Operation of Geophysical and Geotechnical Investigation to Verify the Deterioration of Buildings on Gypseous Soils

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ABSTRACT

Building No. 12- Internal Dormitories for Women at Tikrit University are two stories, constructed as bearing wall system. After a period of operation, several aggressive cracks have been found in the superstructure due to excessive foundation settlement. To detect the main causes led to these problems and damaged in this building,a Geophysical and Geotechnical investigation are carried out. The scope of this investigation included a review of the available data pertinent to the building construction and the problems in the foundation that cause aggressive cracks. Conduct a subsurface investigation that consists of drilling, securing representative samples and field Standard Penetration Tests (SPT). Collecting disturbed and undisturbed soil samples for visual examination and for carrying out basic laboratory testing of select soils, including chemical analyses of soil samples. Investigate the cavities and weak zones underneath the foundation of the building and nearby the building using seismic surface survey and cross-hole test, and Perform a geotechnical engineering analysis using the information obtained from the available investigation and laboratory testing.

Keywords: Geotechnical Investigation, Geophysical Investigation, Cross-hole test, Seismic tests, Seismic Refraction test.

1. INTRODUCTION

In the last decade, the involvement of geophysics and geotechnical methods in civil engineering has become a promising approach [1] and [2].

This investigation will be useful in determining the nature and engineering properties of the proposed site for proper foundation design for the proposed structure [3].

The geophysical investigation is to detect cavities and weak zones underneath foundations and sub-soil conditions of using seismic refraction and cross-hole tests [4].

Geotechnical site investigation is the process of collecting information and evaluating the conditions of the site for the purpose of designing and constructing the foundation for structures, such as buildings, plants or bridges. Various geotechnical parameters are today determined by site- and laboratory investigations. Site investigations require resources such as drilling rigs and mechanical equipment. They are normally penetrating in selected points. The site investigations yield point information and no information about variations in between the different investigation points is given [5].

2. THEORY OF SEISMIC METHODS

The theory of seismic method is based on the fact that the velocity at which seismic wave travels through materials such as soil and rock, varies with the elastic properties of the material [6]. Measurements are made by generating a seismic disturbance at some points on the surface ground and measuring the required time for the disturbance to travel from the source to one or more seismic sensors. The theory of elasticity states that in the interior of a homogenous elastic body [7], two types of seismic waves are propagated. The first type is a compressional wave in which particle moves in the direction of propagation. Hence the stresses in the wave are due to constrained uniaxial compression. The second type of wave is a shear one in which the particle motion is at a right angle to the direction of wave motion. During the passage of a shear wave, the motion is subjected to shearing stress. The velocities of compressional and shear (Vp and Vs) waves are related to the elastic constants through the following equations [8].

$$V_p = [(B + 4/3G)/\rho]^{1/2} \qquad (1)$$

$$V_s = [(G/\rho)]^{1/2} \qquad (2)$$

$$\mu = \frac{1/2(V_P/V_S)^2 - 1}{(V_P/V_S)^2 - 1} \qquad (3)$$

$$Ed = 2G(1 + \mu) \qquad (4)$$

$$G = \rho {V_S}^2 \qquad (5)$$

Where:
B = Bulk modulus (incompressibility), G = Shear modulus or (rigidity), ρ= Density, μ= Poisson’s ratio, Ed = young’s modulus

3. DESCRIPTION AND LOCATION OF BUILDING NO.12

Building No.12 is one of (17 buildings) is located in Salah El Deen Governorate at the North of Tikrit city, inside the campus of Tikrit University. Fig.1. Shows The Projection Image Origin from Google Earth .These buildings are two stories and constructed as bearing wall system .After a period of construction, the southwest part of building No. 12 shows cracks.
So, to diagnose the zone of weak soil or cavities, the situation demand a Geophysical investigation (seismic refraction and cross – hole tests) beside Geotechnical investigations [9].

FIGURE 1. Image Origin from Google Earth

4. METHODOLOGY

4.1 GEOPHYSICAL INVESTIGATION

In this study, three surface seismic profiles were executed on this site (P/1, P/2, and P/3) with lengths 33m as shown in Fig.2 and plate 1a.
ABEM Terraloc 24 channel, seismograph was used in this investigation, (plate 1c), the seismic energy was generated by hammer 25 Kg weight, (Plate 1c). Stacking technique was used up to 20, to increase the signal to noise ratio. The data were recorded on magnetic cassette and played pack on hard copy for processing the result plus – minus method was used in the interpretation to calculate the compressional wave velocity. The total No. of tests is (108) from ordinary and reverse and midway shooting.

PLATE 1. (a) Photo showing seismic field work (b) Hammer 25Kg weight (c) ABEM terraloc 24 channel seismograph

Five seismic cross-hole profiles were executed (S/1, S/2, S/3, S/4, and S/5) down to 10m depth underneath the foundation of building No.12.

Two boreholes (BH. No.1 and BH.No.2) were drilled down to 10m depth for collecting geotechnical samples and encased by plastic pipes with (3 inches) diameter for using as wave receiver boreholes. Three boreholes with 100mm diameter were advanced, and the S.P.T hammer was used to generate the elastic waves, Plate (2a). The measurements were taken using a probe (consists of three geophones, two horizontal, and one vertical), which get down on casing holes, Plate (2b). The results were printed on the seismic record using (Terraloc ABEM). The total No. of the test is 100.

PLATE 2. (a) cross-hole field work and (b) the measurement problem

4.2 GEOTECHNICAL INVESTIGATION

The field investigation to determine the engineering characteristics of the subsurface materials included a Drilling of borings, and performing standard penetration tests (SPT), [10].

The drilling consisted of two test borings, the diameter of these boreholes was 100mm, and the depth was 10m. The drilling was carried using a truck-mounted drill rig with continuous flight augers and rotary drilling. The method of drilling was carried out according to (ASTM D1452 & D5783). Fig .2: Site plan showing surface and cross-hole seismic profiles, and boreholes locations

Undisturbed soil samples (U) were obtained in general accordance with ASTM D-1587, but the disturbed soil samples (D) were obtained in general accordance with ASTM D-1586 at each 1.0m intervals .

During the sampling procedures, the standard penetration tests were performed in the borings in conjunction with the split-barrel sampling, (SS). The standard penetration value (N) is defined as the number of blows of a 63.5 kg hammer, falling 0.76m, required to advance the split-spoon sampler 150mm into the soil (ASTM D-1585).

Water level observations were made after two days of the boring, and the results are noted in the boring logs. Seasonal variations, temperature, and recent rainfall conditions may influence the levels of the ground water table, and volumes of water will depend on the permeability of the soils.

4.3 LABORATORY TESTING

Before laboratory testing, all samples were visually examined for initial classification. The test program was decided by the soil engineer. The actual test proposed for a particular sample depends on the type of sample (U & D) and the nature of its material .A full list of a laboratory testing conducted for this project is Classification Tests, Engineering Tests and Chemical Tests for Soil

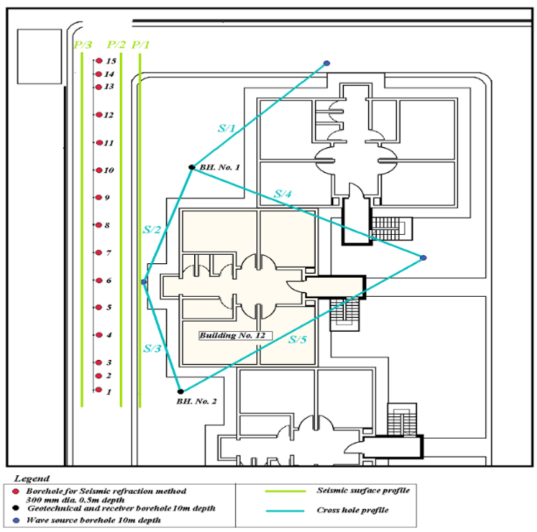

FIGURE 2. Site plan showing surface and cross-hole seismic profiles, and boreholes locations

5. RESULTS AND DISCUSSION

5.1 SURFACE SEISMIC REFRACTION

From the seismograph record of the three surface seismic refraction profiles, the first arrival time of compressional wave was determined as shown in the table (1). From these results two layers of soil were distinguished; Top layer, the compressional wave velocity in the range (328 - 450) m/sec. The depth of first contact ranges (1.44 – 8.12) m.The second layer, the compressional velocity is in the range (1090 - 1967) m/sec.

TABLE 1.
Summary results of surface profiles, (P/1, P/2, and P/3)

Pro file No.	Length m	V_1 m/sec	V_2 m/sec	Depth of contact
P/1	33	328	1090	1.44-2.15
P/2	33	343	1200	2.88-8.12
P/3	33	450	1967	1.44-5.85

5.2 SEISMIC CROSS-HOLE TEST

From the seismograph record of the cross-hole profiles, the first arrival time of compressional and shear waves were determined. The velocities of shear wave VS & compressional wave VP for each depth were calculated and listed in Tables 2.

TABLE 2.
Measured Compressional and Shear Wave Velocities

Depth (m)	S/1 (Receiver = B.H. No.1 X =14.3m)		S/2 (Receiver = B.H. No.1 X =13.0m)		S/3 (Receiver = B.H. No.2 X =15.5m)		S/4(Receiver = B.H. No.1 X =18.5m)		S/5 (Receiver = B.H. No.2 X =22.0m)	
	V_P (m/sec)	V_S (m/sec)	V_P (m/sec)	V_S (m/sec)	V_P (m/sec)	V_S (m/sec)	V_P (m/sec)	V_S (m/sec)	V_P (m/sec)	V_S (m/sec)
1.0	794	230								
2.0			812	209	815	272	685	160	1570	282
2.5	893	216								
3			928	302	1107	310	740	168	1466	301
3.5	1300	310								
4			684	250			486	148	1100	354
5.0	893	234	650	154	1290	352	1088	246	1466	440
6.0	1430	433			1722	484				
6.5							925	210	2200	523
7.0	1787	550	1857	540	1550	516				
8							1540	324	2200	550
8.5	2380	621	2166	650	3100	704				
9							1680	350	3140	687
10.0	2860	790	2166	764	2580	704				

5.3 GEOTECHNICAL INVESTIGATION

Soil Profile

According to the Unified Soil Classification System (USCS), the subsoil profile for the two boreholes can be summarized as follows :

a. The top layer can be classified as light brown to gray highly to moderately gypseous Silty Sand, poorly graded, sand-silt mixtures (SM). In this layer, an amount of debris has been diagnosed visually and from laboratory results. This layer can be considered as a full material layer. The thickness of this layer extends to a depth of 4.0m on borehole No. 2 and 6.0m in borehole No. 1 .

b. The main soil of the second layer is gravel where:
   - A gray slightly gypseous poorly graded gravel, the gravel-sand-silt mixture (GM), this layer extends from the above layer to depth of 8m in Borehole No. 2 and depth of 10m in borehole No. 1.
   - Dark gray slightly gypseous poorly graded gravel – sand mixture with little or no fines was found at a depth of 8.0 and extended to the end of boring .

Details of soil stratification for the boreholes are shown in the “Borehole logs,” and the soil profiles are shown in Fig. 3. Note that in these figures the soil stratification was started from the E.G.L (existing ground level) .

The lines designating the interface between soil strata on the boring logs represent approximate boundaries; the transition between materials may be gradual.

Underground Water Level

Groundwater was not encountered during the drilling.

Strength of the Soil

In this site and for the cohesionless soil layer the number of blows of standard penetration tests indicates that the relative density of the cohesionless soil layer is a loss, for the soil from existing ground level to a depth of 4-6m. After this, the relative density of the soil increased and the layer became dense at a depth of 10m .

Atterberg limits Test Results

The values of liquid limit (L.L.) and plasticity index (P.I.) at different depths are shown in the “Record of test result sheets."

Chemical Properties

The results of the chemical tests for soil samples are shown in the "Record of test result sheets."

- The pH value varies from (8.21) to (8.35)
- The total soluble salts (T.S.S %) vary from (8.10) to (30.10)%
- The organic matter (ORG. %) varies from (0.75) to (2.65)%

Collapsibility and Compressibility Test Results

The collapsibility tests were conducted on undisturbed samples by using consolidation apparatus. A procedure for determining the collapse potential of soil was suggested by Jennings and Knight (1975). The procedure is as follows:

A sample of an undisturbed soil is cut and fit into a consolidometer ring and loads are applied progressively until about 100 kPa is reached.

The sample was left until equilibrium was maintained under this load. At this pressure, the specimen is flooded with water for saturation and left for 24 hours. Then test continued to the specified maximum pressure of (400 kPa). The resulting e-log p curve plotted from the data. The results of the tests were tabulated in Table 3 below. Jennings and Knight have suggested some values for collapse potential as shown in Table 4. These values are only qualitative to indicate the severity of the problem.

According to the results shown in Table 3, the soil can be classified as Trouble soil at the top layers and Moderate Trouble for next layers.
The compressibility test was also conducted on undisturbed samples, the results of the compression index c_c where shown in Table 3.

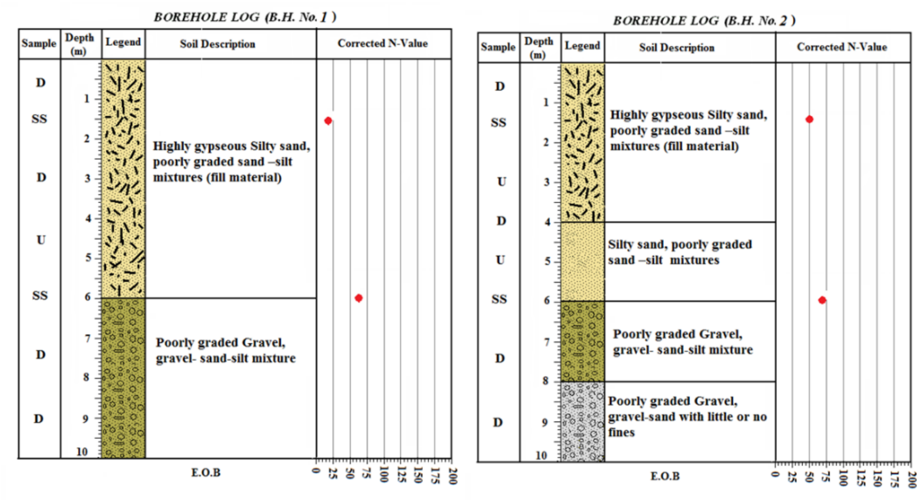

FIGURE 3. Borehole log for BH. No. (1) and No. (2)

TABLE 3.
Results of collapsibility and compressibility tests

Borehole No.	Depth (m)	C_P value %	c_c value
1	3.0	7.63	0.544
2	3.0	6.48	0.694
2	4.5	1.31	0.321

TABLE 4.
Collapse potential values

Collapse potential C_p %	Severity of problem
0-1	No problem
1-5	Moderate trouble
3-10	Trouble
10-20	Sever trouble
> 20	Very sever trouble

6. ANALYSIS OF THE RESULTS

Based on the Geophysical and Geotechnical investigation the following conclusions can be sited:

From the surface seismic refraction survey, it can be concluded that:

a. There is a notable velocity difference for the second layer among the three executed profiles (P/1, P/2 &P/3), (1090 to 1967) m/sec, though the distance between them is little as demonstrated in Table (1).
b. There is a notable depth difference for the interface between the first and second soil layers for the executed profiles (P/1, P/2 &P/3), though the distance among them is little as demonstrated in Table (2), and it is expected that the delay times for Geophones (9 &10) for P/1 and P/3 are the edge of the filled valley at depths (2.15m for P/1) and (5.85m,3.41m respectively for P/3) as shown in figure 4.a and 4.b
c. From above, it can be concluded that the low-velocity values represent a filling material, whereas the high-velocity values represent the original soil layers in this site.

From the cross-hole seismic test, it can be concluded that:

a. There is a weak zone detected at depth (5 m) along with profile S/2 as shown in Table (2).
b. There is a weak zone detected at depth (2 to 4) m along profile S/4 as shown in Table (2).

From the preceding conclusion mentioned above, it can be stated that the foundation of the building was constructed on a layer located at the edge of the filled valley.

The results of the laboratory tests on the samples excavated from the boreholes No. 1 and No.2 confirm the above conclusions

Also reviewing the projection image from Google Earth (Figure 1) taken in 2005 shows a valley lies under the building No. 12 and No.11 and underneath the road behind these buildings. This valley may be burying with loss gypseous soils without any treatment or engineering control in some time before the construction of the Internal Dormitories buildings.

The construction of mat foundation under the south part of Building No. 12 as a rehabilitation method was not workable since the building continue to settle because the layer underneath was compressible soil due to the weight of this foundation.

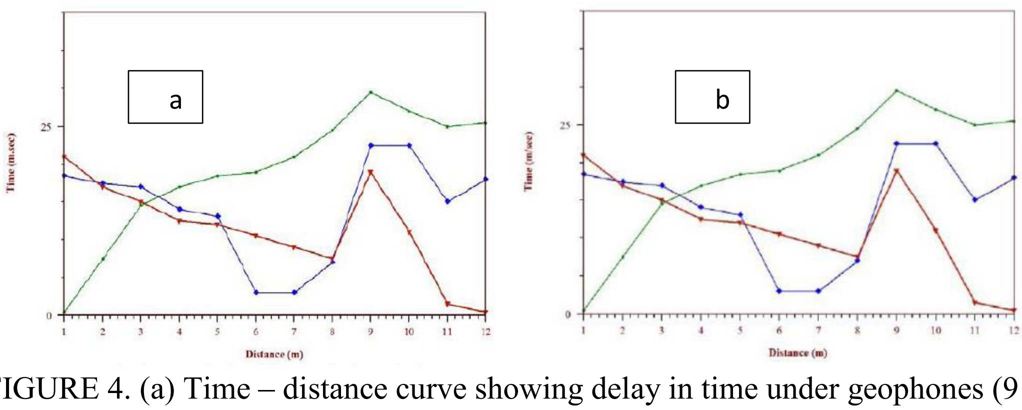

FIGURE 4. (a) Time – distance curve showing delay in time under geophones (9 & 10) for a) P/1 which may represent valley edge for (b) P/3 which may represent valley edge

TABLE 5.
Borehole: No.1
Recorded Of Test Results

ENGINEERING CONSULTING BUREAU
Engineering College – University of Tikrit

Project : Internal Dormitories for Women
Building No. 12

Borehole :No.1
RECORDED OF TEST RESULTS

Field No.	Depth of Sampling (m)		Type	Particle size distribution and hydrometer analysis % pass. by wt. (M.I.T. Classification)				M.C %	Index properties		SPT "N" value/15			Symbol (USCS)	Description of Soil (USCS)	Chemical Tests			
	From m	To m		Gravel	Sand	Silt	Clay		L.L. %	P.I. %						*pH*	*Org* %	*T.S.S* %	*Gyps.* %
1.1	0	2.0	SS	3	87	8	2	6.7	N.P	N.P				SM	Highly gypseous Silty sand, poorly graded sand –silt mixtures (fill material)	8.43	1.56	30.1	27.4
1.2	2.0	4.0	D	4	81	10	5	14.8	N.P	N.P	12	11	13	SM		8.51	1.25	26.3	24.7
1.3	4.0	6.0	D	12	73	9	5	18.0	32.0	13.0				SM		8.42	1.41	21.4	18.5
1.4	6.0	8.0	SS	65	29	4	2	13.8	20.1	3.9	15	50/8	-	GP-GM	Poorly graded Gravel, gravel-sand silt mixture	8.40	1.38	15.0	12.6
1.5	8.0	10.0	D	65	27	5	3	12.5	19.8	N.P				GP-GM		8.21	0.75	10.7	8.6

Water Table was not observed during (March 2011)

TABLE 5.
Borehole: No.2
Recorded Of Test Results

ENGINEERING CONSULTING BUREAU
Engineering College – University of Tikrit

Project : Internal Dormitories for Women
Building No. 12

Borehole :No.2
RECORDED OF TEST RESULTS

Field No.	Depth of Sampling (m)		Type	Particle size distribution and hydrometer analysis % pass. by wt. (M.I.T. Classification)				M.C %	Index properties		SPT "N" value/15			Symbol (USCS)	Description of Soil (USCS)	Chemical Tests			
	From m	To m		Gravel	Sand	Silt	Clay		L.L. %	P.I. %						*pH*	*Org* %	*T.S.S* %	*Gyps.* %
1.1	0	2.0	SS	23	67	7	3	17.4	N.P	N.P	15	45	50/9	SM	Highly gypseous Silty sand, poorly graded sand –silt mixtures (fill material)	8.53	1.65	26.3	23.6
1.2	2.0	4.0	D	26	62	8	4	21.5	N.P	N.P				SM		8.50	1.2	18.9	16.7
1.3	4.0	6.0	D	1	77	16	6	24.6	24.2	5.0	50/8			SM	Silty sand, poorly graded sand –silt mixtures	8.44	1.04	11.0	8.6
1.4	6.0	8.0	SS	58	37	3	2	13.8	20.1	2.7				GP-GM	Poorly graded Gravel, gravel-sand-silt mixture	8.21	1.13	8.3	5.9
1.5	8.0	10.0	D	69	29	2	-	11.3	N.P	N.P				GP	Poorly graded Gravel, gravel-sand with little or no fines	8.24	0.95	8.1	5.2

Water Table was not observed during (March 2011)

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