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EXCAVATABILITY ASSESSMENT FOR THE EOCENE CARBONATE ROCKS AROUND AL-SALMAN DEPRESSION, SOUTH IRAQ

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ABSTRACT

Excavatability or rippability, also called diggability, is the ease of excavation to remove material from the rock mass. The excavation method is assessed using Discontinuity Spacing Index (I_f), the Point Load Index (I_s) and the Geological Strength Index (GSI) of the intact rock. The data originate from seven sites, previously studied in detail in rock masses along the slopes around Al-Salman Depression. Those rock masses were assessed as strong strength, good quality and blocky to very blocky. According to the currently excavation assessments revealed that "Blasting" is not the only feasible method of excavating the studied rock types, as "Hard Ripping" using hydraulic machines, is possible option too.

تقييم قابلية القلع لصخور الايوسين الكاربوناتية المحيطة بمنخفض السلمان، جنوب العراق

لؤي داود يوسف

المستخلص

تعكس قابلية القلع أو التمزيق أو مايسمى بالحفر أيضاً سهولة القلع لأزاحة المواد من الكتلة الصخرية. تم تحديد طريقة القلع باستخدام "دالة المسافة البينية للأنقطاعات (I_f) ودالة التحميل النقطي (I_s) ودالة القوة الجيولوجية (GSI) للصخرة السليمة. تم جمع البيانات من (7) مواقع مدروسة سابقاً بالتفصيل في كتل صخرية على طول المنحدرات المحيطة بمنخفض السلمان. صنفت الكتل الصخرية تلك سابقاً على انها "قوية" و"جيدة النوعية" و"كتلية" الى "كتلية جداً". بينت نتائج حساب قابلية القلع الحالية ان عملية التفجير ليست هي الاسلوب الوحيد للقلع والحفر في الأنواع الصخرية المدروسة، وان عملية "الحفر بقوة" باستخدام الآليات الهيدروليكية هي الخيار الممكن استخدامه ايضاً.

INTRODUCTION

The fundamental objective of excavation process is to remove material from the rock mass. There are two potential objectives in removing the rock: one is to create an opening; the other is to obtain the material for its inherent value (Hudson and Harrison, 1997), whether as crushed or dimension stone. The oldest graphical indirect excavatability assessment method is that of Franklin *et al*. (1971). It considers two parameters: the fracture spacing (If) and strength values of intact rock. Franklin's method has been re-evaluated and modified by many researchers; the most well-known is being Pettifer and Fookes (1994). Although this method allows excavatability to be assessed rapidly, the subdivisions have become outdated as more powerful, more efficient equipment has become available.

Predicting the ease of excavation of rock and rock masses is very significant in earthworks for highway construction, construction industries and other civil engineering

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works, in surface mines, quarries and also for foundations. In order to describe the excavation method of rocks, different terms have been used, related to the principles of excavation and the mechanics of fracture. These include cuttability, rippability, excavatability, diggability and drillability (Tsiambaos and Saroglou, 2010). Studying the physical and chemical properties of the material to be excavated is very important in selection the effective excavation method (Alade and Abdulazeez, 2014). Accordingly, excavation methods may be by Digging, when easy or very easy excavation conditions exist, Ripping, for moderate to difficult excavation conditions, and Blasting for very difficult excavation conditions. Previously, two geotechnical investigation studies (in the Al-Salman Depression area and surroundings) were carried out for marble substitutes (Arteen and Ameer, 2001) and industrial rocks occurrences (Kadhum *et al*., 2011), which led to the availability of rocks that could be used for such purposes. Therefore, the objective of this study is to assess the excavatability of the carbonate rock masses around the Al-Salman Depression.

- **Location**

The Al-Salman Depression is located in 130 Km southwest of the Samawa City within Al-Muthana Governorate, South Iraq. The depression is irregular in shape, located within latitudes 30° 20' 10'' and 30° 33' 23'' N, and longitudes 44° 28' 25'' and 44° 38' 16'' E (Fig.1). The Al-Salman Depression is a large karst landform in the Southern Desert of Iraq, developed within the carbonate rocks of the Middle Member of the Dammam Formation (Sissakian *et al*., 2013).

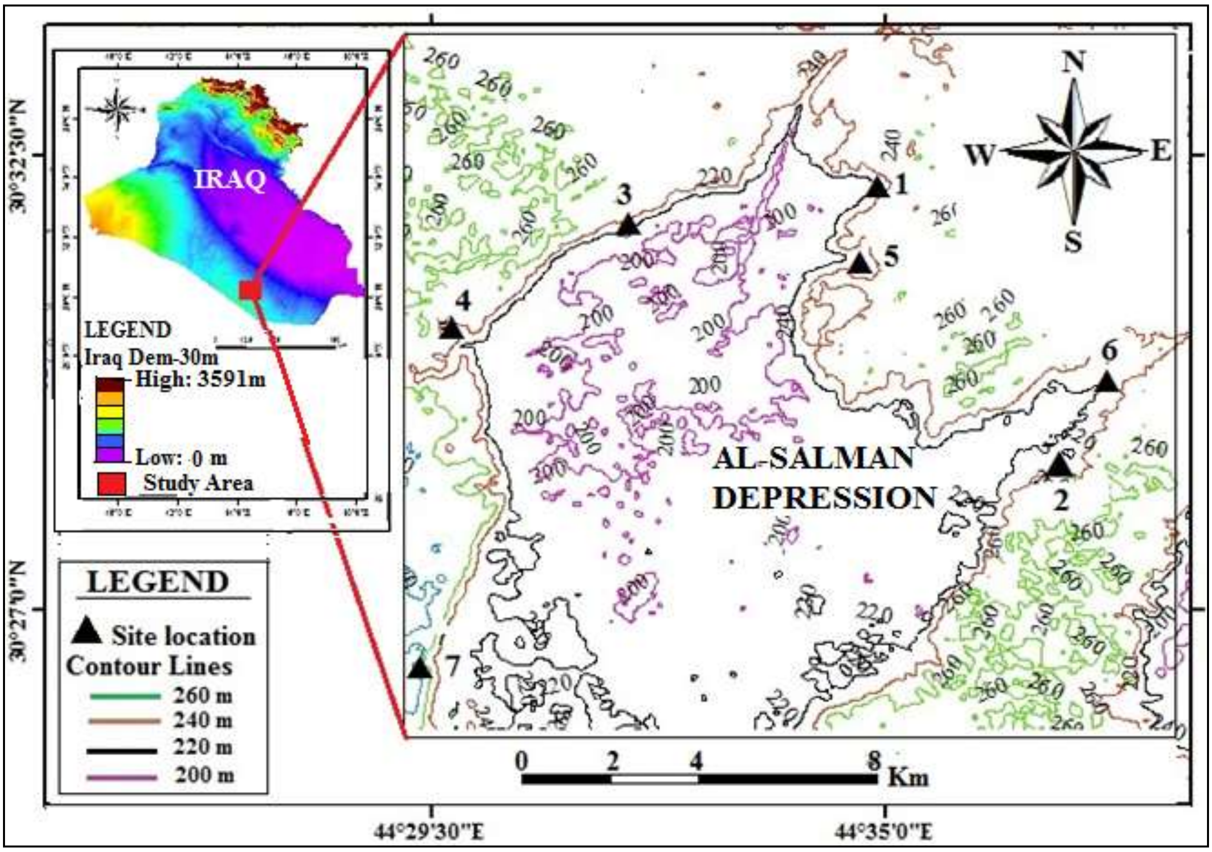

Fig.1: Location map of the studied area

- **Previous Works**

From the geotechnical point of view, few studies have been carried out on the rock exposures of the Middle Member of the Dammam Formation around Al-Salman Depression. These are;

- Arteen and Ameer (2001) carried out a geotechnical study for the marble substitutes in the Salman area. Their investigation indicated that there are three economic layers within the Shawiya Unit of the Middle Member of the Dammam Formation that can be used as dimension stone for decorative and construction purposes.

- Kadhum *et al*. (2011) carried out a geological investigation for mineral occurrences and industrial rocks in the Muthana Governorate, in which Al-Salman depression is located. They pointed out some locations with raw materials suitable for industrial purposes such as, limestone for cement, dolomitic limestone for glass industries and clays for cement and brick industries.

- Yousif *et al*. (2013) determined the landslide possibility index and the landslide hazards of the rock slopes at the Al-Salman Depression and denoted that three sites of the studied rock slopes are of Very Low and the fourth is of Low landslide possibility index, and consequently, they are of low hazards to moderate hazards, respectively.

- Yousif *et al*. (2014) applied Rock Mass Rating and Slope Mass Rating systems on rock slopes at the Al-Salman Depression, for acquiring a better understanding of the influence of the geological and rock strength parameters, and the mechanism of rock failure on slope stability analyses and processes of open cast mining and quarrying.

GEOLOGICAL SETTING OF THE AREA

Geomorphologically, Al-Salman Depression is the largest karst landform in the Southern Desert of Iraq. It is of 'Uvalas' type developed within the Middle Member of the Dammam Formation. It has been formed by the action of surface and ground water (Sissakian *et al*., 2013). The length of the depression is 20 Km, whereas, the width is variable, it is (6.5, 10 and 4.5) Km in the northern, central and southern parts respectively, while, the depth ranges from (5 – 35) m (Sissakian *et al*., 2013). The edges of this depression consist of rock slopes with heights range between (10 – 35) m and slope inclinations between (15 – 70)°, towards the depression. It is developed by the dissolution of the carbonate rocks of the Middle Member of the Dammam Formation (Middle Eocene) by rain water, and the underlying anhydrite rocks of the Rus Formation (Early Eocene) by groundwater (Sissakian *et al*., 2013).

Geologically, the studied area, is mainly covered by the exposures of the Dammam Formation (Eocene age), which is divided into three members: Lower, Middle and Upper (Al-Mubarak and Amin, 1983). According to Jassim and Al-Jibury, (2009), only two units of the Middle Member are exposed in the study area. These are:

1) Shawiya Unit: This is the upper unit; consists of thickly bedded to massive, recrystallized, nummulitic limestone, alternated with thin horizons of limestone and (2 – 3) horizons of shelly limestone.

2) Chabd Unit: The lower part (15 – 20 m) consists of massive limestone, overlain by thinly bedded, nummulitic limestone, followed by (11 – 14) m of massive and crystalline limestone. The middle part (5 – 10 m) consists of alternation of thickly bedded and nummulitic limestone. The upper part (15 m) consists of thickly bedded nummulitic limestone. The depression floor is partly covered by the Zahra Formation (Pliocene – Pleistocene) in addition to by depression fill sediments of the Holocene age (Sissakian *et al*., 2013).

Tectonically, the studied area is located within the Inner Platform of the Arabian Plate, at about 120 Km south of the Anah – Abu Jir Fault Zone, which represents the eastern boundary between the Inner and Outer Platforms (Fouad, 2012).

METHODOLOGY

Three charts of the graphical methods are employed to evaluate the excavation method for the dolomitic limestone of the Middle Member of the Dammam Formation on the slopes of the Al-Salman Depression. These three charts were suggested by Franklin *et al*. (1971), Pettiffer and Fooks (1994) and Tsiambaos and Saroglou (2010).

In the current work, the excavation method is assessed by two approaches; Size-strength graph, that narrates discontinuity spacing and rock strength to select the method of excavation. The intact rock strength of a rock mass has been determined by several different means in the context of research for slope stability assessment. The intact rock strength was determined by the so-called ‘simple means’ (Table 1) that denotes estimating the intact rock strength by hammer blows, crumbling by hand, etc.(Hack and Huisman, 2002)

Table 1: Field estimation of intact rock mass strength (Hoek and Brown, 1997)

Term	Uniaxial Comp. Strength (MPa)	Point Load (*Is*) Index (MPa)	Field estimate of strength
Extremely Strong	>250	> 10	Rock material only chipped under repeated geological hammer blows
Very Strong	100 – 250	4 – 10	Requires many blows of a geological hammer to break intact rock specimens
Strong	50 – 100	2 − 4	Hand held specimens broken by single blow of geological hammer
Medium Strong	25 – 50	1 − 2	Firm blow with geological pick indents rock to 5 mm, knife just scrapes surface
Weak	5 – 25	**	Knife cuts material but too hard to shape into triaxial specimens
Very Weak	1 – 5	**	Material crumbles under firm blows of geological pick, can be with knife
Extremely Weak	0.25 – 1	**	Indented by thumb nail

* All rock types exhibit a broad range of uniaxial compressive strengths, which reflect heterogeneity in composition and anisotropy in structure. Strong rocks are characterized by well interlocked crystal fabric and few voids.

** Rocks with uniaxial compressive strength below 25 MPa are likely to yield highly ambiguous results under Point load testing.

Accordingly, the unconfined compressive strength (UCS) for the first four sites (1, 2, 3 and 4) were determined by hammer blows (Yousif *et al*., 2013), while samples of the last three sites (5, 6 and 7) were measured in the laboratory of the Iraq Geological Survey (Yousif *et al*., 2014). In the current work, the Point Load Index (Is) values for the first four sites were calculated for the mean values (75 MPa) of the estimated range (50 – 100 MPa) of the (UCS) values.

- **Point Load Index (Is)**

The Point Load Index (I_S) values are estimated from the Uniaxial Compressive Strength (UCS) values using the relationship (equation 1) established by Osman (2010):

$$Is = 0.047UCS - 0.3287 \quad \ldots\ldots\ldots (1)$$

The uniaxial (unconfined) compressive strength values were previously measured by Yousif *et al*. (2013 and 2014).

- **Discontinuity Spacing Fracture (I_f) index**

The discontinuity spacing index (If), which is required for the first two charts are calculated from the equation (2) by ISRM (1981):

$$I_f = N / J_v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where; N = Number of major joint sets identified, and J_v = Volumetric Joint Count.

– Volumetric Joint Count (Jv) Index: The volumetric joint (Jv) index is the number of joints per cubic meter, and calculated from the equation (3) suggested by ISRM (1981):

$$J_v = 1/S_1 + 1/S_2 + 1/S_3 + \ldots\ldots + 1/S_n \quad \ldots\ldots\ldots (3)$$

Where; S1, S2, S3 and Sn are the discontinuity spacing of n joint sets.

- **Geological Strength Index (GSI)**

The third approach is the use of Geologic Strength Index (GSI) values and point load index (Is) as proposed by Tsiambaos and Saroglou (2010).

A number of methods have been proposed for the direct quantification of the GSI. These include those of Somnez and Ulusay (1999) and Cai *et al*. (2004) although none of these have been readily adopted for use in open pit slope design. More recently, Hoek *et al*. (2013) proposed their own methodology, providing the open pit geotechnical engineer with an updated methodology to estimate GSI. Hoek *et al*. (2013) identified the need for a quantification scheme that was relatively simple to use and could be readily adopted by industry. The derived relationship used the two well-established parameters of Rock Quality Designation (RQD) and the Joint Condition rating (JCond89) from Bieniawski’s RMR89. The parameters were factored by the authors and summed in order to provide a simple equation to derive GSI numerically as equation (4):

$$GSI = 1.5 \cdot JCond89 + RQD/2 \quad \ldots\ldots\ldots (4)$$

The GSI relates the properties of the intact rock elements/ blocks to those of the overall rock mass. It is based on an assessment of the lithology, structure and condition of the discontinuity surfaces in a rock mass and is estimated from visual examination of the rock mass exposed in outcrops, surface excavations such as road cuts, tunnel faces and borehole cores. It utilizes two fundamental parameters of the geological process (block of the rock mass and condition of discontinuities), hence takes into account the main geological constraints that govern a formation. In addition, the index is simple to assess in the field.

– **Rock Quality Designation (RQD):** Rock Quality Designation (RQD) is defined according to Deere (1964) as “the total length of all the pieces of sound core over 10 cm lengths, expressed as a percentage of the total length drilled. Palmstrom (1982) proposed an approximate correlation between RQD and the volumetric joint count (Jv), which can be used to estimate RQD when drill cores are not available” (equation 5).

$$RQD = 115 - 3.3\ Jv \quad \ldots\ldots\ldots\ldots (5)$$

Because there are no core samples available during the current study, therefore, the aforementioned relationship is used in RQD determination.

– **Joint Condition Rating (JCon):** The joint condition was calculated according to Guidelines for Classification of Discontinuity Conditions (Bieniawiski, 1989) as shown in Table (2). The joint condition results adopted in the current work is based on the data prepared by the GEOSURV’s geologists (Yousif *et al*., 2013 and 2014) and listed in Table (3).

MEASUREMENTS AND CALCULATIONS

The window-scan technique of geological mapping was carried out on the rock slopes around Al-Salman Depression to measure the geotechnical data of the rock masses and its discontinuities within the Dammam Formation sedimentary beds. The discontinuities spacing, persistence, separation (aperture), roughness, infilling materials and weathering states of these discontinuities are measured. A total number of seven sites in which the discontinuities are mapped in accordance to ISRM, (1981) and Wyllie and Mah, (2005), in addition to the field observations, laboratory tests and data processing; UCS, Point Load Index (Is), Volumetric Joint Index (Jv), in accordance with the methods suggested by Hoek and Brown,(1997), are used.

The rock masses are of Strong strength (specimen requires one blow of geological hammer to fracture it). The joint sets are orthogonal and have the following characteristics; spacing is moderate (200 – 600 mm) and medium persistent (3 − 10 m), tight or partially opened apertures, rough to slightly rough and slightly weathered (Yousif *et al*., 2014).

Table 2: Guidelines for classification of discontinuity conditions JCond89, (Bieniawski, 1989)

Discontinuity length (persistence)	< 1 m	1 to 3 m	3 to 10 m	10 to 20 m	> 20 m
Rating	6	4	2	1	0
Separation (aperture)	None	< 0.1 mm	– 1.0 mm	1 – 5 mm	> 5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slicken-sided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard < 5 mm	Hard > 5 mm	Soft < 5 mm	Soft > 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderate weathering	Highly weathered	Decomposed
Rating	6	5	3	1	0

Table 3: Field observation and measurements of the studied sites (Yousif *et al*., 2013 and 2014)

Discontinuities	Site-1	Site-2	Site-3	Site-4	Site-5	Site-6	Site-7
B.P inclination	140/22º	180/32º	155/45º	145/55º	310/34º	240/37º	110/13º
B.P mean spacing (m)	0.25	0.32	0.33	0.40	0.38	0.75	0.81
Joint dip of set-1	180/90	250/90	215/90	180/90	080/90	075/90	065/90
Mean spacing of set-1 (m)	0.44	0.33	0.49	0.35	0.87	0.80	0.58
Joint dip of set-2	252/90	310/90	290/90	262/90	142/90	220/75	160/90
Mean spacing of set-2 (m)	0.5	0.46	0.34	0.29	1.09	0.44	0.63
Joint dip of set-3	314/90		–	165/90	220/90	140/90	260/90
Mean spacing of set-3 (m)	0.33	–	–	0.5	0.64	0.84	0.65
Joint roughness	S. rough	Smooth	S. rough	Smooth	Rough	Smooth	Rough
Persistence (m)	8 – 10	8	6	7 – 10	3	3 – 10	1 – 3
Aperture (mm)	1 – 5	1 – 5	1 – 5	1 – 5	5 – 10	10 – 20	5 – 10
Infill hardness	Soft	Soft	Hard	Hard	Hard	Hard	Hard
Weathering of joint wall	Slight	Slight	Slight	Slight	Slight	Slight	Slight
Ground water	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Intact rock strength (UCS) (MPa)	50 – 100	50 – 100	50 – 100	50 – 100	64	30	64
Point Load Index (Is)	3.2	3.2	3.2	3.2	2.7	1.08	2.7
Jv-Index	7.3	4.69	5.0	6.5	3.63	6.3	4.85
If -Index	0.42	0.47	0.40	0.46	0.82	0.47	0.61

B.P = Bedding plane; S. rough = slightly rough; 140/22º = dip direction/ dip angle

RESULTS AND DISCUSSION

The studied rock beds generally have been stratified horizontally and locally inclined toward the depression. This inclination ranges between 13º (in site 7) to 55º (in site 4). The beds have massive to blocky structure and are dissected by two to three systematic joint sets.

Two different methods are used to predict the excavatability of the studied rocks. The first method is by using the Point Load Strength Index (I_s) evaluated from the uniaxial compressive strength (UCS) using equation (1) and the Discontinuity Spacing Index (I_f) calculated from equations (2) and (3). Pettifer and Fookes chart and Franklin’s Excavation chart are used for this purpose. All the currently tested rock types are of Medium Strong to

Strong strength, and the joints spacing are classified as blocky to massive (Beiniawiski, 1973 and ISRM, 1978).

For the first technique, rock classification and equipment selection suggested by Pettifer and Fookes Chart (Fig.2) shows that the studied rocks in sites (1, 3, 4 and 6) can be excavated by “Hard Ripping” using D8 ripper dozer, while in sites (2, 5 and 7) require “Very Hard Breaking” to be excavated, using D9 ripper dozer. To confirm the results, Franklin’s Excavation chart (Fig.3) was used. It gave different results and indicated the use of “Blast to Loosen” before excavation.

The second method, proposed by Tsiambaos and Saroglou, (2010), considered the (GSI) values and the (Is) Index. The GSI was estimated using equation (4) and their results are listed in Table (4). The GSI values ranged between 59 and 71.5 due to the blocky to very blocky structure and the good (rough, slightly weathered) to fair (smooth to moderately weathered) joint condition of the studied rock types.

The results show that all the studied rock types can be excavated by blasting, or using hydraulic hammers to break (Fig.4). These results are due to the blocky to very blocky structure of the rocks, the RQD values ranged between 79 – 96 and the GSI values between 59 – 71.5.

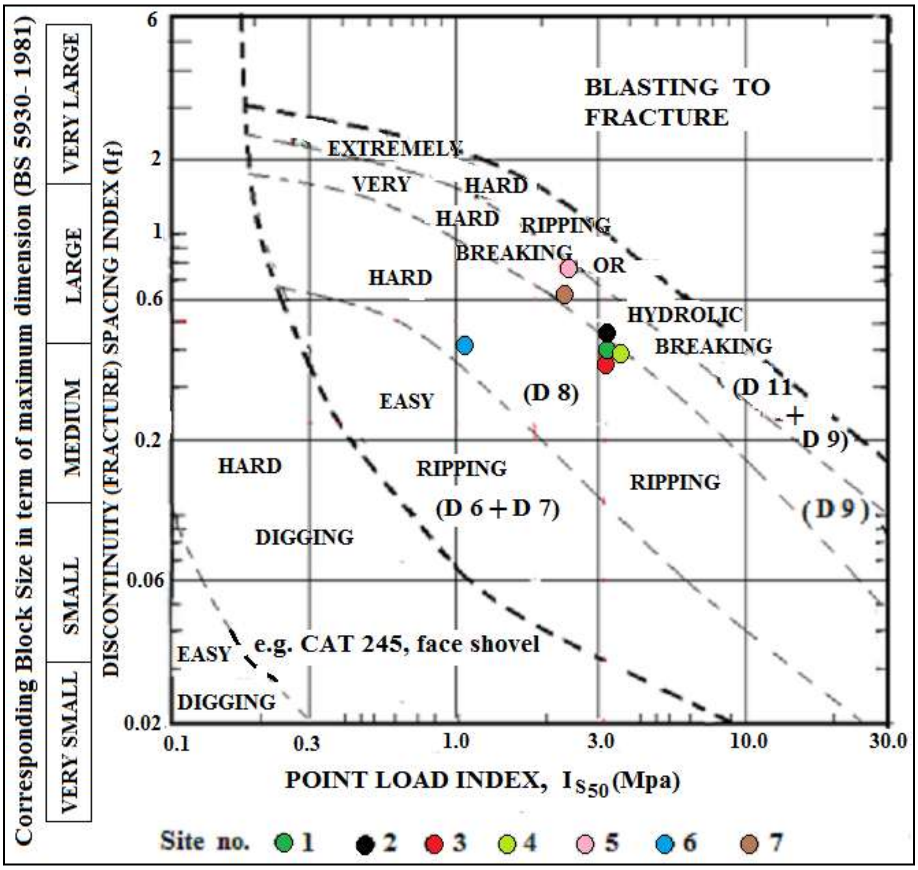

Fig.2: Excavatability assessment of the studied samples plotted on the Pettifer and Fookes (1994) chart

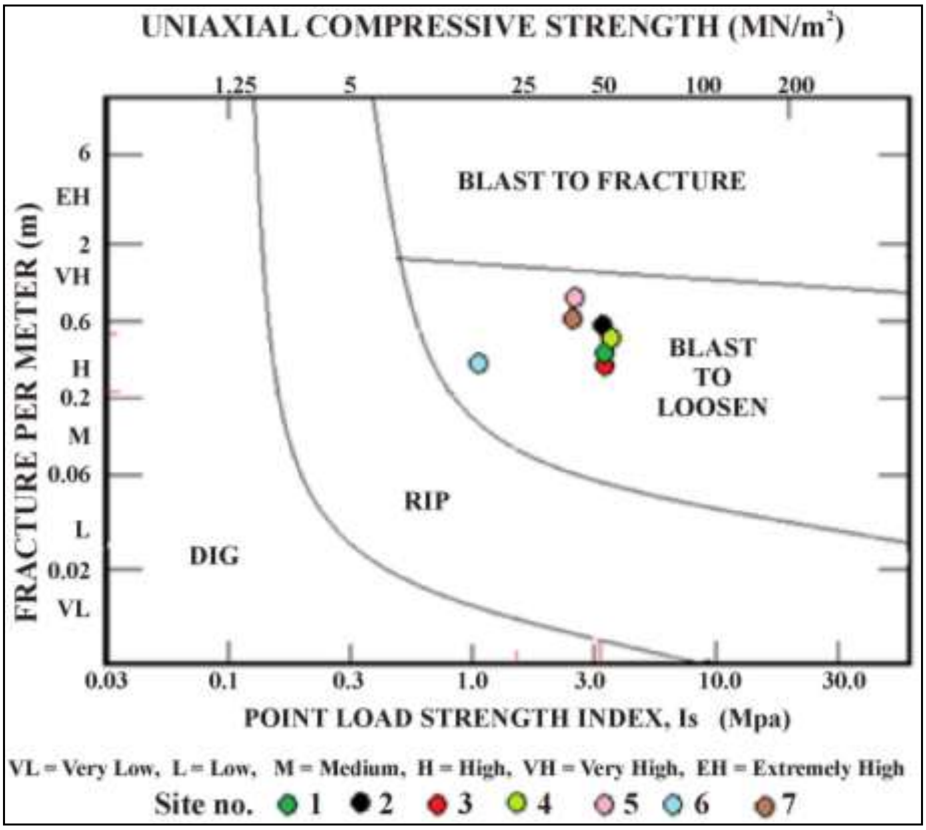

Fig.3: Excavatability assessment of the studied samples plotted on the Franklin *et al*. (1971) excavation chart

Table 4: GSI calculation according to Hoek *et al*. (2013)

Parameter	Site-1	Site-2	Site-3	Site4	Site-5	Site-6	Site-7
Jcon.	13	16	10	13	13	10	16
Jcon.* 1.5	19.5	24	15	19.5	19.5	15	24
RQD	88	88	89	79	94	96	95
RQD/2	44	44	44.5	39.5	47	48	47.5
GSI	**63.5**	**68**	**59.5**	**59**	**66.5**	**63**	**71.5**

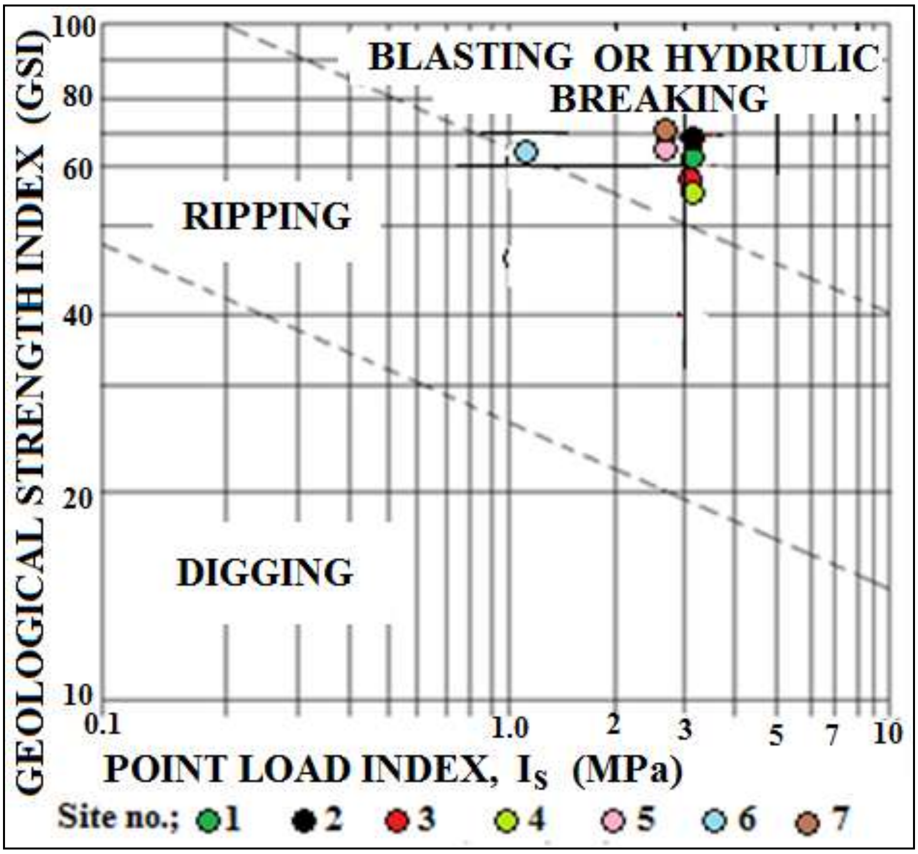

Fig.4: The assessment of the excavatability of the carbonate rocks in Al-Salman Depression according to the Excavation chart proposed by Tsiambaos and Saroglou, (2010)

According to Tsiambaos and Saroglou, (2010), when Is ≥ 3 (UCS > 70 MPa), blasting is required when GSI > 60, such as the rock masses in sites 1 and 2. Hydraulic breakers should be used to loosen the rock mass when GSI is between 45 and 60, such as in sites 3 and 4, although in some cases blasting might be necessary in this zone of the chart. When Is < 3 (UCS< 70 MPa), Blasting is necessary for rock masses with GSI > 65, such as sites 5 and 7. Hydraulic breaking is required for the loosening of rock masses with GSI between 55 and 65, such as site 6. Ripping is successful in rock masses with GSI<55 and rock masses with GSI up to 25 (or 35) can be dug, obviously with increasing difficulty.

CONCLUSIONS

This work is an attempt to assess the excavatability of the Eocene carbonate rock masses around the Al-Salman Depression using If, Is and GSI of the intact rocks of seven sites were previously studied in the study area. The results indicate the following:

- Blasting is not the only feasible method for excavating the studied rocks, where the Hydraulic Ripping and Hard Ripping are possible options too. Although the currently used graphs allow excavatability to be assessed rapidly.
- The “Pettiffer and Fookes Chart” show that all the studied sites can be excavated by “Very Hard Ripping” (Sites 2, 5 and 7) to “Hard Ripping” (Sites; 1, 3, 4 and 6), while the results of “Franklin’s chart” and “Tsiambaos and Saroglou Chart” show that all the rock types must be blasted to loosen or using hydraulic breakers.

- When the "GSI" values are greater than 60 and Is ≥ 3 MPa, the blasting is necessary (Sites; 1 and 2), and the transitional zone, where the hydraulic breakers are required, if the GSI values are between 45 and 60 (Sites 3 and 4). On the other hand, when Is < 3 MPa, blasting is usually required in rock masses with GSI > 65 (Sites 5 and 7) and the hydraulic breakers are used if GSI between 55 and 65 (Site 6). These are for massive, blocky and very blocky rock masses or when joints are tight.
- The knowledge of the physical and mechanical characteristics as well as the behavior of the rock to be excavated is vital for the selection of the most effective method of excavation. The advantage of the used graphical methods is in providing qualitative tools for easy and quick assessment of excavatability.

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