Tunnel are detailed

Test procedures proposed by ISRM were used in the research, The tests used are as follows.

-Point Load Test
-Cone Indenter Test
-Cerchar Hardness Test
-Schmidt Hammer
-Impact Penetration Test

Besides, some site records were taken in the tunnel during excavation, such as penetration rates, propel pressures of the machine, net cutting rates, machine performance data and so on, in order to find relationships between machine excavation performance and rock properties.

Correlation coefficients found for relationships between cutting rate,disc consumption and rock properties were found statistically significant for any prediction

ÖZET

BİR TAM CEPHE TÜNEL AÇMA MAKİNASININ KAZI PERFORMANSINA JEOTEKNİK ÖZELLİKLERİN ETKİSİ

Günümüzde tünel açma makinalarının performansı ve bunlarda kullanılan uç sarfiyatının önceden kestirilmesi, gerek ekonomiklik ve gerekse zaman tasarrufu ele alındığında büyük önem taşımaktadır. Tünel çalışmaları öncesi yapılacak araştırmalara verilecek önem, doğru makina seçimi demek olduğundan, verilmesi gereken çaba ve itina, kendiliğinden ortaya çıkacaktır. Bunun yanında, seçilmiş bir makina ile, verilmiş olan jeolojik yapıda kazının yapılması ve bununla ilgili bilgilerin toparlanıp değerlendirilmesi, aynı ortamda ileride yapılacak benzer çalışmalar için bir temel oluşturacaktır. Diğer bir değişle, hem kazı öncesi hemde kazı çalışmaları süresince gerekli verilerin toplanması mekanize tünel açmanın gelişmesinde faydalı olmaktadır.

Bu araştırmada Kabataş-Baltalimanı Kanalizasyon Projesinde kullanılan tam cephe kazı makinasının farklı iki formasyonda kazı performansı değerlendirilmiş, ayrıca kaya özellikleri ve jeolojik yapı ile ilintisi araştırılmıştır.

Mekanize kazı çalışmalarında, kazı performansı ve uç sarfıyatının önceden kestirilmesi, kayaç özellikleri ile makinanın performansı arasındaki ilintinin bulunması için yıllardan beri araştırmalar yapılmış ve çeşitli yöntemler geliştirilmiştir.

İlk olarak, 2., 3. ve 4. bölümlerde, projenin, bölgenin jeolojisinin ve makinanın tanıtımı yapılmıştır. Bu bölümler ile ilgili bilgiler, STFA İnşaat A.Ş. 'nin ISTANBUL KANALİZASYON PROJESİ, KABATAŞ BALTALIMANI TÜNELLERİ ile ilgili yayınlarından alınmıştır. Söz konusu tünelde kullanılan tam cephe kazı makinası Büyükada ve Trakya gibi iki değişik jeolojik formasyonda kazı yapmıştır. Araştırma boyunca kazı performansı ile ilgili elde edilen veriler değenlendirilerek makinanın değişik formasyonlardaki kazı davranışı araştırıl-

mış ve sonuçta hangi jeolojik formasyonda daha randımanlı olabileceği değerlendirilmiştir.

Daha önce de belirtildiği gibi Baltalimanı Tünelinde iki değişik formasyon ile karşılaşılmıştır, Büyükada ve Trakya Formasyonu.

Büyükada Formasyonu yapı itibari ile Trakya Formasyonundan daha sağlam ve stabildir. Kireçtaşı, yumrulu kireçtaşı ve karbonatlı şeylden oluşmaktadır. Trakya Formasyonu ise silttaşı, kumtaşı ve çamurtaşından oluşmaktadır.

Büyükada Formasyonun'da fay zonlarının dışında jeolojik güçlülerle pek karşılaşılmamıştır. Bunun dışında geçilen bülgeler oldukça serttir.

Trakya Formasyonu ise çok daha faylı, kırıklı ve çatlaklıdır. bu yapı çok büyük jeolojik problemlere neden olmuştur.

Tez çalışması süresince çalışmalar saha ve laboratuar olarak iki kısımda yürütülmüştür. Saha çalışmaları STFA İnşaat A.Ş. 'nin Baltalimanı Şantiyesi, Baltalimanı Tünelinde P ile N Şaftları arasında gerçekleştirilmiştir. Söz konusu tünelden alınan kaya numuneleri üzerinde yapılan deneyler ise İTÜ Maden Kazı ve Mekanizasyonu araştırma laboratuarında yapılmıştır.

Baltalimanı Tuneli'nde kullanılan tam cephe kazı makinesı dizayn açısından sert formasyonlarda kullanılabilecek bir TBM dir. Sözkonusu makina Büyükada ve Trakya gibi gerek yapısal ve gerekse mekanik özellikler açısından birbirinden oldukça farklı iki değişik formasyonda kazı yapmış ve birçok problemlerle karşılaşılmıştır. Sonuçta makinanın kazı performansı olumsuz yönde etkilenmiştir. Makina faydalanma oranları açısından karşılaştırıldığında, Büyükada Formasyonunda bu oran %28.5 olarak gerçekleşirken Trakya Formasyonunda %10 a bile ulaşmamıştır. Bunun en büyük nedeni zemin koşullarının yarattığı problemlerdir. Ancak bunun yanında makinanın uygunluğunu da göz önüne almak gerekir.

Büyükada Formasyonu'nda kazı yapılırken karşılaşılan en büyük problemlerin başında disk yataklarindaki arızalar gelmektedir. Birkaç kez yapılan modifikasyonlarla sorun ortadan kaldırılmış fakat kazı büyük ölçüde aksamıştır. Disk aşınması Trakya Formasyonundakine nazaran çok daha fazla olup bölüm 6.3 te de görüldüğü gibi disk değişimi makina ölü zamanının %16.84 lük kısmını kapsamaktadır. Bu oldukça yüksek bir orandır. Kullanılan TBM, yapısı itibari ile tahkimatsız zemin koşulları için daha uygun olduğundan, özellikle faylı zonların geçişinde tahkimat (çelik hasır+çelik bağ+püskürtme beton) yapılması zorunlu hale gelmiş ve bu da kazı performansını %14 oranında etkilemiştir. Uygun ve tahkimatsız gidilen zemin koşullarında, performansı düşüren diğer bir neden de vagon katarlarının beklenmesidir. Çünkü, makinanın back-up sisteminin yetersiz oluşu ve hafriyatı yüzeye çıkaran nakliye sisteminin hızının, makina kazı hızına yeterli oranda yetişememesi, bu tip problemlerle karşılaşılmasına neden olmuştur. Özellikle tünel uzunluğu arttıkça, bu duraklamalar kendini daha fazla hissettirmiştir.

Trakya Formasyonunda karşılaşılan güçlükler kayanın özelliklerinden dolayı daha fazladır. En büyük problem yaşanılan göçükler, bunların tahkimatı ve bu tip zonların geçiliş süreleridir. Sonuçta bu beklemeler, makina kazı performansını %64 oranında etkilemiştir. Bu problemler bölüm 6.5.3'te ayrıntılı olarak anlatılmıştır. Göçüklerin yaşandığı kaya yapısı genelde kil içeren fay zonları, altere olmuş , çok kırıklı ve çatlak yüzeylerinde kil dolgusu içeren kaya grupları olarak sıralanabilir.

Tahkimatlı geçiş ele alındığında Büyükada Formasyonunun %10 luk kısmında Trakya'da ise %49.5 luk kısmında tahkimatlı geçilmesi zorunlu olmuştur. Bu da makina kazı performansının ne kadar düşük olabileceği konusunda bir fikir verebilir.

Daha öncede belirtildiği gibi kazı hızının bazı kaya özellikleri ile ilintisi de araştırılmıştır. Kazı performansını düşüren birçok problemlerin olmasına rağmen bulunan korelasyon katsayıları kabul edilebilir orandadır. Kazı sırasında performans ile ilgili kayıtlar tutulmuş, yerinde ve laboratuvar deneyleri yapılmıştır. Özellikle laboratuvarda yapılan deneyler ISRM'nin önerdiği şartnameler doğrultusunda gerçekleştirilmiştir. Faydanılan deneyler,

- -Nokta yük deneyi
- -Koni delici deneyi
- -Cerchar sertlik deneyi
- -Schmidt çekici deneyi
- -Impact penetrasyon deneyi

Sözkonusu deneylerin tüm sonuçları 3-7 nolu eklerde verilmiştir. İzleyen bölümde ise kayaç özellikleri ile kazı hızı ve disk tüketiminin birbirleri ile olan ilintisi araştırılmış ve grafik halinde bölüm 7.3'te ayrıntılı olarak açıklanmıştır. Bulunan ilişkilerin korelasyon katsayıları, makina performansını ve disk tüketiminin önceden kestirilmesi için kabul edilebilir doğruluktadır.

Makinenin kazı hızını tahmin etmek için, basınç dayanımı ve RQD değerleri birlikte kullanılarak bulunan korelasyon bağıntısının, ilişkiyi daha doğru ifade ettiği tespit edilmiştir. Bağıntı şu şekildedir.

100-125 bar itme basıncı için,

Net kazı hızı=12.60-1.66(GcxRQD/100)

135-160 bar itme basıncı için

Nat kazı hızı=10.78-1.26Ln(GcxRQD/100)

Disk tüketimi için ise cerchar sertlik değerleri kullanılarak aşağıdaki bağıntılar bulunmuştur.

Disk tüketimi=11.40+226.46xC(0.5)

Disk tüketimi=258.23+52.49xC(1)

Burada,

C(0.5)=0.5 cm delik derinliğinde sertlik değeri

C(1)=1 cm delik derinliğinde sertlik değeri

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CHAPTER 1. INTRODUCTION

The need of continuous excavation systems to replace cyclic drill and blast operations has been realised for many years. When correctly used they reduce the waste of materials, labour and time in tunnelling works.

Excavation by machines, investigation of factors affecting cutter behavior, design of the cutterhead, factors related to machine excavation performance are the main subjects of many research projects. Collecting of data prior to excavation or during the tunnelling operations are usefull for the proper design of tunnel boring machines. Especially, prediction of machine performance and cutter consumption in a given geological formation prior to excavation has a very important role in choosing the excavation method and machine. Because, a well executed programme of geotechnical investigations provides a realistic basis for the costing and planning of tunnelling operations and is therefore essential for the financial success of tunnelling contracts.

Excavation by machines in both Mining and Civil Engineering is basically the same. Excavation machines used in mining are also being used in construction industry in such as underground,sewerage and water tunnels. Objection in both is application to choose the most suitable machine in a given geological structure.

CHAPTER 2. OBJECTIVE OF THE RESEARCH

Baltalimanı Tunnel is a part of Istanbul Sewerage Project being constructed by STFA Cons. Co in Istanbul and A Robbins type 145-168 full-face tunnel boring machine is planned to use in this tunnel. Two rock formation mainly different in geologocal structure are expected to pass during the tunnel works. Bearing in mind that many other tunnelling projects, including Istanbul Metro are planned to be realized in the next future in Istanbul. The following points are thougth to be worth to investigate

- Geotechnical chracteristic of the rock formation and units in the tunnel route
- In-situ and laboratory cuttability characteristics of the rock units encountered along the tunnel route
- Recording the cutting perfomance of the tunnelling machine; including, net cutting rate, disc consumption, and machine downtime
- To investigate the raletionship between machine performance and the characteristic of the rock units
- To accumulate reliable data for a successfull tunnel boring in similar rock formations.

CHAPTER 3. DISCRIPTION OF THE PROJECT

3.1. General

Collector tunnels designed to renew Istanbul's inadequate sewerage network and to clean the very polluted Golden Horn (Haliç) are currently under construction by STFA Construction Co. along The Golden Horn and European side of The Bosphorus. (see Figure 3.1.1.) .[1]

As part of World Bank funded project, some 20 km of circular tunnels varying in diameter from 2.2 m to 4.5 m are being driven. The three contracts awarded to STFA cost in excess of 50 million us dollars and from part of very large plan to provide interception and treatment of raw sewerage prior to its discharge into The Bosphorus and The Marmara Sea. This ambitious pollution abatement programme is sponsored by The Istanbul Metropolitan Municipality and engineered by The Istanbul Water and Sewerage Administration (İSKİ). The master design of the system have been performed jointly by Turkish Consultant UBM and Consultant Taylor Binnie and Partners, who are also responsible for the construction supervision.

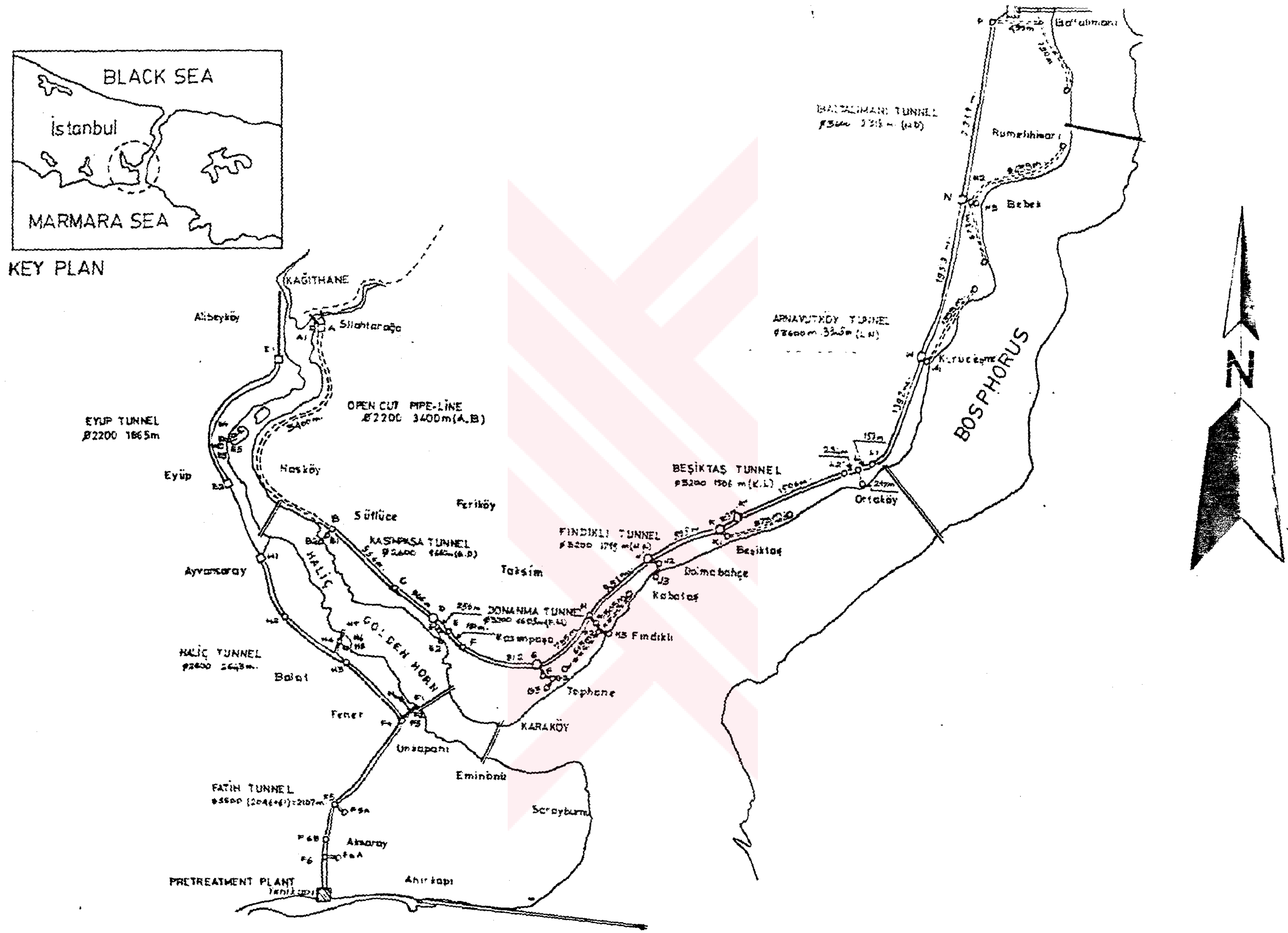


Figure 3.1.1. General Layout Of Istanbul Sewerage

3.2. Parts of the project

The construction region consists of Paleozoic Sedimentary rocks comprising greywacke, shale siltstone, mudstone-conglomerate followed by limestone. The ground conditions vary extensively from soft fill material with high water heads to very strong rock. It was obvious that very robust and powerfull machines which are able to cope with a wide variation of ground conditions would be necessary.

Consequently, in the part between of The South Haliç and North Haliç Interceptors Project, the shield driven tunnelling technique with roadheader type boring machines was chosen. Manholes of upstream ends of tunnels were used as working shafts and tunnels were driven down grade from one end to the other.

The primary lining made up with precast concrete bolted segments were installed immediately after the excavation. Later, the secondary lining was cast insitu using circular telescopic steel shutters. The secondary lining has a PVC liner cast integral with the concrete to protect it from corrosion by hydrogen sulphide gases. In the hand driven connections to the existing sewer system, steel arches and insitu concrete lining were used instead of segments.

The rock strata from Arnavutköy to Baltalimanı contains a greater percentage of silica and quartz and considered to be too strong for being driven by a roadheader machine. Consequently a Robbins full-face TBM machine was purchased for this part of the project.

The pipe jacking method is adapted for tunnelling in difficult water-logged soft and made-up ground condition that exist at Kasımpaşa, Beşiktaş, and Ortaköy shafts D-F, K-K and L2-L1 respectively, reaching a total length of 1082 m. STFA is manufacturing special concrete pipes needed for this part.

First stage of İstanbul Sewerage Project, The South Haliç Conract, comprises the construction of three main tunnels, 6615 m. in total length and diameters varying between 2200-2800 mm, 4 shafts, 12 manholes, 2 vortex chambers and 3 storm surcharge outlets. The construction was completed by the end of 1987 and The South Haliç was handed over to ISKI. The sewerage collected by this collector is discharged, after pretreatment at Ahırkapı plant with 750.000 m3/day capacity to The Marmara Sea by a twin 1200 m. long and 1.6 m diameter buried steel pipe, also installed by STFA (see Table 3.2.1.)

Table 3.2.1. The South Haliç Project And Related Structures
1- Eyüp Tunnel Ø2200, 1860 m. 2- Manholes 3 no: (E1,E2,E3) 3- Sea discharge 1 no: (E4) 4- 1200/1800 Tunnel, 136 m. 5- Ø1200 pipe 100 m. (E4-E5)
1- Haliç Tunnel, Ø2600, 2643 m. 2- Manholes 5, (H1,H2,H3,H4,H8) 3- Sea discharge 1 no: (H7) 4- 1200/1800 tunnel 110 m. 5- Ø2200 pipe 100 m. (H4-H7) 6- Ø1200 pipe 114 m. (H4-H10)
1- Fatih Tunnel Ø2800, 1862 m.,Ø2200, 193 m. 2- Manholes 8 no (F2,F3,F4,F5,F5A,F6,F6A,F6B) 3- Sea discharge 1 no (F1) 4- Ø2200 pipe 764 m (F1-F2) 5- Ø2200 pipe 70 m (F2-F3) 6- Ø2200 pipe 27.5 m (F5-F5A) 7- Ø2200 pipe 35 m (F6-F6B) 8- Ø2200 pipe 78 m (F6-F6B) 9- Ø2800 pipe 420.5 m (F6-Pretreatment)

The second stage of İstanbul Sewerage Project involves the North Haliç and Kabataş-Baltalimanı contracts, which are currently under execution. The North Haliç Collector between Kağıthane and Beşiktaş is 8382 m. in length consisting of 4982 m. tunnel and 3400 m. pipeline. The contract, awarded to STFA in March 1987, involves the contruction of three main tunnels with diameters varying between 2400-3200 mm, 3 egg-shaped 1200/1800 mm branch tunnels 600 m in total length, 10 shafts, 12 overflow and discharge chambers, 62 manholes,a box-culvert 46 m. in length and installation of reinforced concrete of pipes 7300 m in length including branchs with diameters varying between 300-3200 mm (see Table 3.2.2.)

The Kabataş-Baltalimanı contract, awarded to STFA in October 1987, involves construction of 3 main tunnels 7951 m, in total length between Beşiktaş and Baltalimanı, 2 egg-shaped 1200/1800 mm branch tunnels 252 m. in total length 6 shafts, 1 vortex and 6 overflow chambers, 165 manholes, a box-culvert 26 m. in length and installation of reinforced concrete pipes of diameters 300-1200 mm. adding up to 8470 meters. The sewerage collected by North Haliç and Kabataş-Baltalimanı collectors will be discharged to the Bosphorus Waterway after treatment at Baltalimanı treatment plant with 1.1 million/m3 capacity. Specialized civil works in İstanbul Sewerage Project other than tunneling consists of shafts-sinking pipe laying of various types and ground reinforcement by means of jet-grounting, shotcreting and rock anchor (see table 3.2.3).

Table 3.2.2 The North Haliç Project And Related Structures
Interceptor in open cut 1- Ø2200 pipe 3400 m (A-B) 2- Overflow and see discharge 2 no. (A,A1) 3- Pipes in various diameters 215 m. 4- Type manholes 27 no.
1- Kasımpaşa Tunnel, Ø2600, 1660 m. 2- Overflow and sea discharge 2 no. 3- Shafts 3 no. (B,C,D) 4- Manholes 1 no. (HM1) 5- Pipes in various diameters, 1024 m.
Interceptors 1- Overflow and sea discharge 2 no. (E1-E2) 2- Shafts 1 no. (e) 3- Culvert 1 no. (KP1) 5- Type manholes 21 no. 6- Pipes in various diameter 1754 m.
1- Donanma Tunnel, Ø3200,1603 m. 2- Overflow and sea discharge 2 no. (G2,G3) 3- Shafts 3 no. (F,G,G1) 4- Manholes 5 no. (TP1,TP2,TP3,TP4,TP5) 5- 1200/1800 Tunnel, 324 m. 6- Pipes in various diameters 247 m.
1- Fındıklı Tunnel, 1719 m. 2- Overflow and sea discharge 4 no. (H1,H3,J2,J3) 3- Shafts 3 no. (H,J,K) 4- Manholes 6 no. (H2,DB2,DB3,DB4,DB5,DB6) 5- 1200/1800 Tunnel 276+43 6- Pipes in various diameters, 597 m.

Table 3.2.3. The Kabataş-Baltalimanı Tunnels And Related Structures
1- Beşiktaş Tunnel,Ø3200 2263 m. 2- Manholes 1 no. (k,K1) 3- Branch interceptors (B1), 905 m. 4- Branch interceptors (B3), 217 m.
1- Arnavutköy Tunnel, Ø3600, 3345 m. 2- Manholes 5 no. (M,M1,N,N1,N2) 3- Sea discharge 1 no. (N3) 4- 1200/1800 mm. Tunnel, 164.5 m. (N-N1) 5- 1200/1800 mm. Tunnel, 87 m. (M-M1) 6- 2xØ900 pipe 38 m. (N1-N2) 7- 2x0900 pipe 47 m. (N2-N3) 8- Branch interceptor (B6), 1399 m. 9- Branch interceptor (B7), 673 m. 10- Branch interceptor (B6), 2439 m.
1- Baltalimanı Tunnel, Ø3600, 2318 m. 2- Manholes 1 no. (P) 3- Branch interceptor (B9), 730 m. 4- Branch interceptor (B10), 1747 m. 5- Branch interceptor (A1), 436 m.

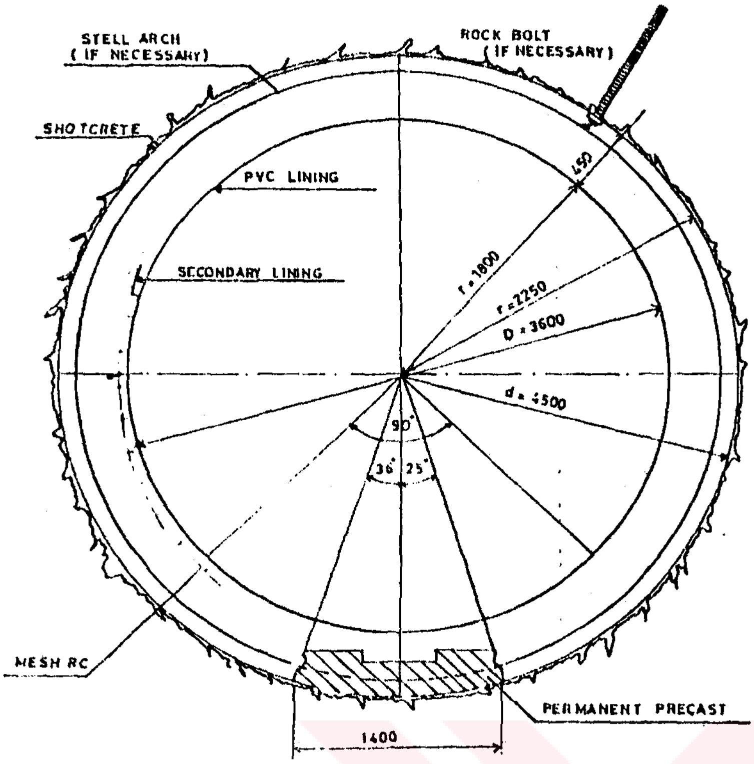
3.3. Tunnel Types and Excavation Method in The Project

There are three types of tunnel in the project, as it is seen in the Figure 3.3.1. Cross section and excavation methods of other tunnels are as follows:

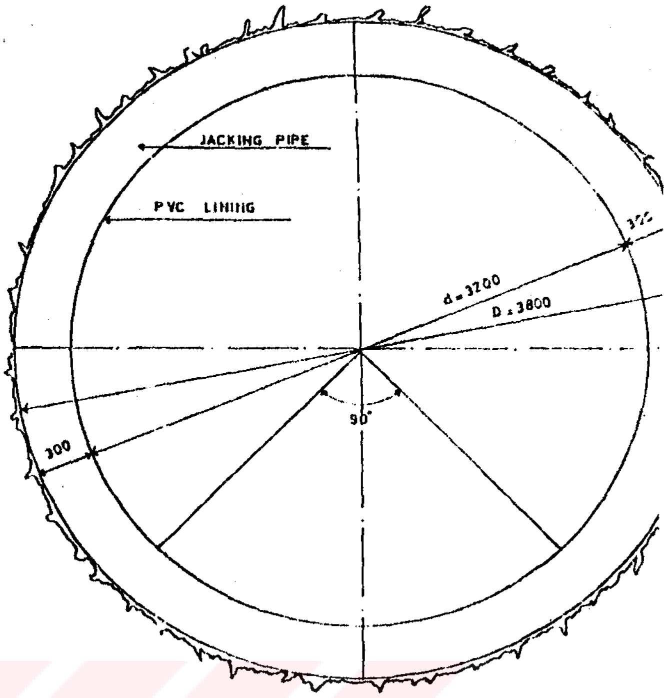
Table 3.3.1. Length, Diamater Of Tunnels And Tunnelling Method In The Project [2]

Tunnel Name	Tunnel Length	Excavation Diameter	Final Diameter	Excavation Method
Eyüp	1865	2.88	2.2	RH
Haliç	2643	3.28	2.6	RH
Fatih	2107	3.48	2.8	RH
Kasımpaşa(B-D)	1660	2.88	2.6	RH
Kasımpaşa(D-E)	256	3.88	3.2	PJ
Kasımpaşa(E-F)	186	3.96	3.2	PJ
Donanma(F-H)	1603	3.96	3.2	RH
Fındıkli(H-J')	1719	3.96	3.2	RH
Beşiktaş(K-K')	310	3.80	3.2	PJ
Beşiktaş(K'-L2)	1506	3.96	3.2	RH
Beşiktaş(L2-L)	153	3.80	3.2	PJ
Arnavutköy(L-L2)	294	3.80	3.2	PJ
Arnavutköy(N-L1)	3345	4.50	3.6	FF
Baltalimanı(P-N)	2318	4.50	3.6	FF

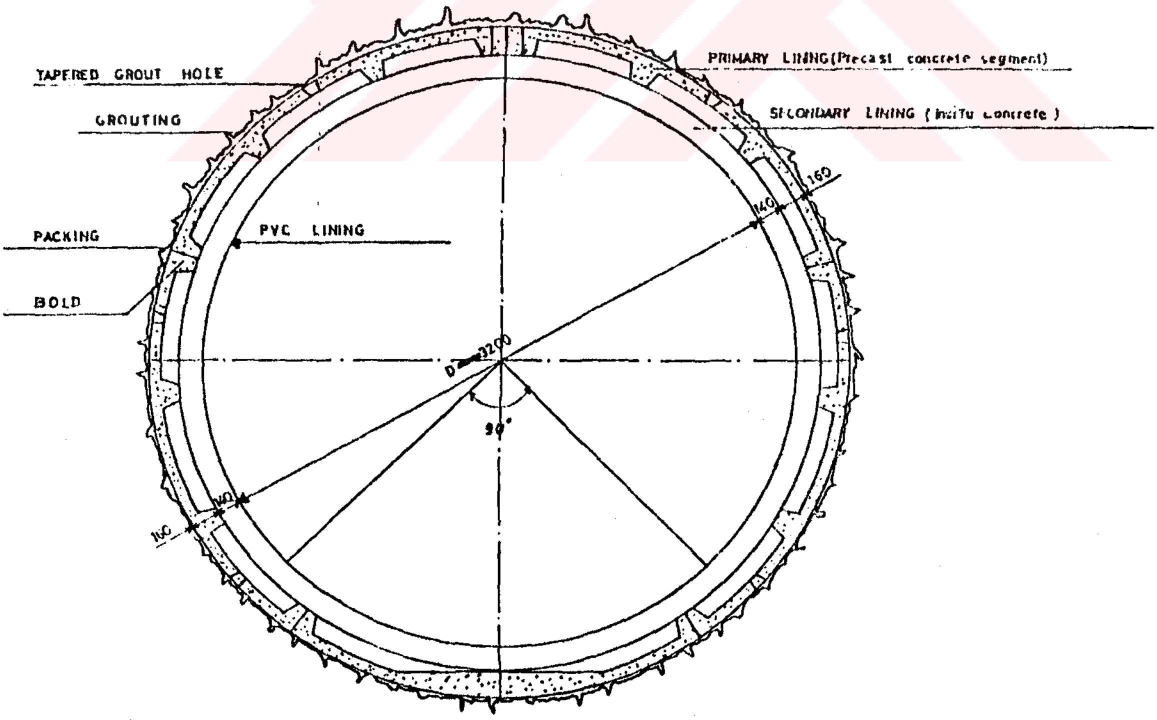
*RH:Roadheader-PJ:Pipe Jacking-FF:Full Face



Tunnel by Full-face Machine



Tunnel by Pipe-Jacking



Tunnel by roadheader

Figure 3.3.1. Types Of The Tunnels In The Project

3.4. Organization

Organization chart of the project is given in Figure 3.4.1. This is related to The North Haliç Interceptors and The Kabataş-Baltalimani Tunnels Project(see chapter 3.2)

Tunnelling activities in Baltalimanı tunnel were carried out on a two shift/day or a three shift/day. Staff member for one shift usually is consisted of 24 men for Baltalimanı Tunnel and they are,

	in a shift	Total
-Tunnel section chief	1	1
-Shift engineer	1	3
-Formen	1	3
-Electric formen	1	1
-Etectrician	1	3
-TBM operator	1	4
-Welder	1	3
-Mechanicman	1	3
-Locomotive driver	2	6
-Workers for shaft top and bottom	3	8
-Workers for shotcerete machine and pipe installation	2	8
-Workers for shotcreting and support installation	4	12
-Unskilled labour	5	15
	24	70

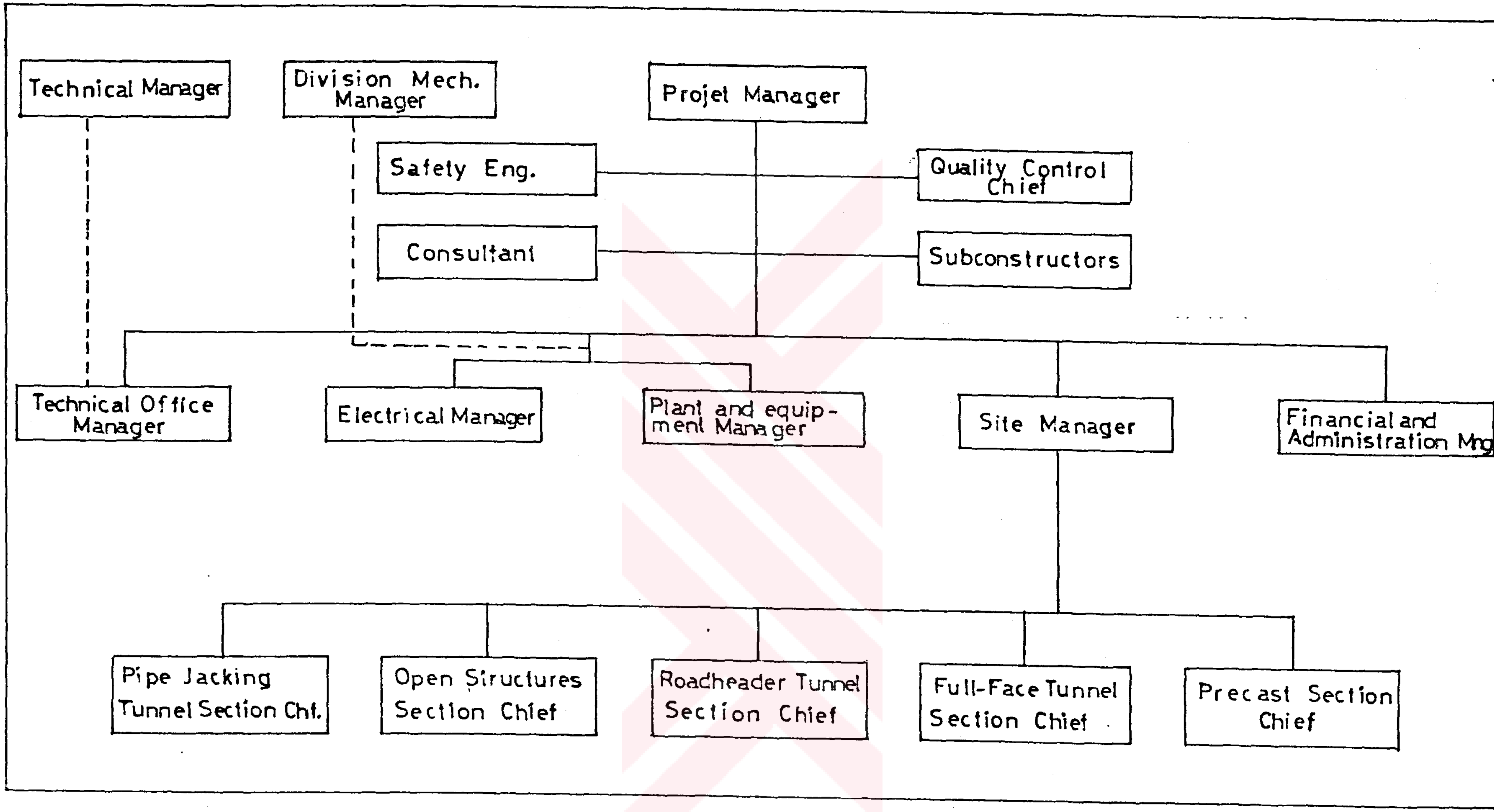


Figure 3.4.1 Organization Chart Of The Project

CHAPTER 4. THE GENERAL GOELOGY OF THE DOLMABAHCE-BALTALIMANI SEWERAGE TUNNEL ROUTE AND ITS SURROUNDINGS

4.1-General

Surface and subsurface geolological studies have been carried out along the 8800 metres long tunnel line from Dolmabahçe to Baltalimanı within a strip of 550 to 600 meters. [3]

Local intense urbanisation and, plant cover produced considerable difficulties during the surface geological studies and in many instances prevented detailed measurements. The geological studies were carried out by out crop mapping techniques and detailed maesurements of strike,dip,joints etc. in the area were carefully made. In the area where there are no out crops the subsurface geology is extrapolated from drill holes data.

4.2-Stratigraphy

Paleozoic rocks representing a continous sedimantation from lower Devonien to Middle Carbonifeous are present within the studied area. These formations are locally covered by 5 to 15 m thick Neogen deposits of clay,silt,sand and boulder of 2-30 m. thick filling and alluvion occur in the valleys.

Devonien and Carboniferous Formations which make up the bedrock are cut by andesite and diabase dykes of 1-30 m. thickness. The Lithostratigraphic units which form the bedrock along the tunnel line are presented in the figure 4.2.1.

4.3 Geologycal Formations Along The Tunnel Line

1-Kartal Formation of Lower and Middle Devonian age, it consists of shale, silty shale, fossiliferous shale and sandy limestone (Dk),

2-Büyükada Formation of Upper Devonian age, consists of limestone-nodular,limestone-corbonate-rich shale (Db),

3-Lower Corboniferous Baltalimanı Formation; consists of chert,silicecous shale,chert with phosphate nodules (Ct),

4-Lower-Middle Corboniferous Trakya Formation; consists of micaceous siltstone-mudstone (Kc); feldspathoidal, micaceous sandstone (greywacke (Kk); quartz conglomerate-micro conglomerate (Kko)

Trakya Formation constitutes the bedrock of the tunnel between Dolmabahçe and Kuruçeşme. However, the mudstone, shale-graywecke and conglomerate units could not be seperately mapped in this area due to strong urbanisation and extensive young cover.

The strong alteration of the bedrock outcrops of the Kartal and Trakya Formations provided difficulties in the recognition of major discontinuities. Detailed observations could only be conducted in recent excavation areas and, in old quarries.

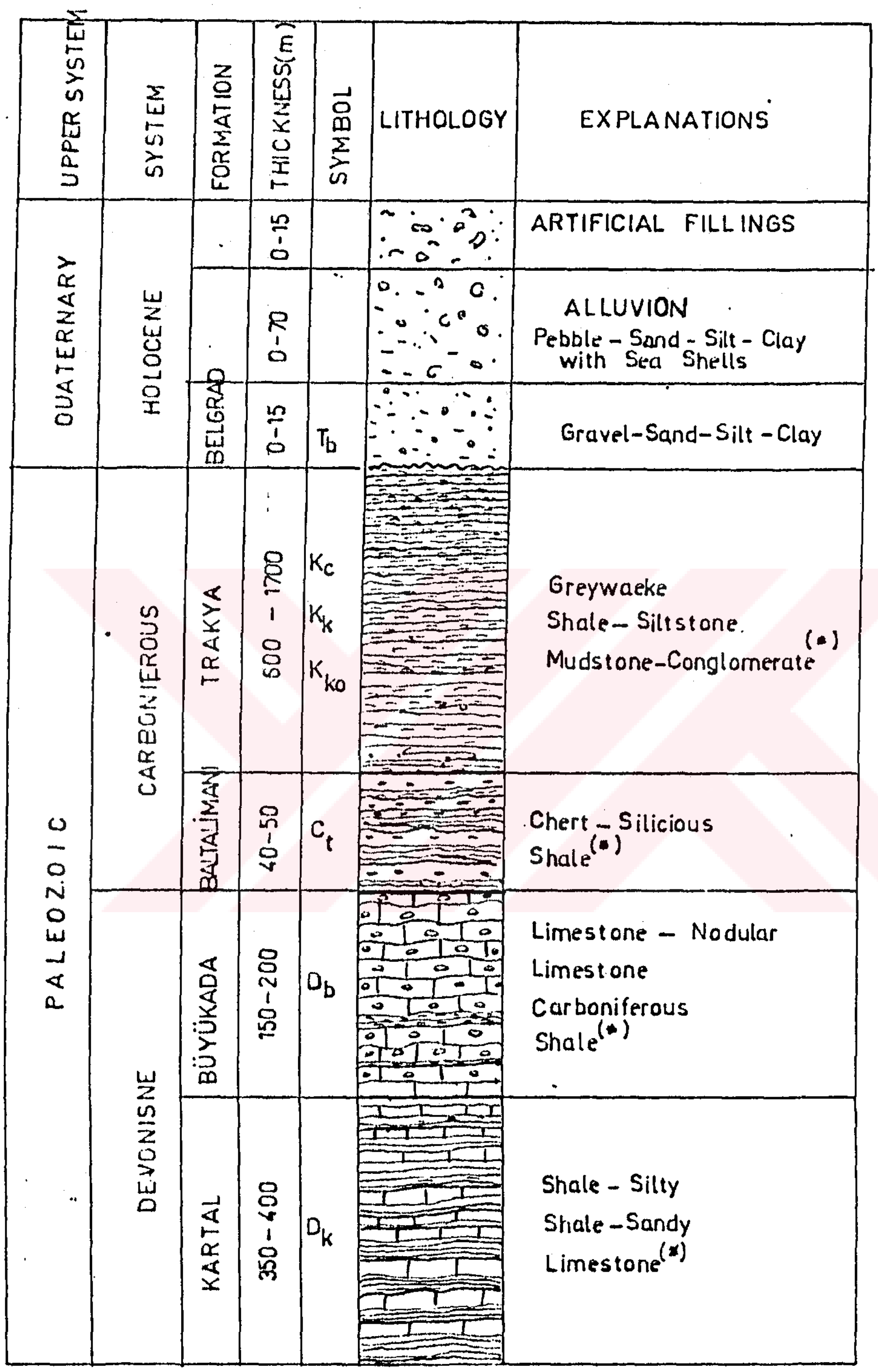


Figure 4.2.1 The General Lithostratigrpohic Column
* Units Intersected By Andesite And Diabase Dykes

Istanbul Paleozoic rocks which are interupted by andesite and diabase dykes of various thickness are in general strongly jointed,folded and faulted. The complexity of the faults, the lateral lithological changes observed in various units are often in distances of a few 10's of meters, the abundance of tectonic contacts, will all provide potential geological problems during the tunnel excavation.

4.4- Shale-Silty Shale-Sandy Limestone-Fossiliferous Shale (Dk) (Lower-Middle Devonian KARTAL FORMATION)

This unit is yellowish brown,porous,medium to thickly bedded and quite fossiliferous at the the lower levels. The upper parts have intercalations of limestone-sandy limestone and mudstone. Especially the fossiliferous lower parts are irregularly and strongly fractured and altered. The sandy limestone beds within Kartal Formation are 10-40 cm thick, dark grey-blue and very hard. No karstic features are observed in these limestone beds. The thickness of Kartal Formation is approximately 250 meters.

4.5- Limestone-Nodular Limestone-Carbonate-Bearing Shale(Db) (Upper Devinian BÜYÜKADA FORMATION)

Büyükada Formation which lies conformably over Kartal Formation starts with thinly-bedded micritic limestone and passes upwards to nodular limestone. Intercalated with the nodular limestone there are carbonate-rich shale and siliceous shale horizons. The nodular limestone is made up of generally 4 cm. locally 8-12 cm large, elliptical nodules which show an increasing clay content toward the rims. The nodules are generally in contact with each other and are parallel to bedding. They have a light grey colour on the otucrops and grey to dark grey colour in the drill cores.

Büyükada Formation is strongly folded, little jointed and has massive appearance. The joints are generally vertical to bedding and have vertical to subvertical dip. Minor Karstic feaatures are observed along the discontinuity surfaces. The apporoximate thickness of Büyükada Formation is 250 meters. Because of the frequent block faulting in the area, the boundaries of Büyükada Formation with the other formations are irregular and often tectonic.

4.6- Chert-Siliceovs shale-chert with Phosphatic Modules (Ct) (Loveer carboniferous-BALTALIMANI FORMATION)

This unit is laminated thinly bedded (7-8 cm), strongly fractured and folded. It is conformably with the underlying nodular limestone and forms a very good "Key Horizon". The chert beds are bluish to black while the siliceous shales are yellowish grey, thinly bedded, locally laminated and contain micro-crystalline quartz. Althougt the unit is very hard, it is easily excavable because of strong jointing and fracturing. It contains first-sized, black chert nodules. The thickness of the

Baltalimanı Formation is 40-50 m.

4.7- Shale-Siltstone-Sandstone-Conglomerate (Lower-Middle Carboniferous- TRAKYA FORMATION)

Trakya Formation is closely jointed and locally strongly folded and it contains turbidites in terms of channelised deposits of coarse sandstone and conglomerate

4.8- Structural Geogology

Although the structure of the Istanbul Paleozoic rocks are studied by various geogolists, it is not known well because of the effects of block faulting, thrust, magmatic intrusions and large number of units.

Most of formation contacts are tectonic in nature which presents major difficulties for the determination of true thickness and relative ages and brings major uncertainties.

It is known that the Istanbul region is affected by Hercynian and Alpine orogenesis with the resulting folding, jointing and faulting.

The Dolmabahçe-Baltalimanı tunnel line lies on the western limb of the large anticline known as the Kocaeli anticlinorium; the strike of the bedding in this region ranges generally between N30E and N30W and shows important variability due to faulting and dykes. The dip of the bedding is generally to the NW and SW and ranges from 8-10° to 90° with a max. around 30-55°. Due to the narrow within of the project area, the major fold axis could not be located precisely; however, abundant N-S striking folds are observed in the nodular limestone between Baltalimanı and Kuruçeşme.

The evaluation of the measured joints along the tunnel line has shown the presence of two major joint sets, One of them strikes N60-80W is subvertical to the bedding and, dips at 65°-85° to the NE or SW; the other joint set strikes N40-80E and dips at 60-85° to the NW or SE (figure 4.8.1, 4.8.2, 4.8.3 and 4.8.4). Together with the bedding these three discontinuities have produced prismatic rock elements.

Two improtant fault systems have been distinguished based on surface geological mapping and data from the drill cores.

One of these fault systems strikes N-S and is responsible for the formation of Bosphorus. The other crosses the first fault system at an angle of 50-80° and strikes E-W.

Both fault systems are faults of pliocene age and have produced horsts and grabens and wide shear zones. The throw on the faults is thought to range from a few meters to 230 m.

A geologycal map of the region where the Baltalimanı Tunnel exist is enclosed in appendix 11.

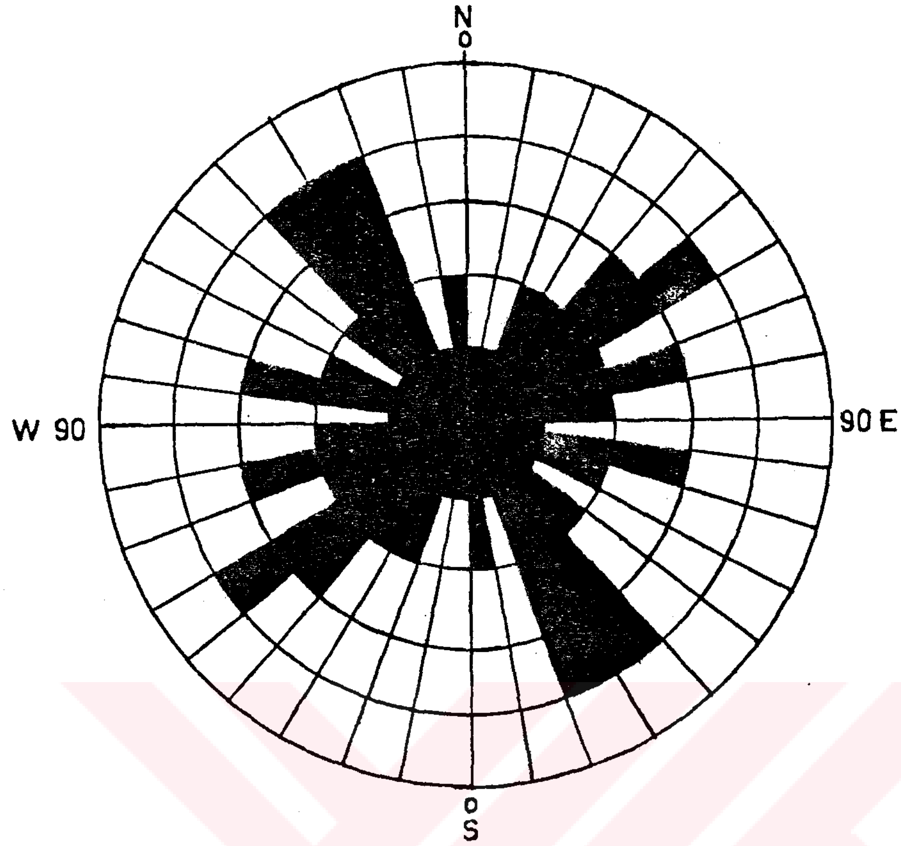


Figure 4.8.1 Rose Diagram Showing Strikes Of Joint In Graywacke

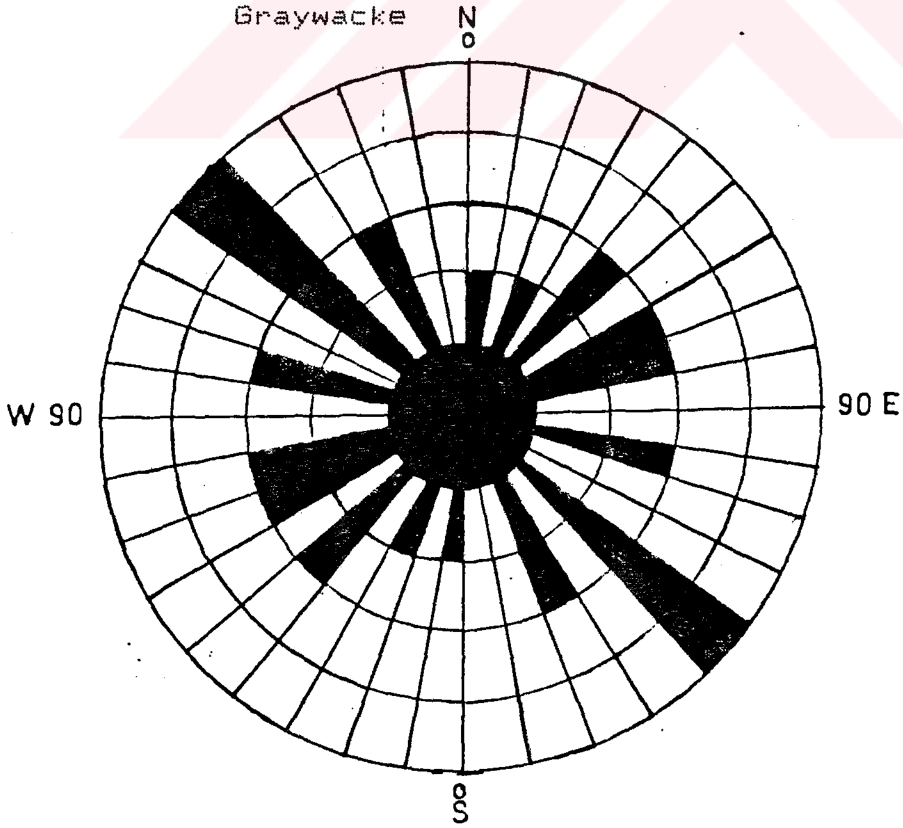


Figure 4.8.2 Rose Diagram Showing Strikes Of Joint In Nodular Limestone

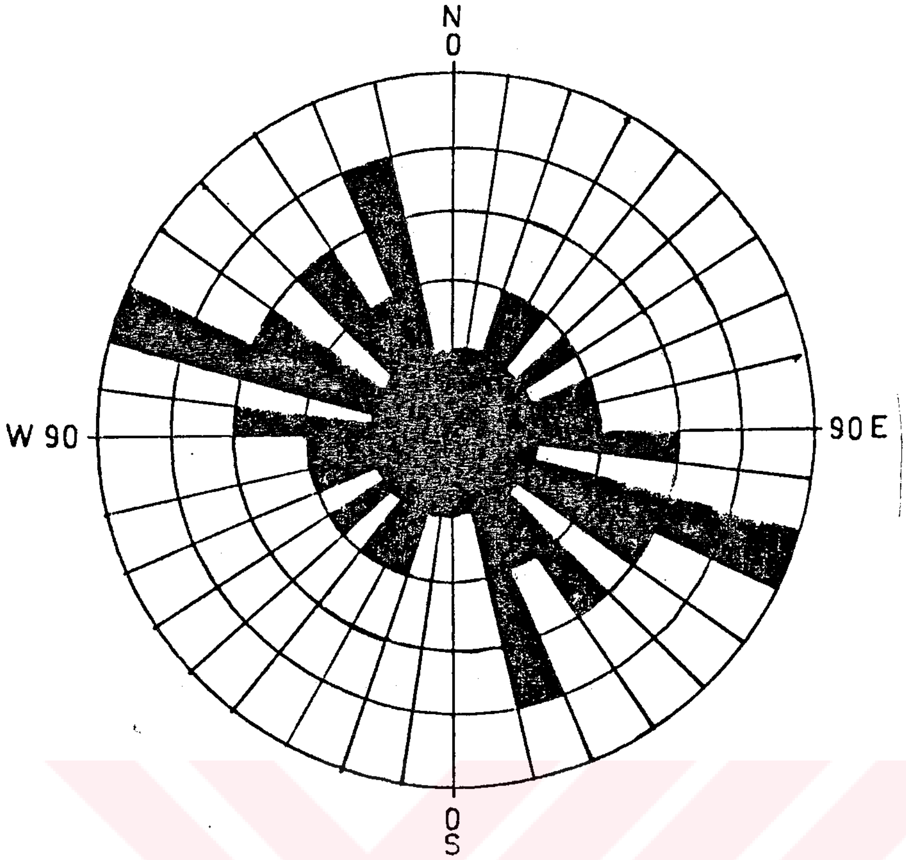


Figure 4.8.3 Rose Diagram Showing Strikes Of Joint On The Out Cropes Of Kartal Formation

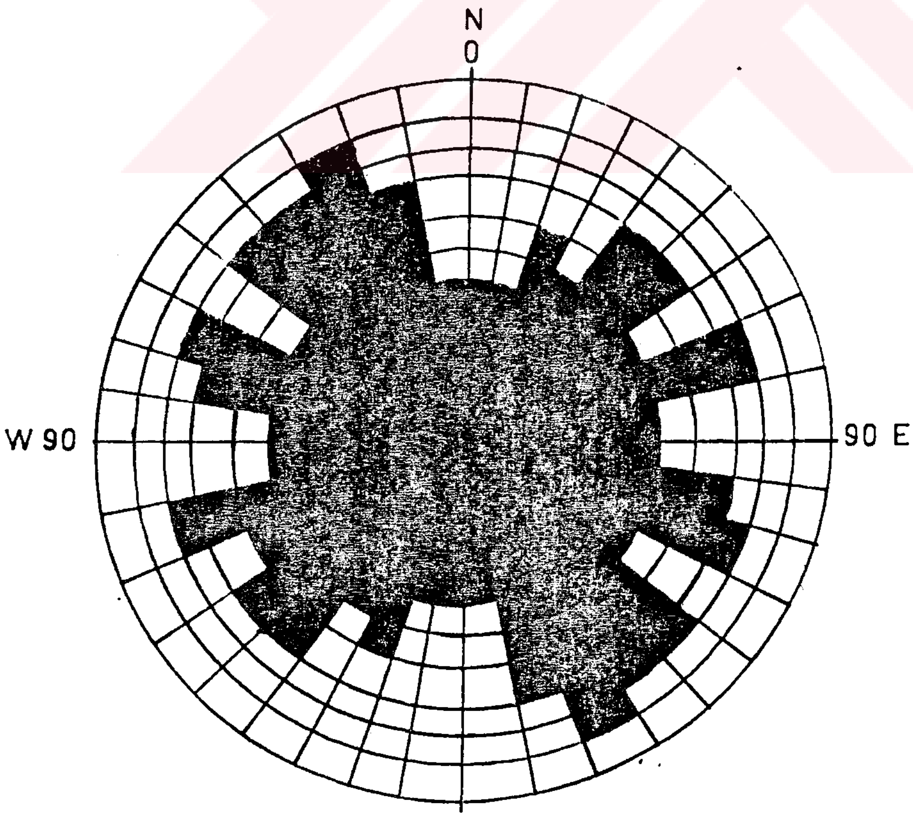


Figure 4.8.4 Rose Diagram Showing Strikes Of Joints In Nodular Limestone And Kartal Formation

CHAPTER 5. DESCRIPTION OF THE TUNNEL BORING MACHINE (TBM) BEING USED IN BALTALİMANI TUNNEL

5.1. General

A Robbins type=145-168 full-face tunnel boring machine (dia. 4500mm) is used in Kabataş Baltalimanı Tunnel projects. This machine was selected according to hard rock conditions on Baltalimanı Tunnel line (figure 5.1.1). [4]

Design of the machine was governed by geological requirements and specifications of the project such as tunnel diameter, rock strenght and type of support. In table 5.1.1., some characteristics of the machine are given.

Table 5.1.1. Some Characteristics Of The Machine [5]

Type	: Hard Rock Boring Machine
Manufacturer	: Robbins
Model	: 145-168
Refurnishment	: Herrenknecht
Machine diameter	: 4500 mm
Weight	: 130 ton
Propel clynders	: 4 pieces
Gripper cylinders	: 2 pieces
Side suppert clynders	: 2 pieces
Roof support clynders	: 8 pieces
Rear support cylinders	: 4 pieces
Primary conveyor belt	
Tensioner Cylinders	: 1 pieces
Primary Conveyor Cylinders	: 2 pieces
Gripper piston shoes	: 2 pieces
Power	
Cutterhead	: 7*125=875 HP
Hyd.pump propel and low pressure + first and third conveyor	: 100 HP (75 Kw)
Hyl. pump gripper and low pressure	: 50 HP (37 Kw)

continued from Table 5.1.1

Second belt conveyor motor	: 50 HP (37 Kw)
Hyd. oil. transfer pump	: 3/4 HP (0.55 Kw)
Transformer	: 2x600 KVA 6000 V
Current	: 380 V - 50 Hz
Control lighting	: 220 - 50 Hz
Disc cutters	
Number	: 35(4 no:12", 31no:15.5")

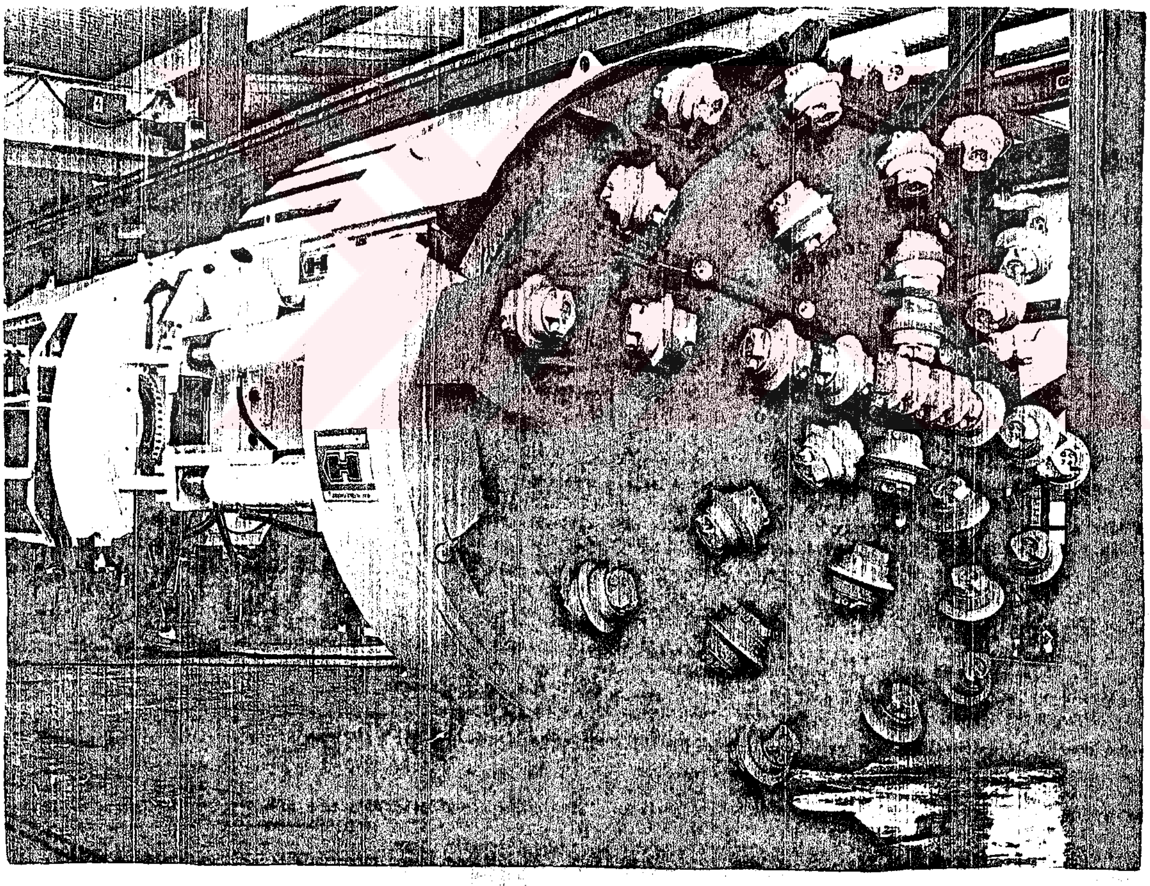


Figure 5.1.1 Robbins Full-Face Machine Refurnished By Herrenknecht Company

5.2- Elements of The Machine

Main structural members of the Robbins' tunnel borring machine are the cutterhead, cutterhead support, main beam, gripper assembly, rear platform and rear support clynders .

During the boring cycle, all of the members except the gripper assembly, advance forward as the propel clynders are extanded. The gripper assembly remains stationary with the gripper clynders expanded against the tunnel walls and provides the reaction point for the propel clynders (figure 5.2.1 A). After the advance (figure 5.2.1. B), the rear support clynders bear against the tunnel muck chute. During the regripping cycle, (figure 5.2.1. C) these rear support clynders support the machine and back-up equipment while the gripper assembly moves forward (figure 5.2.1. D) as the the propel clynders are retracted and the other members are stationary. The gripper assembly support the machine and back-up equipment (figure 5.2.1. E) while the rear support clynders are retracted and back-up system (figure 5.2.1. F)

Cutterhead

The cutterhead, mounted on alarge two-row tapered roller bearing is driven by seven electrical motors through planetary drives which result in a rotational speed of 5.56 rpm. For horizantal boring, the cutterhead is equiped with eight buckets which transport the muck into a conveyor through a chute in the cutterhead

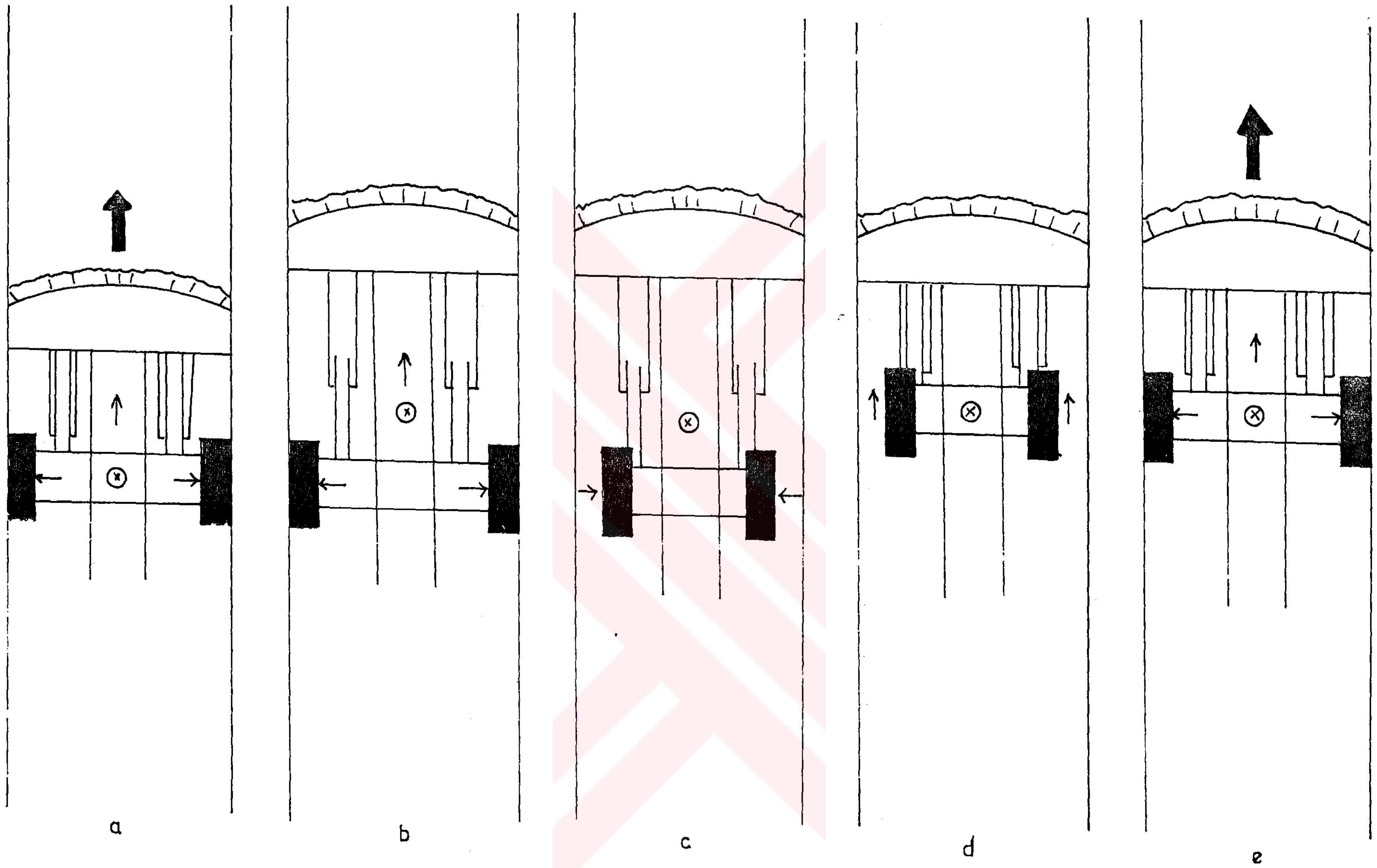


Figure 5.2.1 Movement Of The Machine During The Excavation And Advance Period

support. The bolt-on buckets replace eight of the pedestals when the machine is not boring on an incline of sufficient grade for gravity feed of the muck. The muck is then picked up by the buckets and deposited on the conveyor for disposal using conventional method.

The pedestals are used when boring up an incline of sufficient grade for gravity feed of the muck. The muck is allowed to pass under the cutterhead support and enter a muck chute which controls it as it slides down the incline.

The cutterhead carries 35 disc cutters on itself. The housing are welded directly to the cutterhead, pedestals and buckets. The cutter assemblies are straddle-mounted and bolted on to the cutter housings. (figure 5.2.2)

The below table shows some feature of disc cutters being used.

Disc number	Disc Dia.	Edge Angle	Bluntness Diameter	Width
1-4	12"	72°	3mm	62mm
5-35	15.5"	72°	3mm	62mm

In figure 5.2.3 and 5.2.4, disc assemblies for both disc cutters are shown. Besides, position of all cutters on the cutterhead is given in figure 5.2.5

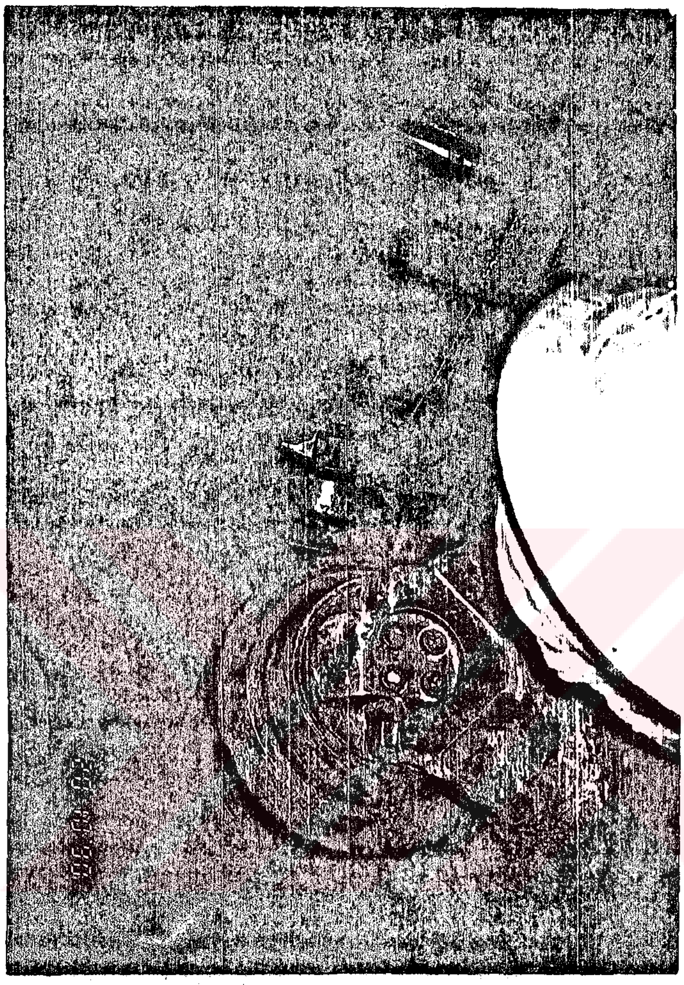
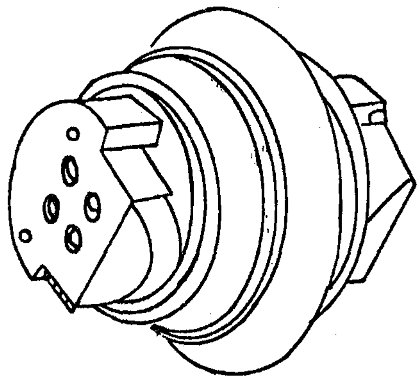
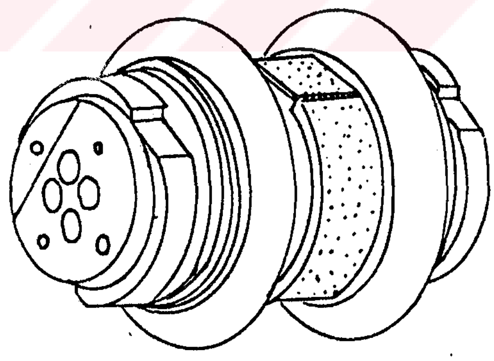


Figure 5.2.2 Disc Cutters On The Cutterhead

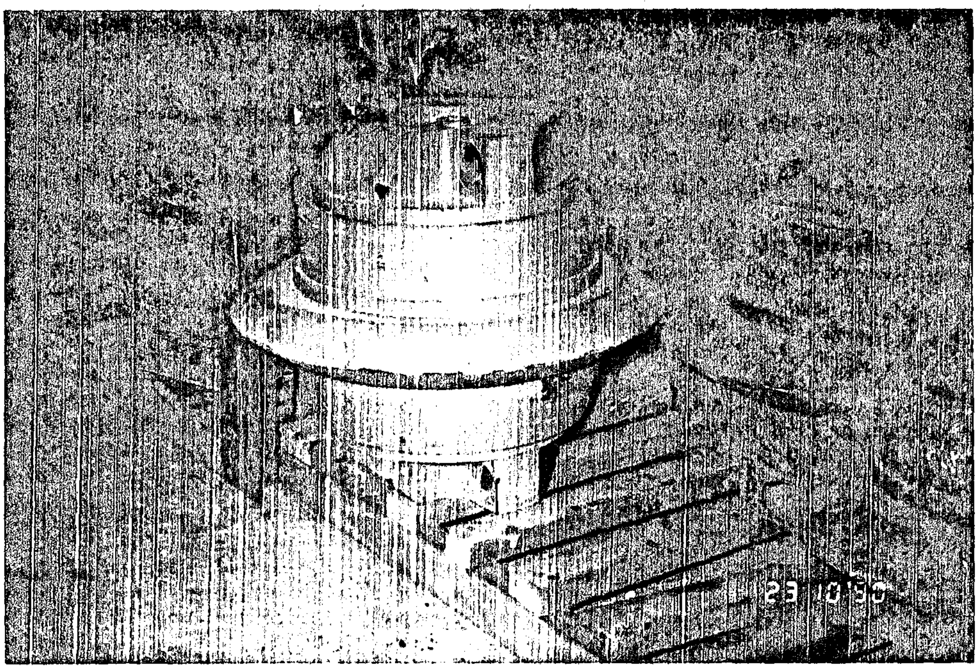


(A)

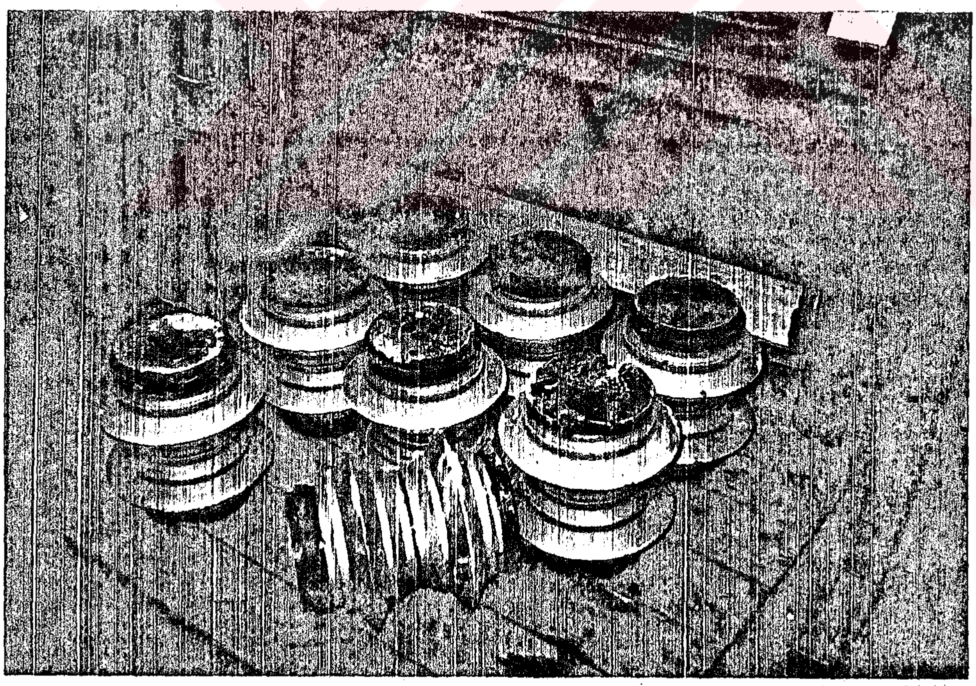


(B)

Figure 5.2.3 Disc Assemblies (A) 15.5" dia. (B) 12" dia.



(A)



(B)

Figure 5.2.4 Disc Assemblies (A) 15.5" dia. (B) 12" dia.

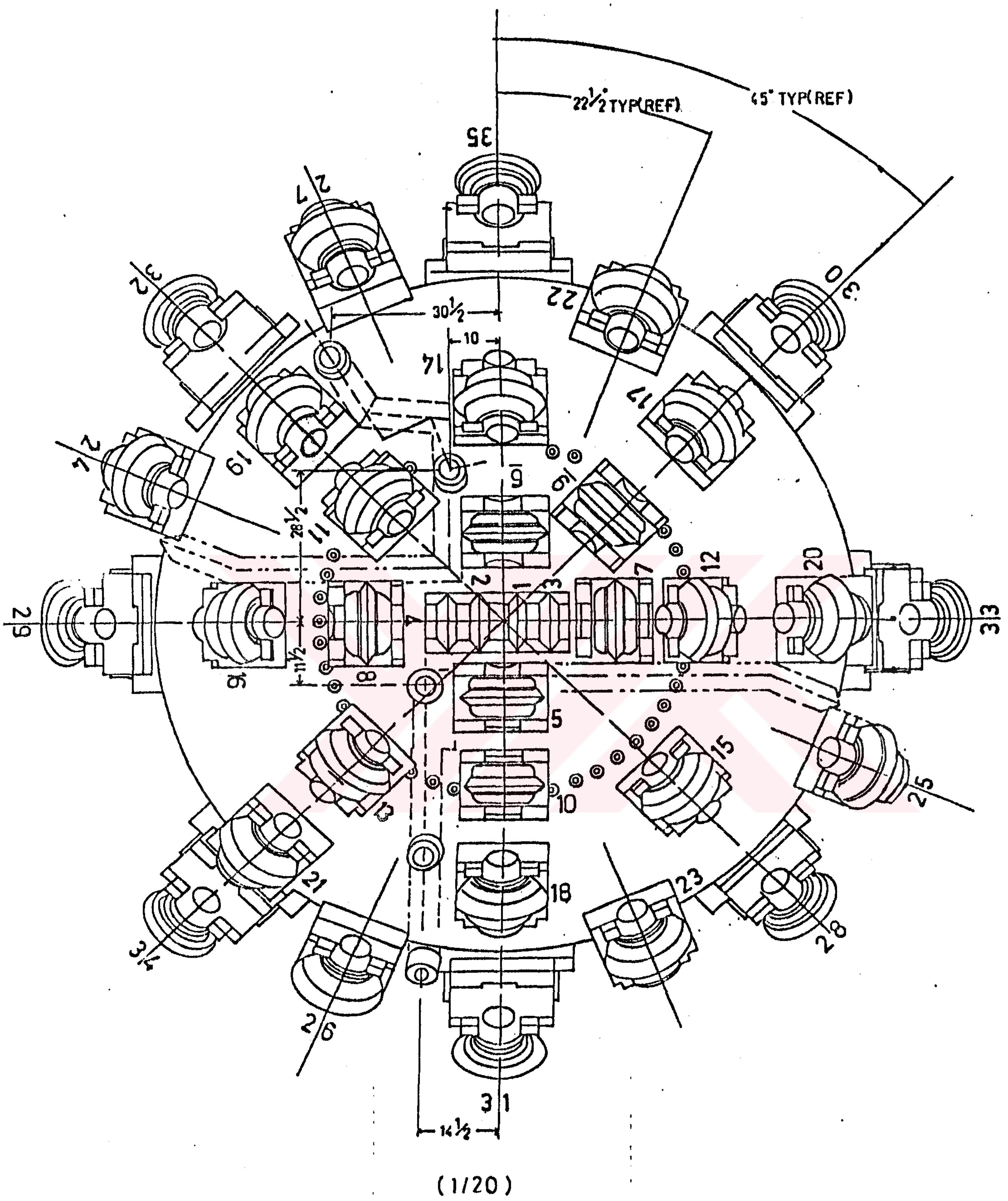


Figure 5.2.5 Position Of Disc Cutters On The Cutterhead

Cutterhead Support

The Cutterhead support is located directly behind the cutterhead. This structure supports the cutterhead bearing, drive motors, main beam, shield and various auxiliary equipment.

Shield

The shield consits of two side supports, two roof supports and a vertical front support which are mounted on the cutterhead support and are used to support the tunnel roof and walls to stabilize and support the front of the machine.

Each side support is actuated by a wedge which is controlled by on 8-inch bore, 10-inch store clinder. The side support reacts a portion of the vertical and lateral forces of the cutterhead, thus stabilizing and supporting the cutterhead. Each cylinder is independently controlled from the high pressure circuit.

Roof supports cover the top 120 degrees of the tunnel. Each support is actuated by two, 4-inch bore, 6-inch stroke and two, 4 inch bore, 1 1/2 inch stroke cylinders. Each roof support is operated by a single control valve in the high pressure circuit. (figure 5.2.6)

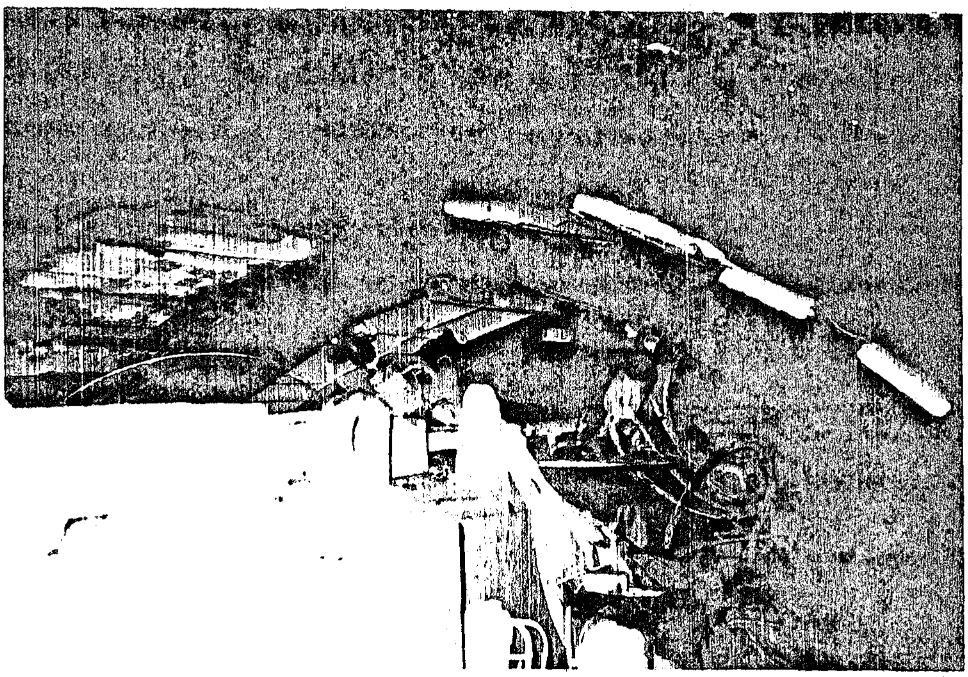


Figure 5.2.6 Roof Supports Of The Machine

Main beam

The main beam is bolted to the rear of the cutterhead support and has ways that accommodate the fore and aft travel of the machine. The main beam reacts cutterhead torque and overturning moments due to steering or uneven rock at the cutting face.

Gripper assembly

The gripper carrier is mounted on the main beam ways with self lubricating bronze bearings and has a fore and aft travel of 48 inches. The gripper cylinder is attached to the carrier by two cylinders referred to as torque cylinders.

The gripper cylinder consists of two, 26 inch bore 18 inch stroke hydraulic cylinders with a common fast reset and horizontal steering controls.(figure 5.2.7)

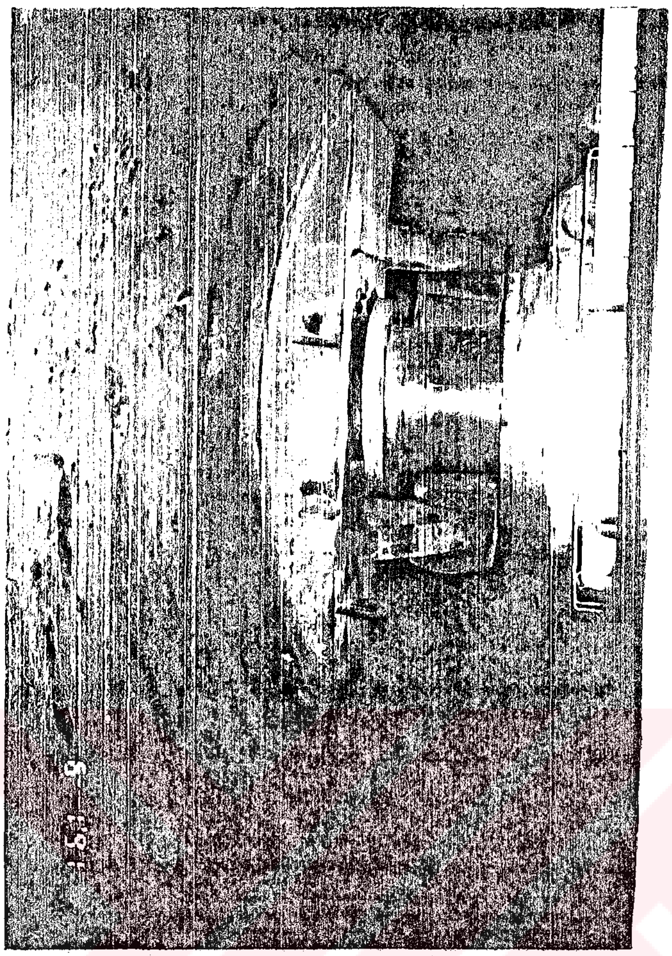


Figure 5.2.7 Gripper Assembly

Torque cylinders

The two torque cylinders attach the gripper to the gripper carrier. These cylinders react cutterhead torque, support the weight of the machine during boring, provide a means of steering and alignment in the vertical plane and react overturning moments from the cutterhead. Each 10 inch bore cylinder is independently controlled. (figure 5.2.8)

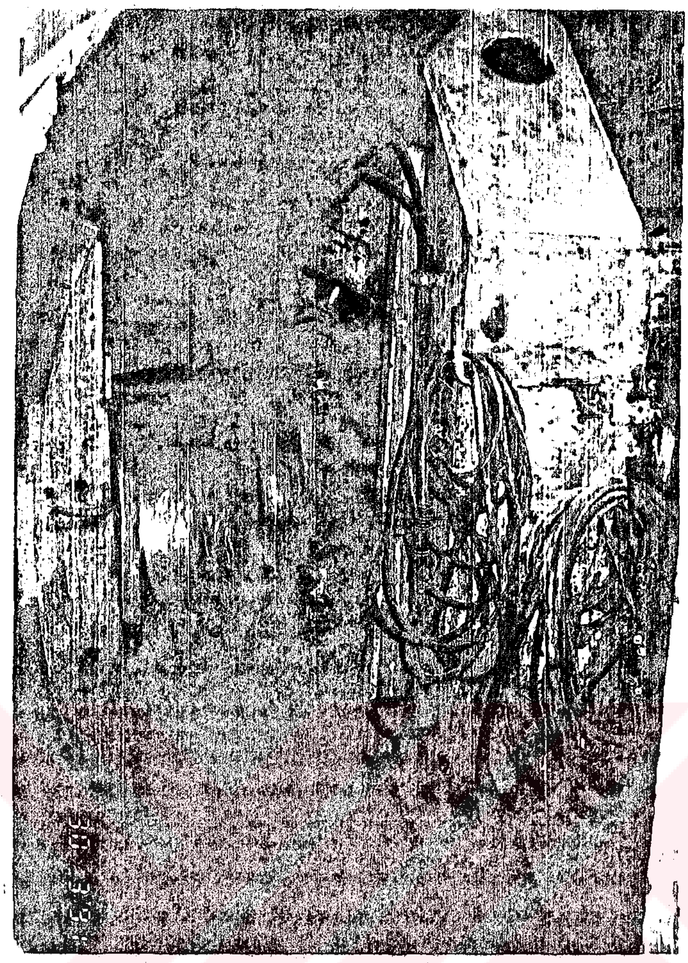


Figure 5.2.8 Torque Cylinders

Propel Cylinders

The four propel cylinders are attached to the forwad side of the gripper shoes and push against the aft side of the cutterhead support. These 11 inch bore, 48 inch stroke cylinders provide the force necessary to advance the machine through the rock and have two common controls high pressure propel and fast reset.

Rear Platform

The rear platform is bolted to the aft end of the main beam, it provides space for the operator's station, the hydraulic system, electriral controls and other auxiliary systems.

Rear Support Cylinders

The four rear support cylinders are located under the rear platform and support the weight of the machine during the regripping cycle or when the machine is not in use. (figure 5.2.9). The 4 inch bore, 34 inch stroke cylinders have a common control.

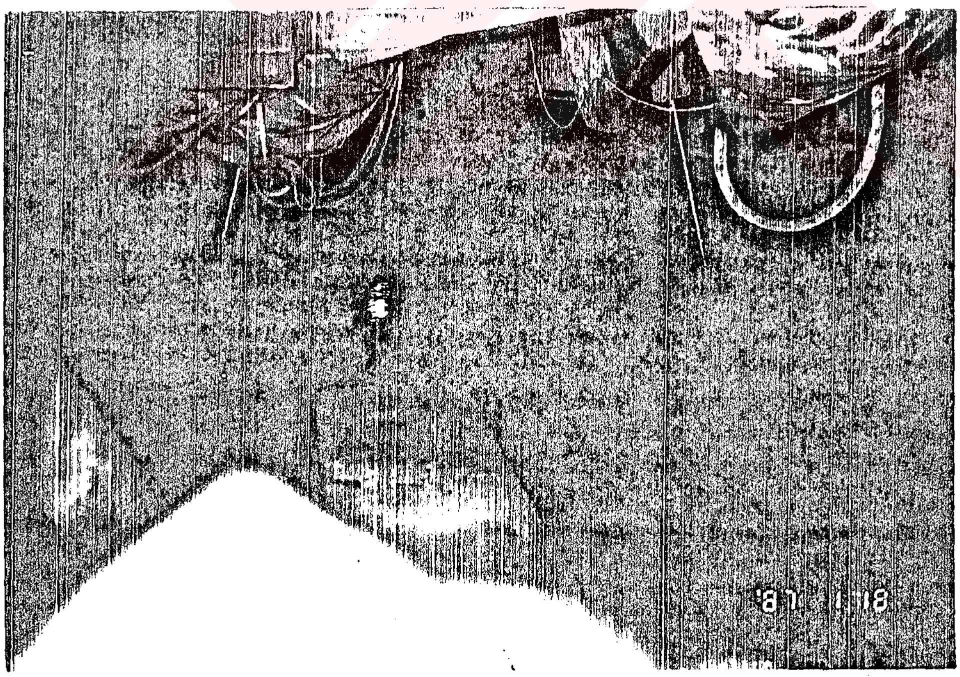


Figure 5.2.9 Rear Support Cylinders

Conveyor Head Pulley Motor

The conveyor head pulley has an internal gear reduction driven by a hydraulic motor. The head pulley speed is 86 rpm with 39 GPM input. The working pressure is 2000 psi The conveyor drive is controlled at the machine operator's station and is pressurized from the low pressure circuit.

Operator's Control Console

It is located on the rear platform behind the gripper carrier. The console Includes hydraulic, electrical controls and indicating devices (figure 5.2.10)

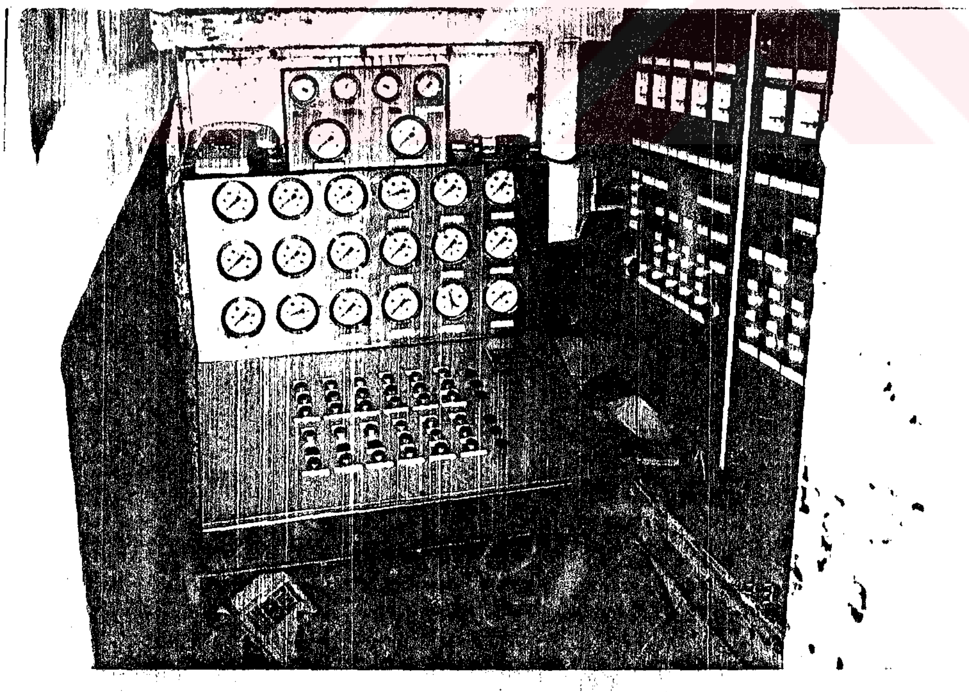


Figure 5.2.10 Operator's Control Consol

Hydraulic

The Hydraulic controls consist of six switches for remotely located, solenoid-operated, directional control valves; eight manuel, directional control valves and the propel pump pressure and volume controls.

Three of the control valves are spring-centered and control the vertical and horizontal alignment and steering of the machine.These functions require the close attention of the operator and should never be operated unless the cutterhead is rotating.

The remaining 11 controls are detent-positioned and control such circuits as the grip and propel which are of an "off-on" nature.

The propel pump pressure and volume controls determine the rate of advance of the machine. The pressure control and the pump hand wheel control are located on the right side of the Control Console.

Electrical

The Electrical pushbutton and selector switches are located at the right of the operator's station.(see figure 5.2.10)

Indicating Devices

The Indicating Devices consist of pressure and temperature gages, flow indicators, ammeters and warning lights. these are located above the hydraulic valves and to the right of the operator's area.

5.3-Back-up System Of The Machine

There are 15 platforms in the back-up. They provide space for auxiliary system of the machine. (figure 5.3.1)

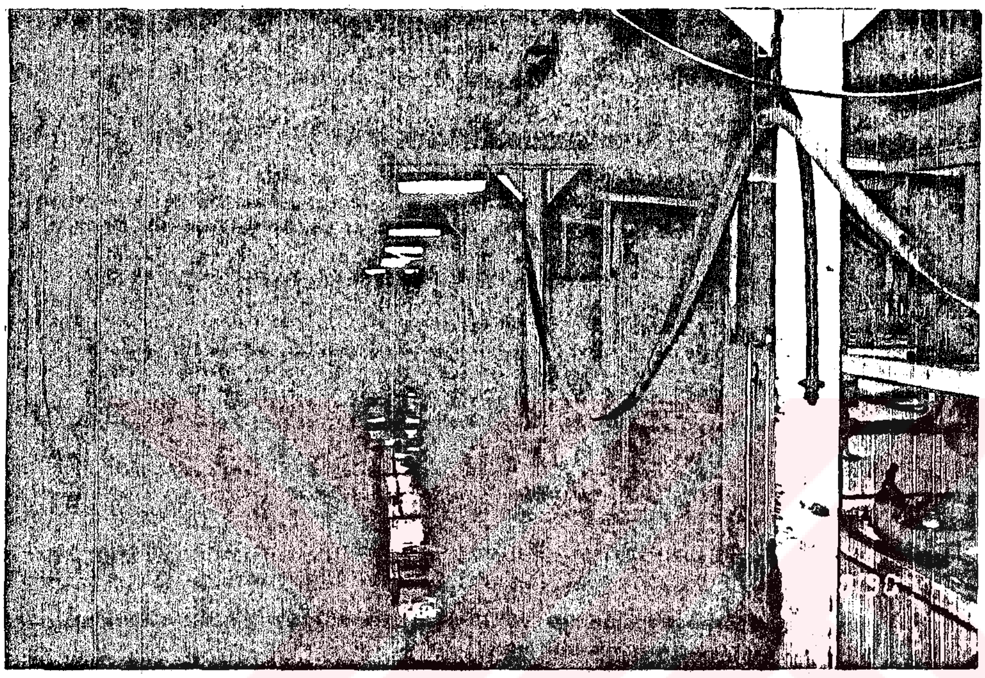


Figure 5.3.1 Back-up System Of The Machine

5.4-Machine Systems

The tunnel boring machine includes the following systems Lube Oil, Seal Pressurizing, Water, Muck Handling, Dust Collection, Hydraulic and Electrical.

Lube Oil

The Lube Oil system provides oil to the main cutterhead bearing, to the six pinions which mesh with the main ring gear and to the six reducers which drive the cutterhead. The system provides constant oil circulation and filtration and has a dry sump bearing and gear cavity. The oil is dispensed through positive oil distrubutors which assure the correct lubrication of the varrious parts.

Three pressure switches are provided to prevent rotation of the cutterhead unless the Lube Oil system is up to operation pressure and that no lines are blocked.

Seal Pressurizing

The Seal Pressurizing system provides air to pressurize the bearing and seal cavity and the cavity between the Gearlock seals and the inner shield and provides lubricated flushing air out through the outer shield. The air carries enough lubricant to lubricate the inner and outer shields.

Water

The Water system provides water to five nozzles mounted on the cutterhead to help control dust and water to flush labyrinth located outside of the seals. Normally, facility water pressure is adequate but a booster pump can be used in case facility pressure is too low.

Muck Handling

The Muck Handling system consists of two ways of moving the muck from the cutterhead area to the near of the machine.

A conveyor is provided for horizontal boring which accepts the muck from the buckets and carries it to the rear of the machine to the trailing equipment which will be furnished by the customer. Operating the machine on an incline of sufficient grade allows gravity feed of muck under the cutterhead support, through the muck chute formed by the anti-back slip structure, to the tunnel muck chute supplied and installed in the tunnel by the customer.

Dust Collection

An air duct is provided on the right side of the rear platform for collection to the air handling system provided by the custommer.The duct is continued forward inside the rear platform and main beam.

The low pressure area at the cutterhead face is improved by the Dust Shield which is a seal between the shield and the cutterhead support.

Hydraulic

The hydraulic system is supplied by two, fixed volume, low pressure pumps and two, high pressure, variable volume pumps-one with a remote volume control.

During the boring cycle, the remote-controled, high pressure pump provides oil to the propel cylinders while the pre-set, variable volume, high pressure pump provides oil to the remaining system which require high pressure.

During the regripping cycle, the low pressure pumps provide oil to the systems for fast reset.

Electrical

The electrical power is provided to the machine at 6000 volts, 3 phase, 50 hertz through a portable power cable. The cable is connected to two transformers through oil fuse cutouts. Two, 400 KVA transformers reduce the voltage to 380 volts for the power circuits and 220 volts for the control circuit. Electrical control cabinets mounted directly to the transformers house the circuit breakers, contactors, starter and relays.

CHAPTER 6 EXCAVATION PERFORMANCE AND DIFFICULTIES ENCOUNTERED DURING THE TUNNEL PROGRESS

6.1 General

A Full-face Machine which is used in Baltalimanı Tunnel excavated through two diffirent rock formation Büyükada and Trakya Formation (See chapter 4). For this reason, excavation performance in these geological formations was evaluated separetely.

All the excavation performance and progress data for the machine in two diffirent geological formation are recorded during the tunnel driving by the author.

6.2 Assessment Of The Machine Performance

Shift time was taken account to calculate excavation performance. Machine Utilization, advance rate, downtime, and penetration rate were evaluated daily and then weekly, according to the following formulas

$$\text{Machine downtime}(\%) = \frac{\text{Actual working time of the machine(hr)}}{\text{Total working time (hr)}} \times 100$$

$$\text{Machine downtime}(\%) = 100 - \text{Machine utilization}(\%)$$

or,

$$\text{Machine downtime}(\%) = \frac{\text{downtime (hr)}}{\text{Total working time (hr)}} \times 100$$

$$\text{Net cutting rate(m/h)} = \frac{\text{Actual advance (m)}}{\text{Actual working time (hr)}}$$

or,

rev.of the cutterhead (mm/rev) <—┐

$$\text{Net cutting rate(m/h)} = \frac{\text{Penetration rate(mm/rev)} \times 5.56 \times 60}{1000}$$

$$\text{Penetration rate(mm/rev)} = \frac{\text{Actual advance (mm)}}{\text{Net Cutting Time(min.)}} \times \frac{1}{5.56}$$

$$\text{Progress rate (m/h)} = \frac{\text{Actual advance (m)}}{\text{Total working time (hr)}}$$

Using these formulas, excavation performance in both geologycal formations was evaluated during 11 months from the beginnig of May'90 to the end of March'91

6.3 Excavation Performance in Büyükada Formation

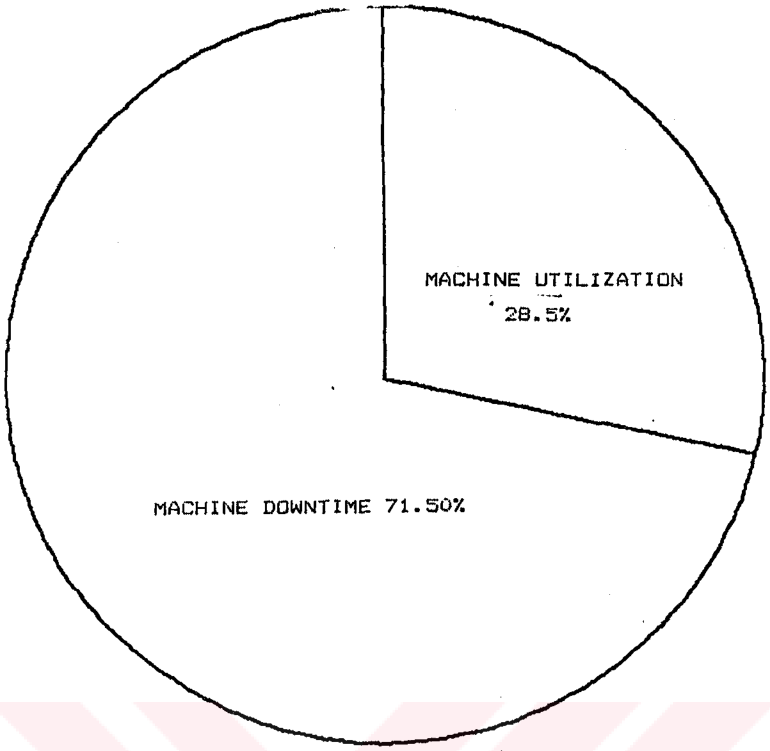
Excavation Performance data is given in appendix 1 for Büyükada Formation Evaluation was made between chainage 0+097.52 and 0+780. Overall performance is as follows,

Machine Utilization	%28.50
Machine downtime	%71.50
Net cutting rate	1.22 m/h
Progres rate	0.35)/h
Average shift advance	3.15 m/shift
Best shift advance	11.5 m/shift
Lowest shift advance	0.60 m/shift
Average daily advance	7.18 m/day
Best daily advance	20.0 m/day
Lowest daily advance	0.22 m/day
Average weekly advance	43 m/week
Best weekly advance	76 m/week
Lowest weekly advance	9.95 m/week

Average monthly advance	197 m/month
Best monthly advance	261.48 m/month
Lowest monthly advance	56.2 m/month
Total advance in Büyükada Formation	683 m

Machine downtime	
Disc changing	%16.84
Disc control	%3.05
Support	%14.04
Mucking and waiting for wagons	%14.47
Mechanical breakdown	%5.11
Electrical breakdown	%1.21
Ground condition	%3.00
Crane failure	%4.20
Conveyor failure	%0.88
Ventilation failure	%0.31
Maintenance	%2.00
Others	%6.39
TOTAL	%71.50

Graphical Evaluation was also made in order to understand better the excavation performance in Büyükada Formation (figure 6.3.1, 6.3.2, and 6.3.3).



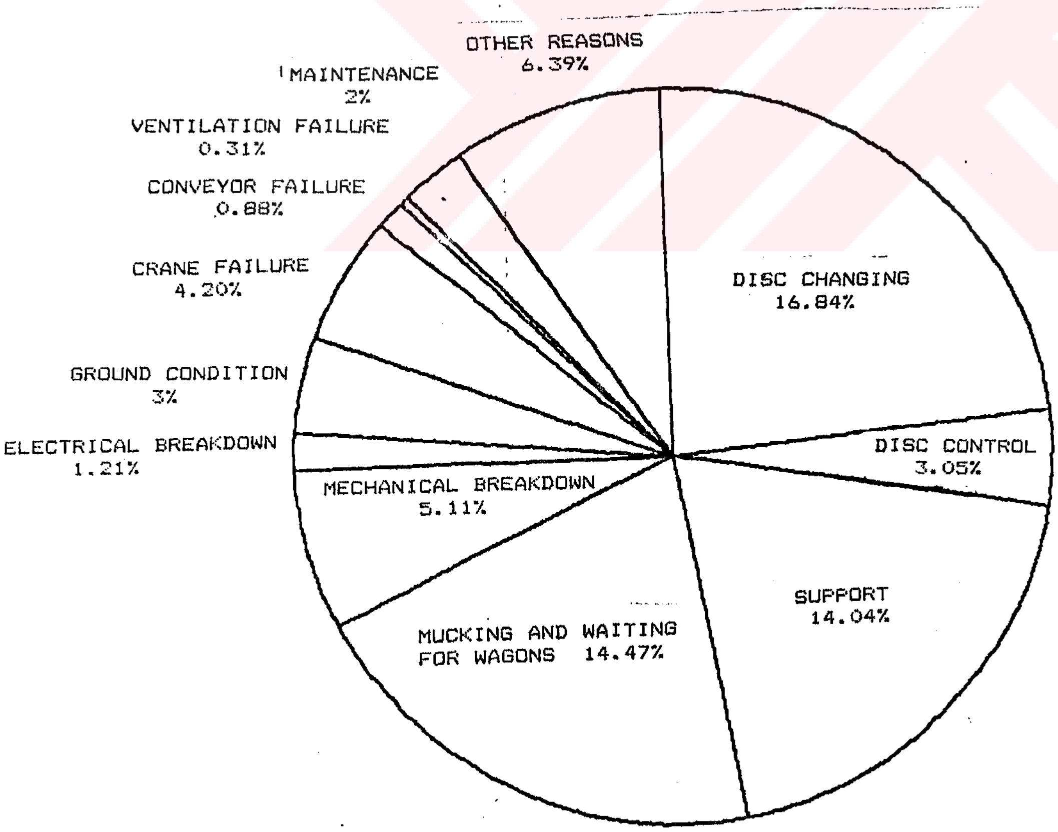


Figure 6.3.1 The Percentage Of The Breakdown In Buyukada Formation

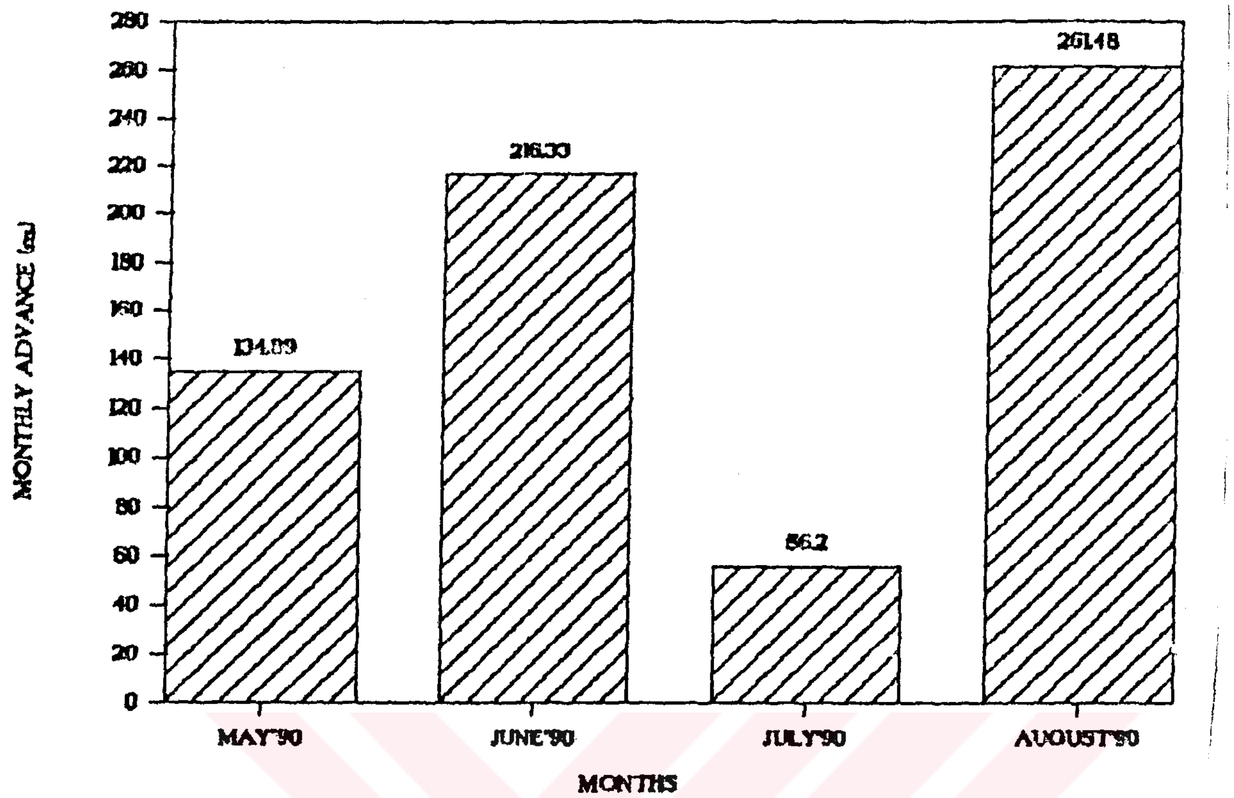


Figure 6.3.2 Monthly Advance In Buyukada Formation

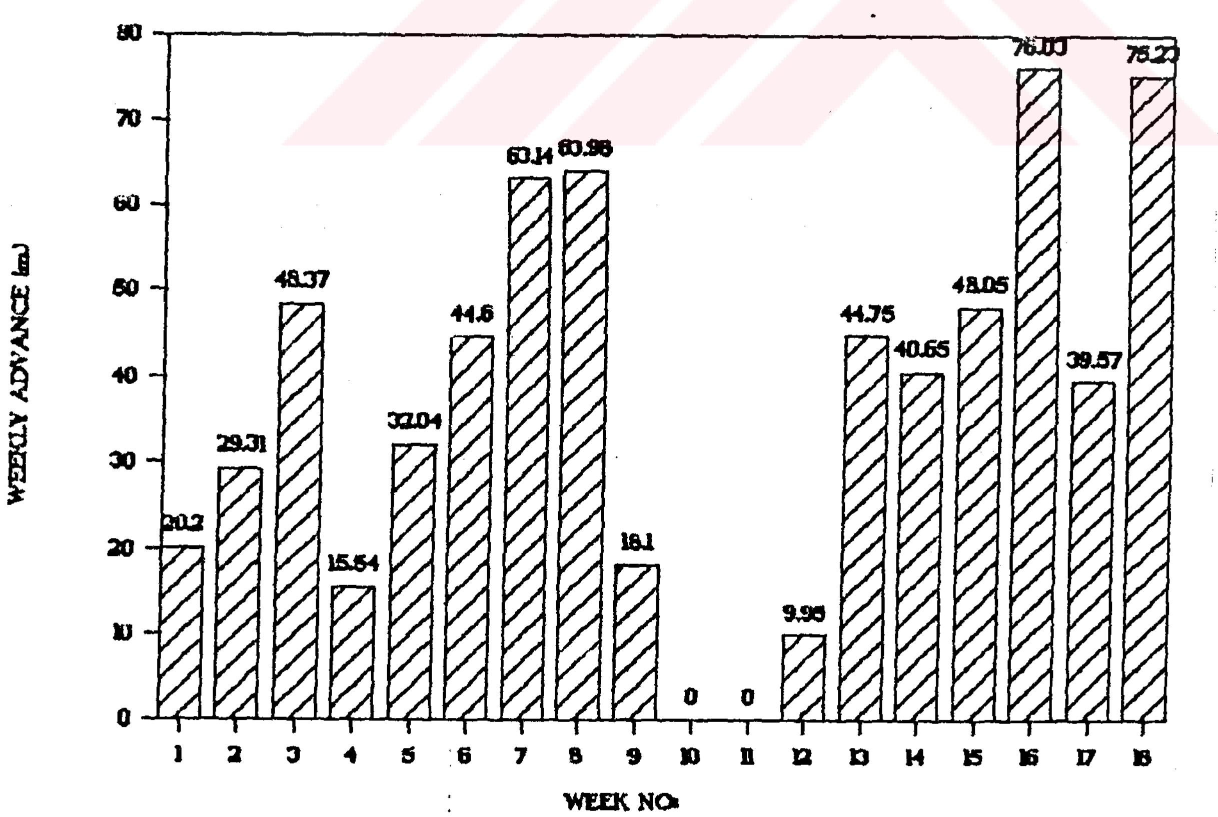


Figure 6.3.3 Weekly Advance In Buyukada Formation

6.4 Excavation Performance in Trakya formation.

Excavation Performance for this formation is given in appendix 2. It includes data between chainge 0+780 and 1+355. Overall performance is as follows

Machine Utilization	%7.40
Machine downtime	%92.60
Net cutting rate	1.70 m/h
Progres rate	0.13 m/h
Average shift advance	1.24 m/shift
Best shift advance	9.57 m/shift
Lowest shift advance	0.20 m/shift
Average daily advance	3.12 m/day
Best daily advance	16.5 m/day
Lowest daily advance	0.50 m/day
Average weekly advance	21.0 m/day
Best weekly advance	66.0 m/week
Lowest weekly advance	1.90 m/week
Average monthly advance	84.0 m/week
Best monthly advance	177.65 m/month
Lowest monthly advance	17.33 m/month
Total advance in Trakya Formation	586.24 m/month

<u>Machine downtime</u>

Support	%44.58
Ground condition	%29.39
Mucking and waiting for wagons	%4.34
Electrical breakdown	%1.39
Mechanical breakdown	%3.00
Belt conveyor failure	%1.75
Disc changing	%0.80
Disc control	%0.17
Maintenance	%0.58
Crane failure	%0.25
Ventilation failure	%0.52
Others	%5.83
Total	%92.60

Graphical evaluation for Trakya Formation is as in the figure 6.4.1,6.4.2, and 6.4.3

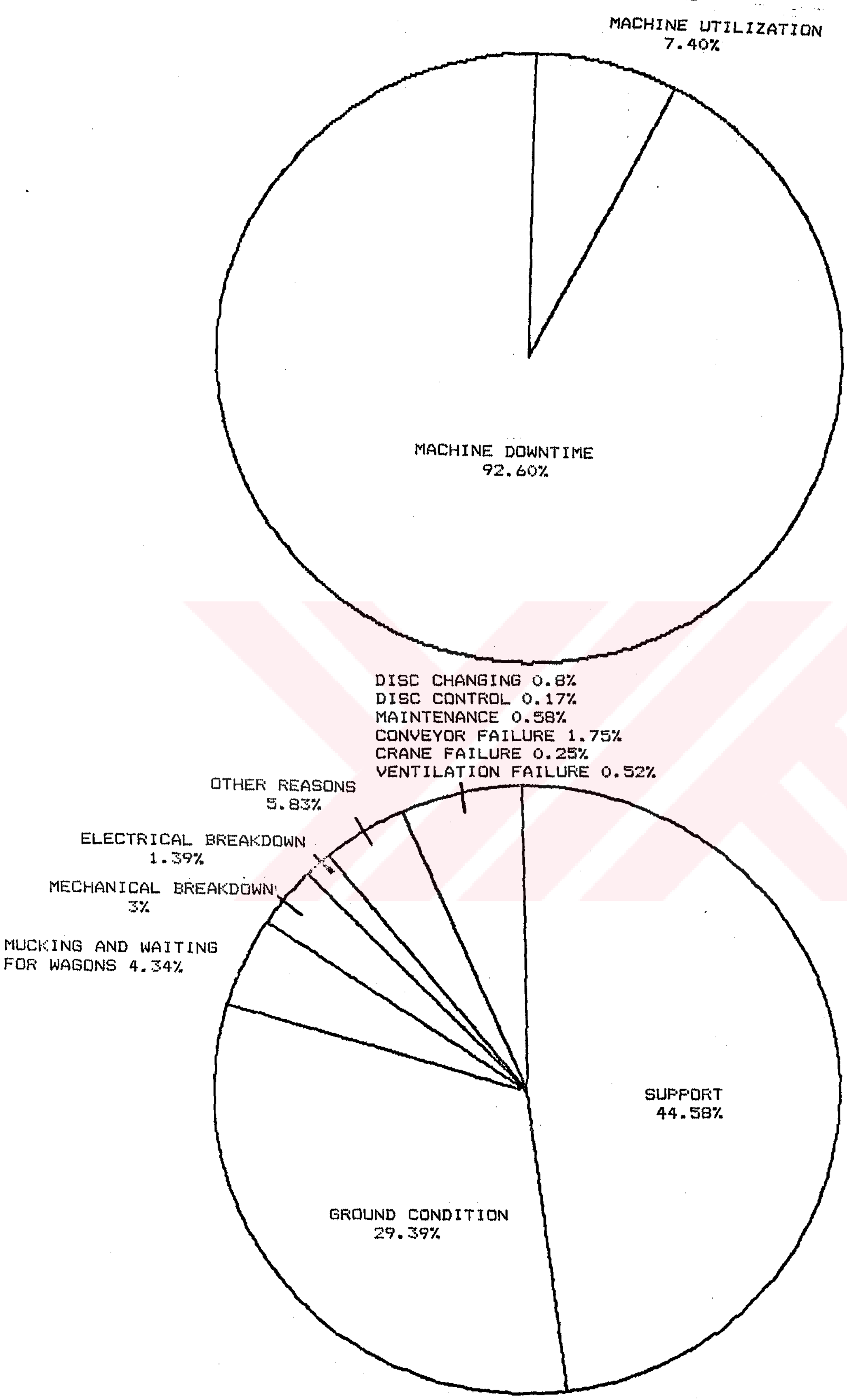


Figure 6.4.1 The Percentage Of The Breakdowns In Trakya Formation

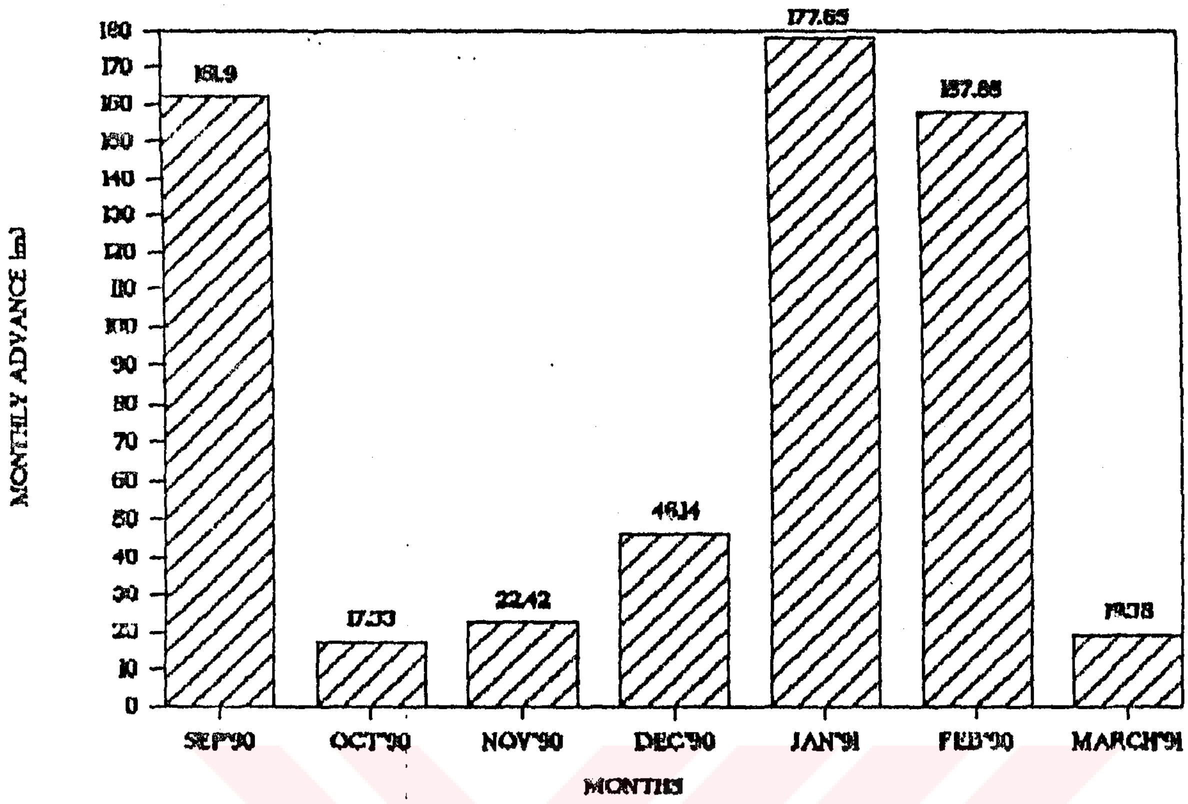


Figure 6.4.2 Monthly Advance In Trakya Formation

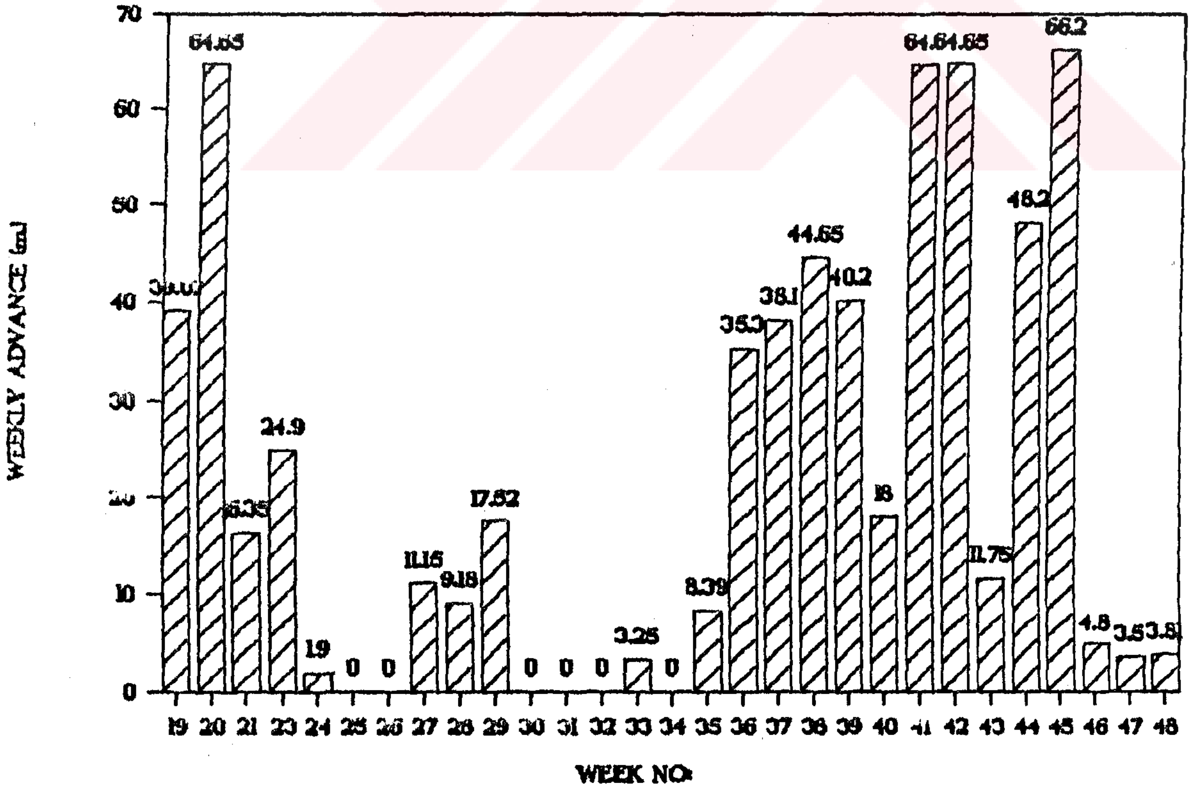


Figure 6.4.3 Weekly Advane In Trakya Formation

6.5 Difficulties Encountered During The Tunnel Progess

6.5.1 General

Excavation with Full-face TBMs is the fastest and most economical way of driving along continuous tunnels through suitable rock, and they have increasingly been used for this reason over recent years. They are now widely used for headrace and water transfer tunnels on major hydroelectric schemes. They are also popular for large sewerage and waste water schemes in many countries.

The essential factors determining the succesful use of TBMs are the capital investment justified by the length of tunnel and suitabality of the ground conditions expected through the tunnel. Derivage by TBMs are quicker and jobs can be finished sooner, so they generally provide tunnels at a lower cost per metre. They do suffer from the drawback of inflexibility if the tunnel unexpectedly runs into faults, soft ground or very bad rock conditions. Many TBMs have become stuck and been lost in this bad situation.

In fairly good to good rock conditions, TBMs cause less stability problems than drill-blast method. Considerable savings on provisional and definite lining are possible. However, in rocks of poor stability, the aplication of ordinary TBMs may lead to a complate fiasco because the excavation is not flexible enough to be adapted to such rock conditions. Therefore extensive site investigation and research are necessary and essential for the succesful use of Tunnel Boring Machines.

6.5.2 Difficulties Encountered In Büyükada Formation

As a result of site investigation and drill holes along Baltalimanı Tunnel Route, Büyükada Formation is found to be massive and more stable than Trakya Formation, and consists of limestone,nodular limestone,carboniferous shale (see chapter 4). The TBM used in this part excavated between chainage 0+075-0+780

- **Chainging of disc cutters**

The major problem encountered in this formation is disc failure which took %16.84 of machine downtime as seen in chapter 6.3 . Chainging of disc cutters takes very much time for such machines

There is a passage hole just under the roof supports (figure 6.5.2.1) to pass in front of the cutterhead and check or change disc cutters.(figure 6.5.2.2)

For changing the worn cutters, the machine is first pulled back about 1 or 1.5 m in order to give way to work easily in front of the cutterhead.

The tunnel wall has to be digged with a hand break to take out out gauge disc assemblies. This is compulsory due to the form of the cutterhead. When the rock is very hard, digging a hole to change gauge assemblies can take very much time

Figure 6.5.2.1 Passage Hole To The Face

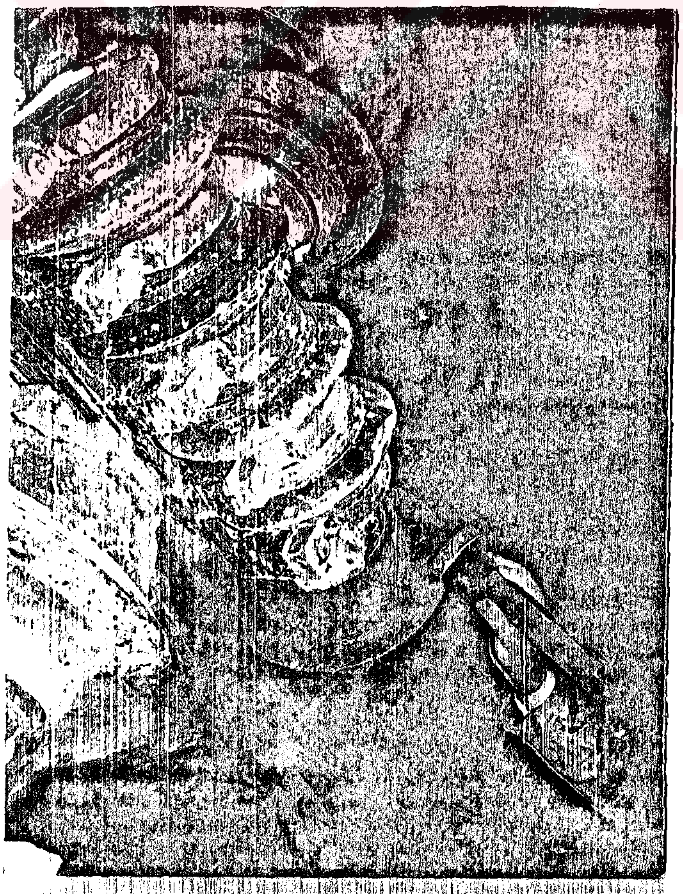


Figure 6.5.2.2 Checking Of Cutters At The Face

Disc assembly is taken out with a little crane on the beam (figure 6.2.3) after unscrewing the assembly from the housing on the cutterhead (figure 6.5.2.4)

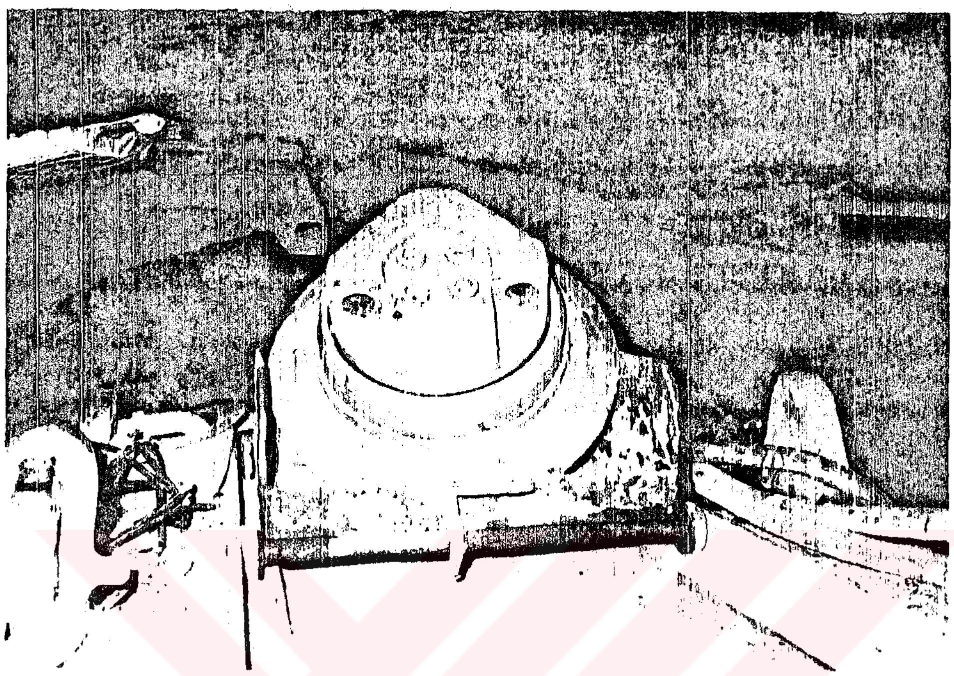


Figure 6.5.2.3 Disc Assembly After The Unscrew

Figure 6.5.2.4 Unscrewing Of The Disc Assembly

This operation is done for each worn disc cutter. Then, assemblies are taken to the workshop for changing worn cutters rings and also if the bearing failure occured.

The changing rig used for worn cutters is seen in figure 6.5.2.5 . For this , disc assembly is put on the rig by a little crane (figure 6.5.2.6) then, as seen in figure 6.5.2.7 load is applied on the assembly to take out worn cutter ring. Job is repeated for each assembly

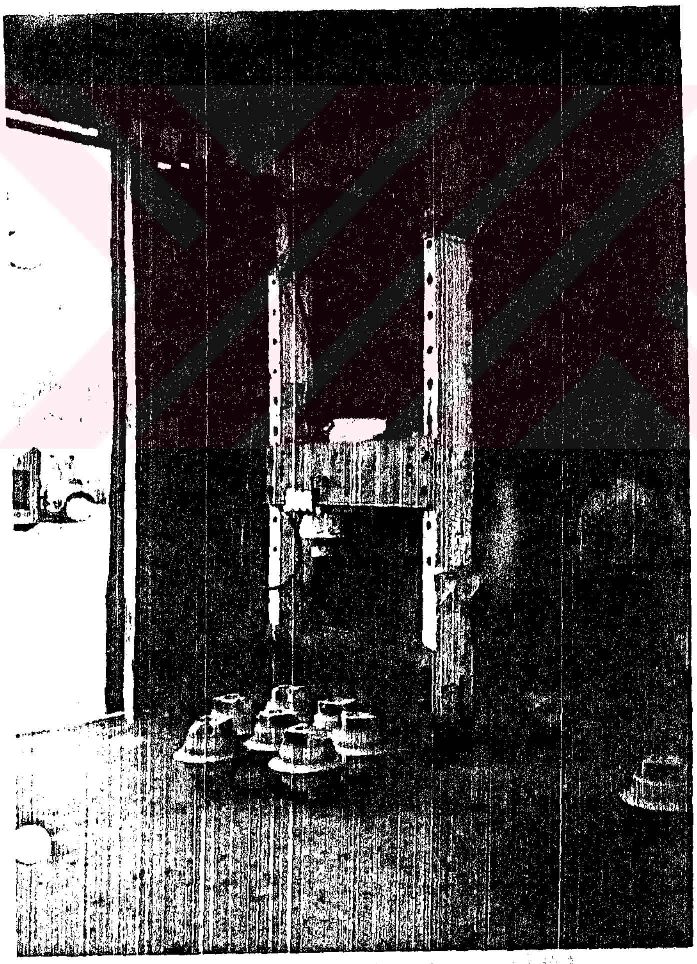


Figure 6.5.2.5 The Rig Being Used For Taking Out Worn Cutter Ring From The Assembly

Figure 6.5.2.6 Putting The Assembly On The Rig

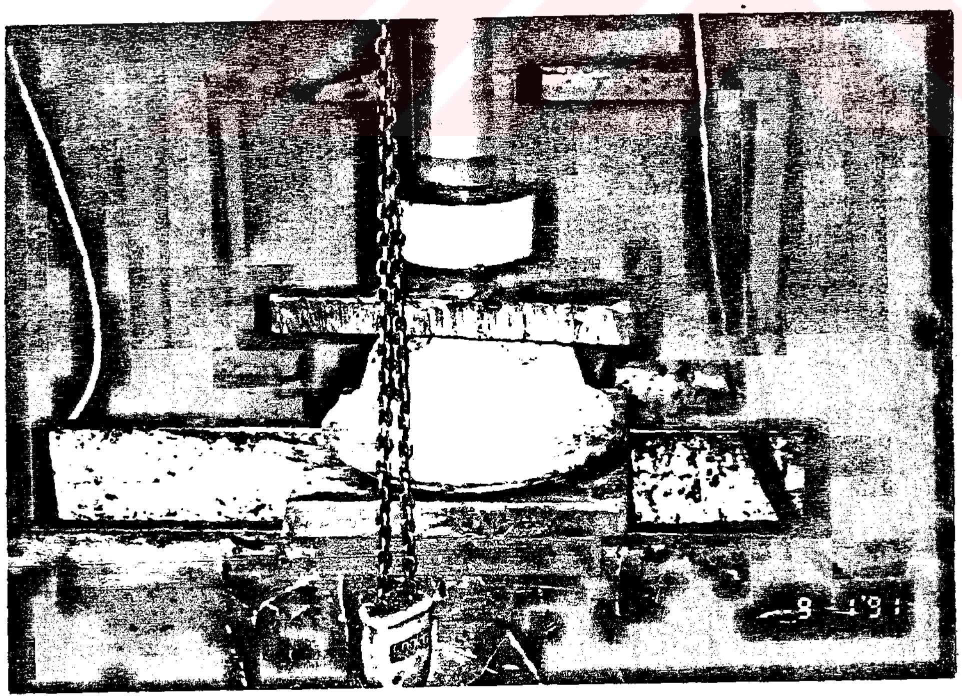


Figure 6.5.2.7 Appliying The Load For Taking Out The Worn Cutter

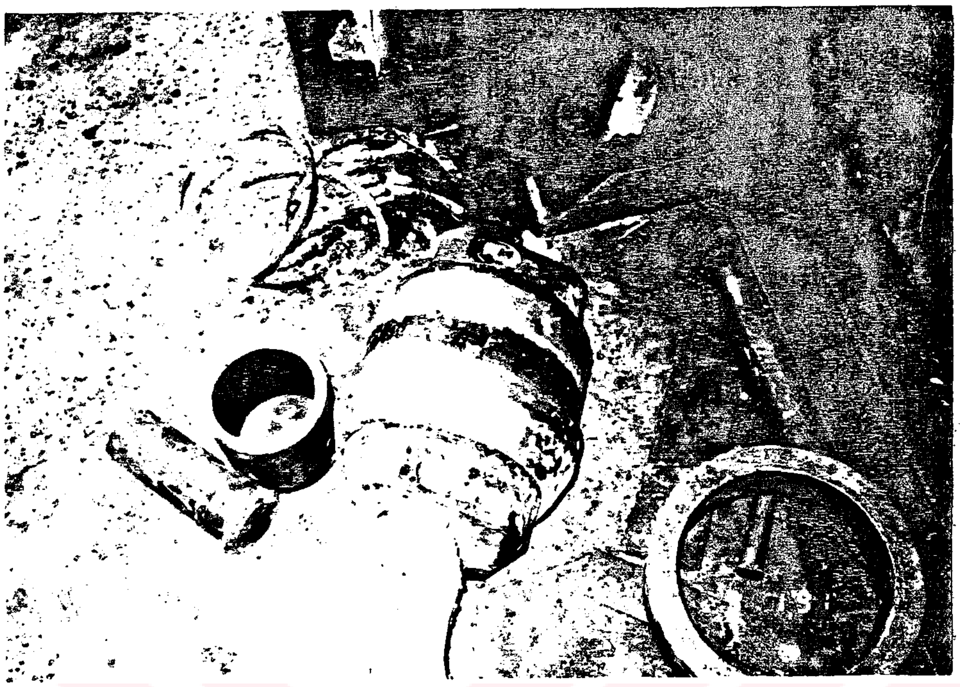


Figure 6.5.2.8 The Hub After Taken Out The Worn Cutter Ring

An extra work has to be done to fix again new cutter rings on the assemblies, this is as follows.(figure 6.5.2.9)

Cutter ring is heated in an oven at 270°-300°C for 2-4 hours or in an oil bath for 20 minutes at 180°-200°. Before installation of cutter ring, burrs and foreign particles are cleaned from hub's cutter retainer shoulder (figure 6.5.2.9 A). Hub assembly is placed on a tool as seen in figure 6.5.2.9 A , then heated cutter ring is dropped over the hub (figure 6.5.2.9 B) , it must be assured the full seating of cutter ring on hub's cutter retainer shoulder (figure 6.5.2.9 C) . If cutter ring does not seat adequately to hub shoulder, a force ring is used to make cutter ring to seat properly (figure 6.5.2.9 A) . After this, the halves of split ring is

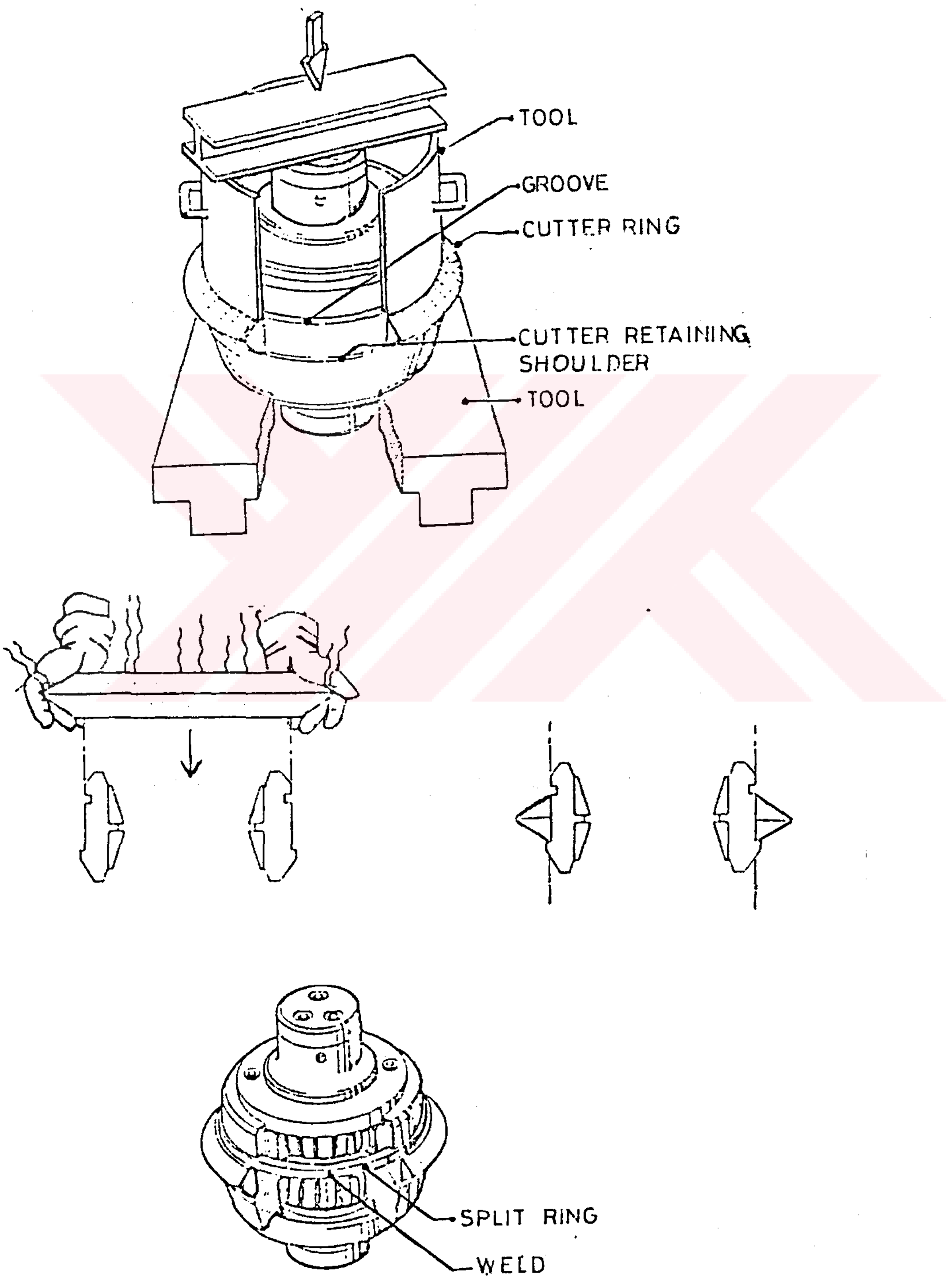


Figure 6.5.2.9 Fixing Of A New Cutter Ring To The Hub

affixed into the groove as seen in figure 6.5.2.9 A and 6.5.2.9 D, and welded at its adjoining ends. So, disc assembly is again ready to use. This is done for each assembly and then, all new assemblies are taken back to the tunnel for installing on the cutterhead.

In figure 6.5.2.10, new cutter rings and figure 6.5.2.11 cutter rings after the usage are given

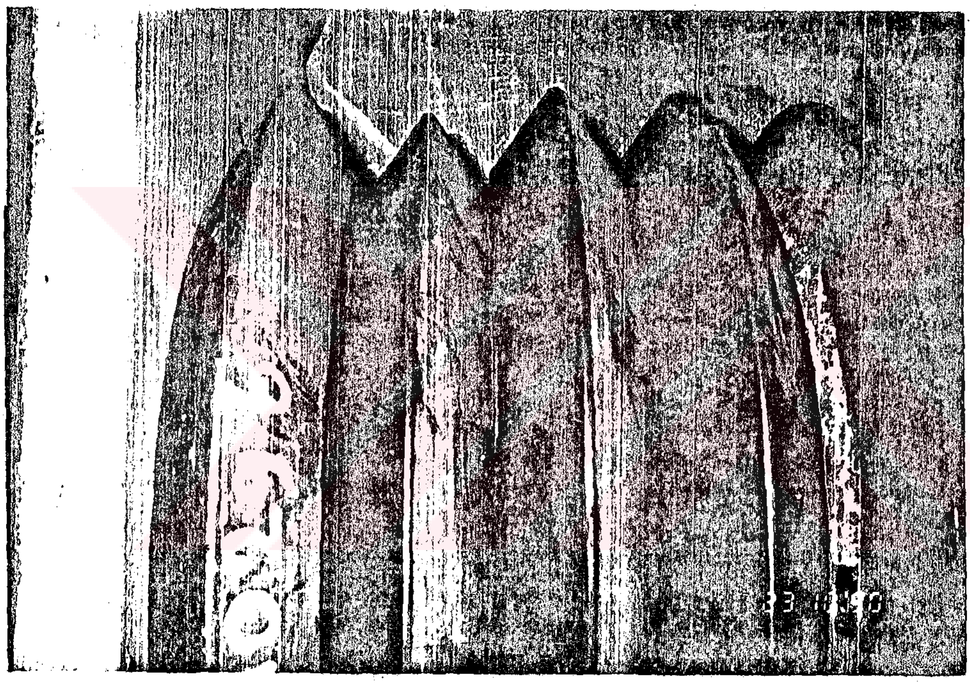


Figure 6.5.2.10 Disc Cutters Before The Usage

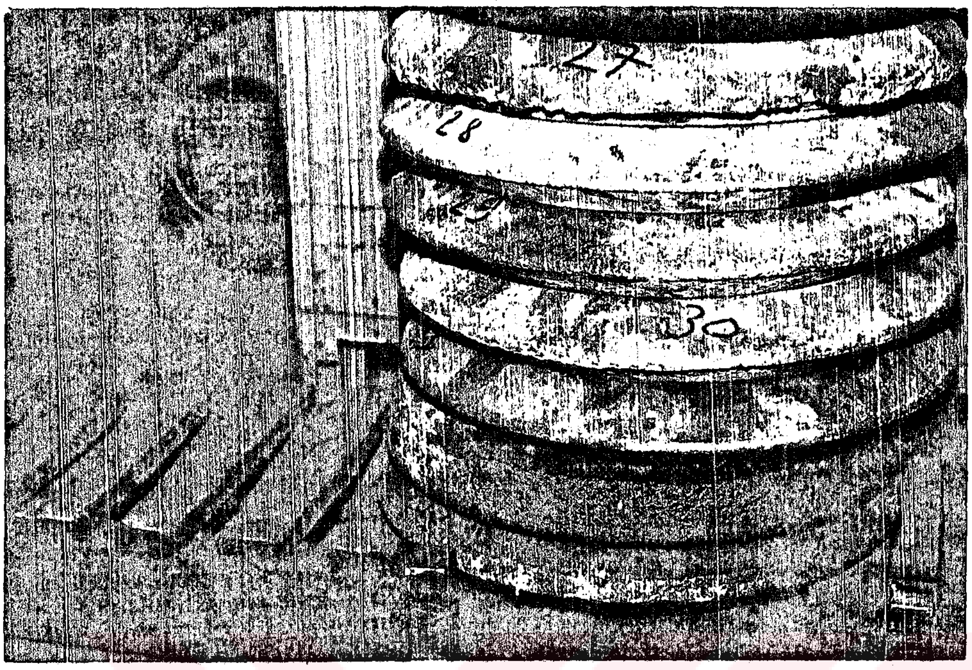


Figure 6.5.2.11 Disc Cutters After The Usage

- Bearing Failure

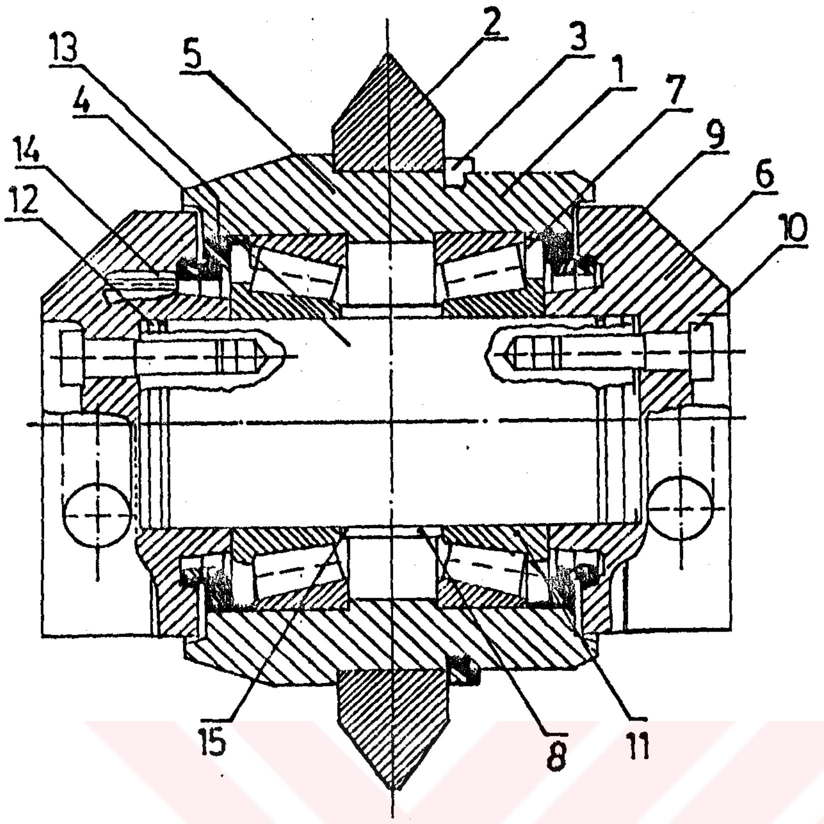
If a bearing failure happens, both cutter ring and bearing has to be changed. Betwwen chainage 0+075.70 and 0+090, all cutters and some bearings were changed due to bearing failure.

At first bearing failure (after and advance of 17 m. from chainage 0+075.70), it was found that installation and bearing tolerance were wrong. So, modification of these was decided and all disc assemblies were taken out for modification.

First problem is involved with 15.5" dia. disc cutter. As seen in figure 6.5.2.12, the part touching the bearing of cover (no: 6) was turned on lathe as 10 mm., a plate was placed between cover and bearing housing in order to distribute the load coming to the bearing (figure 6.5.2.13) Besides, the tolerance was reduced. For twin disc assemblies, only the bearing tolerance was changed (figure 6.5.2.14)

All assemblies were reinstalled, and excavation restarted. In the meantime, disc cutters were often checked. After an anvance of 1.5 m., it was found that some cutters overheated and bearing failure happened again. All cutters were taken out once more for another modification.

After the second modification, excavation was again started, cutters were being controlled at certain intervals. From time to time, bearing failure occured. So, it was found that, two modification made before were not sufficient. For this reason, it was decided to use a new design disc cutter assembly as seen in figure 6.5.2.15 and 6.5.2.16.



Roller cutter 15 1/2"

item	ordering no	piece	Description	weight
00	20601036	1	ROLLER CUTTER 15 1/2"	120.00
01	20601035	1	BEARING COOPLETE	103.00
02	20601028	1	CUTTING RING 15 1/2"	16.00
03	20601034	1	RETAINING RING	1.00
04	20601030	1	AXLE	17.00
05	20601031	1	BEARING BUSH	38.00
06	20601027	2	COVER(WITH SET SCREX 65646914)	14.00
07	20601032	2	ADAPTER RING	1.00
08	20601033	1	SPACER RING	
09	58110833	2	SLIDE RING GASKET	0.50
10	02149253	8	HEAD CAP SCREW SW17 MT 396Na	0.20
11	69792100	2	TAPER ROLLER BEARING	7.10
12	74732101	2	O RING	
13	74732904	2	O RING	
14	65646914	2	SET SCREW	
15	63997973	1	SHIN RING	

Figure 6.5.2.12 First Design Of 15.5" dia. Disc Assembly

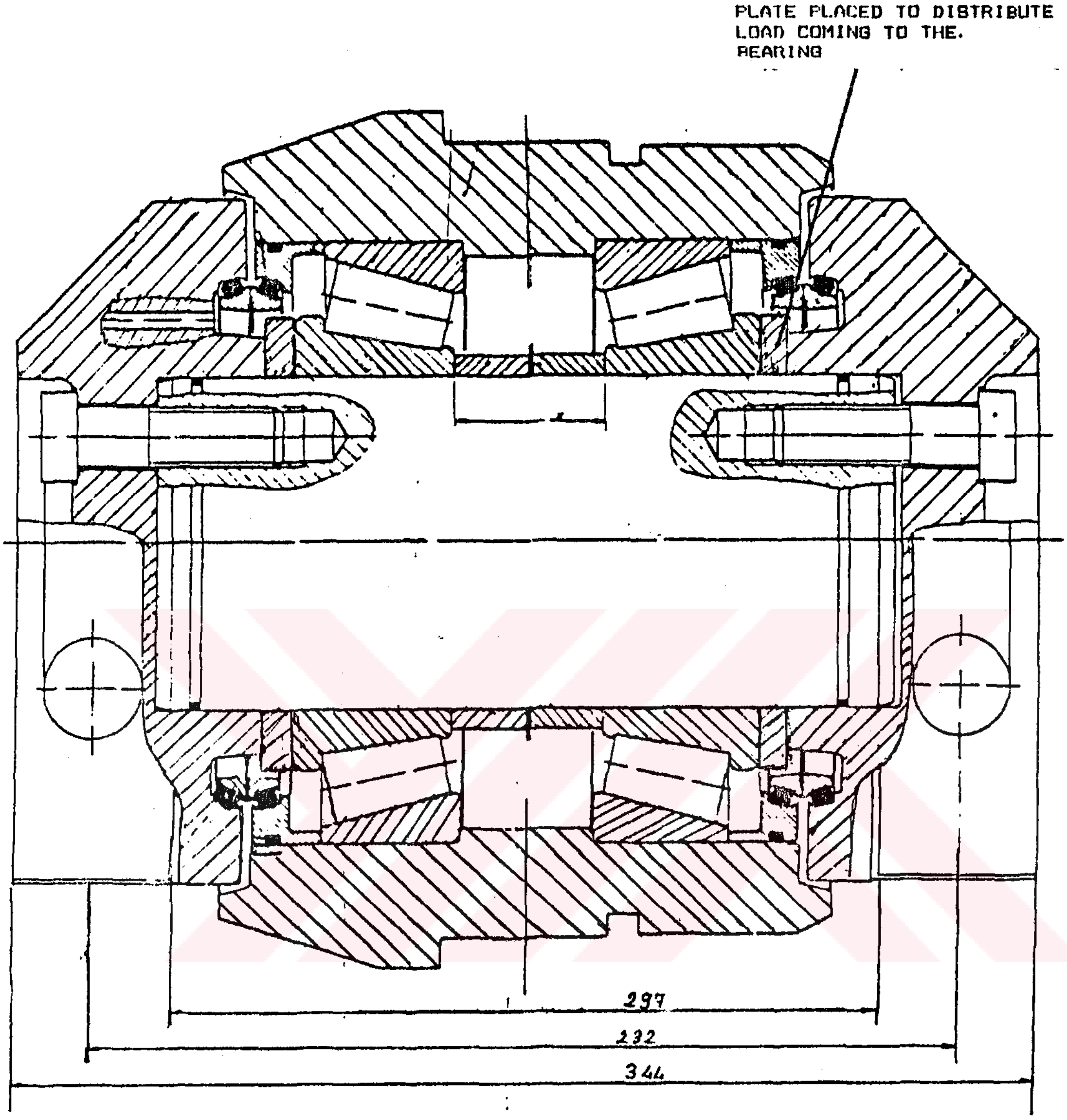
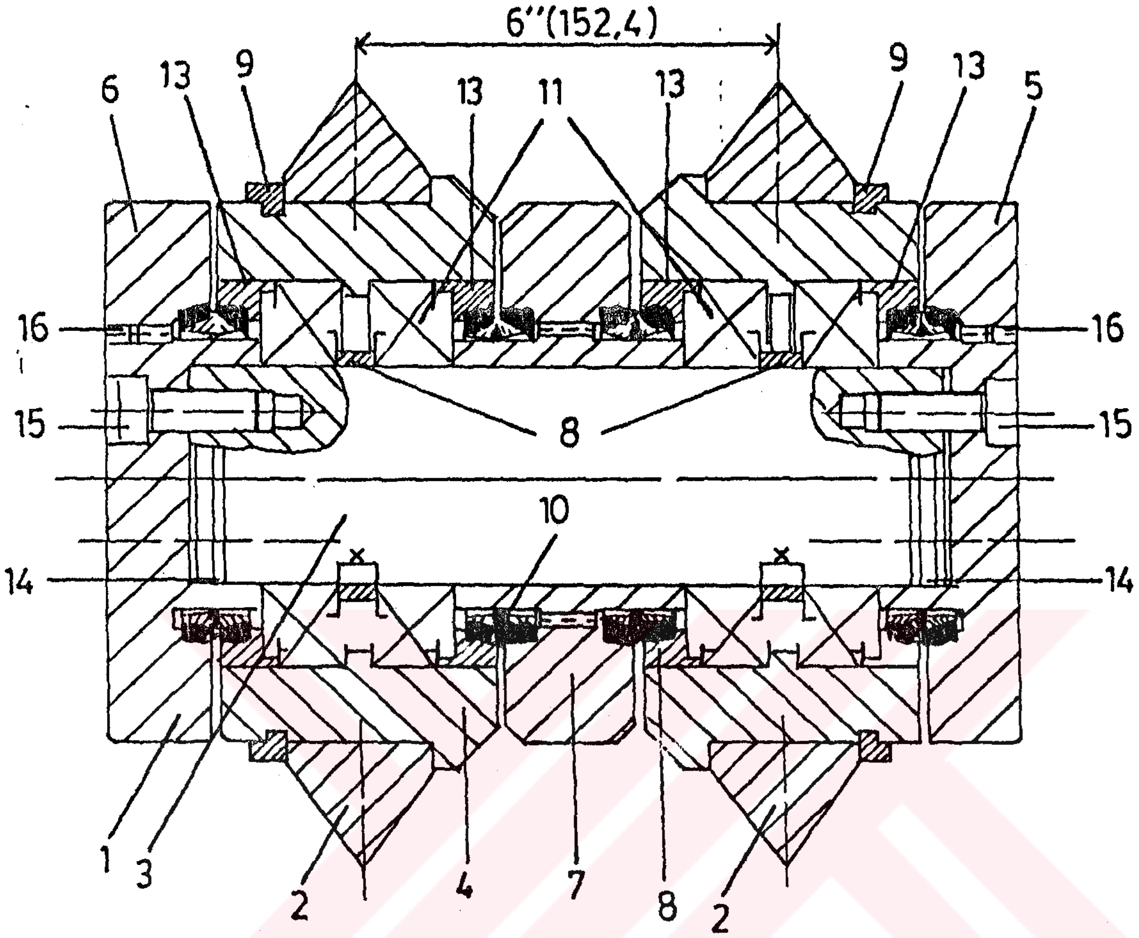
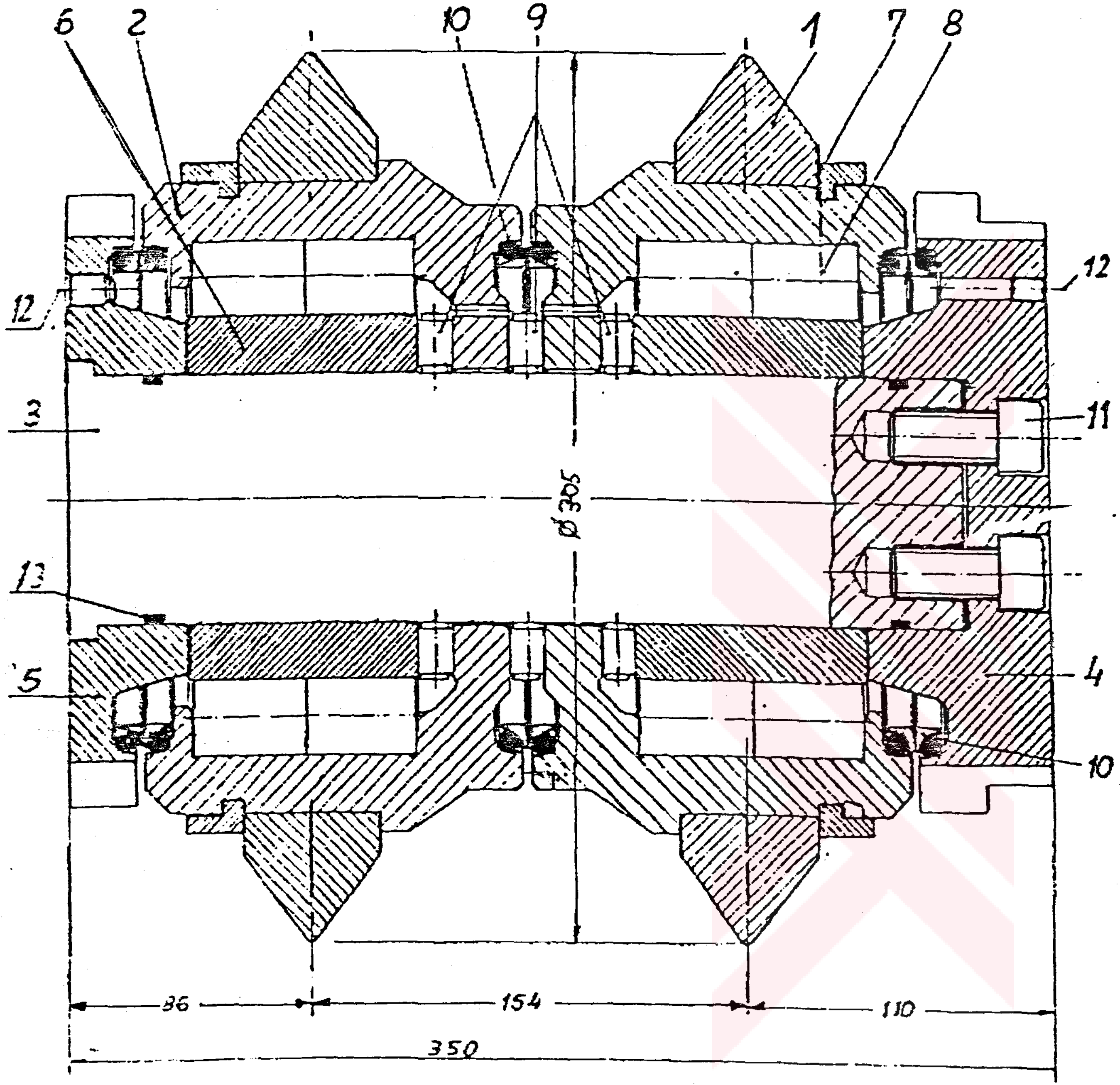


Figure 6.5.2.13 Disc Cutter With 15.5" dia. After The First Modification



ite	ordering no	piece ..	Description	weight
00	20601055	1	CENTRE CUTTER	102.00
01	20601015	1	BEARING COAPLETE	83.00
02	20600186	2	CUTTING RING 12"	9.50
03	20601041	1	AXLE	12.00
04	20601040	2	BEARING BUSH	14.00
05	20601050	1	COVER (WITH SET SCREW 65646914)	8.50
06	20601049	1	COVER (" " " ")	9.50
07	20601045	1	SPACER RING	1.00
08	20601043	4	ADAPTER RING	0.70
09	20600187	2	RETAINING RING	0.60
10	20601046	2	SPACER RING	0.20
11	00012745	4	TAPER ROLLER BEARING	2.05

Figure 6.5.2.14 First Design Of Twin Disc Assembly



ITEM	PIECE NO:	DESCRIPTION
00	1	BREARING RING
01	2	CUTTING RING
02	2	BEARING BUSH
03	1	AXLE
04	1	COVER
05	1	COVER
06	2	BEARING RING
07	2	RETAINING RING
08	72	CLYNDER ROLLER
09	3	AXIAL BEARING
10	6	SLIDE RING GASKET
11	4	HEAD CAP SCREW
12	2	SET SCREW
13	2	O-RING

6.5.2.15 New Design For Twin Disc Assembly

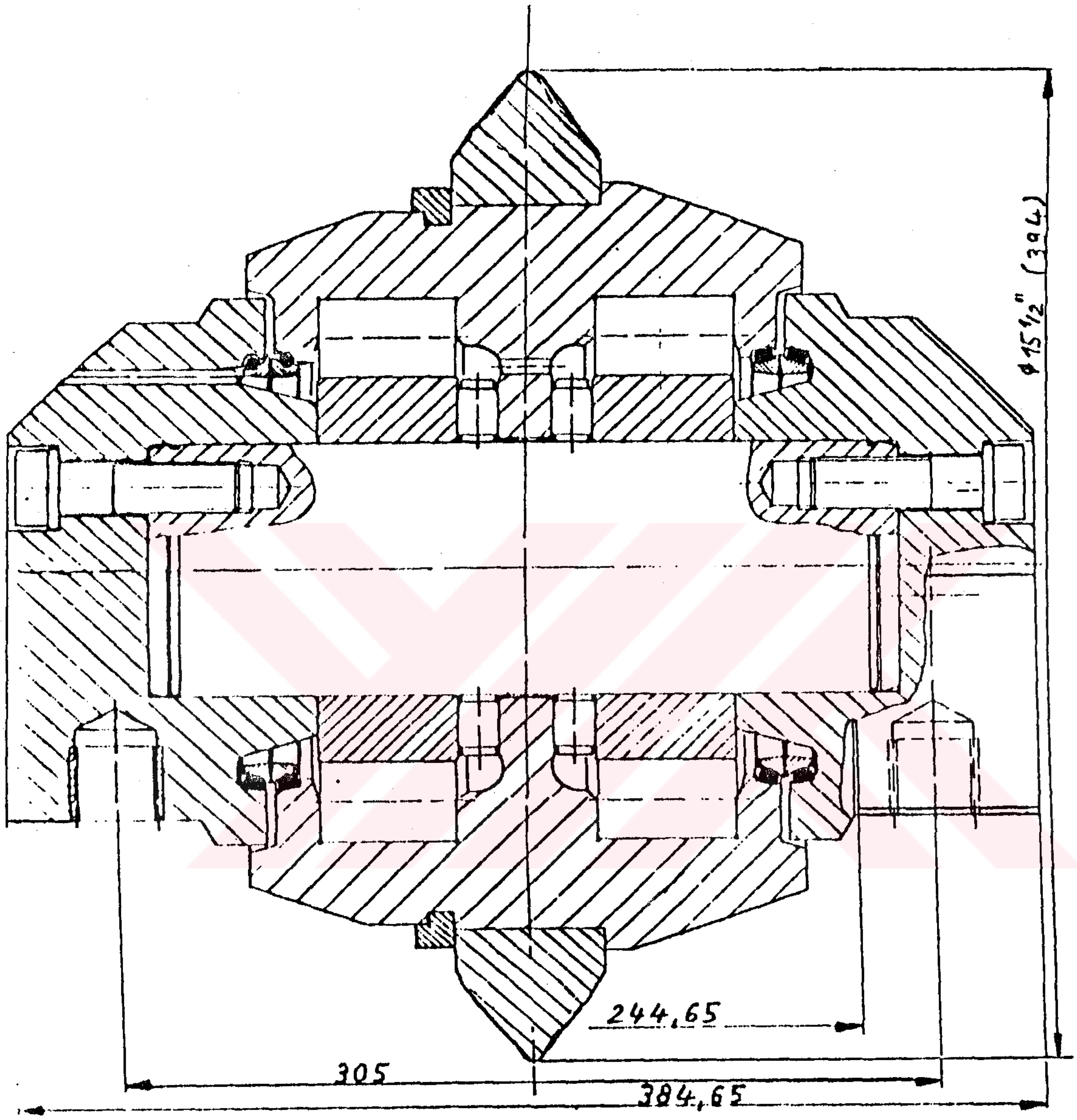
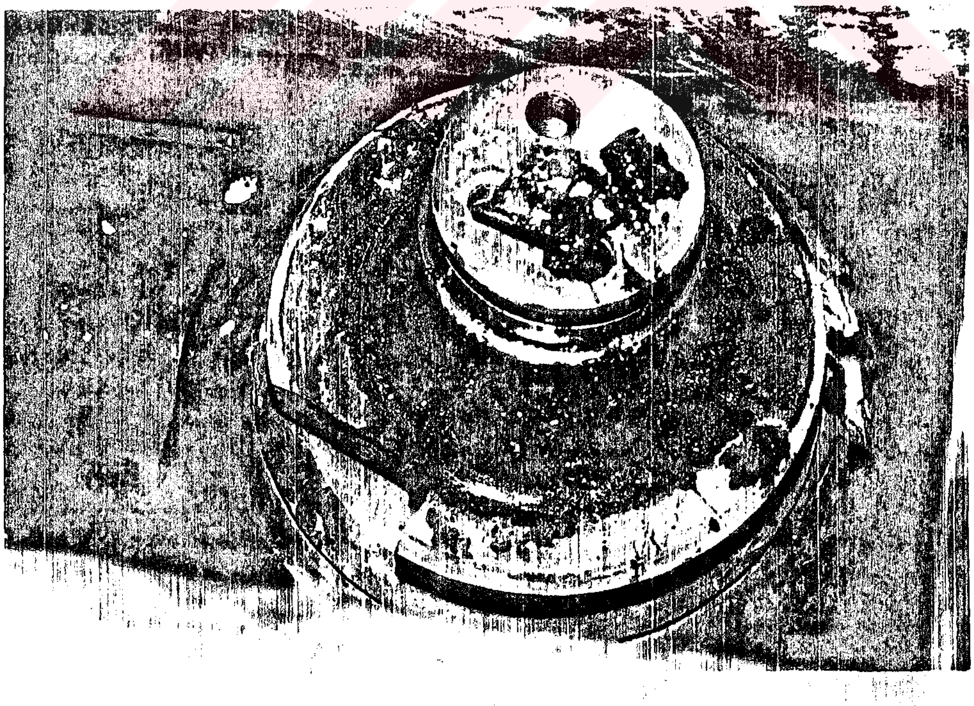


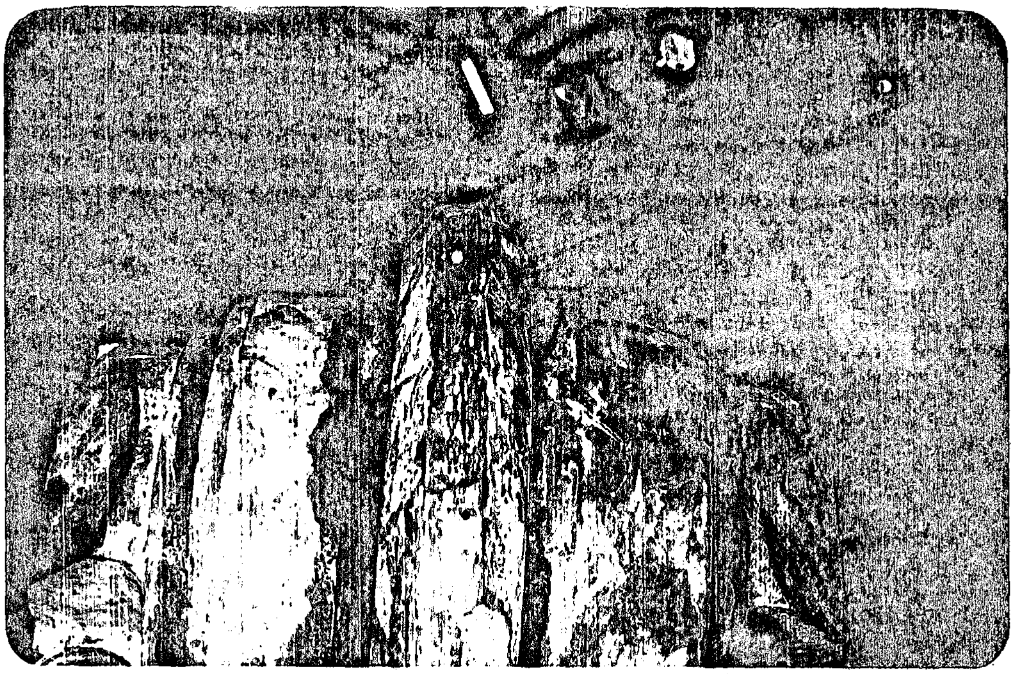
Figure 6.5.2.16 New Design For 15.5" dia. Disc Cutter Assembly

(A)

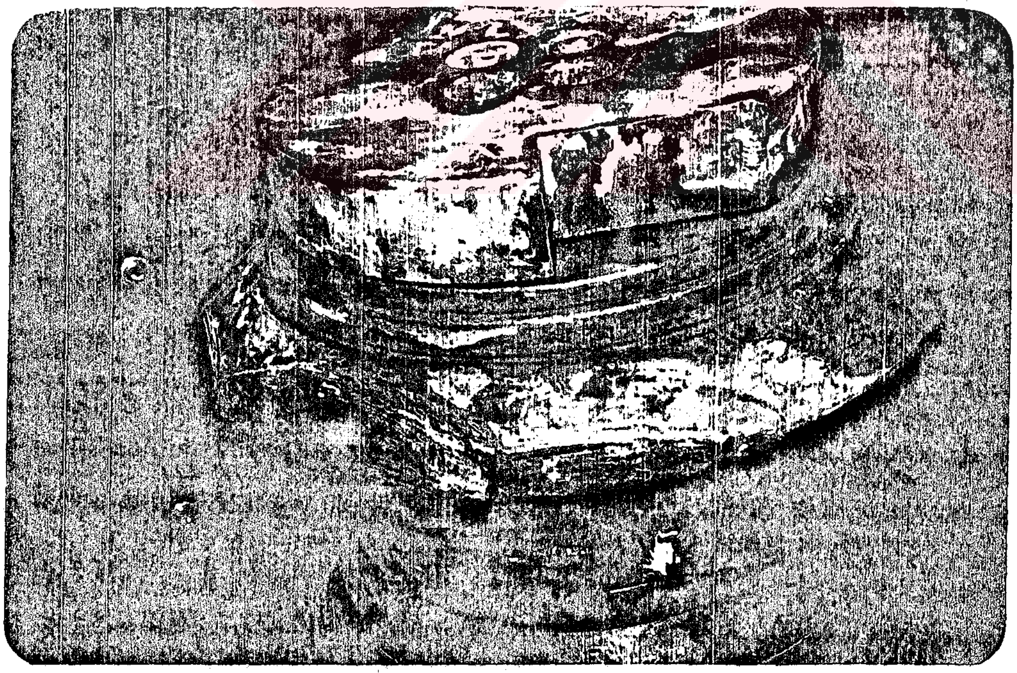


(B)

Figure 6.5.2.17 Bearing Failure

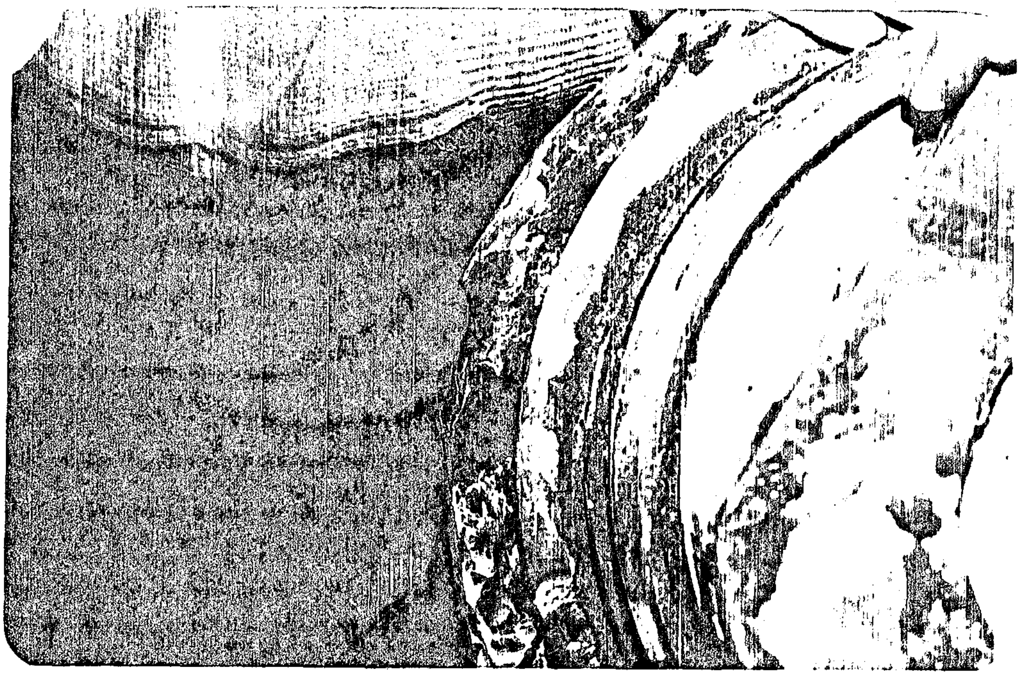


(A)



(B)

Figure 6.5.2.18 Wearing Of Disc Cutters Due To Bearing Failure



(A)

(B)

Figure 6.5.2.19 Wearing And Breaking Of Disc Cutters Due To Bearing Failure

■ Support Installation

The other problem was support installation in faulted or crushed zones in front of the gripper pads. Steel arch+wiremesh+shotcrete and sometimes rock bolt were used as support elements if they are necessary.

As seen in chapter 6.3, support installation took %14.4 of machine downtime. If steel arches were installed behind gripper pads, there was no problem while gripping onto the tunnel walls for advance. But, only the excavation had to be stopped at every 1.2 m. of progress for supporting (figure 6.5.2.20). However, it was also necessary to support in front of the gripper pads due to bad ground conditions. While gripping onto the tunnel walls(on the steel aiches installed) Consequently, the pads caused deformation of steel arches or cracks the shotcrete. Especially in crushed zones, when the pads are pressed against the tunnel walls, overbreaks occured in the places where the gripper pads were gripped.

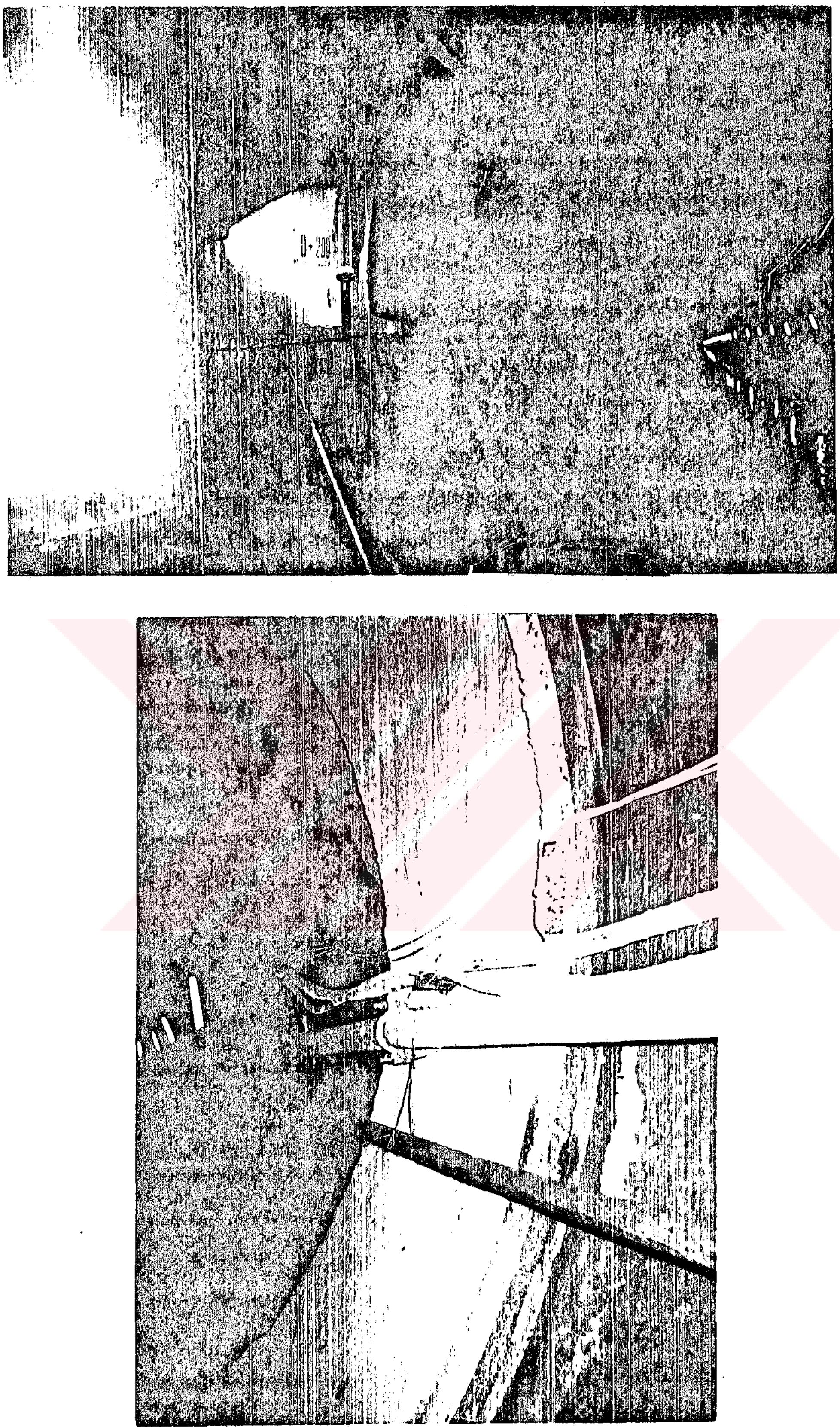


Figure 6.5.2.20 Supporting In Büyükada Formation
(steel arch+wiremesh+shotcrete)

- Mucking And Waiting For Wagons

As seen in chapter 6.3, this delay took %14.47 of machine downtime. Because, back-up system of the machine and speed of crane were not sufficient for keeping up with daily advance. When the machine works without failure or any breakdown, max. daily advance can reach to 20 m. In this stuation, mucking and waiting for wagons took %60-70 of machine downtime. In conclusion, one can say easily that this delay caused machine performance and daily advance rate to decrease to unacceptable levels.

6.5.3 Difficulties Encountered In Trakya Formation

Trakya Formation consists of greywacke, shale-siltsone, mudstone and is closely jointed, locally strongly folded and faulted

The biggest and most important problem encountered through this formation are support installation in front of the gripper pads, overbreaks at crown and sidewalls of the tunnel, sometimes collapses especially in crushed and faulted zones.

Overbreaks and collapses occured at different chainages and supporting of this, passing through them caused the excavation performance of the machine to descrease very much. Besides, pressing on the steel arch+shotcrete by the gripper pads caused another big problem,when clay band exist.

Supporting of the caverns at crown and sidewalls plus supporting by steel arche+wiremwsh+shotcrete took %74 of machine downtime during the excavation through Trakya Formation

■ Support Installation In Front Of The Gripper Pads

When support were installed in front of the gripper pads some problems faced after pressing the pads as in Büyükada Formation. Gripper pistons apply very much load to the tunnel walls as seen in table 6.5.3.1. For this reason they caused deformation of support system (figure 6.5.3.1) and cracks on shotcrete cover (figure 6.5.3.2)

Table 6.5.3.1 Load Applied By The Gripper Pistons

gripper pressure(bar)	load (ton)
200	684
220	752
240	821
260	889
280	957
300	1026
320	1094

When encountered with highly crushed zones or clay band, the pads entered into the sidewalls due to weak ground conditions (figure 6.5.3.1. A). Sometimes, this caused the break of the shaft of the gripper piston, and changing of it could take almost 24 hours.

In order to distribute the load coming to the sidewalls, wooden blocks were placed between pads and support system (figure 6.5.3.3). Another problem caused by the pads was the overbreak on the sidewalls (figure 6.5.3.4), shotcreting was generally made in such places for stabilization.

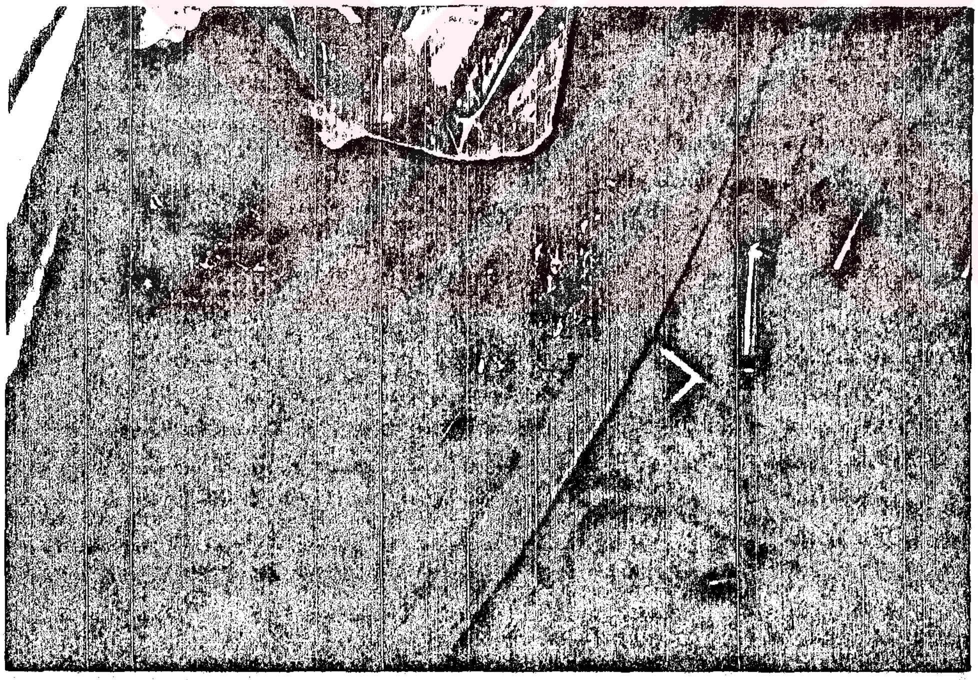


Figure 6.5.3.1 Deformation Of Steel Arches By Gripper Pads

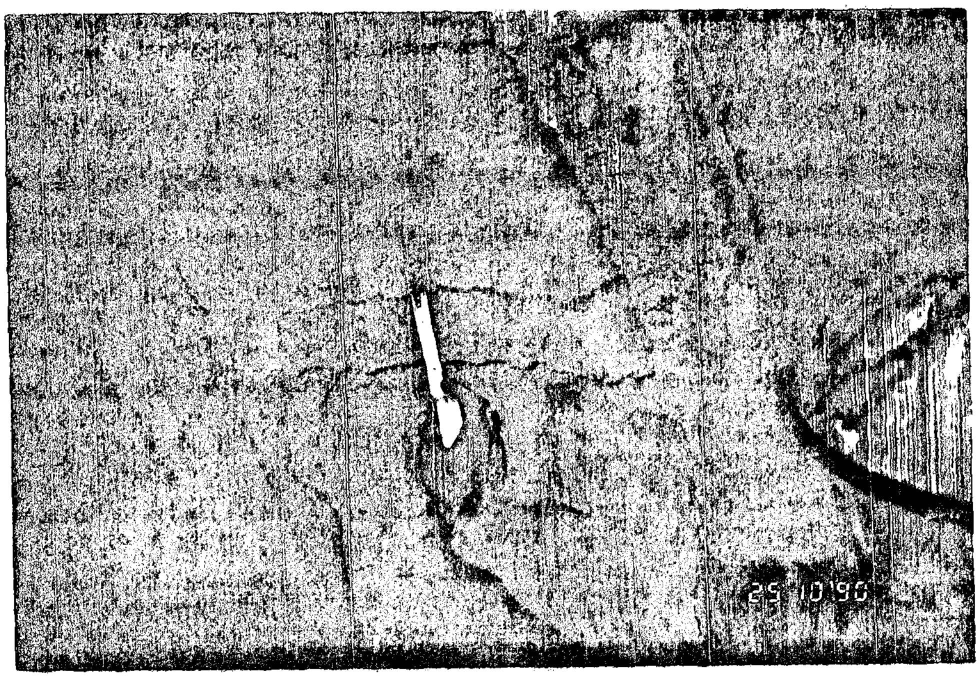


Figure 6.5.3.2 Cracks On Shotcrete Cover Caused By The Gripper Pads

Figure 6.5.3.3 Wooden Blocks Placed Between Grippers And Support System

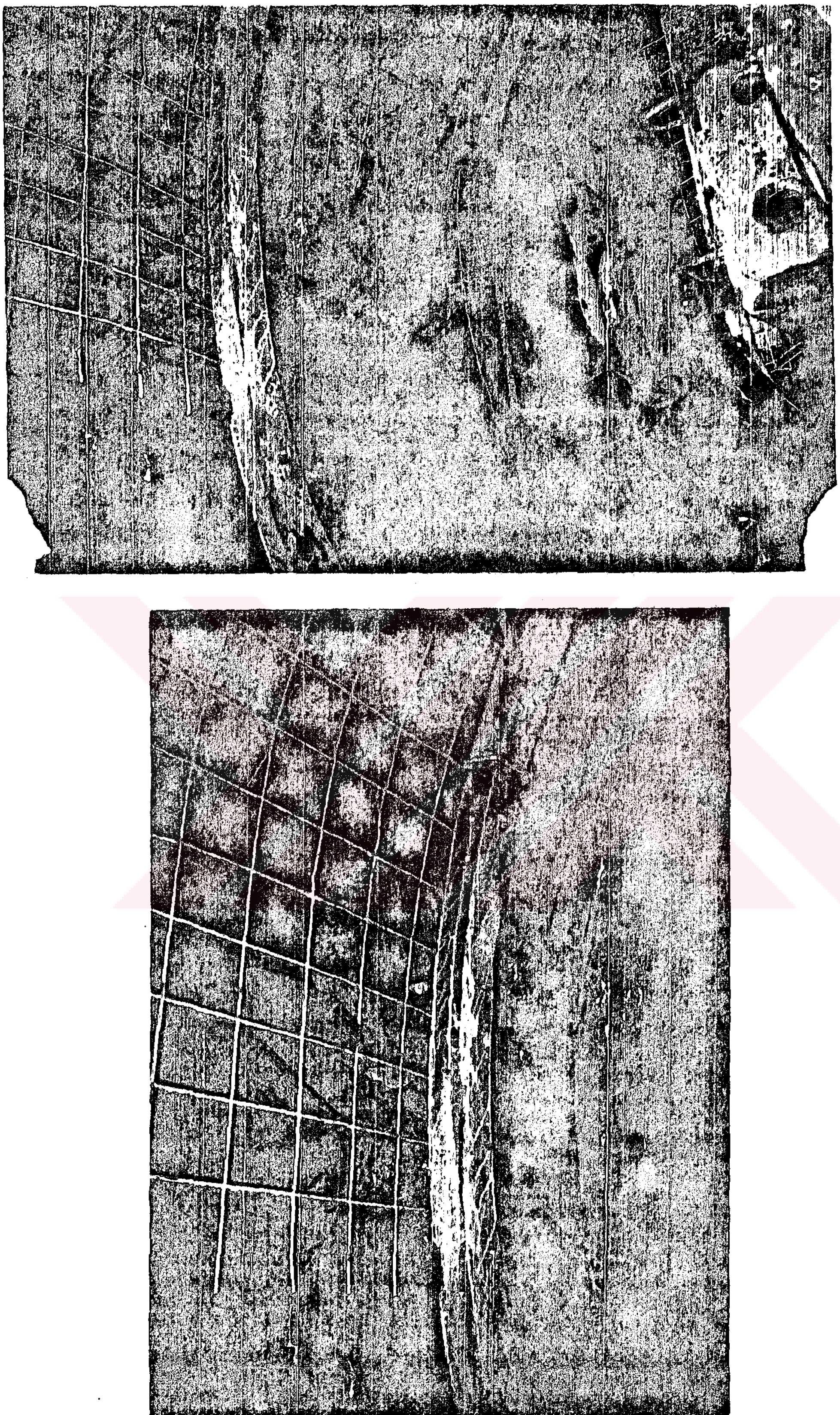


Figure 6.5.3.4 Overbreaks Caused By The Gripper Pads

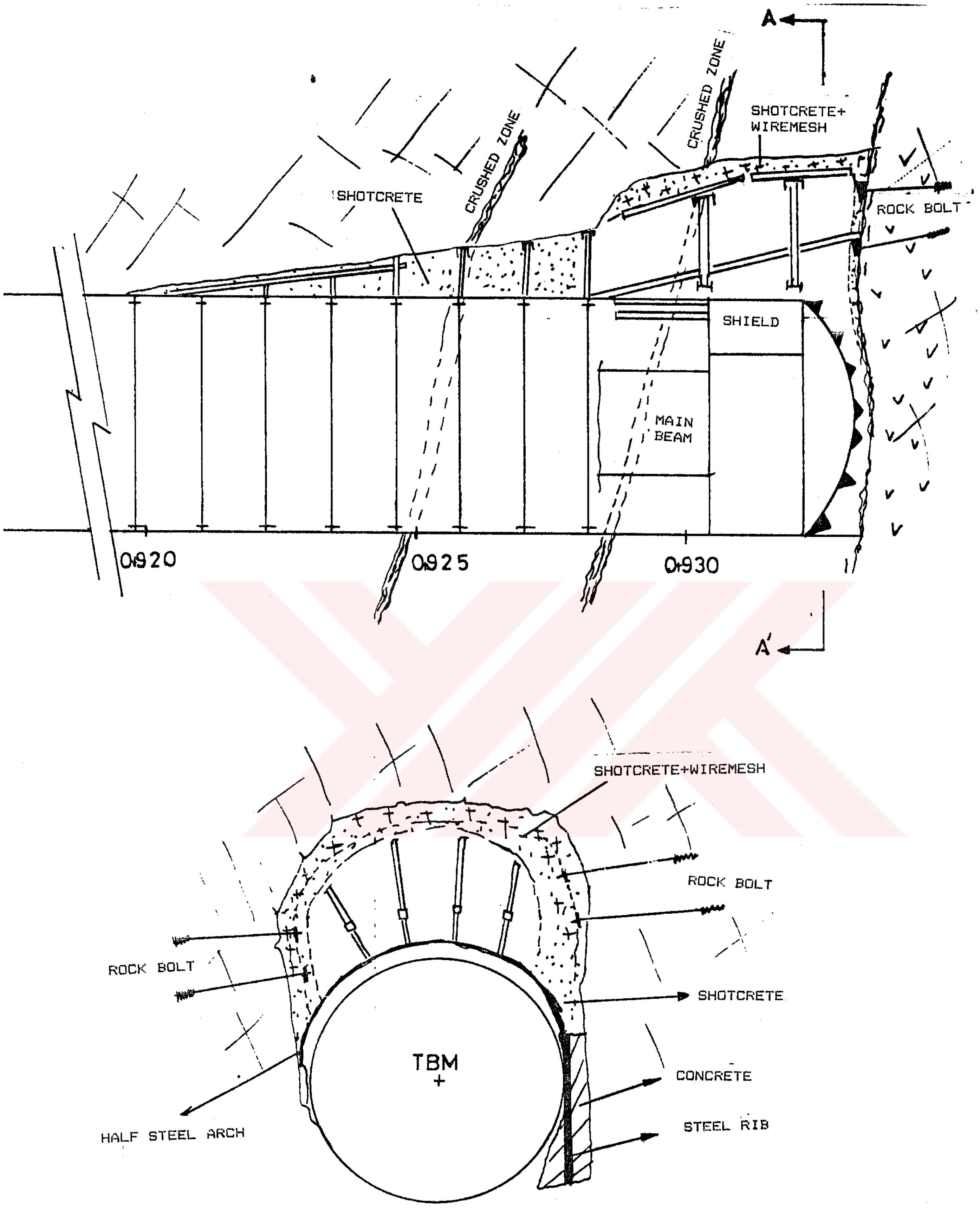
* Collapses

Collapses were the majors problems faced during the excavation through Trakya Formation. A special support system was applied according to the form of caverns in addition to planed support (steel arch+wiremesh+shotcrete)

Collapses took place in different rock conditions, such as, faulted, crushed, fractured or highly alterated zones. Because these collapses took much time to support and to pass, they caused a lower machine downtime. So, they are described in this chapter in detail in terms of their conditions, support system and forms.

Collapse between chainage 0+895-0+935

At the beginning of Trakya Formation. there was no problem in terms of rock conditions. The tunnelling machine (TBM) bored 200 m. without problem. When it is reached the chainage 0+897, especially, on the right shield of the machine, some overbreak started due to highly jointed rock with discontinuties containing clay fill. Geological formation encountered in this section was interbedded highly jointed silstone-mudstone. The collapse between chainage 0+927-0+933 (figure 6.5.3.5), occured in very crushed and fractured zone. Formation is given interbedded siltstone-mudstone, but it is very crushed due to fault zone. It started from right shoulder and enlarged towards the left shield of the machine. Support system used in this collapsed area is described 6.5.3.6 and 6.5.3.7

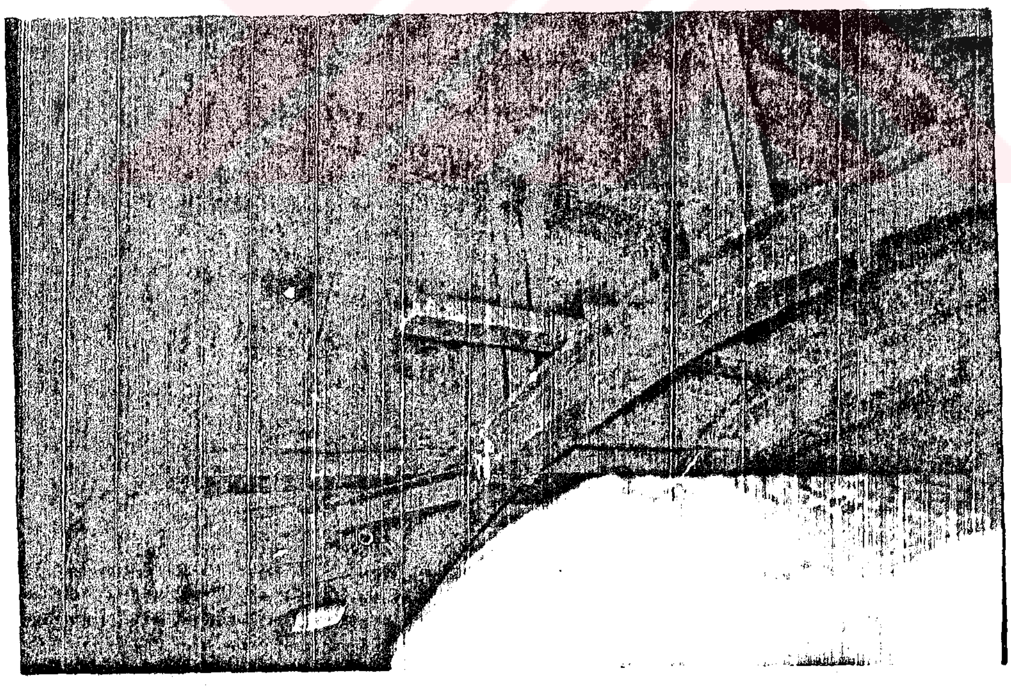


SECTION A-A'

1/100

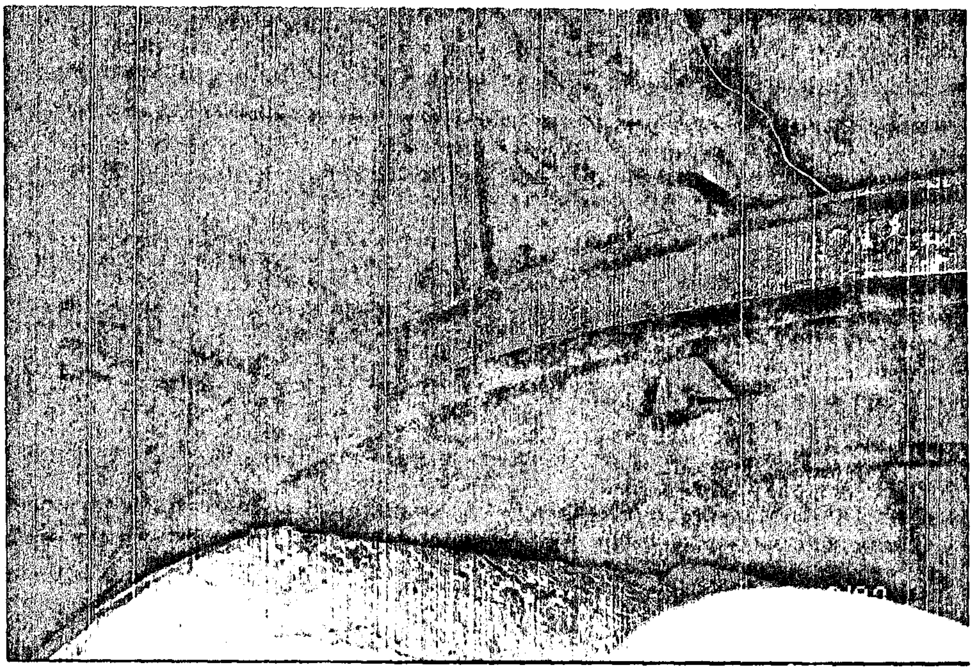
Figure 6.5.3.5 Collapse Between Chainage 0+928-0+935

(A)

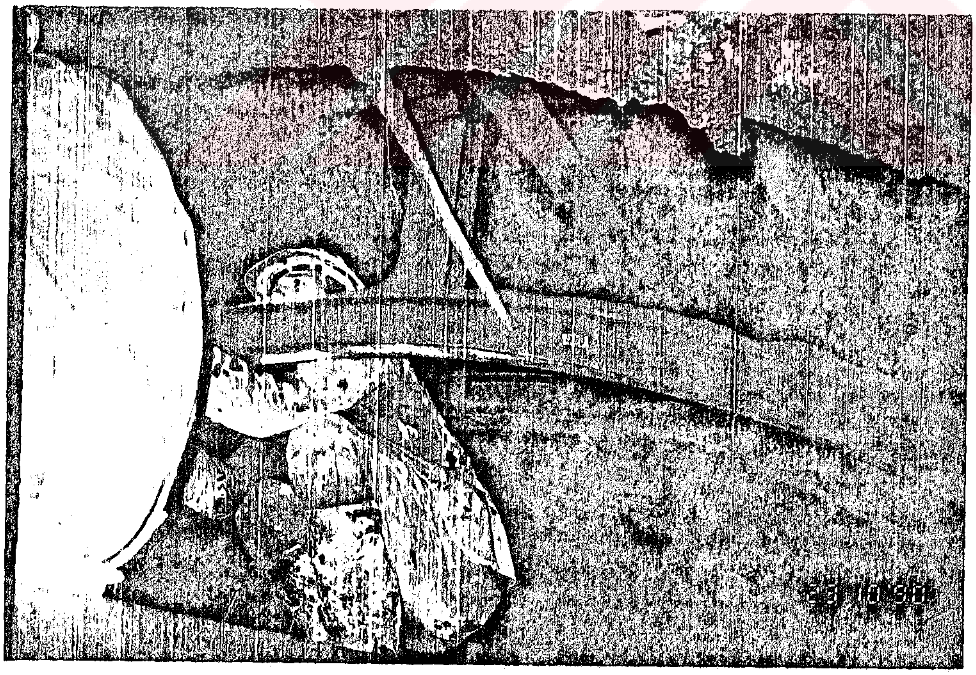


(B)

Figure 6.5.3.6 Support System In Collapsed Area At 0+933



(A)



(B)

Figure 6.5.3.7 Support System In Collapsed Area At 0+933

Collapse Between Chainage 0+935-0+945

Geological and structural conditions produced severe stability problems within 10 m. of the collapsed area. Extensive overbreak from left wall and roof caused some caverns of 1 to 1.5 m. dimension. In this area steel ribs and wiremesh reinforced shotcrete were used with 60 cm intervals.

The tunnel was excavated within grey dark coloured, siltstone banded, medium hard jointed and fractured mudstones. Well developed and to medium closely spaced joints (20-50 cm max) and other nonsystematic discontinuties seperated the rock mass into rock elements of 5-20 cm.

Overbreaks occured during the tunnel excavation are shown in figure 6.5.3.9., when reached chainage 0+945, at left shoulder of the machine with clay fill. (see figure 6.5.3.8) and 6.5.3.10). Support system used in this area is shown in figure 6.5.3.11

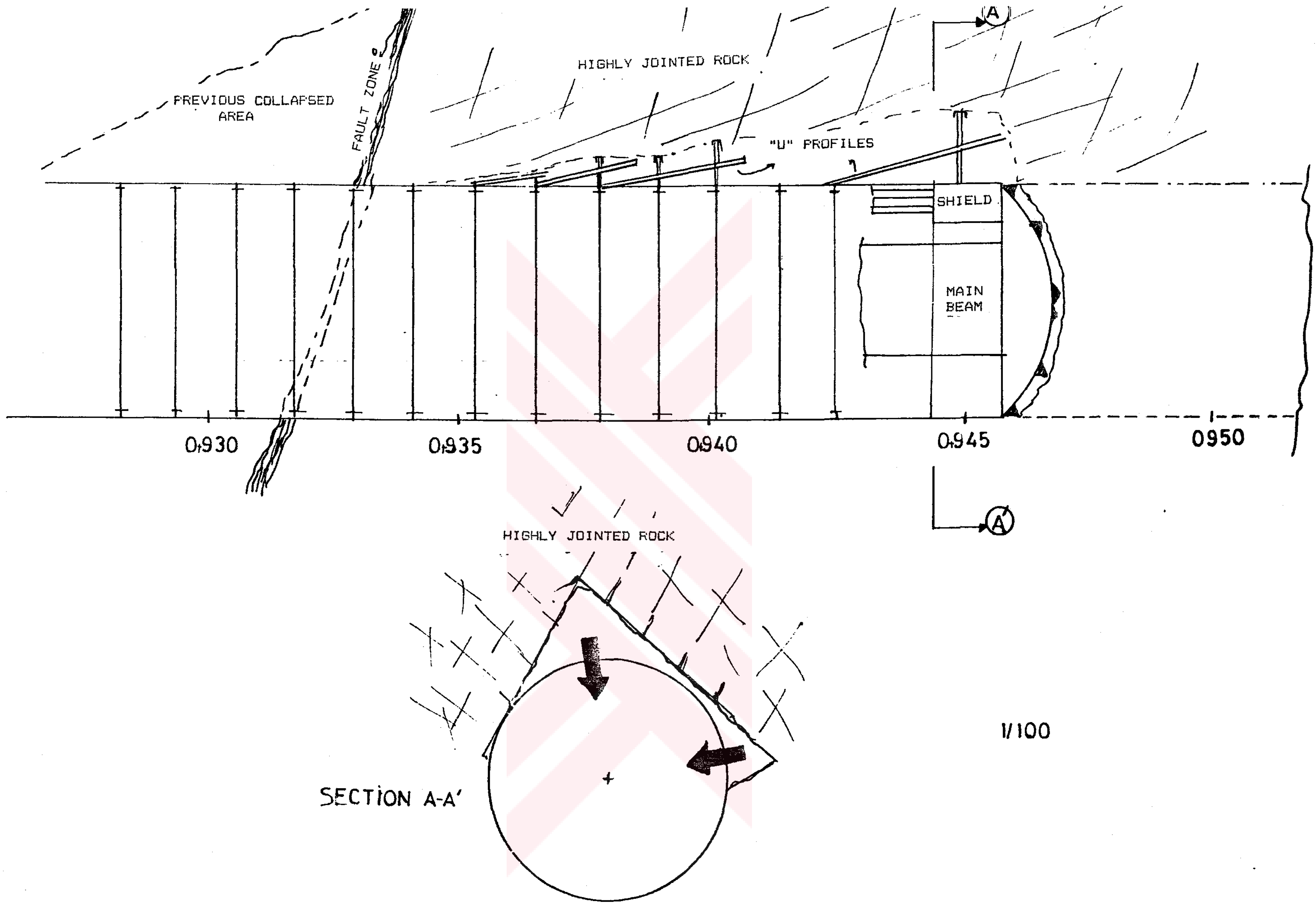
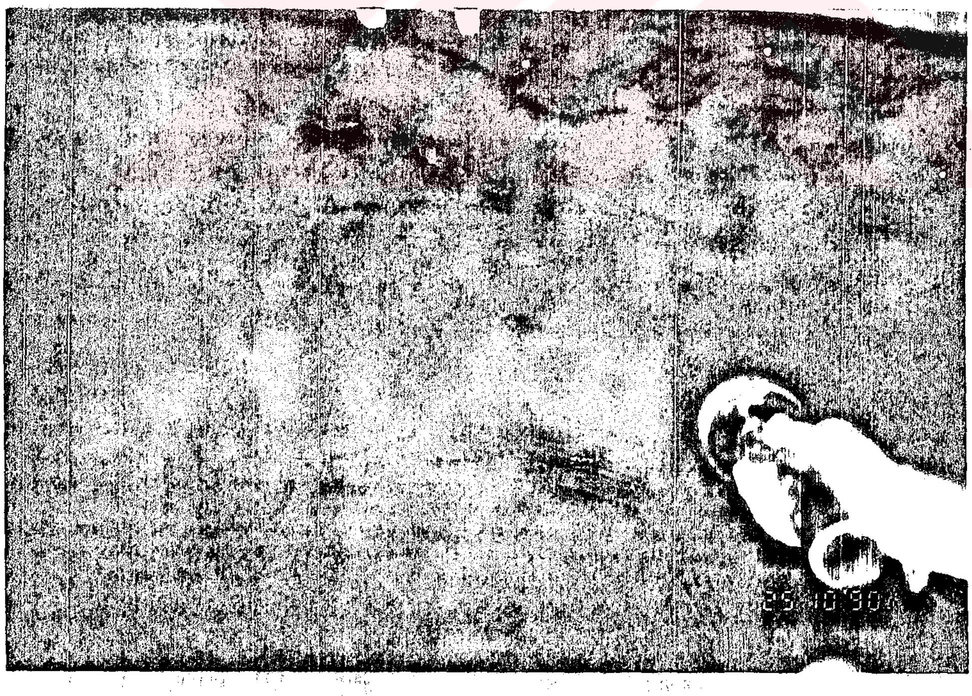


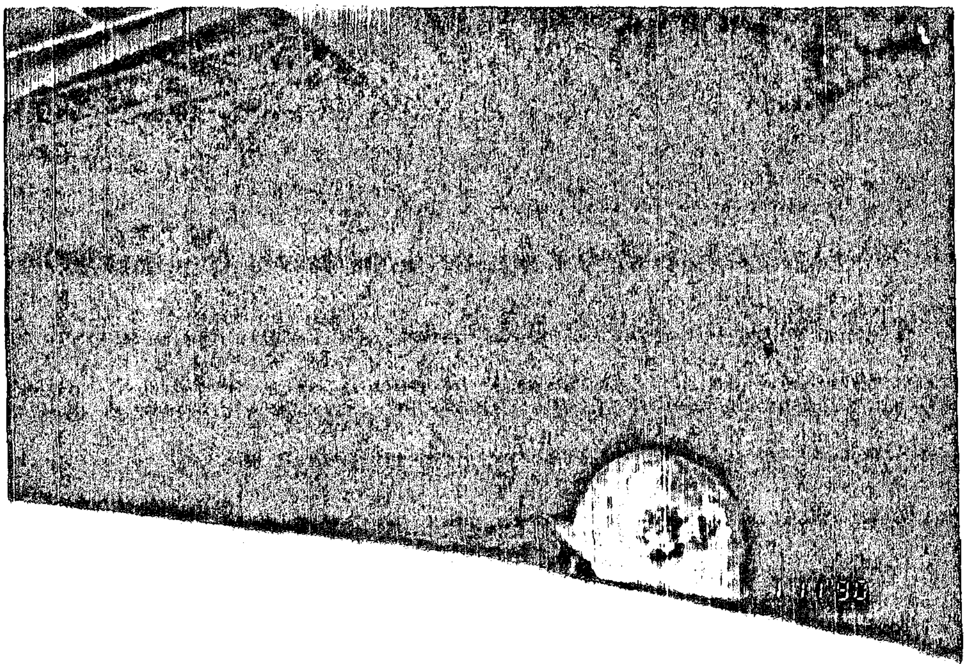
Figure 6.5.3.8 Overbreaks Between Chainage 0+935-0+945

(A)

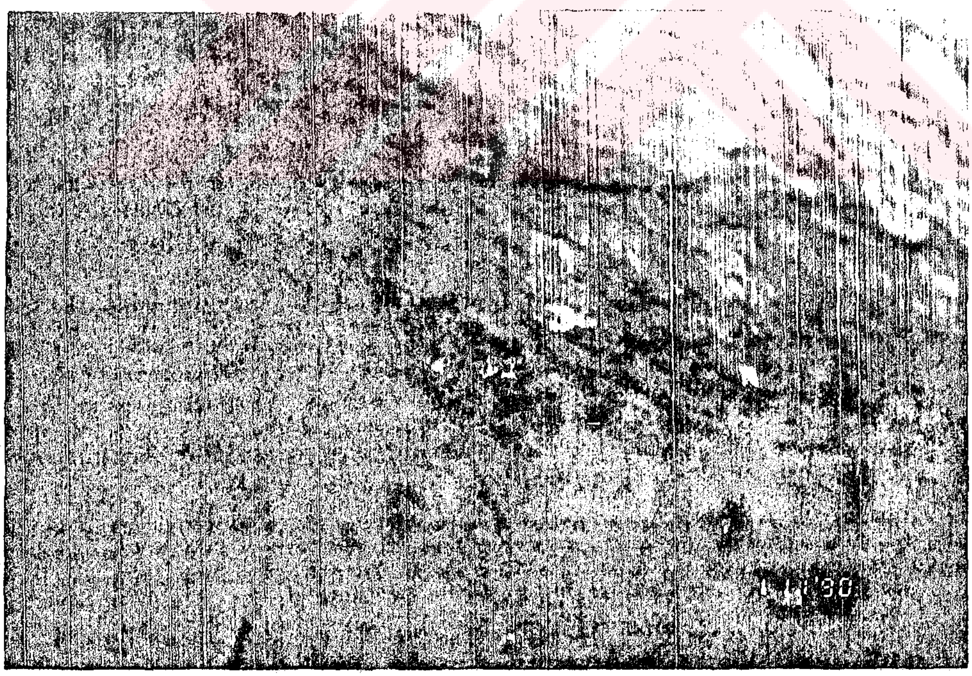


(B)

Figure 6.5.3.9 Overbreaks Occured During The Tunnel Advance



(A)



(B)

Figure 6.5.3.10 Collapse At Chainage 0+945

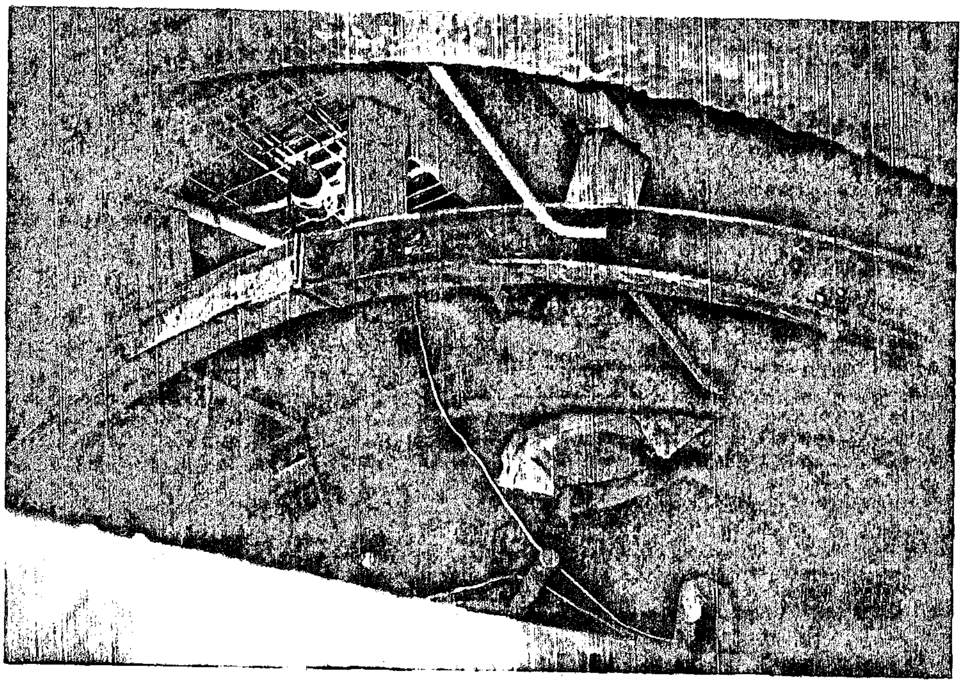


Figure 6.5.3.11 Support System In Collapsed Area At 0+945

The Collapse Between Chainage 0+965-0+982

Three collapses happened between these chainages due to bad rock conditions. (figure 6.5.3.12 and 6.5.3.13)

The collapse between chainage 0+968-0+972 took part in mudstone of Trakya Formation which is green to grenish gray coloured, moderately hard, heavily jointed and fractured, shears zones with clay filled. Rock units are weak to very weak due to joints (see figure 6.5.3.14)

The crushed material within the fault zone having 20-30 cm clay gauge and making an angle of 40-50° with tunnel route and the clay filled vertical joints having an angle of 20-30° caused tunnel collapse in this area.

In this area 40-50 m3 rock material filled the face and burried the cutterhead of the machine

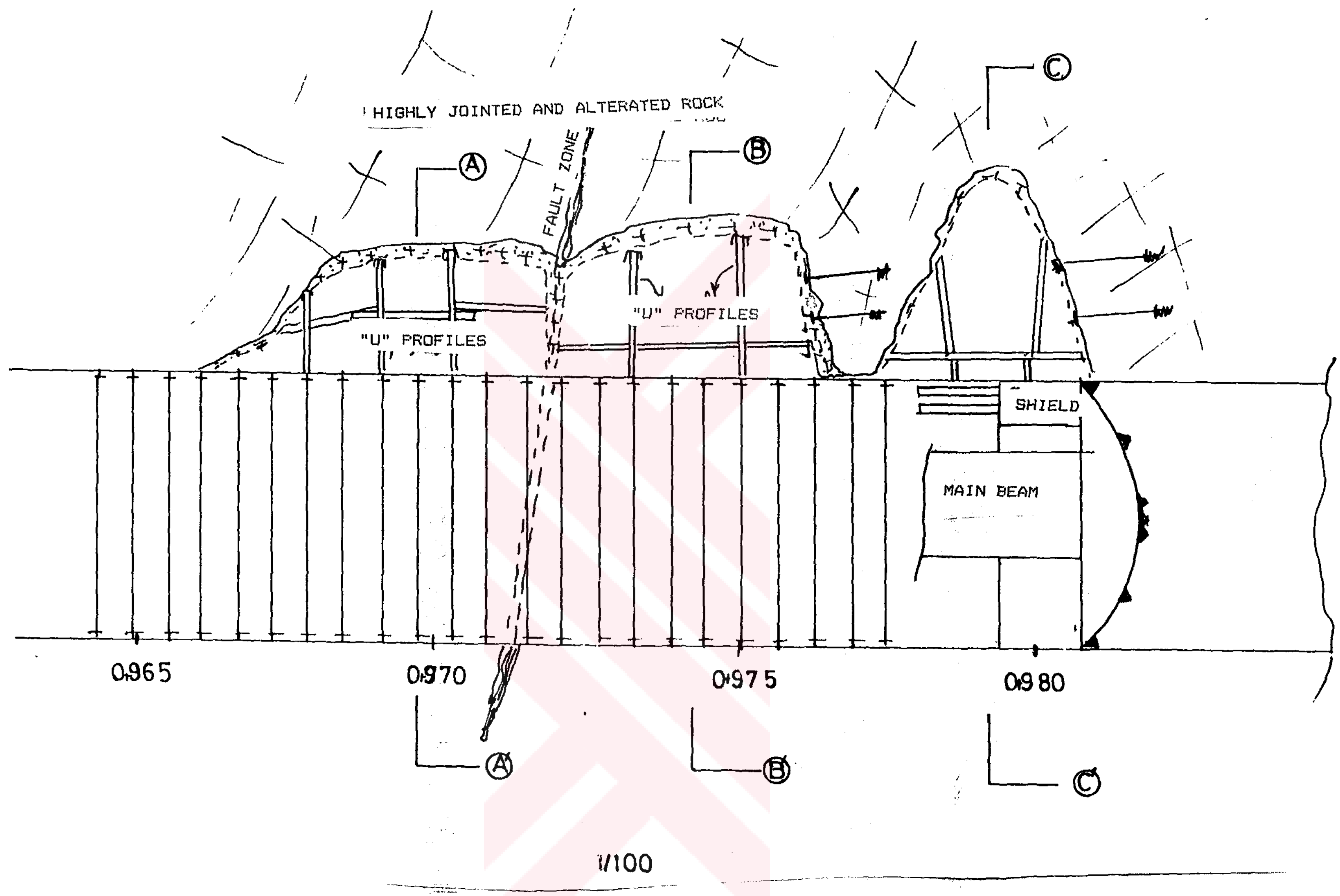


Figure 6.5.3.12 Collapses Between Chainage 0+965-0+982

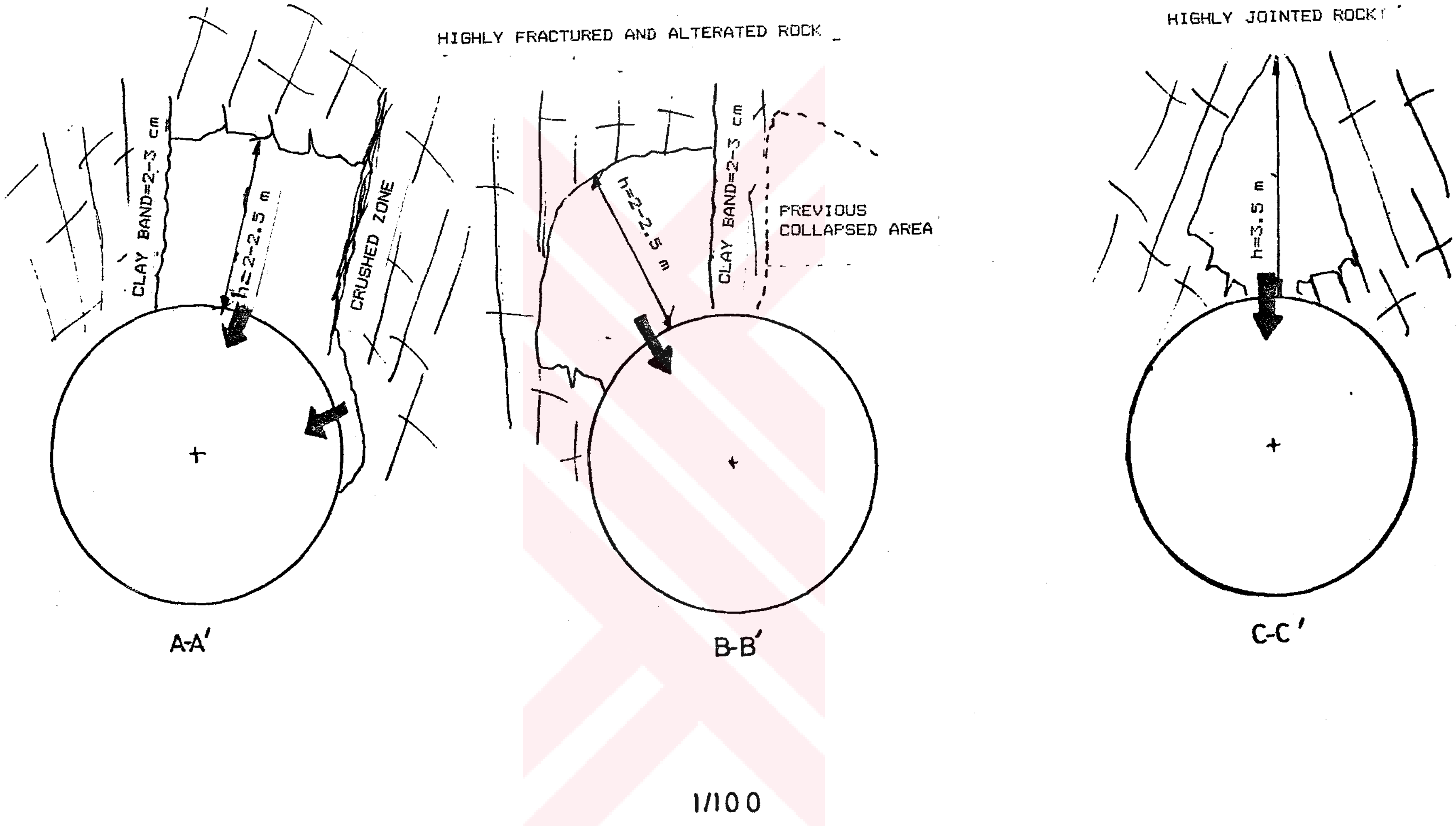
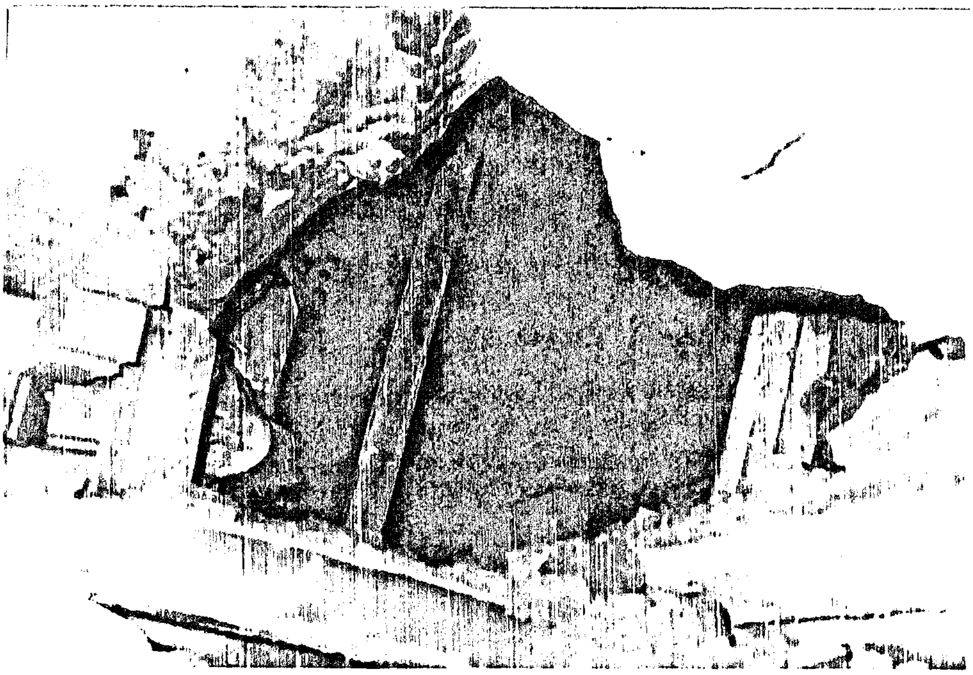
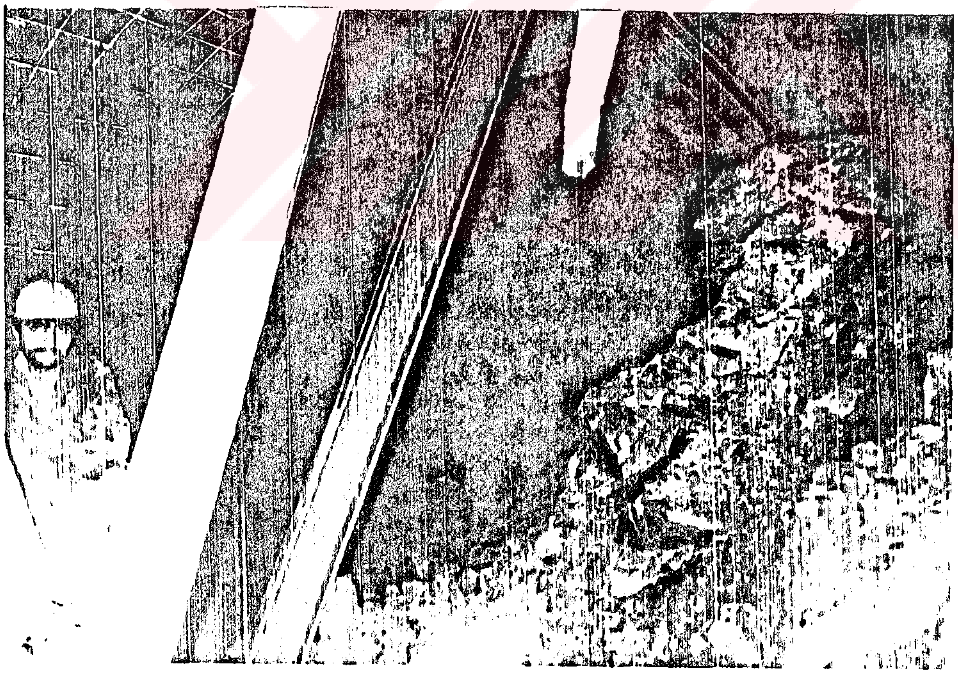


Figure 6.5.3.13 Collapses Between Chainage 0+965-0+982



(A)



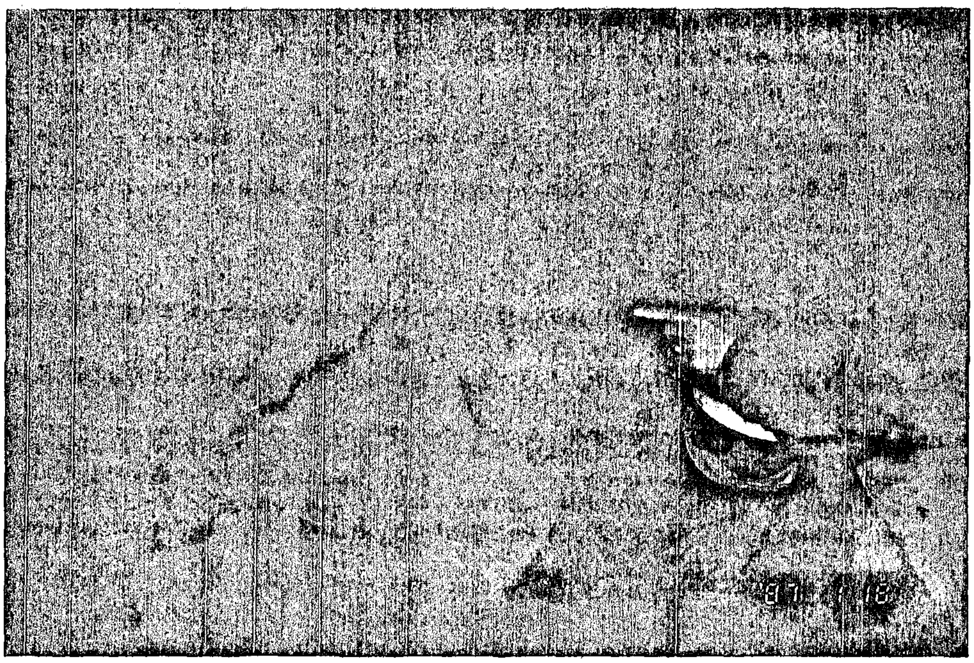
(B)

Figure 6.5.3.14 Supporting In The Collapsed Area At 0+972

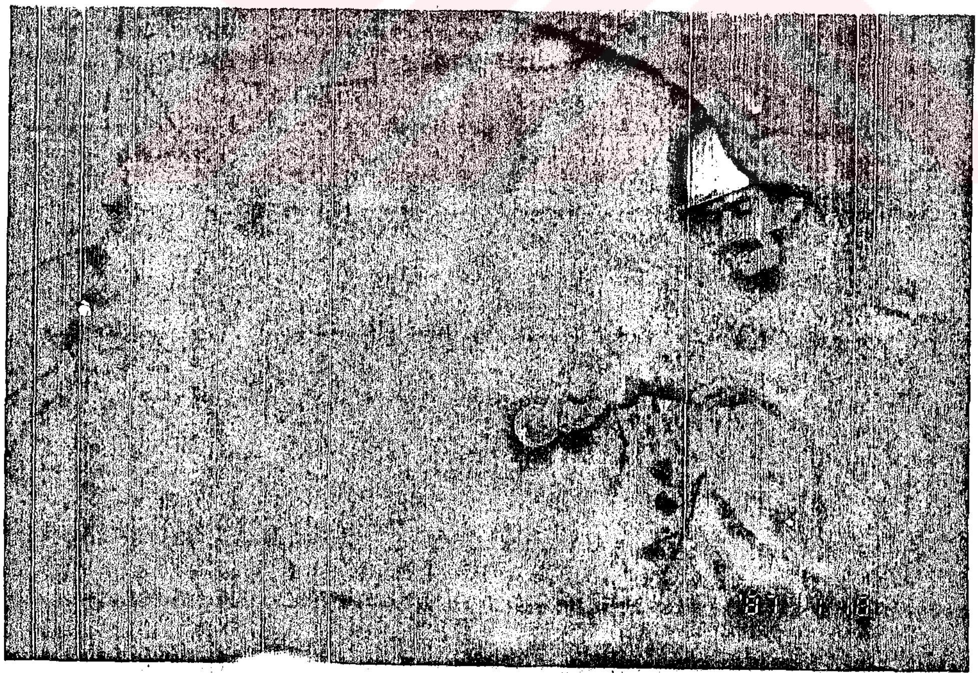
The tunnel boring continued after the completion remedial prevention at chainage 0+972. At chainage 0+974 another collapse occured due to heavily fractured zones and faults. Approximately 45 m3 of material filled the tunnel in this region

At collapsed area, mudstone-claystone of Trakya Formation are heavily fractured, jointed and also water leakage is observed. Discontinuity surfaces are generally opened and filled with clay, calcite and pyrite

In this area "U" profiles, wiremesh+shotcrete, also rock bolts were used as support elements.



(A)



(B)

Figure 6.5.3.15 Collapsed area At 0+974

The third collapse happened at 0+981, (between chainage 0+968-0+982). Geological conditions are the same as in previous collapsed areas. 25-30 m3 loose rock material filled the tunnel at this section and a cavern of 3-3.5 m formed on the left of the roof.

The collapsed area was supported by "U" profiles and surfaces were covered by wiremesh+shotcrete for stabilization.

The Collapse Between Chainage 1+148-1+155

In this section of the tunnel, highly jointed and fractured rock with clay filled siltstone-claystone-mudstone of Trakya Formation were encountered.

Joint sets which intersected each other caused the collapses in this area as seen in figure 6.3.5.16 and 6.5.3.17. Rock blocks collapsed on the shield due to joint sets.

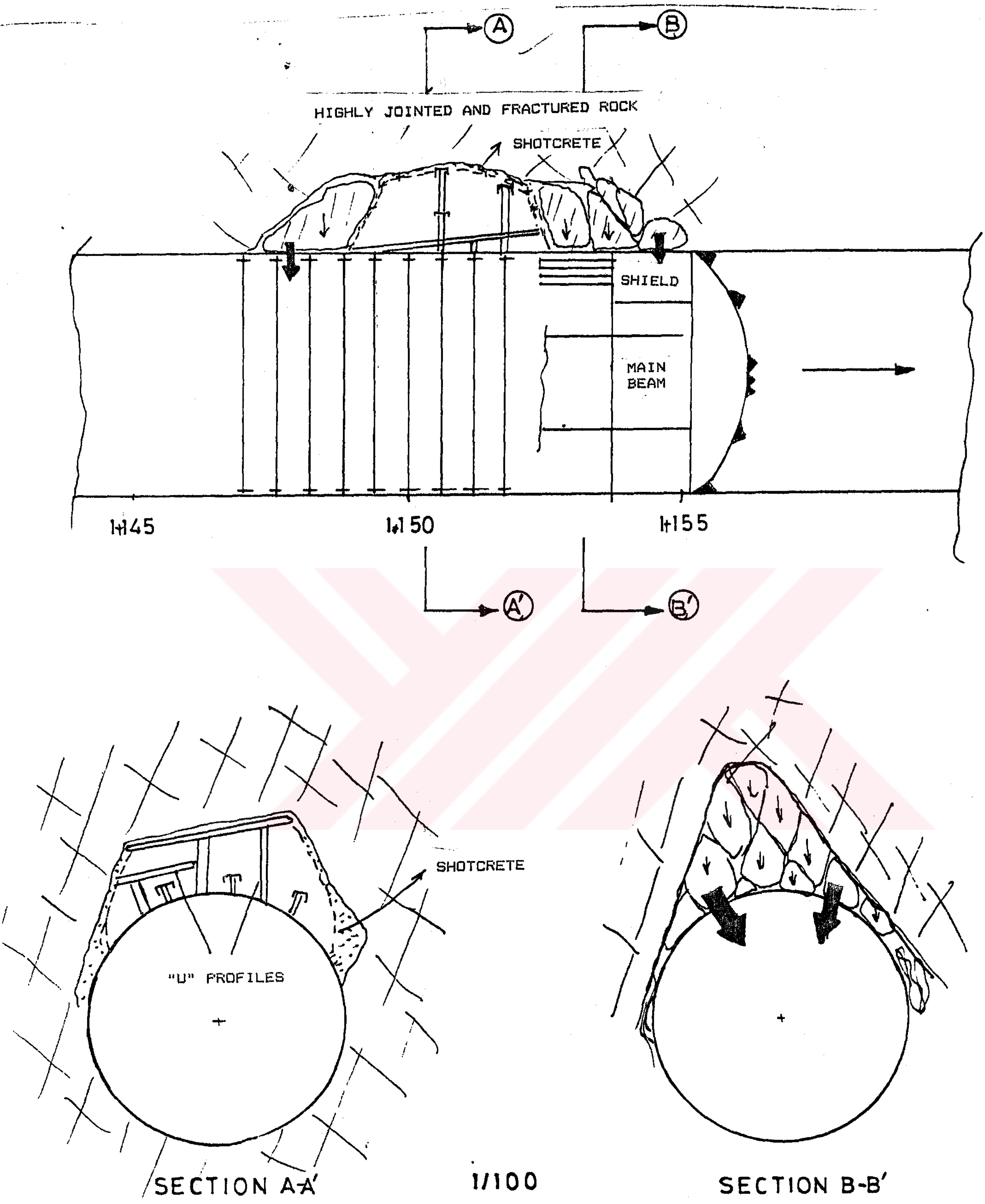


Figure 6.5.3.16 Wedged Rock Blocks Between Chainage 1+148–1+155

(A)

(B)

Figure 6.5.3.17 Wedged Rock Blocks On The Shield

<u>The Collapse Between Chainage 1+220-1+235 (Figure 6.3.5.18)</u>

The main rocks at collapsed area are siltstones and mudstones, although not obvious, some sandstone bands have been recorded.

Trakya Formation in this area is intensely jointed and factured. Joints are generally filled with clay and/or calcite. Nearly at 1+210 an overbreak due to loose fractured rock occured on left hand wall,(figure 6.5.3.19) and later when a fault zone was encountered, the collapse occured. The encountered fault at km 1+223 had 30-40 cm thick clay gauge and strike angle of 30-40° with tunnel axe and dipping of 40-50° SW. Joint sets making an angle of 20-30° with the tunnel axe had an average strike of 30-40° SW-NW

Water income in this section of the tunnel also increased considerably, especially before the fault encountered.

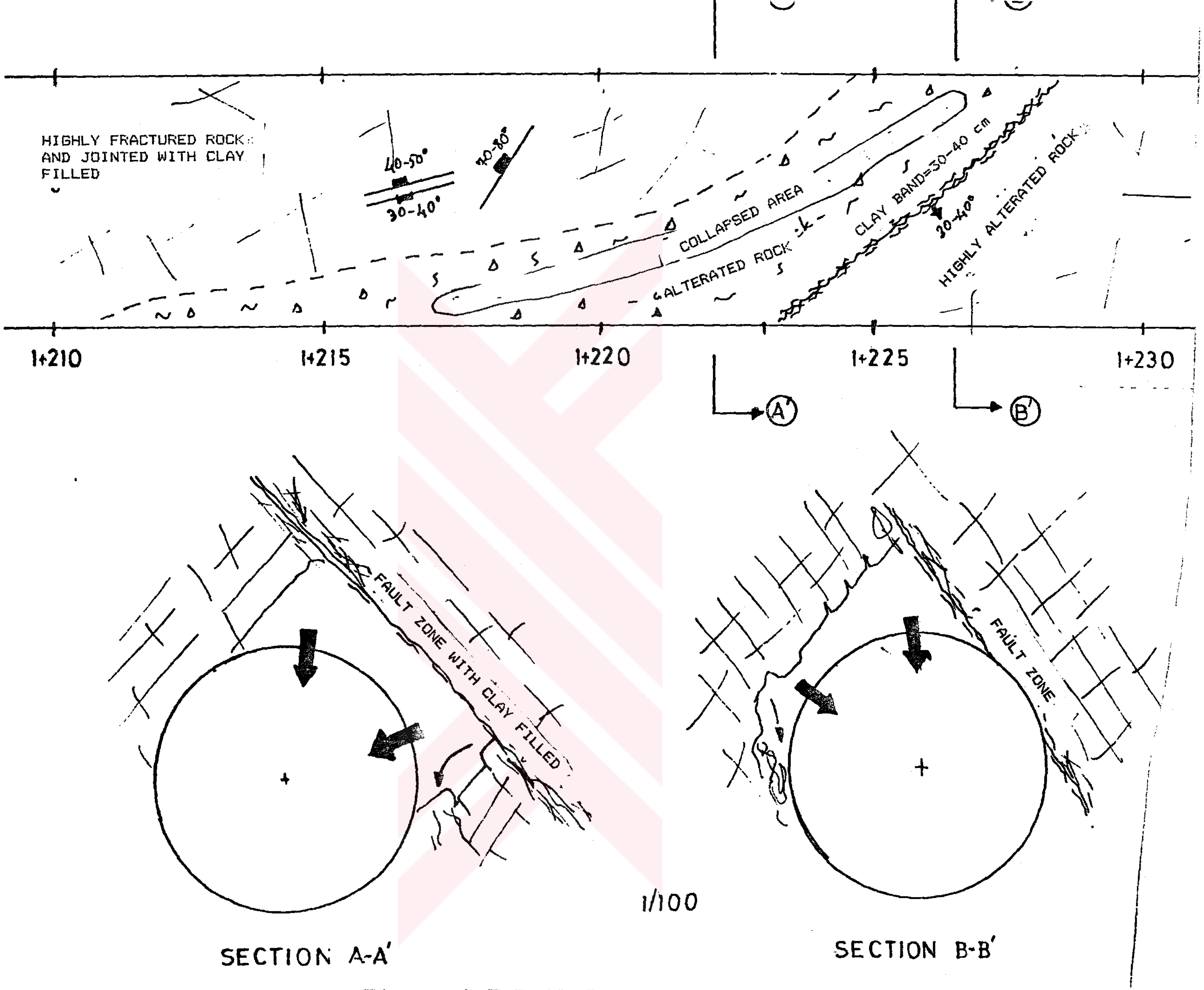
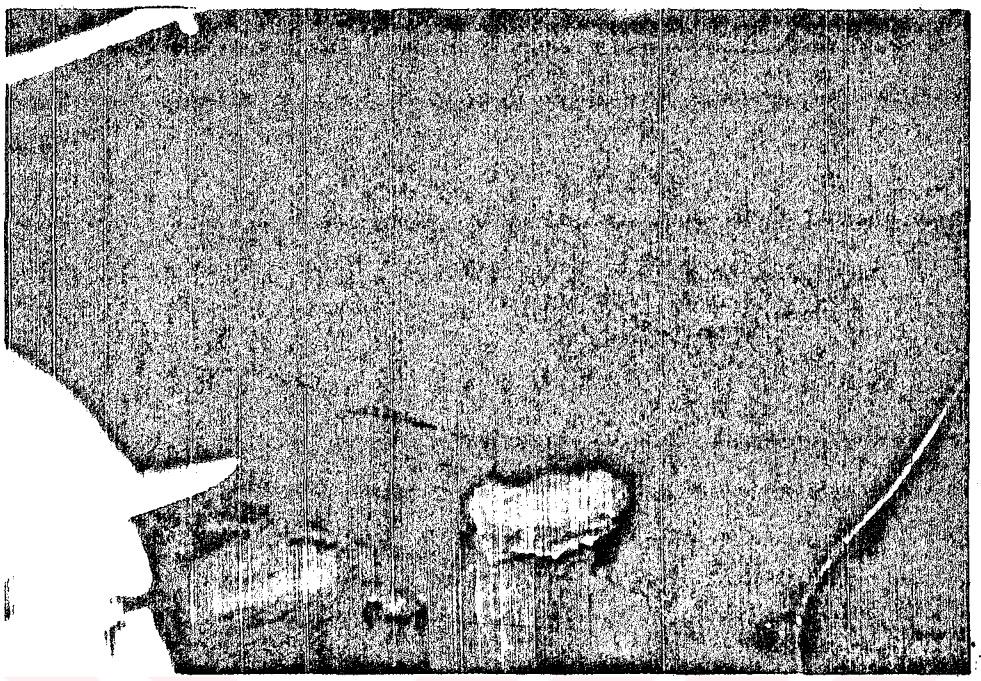
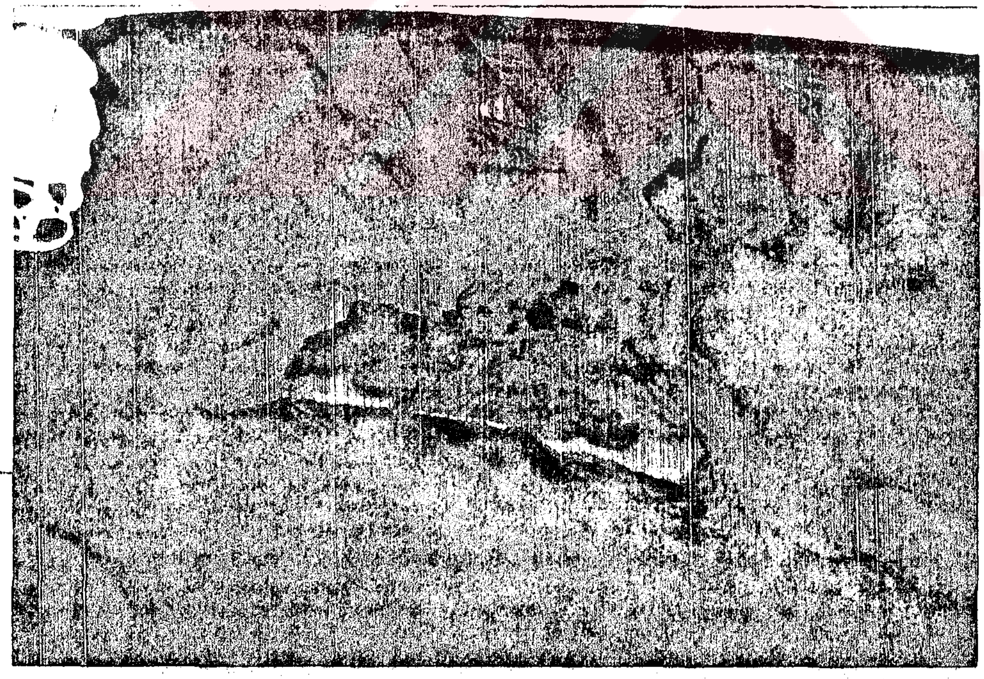


Figure 6.5.3.18 Collapsed Area Between Km 1+215-1+230

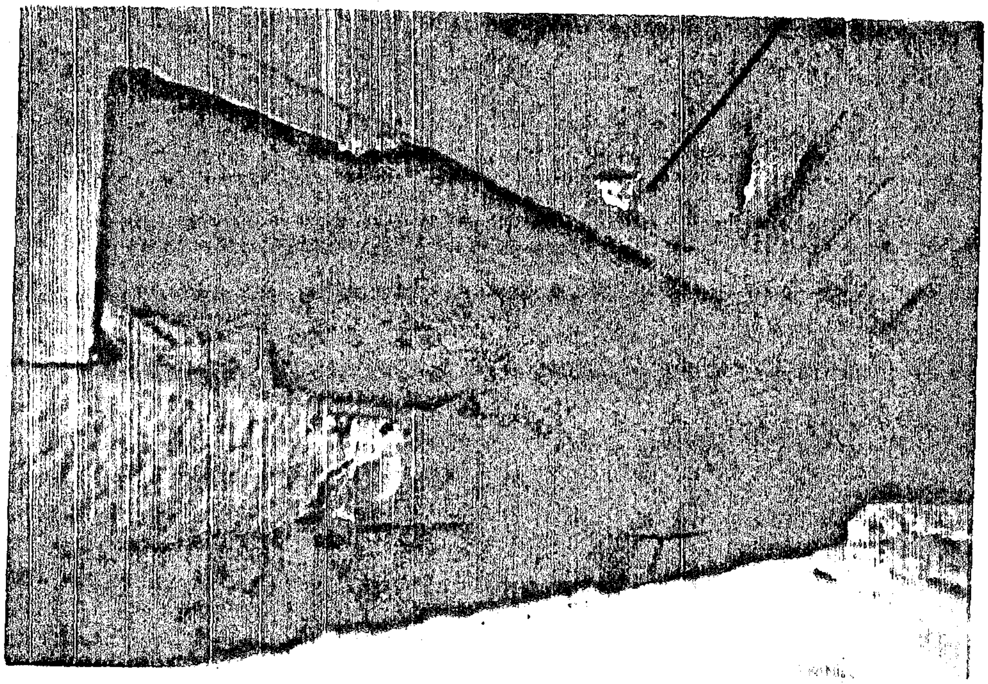


(A)

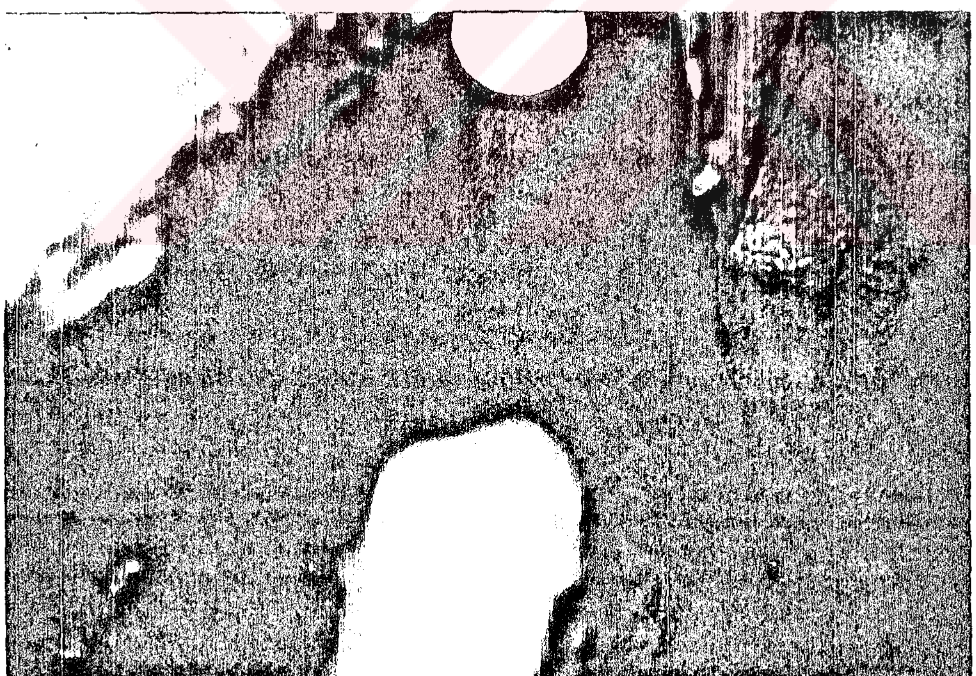


(B)

Figure 6.5.3.19 Overbreaks Before Fault Zone And Supporting By "U" Profiles In The Area



(A)



(B)

Figure 6.5.3.20 Collapsed Area In The Fault Zone At 1+225

CHAPTER 7 RELATIONSHIP OF THE EXCAVATION PERFORMANCE WITH THE ROCK PROPERTIES

7.1 General

Some laboratory and in-situ tests were carried out in order to determine rock properties. Rock samples were taken systematically along the tunnel route at certain intervals, for labroratory tests. Machine performance data such as, disc consumption, average advance rate, net cutting rate, machine downtime, machine thrust, r.p.m. e.t.c were carefully collected including the geologycal conditions encountered in the excavated area. The main objective of this investigation was to find some correlations between machine performance and rock properties. It was obvious that such relationships would be much helpful for any tunnelling work prior to start the excavation.

7.2 Mechanical Tests Used In The Research

Some tests procedures proposed by Interntional Society For Rock mechanics were used in order to determine rock properties in this investigation. Commission for ISRM was held in September 3, 1987 in Montreal for describing test procedures which would be necessary to find rock properties such as cuttability,drillability or boreability of rock.

According to this commision, it is essential that a few tests should be used together in order to determine some rock properties for engineering and project purposes in a similar investigation

ISRM suggest the following tests can be used for rock excavation assessment [6]

1-Hardness of the rock

Preferred tests : Shore Scleroscope
Roell and Korthhaus Sklerograf

Acceptable test : Schmidt Rebound Hammer

2-Strength of the rock

Preferred tests : "Brazilian" indirect test strength
Punch Shear Strength
Uniaxial Compressive Strength
Fracture Toughness

Acceptable test : Point Load Strenth Index

3-Texture of the rock

Preferred test : Quartz Content

Acceptable test : Texture coefficient
Grain size and shapes

4-Abrasivines of the rock

Preferred test : Goodrich Wear Number
Cerchar Abrasivity
Paddle Abrasivines

Acceptable test : Core Cutting Test Abrasivity
L.C.P.C Abrasimeter
Taber Abrasivines

5-Drillability

There are 3 main modes of drilling and cutting for drillabilty tests

(A) Translational

Preferred Tests: Goodrich Drilability
Sievers "J" Number

Acceptable Tests: Core Cuting Test Spesific Energy
VOEST ALPINE Rock Cutability Index
Taber Abradability

(B) Penetrative

Preferred Test : NCB Cone Indenter Test

Acceptable Test : Morris Drillability
Handewith Test
O&K Wedge Test

(C) Percussive

Preferred Test: Impact Hardness Number

Acceptable Tests: Coefficient of Rock Strength
"Protodyakonov" Test

Tests used in the resarch are as follows,

Point Load Strength Index

The Point Load Strength test is intended as an index test procedure for the strength classificasion of rock materials. It may also be used to predict other strength parameters such as uniaxial tensile and compresive strength of the rock.[7]

Rock Specimens in the form of either core, cut block or irregular lumps are broken by the aplication of concentrated load through a pair of sphericaly truncated conical platens.(See Figure 7.2.1)

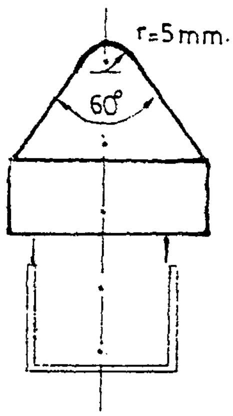


Figure 7.2.1. Spherically Truncated Conical Platens For Point Load Test

The testing machine consists of a loading system and a measuring system for the load P necessary to break the specimen (figure 7.2.2).

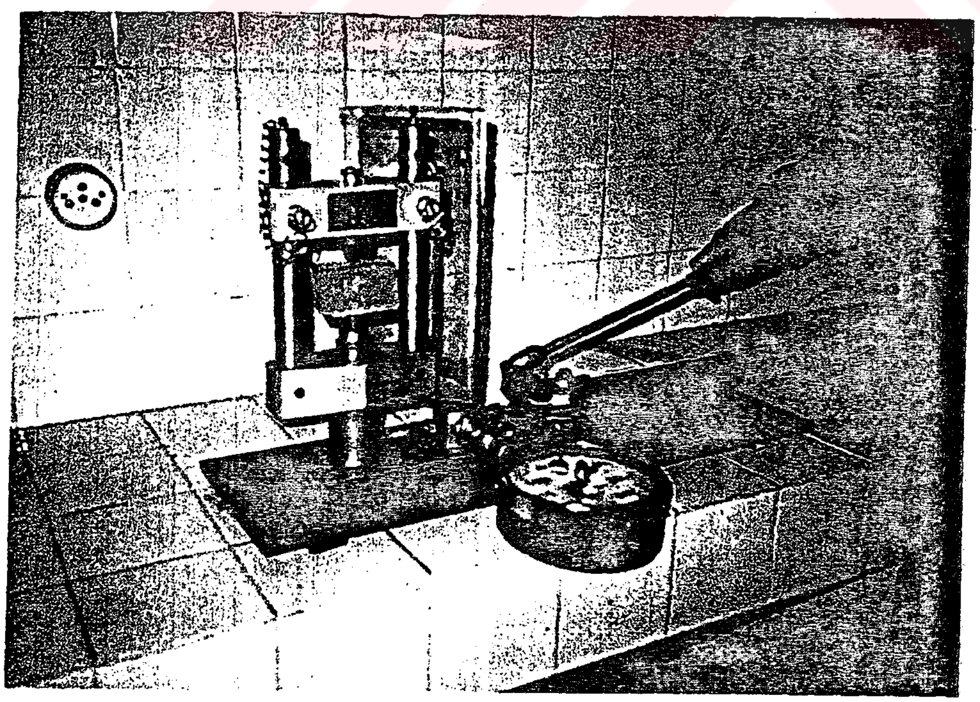


Figure 7.2.2 Point Load Test Machine

Specimen Shape requirements for core, block and irregular lump test are given in the figure 7.2.3

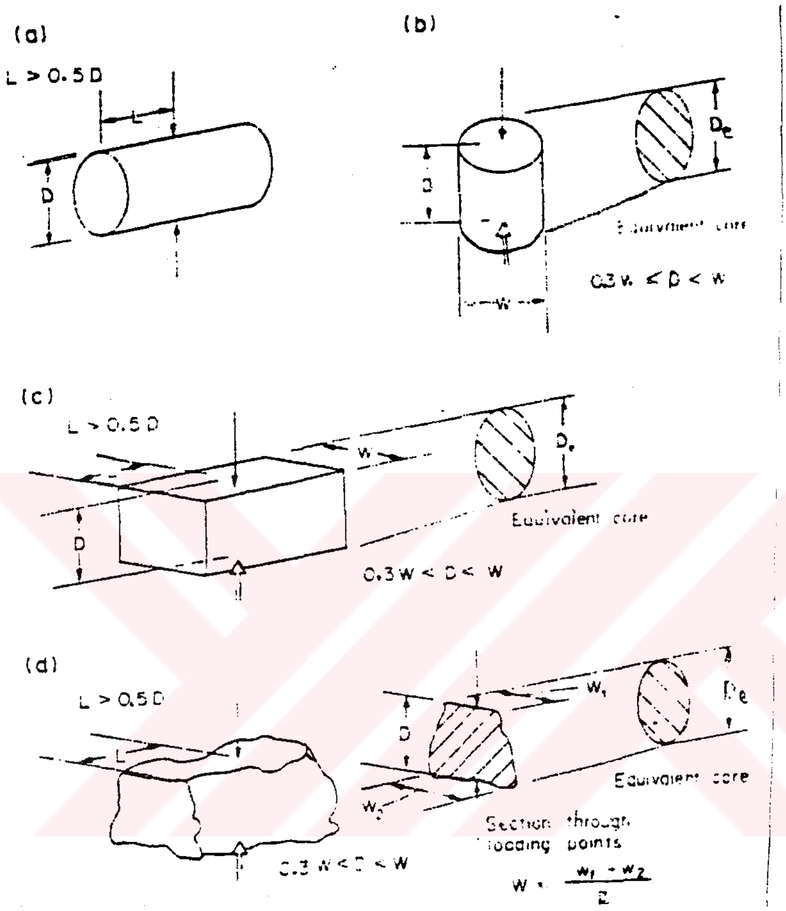


Figure 7.2.3 Shape Requirements For Specimens(a=diametral test,b=the axial test,c=the block test,d=the irregular lump test) [7]

Cut block samples were used throughout the experiments. The following expression is used for calculating point load index

$$Is = \frac{P}{d^2}$$

where,

Is—> point load index (kg/cm^2)

P——> load required to break the specimen (kg)

d——> distance between two platen contacts (cm)

Some broken samples are shown in figure 7.2.4

Figure 7.2.4 Some Tested Samples In The Point Load Experiment

A size correction was also necessary to correct point load strength for an equivalent core size of 5 cm. [7]

The uncorrected Point Load Strength is calculated as P/De^2 where, the "equivalent core diameter" is given by

$$DE^2 = D^2 = \frac{4A}{\pi}$$

where,

A=W.D= *min.cross sectional area of a plane through the platen contact points.*

However, the depth of the prepared samples was almost 5 cm. Therefore, size corrections was done for a few samples during the test.

The size correction factor can be obtained from the expression:

$$F = (De/50)^{0.45}$$

So, size correction may be accomplished by using the formula:

$$Is(50) = F x Is$$

Test results are given in appendix 3

NCB Cone Indenter Test

The NCB Cone indenter, which was developed by MRDE is a portable instrument capable of giving a measure of strength without requiring the preparation of accurately shape and finished specimens. [8]

The instrument (figure 7.2.5.) which works on a similar principle to that employed in metallurgical hardness tester, is designed to determine the hardness of rock by measuring its resistance to indentation by a hardened tungsten carbide cone.

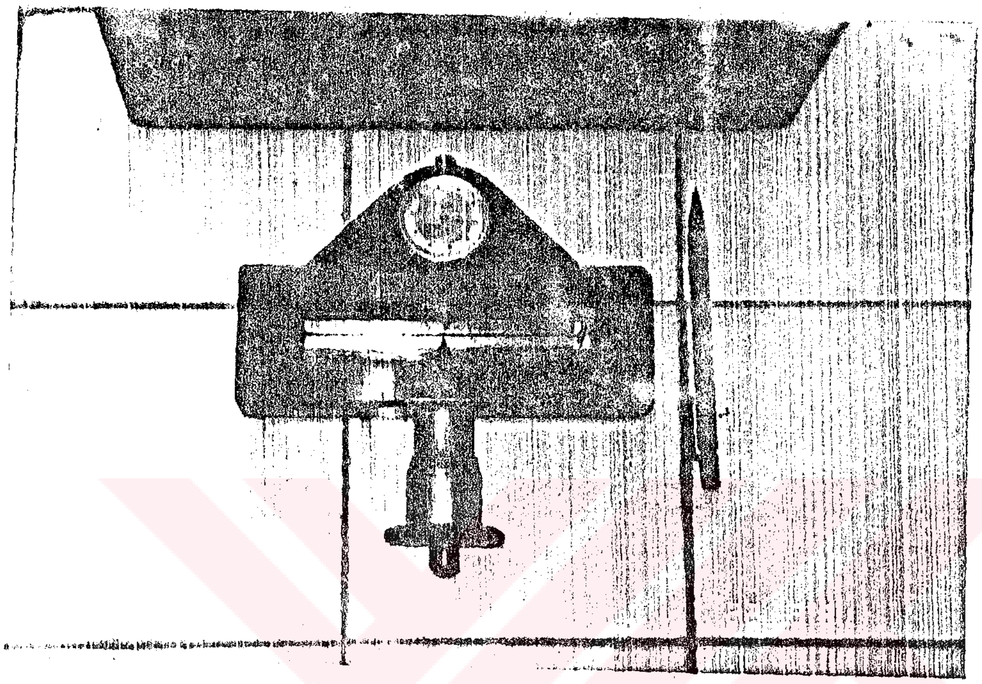


Figure 7.2.5. Cone Indenter Test Instrument

It comprises a portal steel frame 175 mm long in which a steel strip is clamped along a longitudinal axis. In the middle of one longitudinal side of the frame a dial gauge is inserted in such a way that its probe is in contact with one side of the steel strip. In the opposite longitudinal side of the frame a micrometer is fitted with a hollow spindle into which a tungsten carbide tip of 40° is inserted. The micrometer is used to determine the amount of indentation and the gauge the deflection of the steel frame

The cone indenter hardness value for any particular test is obtained by dividing the force necessary to cause penetration by the amount of penetration that has occurred.

Thus, cone indenter number.

$$I=D/P$$

Where,

D——>nominal deflection of steel strip

P——>penetration of specimen by cone

The specimen is set on the steel strip and the micrometer screw is turned until the specimen is just hold in position by cone. The dial gauge is reseted to zero and the micrometer is read (M1). Then the micrometer screw is turned slowly clockwise until the spring deflection, as indicated by the dial gauge, is equivalent to a load of 40N; this should be 0.635 mm approximately. So, the micrometer is read again (M2).

The penetration of the cone into the specimen is P=(M1-M2)-0.635 and the standard cone indenter number is,

$$Is=\frac{0.635}{(M2-M1)-0.635}$$

If Is is less than 0.13 mm proceed as follows, This time, the micrometer screw is turned to 1.27 mm which is equivalent to 110N, then the micrometer is read

(M2). So, the modification cone number is

$$Im = \frac{0.23}{(M2-M1)-1.27}$$

Some rocks will fracture when the standard cone indenter test is done. That's why, the micrometer screw turned until the spring deflection, as indicated by the dial gauge, is equivalent to a load of 12N. This should be 0.23 mm. so, cone indenter number is,

$$Iw = \frac{0.23}{(M2-M1)-0.23}$$

The relationship between the cone indenter numbers and compressive strength is approximately linear [8].To determine compressive strength of rock by cone number the following expresssions can be used (Gc is in kg/cm2 in the equations)

Gc=248xIs(for standard cone indenter number)

Gc=358xIm(for modified cone indenter number)

Gc=16.5xIm(for cone indenter number of weak rocks)

Test results are given in appendix 4

Cerchar Hardness Test [9]

Cerchar Hardness Test is a method to determine hardness of rock by a drillability test.

A tungsten carbide bit, having a length of 8 mm and an inclusive tip angle of 90°, is rotated at a speed of 190 rev/min, and is thrusted under a constant normal load of 20 kg, against the test specimen. The index of hardness is chosen as the time taken in the seconds to drill a hole of 1 cm deep, assuming constant rotational speed.

The apparatus used to realize the hardness test was a heavy type drilling rig as shown in figure 7.2.6.

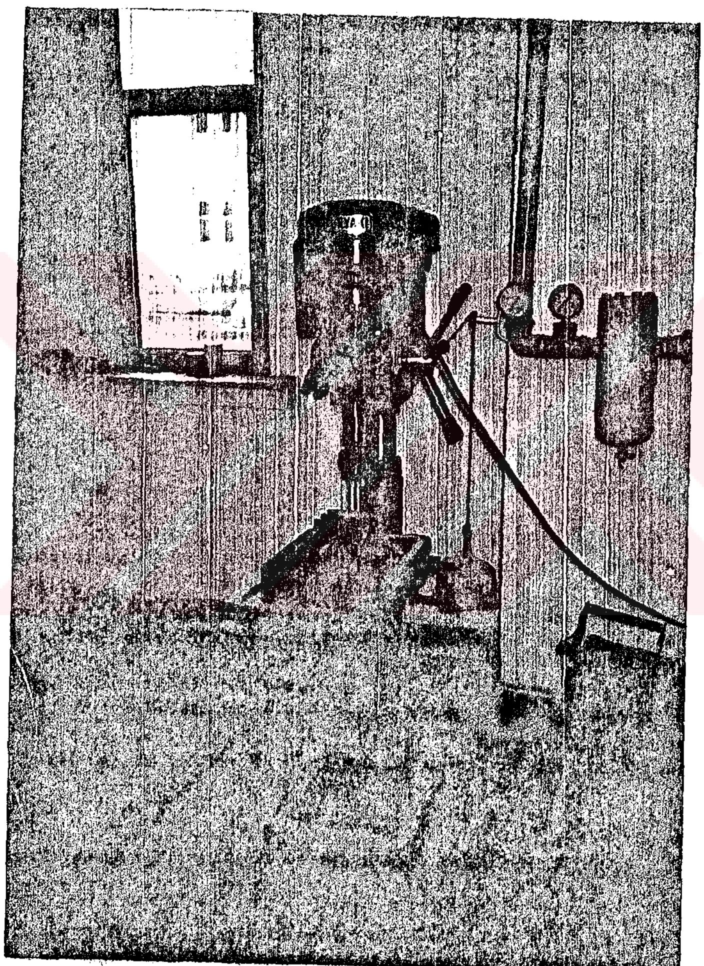


Figure 7.2.6 The Drilling Rig Used In The Cerchar Hardness Test.

This drill rig has five variable rotational speeds of 180 up to 1100 rev/min. Drilling bit used in the experiments were standard bits (DIN 6039) having a form of 8 mm wide and an inclusive tip angle of 110°. (figure 7.2.7) and a speed of 500 rev/mm was used during the experiments.

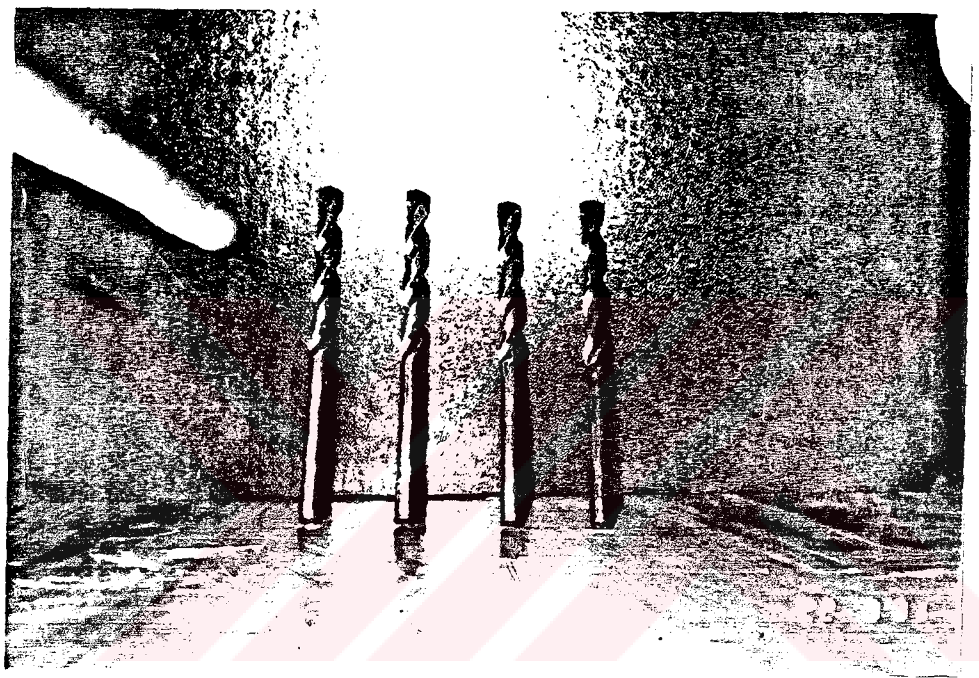


Figure 7.2.7 Bits Used In Cerchar Hardness Test

During the test, it was necessary to hold the rock samples in a vice to ensure the security of the test,(figure 7.2.9) later the vice was placed onto the work table of the drilling set.A special pulling device was constructed in order to satisfy test conditions as described by Cader M. (1973) as shown in figure 7.2.8

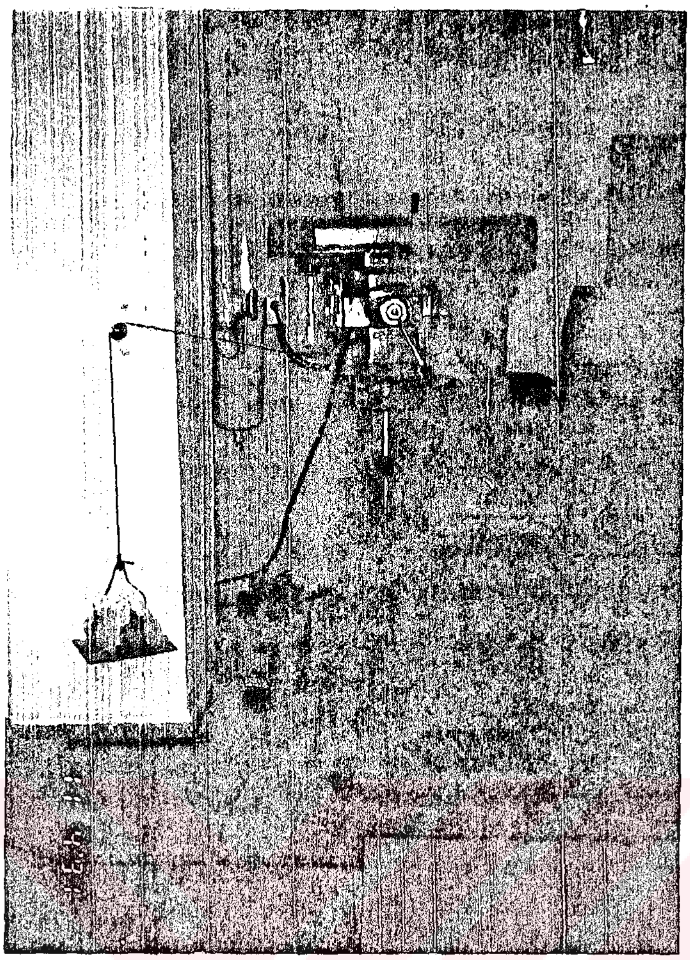
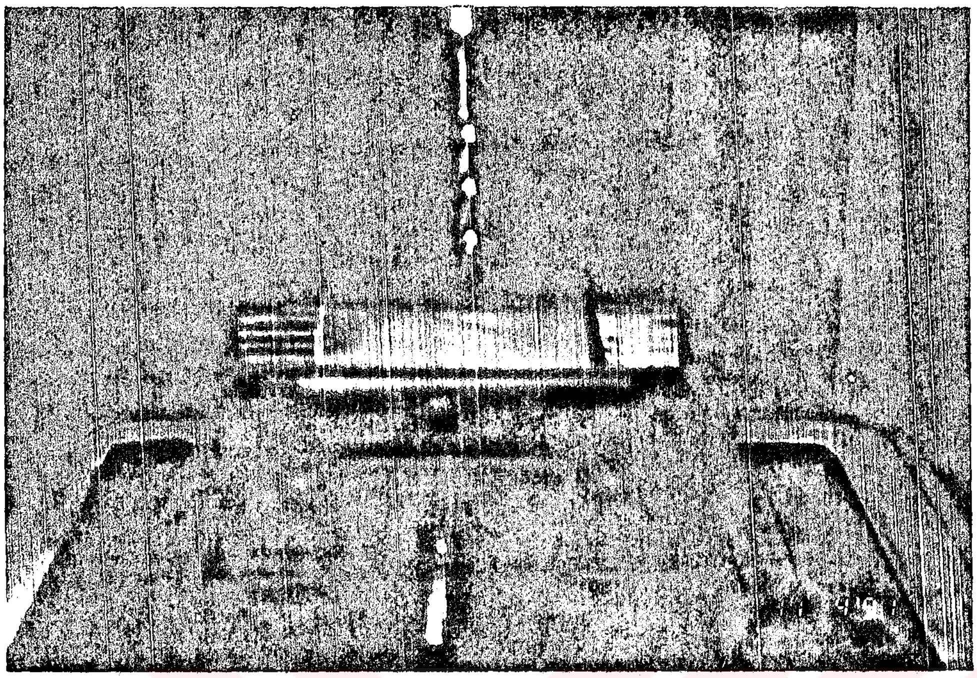
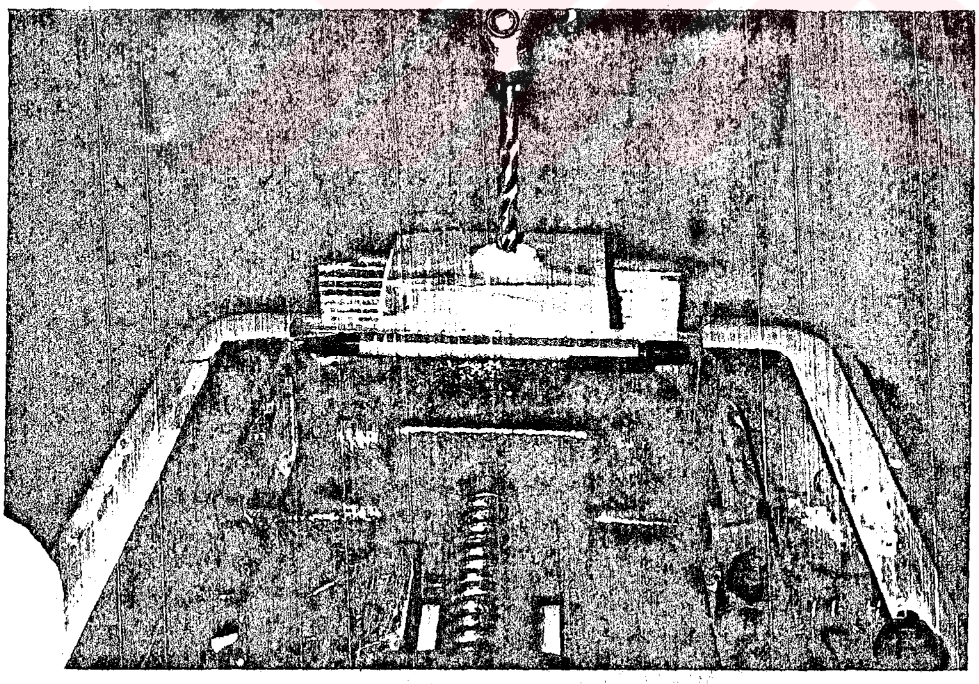


Figure 7.2.8 Pulling System Of The Drilling System

One of the pulleys is attached to the drilling head, the other pulley is screwed down on the wall. The weight table is hung up by means of a steel wire passing through both pulleys. When the drill rig is running, the drill bit is thrusted on rock sample due to the effect of the dead weight which is placed onto the weigth table. Using this technique a thrust force of 20 kg was applied during each test.

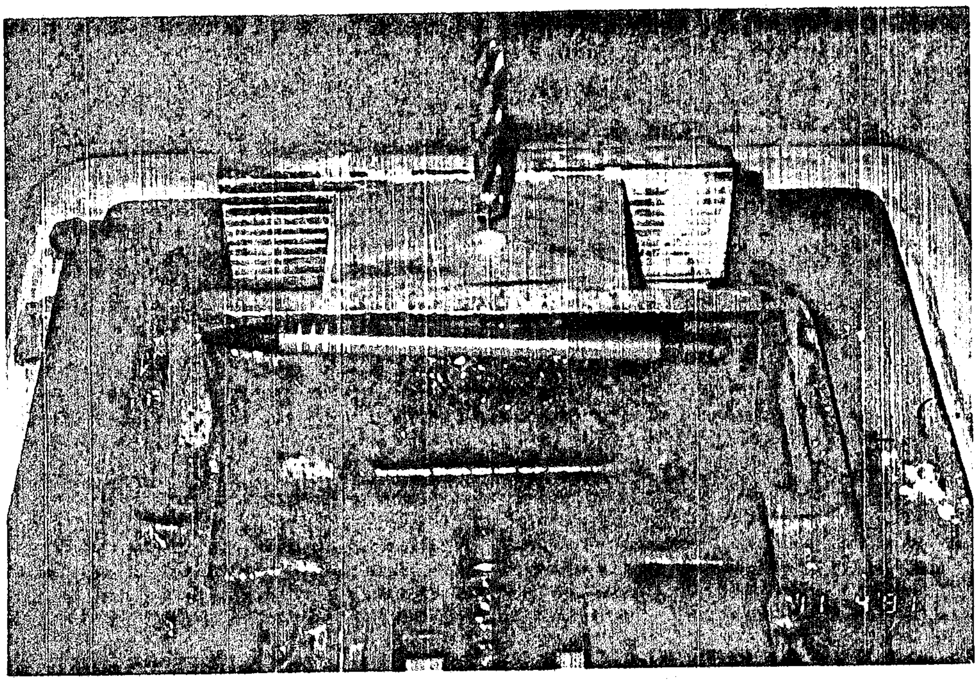


(A)

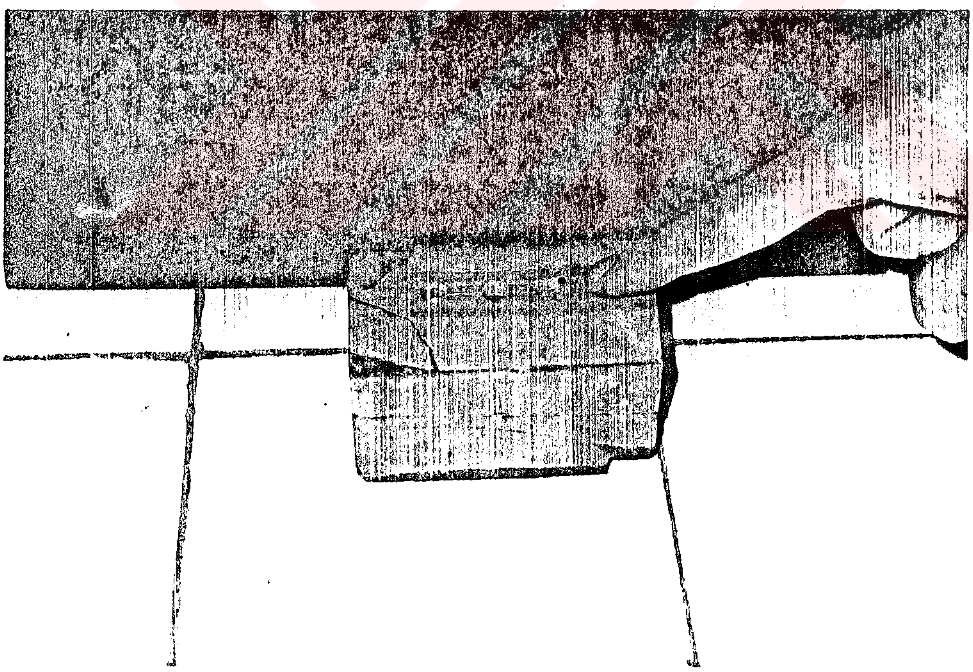


(B)

Figure 7.2.9 Testing Of A Rock Sample On The Work Table



(A)



(B)

Figure 7.2.10 Sample Tested In Cerchar Hardness Test

The index of hardness is chosen as the time taken in seconds to drill a hole of 1 cm deep assuming a constant rotational speed(500 r.p.m.). Also, the time to drill a hole of 0.5 cm was also recorded in order to find the diffirence between the two test results. As seen in figure 7.2.11, there is a good relationship between two test results.

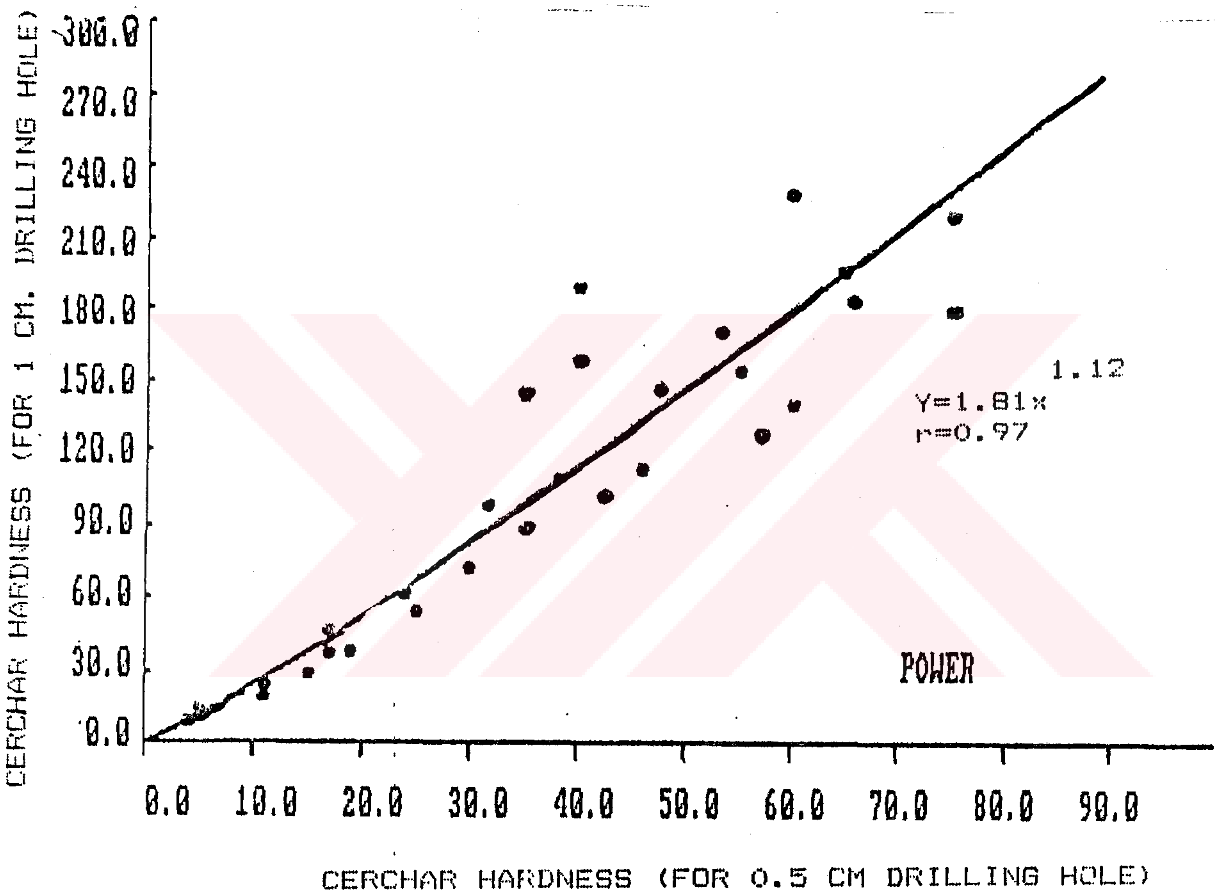


Figure 7.2.11 Relationship Between Two Test Results In Cerchar Hardness

Results of Cerchar hardness test are given in appendix 5

The Schmidt Hammer

The Schmidt Hammer was originally developed to compare the surface hardness of concrete and, through emperical relations, to estimate 28-day cube strengths. Subsequently the schmidt hammer has been used in a similar manner to estimate the uniaxial compressive strengt of rocks from surface hardness data obtained from natural or artificial exposures. [10]

Despite apparently good laboratory correspondence, there are evidance that site correlations may be insufficiently reliable for some design or contract decisions.

Before using the Schmidt Hammer in a tunnel sidewall, surface of wall must be clean. Therefore, the surface was scraped and brushed clean before testing. Each point was then impacted 8 times at certain intervals. All values were recorded and are given in appendix 6

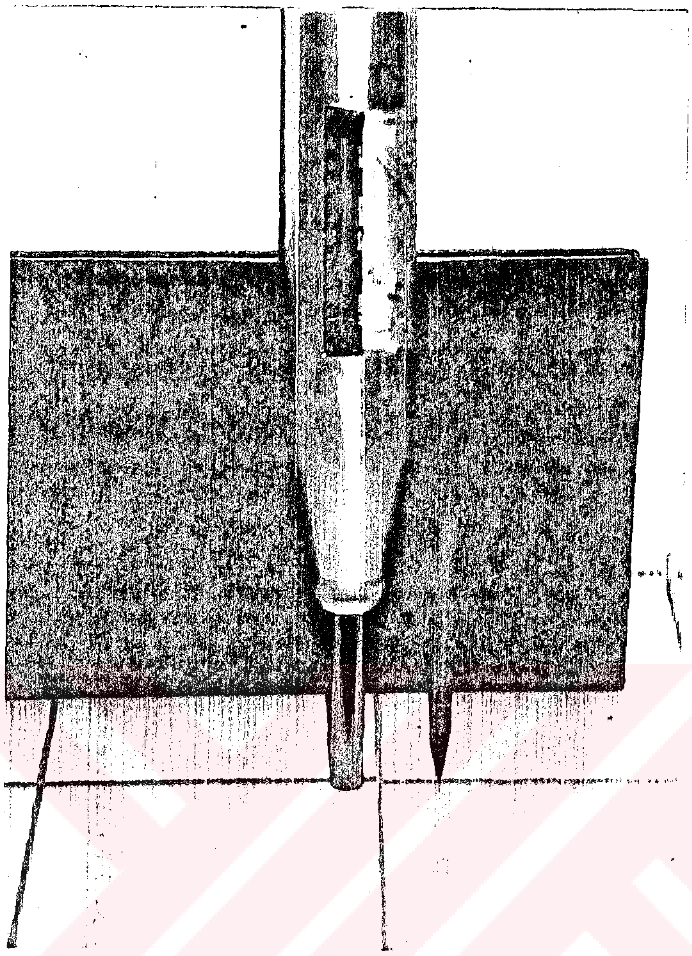


Figure 7.2.12 "N" Type Schmidt Hammer

The Impact Peneration Test

An impact penetrometer working according to the same principle as described by Hudson and Drew [11] was used throughout the site investigations. During the TRRL Tunnelling Trials at Chinnar it was necessary to characterize the tunnel face in terms of cuttability. A 76 mm hardened steel cone was fired into the chalk and the depth of penetration recorded. The resulting values of penetration strength were closely related to the cutting forces; the penetration strength profile and the cutting forces profiles around the pick cutting circle were very similar [11].

A commercially available impex penetrometer using explosives charge and a steel cone 43 mm long was used for indexing The Haliç Tunnel face by K. Sharriar [12]. The penetration depth was recorded at several points of the face and an average value for each zone was calculated. During the experimental test, it was noted that test results were greatly influenced by the discontinuity spacing and the strength of the rock formation. The same site test described above was also used in Baltalimanı in which a TBM is used. All test results are given in appendix 7

7.3 Relationship Between Rock Properties And Cutting Rate And Disc Consumption

7.3.1 Relationship Between Net Cutting Rate And Rock Properties

A) The Effect of Rock Compressive Srength And RQD on Net Cutting Rate

First, it was intended to find a relationship between net cutting rate (m/h) of TBM and compressive strength or the product of compressive strength with RQD as defined by BILGIN as rock mass cuttability index. A similar relationship is shown in figure 7.3.1.1 for The Eyüp Tunnel which is a part of Istanbul Sewerage Project [13]. This assessment is made for a boom tunnelling machine and taken from a technical paper written by BILGIN, SEYREK and SHAHRIAR

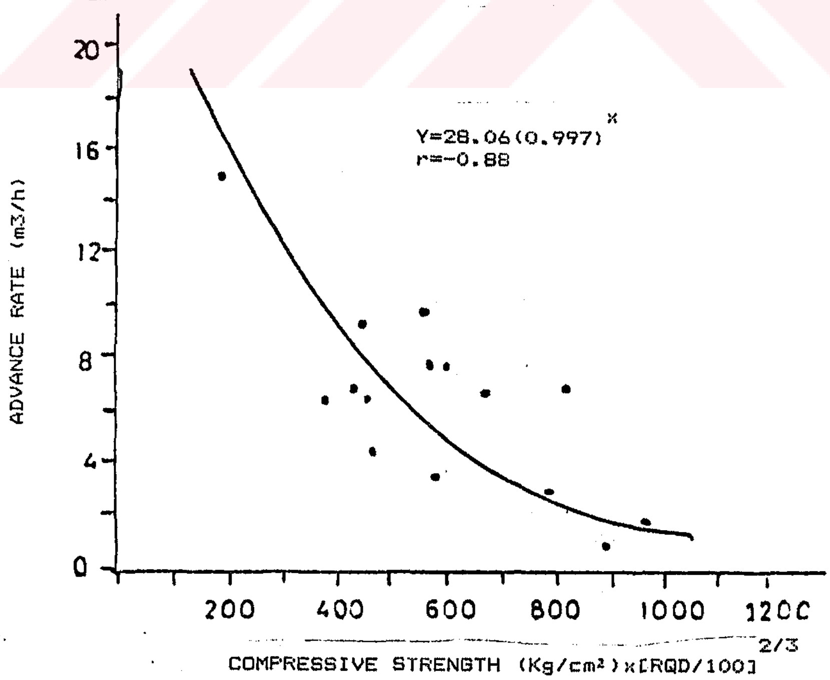
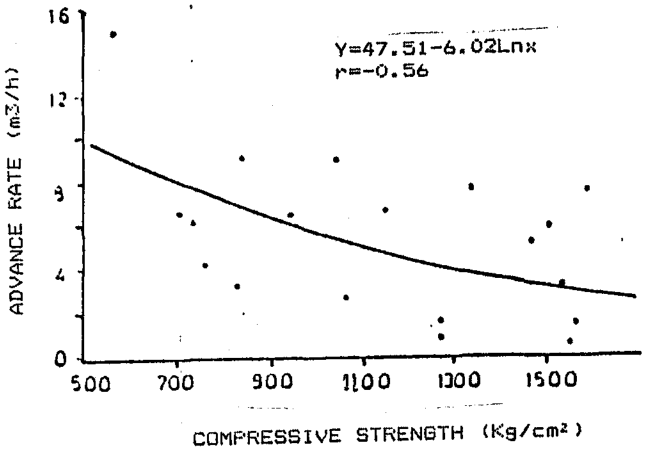


Figure 7.3.1.1 Relationship Between Advance Rate And The Product Of Compressive Strength With RQD [13]

As seen in figure 7.3.1.2.A, in highly fractured and jointed rocks, compressive strength does not give a good indication of rock machineability. However, if data is grouped according to RQD values greater than %50, the machine advanve rate may be reasonably predicted from compressive strength (figure 7.3.1.2.B). A detailed statistical analysis showed that rock mass cuttability index values, defined as the product of compressive strength x $RQD^{2/3}$, are more representative factors in predicting roadheader cutting rates (figure 7.3.1.1).

In order to see, if a same trend exists for full-face tunnelling machine, a similar statistical analysis to previous one was carried out for Baltalimani Tunnel. Bearing in mind that higher penetration rates are expected for high propel pressures; the acumulated data is grouped in two, one for propel pressures between 100-125 bars, and the second for 135-160 bars and so the statistical analysis is carried out for each group.



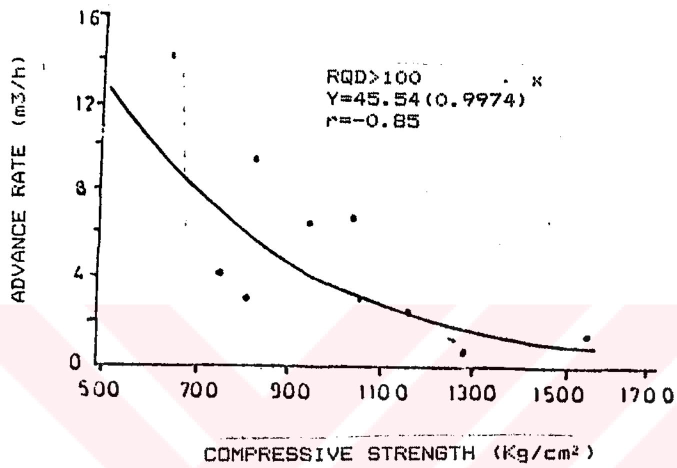
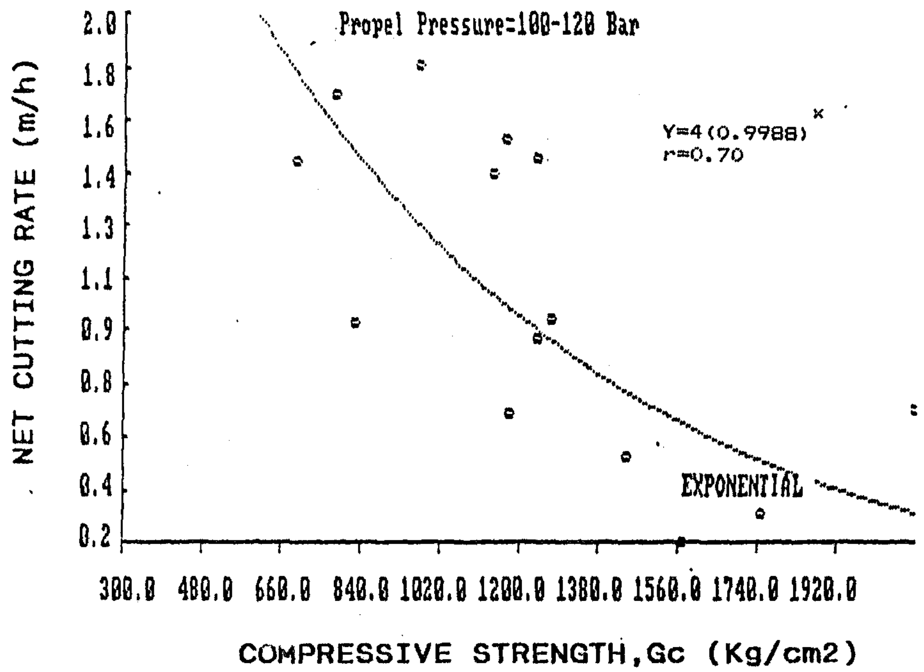


Figure 7.3.1.2 Relationship Between Advance Rate and Compressive Strength (for Eyüp Tunnel)

As seen in figure 7.3.1.3, there are statistically significant relationships between net cutting rates and compressive strength of the rock formations.

The relationship between net cutting rate and RQD values is also shown in figure 7.3.1.4. Correlation coefficient is not good as expected for roadheader machine in Eyüp Tunnel. (figure 7.3.1.5)



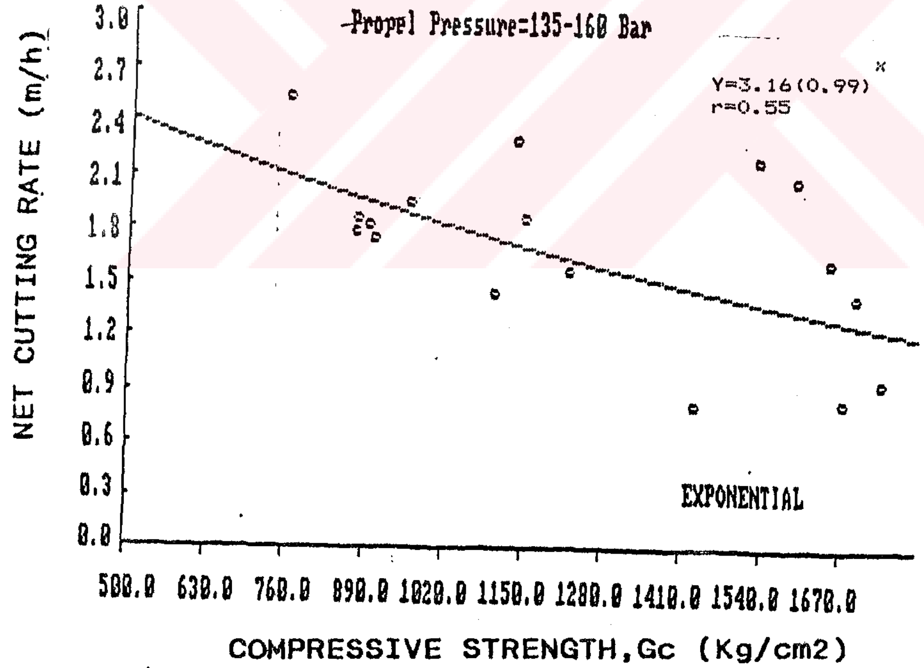
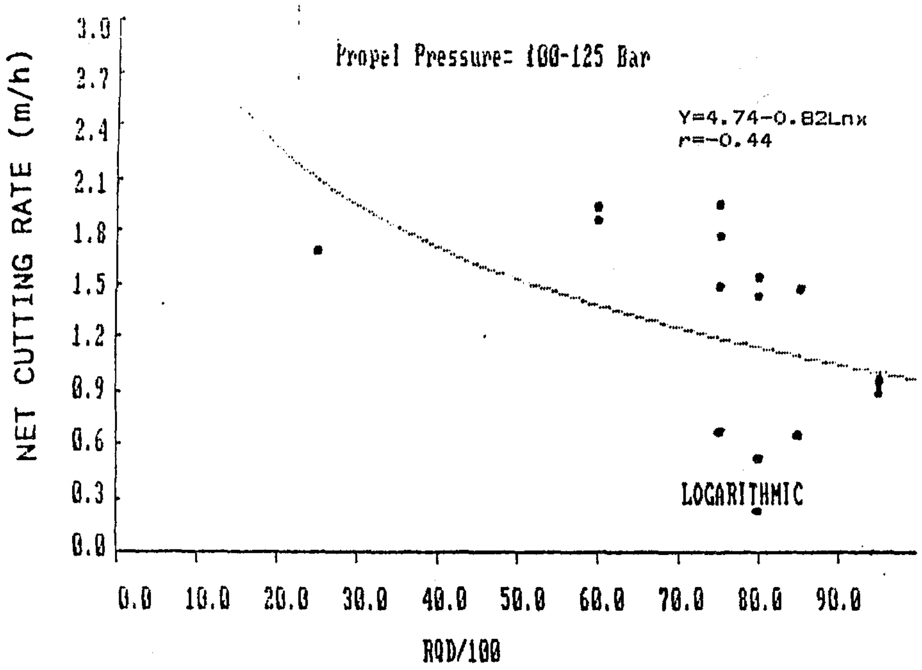


Figure 7.3.1.3 Relationship Between Net Cutting Rate And Compressive Strength (For Baltalimani Tunnel)



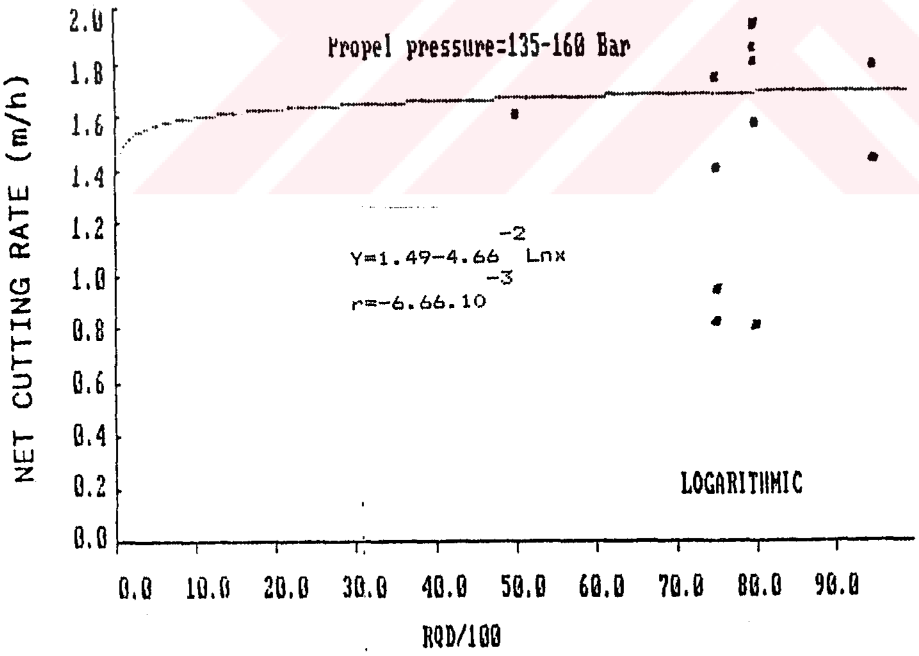


Figure 7.3.1.4 Relationship Between Net Cutting Rate And RQD (For Baltalimani Tunnel)

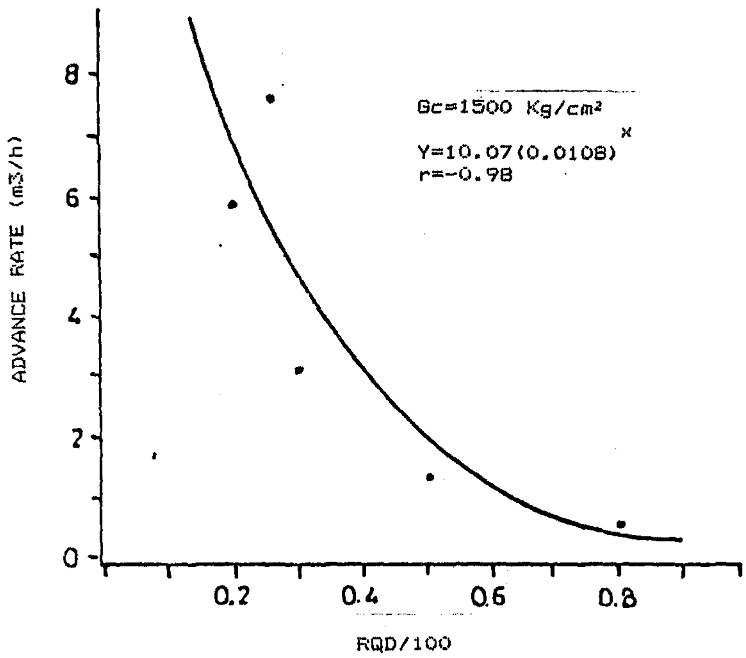
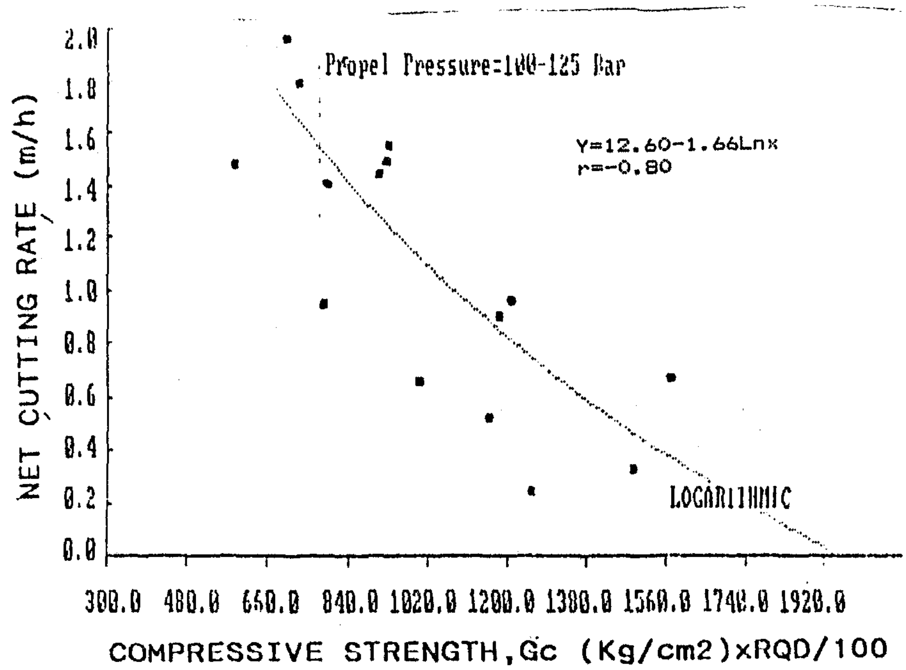


Figure 7.3.1.5 Relationship Between Net Cutting Rate and RQD (For Eyup Tunnel) [14]

However, it is important to note that better correlations are obtained if the compressive strength and RQD values are evaluated together. (see figure 7.3.1.6). The mathematical expressions obtained for each group data is found to be diffirent as expected.



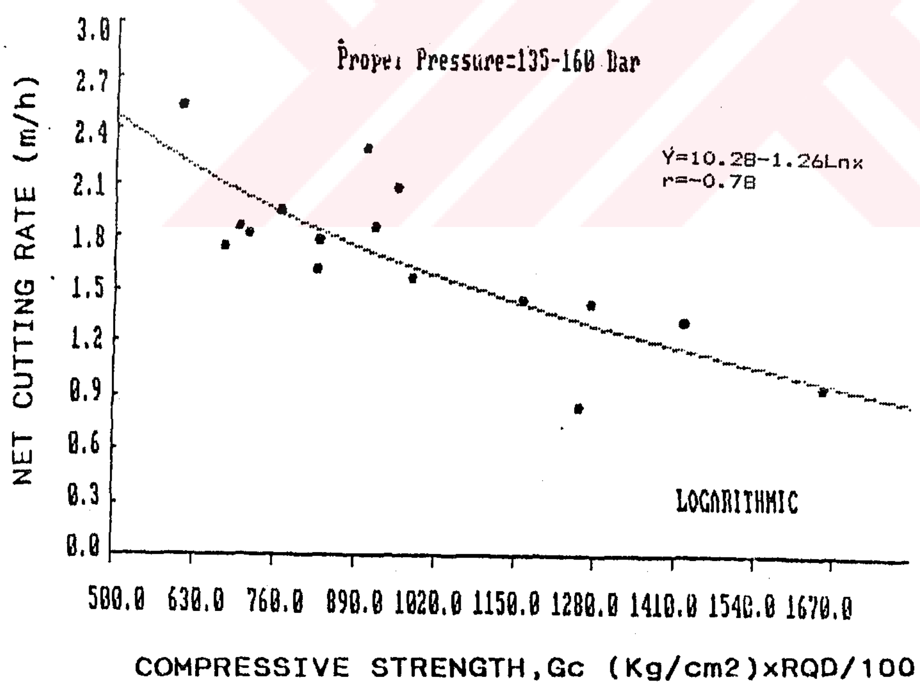
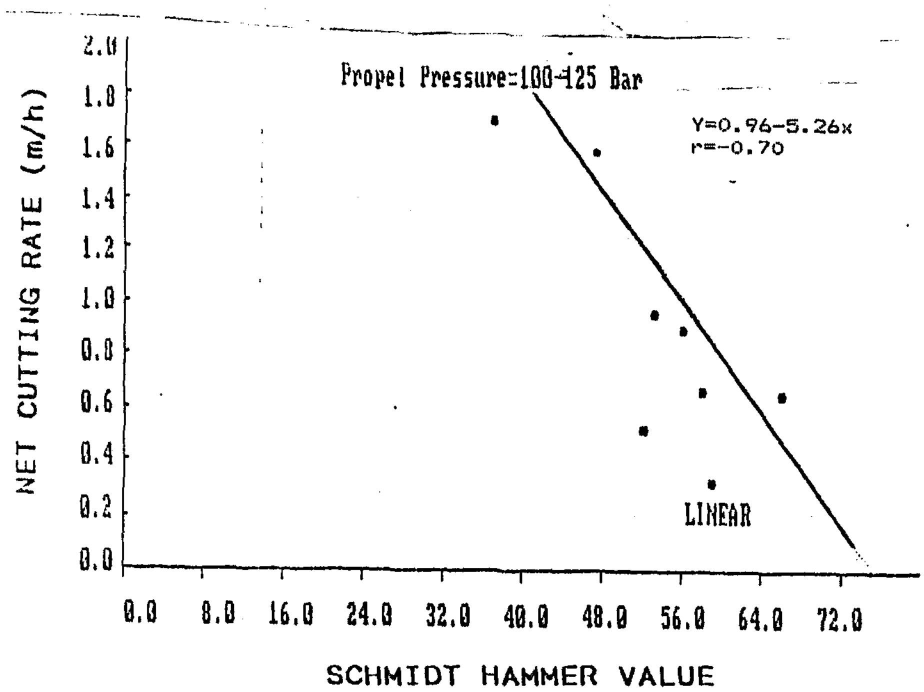


Figure 7.3.1.6 Relationships Between Net Cuting Rate and The Product of Compressive Strength with RQD (For Baltalimanı Tunnel)

B) The Effect Of Schmidt Hammer Values On Net Cutting Rate

The relationship between net cutting rate and schmidt hammer values, are shown in figure 7.3.1.7 and 7.3.1.8 The correlation coefficient for statistical expressions are not very good enough as expected from previous research results as given by BILGIN, SEYREK, ERDINC and SHAHRIAR [14] for Eyüp Tunnel (figure 7.3.1.9)



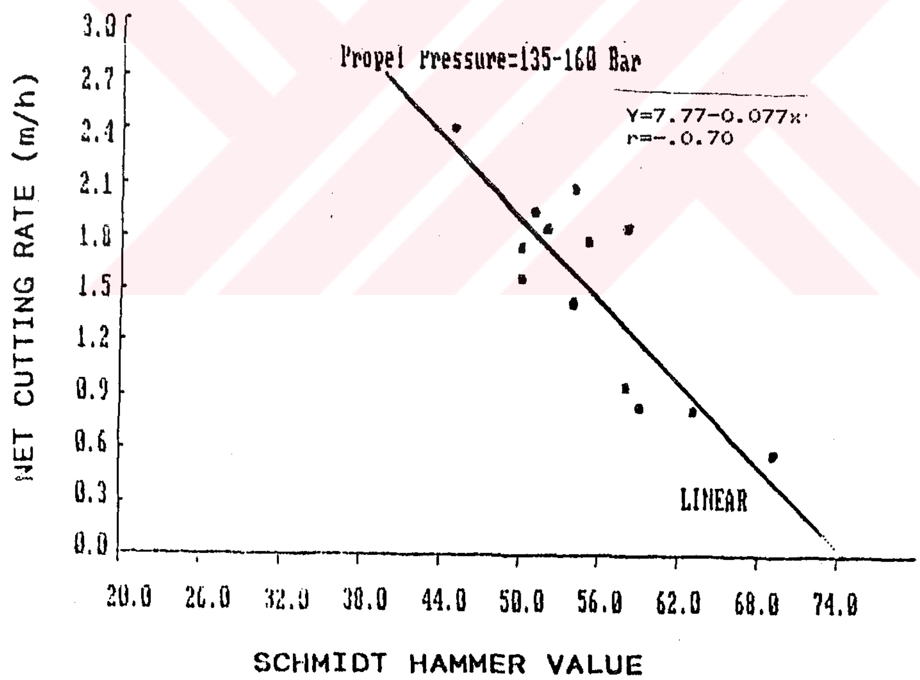
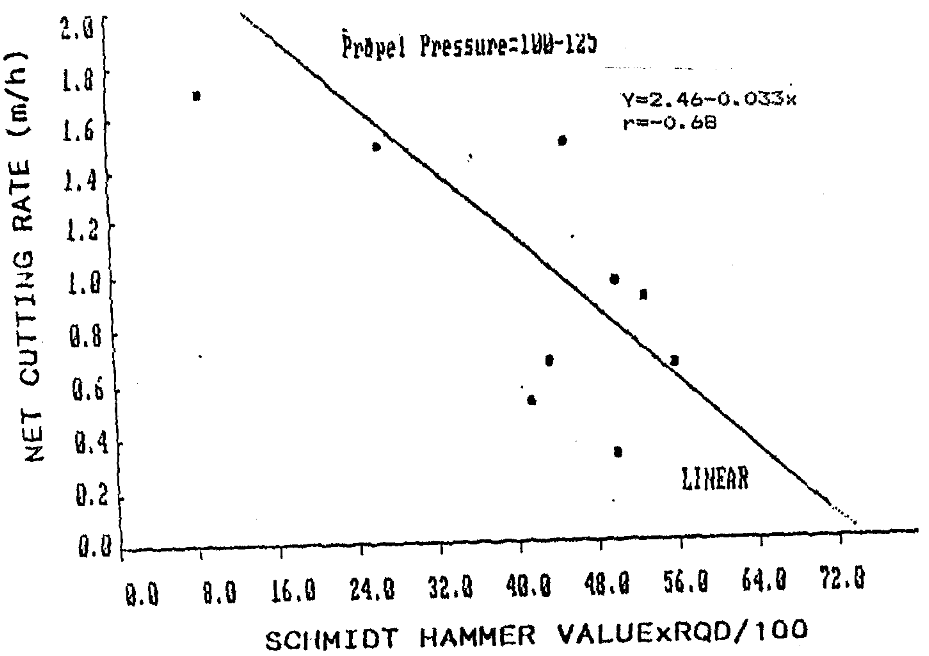


Figure 7.3.1.7 Relationship Between Net Cutting Rate and Schmidt Hammer Values (For Baltalimani Tunnel)



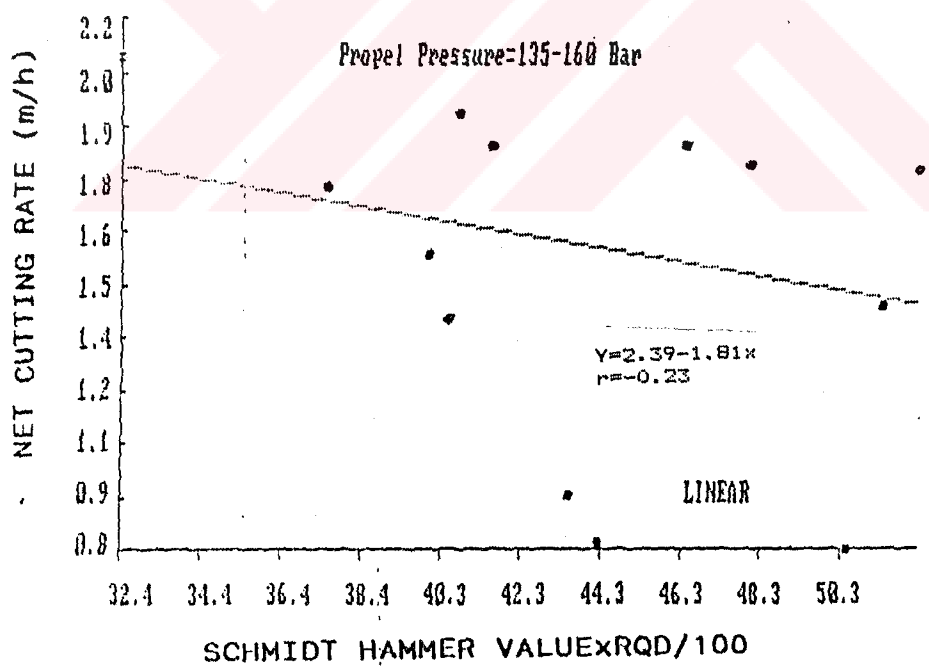
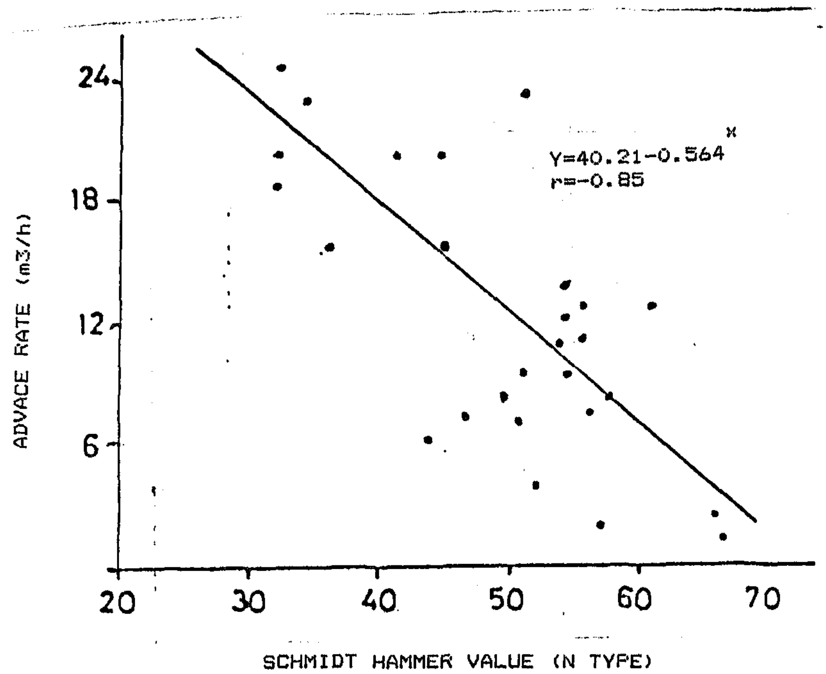
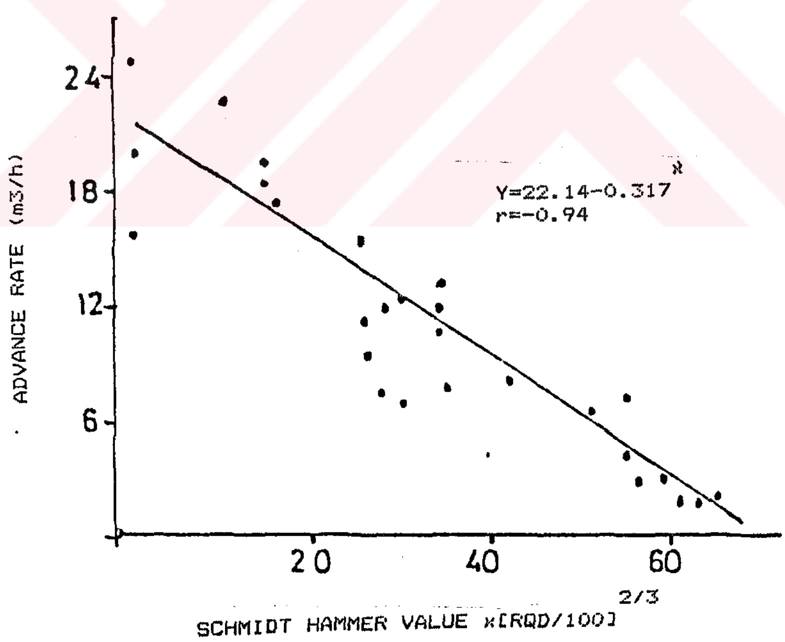


Figure 7.3.1.8 Relationship Between Net Cutting Rate and The Product Of Schmidt Hammer Value With RQD (For Baltalimani Tunnel)



(A)



(B)

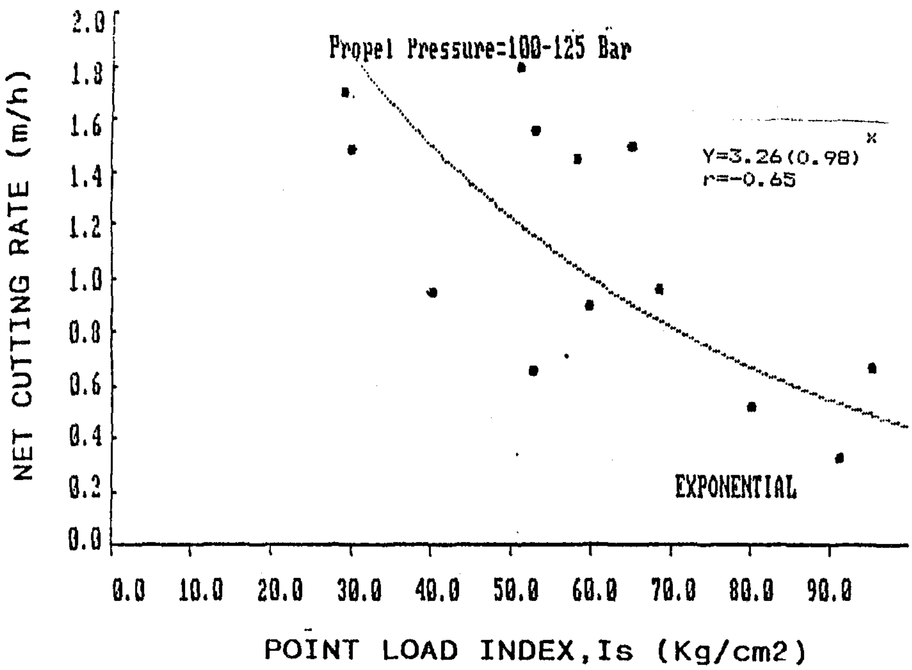
Figure 7.3.1.9 Relationship Between Advance Rate (m3/h) And (A) Schmidt Hammer Values (B) The Product Of Schmidt Values With RQD (For Eyüp Tunnel)

C) The Effect Of Point Load Index On Net Cutting Rate

In figure 7.3.1.10, relationship between point load index and net cutting rate of the machine is given. Correlation coefficients are good enough to predict TBM performance.

The relationship between net cutting rate and the product of point load index with RQD is also shown in figure 7.3.1.11

As seen in figure 7.3.1.11, relationship between net cutting rate and the product of point load index with RQD is more representative for the cutting rate of full-face boring machine(TBM).



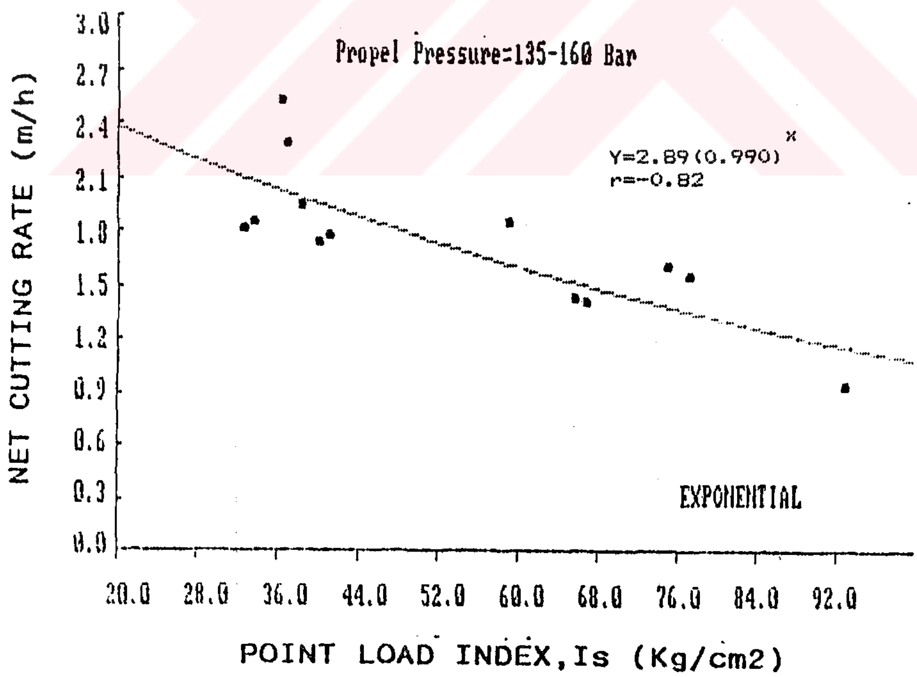


Figure 7.3.1.10 Relationship Between Net Cutting Rate And Point Load Index (For Baltalimanı Tunnel)

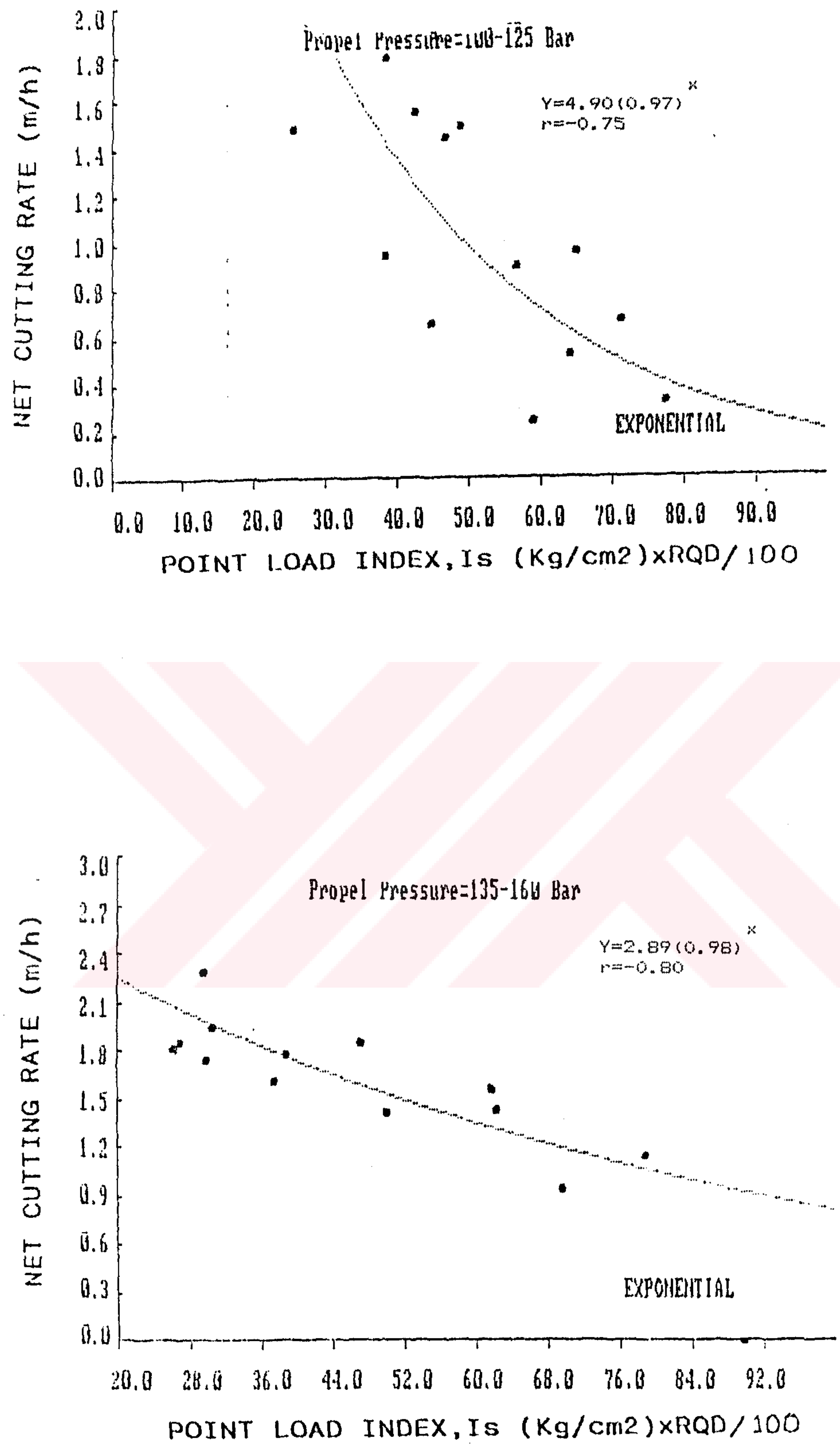


Figure 7.3.1.11 Relationship Between Net Cutting Rate And The Product Of Point Load Index With RQD (For Baltalimanı Tunnel)

D) The Relationship Between Net Cutting Rates And Impact Penetration Values

As stated in chapter 7.2, an impact penetration test was used to characterize rock formation in terms of cuttability. During the experimental tests, it was noted that, test results were greatly influenced by the strength of the rock formation. As seen in figure 7.3.1.12, a good relationship exists between compressive strength of rock and impact penetration values

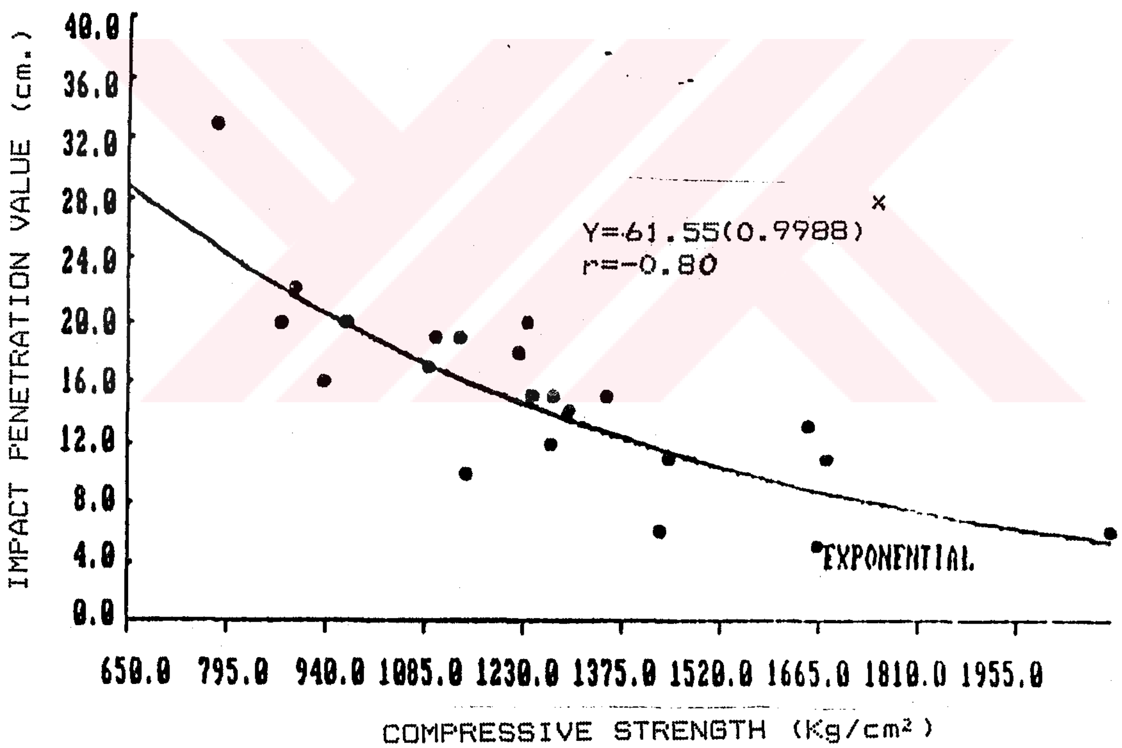


Figure 7.3.1.12 Relationship Between Compressive Strength And Impact Penetration Values (For Baltalimanı Tunnel)

However, it is interesting to note that, a similar relationship was found previously for Eyüp Tunnel As seen in figure 7.3.1.13 [13]. RQD values have also an effect on impact penetration values. Since RQD values are quite high in the rock formation tested for Baltalimanı Tunnel

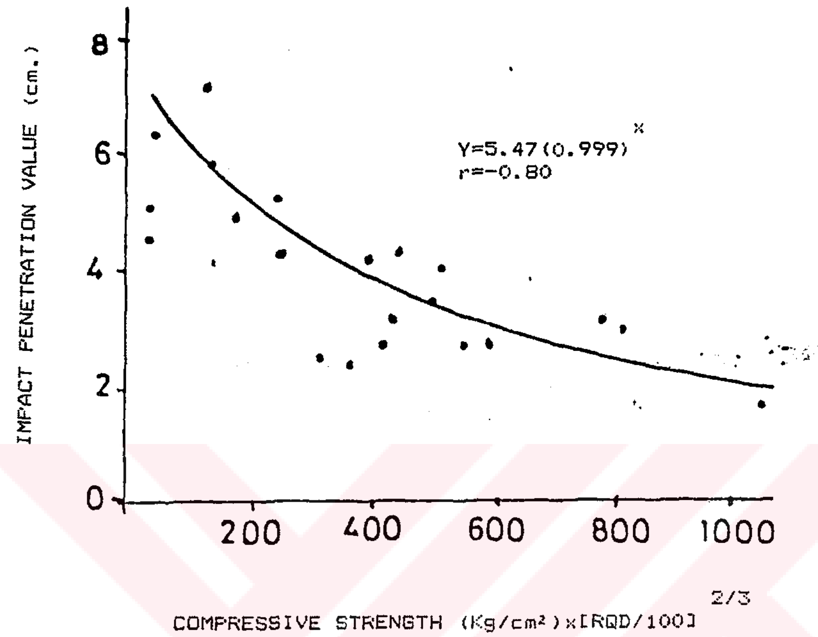
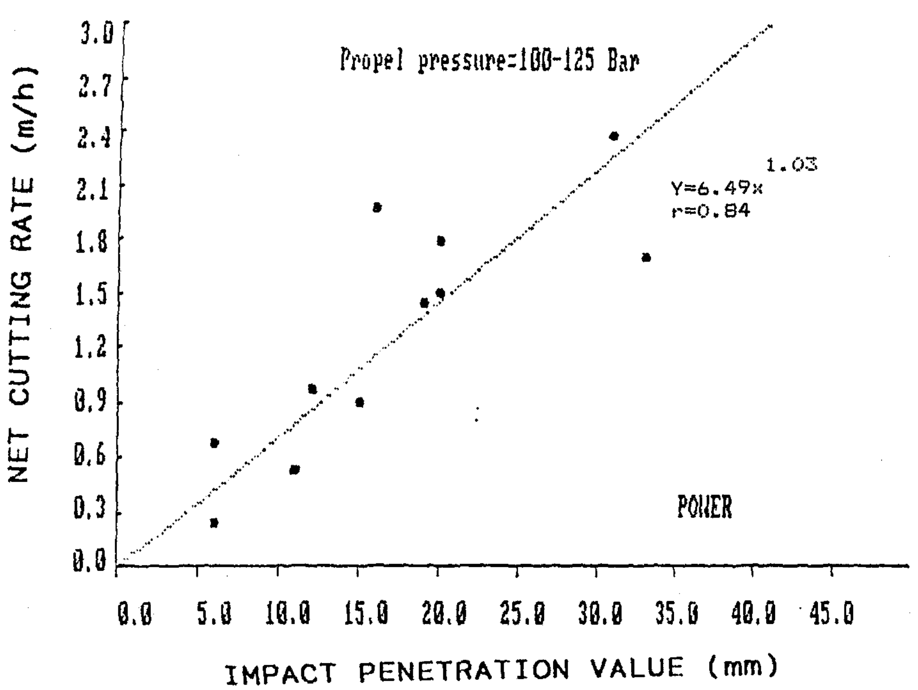


Figure 7.3.1.13 Relationship Between Compressive Strength And The Product Of Impact Penetration Values With RQD (For Eyüp Tunnel)

As seen in figure 7.3.1.14, The relationship between net cutting rate and impact penetration values is significant enough for any reliable prediction. In figure 7.3.1.15, a similar trend is given for Eyüp Tunnel.



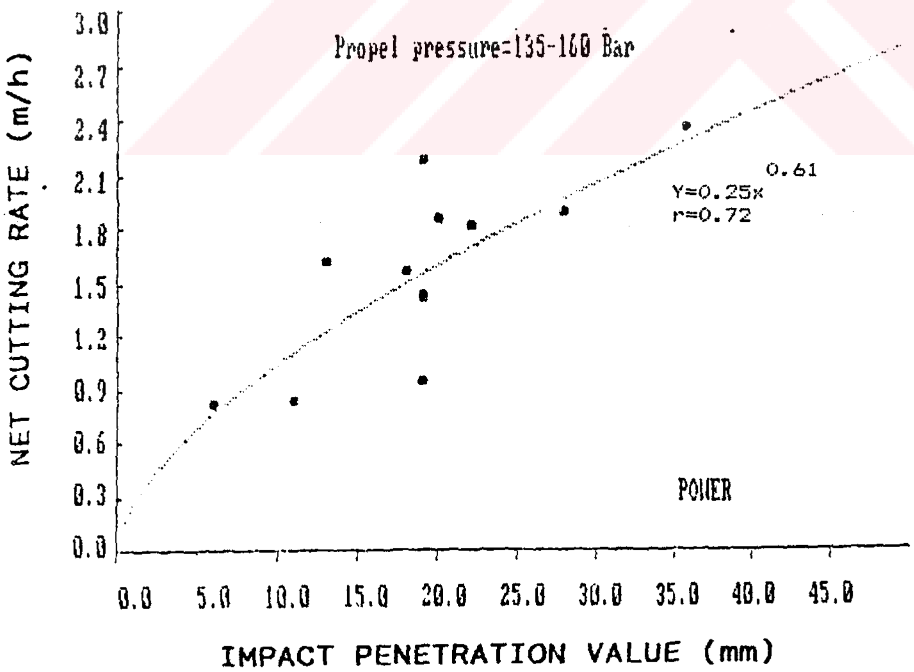


Figure 7.3.1.14 Relationship Between Net Cutting Rate And Impact Penetration Values (For Baltalimanı Tunnel)

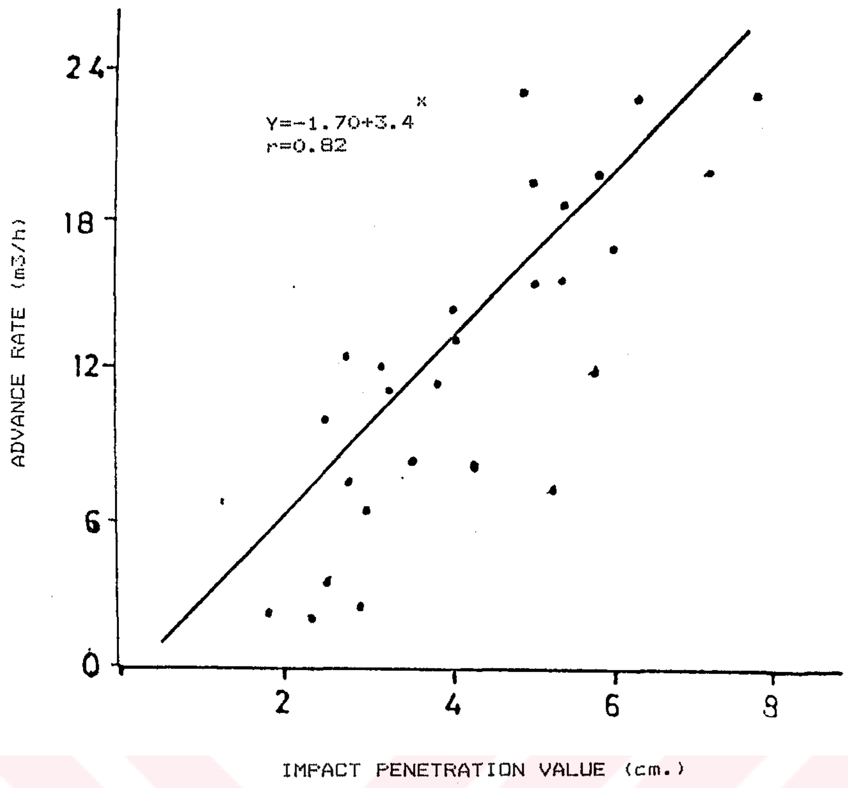
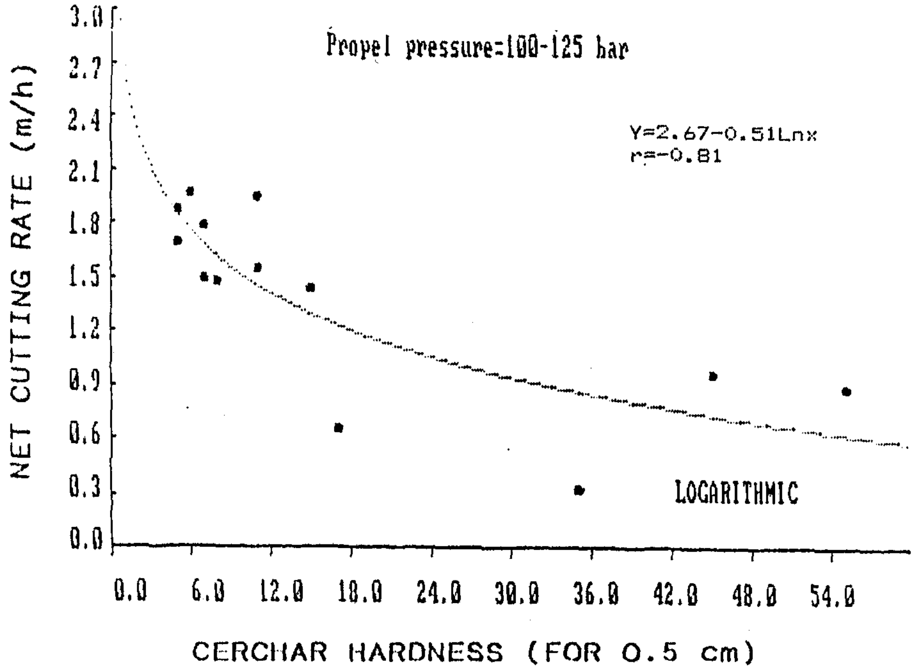


Figure 7.3.1.15 Relationship Between Advance Rates And Impact Penetration Values (For Eyüp Tunnel)

E) The Effect Of Cerchar Hardness On Machine Cutting Rate

Cerchar hardness test is orginally developed in Charbonnage de France to estimate the cuttability and drillability of rock formation, it is an easy and inexpensive test procedure to use.

As seen in figure 7.3.1.16 and 7.3.1.17, net cutting rate is related to cerchar hardness in a logoritmic manner for both test conditions.



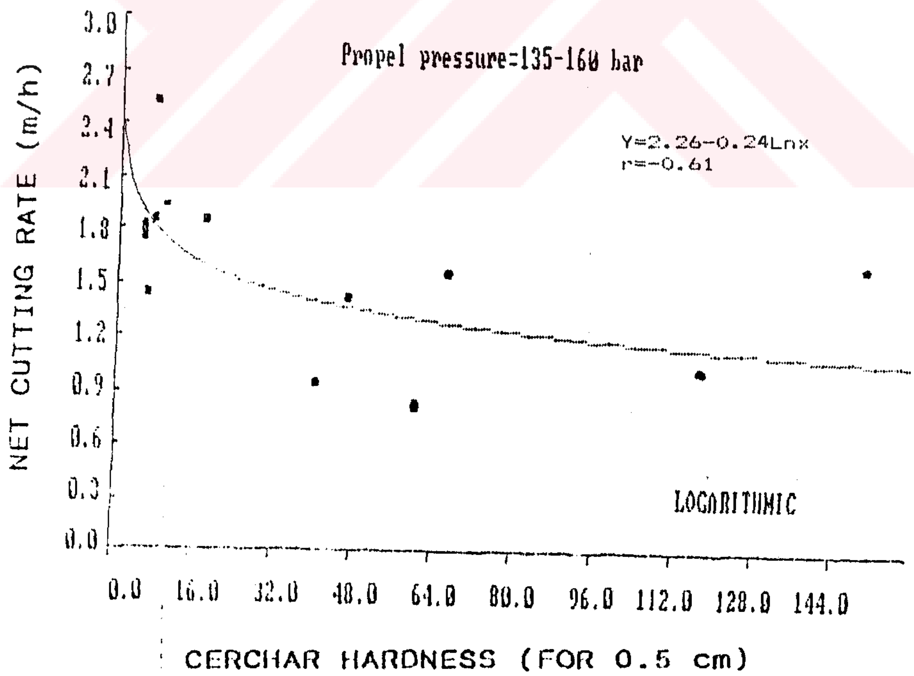
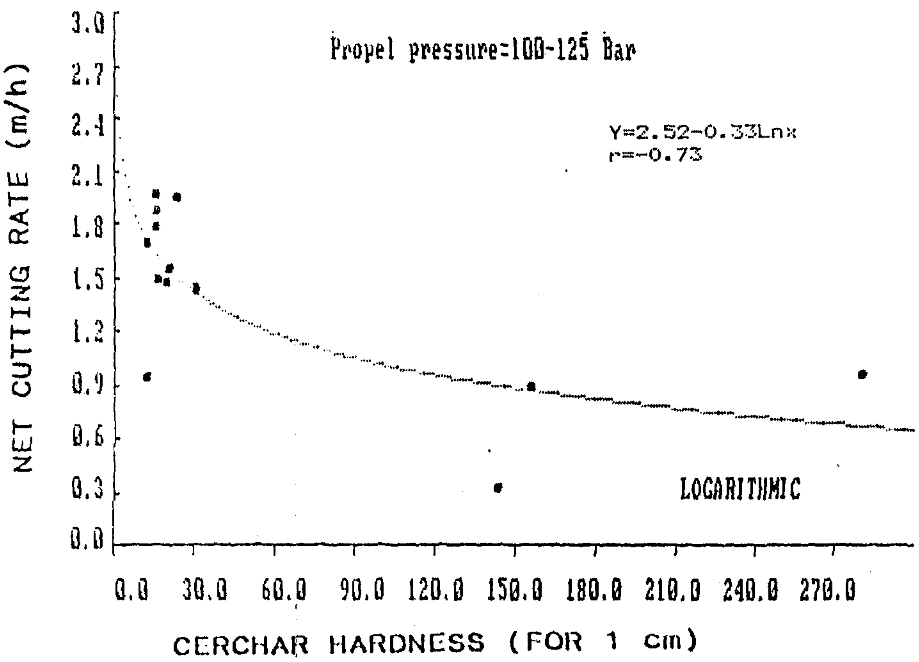


Figure 7.3.1.16 Relationship Between Net Cutting Rate And Cerchar Hardness (For 0.5 cm Drilling Depth)



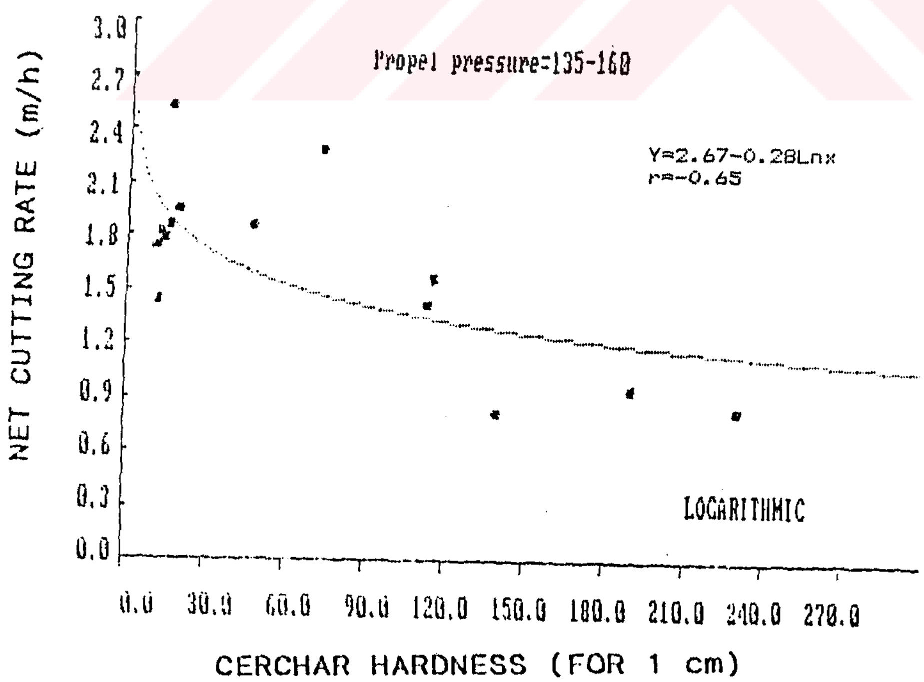


Figure 7.3.1.17 Relationship Between Net Cutting Rate And Cerchar Hardness (For 1 cm Drilling)

7.3.2 Relationships Between Disc Consumption And Rock Properties

As stated in chapter 6.5, disc wear was one of the major problems encountered, especially in Büyükada Formation. This also affected machine performance very much (see chapter 6.3 and 6.4)

Mechanized excavation with a full-face machine (TBM) involves the indentation of the rock face by an array of rolling disc cutting tools. Efficient excavation correlates the formation of large chips as the rock between cutting rolling paths is removed. The process of chip formation is affected by machine operating levels of thrust and torque, by disc cutter geometry, and by rock and rock mass properties. Rock communition is, however, a muttually destuctive action between the rock and cutter, and the indentation response of a given rock also affects the rate of cutter wear. For this reason, relationship between disc consumption (disc/m) and some rock properties were investigated carefully during the execution of the reseach program.

In table 7.3.2.1, disc consumption in Büyükada and Trakya Formation is summarized.

These cutter replacement records were taken between chainage 0+095 and 1+077 during the in-situ investigations, (683 m in Buyükada Formation an 297 m in The Trakya Formation). In order to calculate disc consumption, the following formula was used

$$\text{Disc consumption (disc/m)} = \frac{\text{number of cutters at certain chainages}}{\text{distance betweenthose chainages}}$$

Table 7.3.2.1 Summary Of Disc Consumption For TBM In Büyükada And Trakya Formation(Disc Consumption Per Metre)			
Position Of Disc Cutters	Disc No	Büyükada Formation; limestone, Nodular Limestone, Carboniferous shale	Trakya Formation; Greywacke, Shale Siltstone, Mudstone
Center	1-4	0.02	-
Face	5-26	0.05	-
Gage	27-35	0.04	0.01
Overall	1-35	0.11	0.01

In order to make comparison, some cutter wear records for different tunnels are compared in table 7.3.2.2. This comparison was made according to the average number of cutter replacement per 1000 m. of tunnel [15]

Table 7.3.2.2. Disc Consumption(Disc Number/1000 m.) For Different Tunnel In Some Countries

Tunnel	Tunnel Section	Rock Units Encountered	Position Of Cutters			
			Center	Face	Gage	All Cutters
Culver Goodman	Dansmore	Sandstone	4.46	4.30	10.3	5.97
	Goodman	Shale limestone	1.48	1.31	2.60	1.67
	Culver	Shale limestone	1.05	0.85	1.64	1.08
IC0011	Outbound	Dolostone	0.69	0.85	0.82	0.82
	Inbound	Dolostone	0.65	0.82	0.92	0.85
TARP	-	Dolostone	2.85	0.82	1.51	1.48
Kabatas Baltalimani	Baltalimani	limestone Carboniferous Shale	11	31	28	70

In the following table 7.3.2.3, the rolling distance of each disc cutter is also given in accordance with the revolution of the cutterhead, and table 7.3.2.4 summarizes the average rolling distance for each disc cutter in Baltalimanı Tunnel (for normal wear only, excluding bearing failure)

Table 7.3.2.3. Rolling Distance Of Disc Cutters

Disc Cutter No:	Cutting Radius Of Disc Cutter (cm)	Rolling Distance Of Disc Cutter At One Revolution (cm.)	Rolling Distance Of Disc Cutter At 1 Minute (cm.)	Revolution of Disc cutter at one revolution of cutterhead	Revolution Of Disc Cutter At 1 min
1	5.08	31.99	177.36	0.33	1.85
2	12.70	79.76	443.44	0.82	4.63
3	20.32	127.61	709.51	1.33	7.41
4	27.94	175.46	975.58	1.83	10.19
5	35.51	223.00	1239.90	1.80	10.00
6	43.26	271.67	1510.50	2.19	12.18
7	51.44	323.04	1796.12	2.60	14.48
8	59.97	376.61	2093.96	3.04	16.88
9	68.48	430.05	2391.10	3.47	19.28
10	76.96	483.31	2687.20	3.90	21.67
11	85.42	536.44	2982.59	4.33	24.05
12	93.85	589.38	3296.94	4.75	26.43
13	102.26	646.59	3595.03	5.21	28.99
14	110.97	696.89	3874.72	5.62	31.24
15	118.59	744.75	4140.78	6.00	33.39
16	126.59	794.99	4420.12	6.41	35.64
17	134.54	844.91	4697.71	6.81	37.88
18	142.39	894.21	4971.80	7.21	40.09
19	150.16	943.06	5243.11	7.60	42.27
20	157.78	990.86	5509.17	7.99	44.42
21	165.25	1037.77	5770.00	8.37	46.52
22	172.89	1085.75	6036.77	8.75	48.67
23	180.34	1132.54	6296.90	9.13	50.77
24	187.40	1176.87	6543.41	9.49	52.76
25	193.93	1217.88	6771.42	9.82	54.60
26	199.82	1254.87	6977.07	10.12	56.25
27	204.72	1285.64	7148.17	10.37	57.63
28	209.04	1312.77	7299.01	10.58	58.85
29	212.28	1333.12	7412.14	10.75	59.76
30	215.86	1355.60	7537.14	10.93	60.77
31	218.90	1374.69	7643.29	11.08	61.62
32	220.34	1383.74	7653.97	11.16	62.03
33	222.07	1394.60	7753.98	11.24	62.52
34	223.59	1404.15	7807.05	11.32	62.94
35	224.99	1412.94	7855.93	11.39	63.34

Table 7.3.2.4. Avarage Rolling Distances For All Cutters In Baltalimanı Tunnel

Disc No:	Position Of Disc Cutter	Average Distance (m.)	Average Rolling Distance
1	Center	105.00	61195
2		206.00	42705
3		535.00	587296
4		100.00	53516
5	Face	248.00	147608
6		248.00	179380
7		248.00	213800
8		411.50	434597
9		411.50	497012
10		248.00	319708
11		411.50	619582
12		411.50	680791
13		411.50	746674
14		411.50	804467
15		411.50	859947
16		411.50	917739
17		490.00	982245
18		411.50	1033323
19		411.50	1089950
20		411.50	1144284
21		324.00	763103
22		248.00	718184
23		248.00	749295
24		248.00	778419
25		327.00	973626
26		248.00	830049
27	Gage	19.10	430940
28		222.60	766155
29		128.00	473357
30		148.50	439376
31		186.00	541921
32		248.00	915437
33		148.50	452023
34		245.00	815412
35		19.10	568694

Table 7.3.2.5 summarizes the average rolling distances of center, face and gauge cutters in diffirent tunnels including Baltalimanı Tunnel [15].

The average rolling distance corresponds to the average distance traveled before the replacement, and is equal to the circumference of the cutter travel path multiplied by the number of times that the cutterhead was rotated after the cutter was installed. The number of rotation determined as the ratational rate of the cutterhead multiplied by the clock time elapsed after the installation of the cutters.

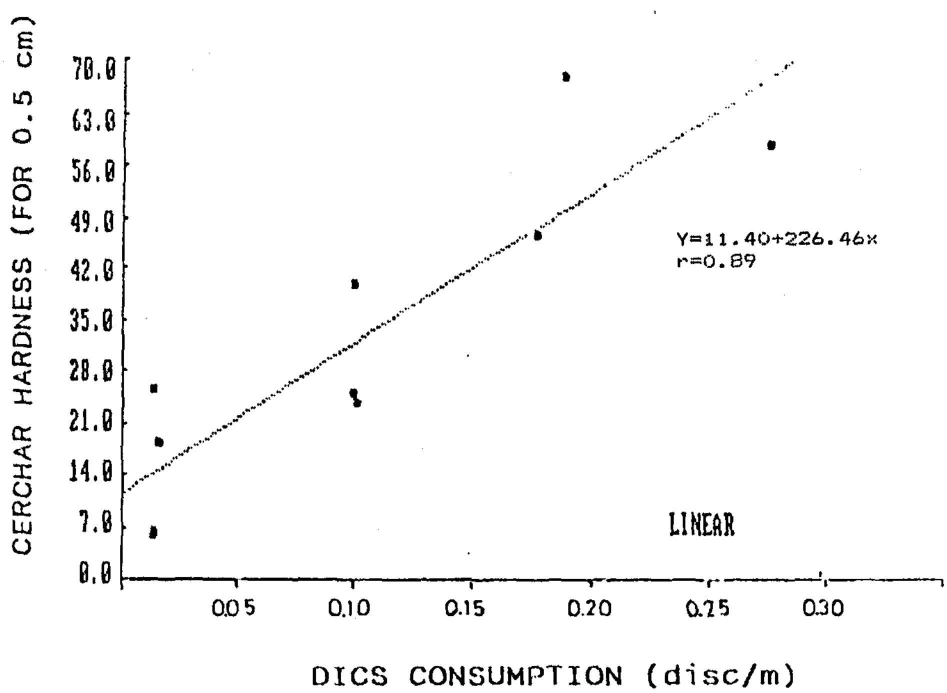
Table 7.3.2.5. Average Rolling Distance Of Disc Cutters In Different Tunnels

$\times(10^6$ m.)

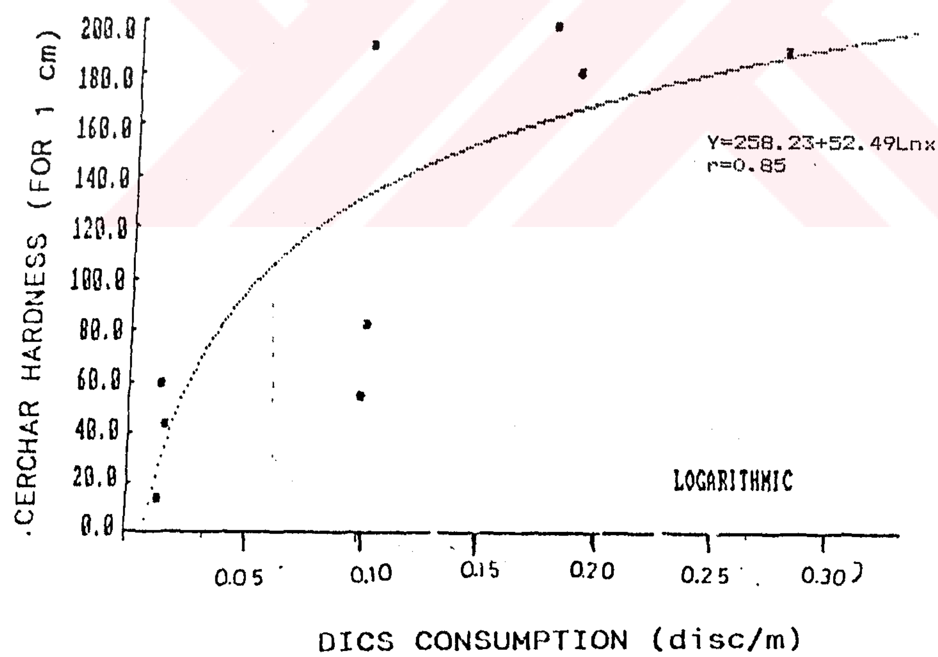
Tunnel	Tunnel Section	Rock units Encountered	Position of Cutters			
			Center	Face	Gage	All cutters
Culver Good-man	Dansmore	Sandstone	0.03	0.29	0.23	0.24
	Goodman	Shale limestone	0.08	0.91	0.86	0.82
	Culver	Shale limestone	0.12	1.34	1.32	1.24
IC0011	Outbound	Dolostone	0.21	1.49	2.57	1.69
	Inbound	Dolostone	0.20	1.43	2.37	1.66
TARP	-	Dolostone	0.05	1.42	1.47	1.14
Kaba-tas Balta-limani	Balta-limani	limestone Carbonife-rous	0.18	0.70	0.60	0.50

All correlation coefficient found for relationships between disc consumption and rock properties are significant to predict disc consumption in the range of geological formations encountered during the tunnel derivage. The highest correlation coefficient was found for cerchar hardness (see figure 7.3.2.1)

Relationship between disc consumption and other rock properties are given in figure 7.3.2.2 and 7.3.2.3. Correlation coefficients are good enough to predict disc consumption by using rock properties such as compressive strength, point load index, cone indenter index and schmidt hammer value.

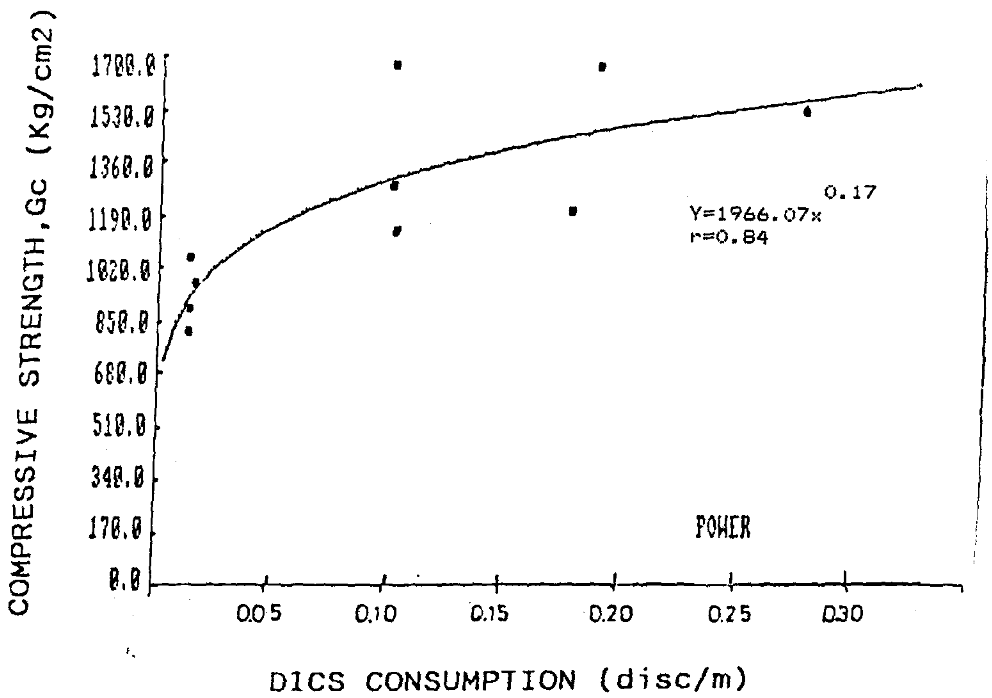


(A)

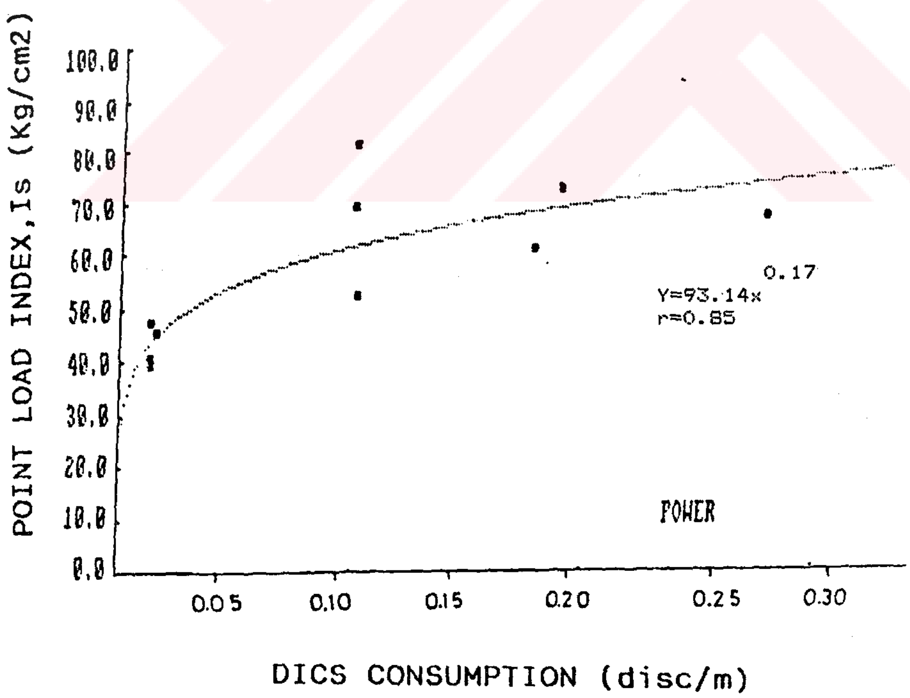


(B)

Figure 7.3.2.1 Relationship Between Disc Consumption And Cerchar Hardness Of Rock (A) For 0.5 cm. Drilling Depth (B) For 1 cm. Drilling Depth

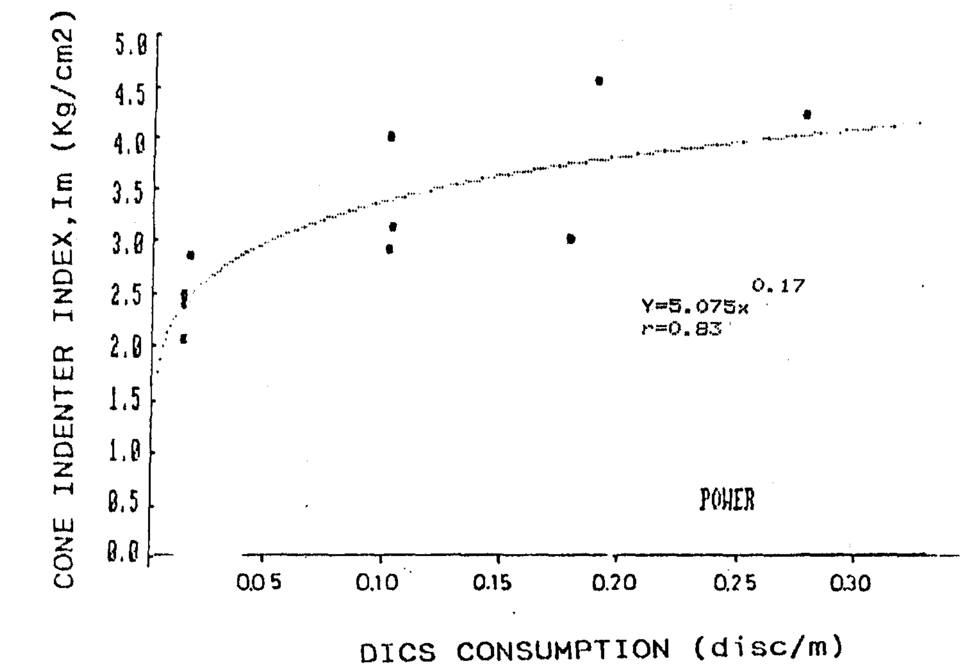


(A)

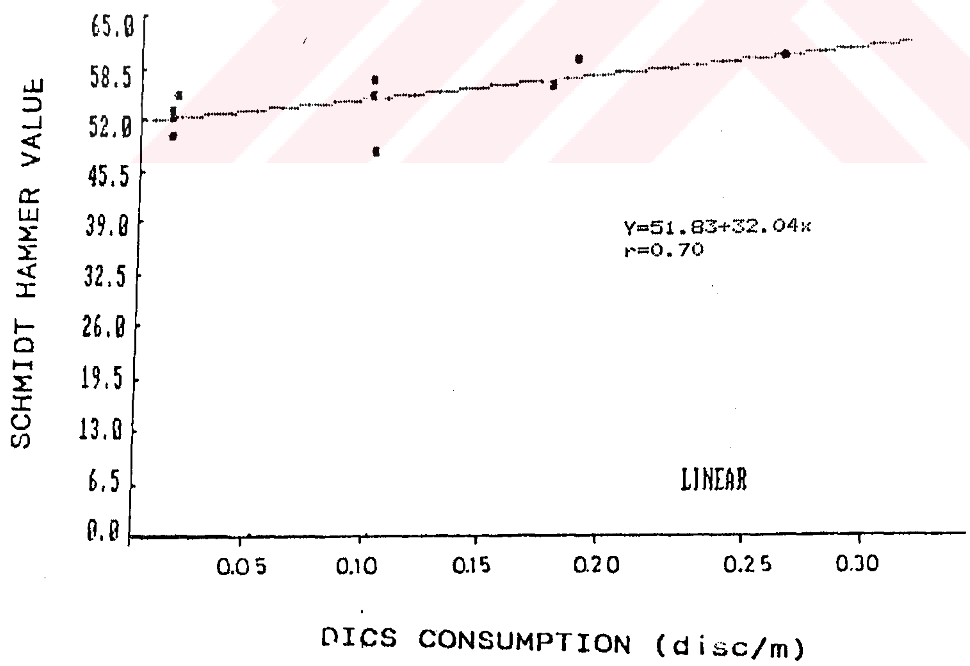


(B)

Figure 7.3.2.2 Relationship Between Disc Consumption And (A) Compressive Strength (B) Point Load Index



(A)



(B)

Figure 7.3.2.3 Relatinship Between Disc Consumption And (A) Cone Indenter Index (B) Schmidt Hammer Value

7.4 Effect Of Thrust Force On Machine Penetration Rate

In the applictions of TBM, peneration rate is used both to estimate the time required to complete a given tunnel and to evaluate the feasibility of machine boring in a specified geological environment.

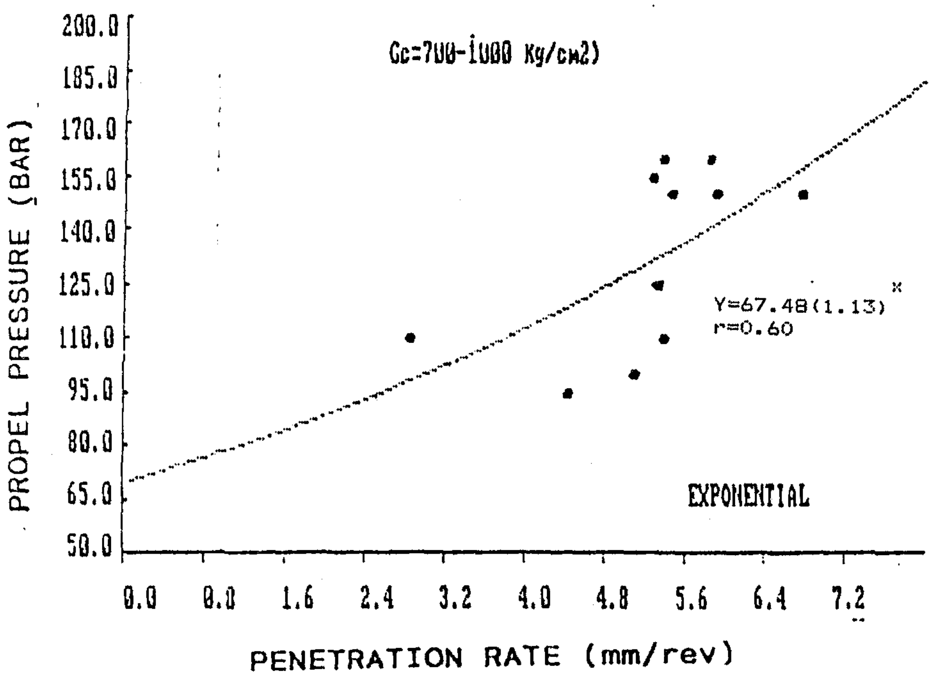
In order to investigate the effect of propel pressure on penetration rate in Baltalimanı Tunnel where a full-face machine is used, the accumulated data is grouped in three categories, first for compressive strength of 700-1000 kg/cm² second for compressive strength of 1000-1300 kg/cm² and third for 1300-1700 kg/cm² of rock strength.

The relationship between penetration rate of full-face machine and propel pressure is shown in figure 7.4.1. and figure 7.4.2

In the graphs, thrust force was also taken into account. In table 7.4.1, theorical and actual thrust force applied by propel clynders are shown. Actual Thrust force is approximately %40 of theorical thruft force. This value is obtained by means of in-situ observations.

Table 7.4.1 Theorical And Actual Thtrust Forces

Propel Pressure (Bar)	Theorical Thrust Force (ton)	Actual Thrust Force (ton)
50	127	90
65	165	120
80	203	145
95	241	172
110	279	200
125	317	226
140	356	254
155	394	281
170	432	309
185	470	336
200	508	363



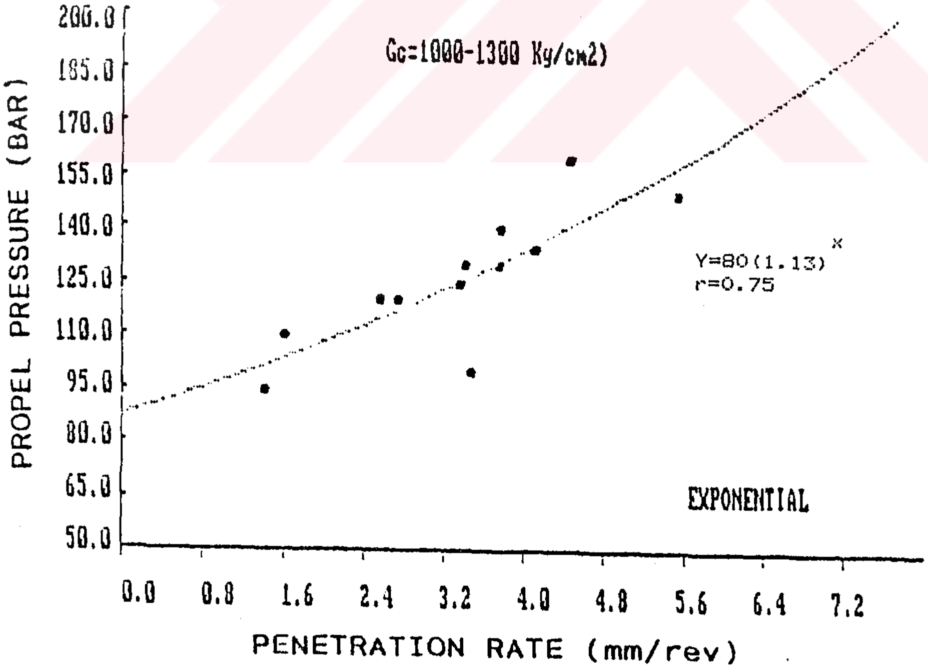


Figure 7.4.1 Relationship Between Penetration Rate And Propel Pressure

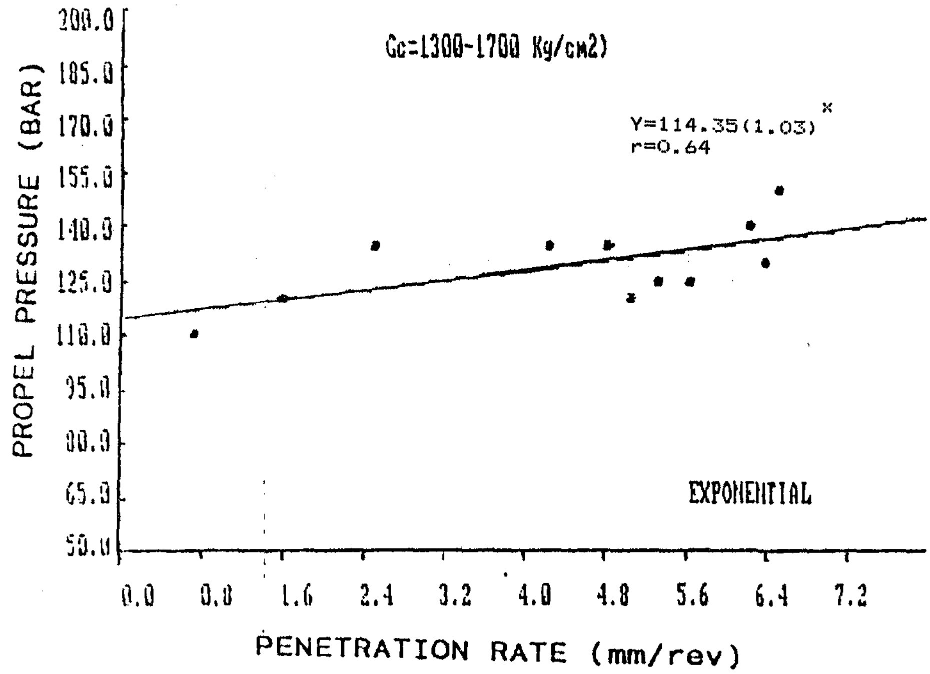


Figure 7.4.2 Relationship Between Penetration Rate And Propel Pressure

CHAPTER 8 CONCLUSIONS AND RECOMMANDATIONS

8.1 Conclusions

A Robbins full-face tunnel boring machine (type 145-168) was used in Baltalimanı Tunnel which is a part of Istanbul Sewerage Project.

Along the tunnel line, two geological formations, "Büyükada and Trakya Formations" exists. Büyükada Formation consists of limestone, nodular limestone, carboniferous shale and Trakya Formation consists of greywacke,shale-siltstone and mudstone.

Büyükada Formation is strongly folded, little jointed and has a massive appearance. The joints are generally vertical to bedding. However, Trakya Formation is closely jointed and strongly folded. During the excavation through Trakya Formatio, collapses occured due to highly jointed and folded rock mass conditions.

In this investigation, the performance of a full-face tunnellıng machine was investigated in two diffirent geological formation as stated above. Machine Utilization is found to be %28.5 in Büyükada Formation and less than %10 in Trakya Formatiom.Excessive disc wear, supporting works and bad ground conditions were the reasons for low machine utilization time. Especially, in Trakya Formation, supporting of the caverns due to the collapses took %74 of machine downtime. Disc changing and supporting works were the main reasons of machine downtime in Büyükada Formation. Difficulties encountered in both geological are explained in detail in chapter 6.5.1. and 6.5.2.

The comparison of machine performance in both geological formation is given in table 8.1.1.

Table 8.1.1. Machine Performance In Büyükada and Trakya Formation

	BÜYÜKADA FORMATION	TRAKYA FORMATION
Machine Utilization(%)	28.50	7.40
Machine Downtime(%)	71.50	92.60
Net Cutting Rate(m/h)	1.22	1.70
Average Monthly Advace(m.)	197	84
Average Weekly Advance(m.)	43	21
Average Daily Advance(m.)	7.18	3.12

In order to determine rock properties, the following insitu and laboratory tests were carried out in-situ tests

-Schmidt Hammer, sh

-Impact Penetration, Ip (mm.)

-The measurement of RQD

Laboratory tests

-Point Load Index, Is, kg/cm²

-Cone Indenter Index, Im, kg/cm²

-Cerchar Hardness Test, C(1) and C(0.5)

-Compressive Strength derived from point load and indenter indexes; Gc, kg/cm²

Tests results in diffirent rock unit are summarized in table 8.1.2.

Table 8.1.2. Test Results In Diffirent Rock Units In Baltalimanı Tunnel

Rock Units	Point Load Index kg/cm² Is	Cone Indenter Index kg/cm² İm	Cerchar Hardness		Schmidt Hammer Sh	Impact Penet-ration value (mm)	Comp. Strgt. Kg/cm²
			C(0.5)	C(1)			
Lime-stone	29 93	2 5.83	5 55	12 280	37 61	6 33	779 2094
Dia-base	52 91	3.33 4.19	17 75	39 143	54 56	5 6	1175 1746
Silt-stone	30 53	1.93 2.58	5 11	9 20	50 60	16 22	692 1166
Sand-stone	41 75	3.14 5.25	5 19	15 38	44 52	-	1060 545

Some relationship between net cutting rate, disc consumption and rock properties were also investigated. Correlation coefficients found are significant enough to predict the machine performance in the rock formation having similar properties.

The statistical relationships obtained between machine cutting rate and rock properties are as follows :

Table 8.1.3. Correlations Expressions

	100-125 bar propel pressure	135-160 bar propel pressure
Net Cutting Rate	12.60 -1.66(GcxRQD/100) r=-0.80	=10.78 -1.26ln(GcxRQD/100 r=-0.78
Net Cutting Rate	3.96-5.26xSh r=-0.70	=5.77-0.077xSh r=-0.70
Net Cutting Rate	$4.90 \times (0.97)^{(Is \times RQD/100)}$ r=-0.75	$=2.89 \times (0.98)^{(Is \times RQD/100)}$ r=-0.80
Net Cutting Rate	$6.49 \times (Ip)^{(1.03)}$ r=-0.84	$=0.25 \times (Ip)^{(0.61)}$ r=-0.72
Net Cutting Rate	2.67-0.51ln[C(0.5)] r=-0.81	=2.26-0.24ln[C(0.5)] r=-0.61
Net Cutting Rate	2.52-0.33ln[c(1)] r=-0.73	=2.67-0.28ln[C(1)] r=-0.65

Expressions found to predict disc consumption are as follows,

Disc Consumption=11.40+226.46xC(0.5) r=0.89

Disc Consumption=258.23+52.49xC(1) r=0.85

$\text{Disc Consumption}=1966.07 \times (Gc)^{0.17}$ r=0.84

$\text{Disc Consumption}=93.14 \times (Is)^{0.17}$ r=0.85

$$\text{disc Consumption}=5.075\times(Im)^{0.17} \qquad r=0.83$$

$$\text{Disc Consumption}=51.83+32.04(Sh) \qquad r=0.70$$

8.2 Recommendations

During the excavation through Büyükada and Trakya Formation, many problems were encountered, especially due to bad rock conditions, such as hard rock and faulty zones in Büyükada Formation, highly jointed, fractured and altareted rocks and faulty zones in Trakya Formation.

These geological formations caused the machine performance to decrease very much. The machine utilization time found in both formation are too low. It is strongly recommended to use roadheaders with shield in rock conditions similar to ones in Trakya Formation and probably conventional drilling and blasting techniques in very hard massive rock. Mixshield TBM could be also used in such rock conditions.

In appendix 8 and 9, some geological difficulties and the precaution to be taken are summarized [16]

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APPENDIX

APPENDIX 1

Summary Of Machine Performance In Büyükada Formation

Week No	01	02	03	04	05	06
Date 1990	30/04 05/05	06/05 12/05	14/05 19/05	25/05 26/05	28/05 02/06	04/06 09/06
Support (hr)	-	-	20	53.07	38.29	9.91
Chainging of cutters (hr)	13.32	22.58	15.92	-	6.00	-
Disc cutter control (hr)	6.73	6.52	5.08	-	3.25	2.82
Mucking and waitting for wagons (hr)	5.50	18.31	24.81	-	20.74	23.14
Maintance (hr)	2.76	-	-	-	-	1.25
Belt conveyor (hr)	1.00	-	-	-	-	1.08
Crane failure (hr)	11.63	12.50	2.00	-	9.84	37.99
Ground condition (hr)	-	-	4.50	47.01	-	-
Ventilation problem (hr)	-	0.75	-	-	-	1.00
Electrical (hr)	-	-	5.16	-	-	3.67
Mechanical (hr)	-	12.00	0.75	-	2.00	4.75
Other reason (hr)	-	1.58	11.49	10.98	2.88	23.08
Weekly working time (hour)	60	120	120	120	120	144
Actual time(hr)	19.06	45.76	30.29	8.94	37.00	35.31
Weekly advance (m)	20.20	29.31	48.37	15.54	52.04	44.60
Avaradge daily advance (m)	3.37	4.88	8.06	2.59	8.67	7.43
Avaradge shift advance (m)	3.37	2.44	4.03	1.30	4.34	2.47
Net cutting rate (m/h)	1.23	0.70	1.64	1.85	1.41	1.37

CONTINUED FROM APP. 1

Summary Of Machine Perfomance In Büyükada Formation

Week No	07	08	09	10	11	12
Date 1990	11/06 16/06	18/06 23/06	25/06 30/06	02/07 07/07	09/07 14/07	16/07 21/07
Support (hr)	11.00	–	16.00	H	S	–
Chainging of cutters (hr)	1.00	25.64	62.50		T	52.86
Disc cutter control (hr)	1.68	4.46	4.00	O	O	3.50
Mucking and waitting for wagons (hr)	26.59	25.41	9.43		P	10.07
Maintance (hr)	7.19	4.00	5.92		I	2.48
Belt conveyor (hr)	–	–	–	L	N	1.90
Crane failure (hr)	–	2.00	–		G	–
Ground condition (hr)	5.00	–	–	I	I	–
Ventilation problem (hr)	–	–	–		O	–
Electrical (hr)	–	–	4.00		F	–
Mechanical (hr)	23.99	17.17	6.45	D		–
Other reasons (hr)	39.73	4.50	1.50			2.50
Weekly working time (hour)	152	144	144	A	W	120
Actual time(hr)	35.82	60.82	34.20		O	46.69
Weekly advance (m)	63.14	63.98	18.10		R	9.95
Avaradge daily advance (m)	10.52	10.66	3.02	Y	K	1.66
Avaradge shift advance (m)	3.50	3.55	1.00			0.83
Net cutting rate (m/h)	1.95	1.14	0.61			0.25

CONTINUED FROM APP. 1

Summary Of Machine Performance In Büyükada Formation

Week No	13	14	15	16	17	18
Date 1990	23/07 28/07	30/07 04/08	06/08 11/08	13/08 18/08	20/08 25/08	27/08 01/09
Support (hr)	-	1.50	-	-	96.63	32.15
Chainging of cutters (hr)	7.00	66.58	48.75	12.00	-	-
Disc cutter control (hr)	4.83	3.58	5.15	4.16	1.00	3.75
Mucking and waitting for wagons (hr)	17.27	17.82	19.62	32.58	8.13	27.76
Maintance (hr)	5.50	-	2.50	2.66	0.75	4.75
Belt conveyor (hr)	5.58	-	-	5.92	-	2.00
Crane failure (hr)	-	-	4.66	0.66	2.25	-
Ground condition (hr)	3.00	-	-	-	-	-
Ventilation problem (hr)	-	-	-	4.50	-	-
Electrical (hr)	2.25	7.00	-	-	-	2.00
Mechanical (hr)	12.25	-	3.50	9.00	5.75	3.75
Other reasons (hr)	11.75	3.00	3.50	3.00	3.58	3.75
Weekly working time (hour)	120	120	120	120	140	120
Actual time(hr)	50.57	20.52	32.32	45.52	21.91	40.09
Weekly advance (m)	44.75	40.65	48.05	76.03	39.57	75.23
Avaradge daily advance (m)	7.46	6.67	8.00	12.67	6.60	12.54
Avaradge shift advance (m)	3.73	3.39	4.00	6.34	2.33	4.18
Net cutting rate (m/h)	0.86	1.94	1.44	1.70	1.70	1.65

APPENDIX 2
Summary Of Machine Performance In Trakya Formation

Week No	19	20	21	22	23	24
Date 1990	03/09 08/09	10/09 15/09	17/09 22/09	24/09 29/09	01/10 06/10	08/10 13/10
Support (hr)	48.00	50.06	104.6	82.42	99.94	101.0
Chainging of cutters (hr)	-	-	-	-	-	-
Disc cutter control (hr)	-	1.00	-	-	-	-
Mucking and waitting for wagons (hr)	19.36	24.01	-	5.67	-	-
Maintance (hr)	2.50	2.09	1.92	0.83	1.50	-
Belt conveyor (hr)	34.25	-	-	0.75	-	-
Crane failure (hr)	-	-	-	-	-	-
Ground condition (hr)	-	4.97	20.73	-	39.93	43.00
Ventilation problem (hr)	-	1.00	-	-	-	-
Electrical (hr)	-	0.50	-	2.56	1.00	-
Mechanical (hr)	1.42	8.95	-	1.50	-	-
Other reasons (hr)	12.06	15.17	30.15	36.28	-	-
Weekly working time (hour)	144	144	168	144	144	144
Actual time(hr)	26.41	36.05	10.64	13.99	1.63	-
Weekly advance (m)	39.07	64.65	16.35	24.90	1.90	-
Avaradge daily advance (m)	6.51	10.77	2.34	4.15	0.32	-
Avaradge shift advance (m)	2.00	3.60	0.78	1.38	0.11	-
Net cutting rate (m/h)	1.64	2.00	1.64	1.63	1.10	-

CONTINUED FROM APP. 2

Summary Of Machine Performance In Trakya Formation

Week No	25	26	27	28	29	30
Date 1990	15/10 20/10	22/10 27/10	29/10 03/11	05/11 10/11	12/11 17/11	19/11 24/11
Support (hr)	-	115.2	113.8	96.48	77.00	28.00
Chainging of cutters (hr)	-	-	-	-	-	-
Disc cutter control (hr)	-	-	-	-	-	-
Mucking and waitting for wagons (hr)	-	-	-	-	-	-
Maintance (hr)	-	3.75	4.50	-	-	-
Belt conveyor (hr)	-	2.50	-	-	-	-
Crane failure (hr)	-	-	-	-	-	-
Ground condition (hr)	144	23.75	4.37	10.48	67.00	116.0
Ventilation problem (hr)	-	-	-	-	-	-
Electrical (hr)	-	3.00	11.42	13.75	-	-
Mechanical (hr)	-	1.57	0.50	6.10	-	-
Other reasons (hr)	-	10.33	3.67	4.25	-	-
Weekly working time (hour)	144	168	144	144	144	144
Actual time(hr)	-	7.85	5.67	12.94	-	-
Weekly advance (m)	-	11.15	9.18	17.52	-	-
Avaradge daily advance (m)	-	1.59	1.53	2.92	-	-
Avaradge shift advance (m)	-	0.53	0.51	0.72	-	-
Net cutting rate (m/h)	-	1.70	1.84	1.59	-	-

CONTINUED FROM APP. 2

Summary Of Machine Performance In Trakya Formation

Week No	31	32	33	34	35	36
Date 1990 / 1991	26/11 01/12	03/12 08/12	10/12 15/12	17/12 22/12	24/12 29/12	31/12 05/01
Support (hr)	–	107.6	24.00	108.2	38.08	–
Chainging of cutters (hr)	–	–	–	–	–	–
Disc cutter control (hr)	–	–	–	–	3.75	0.50
Mucking and waitting for wagons (hr)	–	2.76	–	–	5.26	18.67
Maintance (hr)	–	–	–	–	2.30	–
Belt conveyor (hr)	–	–	–	–	5.46	2.00
Crane failure (hr)	–	–	–	–	–	–
Ground condition (hr)	144	28.90	120	32.93	1.95	–
Ventilation problem (hr)	–	–	–	–	–	–
Electrical (hr)	–	–	–	2.00	–	–
Mechanical (hr)	–	–	–	2.38	48.26	13.75
Other reasons (hr)	–	2.25	–	15.88	15.11	14.28
Weekly working time (hour)	144	144	144	168	144	72
Actual time(hr)	–	2.45	–	6.57	23.83	22.80
Weekly advance (m)	–	3.25	–	8.39	35.30	38.10
Avaradge daily advance (m)	–	0.54	–	1.20	5.88	12.70
Avaradge shift advance (m)	–	0.18	–	0.40	1.96	4.23
Net cutting rate (m/h)	–	1.37	–	1.25	1.49	1.73

CONTINUED FROM APP. 2

Summary Of Machine Performance In Trakya Formation

Week No	37	38	39	40	41	42
Date 1991	07/01 12/01	14/01 19/01	21/01 26/01	28/01 02/02	04/02 10/02	11/02 17/02
Support (hr)	15.42	43.67	107.4	82.83	143.5	69.81
Chainging of cutters (hr)	35.33	-	-	-	-	-
Disc cutter control (hr)	1.75	0.83	-	-	-	-
Mucking and waitting for wagons (hr)	17.46	20.72	12.07	29.47	-	28.87
Maintance (hr)	1.00	-	1.00	-	-	2.00
Belt conveyor (hr)	24.56	-	-	4.25	-	-
Crane failure (hr)	6.70	-	-	2.00	-	-
Ground condition (hr)	-	2.00	6.00	8.88	6.00	23.12
Ventilation problem (hr)	-	-	-	-	-	-
Electrical (hr)	-	29.00	-	-	-	-
Mechanical (hr)	10.84	8.17	9.05	1.40	1.00	10.15
Other reasons (hr)	25.64	16.40	1.00	10.62	10.22	13.08
Weekly working time (hour)	168	144	144	168	168	168
Actual time(hr)	29.43	23.24	8.21	28.55	7.37	20.97
Weekly advance (m)	44.45	40.20	18.00	64.55	11.75	48.20
Avaradge daily advance (m)	6.37	6.70	3.00	10.70	1.68	6.89
Avaradge shift advance (m)	2.12	2.23	1.00	4.61	0.84	3.44
Net cutting rate (m/h)	1.46	1.80	2.13	2.40	1.60	2.34

CONTINUED FROM APP. 2

Summary Of Machine Performance In Trakya Formation

Week No	43	44	45	46	47	48
Date 1991	18/02 24/02	25/02 31/03	04/03 10/03	11/03 17/03	18/03 24/03	25/03 31/03
Support (hr)	51.55	40.75	105.4	109.5	60.24	9.00
Chainging of cutters (hr)	-	-	-	-	-	1.00
Disc cutter control (hr)	-	-	-	-	-	-
Mucking and waitting for wagons (hr)	34.35	-	-	-	-	2.00
Maintance (hr)	2.00	-	-	-	-	1.00
Belt conveyor (hr)	-	6.25	-	-	-	-
Crane failure (hr)	3.00	-	-	-	-	-
Ground condition (hr)	19.95	117.4	55.73	55.00	104.0	139.9
Ventilation problem (hr)	-	-	-	-	-	-
Electrical (hr)	-	-	-	-	-	-
Mechanical (hr)	3.00	-	1.75	-	-	7.46
Other reasons (hr)	25.80	-	-	-	-	3.50
Weekly working time (hour)	168	16P	168	168	168	168
Actual time(hr)	28.25	3.57	5.14	3.45	3.73	4.08
Weekly advance (m)	66.20	4.00	4.80	3.50	3.81	7.02
Avaradge daily advance (m)	9.46	0.57	0.69	0.50	0.54	1.00
Avaradge shift advance (m)	4.73	0.29	0.34	0.25	0.27	0.50
Net cutting rate (m/h)	2.34	1.27	1.05	2.00	1.00	2.25

APPENDIX 3

Results Of Point Load Test

Formation	Km	No	d (cm)	P (Kg)	Is Kg/cm²	De	F	I50
limestone	0+100	1	5.0	1442.6	58	-	-	58
		2	4.5	1370.47	66	-	-	68
		3	4.8	1298.34	56	-	-	56
		4	4.6	1009.82	48	-	-	48
		5	4.5	1370.47	68	-	-	68
limestone	0+120	1	5.0	1442.6	58	-	-	58
		2	4.1	1009.82	60	-	-	60
		3	5.4	937.69	32	-	-	32
		4	4.3	937.69	51	-	-	51
limestone	0+140	1	4.8	1442.6	63	-	-	63
		2	5.2	1731.12	64	-	-	64
		3	4.3	1586.86	86	-	-	86
		4	4.0	1370.47	86	-	-	86
		5	4.5	1009.82	50	-	-	50
limestone	0+160	1	5.2	2308.16	89	-	-	89
		2	4.5	2885.20	95	-	-	95
		3	5.3	2091.77	74	-	-	74
		4	4.9	1586.86	66	-	-	66
		5	4.4	937.69	48	-	-	48
limestone	0+180	1	5.1	504.91	19	-	-	19
		2	5.1	1731.12	66	-	-	66
		3	4.2	937.69	53	-	-	53
		4	5.3	432.28	15	-	-	15
limestone	0+200	1	4.0	1298.34	81	-	-	81
		2	4.6	937.69	44	-	-	44
		3	3.7	721.30	53	48.36	0.95	50
		4	3.7	1442.60	105	49.00	0.96	10
limestone	0+220	1	4.5	2019.64	100	-	-	100
		2	3.6	504.91	30	47.68	0.90	35
		3	3.5	1731.12	141	48.86	0.95	134
		4	4.6	1009.82	48	47.92	0.91	44
limestone	0+240	1	3.7	1370.47	100	40.00	0.96	58
		2	4.3	1154.08	62	-	0.97	68
		3	3.9	1370.47	90	47.92	0.91	56

CONTINUED FROM APP. 3

Results Of Point Load Test

Formation	Km	No	d (cm)	P (Kg)	Is Kg/cm²	De	F	I50
limestone	0+260	1	4.7	1442.6	58	-	-	58
		2	4.0	1370.47	68	-	-	68
		3	3.8	1298.34	56	-	-	56
		4	3.8	1009.82	48	-	-	48
limestone	0+280	1	4.4	1370.47	71	-	-	71
		2	4.1	937.69	56	-	-	56
		3	3.8	1009.82	70	-	-	70
limestone	0+320	1	4.6	1442.6	58	-	-	58
		2	3.8	1370.47	68	-	-	68
		3	3.9	1298.34	56	-	-	56
		4	4.3	1009.82	48	-	-	48
diabase	0+340	1	4.1	2302.16	137	-	-	137
		2	4.3	2019.64	109	-	-	109
		3	4.5	3462.24	171	-	-	171
		4	4.8	1442.60	63	-	-	63
limestone	0+360	1	4.4	1154.08	60	-	-	60
		2	4.0	721.30	45	-	-	45
		3	4.3	1298.34	70	-	-	70
		4	3.8	1226.21	85	-	-	85
limestone	0+400	1	3.7	2091.77	153	-	0.96	148
		2	4.0	1154.08	72	49.00	0.96	69
		3	4.3	3462.24	187	48.36	0.95	178
		4	3.9	1154.08	76	45.00	0.93	71
limestone	0+420	1	4.0	3895.02	243	40.00	0.96	233
		2	3.8	2452.42	170	-	-	170
		3	3.4	1154.08	100	45.00	0.93	93
limestone	0+425	1	3.8	2019.64	140	35.43	0.94	132
		2	3.9	1370.47	90	45.00	0.93	84
		3	3.9	1009.82	66	38.45	0.91	60
		4	3.9	1586.86	104	56.00	0.92	96
limestone	0+440	very hard						
limestone	0+450	1	3.9	1370.47	90	39.00	0.90	81
		2	4.8	2885.20	125	48.00	0.90	112
		3	4.8	1947.51	84	55.00	0.85	71

<u>CONTINUED FROM APP. 3</u>
Results Of Point Load Test

Formation	Km	No	d (cm)	P (Kg)	Is Kg/cm²	De	F	I50
diabase	0+460	1 2 3	4.9 4.8 4.8	1081.95 1442.60 1154.08	45 63 50	- - -	- - -	45 63 50
diabase	0+465	1 2 3	5.0 4.2 4.8	1731.12 2885.20 2596.68	69 164 113	- - -	- - -	69 164 113
limestone	0+485	1 2 3	4.8 4.8 4.8	2308.16 1154.08 2885.20	100 50 125	- - -	- - -	100 50 125
limestone	0+510	1 2 3	4.8 4.8 4.8	1803.25 1442.60 1370.47	78 58 71	- - -	- - -	78 58 71
limestone	0+550	1 2 3 4	4.9 4.9 5.2 5.2	1658.99 1731.12 1731.12 1731.12	69 72 64 64	- - - -	- - - -	69 72 64 64
limestone	0+585	1 2 3	5.2 4.8 5.3	1875.38 2308.16 1370.47	69 100 49	- - -	- - -	69 100 40
limestone	0+600	1 2 3	5.2 4.8 5.3	1226.21 2885.20 2380.29	45 125 85	- - -	- - -	45 125 85
limestone	0+615	1 2 3	5.2 4.8 5.3	1154.08 721.30 937.69	57 28 30	- - -	- - -	57 28 30
limestone	0+645	1	5.3	1154.08	41	-	-	41
limestone	0+680	1 2 3	5.1 5.2 5.2	1370.47 577.04 2308.16	53 21 85	- - -	- - -	53 21 85
limestone	0+690	1 2 3 4	5.1 5.0 5.1 5.0	1370.47 793.43 1009.82 937.69	53 32 39 37	- - - -	- - - -	53 32 39 37

CONTINUED FROM APP. 3

Results Of Point Load Test

Formation	Km	No	d (cm)	P (Kg)	Is Kg/cm²	De	F	I50
siltstone	0+735	1	5.3	1009.40	36	–	–	36
		2	4.8	937.69	41	–	–	41
		3	4.8	2163.90	94	–	–	94
		4	4.9	504.91	21	–	–	21
siltstone	0+750	1	5.2	1154.08	43	–	–	43
		2	5.0	937.69	37	–	–	37
		3	4.7	1370.47	62	–	–	62
		4	5.2	577.04	21	–	–	21
siltstone	0+780	1	4.9	1442.60	60	–	–	60
		2	5.2	2380.29	88	–	–	88
		3	5.0	937.69	37	–	–	37
		4	5.3	1731.12	62	–	–	62
siltstone	0+805	1	4.8	937.69	41	–	–	41
		2	5.1	937.69	36	–	–	36
		3	5.0	793.43	32	–	–	32
siltstone	0+830	1	4.9	1009.82	42	–	–	42
		2	4.9	865.56	36	–	–	36
		3	4.9	1009.82	42	–	–	42
siltstone	0+865	1	4.8	1009.82	44	–	–	44
		2	4.7	793.43	36	–	–	36
		3	4.9	1009.82	42	–	–	42
siltstone	0+910	1	4.5	865.56	43	–	–	43
		2	4.8	721.30	31	–	–	31
		3	5.0	577.04	23	–	–	23
		4	4.9	1442.60	60	–	–	60
siltstone sandstone	0+953	1	5.2	1009.82	37	–	–	37
		2	4.9	721.30	30	–	–	30
		3	5.1	649.17	25	–	–	25
		4	5.2	577.04	21	–	–	21
andstone	1+025	1	5.0	2885.20	115	–	–	115
		2	4.9	2596.68	108	–	–	108
		3	5.1	1442.26	55	–	–	55
diabase	1+058	1	4.8	1875.38	81	–	–	81
		2	5.0	2163.90	86	–	–	86

CONTINUED FROM APP. 3

Results Of Point Load Test

Formation	Km	No	d (cm)	P (Kg)	Is Kg/cm²	De	F	I50
sandstone	1+103	1	5.0	1875.38	75	-	-	75
		2	4.6	2019.64	96	-	-	96
		3	4.8	1731.12	75	-	-	75
sandstone	1+174	1	4.8	1442.26	63	-	-	63
		2	4.9	2163.90	90	-	-	90
		3	4.2	1154.08	65	-	-	65
sandstone	1+210	1	4.4	1731.12	89	-	-	89
		2	5.0	649.17	26	-	-	26
		3	4.8	1298.34	56	-	-	56

APPENDIX 4

Results Of Cone Indenter Test

Formation	Chainage	no:	M1	M2	Im	Ave. Im
limestone	0+100	1 2	6.325 6.275	7.950 7.975	3.58 2.95	3.27
limestone	0+120	1 2	6.850 6.900	8.575 8.610	2.79 2.89	2.84
limestone	0+140	1 2	9.150 5.475	6.825 7.225	3.14 2.65	2.90
limestone	0+160	1 2	6.650 6.900	8.250 8.525	3.85 3.58	3.72
limestone	0+180	1 2	5.435 5.425	7.075 7.435	3.43 1.72	2.57
limestone	0+200	1 2	6.025 6.000	7.700 7.800	3.14 2.40	2.77
limestone	0+220	1 2	5.000 5.825	6.975 7.560	4.16 2.73	3.45
limestone	0+240	1 2	5.400 5.850	7.225 7.650	2.29 2.40	2.35
limestone	0+260	1 2	5.250 4.925	7.200 6.750	1.87 2.29	2.08
limestone	0+280	1 2	6.750 6.700	8.575 8.625	2.29 1.94	2.12
limestone	0+320	1 2	6.775 6.750	8.500 8.725	2.79 1.80	2.30
diabase	0+340	1 2	4.250 4.380	5.825 5.975	4.16 3.91	4.04
limestone	0+360	1 2	6.625 6.575	8.300 8.320	3.14 2.67	2.91
limestone	0+400	1 2	5.180 4.725	6.700 6.220	5.08 5.64	5.36
limestone	0+420	1 2	5.675 5.850	7.270 7.425	3.91 4.16	3.04

CONTINUED FROM APP. 4

Results Of Cone Indenter Test

Formation	Chainage	no:	M1	M2	Im	Ave. Im
limestone	0+425	1	6.950	8.725	2.51	2.93
		2	6.075	7.725	3.34	
limestone	0+440	1	7.700	9.200	5.52	5.86
		2	7.125	8.600	6.19	
limestone	0+450	1	4.775	6.325	6.54	3.96
		2	4.875	6.525	3.36	
diabase	0+460	1	6.650	8.250	3.85	3.34
		2	5.930	7.650	2,82	
diabase	0+465	1	4.850	6.490	4.54	4.30
		2	5.000	6.600	3.85	
limestone	0+485	1	–	–	–	–
		2	–	–	–	
limestone	0+510	1	4.500	6.000	5.52	5.11
		2	4.360	5.900	4.90	
limestone	0+550	1	3.900	5.480	4.10	4.40
		2	3.875	5.410	4.70	
limestone	0+585	1	4.500	6.185	3.06	2.73
		2	4.075	5.875	2.40	
limestone	0+600	1	–	–	–	–
		2	–	–	–	
limestone	0+615	1	4.000	5.620	3.63	3.02
		2	4.025	5.825	2.40	
limestone	0+645	1	3.875	5.650	2.49	2.35
		2	3.780	5.625	2.21	
limestone	0+680	1	5.720	7.400	3.10	4.04
		2	6.200	7.725	4.98	
limestone	0+690	1	5.375	7.325	1.84	2.13
		2	5.330	7.125	2.42	
siltstone	0+735	1	4.880	6.600	2.82	2.98
		2	4.900	6.275	3.14	

CONTINUED FROM APP. 4

Results Of Cone Indenter Test

Formation	Chainage	no:	M1	M2	Im	Ave. Im
siltstone	0+750	1 2	4.825 4.825	6.575 6.520	2.65 2.99	2.82
siltstone	0+780	1 2	4.680 4.675	6.225 6.140	4.62 6.51	5.57
siltstone	0+790	1 2	2.440 2.200	4.000 4.580	4.34 1.14	2.74
siltstone	0+805	1 2	4.200 4.175	6.175 6.000	1.80 2.29	2.05
siltstone	0+830	1 2	4.450 5.000	6.200 6.775	2.05 2.51	2.28
siltstone	0+865	1 2	5.725 5.425	7.475 7.750	2.65 2.79	2.72
siltstone	0+910	1 2	5.250 5.225	7.200 7.125	1.87 2.00	1.94
siltstone sandstone	0+953	1 2	3.250 2.350	5.175 4.425	1.94 2.10	2.02
sandstone	1+025	1 2	5.075 5.125	6.575 6.650	5.52 4.98	5.25
diabase	1+058	1 2	2.750 3.000	4.325 4.650	4.16 3.34	3.75
sandstone	1+103	1 2	5.600 5.700	7.300 7.350	2.95 3.34	3.14
sandstone	1+174	1 2	4.800 4.750	6.400 6.400	3.85 3.34	3.60
sandstone	1+210	1 2	4.350 5.400	3.850 2.950	3.85 2.95	3.40

APPENDIX 5

Results Of Cerchar Hardness Test

Formation	Chainage	Hole depth (cm)	Hardness index
limestone	0+100	0.5 1.0	17 40
limestone	0+120	0.5 1.0	40 158
limestone	0+140	0.5 1.0	45 280
limestone	0+160	0.5 1.0	50 235
limestone	0+180	0.5 1.0	60 300
limestone	0+200	0.5 1.0	15 30
limestone	0+220	0.5 1.0	25 54
limestone	0+240	0.5 1.0	24 62
limestone	0+260	0.5 1.0	66 115
limestone	0+280	0.5 1.0	6 12
limestone	0+320	0.5 1.0	7 15
diabase	0+340	0.5 1.0	57 128
limestone	0+360	0.5 1.0	7 16
limestone	0+400	0.5 1.0	46 113
limestone	0+420	0.5 1.0	40 90

CONTINUED FROM APP. 5

Results Of Cerchar Hardness Test

Formation	Chainage	Hole depth (cm)	Hardness index
limestone	0+425	0.5 1.0	- -
limestone	0+440	0.5 1.0	- -
limestone	0+450	0.5 1.0	- -
diabase	0+460	0.5 1.0	17 39
diabase	0+465	0.5 1.0	35 143
limestone	0+485	0.5 1.0	150 very hard
limestone	0+510	0.5 1.0	60 230
limestone	0+550	0.5 1.0	75 220
limestone	0+585	0.5 1.0	17 47
limestone	0+600	0.5 1.0	60 140
limestone	0+615	0.5 1.0	9 19
limestone	0+645	0.5 1.0	5 14
limestone	0+680	0.5 1.0	30 72
limestone	0+690	0.5 1.0	6 12
siltstone	0+735	0.5 1.0	5 12
siltstone	0+750	0.5 1.0	7 15

<u>CONTINUED FROM APP. 5</u>

Results Of Cerchar Hardness Test

Formation	Chainage	Hole depth(cm)	Hardness index
siltstone	0+780	0.5 1.0	11 20
siltstone	0+805	0.5 1.0	7 15
siltstone	0+830	0.5 1.0	5 11
siltstone	0+865	0.5 1.0	6 15
siltstone	0+910	0.5 1.0	7 15
siltstone sandstone	0+953	0.5 1.0	8 19
sandstone	1+025	0.5 1.0	19 38
diabase	1+058	0.5 1.0	75 180
sandstone	1+103	0.5 1.0	5 15
sandstone	1+174	0.5 1.0	11 23
sandstone	1+210	0.5 1.0	9 19

APPENDIX 6

Results Of Schmidt Hammer

Formation	Km	Point no:	Records	Ave.
limestone	0+100	1 2	46/52/50/54/53/53/55/54 64/60/62/60/58/61/60/62	56.40
limestone	0+120	1 2	59/58/58/62/63/62/62/62 52/62/62/57/59/58/56/61	59.75
limestone	0+140	1 2	50/50/52/55/52/51/52/50 44/57/53/57/55/58/54/54	52.75
limestone	0+160	1 2	60/60/62/66/62/61/62/59 50/54/58/54/56/56/59/60	58.68
limestone	0+180	1 2	38/33/29/30/29/26/37/40 43/38/48/43/40/44/38/38	37.12
limestone	0+200	1 2	S U P P O R T	
limestone	0+220	1 2	60/59/58/54/66/60/62/61 58/63/60/62/64/63/60/59	60.56
limestone	0+240	1 2	48/32/42/52/53/54/52/50 55/44/50/54/46/47/43/44	48.00
limestone	0+260	1 2	51/55/52/48/42/48/45/51 48/56/54/47/47/52/53/54	50.18
limestone	0+280	1 2	54/52/58/52/50/52/51/52 50/53/56/56/55/54/56/57	53.62
limestone	0+320	1 2	S U P P O R T	
diabase	0+340	1 2	S U P P O R T	
limestone	0+360	1 2	53/50/50/56/62/64/65/66 60/68/63/68/60/66/64/67	61.37
limestone	0+400	1 2	56/53/62/51/53/48/52/52 52/50/58/57/54/44/54/53	53.68
limestone	0+420	1 2	63/61/61/59/66/62/62/61 52/50/54/52/50/58/55/57	57.68

CONTINUED FROM APP. 6

Results Of Schmidt Hammer

Formation	Km	Point no:	Records	Ave.
limestone	0+425	1 2	50/48/49/50/51/52/59/60 48/54/53/59/50/59/46/48	52.24
limestone	0+440	1 2	55/54/60/59/64/64/64/64 57/55/60/62/62/60/61/64	58.47
limestone	0+450	1 2	63/61/58/70/60/67/63/70 60/66/62/64/63/70/69/60	64.12
diabase	0+460	1 2	69/70/70/69/72/71/68/70 60/60/62/64/59/63/61/65	65.81
diabase	0+465	1 2	60/61/58/60/62/67/64/58 49/55/62/57/60/54/65/59	59.43
limestone	0+485	1 2	S U P P O R T	
limestone	0+510	1 2	56/61/60/61/58/58/60/61 54/59/55/54/62/57/62/60	58.62
limestone	0+550	1 2	61/61/65/62/60/62/60/62 60/61/62/58/64/60/58/57	60.81
limestone	0+585	1 2	62/63/59/62/60/63/62/63 54/53/54/53/56/53/55/57	58.00
limestone	0+600	1 2	54/62/63/59/61/62/63/60 57/62/66/69/66/64/68/67	62.69
limestone	0+615	1 2	44/52/52/46/54/53/54/54 40/49/54/59/55/52/52/52	51.37
limestone	0+645	1 2	56/58/52/53/59/56/56/59 59/46/46/50/52/58/61/62	55.18
limestone	0+680	1 2	S U P P O R T	
limestone	0+690	1 2	S U P P O R T	
siltstone	0+735	1 2	64/65/66/64/67/64/63/63 50/58/58/62/64/56/52/50	60.37

CONTINUED FROM APP. 6

Results Of Schmidt Hammer

Formation	Km	Point no:	Records	Ave.
siltstone	0+750	1 2	48/52/56/52/48/54/55/56 45/50/53/54/52/50/55/51	51.93
siltstone	0+780	1 2	S U P P O R T	
siltstone	0+805	1 2	S U P P O R T	
siltstone	0+830	1 2	40/40/50/50/51/44/49/55 53/52/42/49/53/51/60/59	49.87
siltstone	0+865	1 2	S U P P O R T	
siltstone	0+910	1 2	43/52/48/42/52/55/55/55 48/57/50/50/55/58/52/52	51.75
siltstone sandstone	0+953	1 2	S U P P O R T	
sandstone	1+025	1 2	S U P P O R T	
diabase	1+058	1 2	60/56/56/50/50/48/50/50 48/60/52/52/52/60/52/60	54.00
sandstone	1+103	1 2	45/42/48/40/40/40/44/42 42/41/40/47/44/48/50/51	44.00
sandstone	1+174	1 2	53/52/49/50/50/50/52/49 40/40/50/50/51/52/53/52	50.00
sandstone	1+210	1 2	S U P P O R T	

APPENDIX 7

Results Of Impact Penetration Test

Km	Formation	No:	Records	Avarege
0+100	limestone	1 2 3	13 16 15	14.67
0+120	limestone	1 2 3	18 15 17	16.67
0+140	limestone	1 2 3	14 12 10	12.00
0+160	limestone	1 2 3	13 15 16	14.67
0+180	limestone	1 2 3	34 33 31	32.67
0+200	limestone	1 2	17 22	19.50
0+220	limestone	1 2	14 16	15.00
0+240	limestone	1 2	13 16	14.50
0+260	limestone	1 2	16 20	18.00
0+280	limestone	1 2 3	16 22 18	18.67
0+320	limestone	1 2	18 22	20.00
0+340	diabase	1 2	4 6	5.00
0+360	limestone	1 2	18 21	19.50

CONTINUED FROM APP. 7

Results Of Impact Penetration Test

Km	Formation	No:	Records	Avarege
0+400	limestone	1 2 3	20 18 20	19.30
0+420	limestone	1 2 3	19 20 17	18.67
0+425	limestone	1 2	13 10	11.50
0+440	limestone	1 2	5 6	5.50
0+450	limestone	1 2	6 7	6.00
0+460	diabase	1 2	7 6	6.00
0+465	diabase	-	-	-
0+485	limestone	1 2	10 16	13.00
0+510	limestone	1 2	10 12	11.00
0+550	limestone	1 2	19 18	18.50
0+585	limestone	1 2	9 11	10.00
0+600	limestone	1 2	5 7	6.00
0+615	limestone	1 2	1 2	8.50
0+645	limestone	-	-	-
0+680	limestone	-	-	-
0+690	limestone	-	-	-

CONTINUED FROM APP. 7

Results Of Impact Penetration Test

Km	Formation	No:	Records	Avarege
0+735	siltstone	1	24	22.30
		2	23	
		3	20	
0+750	siltstone	1	25	20.00
		2	16	
		3	19	
0+780	siltstone	-	-	-
0+805	siltstone	-	-	-
0+835	siltstone	-	-	-
0+865	siltstone	1	18	45.67
		2	15	
		3	14	

APPENDIX 8

			Nature of principal potential delays		
	Geological features	Condition	Machine	Tunnelling operation	Solution to minimise delay
Major features	Fault gouge / Seatearth	Moisture content, thickness and geometry important	Low machine utilisation due to tunnelling operations. Steering problems likely.	Support, mucking and bracing—all dependent upon geometry.	Machine design permitting early installation of roof and wall support. Good access to invert and face for hand mucking. Experienced driver to reduce steering problems. Minimise gap between cutting head and roofshield at crown.
	Intense jointing (shattering)	Spacing less than 0.15 metres.	Low utilisation. High cutter costs in very strong rock.	Support, mucking and possible bracing	
	Sub-parallel to parallel discontinuities	Critical angle about 10-15° for weaker rocks	Low utilisation. Steering.	As above. Overbreak highly dependent upon geometry. Bracing can be main problem.	As above. Machine design with one set of pads preferable.
	High to complete weathering.	Rock Type important	Strong rocks-low utilisation. Weak rocks-low utilisation	Machine mucking system As with fault gouge	As with gouge. Mucking system with proven ability to handle material with high clay content.
	Major water inflows	Greater than $3000\ m^3$/day in short zones	Low utilisation. General deterioration of pure argillaceous rocks. Electrical.	Support, pumping, mucking and silting of tunnel. Labour problems. Track laying.	Advance probing and possible grouting. Waterproofed electrical equipment, and large pumps available.
	Extremely strong rock	Greater than $200\ MN/m^2$	Low penetration. High cutter costs and maintenance.	Potentially good tunnelling media as joints can be tight	Selection of machine with proven ability to cut hard rock. Step up planned maintenance.
	Mixed face condition	Extreme variation Geometry important	High cutter costs. Estimate as full face of harder rock. Steering—dependent on geometry. Maintenance.	Bracing	As above—non-carbide cutters preferable. Experienced driver essential

APPENDIX 9

Minor conditions	High jointing	0.5-0.15 metres spacing	Higher cutter wear in very strong rocks.	Support and mucking	
	Open joints	No filling or non-cohesive filling. eg clay		Support	
	Inclined joints	Non-cohesive joints Critical angle about 20-50° to the vertical		Support	
	Slickensided joints	Joints smooth planar. Important when working in conjunction with above or sub-parallel joints		Support	These factors create only potentially poor tunnelling ground and high delays will generally only be encountered where these factors work in combination with each other. As above the solution to minimise delays is the use of a machine design permitting clear access for tunnelling operations and maintenance.
	Weathering	Rock type important.	Faint to slight weathering can have large effect in pure argillaceous rocks	Support and mucking	
	Anisotropy eg shaley bands in sandstones	Banding ± 0.2m. from soffit level		Support	
	Bedding planes argillaceous content.	Closely spaced planes forming prominent weakness planes.		Support and mucking both grading directly with argillaceous content.	
	Weak rocks	Less than 5 MN m² (Non-halite rocks)	Low utilisation. Steering problems	Support. Mucking and bracing.	
	Distributed water inflows	Rock type susceptible to water eg argillaceous rocks.		Support and mucking Potential labour problems. Track laying, pumping, silting	All electrical equipment must be shielded or preferably waterproofed.
	Mineralisation	Effective healing of joints and minor faults	High utilisation.	Good tunnelling conditions	Keep driving

APPENDIX 10

Summary Of The Geotechnical Properties Of The Rock Formation

Formation	Km	RQD (%)	Is kg/cm²	Im kg/m²	σc kg/cm²	Cerchar Hardness (cm) 0.5	1	Schmidt Hammer
limestone	100	95	59.60	3.26	1239	55	155	56.00
limestone	120	80	53.00	2.84	1091	40	158	59.75
limestone	140	95	68.40	2.89	1270	45	280	53.00
limestone	160	80	62.67	3.71	1353	50	235	59.00
limestone	180	25	29.00	2.57	779	5	12	37.00
limestone	200	80	58.33	2.77	1137	15	30	–
limestone	220	80	59.67	3.44	1272	25	54	60.00
limestone	240	80	79.67	2.34	1295	24	62	55.00
limestone	260	80	77.33	2.08	1223	66	115	50.00
limestone	280	95	65.67	2.11	1100	6	12	54.00
limestone	320	75	51.00	2.29	971	7	15	–
diabase	340	80	86.00	4.00	1662	57	128	–
limestone	360	75	65.00	2.90	1234	7	16	61.00
limestone	400	75	66.67	5.36	1693	46	113	54.00
limestone	420	75	93.00	4.00	1739	40	190	58.00
limestone	425	80	80.00	2.92	1444	–	–	52.00
limestone	440	75	–	5.85	2094	–	–	58.00
limestone	450	80	78.42	3.94	1568	–	–	64.00
diabase	460	85	52.67	3.33	1175	17	39	66.00
diabase	465	85	91.00	4.19	1746	35	143	59.00
limestone	485	50	75.00	–	1650	150	–	–
limestone	510	75	69.00	5.11	1674	60	230	59.00
limestone	550	80	67.25	4.39	1526	75	220	61.00
limestone	585	80	59.00	2.78	1147	17	47	58.00
limestone	600	80	65.00	–	1430	60	140	63.00
limestone	615	80	38.33	3.00	959	9	19	51.00
limestone	645	95	41.00	2.35	872	5	14	55.00
limestone	650	80	37.00	4.04	1130	30	72	–
limestone	690	95	40.25	2.13	824	6	12	–
siltstone	735	80	32.67	2.98	893	5	12	60.00
siltstone	750	80	33.67	2.82	875	7	15	52.00
siltstone	780	80	53.00	–	1166	11	20	–
siltstone	805	80	36.33	2.00	758	7	15	–
siltstone	830	75	40.00	2.58	902	5	11	50.00
siltstone	865	75	40.67	2.72	934	6	15	–
siltstone	910	75	32.25	1.93	700	7	15	52.00

CONTINUED FROM APP. 10

Summary Of The Geotechnical Properties Of The Rock Formation

Formation	Km	RQD (%)	Is kg/cm²	Im kg/m²	σc kg/cm²	Cerchar Hardness (cm)		Schmdit Hammer
						0.5	1	
siltstone mudstone	930-935,	0-25	highly fractured, jointed and alterated zone.					
siltstone	935-945,	25-50	jointed rock (wedged block, systematical joint sets which interrupted each other)					
siltstone sandstone	953	85	30.00	2.02	692	8	19	-
siltstone mudstone	965-982,	< 25	jointed and sheared rock unit, fault zone.					
sandstone	1025	60	55.00	5.25	1545	19	38	-
diabase	1058	60	83.50	3.75	1590	75	180	54.00
sandstone	1103	60	75.00	3.14	1387	5	15	44.00
siltstone	1148-1155,	50-75	systematical joint sets which interrupted each other (with clay filled)					
sandstone	1174	60	64.00	3.60	1348	11	23	50.00
sandstone	1210	60	44.00	3.40	1060	9	19	-
siltstone mudstone	1220-1235,	0-25	intensively jointed and fractured rock (filled with clay), fault zone					

CONTINUED FROM APP. 10

Summary Of The Geotechnical Properties Of The Rock Formation

Formation	Km	Impact Penetration (mm)	Penetration (mm/rev)	Propel Pressure (Bar)	Cutting rate (m/h)
limestone	100	15	2.69	120	0.88
limestone	120	17	1.76	95	0.58
limestone	140	12	2.89	120	0.95
limestone	160	15	6.39	130	2.11
limestone	180	33	5.10	100	1.68
limestone	200	19	4.33	100	1.43
limestone	220	15	4.26	130	1.41
limestone	240	14	4.69	130	1.55
limestone	260	18	4.71	140	1.55
limestone	280	19	4.33	135	1.43
limestone	320	20	5.38	110	1.77
diabase	340	5	5.05	120	1.67
limestone	360	20	4.47	125	1.47
limestone	400	19	4.24	135	1.40
limestone	420	19	2.85	135	0.94
limestone	425	11	1.58	120	0.52
limestone	440	6	2.01	110	0.66
limestone	450	6	0.73	110	0.24
diabase	460	6	1.99	110	0.66
diabase	465	-	1.00	110	0.33
limestone	485	13	4.82	135	1.59
limestone	510	11	2.50	135	0.82
limestone	550	19	6.53	150	2.15
limestone	585	10	5.59	160	1.84
limestone	600	6	2.43	150	0.80
limestone	615	9	5.83	160	1.92
limestone	665	-	5.36	160	1.77
limestone	650	-	6.89	150	2.27
limestone	690	-	2.85	110	0.94
siltstone	735	22	5.44	150	1.79
siltstone	750	20	5.58	150	1.84
siltstone	780	-	4.64	100	1.53
siltstone	805	-	7.55	155	2.49
siltstone	830	-	5.26	150	1.74
siltstone	865	16	5.89	110	1.94
siltstone	910	-	6.59	95	2.17

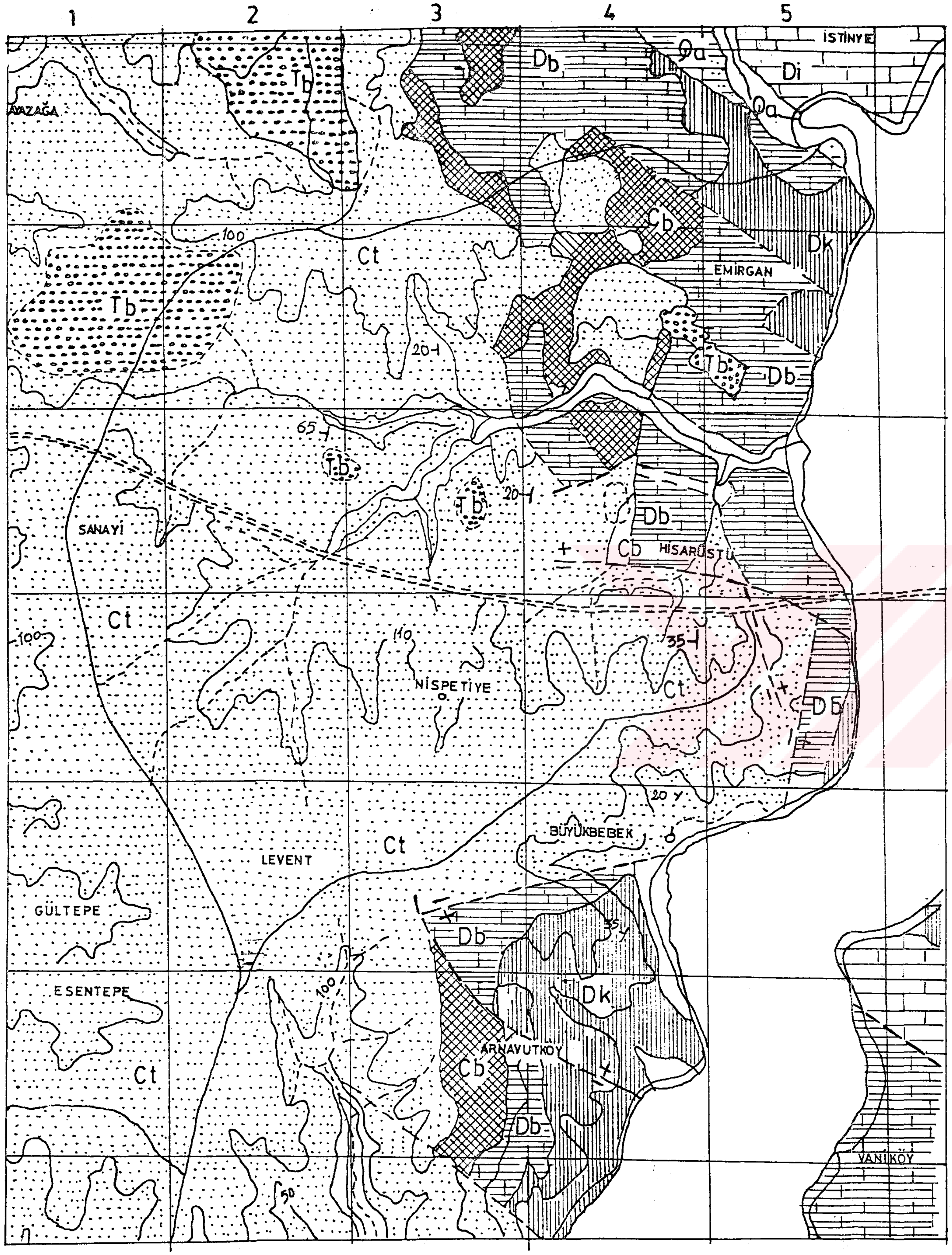
CONTINUED FROM APP. 10

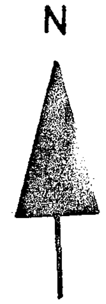
Summary Of The Geotechnical Properties Of The Rock Formation

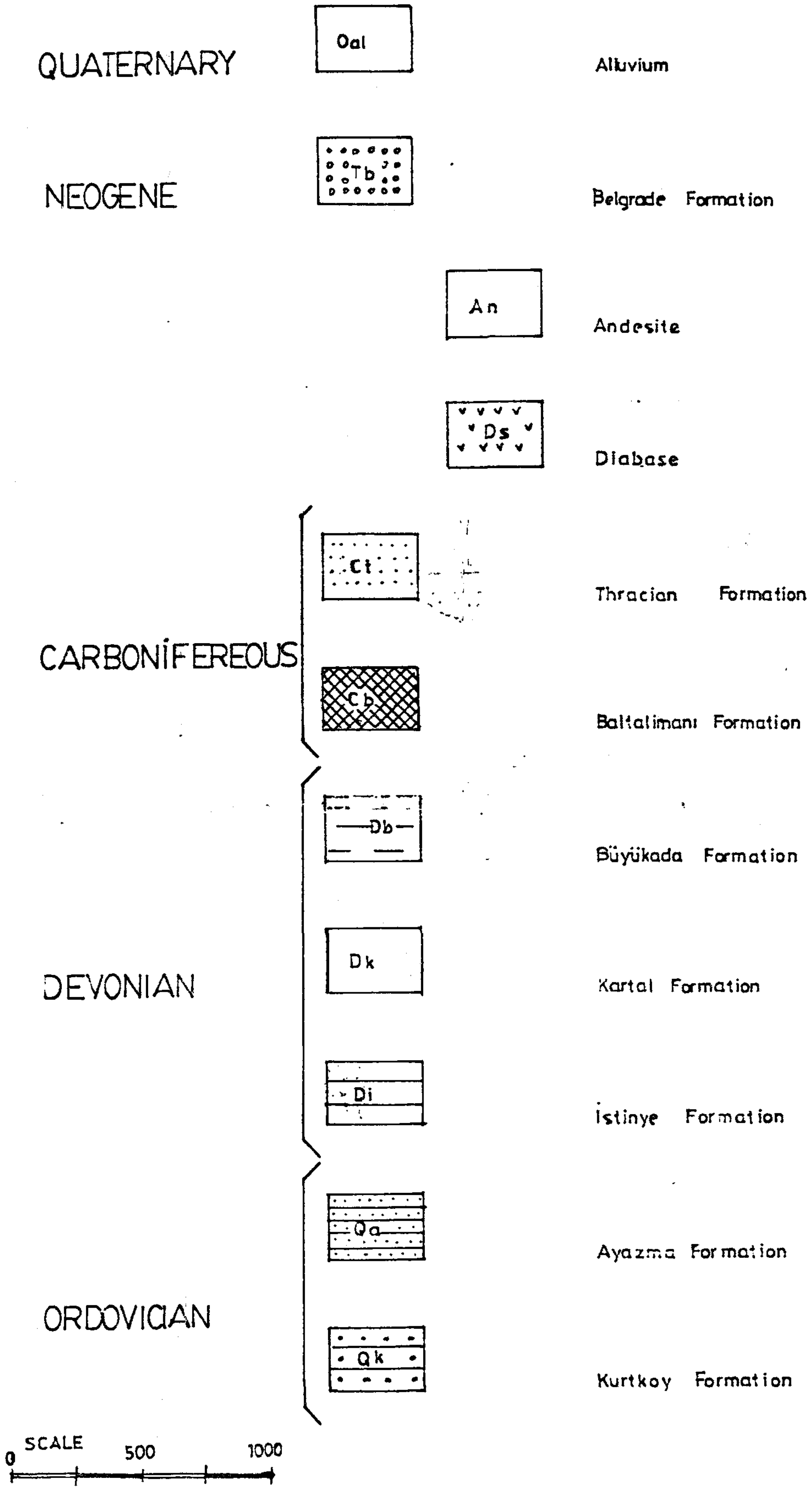
Formation	Km	Impact Penetration (mm)	Penetration (mm/rev)	Propel Pressure (Bar)	Cutting rate (m/h)
siltstone mudstone	930-935,	0-25	highly fractured, jointed and alterated zone.		
siltstone	935-945,	25-50	jointed rock (wedged block, systematical joint sets which interrupted each other)		
siltstone sandstone	953	-	4.43	125	1.46
siltstone mudstone	965-982,	< 25	jointed and sheared rock unit, fault zone.		
sandstone	1025	-	5.32	125	1.75
diabase	1058	-	6.23	140	2.00
sandstone	1103	-	5.63	125	1.86
siltstone	1148-1155,	50-75	systematical joint sets which interrupted each other (with clay filled)		
sandstone	1174	-	5.83	100	1.92
sandstone	1210	-	7.11	85	2.35
siltstone mudstone	1220-1235,	0-25	intensively jointed and fractured rock (filled with clay), fewtt zone		

APPENDIX 11

GENERAL GEOLOGICAL MAP







BIOGRAPHY

Mehmet Cigla was born in 1966 in Havsa-Edirne, he went to elemantary and secondary school in Havsa, and started high school in 1981 and finished in 1984, at the same year he entered to MINING FACULTY OF ISTANBUL TECHNICAL UNIVERSITY and gratuaded in 1988. He began his his M.Sc. program in the same depertment concerning the mechanized excavation and finished in 1991. During his postgraduate studies he worked as a site engineer in Baltalimani Tunnel, currently he is employed in STFA Construction Co.