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Full Length Research Paper

Applicability of excavatability classification systems in underground excavations: A case study

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In this study, applicability of the excavatability classification systems in underground excavations is investigated. For this purpose, the entrance portal of the Konakönü (Araklı-Trabzon) tunnel, excavated in volcanic rocks within the scope of Black Sea coastal highway project, is chosen as pilot study area. The entrance portal of tunnel is excavated through the rocks of Eocene-aged Kabaköy formation of basaltic-andesitic tuffs, aglomerate and basalt. In excavation, basaltic and andesitic tuffs were ripped by using hydraulic breaker; aglomerate and basalt were excavated by using explosives. Based on the results obtained from field and laboratory studies, rock masses are classified in terms of excavatability. According to Pettifer and Fookes (1994), basaltic and andesitic tuffs are included in "hard ripping", aglomerate and basalt in "blasting required" categories. With reference to Tsiambaos and Saroglou (2009), basaltic and andesitic tuffs fall in "ripping", agglomerate and basalt in "hammer and blasting" categories. It was found out that the classifications made according to these two methods are completely compatible with in-situ excavation works. Also, it is determined that the parameters give the best results for determining excavation class in underground excavations are GSI (Geological Strength Index), $I_{s\,(50)}$ (Point load strength index) and I_f (Discontinuity spacing index).

Key words: Blasting, excavatability classification systems, Konakönü tunnel, ripping, underground excavations.

INTRODUCTION

Excavatability is the expression for snapping off degree of the rocks from whereabouts via excavation equipments; whereas rippability is the relative statement for the rocks to be ripped and ruptured by a ripper-dozer (Ceylanoğlu et al., 2007). Selection of the right excavation method and equipment in surface and underground excavations depend on the excavatability properties of rocks.

Authentic studies made to determine the excavatability characteristics of the rocks will contribute to applicability of engineering projects. A fair assessment of geotechnical characteristics of rock masses and determination of excavation method suitable for this will reduce the excavation coast and the problems confronted to the least. Therefore, many researchers developed a number of preliminary empirical excavatability and rippability classification systems to determine excavatability by taking material and mass features of rocks into consideration (Atkinson, 1971; Franklin et al., 1971; Bailey, 1975; Weaver, 1975; Kirsten, 1982; Abdullatif and Cruden, 1983; Scoble and Müftüoğlu, 1984; Singh et al.,1986; Smith, 1986; Bozdağ, 1988; Paşamehmetoğlu et al., 1988; Karpuz, 1990; Pettifer and

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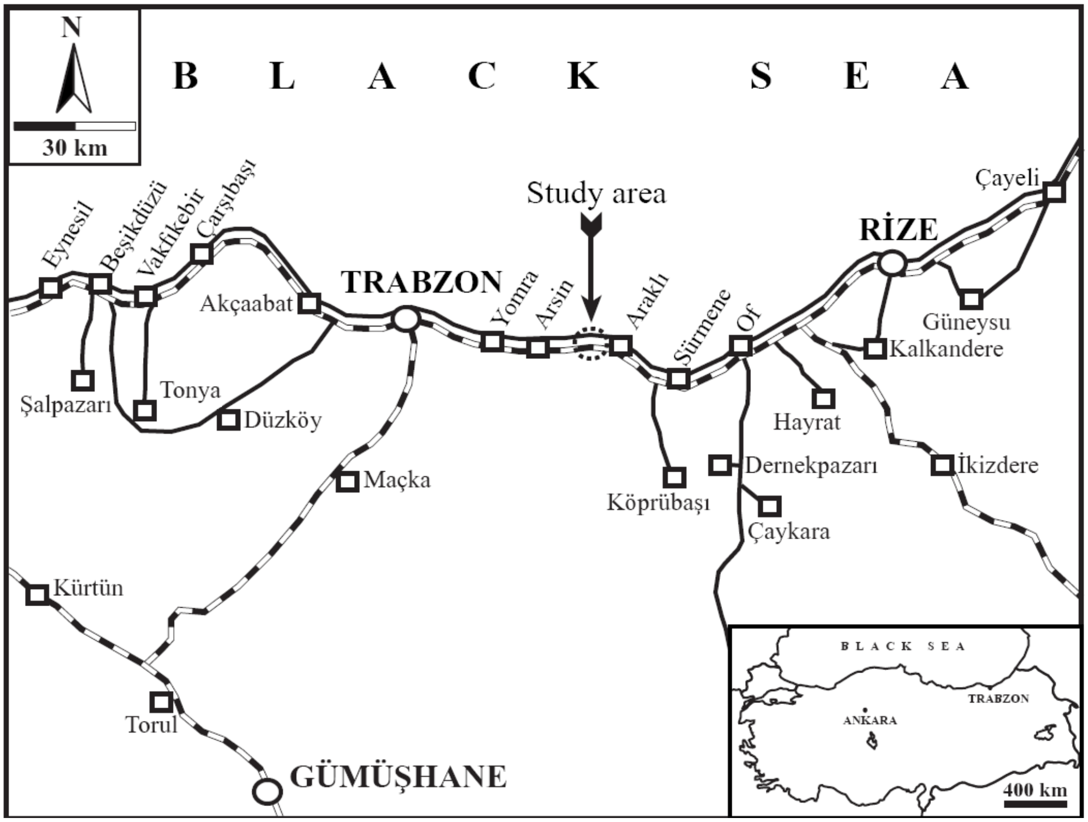

Figure 1. Location map of the study area.

Fookes, 1994; Hoek and Karzulovic, 2000; Ceylanoğlu et al., 2007; Tsiambaos and Saroglou, 2009). Most of these reformed systems depend on the data gained from field observations, laboratory experiments and test excavations made in-situ. In this study, rock masses located on entrance portal of Konakönü (Araklı-Trabzon) tunnel (Figure 1) were classified according to excavatability classification systems proposed by Franklin et al. (1971), Kirsten (1982), Abdullatif and Cruden (1983), Pettifer and Fookes (1994), Hoek and Karzulovic (2000) and Tsiambaos and Saroglou (2009).

In classification systems referenced, rock material and mass characteristics such as σ_{ci} and σ_{cm} (Uniaxial compressive strength of intact rock and rock mass), $I_{s\,(50)}$ (Point load strength index), I_f (Discontinuity spacing index), J_v (Volumetric joint count), Q (Rock mass quality), basic RMR_{89} (Rock mass rating) and GSI (Geological Strength Index) are used as input parameters. By evaluating the obtained results, it is investigated that whether excavation classes found by excavatability classification sysytems show similarities with methods applied during excavation stage.

MATERIALS AND METHODS

Engineering properties of discontinuities in rock masses located in entrance portal of Konakönü (Arakli-Trabzon) tunnel were determined by conducting scan-line surveys through the tunnel interior. A number of cubic and cylindirical shaped-samples were prepared from rock blocks, compiled during field works, in the laboratory. The dimensions of cylindrical samples prepared from agglomerate and basalt are arranged as its length will be two and a half times its diameter. Core samples were unable to be taken from andesitic and basaltic tuffs, instead cubic samples were prepared. On these samples, uniaxial compression tests and on irregular-shaped samples point load tests were applied with reference to ISRM (1981, 1985) standards. Through the help of data obtained from field and laboratory works, rock masses are classified according to Q (Barton et al., 1974) and RMR_{89} (Bieniawski, 1989) systems and GSI (Hoek and Marinos, 2000) values were determined. Besides, the strength features of rock masses were defined by empiricial failure criteria of Hoek-Brown (Hoek et al., 2002).

Geology of study area

The study area is located in northern part of Eastern Pontide Tectonic Unit, Black Sea region, Turkey. Eocene-aged Kabaköy

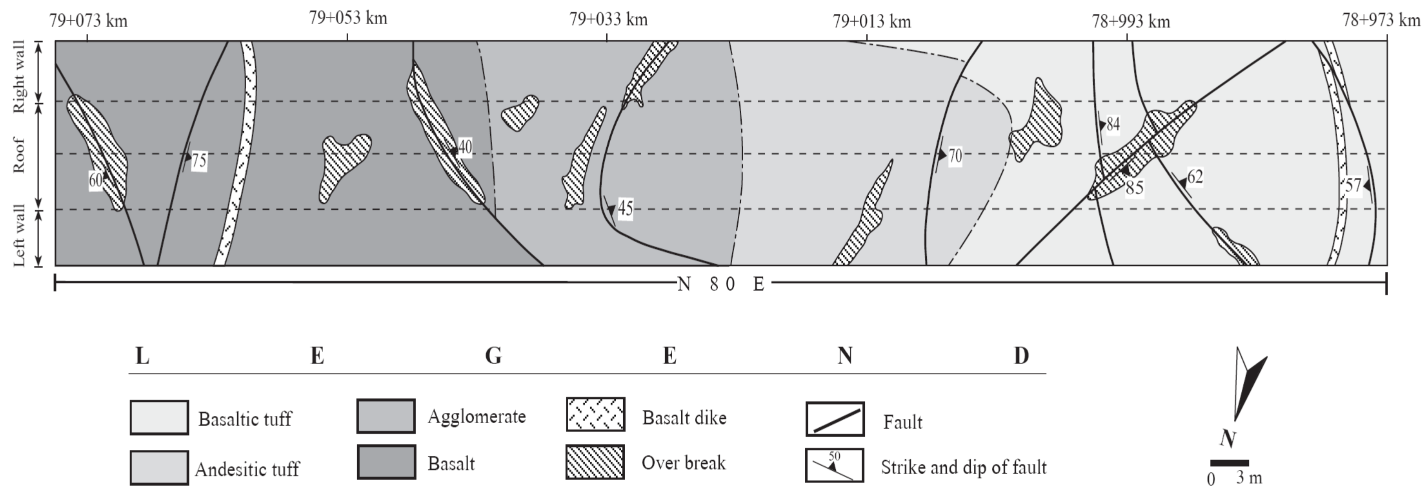

Figure 2. 1:1000-scaled geological map for entrance portal of tunnel interior.

Formation showing wide expansion along Konakönü (Araklı-Trabzon) tunnel route was first described by Güven (1993). This formation lithologically consists of andesite-basalt and their pyroclatics. The following volcanic rocks comprising basaltic tuff, andesitic tuff, agglomerate and basalt are orderly located in entrance portal of tunnel (Figure 2). Basaltic tuffs have pale green and andesitic tuff have light gray colours. Tuffs contain sporadic pyrite occurrences and haematitisation are commonly seen in some places throughout the outcrops. Agglomerate consists of rounded-basalt pyroclastics having diameters of between 2 to 30 centimeters. Chloritisation is seen as patches in cement material of rock. Basalts are in dark to dark gray colour and they present a massive texture without any observable weathering products (Kaya, 2008).

Engineering properties of rock materials, masses and discontinuities

Point load and uniaxial compression tests are performed on samples gathered from rock units of investigated area and results of experiments are given in Table 1. On the ground of point load strength index and according to the classification proposed by Bieniawski (1975) basaltic tuff falls in very low-strength, andesitic tuff low-strength, agglomerate medium-strength and basalt high-strength classes. According to uniaxial compressive strength classification recommended by Deere and Miller (1966) from these rock units, andesitic tuff and agglomerate fall in low-strength group, basaltic tuff very low-strength, whereas basalt is in high-strength classes. To determine engineering properties of discontinuities rock masses have, according to ISRM (1981) definition criterias scan-line surveys of tunnel interior were carried out and engineering features of discontinuities such as spacing, persistency, roughness, filling, aperture, weathering degree and ground water condition were determined (Table 2). By drawing on engineering properties of discontunities, J_v (Palström, 1982) and RQD (Rock quality designation) (Deere, 1964) parameters were defined. Through the help of data obtained, rock masses were classified by using Q ve RMR_{89} classification systems. Furthermore, GSI values of rock masses were identified and by utilizing Hoek-Brown empirical failure criteria, σ_{cm} parameterswere calculated. The average values of obtained results are presented on Table 3.

Assesment of rock masses according to excavatability classification systems

In this study, excavatability classification systems, commonly used for determination of excavatability, proposed by Franklin et al. (1971), Kirsten (1982), Abdullatif and Cruden (1983), Pettifer and Fookes (1994), Hoek and Karzulovic (2000), Tsiambaos and Saroglou (2009) are utilized. To make it easy basaltic tuff is signed as A1, andesitic tuff A2, agglomerate A3 and basalt A4, accordingly. In order to define excavation class in excavatability classification system of Franklin et al. (1971) discontinuity spacing and σ_{ci} or $I_{s(50)}$ values are used as input parameters. It is determined that, according to classification recommended by Franklin et al. (1971) andesitic tuff, basalt and agglomerate fall in “blast to fracture” on the other hand basaltic tuff falls in “blast to loosen” classes (Figure 3). To designate excavation class in excavatability classification system proposed by Kirsten (1982) σ_{ci}, J_s (relative ground structure number - taken 1 for rock material) parameters and RQD, J_n (joint set number), J_r (joint roughness number) and J_a (joint alteration number) values of input parameters in Q rock mass classification system are used. By imposing the geomechanical properties of rocks N (excavatability index) value was determined and rock masses were evaluated in terms of excavatability. Excavatability index (N) was defined by the following equation:

$$N=\sigma_{ci}\left[\frac{RQD}{J_n}\right]J_s\left[\frac{J_r}{J_a}\right] \quad (1)$$

The values of input parameters and definitions used in excavatability classification sytems proposed by Kirsten (1982) are

Table 1. Mechanical properties of rock materials.

Properties (average values)	Basaltic tuff	Andesitic tuff	Agglomerate	Basalt
Test number	15	17	14	17
$I_{S(50)}$ (MPa)	0.80	1.80	3.03	6.09
Standard deviation	±0.06	±0.18	±0.82	±1.09
Definition (Bieniawski, 1975)	Very low strength	Low strength	Medium strength	High strength
Test number	10	11	10	13
σ_{ci} (MPa)	18.58	29.42	38.92	143.62
Standard deviation	± 0.88	± 3.51	± 5.55	± 8.75
Definition (Deere and Miller, 1966)	Very low strength	Low strength	Low strength	High strength

Table 2. Engineering properties of discontinuities.

Properties (average values)	Basaltic tuff	Andesitic tuff	Agglomerate	Basalt
Joint set number	3	3	2	2
Spacing (cm)	Close spacing (15.4)	Moderate spacing (29.3)	Moderate spacing (34.6)	Moderate spacing (29.5)
Persistency (m)	Moderate persistency (9.8)	Moderate persistency (8.3)	Moderate persistency (8.7)	Low persistency (2.9)
Aperture(mm)	Open (1.2)	Open (1.8)	Open (2.1)	Open (2.3)
Filling	Swelling clay fillings	Swelling clay fillings	Swelling clay fillings	Swelling clay fillings
Roughness	Smooth, undulating	Smooth, undulating	Smooth, undulating	Rough, undulating
Weathering degree	Moderately weathered	Moderately weathered	Slightly weathered	Slightly weathered
Ground water condition	Minor seepage, specify dripping discontinuities	Minor seepage, specify dripping discontinuities	Dry walls and roof, no detectable seepage	Dry walls and roof, no detectable seepage

given on Table 4. According to recommended classification it is determined that basaltic-andesitic tuffs and agglomerate fall in "hard ripping" and basalt falls in "very hard ripping" classes (Table 5). In excavatability classification system of Abdullatif and Cruden (1983) to determine excavation class of rock masses were evaluated, by using basic RMR_{89} and Q values as input parameters, in terms of excavatability. According to classification proposed by Abdullatif and Cruden (1983), basaltic-andesitic tuffs and agglomerate are classified as "ripping" and basalt as "blasting" (Figure 4). In excavatability classification sytems recommended by Pettifer and Fookes (1994) I_f and $I_{s(50)}$ values are used as input parameters. I_f was determined with Equation 2 by utilizing J_v:

$$I_f = \frac{3}{J_v} \quad (2)$$

With reference to classification of Pettifer and Fookes (1994), it is determined that basaltic and andesitic tuffs fall in "hard ripping" class and agglomerate and basalt fall in "blasting required" classes (Figure 5). In excavatability classification systems proposed by Hoek and Karzulovic (2000), GSI and uniaxial compressive strength (σ_{cm}) of rock masses are used as input parameters. According to classification proposed by Hoek and Karzulovic (2000) basaltic and andesitic tuffs are classified in "digging" group; and agglomerate and basalt in "ripping" group (Figure 6). On the other hand, in excavatability classification system

Table 3. Engineering properties of rock masses.

Properties (average values)	Basaltic tuff	Andesitic tuff	Agglomerate	Basalt
J_v (joint /m^3)	6.47	3.41	2.74	2.87
RQD (%)	85	89	96	95
σ_{cm} (MPa)	0.668	1.38	1.16	6.837
Q	0.070	0.074	0.139	0.211
Definition (Barton et al., 1974)	Extremely poor	Extremely poor	Extremely poor	Exceptionally poor
Basic RMR_{89}	44.9	46.7	54.2	63.3
Definition (Bieniawski, 1989)	Fair	Fair	Fair	Good
GSI	41	46	54	60
Definition (Hoek and Marinos, 2000)	Very blocky	Very blocky	Blocky/very blocky	Blocky/very blocky

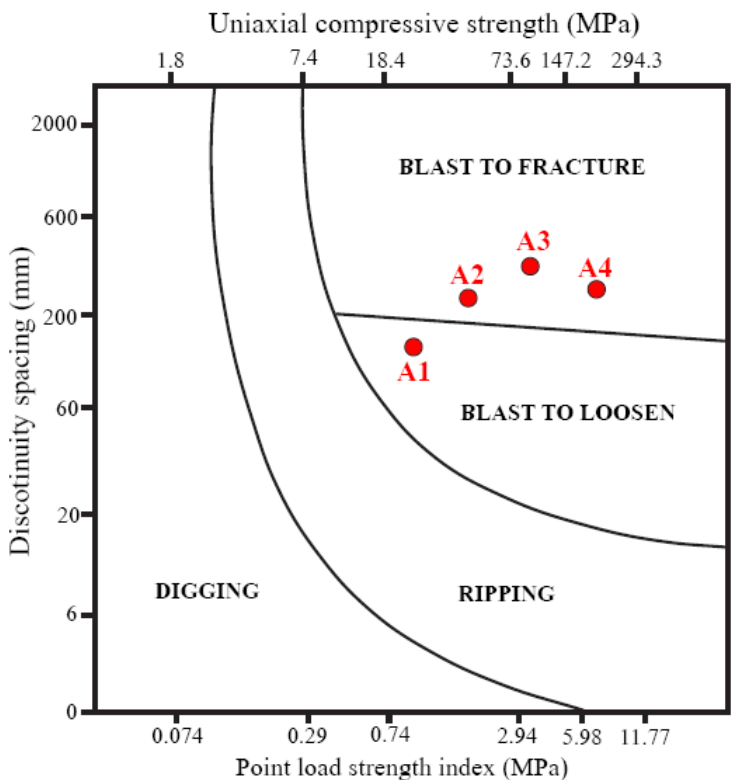

Figure 3. Assesment of rock masses with reference to excavatability classification system of Franklin et al. (1971).

recommended by Tsiambaos and Saroglou (2009) GSI and $I_{s(50)}$ values are used and they proposed two different GSI charts to evaluate rock masses in terms of excavatability, provided that $I_{s(50)} \geq 3$ MPa and $I_{s(50)} < 3$ MPa. Proposed GSI charts determining excavatability class of andesitic and basaltic tuffs (with the condition of $I_{s(50)} < 3$ MPa) and for that of agglomerate and basalt (with the condition of $I_{s(50)} \geq 3$ MPa) are given in Figures 7 and 8, accordingly. According to classification of Tsiambaos and Saroglou (2009); basaltic and andesitic tuffs are in “ripping” class, agglomerate and basalt are in “hammer and blasting” class.

Comparison of proposed excavation methods with in-situ excavation works

In rock environment, when going down from surface into deep

Table 4. Input parameters used in determining excavatability index (N) proposed by Kirsten (1982).

Properties (average values)	Basaltic tuff	Andesitic tuff	Agglomerate	Basalt
σ_{ci} (MPa)	18.58	29.42	38.92	143.62
RQD (%)	85	89	96	95
J_a	10	10	10	10
J_n	3	3	2	2
J_r	2	2	2	3
J_s	1	1	1	1
N (excavatability index)	13.00	21.77	62.72	340.37

Table 5. Assessment of rock masses with reference to excavatability classification system of Kirsten (1982).

Excavatability degree	Total rating	Basaltic tuff	Andesitic tuff	Agglomerate	Basalt
Blasting	N > 10000	-	-	-	-
Extremely hard ripping/blasting	1000 < N< 10000	-	-	-	-
Very hard ripping	100 < N <1000	-	-	-	340.37
Hard ripping	10 < N <100	13.00	21.77	62.72	-
Easy ripping	1 < N <10	-	-	-	-

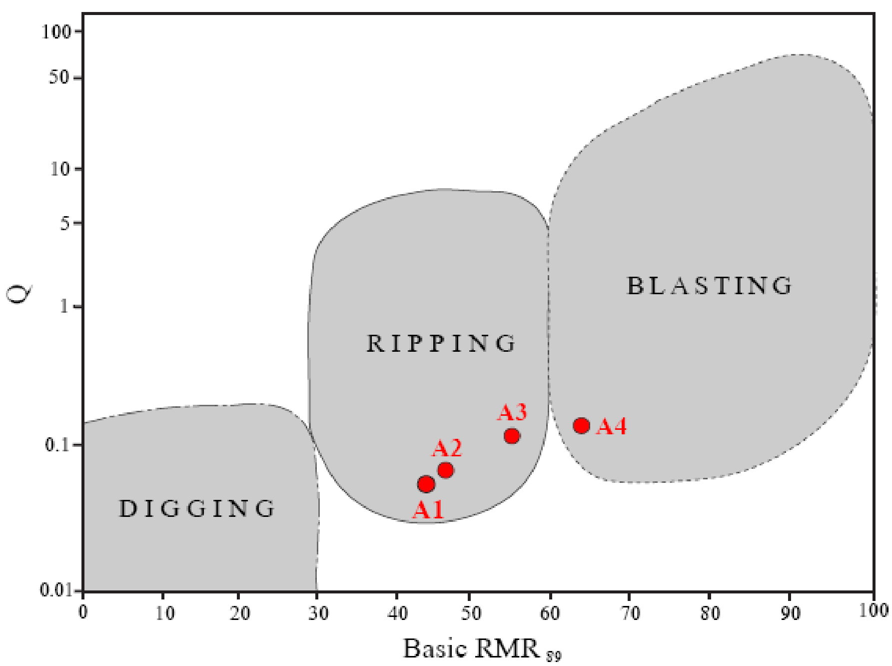

Figure 4. Assesment of rock masses with reference to excavatability classification system proposed by Abdullatif and Cruden (1983).

inside the indicated resistance against excavation increases with subject to decreasing affect of weathering. In many excavatability classification systems proposed by various researchers input parameters of weathering degree of discontinuity surface, its

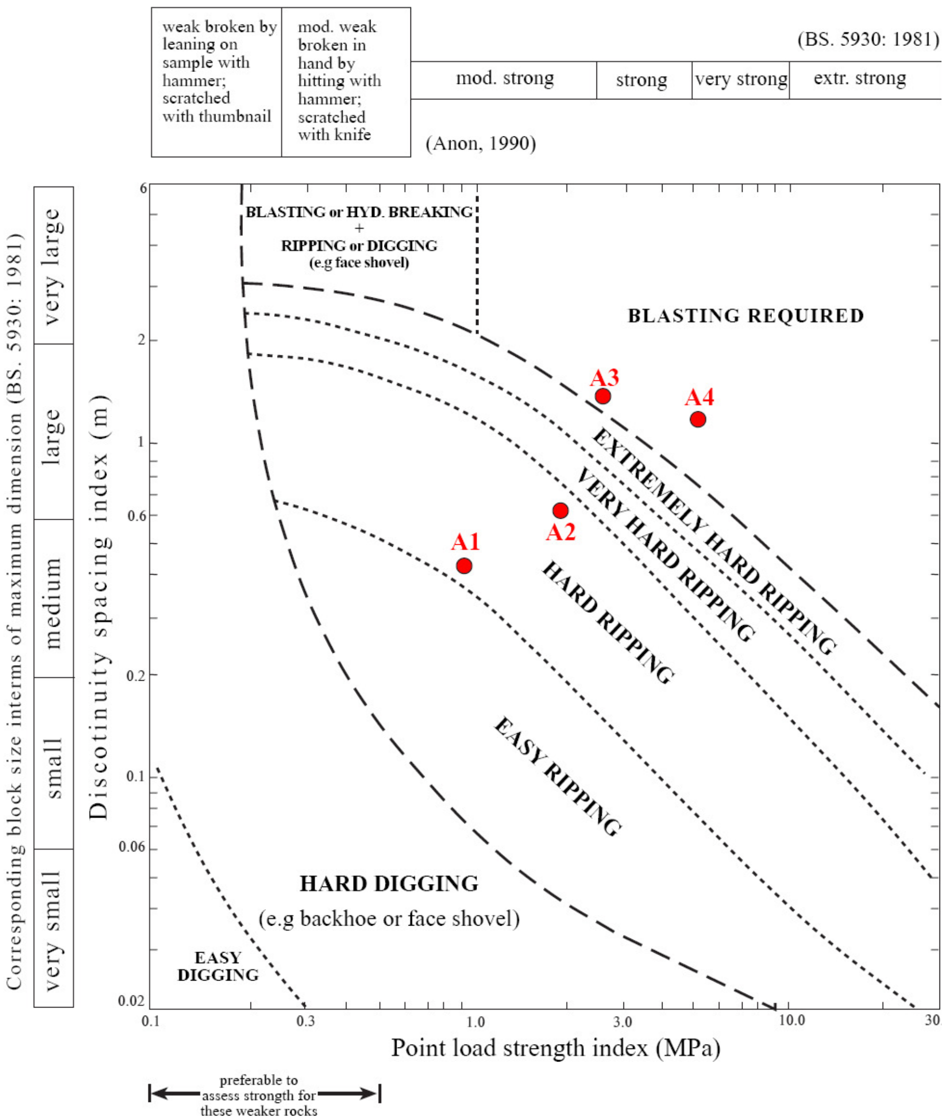

Figure 5. Assesment of rock masses with reference to excavatability classification system recommended by Pettifer and Fookes (1994).

roughness, aperture, ground water condition, and filling, affected easily from surface conditions are used. Usually, by using these parameters, trying to determine the excavation method can cause problems in application stage. The most important parameters, least effected from surface conditions, affecting excavatability in underground excavations are block dimension and strength of rock material. To determine excavation method according to excavatability classification systems using these parameters gives better results in application stage and contributes to applicability of project. Excavatability classification systems suggested by Pettifer and Fookes (1994) and Tsiambaos and Saroglou (2009) have been using these parameters effectively. During excavation of entrance portal of Konakönü Tunnel, to advance through the tunnel, hydraulic breaker is used for basaltic and andesitic tuffs; and explosives are used for agglomerate and basalt. At the end of analyses performed, it is indicated that the classifications made according to proposed methods of Pettifer and Fookes (1994) and Tsiambaos and Saroglou (2009) show exact similarities with the methods applied during excavations.

RESULTS

In order to investigate applicability of six different known excavatability classification systems, commonly used in

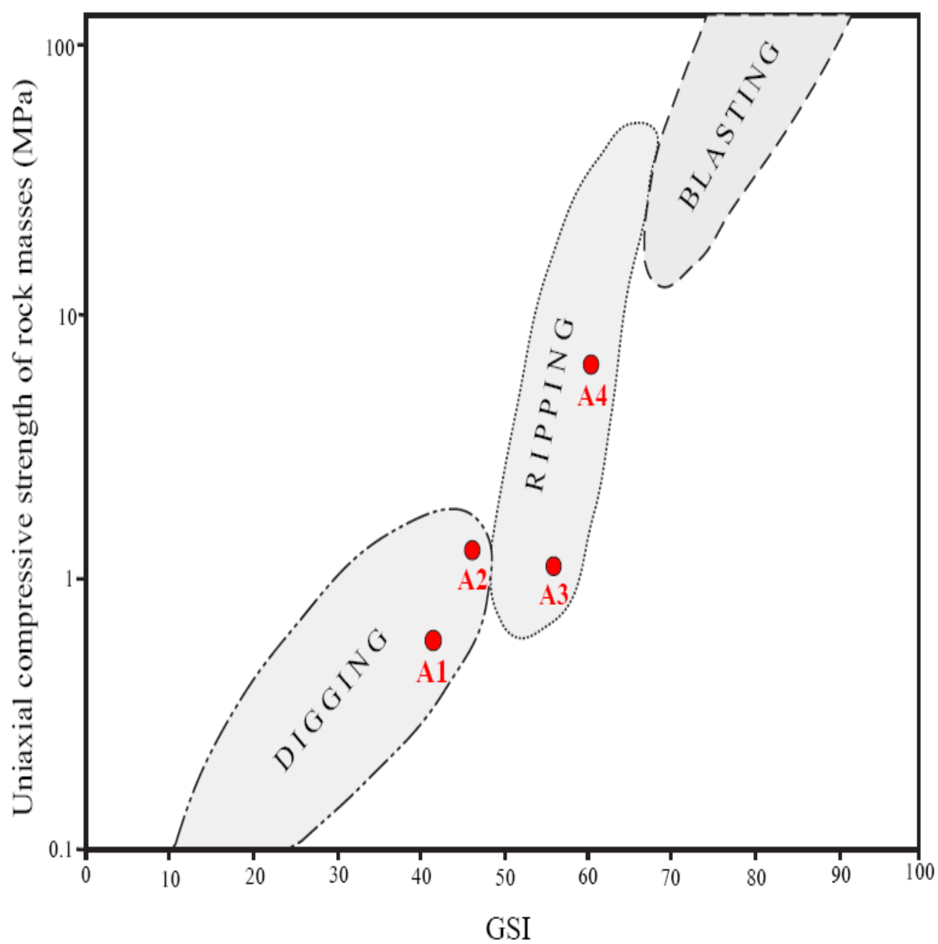

Figure 6. Assesment of rock masses with reference to excavatability classification system of Hoek and Karzulovic (2000).

determining excavatability properties of rock masses, in underground excavations, entrance portal of Konakönü (Arakli-Trabzon) tunnel was chosen as the pilot study area and rock masses located herein were classified in terms of excavatability. The results obtained from performed study and works are as follows:

1) According to classification system proposed by Franklin et al. (1971), it was determined that andesitic tuff, basalt and agglomerate were classified as in "blast to fracture" and basaltic tuff were classified "blast to loosen" classes, respectively.
2) With reference to excavatability classification system proposed by Kirsten (1982), basaltic-andesitic tuffs and agglomerate fell in "hard ripping" and basalt fell in "very hard ripping" classes.
3) According to excavatability classification system recommended by Abdullatif and Cruden (1983), basaltic-andesitic tuffs and agglomerate were included in "ripping" and basalt was included in "blasting" classes.
4) Considering the excavatability classification system of Pettifer and Fookes (1994), it is determined that basaltic and andesitic tuff were classified as "hard ripping", agglomerate and basalt were as "blasting required".
5) According to excavatability classification systems proposed by Hoek and Karzulovic (2000), basaltic and andesitic tuffs fell in "digging" and agglomerate and basalt fell in "ripping" classes.
6) With refercence to excavatability classification system of Tsiambaos and Saroglou (2009) basaltic and andesitic tuffs were in "ripping" agglomerate and basalt was in "hammer and blasting" classes, respectively.
7) In excavation stage, basaltic and andesitic tuffs were ripped by using hydraulic breaker; agglomerate and

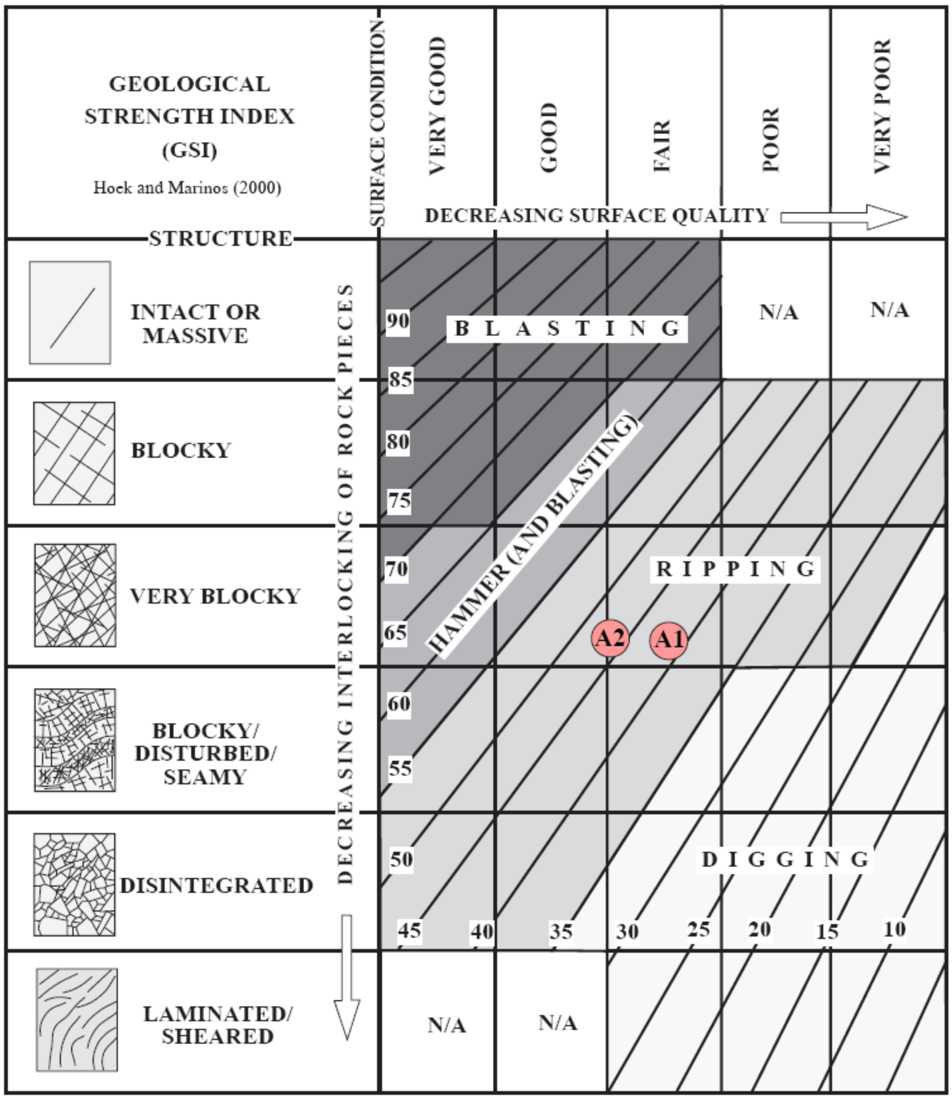

Figure 7. Evaluation of rock masses consisted of andesitic and basaltic tuffs with reference to excavatability classification systems ($I_{s(50)}$ < 3 MPa) proposed by Tsiambaos and Saroglou (2009).

basalt were excavated by using explosives.

8) At the end of the analyses made, it was determined that classification of Pettifer and Fookes (1994) and classification made according to methods proposed by Tsiambaos and Saroglou (2009) reflected exactly results of the methods applied during excavation.

DISCUSSION

In underground excavations, excavatability property of rock mass is controlled by block dimension and strength of rock material. Excavatability classification systems proposed by Pettifer and Fookes (1994) along with Tsiambaos and Saroglou (2009) have been using these parameters effectively. Among the investigated excavatability classifications, it is determined that applications of these two classification systems are suitable for underground excavations as well as surface excavations. At the conclusion of assesments made, it was established that the parameters providing the best result in determining excavation class of rock materials in

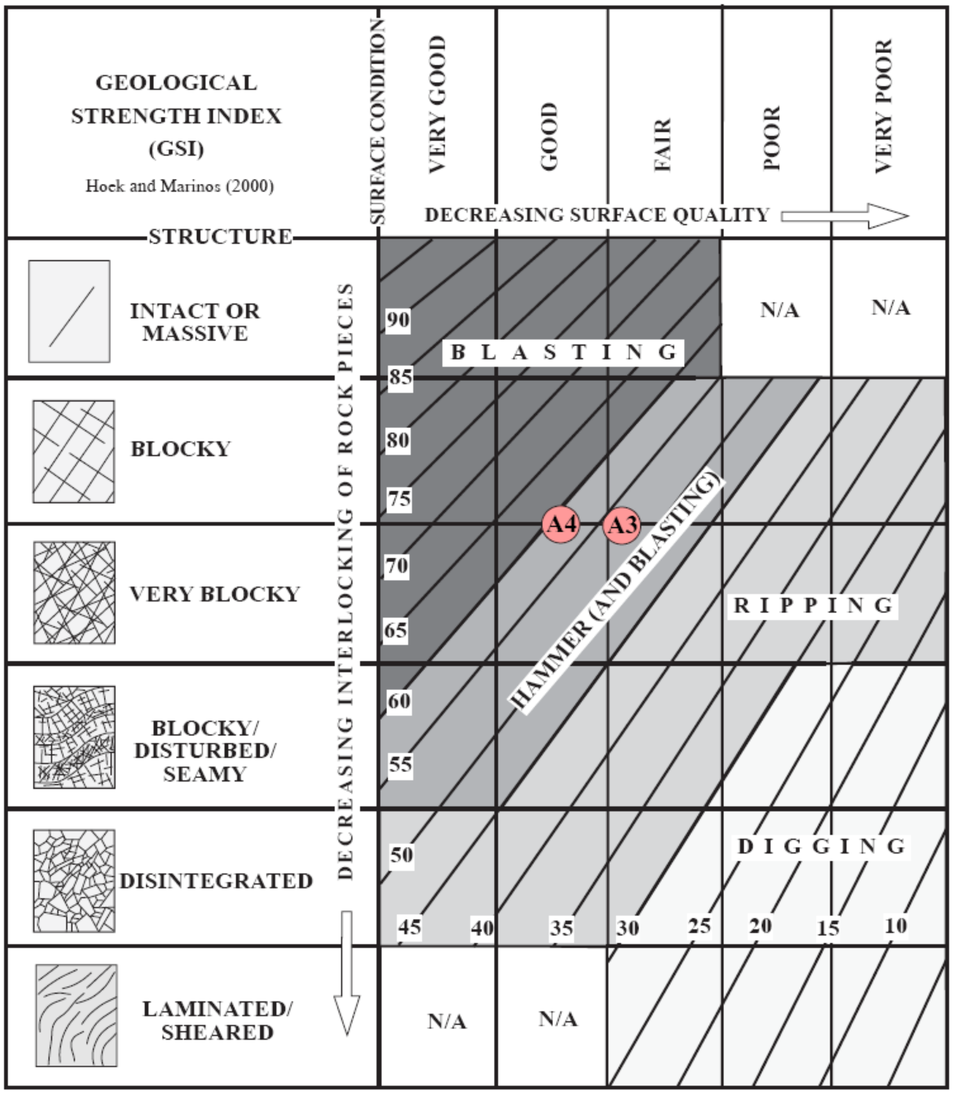

Figure 8. Evaluation of rock masses consisted of agglomerate and basalt with reference to excavatability classification systems ($I_{s(50)} \geq 3$ MPa) proposed by Tsiambaos and Saroglou (2009).

underground excavations are GSI, $I_{s(50)}$ and I_f values.

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