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Seismic Classification of Selected Sites Base on Dynamical and Geotechnical Properties for Karbala City, Iraq

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Abstract

Iraq is located near the northern end of the Arabian plate, Which goes north relative to the Iranian plate, is expected to be an active tectonic country. During the past decade, seismic activity in Iraq has been observed to increase. Earthquakes are one of the disasters that cannot be accurately predicted with time, size, location, and intensity despite progress in seismic prediction. With the current state of scientific knowledge, it is difficult to predict when an earthquake will occur, although potential areas and expected magnitude are known based on seismic maps. Geotechnical earthquake engineering problems in civil engineering require characterization of dynamic soil properties using geophysical methods. The main objective of this study is to determine a data for the geotechnical and dynamical properties of different soil sites in Karbala City in Iraq using the results of drilling and seismic refraction survey method, and the seismic classification of those sites. From the collected results , it was observed that the shear wave velocities (Vs) were ranged from (300-420) m/s in the site of K.S.1, (280-450) m/s, in the site of K.S.2, respectively .While (450-540) m/s in the site of K.S.3. Karbala site soils are classified according to different seismic codes basing on Vs,30 value are : the site soils are classified as types (D and C) , according to the PISC and FEMA, while according to Eurocode 8 : (C and B) .

Keywords: *Seismic site classification, Dynamic parameters, Shear wave velocity, Seismicity map, Karbala city.*

1-Introduction

Geological engineer perform geotechnical examinations to obtain information's about the geodynamic parameters of underlying soil and rocks to design foundations for any proposed structures. A geotechnical examination will incorporate surface investigation and subsurface investigation of a location side by side to the geophysical strategies.
Geophysical strategies are too utilized for subsurface examinations, as well the estimation of seismic waves (compressional, shear, and Rayleigh waves), surface-wave strategies and cross-hole or down-hole strategies etc. (Craig 2004).

Nowadays, during designing of vital structures such as power plants, towers, dams, subway and foundations for diverse purposes, performing geotechnical and dynamic examinations are basic to control the stabilization of structures.

Currently the most common economic dynamic test utilized in-situ test is the standard penetration test SPT, which used to decide the soil resistance and the geotechnical parameters, In addition to taking samples for laboratory analysis.

Investigations can incorporate the evaluation of the risks to people, property and the environment from natural hazards such as landslides, sinkholes, earthquakes, debris flows, liquefaction and rock falls (Smith 1998). The geotechnical engineer and engineering geologist then join forces to determine and design the type of foundations,

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earthworks, and pavement subgrades required for the intended man-made structures to be built. (Das 2008), (Rao 2011).

A geotechnical geophysics survey using the surface non- invasive geophysical methods can provide reliable information about the nature and variability of the subsurface between existing boreholes which allow the geotechnical data to be extrapolated over wider areas and enable engineers to reduce the number of required boreholes since the drilling process is very costly or may not be possible in some locations . Therefore, it is a prerequisite for the successful and economic design of engineering structures and earthworks (Hunt, 2005; Das, 2006).

The engineering properties of the different strata of numerous geophysical and soil investigation reports for ventures in Iraq, and the parameters are assessed from field and research facility tests comes about of the accessible geophysical and geotechnical examination reports collected from diverse engineering resources. Dynamic soil characteristics may be recognized from a diverse domain and / or laboratory examinations, They can moreover be assessed utilizing reasonable observational relationships set up from prior standard field and research facility examinations carried on a specific sort of soil (Al-Khafaji, 2010).

Earthquakes are among the foremost dangerous normal catastrophes influencing urban populaces. Auxiliary harm caused by the seismic tremors shifts depending not as it were on the seismic source and proliferation properties but moreover on the soil properties. (Şisman, 2013).

Field tests used to evaluate the soil dynamic has many advantages, usually this type of tests do not need sampling, which can cause a changes in stress and structure condition of the sample. moreover, these tests measuring the response of relatively huge volume of soil. these tests classified according to the strain magnitude as low-strain and high-strain, Low-strain tests are based on the theory of wave spreading in the materials . Some of the low-strain field tests are seismic reflection test. seismic refraction test, suspension logging test, steady-state vibration or Rayleigh wave test, spectral analysis of surface wave test (SASW) (Sitharam et al., 2004). the previous studies confirming this research are:

Al-Khafaji, A., J (2010) Geophysical and Geotechnical Investigations of Soil Underneath the Foundation of Al-Abbas Holy Shrine Site in Karbala`a Governorate". He found presence cavities and weak zones within the soil by using GPR, boring methods and the cross hole. The elastic moduli of soil and geotechnical index of Underneath layers were estimated by using the velocities of seismic waves (Vp and Vs).

Al-Bahrani, (2013) Examined application of designing geophysical overview utilizing Standard Penetration test for Geotechnical Purposes in Baiji Gasification Plant. He taken note that the normal shear wave speed within the upper 30m (Vs,30) is computed specifically from experimental connection with SPT and the coming about speed (332-410m/sc) is utilized in soil classification concurring to European Standard (EC8) that drop inside categorize (B).

Shafiqu, and Sa'ur, (2016). Concluded from the data base collected it has been observed that the average vertical shear wave velocities were ranged from (225-476) m/s in the North, (111-408) m/s in the Middle, (268-659) m/s in the western south, (131-380)m/s in the eastern south and (102-365) m/s in the South of Iraq.

2. Study Area

The study area lie nearly about 100-120 km south and southwest of Baghdad governorate, which is located in the middle of Iraq in Karbala governorate. The elevation of Karbala city is about 40 m above the sea level. The study area is as shown in Figure (1).

3-Aims of study

The main objective of this study is to determine a data for the geotechnical and dynamical properties of different soil sites in Karbala City in Iraq using the results of drilling and seismic refraction survey method, and the seismic classification of those sites .

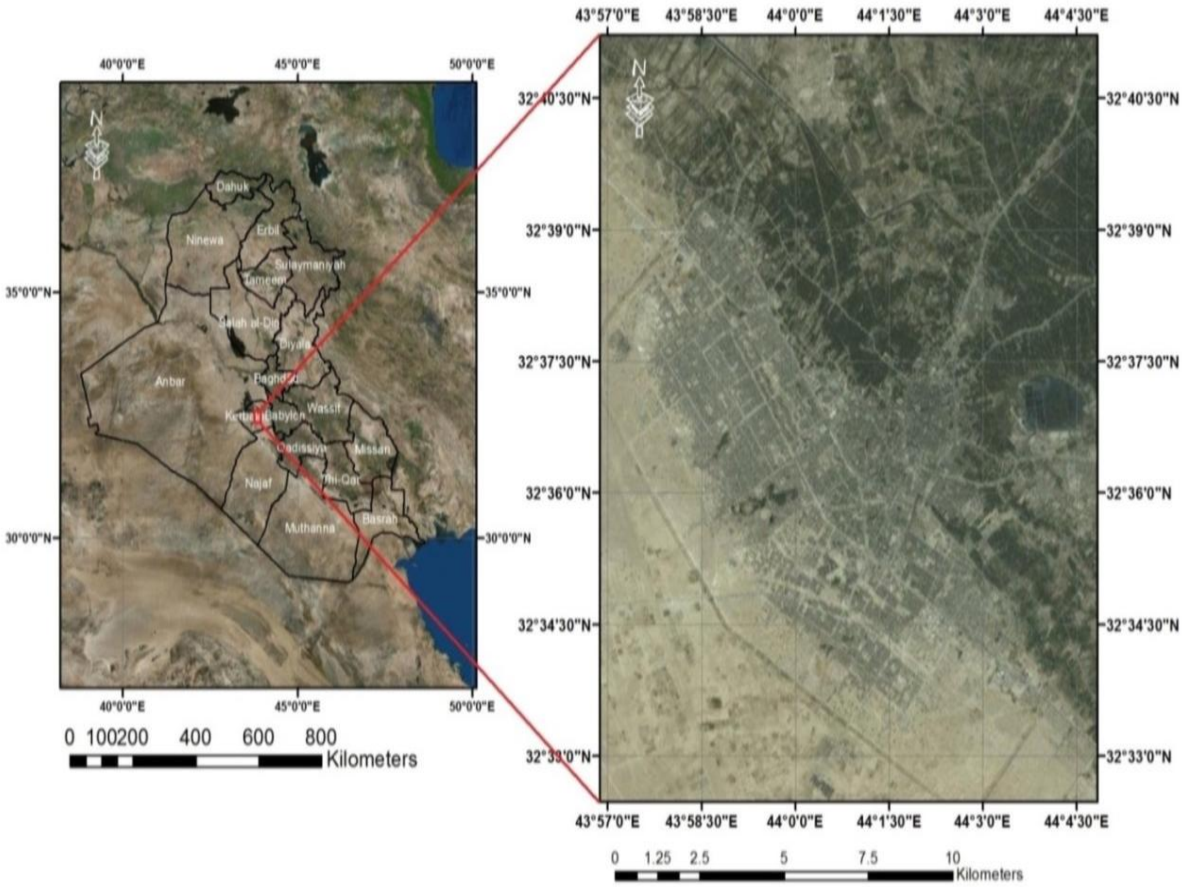

Figure 1: Location map of the project area

4- Geology of study area

In general, the exposed units in Karbala governorate are: Injana Formation (Upper Miocene) , Dibdibba Formation (Pliocene - Pleistocene),Quaternary deposits. According to the sites chosen, they were in the Quaternary deposits area. These deposits cover most of the study area, and can be described as follows: Aeolian deposits, Wadi Fill Sediments (Al-Khateeb & Hassan ,2005). And Colluvial sediments (Lateef & Barwary 1984). Figure 2 illustrate geological map of the study area.

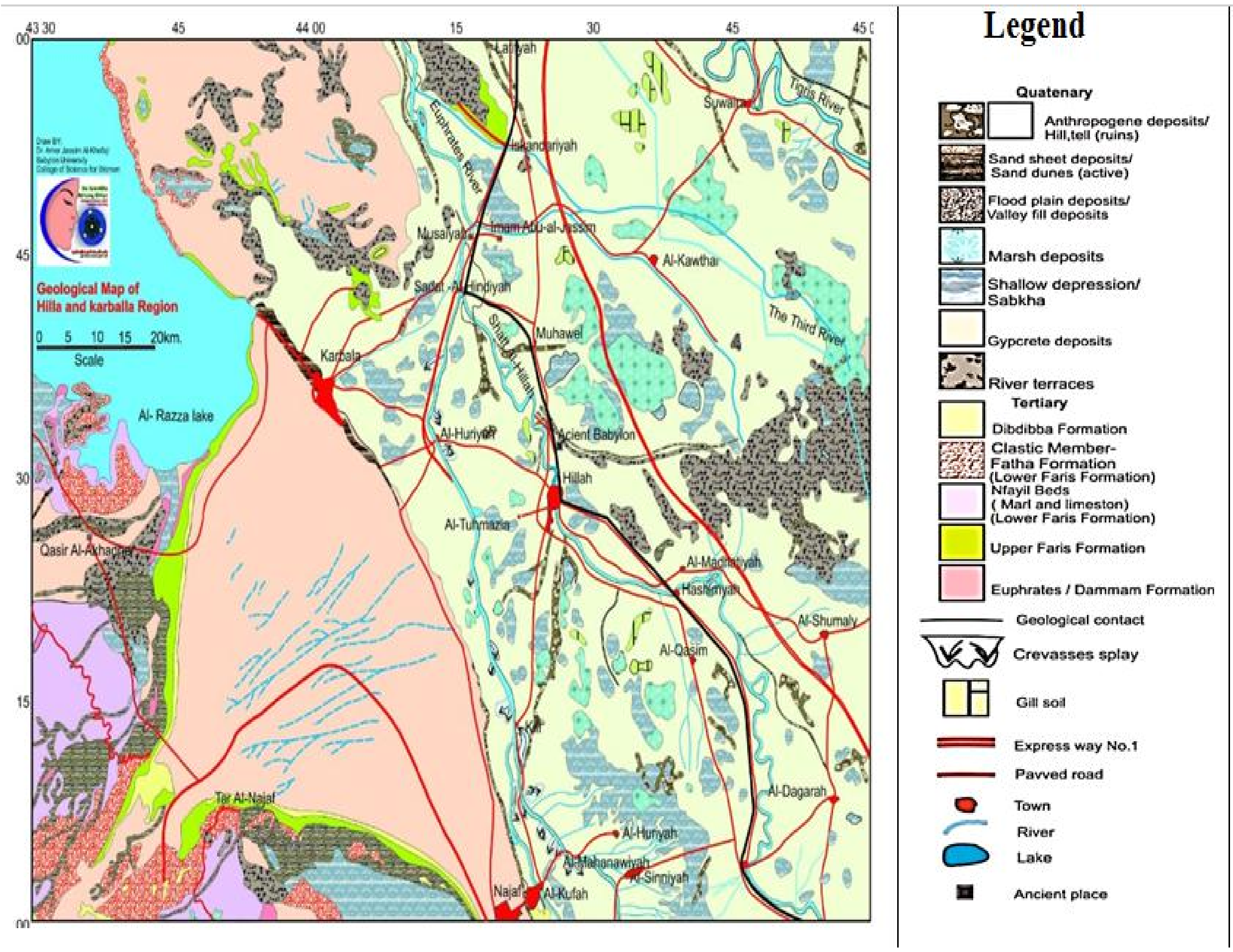

Fig. 2:A geological map of the study area (Al-Ameri and Al-Khafaji ,2014).

5- Tectonic of the study area:

According to the tectonic map of Buday (1973) and the tectonic position of the study area (Karbala city) is located nearly the bounder between the Unstable shelf represented by Mesopotamia Zone and flood plain and the Stable shelf represented by the western desert region, at the Unstable Shelf within Euphrates subzone as showing in (Figure 3). The direction of Abu Jir Fault is N-S which separates the Stable and Unstable shelves(Al-Mashhdani ,1984).

The surface structure of the area, If you look well in the area near the Abu Jir Fault Zone where most of the depressions and ridges are distributed along this fault developed by its effect.

Hassan and Al-Khateeb (2004) , described the surface structural features for Abu Jir Fault as following, the presence of a numerous Salifurous , Gaseous and Water seepages indicates fault area . By field observation the strata are horizontal to sub- horizontal (Hassan and Al-Khateeb , 2004).

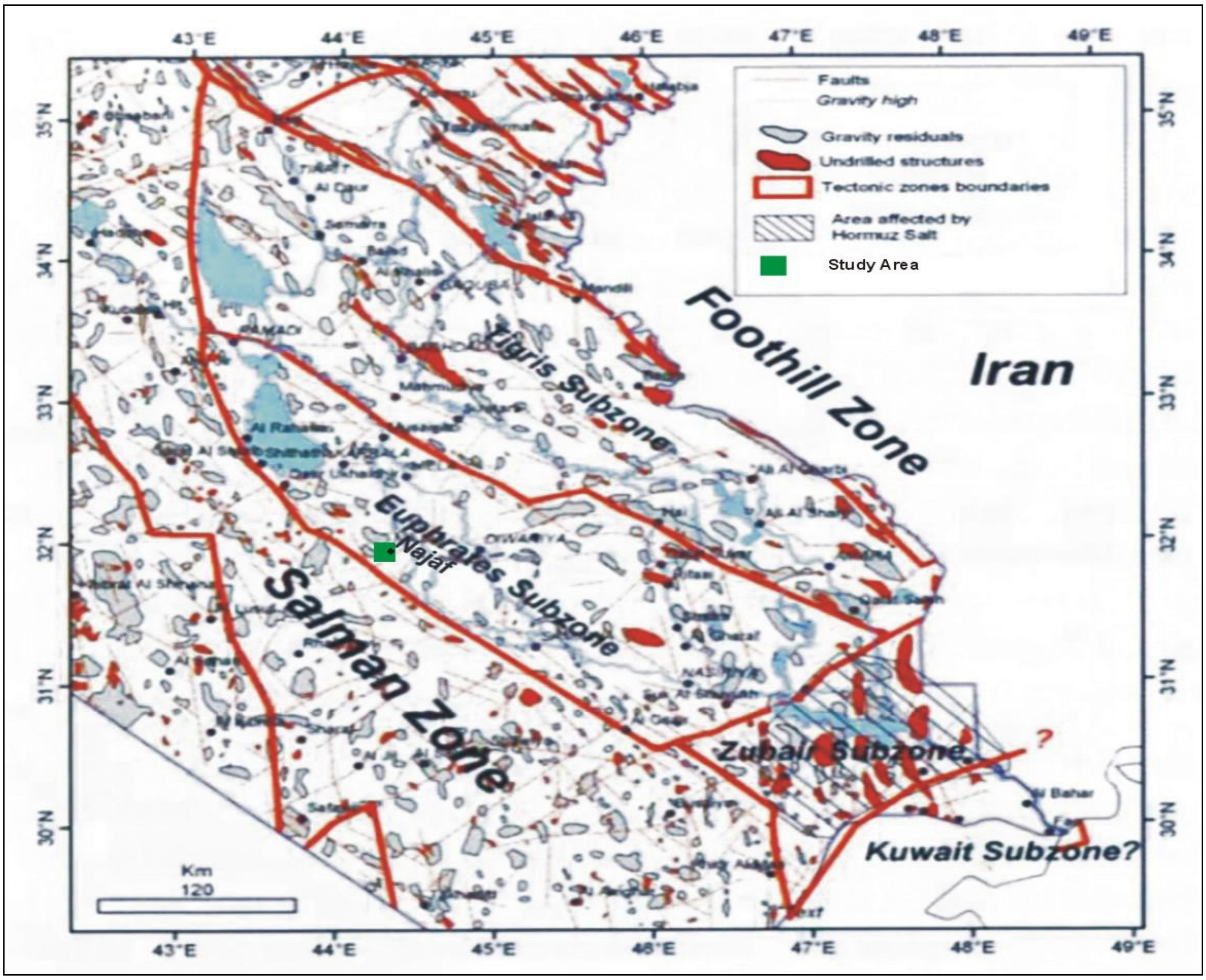

Figure 3: Location of the study area on the tectonic map (after Jassim and Goff , 2006).

6-Seismicity of the Study Area

Iraq is located near the northern tip of the Arabian plate, which is advancing northwards relative to the Eurasian plate, and is predictably, a tectonically active country. The northern zone depicts the highest seismic activity in the country, where the central and southern part of Iraq are characterized by moderate to low seismic activity. Seismic activity in Iraq increased significantly during the last decade. So structural and geotechnical engineers have been giving increasing attention to the design of buildings for earthquake resistance. The Iraq region, although not directly located in a dense group of recent earthquake epicenters, but the geodynamic formations show moderate to high seismic hazards. This will be associated with the increasing vulnerability of major cities with a high population density. Seismic research, seismic monitoring and seismic awareness have seen better times in the past two decades (Alsinawi and Al-Qasrani , 2003). Figure 4. Seismicity map of Iraq .

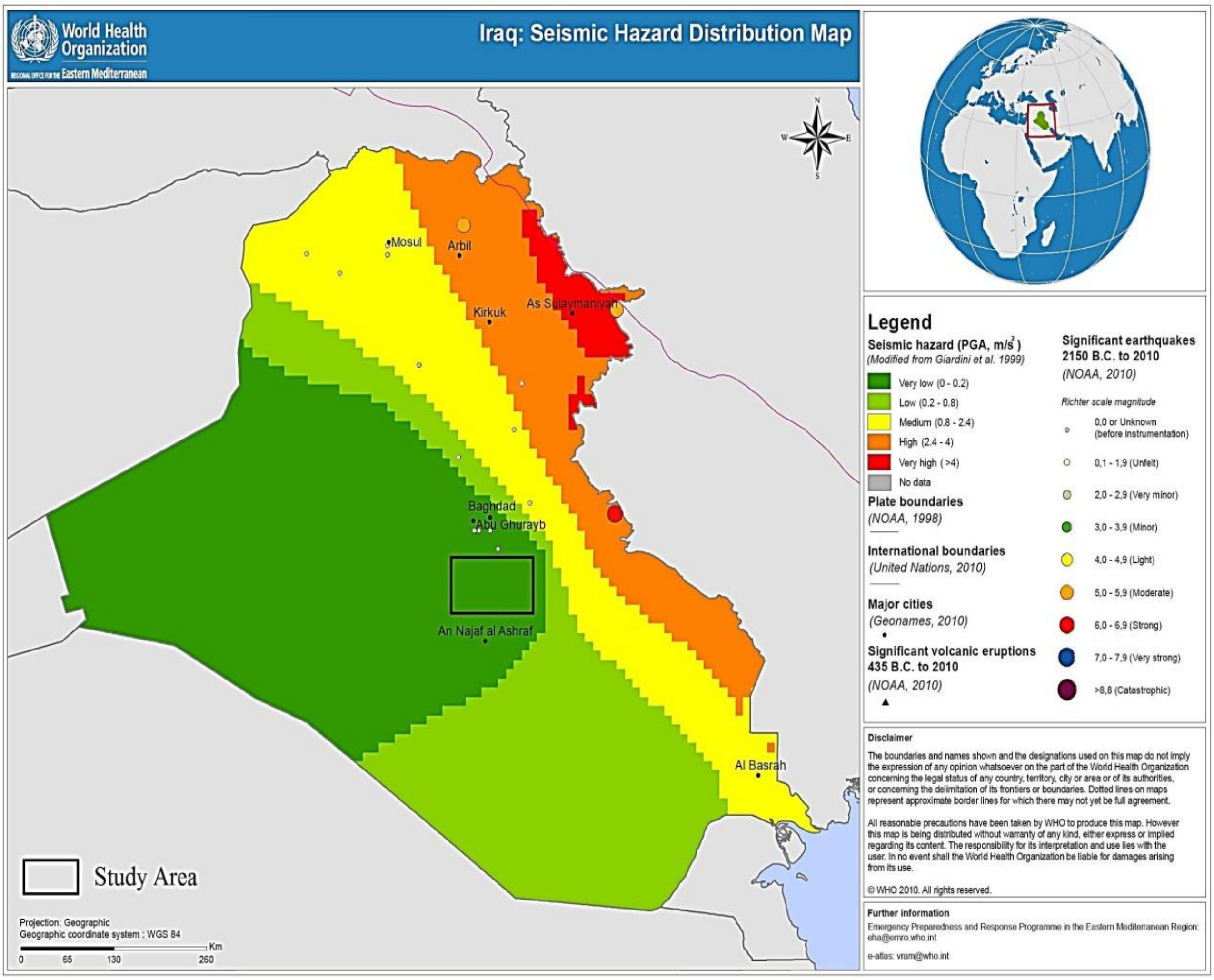

Figure 4: Seismicity map of Iraq (WHO, 2010).

7-Methodology

The research methodology includes three stages of work:

I. Data collection stage

All of the available publications about the study area (journals, papers, theses, and reports)**,** maps, including seismic, geologic maps and satellite images and studied in order to make a better idea about the study area.

The engineering properties of the various layers of many site investigation reports for projects in Karbala city, and the parameters are evaluated from field and laboratory tests results of the available geotechnical investigation reports collected from different engineering resource about soil investigation reports were collected from various public and private organizations such as Andrea Engineering test Labs, National Center for Construction Laboratories (NCCL), Scientific and Engineering Consultancy Bureau - University of Technology. The available geotechnical reports were collected from different three projects like Karbala Telecommunications Building , Karbala Justicial Planning Offices, Karbala Sewage Treatment Plant, as shown in Table (1).

Table 1: The projects in some locations of Karbala city and symbols.

No.	Site	Project	Site symbol
1	Karbala	Karbala Telecommunications Building	K.S.1

2	Karbala	Karbala Justicial Planning Offices	K.S.2
3	Karbala	Karbala Sewage Treatment Plant	K.S.3

II. Laboratory and field geotechnical tests stage

The important laboratory tests that can be accomplished in this research are as shown in the Table 2.

Table 2: Show test types and Specifications that were conducted in the research.

No.	Test Types	Specifications
1	Soil classification	ASTM D 422-36 , (1998)
2	Direct shear test	ASTM D 3080 / D3080M-98.
3	Unconfined compression test	ASTM D 2166-00.
4	Unconsolidated undrained triaxial compression test (UU test)	ASTM D 2850-95
5	Consolidated undrained triaxial compression test (CU test)	ASTM D4767-04
6	Field density (Core Cutter Test)	BS 1377:1999

III. Field work stage

Field work was carried out in a gradual geophysical investigation of the sites:

1- Measurement of seismic waves (Vp and Vs)

The seismic waves (Vp and Vs)were determined by seismic refraction survey method. The purpose of the seismic refraction survey is to evaluate the velocities of seismic waves (Vp and Vs) for subsoil layers for locations chosen for this study. This was done using ABEM Terraloc Mark 6, (2009) device. This device represents a high analytical capacity of seismic recorders in shallow depth and consists of separately two units. Plate (1a,b) shows seismic waves (Vp and Vs)were determined by seismic refraction survey method.

Plate (1. a,b) Shows (Vp and Vs) refraction field work for study site.

8. Soil Parameters

The soil parameters investigated for most Karbala soil are evaluated and collected from different resources as mentioned before. Geotechnical reports had soil properties like: c, ϕ ,γ_{wet}, γ_{dry} that were evaluated by laboratory or field tests, as these reports had different well records describing soil types and giving depth of the level groundwater. From the geophysical investigation with V_s, V_p , which was done using the ABEM Terraloc Mark 6, (2009). . These parameters with their standard units are listed in Table 3 below

Table 3: Soil Parameters Investigated for Karbala Soils

Geotechnical investigation	Units	Geophysics investigation	Units
γ_{wet} :wet unit weight	KN/m^3	Vs: Shear wave velocity	m/sec
γ_{dry} :dry unit weight	KN/m^3	Vp :Compression wave velocity:	m/sec
γ_{sat} :Saturated unit weight	KN/m^3	E_d: Dynamic modulus of elasticity	KN/m^2
C: Cohesion	KN/m^2	G_d: Dynamic shear modulus	KN/m^2
ϕ: Friction angle	Degree	ν: Poisson's ratio	{-}

8.1. Calculation for the dynamic parameters

Dynamic parameters such as; Vs and Vp are evaluated by geophysical investigations that been done using ABEM Terraloc Mark 6, (2009) device, while other parameters like; *E*, *G* and *υ* are calculated by mathematical equations relationships

$$v = \left[\frac{\{(vp)^2 - 2(vs)^2)}{2\{(vp)^2 - 2((vs)^2)}\right] ....1$$

$$G = \rho \ \ VS^2 ....2$$

$$Ed = 2G(1 + v) ....3$$

Where:
V_s: Shear wave velocity [m/s]
V_p: Compression wave velocity [m/s]
E_d: Dynamic modulus of elasticity [kN/m2]
G_d: Dynamic shear modulus or (Rigidity) [kN/m2]
υ : Poisson's ratio [-]

9. Results

Geotechnical parameters data were collected in Karbala city from various selected locations, which collected for geotechnical properties from geotechnical reports. While the velocity of seismic waves were measured by geophysical methods by using ABEM Terraloc Mark 6, (2009) device at the sites chosen for the study area. The dynamic properties were calculated from the mathematical equations above and Table 4 gives the range of the final results values.

Table 4: Soil properties in different sites in Karbala city.

	Site	Depth	Soil Type	W.T	γ_{wet}	γ_{dry}	C	ϕ	V_p	V_s	E_d 10^3	G_d 10^3	ν
		m		m	kN/m^3	kN/m^3	kN/m^2	°	m/s	m/s	kN/m^2	kN/m^2	-
1	K.S.1	0-4	Brown Medium Coarse Sand + Pebbles	No W.T	15.64	15.26	0	38	780	300	398	141	0.413
		4-8	Brown very Dense Clayey Silty Sand +	No W.T	14.48	13.49	0	39	972	360	534	188	0.420

			Pebbles										
		8-10	**Yellow very Dense Sand + Pebbles**	**No W.T**	**16.66**	**15.89**	**0**	**30**	**1176**	**420**	**838**	**294**	**0.426**
2	**K.S.2**	**0-3**	**Fill material Brown Sand +Gravel +Gypsum**	**1.7**	**16**	**14.6**	**0**	**38**	**812**	**280**	**359**	**125**	**0.432**
		3-10	**Yellow, Brown, Red Medium to Very Dense Silty Sand &Clayey Silty Sand +Gypsum+Iron Oxide +Gravel**	**1.7**	**17.8**	**15.67**	**0**	**40**	**1260**	**450**	**1027**	**360**	**0.427**
3	**K.S.3**	**0-11**	**Brown Dense Clayey Silty Sand +Gravel**	**13**	**15.48**	**15.26**	**0**	**41**	**1260**	**450**	**893**	**313**	**0.426**
		11-15	**Dense to Very Dense Light Brown Silty Clayey Sand**	**13**	**16.64**	**13.76**	**0**	**46**	**1350**	**540**	**1362**	**485**	**0.404**

10.Seismic site soil classification approaches

Site soil and ground types conditions are important in determining Seismic Design Category and it classified based on Iraqi and international standards as shown in Table 5.

Table 5 : Show International and Iraqi standards and ground types .

No.	International and Iraqi standards	Ground type	Table No. standards	References
1-	Preliminary draft of Iraqi Seismic Code, 303	A,B,C,D,E ,F)	Table 6	PISC (2013)
2-	Federal Emergency Management Agency	(A,B,C,D,E ,F)	Table 7	FEMA (2010)
3-	European Standard(EC8)	(A,B,C,D,E,S1or S2)	Table 8	Eurocode 8, 2004.

The measurement methods depending on one of the three from Seismic site soil classification approaches:
- Note that this method was used in this research. *Vs* value calculation approach, the site soil should be classified according to the value of the average shear wave velocity, *Vs,30* , which represents estimation of average shear wave velocity in the upper 30 m of soil and could be calculated in accordance with the following expression:

$$V_{s,30} = \frac{H}{\sum_{i=1,N} \frac{h_i}{v_i}}$$

Where:

H*:* Total depth of soil less than or equal to 30m,
hi and *v*i*:* represent the thickness (in metres) and shear-wave velocity of the *i-th* formation or layer, in a total of *N*, found in the top 30 m.
- N value approach, used for site soil classification by N value of Standard Penetration Test (SPT).
- Su value approach, using the undrained shear strength value(*su*) in the site classification of soil.

Table 6: Site soil classification (after PISC, 2013).

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Site Class Definition	V_s	N or N_{ch}	S_u
A Hard rock	>1500 m/s	-	-
B Rock	760 to 1500 m/s	-	-
C Very dense soil or soft rock	370 to 760 m/s	>50	>100kPa
D Hard soil	180 to 370 m/s	15 to 50	50 to 100 kPa
E Soft clayey soil	<180 m/s	<15	<50kPa
	Each side section thickness greater than 3m for soil profile of the following characteristics: - Plasticity Index PI > 20. - Water content w ≥ 40%. - Undrained shear strength S_u<25kPa.		
F Soil types that require a special field assessment	1. Soil exposed to possibility of collapse. 2. Silt and/or clayey soil of high organic content. 3. Clayey soil of very high plasticity index. 4. Very thick clayey soil of weak /medium strength.		

Table 7: Site class and soil types (after FEMA, 2010).

Site Class	General Description	V_s	N Blows/foot	S_u
A	Hard rock	>5000 ft/sec >1524 m/s	-	-
B	Rock	2500-5000 ft/sec 762-1524 m/s	-	-
C	Very dense soil and soft rock	1200-2500 ft/sec 365-762 m/s	>50	>2000 psf >95kPa
D	Stiff soil	600-1200 ft/sec 182-365 m/s	15 - 50	1000-2000 psf 47-95 kPa
E	Soft clay soil	<600 ft/sec <182 m/s	<15	<1000 psf <47kPa
F	Unstable soils	-	-	-

Table 8. Ground Types according to the European Standard, after Eurocode 8, 2004.

Ground type	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ (m/ s)	N SPT (blows/ 30cm)	c_u (kPa)
A	Rock or other rock-like geological formation including at most 5m of weaker material at the surface.	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterized by a gradual increase of mechanical properties with depth.	360-800	> 50	> 250
C	Deep deposits of dense or medium- dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180-360	15 - 50	70-250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	<15	< 70
E	A soil profile consisting of a surface alluvium layer with *Vs* values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material *Vs* 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10m thick, of soft clays/silts with a high plasticity index (PI> 40) and high water content	< 100 (indicative)		10-20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A E or S_1			

11. Seismic site soil classification for Karbala City.

According to the Preliminary draft of Iraqi Seismic Code, submitted to Central Organization for Standardization and Quality Control COSQC, 2013, FEMA, 2010 and Eurocode 8, 2004 Karbala site soils can be classified depending on the average shear velocity *Vs* as shown in Table 9. The available geophysical investigations in Iraq provides *Vs* values for depths from 10 m to 15m.

Table 9: Karbala site soil classification.

No.	Site	Total depth of Geophysical Explorations (m)	*Vs (m/s)*	PISC 2013 and FEMA 2010	Eurocode 8 2004
1	K.S.1	10	205	D	C
2	K.S.2	10	230	D	C
3	K.S.3	15	478	C	B

12. Conclusions

The most important conclusions drawn from the results can be:

1- The results provided in the seismic classification of Karbala city can be used as guideline for risk assessment and management under earthquake effects of future probable event.

2. The P-wave velocities (Vp) were ranged between (780-1176) m/s in the site of K.S.1, (812-1260) m/s in the site of K.S.2, (1260-1330) m/s in the site of K.S.3. in the center of Karbala city, Iraq.

3. The S-wave velocities (Vs) were ranged between (300-420) m/s in the site of K.S.1, (280-450) m/s in the site of K.S.2, (450-540) m/s in the site of K.S.3. in the center of Karbala city, Iraq.

4.Karbala site soils are classified according to different seismic codes basing on *Vs,30* value as shown in Table 9 , according to the Preliminary draft of Iraqi Seismic Code and FEMA, 2010 the sites soils are classified as types (D and C) while according to Eurocode 8, 2004 sites soils are classified as types (C and B) and concluding that Karbala soils are ranging between : hard soil or very dense sand ,gravel or dense or medium –dense sand, gravel or stiff clay for site of the Karbala city in Iraq.

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