Data Base for Dynamic Soil Properties of Seismic Active Zones in Iraq

Qassun Sa'ad Al-Deen Mohammed Shafiqu
Assistant Professor
Department of Civil Engineering
College of Engineering, Al-Nahrain University
qassun@yahoo.com

Ruba Hanna Sa'ur
Engineer
Department of Civil Engineering
College of Engineering, Al-Nahrain University
rubasaur@yahoo.co.uk

ABSTRACT

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. 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. Dynamic properties play a vital role in the design of structures subjected to seismic load. The main objective of this study is to prepare a data base for the dynamic properties of different soils in seismic active zones in Iraq using the results of cross hole and down hole tests. From the data base collected it has been observed that the average vertical compressional wave velocities were ranged from (1125-2500) m/s in the North, (306-1544) m/s in the Middle, (805-1812) m/s in the western south, (377-1326) m/s in the eastern south and (334-1404) m/s in the South of Iraq. And 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.

Key words: data base, soil, dynamic properties, seismic zones, Iraq

قاعدة بيانات لخواص التربة الديناميكية لمناطق العراق ذات النشاط الزلزالي

قاسيون سعد الدين محمد شفيق
أستاذ مساعد
قسم الهندسة المدنية
كلية الهندسة - جامعة النهرين

ربى حنا ساعور
مهندس
قسم الهندسة المدنية
كلية الهندسة - جامعة النهرين

الخلاصة

يقع العراق بالقرب من الطرف الشمالي من الصفيحة العربية التي لها علاقة بالصفيحة الأوراسية عند التقدم شمالاً، ومن المتوقع ان يكون العراق من البلدان النشطة تكتونيا ونتيجة للزيادة الملحوظة للنشاط الزلزالي في العالم خلال العقود الأخيرة خاصة في منطقة الشرق الأوسط فقد اولى المهندسون اهتمام كبير في تصاميم الأبنية المقاومة للزلازل. ان الخواص الديناميكية تلعب دورا مهما في تصميم المنشآت المعرضة للقوى الزلزالية. الهدف الرئيسي من هذه الدراسة هو اعداد قاعدة بيانات للخصائص الديناميكية لأنواع مختلفة من التربة للمناطق النشطة زلزاليا في العراق وذلك بالاعتماد على نتائج فحصي cross hole و down hole ، حيث لوحظ من قاعدة البيانات التي تم جمعها أن معدل سرع الموجة الانضغاطية تتراوح بين (2500-1125) م/ثا في المنطقة الشمالية و (1544-306) م/ثا في المنطقة الوسطى و (1812-805) م/ثا في الجنوب الغربي و (1326-377) م/ثا في الجنوب الشرقي و (1404-334) م/ثا في المنطقة الجنوبية من العراق. وكان معدل سرع موجة القص تتراوح بين (476-225) م/ثا في المنطقة الشمالية و (408-111) م/ثا في المنطقة الوسطى و (659-268) م/ثا في الجنوب الغربي و (380-131) م/ثا في الجنوب الشرقي و (365-102) م/ثا في المنطقة الجنوبية من العراق.

الكلمات الرئيسية: قاعدة بيانات ، تربة ، الخصائص الديناميكية ، المناطق الزلزالية ، العراق

1. INTRODUCTION

Tectonically Iraq is located in a relatively active seismic zone at the northeastern boundaries of the Arabian Plate .The corresponding Zagros - Tauros Belts manifest the subduction of the Arabian plate into the Iranian and Anatolian Plates .The seismic history reveals annual seismic activity of different strength. The north and northeastern zones depicts the highest seismic activity with strong diminution in the south and southwestern parts of the country.

The territory of Iraq, although not directly located on a dense cluster of recent earthquake epicenters; but the geodynamic configurations show a medium to high seismic risk. This will be coupled with the increasing vulnerability of the major highly populated cities .The state of seismological research, seismic monitoring, and seismic hazard awareness have seen better times during the last two decades, **Alsinawi and Al-Qasrani , 2003**.

Determination of dynamic soil properties is an utmost critical and important aspect of geotechnical earthquake engineering problems.. Evaluation of dynamic soil properties by field tests has a number of advantages, as these tests do not require sampling that can alter the stress and structural conditions in soil specimens. Further. the tests measure the response of relatively large volumes of soil. However, these field tests can be again classified based on the range of magnitude of strain as low-strain and high-strain tests. Low-strain tests are based on the theory of wave propagation 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), seismic cross-hole test, seismic down-hole test and seismic cone test, **Sitharam et al., 2004**. The field tests which are generally used in Iraq for determining the dynamic properties of soils used in designing purposes is the seismic cross-hole and down-hole tests. So it became necessary to study the dynamic parameters of soils in different regions of Iraq.

In this study, a data base for the dynamic properties of Iraqi different soils using cross hole and down hole test results will be prepared. This will require getting information for dynamic soil properties of different zones in Iraq from varying geophysical and geotechnical investigation tests reports.

2. THEORETICAL WORK

2.1 Resource of Data and Presentation

The current study based on experimental results for underground conditions and the engineering properties of the various strata of many geophysical and soil investigation reports for projects in Iraq which is collected from engineering consulting bureaus of Baghdad, Al-Nahrain and Technology universities, also from National Center of Construction Laboratories and Research (NCCLR), and from other sources. Geophysical and soil investigation reports were for projects of water treatment plants and pumping stations, multi-story buildings, electrical substations, stadiums, oil refinery and other projects located at north, middle, western south, eastern south and south regions of Iraq as shown in **Table. 1** and **Fig. 1**.

2.2 Geotechnical and Geophysical Parameters Investigated for Iraq Soils

The geotechnical and geophysical parameters for Iraq soils are collected from different projects reports as mentioned before, the collection of data was performed depending up on reports containing both soil investigation and geophysical investigation data, borehole logs of each report are examined well so as the data of the geotechnical and geophysical investigations for each project are collected either from the same borehole or two adjacent ones which have the same soil layers profile. These parameters with their standard units are listed below:

γ_{wet} : unit weight [kN/m^3]
γ_{dry} : dry unit weight [kN/m^3]
ϕ : friction angle [°]
c : cohesion [kN/m^2]
V_s: shear wave velocity [m/s]
V_p: compression wave velocity [m/s]
E_d: dynamic modulus of elasticity [kN/m^2]
G_d: dynamic shear modulus [kN/m^2]
υ : poisson's ratio [-]

If there is some unavailable strength soil parameters (c or ϕ) for particular layers within the reports they would be either evaluated from N value (SPT) or estimated according to type of soil.

3. SOIL PARAMETERS EVALUATION

Soil parameters such as; γ_{wet} ,γ_{dry} , c, ϕ are evaluated from field tests or laboratory tests, other dynamic parameters such as; V_s and V_p are evaluated by geophysical investigations in which other parameters like; E_d, G_d and υ are given by, **Doyle**, **1995**:

$$G_d = \rho\ V_s^2 \tag{1}$$

$$E_d = 2\ G_d\ (1+\upsilon) \tag{2}$$

$$\upsilon = \left[\frac{1/2(V_p/V_s)^2-1}{(V_p/V_s)^2-1}\right] \tag{3}$$

3.1 Field Testing

3.1.1 Standard penetration test (S.P.T)

The Standard Penetration Test, or SPT, is the most widely used in-situ test, in a great variety of geotechnical exploration projects, in Iraq and throughout the world, as an indicator of the density and compressibility of granular soils. It is also commonly used to check the consistency of stiff or stony cohesive soils and weak rocks. Estimation of the liquefaction potential of saturated granular soils for earthquake design is often based on these tests. This test method provides a soil sample for identification purposes and for laboratory tests appropriate for soil obtained from a sampler that may produce large shear strain disturbance in the sample, **ASTM D 1586 – 99**.

Many local correlations and widely published correlations which relate SPT blow count, or N-value, and the engineering behavior of earthworks and foundations are available, **Fig. 2** shows a useful relationship between N - values and shear wave velocities. **Table 2** and **Table 3** shows the relationships between N-value and friction angle ϕ and unconfined compressive strength q_u, respectively. The test is performed using a barrel split spoon sampler which is driven into the cased borehole by means of a 65 kg hammer falling freely through a height of 760mm onto the top of the boring rods as shown in **Fig. 3**, different methods of releasing the hammer are used in different countries. The borehole must be cleaned out to the required depth, care being taken to ensure that the material to be tested is not disturbed. Initially the sampler is driven 150mm into the sand to seat the device and to bypass any disturbed sand at the bottom of the borehole. The number of blows required to drive the sampler a further 300mm is then recorded: this number is called the standard penetration resistance (N). The number of blows required for each 75mm of penetration (including the initial drive) should be recorded separately. If 50 blows are reached before a penetration of 300 mm, no further blows should be applied but the actual penetration should be recorded. At the conclusion of a test the sampler is withdrawn and the sand extracted. Tests are normally carried out at intervals of between 0.75 and 1.50m to a depth below foundation level at least equal to the width (B) of the foundation, **Craig, 2004**. The SPT has been used for many purposes. At its simplest, it is a low quality sampler. At its most useful it is a rapid, inexpensive, qualitative test which can provide data even when other techniques of sampling or testing are not viable or cannot be justified financially. Due to the collected reports the SPT was performed for each test boring at different intervals depending on the stratification of the soil.

3.1.2 **Field density** (Core Cutter Test)

This method provides the determination of bulk field density $\boldsymbol{\gamma_{wet}}$ of the surface layers of soil or at the base of test pit; it is suitable for soft fine grained soils. A steel cylinder (core cutter) is driven into the ground, dug out and the soil shaved off level. The mass of soil is found by weighing and deducting the mass of the cylinder. Determining the water content of small samples taken from both ends of the cylinder, **BS 1377:1999**. Then the dry density γ_{dry} can be determined easily after obtaining the water content w% of the soil.

3.2 Laboratory Testing

3.2.1 **Soil classification (Sieve analysis and hydrometer**)

According to **ASTM D 422-36** this test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data.

3.2.**2 Direct shear test**

This test method covers the determination of the consolidated drained shear strength of a soil material in direct shear it is suitable for cohesionless soils. The test is performed by inserting deformation to a specimen at a controlled strain rate on or near a single shear plane determined by the configuration of the apparatus. Generally, three or more specimens are tested, each under a different normal load, to determine the effects upon shear resistance and displacement, and strength properties such as Mohr strength envelopes, **ASTM D 3080 / D3080M-98**.

3.2.3 **Unconfined compression test**

This test method covers the determination of the unconfined compressive strength of cohesive soil in the undisturbed, remolded, or compacted condition, using strain-controlled application of the axial load. This test method provides an approximate value of the strength of cohesive soils in terms of total stresses. This test method is applicable only to cohesive materials which will not expel or bleed water (water expelled from the soil due to deformation or compaction) during the loading portion of the test and which will retain intrinsic strength after removal of confining pressures, such as clays or cemented soils, **ASTM D 2166-00**.

3.2.4 **Unconsolidated undrained triaxial compression test (UU test**)

This test method covers determination of the strength and stress-strain relationships of a cylindrical specimen of either undisturbed or remolded cohesive soil. Specimens are subjected to a confining fluid pressure in a triaxial chamber. No drainage of the specimen is permitted during the test. The specimen is sheared in compression without drainage at a constant rate of axial deformation (strain controlled). According to **ASTM D 2850-95** this test method provides data for determining undrained strength properties and stress-strain relations for soils.

3.2.5 **Consolidated undrained triaxial compression test (CU test)**

This test method covers the determination of strength and stress-strain relationships of a cylindrical specimen of either an undisturbed or remolded saturated cohesive soil. Specimens are isotropically consolidated and sheared in compression without drainage at a constant rate of axial deformation (strain controlled). The provided calculations are of total and effective stresses, and axial compression by measurement of axial load, axial deformation, and pore-water pressure. This test method provides data useful in determining strength and deformation properties of cohesive soils such as Mohr strength envelopes and Young's modulus. According to **ASTM D4767-04** three specimens are tested at different effective consolidation stresses to define a strength envelope. The determination of strength envelopes and the development of relationships to aid in interpreting and evaluating test results are beyond the scope of this test method and must be performed by a qualified, experienced professional.

3.2.6 **Consolidated drained triaxial compression test (CD test)**

This test method covers the determination of strength and stress-strain relationships of a cylindrical specimen of either intact or reconstituted soil. Specimens are consolidated and sheared in compression with drainage at a constant rate of axial deformation (strain controlled). This test method provides for the calculation of principal stresses and axial compression by measurement of axial load, axial deformation, and volumetric changes. This test method provides data useful in determining strength and deformation properties such as Mohr strength envelopes. According to **ASTM D7181-11** three specimens are tested at different effective consolidation stresses to define a strength envelope. If this test method is used on cohesive soil, a test may take weeks to complete. The determination of strength envelopes and the development of relationships to aid in interpreting and evaluating test results are beyond the scope of this test method and must be performed by a qualified, experienced professional.

3.3 Geophysical Investigation

3.3.1 Cross hole test

This technique consists of drilling two to three boreholes to depths below the proposed foundation and requires the generation of elastic waves at certain depth down a borehole. For this purpose SPT test hammer was used and the energy is transferred to the base of the borehole by means of drill rods, **Davis and Schultheiss, 1980**. Vertical shear and compressional waves propagating in a horizontal layer were detected by two receivers placed in adjacent boreholes at the same depth as the energy source, as shown in **Fig. 4**. Galvanized pipes 7.5cm diameter were used for casing the boreholes. The space between the pipe and borehole wall was filled by a soil material to make firm contact between the Galvanized pipes and the borehole shaft.

The measurements were taken using a probe (consists of three geophones, two horizontal, and one vertical), which get down on casing holes. The results of shear wave velocity V_s and compressional wave velocity V_p were printed on seismic record using (Terraloc ABEM), **ASTM D 4428/D 4428M – 00** .

3.3.2 **down-hole test**

The basic seismic down- hole test consists of measuring the time of arrival of wave from a source to a detector which occupies successive positions down a borehole, as shown in **Fig. 5**, a three component geophone lowered down and fixed against the soil wall using a clamping device so that a good coupling could be made between the instrument and the medium, **Davis and Schultheiss, 1980**. The source used for generating elastic wave (compressional and shear waves) is placed at the surface some distance from the hole and testing is carried out at 3m interval by striking a plate with impact hammer . The detecting and recording equipment consists of three component geophones (two are horizontal and one is vertical) (borehole picks) with a packer to fix the probe at the required depth, coupled to the ABEM Teraloc seismograph which record the results of shear wave velocity V_s and compressional wave velocity V_p, **ASTM D 7400 – 08**.

4. RESULTS AND DATA BASE PREPARED

Soil shear strength and dynamic parameters for soils in seismic active zones of Iraq from different locations (North, Middle and South) are collected. They are collected from geotechnical and geophysical reports of important projects in these zones and are given as database finally arranged in **Table 4**.

5. SITE SOIL SEISMIC CLASSIFICATION

Site soil is classified according to **the Preliminary draft of Iraqi Seismic Code** submitted to Central Organization for Standardization and Quality Control COSQC, **2013** and Federal Emergency Management Agency**, FEMA**, **2010**, as shown in **Table 5** and **Table 6** respectively ,while according to the European Standard, **Eurocode 8, 2004**, site soil is classified to type (A,B,C,D,E S_1or S_2) as shown in **Table 7**, depending on one of the three methods:

1. V_s value method, the site soil should be classified according to the value of the average shear wave velocity, $V_{s,30}$, which represents a measurement or estimation of average shear wave velocity in the upper 30 m of soil and could be computed in accordance with the following expression:

$$V_{s,30} = \frac{H}{\sum_{i=1,N} \frac{h_i}{v_i}} \tag{4}$$

where H is the total depth of soil less than or equal to 30m, h_i and v_i denote the thickness (in metres) and shear-wave velocity of the *i-th* formation or layer, in a total of N, existing in the top 30 m.

2. N value method, another method used for site soil classification by N value of SPT (Standard Penetration Test).

3. S_u value method, using the undrained shear strength value s_u or c_u in the classification of site soil.

5.1 Site Soil Seismic Classification of Iraq Soils

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** Iraq site soils can be classified depending on the average shear velocity V_s as shown in **Table 7**. The available geophysical investigations in Iraq provides V_s values for depths from 10 m to 22m.

6. CONCLUSIONS

The following conclusions from the collected database may be drawn :

1. The average vertical compressional and shear wave velocities, as well as, the corresponding average dynamic moduli for soil layers are shown in **Table 4**, together with the soil parameters γ_{wet} ,γ_{dry} , c, ϕ evaluated. Thus, database of the soil and dynamic parameters for seismic active zones in Iraq are prepared to be used as input data for simulation of different geotechnical problems under earthquake effects using FEM softwares.
2. The compressional wave velocities were ranged from (1125-2500) m/s in the North, (306-1544) m/s in the Middle, (805-1812) m/s in the Western south , (377-1326) m/s in the Eastern south and (334-1404) m/s in the South of Iraq.
3. The 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.
4. Modulus of Elasticity was ranged from (290.15-1409.8) MN/m^2 in the North, (57.9-1107.4) MN/ m^2 in the Middle, (457-2472.2) MN/ m^2 in the Western south , (90.15-1082.8) MN/ m^2 in the Eastern south and (61.8-682.52) MN/ m^2 in the South of Iraq.
5. Shear modulus of Elasticity was ranged from (98.09-475.98) MN/ m^2 in the North, (20.33-378.73) MN/ m^2 in the Middle, (154.6-868.03) MN/ m^2 in the Western south , (31.5-374.17) MN/ m^2 in the Eastern south and (21.23-233.14) MN/ m^2 in the South of Iraq.
6. Iraq site soils are classified according to different seismic codes depending on $V_{s,30}$ value as shown in **Table 8** , according to the Preliminary draft of Iraqi Seismic Code and FEMA, 2010 the sites soils are classified as types (E,D and C) while according to Eurocode 8, 2004 sites soils are classified as types (D, C and B) and concluding that Iraq soils are ranging between;
   a) Very dense soil , soft rock or gravel for WS_1 and WS_3 sites of the Western south region in Iraq.
   b) Soft clayey soil or loose-to-medium cohesionless soil for M_3 site of the Middle region in Iraq , also S_3 and S_4 sites of South region in Iraq.

REFERENCES

- Alsinawi S.A., Al-Qasrani Z.O. 2003, *Earthquake Hazards Considerations for Iraq*, Fourth International Conference of Earthquake Engineering and Seismology,12-14 May, Tehran, Islamic Republic of Iran.

- ASTM D 1586 – 99, *Penetration Test and Split-Barrel Sampling of Soils*.

- ASTM D 2166-00, *Unconfined Compressive Strength of Cohesive Soil*.

- ASTM D 2850-95, *Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils*.

- ASTM D 3080/D3080M- 98, *Direct Shear Test of Soils Under Consolidated Drained Conditions*.

- ASTM D 422-36 (1998), *Particle-Size Analysis of Soils*.

- ASTM D 4428/D 4428M – 00, *Standard Test Methods for Crosshole Seismic Testing*.

- ASTM D 7400 – 08 , *Standard Test Methods for Downhole Seismic Testing*.

- ASTM D4767-04, *Consolidated Undrained Triaxial Compression Test*.

- ASTM D7181-11, *Method for Consolidated Drained Triaxial Compression Test for Soils*.

- Bowles, J. E. 1997, *Foundation Analysis and Design*, 5th Edition, McGraw-Hill, New York.

- BS 1377 : 1999 ,*Core Cutter Insitu Density Test*, Pare 9.

- Clayton, C.R.I. 1995. *The Standard Penetration test (SPT)*: Methods and use, CIRIA Report 143, London.

- Craig R.F. , 2004, *Craig's Soil Mechanics* ,Seventh edition, Taylor & Francis e-Library.

- Davis A. M. and Schultheiss P. J., 1980, *Seismic Signal Processing in Engineering Site - Investigation A Case History* ,Ground Engineering , May 1980.

- Department of Defense Handbook, 1997, *Soil Dynamics and Special Design Aspects*, MIL-HDBK-1007/3

- Doyle, H., 1995, *Seismology*, John Wiley & Sons, Chichester, New York.

- ECB report , 2013, *Installation of 10000 m^3 Oil Storage Tank in Shuaiba Warehouse in Basrah*, Engineering Cnsultancy Bureau, Aug.2013.

- Eurocode 8, 2004, *Design of Structuresfor Earthquake Resistance*, Part 1 , The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC.

- FEMA, 2010, *Earthquake-Resistant Design Concepts, an Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, P-749 / Dec. 2010.

- Sitharam T. G. , GovindaRaju L.and Sridharan A., 2004, *Dynamic Properties and Liquefaction Potential of Soils*, Special Section: Geotechnics and Earthquake Hazards, Vol. 87, No. 10, 25 November.

- Terzaghi, K. and Peck, R.B., 1967, *Soil Mechanics in Engineering Practice*, John Wiley, NewYork. 729.

- *The Preliminary Draft of Iraqi Seismic Code* , 303, submitted to Central Organization for Standardization and Quality Control COSQC, 2013.

NOMENCLATURE

c = cohesion, kN/m^2.
E_d = dynamic modulus of elasticity, kN/m^2.

G_d = dynamic shear modulus, kN/m^2.
N = no. of blows for standard penetration test (SPT), blow.
q_u= unconfined compressive strength, kN/m^2.
V_p = compression wave velocity, m/s.
V_s = shear wave velocity, m/s.
$V_{s,30}$= average shear wave velocity in the upper 30 m of soil, m/s.
γ_{dry} = dry unit weight, kN/m^3.
γ_{wet} = unit weight, kN/m^3.
υ = Poisson's ratio, dimensionless.
ϕ = friction angle, degree.

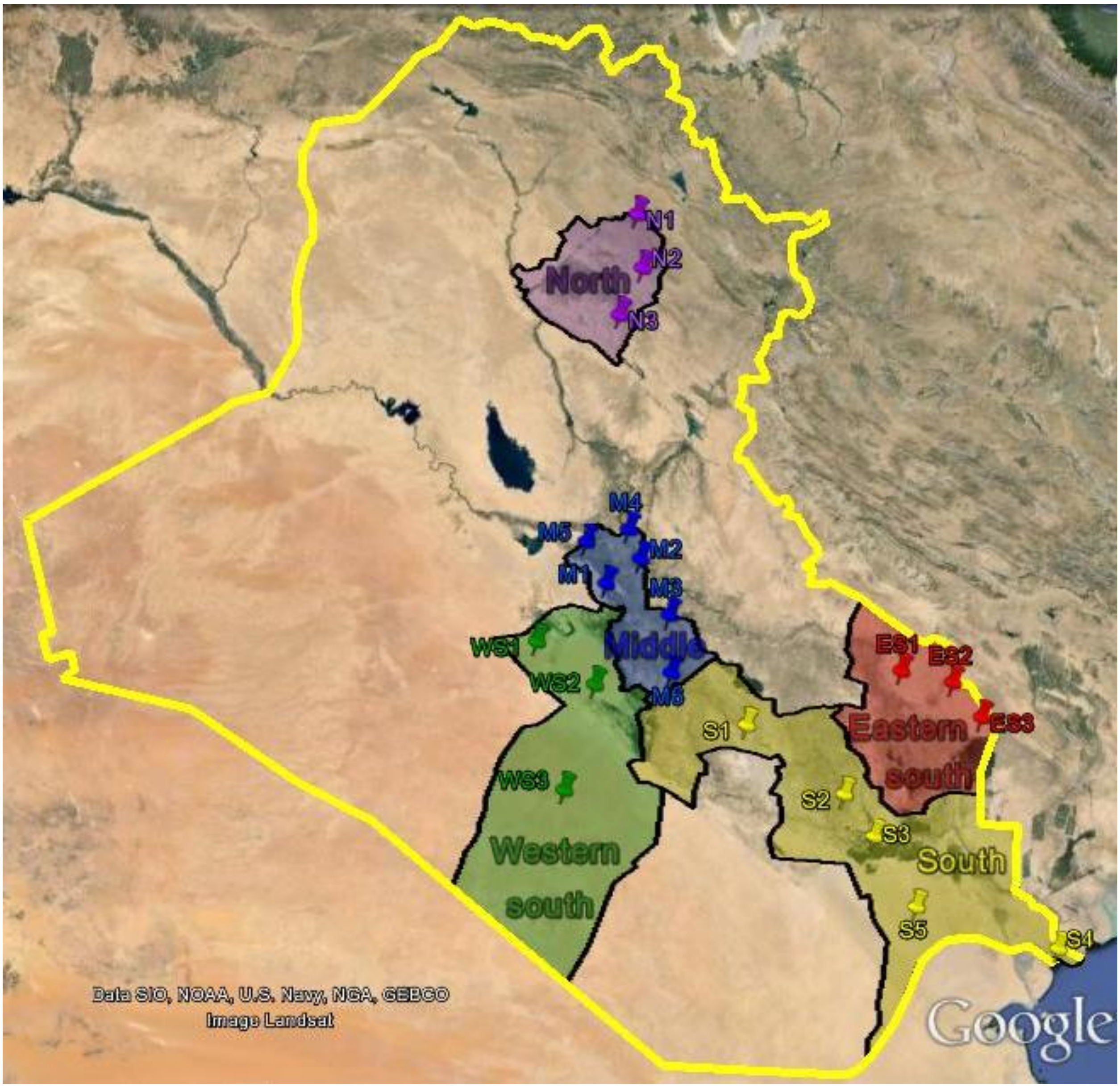

Figure 1. Projects locations in Iraq**.**

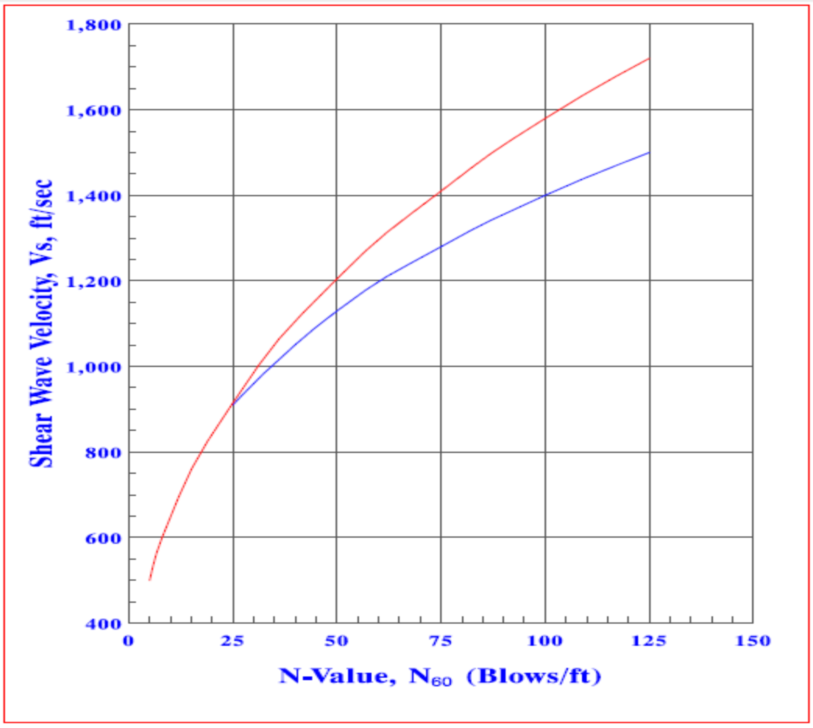

Figure 2. Relation between number of blowes per foot in standard penetration test and velocity of shear waves, **after department of defense handbook, 1997.**

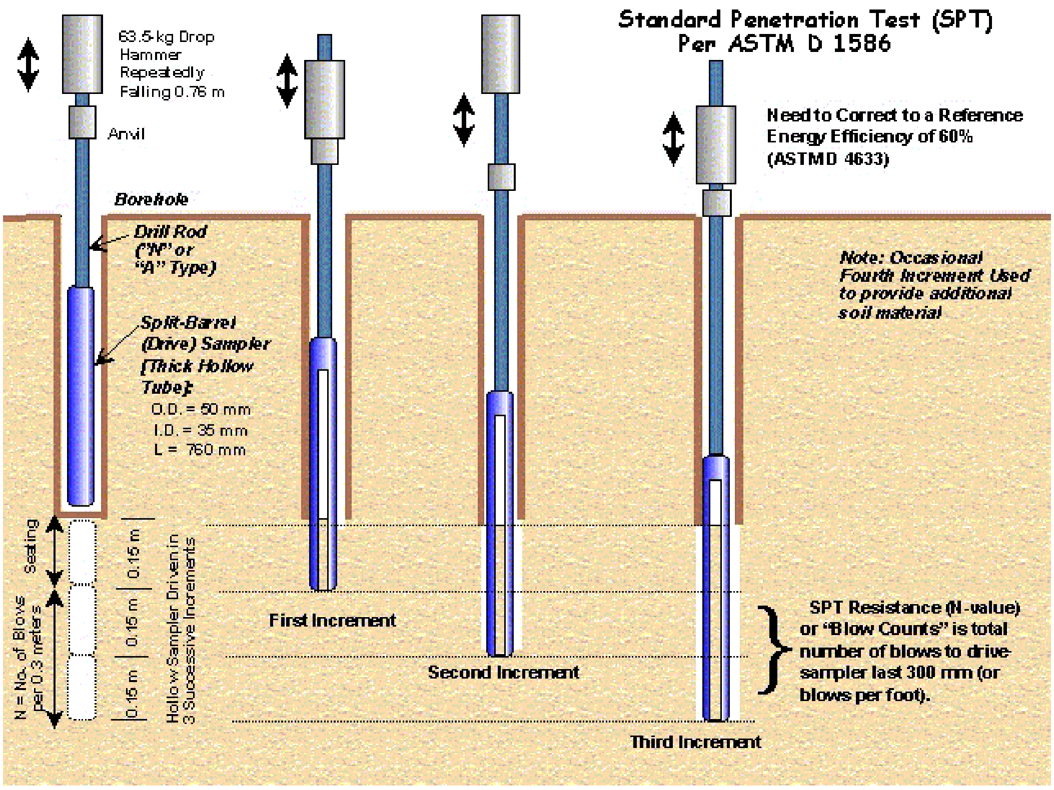

Figure 3. Standard penetration test ,**after Clayton, 1995**.

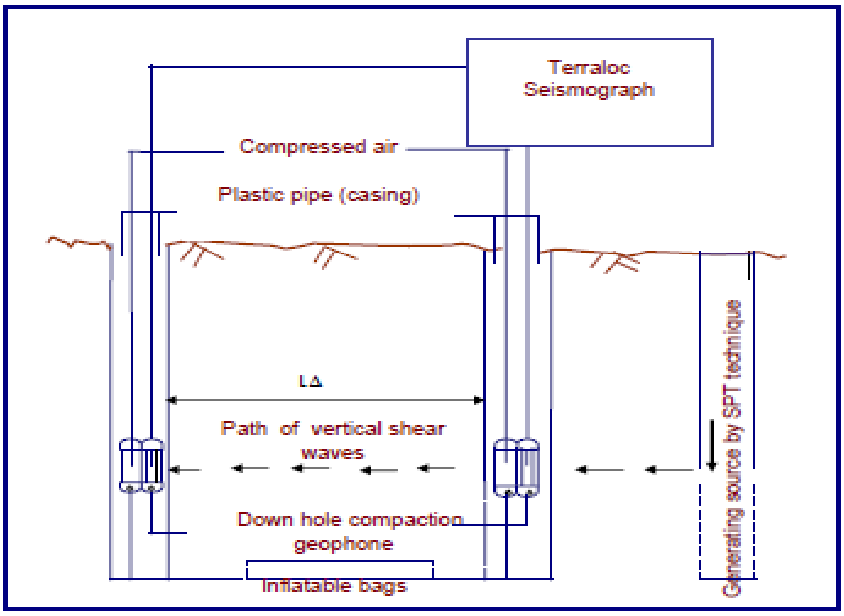

Figure 4. Cross hole test procedure, **after Davis and Schultheiss 1980.**

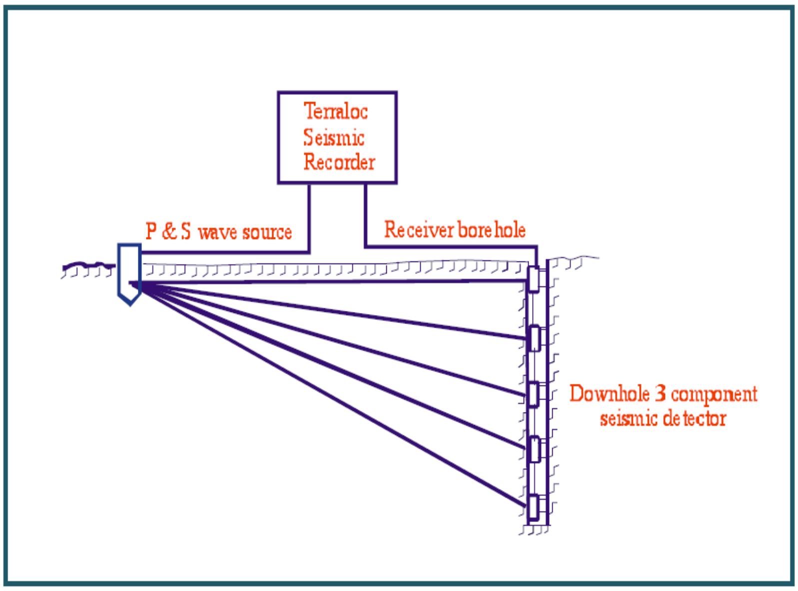

Figure 5. Down hole test procedure, **after Davis and Schultheiss 1980**.

Table 1. The available projects in Iraq with their site areas and symbols.

No.	Zone	Site	Project	Site Symbol
1	North	Kirkuk	Kirkuk North Gas Company 1 June Depot	N_1
2		Kirkuk	Kirkuk Cement Factory	N_2
3		Kirkuk	Kirkuk North Gas Company	N_3
4	Middle	Baghdad	Al Karkh Pumping Station	M_1
5		Baghdad	Al Zawra Stadium	M_2
6		Baghdad	Eiwa'n Al Madain	M_3
7		Baghdad	Al Taji Stadium	M_4
8		Baghdad	Al Qudus Gas Turbine Power Plant	M_5
9		Babylon	Hilla Power Plant	M_6
10	Western South	Karbala	Karbala Cultural	WS_1
11		Karbala	Karbala Al Abbasia Sacred Shrine	WS_2
12		Al Najaf	Al Najaf Al Salam Housing Complex	WS_3
13	Eastern South	Missan	Al Amarah Water Intake Depot	ES_1
14		Missan	Halfaya Oil Field	ES_2
15		Missan	Missan Oil Export Pipe Line	ES_3
16	South	Al Dewaniya	Al Dewaniya Pumping Station	S_1
17		Al Nasiriya	Al Nasiriya Oil Depot	S_2
18		Al Nasiriya	Al Nasiriya Water Intake Refinery	S_3
19		Al Basrah	Faw Depot Turbine	S_4
20		Al Basrah	Al Sheiba Oil Refinery	S_5

Table 2. Correlations with N values of cohesionless soils, **after Bowles, 1997**.

Description	Relative Density, *Dr* (%)	Friction Angle, φ'(Deg.)	N Value
Very loose	Less than 15	25 - 28	< 4
Loose	15 - 60	29 - 32	4 - 10
Medium	60 - 75	33 - 35	10 - 30
Dense	75 - 90	36 - 40	30 - 50
Very dense	Over 90	41 - 45	Over 50

Table 3. Correlations of unconfined compressive strength q_u-N value ,**after Terzaghi and Peck, 1967.**

Consistency	N Value	q_u (kN/m^2)
Very soft	<2	>24
Soft	2-4	24-50
Medium	4-8	50-100
Stiff	8-15	100-200
Very stiff	15-30	200-400
Hard	>30	>400

Table 4. Soil properties in different locations of Iraq .

No.	Site	Depth (m)	Soil Type	WT (m)	γ_{wet} (kN/m^3)	γ_{dry} (kN/m^3)	c (kN/m^2)	ϕ (^{o})	V_p (m/s)	V_s (m/s)	E_dx10^3 (kN/m^2)	G_dx10^3 (kN/m^2)	ν
1.	**N_1**	0-10	Very stiff to hard brown lean CLAY (CL)	3.8	20.1	17	130	0	1250	312	585.43	199.53	0.467
2.	**N_2**	0-2.5	Stiff brown sandy SILT (ML)	>25	19	16.8	0	32	1125	225	290.15	98.09	0.479
		2.5-15	Very stiff to hard brown lean to fat CLAY (CL,CH)		20.6	18.2	227	0	1250	321	634.86	216.38	0.467
		15-20	Very dense silty GRAVEL with SAND (GM)		20.6	18.2	0	42	2500	476	1409.8	475.98	0.481
3.	**N_3**	0-10	Stiff to very stiff brown lean or fat CLAY (CL,CH)	2.58	21.0	18.1	120	0	1541	304	585.82	197.91	0.48
4.	**M_1**	0-6	Medium stiff to stiff brown fat CLAY (CH)	0.63	19.8	15.8	50	0	641	189	209.16	72.13	0.45
		6-12	Very stiff brown lean CLAY (CL)		19.0	14.5	100	0	675	248	338.44	119.17	0.42
		12-15	Medium dense to dense silty clayey SAND to silty SAND with gravel		19.0	15.0	0	37	750	225	284.46	98.09	0.45
5.	**M_2**	0-7	Medium to hard brown lean to fat CLAY (CL,CH)	2.3	19.6	15.8	60	3	914	276	441.56	152.26	0.45
		7-9	Very stiff grey sandy SILT (ML)		20.6	17.1	0	34	687	195	233.25	79.88	0.46
		9-14	Stiff to Hard brown lean CLAY (CL)		20.0	18.0	200	0	945	221	292.87	99.61	0.47
		14-15	Medium to dense grey silty SAND		20.0	18.1	0	41	1014	327	628.09	218.09	0.44
6.	**M_3**	0-8.5	Medium to hard brown lean to fat CLAY (CL, CH)	3.86	20	16.3	35	0	454	161	151.00	52.8	0.428
		8.5-11	Very stiff brown SILT (ML)		19.6	17	200	0	625	232	305.41	107.54	0.42
		11-12	Very stiff brown fat CLAY(CH)		19.6	17.2	240	0	1000	227	303.29	102.95	0.473

No.	Site	Depth (m)	Soil Type	WT (m)	γ_{wet} (kN/m^3)	γ_{dry} (kN/m^3)	c (kN/m^2)	ϕ (°)	V_p (m/s)	V_s (m/s)	$E_d x10^3$ (kN/m^2)	$G_d x10^3$ (kN/m^2)	ν
7.	M_4	0-7.5	Stiff to very stiff brown lean to fat CLAY(CL-CH)	2.2	19.8	17.1	65	10	841	165	162.7	54.97	0.48
		7.5-11	Medium to very dense grey silty SAND (SM)		19.0	16.5	0	38	1025	279	440.3	150.8	0.46
8.	M_5	0-1	Brown to grey clayey silt to sandy silt with filling materials, organic to salts (ML)	1.3	19.00	15.8	28.7	0	322	140	105	37.96	0.383
		1-15	Brown to Grey Silty CLAY to Clayey Silt (ML,CL,CH)		18.88	14.7	31.5	0	776	219	268.9	92.34	0.456
		15-20	Grey Sand to silty or clayey SAND to Gravilly SAND		22.31	17.04	0	38	1544	408	1107.4	378.73	0.462
9.	M_6	0-2.4	Grayish sandy silty CLAY soil, medium consistency	1.5	16.18	14.5	144	0	306	111	57.9	20.33	0.424
		2.4-16	Grayish silty sand soil, medium dense		18.44	16.5	0	38	450	183	176.33	62.98	0.4
10.	WS_1	0-4.5	Dense white to yellow slightly to moderately gypseous SAND with silt to silty SAND with gravel (SP,SM)	0.8	18.8	18	0	37	1433	284	457.0	154.6	0.478
		4.5-12	Dense to very dense white to yellow SAND with silt (SP,SM)		19.4	18	0	35	1733	550	1727.2	598.46	0.443
		12-22	Very dense white to yellow SAND with silt to silty SAND (SP,SM)		19.4	18	0	35	1650	563	1801	627.1	0.436
11.	WS_2	0-10.5	Stiff brown silty to moderatly gypseous fat CLAY (CH)	1.5	18.5	14.7	100	0	1416	312	541.76	183.65	0.475
		10.5-14	Very loose to medium green to yellow marly SAND (SM)		19	17.1	0	50	1474	289	479	161.83	0.48
12.	WS_3	0-1.2	Medium- dense light brown slightly gypseous silty SAND (SM)	0.9	19.1	17	0	43	805	268	458.15	159.3	0.438
		1.2-7	Medium- dense to very dense light brown SAND (SP)		19.5	18	0	40	1450	557	1743.5	616.95	0.413
		7-10	Very dense light brown silty SAND (SM)		19.6	18	0	39	1812	659	2472.2	868.03	0.424

No.	Site	Depth (m)	Soil Type	WT (m)	γ_{wet} (kN/m^3)	γ_{dry} (kN/m^3)	c (kN/m^2)	ϕ (^{o})	V_p (m/s)	V_s (m/s)	$E_d x10^3$ (kN/m^2)	$G_d x10^3$ (kN/m^2)	ν
13.	ES_1	0-7.6	Medium stiff to stiff brown lean to fat CLAY (CL,CH)	0.6	19.5	15.1	80	0	500	176	175.96	61.57	0.429
		7.6-9	Loose grey silty SAND		19.5	15.7	0	29	600	200	228.51	79.51	0.437
		9-10	Stiff brown lean CLAY (CL)		19.5	15.7	60	8	600	250	346.6	124.23	0.395
14.	ES_2	0-5	Medium stiff to stiff brown lean to fat CLAY (CL,CH)	0.6	18.0	14.6	65	0	377	131	90.15	31.5	0.431
		5-8	Stiff brown lean to fat CLAY (CL,CH)		19.5	15.8	60	0	604	250	347.98	124.28	0.4
		8-17	Stiff brown lean CLAY (CL)		20.8	15.9	60	8	1362	420	1082.8	374.17	0.447
15.	ES_3	0-9	Medium stiff to stiff brown lean to fat CLAY (CL,CH)	0.6	19.7	15.7	80	0	696	179	188.5	64.37	0.464
		9-18	Stiff brown lean CLAY (CL)		20.9	16.1	60	0	1167	380	886.78	307.76	0.44
16.	S_1	0-1.5	Brown lean CLAY(CL)	0.3	18.5	14.4	94	0	625	188	193.28	66.65	0.450
		1.5-2	loose grey silty SAND layer (SM)		20.0	15.0	0	30	909	185	213.45	72.21	0.478
		2-10	Medium stiff to very stiff brown to green marly lean to fat CLAY (CL,CH)		19.3	14.7	60	5	909	200	232.17	78.73	0.475
17.	S_2	0-4	Very stiff brown lean CLAY (CL)	4	19.07	15.1	34	0	600	200	223.45	77.75	0.437
		4-10	Stiff to hard brown lean to fat CLAY (CL,CH)		19.93	15	112	0	750	240	337.6	117.1	0.442
18.	S_3	0-12	Soft to medium black, brown, green light, green lean to fat CLAY (CL,CH)	1.7	19.5	15.2	90	3	434	110	70.54	24.06	0.466
		12-14	Loose grey silty SAND (SM)		20.8	18	0	41	500	145	129.7	44.6	0.454
		14-15	Very stiff brown, green lean CLAY(CL)		20.8	17	191	0	600	166	170.56	58.45	0.459
19.	S_4	0-10	Very soft to very stiff brown lean or fat CLAY(CL,CH)	1.0	18.37	13.92	40	0	550	138	104.6	35.7	0.466
		10-13	Grey silty SAND (SM)		19.63	15.54	0	37	334	103	61.8	21.23	0.455
		13-15	Very soft to very stiff brown lean CLAY (CL)		20.02	16.03	48	0	450	102	62.57	21.24	0.473
20.	S_5	0-3.7	Grey gypseous SAND (SM)	1.8	18.18	-	5.33	38.6	566	230	244.6	87.29	0.401
		3.7-15	Grey gypseous silty SAND (SM)		19.16	-	8.4	40.5	1404	365	682.52	233.14	0.463

Table 5. Site soil classification (after the Preliminary draft of Iraqi seismic code, submitted to **Central Organization for Standardization and Quality Control COSQC, 2013** .

<table>
<tr><th>Site Class Definition</th><th>V_s</th><th>N or N_{ch}</th><th>S_u</th></tr>
<tr><td>A
Hard rock</td><td>>1500 m/s</td><td>-</td><td>-</td></tr>
<tr><td>B
Rock</td><td>760 to 1500 m/s</td><td>-</td><td>-</td></tr>
<tr><td>C
Very dense soil or soft rock</td><td>370 to 760 m/s</td><td>>50</td><td>>100kPa</td></tr>
<tr><td>D
Hard soil</td><td>180 to 370 m/s</td><td>15 to 50</td><td>50 to 100 kPa</td></tr>
<tr><td rowspan="2">E
Soft clayey soil</td><td><180 m/s</td><td><15</td><td><50kPa</td></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td>F
Soil types that require a special field assessment</td><td colspan="3">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.</td></tr>
</table>

Table 6. 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 7. 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	< l5	< 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 with *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			

Table 8. Iraq site soil classification.

No.	Site	Max. depth of Geophysical Investigations (m)	V_s (m/s)	Iraqi Seismic Code and FEMA 2010	Eurocode 8
1	N_1	10	312	D	C
2	N_2	20	330	D	C
3	N_3	10	304	D	C
4	M_1	15	217	D	C
5	M_2	15	245	D	C
6	M_3	12	177	E	D
7	M_4	11	190	D	C
8	M_5	20	240	D	C
9	M_6	16	198	D	C
10	WS_1	22	466	C	B
11	WS_2	14	306	D	C
12	WS_3	10	514	C	B
13	ES_1	10	185	D	C
14	ES_2	17	237	D	C
15	ES_3	18	243	D	C
16	S_1	10	198	D	C
17	S_2	10	222	D	C
18	S_3	15	116	E	D
19	S_4	15	124	E	D
20	S_5	15	319	D	C