Ultrasonic Method as a Tool for Geotechnical Parameters Estimation at Proposed Engineering Site/ Western Iraq

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Abstract. The objective of the present research is to confirm the possibility of ultrasonic methods as geophysical tool for the estimating of geotechnical parameters for engineering purposes. Thirty seven (37) rock samples were collected at different depths of borehole drilled at the study area, and both primary and secondary waves velocity (Vp and Vs) were measured in laboratory. To evaluate the rock competence as foundation material for engineering works, some important geotechnical parameters including Poisson’s ratio(σ), Stress Ratio(Si), Material index(Im), Concentration index(Ic), and Density gradient( Di) were calculated. The obtained results demonstrate that the first surface layer is characterized by incompetent to fairly competent materials, the second layer (Anah Formation) is characterized by alternation of the moderately competent (limestone) with thin incompetent (coralline limestone) layer, while the third layer (Baba Formation) which composed of dolamatic limestone is characterized by good geotechnical parameters, reflect good competent rocks representing more suitable rocks as foundation layer for civil engineering constructions at the investigated site. The results also confirm the efficiency of ultrasonic method in estimating and assessing the geotechnical parameters of rock samples in pre-construction studies.

1. Introduction

Because all engineering structure is founded on geological earth materials, therefore, it is needed to perform pre-construction survey of the proposed site to determine the strength and the suitability of the earth materials to ensure its reliability[1]. Obtaining sufficient information about the subsurface situation is required for evaluating the situation of the subsurface that make appropriate decisions for a more efficient and safe design of the proposed sites. Besides geotechnical investigation, some geophysical methods are widely used to provide direct information about the engineering properties of the rocks or soil which includes competence, strength and stability, which can help in enhancement of the site investigation programme[2].

The most commonly employed geophysical methods for geotechnical site investigation especially in the study of rocks foundation are seismic methods. The reason of this is the velocity of propagation of elastic waves depends on the elastic properties of rocks in which they propagate. It was shown that the sound velocity of rock is closely related to its dynamic properties [3,4]. Many soil parameters may be acquired by the use of seismic methods, such as elastic dynamic and geotechnical properties [5,6,7,8]. Thus, the results from seismic measurements may help in rocks engineering. One of the most effective seismic methods which are commonly used to evaluate and estimate material properties is ultrasonic
technique. It has been widely used in both site and laboratory to determine engineering properties of rocks. Ultrasonic technique involves sending elastic pulse through core sample to calculate the wave’s velocities as they transmit through material, which in turn are used to estimate engineering properties.

Ultrasonic techniques have been used by several authors to evaluate and predicate the mechanical properties of various rock samples in laboratory [9,10,11,12,13,14]. In Iraq, it is believed that there are few researches that utilize ultrasonic technique for delineating some geotechnical and physical properties of different rock samples [15,16,17,18,19].

This study aims to verify the suitability of the ultrasonic technique for the estimating of some important geotechnical parameters necessary for evaluating the situation of the subsurface for engineering purposes. Also to determine the competency of rock in order to recommend a suitable foundation layer for the proposed engineering site.

2. Geological Condition

The study site is located in the western part of Iraq, NW AL-Anbar governorate, at latitudes N: 34º 25' 0" - 34º 30' 0" and longitudes E: 41º 42' 0" - 41º 45' 0". (figure 1).

![Figure 1](image.png)

Figure 1. Location map showing the borehole from which samples were collected.

The site characterized by irregular topography and the main exposed rocks are L.Miocene – Holocene deposits [20]. The L.Miocene rocks in the site are Euphrates Formation. The Euphrates Formation divided into two main members, which are lower and upper members [21]. The lower member composed of basal conglomerates, while the upper member composed of brecciated rock, chalcky limestone, dolomatic limestone and marly limestone, the Holocene deposits forms an irregular cover represented by gravel, sand, conglomerate, river terraces and river shoulders [22].

The investigated site represents a proposed engineering site for constructing a new dam near Rawa city, close to both sides of Euphrates river. For this purpose some exploration boreholes were drilled, and one of these wells was selected to achieve the current study. The selected borehole lies at the right bank of Euphrates River as shown in figure 1. According to borehole information, the rock sequence in the site from top to bottom consists of three main layers. The first layer consists of sandy gravel deposits, with thickness about 3.5 m. The second layer represented by Anah Formation. The Anah Formation is composed of recrystallized, massive, hard, coralline and fossiliferous limestone [23]. The thickness of this formation about 28 m. The bottom formation which extends from depth of 32 m to end of poring (100 m) is Baba Formation. Baba Formation is composed of hard dolomitic limestone.
3. Samples collection and preparation
Thirty seven hand samples were collected from borehole at an interval of almost 0.5 m, and in some intervals the spacing is 1 m and 2 m. The numbers of collected samples from each formation in the borehole are illustrated in table 1. All samples were brought to laboratory and calibrated to be in a cubic shape with length more than 10 cm and diameter of 5 cm. End surface of the samples were refined to a suitably smooth plane to provide fine coupling between the transducer face and the rock surface.

Table 1. Number of collected samples from different formations.

| Formation     | Number of samples | Vertical interval distance between samples (m.) |
|---------------|-------------------|-----------------------------------------------|
| Quaternary deposits | 3                 | 0.5                                           |
| Anah          | 25                | 0.5                                           |
| Baba          | 6                 | 2                                             |
|               | 3                 | 1                                             |

4. Velocity measurements
Compressional and shear wave velocities of core samples were measured using a New Sonic Viewer (model-5217A). The ultrasonic impulses are transmitted to the core sample and then the transit time (T) is recorded. The core sample was placed between the transmitter and receiver; the transducers were pushed to the ends of sample until a stable transit time (T) was recorded. Vaseline was used as a special grease to ensure good coupling between the surface of sample and transducers. The values of compressional and shear wave velocity (Vp and Vs) were obtained using the following equations:

\[
V_p = \frac{L}{T_p}\quad (1)
\]

\[
V_s = \frac{L}{T_s}\quad (2)
\]

Where:
L = length of the sample (cm)
Tp and Ts = transit time in micro second (P and S wave).

The compressional velocity (Vp) values of samples at the study area varied from 2735 m/s to 6666 m/s with an average value of 5361 m/s, while the shear velocity (Vs) values varied from 1363 m/s to 3551 m/s with an average value of 2608 m/s.

5. Geotechnical parameters for the investigated site
Knowledge of geotechnical parameters for soil or rocks helps in estimating of the competence of the subsurface and gives a good understanding on the quality of the subsurface rocks for engineering purposes. Depending on Vp and Vs, as well as density values, a number of geotechnical parameters for the investigated site were calculated. These parameters include material index, concentration index, poisons ratio, stress ratio and density gradient. The equations used to compute these parameters are listed in table 2. When the values of geotechnical parameters are known, the strength or competence of rocks for engineering works can be simply evaluated.
Table 2. list of the equations used to compute geotechnical parameters

| Geotechnical parameter       | Equation                     | Reference |
|------------------------------|------------------------------|-----------|
| Material index (Im)          | \( Im = \frac{3 - (Vp/Vs)^2}{(Vp/Vs)^2 - 1} \) | [1][7]    |
| Concentration index (Ic)    | \( Ic = \frac{3(Vp/Vs)^2 - 4}{(Vp/Vs)^2 - 2} \) | [1][8]    |
| Poisons ratio (\( \sigma \)) | \( \sigma = \frac{0.5(Vp/Vs)^2 - 1}{(Vp/Vs)^2 - 1} \) | [6]       |
| Stress Ratio (Si)            | \( Si = 1 - 2(Vs/Vp)^2 \) | [8]       |
| Density gradient (Di)        | \( Di = \left[ Vp^2 - \frac{4}{3} Vs^2 \right]^{-1} \) | [24]      |

The definition and ranges of these parameters is explained in detailed by [1, 5, 7, 8, 25, 26] as shown in table 3. Depending on these ranges, the quality and competence of the sample rocks for the study site were evaluated.

Table 3. Ranges of material index, Poisson's ratio, Concentration index and stress Ratio corresponding to the soil competent degree.

| Description Parameters | Incompetent to slightly competent | Fairly to moderately competent | Competent materials | Very high competent |
|------------------------|-----------------------------------|--------------------------------|---------------------|-------------------|
| Material index (Im)    | (-1) to (-0.5)                    | (-0.5) to (0.0)                | 0.0-0.5             | 0.5-1             |
| Poisons ratio (\( \sigma \)) | 0.49 - 0.41                   | 0.35 – 0.27                    | 0.25 – 0.16         | 0.12-0.03         |
| Description Parameters | Weak                              | Fair                           | Good                |
|                        | Incompetent                       | Fairly competent                | Competent           |
|                        | Very soft                         | Soft                           | Fairly compacted    | Moderate compacted |
|                        | Soft                              |                               |                     | Compacted          |
| Concentration index (Ic) | 3.5 - 4                         | 4 -4.5                         | 4.5 -5.0            | 5.0 – 5.5         |
|                        | 5.5 -6.0                          |                               |                     |                   |
| Stress Ratio (Si)       | 0.7 – 0.61                        | 0.61- 0.52                     | 0.52 – 0.43         | 0.43- 0.34        |
|                        | 0.34 - 0.25                       |                               |                     |                   |

6. Results and Discussion
The main geotechnical parameters including Poisson’s ratio, Stress Ratio, Material index, Concentration index, and Density gradient calculated from the results of Vp and Vs measurement for the samples are listed in table 4. These parameters showed wide ranges in values as a result of the rocks composition, degree of consolidation or compaction, fracturing, and variations in physical properties. As mentioned previously, according to borehole information, the site of investigation consists of three geologic layers (Holocene deposits, Anah Formation and Baba Formation).
Table 4. The main geotechnical parameters obtained from the velocity measurement for the core samples at the study area.

| Sample No. | Depth (m.) | Vp m/s | Vs m/s | Material index (Im) | Concentration index (Ic) | Poissons ratio (σ) | Stress Ratio (Si) | Density gradient(Δρ) |
|------------|------------|--------|--------|-------------------|-------------------------|-------------------|-----------------|---------------------|
| 1          | 2.5        | 2857   | 1363   | -0.41             | 3.84                    | 0.35              | 0.54            | -0.48              |
| 2          | 3          | 5470   | 2557   | -0.44             | 3.77                    | 0.36              | 0.56            | -0.47              |
| 3          | 3.5        | 5612   | 2864   | -0.30             | 4.09                    | 0.32              | 0.48            | -0.51              |
| 4          | 4          | 3301   | 1694   | -0.29             | 4.11                    | 0.32              | 0.47            | -0.51              |
| 5          | 4.5        | 5465   | 2670   | -0.37             | 3.91                    | 0.34              | 0.52            | -0.49              |
| 6          | 5          | 5864   | 3106   | -0.22             | 4.28                    | 0.31              | 0.44            | -0.53              |
| 7          | 5.5        | 5592   | 2972   | -0.21             | 4.30                    | 0.30              | 0.44            | -0.53              |
| 8          | 6          | 6018   | 2731   | -0.48             | 3.70                    | 0.37              | 0.59            | -0.46              |
| 9          | 6.5        | 3197   | 1636   | -0.29             | 4.10                    | 0.32              | 0.48            | -0.51              |
| 10         | 7          | 6292   | 3146   | -0.33             | 4.00                    | 0.33              | 0.50            | -0.5               |
| 11         | 7.5        | 4919   | 2370   | -0.40             | 3.87                    | 0.35              | 0.54            | -0.48              |
| 12         | 8          | 5160   | 2385   | -0.46             | 3.75                    | 0.36              | 0.57            | -0.47              |
| 13         | 8.5        | 5679   | 3145   | -0.12             | 4.59                    | 0.28              | 0.39            | -0.56              |
| 14         | 9          | 6494   | 3551   | -0.15             | 4.49                    | 0.29              | 0.40            | -0.55              |
| 15         | 9.5        | 6578   | 3012   | -0.47             | 3.72                    | 0.37              | 0.58            | -0.46              |
| 16         | 10         | 5757   | 2740   | -0.41             | 3.83                    | 0.35              | 0.55            | -0.48              |
| 17         | 10.5       | 6666   | 2805   | -0.57             | 3.55                    | 0.39              | 0.65            | -0.44              |
| 18         | 11         | 6453   | 3117   | -0.39             | 3.87                    | 0.35              | 0.53            | -0.48              |
| 19         | 11.5       | 6132   | 3066   | -0.33             | 4.00                    | 0.33              | 0.50            | -0.50              |
| 20         | 12         | 5059   | 2097   | -0.59             | 3.52                    | 0.40              | 0.66            | -0.43              |
| 21         | 12.5       | 6080   | 3098   | -0.30             | 4.08                    | 0.32              | 0.48            | -0.51              |
| 22         | 13         | 5798   | 2899   | -0.33             | 4.00                    | 0.33              | 0.50            | -0.50              |
| 23         | 13.5       | 6271   | 2571   | -0.60             | 3.51                    | 0.40              | 0.66            | -0.43              |
| 24         | 14         | 6143   | 3078   | -0.33             | 4.00                    | 0.33              | 0.50            | -0.50              |
| 25         | 14.5       | 2735   | 1399   | -0.29             | 4.10                    | 0.32              | 0.47            | -0.51              |
| 26         | 15         | 2745   | 1414   | -0.28             | 4.13                    | 0.32              | 0.47            | -0.52              |
| 27         | 15.5       | 6080   | 2659   | -0.52             | 3.6                     | 0.38              | 0.62            | -0.45              |
| 28         | 16         | 6140   | 3182   | -0.26             | 4.17                    | 0.32              | 0.46            | -0.52              |
| 29         | 18         | 5609   | 2313   | -0.59             | 3.52                    | 0.40              | 0.66            | -0.43              |
| 30         | 20         | 5174   | 2165   | -0.58             | 3.53                    | 0.39              | 0.65            | -0.43              |
| 31         | 22         | 5314   | 2667   | -0.33             | 4.02                    | 0.33              | 0.50            | -0.50              |
| 32         | 23         | 6555   | 2774   | -0.56             | 3.56                    | 0.39              | 0.64            | -0.44              |
| 33         | 26         | 6351   | 2703   | -0.56             | 3.57                    | 0.39              | 0.63            | -0.44              |
| 34         | 31         | 5392   | 2806   | -0.26             | 4.18                    | 0.31              | 0.46            | -0.52              |
| 35         | 32         | 4539   | 2631   | 0.01              | 5.04                    | 0.25              | 0.33            | -0.60              |
| 36         | 33         | 4749   | 2732   | -0.01             | 4.97                    | 0.25              | 0.34            | -0.59              |
| 37         | 34         | 4117   | 2386   | 0.01              | 5.04                    | 0.25              | 0.33            | -0.60              |

In order to evaluate the rocks competence at the investigated site, the variations in geotechnical characters of rocks with depth are plotted, (figure 2 ). Figure 2A shows the variation of Poisson’s ratio (σ) and Stress Ratio (Si) with depth .The Poisson’s ratio (σ) and Stress Ratio (Si) for the first geologic layer ranging from (0.32 – 0.36) and (0.48- 0.56) respectively, indicating incompetent to fairly competent materials based on Table 3. For the second geologic layer (Anah Formation) , the values of Poisson’s ratio (σ) and Stress Ratio (Si) ranging from (0.28- 0.40) and (0.39- 0.66 ) respectively.
Figure 2. Variation of geotechnical parameters with depth: (A) Poisson ratio and stress ratio vs depth (B) Material index vs depth (C) Concentration index vs depth (D) Density gradient vs depth
According to table 3, the higher values represent incompetent materials while lower values represent moderately competent materials. The incompetent rocks at Anah Formation maybe refer to fractured limestone or coralline and fossiliferous limestone, while moderately competent rocks refer to hard limestone as described by borehole information. The incompetent rocks are observed at depths from 18 m to 20 m and from 23 m to 26 m, and also appear as a thin bed with thickness about 0.5 at depths 12 m, 13.5 m and 15.5 m. Baba Formation which composed of hard dolomitic limestone is characterized by relative low values of Poisson’s ratio ($\sigma$) about 0.25 and low values of Stress Ratio (Si) ranged between 0.33 to 0.34. These values reveal good competent rock material.

The variation of the material index (Im) with depth has been shown in figure 2B. The material index (Im), which classifies the level of material competence from the foundation viewpoint, ranged from -0.30 to -0.44 in the first surface layer, this range reflect incompetent to fairly competent rocks. For the second layer (Anah Formation), the calculated material index appears values ranged between -0.59 and -0.12 ,this range indicate incompetent to moderately competent materials. The third layer (Baba Formation) at the investigated site have values of material index ranging from -0.01 to 0.01, which according to table -3, reflects good competent materials.

The variation of concentration index (Ic) with depth has been shown in figure 2C. The concentration index (Ic), which describes the level of material compaction, have values ranging from 3.77 to 4.09 in the first surface layer. According to table 3, this range refers to incompetent (soft) rocks. Concentration index values varied from 3.51 to 4.59 in the second layer (Anah formation) showing soft to fairly compacted rocks. The deepest layer at the investigated site (Baba Formation) has higher values of concentration index ranging between 4.97 and 5.04, suggesting according to table 3, moderate compacted rocks.

The higher values of density gradient (Di) are observed in the first layer and at some depths interval in the second layer, which indicating incompetent to fairly competent rocks. While the lower values of density gradient (Di) are shown in the third layer, reflecting good competent rocks,(figure 2D).

In conclusion, from engineering viewpoint, the obtained results indicate that the evaluated rock competence were related with lithological, textural variations in rocks composition and structural situation of the site. The poor geotechnical parameters were appeared within Holocene deposit indicating incompetent to fair competent rocks, therefore it represents unsuitable rocks as foundation layer for civil engineering purposes, while Baba formation which composed of dolomitic limestone was characterized by good geotechnical parameters, reflect good competent rocks, and hence it represents more suitable rocks as foundation layer for civil engineering constructions at the investigated site. The alternation of the moderately competent (limestone) with incompetent (fractured and/or coralline limestone) layers suggests suitability of Anah formation for fairly and low load engineering constructions.

7. Conclusion

This study aims to estimate some geotechnical parameters required for evaluating the situation of the subsurface for engineering purposes using ultrasonic technique. For this purpose, laboratory measurements for thirty seven (37) rock samples collected at different depths of borehole drilled at the study area were carried out in order to calculate seismic wave velocities. From obtained velocity values (Vp and Vs) some geotechnical parameters including Poisson’s ratio ($\sigma$), Stress Ratio (Si), Material index (Im), Concentration index(Ic), and Density gradient (Di) were estimated.

In order to evaluate the rocks competence as a foundation layer for engineering purposes, the variations of geotechnical characterize with depth were evaluated. The obtained results show that the rocks competence at the investigated site were correlated 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 materials, reflecting unsuitability as a foundation layer for construction purposes. The second layer was characterized by a transition of the moderately competent (limestone) with thin incompetent (fractured and/or coralline limestone) layers suggesting suitability for moderately competent purposes. The third layer which composed of dolomatic limestone was classified as fairly competent to moderately competent layer, and 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.

8. References

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