Assessment of Rocks competency for pre-foundation study using ultrasonic approach

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Abstract
The aim of the current research is to use the ultrasonic wave velocity for assessment of rock competency for pre-foundation study at engineering site near Rawā city. Thirty seven (37) rock samples were gathered from different depths of well drilled at the site. Both compressional and shear waves velocity (Vp and Vs) were measured in the laboratory. To assess the competency of rocks as foundation materials, some geotechnical properties include Poisson’s ratio(σ), Effective angle of internal friction (φ), Material index(Im), and Coefficient of lateral earth pressure at rest (Ko) were calculated. The results of the study showed that the first layer characterized by incompetent to fairly competent materials, the second layer (Anah Formation) composed of alternation of the moderately competent (limestone) with thin incompetent (fractured coralline limestone) rocks, while the third layer (Baba Formation) which composed of dolomitic limestone characterized by good competent rocks. Depending on above mentioned results, the third layer (Baba Formation) is more suitable as foundation rocks for constructions purposes at the investigated site. The results also confirm that the ultrasonic wave velocity is effective method in evaluating the geotechnical properties of rock in pre-construction works.

1. Introduction
Assessment of rocks competency in pre-construction of civil engineering structures such as dams, roads, and tunnels is an essential work to prevent the failure and collapse of engineering structure [1]. The sources of construction failure can be attributed to several factors amongst are incompetent foundation rocks and poor construction materials [2]. The establishment of any engineering building on less competent layer always causes a serious risk to the building leading to its failure. Thus, the pre-foundation studies has become required to assess the subsurface condition that make suitable decisions for a safe design of any proposed engineering structures[3, 4].

The suitable design and construction of any building foundation can be accomplished only when the character of the host rocks or soil are established. Therefore, it is important in pre-construction studies to investigate the mechanical properties of soil or foundation rocks and assess its suitability for design and construction of engineering structures. Sometimes, the site engineers fail to take account of pre-construction studies in their project planning stage because the cost and other considerations including rules in structural design [5].

In addition to geotechnical investigation, the geophysical methods are one of the most suitable techniques which used for providing information about the engineering properties of the foundation rocks which can help for site investigation studies, in rapid and cost-effective manner[2,6]. Therefore, geophysical investigation is important to reveal the prospect subsurface geologic problems and suggest potential solutions before the construction of engineering buildings[4]. Such information about the subsurface layers can serve as the first most essential step before construction [7].

Seismic methods is one of the most employed geophysical method in site investigation because the velocities of wave propagation depend on the elastic properties of material in which propagated [8]. Many geotechnical properties can be determined by using seismic methods, [9, 10, 11, 12]. These properties obtained from velocities data are very essential in engineering and geotechnical constructions[13]. Ultrasonic method considers one of the effective seismic methods which usually
used to assess and evaluate rock properties. It widely used in both laboratory and site to determine engineering properties of rocks. Ultrasonic method have been used by many researchers to predicate and characterize various mechanical properties of rock samples and they concluded that these method is within the paramount ways to investigate these properties[13, 14]. The current research aims to conduct geophysical study using ultrasonic method for assessment of rocks competency and its suitability as foundation rocks to recommend the best foundation layer for the proposed construction site in the study area.

2. Study Area and Geological Condition

The study area lies between the latitude of 34° 25′ - 34° 30′ N and the longitude of 41° 42′ -41° 45′ E. It is situated near Rawa city, northwest AL-Anbar province in the western part of Iraq (figure 1).

![Figure 1. Location map of the study area.](image)

Lower Miocene – Holocene sediments are the main rock units exposed in the study area. The investigated area is a proposed site for constructing a new dam near Rawa city, not far off both sides of Euphrates river. For this purpose some exploration wells were drilled, and one of these wells was chosen to achieve the present study. The selected well lies close the right bank of the Euphrates River as illustrated in figure 1. Based on well data, the rock sequence from top to bottom involves three main layers. The first layer which has a thickness about 3.5m and consists of sandy gravel deposits. The second layer was Anah Formation. Anah Formation involves recrystallized, massive, hard, coralline and fossiliferous limestone [15]. The thickness of this formation about 28m. The last formation was Baba Formation which characterized by hard dolomitic limestone and extended from depth of 32m to end of poring (100m.).

3. Materials and samples preparation

Thirty seven core samples were gathered from borehole at different depths from 2.5m to 34 m. Table 1 illustrates the depth interval and the numbers of samples collected from different formations in the borehole. All samples were taken to laboratory and regulated to form a cubic shape with length of 10 cm and section of (5 cm. x 5cm). With the aim of providing a good contact between transducers and
the samples to ensure accurate transit time measurements, the samples were polished to a proper smooth plain surface and special paste was used.

**Table 1.** Number of samples gathered from different formations and depths.

| Formation          | Number of samples | Vertical interval distance between samples (m.) |
|--------------------|-------------------|-----------------------------------------------|
| Quaternary deposits| 3                 | 0.5                                           |
| Anah               | 25                | 0.5                                           |
| Baba               | 6                 | 2                                             |

4. **Laboratory measurements.**

Laboratory measurements for both compressional and shear wave velocities for all core samples have been conducted. The New Sonic Viewer device (model-5217A) which is available in the Geology Department, University of Baghdad was used to conduct these measurements. The device contains transducers (transmitter and receiver) for each of compressional and shear waves providing ultrasonic waves. According to the measurement procedure, the transducers should be placed on the two parallel sides of the core sample and then a series of ultrasonic impulses transmitted through the core sample should be generated and then the transit time (T) is recorded. The compressional and shear wave velocity (Vp and Vs) are calculated by dividing the sample length (L) to the transit time of the propagated waves (T). Based on seismic waves velocities (Vp and Vs) values some geotechnical properties can be determined.

When the information about geotechnical parameters are available, the strength and competence of soil and rocks for engineering aims can be simply assessed. Depending on the ranges of geotechnical parameters values (Table. 3), the quality and competence of the samples for the interested area were evaluated.

**Table 2.** Ranges of Poisson's ratio and material index, corresponding to the rocks competent degree [11]

| Description Parameters | Incompetent to slightly competent | Fairly to moderately competent | Competent materials | Very high competent |
|------------------------|----------------------------------|--------------------------------|---------------------|--------------------|
| Poissons ratio (σ)     | 0.49 - 0.41                      | 0.35 – 0.27                    | 0.25 – 0.16         | 0.12-0.03          |
| Material index ( Im)   | (-1) to (-0.5)                   | (-0.5) to (0.0)                | 0.0-0.5             | 0.5-1              |

5. **Results and Discussion**

Knowledge of the seismic velocity values of the rocks samples help to determine its geotechnical properties using related equations. The Laboratory measurements for the rock samples of the study area have shown that the compressional (Vp) and shear-wave (Vs) velocities were characterized by wide range of variations with depth. These variations are related with rocks type, composition, degree of compaction, fissuring, fracturing, and other many properties. The compressional wave velocity (Vp) value for the first, second and third layers ranged (2857 m/s - 5612m/s), (2745m/s-6666 m/s) and (5174m/s-6555m/s) respectively, while the shear wave velocity value for the first, second and third layers ranged (1363m/s-2864), (1399 m/s - 3551 m/s) and (2165 m/s - 2774 m/s) respectively.
Depending on the velocity (Vp and Vs) values, some important geotechnical parameters were calculated for all core samples. In order to assess the competency of the subsurface rocks, the integration of these results were used. In the current study, the following geotechnical parameters were calculated and evaluated to determine the best suitable layers for construction of the proposed site.

5.1 Poisson’s ratio (σ)

Poisson’s ratio (σ) is one of the essential parameters used in engineering studies. It represents the ratio of the lateral expansion (or contraction) deformation to longitudinal extension deformation. For most rocks materials, the Poisson's ratio value lies within the range 0 to 0.5, where high competent rocks have lower Poisson’s ratio and vice versa. Poisson’s ratio (σ) for all core samples were calculated from using the following formula [10,11]

\[
\sigma = \frac{0.5(V_p / V_s)^2 - 1}{(V_p / V_s)^2 - 1}
\]

The vertical variations of Poisson’s ratio (σ) values are presented in figure 2. The results showed that the surface geological layer has values ranged from (0.32 – 0.36), refer to incompetent to fairly competent rocks. The second geological layer (Anah Formation), characterized by values ranged from (0.28- 0.40). Based on Table 2, the higher values characterize incompetent rocks whereas lower values characterize moderately competent rocks. The moderately competent rocks denote to limestone layer, while incompetent rocks refer to fractured or coralline limestone, as appeared in borehole information. The incompetent rocks were observed at depths from 18 m to 20 m and from 23 m to 26 m, and also were appeared as a thin bed with thickness about 0.5 at depths 12 m, 13.5 m and 15.5 m. The values of Poisson’s ratio (σ) of the third geological layer (dolamatic limestone) are relatively constant about 0.25. This value reveals that Baba formation rocks (dolamatic limestone) represents good competent rock material.

![Figure 2. Variation of Poisson's ratio (σ) with depth](image)

5.2 Effective angle of internal friction (φ)
The second geotechnical parameter calculated in the current study was Effective angle of internal friction ($\phi$). It is widely applied for evaluating the engineering properties of rocks and soil. Its value increase in dense rock and soil and decrease for soft or loose soil. The Effective angle of internal friction ($\phi$) is given in term of velocity ratio as follow [9,16]:

$$\sin \phi = \frac{2}{(V_p/V_S)^2}$$  \hspace{1cm} (2)

The vertical variations of this parameter was plotted as shown in figure 3. The surface layer (Holocene deposits) characterized by low values ranged from (25.9°-31.39°) reflect the heterogeneity of this layer because of the lithological changes and the variations in degree of consolidation. The second geological layer (Anah Formation) characterized by wide range of values ranged from (19.64°-37.83°). The lower values denote to fractured coralline limestone representing incompetent rocks, while higher values denote to hard limestone indicating competent or moderately competent rocks. For the rocks of Baba formation, the values of Effective angle of internal friction ($\phi$) were stable and increased to be between (41.44° – 42.21°) due to increasing compaction of dolomitic limestone. This indicating good competent rocks layer.

**Figure 3.** Variation of Effective angle of internal friction ($\phi$) with depth

### 5.3 Material Index (Im)
Material index is one of the important geotechnical parameters refers to the degree of materials efficiency. The material index is used for material classification for site evaluation purposes and it is influenced by material content, degree of consolidation, joints, fractures, and the presence of liquids in porous, which influence the elasticity of materials[16]. The material index can be calculated in term of velocity ratio [12,16] as following :-

$$\text{Im} = \frac{3-(V_p/V_S)^2}{(V_p/V_S)^2 - 1}$$  \hspace{1cm} (3)
This parameter categorizes the level of rocks competence from the engineering viewpoint. The rock properties for engineering purposes can be categorized into four categories based on its material index and Poisson’s ratio (Table 2). Figure 4 describes the variations of the material index (Im) values with respect to depth. The range of this parameter for the upper layer is between -0.30 to -0.44 reflects incompetent to fairly competent rocks. For the rock of Anah Formation, the values of this parameter ranged between -0.59 and -0.12 indicating incompetent to moderately competent materials. Baba formation rocks characterized by higher values of material index ranged from -0.01 to 0.01. According to table 2, this range within good competent rocks.

![Figure 4. Variation of Material Index (Im) with depth](image)

5.4 Coefficient of lateral earth pressure at rest (Ko)
The coefficient of lateral earth pressure at rest (Ko) is very important coefficient in geotechnical engineering because it affects the strength and consolidation manners of rocks and soil and also because it is considered in design of engineering structures. For most materials its values lie between (0-1). The behavior of this coefficient is the same as the behavior of poison's ratio, where its values decrease for dense consolidated sediments, whereas increase for loose unconsolidated sediments. The coefficient of lateral earth pressure at rest (Ko) can be computed in terms of velocity ratio \([11,12]\) as follows:

\[
K_o = \left(\frac{V_P}{V_S}\right)^2 - 2 \left(\frac{V_P}{V_S}\right)
\]

The variations of this parameter with depth were plotted as illustrated in figure 5. The surface layer (Holocene deposits) characterized by values ranged from (0.47 – 0.56) indicating unconsolidated sediments. The rocks of Anah Formation characterized by values ranged from (0.38- 0.66).
The higher values describe unconsolidated layers, whereas lower values describe dense and consolidated layer. The consolidated rocks denote to limestone layer, while unconsolidated rocks refer to fractured or coralline limestone, as appeared in borehole information. The values of this Coefficient for the third geological layer (dolamatic limestone) showed constant and lower values (0.33). This value reveals that Baba formation rocks (dolamatic limestone) represents dense consolidated dolomitic limestone, indicating good competent rocks.

In conclusion, from geotechnical viewpoint, the results indicate that the dolamatic limestone (Baba Formation) is more geotechnically stable rather than other layers because it has good geotechnical parameters. Therefore the rocks of Baba Formation are good competent rocks and represent the most suitable rocks as foundation layer at the studied site, while the rocks of surface layer (Holocene Deposits) which was characterized by poor geotechnical parameters, classified as unsuitable rocks as foundation layer. Anah Formation characterized by alternation of the moderately competent (limestone) with thin incompetent (fractured coralline limestone) rocks maybe suitable for moderately or low loaded engineering structures.

6. Conclusion
This study aims to assess the rock competence as foundation materials for preconstruction of an engineering project using ultrasonic technique. For this purpose, laboratory measurements for thirty seven (37) core samples collected at different depths of the drilled borehole were carried out to calculate seismic wave velocities. Some geotechnical parameters including Poisson’s ratio (σ), Effective angle of internal friction (φ), Material index (Im), and Coefficient of lateral earth pressure at rest (Ko) were calculated based on velocity (Vp and Vs) values. With the aim of evaluate the rocks competence as a foundation rocks for engineering purposes, the variations of geotechnical characterize with depth were evaluated. The acquired results showed that the rocks competence at the area were related with lithological and structural situation of the site and increased with depth. Depending on the values of calculated parameters, and from engineering point of view, the rocks at the investigated site showed different degrees of competence. The first surface layer was classified as incompetent to fairly competent rocks, reflecting unsuitability as a foundation layer for construction purposes. The
second layer was characterized by alternation of the moderately competent (limestone) with thin incompetent (fractured coralline limestone) rocks suggesting suitability for moderately engineering constructions. The third layer which composed of dolomitic limestone (Baba formation) was characterized by good geotechnical properties and classified as a competent layer. The rocks of baba formation represents most suitable layer as a foundation material for proposed dam at the study area. Finally, the obtained results also showed that the ultrasonic method is useful tool to estimate geotechnical properties of rock samples in pre-construction studies.

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