# The Suitability of Limestone from Pilaspi Formation (Middle-Late Eocene) for Building Stone in Koya Area, NE Iraq

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***Abstract*—Suitability of limestone rocks has a crucial importance when stones are used for constructing modern structure. The purpose of this study is to clarify the links between physical, mechanical properties of limestone rocks, also their quality to use as building materials. A total of six limestone rock samples were collected from three different outcrops locations within Pilaspi Formation in Koya area. Engineering geological and geotechnical properties of the limestone rocks in the study area were determined based on the field studies and laboratory tests. The field studies included observations/ measurements of rock mass characteristics such as color, grain size, orientation, bedding thickness and weathering state of the rock materials also spacing, persistence, roughness and infilling material of the discontinuities. Laboratory tests were carried out for determining water content, water absorption, density, uniaxial compressive strength, slake durability and porosity of the rock materials. The study results go well with the national and international standards (Iraqi Standards, 1989; American Society for Testing and Materials, 2004; International Society for Rock Mechanics, 1981) and have shown that the limestone rocks are acceptable for building stone.**

***Index Terms*—Building materials, limestone, physical properties, Pilaspi formation, slake durability.**

## I. Introduction

Limestone is one of the most common rock types in the world and is widely exploited for use in construction materials and other engineering works. Because of its range of properties and a good quality, it is easily adapted to use in a variety of structural and architectural application. There are other reasons to choose an advocate of these rocks for study, according to, first, the high prevalence and thickness of these rocks in large areas of Iraq particularity in the Kurdistan region, whether that is as the outcrops or subsurface rocks, second, the rocks of limestone of significant economic importance in engineering industries in terms of quality and quantity values, third, the result of this study becomes of importance not only to the study site, but vast areas of Kurdistan province. These have been done to prepare a study on the physical and mechanical properties of these rocks. Some studies were carried out on the same purpose, (Dhaher, 2009) examined the physical and geochemical properties of some rock units of Pilaspi Formation in Shaqlawa area, and he concluded that the rocks are durable and strong enough to be used as engineering purposes. Saleh (2012) used several samples were taken from different limestone quarries located in Nineveh governorate (NW Iraq), the results have led to widely used in decoration, covering of the outer walls as well as concrete aggregate. The results confirm the suitability of some limestone samples for using as a building stone. This research programmed concerned with the selection of three different outcrops location of limestone within Pilaspi Formation in Koya area in order to point out the different parameters which are links with field studies and laboratory tests to evaluate the suitability of limestone for construction purposes. The locations of studied samples are bounded by UTM grid 3994000 and 3997000 North, (38) 464000 and (38) 469000 East, as shown in (Fig. 1 and Table I).

Table I
Locations of the Studied Limestone Samples

| Location No. | Formation | Coordinates (North and East lines) |
|---|---|---|
| 1 | Pilaspi | 3996333 N and (38) 498267 E |
| 2 | Pilaspi | 3994233 N and (38) 470067 E |
| 3 | Pilaspi | 3995333 N and (38) 464466 E |

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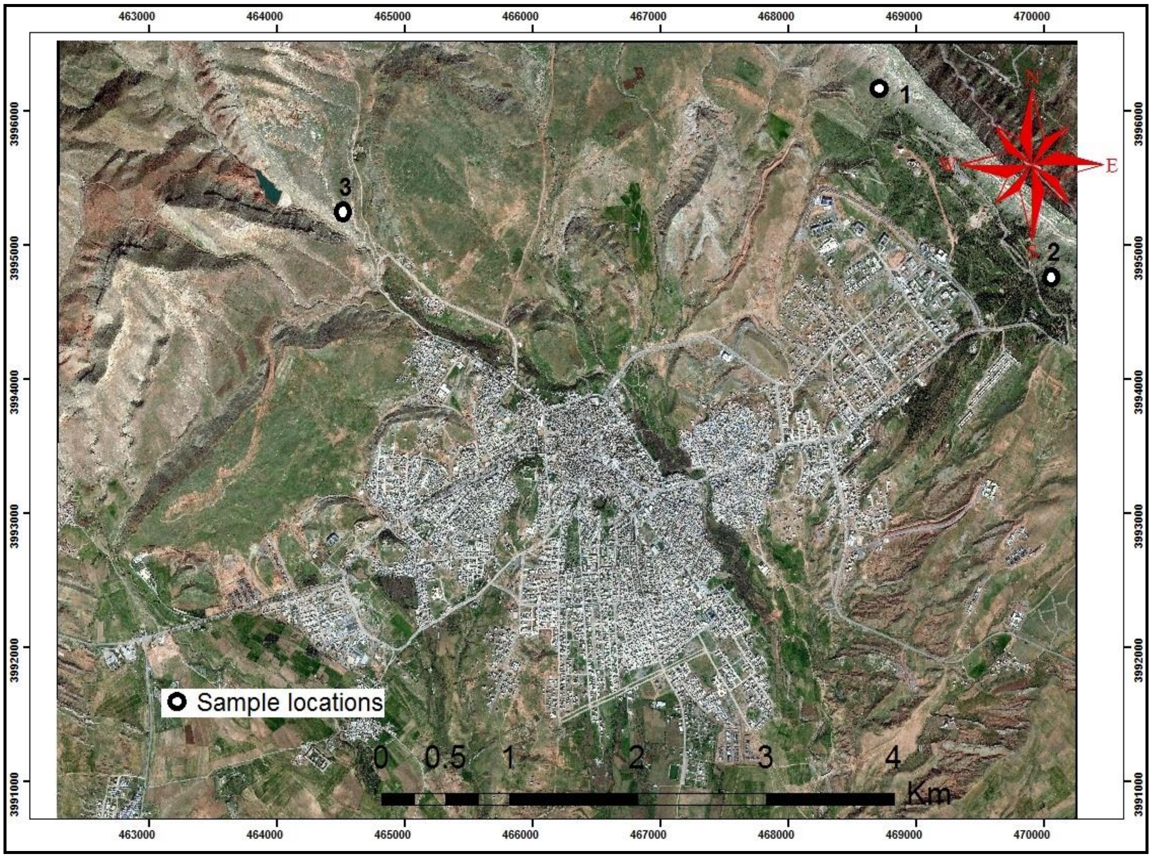


Fig. 1. Satellite image of Koya city which indicates the sample locations.

## II. Geological Setting

Tectonically the studied area is located in the High Folded Zone of the Unstable Shelf area and according to geography it is located of NE Iraq, Haibat-Sultan homocline structure is considered part of the southwest limb of Haibat-Sultan anticline which is asymmetrical anticline extending in the (NW-SE) trend, that is parallel to the Zagros fault thrust zone (Buday, 1980; Buday and Jassim, 1987; Jassim and Goff, 2006). The studied samples were collected from three different outcrops locations in Koya area are belonging to Pilaspi Formation (Middle-Late Eocene). The Pilaspi Formation is exposed in the entire studied region; it is seen as continuous high ridges surrounding the anticlinal structures with very common flat iron morphology, while in the other places it forms the carapace of main body of the Haibat-Sultan homocline structure. According to (Bellen, et al., 1959) the Pilaspi Formation was first described by Lees in 1930 from the Pilaspi area of High Folded Zone also they added that the original type section was submerged under the reservoir of the Darbanikhan dam during the sixtieth of the last century. The resistant Pilaspi Formation forms a conspicuous ridge between the less resistive Gercus and Fatha Formations throughout the high folded zone. It is about (100 – 200 m) thick, variation in thickness such as in the Pirmam area (120 m), Koysanjaq (56 m), Shaqlawa (70 m), and in Hareer (52 m) due to different in the weathering processes action and rapidly subsidence of the sedimentary basin from one region to another (Bellen et al. 1959; Buday, 1980; Youkhana and Sissakian, 1986; Jassim and Goff, 2006). In the studied area the Pilaspi Formation forms continuous steep ridges of Hogback type at the crest of Haibat-Sultan homocline structure it consists mainly of grey, light grey, yellowish white color well bedded limestone, and sometime crystalline to dolomitic limestone.

## III. Methodology

Engineering geological and geotechnical properties of the limestone rocks in the study area were determined based on the field studies and laboratory tests. The description of rock material and the main discontinuities were based on the suggested methods by (Anon, 1972; New Zealand Geotechnical Society, 2005). The field studies included observations/ measurements of the rock mass characteristics such as color, grain size, orientation, bedding thickness and

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weathering state of the rock materials, also spacing, persistence, roughness and infilling material of the discontinuities (except the bedding plane, the rock mass are intersecting by two set of joints), as shown in Tables II and Table III.

TABLE II
ROCK MATERIAL PROPERTIES OF THE STUDY AREA

| Location No. | Lithology | Color | Grain size | Weathering state |
|---|---|---|---|---|
| 1 | Limestone | Yellowish gray to Light gray | Fine | Fresh to slightly weathered |
| 2 | Limestone | Yellowish gray | Fine | Fresh to slightly weathered |
| 3 | Limestone | Light gray | Fine | Fresh to slightly weathered |

Six limestone rock samples were collected from three different outcrop locations at the field for laboratory testing. Some physical and mechanical tests have been done on the limestone samples according to the requirements of the national and international standards (Iraqi Standards, 1989; American Society for Testing and Materials, 2004 and International Society for Rock Mechanics, 1981), Tables IV and V. Laboratory tests are included water content (w%), density & water absorption, uniaxial compressive strength by using point load test, slake durability & porosity, as shown in Tables VI, VII, VIII and IX, respectively.

TABLE III
MAIN DISCONTINUITY (BEDDING PLANE AND JOINTS) PROPERTIES OF THE STUDY AREA

| Location No. | Orientation (dip dir./ amount) | Thickness of layers (m) | Spacing (m) | Persistence | Roughness | Infilling materials |
|---|---|---|---|---|---|---|
| 1 | 230/ 42° | 0.18 – 0.9 | 0.2 – 0.5 | 0.7 m to < 7 m | Smooth- rough | Thin layers of clay (0.3 cm) |
| 2 | 228/ 48° | 0.4 – 1.0 | 0.3 – 0.6 | 0.7 m to < 7 m | Smooth- rough | Thin layers of clay (0.2 cm) |
| 3 | 220/ 45° | 0.3 – 0.6 | 0.15 – 0.5 | 0.3 m to < 6 m | Smooth- rough | Thin layers of clay (0.5 cm) |

TABLE IV
STANDARD SPECIFICATION OF PHYSICAL AND MECHANICAL PROPERTIES OF LIMESTONE FOR CONSTRUCTION MATERIALS (IRAQI STANDARDS, 1989 AND AMERICAN SOCIETY FOR TESTING AND MATERIALS, 2004)

| Type | Class | Density (gm/ cm$^3$) | Absorption % | Compressive strength (MPa) | Grade |
|---|---|---|---|---|---|
| I | A | 1.76 – 2.16 | 12 | 12 | Low |
| II | B | 2.16 – 2.56 | 7.5 | 28 | Moderate |
| III | C | ≥ 2.564 | 3 | 55 | High |

TABLE V
STANDARD SPECIFICATION OF SLAKE DURABILITY INDEX ($ID_1$)%
ACCORDING TO (INTERNATIONAL SOCIETY FOR ROCK MECHANICS, 1981)

| ($Id_1$) % | Grade | Class |
|---|---|---|
| < 60 | Very low | A |
| 60 – 85 | Low | B |
| 85 – 95 | Medium | C |
| 95 – 98 | Medium to high | D |
| 98 – 99 | High | E |
| > 99 | Very high | F |

TABLE VI
RESULTS OF WATER CONTENT (W%)

| Location No. | Sample No. | Wet weight (gm) | Dry weight (gm) | Natural water content (w %) |
|---|---|---|---|---|
| 1 | S1 | 221.58 | 220.7 | 0.3987 |
| | S2 | 193.4 | 192.9 | 0.2592 |
| 2 | S3 | 242.7 | 242 | 0.2892 |
| | S4 | 176.7 | 176.2 | 0.2837 |
| 3 | S5 | 607.9 | 607.4 | 0.08231 |
| | S6 | 352.4 | 352.2 | 0.05678 |

TABLE VII
RESULTS OF DENSITY AND WATER ABSORPTION

| Location No. | Sample No. | Weight in air (g) | Weight of stone after (24 hrs) been in water (g) | Pore water weight (when the rock sample is fully saturated) | Weight in water (g) | Weight of total displaced water ($W_B$) | Weight of displaced water by solid ($W_S$) | Water content in saturated state (m %) | Dry density (g/cm$^3$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | S1 | 220.7 | 225.8 | 5.1 | 135.6 | 90.2 | 85.1 | 2.31 | 2.45 |
| | S2 | 192.9 | 197.1 | 4.2 | 116.5 | 80.6 | 76.4 | 2.18 | 2.39 |
| | Average | | | | | | | 2.2 | 2.42 |
| 2 | S3 | 242.9 | 248.1 | 5.2 | 177.2 | 70.9 | 65.7 | 2.31 | 2.0 |
| | S4 | 176.2 | 180.6 | 4.4 | 107.3 | 73.3 | 68.9 | 2.5 | 2.4 |
| | Average | | | | | | | 2.4 | 2.2 |
| 3 | S5 | 607.4 | 620.7 | 13.3 | 384.3 | 236.4 | 223.1 | 2.19 | 2.57 |
| | S6 | 352.2 | 355.6 | 3.4 | 220.1 | 135.5 | 132.1 | 1.0 | 2.59 |
| | Average | | | | | | | 1.6 | 2.58 |

TABLE VIII
RESULTS OF THE POINT LOAD TESTS AND RELATED UNIAXIAL COMPRESSIVE STRENGTH OF THE COLLECTED ROCK SAMPLES FROM THE STUDY AREA

| Location No. | Test No. | Diameter (mm) | Load P (MN) | Is = P/ D$^2$ (MPa) | $Is_{(50)}$ (MPa) | Uniaxial Compressive Strength (UCS) = 22.5 × $Is_{(50)}$ (MPa) | Average UCS and description |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 46 | 0.009 | 4.5 | 4.275 | 96.18 | (81) Strong |
| | 2 | 52 | 0.006 | 3.0 | 3.03 | 68.18 | |
| | 3 | 43 | 0.0011 | 6.11 | 5.71 | 128.47 | |
| | 4 | 55 | 0.0081 | 2.667 | 2.79 | 62.82 | |
| | 5 | 63 | 0.0079 | 1.994 | 2.211 | 49.75 | |
| 2 | 1 | 60 | 0.012 | 3.338 | 3.62 | 81.52 | (84) Strong |
| | 2 | 60 | 0.0045 | 1.25 | 1.35 | 30.52 | |
| | 3 | 52 | 0.0012 | 4.655 | 4.73 | 106.52 | |
| | 4 | 57 | 0.0013 | 4.052 | 4.29 | 96.7 | |
| | 5 | 45 | 0.0099 | 4.89 | 4.67 | 105.1 | |
| 3 | 1 | 42 | 0.012 | 7.05 | 6.486 | 145.93 | (182) Very strong |
| | 2 | 48 | 0.01 | 10 | 10 | 225 | |
| | 3 | 50 | 0.025 | 10.08 | 8.35 | 188.04 | |
| | 4 | 56 | 0.02 | 6.451 | 6.77 | 152.32 | |
| | 5 | 44 | 0.18 | 9.47 | 8.94 | 201 | |

TABLE IX
RESULTS OF SLAKE DURABILITY AND POROSITY OF LIMESTONE SAMPLES

| Location No. | Sample No. | Slake durability ($Id_1$) | Porosity (n%) |
|---|---|---|---|
| 1 | S1 | 99.3 | 5.65 |
| | S2 | 99.1 | 5.21 |
| | Average | 99.2 | 5.43 |
| 2 | S3 | 99.0 | 7.33 |
| | S4 | 99.0 | 6.00 |
| | Average | 99.0 | 6.66 |
| 3 | S5 | 99.55 | 5.62 |
| | S6 | 99.75 | 2.50 |
| | Average | 99.65 | 4.06 |

## IV. RESULTS AND DISCUSSION

The results obtained from the field studies led to that the limestone rocks have fine grain size, fresh to slightly weathered, moderately to thickly bedded. The discontinuities are moderately spaced, smoothly rough with thin layers of clay materials and their persistence ranges from 0.3 m to < 7 m. The physical and mechanical properties were investigated according to the national and international standard specification. To obtain the best representative value for rock property, six samples within three different outcrop locations in Koya area were collected, tests for each sample were done and so the results of these tests were discussed herein, in order to evaluate the quality of studied limestone rocks as construction and building materials. Tables VI and VII give the result of some physical properties such as natural water content ranges from 0.05% to 0.39% with an average value of 0.22%, water content in saturated state with an average ranges from 2.2% to 2.58%, dry density with an average value ranges from 1.6 to 2.4 g/cm$^3$. This shows that samples have low effective porosity (Khanal and Tamrakar, 2009). Building stones that exhibit low water absorption or low porosity values are generally found to be relatively more durable. Water will be disable to penetrate non-pores stone types, therefore disable to promote damage in construction model structure (Miglio and Willmott, 2010), also (Jacobsen and Aarseth, 1999) proved that the building material′s surface with low degree of water absorption and porosity will be little or no effect by weathering agents such as wind or rainfall.

Table VIII shows the results of mechanical property such as compressive strength of limestone ranges from 81 to 182 MPa pointed out that this range have strong to very strong and inversely proportional with the lower water absorption (Naghoj, et al., 2010). As a result all these physical and mechanical properties pointed out that the studied limestone samples are belonging to Class C and Type III (high density), Table IV, according to (Iraqi Standards, 1989; American Society for Testing and Materials, 2004) respectively. Table IX gives the results of the slake durability tests with average value range from 99% to 99.65%, and porosity from 2.5% to 7.33%. These physical properties were carried out to examine by (International Society for Rock Mechanics, 1981) and indicated that the studied limestone samples are belong to Class F (very high) slake durability with lower porosity, Table V.

According to the obtained results, the investigated limestone rocks are acceptable, compact, strong to very strong enough and have very high slake durability. They show fresh-slightly weathering processes without micro cracks or fractures. As a result of the study, it is concluded that the studied limestone in Koya area within Pilaspi Formation could be used as construction material in accordance with national and international standard specification. A durable building stone is one which resists the weathering elements in the atmosphere, stone durability is closely related to both pore structure and strength, building material must be resist to physical and chemical weathering processes which are considered the main causes of building stone decay, therefore durability test method must be used to assess and select the stone which is most suitable for building materials (Ross, et al., 1990; Benavente, et al., 2004).

## V. Conclusion

Based on the results of this study the following conclusions have been reached out:

- The distinct rock have been recognized as limestone shows fine grained size, fresh-slightly weathering, high durable, strong-very strong and free from visible defect which affect on the appearance or strength.
- The thickness of rock mass layers are moderately to thickly bedded and the discontinuity spacing are closely to moderately spaced give an indication of the large size of blocks that are suitable for using as dimension stone.
- Based on national and international standards specification for using of limestone in construction materials. The limestone rocks in the study area proved that they are belonging to Class C, Type III (high density), Class F (very high slake durability with low porosity) according to Iraqi Standards (1989), American Society for Testing and Materials (2004) and International Society for Rock Mechanics (1981), respectively, to be used as construction and building materials such as walls, foundations and covering building for beautiful appearance, etc.

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