Using Seismic Cross-Hole Method to Evaluate Soil Improvement for Outside Wall in Al-Abbas Holy Shrine in Holy Karbala, Iraq

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Abstract
The aim of this study is to use the seismic cross-hole survey in evaluating the injection work to fill the cavities spread in the soil underneath the old foundation of the outer wall of the Al-Abbas holy shrine. A seismic cross-hole survey was conducted for eight profiles, four of these are applied before grouting and four profiles are done after grouting at Al-Imam Musa Al-Kadhum and Al-Imam Sahib Al-Zaman gates. Using the longitudinal and shear wave velocities for different depths ranging from 1 to 15 m. The results of the survey indicate that the soil injection process was successful and effective in filling the cavities. The results of cross-hole survey after the grouting show the percent of variation is 0.7-77 percent for seismic shear wave velocity more than before grouting to variant depths.

Keywords: Seismic Cross-hole survey; Injection evaluation; Applied geophysics; Engineering geology; Geotechnical evaluation

1. Introduction

Geophysical methods are used in geotechnical investigations in engineering sites by calculating the shear velocity (Shaker, 2012), which represents a dynamic reaction of the soil (Al-Khafaji, 2010; Alkafeel Center, 2020). In seismic surveys, the longitudinal and shear seismic velocities are calculated of the soil layers. (Bell, 1980; Alkafeel Center, 2020). The cross-hole method is considered one of the most important seismic methods in determining the lateral and vertical changes of soil modulation underneath the foundations of buildings, in addition to its uses in calculating the geotechnical properties of geological formations and sediments (McCann, et al., 1975; Alkafeel Center, 2015). The study area located 105 Km southwest of Baghdad, coordinates at latitude 32°37′ and longitude at 44°01′ (Fig. 1).

The study area is a very important because it is one of the religious ancient significant features of Kerbala City for the entire Islamic world. Al-Abbas Holy shrine is a religious and archaeological site. This holy shrine was built more than 600 years ago. For Al-Abbas sacred holy big wall surrounded from four sides, this wall is straight except at south side where it has a curved shape. Appearance of cracks in some location of out wall and gates, (Plate 1), and from previous studies referred to the existence of weak zones and cavities in soil underneath the foundations lead to study this location (NCCL, 1992; Al-Khafaji, 2010; Alaatabi, et al., 2022). The foundations require more loading support to be considered for constructional expansion that will be a problem in the future.

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Therefore, this study aims to evaluated the percent responsible soil for the grouting suitable material such as borderlines cemented and accessories liquid interplast HE50 mater to fill the locations of cavity and weak zones that determine by past studies to be treated before adding more establishments above this old foundation and then show if there is a need to put the other grouting program to improve the geotechnical properties such as rigidity, stiffness, etc. underground surface and underneath the foundation of dome at Mossa Al-Kadhom and Al-Imam Sahib Al-Zaman Gates or no. In the field of geophysical exploration surveys, the seismic is considered one of the most important methods because it has high accuracy, great discriminating ability and high resolution (Telford et al., 1981; Al-Banna et al., 2014). This method is affected to determine the successful percent of grouting by using the seismic wave velocities, shear wave is more affected than compressional wave to this aim.
2. Materials and Methods

2.1. Field Work

This study used geophysical method to evaluate the injection grouting process for soil. The results of this work gave a clear picture and good idea of the size of the problem and the percentage of its treatment, as it provided the structural engineer with good information about the behavior of the soil after treating it by injecting the soil using salt-resistant cement and an additive that increased the speed of solidification of cement materials. This study gave important information about the soil and the foundation before deciding to add a new load above the foundation of Al-Abbas Shrine.

The field exploration in this study consists of 7 boreholes distributed outside and inside at Mossa Al-Kadhom and Al-Imam Sahib Al-Zaman Gates of Al-Abbas sacred holy shrine, five of these boreholes are casing by plastic pipe, four boreholes are used to generate the longitudinal and shear waves in a seismic cross-hole survey a long four profiles before and after grouting. According to the field exploration we are using two main investigation methods, they are:

2.1.1. Boring

After the boreholes significant on the ground surface of Al-Abbas Holy shrine through cut and fracture the concrete bed by jackhammer. seven boreholes were drilled inside and outside the holy shrine near the Mossa Al-Kadhom and Al-Imam Sahib Al-Zaman Gates. The locations of these boreholes are shown in Fig. 2 with depth ranging between 15-17 m below the ground surface inside and outside the holy shrine. Then casing by plastic pipes to be high pressure vertical compression PVC and cement material around the pipe. The drilled boreholes by normal auger using Acker type drilling rig (Al-tai, 2019).

2.1.2. Cross-hole Seismic Method

The cross-hole seismic is a suitable main geophysical method that was used in study area to determine the location of cavities and weak zones underneath the foundation of Al-Abbas holy shrine to answer the question," Did the grouting program to be successful or no to improve the soil properties by treatment the cavities and weak zone?". For this reason, four selected profiles were surveyed in the study area. The profile of cross hole has a number and consists of two or three boreholes one of them used as source to generate seismic waves and the other to receive it (Fig. 2). These profiles cover the wall gates of Al-Imam Mossa Al-Kadhom and Al-Imam Sahib Al-Zaman, all of these consisted of eight depth stations or more.

Fig. 2 shows the location of boreholes that were drilled at study area and casing by PVC pipe plastic, and then used these boreholes in the seismic cross hole survey. Each cross hole seismic profiles consists of three boreholes, one of these is used to generate the longitudinal and shear seismic waves, and the other two boreholes are used to receive these waves as in the profile No. S12 or it consists of two boreholes, one of them used to generate the longitudinal and shear seismic waves, and the other to receive it, as in profiles No. S11, S13, and S14.
2.1.3. Instrumentation

Plate 2 shows the geophysical instruments and drilling machine that were used in field work:

- Drilling machine Mode; MEGA TRUCK (235 PSCRD).
- ABEM Terraloc Mark II seismic system made in Sweden (ABEM, 1983) used to record all of the seismic cross-hole profiles; it has a high ability of analysis of seismic recording to shallow depth.
- The ABEM Terraloc consists of two main separated units as follows:
  - Field information unit, and Printer unit
  - As well as boreholes pickup model 3315 is a seismic down hole, cross hole, up hole receiver designed to measure P and S wave velocities in borehole. It consists of a three components geophone. (OYO, 1983).

Plate 2. Instrumentations are using in the field work (a) Drilling machine ;(b) ABEM Terraloc Mark II seismic system, and boreholes pickup
3. Results

3.1. Interpretation

Here, the velocity of the longitudinal and transverse seismic waves was calculated and used to determine the locations of the weak zones and cavities underneath the foundation of holy shrine. The vertical shear component $S_h$ penetrating through the horizontal layer and then recorded in borehole receiver and to calculate the velocity of that way (Alkafeel Center, 2020; Davis and Schulthesis, 1980).

First, measuring the distance between the seismic wave generation and the receiver well in which the seismic waves are recorded (McCann et al., 1975). When the seismic cross -hole profile consists of three boreholes, first is the source and the other are receiver of seismic waves (Alkafeel Center, 2020), there are two distances ($X$) between the well of source and near receiver well, and $X$ is between the well source and well receiver across the foundation. For these boreholes calculate the distance between two receiver boreholes $\Delta x$ (Hamdi et al., 1993). Travel times of seismic cross hole survey and distance are used to determine P and S wave velocities in m/sec units as in equations 1 and 2 (Boore, 2006).

$$V_p = \frac{X}{T_p} \quad (1)$$

$$V_s = \frac{X}{T_s} \quad (2)$$

Between two receiver boreholes, the velocity determines as in equations 3 and 4 (Al-Khafaji, 2004).

$$\Delta V_p = \frac{\Delta X}{\Delta T_p} \quad (3)$$

$$\Delta V_s = \frac{\Delta X}{\Delta T_s} \quad (4)$$

Fig.3. Seismic record from study area shows P-W and S-W

The relation between velocity and depth were constructed to show the velocity-depth Graph which is very important that is the best way to get clear idea about changing velocity with depth (Alkafeel Center, 2015) or refers to the elastic moduli, density change (Figs. 4 and 5).

* From the In-Situ test, drilling information, soil profile and results of seismic wave velocities for S11, S12, S13, and S14 find as follow:
* The seismic wave velocities are calculated for these seismic cross hole profiles, (Table 1).
* Relationship between seismic wave velocities with depth for profile S11, S12 and S13 at Al-Imam Mosa Al-Kadhum Gate before grouting (Figs. 4 and 5).
* Relationship between seismic wave velocities with depth for profile S14, at Al-Imam Sahib Al-Zaman Gate before grouting (Figs. 5 and 7).
Table 1. Results of Seismic wave velocities for cross hole profiles S11, S12, S13 and S14 at Al-Imam Mossa Al-Kadhum and Sahib Al-Zaman gates before grouting.

| Depth (m) | S11 | S12 | S13 | S14 |
|-----------|-----|-----|-----|-----|
|           | Vp  | Vs  | Vp  | Vs  | Vp  | Vs  | Vp  | Vs  | Vp  | Vs  |
| 1         | 544 | 131 | 174 | 164 | -   | -   | -   | -   |
| 2         | 1667| 333.5| -   | -   | -   | -   | 3543| 472 |
| 3         | 615 | 133 | -   | -   | -   | -   | 2657| 317 |
| 4         | -   | -   | -   | -   | -   | -   | 1733| 248 |
| 5         | -   | -   | 1633| 297 | 874 | 186 | 1155| 208 |
| 6         | 800 | 182 | 1225| 245 | 1202| 214 | 1300| 221 |
| 7         | 571 | 133 | 1960| 272 | 1241| 221 | 1155| 225 |
| 8         | 1000| 210 | 1960| 272 | 855 | 180 | 1733| 274 |
| 9         | 1333| 216 | 891 | 188 | 1539| 243.5| 1733| 274 |
| 10        | 1539| 286 | 1225| 223 | 1749| 332 | 2080| 315 |
| 11        | 1600| 296 | 2450| 327 | -   | -   | 2600| 385 |
| 12        | -   | -   | -   | -   | -   | -   | 945 | 204 |
| 13        | 2667| 476 | 2450| 350 | 2405| 393 | 2600| 541 |
| 14        | 3333| 488 | 2882| 490 | 2636| 481 | 3467| 547 |

Fig. 4. Relationship between seismic wave velocities with depth for profile No. S11, S12, S13 at Al-Imam Mosa Al-Kadhum Gate before grouting. a. shear wave. b longitudinal wave.

Fig. 5. Relationship between longitudinal and shear wave velocities with depth for profile No. S14 at Al-Imam Sahib Al-Zaman Gate before grouting (-Vp, -Vs).

- The cavity and weak zone in soil underneath the foundation continued at 8m depth below the natural ground surface inside the sacred shrine 34.17 m above sea level (Table 2).
- The foundation of the wall around the sacred of Al-Abbas Holy Shrine at these two gates reaches at 5 m. depth, this fact is determined by using seismic cross hole survey for once time.
Table 2. The location of cavities and weak zones within subsoil underground the cross-hole profiles S11, S12, S13 and S14 at Al-Imam Mosa Al-Kadhum and Sahib Al-Zaman gates before grouting.

| Profile No. | B.H. No.  | Depth of cavities m. | B.H. No. | Depth of weak zones |
|-------------|------------|----------------------|----------|---------------------|
| S11         | B20        | 4-7                  | B20      | 8-9                 |
| S12         | B18, B19   | 1.5, 5, 8,9          | B19      | 6-7                 |
| S13         | B27        | 5.5                  | B27      | 6                   |
| S14         | B26        | 4.5 - 8              |          |                     |

The amount of cement material is 69.500 ton and assist of chemical material is 923 litters, this material is used to speed of lithification for mixture when the ground water find within the soil and out of it by making agile or gelatin inside the cavity, after the grouting resurvey the profiles No. S12, S13 and S14 then calculated the seismic cross-hole velocities specially shear wave and show variation with same depth station before grouting that mean calculation of variation in percent of shear wave velocity before and after grouting (Table 3, Figs. 6 and 7), the relationship between shear wave velocities with depth at Al-Imam Mosa Al-Kadhum Gate, and at Sahib Al-Zaman gates before and after grouting.

Table 3. Results of Seismic wave velocities variation for cross hole profiles S12, S13 and S14 at Al-Imam Mosa Al-Kadhum and Sahib Al-Zaman gates before and after grouting.

| Depth m. | Before grouting | After grouting | Percent of variation (%) |
|----------|-----------------|----------------|--------------------------|
|          | VS m/sec | ΔVS m/sec | VS m/sec | ΔVS m/sec | VS m/sec | ΔVS m/sec | VS m/sec | ΔVS m/sec | VS m/sec | ΔVS m/sec | VS m/sec | ΔVS m/sec |
| 1        | 131       | -         | 164       | -         | -         | 576      | 506      | -         | 77       | 67       |          |          |
| 2        | -         | -         | 472       | -         | -         |         | 540      | -         | -         | 13       |          |          |
| 3        | -         | -         | 443       | -         | -         | -        | 472      | -         | -         | -         | 6         |          |
| 4        | -         | -         | 317       | -         | -         | -        | 425      | -         | -         | -         | 25        |          |
| 4.5      | -         | -         | 248       | 147       | -         | 236      | -         | -         | -         | 27        |          |          |
| 5        | 297       | 186       | 208       | 173       | 612       | 298      | -         | 242       | 51       | 37       | -         |          |
| 5.5      | -         | -         | 204       | -         | -         | -        | -         | -         | -         | -         | -         | -         |
| 6        | 245       | 214       | 221       | 193       | 332       | 194      | 305      | -         | 24       | -         | -         |          |
| 7        | 272       | 221       | 225       | 170       | 275       | 237      | 297      | -         | 0.7      | 6         | -         |          |
| 8        | 272       | 180       | 274       | 185       | 296       | 248      | 273      | -         | 7        | 27        | -         |          |
| 9        | 188       | 243       | 274       | 229       | 175       | 349      | 305      | 212       | -         | -         | 10        | -         |
| 10       | 223       | 332       | 315       | 280       | -         | 346      | 286      | -         | -         | 9         | 2         |          |
| 11       | 327       | -         | 385       | 224       | -         | 495      | 340      | -         | -         | 22        | 34        |          |
| 12       | -         | -         | 202       | -         | -         | 664      | -         | -         | -         | 69        |          |          |
| 13       | 350       | 393       | 541       | 709       | -         | 611      | 708      | -         | -         | 11        |          |          |
| 14       | 490       | 481       | 547       | 425       | 576       | 610      | 611      | 664       | 15       | 21        | 40        | 36        |
Fig. 6. Relationship between shear wave velocities with depth for profile No. S12 at Al-Imam Mosa Al-Kadhum Gate, a. Vs and b. ΔVs before and after grouting.

Fig. 7. Relationship between shear wave velocities with depth a. for profile No. S13 at Al-Imam Mosa Al-Kadhum Gate, b. for profile No. S14 at Al-Imam Sahib Al-Zaman Gate before and after grouting.

4. Discussion

The Mossa Al-Kadhim gate is more affected by settlement than the area in Al-Abbas holy shrine plate 1. New modern fissures were found that refer to some settlements of the foundation are applying. This is because a water table in the study area rising and sometimes descending during many years ago that led to variety in the size of voids and change in porosity. Why using cross hole seismic method? And why the depth investigation reaches to 15 -17 m.? The answers to these questions are the following:

- The cross hole seismic method is the best technique used to determine the locations of cavities and weak zones within the soil underneath foundation of the building.
- The results of cross hole survey in report by (NCCL, 1992) shows that the soil from Natural Ground Surface N.G.S at 11 m. depth is weak.

4.1. Profile No. 11

V_p is 615 m/sec and V_s is 133 m/sec is very low at 4 m depth, a fracture in the foundation may be found at this depth. This profile served the area at Mussa Al-Kadhum Gate. At this Gate it is found Major crack. The volume of cracks in wall and dome at the Mussa Al-Kadhum Gate increases during a
long time that means a settlement (Figs. 4 and 5, Table 2). This profile unable to resurvey after grouting because the borehole B.H. 20 was failed.

4.2. Profile No. S12

This profile is located between profiles S11 and S13. The profile S12 consists of three boreholes, one as a source to generate the seismic wave and other two boreholes B18 and B19 as receivers of seismic wave. B18 is near the S12 and borehole B19 is farther than S12 it is located outside the sacred shrine. The seismic wave penetrates through the foundation at the depth 1 m, but it is very low because the cavities influence which increases the attenuation of wave and the waves arrival at borehole No. B19 with delay time (Figs. 4, 6 and Table 2). The seismic waves are not detected at depth of 2 to 5m, because the soil is very loose with cavities that could not generate the waves in borehole S12. At depth 9 m, there are weak zones or cavity filled with water, Vp is about 891 m/sec and Vs is about 188 m/sec because the Vs is attenuated in that depth. In depth of 8 m, Vp is about 855 m/sec and Vs is about 180 m/sec which refer to lose soil underneath the foundation at this depth.

4.3. Profile No. S13

The seismic velocity of shear wave reflects a weak zone at 6m depth, (Table 2). Within profiles S11, S12 and S13 the seismic waves are generating in one borehole. While the seismic waves are recorded for S12 at 1 m. depth the wet drop down at 4m depth that refers to cavities between 1 to 4m depth. Therefore, we cannot record the seismic waves at locations of depths 2, 3, 4, 5 and 5.5m in profile S12, and locations of 1, 2, 3 and 4m depth in profile S13 to locations of depth at 1, 2 and 5m, for profile S11, that indicates cavities beneath the surface in this zone from 1 to 5.5m (Fig. 4 and 5, Table 2).

4.4. Profile No. S14

This profile is located at Sahib Al-Zaman Gate west of the project (Fig. 4 and 7, Table 2). The depth of foundation reaches at 4.5m which indicated by the values of Vp is between 2657 to 3543 m/sec and Vs is between 317 to 472 m/sec. The cavities and weak zones are located between 4.5 to 9m in soil underneath the foundation. The foundation reaches at 5m depth, and the Vp = 607 m/sec and V\text{s} = 147 m/sec refers to cavity, and we show cracks in wall that mean a settlement. The presence of cracks in the wall is evidence that mean a settlement is continuing. The soil is changeable at 13m depth which recognized by Vp becomes (3037 m/sec. The Vp is 924 m/sec Vs is 202 m/sec which indicated the soil at this depth is low velocity layer LVL. (Fig. 2, 3 and 4, Table 2).

5. Conclusions

After the grouting the percent variation of shear wave, velocity ranges from 0.7 to 77% that means the grouting is affective to fill cavities underground surface at Al-Imam Mossa Al-Kadhum and Al-Imam Sahib Al-Zaman Gates. The station 6m depth at S12 shows the shear wave velocity ΔV\text{s} is 214 m/sec and 194 m/sec before and after grouting respectively. These two values mean that the grouting process was not affective or not apply for this depth.

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