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ENGINEERING GEOLOGY OF SELECTED ABANDONED ANDESITE QUARRIES, IN IZMIR-TURKEY

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ABSTRACT

Andesites have been widely used as building stones in the city of Izmir over centuries. There are now numerous old abandoned andesite quarries in the city area of Izmir. Recently, there has been an increasing interest shown to make use of these quarries, because of the shortage of free space in the city centre. Detailed engineering geological studies were carried out at three abandoned andesite quarries, in order to assess the stability of their slopes. Slope failure modes and critical areas were identified and suggestions were made for their reinforcement. Of these quarries, the first one at Göztepe area is being used as open air theatre and car park after its slopes were reinforced, the second one at Bayraklı area is planned as sporting and recreation area and motorway is planned passing through the third andesite quarry at Osmangazi area.

INTRODUCTION

Izmir is the third largest city in Turkey having population over 3.0 million. Izmir has been a famous and popular city throughout its history because of its location and natural beauty. The city is founded on Miocene aged volcanic rocks, Neogene sedimentary rocks and Quaternary sedimentary

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deposits. The observations have shown that generally, local materials have been used in constructions in the city. While the good quality andesites were used as building stones in the past. Tertiary limestones are nowadays being used as source of construction materials for building roads and manufacturing concrete in the city.

The building stones and other construction materials have been obtained from the quarries located near the city centre. As the city has expanded over the years, the location of the andesite quarries remained in the middle of dwelling areas, their operations were stopped and new quarries were opened up near the city boundary. Andesite quarries were abondened often without taking any precautions against slope instability. While some of the quarry sites were left by themselves, some others have been used as rubbish dumping grounds. Presently, there is a great demand to use these abandoned quarries because of the shortage of available land as construction site in the city area for the general public use.

In this paper, initially, the geology of Izmir will be briefly explained, locations and states of the abandoned andesite quarries will be presented. The details of the engineering geological studies carried out at three selected abandoned andesite quarries will be discussed. The engineering geological studies involved detailed discontinuity mapping of the quarry slopes, stereonet analysis of the discontinuity data, identification of the likely slope failure modes and areas and suggestions for the reinforcement of slopes. Of these quarries, the first one at Göztepe area is now being used as open air theatre and car park after its slopes have been reinforced, the second one at Bayraklı is planned to be used for sporting and recreation activities and a major motorway is planned passing through the third andesite quarry at Osmangazi area of the Izmir city.

GEOLOGY OF THE IZMIR CITY

The geology of the Izmir city centre and its surroundings have been investigated by various researches going back to 19th century (Strikland 1880; Phillipson 1911; Akartuna 1962 and Dora 1964). These studies have shown that the rock types around the Izmir city centre are consist of Cretaceous and Tertiary sedimentary rocks and Neogene volcanic rocks. The Cretaceous rocks are composed of thickly bedded limestones, marl, chert and thinly bedded limestones. The Tertiary sedimentary rocks are consisted of Paleocene aged Bornova Flysch and Neogene aged conglomerate, claystone, marl and freshwater limestone. Neogene volcanic rocks are consisted of andesitic tuffs, agglomerates and lavas.

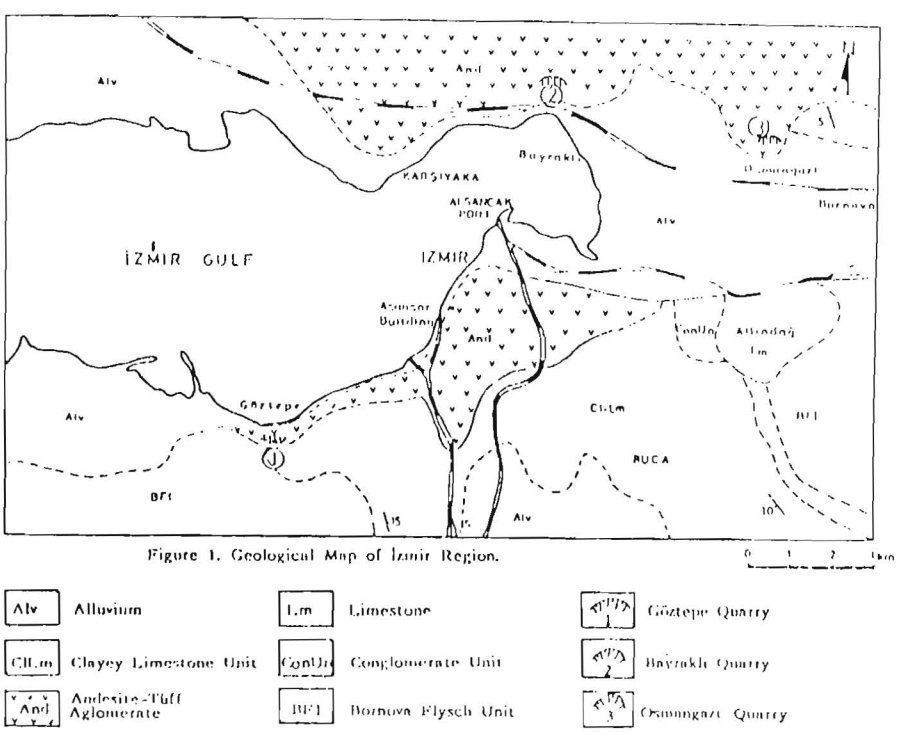


Figure 1. Geological Map of İzmir Region.

Figure 1. Geological Map of Izmir and Its Surroundings.

Plains and sea shores are covered with recent sediments. The geological map of Izmir is given in Figure 1. The stratigraphy and approximate thicknesses of the geological units are given in Figure 2.

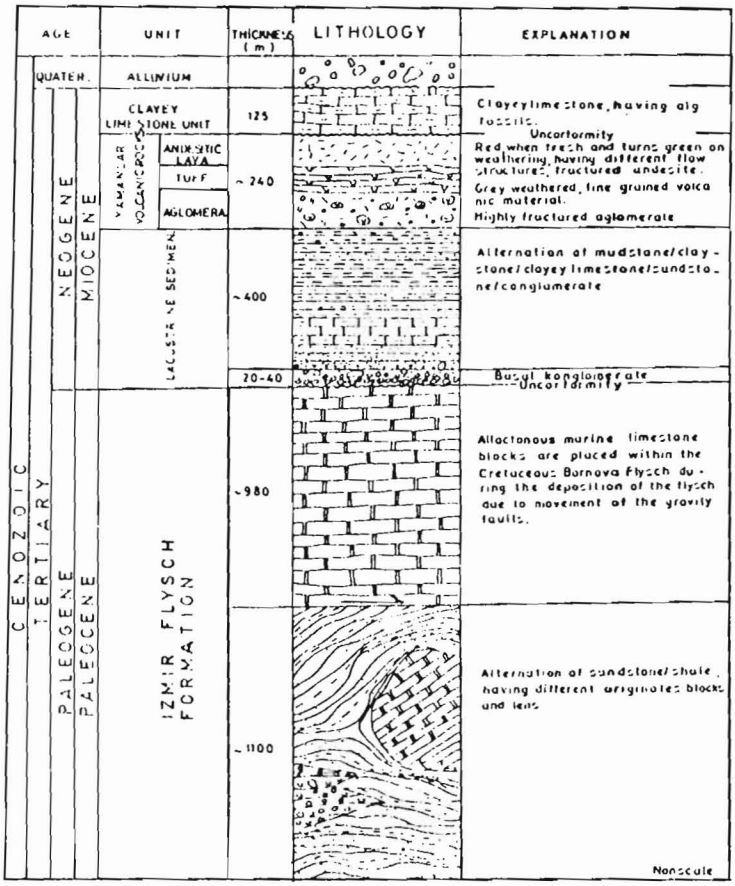


Figure 2. Stratigraphic Section of the Geological Units in and Around Izmir.

Andesitic tuffs and aglomerates lie on Neogene aged Marl and clay layers around Izmir. Tuffs are yellowish brown and creamy coloured and varies in thicknesses from a few cm to few meters. Aglomaretas are consist of blocks and large gravel sized andesitic lavas and tuffaceous cement materials and reddish brown in colour and have varying thicknes. Andesitic lavas are found laying over the tuff and aglomerate layers and cover widespread areas. The magmatic activities which caused the formation of these volcanic rocks have taken place in Miocene. The volcanic rocks are poured out at various times in sequence of tuffs, aglomerates, and lavas. There may be several lava flows poured out from the same volcano and laying in varying directions in an area. The earlier poured out lavas found to be altered by the later ones. The alteration processes generally change the engineering properties of the earlier formed lavas. Andesites have been subjected to weathering processes after their formation, and they are greyish brown when fresh and reddish brown when weathered.

The main structural features found in andesites are flow structures, cooling joints and tectonic joints. Flow structures generally dip at low angles and have rough surfaces and are generally tightly closed. The cooling joints are developed vertical to the flow structures and have smooth surfaces and tend to be open with varying width. They are developed in two directions vertical to each other. The tectonic joints are developed parallel to the main fault and graben directions running in east-west direction in and around Izmir.

ANDESITE QUARRIES

Andesites were extensively used as building stones in the past in and around Izmir, becasue of their attractive appearence.

However, the use of andesite as construction material is very limited nowadays. At present, andesites are used as sub-base material in roads as fill material in foundations, and for building of walls. There are numerous and varying sized abandoned andesite quarries within the city area of Izmir. There quarries were located at the periphery of the city when they were first opened. As the city expanded, they remained within the city area and were stopped operating. These quarries were generally advanced in the direction of good quality rock. When the good quality rock run out in a quarry, the next quarry were opened up near the old one.The rock mass was quarried by blasting.Andesitic rockmass were dislodged from their original position either by chaimber blasting or by undermining of the quarry face, thus a large quantity of materials were obtained after each operation. Then, the larger blocks were broken down to small pieces, either by secondary blasting or hammering. Thus andesite blocks were trimmed and brought to the required shape in the quarry size. At present, andesite quarries are not used as source of building stones any more. The location of major abandoned andesite quarries are shown in Figure 1.

Recently, there has been an increasing demand to make use the disused andesite quarry sites for public use because of the shortage and high cost of free sites in the city area. However, as the disused andesite quarries were abandoned without taking any precautions against the slope failures, they are generally in a disorganizing state. Thus, detailed engineering geological studies are required before such sites are used for construction purposes.

Detailed engineering geological studies were carried out at three selected andesite quarries to assess their slope stabilities. These quarries are located at (1) Göztepe,

(2) Bayraklı and (3) Osmangazi district of the city. The details of these studies are given below:

(1) Göztepe Andesite Quarry

This quarry is located in south of the Gulf of Izmir and at the northern outskirts of the volcanic dome known locally as Susuzdede (Figure 1). The quarry site is 120 m x 110 m and its slopes are highly steep and reaches up to 50 m in heights. This quarry is now in the middle of heavily buil area. Although its exact date is not known, the quarrying operations were believed to be stopped in the early sixties without taking any measures against the slope failures. Slope failures were noticed during the site clearence operations to construct an open air theatre and multy-storey car park in this quarry site by the Konak Municipality, in November 1988. Thus, a detailed engineering geological study was carried out in the quarry area. 1/1000 scale Engineering geological map of the quarry slopes were carried out as part of this study (Fig. 3). The main discontinuities and other important features are shown on this map. The main discontinuities are generally dipping at high angles into the south in the quarry, enabling the quarry slopes to stand at high angles. The crushed zone running E-W in the south of the quarry has caused the slope failures during the site clearance. The crushed zone is 3-4 m. thick and andesite blocks are found crushed to gravel, sand, silt and clay sized materials and is water bearing. While the andesites found laying in south of the crushed zone is highly weathered and frequently jointed, the andesites found laying in north of the crushed zone is relatively less weathered and widely fractured.

Tests were carried out fresh-slightly weathered and moderately weathered andesite samples according to the ISRM (1980), and their results are given in Table 1.

These results show that weathering has a marked influence on the engineering properties of andesites. As the weathering grades of andesites increase their unit weight and strength decrease and porosity increase (Table 1).

Rock mass shear strength parameters were determined from the back-analysis of the already slided andesite blocks and block sliding experiments carried out in the quarry site as suggested by Hoek and Bray. The surface sliding friction angles of the discontinuities were found to be varying between 33^{o} and 42^{o}. While smooth and fresh cooling joints and clay filled joints have given lower surface friction angle values, rough discontinuities such as flow structure and tectonic joint surfaces have given higher surface sliding friction angle values. For slope stability analysis, the mean surface friction angle values are taken to be 37^{o}.

The types of slope failure modes expected in the quarry slopes are shown in Fig-3. Some parts of the slopes were found to be at critical state of stability when this study was carried out. The following measures were recommended for the reinforcement and the protection of the slopes, before any construction is made in the quarry size.

a. Rock fall zone : Critical blocks were suggested be removed. Rock bolting and wiremeshing were recommended to increase the stability of andesite blocks. Additionally, a sand filled corridor (zone) should be left between the toe of the slope and the planned building in order to stop the unprecedented rock falls.

b. Wedge failure zone : Slope face angle was suggested to be lowered by blasting and rock bolting of the critical wedges was recommended.

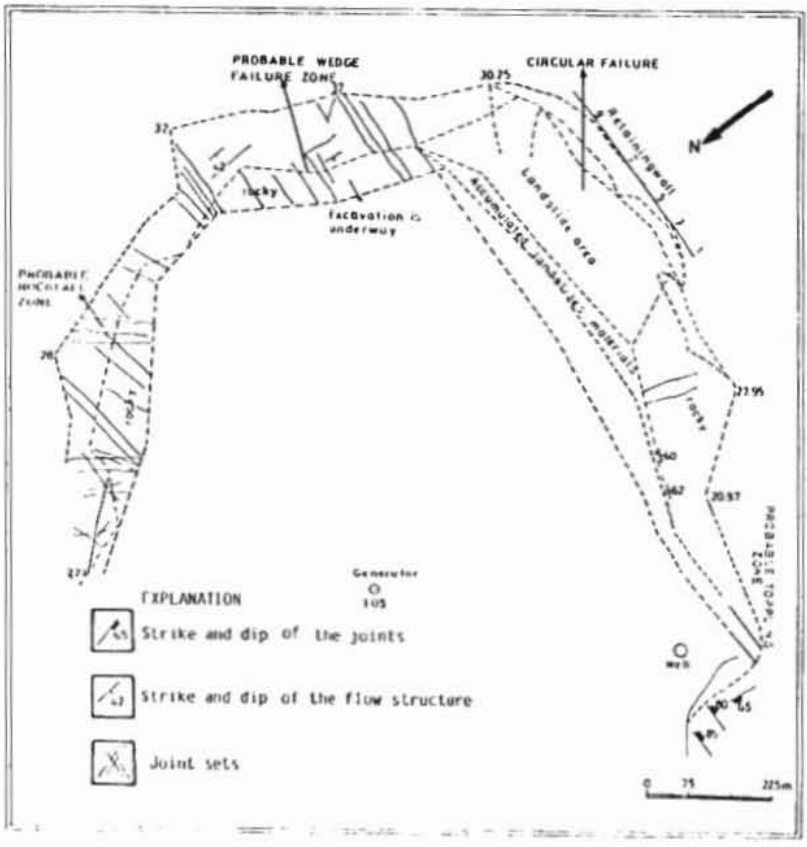


Figure 3. Engineering Geological Map of the Andesite Quarry at Göztepe.

c. **Circular sliding zone** : The slope angle was suggested to be lowered and a reatining wall was recommended to be built at the toe of the sliding mass.

d. **Toppling zone** : Andesite blocks prone to toppling, were suggested to be removed by dislodging them.

Most of the above mentioned measures were undertaken and since then a large building housing an open air theatre and a multy storey car park were built in the quarry site.

(2) Bayraklı Andesite Quarry

This quarry is located over the steep andesite slopes, at 70 m. above the sea level in the northern part of the Gulf of Izmir. The quarry was opened up by advancing into the slope and extends over an area of 13500 m^2. This quarry is located in relatively less developed part of the city and have been used as a source of construction materials until recently. 2-3 storey houses have been built by the crest of the quarry slopes, after the major quarrying operations were stopped. This quarry is in a relatively orderly state at present and the site is planned to be used for construction of a sport centre complex.

Engineering geological studies were undertaken to assess the stability of the quarry upon the request made by the Karşıyaka Municapility. Figure 4 shows the engineering geological map of the quarry. The major discontinuity and weathering profile of the quarry slopes are also shown on this map. Andesites are found in varying grades of weathering in the quarry.

There are three types of discontinuities found in the quarry; flow band structures, cooling joints and tectonic joints. The flow band structures are tightly closed, and have rough surfaces and dip at 27^{o}-30^{o} to the in and around the quarry. Cooling joints have smooth surfaces and dip at high angles, and are slightly widely open. There is about 1 meter thick shear zone running in SE-NW direction in north of the quarry. The tectonic joints are generally found running parallel to the tectonic crushing zone and rough, clay filled (1-3 cm). Andesites are found to be

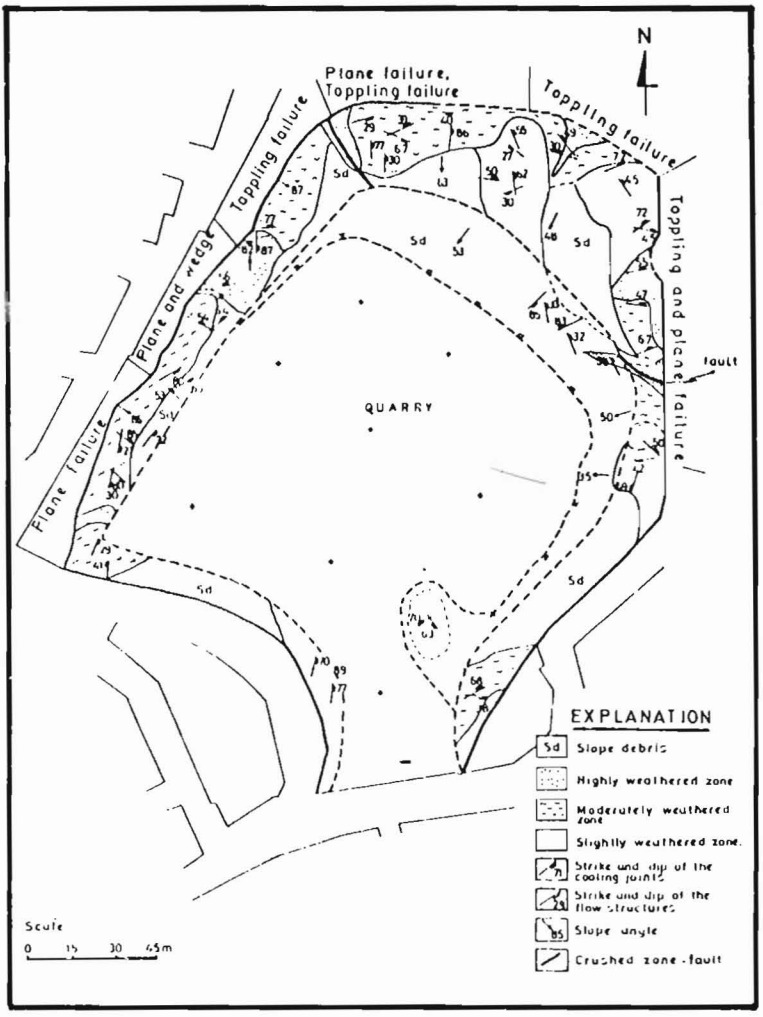


Figure 4. Engineering Geological Map of the Andesite Quarry at Bayraklı.

highly weathered and crushed to fine sand and silt sized materials along the crushing zone. Laboratory test results given in Table-1, are also applicable for the andesites found in this quarry.

Detailed discontinuity measurements were carried out along the quarry slopes. Analysis of the discontinuity measurements has shown that mainly toppling, wedge and plane type of rock slope failures are expected around the quarry (Figure-5).

TABLE 1. RANGE OF TEST RESULTS FOR THE FRESH AND WEATHERED ANDESITES.

TESTS	FRESH - SLIGHTLY WEATHERED	MODERATELY WEATHERED
Schmidt Hammer	53 - 50	41 - 39
Uniaxial Compressive Strength (MN/m^2)		
(a) Dry	147.8 - 113.6	95.6 - 66.5
(b) Saturated	111.9 - 90.9	74.2 - 45.6
Unit Weight (kN/m^3)		
(a) Dry	25.8 - 24.7	25.3 - 24.3
(b) Saturated	26.0 - 25.0	25.5 - 25.1
Porosity (%)	2.8 - 2.1	8.3 - 2.7
Point Load Strength (a) Dry (MN/m^2)	9.2 - 6.9	5.9 - 4.8
Triaxial Strength Parameters (a) Dry		
1- Cohesion (MN/m^2)	28.0 - 17.0	17.0 - 10.0
2- Friction Angle	62." - 55."	55."
Block Sliding (Ø)	Rough : 42^o	Smooth 37^o

N.B. Tests were carried out according to the ISRM (1981).

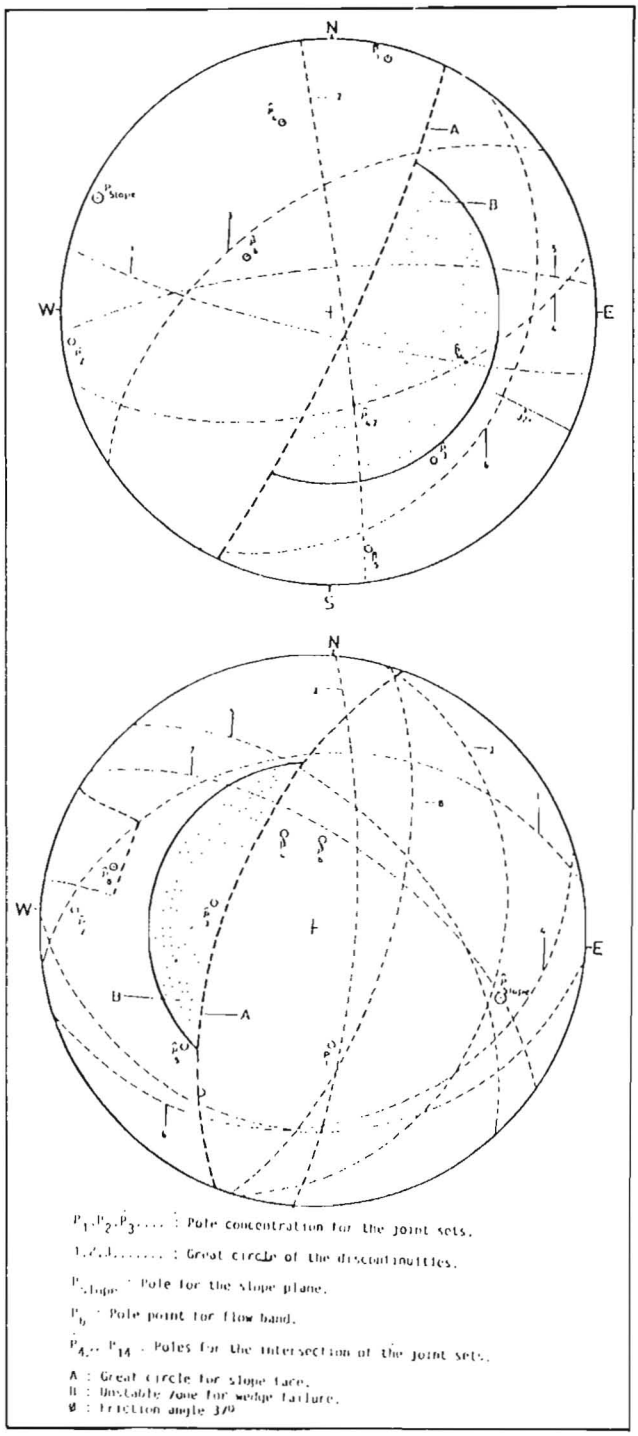


Figure 5-6. The Stability Analysis of the Discontinuity Data of the Western and Northern Slope of the Bayrakli Andesite Quarry.

Figure 5 shows the stereonet analysis of the discontinuities measured in the western slopes of the quarry. Surface friction angle of the discontinuities were taken as $\emptyset = 37^{o}$ from the block sliding experiments carried out in the field. This protection indicates that there is a possibility of wedge types failure in this slope. Figure-6 shows stereonet analysis of the discontinuity data obtained from the northern slope of the quarry. Rock falls and toppling type of failures are expected in this part of the quarry. Additionally, the analysis of the discontinuity data obtained from the eastern slope of the quarry indicated that there was not any major discontinuity concentration likely to cause slope failure in this area.

Rock bolting and wiremeshing type of rock slope reinforcement and drainage of the surface water were suggested to increase the stability of slopes. Additionally, a retainning wall was proposed to be built around the quarry to stop falling rock blocks to roll away from the toe of slopes before any construction activity is started in the quarry size.

(3) Osmangazi Andesite Quarry

There are several disused andesite quarries located between Bayrakli and Bornova districts in NE of the Gulf of Izmir. At present, these quarries are located in a scarcely built area and a major motorway is planned passing through these quarries. Figure 7 shows 1/100 scale discontinuity and weathering grade map of the eastern slope of a selected quarry in the area. The mapped part of the quarry is about 50 m long and 12 m high. The slope angle of the quarry face changes along the eastern slope. The stereographic projection and the stability analysis of the discontinuities measured in each section of the eastern slope are carried out separately.

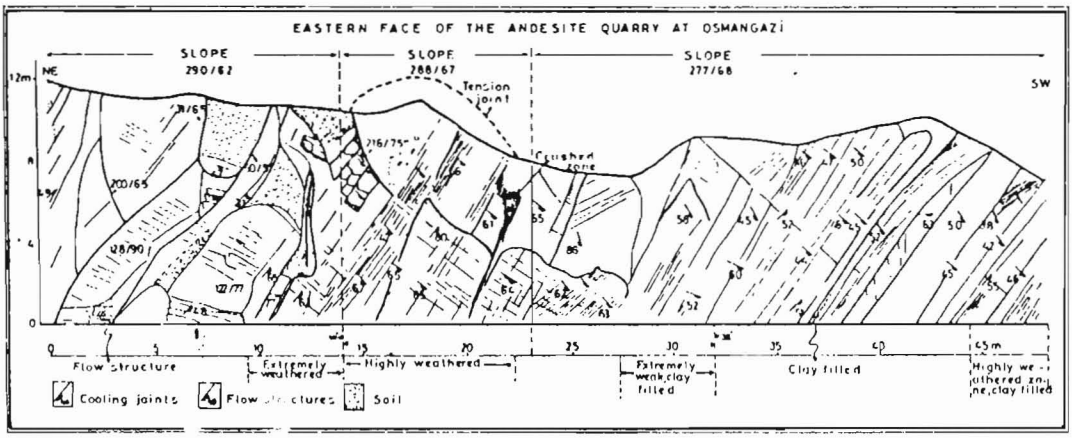
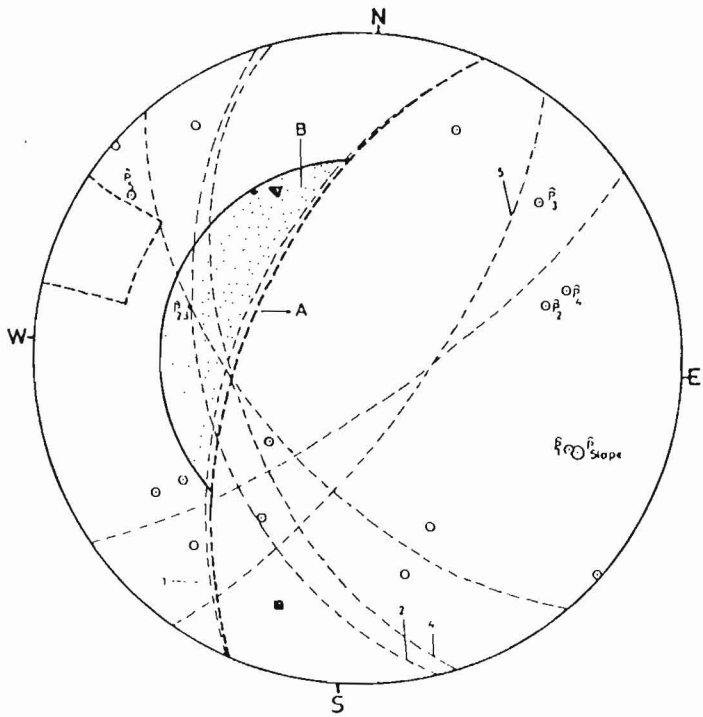


Figure 7. Discontinuity and Weathering Map of the Osmangazi Andesite Quarry.

Section 1 : It is 14 m long and its slope face stands at 290/62. Contour diagrams of the discontinuities are given in Figure-8. Stability analysis of the discontinuities indicates that planer slope failures are likely to take place along the discontinuities dipping at 290/60 and rock falls and toppling of andesite blocks are expected associated with the pole concentration $\hat{P}5$.

Section 2 : It is 10 m long and highly weathered and its slope face stands at 288/67. The contour diagrams of the discontinuities are shown in Figure 9. Wedge failures are possible over the discontinuity plane represented by the pole $\hat{P}1$. Additionally, rock falls are possible in this section.

Section 3 : It is about 25 m long and its slope face stands at 277/68. The contour diagrams and the great circles of these discontinuities are shown in Figure 10. Rock falls and toppling type of failures are expected associated with the discontinuity 106/72. Additionally, pole $\hat{P}5$ falls into



P_{23} : Pole for the intersection of the joint sets.
0 : Pole points for cooling joints.
Δ : Pole points for flow joints.
X : Pole points for tectonic joints.
A : Great circle slope plane .
B : Unstable zone for wedge failure.

Figure 8. Stability Analysis of the Discontinuity Data of the Osmangazi Andesite Quarry, Using Stereographic Projection Technique.

the toppling envelope indicating possibility of toppling failure associated with this discontinuity.

While rock falls and wedge failures are very common in the disused andesite quarries in this area, planer and toppling types of failures are scarce.

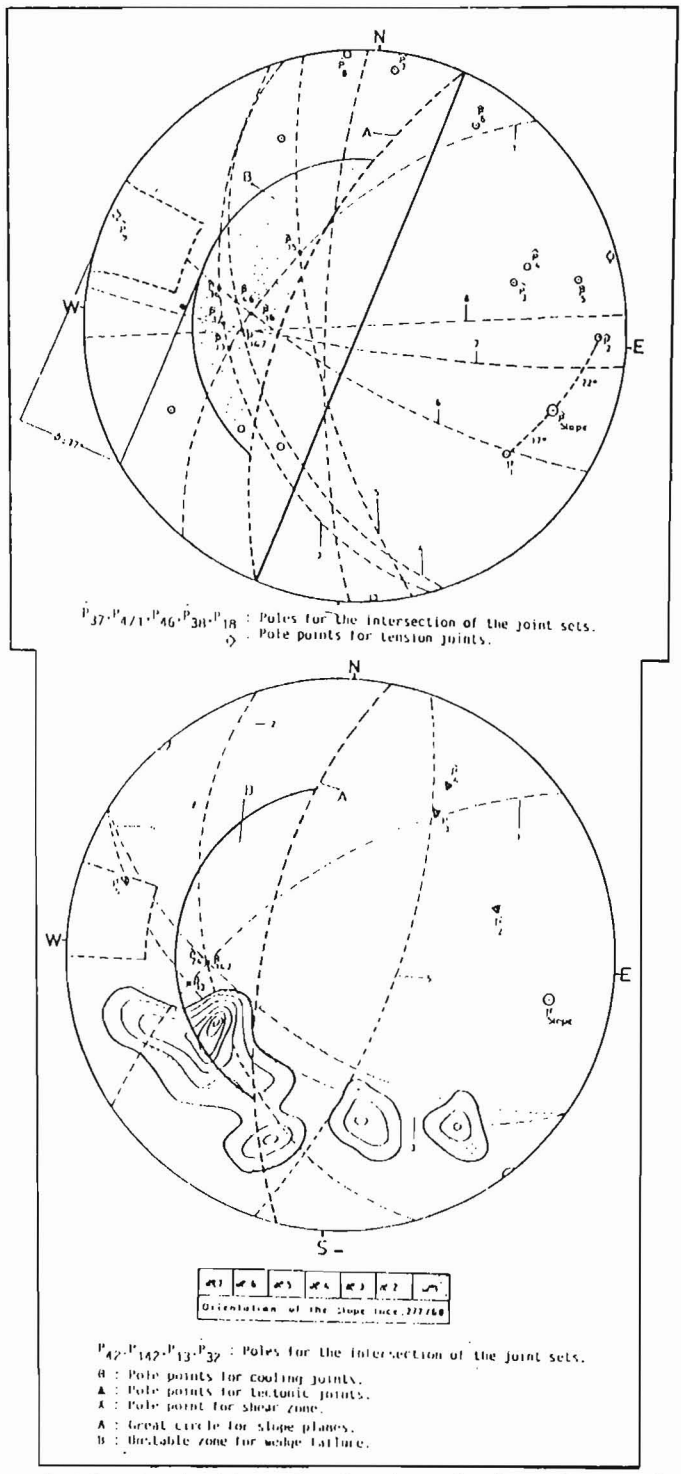


Figure 9-10. Stability Analysis of the Discontinuity Data of the Osmangazi Andesite Quarry, Using Stereographic Projection Technique.

DISCUSSION

Andesitic lavas are wide spread in and around Izmir city centre. Although andesites are poured out from different volcanos, they have a number of common features i.e. appearence, cooling joints, flow bands, and tectonic joints. Andesites are reddish pink in colour and have porphyritic textures. They have also well defined cooling joints, flow band structures and tectonic joints developed parallel to the main structural features. The rock material and mass properties are changed by weathering and alteration processes. These processes not only change the appearence of andesitic lavas but also changes their engineering properties (Table 1).

Rock mass behaviour of andesites are mainly controlled by weathering and alteration profiles and discontinuities. Andesites weather more easily along the open discontinuity surfaces along which groundwater move freely. As the porosity and permeability of andesites are low, weathering can not penetrate easily into them. Alteration is much more effective process in andesites. Earlier formed andesites are often wholly altered by the later flown andesitic lavas. Thus alteration is a much more extensively effective process. Alteration not only changes the colour, but also their intact and mass properties. Montmorillonite type clay minerals are produced along the discontinuities and the andesites are changed to weak soil by these process.

Structural features such as flow structures, cooling joints and tectonic joints are important features not only for development of the weathering and alteration profiles in the rock mass, but also for the stability of the slopes. Flow structures are generally found dipping at relatively low angles (30^{o}-40^{o}), cooling and tectonic joints dip at

high angles in the andesitic rock mass. While the flow structures have relatively rough, and closed surfaces. The cooling joints have smooth and often open surfaces, and the tectonic joints are generally rough and clay filled. The surface properties and position of the discontinuities are important features controlling the behaviour of the rock mass in andesites.

The stability of the slopes in abandoned quarries are mainly controlled by the weathering and the discontinuities. Completely weathered andesites behave like soil and circular type of slope failures are expected in them. Plane, wedge, and toppling type of slope failures are expected in fresh and partially weathered andesites. While the low angle dipping and daylighting discontinuities, cause planer sliding, the high angle dipping discontinuities cause toppling and rock falls type of slope failures. The intersecting and the intersection line daylighting discontinuities at high angles cause wedge failures in the quarries. Therefore, while the flow band structures are important for planer sliding, cooling and tectonic joints are important for toppling, rock fall and wedge type failures in the abandoned quarries.

The abandoned quarries have been exposed to weathering over a long time. The weathering processes not only changed the intact properties of andesites, but also caused stress relases in the quarry slopes. Additionally, these quarries were stopped as the city expanded and have been left by themselves without giving any considerations to their stabilities. While some of the slopes have been standing still since then, some others have been experiencing slope failures. The abandoned andesite quarry sites should only be used, only after their slopes are closely inspected and instable parts are reinforced. As these quarries are now remain within the divelling zones and often buildings are

built very near to their crests, it is impracticable to increase the stability of the quarry slopes by lowering their slope angles. Thus, generally, wiremeshing, rockbolting, shortcreating and retaining wall type of reinforcements are recommended for increasing the stability of these quarry slopes.

CONCLUSIONS

The disused andesite quarries are increasingly being used as contruction sites for buildings for public purposes, in Izmir. Detailed engineering geological studies and slope stability analysis should be carried out before any constructions made in such disused quarry sites.

Rock mass properties of andesites are affected by alteration, flow structures and cooling and tectonic joints. While the wedge and toppling failures are generally associated with the cooling and tectonic joints, planer failures are associated with the flow structures, and the circular failures often take place in highly weathered and/or jointed rock mass. Wedge and toppling types of slope failures are more common then planner and circular failures in andesite quarries. As the dissused andesite quarries are generally located in heavily built areas, it is impractical to increase their stability by cutting their slopes down. Thus, rock bolting wire meshing and retaining wall type rock reinforcements have to be applied.

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