

### **B-3) - SEISMIC RECONNAISSANCE FOR GROUNDWATER DEVELOPMENT IN THE WADI IBRAHIM AREA**

**ÖZET :** *Kutsal Mekke şehrinin özellikle hac dönemi sırasında içme suyu ihtiyacı çok önemli olmaktadır. Neticede yüzeye yakın su depolayan geçirgen tabakaların ve buna ilave olarak derinlerde yeralan temel anakaya içerisinde hapsedilmiş yer altı suyunun bulunması önemli ve ihtiyaç duyulan araştırmalardır. Mekke şehrine yakın olması nedeniyle Wadi Ibrahim içerisinde gömülü bulunan vadilerin araştırılması bu çalışmaların esasını teşkil etmektedir. Sismik refraksiyon çalışmalarının amacı vadilerin şekillerini ortaya koyduğu gibi su taşıyan granüler malzemelerinin kalınlıklarını ortaya koymaktır. Sığ refraksiyon çalışmalarının sonuçları süratli bir biçimde temel kaya şeklinin sondaj programından önce belirlenmiş olmasıdır. Araştırmalar göstermiştir ki Wadi- Ibrahim içerisinde 5 ayrı sismik hız değerleri bulunmuştur. Gömülü vadiler içerisinde elde edilen hız değerleri yüzeye yakın kuru malzemeler içerisinde 265-500 m/sn bunu takiben kısmen nemli ıslak seviyelerde bu değerler 1200-1300 m/sn suyla doymuş olan alüvyonda 1440-1923 m/sn suyla doymuş temel kayada ise 2083-3280 m/sn masif temel kayada ise 4100 m/sn elde edilmiş olup bunun üzerindeki hız değerleri kuru temel kayayı karakterize etmektedir. Bu çalışmalar sırasında elde edilen diğer bir sonuçta temel kayanın kötü "E" sınıflanan bölgede oldukça yararlı akifer zonlarının bulunduğu görülmüştür.*

#### **1. INTRODUCTION**

The demand for drinking water in the Holy City of Mecca has become an acute problem in recent years, particularly during the Hajj period. Consequently, the delineation of shallow permeable grounds favorable for groundwater storage and location of deep bedrock aquifer suitable for upward circulation of groundwater are important and needed information.

The existence of major buried valley within the catchment area of Wadi Ibrahim is considered one of the important groundwater sources due to its proximity to the populated area of the Holy City of Mecca.

The purpose of the seismic-refraction studies was to get some information about the thickness of the alluvium as well as to investigate the shape and content of the valley. Results obtained from shallow-refraction studies are useful since they provide rapidly a picture of the bedrock configuration, and guide a subsequent drilling program.

The main advantage of the Seismic-refraction method appears to be the quick elimination of location from a test drilling schedule or placing of the drilling machine in the

proper location at a good site. It may even guide the driller, who may have struck a boulder in his operations and thought it to be bedrock.

## **2. PRINCIPLES OF MEASUREMENT AND INTERPRETATION**

For determining the depth of the layers less than 100-200 m in thickness, refraction is the only suitable method. The reflection is of no use, because the travel-times too short.

The recording unit was a 12-channel BISON instrument (type Geo Pro 8012A) is a microcomputer-controlled and can be used for reflection and refraction seismology.

The energy used during the course of seismic-refraction work was either a 75 kg weight drop falling down from about two meters or a 5 kg sledge-hammer (please see Fig-2a).

Elastic waves that are developed from a localized source which described above decrease in amplitude with distance from the source. The reduction of wave amplitude largely due to energy losses by internal damping within the medium. In order to improve signal-to-noise ratio (S/N) and increase the peak-to-peak amplitude of elastic wave, all geophones are buried into the ground and covered by sand. Before the planting of geophones into the ground, the soil was saturated with water.

Refraction lines run at the site were 55 and 110 meters in length. Vertical geophones were spaced 5 m and 10 m intervals with the first geophone positioned 2.5 m to 5 m from the energy source, respectively.

Each spread was overlapped the previous spread with 2 geophones so that the geophones No. 11 and 12 in the first spread corresponds to the the 1 and 2 in the subsequent spread.

A semi-spherical-shaped weight was then dropped repeatedly from a height of about 2 meters on a steel plate (25x25x1 cm). Please see Fig-2a.

The seismic-refraction lines were shot across the valley but parallel to the main resistivity line (please see Fig-2b).

Twenty profiles were probed by the seismic method within the catchment area of Wadi Ibrahim. For each probing station, the depth distribution of the P-wave velocities are evaluated and plotted. The seismic recording were converted to depths through the use of conventional time-intercept method (Redpath - 1973).

In order to check on the first-layer velocity at the center, a shot in the middle of the spread has been added.

Additional intermediate shots would help resolve the groundwater table (GWT) in the detail, and eventually, permit more detailed mapping of water-saturated alluvium.

### **3. DETECTION OF THE WATER-BEARING CAPACITY OF ALLUVIAL MATERIAL BY USING COMPRESSIONAL WAVE VELOCITY**

In very loose, unconsolidated soil, the velocity of longitudinal waves (P-waves) may be very low even lower than that of sound in air (340 mps). Ref (2) p. 56. Please see the near surface materials in Figs-3a-3u. The reason for that is the absorption of the energy by the loose and weak cemented pieces as a result of their inelastic activities during dynamic loading.

Eventually, inelastic activities of the dry sands subjected dynamic loading caused anomalous time delays.

In a saturated medium, however, the seismic P-wave velocity is very near to the value of 1463 mps which corresponds to the velocity of compression waves in water. An increase of 1000 mps in velocity is the best indicator of the unconsolidated sediments is becoming saturated with water.

#### **3.1 Previous Studies of the Shallow Refraction Method Applied to Groundwater Problems**

According to Hasselstrom, B.1969, in porous soils such as sand and gravel, a saturation with water will be accompanied by a change of the seismic velocity from about 300-900 mps above groundwater table to about 1200-1800 mps above groundwater level. He also suggest that above described velocity contrast which in general is large enough to allow a satisfactory determination of the groundwater level. He also concluded that, the detailed seismic rock velocity determination not only opens an indirect way of prospecting for water infissured zones in bedrock, but should also proved to be useful in finding certain types of mineralized zone.

Sjögren, et.all , suggested that the groundwater in the platau coincides with the interface between the velocity layers 400-500 mps and 1250 mps in the sand layer.

According to the report presented by ITALCONSULT in 1967:

- i) “An upper low-velocity horizon (0,4-1,3 km/sec) consisting of the aerated zone and beds of dry alluvium”
- ii) “An intermediate horizon with a seismic velocity of between 1,5 and 2 km/sec corresponding to the water-bearing part of the alluvial cover and, in part, to the altered rock”
- iii) “A high-velocity substratum (5-6 km/sec) corresponding to the compact basement complex.”

Zody, A.R. (1963) made extensive resistivity surveys near San Jose, Clifornia.

He concluded that, P-wave velocity on the order of 1280-1300 mps corresponds to the dry gravel and boulder layer which becomes somewhat damp and moist.

In order to provide a better basis for determining the high-water yield area, the resistivity data (transversal resistance) obtained ABEM TERRAMETER and GISH-ROONEY was examined to see if any consistent relationship could be found between “true resistivity” permeability, P,wave velocity and degree of compaction of alluvial materials (Res 2 and 5). On the basis of information obtained from surface seismic and resistivity measurements, the results can be summarized in the following form[Kuran,1975]:

- i) The maximum amount of water yielding-material was described as gravel GP, having a maximum size of 7-7,5 cm in diameter accompanied by a change of the seismic velocity from about 195-207 mps above groundwater table to about 1800 mps below the groundwater table. See Fig-3.1a.
- ii) Field studies also show that the location of the borehole of maximum yield can be determined by the true resistivity value of 160 ohm.m.in Dalaman-Muğla area.
- iii) Curve No:1 in 3.1b is obtained from the jointed granite which allows large amounts of water to infiltrate into the alluvium from the weathered zone. Curve No:4 was obtained from an impermeable layer such as CL-CH placed on top of materials such as GP-SP ,SP which has been placed on an impermeable layer of CL-CH-ML. It is interesting to note that the aquifer transmissibility of curve No:1 is 16 times greater than that of curve No:4. Ref.2 p. 59.  
This result shows that the permeability of water-bearing materials depends not only on the structure of water-bearing materials but also strongly depends on the texture of overlying and underlying materials.
- iv) When the compactness of the aquifer system increases, the amount of water decreases. Since the velocity of sound in a sediment is sensitive to variations in its degree of saturation, compressional wave velocity decreases from 1800 mps to 1600 mps.

It is interesting to note that in-situ permeability value of the gravel bed increases dramatically from  $10^{-4}$  to  $10^{-1}$  (within the depth of 14.9 and 22.30 meters) as the permeability test approaches to the weathered granite bedrock. Because the granitic rocks allows large amount of water to infiltrate into the alluvium from the weathered zone (please see Fig 3.1c).

### 3.1.1. Results from Present Study

Having summarized some results from previous studies, it is now useful to start with an example of a seismic refraction work which was carried out near a well where the depth to water was known (please see Fig-3a).

The predicted depth for water from seismic work is indicated as 5,32-6 m and according to local authorities the depth to water was about 7 meters.

In June 23, 1984 , the measured static water table was 3,80 m and the depth of the well was about 13 meters (according to Mr. O.Dumlu). The discharge of the well is said to be 9 lt/sec.

A saturation with water was accompanied by the P-wave velocity from about 342-423 mps above groundwater table to about 1470-1896 mps below the groundwater table.

Because of the possibility of obtaining large quantities of groundwater from permeable deposits and weathered bedrock, the depth of the well should be extended more than 22 meters (the depth to bedrock is about 22 meters).

### 3.2 Determination of the Thickness and Quality of water-bearing Rock Layers by Seismic Method

It is generally accepted that, in volcanic igneous rocks, the movement of water is restricted to joints, bedding planes and fissures. Consequently, the decomposed rocks has a high porosity and permeability; and if the weathering extends to depth, it forms an ideal reservoir for underground water. But, however, the solid igneous rocks contain no water.

The elastic wave velocity in rocks is variable owing to crack porosity and degree of cementation. Helfrich., 1971., showed that there is considerable dependence of the P-velocity with degree of jointing. Columns (1) and (2) of Table III show the degree of jointing and seismic velocity respectively. The jointing factor characterizes also the rock mass quality as indicated by column No:4.

The classification of rock property by using in-situ and laboratory  $E_d$  values also gives important clue about the rock mass quality. Table III.

This technique has been developed in 1960 by Kudo, and used in many geotechnical project in Turkey. Refs (10,11,12).

Considerable experimental work has been done on the effects of fracturing on elastic properties of some rocks. In order to determine Crack Coefficient (K) in the foundation rock (please see Column 5 of Table II) it is necessary to use the laboratory  $E_{dlab}$  , and field  $E_{dfield}$  values. This can be obtained by using the following expression given by Kudo (1960);

$$E_{dmax} - E_{dfield} / E_{dmax} = K. \text{ (In this expression } E_{dmax}=E_{dlab}\text{).}$$

This tentatively called the crack coefficient, and with this, general classification of the rock quality or structural quality of bedrock within the Wadi - Ibrahim area can be estimated. (Please see Fig-3.2a and also see Table I, Column 8 & 9).

#### **4. RESULTS AND RECOMMENDATIONS**

As a result of the seismic work, many areas where geologic control was lacking was eliminated as possible buried valley locations with a few refraction profiles. Existence of buried valleys was confirmed at several locations and their depths were determined. On the basis of distribution of P-wave velocities recorded at various profile locations and inferred sub-surface structure, the studied portion of Wadi Ibrahim can be conventionally subdivided into five layers (please see Fig-3a-3u).

- i) Dry, near-surface material (265-500 mps).
- ii) Damp and moist layer (1200-1300 mps).
- iii) Water saturated alluvium (1440-1923 mps).
- iv) Water saturated weathered bedrock (2083-3280 mps).
- v) Massive bedrock > 4100 mps, dry.

Figures- 3a through 3u are diagrammatic sections along the profiles showing depth to the various layer inferred from seismic data. Since the velocity of elastic wave is dependent on porosity and degree of weathering of material, the sub-division of the foundation rock is, therefore, based on field results from changes in P-wave velocity and is independent of material types or visual classification.

The more important conclusions are as follows :

- i) The sand is extremely irregular in thickness especially along the profiles which shown in Figs. 3b,c,d. The shape of valley is “V”-shaped along the above mentioned profiles, and gradually becomes trapezoidal-shaped as we go towards southwest as shown in Fig-3e,f and g.
- ii) The existence of the weathered bedrock is one of the most important factor controlling the occurrence of groundwater is a alluvial material in Wadi Ibrahim. (please see Figs 3d,e,f). When the P-wave velocity exceed 4000 mps

in bedrock , no water saturation can be seen in alluvium which is located above the granitic rocks (please see Figs 3e,g).

- iii) The most prominent features of the cross-section are the highh seismic-wave velocity increase with distance across the Northern flank of the valley which indicates definite increase in cementation and compaction (see Fig 3.2a). Northern flank of the wadi, more resistant to weathering than the southern flank. The lowest P-wave velocity was observed in the central part of the valley. The quality of weathered rock in the central part of valley can be described as “Bad” (E). it is beleived that these saturated zones are largely derived from the weathered zone within the basement. This means that basement rocks described as “Bad” can serve as a useful aquifer.
- iv) Groundwater storage along the profile VES-5, 6,7 was foud very uniform and it is completly different from other profiles.
- v) The section shown in Fig 3h indicates that the “Massive Bedrock” dipping westward while the same rock at the location of VES-5,6,7 was in horizontal position –Fig 3f.

#### THE DELINEATION OF TARGET ZONES

From our present knowledge of Wadi Ibrahim area, the following recommendation can be made for the delineation of Target Zones. Since the alluvial material is extremely irregular in thickness, it was not possible to find the target zones by using the resistivity data only.

This is mainly due to lack of sounding points across the valley. Much more resistivity depth probes should be conducted in the valley.

In suite of the irregularities, it would appear that from the continuous seismic-investigation across the valley makes it possible to evaluate the probable old river channels which have been filled with gravel and alluvium.

The recommended borehole locations can be seen along the cross-sections. During the selection of target zones, the maximum thickness of weathered bedrock, the maximum thickness of saturated alluvium, the rock quality (from the Table II and III), and the range of P-wave velocities were taken into consideration.

#### 5. GROUNDWATER QUALITY

Since no previous inforrmation existed regarding the groundwater quality at greater depths in Wadi Ibrahim, it was desired to find out the groundwater salinity by using electrical soundings.

Inasmuch as the formation factor “F” was already calculated for Wadi Na’man area Ref(7), a semi-quantitative definition of groundwater salinity may be made by the application of surface electrical techniques.

The data indicates a constant relationship between alluvial aquifer resistivity and water resistivity may be expressed as:

$$\rho_o = 2.28 \rho_w \quad \text{Ref 7, Fig 5b.}$$

The resistivity of the water in Wadi Na’man was determined from conductivity measurements, whereas the aquifer resistivity was determined from surface geoelectrical measurements Ref (6).

Having determined F, the resistivity of the water at any other site can be determined using  $\rho_o$  and F. A series of resistivity measurements were carried out across the valley in Wadi Ibrahim by the USGS team.

One of the interpretation of the apparent resistivity curves was done by Dr. H. Sadek (personal communication). The interpretation obtained by a computer program which was provided by Hagconsult (Mr. H. Rydstroem), and prepared by the university of Lulea, Sweden and Atlas Copco ABEM (please see Fig 5a).

The interpreted formation resistivity was  $\rho_o = 2087$  ohm-cm, using  $\rho_o = 2087$  and  $F = 2.28$ , the anticipated groundwater salinity was found on the order of 500 ppm (please see resistivity-salinity nomogram in Fig 5c).

The value of the groundwater conductivity (C) in the alluvial material (between 3.60-10.19 m) was about 1092  $\mu\text{mohs/cm}$ , while the groundwater possessed resistivity of  $\rho_w = 915$  ohm.cm ( $C = 1 / \rho_w$ ).

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