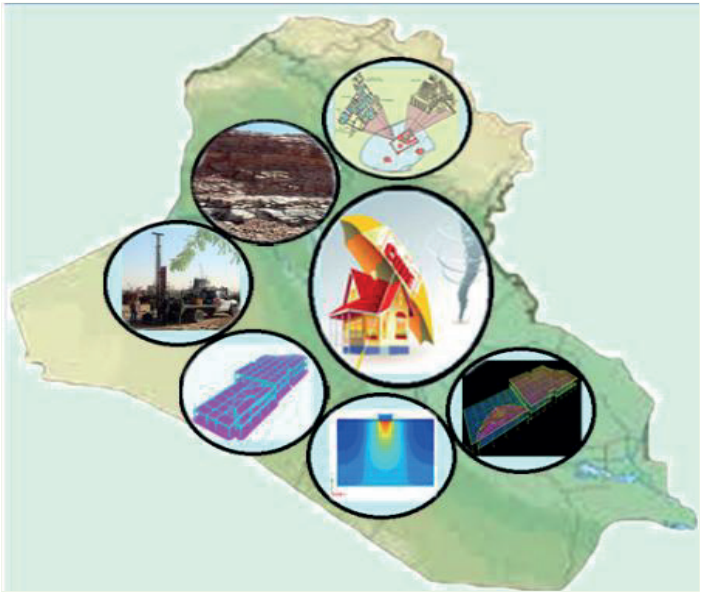
DOCTORAL THESIS

Analysis of Shallow Foundations in Three Different Regions in Iraq



Entidhar Al-Taie

Soil Mechanics

LULEÅ UNIVERSITY OF TECHNOLOGY

Analysis of Shallow Foundations in Three Different Regions in Iraq

A THESIS SUBMITTED

BY

Entidhar Talib Humadi Al-Taie

To

DEPARTMENT OF CIVIL, ENVIRONMENTAL AND NATURAL RESOURCES ENGINEERING

DIVISION OF MINING AND GEOTECHNICAL ENGINEERING

LULEÅ UNIVERSITY OF TECHNOLOGY

AS PARTIAL FULFILLMENT OF THE REQUIREMENT

FOR THE DEGREE OF

Doctor of Philosophy

In

Soil Mechanics and Foundation Engineering

SUPERVISORS
Professor Sven Knutsson
Professor Nadhir Al-Ansari

Printed by Luleå University of Technology, Graphic Production 2016

ISSN 1402-1544
ISBN 978-91-7583-522-8 (print)
ISBN 978-91-7583-523-5 (pdf)

Luleå 2016

www.ltu.se

This work is dedicated with love and grateful to:

My great mother: your tips and love always with me,

My father and my sister: your spirits always with me,

My husband Abdul Rahman: your support is inestimable,

Eva, Alaa, Oudai and Zina: your trust encouraged me,

Wahag, Awag, Mnar and Ibrahim: you are my happiness.

ACKNOWLEDGEMENT

This Doctoral thesis is the outcome of my work carried out at the division of Mining and Geotechnical engineering at the department of Civil, Environmental and Natural Resources in Luleå University of Technology. I like to express my special appreciation and thanks to:

- My supervisors Professor Sven Knutsson and Professor Nadhir Al-Ansari for their continued support, encouragement, guidance during all the stages of the work.
- The Iraqi Ministry of Higher Education and Scientific Research for offering the opportunity to take the doctoral through their financial support.
- Universities / Engineering college of Mosul and Basrah for their technical and financial support during my field and laboratory works.
- All my friends who supported me and incentive me to strive towards my goal.
- My aunt Khawater Al-Zubaidi for her help and support.
- A special thanks to my family. Words cannot express how grateful I am. Especially to my mother spirit (your prayer for me was what sustained me thus far).

At the end I would like express appreciation to my beloved husband Abdul Rahman who spent sleepless nights with and was always my support in the moments when there was no one to answer my queries.

"God keeps Iraq and restores his peace and love"

Entidhar Altaie
Luleå – November, 2015

ABSTRACT

Cost, time and quality are the main targets in the design and implementation of any foundation. It represents an important part of any building, dam, bridge, tower, etc. The design of foundations requires: the load that will be transmitted by the structure to the foundation, knowledge of the geological conditions in order to understand the type of soil that is presented under the foundation e.g. soil nature, soil layers and groundwater depth, the behavior and stress of soil. In addition the standards of the building codes are of importance. Most problems that appear in Iraq during implementation and after finishing are related to soil and concrete problems. Especially, problems due to water or aggregate (stone and sand) or in cement manufacturing. This thesis aims to analyze soil and shallow foundations of buildings to reach the optimal type should be used to minimize cost with control over quality. Also, suggested a new sustainable material mixture for the three regions of Iraq. Mosul, Baghdad and Basrah are the regions chosen for study due to the great variation in the geology and the soil conditions. Soil investigations were done for twenty three sites in different locations of the three regions in Iraq. The geotechnical assessment included field investigations and laboratory tests. Laboratory testing was carried out to aid soil classification and to evaluate the engineering properties for the subsurface soil. The results obtained from soil exploration were adopted in the calculations of settlements and bearing capacities for foundation design. The results indicated that the soil in Mosul had high to very high plasticity. In Baghdad, the results showed that the soil had medium plasticity. Plasticity of soil in Basrah region was medium to low. The outcomes from the calculations which were based on field and laboratory tests were used to obtain the average and minimum values of the bearing capacity to be used in the proposed model. Computer models were conducted using STAAD Pro.*v8i,* SAP2000 & SAFE and PLAXIS softwares for design and analysis. All the models were applied for the three regions (Mosul, Baghdad and Basra) in Iraq. The building used in all softwares was (an existed building from Mosul university) of two stories (ground & 1st flower). Mat foundation was suggested for the building. A new concrete mixture using crushed bricks as a coarse aggregate was used to study the effect of foundation stresses on the soil. Results obtained from the softwares indicated that: the soil in some sites requires improvement before implementation of any building. The suitable type of foundation that should be used in the three regions of Iraq is shallow foundation type (continuous or strip and raft). Deep type foundation is suitable to be used for some parts of Basrah region. Finally, the results' showed that using a crushed bricks as an aggregate in the concrete mixture will reduce the base pressure under the foundation as well as it is a durable material with low weight.

1. Entidhar Al-Taie, Nadhir Al- Ansari, Sven Knutsson**,** 2012**, *Progress of Building Materials and Foundation Engineering in Ancient Iraq,*** Advanced Materials Research Vols. 446-449 (2012) pp 220-241, Online available since 2012/Jan/24 at www.scientific.net.

2. Entidhar Al-Taie, Nadhir Al-Ansari and Sven Knutsson, 2012, ***Materials and the Style of Buildings used in Iraq during the Islamic period,*** Journal of Earth Sciences and Geotechnical Engineering, vol. 2, no. 2, 2012, 69-97. http://www.scienpress.com/Upload/GEO/Vol%202_2_6.pdf

3. Entidhar Al-Taie, Nadhir Al-Ansari and Sven Knutsson, 2012, ***The Progress of Buildings Style and Materials from the Ottoman and British Occupations of Iraq,*** Journal of Earth Sciences and Geotechnical Engineering, vol. 2, no.2, 2012, 39-49. http://www.scienpress.com/Upload/GEO/Vol%202_2_4.pdf

4. Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson and Tarek Edrees Saaed, 2013, ***Foundation Assessment in Different Parts of Iraq Using STAAD Pro V8i***, Journal of Civil Engineering and Architecture, Mar., Volume 7, No. 3 (Serial No. 64), pp. 273-281, USA. http://www.scienpress.com/Upload/GEO/Vol%204_4_3.pdf

5. Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2014, ***Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i***, Engineering, 6, 292-303, Published Online May 2014 in SciRes. http://www.scirp.org/journal/eng http://dx.doi.org/10.4236/eng.2014.66033.

6. Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2014, ***The Need to Develop a Building Code for Iraq,*** Engineering, 6, 610-632, Published Online September 2014 in SciRes. http://www.scirp.org/journal/eng , http://dx.doi.org/10.4236/eng.2014.610062.

7. Entidhar Al-Taie, Nadhir Al-Ansari, Tarek Edrees Saaed and Sven Knutsson, 2014, ***Bearing Capacity Affecting the Design of Shallow Foundation in Various Regions of Iraq Using SAP200 & SAFE softwares,*** Journal of Earth Sciences and Geotechnical, Engineering, vol. 4, no. 4, 35-52. http://www.scienpress.com/Upload/GEO/Vol%204_4_3.pdf

8. Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2015, ***Estimation of settlement under shallow foundation for different regions in Iraq using SAFE software***, Engineering, 2015, 7, 379-386. Published Online July 2015 in SciRes. http://www.scirp.org/journal/eng, http://dx.doi.org/10.4236/eng.2015.77034 .

9. Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2015**, *Evaluation of Foundation Settlement under Various Added Loads in Different locations of Iraq Using Finite Element***, *to be submitted to an international journal.*

10. Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2015, ***Effect of Material Used in Concrete Mixture on the Foundation Stresses on Soil,*** Engineering, 2015, 7, 668-675, Published Online October 2015 in SciRes. http://www.scirp.org/journal/eng, http://dx.doi.org/10.4236/eng.2015.710058

Table of Contents

THESIS CHAPTERS

PART ONE

1. General Background

Cost, time and quality are the main targets for the design and implementation of any foundation. It represents an important part of any building, dam, bridge, tower, etc. The design of foundations of structures requires: the loads that is transmitted by the structure to the foundation, knowledge of the geological conditions in order to understand the type of soil that is present under the foundation e.g. soil nature, soil layers and groundwater depth, the behavior and stress condition of the soil. In addition the standards of the building codes are of importance. It is important to have a good feedback about the project site, because soil nature is heterogeneous. For soil, field investigations and laboratory tests are often required. In addition, information about the geology of the site will be helpful for the designer. Therefore, tests and identifications for soil and rocks must be ` achieved at each new site before conducting any analysis. Soil is also a foundation for the structure and carries the entire load coming from above. The parameters of soil that must be defined for design purposes are: the grain size distributions, shear strength, plasticity, and compressibility (*Bowles, 1996; Das, 2011*). For that, design process must start with site investigations to define the types and the mechanical and the chemical properties of the soil. This should be done as all types of soil do not have the same and unique stress-strain relationship. Its behavior is affected by the pressure, time, environment, and many other parameters. The properties found in the soil samples from any location are affected by various factors such as geology of the area, topography, and the methods of soil sampling (disturbed and undisturbed) (*Kameswara Rao, 2011; Das, 2011*).

Designing and modeling of foundations and structures need two engineering disciplines: the structural engineer to design the structure and the geotechnical engineer to obtain the settlement and bearing capacity of the soil. An overview of the actors and factors must be considered when realizing the structure and foundation. Figure 1.1 illustrates the factors and actors which are involved in modeling foundation structures (*Breeveld, 2013*).

The oldest civilizations in the world started in Iraq and many of the remnants ancient buildings still exist till now. Now a day, the Iraqi designers are adopting new style in their designs which is unsuitable for the environment of Iraq e.g. the interfaces of buildings designed from many concrete decorations works, the insulations in the buildings not considered. This has been reflected on the quantities of materials used and the time of implementation of construction projects. Although, climatic conditions, soil and geology of Iraq is not the same all over Iraq, however, the design and materials used in the constructions are the same. Designers were paying attention to the outside building's aesthetic without attention to the internal constructions and building services. Moreover, these constructions takes long time to implement, costly, and the thermal insulations are not considered for the buildings by designers.

Normally, in Iraq foundations are constructed by use of reinforce concrete. Concrete is a building material that maintains its properties in a good condition during the life of the building (*Babor, et al, 2007*). Concrete is a mixture of cement, aggregate (sand and gravel) and water, mixed by certain percentages in order to achieve certain properties when hardened. Concrete problems in Iraq mostly related to the water salinity and aggregates (stone and sand) (*Al-Haiti, et, al, 2007; Abboud, 2013*). These problems appear in the building's columns or roof or some times in the floors. For that, a necessary experiments should be conducted to prevent any damages occurs during or after constructions due to concrete use in the buildings.

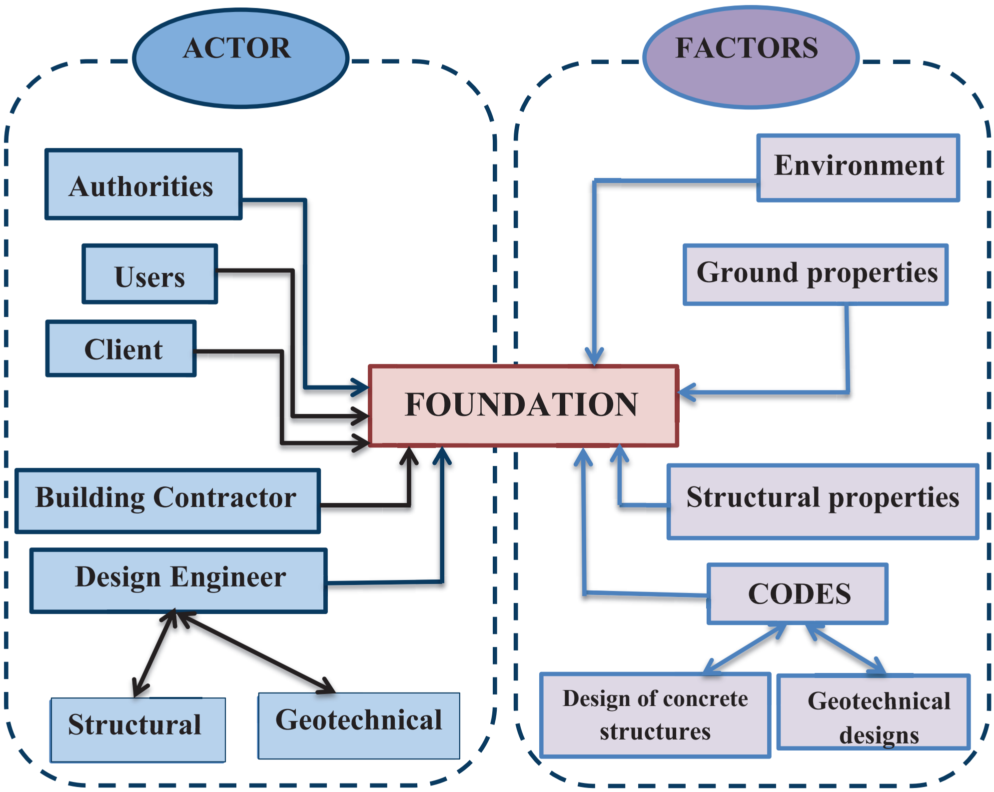


Figure1. 1: Actors and factors involved in modeling foundations (*Breeveld, 2013*).

1.1.The novelties of the work

The novelties and the contribution of the thesis work are as follows:

- Reviewing the historical types of foundations and materials that were used in Iraq for buildings since the dawn of civilization until now.
- Geotechnical assessment for three regions of Iraq of different geology and soil properties (north, middle, and south).
- Coupling between SAP2000 and SAFE for foundation design.
- Comparison of the stresses of constructed building using sustainable materials (crushed bricks in concrete mixture) to the stresses of the same building used of the previous standard concrete on the soil for the three locations.

1.2.Objectives

It is obvious that the geology and the soil properties in Iraq vary greatly in the northern, middle and southern parts of the country. The aim of the analysis of the shallow foundation is to reach the optimal foundation type that should be used to minimize cost with better control over quality.

The main objectives of the thesis are:

1. Geotechnical assessments to define the physical and mechanical properties of the soil in the study areas.

2. Verify the base pressure and settlements under shallow building foundation in the study areas using the suitable softwares.
3. Evaluating soil stresses from building constructed by the suggested new sustainable material (crushed bricks in concrete mixture) to be used for the study areas.

1.3.Methodology

To achieve the aims of this study, the research work was carried out in three different regions (Mosul in the north, Baghdad in the middle, and Basra in the south of Iraq) according to the following:

- Geotechnical assessments: Samples were collected from different locations in the three regions. Standard penetration tests (SPT) have been done in some sites. Laboratory tests: Atterberg limits test, sieve and hydrometers test, oedometer, direct shear, unconfined compression tests were conducted.
- Computer Modelling: Using STAAD Pro*v8i* and SAP200&SAFE softwares for foundation design and analysis of a building in the three regions to choose the optimal type of foundation for the three regions. PLAXIS software and numerical calculations were used to evaluate the settlement under different added loads in the three regions.
- Using STAAD Pro*v8i* software to evaluate the base pressure under foundation using new concrete mixture with sustainable material (crushed bricks).

1.4.Thesis outline

The thesis comprises two parts. The first one includes the chapters that describe the methodology of work (geotechnical assessments), computer models and the performance analysis. It ends with a discussion of the modeling outputs. The second part contains ten scientific articles that are related to the objectives of the thesis.

Part I: Consists of 7 chapters. A brief summary for each chapter is given below:

Chapter 1

General introduction to the thesis.

Chapter 2

Historical review of the types of foundations and materials used in Iraq since the dawn of civilization, up until now.

Chapter 3

Clarifying the criteria for foundation design and their importance for safe and stable foundation. The importance of building codes is briefly described and a simple comparison between European and American codes is performed. The requirements for materials used in foundations and their problems in Iraq are presented. Study the possibility of use of sustainable material (new concrete mixture).

Chapter 4

Describe the geology and the soil conditions in the three regions (Mosul, Baghdad, and Basra) of Iraq. Explain the soil investigations and laboratory tests that had been conducted in the study areas. The parameters established from these investigations, I used for the analysis and design of foundations.

Chapter 5

Finding the suitable foundation for each region using STAAD Pro and SAFE softwares for the design and analysis. Settlements were estimated in the three regions using SAFE software. PLAIXS software was used to estimate settlements under different added loads. New parameters (density and modulus of elasticity) of new concrete mixture (use crushed bricks) used in STAAD Pro software to check the effect of foundation stresses on the soil beneath it.

Chapter 6

Discussion and assessment of the results.

Chapter 7

Conclusions, recommendations and future work.

Part II: *Appended papers*

The following papers are appended in the second part of the thesis.

- ***Paper one***

  Entidhar Al-Taie, Nadhir Al- Ansari, Sven Knutsson, 2012, ***Progress of Building Materials and Foundation Engineering in Ancient Iraq***, Advanced Materials Research Vols. 446-449 (2012) pp 220-241, Online available since 2012/Jan/24 at www.scientific.net.

- ***Paper two***

  Entidhar Al-Taie, Nadhir Al-Ansari and Sven Knutsson, 2012, ***Materials and the Style of Buildings used in Iraq during the Islamic period,*** Journal of Earth Sciences and Geotechnical Engineering, vol. 2, no. 2, 2012, 69-97.
  http://www.scienpress.com/Upload/GEO/Vol%202_2_6.pdf

- ***Paper three***

  Entidhar Al-Taie, Nadhir Al-Ansari and Sven Knutsson, 2012, ***The Progress of Buildings Style and Materials from the Ottoman and British Occupations of Iraq,*** Journal of Earth Sciences and Geotechnical Engineering, vol. 2, no.2, 2012, 39-49.
  http://www.scienpress.com/Upload/GEO/Vol%202_2_4.pdf

- ***Paper four***

  Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson and Tarek Edrees Saaed, 2013, ***Foundation Assessment in Different Parts of Iraq Using STAAD Pro V8i***, Journal of Civil Engineering and Architecture, Mar., Volume 7, No. 3 (Serial No. 64), pp. 273-281, USA.
  http://www.scienpress.com/Upload/GEO/Vol%204_4_3.pdf

- ***Paper five***

  Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2014, ***Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i,*** Engineering, 6, 292-303, Published Online May 2014 in SciRes.
  http://www.scirp.org/journal/eng, http://dx.doi.org/10.4236/eng.2014.66033.

- ***Paper six***

  Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2014, ***The Need to Develop a Building Code for Iraq,*** Engineering**,** 6, 610-632**,** Published Online September 2014 in SciRes.
  http://www.scirp.org/journal/eng **,** http://dx.doi.org/10.4236/eng.2014.610062.

- ***Paper seven***

  Entidhar Al-Taie, Nadhir Al-Ansari, Tarek Edrees Saaed and Sven Knutsson, 2014, ***Bearing Capacity Affecting the Design of Shallow Foundation in Various Regions of Iraq Using SAP200 & SAFE softwares,*** Journal of Earth Sciences and Geotechnical Engineering, vol. 4, no. 4, 35-52.
  http://www.scienpress.com/Upload/GEO/Vol%204_4_3.pdf

- ***Paper eight***

  Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2015, ***Estimation of settlement under shallow foundation for different regions in Iraq using SAFE software***, Engineering, 7, 379-386. Published Online July 2015 in SciRes,
  http://www.scirp.org/journal/eng , http://dx.doi.org/10.4236/eng.2015.77034

- ***Paper nine***

  Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson, 2015, ***Evaluation of Foundation Settlement under Various Added Loads in Different locations of Iraq Using Finite Element***, *to be submitted to an international journal.*

- ***Paper ten***

  Entidhar Al-Taie1, Nadhir Al-Ansari, Sven Knutsson, 2015, ***Effect of Material Using in Concrete Mixing in the Foundation Stress on Soil,*** Engineering, 2015, 7, 668-675, Published Online October 2015 in SciRes.
  http://www.scirp.org/journal/eng, http://dx.doi.org/10.4236/eng.2015.710058

2. Introduction

The history of foundation types and materials which are used in Iraq will be reviewed for the period between 150,000 BC- 1958 AD in this chapter. The aim of this review was to highlight the types of foundations and materials which were used and enabled these buildings to remain for a long period of time (*for more details see papers No. 1; 2 and 3*) (*Al-Taie, et, al, 2012*).

Buildings reflect the culture, environment and economy of the society. Humans have recognized the importance of constructions since the beginning of civilization. The prevailing methodology was that the weight is moved starting from the roof to the columns then to the foundations and then to the soil. Humans recognized the importance of foundations to hold the structures (*Kamona, 2010*). Iraqi history can be divided into three periods: Ancient Iraq, Islamic period, and the Ottoman and British occupations and the present situation.

2.1. Ancient Iraq (150,000 BC- 226 AD)

Humans started to build circular habitations with the foundations over the ground using natural large stones for construction (Figure 2.1). Later, they began to build rectangular constructions with foundations under the ground surface. Materials used for foundations were stones in the northern part of Iraq. Palaces were built in square shapes with foundations that had thicknesses ranging from 2.80 to 3.20m for the outside walls (Figure 2.2). The foundation of the internal walls had a thickness ranging from 1.60 to 2 m. Liben (mixture of clay and the remains of barley) was used in construction of the foundations of convex-straight type, which was put in zigzag rows (*Seton, 1993; Yuosaf, 1982*) (*for more details see paper No.1*).

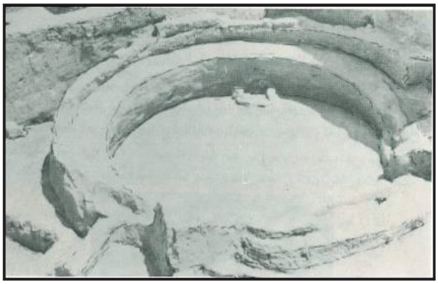


Figure 2.1: The Round House (*Yuosaf, 1982*).

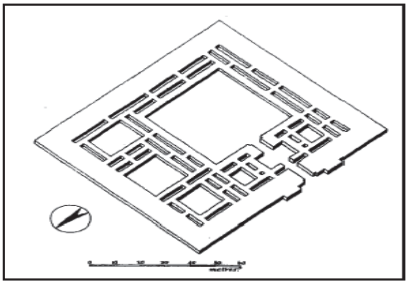


Figure 2.2: Foundation palace plan (*Sileman, 1985*).

The foundation type used was terraces for palaces, Ziggurats (they are solid high building consisted of several layers topped with small temple) and temples were built in north, center and south parts of Iraq. In the northern part of Iraq, the Assyrian built their town Dor-Churkin or Khorspad on 12m high terraces as a foundation (Figure 2.3). Helan (local limestone) and trimmed stone material was used for the buildings (*George Rawlinson, 2012*). In central part of Iraq, Ziggurats were composed of five to seven layers, such as Ziggurat of Dor- Kurigalzu and the Babylon tower. The construction material was made of square liben (45*45*10cm) which was made of silty clay soil or sandy clay soil. Tar and lime were used as plaster in the foundations of the buildings. They are moisture proof and have good cohesion (*Mohammad, 1977*). In the southern part they used liben material in the terraces' constructed as foundations.

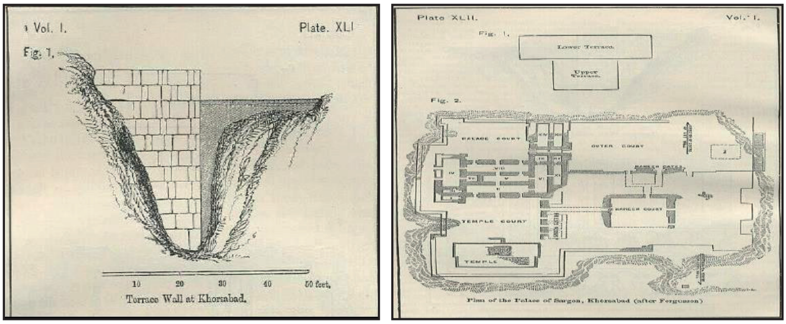


Figure 2.3: Details of Khorsabad's Terrace and palace (*George Rawlinson, 2012*)

2.2. Islamic period (637- 1639) AD

The Islamic engineers used to prepare the plan drawing and calculated the cost and quantities of materials required in the constructions (*Al-Mosawi, 1982*). The weather conditions, availability of construction materials, appropriate construction and harmony with the surrounding environment, the topography and the soil type were all factors taken into consideration. At the beginning of this period, the first foundation type used was mud mixed using a special technique referred to as "Bakla". Later stones were used for the construction of the foundations of the palaces and mosques. Houses had basements under the ground to be used during summer. The roofs of the basements had shapes like arches to provide strength, durability to bear the loads over them. The construction materials used in the buildings in Mosul city were natural stones, geometric stones (stone is cutting in forms of square or rectangular cubes), gravel and wage (burnt mud on temperature between 950^o to 1200^o). The type of foundations was continuous or stripe and most of the buildings had basements (*Al-Mosawi, 1982*). The second types of foundation used for the buildings and fence (around Baghdad city) were spread. The material used in construction was liben of two sizes; the first was of size (0.915*0.915) m and weighing 200Kg and used for foundation. The second size was (0.915*0.458) m and weighing 100 kg. A terrace was the third type of foundation used for the minarets of the mosques such as Caliphs mosque, and the famous Samara mosque (Malwya), etc. (*Al-Alaaf, 1999*) (*for more details see paper No.2*).

2.3. Ottoman and British occupation period (1639-1958) AD

During the Ottoman period no real development in buildings took place. Despite the changes in the ways of buildings construction all the methods used local natural materials for constructions. This gave a special identity to the buildings. The constructions focused on the building of mosques like Alkhaski mosque, Ahmadiyya mosque, and Hayderkhanah mosque. Locally available raw materials were mixed in different ways to get it stronger and stiffer to suit the Iraqi climate. The foundations were (1.5-1.0) m in depth below ground surface for good ground, but in bad ground their depth reached 3m below ground surface. Foundation material used was broken wage and lime with ash as mortar. This type of mortar was used up to 1m over the ground (*Reuther, 2005-2006*). Al-Qishla famous building located on the bank of Tigris River in Baghdad. It is considered as a turning point in the history of Iraqi construction. It was built in a new style influenced by the Italian style and was built to be military barracks. Local materials like wage and gypsum were used during its construction. The type of foundation used was strip (Figure 2.4) with dimensions of 2m width in the top

(same as the walls of the building) ended inside the ground with 6.5m width. A layer of stone was put under bricks foundation (*Al-Silq, 2011; Ministry of Culture and Information, 1987*).
The British occupation period marked the start of new ways and styles of design, building, and materials used. The new materials such as cement and iron (Schliemann is H shape of iron used in the roofs of the building) were used for the first time in Iraq during this period (*Al-Sultani, 2009*) (*for more details see paper No.3*).

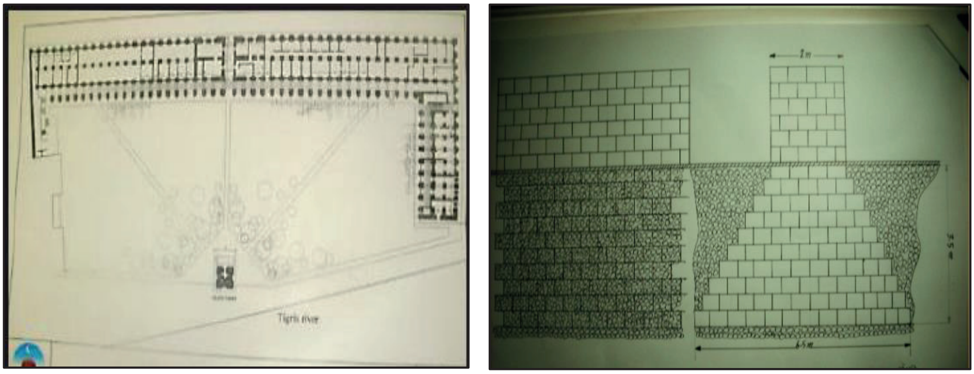


Figure 2.4: Plan and Foundation of Qishla building (*Ministry of Culture and Information, 1987).*

Present situation

From 1958 to the present, the style of building changed in Iraq. New and modern construction materials, equipments and technologies started to be used. The Iraqis sought to take advantage of modern technology and materials for their work (*Abdul Rasul, 1987*). Construction with new style is not suitable to the environment of Iraq. The modern buildings developed and grew among urban pattern. The new pattern of the city was different from of traditional city planning which developed randomly according to the expansion circumstances (*Nasir, 2009*). The types of foundations used are of two types: shallow and deep (Figure 2.5). Most of middle and some of the south areas of Iraq use the raft foundation type. Whilst, in other parts of the southern of Iraq is more likely type to be used piles, because the soil properties are not very good.

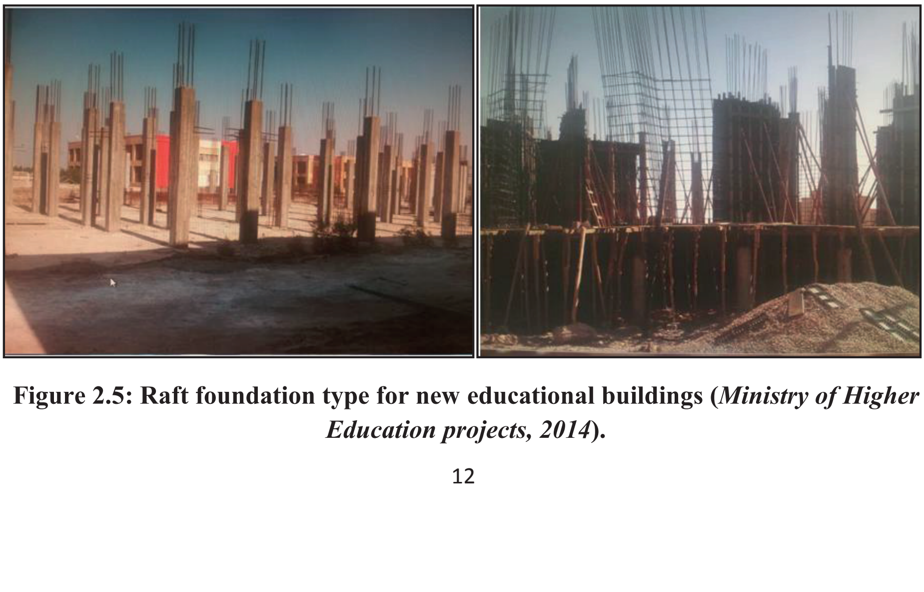


Figure 2.5: Raft foundation type for new educational buildings (*Ministry of Higher Education projects, 2014*).

3. Introduction

Foundation is the most important part which connects the superstructure with ground. They are often divided into two categories: shallow which include two types and deep foundations include different types as shown in figure3.1. All materials used in buildings are artificial materials. They are produced according to the international standards or codes, such as steel, concrete, etc. and the properties are well known for the structural engineers. Soil is natural materials need site investigations and laboratory tests to defined its properties. In addition, information regarding the geology at the site will help the designer. Therefore, tests and identifications of the soil and rock have to be done at each site before conducting any analysis and design (*Bowles, 1996; Coduto, 2001*).

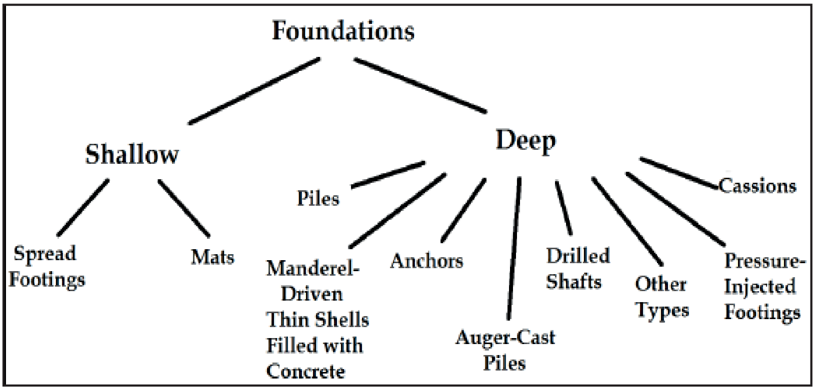


Figure 3.1: Foundations types (*Coduto, 2001*).

3.1. Parameters affecting design of foundation

Soil parameters that must be defined for design purposes are: the grain size distributions, shear strength, plasticity, and compressibility. These parameters can be determined both by field and laboratory tests (*Lui, et al, 2008; Das, 1999*). The important requirements for the design of safe and stable foundations are: stability i.e. bearing capacity and settlement.

3.1.1. Bearing capacity

Bearing capacity is defined as the capacity of the soil to carry the load applied from superstructure and foundation. This has to be done without shear failure or excessive settlement. The maximum stress that can be applied to a given soil without getting shear failure is called the ultimate bearing capacity ($\mathbf{q_{ult}}$). While, the allowable bearing capacity is the maximum soil pressure that can be applied taking a factor of safety into consideration as well as other factors like settlement (*Das, 2011*).

The stress from the foundation is transmitted into the under laying soil layers and this influences the stresses. The stress increase has to be considered for both shallow and deep foundations. Figure (3.2) shows the theoretical vertical stress distribution under a square footing and pile foundation from the ground surface. The vertical stress is decrease with depth. The stress under the square foundation decrease until the depth under the foundation became 5B (width of the foundation) the stress value will be zero (*Bowles, 1996*).

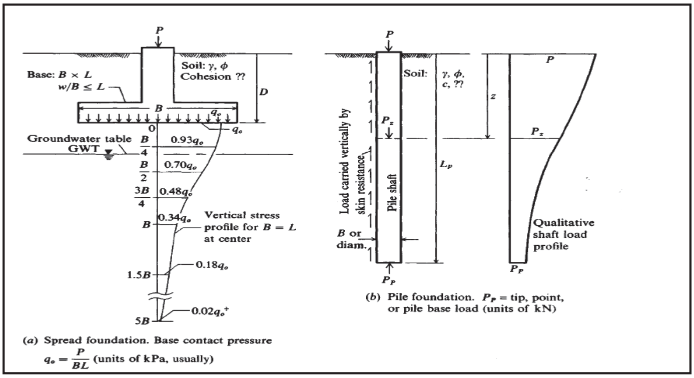


Figure 3.2: The theoretical vertical stress distribution under a square footing and pile (*Bowles, 1996*).

Bearing capacity of a soil depends upon different factors such as the original stresses in the soil strata, groundwater level, mechanical properties i.e. density, shear strength. In addition the type, geometry and foundation level of the footing also have impact on the bearing capacity (*Das, 2011*).

3.1.1.1. Calculations of bearing capacity

The bearing capacity of a soil is obtained by using the general bearing capacity equation. Parameters used in this can be obtained by using field test methods such as standard penetration test (SPT), cone penetration test (CPT) and plate loading test. Parameters can also be obtained from laboratory tests performed on samples taken. These are preferably to be undisturbed if clays are involved. Laboratory test are frequently direct shear, unconfined compression and/or triaxial tests. From these the angle of friction (**φ**) and cohesion (**c**) is evaluated. The ultimate bearing capacity (**q_{ult}**) can be obtained by using the general bearing capacity equation (*Das, 2011*):

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where: c: cohesion of soil (kPa).

q: effective stress at the level of the foundation (kPa); due to overburden.

B: width of foundation (m).

γ: unit weight of soil (KN/m^3).

N_c, N_q, N_γ: bearing capacity factors, (obtained from tables and being based upon analysis of failure modes).

S_c, S_q, S_γ: shape factors.

d_c, d_q, d_γ: depth factors.

i_c, i_q, i_γ: load inclination factors.

g_c, g_q, g_γ: ground inclination factors.

b_c, b_q, b_γ: base inclination factors.
The depth, shape, and load inclinations are empirical factors depend on experimental data.
Moreover, unconfined compression test can be used to obtain undrained shear strength (C_u) value, depending upon the measurement of unconfined compression strength (q_u) (*Gunaratne, 2012*):

$$C_u = {}^{1}/_{2}\, q_u \quad \ldots\ldots 2$$

Where: C_u = undrained shear strength (kPa).
q_u = ultimate unconfined compression strength (kPa).
Then use the (C_u) value in equation (No. 1) to calculate the bearing capacity of the soil.
Another method for determine the bearing capacity of soil use of the standard penetration test (SPT). The measured of N values from SPT field test should be corrected using a formula recommended by Terzaghi and Peck, 1967. The N correction value use to define the empirical values for relative density (D_r), unit weight (γ_{wet}), angle of internal friction (ϕ) and unconfined compression strength (q_u) from specified tables (*Bowles, 1996*).

3.1.2. Settlement

Foundation settlement must be estimated carefully to ensure stability of buildings, towers, bridges, etc. Settlement is divided into immediate (or elastic) and consolidation settlement (primary and secondary phases) as shown in figure 3.3 (*Liu, et al, 2008*).
Foundation settlements (immediate, consolidation) are estimated depending on the calculated stresses in the soil mass related to foundation pressure (*Shahriar, et al. 2013*). Immediate settlement is usually estimated according to the elastic theory, which assumes that the soil may behave elastically (*Murthy, 2002*). While, the consolidation settlement is strain analysis of saturated clay subjected to the increase of stress (Das, 1999).

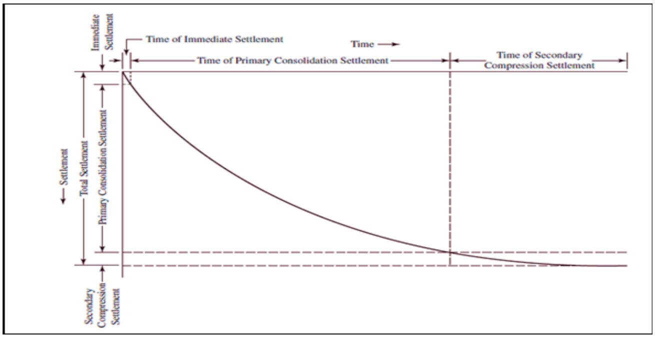


Figure 3.3: Time-settlement relation (immediate settlement, consolidation, and secondary compression settlement), (*Liu, et al,*

3.1.2.1. Settlement calculations

Immediate or elastic settlement depends upon the type of foundation and the soil on which it is resting. The Poisson's ratio (μ') and the modules of elasticity (E_s) are the parameters used to calculate immediate settlement under shallow foundation as (*Bowles, 1996*):

$$S_e = q_o B \frac{1-\mu'}{E_s} I_s \ldots \mathbf{3}$$

Where: S_e = immediate settlement for flexible foundation (m).
I_s = influence factor (depend on L/B and depth of foundation and Poisson's ratio).
B = width of foundation (m).
q_o = applied pressure (kPa).

The immediate settlement under rigid foundation is estimated according to the following formula (*Das, 1999*):

$$S_{e(rigid)} = 0.93 S_{e(flexible)} \ldots \mathbf{4}$$

The consolidation settlement is the process of soil volume decrease under vertical strain. It calculated for normal and overconsolidated soils depending on the parameters (compression index **C_c**, swelling index **C_s**, and void ratio **e)** obtained from the oedometer test. The following equation is used to calculate settlement in the normal consolidation soil (soil has the initial vertical stress equal to the final vertical stress) (*Murthy, 2002*):

$$S_c = \frac{C_c}{1+e_o} H \log\left(\frac{\sigma_o' + \Delta\sigma'}{\sigma_o'}\right) \ldots \mathbf{5}$$

Where: S_c = consolidation settlement (m).
H = thickness of soil layer (m).
σ_o'= effective overburden pressure (kPa).
$\Delta\sigma'$ = change in the effective stress (kPa) due to loading.

While, for overconsolidated soil (soil has final effective stress is less than the initial vertical stress) the following equations are using:

$$S_c = \frac{C_s H}{1+e_o} \log\left(\frac{\sigma_o' + \Delta\sigma'}{\sigma_o'}\right) \ldots \text{for } \sigma_o' + \Delta\sigma' \leq \sigma_c' \ldots \mathbf{6}$$

$$S_c = \frac{C_s H}{1+e_o} \log\frac{\sigma_c'}{\sigma_o'} + \frac{C_c H}{1+e_o} \log\left(\frac{\sigma_o' + \Delta\sigma'}{\sigma_c'}\right) \ldots \textbf{for } \sigma_o' + \Delta\sigma' > \sigma_c' \ldots \mathbf{7}$$

3.2. Building codes

Building codes are documents containing standardized requirements which specify the minimum acceptable limit of safety for buildings. These codes are based upon the experience of engineers, experimental work and specific conditions. They determine the limitations for buildings against various risks like fire, structural collapse and amenity issues like ventilation, lighting, dampness, sound insulation and sanitation (*Building code, 2013; Cote, et al, 2008*).
First code was written by King Hammurabi (3000 BC) during early civilization in Babylon (*Yeager, 2013*). The code specified the rules of payment and the punishments to the builders caused harmful for people or buildings. Rules and regulations were introduced due to the disasters that were experienced in different parts of the world such as burning of Rome in 64 ADs, fires of London's in 1666 ADs, and the earthquake that hit San Francisco in 1906 (*Yeager, 2013*).

Most of the countries have their own national building codes. They are usually adopted and developed by governmental building institutes. Such codes are mainly based on one of the International codes (American codes or European codes).

3.2.1. American codes

United States of America issued two international codes: International Building Code (IBC) since 1997 and Building code requirements for structural concrete and commentary (ACI-318) since 1989 (*Ghosh, 2013*). In this thesis work was focused on the ACI-318.

- **ACI-318 (Building code requirements for structural concrete and commentary)**

Code is a document collecting many practice standards provided to the architects and civil, electrical and mechanical engineers (*ACI committee 38-08, 2008*). ACI-318 is the basic document for concrete building's design in USA, and it covers design materials and structural construction concrete for both reinforcing and precast and prestressed concrete. Additionally, the resistance factors (they are concrete strengths factored used in checking ultimate limit states) are increased by 10 to15 % during the last thirty years. Furthermore, it specifies the resistance factors, the design resistance and the load factors. The code was adopted by the IBC and become legal (*Nowak, et al, 2007*). ACI code covers 23 topics that deal with design and implementation of concrete, with six appendixes presenting all the requirements needed. For design of foundations the important codes to deal with are those dealing with geotechnical designs. They include geotechnical requirements. Concrete structure design code includes strength and serviceability requirements. Materials code includes all the materials used in concrete, as follows:

➔ *Geotechnical requirements*: This part is identifying the soils and the types of foundations that should be chosen in different situations are: Foundation walls, Retaining walls and Embedded posts and Poles, and Shallow and Deep foundations, etc. All the requirements for the types of tests and the equipment and its calibrations follow the American Society for Testing and Materials (ASTM) (*International code council, 2012*).

➔ *Strength and serviceability requirements:* The *demand* is considered as the strength required, while the *supply* as the actual strength. The required strength (U) kPa expressed as the design of the loads such as dead, live, wind and other loads. ACI code specifies the design requirements, shears and moments to be obtained from service loads by using the following relations (*ACI committee, 2011; Assakkaf, 2002*):

$$\boldsymbol{U = 1.2D + 1.6L} \quad \ldots \quad \mathbf{8}$$

For resisting wind load or earthquake load

$$\boldsymbol{U = 0.75(1.2D + 1.6L) + (1.0W or\ 1.0E)} \quad \ldots \quad \mathbf{9}$$

For lateral loads

$$\boldsymbol{U = 1.4D + 1.7L + 1.7H} \quad \ldots \quad \mathbf{10}$$

For temperature change:

$$\boldsymbol{U = 0.75(1.4W + 1.7L + 1.7T)} \quad \ldots \quad \mathbf{11}$$

Where: D = Dead load (kN/m^2).
L = Live load (kN/m^2).
W = Wind load (kN/m^2).
H = Loads due to weight and pressure of soil, water in soil or other materials (kN/m^2).
E = Load effects due to earthquake.
T = Cumulative effect of temperature, creep, shrinkage, differential settlement and Shrinkage-compensating concrete.

➔ *Materials:* The materials used in the foundations are reinforced concrete. Testing must be done for any materials used in concrete constructions to define if the materials are of the specified quality. Materials are cement, aggregates, water, admixtures and steel reinforcement. All the materials are conforming to the relevant specifications of ASTM.

3.2.2. European code [Eurocode]

Eurocodes are tools for safety of buildings and reliability enhancement. The objectives of Eurocodes are to improve civil engineering works and compliance of building. And putting a framework to harmonize the technical specifications for construction products and being the basis for specifying contracts. From 2007, until now, the Eurocodes are in a continuous evaluation process. Eurocode structure includes 58 documents of standards (Figure 3.4) (*Calgaro, 2006; Bond, et al, 2008*). Each part of the Eurocodes has a symbol and number to explain the purpose of the standard.

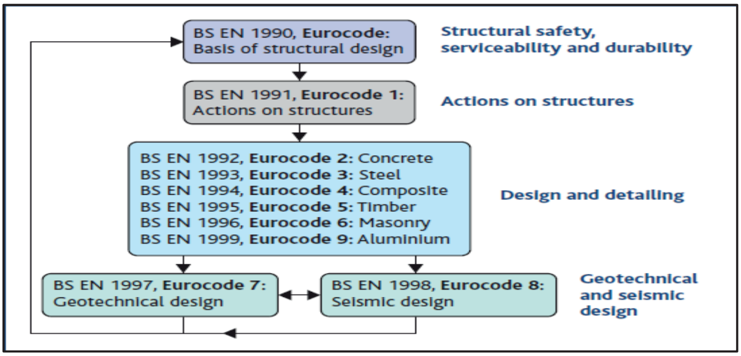


Figure 3.4: The Eurocodes structural (*Bound, et al, 2006*).

For design of foundations the important codes to deal with are the geotechnical design which includes geotechnical requirements and Basic of structural design, as follows:

➔ *Geotechnical design (EC7)***:** geotechnical design code is divided into three parts:

- ❖ ***ENV 1997-1*** includes basic geotechnical design (*European Committee for Standardization, NVE 1997-1, 1999*). Three categories are important, for geotechnical design requirements:
  - *Category 1*: Adequate only if there is no excavation under the water table. Structures are simple and based on experience and qualitative geotechnical investigations.
  - *Category 2*: Conventional types of structures and foundations are covered. Routine procedures for field and laboratory testing. Types of structures complying with geotechnical category are spread and raft foundations; piled foundations; walls and other structures retaining or supporting soil or water; etc.
  - *Category* 3: Structures that involve abnormal risks, unusual or exceptionally difficult ground or loading conditions and those in highly seismic areas that does not follow the limits of geotechnical categories mentioned in 1 and 2.
- ❖ ***ENV 1997-2*** includes all requirements needed for the design assisted by laboratory testing.
- ❖ ***ENV 1997-3*** includes all requirements needed for the design assisted by field testing (*European Committee for Standardization, NVE 1997-2 & 3, 1999*).

➔ *Materials*: Materials used in concrete must be suitable and do not contain harmful ingredients. These materials are cement, aggregates, water, admixtures and reinforcing steel. All the materials should be conforming specifications of EN (European Committee for Standardization ENV 1992-1-1, 2004).

➔ *Basic of structural design*: Eurocode EN1990 explains the requirements and principles for safety, durability and serviceability for structures. The basic requirements of a structure are influenced by serviceability and actions (resistance, durability), which are suitable for the design purpose. The structural Eurocodes are based on two limit states: the ultimate limit (ULS), and the serviceability limit states (SLS). The ultimate limit state requirements are subdivided into five broad categories as shown in figure 3.5. Each category has set of partial factors values (they are adjusting parameters to derived appropriate values for design calculations). They are connected to each other's and must be added in corresponding design calculations (*Orr, 2010; Smith, 2013*).
The calculation steps in foundation design are carried out according to STR (Strength) and GEO (Geotechnical). They are actions, materials and resistance. EN 1991 is a part that explains the actions (permanent and imposed) on structures (*Formichi, 2008*). The safety matters in the Eurocode should be decided by the National Annex, which includes information about the parameters for national choice and is known as Nationally Determined Parameters (NDPs). These parameters are related to geographical or climatic conditions such as snow map or wind map or way of life. Therefore, different levels of protection may prevail at a local regional or national level (*Calgaro, 2008*):

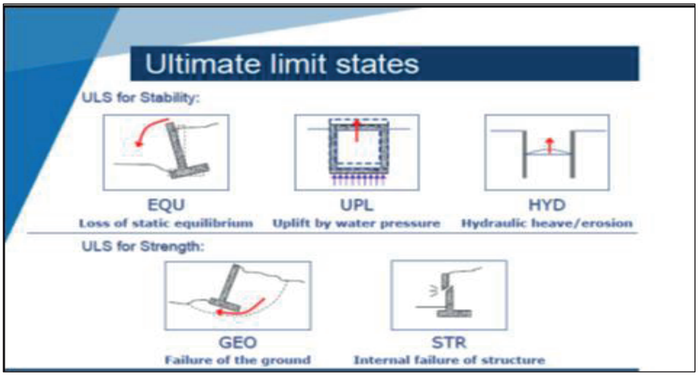


Figure 3.5: The categories of Ultimate limit state.

EN 1997 covers two approaches for determining the combination of actions for STR ultimate limit state. The first approach is applying in to the geotechnical actions as well as the actions on/from the structure. The second approach is applying in to the geotechnical actions and, simultaneously, applying partial factors to the other actions on/from the structure. **G** is permanent actions, **Q** is variable actions and **A** is accidental actions and can be found using the following equations:

First approach:

$$\sum_{j\geq 1} \gamma_{G,j}\, G_{K,j} + \gamma_P P + \gamma_{Q,1} Q_{K,1} + \sum_{j\geq 1} \gamma_{Q,i}\, \psi_{0,i} Q_{K,I} \quad \ldots\ldots 12$$

Second approaches:

$$\sum_{j\geq 1} \gamma_{G,j}\, G_{K,j} + \gamma_P P + \gamma_{Q,1} \psi_{0,1} Q_{K,1} + \sum_{j\geq 1} \gamma_{Q,i}\, \psi_{0.i} Q_{K,I} \quad \ldots\ldots 13$$

$$\sum_{i\geq 1} \xi_j \gamma_{G,j} G_{K,j} + \gamma_P P + \gamma_{Q,1} Q_{K,1} + \sum_{i\geq 1} \gamma_{Q,i} \psi_{0.i} Q_{K,I} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{14}$$

Where: $\sum$ = Implied 'the combined effect of'.

Ψ_o = A combination factor.

ξ = A reduction factor for unfavorable permanent actions G.

γ_G = A partial factor for permanent actions.

γ_p = A partial factor for prestressing actions.

γ_Q = A partial factor for variable actions.

P = Represents actions due to prestressing.

All the partial and combination factors values can be found in Annexes of EN1990.

Euro code gives three approaches (DA1, DA2, and DA3) for determining the loads. Using of these approaches depends upon many factors related to loads or actions *A*, material's properties *M,* and resistance of soils *R* (*for more details see paper No. 6*).

3.3. Requirements of the materials used in foundation constructions

Foundations are extremely important and would normally be constructed by using reinforce concrete. Concrete is a building material that maintains its properties in a good condition during the life of the building. Materials used in foundation construction and their problems in Iraq will be explained in the following sections.

3.3.1. Cement

It is construction material, made by mixed of calcareous and limestone or marl or chalk at high temperatures. Cement is fine powder when mixed with water become a binding material has cohesive and adhesive properties to bind the aggregates to gather to produce a complete solid unit (*Oss, 2005*). Cement is produced by using high temperature to burn a mixture of calcareous and argillaceous substances, the mixture is known as clinker (*Oss, 2005*).

Cement industry is one of the important strategic industries in Iraq. It depends on the raw materials, such as limestone, clay, gypsum, iron dust, Flint and sand, which are available in Iraq in different places (Figure 3.6). Limestone is the main raw material that represents about 70% of the total raw materials used throughout the cement industry. According to the percentage of dolomite ($MgCO_3$) in limestone ($CaCO_3$), it can be divided into three types: pure limestone (100% $CaCO_3$); dolomitic limestone ($CaCO_3$ ± 7% $MgCO_3$) and dolomite ($CaCO_3$ ± 20% $MgCO_3$). There is a major problem in some of the limestone quarries sites due to the presence of dolomite lime stone layers. These layers are not suitable for cement industry because they contain a high percentage of magnesium oxide with overlapping of limestone layers. It will affect cement volume (Figure 3.7) (*Al-jaff, et al, 2014*). The important materials for the cement industry are limestone and clay; their components must be conforming to the Iraqi specification limits (which is depending on ASTM and BS standards) shown in table (3.1).

Table 3.2 shows the components of limestone and clay for different quarries in Iraq (*GEOSURV-IRAQ, 2012*). The shaded cells within the table mean that the values are not within the limits of the Iraqi specifications. If the value of (MgO) is not within the specification limit, it will affect the volume of cement during its hydration process i.e. the chemical reaction of cement and water, making the cement to become a binder material. The lime saturation factor (LSF) represents the value of the free active lime in cement and will affect the reaction and union between silica and aluminium. While, the values of Alumina factor (AM) and Silica factor (SM) of the clay used in the cement production affect the production of clinker (*GEOSURV-IRAQ, 2012*).

Table 3.1: Iraqi Specifications for limestone and clay (*Al-jaff, et al, 2014*).

Limestone components	Iraqi Specifications %	Clay components	Iraqi Specifications %
MgO	≤ 2	SO3	< 3
SO_3	< 0.6	MgO	< 7
CaO	≥ 50	CaO	< 20
Fe_2O_3	~ 0.1- 0.4	Silica factor (SM)	1.5-4.0
Lime saturation factor (LSF)	0.66 < LSF< 1.02	Alumina factor (AM)	1.4-3.5

Figure 3.6: Stone quarries in western of Iraq (*Al-jaff, et al, 2014*).

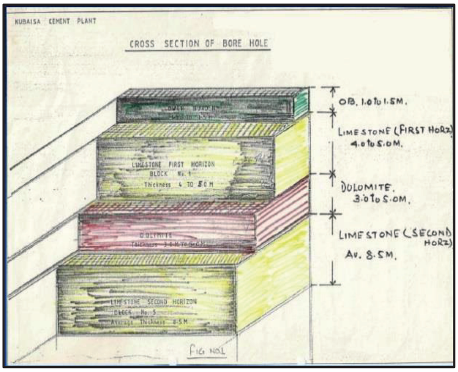


Figure 3.7: Section of limestone layers for Kubaisa site (*Al-jaff, et al, 2014*).

Table 3.2: Results for analysis of cement raw materials (*GEOSURV-IRAQ, 2012*).

Cement quarries	Analysis results for limestone %						Analysis results for clay %						
	SO_3	MgO	CaO	Al_2O_3	Fe_2O_3	LSF	SO3	MgO	Al_2O_3	CaO	Fe_2O_3	SM	AM
Hamam alil	0.5	0.67	48.12	2.13	1.83	0.16	0.2	4.43	9.77	18.29	5.17	2.7	1.89
Badush	0.3	1.3	50.4	1.9	1.14	0.22	-	-	-	-	-	-	-
Sinjar	0.09	0.7	47.7	2.3	1.1	0.2	0.2	4.0	9.0	16.3	4.6	2.7	1.96
Al-Tamim	0.4	1.2	51.3	0.9	0.7	0.4	0.07	4.6	8.9	21.0	2.6	3.4	3.42
Al-Kaem	0.4	0.5	52.0	0.5	0.5	0.91	0.35	3.6	8.5	24.3	3.8	2.9	2.24
Kubasa	0.5	1.4	54.2	0.5	0.4	0.79	0.4	3.2	3.5	32.5	2.6	3.74	1.4
Fallujah	0.5	1.7	52.8	0.3	0.4	0.88	-	-	-	-	-	-	-
Karbala	0.3	0.6	51.09	1.16	1.03	0.31	-	2.3	2.8	30.9	1.7	7.51	1.65
Kufa	1.07	2.10	50.92	0.69	0.45	0.35	2.03	6.26	12.26	15.22	6.3	-	1.95
Muthanna	1.5	1.0	51.6	0.7	0.6	0.38	0.5	5.4	9.3	17.4	5.1	2.9	1.82

3.3.2. Aggregate

The allowable value of sulphate salts and chlorides in sand and gravel (aggregate) must conform to the Iraqi specifications (Table 3.3). Test results for sulphate and chlorides in sand and gravel for Baghdad and Basrah exceeded the limit values (Table 3.3). Mosul aggregates are within the Iraqi specifications. Sulphate salts are considered as a major problem affecting concrete durability. Because sulphate is a highly soluble salt, it always can be found in the forms of potassium sulphate (K_2SO_4), calcium sulphate ($CaSO_4$) and magnesium sulphate ($MgSO_4$). Sulphate reacts with cement leading to concrete deterioration. The reaction will softening the concrete, mass losing and in some cases it leads to expansion and loss of its elasticity and strength (*Habeeb, et al., 2010; Guangehng, et al., 2007*). The process is called sulphate attack. White finely crystalline salts appear at the surface of mature and hardened concrete which is referred to “efflorescence”. This process is one of the main contributing factors to the deterioration of concrete. These salts appear near or in cracks and cause different damages in buildings such as degradation of a dry wall, bulging and dislodging of floor, and corrosion of metals (*Novak, et al., 1989).*

Table 3.3: Sulphate salts and chlorides specifications for sand and gravel.

Material	Maximum limits according to the Iraqi Specifications (%)	Test results for Baghdad and Basrah (%)
SO3 for sand	0.5	0.78-0.83
Cl for sand	0.10	0.05-0.09
SO3 for gravel	0.10	0.14-0.16
Cl for gravel	0.10	0.05-0.09

3.3.3. Water

In general, water suitable for drinking and with no perceptible taste or odour is able to be suitable to produce concrete (*Olugbenga, 2014*). Also, some non-potable water including recycled wash water is acceptable for use in concrete but must be tested to make sure that no harmful effects will result such as segregation, cracks, etc. Water should be clear or include limited percentage of sulphate salts and chlorides that will not cause harmful effect in concrete. These limits are documented in the Iraqi specifications for water which is not used for drinking (Table 3.4). The percentage of sulphate salts and chlorides for the water of Tigris River in Mosul, Baghdad and Basrah and of Euphrates River at Basra are shown in table 3.4 (*Iraqi Ministry of the Environment, 2012*). The effect of sulphate salts and chlorides causes segregation in concrete (it is a separation of some size groups of aggregates from cement mortar) (Figure 3.8). The results in table 3.4 show that total dissolved salts are increasing downstream toward Basrah. This is due to the fact that water from all irrigated areas is drained in the Tigris River. The effect of water that contains a high percentage of different type of salts appears mostly in the buildings constructed in Baghdad and Basrah due to the salt percentage increase in the two rivers water.

3.4. New concrete mixture

Iraqis from ancient eras used mud in their building and architecture because Mesopotamian soil is muddy and fertile. They used it in different methodologies according to the nature and

Table 3.4: Iraqi specifications for water of Tigris and Euphrates Rivers test (*Iraqi Ministry of the Environment, 2012*).

Chemical tests	The limits of specification (g/l)	Water of Tigris River in Mosul (g/l)	Water of Tigris River in Baghdad (g/l)	Water of Tigris River in Basrah (g/l)	Water of Euphrates River in Basrah (g/l)
Mg	0.15	0.03	0.03- 0.07	0.2-0.4	0.6-0.7
SO_4	1	0.08 - 0.1	0.15 - 0.3	0.3	0.52
Cl	0.5	0.026 - 0.03	0.05 - 0.1	0.3-0.43	1.0
TDS	1.5	0.19 - 0.25	0.5 - 0.78	1.0	2.5-3.0

Figure 3.8: Slab segregation in educational building in Baghdad (*Baghdad University, 2015*).

the function of the building. It was used either in its pure form or by mixing it with other materials such as straw (*Abdul Razzaq, 2012*). Nowadays, concrete becomes the most widely used construction material. Many researchers studied the effect of replacing a natural coarse aggregate by crushed clay bricks on the properties of the concrete. The most successful tests conducted for concrete mixture using crushed new clay brick as a coarse aggregate was carried out by *Khalaf* (*2006*). The materials used by *Khalaf* were: ordinary Portland cement (BSI2000a, b; ASTM 1994), fine aggregate, four types of clay bricks and granite. The experimental procedure was designing a concrete mixture for each of the four new bricks and granite as a coarse aggregate (*Khalaf, 2006*). The crushed new brick absorption of water was ranging between 6.2 to 12.4% by weight in relation to the material in its dry state. The results of the concrete density obtained from all the mixtures phases were for 28 days of pouring concrete. Also, concrete compressive strength was obtained for 7, 14, 28 days for all phases (*Khalaf, 2006*). The results of compressive strength (f'_c) of normal concrete and air-entrained concrete were 37.6 and 52.5 N/mm^2 respectively. While, the density of the normal concrete and air-entrained concrete was 2,158 and 2,125 kg/m^3 respectively using crushed bricks as aggregates in the mixture (*Khalaf, 2006*). The relationship between modulus of elasticity of concrete and compressive strength as defined in the ACI code (ACI-318) is as follows (*Anbuvelan, et al., 2014*):

$$E_c = 4734\sqrt{f'_c} \quad \text{.....15}$$

Where: f'_c = compressive strength of concrete (N/mm^2).

4. Introduction

Geologically Iraq can be divided into three major regions (Figure 4.1). These are the mountains and foothills, Mesopotamian plain, and deserts (Jazira, Northern desert and Southern desert). Generally, sedimentary rocks and Quaternary sediments are the main surface exposed rocks in Iraq. Carbonates and fine clastics, gypsum, marl, shale and phosphorites are the main types of exposed sedimentary rocks. Central and southern parts of Iraq are covered by Quaternary sediments especially the flood plain of the Tigris and Euphrates Rivers and their tributaries. Quaternary sediments are of different types of alluvial sediments brought by the two rivers. The surface geology of Iraq generally represents the youngest sediments (Quaternary and Neogene) that lie within the central depression (*Sissakian, et al, 2012*; *Jassim and Goff, 2006*).

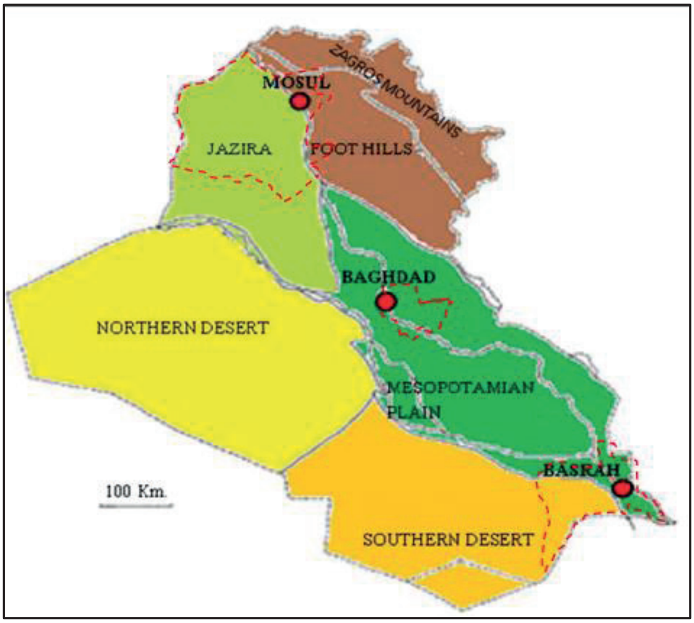


Figure 4.1: Physiographic map and location of the study areas (Mosul, Baghdad and Basrah) (*Buringh, 1960*).

The soil conditions of the three study areas are explained as follows:
Mosul region is located in the foothill and Al-Jezira zones (Figure 4.1) which are covered by different soils types such as expansive clay, gypsum, etc. Some of these types can cause engineering problems (collapse, swelling, soluble in gypsum, volumetric change; etc.). Clay soil covers most of Mosul area and it is moderately to highly expansive type in most of the locations. Alluvium sediments are usually located near the banks of the Tigris River, and primary gypsum is located in the western part of Mosul. The main soil problems in Mosul area are the gypsum and expansive clay soil (*Al-Imam, 2013; Al-Ashou, 1977; Al-Zubaydi, 2011; Khattab, et al, 2009*).

Baghdad region is located in the central part of Iraq, in the upper part of Mesopotamian plain (Figure 4.1). Early human activities affected the soil formations because they were depending mainly on irrigation and farming practices. Over the years, soil became a sequential stratum from alluvial and sand sediment. The changing course of the river caused changes in its flood plain and thus changed the sequences of the deposited layers. These changes gave the soil at Baghdad unexpected characteristics. Quaternary sediments covering the Mesopotamia plain vary in thicknesses from few meters up to 180m. Soil is mostly of fluvial origin (clayey and silty) with some gypsiferous soil, and sand. Moreover, the soil is saline because of the arid climate (*Buringh, 1960; Ali, 2012; Fouad, et al, 2011*).

Basrah region is located in the lower part of the Mesopotamian plain and the southern desert, south of Iraq (Figure 4.1). The stratification of Basra's soil is of an irregular nature and consists of different strata and lenses as a result of the depositions of the Tigris and Euphrates Rivers through the geological history. Quaternary sediment consisting of lacustrine, deltaic, fluviatile and Aeolian sediment replaced each other both vertically and horizontally. In the upper part of this region, the soil consists of layers where their surfaces are naturally consolidated. In general, the ground surface of Basrah city is flat and its soil consists of silt and clay with little amount of sand. The main problems with the soil in this area is the salinity (sabkha) and gypsum (*Muttashar, et al, 2012; Al-Jabberi, 2010; Karim,et al,2010; Daham, 2010*).

Soil investigation (field and laboratories) was carried out for 23 sites in Mosul, Baghdad and Basrah regions respectively (Figure 4.1). The results obtained were used to calculate settlements and bearing capacities to be used in the analysis of foundation design.

4.1. Geotechnical Assessments

The geotechnical assessments included field investigations and laboratory tests. Undisturbed and disturbed samples were taken from all sites and standard penetration test (SPT) was performed. Moreover, groundwater table level was recorded for each site. Laboratory tests carried out to classify and to evaluate the engineering properties of subsoil (*Lamb, 1951*) (Figure 4.2).

Figure 4.2: Field work, collected samples and spilt spoon (upper pictures) and Laboratory tests for the samples (lower pictures).

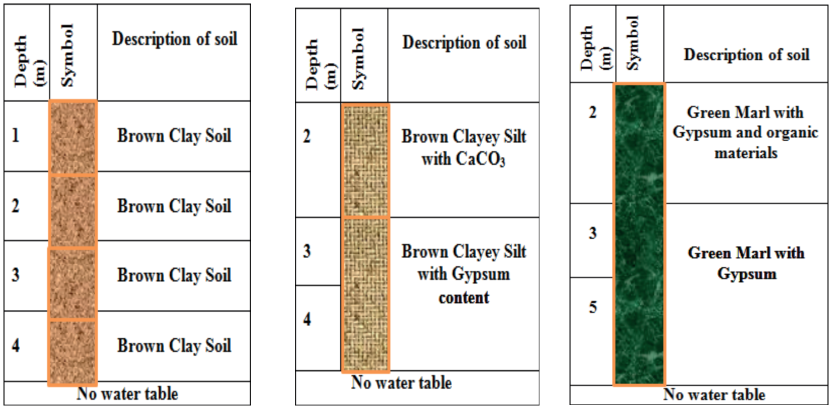
4.1.1. Field investigations

23 exploratory boreholes were drilled to a depth between 4 to 24m from ground surface at different locations in three regions (Table 4.1). Boreholes were drilled using continuous flight auger and rotary drilling rig using wash boring method according to ASTM standards. Undisturbed samples were extracted using thin walled Shelby tube. These samples are regarded to represent the true in-situ structure and water contents of the soil. The sample tube being 75mm in diameter and 200mm long were filled completely and trimmed off. After this tubes were capped with paraffin wax and properly sealed at both ends. The disturbed samples were collected by driving a 40mm outer diameter of the standard split spoon to different depths of the boreholes. The procedure used was according to the standards of American Society for testing and materials (ASTM).

Table 4.1: Location, depth and number of samples tested for the three regions.

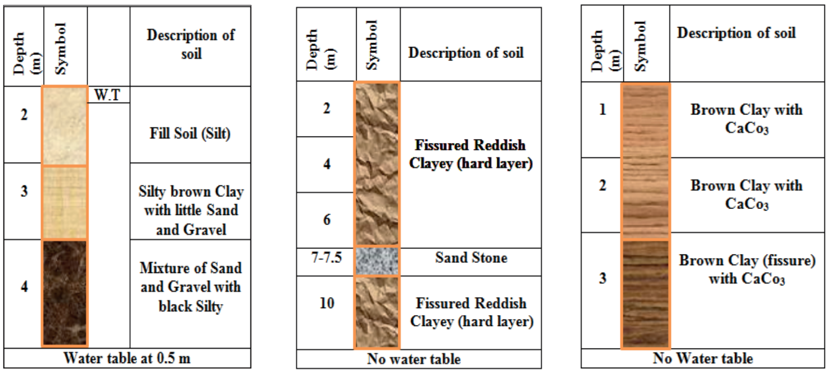
Regions	Locations	No. of samples	Depth, m
MOSUL	Al- Hamedat	3	1, 2, 3
	Al-Qush	3	2, 3, 4
	Sinjar	3	2, 3, 5
	Hai Al-Thaqafi	3	2, 3. 4
	Hai Al-Arabi	4	2,4, 6, 10
	Hai Al-Hindia	3	1, 2, 3
	Hai Al-Shaimaa	3	2, 3, 5
	Ba'shiqah	3	1, 2, 3
	Al-Rashidia	3	1, 2, 4,
BAGHDAD	Al-Karada	4	2, 4, 8, 13
	Abu Nawas	4	2, 6, 10, 13
	Airport street	4	2, 4, 8, 13
	Al-Mustansiriya intersection	4	2, 4, 8, 10
	Al-Jadrea	4	2, 4, 8, 13
BASRAH	Al- Rumaila	3	1, 5, 10
	Garmat Ali	3	3, 15, 21
	Bab Al-Zubair	4	2, 9, 15, 23
	Al-Bradheya quarter	4	3, 8, 16, 24
	Al-Fao coast	4	3, 10, 15, 23
	Al-Hussain quarter	3	2, 9, 15
	Al-Qurna	3	2, 6, 10
	Al-Hartha	4	2, 6, 13, 24
	Safwan district	3	2, 6, 10

The soil profiles for the nine sites in Mosul region are illustrated in figures (4.3- 4.5). The profiles show that in most sites soil layers are of brown or red or green clay the depth of these layers are between 1 to 4m. Two sites have clay with silt layers.



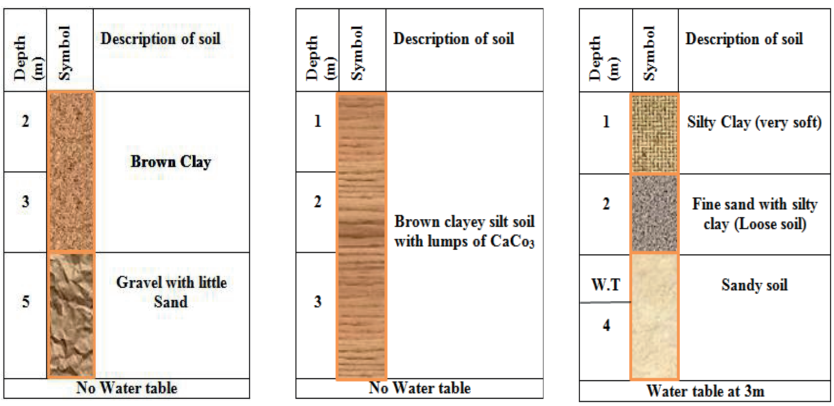
(a) (b) (c)

Figure 4.3: Soil profiles for: a.) Al- Hamedat site, b.) Al-Qush site and c.) Sinjar site.



(a) (b) (c)

Figure 4.4: Soil profiles for: a.) Hai Al-Thaqafi site, b.)Hai Al-Arabi site and c.) Hai Al-Hindia site.



(a) (b) (c)

Figure 4.5: Soil profiles for: a.) Hai Al-Shaimaa site, b.)Ba'shiqah site and c.) Al-Rashidia site.

The soil profiles for the five sites in Baghdad region are illustrated in figures (4.6 and 4.7). The profiles showed that all sites have brown clayey silt from 2 to 8m, or (silty clay from 4 to 6m), silty sand and sand with some organic or salt or both from 9 to 13m. The SPT test in most sites ended with N > 50 which indicate dense layers.

Depth (m)	symbol	N (SPT)	Description of soil
2		>50	Brown clay with silt
4 W.T		24	Brown silty clay to clayey silt
8		>50	Brown clayey silt with organic
13		>50	Brown silty sand
Water table at 5m			

(a)

Depth (m)	symbol	N (SPT)	Description of soil
2		30	Brown clayey silt with salt and organic
6		28	Brown silty clay to clayey silt
10 W.T		25	Brown to black sandy clayey silt
13		32	Grey sand to silty sand
Water table at 8m			

(b)

Depth (m)	symbol	N (SPT)	Description of soil
W.T 2		18	Brown grey lean silty clay with organic
4		25	Medium to stiff brown silty clay
8		45	Greenish fine silty sand with spot of salts
13		>50	Grey dense to very dense sand
Water table at 1.20m			

(c)

Figure 4.6: Soil profiles for: a.)Al-Karada site, b.) Abu Nawas site and c.) Airport Street site.

Depth (m)	symbol	N (SPT)	Description of soil
2 W.T		39	Brown silty clay with organic
6		23	Brown clayey silt
10		26	Brown silt
13		>50	Grey silty sand
Water table at 2.5m			

(a)

Depth (m)	symbol	N (SPT)	Description of soil
2		10	Brown sandy lean silty clay with salt and organic
W.T 4		32	Medium greenish grey clayey silty sand with traces of salt
8		>50	Dense to very dense grey fine silty sand
13		>50	Dark grey dense to very dense medium to coarse sand with fine grain gravel
Water table at 4.5m			

(b)

Figure 4.7: Soil profiles for: a.) Al-Mustansiriya intersection and b.)Al-Jadrea site.

The soil profiles for the nine sites in Basra region are illustrated in the figures (4.8 - 4.10). Three types of layers can be recognized in the soil profiles. First is brown silty clay or soft to medium silty sand from 1 to 3m. Second layer is silt or soft silt from 4 to 18m depth. Third layer is dense silty sand from 19 to 24m. Two sites had different soil types (one is had sand and the other had silt).

Depth (m)	Symbol	N (SPT)	Description of soil
1		20	Medium white poorly graded sand
5		41	Dense brown sand
10		>50	Very dense brown silty gravel with sand
Water Table >10m			

(a)

Depth (m)	Symbol	N (SPT)	Description of soil
3		6	Brown silty clay
15		4	Grey to brown clayey silt
21		31	Dense grey silty sand
Water Table = 0.85m			

(b)

Depth (m)	Symbol	N (SPT)	Description of soil
2		0	Grey silty clay
9		5	Grey clayey silt
15		5	
21		46	Green dense silty fine sand
Water Table = 1.5m			

(c)

Figure 4.8: Soil profiles for: a.) Al- Rumaila site, b.) Garmat Ali site and c.) Bab Al-Zubair site.

Depth (m)	Symbol	N (SPT)	Description of soil
3		8	Medium to stiff brown silty
8		1	Very soft grey silt with low plasticity
19		1	
24		26	Very stiff grey silt
Water Table = 0.8m			

(a)

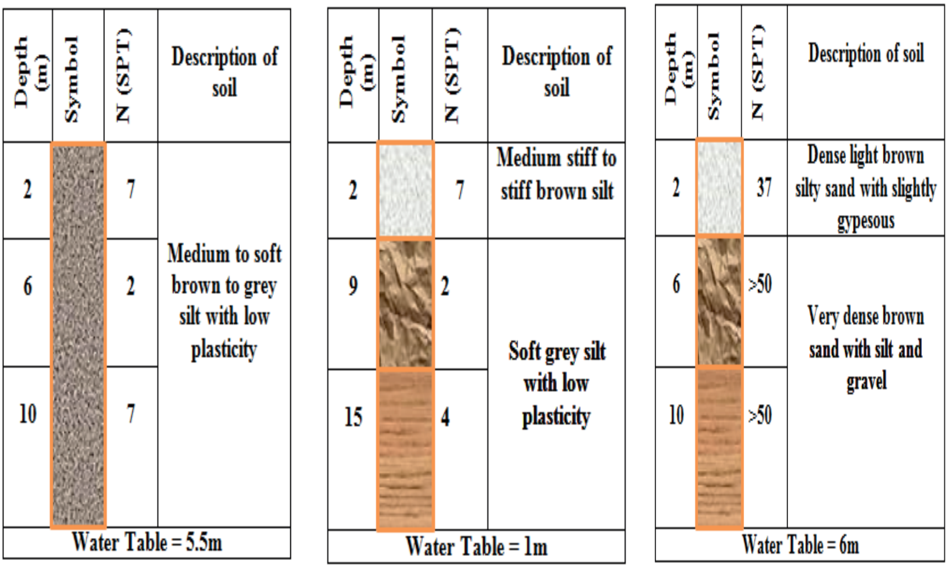
Depth (m)	Symbol	N (SPT)	Description of soil
3		2	Soft grey sandy silt
10		3	Soft grey silt with low plasticity
15		13	Medium dense grey silty
23		25	Stiff to very stiff grey silt with low plasticity
No Water Table			

(b)

Depth (m)	Symbol	N (SPT)	Description of soil
2		2	Soft grey sandy silt
6		2	Soft grey silt with low plasticity
13		13	Medium dense grey silty sand
24		>50	Very dense grey silty sand
Water Table = 1.5m			

(c)

Figure 4.9: Soil profiles for: a.) Al-Bradheya quarter, b.) Al-Fao coast and c.) Al-Hartha site.



(a) (b) (c)

Figure 4.10: Soil profiles for: a.) Al-Qurna site, b.) Al-Hussain quarter and c.) Safwan district site.

4.1. 2. Laboratory testing

The tests included the determination of natural water content (w/c), unit mass (γ), Atterberg limits (LL, PL), particle size analysis (sieve and hydrometer); shear strength (direct shear and unconfined compression tests) and consolidation tests for soil. All the tests were performed according to ASTM, AASHTO (The American Association of State Highway and Transportation Officials standard) and BS (British Standard).

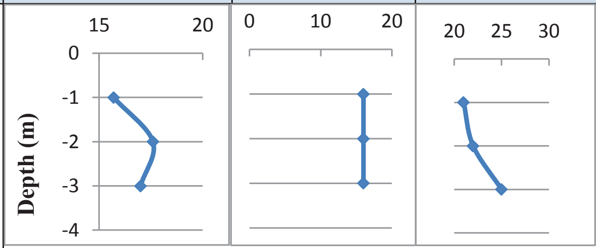
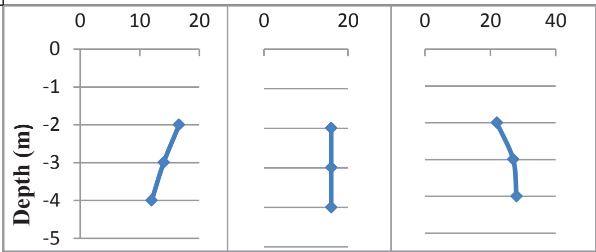
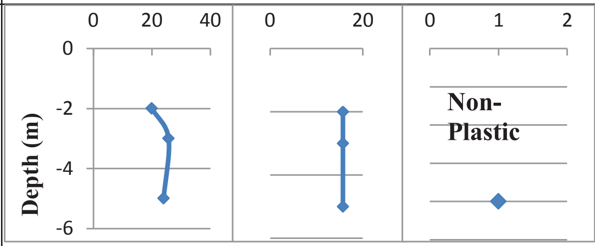
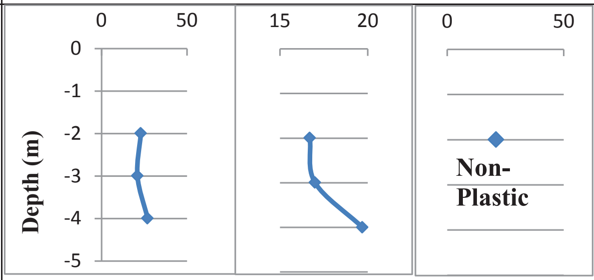
The results obtained from physical and Atterberg limits tests for all samples from all sites for Mosul, Baghdad and Basrah regions are shown in tables 4.2, 4.3 and 4.4 respectively.

Table 4.2 (Mosul region) shows the relations between water content (w/c), unit weight (γ) and plastic index (PI) with the depth. W/c values for almost all sites increases with depth. In the exceptional sites the values changed due to the weather effect the active zone. γ was increasing with depth due to the soil pressure on the lower layers and in some other site it was not changing with depth. PI values of the soil shows the value of the soil density which was increasing with depth in most sites and it was not increasing in the exceptional sites because the soil was sand and gravel.

Table 4.3 (Baghdad region) shows the relations between water content (w/c), unit weight (γ) and plastic index (PI) with the depth. The value of w/c was changing with depth in all sites. The value of γ was almost constant with depth. PI was increasing with depth and the last layers of the soil were non-plastic in all the sites due to the type of the soil which was sand.

The relations between water content (w/c), unit weight (γ) and plastic index (PI) with the depth are show in table 4.4 for Basrah region. W/c value was increasing with depth in all sites. And γ values were not changing with depth in some sites and in the others it was increasing with depth. While, PI values were increasing with depth except in two sites they were non-plastic due to the soil types (silty sand and sand).

Table 4.2: Physical, Atterberg limits and grain size analysis results for Mosul area.

Location	W/C %	γ_d kN/m^3	PI %	Grain size analysis
Al-Hamedat				47% clay 45% silt at 1m depth. 47% clay 45% silt at 2m depth.
Al-Qush				40% clay,53% silt 7% sand at 2m depth. - 40% clay,51% silt 9% sand at 4m depth.
Sinjar				- -
Hai Al-Thaqafi				20% clay,43% silt,18% gravel 19% sand at 2m depth. 3% clay,4% silt 48% gravel, 45%sand at3m depth. 6% clay, 16% silt, 78% depth.

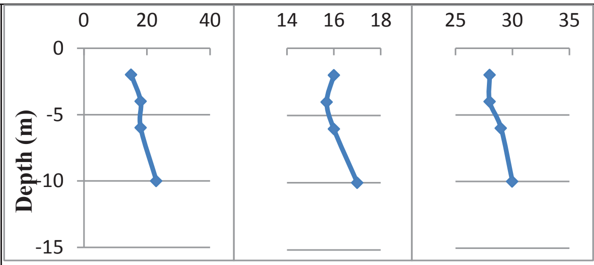
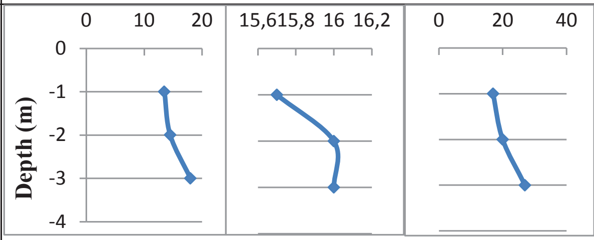
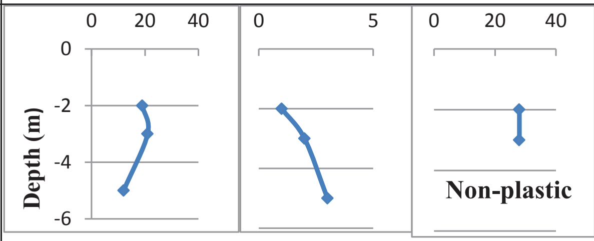
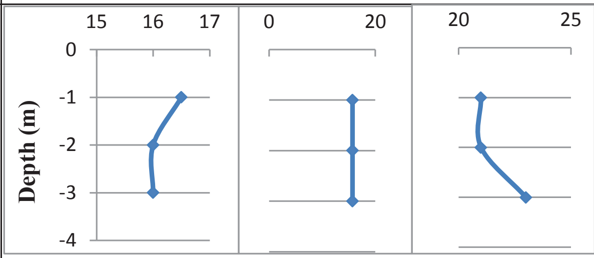
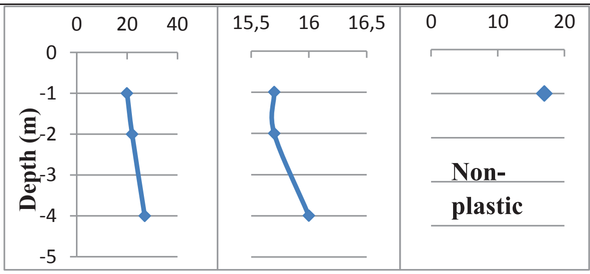
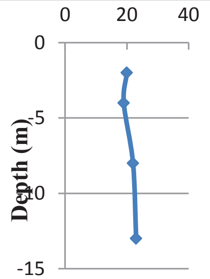
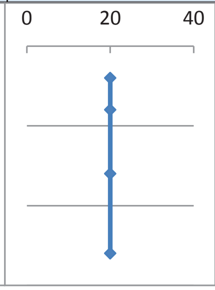
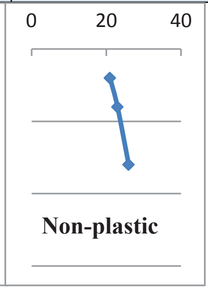
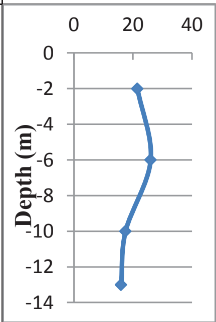
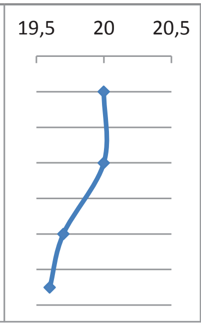
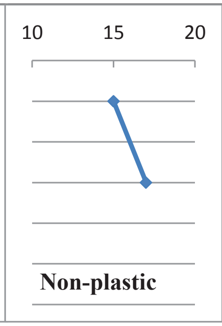
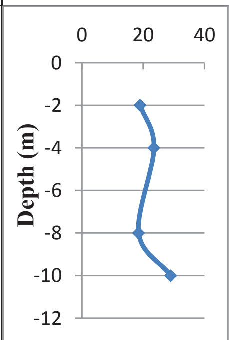
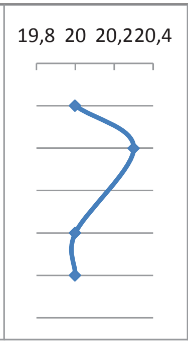
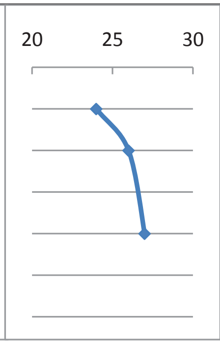
Hai Al-Arabi		26% clay, 53% silt, 21% sand at 2 to 4m depth. 26% clay, 52% silt, 22% sand at 6 to 10m depth.
Hai Al-Hindia		35% clay, 56% silt, 9% sand at 1m depth. 38% clay, 56% silt, 6% sand at 2m depth. 40% clay, 55% silt, 5% sand at 3m depth.
Hai Al-Shaimaa		45% clay, 51% silt, 4% sand at 2m depth. 47% clay, 47% silt, 6% sand at 3m depth. 2% clay,2% silt 80% gravel, 16% sand at 5m depth.
Ba’shiqah		46% clay, 54% silt at 1m depth. 33% clay, 58% silt, 9% sand at 2m depth. 36% clay, 57% silt, 7% sand at 3m depth.
Al-Rashidia		19% clay, 46% silt, 35% sand at 1m depth. 12% clay, 40% silt, 48% sand at 2m depth. 0.5% clay, 7.5% silt, 92% sand at 4m depth.

Table 4.3: Physical, Atterberg limits and grain size analysis results for Baghdad area.

Location	W/C %	γ_t kN/m^3	PI %	Grain size analysis
Al-Karada				48% clay, 50% silt, 2% sand at 2m depth. 41% clay, 54% silt, 5% sand at 4m depth. 46% clay, 53% silt, 1%sand at 8m. 11% clay, 12% silt, 77% sand at 13m.
Abu Nawas				37% clay, 60% sil, 3% sand at 2m depth. 34% clay, 46% silt, 20% sand at 6m depth. 14% clay + silt, 86% sand at 10m depth.
Al - Mustansiriya				51% clay, 38% silt, 11% sand at 2m depth. 40% clay, 49% silt, 11% sand at 4m depth. 26% clay, 71% silt,2% sand at 8m depth. 12%cly,17%silt, 71%sand at 10m depth.

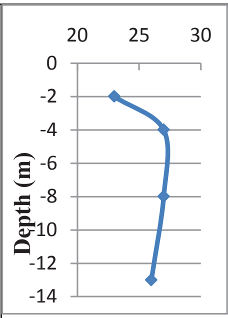
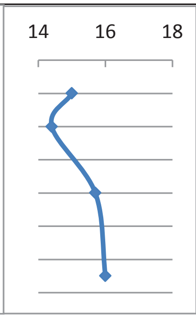
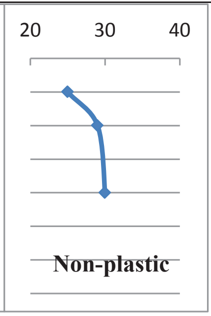
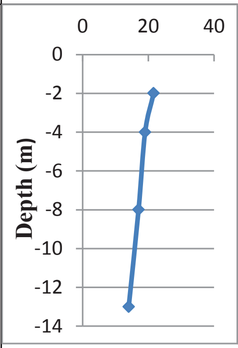
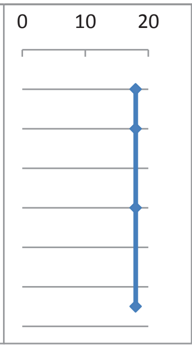
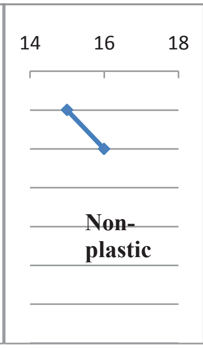
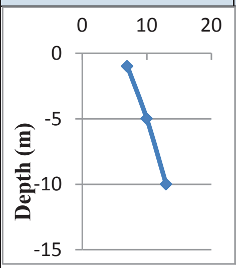
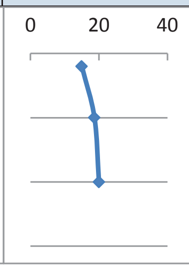
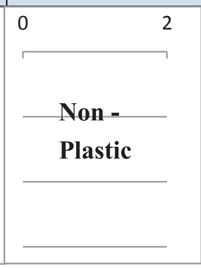
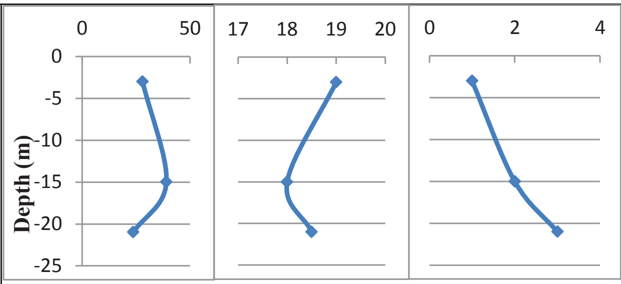
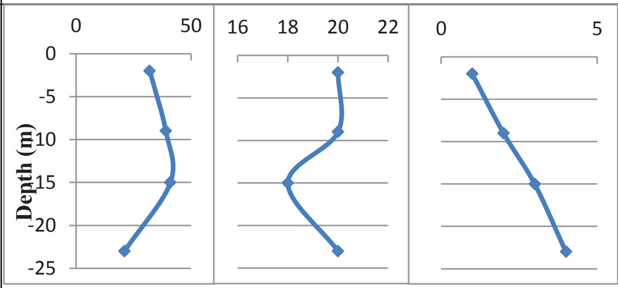
Airport Street				33% clay, 62% silt, 5% sand at 2m depth. 36%, 50% silt, 14% sand at 4m depth. 6% clay + silt, 94% sand at 13m depth.
Al- Jadrea				38% clay, 40% silt, 22% sand at 2m depth. 12% clay, 29% silt, 59% sand at 4m depth. 9% clay, 16% silt, 75% sand at 8m depth. 13.5% clay + silt, 86.5% sand at 13m depth.

Table 4.4: **Physical, Atterberg limits and grain size analysis results for Basrah area.**

Location	W /C %	γ_t KN/m^3	PI	Grain size analysis
Al-Rumaila				4% clay + silt, 9% gravel, 87% sand at 1m depth. 2% clay+ silt, 14% gravel, 84% sand at 5m depth. 12% clay,17% Silt,49%gravel, 22% sand at 10m depth.

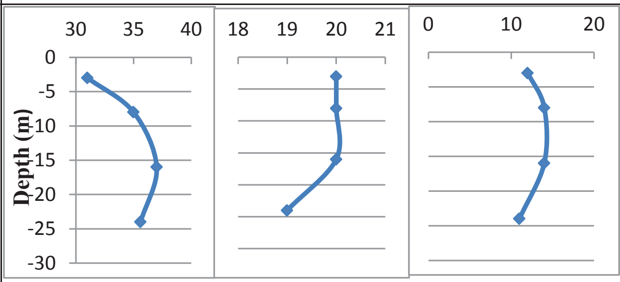
<table>
<tr>
<td>Garmat Ali</td>
<td>
</td>
<td>20% clay, 80% silt at 3m depth.

15% clay, 81% silt, 4% sand at 15m depth.

19% clay, 44% silt, 37% sand at 21m depth.</td>
</tr>
<tr>
<td>Bab Al-Zubair</td>
<td>
</td>
<td>23% clay, 73% silt, 4% sand at 2m depth.

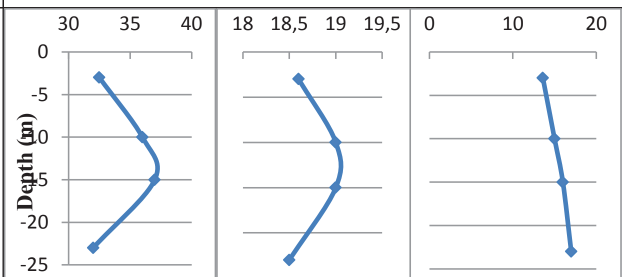
64% clay, 35% silt, 1% sand at 9m depth.

16% clay, 80% silt, 4% sand at 15m depth.

19% clay, 15% silt, 66% sand at 23m depth.</td>
</tr>
<tr>
<td>Al-Bradheya quarter</td>
<td>
</td>
<td>28% clay, 72% silt at 3m depth.

40% clay, 56% silt, 4% sand at 8m depth.

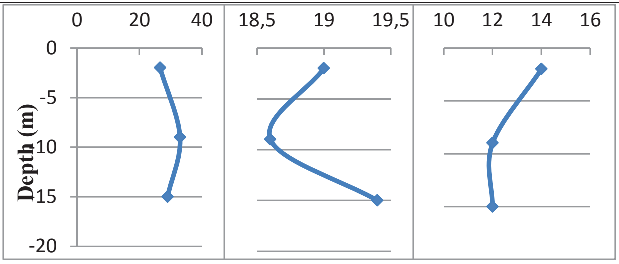
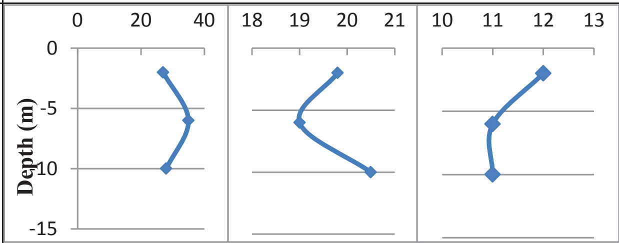
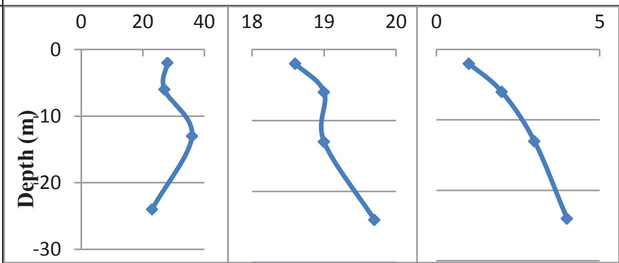
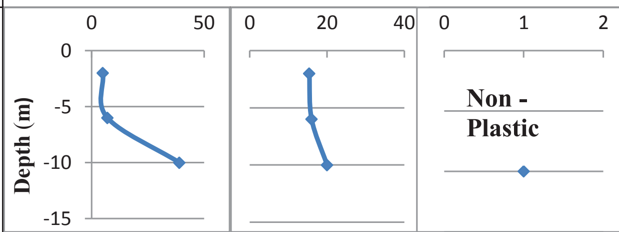
22% clay, 77% silt, 1% sand at 16m depth.

6% clay, 27% silt, 67% sand at 24m depth.</td>
</tr>
<tr>
<td>Al- Fao coast</td>
<td>
</td>
<td>16% cay, 82% silt, 2% sand at 3m depth.

13% clay, 79% silt, 8% sand at 10m depth.

19% clay, 77% silt, 4% sand at 15m depth.

19% clay, 81% silt at 23m depth.</td>
</tr>
</table>

Al- Hussain quarter		13% clay, 77% silt, 10% sand at 2m depth. 8%clay, 91% silt, 1% sand at 9m depth. 13% clay, 85% silt, 2% sand at 15m depth .
Al- Qurna		14% clay, 86% silt at 2m depth. 15% clay, 83% silt, 2% sand at 6m depth. 13% clay, 87% silt at 10m depth.
Al- Hartha		10% clay, 64% silt, 26% sand at 2m depth, 12% clay, 88% silt at 6m depth. 13% clay, 87% silt at 13m depth. 10% clay, 14% silt, 76% sand at 24m depth.
Safwan district		4% clay + silt, 7% gravel,89% sand at 2m depth. 9% clay + silt, 16% gravel, 75% sand at 6m depth. 9% clay + silt, 8% gravel, 83% sand at 10m depth.

As far as the results obtained from the direct shear test (drained) and unconfined compression test. The odometer tests were done for drained of one-dimensional consolidation test. The parameters values of the three tests presented in table 4.5 for the three locations. The reading from the odometer test between load added and the change in the specimen height used to draw e-log σ curve. From this curve the following parameters were obtained: preconsolidation pressure (Pc), compression index (Cc), swelling index (Cs) and initial void ratio (e). The results of Mosul for the explored sites showed that most soil was overconsolidated. For Baghdad the upper layers of soil mostly overconsolidated and lower layers almost normal soil. While, for Basrah soil layers almost were overconsolidated.

Table 4.5: Results from direct shear, unconfined compression and odometer tests.

Region	Location	Shear strength parameter		unconfined compression q_u (kPa)	Consolidation results			
		ϕ^o	C kPa		e_o	C_c	C_s	P_c kPa
MOSUL	Al- Hamedat	20	40	-	0.650	0.126	0.019	120
	Al-Qush	15	25	-	0.558	0.197	0.033	70
	Sinjar	28	15	-	0.645	0.065	0.011	120
	Hai Al-Thaqafi	28	2	-	0.688	0.156	0.014	90
	Hai Al-Arabi	20	25	-	0.682	0.123	0.081	150
	Hai Al-Hindia	24	16	-	0.734	0.23	0.021	100
	Hai Al-Shaimaa	21	17	-	0.668	0.184	0.035	105
	Ba'shiqah	25	15	-	0.767	0.28	0.028	100
	Al-Rashidia	28	0	-	0.677	0.21	0.022	90
BAGHDAD	Al-Karada	-	-	370.6	0.647	0.156	0.054	120
	Abu Nawas	-	-	80	0.670	0.174	0.010	165
	Airport street	-	-	87	0.671	0.22	0.029	95
	Al-Mustansiriya intersection	-	-	120	0.748	0.162	0.03	130
	Al-Jadrea	-	-	76	0.741	0.108	0.006 7	105
BASRAH	Al- Rumaila	33,38, 41	4, 2, 0	-	Depended on SPT test			
	Garmat Ali	-	-	94.5	0.89 2	0.267	0.024	135
	Bab Al-Zubair	-	-	78.5	0.74 5	0.186	0.028	85
	Al-Bradheya quarter	-	-	52	0.85 0	0.363	0.090	94
	Al-Fao coast	Depended on SPT test						
	Al-Hussain quarter	-	-	125	0.72	0.208	0.042	110
	Al-Qurna	-	-	32	0.90	0.21	0.038	114
	Al-Hartha	-	-	24	0.8 0.93	0.191 0.224	0.029 0.027	90 171
	Safwan district	31	0	-	Depended on SPT test			

5. Introduction

Computer modelling is a method that was used during the last 40 years by designers, architects and geotechnical engineers. They cover all expected problems that might arise during or after construction. In this research the design and analysis of structure and foundation was carried out using STAAD Pro.*v8i,* SAP2000 &SAFE softwares. Choose of these two software to evaluate and compression of the base pressure. Evaluation of soil settlement under foundation was conducted using SAFE and PLAXIS softwares. All the models were applied for the three locations used in the work (Mosul, Baghdad and Basra) in Iraq. The same building was used in all locations for comparison needs. The analysis carried out by the softwares was for an existing building of two stories (ground & 1st flower) in the University of Mosul. Mat foundation used for the building (Figure 5.1).

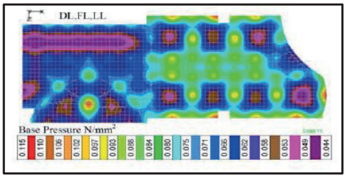
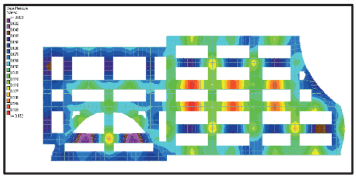
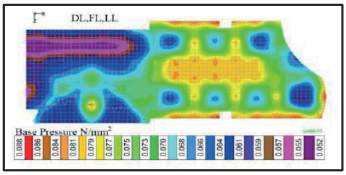
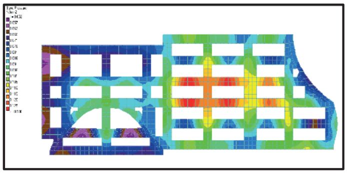
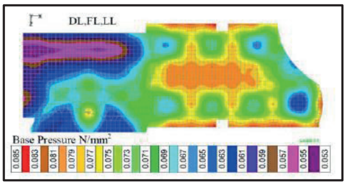
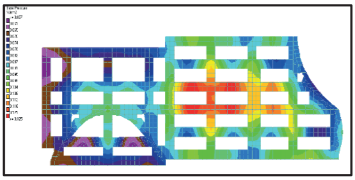
Figure 5.1: The building used in the work (Mosul university project).

5.1. STAAD Pro *v8i* model

STAAD Pro.*v8i* program is software for analysis and design of structures and foundations. The software was originally developed to be used in the analysis and design for different constructions work such as structural and foundations, bridges, dams, etc. (*Subramani, et al, 2012*). STAAD Pro*v8i* program is chosen to be used because of its easy interface use, offering finite element, supports several steel, concrete and timber design codes. It can make use of various forms of analysis. Also contains codes of several countries such as USA, BS, Canada, Russia, France, India, China, Euro, Japan, etc. (*Bhattacharjee, et al, 2007*). The procedure of using the software includes modeling the structure and foundation, applying properties, specifications, loads and load combinations. Also, it is an effective tool for the three dimensional model analysis and multi-material designs because this analysis show the moment loads in there directions (*Meer, 2013*).

In this research, the analysis required was the base pressure of the building on the under laying soil. Started with create the building model used graphical environment, and then added material properties. The bearing capacity used to define the load combinations was depended on test and calculated done by the three universities (Mosul, Baghdad and Basrah) according to ACI code. The analysis had been conducted for comparison purposes. Analysis was conducted to the model and the results were presented in a form of contour. The results of the design of a building model in STAAD Pro software and analysis are shown in table 5.1. The results showed that in Mosul both types of foundation had base pressure values less than the soil bearing capacity. For Baghdad results showed base presser value under raft foundation almost near to the calculated value. The base pressure under continuous type was exceeded the calculated value. While, Basrah results showed that base pressure values under both foundation types exceeded the calculated value (*for more details see paper No. 4*).

Table 5.1: Results obtained from STAAD Pro and bearing capacity values used.

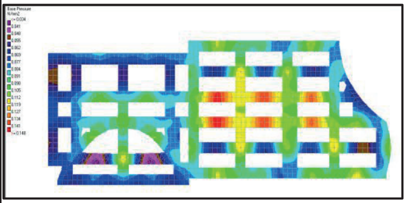
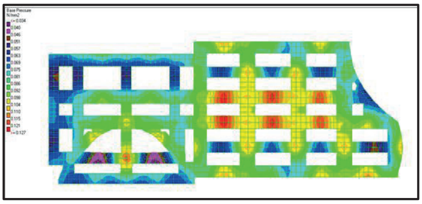
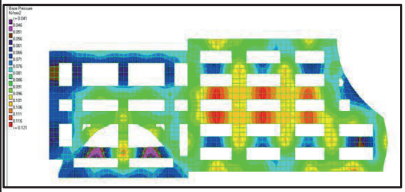
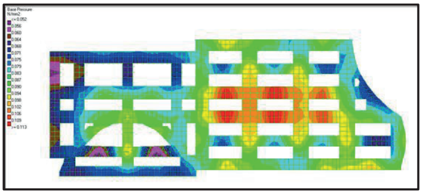
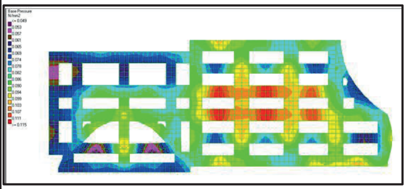
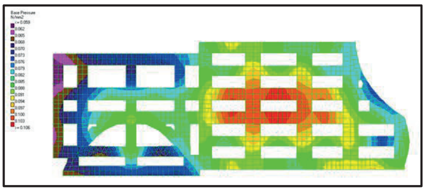
Location	Base pressure value under raft foundation	Base pressure value under Continuous foundation	Bearing capacity value
Mosul	 Base pressure = 44-89 kPa	 Base pressure = 58-153 kPa	300 kPa
Baghdad	 Base pressure = 50-79 kPa	 Base pressure = 62-125 kPa	70 kPa
Basrah	 Base pressure =53- 83 kPa	 Base pressure = 61-125 kPa	50 kPa

The thesis work was done for design and analyses of a building model mentioned above using STAAD Pro software depended on the shear strength parameters obtained in (table 4.5). They were used to calculate the bearing capacity to be used in the software. The load combinations defined according to ACI code. Bearing capacity values used for thesis work were the average and minimum values (Table 5.2). The loads were not distributed evenly and were subjected to concentric vertical loads. Table 5.3 shows only the results of base pressure under continuous foundation (*for raft foundation sees paper No. 5*)

Table 5.2: Results of calculated bearing capacity values for all locations.

Locations	Bearing capacity values (KPa)	
	Average	minimum
Mosul	177	77
Baghdad	125	68
Basrah	84	24

Table 5.3: Base pressure distribution under continuous foundation for the three locations.

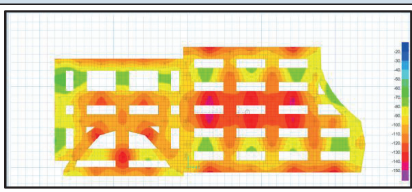
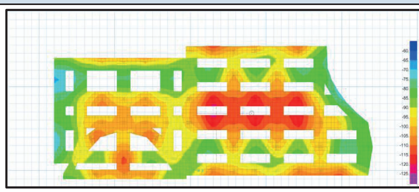
Location	Base pressure using average bearing capacity value	Base pressure using minimum bearing capacity value
Mosul	 Base pressure = 46- 126 kPa	 Base pressure = 52- 80 kPa
Baghdad	 Base pressure = 51-121 kPa	 Base pressure = 52-113 kPa
Basrah	 Base pressure = 53-115 kPa	 Base pressure = 62- 106 kPa

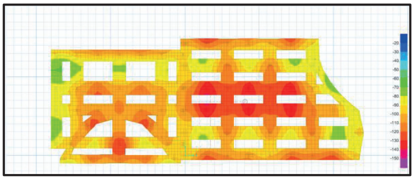
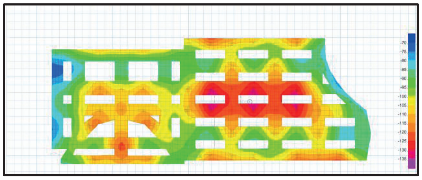
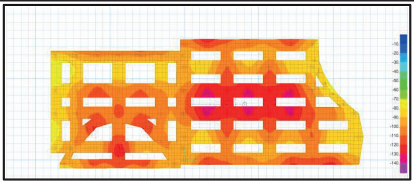
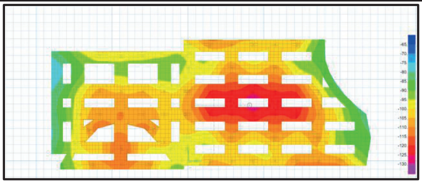
The colors of the contours reflect the values of the base pressure distribution under the foundation. The violet, pink, blue and green colors indicating that the base pressure is low to medium. Yellow and red colors indicating that the base pressure is high or exceeds the limit value. The results for Mosul (for both bearing capacity values) showed that the red zones were not that much to affect the building. Baghdad results for average bearing capacity showed that the red zones do not affect the foundation. For minimum bearing capacity, the red zones were more effective on the foundation. For Basrah, the red zones for both bearing capacity values occupied large zones which can affect the foundation.

5.2. SAP2000 & SAFE softwares

SAP2000 and SAFE are softwares for structural and foundation design and analysis. SAP2000 program is structural analysis program, specialist for general structures design such as buildings, dams, towers, etc. It has advantages such as powerful and completely integrated design program for concrete, steel, cold formed steel, and aluminium. The program includes a wide variety of national and international design codes. Moreover, the program has a capability of export and import for/from other popular drafting and design programs (*Soni Priya, et al, 2012; Abdulwahid, et al, 2013*). SAFE is a finite element software specialist for concrete slab\ beam and basement\ foundation systems for analysis and design. It has many capabilities such as strong graphic tools for drawing various shapes and patterns, system of the mesh generator. In addition, different load combinations can be created, and the capability of presenting the loading states by 3D animation. The variety of outputs given by the software can be used to study the behaviour of loads and deformations. Moreover, the program has the capability to import and export models and design from other programs (*Hassani, et al, 2006; Alashorafa, 2008*). The model structure of the building used in this research was designed and analyzed using SAP2000 software. The analysis which was performed aimed to check the deformations for the columns, beams and slabs of the structure.
The structure model (beams, columns and slabs) of the building was designed and analyzed then exported to SAFE software with all loads on each column. In SAFE program, the raft and continuous foundation types for the building were designed and analysed. The calculated bearing capacity (average and minimum) from table 5.2 were used for each location. The results obtained from the program for continuous foundation were illustrated in table 5.4(*for raft type see paper No.7*).

Table 5.4: Base pressure distribution under continuous type of foundation for the three locations.

Location	Base pressure using average bearing capacity value	Base pressure using minimum bearing capacity value
Mosul	 Base pressure = 50-130 kPa	 Base pressure = 70-95 kPa

Baghdad	 Base pressure = 68-120 kPa	 Base pressure = 70-125 kPa
Basrah	 Base pressure = 70-120 kPa	 Base pressure = 80-125 kPa

The contour colors reflect the value of the distribution of the base pressure under the foundation. The blue, green, yellow colors indicated low to medium values of the base pressure. While, orange and red colors indicated high limit. Dark red and violet exceeds the limit value.

Also, SAFE software was used to estimate the settlement in soil beneath the foundation. The principle of the software is the ability to compute displacements as resultant of stresses in order to ensure a safe and economical design. Modeling the soil is difficult because soil has very complex nature. To obtain the results of displacement under foundation Winkler foundation model used in the software. It was assumed that the displacement at any point on the foundation is proportional directly to the foundation surface pressure. The software deal with soil as spring and depend on subgrade reaction value. The software is depending on the Winkler model to calculate the displacement (*Rajpurohit, et al, 2014*) (*for more details see paper No. 8*).

5.3. PLAXIS modelling

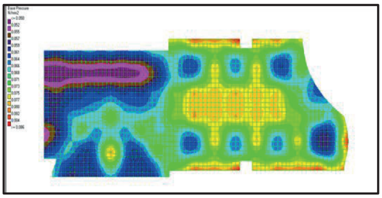
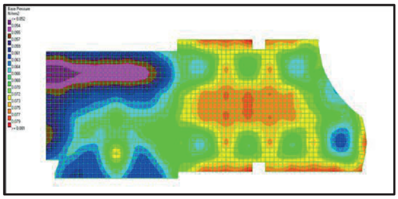
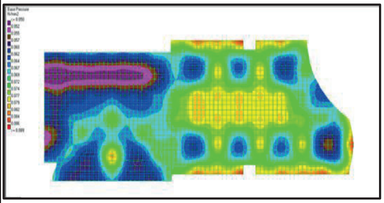
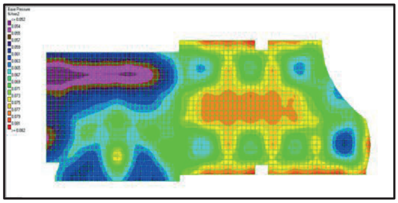
PLAXIS 2D software is usually used for geotechnical work and problems based on finite element method. It deals with materials that behave differently under loading, unloading and reloading (*Bajad, et al, 2012*). PLAXIS 2D software used to simulate the soil behaviour under raft foundation for different sites. The modeling resulted in values of settlement under different added loads (56, 63.5, 68, 75 and 93) kPa. Theses loads present the dead and live load for buildings with two, three and four stories, respectively. The same building was used in different sites with different soil conditions. The models of soil used in the software were Harding soil (HS is an elastoplastic type for simulation of soil behaviour) for the cohesion soil. It was used because it represents a form of soil accurately. Mohr-Coulomb (MC is a linear perfectly-plastic model used for general soil behaviour) model for cohesionless soil. The results focused on the behaviour of the soil under different loads. The parameters that was used in the modeling was obtained from the field and laboratory tests such as ɣ, e, Cc, Cs etc. (*for more details see paper No. 9*).

5.4. STADD Pro*v8i* modelling with new concrete properties

The concrete properties used in software were based on the results mentioned in chapter 3.The values of the density and the Modulus of elasticity of concrete for both normal strength and air-entrained concrete were 2,158 and 2,125kg/$m^3$and 2,902 and 2,9179 N/mm^2 respectively, used for the concrete properties in STAAD Pro software. The analysis was done for the three regions (Mosul, Baghdad and Basrah). The results obtained from analysis are shown in table 5.5 for Baghdad region only as example (*for more details see paper No. 10*).

The colors of the contours reflect the values of the base pressure distribution under the foundation. The violet, pink, blue and green colors indicating that the base pressure is low to medium. Yellow and red colors indicating that the base pressure is high or exceeds the limit value. The contours show that the most dominating colors were the blue and green. This means that the base pressure in all the results were less than the calculated values of bearing capacity.

Table 5.5: Base pressure distribution using new concrete mixture for Baghdad.

Type of concrete mixture	Base pressure using average bearing capacity value (kPa)	Base pressure using minimum bearing capacity value (kPa)
Air-Entrained	 Base pressure = 77	 Base pressure = 75
Normal Strength	 Base pressure = 82	 Base pressure = 79

6. Introduction

The results from field and laboratory tests and modelling presented in chapters four and five. These results were to obtain the base pressure and the settlement values for each region. The work was done for both raft and continuous types of foundation. These results will be discussed and summarized in this chapter.

6.1. Geotechnical assessments

The results obtained from field and laboratory tests for the three different regions in Iraq were used in the geotechnical assessments of the studied areas. The tests conducted to define the values of w/c, γ, LL, PL, PI, c, ϕ, e, Cc, Cs parameters and SPT test are shown in tables 4.2, 4.3, 4.4 and 4.5. Mosul region results (table 4.2) indicate that most of the soil is clay (CH-CL) of medium to high plasticity. Except the soil of one site which was silty sand (SM-ML) of medium plasticity. The deep layers of the soil in some sites were non-plastic. The strength parameters of soil shown in table (4.5) were C (0- 40) kN/m^2 and ϕ (15-28)^o were drained. From the odometer test almost halve the sites have overconsolidated soil. The ground water in the studied sites is lower than the maximum drilling depth. For Baghdad and Basrah regions the results of the unconfined compression strength values of soil $\mathbf{q_u}$ were between (76-370.6) kPa and (24-94.5) kPa respectively. These values of shear strength parameters for two sites at Basrah were higher than the other sites. The unconfined compression strength values for 3 sites in Baghdad were higher and the other 2 were same values of Mosul. The soil types of the two regions were silty clay (CL-CH), silty sand (SM-ML) and sandy (SP or SW). Baghdad soil (for the studied sites) has medium plasticity and the ground water level was between 1.20 to 8 m. While, for Basrah soil plasticity was medium to low and the ground water level was between 0.8 to 10 m in the studied sites.

6.2. Bearing capacity

The results obtained from STAAD Pro*v8i*, and SAFE softwares were used to evaluate the base pressure under two types of foundations (raft and continuous). The bars in figures (6.1, 6.2 and 6.3) reflect the contours results and presented the comparisons of the values of base pressure. The blue and red present the raft and continuous types with ACI code, respectively. While, the green and violet bars are represent the raft and continuous types with EC code. For Mosul region figure 6.1 show the values of base pressure obtained from the analysis conducted in the two softwares according to ACI code, for raft and continuous foundation types (99, 100,75,92,126,130,92 and 90) kPa, respectively. They were either equal or did not exceed the calculated values of the average and the minimum bearing capacity (Table 5.2). That means the building is not in failure condition. Continuous type of foundation is believed to be the right choice for this area that is due to low values of base pressure under continuous type. Comparing the results obtained from both softwares for raft foundation according to Eurocode (EC) with the values obtained using ACI code (Figure 6.1) indicates that the compression show that the values from EC were higher than values from ACI for the minimum bearing capacity. For that both codes can be used for the areas of Mosul with average bearing capacity. For Baghdad region (Figure 6.2) the results obtained for the average values of the bearing capacity and for both types of foundation were (87, 95,121, and 120) kPa. They were less than the calculated values of the bearing capacity (125) kPa, that mean the building is not in failure condition. While, results obtained from the two softwares for the minimum value of the bearing capacity for both types of foundation were (90, 79,113 and 125) kPa. They were higher than the calculated value of bearing capacity (68) kPa, that mean the building is in failure condition. Whilst, the results obtained using EC and ACI codes in SAFE software were almost the same, although it was slightly higher for the former. Both raft and continuous types of foundation can be used for this region where the values of base pressure were less and equal to the calculated bearing capacity (Figure 6.2). Results from Basrah region (Figure 6.3) indicated that the base pressure for raft foundation (81, 81) kPa was lower than the calculated value of bearing capacity (84) kPa i.e. the building not in failure condition. The result for the minimum bearing capacity value for raft foundation (77, 96) kPa showed that it exceeded the calculated value for the whole area under foundation (24 kPa) i.e. the building is in failure condition. While, the base pressure under continuous foundation for the average and minimum values sites (115, 120, 106 and125 kPa) exceeded the calculated values (Table 5.2). Therefore, raft Foundation is recommended for sites of average bearing capacity values and deep for the sites with minimum bearing capacity. The same is true when EC code is used in both softwares (Figure 6.3).

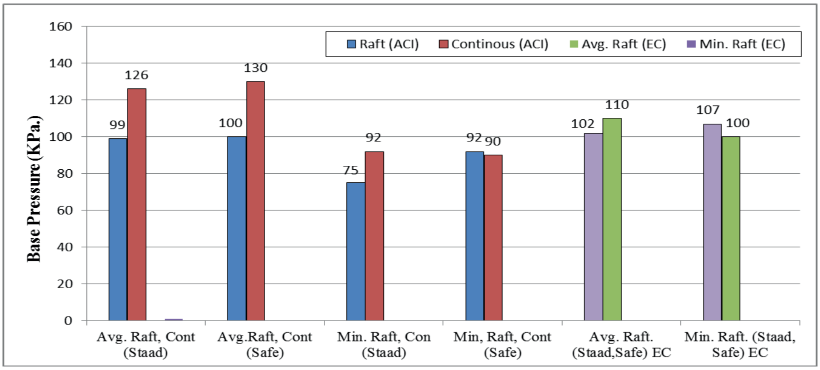


Figure 6.1: Base pressure values for two types of foundation, for ACI &EC codes for Mosul regions.

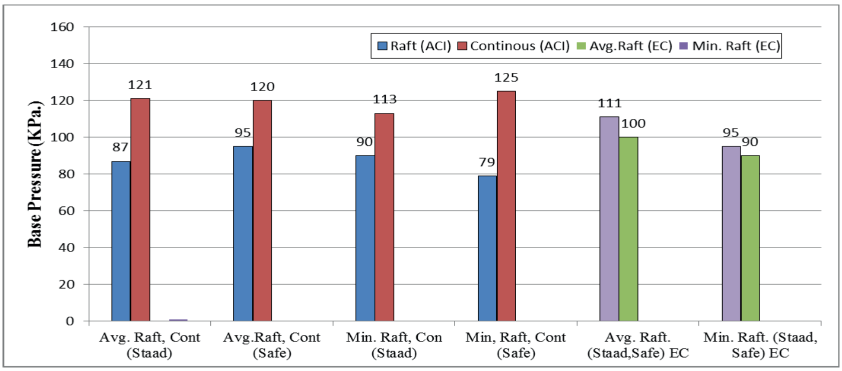


Figure 6.2: Base pressure values for two types of foundation, for ACI &EC codes for Baghdad regions.

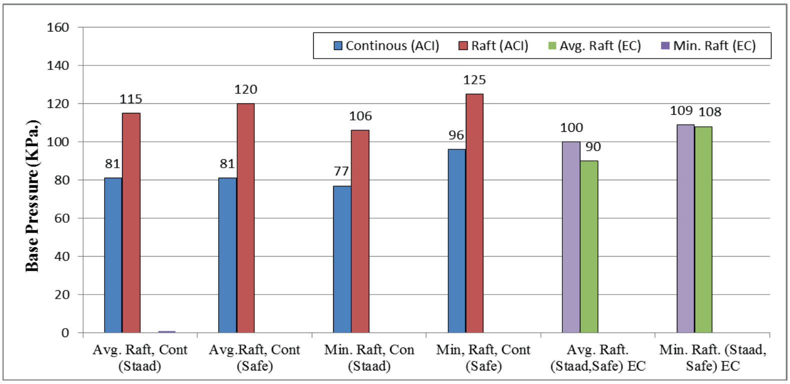


Figure 6.3: Base pressure values for two types of foundation, for ACI &EC codes for Basrah regions.

6.3. Settlement

6.3.1. SAFE software

The results obtained from SAFE software for the raft and the continuous types of foundations are shown in table 6.1. The values are close to each other for both types of foundations and for the two sites with average and minimum bearing capacity values.

Table 6.1: Settlement results values from SAFE software.

Regions	Foundation type	Settlement value using average bearing capacity value (mm) (No.1)	Settlement value using minimum bearing capacity value(mm) (No.2)
MOSUL	Raft type	5	11
	Continuous type	6	15
BAGHDAD	Raft type	8	14
	Continuous type	9	16
BASRAH	Raft type	11	36
	Continuous type	13	42

The results for Mosul show that the values of settlement in column (No. 1 in Table 6.1) for both types of foundation were relatively very low. While, settlement values in column (No. 2 in Table 6.1) for both types were higher than the values in column (No. 1) but less than the EC standard limits. Forthat the best type of foundation to be recommended in Mosul region is the continuous type because of the low values of settlement and it is more economical. According to the cost of implementation the total volume of raft foundation is 955m^3, while it is 248m^3 for continuous foundation. Settlement values for Baghdad region showed in column (No.1) for the two types of foundation were close to each other. The values of settlement showed in column (No.2) for the two types of foundation were higher than those showed in column (No.1). The suitable types of foundations to be recommended are raft and continuous due to low settlement which is less than the limit of EC standards (25mm for isolated shallow foundation and 50mm for raft foundation (*Das, 1999*)). Settlement values obtained for Basrah region under raft foundation was 11mm and for most areas under continuous foundation was 13mm. Both types of foundation are suitable to be used but this is not the right chose due to the bearing capacity value. While the results of settlement under both types of foundations (raft and continuous) for the whole area were 36 and 42mm respectively. The suitable type of foundation to be recommended is deep type.

6.3.2. Numerical calculations

The results obtained from numerical calculations for settlement versus load with maximum and minimum bearing capacity values are shown in figures 6.4 and 6.5.

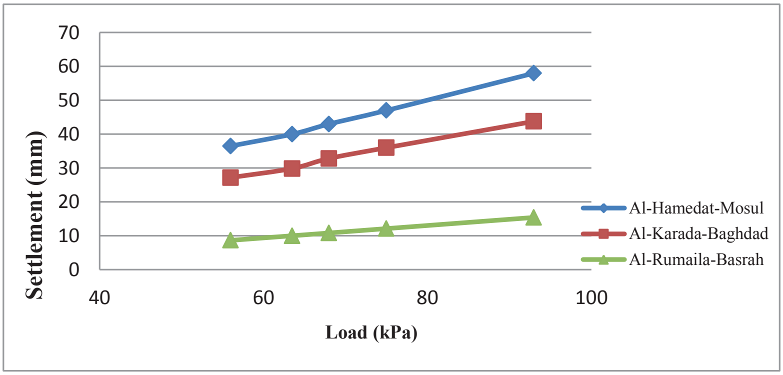


Figure 6.4: Settlement versus load for 3 sites in the three regions.

The settlement values obtained from the calculations indicates (Figure 6.4) that all the values of the settlements were increasing linearly. This relation is logical because the domain of loads used was not wide so it shows linear relations. For Mosul region (Al-Hamedat site) had the maximum value of bearing capacity but the settlement value obtained was higher (settlement value under max. load was 58mm) than that in the other sites. That means the soil for this site (clay) has high compressibility. While for Basrah region (Al-Rumaila) had minimum settlement value (settlement value under max. load was 15 mm) compared to the other two sites due to the presence of sand soil layers of immediate settlement. Figure 6.5 shows that the settlement values for the three sites in the three regions were increasing linearly also. The settlement values for Mosul and Baghdad regions (Al-Rashidia and Al-Jadrea, respectively) were nearly close to each other (settlement values under max. load were 25mm and 23mm respectively). This is due to the fact that soil layers for both sites have almost are similar to each other (silty clay, silty sand, sand) and were located near the bank of Tigris River. Basrah region, (Al-Hartha site) showed higher settlement values (settlement value under max. load was 65mm) relative to the other two sites due to the presence of loose soil layers at depth ranging from 3 to 19 m.

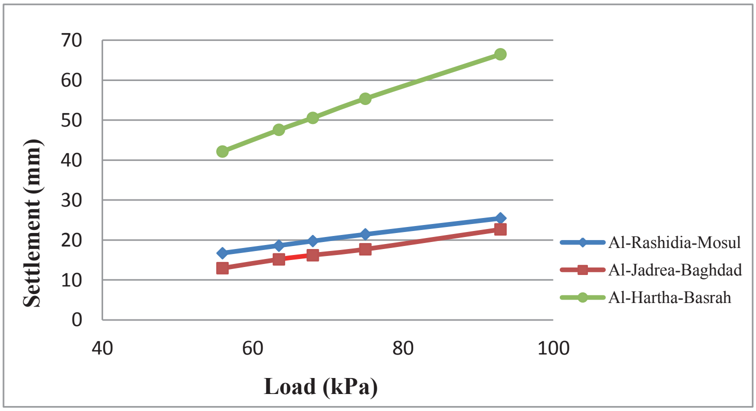


Figure 6.5: Settlement versus load for 3 sites in the three regions.

6.3.3. PLAXIS software

The results obtained from PLAXIS software are shown in figures 6.6 and 6.7 for the same loads and sites that were used in the numerical calculations. The soil models used were elastoplastic (HS) and linear perfectly-plastic (MC) behaviour of soil model. The level of groundwater was stated in the model for each site. A comparison between the settlements values for the different sites in the three regions are shown in the following figures.

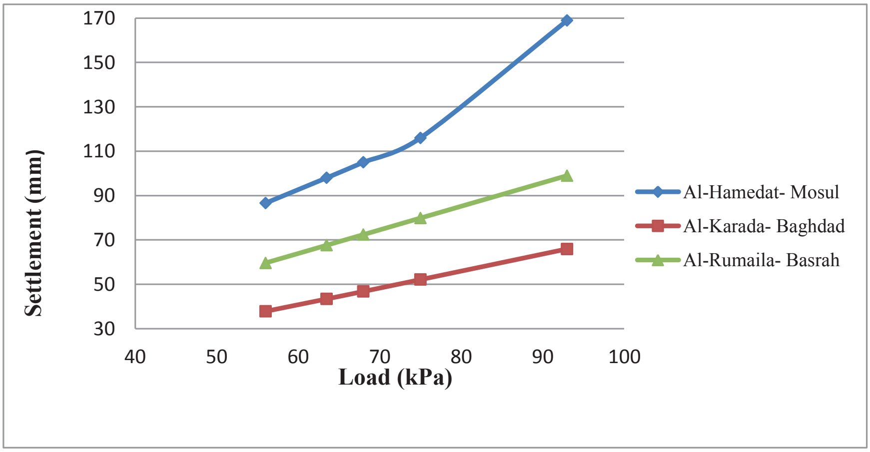


Figure 6.6: Settlement versus load for 3 sites in the three regions.

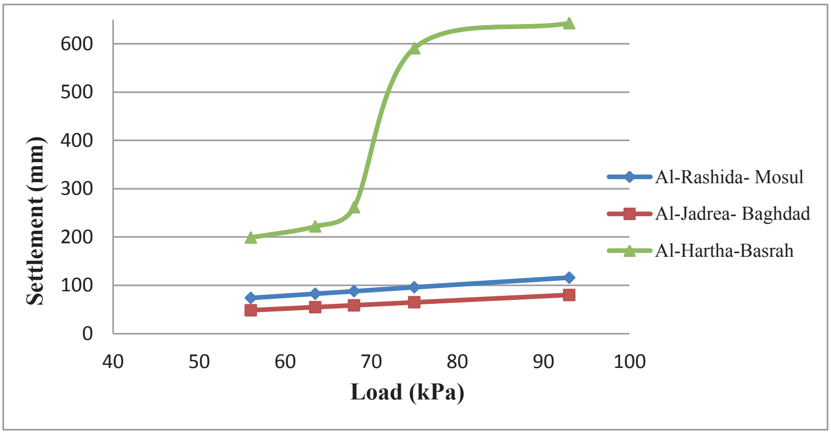


Figure 6.7: Settlement versus load for 3 sites in the three regions.

Figure 6.6 show the comparison of the results of settlements values between Mosul, Baghdad and Basrah. Mosul site show the highest value (settlement value under max. load was 149mm) due to the fact that the soil layers (clay) of high compressibility. Also, the soil model used in the software was HS, which is modelling the soil more accurately. Whilst, Basrah site has a settlement value higher (settlement value under max. load was 99mm) than Baghdad site (settlement value under max. load was 65mm) due to the soil model used in the software MC, which is an elastic perfectly-plastic model. Also, these differences are due to the parameters of soil used in the PLAXIS. Hardening soil (HS) model which used for Mosul site was based on the stiffness parameter of the soil obtained from the oedometer tests. And the elastoplastic behaviour of the model is more accurate because it requires three different stiffness parameters approximation to real soil behaviour. While, Mohr-Coulomb (MC) model which was used for Basrah site is based mainly on the elastic parameters of the soil, which are the Modulus of elasticity and the Poison's ratio. For Baghdad site the two models were used (HS and MC) based on the soil parameters obtained from the tests mentioned above and the elastoplastic and perfectly plastic behaviour of models. Figure 6.7 show that the settlement of soil for Mosul and Baghdad sites are nearly close to each other (settlement values under max. load were 116mm and 81mm) due to the similarity of soil layers where they were both near the bank of Tigris River. Moreover, two models were used (HS and MC) for both sites and the results were logical linear increase due to the range of load change which was between 56 to 93 kPa. For Basrah site the settlement of soil was very high (settlement value under max. load was 643mm) due to the looseness of soil layers and low bearing capacity value (24 kPa). High value of settlement in the soil was not clear when numerical calculations were conducted.

6.4. New concrete mixture use in STAAD Pro*v8i* software

The results obtained from the use of new concrete mixture (normal strength and air-entrained) in STAAD Pro software are shown in table 6.2. The work conducted was to evaluate the values of the base pressure under foundation in the three regions. The values of the base pressure were lower compared to the results obtained when using standard concrete. This was due to the low density values of the new concrete mixture with the crushed bricks for the two types. The density of the normal concrete and air-entrained concrete were 2,158 kg/m^{3}and 2,125 kg/m^3 respectively. The modulus of elasticity values used in the software for the normal and air-entrained concrete were 2,902 N/mm^2 and 2,9179 N/mm^2 respectively. Whilst, the density value of the standard concrete values in the software according to ACI code was 2,3562 kg/m^3. Table 6.2 illustrates the comparison of the base pressure values for the new concrete (normal strength and air-entrained) and the standard concrete which conducted previously for the three different locations in Iraq. Table 6.2 show the values which based on the contours of the base pressure obtained from STAAD Pro software (shown in table 5.5). The values of the base pressure shown in table 6.2 clarify that all values of base pressure for the two new concrete were lower than that obtained from standard concrete used in previous work (*paper No. 5*) for the three regions (*for more details see papers No. 5 and 10*).

Table 6.2: Comparison between effect of using standard concrete and new concrete.

Region	Bearing capacity value	Maximum base pressure value for standard concrete (kPa)	Maximum base pressure value for Normal Strength (kPa)	Maximum base pressure value for Air-Entrained (kPa)
MOSUL	Average	102	94	91
	Minimum	89	84	82
BAGHDAD	Average	96	89	86
	Minimum	88	82	81
BASRAH	Average	90	84	82
	Minimum	80	77	76

7.1. CONCLUSIONS

To fulfill the objectives of the thesis work, geotechnical assessment (field and laboratory test) was conducted to define the bearing capacity and settlement in three different regions in Iraq. Design and analysis of building model was conducted using softwares (STAAD Pro*v8i*, SAP2000 & SAFE and PLAXIS). Moreover, construction materials were studied and new sustainable material mixture was used in the design and analysis of a building to evaluate the effect of building stresses on soil for the study areas. The purposes of the thesis work were fulfilled with following conclusion remarks:

- The results of the geotechnical assessments for the soil of most areas explored in Mosul region (north of Iraq) was clayey except in one site where it was silty sand. Soils of the explored sites are classified as clay with low plasticity (CL) for the upper layers and clay with high plasticity (CH) for lower layers. The soil is characterises by its high to medium plasticity. For most investigated sites, the ground water level was deep.
  In Baghdad region(middle of Iraq), the soil of the explored sites is composed of layers of silty clay (medium to stiff (CL)), followed by silty sand, sandy silt with medium to hard (CH) and the lower layers are sand with very dense (ML,SM). The plasticity of the soil in Baghdad is medium. The ground water depth was between 1.20 to 8 m below ground surface.
  In Basrah region (south of Iraq), the soil in the studied sites can be divided into two groups. First group consist of upper soil layer of medium to stiff clayey silt (CL-CH), followed by layer of medium stiff silty sand (SM) and finally layer of dense to very dense silty sand (SM). The second group the upper soil layers are of medium stiff to soft silt (ML) and the lower layers stiff to very stiff silt (ML). The plasticity of Basrah soil was medium to low and the ground water depth was 0.8 to 10 m below ground level.

- The results obtained for the building model used in STAAD Pro*v8i* Software to evaluate the base pressure values based on the calculated values of bearing capacity for the three regions. Also, the results of base pressure obtained when used SAP2000 software to model the structure of the building then exported to SAFE software with all loads. Moreover, the settlement values obtained to check the stability of the building on the soil. According to these results obtained from all softwares, the suitable foundation to be used in each region are:

  - According soil physical and mechanical properties of Mosul and northern area of Iraq in foothill zone, the suitable and economic type of foundation to be used is shallow foundation (continues) and for building with basement raft foundation is recommended.

- The suitable recommended type of foundation to be used is in some parts of Baghdad and middle region of Iraq is shallow type (continues and raft). It should be mentioned that for high rise buildings constructed in the parts of low bearing capacity the use of deep foundation is recommended.

- Mat foundation is recommended to be used in the parts of Basrah and southern regions that has soil layers of first group. While, Deep foundation is recommended for parts having low bearing capacity in the south.

- The results obtained from STAAD Pro*v8i* model using new sustainable material (crushed bricks as aggregate in concrete mixture) indicated the stresses (dead loads) of the building were lower on the soil beneath the foundation in the three study regions. The low base pressure will change the size and type of foundation to be used and this will reduced the costs of buildings due to the availability of the materials suggested as local and durable.

7.2. FUTURE WORK

The future research works can be focused on the following

- Soil problems in Iraq where it is expansive, salinity and gypsiferous. More research should be conducted to improve understanding of soil mechanical properties.

- Conducting ground investigations for more sites and regions. Using other techniques such as cone penetration test (CPT) in field exploration and compare its results with results obtained from standard penetration test (SPT). Using modern tools (geotechnical softwares) to evaluate the behaviour of the soil layers under added loads.

- Design and analysis for more and different types of buildings to evaluate the base pressure and settlement of soil for different sites in different regions in order to suggest a code to be used suitable for Iraqi conditions.

- Experimental works should be conducted for the mixed materials used in the heritage buildings such as "Al Sarowge" which is durable and look like concrete. Tests should focus on the compressive strength of these materials which must be equal or nearly to the compressive strength of the concrete. It is important to improve building materials.

- More experimental work should be done to use the local and sustainable materials in concrete mixtures to minimize the stresses of building on soil. This can improve the structures and foundations of the buildings and minimize the costs of constructions.

- Abdul Rasul, S. (M.A.), (1987), *Traditional Buildings in Baghdad*, Field Work study carried in Karkh side, Directorate of library for printing and publishing, Mosul University, Iraq,
- Abdul Razzaq, N. K. (2012), Planning and design characteristics of the buildings and settlements of mud in Iraq, journal of planned and development, vol. 25, pp. 93-111.
- Abdulwahid, M.Y.; Al-Qasem, I. A. and I. Arman, I. (2013), Determination of load transfer in reinforced concrete solid slabs by finite element computer analysis, Journal of Mechanical and Civil Engineering (IOSR-JMCE), 8(3), PP01-07. www.iosrjournals.org
- Aboud, R.K. (2013), Effect of Fine aggregate's Sulphate in same properties of Concrete, M.Sc. thesis, Baghdad University, Iraq.
- ACI Committee (2011) Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, Farming ton Hills. www.concrete.org210.42.35.80/G2S/ewebeditor/uploadfile/20110806224616634.PDF
- ACI Committee 318-08(2008), Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, Farmington Hills.
- Al Mosawi, M. A. (1982), Historical Factors for the Establish and Development of Arab- Islamic cities, edited by Alrashed house for publishing, Baghdad.
- Al Silq, G. M. R. (2011), City of Stories, 1st edition, Iraqi cultural support association, Baghdad.
- Al Sultani, K. (2009), ARCHITECTURE and ARCHITECTS, 1st edition, general of cultural affairs house press, Baghdad.
- Al-Alaaf, K. (1999), Old Baghdad, Arab house for encyclopedias, 2nd edition, Beirut.
- Alashorafa, M. A. (2008), Modifications of Conventional Rigid and Flexible Methods for Mat Foundation Design, M.Sc. thesis, Islamic University of Gaza, Faculty of Engineering.
- Al-Ashou, M. O. (1977), Expansive properties of the clay in Mosul area, M.Sc. thesis, College of Engineering, University of Mosul.
- Ali, S. M. (2012), Hydrogeological Environmental Assessment of Baghdad Area, *PhD thesis*, University of Baghdad, College of Science.
- Al-Hiti, A.A. and Al- Jabari, A. T.(2007), Study of landslides and cracks buildings executed on clay soils and ways of strengthening, Iraqi journal for civil engineer, vol. 9, pp89-112.
- Al-Imam, B. M. A. A. (2013), Primary Study to Execution and Testing Geotechnical Model Based on GIS Technique in the Left Side of Mosul City, PhD thesis, College of Engineering, University of Mosul.
- Al-Jabberi, M. H. A.(2010), Sedimentological and environmental aspects of subsurface Basrah sediments-south Iraq, Mesopotamian Journal of Marine Science, 25(2), pp176-187. www.iasj.net
- Al-Jaff, M.A. and Danka, N.F. (2014), Primary raw materials in the cement industry reality and future prospects, State Company for Iraqi Cement, Ministry of Industry and Minerals, Baghdad. http://uotechnology.edu.iq/dep-production/ext_files/ciment.pdf

- Al-Zubaydi, A. H. T. (2011), Effect of Wetting and Drying Cycles on Swell/Collapse Behaviour and Cracks of Fine–Grained Soils, *Tikrit Journal of Engineering Sciences*, 18(4), pp71-79.
- Anbuvelan, K. and Subramanian, K. (2014), An Empirical Relationship between Modulus of Elasticity, Modulus of Rupture and Compressive Strength of M60 Concrete Containing Metakaolin, Research Journal of Applied Sciences, Engineering and Technology, vol. 8, No. 11, pp. 1294-1298.
- Assakkaf, I. (2002), Rectangular R/C Concrete Beams: Tension Steel Only, Introduction to Structural Design, Department of Civil and Environmental Engineering, University of Maryland; College Park. www.assakkaf.com/courses/ENCE355/Luctures/part1/chapter2a.pdf
- Babor, D. and Goldschmidt, M.(2007), Treated and terminated: Sulphuric acid attack, Building Institutului Politehnic DIN IASI, Germany, pp 65-69.
- Bajad, S. P. and Sahu, R. B. (2012), An experimental Investigation on Interference of piled Rafts in Soft Soil, civil and environmental research journal, India, Vol. 2, No. 2, pp 49-59
  www.iiste.org
- Bhattacharjee, B. and Nagender, A.S.V. (2007), Computer Aided Analysis and Design of Multi-Storeyed Buildings, BSc. Thesis, National Institute of Technology Roukela, Roukela.
- Bond, A. and Harries, A. (2008), Decoding Eurocode 7—Basis of Structural Design. Taylor & Francis, London.
  www.decodingeurocode7.com
- Bound, A.J., Brooker, O., Harris, A.J., *et al*. (2006) How to Design Concrete Structures Using Eurocode 2. The Concrete Center, Michael Burbridge Ltd., Maidenhead.
  http://www.civilworx.com/Pdfs/How%20to%20design%20concrete%20structures%20using%20Eurocode%202.pdf
- Bowles, J.E. (1996), Foundation Analysis and Design, 5th Edition, McGraw-Hill Companies, Inc., Singapore.
- Breeveld, B.J.S. (2013), Modelling the Interaction between Structure and Soil for Shallow Foundations- A Computational Modelling Approach, MSc thesis, Delft University of technology.
- Building Code (2013), chapter 14.
  http://www.co.ozaukee.wi.us/DocumentCenter/Home/view/315.
- Buringh, P. (1960) Soils and Soil Condition in Iraq. Ministry of Agriculture, Baghdad.
- Calgaro, J.A. (2006), The Eurocodes History and Present, Workshop of Building the Future in the Euro-Mediterranean Area, 27-29 November 2006, Varese.
  http://elsa.jrc.ec.europa.eu/eurocodes2006/pdf/pres090.pdf
- Calgaro, J.A. (2006), The Eurocodes History and Present. Workshop of Building the Future in the Euro-Mediterranean Area, 27-29 November 2006, Varese.
  http://elsa.jrc.ec.europa.eu/eurocodes2006/pdf/pres090.pdf
- Calgaro, J.A. (2008) Eurocodes a Tool for Building Safety and Reliability Assessment. EU-Russia Cooperation on Standardization for Construction, Moscow.
  http://eurocodes.jrc.ec.europa.eu/doc/Moscow08/Moscow08_9_Calgaro2.pdf
- Coduto, D.P. (2001), Foundation Design: Principle and Practices, 2nd Edition, Prentice Hall, Upper Saddle River.

- Cote, A.E. and Grant, C.C (2008), Codes and Standards for the Built Environment. Chapter3, section 1, 5166. http://www.nfpa.org/~/media/files/forms%20and%20premiums/fire%20protection%20handbook/codesfph.pdf.
- Daham, H. (2010), Physio-chemical properties of some sabkha soil for some selected site From Basrah and their influence on engineering construction, Journal of Basra researches, vol. B6, No. 36, PP24-34.
- Das, B.M. (1999), Fundamentals of Geotechnical Engineering, Brooks/Cole, Pacific Grove.
- Das, B.M. (1999), Shallow foundations; bearing capacity and settlement, CRC press LLC, USA.
- Das, B.M. (2011), Principles of Foundation Engineers, 7TH edition, Cengage learning, Stamford, USA.
- European Committee for Standardization ENV 1992-1-1 (2004), Eurocode 2: Design of Concrete Structures-Part 1-1: General Rules and Rules for Buildings, CEN national Members, Cairo.
- European Committee for Standardization, NVE 1997-1(1999), Geotechnical Design-Part1: General Rules, CEN National Members, Brussels.
- European Committee for Standardization, NVE 1997-2 (1999), Geotechnical Design—Part 2: Design Assisted by laboratory Testing, CEN National Members, Brussels.
- European Committee for Standardization, NVE 1997-3 (1999), Geotechnical Design—Part 3: Design Assisted by Field Testing, CEN National Members, Brussels.
- Formichi, P. (2008), Eurocode 1-Actions on Building Structures, EU-Russia Cooperation on Standardization for Construction, Moscow. http://eurocodes.jrc.ec.europa.eu/doc/Moscow08/Moscow08-9-Formichi.pdf
- Fouad, S. F. A. and Sissakian, V. K. (2011), Tectonic and Structural Evolution of the Mesopotamia Plain, Journal of Iraqi Bulletin Geological and Mining, Special Issue (Geology of the Mesopotamia Plain), No.4**,** pp 33-46.
- George Rawlinson, M. A. (2012),The Seven Great Monarchies Assyria, of the Ancient Eastern World, vol.1. http://www.gutenberg.org/files/16162/16162-h/16162-h.htm
- GEOSURV-IRAQ (2012), Results checking quarries cement, Iraqi Geological survey, ministry of Industry and Minerals.
- Ghosh, S.K. (2013), The Concrete Provisions of the 2012 IBC and ACI318-11, *Building Safety Journal*, 31-35. http://www.skghoshassociates.com/sk_publication/Ghosh_article_Feb_BSJ.pdf
- Guangeheng, L.; Youjun, X. and Xuguang, T. (2007), Evaluating Deterioration of Concrete by Sulfate Attack, Journal of Wuhan University of Technology-Material Science Education, vol. 22, No.3, China.
- Gunaratne, M.(2012), The Foundation Engineering Handbook. Taylor & Francis Group, New York.
- Habeeb, G.A.; Mahmud, H.B. and Hamid, B.A.A. (2010), Assessment of deterioration in RHA-concrete due to magnesium sulphate attack, international journal of minerals, metallurgy and materials, vol.7, No.6, pp 691-696.
- Hassani, A. and A. Jamshidi, A.(2006), Modelling and structural design of a concrete block pavement system, *8th International Conference on Concrete Block Paving*, San Francisco, California, pp 389-398.

- International Code Council (2012), 2009 International Building Code. First Printing, Dallas. https://law.resource.org/pub/us/code/ibr/icc.ibc.2009.pdf
- Iraqi Ministry of the Environment (2012), Environmental reality of Iraq, annual report.
- Jassim, S. Z. and Goff, J. C. (2006), Geology of Iraq, 1st edition, published by Dolin, Prague and Moravian Museum, Brno, printed in the Czech Republic.
- Kameswara Rao, N.S.V. (2011), Foundation Design theory and practice, John Wiley & Sons (Asia) Pte Ltd, Singapore.
- Kamona, H.A. (2010), Employment of Local Environmental Resources in the Built Unit of the Urban Fabric within the Framework of Preserving the Architectural Heritage, The Planer and The Development Magazine, Baghdad University, vol.22,pp1-20.
- Karim, H.H., Ali, H.Z. and Hamdullah, A.H. (2010), Digitally Processed Geophysical Data Sets for Identification of Geological Features in Southern Iraq. Engineer & Technology Journal, 28, pp 236-252.
- Khalaf, F. M. (2006), Using Crushed Clay Brick as Coarse Aggregate in Concrete, journal of materials in civil engineering © ASCE, Vol. 18, No. 4, pp 518-526.
- Khattab, S.A.A. and Al-Omary, A.M.A. (2009), Effect of Disturbance and Gypsum Content on Soil Water Characteristic Curve. 2nd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering, Near East University, Nicosia, North Cyprus, 28-30, pp 426-433.
- Lambe, T. W. (1951), Soil Testing for engineers, John Wiley & sons Inc.
- Liu, C. and Evett, J. B. (2008), Soils and Foundations, 7th edition, Pearson prentice Hall, USA.
- Meera, C.M. (2013), Pre-engineered building design of an industrial warehouse, International Journal of Engineering Sciences & Emerging Technologies, vol. 5, No. 2, 75-82.
- Ministry of Culture and Information (1987), THE QUSHLA, department of antiquities and heritage, Republic of Iraq.
- Mohammad, M. L. (1977), The Iraqi Ancient History, Till the End of third thousand BC.
- Murthy, V.N.S. (2002), Geotechnical Engineering: Principles and practices of soil mechanics and foundation engineering, Marcel Dekker Inc., New York, USA.
- Muttashar, W.R. ; Al-Amari, F.K. and Al-Hussein, M.A.A. (2012), Geotechnical analysis for types of surficial fine-grained soils at eastern side of Basra region, Southern Iraq, J. Thi-Qar University, V.7,No.2, pp101-112.
- Nasir, R.S. (2009), The Impact of Modernity Architecture on Planning of Baghdad City- Al Khulafa'a Street as a sample, M.Sc. thesis, The Higher Institute of Urban and Regional Planning, University of Baghdad.
- Novak, G.A. and Colville, A.A. (1989), Efflorescent mineral assemblages associated with cracked and degraded residential concrete foundations in southern California, cement and concrete research, vol. 19, pp 1-6, USA.
- Nowak, A.S. and Rakoczy, A.M. (2007), Reliability-Based Calibration of Design Code for Concrete Structures (ACI-318), University of Nebraska-Lincoln.
- Olugbenga, A. (2014), Effects of Different Sources of Water on Concrete Strength: A Case Study of Ile-Ife, journal of civil and environmental research, vol. 6, No. 3.
- Orr, T. (2010), The Concepts of Eurocode 7 for Harmonized Geotechnical Design in Europe, Trinity College; Dublin.

http://doktoranci.pwr.wroc.pl/pliki/pokl/orr1.pdf

- Oss, H.G.van (2005), Background Facts and Issues Concerning Cement and Cement Data, report of U.S. Geological survey, science for a changing world, USGS.
- Rajpurohit, V. K.; Gore, N.G. and Sayagavi, V.G. (2014), Analysis of Structure Supported on Elastic Foundation, International Journal of Engineering and Advanced Technology (IJEAT), vol. 4, No. 1, pp1 -6.
- Reuther, O.(2005-2006), The Iraqi House in Baghdad and other Iraqi towns, translated by: Kpabo M., first published in Arabic by Al Warrak Publishing Ltd- UK.
- Seton, L.(1993), The Archaeology of Mesopotamia from The Old Stone Age Till the Persian Conquest, translated Tilb M., Revised Edition, and Al Sham press, Damascus.
- Shahriar, M. A.; Sivakugan, N.; Urquhart, A.;Tapiolas M. and Das, B. M. (2013), A study on the influence of ground water level on foundation settlement in cohesionless soil, the 18th International conference on soil mechanics and geotechnical engineering, Paris.
- Sileman, T. (1985), Studies in the Ancient Civilization of Western Asia from Ancient Times to 1190 BC.M, Damascus House, first edition, Damascus.
- Sissakian, V.K. and Saeed, Z.B. (2012), Lithological map of Iraq compiled using GIS techniques, Journal of Iraqi Bulletin of Geology and Mining, vol. 8, No. 3, pp1-13.
- Smith, I. (2013), Retaining Walls and Geotechnical Design to Eurocode 7, Edinburgh Napier University.
  www.ice.org.uk/../retaining-walls-and-geotechnicaldesign-to-eurocde
- Soni Priya, K.; Durgabhavani, T.; Mounika, K.; Nageswari, M. and. Poluraju, P.(2012), Non-Linear Pushover Analysis of Flat slab Building by using SAP2000, International Journal of Recent Technology and Engineering (IJRTE), 1(1), PP 29-33.
- Subramani, T., Ponnuvel, D. and Deans, D.(2012), Seismic and Stability Analysis of Gravity Dams Using Staad PRO, International Journal of Engineering Research and Development, 1, pp 44-45.
- Yeager, M.(2013), History of Building Codes, Buyer's Choice Home Inspection, Thoroughness and Accuracy Matters.
  www.buyerschoiceinspections.com/history-of-building-codes.
- Yuosaf, S. (1982), History of Iraqi Architecture in Various Eras, edited by Alrashed house for publishing.

PART II: APPENDED PAPERS

PART TWO

Paper I

Advanced Materials Research Vols. 446-449 (2012) pp 220-241
Online available since 2012/Jan/24 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.446-449.220

Progress of Building Materials and Foundation Engineering in Ancient Iraq

Entidhar Al-Taie, Nadhir Al- Ansari, Sven Knutsson

Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology,97187 Lulea, Sweden.

Entidhar.altaie@ltu.se, Nadhir.ALAnsari@ltu.se, Sven.Knutsson@ltu.se

Keywords:
Assyrian, Babylonian, Mesopotamia, liben, mud, bricks, ziggurat, stones, built, temples, plan, mortar, tar.

Abstract
Humans realised the importance of housing since the dawn of history. The first man used the caves as shelter. When agricultural activities dominated the life style of humans, villages started to be constructed. Later these were developed into cities.
The dawn of civilization started in Iraq. The inhabitants in that time used the available natural materials in their construction. Reviewing the progress of engineering practices of ancient Iraq, reveals the facts that the inhabitants were aware of the principles of construction and engineering. The materials used and the design of the buildings were very suitable from both environmental and engineering perspectives.
This work is a critical review of the progress and development of engineering practices and construction materials used in ancient Mesopotamia

1. Introduction:

Buildings reflect the culture, environment and economy of the society. Humans recognized the importance of buildings before the dawn of civilization. In the beginning of human life, people were using caves and stones to build their homes in mountainous areas; in plan areas they used clay while in the marshes they used reeds and papyrus. All these were isolated housing units. The situation changed when humans used agricultural activities to survive. At this stage of agriculture and domestication of animals they were in need for larger houses to accommodate the expansion needs of animals and storage of surplus from agriculture. Then they required temples so that the "gods" guard them and their property. Agricultural activities require community work and that developed the signs of small villages which were later developed to cities. At this stage the buildings took new forms as well as the construction materials. The cities increased its development and diversified construction materials and components introduced in new form, such as marble stone and brick glazed with prominent images or sculptures [2].
Building systems depend on the unit construction, which consists of natural or artificial materials or their mixtures. Construction work means the use of units bounded by the material used and the distribution of weights should be homogenous. The prevailing methodology was that the weight are moved starting from the ceiling to the columns and foundations and then to the soil. [3].
The unique specification of Iraq (presence of plan areas and Tigris and Euphrates Rivers) encouraged the humans to use this land. The civilization started in Iraq 7000 years ago. At that time human history marked the rise the art of architecture and construction in Mesopotamia, and the world was witness to the construction activities in Iraqi for hundreds of years ago The most important factors that helped the creativity and activity was the beliefs religious peoples that inhabited in Mesopotamia, have to serve their Gods by building temples of luxury and decent. From here it is clear that the prosperity of architecture and growth began in the temples and the back of excellence in it. The most important building found in cities buried is the temples, which contained either the tower or ziggurat topped with a house of the greatest God of the city.

The Semites and the Sumerians developed the cornerstone of human civilization, the first (dating back to 3500BC) through the revival of land for agriculture and housing. Settlement began in the southern part of Mesopotamia through the construction of huts in small villages in the high places and far from the river to avoid flooding. These later developed to cities. People in these cities were interested in the construction of dams to be protected them from external aggression and also from the flood. From this perspective, walled cities like the city of Kish, Uruk (Warka) were built. Temples of mud brick decorated with metal and stone works, and invented the cuneiform writing, as well as maps and measuring instruments shown by the statue of king Codaa ruler of Kish.
After this successive civilizations dominated Iraq. The remains of the buildings are distributed all over Iraq (Figure1.1). The buildings and construction materials used during that period of time will be reviewed and discussed.

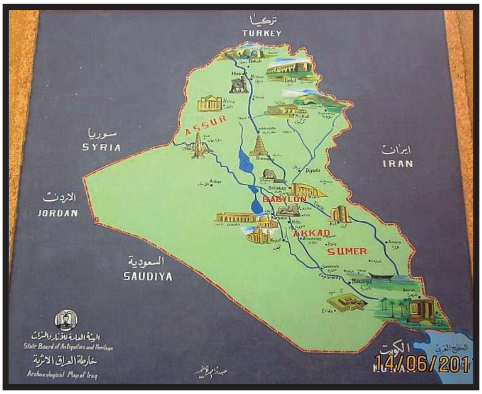


Fig. 1.1: Archaeological Map of Iraq [5]

2. The Old Population of Iraq (Stone ages, 150,000BC to 8000BC)

In Mesopotamia the oldest civilizations were discovered. They were:

2.1 Old Stone Age (Palaeolithic) (150,000 BC to 12000 BC): About 100,000 year ago, people lived in caves in northern Iraq and used its stones for the manufacture of their instruments. The oldest caves are Zouza cave, Hazairmrd cave in Sulymaniyah city. The dimensions of one of the well known caves "Shanider" in Rawanduz Mountains, 25 m for the width, 8m for high of the entrance to the cave, 40m long and 53m wide from inside[6] (Figure 2-1).

A. Outside view of Shanider Cave **B.Cave plan**

Fig. 2-1: Shanider Cave [7]

2.2 Median Stone Age (Mesolata) (12000 BC to 8000 BC): About **10000** years BC**:** The inhabitants move to plains near the caves and began to settle and cultivate the land. Zawe Jamie settlement was one of the oldest discovered and located on the banks of the Zab River to the west of the Shanider cave (Figure 2.2). The foundations of the houses built by the people of the settlement were of mud. The houses were circular in shape having a diameter of about 4m. The thickness of the walls was 1.65m, and the foundation was made of natural large stone [8].

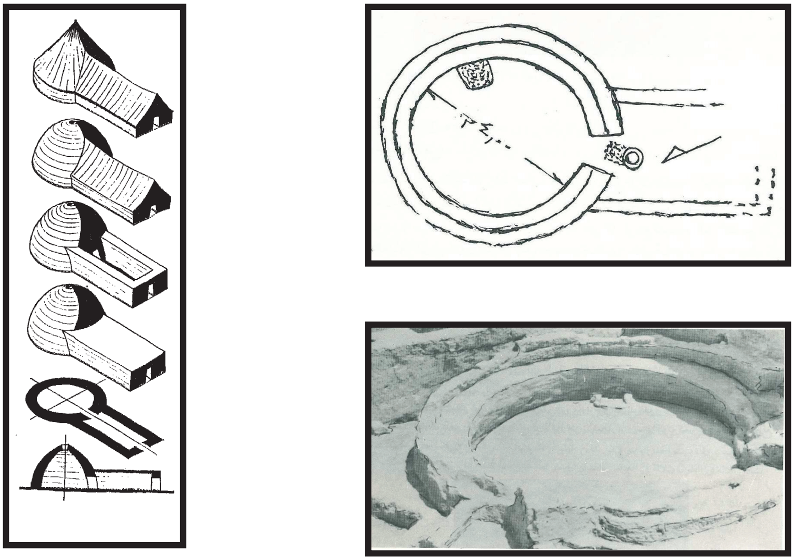


Fig. 2.2: The Round House and its Plan [1, 8]

2.3 The Neolithic Age (8000 BC to 5000 BC) : The relics and remains of villages discovered in Iraq belonging to this age reflected the development that took place in people's life. At this stage the people left the caves and started to live in villages. Garmo village that dates back to 6700 BC is an example in the northern part of Iraq. In this village a new style of buildings appeared. The houses were rectangular in shape and contain more than one room. The materials used for building were mainly mud. They also used stones in the foundation. Columns were used and the walls they were stuffed with strand of willow twigs. The floor was covered with mud and wood and reed were used in the ceiling.

In Joukh Mary village, which is located in north-western of Iraq, the basis of the tower was found at the entrance of the village which is built of material liben (mixture of clay and at the remains of barley). The foundations of the house in the village were rectangular in shape. The houses contains number of rooms, the walls were build with liben long-like Cigar of long size. These were arranged as bands of three vertical columns and three horizontal columns (). [1][4].

2.4- Pre- Strains Age (6000 BC to 3000 BC): This period extends from 6000 to 3000 BC, it include Stone Age Metal and characterized by unique type of buildings. Some of the buildings were circular in shape with diameter ranging between 5 to 7.5 m in the form of bees cells (Figure 2.3). The foundation material were stones while the walls were built by mud, the roofs were pinned in the domes. Other types of houses were also found. Their diameter was about 18 m and the thickness of the walls was 1 m.

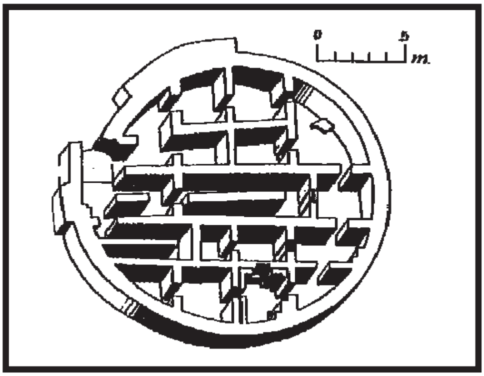


Fig. 2.3: Around house in Taba Gawr [8].

Another site is the Tel Halif located on the river Alkabour. This site represents the development of farming villages in the methods of organization and construction of buildings. Streets paved with natural stones were noticed and clay was the basic materials for construction.

The early inhabitant in the south of Iraq lived in huts of reeds and then they developed their building and used bricks made of mixture of mud and barely (liben) which is not grilled and it was used for building houses and temples.

At Jamdat Naser site, the foundations of large building, believed to be a palace, was found. Houses were constructed from raft (clay mixed with straw). Villages became cities. They used liben having convex- straight shape. The buildings were built with foundation under the ground surface, where earlier, buildings where built on the surface of the ground directly. Temples were separated from other buildings [4][8].

At Warka age (following Al Obedian Age) buildings (houses, some built with canes and papyrus , clay, and some are built from bricks) were found in Eridu. High temples were also found. They were constructed of stucco and stones. They had massive walls supported by substrates from inside and sometimes from outside. They were decorated with cones of grilled mud and some of the collared stones (black, white and green). In Eridu, multiple layers of temples were discovered, which ended with ziggurat's temple (III). This was built with small size bricks (21*12*7cm) of reddish clay, while temple(IV) was built with medium size bricks (29*12*8,26*13*7cm)of greenish clay, and temple(V) was built with large bricks (42*20*8,41*22* 8cm) of light- coloured clay with dark joints(Figure 2.4).

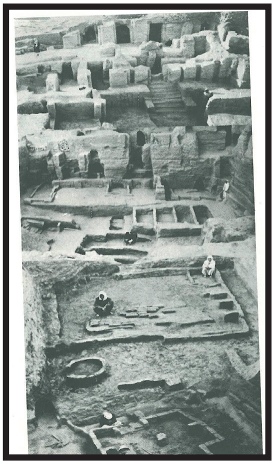


Fig. 2.4: Multiple layers of Eridu temple [9].

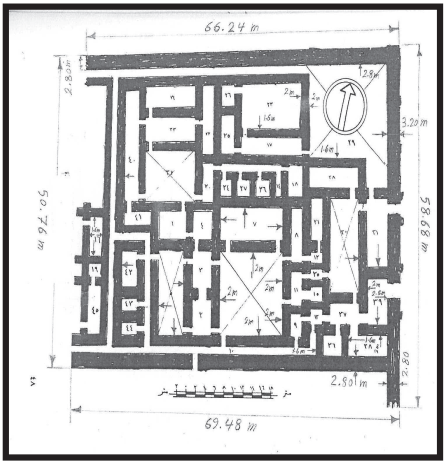


Fig. 2.5: Plan of north [1]

Two similar palaces were also built in Eridu. One of them is the north palace(Figure 2.5), which was built in rectangular shape. Its width is 45m and the length is 68m. The walls were 2.60m thick. They were built with bricks (convex- straight type). The outer walls, which represent the wall that protects the building, had thicknesses range of 2.80 to 3.20m. This also represents the thickness of the foundations of the building. The internal walls had thickness range of 1.60 to2 m. The palace has two thick walls outside, with narrow corridor to protect the palace from moving.

New style of building was also noticed in Eridu. These are temples built on artificial hill, which can be climbed by side slopes upward. The people learned to use adobe industry. They used bricks made of liben of mud (scale49*26*8cm), which were used to built houses and cover them with mud [1].

In Tel Al Aquer, located 50 miles south of Baghdad, walls about 2m thick coated with layer of mud 3 to 5cm thick were found as parts of what is known as colored temple. These walls were decorated from the outside with wavy interventions made of white plaster; with one block of solid cemented liben as the terrace built up to height of 5m.It was built in two stages set up on land which is furnished with mud. The shape of the terrace looks like the letter D (Figure 2.6). Adorn the walls of the terrace, successive interventions representing the pillars of consolidation, up 4,60m height. go They end in to a cornice with five lines of mosaic cones made of grill clay(flat from one side and painted from the other side) with diameter of 8cm, and 20cm long(Figure 2.7).

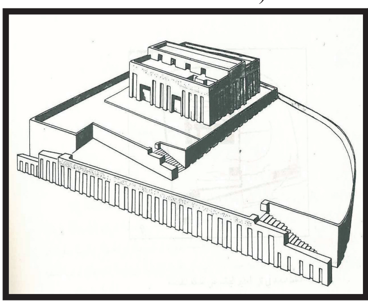


Fig.2.6: in Tel AL Aqure [1]

Fig.2.7: The Colored Mosaic of cones Temple [34]

There is also a stairway up to the bench in the lower ends of the north-eastern side which is bordered by a third-party socket and the inside a small channel to drain rain water. The highest terrace is coated with a layer of asphalt on which they built the walls of the temple.[1][6][9]
The pattern of construction was more developed where they started to use pottery and twisted nails to decorate the buildings. High temples (ziggurats) were also built. These building are important characteristics of Mesopotamia civilization.
In Warka a groups of arched complex buildings were built representing the largest urban Sumerian engineering work. They built a temple based on foundation (terrace) of the limestone, dimensions 75*29 m, and it was decorated with cones mosaic made of red, black and white pottery (length10-15 cm), mounted on the wall covered by a layer of clay. The temple was referred to as the limestone temple (Figure2.8).
In this period the buildings were characterized by use of a rectangular box of liben with square sections. Square plates of limestone were found for the first time in these building. These plates had a hole carved in the centre. No body knows the exact use of these plates and it was suggested that they might be bases for flags or foundation stones or paintings (Figure 2.9).They also used liben (convex-straight type), which was put in zigzag rows (Figure2.10. Most of the buildings had underground foundations. This stage represents the end of the pre-historical period and the bases of Iraq's civilization [4].

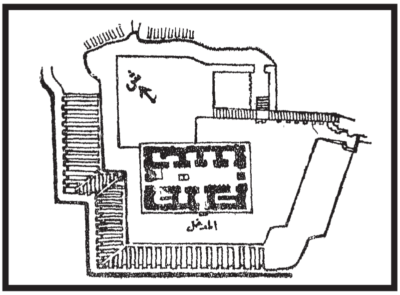


Fig. 2.8: The Limestone [10] Temple.

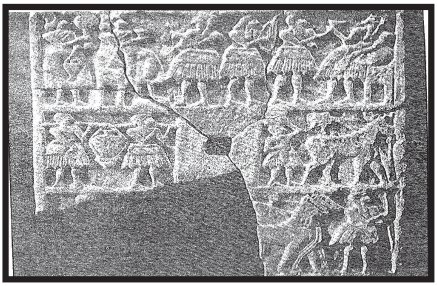


Fig. 2.9: Limestone [1] plates.

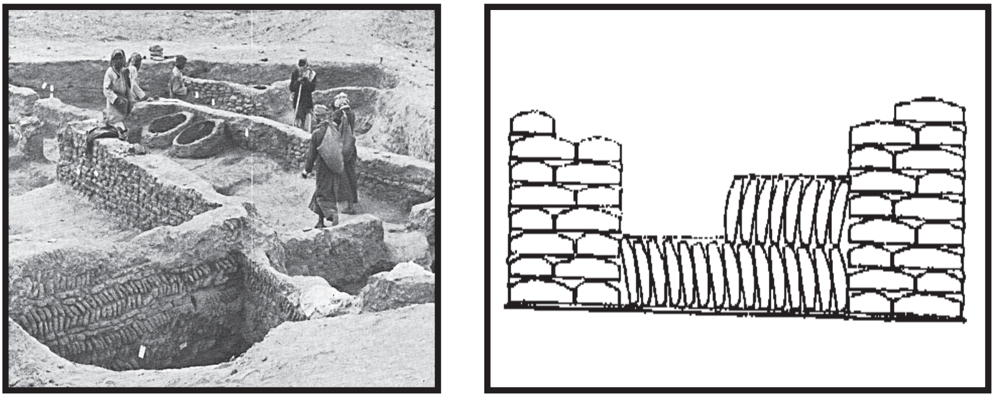


Fig. 2.10: Liben (convex-straight type)/8 used//8 in [8] rows.

2.5 Beginning of the Era of Dynasty (3000 BC to 2370 BC) :
The construction of buildings and temples in this era continued to be maintaining the same structure and materials used before. It should be mentioned however that the size and heights of the buildings were much larger. The dominant building material was liben (convex-straight type).

3. Historical Time in Mesopotamia (2370 BC to 539 BC):

3.1- Akkadian Empire (2370 BC to 2159 BC): Engineering work in this era was characterized by the use of liben (size52*52cm) having square cross section. Palaces were more important than temples in this stage.

King Naram Sin built two palaces at Tel Bark; one of them is a fort and hostel for travellers. It consist of 4 courts (one large and three smaller), number of rooms and halls. Square wall (thickness 10m) was surrounding the palace. The second palace was built in square shape (100*100m). The walls were thick and it contains many cellars (Figure 3.1).

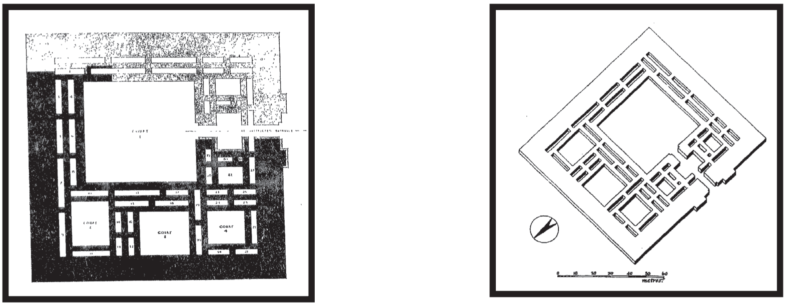


Fig. 3.1: The foundations plan of palace and fort Akkadian king Naram Sin in Tell Brak. [8,11]

3.2 The Third Dynasty of Ur (2111 BC to 2003 BC):
Temples built by king Ur-Nammu (2111-2094BC) are the main features of engineering work in this era. He invented the idea of building high ziggurat. The building was located in such away that they were parallel to the geographic directions. The builders were aware of the importance of wind and sun rise and sun set directions. The king made huge projects, among which is surrounding the city Ur with great wall (27m thick) made of mud. The aerial view of the city looks oval in shape. Prallal to the city wall a barricade of brick clay was constructed. The upper part of the barricade had slope. One of the king's achievements was the high and big ziggurats, which were solid building by liben coated with bricks from the out side, consisted of several layers topped with small temple called the top temple with another temple at the bottom. All the building was surrounded by a big wall containing many rooms [14].

The famous ziggurat of Ur-is red in colour due to the use of grill wage. It was constructed in three layers and on the top layer the temple was built. The structure was built from thee outside with either grilled wrapped bricks (brick red) with thickness of 2.4m between the mortar tars compatible with canes woven in thick layers, the inside part was built with grill wage. Lower layer of ziggurat (61*45.7m) was built in with high of about 15m above the terrace of liben. The dimensions of second layer is36*26 m with high of 5.70 m, the third layer is 20*11m with high of 3m, and the amount of slope to the interior ribs are about 11.70cm per meter[10].

It has three stairs, one in the middle, 28m long with 93 steps and its width about 2.70 to 3m, with high of 12m. The other two are on the sides of the building with high of 12m, length of 29.50m, with 100 stairs each. Each ladder rack with 82 steps, depth and the high per step is the same as of the stairs, and the two stairs join to the central and continues to climb to the second layer [1]. One of the unique characteristics of the structure is that the walls look concave although they are vertical (Figure 3.2). Fire was used to dry the bricks used inside. Holes penetrating the outer casing were made possibly to grow trees [12].

Another peculiar structure which was built by King Ur- Nammu is the royal cemetery. It was built under the ground with burial chambers and corridors. All these were covered by arches made of mud brick, and can be accessed through the ladder and its entrance triangle shape (Figure 3.3).

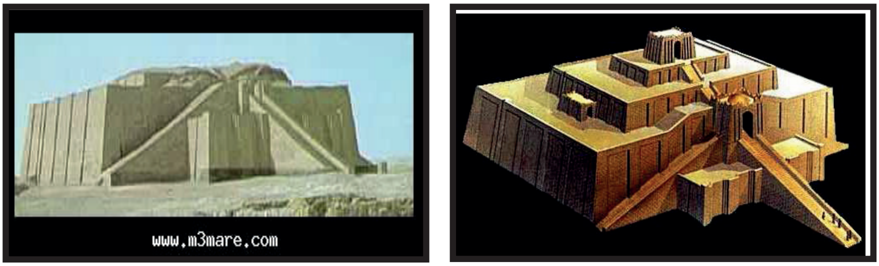


Figure 3.2: The Ur Ziggurat. [13]

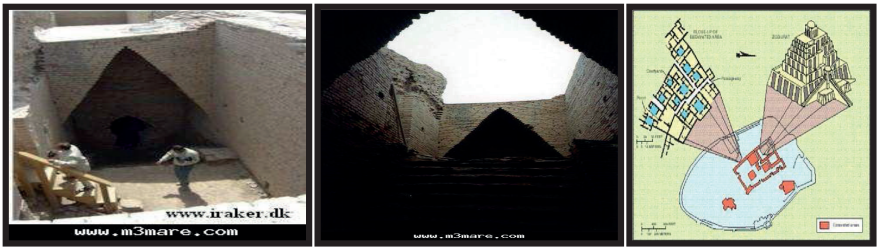


Fig. 3.3: The entrance to the royal cemetery of king Ur Nammu [13]

People's homes were built in the style apart from one house belonging to Prophet Abraham. This house had an internal library and some overlapping and adjacent rooms. They were separated by corridors of semi-circular arches and there are stairs between the rooms which indicate that the house was on different levels. Houses in the city of Ur were containing heavy water drainage systems, which is the first of its kind at the time. The technique used in the building the houses reflects the skill of creative engineers and architects. The building materials used were grill liben and the ground was covered with alvrchi (pieces of slabs of grilled clay with different measurements) (Figure3.4).

Fig. 3.4: House of the Prophet Ibrahim at Ur city [13].

Warka ziggurat was built in a different way, as encapsulated from the outside with a layer of compressed liben. Layers of mats made of reeds were put between the layers of mud at equal distances to increase the connectivity between the layers of liben. Belt of reed was used in the upper layers and ropes (about 70cm thick) were laid in holes penetrating the heart of the building in horizontal channels assist the outer walls (Figure 3.5).

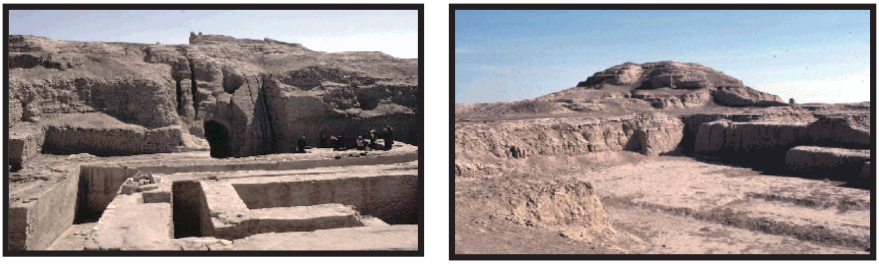


Fig. 3.5: Warka ziggurat and the temple beside it [15].

Temples have been built in all the eras with liben and it was noted that asphalt material was installed in the lower part some of the outer walls of the temples for supporting them. Statues (made of bronze or wood or stone) in the form of a nail were placed in the foundations in the four corners of the palaces and temples called the foundation statues. They are usually representing the king holding a bowl of construction (Figure 3.6). Some times these statues represent animals or humans and are called human or animal nails. Pillars and columns of sandstone were also found. They were of square shape (50*50 cm) and about 10 cm thick. These were laid in circular shape and coated by a layer of layer of lime mixed with fine gravel [17].

Fig. 3.6: The statue of Ur-Nammu used as nails in the foundation [16].

3.3 The Old Babylonian Era: (From 1894BC years to 1595BC years) This era is characterized by the building of huge splendour palaces in spite the fact that building temples also continued. The area of the palace was usually 200*140m. In the middle of the area there is a court and rooms are built around it. One of these rooms is the meeting room which is big and semi rounded with stairs. Beside this room is the king's throne room which is the biggest room in the palace. The construction material is limestone while for temples it was liben[1].

In the kingdom of Ashnona (same period but on Diyala River), temple of Abu was found on old based on several layers of the same structural temple, built with liben (level-straight type) and was square in shape with protector wall for the exterior walls(Figure 3.7). Another temple was built in Tel-Khafaji, oval in shape, was also built with liben (level-straight type)(Figure 3.8).Wage was use as a base for the walls and some times it consists of small bricks arranged in such away to form panel that might be 2 to 3m high. These were used to decorate the walls (e.g. Ishtar Gate).

In this era they continued building ziggurats, which where either of the type containing stairs or the kind of slopes. They had a height of two layers to seven layers. The ziggurats built in this period characterized by their altitude and the method of construction which is distinctive (e.g. Dor-Kurigalzu presently known as Aqarqouf). It reached a total height of 78m with a area of its base reaching 78*78m. The hight of its first layer is 33m. The technique that they used was to build the tower with a square base and the height of the tower equals the side length of the base side length (Figure 3.9). Using the length of the lateral stairs (50 m) the height of the first layer was calculated and the dimensions of the other layers was also calculated using the height and width of the stairs as in table 1 [1]. The method of construction was strange. It consisted of layers of liben, in each layer 8-9 rows of liben. These layers were separated by layers of mats made of reeds furnished by a layer of gravel and sand (8cm thick). Rolls of rope (diameter 10cm) penetrates the building were also used to strengthen the construction [19] [1]. One of the main features of construction for this period is the magnitude of the walls (average thickness 3m). Temples were built in a different way from previous eras, where they are rectangular in shape and the entrance to one side, which represents the interface. The heart of the building can not be accessed directly from the entrance. There are vestibule sides at the entrance point.

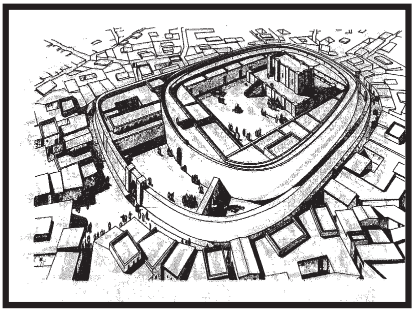


Fig. 3.7: Ashnona temple. [8]

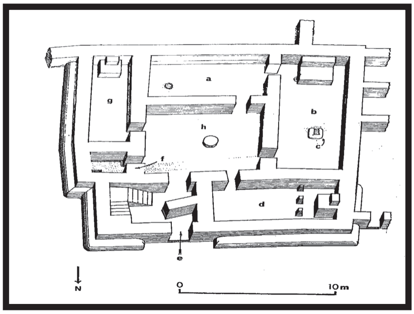


Fig. 3.8: Tel-Khafaji temple [8].

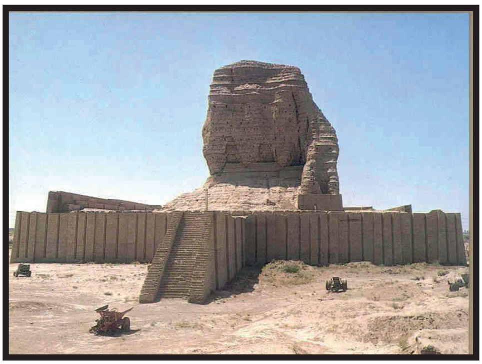


Table 1: Dimension of layers.

layer	Height(m)	Area(m)
1	33	78*78
2	18	62*62
3	6	50*50
4	6	40*40
5	6	30*30
6	9	15*15

Fig. 3.9: Ziggurat of Dor- Kurigalzu (Aqarqouf)/18

The four corners of the building had fortified wall and on the north-west in the inner part of the bench put a statue of worship. This scheme differs from previous one of moderation and internal court surrounded by rooms. The construction material was made of square liben (45*45*10cm), this liben was made of silt clay soil or sandy clay soil. The mortar material was used as an adhesive for liben or brick was made of mixed mud with water and some times straw is add in order to preserve the construction from natural symptoms for a longer period. Tar and asphalt were also used as plaster in foundations of the buildings and walls because they are available since ancient times in Hit. In addition, lime was used as plaster to build the foundations and walls because it is moisture proof and good cohesion [12].

4- Historical Times: The Assyrians (4000 BC to 612 BC):

The most important cities of Assyrian kingdom were Assyria (built on the projection of rock limestone), Kaleh and Nimrod. The kings of this kingdom were interested to build those cities and fortified them by walls and high defence towers as well as the construction of palaces, temples and ziggurats from stone material. The buildings were characterized by the carved the winged bulls and winged lions from stone, inscriptions and writings.

In the city of Kaleh, several palaces were built and entrances were decorated by huge statues. In the south western corner of the city, they built a palace called (Governor's Palace). It has a large courtyard located in the north, a large and long hall, offset-like hall in the south and ensures many rooms on the east and west sides.

The building material for foundations was liben except some foundations, based in the southern part, wage was used. The walls of southern halls were covered with a layer of asphalt from the base to a height of 65cm.The ground floors were coated with bricks.

The city of Dor-Churkin (Khorspad) is almost square in shape (1760*1675m), having thick walls (66.7m) which made it like a fort. The walls had 7 doors [8]. On both side of each door, there were eruptions winged. This is evidence on the evolution of greatness of architecture and construction at the time (Figures 4.1and 4.2).

Fig. 4.1: The palace entrance [7].

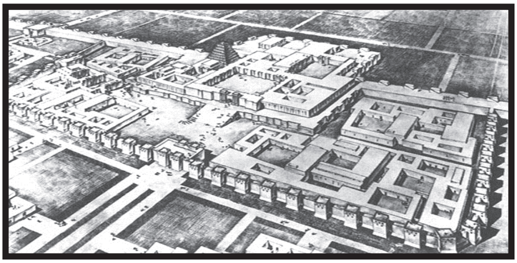


Fig. 4.2: Khorsabads palace, temple, and ziggurat [21].

Avery large palace inside the fence was also built on a terrace 12m height from the ground level. They used stones (cubic in shape) as building material. The palace complex contains 200 rooms and 30 courts as well as a temple and ziggurat. The ziggurat base was square in shape (42*42 m). It consists of 7 terraces (layers) having individual height of 6.1m which makes the total height 42.7m. Each terrace had a different colour. The areas of the terraces were decreasing from the ground to the top. Individual terrace might accommodate one building or more (Figure 4.2)[21]. In certain occasions, the terrace is composed of two rectangles with different dimensions one above the other (Figures 4.3 and 4.4). The terraces were painted by coloured chalk. The colours of the first 4 terraces were white, black, rose and blue respectively. The colour of the remainder terraces is not known because they perished. Spiral stairs were built to climb the ziggurat (Figure 4.4).

Ninevah city was the capital for a long period of time for the Assyrian empire. Palaces, temples, barracks were built. The city was surrounded by a large fence. It was fortified by castles. The length of its outer wall is about 5km and it has 15 gates. Nrkal gate was the biggest. Its height was 16.5 m and it was built on a terrace of liben (5 m above the surrounding plain) which makes the overall height 21.5m.Its entrance is 20.70m long and 7.80m wide, containing two towers on each side of the entrance. Stones were used to build the gate (Figures 4.5 and 4.6).

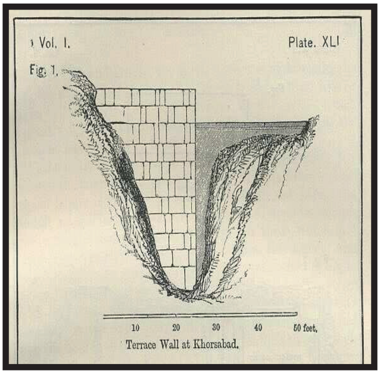


Fig. 4.3: Terrace of Khorsabad [20].

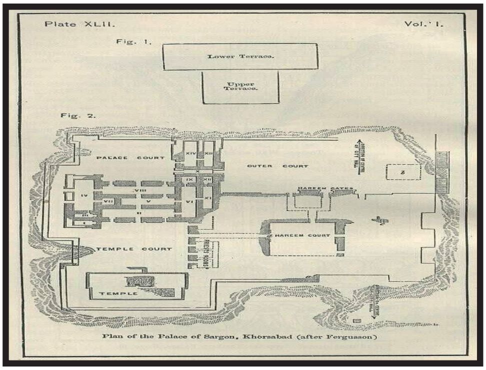


Fig. 4.4: Details of Khorsabad's Terrace and palace [20].

The second big gate in the wall is called" Shamash". It rises about 10m from tiling and the length of her forehead from the east entrance is 66m, and its entrance is 4.55m I width. The outer gate interface was built from helan (local limestone) trimmed stone. In the interface 6 towers were built. The dimensions of these towers are 3.5m in width about 22.50m high. These towers are connected with the wall which is built with stones also. The walls are 10m above the ground level. Other towers on the wall have the same dimensions apart from the two on the west side. They are 9.5m wide with a portlet 6.75 m wide and the opening decreases in width till it reaches 4m.
Between western and eastern entrances a long the corridor (61m) exists, paved by stones, some of the stones were engraved with the name of King Sennacherib [1].

Fig. 4.5: Nrkal Gate and city Wall [22,23].

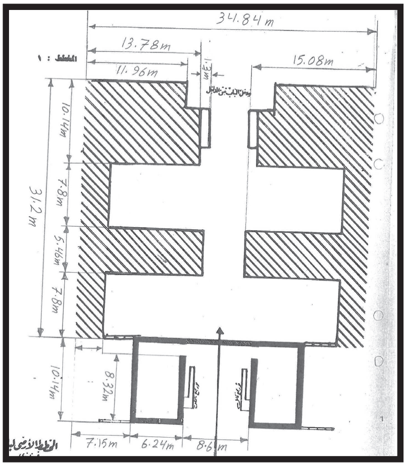


Fig. 4.6: Plan of Nrkal Gate [1].

The use the stone in the foundations and construction of the Assyrian building was very common because it was provided in the northern area from the mountains. They also used limestone and alabaster to coat huge walls. They used it for columns bases and thresholds for doors, as well as in paving the halls of the important buildings. They used solid rocks such as diorite, basalt and other to carve statues and panels and prominent images. Lime was used to join the small stones and was not used for big stones. Limestone was used to build columns that are 4 m high and at its top end spiral crown was put. The section of the columns was either square or circular and at the base there are animal statues. Some of the columns were polygonal with either 8 or 16 ribs.

Marvellous tunnel (Khariz) was dug 25m under the ground for collecting ground water in Arabella (Arbil). Ventilation opening were built at 42m intervals. These ventilations were used for maintenance and cleaning of the channel [4].

5. Last Babylonian Times (646 BC to 539 BC):

Babylon was the capital of the Babylonian kingdom. The city was surrounded by two walls, the outer one has a perimeter of 18-20km and it consists of three parts. were built with liben and bricks. The internal wall consists of two walls: the first within the city having thickness of 6.52m was built with liben and bricks, the second were smaller with thickness of 3.72m built with liben. The internal wall contains 8 gates leading to the city, behind these two walls a moat of water exists (Figure 5.1). The distance between the two walls were 2 km. Within this area the houses of ordinary people are built. Usually the houses were above the level of the street by building bench of liben. Wage and mortar tar were used for the walls. Crusader shape was the prevailing design for the houses. Above the foundation, liben was used. All the walls were plastered and painted bright white.

The city of Babylon characterized by its perpendicular streets ending at the gates of the city. Ishtar was the most famous gate. Its height is 14 m and it leads to Processions Street which was devoted to the celebration. The width of the street is 63 m and paved with sheets of stones, some of them are red stone and others are of limestone.

Number of big houses was built in Babylon. The most interesting one is that located south of the city on the procession street. It covers an area of 310*200 m, with a grand entrance and consists of hundreds of rooms and other accessories such as yards. Five yards were built in that house, the largest one of is 60*50 m representing the Throne room (Figure 5.2). The summer palace which was referred to as “Babylon Mountain” due to its height was built in a square shaped having an area 250*250m. It was 18 m above the level of the street. It contains two main halls, the eastern and western, rooms and other accessories. All the walls of the palace built with bricks, plaster. Flooring consists of pouring by mixture of lime, sand and plaster with colour additives that gave a unique technology. Construction techniques and decorations reached its climax in the Babylonian era using glazed bricks to decorate the walls and floors and bench throne. Columns having crowns helical were also built (Figure 5.3).

The most important materials used in building palaces, temples and other buildings were large stone of basalt and diorite and other hard rocks. They were used in the foundations and in the work of hook and spin, which is based upon the big doors.

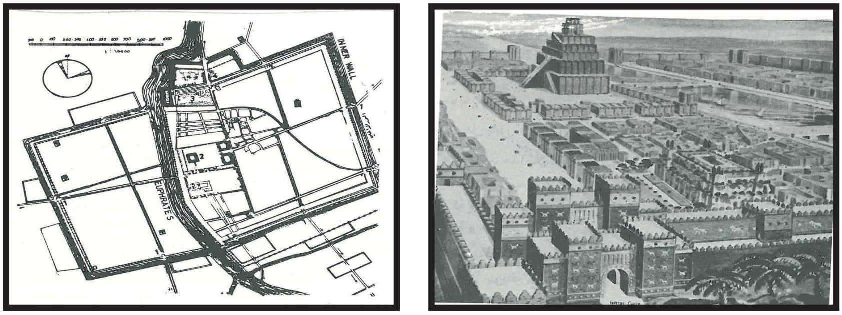


Fig. 5.1: Plan of Babylon City and its model [24].

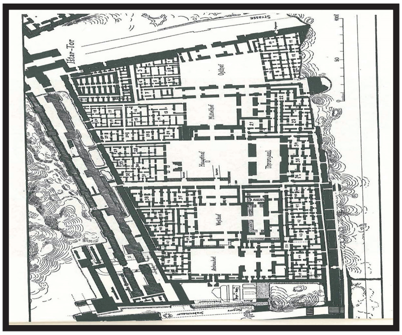


Fig. 5.2: South palace Plan [8].

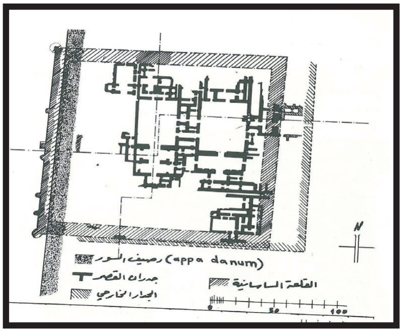


Fig. 5.3: Summer palace Plan [1].

Marble was used to cover the stairs. Hard stones were used in the construction of the pillars of the bridges on the Euphrates River. Liben 30*30cm in size and wage made of grilled liben were used in the constructions. They grilled liben in special furnaces.

Glazing wage for inscription on the walls and doors were used having different colours. For the white colour they used tin oxide and for red, blue and yellow they used copper oxide, copper with a little lead, antimonies lead respectively. Mortar was used as an adhesive for bricklaying or liben which is mixture of soil with water to make mud. The asphalt and tar have been used to prevent the commune of moisture in building foundation and walls, also they used lime commune as a good cohesion to prevent moisture in the building, foundations and walls. Timber was used in the roofing of palaces and temples and also in making the doors [12].

The Babylonians used pillars instead of piers. Pillars built with bricks in semi-circular or triangle shape. Each pillar is composed of four interrelated pillars and some of them were rectangular, oval and both are built of bricks. They have the same diameter at the top and bottom, the diameter at the bottom was gradually descending to the top.

The Babylonians used bricks to built domes. In Sharubak a room was found having a round-roofed bricks. The bricks were laid horizontaly one on top of the other. The number of bricks was decreasing in a descending order to the top. This technique is still in use now and is called the capollay [10].

The most important monument in the city is the Hanging Gardens of Babylon, which was built in the northeast corner of the southern palace (Figur4.4)[24]. The building is almost rectangular (size 42*30m). Its floor is lower than that of the palace and it contains14 similar rooms (2.20*3m). These rooms were distributed on both sides of narrow corridor.A well with three openings beside each other was found in one of middle rooms. Roofs of these rooms were arched and a thick layer of soil was laid on the roofs for agricultural purposes (Figure 5.4).

Fig. 5.4: Imaginary site for Hanging Garden [10].

Five large temples were found in Babylon, the largest is the temple of god Murdoch (Temple Aasangkela). It contains the famous Tower of Babel, which has a square base (91.55*91.55m). The sides of the tower are parallel to the geographic directions. The inner portion was built using liben while the outer part was built with bricks (15m thick). The foundation is built on a layer of pure mud, which is with impermeable.

Hooks of wood were found linked to the base from the inside through the cavities and the other end tied to the mud layer. They intended to tighten the base strongly to the foundations.

The tower consists of seven layers getting smaller in size in the upward direction. Climbing the tower can by achieved through three staircases. The middle stair case is 62m long and 9m wide. The lateral staircases are connected to the middle at the second and third layers respectively. The temple is composed of a group of buildings and rooms surrounding the courtyard (Figure 5.5). The dimensions of the seven layers of the tower are tabulated in table 2 [1].

Table 2: Dimensions of the seven layers of Babel tower [1].

layer	Longed(m)	Width(m)	Height(m)
1	91.55	91.55	33.52
2	79.45	79.45	18.31
3	61.14	61.14	6.13
4	51.99	51.99	6.13
5	42.38	42.38	6.13
6	33.67	33.67	6.13
7	24.52	24.52	15.21

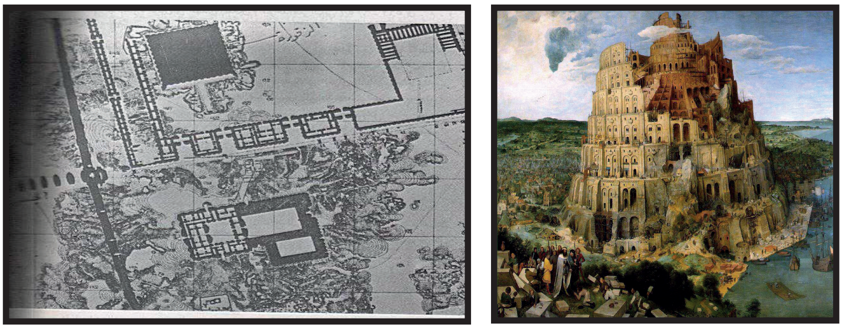


Fig. 5..5: Plan view of Ziggurat and Temple Aasangkela and imaginary photo of Babel Tower[1].

The Ishtar temple went into three periods of construction. It is rectangular in shape (37.12*31.05m) having 20 facilities and the courtyard. Its plan is identical to other temple plan prevailing in old Iraq. A huge wall built with mud and sanctified clay surrounds the temple. There is a square courtyard in the middle. On the west side of the silo there are three entrances. The middle entrance is important because it is similar to the main entrance of the temple. Surrounding the temple is a pavement build with bricks and tar to protect the external walls. At both sides of the wall a set of sorties were built to support the wall (Figure 5.6).

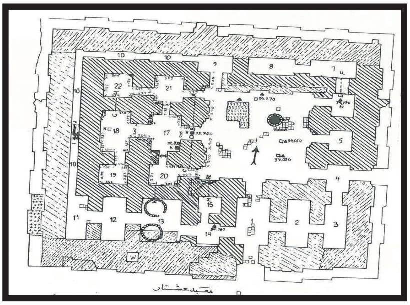


Fig. 5.6: Plan of Ishtar Temple and photo of inside temple [1,25]

In summary, there are three patterns of building construction for ziggurat or towers. They are: Rectangular tower or ziggurat which can be climbed through ladders by three stairs, one in the middle and the others two from sides. This type had spread in the southern part of Mesopotamia (e.g. Tower of Ur, and Uruk Tower). The second type which has been spread in the northern part of Iraq, is the square ziggurat or tower. This type can be climbed through gentle ramps built on its front (e.g. towers of Assyria, Kaleh, and Dor-Sharukeen) (Figure 5.7). The third type is that having square base and climbing is done to the lower floors by stairs and to other floors by ramps as in the tower of Babel.

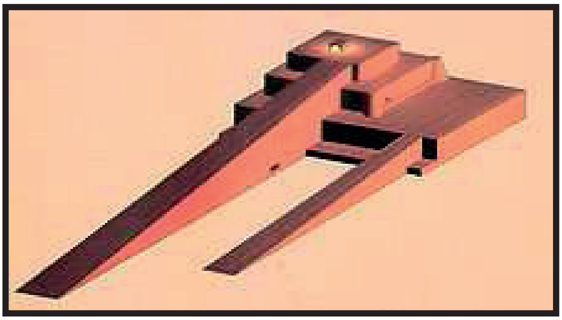


Fig. 5.7: Second model of ziggurat [26].

6. Foreign Rule of Mesopotamia (539 BC to 637 AD):

6.1- The Persians (Alakmignon) (539 BC to 331 BC): After the fall of the Kingdom of Babylon by the Persians, they re-reconstructed the Babylonian cities and palaces were built. The remains of their buildings are so little.

5.2- Romans (331 BC to 323 BC): Alexander the great defeated the Persian state and made Babylon his capital. The most important construction was building the Romanian playground**,** which consists of bleacher playground semicircular and in front of it courtyard divided into two parts by semicircular columns jointed by polygonal pillar (Figure 6.1).

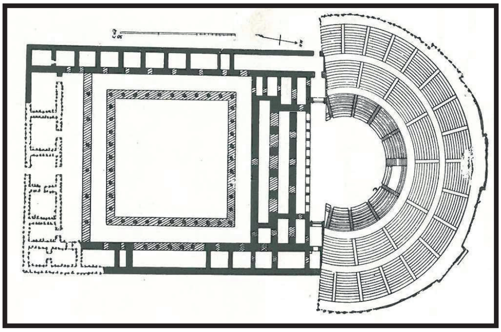


Fig. 6.1: The Romanian Playground [1].

6.3- The Persians (Alfrthein) (126 BC to 227 AD): Alfrtheon had built their capital in Tifuson (Al-Madaien), also they reconstructed the Iraqi cities (Babylon, Kish, Navarre, Warka and Assyria), and built temples on the Romanian style. Their buildings were characterized by huge walls built with liben in large sizes.
In Ashur city, the buildings were unique by its columns. Geometric shaped stones were used instead of liben. They started to build open Iwan with squares courtyard surrounded by colonnaded (peristyle) (Figure 6.2).

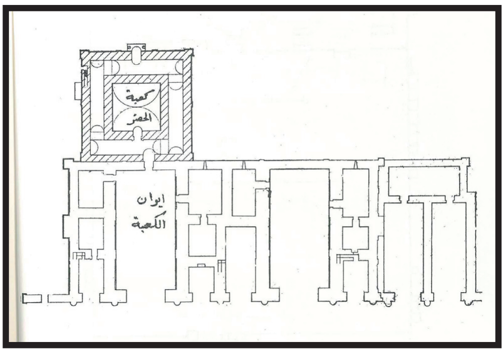


Fig. 6.2: Plan of Persian open Iwan [1].

Many cities were built between Iraq and Levant as trading caravan's centres. The inhabitants of the Assyria city reconstructed their city, and built houses and two types for rich and ordinary people. They used bricks and plaster and the high level class houses were characterized by its precision and accuracy of the horizontal distances. The Iwan became the most important place in the house or palace. The floor was tilled with pieces of geometric tile. The building adopted provided suitable places to live according to the seasons, sun falls, and the air and termination times of the day. In addition to use the geometric stones in foundations, the development of vertical walls that are covered at the top by a layer of mortar and plaster, the crakes were filled with same mortar. The second type of houses for the ordinary people, stones of irregular shapes were used (yellow brittle limestone - hallan). The stones were fixed with liben, in the same way the Assyrians used to build the deep foundations over liben. The liben was pure, yellow coloured and contains small size of unknown source material. Most of these houses have Iwan which is opened from north. Mortar plaster was used for constructing the sanitary system. There were foundations for the walls (Figure 6.3).

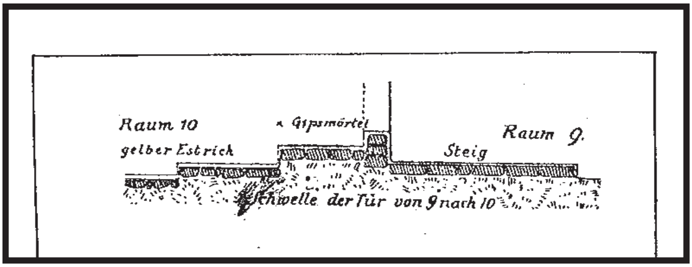


Fig. 6.3: Cross section showing the foundation (scale 1:40) [27].

6.4- The Sasanian (224 AD to 637 AD): Tesfon was the capital of Mesopotamia in this era. A famous palace known as Ewan Chosroes (tesfon arch) (Figures 5.4)[29], was constructed with plaster and bricks. The area of the palace is 300m^2. The width of the entrance of the ewan was 25.63m and it was 43.72 m long and the thickness of the bottom walls about 3m.[1]
. The walls from the interior side were covered with layer of plaster containing decorations and many pictures (Figures 6.4 and 6.5).

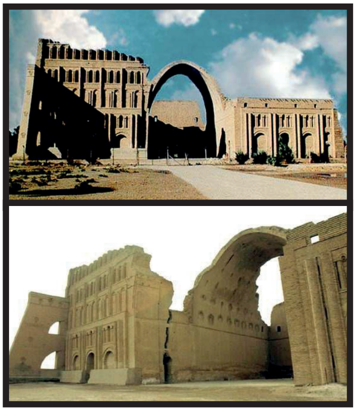


Fig. 6.4: The Photo of Ewan Chosroes [29].

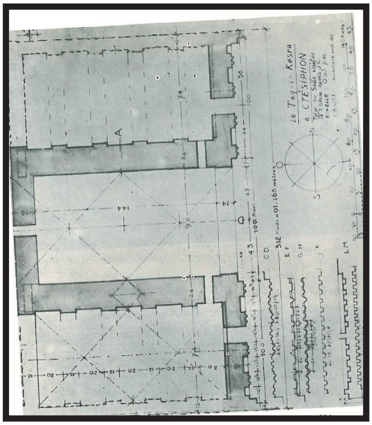


Fig. 6.5: Plan of Ewan Chosroes [1].

6.5- The Hatra City (250 BC to 226 AD): This city grew up in the desert between the Romans and Persians empires. It is located southwest of Mosul city, because it became a military center for Frthein, many Arabs lived in the city seeking protection for their temples. For this reason the city contains many temples in addition to the towers, walls and palaces.

A wall 8km long built by mud surrounds the city from outside with and surrounded by a deep trench outside. The internal wall is 6km long and composed of two walls with 12m distance between them. The material used for building stones. The city has 163 towers, with 4 doors parallel to the geographic directions. [28]

The Hatra temple is one of the important buildings in the city because of its characteristic architectural art and construction technology used (Figure 6.6). It has a rectangular shape (length of 437.5m, width 322.5m). Another wall exists extending from the northern wall to the southern wall to separate the court from the buildings. It contains several buildings, some of which were built similar to the Greek style with geometric shaped stones [1].

Another famous temple is called Marm. It has a rectangular shape (22*17m). The rooms are also rectangular (14*11m). They were built on a platform, surrounded by rows of columns in a circular form, down of them exists a second row of columns. To approach the temple room, one must limb 7 stairs having a height of 1.6m. This type of construction is called Dipteral[28] (Figure 6.7).

Most prominent features of Hatra buildings is the use of geometric stones with plaster as mortar material, also they used hooks to connect the stones. The gaps between stones were filled with a mixture of cement plaster and small stone.

New method was used in roofing, where stones used in the geometrically trimmed in roofs shaped as semi-cylindrical. Some of the arches and vaults extend for more than a half circle. They were built in radiation style (Figure 6.8).

The construction in Hatra area is characterized by strong, beauty and art, and show advanced civilian emulate the great civilizations.

In ancient Mesopotamia, the use of stone was very common in northern Iraq because of it is availability. In addition, liben as a sacred substance was also used in the construction of temples. The central and southern regions, which are characterized by silty soil, the use of liben, bricks and grilled liben was the prevailing materials in construction because of the lack of stone. Bricks and clay used in advanced techniques reflecting sophisticated engineering. At certain occasions, stones were used in the construction in southern Iraq when it is available (e.g. Uruk). In the marshes, the reed and papyrus are used for building houses (Figure 6.9). Cane was used some times in some buildings as pillar in the ziggurats.

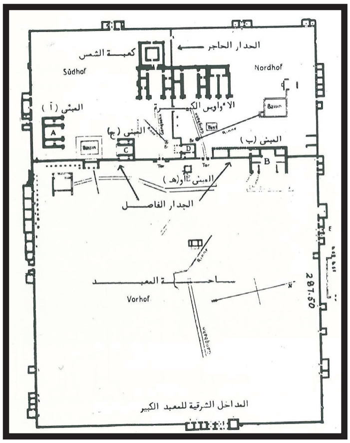


Fig. 6.6: Plan of Hatra Temple [1]

Fig. 6.7: Marm temple [30].

Fig. 6.8: Building Style in Hatra [31].

Fig. 6.9: The marshes house built from reed and papyrus [33].

7. Summary:

During the Old Stone Age (150 000 to 12 000 BC) people in the old Mesopotamia lived in caves. They were hunters. Later in (12000- 8000BC) people started to cultivate the land and gradually transformed to farmers. The advances in the life style forced them to leave their caves and live near their land in simple designed houses. Gradually with time progress these isolated houses became villages and later cities. They used the available material in their buildings. All the buildings were made of mud and or limestone, which are the most abundant material in Mesopotamia.

Religious believes had its influence on the construction of buildings. In the late stages of the Stone Age, the inhabitants of Mesopotamia started to build temples. These temples started as simple buildings and then it was growing in size and height with time. This is due to the fact that the higher the temple is the closer the person will be to his God.

Foundations for buildings did not exist till late Stone Age. The foundations started as simple stones put in a row and then they used rafts for their temples as it was growing in size.

The materials used were simple and the stones were irregular in shape at the start. Then it is well recognized that with time, the stones used were of regular geometric shape. The dimensions of the stones were relatively small at 8000 BC and they started to use bigger stones with time progress.

No decorations were noticed in earlier buildings and later colored and sculptures were used as well.

The strength of the buildings and distribution of the forces were not that sophisticates as a start. With time progress, the ancient engineers used various methods to strengthen the foundations as well as the walls.

It is noteworthy to note that the geology of the area played an important role in the selection of building materials. In the north of Mesopotamia, the available material is limestone while is the central and southern parts it was mud. In view of this fact, limestone was the most abundant material used in constructions in the north while mud was the predominating material in central and southern parts of Iraq.

When we look at the materials they used and the thicknesses of walls, it is evident that they were perfect for the weather conditions in Mesopotamia where they were conserving the heat in winter and keeping the buildings cold in summer.

8. Conclusions:

The birth of the idea to establish the first permanent home dated back to more than 6000 BC. Humans used engineering innovative that led him to use the advanced construction material available in the environment and make it suitable for construction. Solutions were found and technical obstacles were solved, and the result was building the most beautiful and most luxurious palaces and temple and ziggurats. It is astonishing to see these achievements were done using natural materials and very simple tools.

Ancient people in Iraq were looking forward to get closer to the source of the sky God and to achieve this goal, they built towers and ziggurats. These carried the art of construction projects for the ultimate graphics and this is indicates that the construction in Iraq had relied on maps and engineering calculations on the distribution of loads and taking into consideration the direction of wind and weather effects. All these achievements also imply that they had good knowledge about the principles of geology, chemistry and other sciences which allowed them to execute these huge projects.

Terraces were used as the base ground for constructing the big temples and ziggurats. It was designed to take the heavy load of the building.

The materials they used like brick for being a good insulating material, keeping the heat in winter and summer, retains moisture and is used as engineering material(mortar) also has a long life in construction.

Now a day in Iraq, the prevailing building materials are cement and iron. These materials raise the heat of the building during summer and cool them during winter. On the contrary to these materials, the materials used by ancient inhabitants of Iraq were good thermal isolators.

Engineers and contractors in Iraq should learn from the ancient engineering practices in Iraq. Adopting some of these techniques and the construction materials which were used will definitely improve the quality of buildings.

References:

[1] S.Yuosaf, History of Iraqi Architecture in Various Eras, edtied by Alrashed house for publishing, 1982.

[2] Dr.H.A. Kamona., Employment of Local Environmental Resources in the Built Unit of the Urban Fabric within the Framework of Preserving the Architectural Heritage, The Planer and The Development Magazine, Baghdad University, vol.22 (2010)1-20.

[3] www.Babylontimes.net.

[4] Dr. A. Sousa , History of Mesopotamian Civilization, In The Light of Irrigation Agricultural Projects, Al Huriya Printing House, Baghdad, vol.1, 1981.

[5] www.En.wikiwdia.org.

[6] Dr. A. H. Zayed, Middle Immortal, Introduction in the History of Civilization of The Near East from Ancient Times Till 323 BC.M., Al Nahda Al Arabian House, 1967.

[7] www.donsmaps.com.

[8] L. Seton, The Archaeology of Mesopotamia from The Old Stone Age Till The Persian Conquest, translated Tilb M., Revised Edition, Al Sham press, Damascus, 1993.

[9] F. Safar, M. A. Mustafa, L. Seton , Eridu, state organization of Antiquates and heritage,1981.

[10]L. D. Port, The Mesopotamia, Assyrians and Babylonians Civilization, translated by Kamal M., second edition, the state Egypt republic for books, 1997.

[11] Dr. T. Sileman , Studies in the Ancient Civilization of Western Asia from Ancient Times to 1190 BC.M, Damascus House, first edition, 1985.

[12] Dr. M. L. Mohammad, The Iraqi Ancient History, Till the End of third thousand BC., 1977.

[13] www.m3mare.com.

[14] F. Bassmachi , Treasures of The Iraqi Museum, The Harrua House for Printing and Publishing, Baghdad, 1972.

[15] www.aregy.com

[16]www.iraqfineart.com

[17] www.ar.wikipedia.org.
[18] www.iraker.dk
[19] www.shmskrabla.com.
[20] M. A. George Rawlinson, The Seven Great Monarchies Assyria, of the Ancient Eastern World, vol.1.
[21]www.mesopot.com
[22] www.dm3twlh.com
[23]www.hesnoman.com
[24]www.vb3.nghmat.com
[25]www.iraqiforum.com
[26]www.elaphbolg.com
[27] V.Andrei , H.Lentsin ,Hellenistic City of Assyria, translated by A Hassan A. R. K., Press book Printing and Publishing House, Mousal University, 1987.
[28] A. R. Al Husanai , Iraq's Ancient and Recently, third edition, Al Erfan Press, Saida, 1958.
[29]www.quran-m.com
[30] www.dam-flower.com
[31]www.top22arab.com
[32] J. C. Margon , The Ancient Population of Mesopotamia, The Northern Syria, translated by Salim S. Al Essa, Alaa Al Dean publishing House, Damascus , 1999.
[33]www.arab-eng.org
[34] www.Mesopotamia.com\facbook.

Trends in Civil Engineering

10.4028/www.scientific.net/AMR.446-449

Progress of Building Materials and Foundation Engineering in Ancient Iraq

10.4028/www.scientific.net/AMR.446-449.220

Paper II

Journal of Earth Sciences and Geotechnical Engineering, vol. 2, no. 2, 2012, 69-97
ISSN: 1792-9040(print), 1792-9660 (online)
Scienpress Ltd, 2012

Materials and the Style of Buildings used in Iraq during the Islamic period

Entidhar Al-Taie [1], Nadhir Al-Ansari [2] and Sven Knutsson [3]

Abstract

The Islamic period in Iraq lasted 1002 years (637-1639 AD). During this period big cities were constructed and old cities were reconstructed. There was development of the materials used and the design. Bricks, grill wage, plaster, gypsum and marble and stones were used. The environmental conditions were taken in the design of the buildings. The walls were thick and basements and badgur were established. This makes it easier to cool or heat the house. Tar was used to protect the buildings from moisture. New style of buildings was established using new engineering innovations. Well-designed arches and domes were noticed during this period. Islamic buildings had special features such as minarets, arches, domes, vaults, gilding, patterns and decorations.

Keywords: mosque minaret, liben wage, tower fence, Umayyad era, Abbasid era, emirate house, dome decorate, mud brick.

1 Introduction

The style of construction and the materials that were used in Iraq passed through different stages during Iraqi history. The history of Iraq can be divides into several stages: The oldest

[1] Department of Civil, Environmental and Natural Resources Engineering

Lulea University of Technology, Sweden, e-mail: Entidhar.altaie@ltu.se
[2] Department of Civil, Environmental and Natural Resources Engineering
Lulea University of Technology, Sweden, e-mail: nadhir@ltu.se
[3] Department of Civil, Environmental and Natural Resources Engineering
Lulea University of Technology, Sweden, e-mail: Sven.Knutsson@ltu.se

is what known as the ancient stage **(150000 BC- 226 AD)**.This stage ended at the Islamic age [1]. The Islamic period includes the Rasheden Caliphs Era (637- 661) AD, The Umayyad Era (661- 750) AD, The Abbasid Era (750- 1258) AD, and The Mughal Era (1258- 1639) AD. The third stage extends from (1639 AD onward). This includes the Ottoman Empire, British occupation and finally the Iraq independence.

The Islamic period is characterized by the establishment of big new cities such as Basra, Kufa, and Wasit (Figure 1). In addition, existing cities like Mosul and Anbar were reconstructed. The political, military, and administrative environment helped to achieve these establishments. The cities were characterized by its collector Mosque, emirate house, the places, and the schools, [2].

All the buildings were characterized by an internal courtyard or garden. The courtyard might have ceiling some times. Another feature was the presence of more than one courtyard, and they act as a filter for dust and acts to moderate the air temperature inside the house. Generally, the buildings can be classified into three categories as: buildings surrounded by fence such as palaces and khans, and buildings of a religious nature such as mosques and the shrines, and public houses, [3]. The Islamic buildings are characterized by two main features. They describe the function for which the building was constructed for, and they did not pay that much attention to the external appearance of the building. The Islamic engineer followed firm steps in their work. They used to prepare the plan drawing and calculated the cost and quantities of material required for the construction [4]. The most important features characterizing the Islamic building were the minarets, the domes, the columns, the decorations, inscriptions and the calligraphy which was use in the inscriptions [5].

Style of buildings, material used for construction and the development through the beginning of the Islamic period to the Ottoman Era will be discussed in this paper.

Figure 1: Map of Iraq [46]

2 Rasheden Caliphs Era (632-661) AD

Islamic conquest of Iraq started 637 AD. At the beginning of the conquest, **Basra city** was established. The city was actually an army camp to accommodate the soldiers and their families. It was built using canes. Later the camp was developed and re styled. A mosque, emirate house and finance house were built. These buildings were within the center of the city. Surrounding these buildings were the markets, public bathes and residential houses [4]. Streets were also established and all of them led to the mosque. The mosque was open courtyard surrounded by wall. Later part of the courtyard was covered by ceiling to protect worshipers from hot sun. The material used was mud and liben (This is a mixture of clay, water and barley). It was mixed in a special technique referred as “Bakla”: in this technique they dig a trench and they mix the clay with water and barley inside the trench. The mixture is very well compacted and later they build the walls on top of it [6].

Kufa was the second city to be built at 638 AD. It was built in a similar way to Basra city. The materials used for building were mud and liben. The emirate house was built on the southern side of the mosque over foundations having depth of 90cm. The materials were also similar to those used for building Basra city [6]. Figure 2 shows the plane of mosque and emirate house. Later bricks were used in building but to a limited extent. Wage was used for building houses but limited [7].

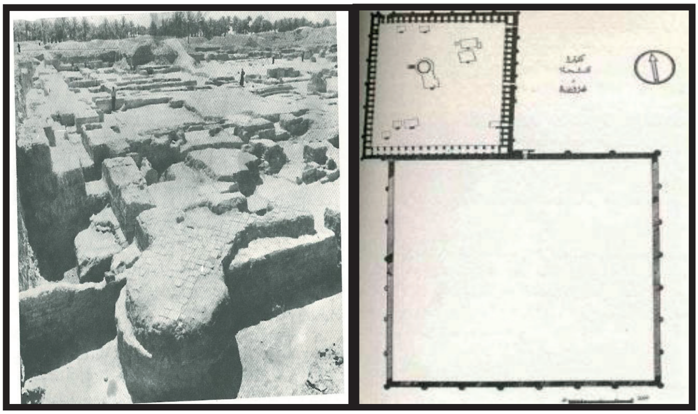


Figure 2: The Planned of the Mosque and the Emirate's House and Photo of Emirate's House Foundations [8]

3 Umayyad Ears (661- 750) AD:

This period marks major development of construction and architectural work. The engineers modified the style of buildings that they saw in conquest countries and mix it with the Islamic style. The weather conditions, availability of construction of building for the environment were taken into firm and the topography and the soil type were taken into consideration. Straight roads were straight about 50 m wide. The centre of the city usually has the mosque, emirate house and house of finance. These are surrounded by markets and residential areas [10]. Mosques at that period were considered as governmental house besides its religious purpose. All financial, political and educational transaction was executed at the mosque. In view of this, every city must have a mosque at that period. Engineers were very keen to build the mosques in such a way to reflect the spirit of religion and it also reflects the engineering development [5].

Basra city was headquarters of Umayyad Government in Iraq and was on the way connecting Sham (Syria, Jordan, Palestine, and Lebanon) and the Persian Empire. In addition it was an important port. For these reasons it developed quickly and covered an area of (15*15) km.

A number of merchants lived in Basra and built luxury palaces on the banks of the rivers. The main mosque in the city was reconstructed. They used wage and plaster in its reconstruction, the foundations were used stones and they furnished the ground with read stones [11, 12]. Figure (3) shows the mosque. The house of government was reconstructed in a similar way (Figure 4).

Figure 3: Basra Mosque with its Minaret [13]

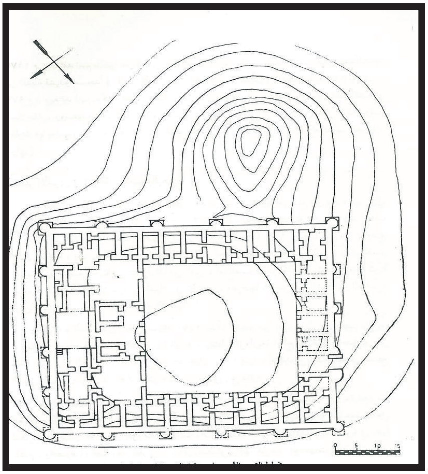


Figure 4 : Plan of Umayyad Palace in Basra [5]

The style of construction used to depend on the structural system and the bearing walls. During these period columns, reinforced pillars, and arches of different types (semi-circular, horseshoe, and spire) were used [14]. The external walls of palaces were 1.20 m thick using liben which is the prevailing material south of Iraq. This mixture is durable and does not shrink like mud. The mortar used was from the same mixture. To protect these walls from rain and moisture, they started to build 18 cm thick outer cover from wage cooked. The lime used for this part was the extinguisher lime (al Nora). This material is resistant to weathering and erosion. In certain occasions they used to mix the extinguisher lime with ash which makes the mixture more resistant. The internal walls were coated with thin layer of 30mm thickness of the extinguisher lime. Sometimes these walls were decorated with inscriptions. All the houses had more or less the same design. They had central court which is about 1m lower than the other parts of the house. In the middle of the court, they usually build a small pool to store water for daily uses. The court is surrounded by wood columns with inscriptions crowns to prevent rooms from heat of the sun [9]. Houses had basements under the ground to be used during summer due to the hot temperatures. These basements had their roofs shaped like arch to provide strength and durability to bear the loads over them and for thermal insulation. Chimney like structure was built starting at the basement to the top roof and they were called Al Malkuf. The upper outlet was opposite the direction of the wind so that it allows air flow inside the structure. All the rooms were connected to this structure by special openings to allow the ventilation. Teaching and prayer rooms were characterized by a hollow structure referred to as "kowa" to allow light in and also for ventilation [4]. Basra city was characterised by its gardens and public bathes. In one of its suburbs" Shaaba" the remains of an Umayyad palace exist (Figure 4).

Kufa City was expanded and it covered an area of (15*9) km, the main mosque was reconstructed and expanded as well (Figure 5). It had a quadrate shape of dimensions (110*116*109*116) m. The height of wall was 20 m supported by semicircular towers in same high .The depth of the foundations for the walls were 5.5m. The towers were distributed on the four corners of the mosque. The materials used in the construction were wage and plaster. Roof of prayer house was raised by columns with beautiful crowns with a diameter (0.90-1.10) m. It consists of sandstone pieces sculptured and ranked over each other. They were tied together by iron rods which penetrate a lead cylinder. The mosque can accommodated 60,000 persons [6, 14].

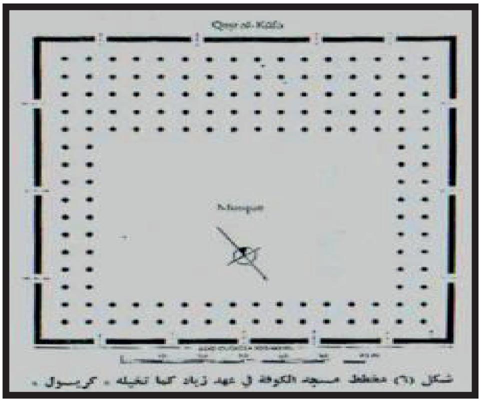


Figure 5 : Planned for Kufa Mosque [15]

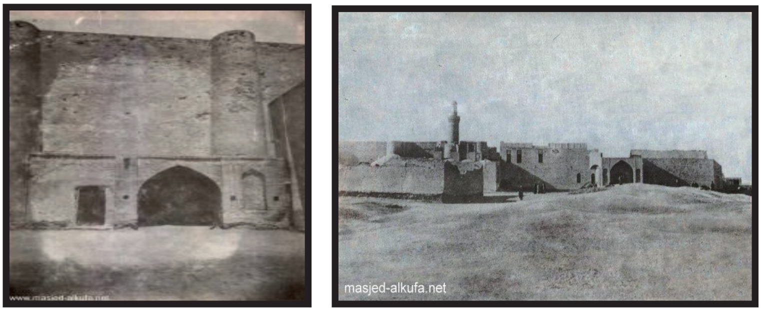


Figure 6 : Photo for Mosque [16]

The emirate house was built in a square shape with dimension (176*176) m (Figure 7). The house was surrounded by two walls. The external wall had ribs of 176 m long. The average thickness of wall was 3.6 m. It was supported by semicircle towers from the external side, their diameters about 3.6m. All the ribs had 6 towers apart from the northern rib which contained two towers only. The ribs of the internal wall were 170 m long each .The thickness of the wall was 1.8 m. The materials used in the construction were wage (36*36*9) cm and plaster [13; 16]. The wall contains semicircle towers (3m in diameter) except the northeastern side. The palace was built in a square shape (61*61) m with thick walls (3m) (Figure 8) wage and plaster were used as construction materials. The outer side is of wage painted blue. The palace has a complex design with many interns leading one to other. The entrance width was 1.80 m [14; 6 and 45].

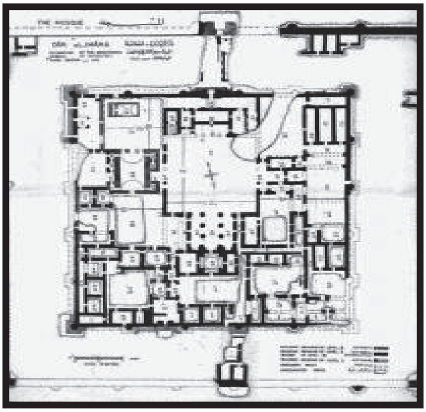


Figure 7: The Planned for Kufa Emirate House [8]

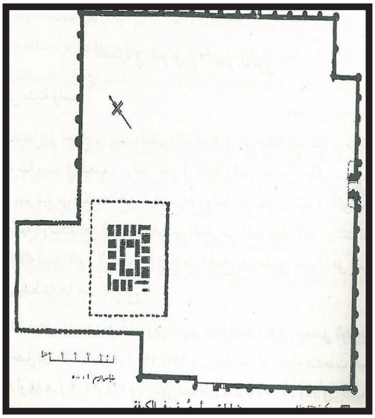


Figure 8 : The Planned for Umayyad Palace in Kufa [6]

Mosul city resembles other cities in its construction. The construction materials for the buildings in Mosul were stones, geometric stones, gravel and wage. In addition it had a wall surrounding it, which was built with wage. A wide trench was constructed surrounding the wall from the outer side and they used to fill it with water from Tigris during any attack on the city [4].

Wasit city was established at (701- 703) AD, on the western bank of Tigris, and became the headquarters of Umayyad emirate in Iraq. It was located between Kufa, and Mosul, Ahwaz, Egypt and Basrah. The main features of the city were very similar to other cities in Iraq. The main mosque had the dimensions of (182.88*182.88) m, and its walls 2.5m thick. In the middle it had a rectangular courtyard surrounded by five corridors (Figure 9). Remains of the foundation showed that at the intersection of the tiles and corridors, columns were constructed from several parts of sandstones. They were connected together by a hole in the middle; through this hole an iron cylinder filled with lead was placed to join the successive sandstones blocks together. The construction materials were wage and plaster. The building was characterized by simplicity and attractive view. The emirate house had the dimensions of (365.76*365.76) m. Square columns were constructed using square wage. Three blocks (madamiq) were used in the foundations of the corridors linked together at the base. Each part of the house contains 19 corridors. The most important feature in that house was its green Dome. The dome was overlooking all palace facilities. It was built by stones. It was seen from a distance of 25 km [15; 6]. The city was surrounded by huge wall from three sides and river Tigris was on it’s the fourth side. The walls were 4.5m thick and 2m in height. The walls were supported by towers and they had 6 big entrances (Figure 10). A trench was surrounding the walls from outside. The city had 4 main roads. Each road was 7.32m wide [4]. All Islamic cities have public bathes. They have the same design and are composed of small entrance lead to a room for changing clothes followed by three parallel rooms (cool, warm, and hot). All these rooms were provided with water basin. Water transport pipes were made of clay. Inside the bath, all rooms have domes for lighting and they did not allow the entry of air. The bath ground was furnished with marble, while its building materials were wage, stone and marble to bear water [17]. The city was expanding rapidly because it was the capital and numbers of hotels (khans) were built.

In Nahrown area (near Baghdad nowadays) Umayyad palace was established (Figure 11).

It had rectangular shape. In the middle there was a courtyard overlooking the Ewan’s. This design was prevalent later. The palace had plaster decorations

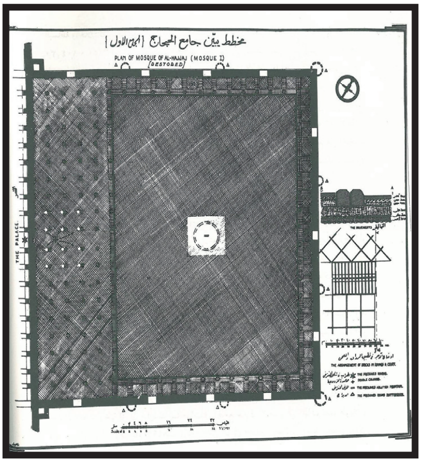


Figure 9: Planned for Wasit Mosque [5]

Figure 10: Photo for Gate of Wasit City [13]

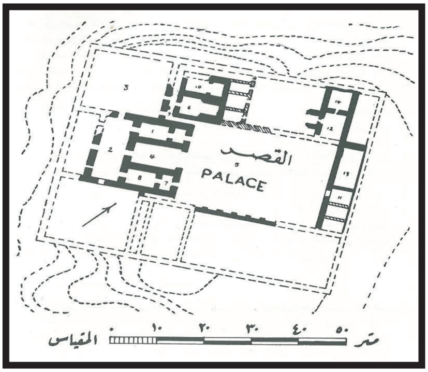


Figure 11: Planned for Umayyad Palace in Nahrawan [18]

4 Abbasid Eras (750 – 1639):

This period marks the transfer of power to Abbasid. They changed the capital city to Baghdad later to Samara. Baghdad was chosen because of its strategic site in the middle part of Iraq. The buildings were characterized by architectural decorations and large dome roofs, arches, and unique shaped columns [19]. Baghdad was built in 762 AD. It had a circular shape and surrounded by huge solid walls (Figure 12 and 13). The caliph palace was located in the center and a mosque was attached to it. The size of the palace was double the size of the mosque. Around the palace and the mosque were governmental offices. The city was planned as rings and the further away from the center the wider the ring is. Three walls can be noticed. The first wall surrounds the central courtyard and followed by the middle wall. Between these two walls are the residential sites. The area between the middle and external wall was left empty. Big trench surrounded the external wall and it was filled with water from Euphrates and Tigris Rivers by canals. Euphrates canal is referred to as Issa branch while the Tigris canal was referred to as Aldajael branch. To inter the city, four bridges were constructed on the trench leading to four gates. These gates were facing certain destinations so they were referred to as: Basrah, Kufa, Sham and Khorasan. The streets were divided Baghdad into four pivotal sections. The widths of the streets were 30.58 m (Figure 13) [18].

The palace had a square shape (365.76*365.76)m (Figure 14). The material used for construction was lebin of two sizes. The first was square in shape “Aljaafari or Aledam” (0.915m*0.915m) weighing 200Kg. The other was rectangular shaped (0.915*0.458) m"munasif" and weighing 100 kg. The first was used in the foundations and the second type was cooked to form wage which was used with plaster to build the palace. The Palace was consists of Ewan in the front having an area of (27.43*18.29) m. In the front of the Ewan was a board place (18.29*18.29) m, thickness 18.29 m.

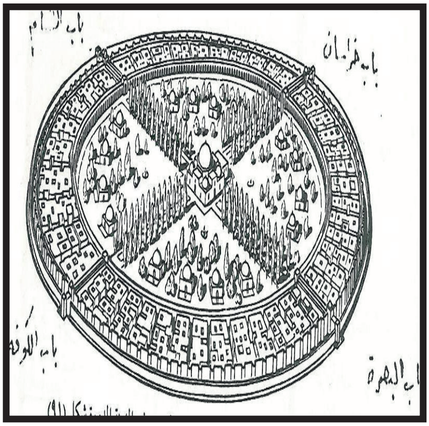


Figure 12: The Scheme Model of Baghdad [6]

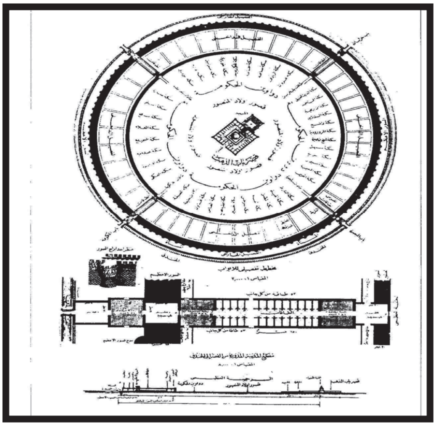


Figure 13: planned of City and Design of One Gate [23]

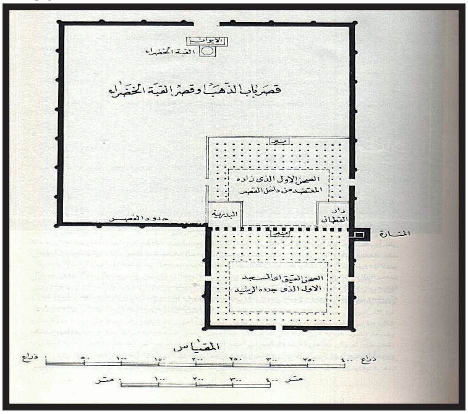


Figure 14 : Plan of Mosque and Gold Door Palace [24]

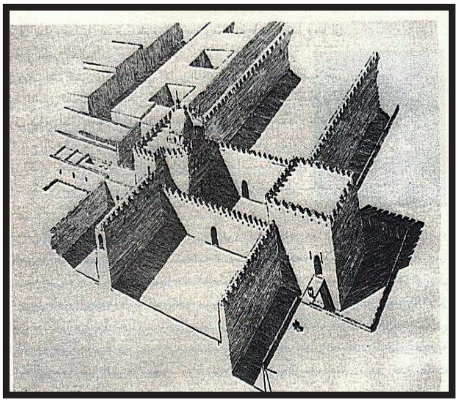


Figure 15:Section Door and Fence of City [24]

Figure 16: Photo of One Door of Baghdad and Part of Fence [26]

Over the board at a height of 40 m, another board of the same dimensions exists and over it a green dome was built. The palace was referred to as Bab Aldhab palace. This is so because it was built with marble and stones that were coating with gold. Over the dome was putting statue of a knight on his horse to determine the direction of the wind. Gold Coatings were used to decorate the walls and columns crowns. Wage, plaster, and stones were used for corridors, vents trimmings and columns build. The mosque was square shaped (182.88*182.88) m. Jaafari liben was used for the foundations and liben and mud for building (figure 14). The city was surrounded by external wall and another inner great wall. The walls had 4 entrances which were (1972) m apart. A dome was built on each gate so that the caliph can set there. The thickness each wall was (18.29) m [21; 22].

The space between the two walls is (170.70) m and it was referred to as "Al feasal" and within that space there were no buildings because it was used for military maneuvering. The external wall was 17 m in height and it was (18.29) m wide at the bottom. The great inner wall was (30) m height and its width at the bottom was (45) m and decreases toward the top till it reach (12) m. both walls were built using jaafari liben in their foundations and liben and mud for the main wall. Each raw within the wall (162000) jaafary liben pieces that weight 117 kg were used. This is so because liben can be easily penetrated by catapult. The fence was supported from the exterior side by 113 rounded towers (28 between Khorasan and Sham and 29 between Basra and Kufa). The height of each tower exceeding the wall by (4.575) m. Behind each gate was built corridor dimension (76.75*18.29) m. They had arches was built from wage and plaster (Figures 15 and 16).the corridors and water canal surrounding the city were lined with a cement like material called "Al Sarowge" made of extinguished lime and other material such as ash. This material was durable [24; 25].

Baghdad was expanding on both sides of the River Tigris. The eastern side "Al Rusafa" was allocated to the army commander's residence and princes. The western side "AL Karkh" was allocated for industrial and marketing activities. Later merchants built huge luxury houses (Figure 17) on this side. The common building material was mud apart from the important governmental buildings where they used wage and plaster and sometimes marble. Within the palaces (e.g. Kwled, Rusafa and Fordwas palaces) silver, gold, wood and glass decorations were used [17].

Figure 17: The Entrance of Kwled Palace, [26]

Mosques were used for religious, social and educational purposes. They were characterized by diversity in the plans and the height of their minarets (e.g. Alhadhir, and Kamria mosque) Al kulapha mosque (Figure 18) which was built in rectangular shape (area of 31*17.50 m).

It consists of minaret build on square base (3.50*3.50) m, and height 3.50 m, the total height of the minaret was 11.70 m. The materials used in building the mosque were wage and plaster. They used wage glazed in building the minaret, [6].

Thirty five schools were built in Baghdad and some other cities during the period (1227-1234). The most famous were Nedhamia and Sharabia School. The biggest school was referred to "Mustansiriya" (figure 19 and 20). It was consider as the first Islamic university at that time.

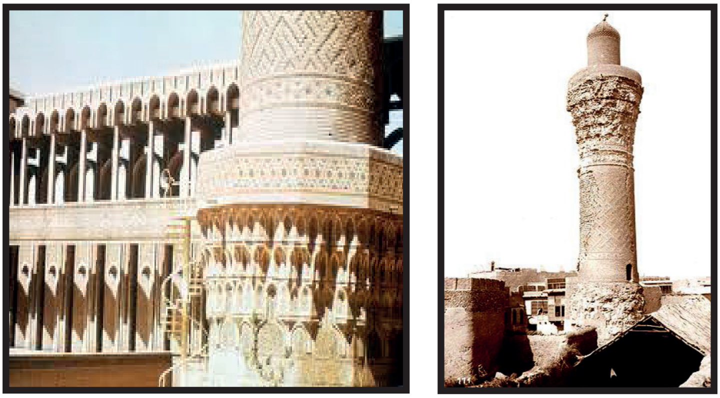


Figure 18: Photo of Caliphs Mosque and Minaret. [27]

Mustansiriya building was rectangular in shape covering an area of (4836) m^2. The construction area was (3121) m^2. It consists of middle wide courtyard area of (1710) m^2, surrounded by corridors, in the middle of each side there was big Ewan its width about 6 m, and height 10 m, on both side of Ewan there were two study halls. Mustansiriya was two floor building containing lecture theaters, halls, Ewans, library, pharmacy, hospital, kitchens, bath rooms, dar alhaddath and dar Al-Quran [28]. The building was very well ventilated

Figure 19: Photos of Mustansiriya [29, 30]

Like all Abbasid buildings the materials used in school building were wage, plaster, and liben. Most famous thing in Mustansiriya was its amazing water watch (Figure 21). It had two Baz birds each one stand up over basin, falling down from their mouths two golden nuts each hour then it opens one of twelve golden doors marking one hour [31].

Sharabia school is one of three schools were established with the same name in the middle of Abbasid era, in Baghdad, Wasit, and Mecca (Figures 22 and 23). The school is one of the luxuries and unique features that are still fixed on since Abbasid period till now a day.

It was consist of two flowers, overlook a rectangular courtyard of area 40 m^2. All the schools had the same design [15].

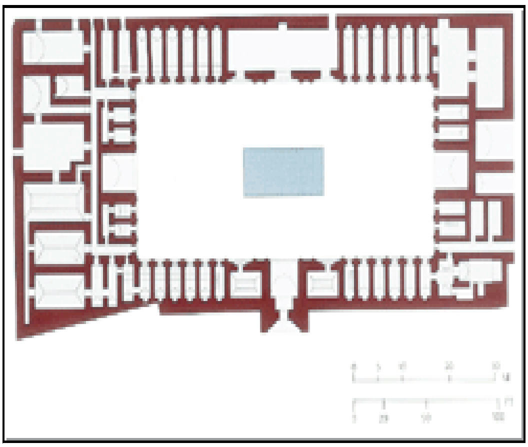


Figure 20: Plan of Mustansiriya for the two floors [32]

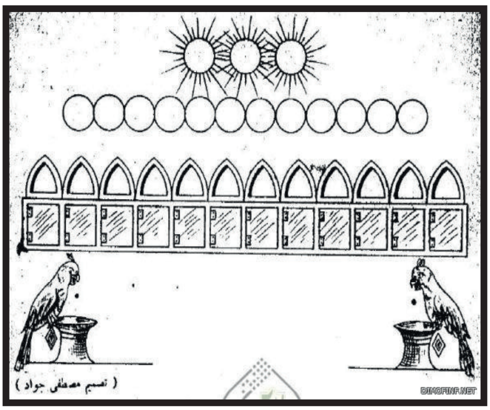


Figure 21: Plan of the Water Clock [31]

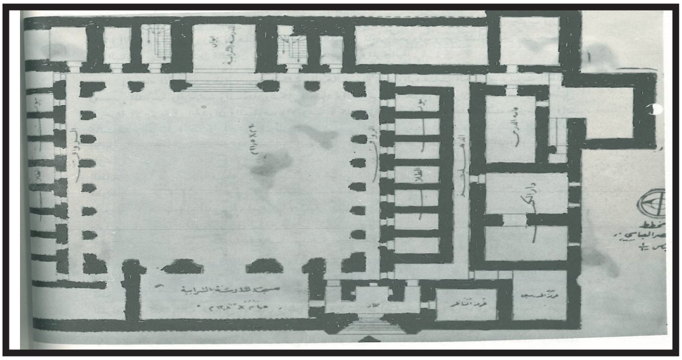


Figure 22: Plan of Sharabai School in Baghdad [18]

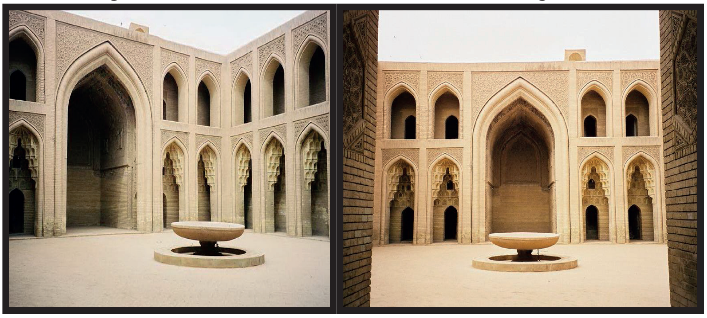


Figure 23: Photos of Sharabai School in Baghdad [33]

The School in Wasit is slightly different (Figure 24 and 25) [6]. This school was characterized by its decorations.

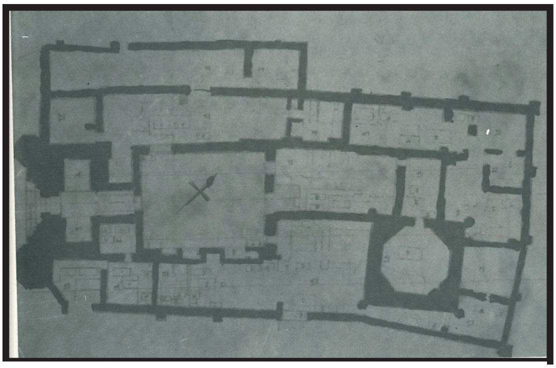


Figure 24: Planned for Sharabia of Wasit [6]

Figure 25: Photo for Sharabia of Wasit [34]

Samarra: This city was established in 836 AD after carful engineering planning and design. It was surrounded by an octagonal fence; the length of each rib was 630 m. Towers were built from the exterior side to protect the fence. Large blocks of liben were used in the foundation of fence. Many palaces were built in Samarra; the most important was referred to as Caliph Palace (Figure 26). The length of its frontal view is 700 m and the distance from the main door to the end about 800 m. The palace had three Ewans. The middle was the largest. It was rectangular in shape (17.5*8) m, and it was 12 m height. It had tapered roof trimmings. It also includes a big door (width 3.8 m and height 7 m). The other two side Ewans were smaller (4.5*4) m. Behind these Ewans were back rooms followed by the Throne hall. The palace has a second floor and basements. The height of the Walls reaches 6 m.

The wall foundations were strengthening by plaster decorations. Two basements or crypts were built inside the palace in the northern and eastern sides. The small crypt was dug to 10 m depth in solid rocks. It had dimensions of (21*21) m. It was connected to three caves. The walls were decorated with carved plaster. The big cave was of square shape (dimensions (180*180) m). Inside this cave was a large and extensive pool (diameter 80 m), connected to

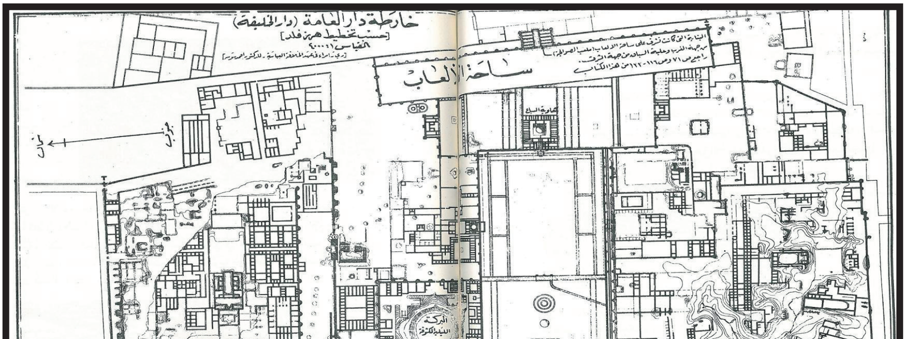


Figure 26: Plane of Dar Alama (Caliph Palace) [6]

Khariz (khariz is tunnel dug underground to collect ground water). The big crypt had many divisions and its upper part contains number of rooms. It is believed that it was used as treasury [35].

Water distribution network was established within the palace. The main pipes were made of lead, while the secondary pipes were made of blue glass or pottery. Other palaces include Jawasaq khaqani palace (Figure 27) which is located on the east bank of the Tigris southern Dar Alama palace. This palace was very large and contains throne hall, many large T shape halls, family rooms, internal gardens, soalagan (polo) courtyard, and field race. Wage was the material used for the foundations and walls. Marbles were also used for the walls. The lower portions of all the walls were decorated using plaster coating [32; 36].

The total area of the Gypsum palace is (130000) m^2 (Figure 28) [6]. The palace inside is a square building (140*140) m, surrounded by external wall, its length about 370 m, supported with 100 towers. The towers at the corners had a diameter 3 m, while other towers were smaller in size and prismatic in shape (2*1.40 m). They were located at a distance of 80 cm from the wall. Inside the palace there is a big hall (15.40*15.40 m), the thickness of its walls 2.20 m, and its roof was a big dome.

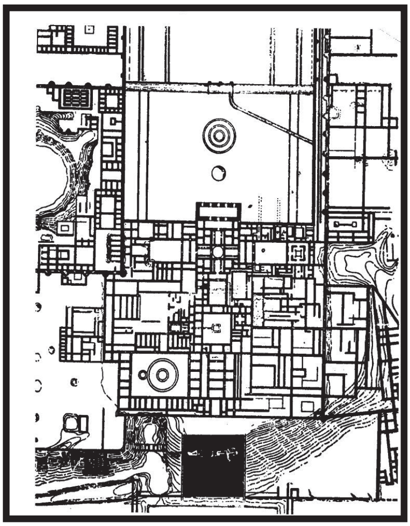


Figure 27: Planned of Jawasaq

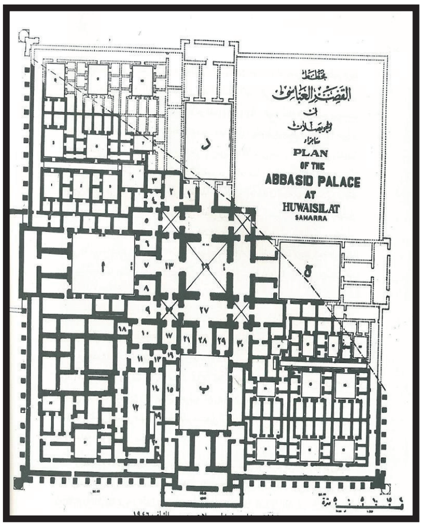


Figure 28: Planned of Gypsum Palace

The big hall is connected to four rectangular halls (16.60*6.60) m. The entrances to these halls were located in the middle of each rib of the square halls and they were 3.60 m wide. These halls are leading to rectangular open Ewan (7.80*6.20) m. The rectangular halls are connected to a rectangular open courtyard dimension (80.22*18.80) m, leading to rectangular corridor connected with palace entrance with two identical doors. The most important feature of this palace is the materials used. They were mixed plaster with stones (boulder) looking like concrete [6]. They also used extinguished lime and ash in foundations and the main walls of salons and halls. The offices were built with wage (25*25*7) cm, and plaster. The grounds of halls, Ewans, and salons furnished with square wage (36*36) cm. Other palace facilities furnished with sand mixed with plaster. Bath's walls were coated with tar over plaster layer. The walls were having gypsum decorations and inscriptions were also coated with tar to prevent moisture effect in gypsum. The fence was built with liben [35].

Pre Islamic style of buildings (Hairi style) was used in building Blkuar palace (Figure 29). This includes one big main hall for the caliph with a big door and two side wings halls for caliph's followers with smaller doors. This style became dominant in most materials used in its building large wage (called qiz) and plaster, [7, 18].Asheq (Figure 30) was another palaces located on Ashaq River. It has dimension (131*96) m, and it was built with wage and plaster [7]. Al Mutawakkil caliph was order to build the main big mosque in Samarra in 825 AD and it was referred to as "Al Mutawakkil mosque" (Figures 31 and 32). It was rectangular in shape (444*376 m). They were supported by 40-44 towers built by wage and plaster. The corner towers were bigger with a base dimension of (5.45*5.25) m, and the small towers with base dimensions of (3.90*2.25) m. the foundation of the walls were from liben and wage and plasters was used to build the walls. The mosque itself was constructed in rectangular shape (240*185) m, composed of courtyard containing rounded large fountain built using single piece of granite stone. The courtyard is surrounded by prayer house, and two washing places

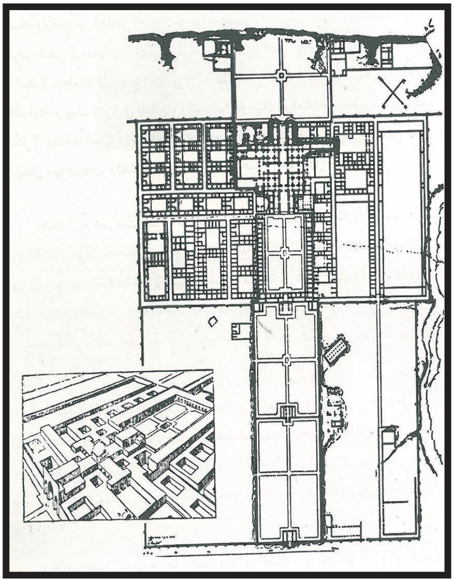


Figure 29 : Blkuar Palace planned

Figure 30: Photo of Al Asheq palace [29]

on both sides and rear part. The walls were 2 m thick and 10 m height. There exist 25 galleries inside the mosque composed of 24 rows of columns. Each row 9 columns made of pink marble and columns base is (2.70*2.70) m. the base of the columns are composed of plaster and wage. They have octagonal shape at the base and then cylindrical shape with marble and plaster crown at the top having decorations. The walls of the mosque were coated by mirrors (glazed mosaics and gilding). The unique feature of this mosque is its minerate which is referred to as “Malwya” (Figures 31 and 32) [39, 35]. It was built on two square bases. The lower base dimension (31.80*31.80) m, which represent foundations. The upper (30.50*30.50) m was rising from ground surface 4.20 m, decorated with pointed arches and bends some of them covered the spiral stair go up to minaret. Minaret was rising 50 m from the base and spins counter clockwise five times to reach the top by 399 steps of spiral stair of width 2.5m. The area of minerate decreases upward starting from 2.5 m^2 until be 1.90 m^2. At the top, the minerate is cylindrical shape with 6 m height. To reach top, a spiral stairs are used built inside the cylinder.

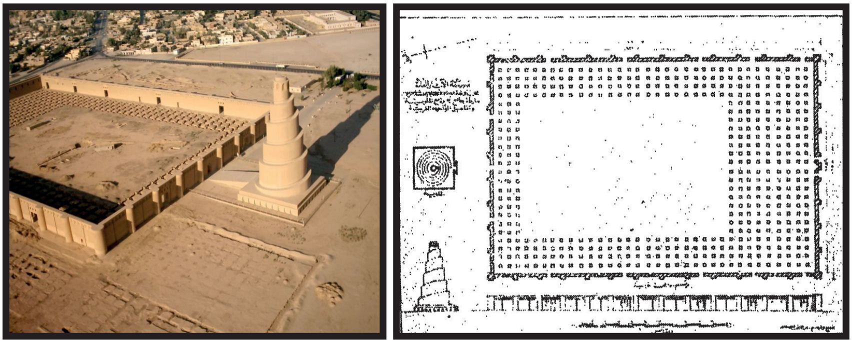


Figure 31: plan Samara mosque with minaret [18]

Figure 32: Photo Samara Mosque and Menirate [38]

Abu Dalaf mosque is the second mosque in Samarra region having a spiral minerate. The minerate of this mosque is 19 m in height (Figure 33) [15]. It's rectangular in shape (215.47*138.24 m). Its stairs spin three times counter clockwise. Its base is square (18.87*10.60) m and extends above the ground 2.70 m. It was built from wage and plaster. The mosque was rectangular (215.47*138.24) m. The mosque has internal courtyard surrounded by galleries from all sides. Each gallery was 13500 m^2 constructed by wage and plaster. The external wall was built by liben and coated from both sides with thick plaster layer, its height is 7 m, and its thickness is 1.80m. Semicircular towers were built supporting the wall. The ones in the corner were relatively larger. They were built on square base (3.60 m the length of each side) and their lower part was 5.5 m height built using wage and the rest with liben. The remainders were built on semicircular base having diameter of 3.1 m. they used liben to build every pair of towers and the following tower was built using wage. Plaster was used in all the towers.

Figure 33: photos of Abu Dalaf mosque, [37].

The houses in Samarra were more or less similar in their design (Figure 34) [6]. They have ground floor only with numbers of courtyards having F shape rooms. The houses also contain one or two crypt dug in rock layer. Holess resembling wells were constructed at the top to give light to the crypt. Stable military camp was also constructed in Samarra (Figure 35) [6]. It contains houses for the military leaders and barracks for soldiers surrounded by external long fence, the camp covers an area of 420 acres, [6].

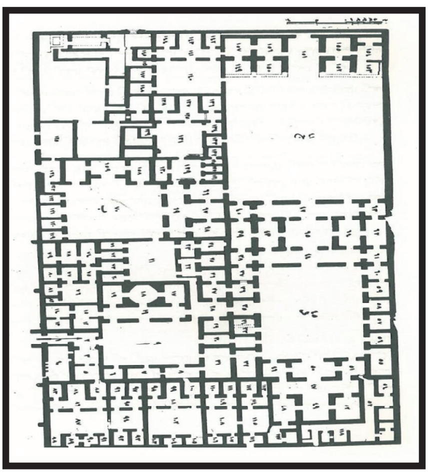


Figure 34: Plan of Samara House [6].

Figure 35: Plan Samara Camp Stables [6].

Ukhaydir fort is located in western desert to the southern east on Karbala city (now a day) about 50 km, was built 778 AD (Figure 36 and 37) [39; 40 and 3]. It was serving as rest and defense place on the caravan route of trade from the Mediterranean and Damascus to Kufa, Baghdad, and Basra. It is rectangular in shape (112*82 m). It consists of palace, mosque, and independent houses surrounded by rectangular fence. The fort was protected by two walls. The external one was built with liben supported from outside by semi-circle towers. The wall dimensions were (635*311*540*610) m. The main gate was through the west rib. The internal Fence is of irregular dimension (175*169) m, in each corner there is a tower of diameter 5 m. In the middle of each rib a tower was built having an entrance. The overall number of towers is 48 built with limestone to a height of 17 m. An arch at the top of each tower was built which added another 2m to the height of the tower. The towers had defense corridor punctuated by fighting openings. The main palace building inside the fort was adjacent to its north side with three floors. It was supported by 26 round towers having a diameter of 1.2 m. There exists a roofed lobby (15.50*9) m for entering the palace. The living wing contains several parts, each part has small courtyard surrounded from both sides by reception Ewans. The ceiling was built as arches and domes. The materials used were wage and plaster, and its foundations were terrace high above the ground. The Palace was surrounded by several houses resembling warfare castles. Several fountains were built inside the palace. The engineers built an advanced water distribution system within the fort. The baths were built using bricks and hydrated lime.

5 Mughal Eras (1258 – 1639) AD:

In the beginning of this period there were no constructions. In 1259 AD, construction started. There was focusing on shrines, schools, palaces and mosques. The most famous schools were Khan Murjan, Ovauah, and Acoli mosque.

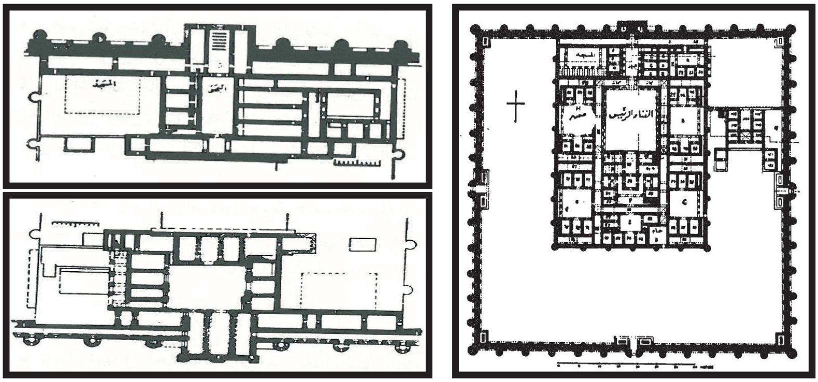


Figure 36: Planned of Ukhaydir Fort with first, second Floors [40]

Figure 37: Photo for Ukhaydir Fort [41]

Khan Murjan (figures 38 and 39) [43; 17 and 42] was built on strong and solid foundations. It was of two floors building (33*31m) beautifully coordinated apart from the northern part which was trimmed. There were three entrances to the school consisted of three hollows. The small one 3m, the middle one 3.3m, and the large one 3.5m, and their height was the same as that of two floor building. After the entrance, there is a small rectangular corridor connected to wider one and then leading to a Ewan. The Ewan opens to a courtyard (17.90*17.90) m. In the middle of the southern rib exist a chapel (12.30*5.30) m. the ceiling of the chapel had three domes. The middle is the largest. The school had two floors. The lecture rooms were located in the upper floors. There were four stairs located at each corner of the building. They were built using wage. Beside the main entrance, a cylindrical minaret was constructed for the nearby mosque. The building contains various motifs, inscriptions, embellishment, and gilding.

The Khan was located on the opposite of the school. It was luxury building with two entrances and number of windows. It was used as hotel and also for trade. It was a rectangular lobby (30.25*11.40) m, and its maximum height 14 m. All the 22 Khan rooms were surrounding the lobby. The first floor contains 23 rooms. Their openings is toward the outdoor balcony (height 6m). The rooms surrounded the courtyard.

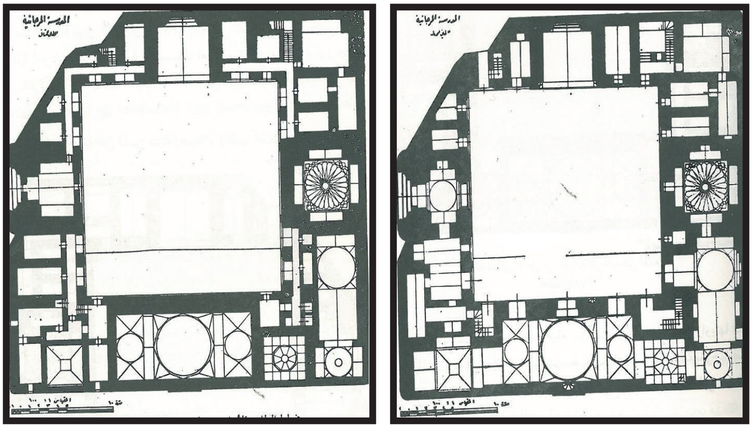


Figure 38: Plan of Murjan School 1st and 2nd

Figure 39: Photo for Khan Murjan [44]

6 Conclusions

The duration of the Islamic period in Iraq lasted 1002 years (637-1639 AD). This area had its unique features in building's style and the materials used. The main engineering aspects in this context are:

- Available materials were used in the buildings. In the southern parts of Iraq, clay and plaster were the main building materials while limestones were used in the north. During this period there was development of the building material where bricks, grill wage, plaster, gypsum and marble and stones were used.
- The cities were pre-planned. They had the same main features (Governmental palace, mosques, gardens, schools, public baths and residential places). Ewan's, courtyards and inside gardens were introduced.
- The design of the buildings took the environmental conditions into consideration. The walls were thick and basements and badgur were established. This makes it easier to cool or heat the house. Tar was used to protect the buildings from moisture.
- New style of buildings was established using new engineering innovations. Well-designed arches and domes were noticed during this period.
- Islamic buildings had special features such as minarets, arches, domes, vaults, gilding, patterns and decorations.

Three types of foundations were noticed through this period. The first bakla (mud was used in this type), stripe foundations (brick and plaster or the big, or the big weight liben- al jafarei were used), and the terraces type foundation.

References:

[1] E. Al-Taie, N. Al-Ansari, S. Knutson, *Progress of building materials and foundation engineering in ancient Iraq*, Journal of advanced materials research, vol. 446-449(2012),

pp220-241.

[2] *History of Islamic Architecture*, University of Alexandria, College of Engineering. www.kfnl.org.sa.

[3] M. O. Russe*: Islamic Monuments in Iraq*, translated by Dr. N. Arision, foreign arts 60-94, 1990.

[4]M. A. Al Mosawi: *Historical Factors for the Establish and Development of Arab- Islamic cities*, edited by Alrashed house for publishing, Baghdad, 1982.

[5] Dr. A. H. AlKarbotaly: *Arab-Islamic civilization, Arab Islamic civilization, politics, administration, justice, war, sociology, economics, education, , culture and the arts*, Khanji library, Cairo, second edition, 1994.

[6] S. Yuosaf: *History of Iraqi Architecture in Various Eras*, edited by Alrashed house for publishing, Baghdad, 1982.

[7] A. R. Al Husanai: *Iraq's Ancient and recently*, third edition, Al Erfan press, Sidon, 1958.

[8] www.alnajaf2012.com., *AlNajaf Alashraf capital of Islamic culture 2012*.

[9]H. H. Sailh: *From Basra History*, www.mesopot.com.

[10] Dr. A, Al Bahnace*: Arab Art Aesthetic,* National Council for Culture, Arts and Letters, Kuwait, 1990.

[11] J. N. Al Modawer : *Iraq's History in the Era of the Abbasid civilization Called Islam in Dar Al- Salaam*, Dar Alafak Alarabia, Egypt, first edition, 2003.

[12] Al Adhimy A. DH.,: *Short History of Basra*, publisher Religious culture library, Boor Saied, 2001 .

[13] www.al-shaaba.net, *An article of Iraqi from south*, First mosque in Basra, 2011-01-23.

[14] K. Al Sultany: *Architecture in the Umayyad Era*, Achievement and Exegesis, Almada house for printing and publishing, Damascus, 2006.

[15] www.isesco.org.ma. Dr. Al Kasser E. Y.,(2008): *Lights on Architectural Heritage of*

Islamic Civilization in Iraq, publications of the Islamic Educational, Scientific and Organization, ISESCO,

[16] www.diwanalarab.com

[17]Y. Sheriff,: *The Entrance of the History of Arab Islamic Architecture and evolution*, Alhurya house for printing, Baghdad, May, 1980.

[18] Dr. I. S. Hamed, Dr. T. M. Al Ameed, and others: *Civilization of Iraq*, part 9, Dar Alawayil, Beirut, 1985.

[19] A. Aewob: *Abbasid History of Political and Cultural,* word book company, Beirut, 1989

[20] A. K. AlAlaaf: *Old Baghdad, Arab house for encyclopedias*, Beirut, 2nd edition, 1999.

[21]Dr. S. A. Alali,: *Baghdad Administrative Features of Urban*, Planning Study, house cultural affairs general, Baghdad, 1988.

[22]H. Al alawi: *of The Cultural History of Baghdad*, the new Iraqi culture Magazine, Vol. 328, 2008

[23] A. K. AlAlaa*,: Old Baghdad*, Arab house for encyclopedias, Beirut, 2nd edition, 1999.

[24]M. Makya, Dr. M. Jawad, Dr. A. Sousa, N. Marwf,: *BAGHDAD*, dar al-warrak publishing Ltd., 1st edition, 2005.

[25] S. A. Hasani, A. A. Duri,: *BAGHDAD*, book house Lebanese, school library, 1st edition, 1984.

[26] www.mofa.gov.iq, Republic of Iraq\ ministry of foreign affairs\ tourist guide

[27] www.flickriver.com, Baghdad@yahoo.com's photos stream.

[28] Dr. M. J. AlMashadani, Dr. S. AlHeati and others*,: Civilization of Iraq*, part 8, Dar Alawayil, Beirut, 1985.

[29] www.v3bir.com,

[30] http://:Iraqi-toursi-mboard, *Tourist gateway to Iraq.*

[31] Dr. Jawad M.,: *The Effects of The Abbasids in Iraq*, www.boni-alabbas.com

[32] F. M. Shfiai,: *Arab Islamic Architecture Past, Present and Future*, deanship of library affairs ,University of King Saud, 1982.

[33]www.al-shaaba.net, *Harun al-Rashid prince of the caliphs*

[34] www.aknews.com, important archaeological discoveries in Tel Bakar south of Kut.

[35] A. A. Al Baki,: *Samarra The Capital of The Arab State in The Abbasids*, part 1, house cultural affairs general, 1st edition, 1989.

[36] A. Z. Salum,: *The First Abbasid Period*, part 3, organization of youth league, Alexandria

[37] www.dijlh.net, an art from south of Iraq, munaf al mosawi, 2010\02\10.

[38] www.vb.uiraqu.com, tour round the word, 2010- 12-03.

[39] League of Arab States: *Archaeological Sites in The Arab Countries*, part 1, cultural office , madkor printing and sons, Cairo, 1971.

[40] Th. Awkasha,: *Aesthetic Values in Architecture Islamic Art History eye Hear and Ear See*, Dar Alshark for printing, 1st edition, 1994.

[41] www.alhandasa.net. The architecture in Karbala and Fort Ukhaydir.

[42] Sh. Tartoor,: *Algelauria State*, house of guide for printing and publishing and distribution, Egypt, 1987.

[43] http://www.bonah.org

[44] www.shaaubmagazine.com., Khan Murjan told from the memory of Algelaura period, Shaaub Magazine.

[45] Dr. H. Jayt*,: Kufa Establishment City of the Arab Islamic*, Kuwait origination for the advancement of scientific, 1st edition, 1986.

[46] http://musingsoniraq.blogspot.se, *Musing on Iraq (Iraq news, politics, economics, society)*,"A look into Iraq's greation, governance, and disputed territorig, o4/02/2011.

Paper III

Journal of Earth Sciences and Geotechnical Engineering, vol. 1, no.3, 2012, 41-51
ISSN: 1792-9040(print), 1792-9660 (online)
International Scientific Press, 2012

The Progress of Buildings Style and Materials from the Ottoman and British Occupations of Iraq

Entidhar Al-Taie [1], Nadhir Al-Ansari [2] and Sven Knutsson [3]

Abstract

The period of ottoman occupation of Iraq was characterized by the same style of buildings and they used local materials as did their predecessors. At the beginning of ottoman occupation, governors were focusing on build mosques and religion schools (Tkaya). Houses were built in random styles depending on the experiences of the builders. For this reason, the houses became irregular and expanded randomly. This lead to the shrinkage of the areas of the roads where they became very narrow and used to referred to as “Drbuna”. At the end of the ottoman period the style of buildings changed and it was reflecting European renaissance influences such as the government campus known as “Qishla”. In 1917 the British army occupied Iraq. During this period the buildings were more inclined to the European style. New materials were used for the first time like cement and iron (Schliemann). The new materials and design destroyed the Iraqi heritage and cultural identity. It is believed that the new housing style did not take into consideration the Iraqi environment.

Keywords: ottoman era, cement material, mosque buildings, religion schools, iron (Schliemann).

1 Introduction

During the long history of Iraq, since prehistoric times the style of construction and developed methods of build was changing with time. Despite the changes all the methods used local natural materials for construction. This gave a special identity to the buildings.

[1] Department of Civil, Environmental and Natural Resources Engineering
Lulea University of Technology, Sweden, e-mail: Entidhar.altaie@ltu.se
[2] Department of Civil, Environmental and Natural Resources Engineering
Lulea University of Technology, Sweden, e-mail: nadhir@ltu.se
[3] Department of Civil, Environmental and Natural Resources Engineering
Lulea University of Technology, Sweden, e-mail: Sven.Knutsson@ltu.se

Locally available raw materials were mixed in different ways to get it stronger and stiffer which suited the Iraqi weather.

The roots of the basic features of the Iraqi civilization focused on ancient Mesopotamia civilization. Then during the Abbasid period it was clearly specified in its characteristic features. The same style of construction was maintained up to (1639- 1917) AD.

Ottoman rulers were concentrating their efforts to defend the borders of their empire. For this reason no real development in buildings took place during that period. Most of the efforts were concentrated on only reconstruction of old buildings and building some new mosques and religion schools. Some small towns were established on the trading roads. Near the end of Ottoman occupation they began to construct new buildings. The design of the buildings clearly reflects European renaissance influences. One of the main buildings of this style still exists and known as “Qishla”.

The British occupation to Iraq started in 1917. This occupation brought a new style of building and introduced the use of new building materials. These materials were not used before such as cement, iron (Schliemann), and concrete. As a consequence the techniques of building arches were completely changed [1]. These changes in style of building and materials are still in use in the present time.

This paper will demonstrate the most important characteristics of construction during the ottoman occupation period of Iraq and its developments. It will also describe the building style and newly introduced materials by the British occupation of Iraq which deviated from the traditional Iraqi architectural heritage.

2 Ottoman occupation periods (1639- 1917) A.D.

At the beginning of the Ottoman state, the style of building did not change. The houses maintained its traditional design which consisted of interior courtyard surrounded by the rooms and its services facilities. Ottomans governors were focusing on reconstructing mosques, shrines and building new mosques in different parts of Iraqi. Also they established many on the trade roads small towns around a central building known as “Khan” (Figure 1). This Khan represents the central market place. These towns such as Mahmoudia and Yousefayah were built randomly without pre engineering planning. The houses were not built according to a specific style. The style used was based on the financial ability of the owner and the experiences of the builders [2].

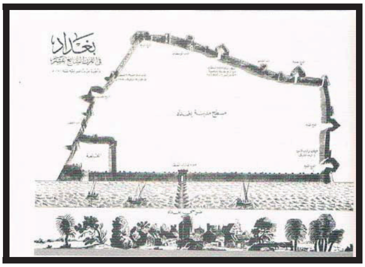


Figure 1: Khans on trade roads

Figure 2: Baghdad Map on Nineteen century [3]

Baghdad city had remained without major changes. They kept its walls which were built with wage from the east side. The walls contained towers and surrounded by deep trench with four gates in the walls (Figure 2) [3]. Many parts of the city were inundated by the Tigris River floods and destroyed. Destroyed houses were reconstructed in accordance to the wishes of the owners and their financial capability. As a consequence there was no uniform or special design and symmetry. The walls look retorted and the roofs were irregular. Roads became narrower because of the expansion of houses. Wide roads became narrow alleys (Drbuna) (Figure 3).

The houses were either built as one or two floors. One floor built houses consists of middle open rectangular or square courtyard surrounded by Ewan's and rooms and all houses contain basement to be used during the hot climate. In the two floors houses (Figure 4), the first floor contains one or two corridors (Tarma), basement, food store, and the kitchen. The second floor consisted of connected bed rooms with each other's by tarma and have external openings for ventilation and lightening. Some of them have prominent windows called "shanashil" overlooking the road.

Materials used in buildings were wage, mud, gypsum and mud mixed with hay as binder. These materials are easily cracked and for this reason they used stones without any metrologic and mixing base considerations. These stones were called wastani, jabal, mhyar, and babbly.

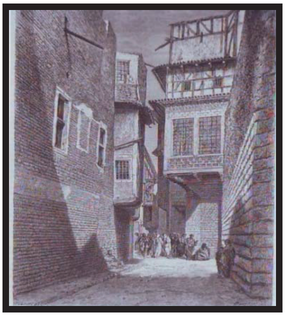


Figure 3: old Baghdad alleys [4]

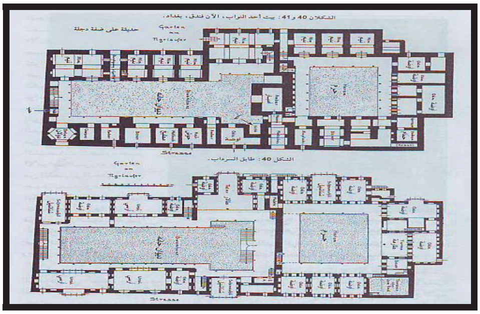


Figure 4: plan of two floor house with basement [5]

The foundations were (1.5-1.0) m in depth for good ground, but in bad ground their depth reached 3m. It was not required to build the width of foundation wider than walls in the houses. Foundations material used was broken wage and lime with ash as mortar. This type of mortar was used up to 1m over the ground [5; 6].The style of houses had different designs and shapes all over Iraq. This was due to the fact that building was mainly dependent on the availability of raw material and the expertise of the builders. In the west part of Iraq the houses were very simple consisted of an entrance which were slightly above the ground called (Ataba) to prevent water and insects going inside the houses. The design of the house was composed of a central room surrounded by other rooms. The roof was dome shaped and wall thickness was about 50cm. All walls have unopened arches used to put things in it. House courtyard (Figure 5) was rectangular or square placed in one side of the house. Materials used for building were plaster, stones (because it is available in the area) and gypsum used in foundations because it resists moisture. Also they used wood for entrance ceiling. Figure 6 shows the material used in building units.

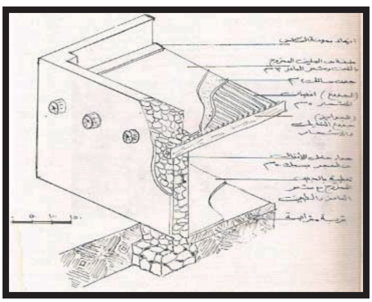


Figure 5: house plan in west of Iraq [7]

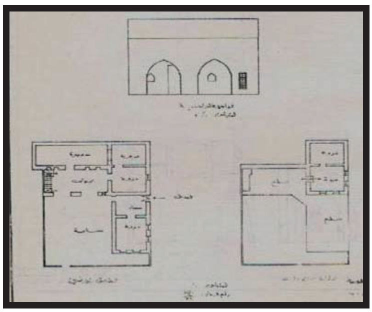


Figure 6: raw materials used in built units [7]

Ottoman governors were more concerned to build mosques like Alkhaski mosque, Ahmadiyya mosque (Medan), and Hayderkhanah mosque (Figure 7) as well as Quran teaching schools (Tkaya) such as Albanndnaiji (Mandalawi) tkaya, Khalidiya tkaya, and Sheikh Hassan Altayar etc. Hayderkhanah mosque was a distinctive building. It was built in square shape symmetric angles. It had three very big entrance doors, wide courtyard and winter chapel on its top large dome. On its side they built a very high minaret and summer chapel on the right of the winter chapel (Figure 8). A school was built and connected with the mosque. Materials used in its building were wage, gypsum, and marble. They also used columns and cylinders brought from neighboring countries, [8; 9 and 16].

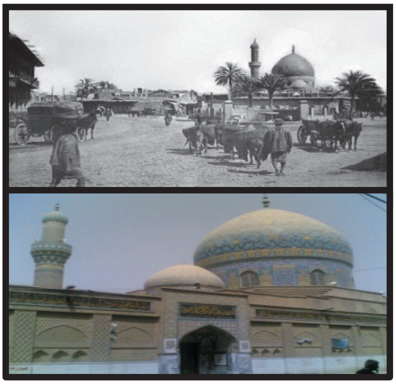


Figure 7: Hayderkanah Mosque [10]

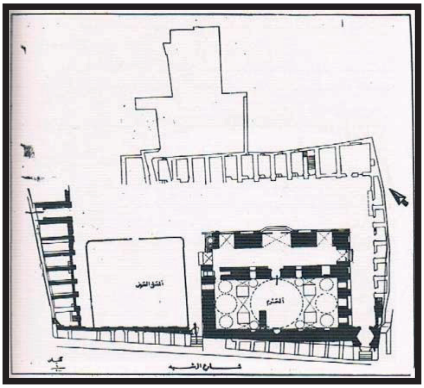


Figure 8: plan for Hayderkanah Mosque [8]

The most famous Tkaya was Albanndnaiji Mandalawi. It consists of a house of prayer, mosque, small school (Tkaya) for teaching science of mental and spirituality. Tkaya area was 1200 square meter, rectangular in shape (Figure 9). It had one main entrance in the middle of the eastern side. There were no decorations and windows on its front view. The entrance was connected to a narrow corridor ended with door of two parts (2*1.50) m. The building was one floor containing all units of structural, religious, residential, and services. In front of these units there were walkways and corridors. Open rectangular courtyard was in the middle of the building with a dimension of (22*21) m. There was a square garden in the middle of the courtyard (10*10) m and well for water tkaya need.

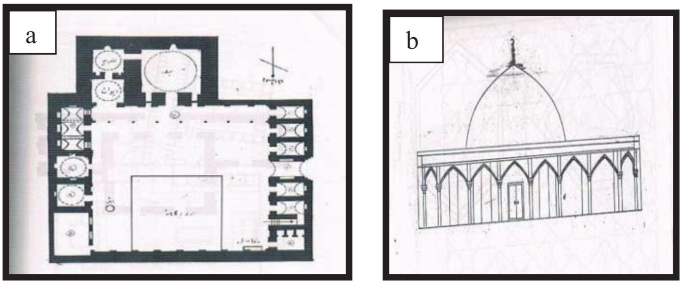


Figure 9: a-plan of Tkaya Albanndnaiji (Mandalawi), b- front view [11]

The structural units were distributed around the courtyard. Walls were built with thickness of 1m to keep moderate temperature inside the building. Wood was used to make columns with crowns holed roofs. Materials used in the building were wage and gypsum. Ground was furnished by small square wage (20*20*4) cm. Another famous Tkaya called "Khalidiya" (figure 10) was built and the building material was wage and gypsum. It was constructed on a rectangular land dimension (30*21.3) m. The Tkaya had similar design of Mandalawi Tkaya. It had one floor and one entrance and a middle courtyard (10*9.5) m which was the only source for air and light. Building was designed in such a way that courtyard separated the structural and religious units. Thickness of the walls was (2-3) m to bear the weight of the domes built over them. The prayer house was coated from the outside by tiles and blue glazed wage [11].

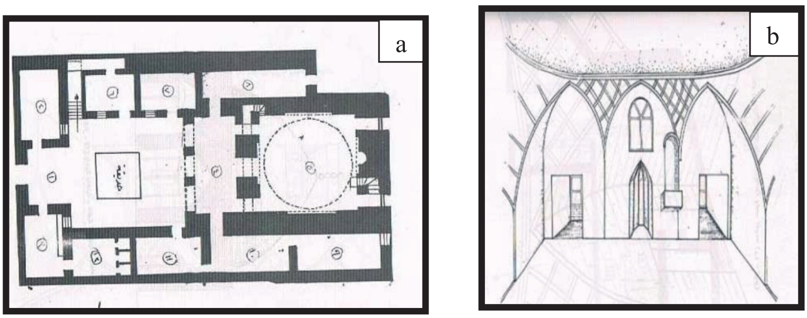


Figure 10: a- plan of Khalidiya Tkaya, b- front view [11]

At the end of the Ottoman period the style of buildings was changed. A new type started which was influenced by the European renaissance, mainly Italian style. The new style was shown in Qishla building which was built to be a military barracks. This building is considered as turning point in the history of Iraqi construction [12]. Qishla was built in

(1851- 1853) AD, on the west bank of the Tigers river. The building consisted of two floors as L shaped (Figure 11). It had a square hollow tower in the middle of its courtyard, height 33m and its base dimension (9*9) m. The tower had four clocks in it upper part facing the four geographic directions. On the top of the tower ribbed dome was built. On its top a sign showing the geographic directions and winds was installed. Local materials like wage and gypsum were used in its construction and wage technology was used for the roofing (Figure 12), [13; 14].

Figure 11: Qishla building like Italian design [15]

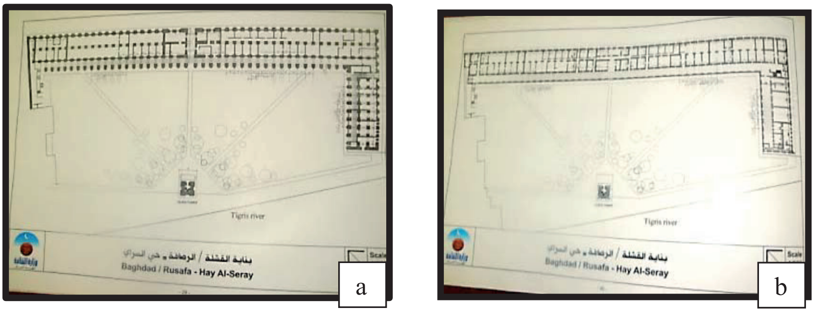


Figure 12: plan of Qishla building, a- ground floor, b- first floor [13]

3 British occupation period (1917-1958) AD:

Construction stopped in the first 12 years of the British occupation of Iraq. The construction first started with roads and bridges planning and building. Fixed bridges replaced the floating bridges between the two sides of Baghdad [17]. Planning and building was made by British engineers and architects. British engineers were implementing British designs. This period of Iraqi buildings history marked the start of a new ways and styles of design, building, and materials used (Figure 13). Materials such as cement and iron (Schliemann) were firstly used in Iraq at that period. In addition, local product like bricks used in a new technique referred to as stone technology on outer side of the walls [18]. The British were striving to apply the modern and organized urban planning. The towns were built similar to the British style. The British experience dealing with bricks helped them to construct the building in such a way to suit the hot weather.

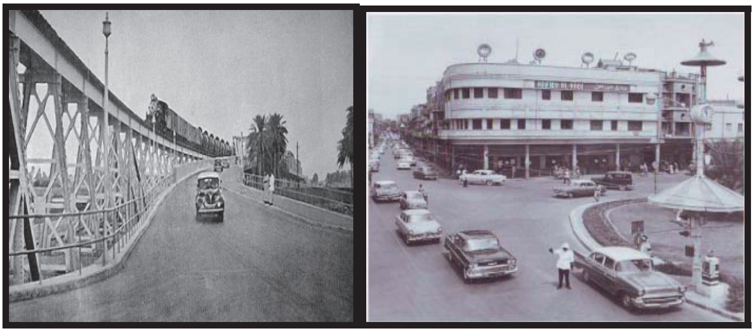


Figure 13: Baghdad in the new planning [4; 19]

Residential areas had been developed and houses started to be built in straight lines, adjacent to the new streets. Walls were still built using raw brick and shanashil (which was made of several overlapping frames made from wrought wood with skylights and round windows) changed to open balconies. The Iraqi house (Figure 14) in this period had an English-Baghdadi style. Baghdad was divided into three parts. The first resembled the old center of the city which included the old houses with shanashil and narrow roads. The second part was the new neighborhood resembled the British houses style which was far away from each other. They were usually built along the Tigris bank from north and south. The third part was the rural clay houses or random homes proliferating in the suburbs of Baghdad. People from villages used to live there [4].

Figure 14: The Iraqi local Style Houses (English Baghdadi), [4]

4 Independent Iraq period (1958- present):

During this period the style of building had changed in Iraq for different reasons. Modern building materials, equipment and technology were used. The Iraqis sought to take advantage of modern technology and materials in their work. The style of buildings, its suitability to the environment and culture were forgotten. The objective was to implement the modern western life elements style irrespective of its suitability to Mesopotamian environment [20]. The modern buildings were characterized by manifestations not related to the country`s civilization or climatic conditions. The buildings became concrete masses full with foreign shapes without any character related to the authentic civilization heritage (Figure 15).

Figure 15: Modern Buildings in Baghdad [21; 22]

5 Conclusions

Ottoman period was characterized by its continuation of the old style of building. It was characterized by the presence of a courtyard in the middle of the building surrounded by all other facilities. The constructions were executed depending on the experiences of the builders not on the pre-engineering planning. Materials used in building were local such as wage, gypsum, and mud. The country was neglected because of the invasions and floods which destroyed most of the Iraqi towns. Some signs of development were noticed at the end of Ottoman period where some buildings showed European renaissance. These buildings were different in their design but it was built using the same local materials. During the British occupation period, the style of buildings was completely changed in design, building, and materials used. This was due to the fact that British engineers implemented the design style, materials and technology that they used in their home country to Iraq. They imported materials such as cement, iron (schlieman), and concrete. The buildings were note suitable for the Iraqi environment. Iraqi engineers and architects also adopted the western ideas without pay any attention to the harsh climatic conditions that does not suit this style. Towns became full with concrete hybrid masses which make bad effects on the environment. Old engineers used the local materials because they were more suitable to Iraqi climatic conditions and friendly to the environment.

References:

[1] www.ahewar.org, Aesthetics of space in architecture Baghdadia, Sarmad Al-Sarmadi, *Journal of Modern Hewar*, **Vol.3049**, (30\06\2010).

[2] Dr. S.Al Ail, others, *Baghdad in History*, Dar Al hurrya printer, first edition, Baghdad, (1982).

[3] M. Makya, Dr. M. Jawad, Dr. A.Sousa, N. Marwf,: *BAGHDAD*, dar al-warrak publishing Ltd., 1st edition, (2005).

[4] S. Peeri, *BAGHDAD modern architecture and heritage*, translated by: J. L. Chehayed, Archange Minotaure publishing, Paris, (2008).

[5] Dr. Ing Reuther O., *The Iraqi House in Baghdad and other Iraqi towns*, translated by: Kpabo M., first published in Arabic by Al Warrak Publishing Ltd- UK, (2005-2006), ISBN 1 900 700 999.

[6] A.K.Al Allaf, *Old Baghdad from 1869- 1917*, AlMaaref press, Baghdad, (1960).

[7] Abdul Rasul S. (heritage specialist), *Architectural Heritage in Ana and Rawa*, Ishtar Company for printing and publishing Ltd, Baghdad, (1988).

[8] S.Youssef: *History of Iraqi Architecture in Various Eras*, edited by Alrashed house for publishing, Baghdad, (1982).

[9] A. Al Kosaira, *Baghdad Mosques in Ottoman Era*, PhD. Theses, Cairo University, Heritage Collage, (1981).

[10] http://Islamicbooks.info, Baghdad in the late Ottoman era.

[11] Dr. Al Draghi A. M. H., *Connectivity and Hospices Baghdadi in Ottoman period (1635-1917) Planning and architecture*, Dar Alshown public cultural, Baghdad, (2001).

[12] Y. H.Abdul Mejid, THE QISHLA COMPLEX, *Eng. & Technology Journal*, **vol 19**, No. 1, (2000), 117-134.

[13] Seminar of the Ministry of Culture, QISHLA Building- Past and Future, Baghdad, March 30, (2004).

[14] G. M. R. Al Silq, *City of Stories,* Iraqi cultural support association, 1st edition, Baghdad, (2011).

[15] www.dijlh.net, Landmarks of the Capital of Iraq beloved, (09\13\2011).

[16] H.M. Hassan, *The Iraqi House in Ottoman era*, M.Sc. Theses, Baghdad University, Literature Collage,(1982).

[17] *Bulletin on The City of Baghdad*, Prepared by: Division of Counseling and Translation, Ministry of the Interior, the local administration press, Baghdad, (1962).

[18] Dr. K. Al Sultani, *ARCHITECTURE and ARCHITECTS*, general of cultural affairs house press, first edition, Baghdad, (2009).

[19] www.iraqitorath.com, Bridges of Old Baghdad.

[20] S. (M. A.) Abdul Rasul, *Traditional Buildings in Baghdad*, Field Work study carried in Karkh side, Directorate of library for printing and publishing, Mosul University, Iraq, (1987).

[21] www.diahalshaher.forumarabia.com, Famous places of Baghdad beloved, Diah Alshaher, (24/05/2011).

[22] http://vb.uiraqi.com, Tour around world, Iraq, Baghdad.

Paper IV

Mar. 2013, Volume 7, No. 3 (Serial No. 64), pp. 273-281
Journal of Civil Engineering and Architecture, ISSN 1934-7359, USA

Foundation Assessment in Different Parts of Iraq Using STAAD Pro V8i

Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson and Tarek Edrees Saaed

Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology, Lulea 97187, Sweden

Abstract: Foundation is considered as one of the main parts of any structure. The type of foundation used is highly dependent on the type and properties of soil. The design of foundations requires many factors that should be defined. There are number of differences in the geological and soil conditions in Iraq. As a consequence, these differences are reflected on the type of foundation to be used. Despite these differences, same materials and style of buildings are used all over Iraq. The main problems of Iraqi soil are high gypsum content, salinity and shallow water table depth. These factors that influence the foundations are the soil properties and the amount of loads that transmitted by the superstructure. The situation has been analysed through a case study which illustrated the link between soil and foundation types in three different parts of Iraq (Mosul, Baghdad and Basra). One building was analysed using "STAAD (structural analysis and design). Pro" software in these regions. It is evident that Iraqi designers and engineers require local code to define all the loads, materials and design of the foundation to be used. The use of local materials might be very effective from both engineering and economic perspectives.

Key words: Gypsum, bearing capacity, Iraqi soil, raft foundation, foundation design, base pressure.

1. Introduction

Iraq can be divided topographically into three major regions. These are the mountains and foothills, Mesopotamian plain and deserts (Fig. 1). Due to the differences in the geology and physiography of the country, the soil characteristics and types are different.

The most important properties of soil to be looked at are density, allowable pressure, shear resistance, settlement and effect of ground water. The soil must be able to hold loads of any engineering structure without causing any shear failure or settlement effects on the structure. The most important factor that affects the foundations is the shear resistance or ultimate bearing capacity (q_{ult}) of the soil. Buildings are collapsed or destroyed mainly due to the effect of soil shear failure [1, 2].

In this paper, soil condition in Iraq will be presented and evaluated. Its effect on the foundation of a building will be assessed. There are number of differences in the geological and soil conditions in Iraq. Despite these differences, same materials and style of buildings are used all over Iraq. The attention is not paid for the climate conditions or the different nature of Iraqi geology. Three different locations having different soil and geological characteristics were chosen in Mosul (northern of Iraq), Baghdad (centre of Iraq) and Basra (southern of Iraq). STAAD (structural analysis and design) Pro V8i software was used in this research for design and analysis. The program was used to clarify that different types of foundation can be used for the different regions of Iraq.

2. Soil Conditions in Iraq

Soil conditions in Iraq according to the physiographic provinces are as following.

2.1 The Mountains and Foothill Region

This region is confined to northern and north-eastern part of Iraq. Parts of this area consist of rocks with very thin layers of soil. The soils in the

Corresponding author: Nadhir Al-Ansari, professor, research fields: water resources and environmental engineering. E-mail: nadhir.alansari@ltu.se.

Fig. 1 Physiographic map of Iraq [3].

valleys and plains were accumulated due to physical, chemical and biological processes. Soil salinity is not a major problem in this area.

Mountains are confined to a relatively narrow strip to the north and east part of Iraq while the foothills are located to the west and south-west of this region. Foothill area is characterized by extensive plains and large towns like Mosul, Kirkuk and Erbil which are built within these plains [3]. Near the large river (Tigris River and its tributaries), three levels of accumulated terraces exist running parallel to the river banks. They consist of gravels, boulders, sands and clays that are poorly cemented. Flat areas between anticlines are covered by sheet run-off sediments. They comprise clay, sand and silt, and sometimes coated by scattered gravels. Most of the rocks and soil of this region are gypsum, sandstone and limestone. Valleys are locally developed with fill deposits, flood plain and sabkha sediments. Sand dunes are combined within the synclinal areas within the foothill area. The groundwater table in this area is about 20 m to 30 m deep. Moreover, the groundwater is not saline [4].

2.2 The Mesopotamian Plain

It is an area that extends from north west of Baiji city stretching to the Arabian Gulf. Fifty percent of the southern part of this plain is covered with water (marsh area). Soil of this area is covered by flat lying alluvium sediments brought by the Tigris and Euphrates Rivers. The soil contains (20%-30% lime) calcareous, saline and alluvial soils. Mesopotamia flood plain consists of quaternary fluvial origin sediments about 280 m thick, alluvial fans 50 m thick on the flanks and Aeolian sediments. The quaternary deposits near Baghdad are 80 m thick, and it increases to more than 250 m south east Basra. The plain sediments include levee silts and clays, plain flood clays and stacked river channel sand bodies with accidental marsh deposits. Furthermore, the area has complicated process of salinization. In some parts of this region, gypsum exists from the surface to 1 m depth. The ground water is shallow where the water table depth ranges from 1 m to 5 m between Baghdad and Kut City. South of Kut City to Basra City the water table depth is less than 1 m deep. In general, the ground water is extremely saline in the south eastern parts of this region [3-6].

2.3 The Deserts

They are covering more than half the area of Iraq. There are three main deserts, which are as following:

(1) Jezira desert: It is located northwest Iraq. The upper part of Al-Jezira is partly steppe area and partly desert. Large numbers of salt playas and thick gypcrete soil exist. The thickness of the gypcrete soil varies from 30 cm in the most elevated parts to more than 8 m in low areas. The soil covering the depressions usually contains a high percentage of gypsum, averaging 30% and might reach 80% in some local areas. Jezira area contains several major salt playas. These are the largest Sunailsla, the Bowara and the Twawila playas. The depth of ground water in Jezira area is between 10 m and 20 m;

(2) Western or northern desert (Rutba zone): This area is characterized by its quaternary sediment, which is confined to wadis and depressions. Rock fragments with thin veneer of loam covers large areas. Wadi fills sediments reach several meters in thicknesses and consist of boulders, cobbles and pebbles of limestone.

Wadi beds are partly coated by aeolian sand. In the western desert, the depth of ground water is 10 m in the area near the river to more than 250 m near the Iraq-Jordan, Saudi border;

(3) The southern desert (Salman zone): Very wide sand sheets coupled with active dunes are covering the area. Soil in this area is limy and sandy in southerly part and sandy dune in eastern part. The groundwater in this area is between 50 m and 100 m deep [1, 4].

The main problems of Iraqi soil are the relatively high gypsum content, salinity and shallow ground water depth. Mesopotamia soil has characterized by its high salt content. This is mainly due to the presence of gypsum and shallow water table, which enhances the evaporation of groundwater and as a result increases the salinity in the soil. In view of these facts, the ground water depth plays an important role in affecting the type of foundation used.

3. Soil Properties Effecting Foundation

The type of foundation to be used should be stabiles, safe, economical, capable to hold the loads to be applied and environmentally suitable. According to the source of loads, they are divided as dead, live and environment loads. Direction and magnitude of these loads may change during the life of the structure. The design and construction must give stable results for load bearing on the foundation. All loads to be applied should be in accordance to local codes [7, 8].

Bearing capacity defines the strength of geotechnical requirement. It is the most important load that affects the foundation design. Allowable stress on the foundation must not cause excessive and differential settlements or soil shear failure. Bearing capacity analysis should be based on assuming the worst soil condition during the suggested life time of the structure. There are number of methods established for the analysis of the unit ultimate bearing capacity. Meyerhof (1963) suggested the most comprehensive and general bearing capacity equation, because it includes all the factors affecting the foundations [9]. The equation is as following:

$$q_n = c\,N_c F_{cs} F_{cd} F_{ci} + q\,N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma\,B\,N_\lambda F_{\gamma s} F_{\gamma d} F_{\gamma i} \quad (1)$$

where,

c = cohesion (kN/m^2);

q = effective stress at the level of the bottom of the foundation (kN/m^2);

γ = unit weight of soil (kN/m^3);

B = width of foundation (= diameter for a circular foundation) (m);

F_{cs}, F_{qs}, F_{rs} = shape factors;

F_{cd}, F_{qd}, F_{rd} = depth factors;

F_{ci}, F_{qi}, F_{ri} = load inclination factors;

F_c, F_q, F_r = bearing capacity factors.

The factor of safety used in the design of foundation takes into considering the dead and live loads for the bearing capacity of soil. The relationship between deflection of soil and pressure is referred to as the modulus of sub grade reaction. This is used in the analysis of foundation of the structure. Its value depends on the soil type. To calculate the value of sub grade reaction (k_s) from the allowable bearing capacity q_a, the following equation is used [1, 10]:

$$SI:\ k_s = 40(SF)q_a \quad \text{kN/m}^3 \quad (2)$$

$$q_a = q_{ult}/SF \quad (3)$$

where,

SF = safety factor;

q_a = allowable bearing capacity;

q_{ult} = the ultimate soil pressure at the smaller allowable settlement ΔH = 0.0254 m and k_s is $q_{ult}/\Delta H$. Therefore, 40 is smaller displacement that can always be used.

4. Finite Element Software

Finite element software is a tool used in the design, analyses and solution of the problems of existing structures. They include many standards and codes for design. These kinds of software have been used all over the world by engineers working in industrial, sport, transportation and other facilities [11]. Many types of design and analyses software have been used with the last 30 years by different companies and universities such as: STAAD Pro., SAP 2000, ETABS, SAFE, and LUSAS, etc.. Generally, they use finite element method in the analysis. But there are some that use nonlinear analysis. These kinds of software are used efficiently for the design of buildings under the effect of seismic and earthquake [12-14].

As structural analysis and design software STAAD Pro V8i, STAAD Pro is an inclusive and integrated finite-element analysis and design software for civil and structural engineers. It sustains several concrete, timber, steel, and aluminium design codes. In addition, it has ISO 9001 certification [15-17]. The steps of using STAAD Pro for design and analysis are as following:

(1) Drawing the geometry structure using various methods;

(2) Specifying the profile of columns, beams and plates;

(3) Specifying the foundations, constants and supports;

(4) Specifying the loads added to the structure;

(5) Analysing the model using a suitable method of analysis such as 1st order static analysis, geometric non liner analysis, and 2nd order p-delta analysis (It is the analysis depending on the value of the secondary moment, which is equal to the axial force in the member (P), and Delta is the distance of one end of the member which is offset from the other end).

It has visualization tools, powerful design and analysis engines with advanced static and dynamic analysis capabilities. Loads can be added as member loads, nodal loads, trapezoidal pressure loads and uniform pressure over any area. The output of the software (programme) results includes shears, displacements and moments in the graphical and tabular forms. In addition to shears and moments at any point of the element and nodes can be obtained easily from the software output [18, 19]. It is widely used in Iraq for the design and analysis. It is also used to train students in the various universities.

5. Case Studies

An educational building in Mosul University with two floors (ground and first floors) having raft foundation type has been selected. The same building was used for the analysis at Baghdad and Basra Universities due to the differences in their soil conditions. The design loads (live and dead) which were uploaded in the program for all the three areas (Mosul, Baghdad and Basra) were the same. The code used was ACI (American Concrete Institute) because the majority of Iraqi designers are using this code. Bearing capacities of the three regions are shown in Table 1 (the magnitudes were taken out from ground investigations of the three projects in each region).

The loads which were uploaded were as following:

(1) Dead load:

- 25 kN/m^2 for foundation (normal dead load + some heavy equipment);
- 21 kN/m^2 for first floor (18 kN/m^2 for partitions + 3 kN/m^2 for finish load);
- 7.5 kN/m^2 for second floor (4.5 kN/m^2 for finish load + 3 kN/m^2 for partitions);

(2) Live load:

- 5 kN/m^2 for first floor;
- 3 kN/m^2 for second floor.

In addition to the above loads, the self-weight of the structure was calculated directly by the program.

Fig. 2 shows the model of the building that was used in the program. Exactly the same loads were used for the three regions (Mosul, Baghdad and Basra) as they are tabulated in Tables 2 and 3.

Table 1 Value of bearing capacity.

No.	Area	Bearing capacity (kN/m^2)
1	Mosul	300
2	Baghdad	70
3	Basra	50

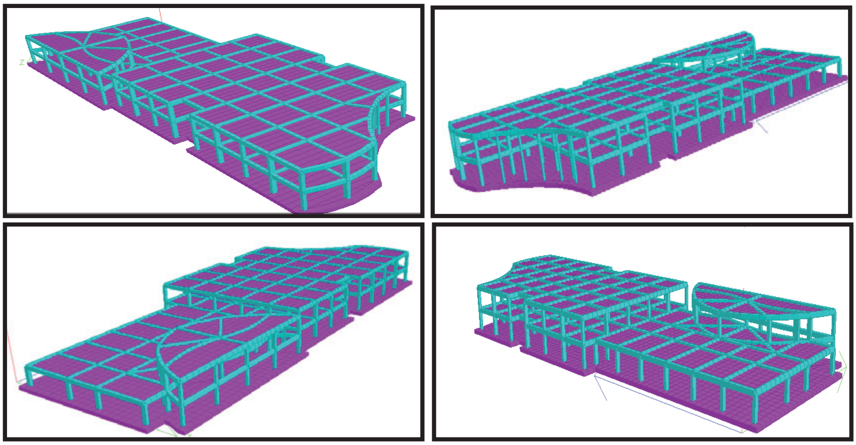


Fig. 2 Building model draw in STAAD Pro V8i.

Table 2 Basic load cases.

No.	Name
1	Load Case 1/Self weight
2	Load Case 2/Finish load-partitic
3	Load Case 3/Total live load
4	Load Case 4/Partial live load 1
5	Load Case 5/partial live load 2

Table 3 Combination load cases [20].

Comb.	Combination L/C name	Primary	Primary L/C name	Factor
6	Combination load Case 6	1	Load Case 1/Self weight	1.20
		2	Load Case 2/Finis load-partitic	1.20
7	Combination load Case 7	1	Load Case 1/Self weight	1.20
		2	Load Case 2/Finis load-partitic	1.20
		3	Load Case 3/Total live load	1.60
8	Combination load Case 8	1	Load Case 1/Self weight	1.20
		2	Load Case 2/Finis load-partitic	1.20
		4	Load Case 4/Partial live load 1	1.60
9	Combination load Case 9	1	Load Case 1/Self weight	1.20
		2	Load Case 2/Finis load-partitic	1.20
		5	Load Case 5/Partial live load 2	1.60
10	Combination load Case 10	1	Load Case 1/Self weight	1.00
		2	Load Case 2/Finis load-partitic	1.00
11	Combination load Case 11	1	Load Case 1/Self weight	1.00
		2	Load Case 2/Finis load-partitic	1.00
		3	Load Case 3/Total live load	1.00
12	Combination load Case 12	1	Load Case 1/Self weight	1.00
		2	Load Case 2/Finis load-partitic	1.00
		4	Load Case 4/Partial live load 1	1.00
13	Combination load Case 13	1	Load Case 1/Self weight	1.00
		2	Load Case 2/Finis load-partitic	1.00
		5	Load Case 5/Partial live load 2	1.00

Fig. 3 shows the analysis of the building design. In Cases 1 and 2, the load is assumed to be distributed on the whole building (full floor area). In Case 3, however, the uploading was like a checker board pattern, while Case 4 was opposite to Case 3. The base pressure distribution on the soil beneath the foundation is shown in Figs. 3-8. Fig. 3 shows the contour of the load Cases 1 and 2 for Mosul University. It can be noticed that most of the area of the raft has blue colour. This implies that the base pressure in this area does not exceed the range from 70-75 kN/m^2 for the both cases. The maximum soil pressures for the Cases 1 and 2 are 103 kN/m^2 and 115 kN/m^2, respectively. They are much lower compared with the real soil pressure taken out from soil investigations (Table 1). In such a case, it is better to choose another type of foundation that will be more suitable to save time and money. In Cases 3 and 4 in Fig. 4, the maximum soil pressures for the both cases were 111 kN/m^2 and 110 kN/m^2, respectively. Most of the area beneath the raft has blue colour and its pressure does not exceed 73 kN/m^2. In such a case, it is better to choose another type of foundation because the base pressure is lower than what is it in the soil.

The analysis of the building in Baghdad soil is shown in Figs. 5 and 6. The pressure of soil under the

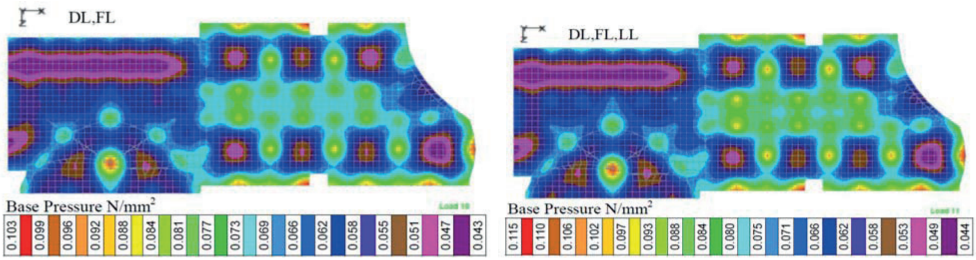


Fig. 3 The base pressure contour for Mosul University (Case 1 and Case 2).

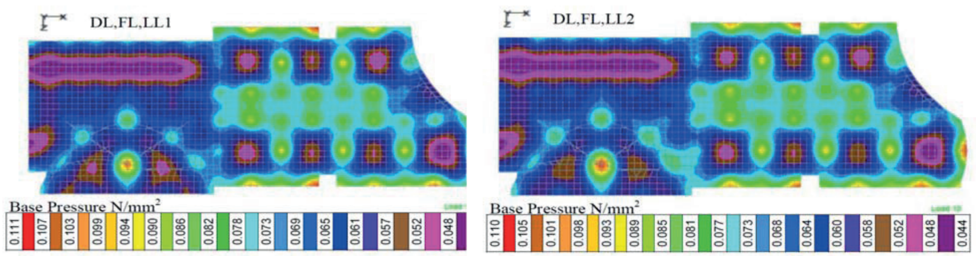


Fig. 4 The base pressure contour for Mosul University (Case 3 and Case 4).

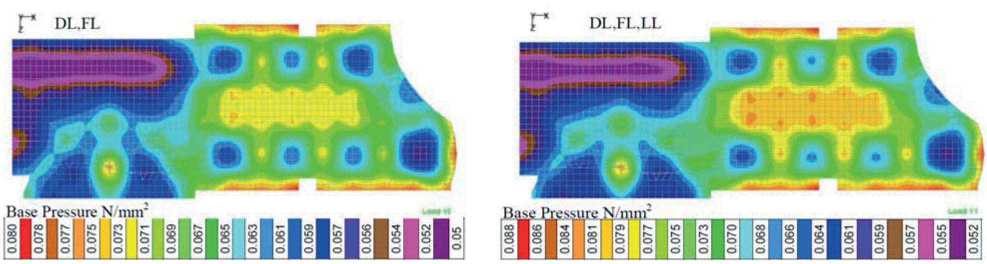


Fig. 5 Base pressure contour for Baghdad University (Case 1 and Case 2).

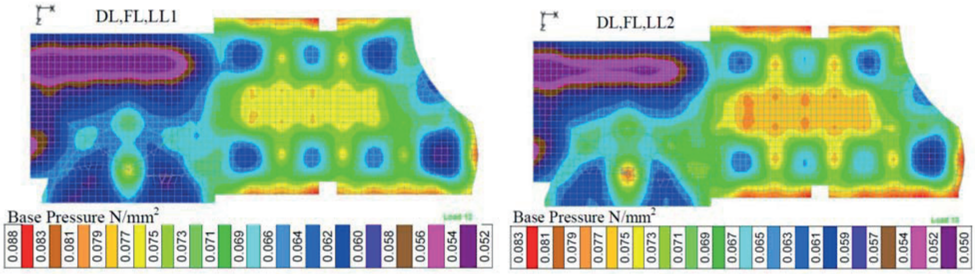


Fig. 6 Base pressure contour for Baghdad University (Case 3 and Case 4).

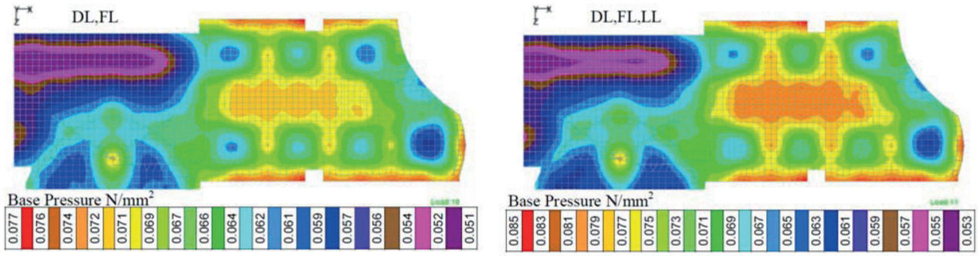


Fig. 7 Base pressure contour for Basra University (Case 1 and Case 2).

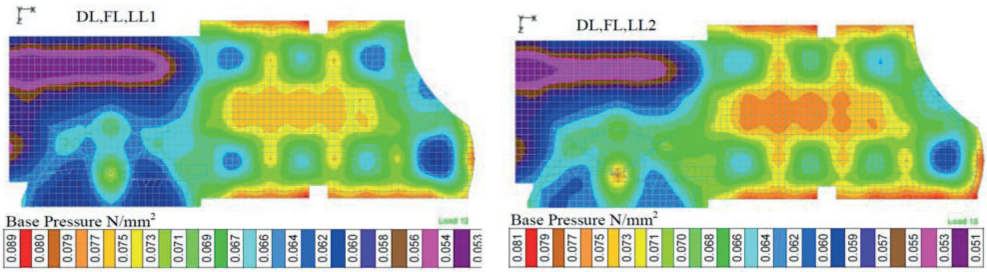


Fig. 8 Base pressure contour for Basra University (Case 3 and Case 4).

raft was between 63 kN/m^2 and 69 kN/m^2 for Case 1 in Fig. 4, and the maximum was 80 kN/m^2 as shown in the index bar. For Case 2, the base pressure was 68-77 kN/m^2 and the maximum was 88 kN/m^2 in few places. The type of the raft foundation is suitable in this case. Furthermore, two types (raft and continuous) of foundations can be used in this case. Fig. 6 illustrated Cases 3 and 4, which show the soil pressure under the foundation was 64-75 kN/m^2. The maximum was 86 kN/m^2 for Case 3. Where the base pressure for Case 4 was 65-73 kN/m^{2}and maximum was 83 kN/m^2. In such a case, the raft type is a good chooses, or it is possible to use two different types for left and right parts.

Fig. 7 clarifies the analysis contour of Basra University building for the load Cases 1 and 2. The distribution of the soil pressure under the foundation was 60-70 kN/m^2 in Case 1 and the maximum was 77 kN/m^2. While in Case 2, the base pressure was 77 kN/m^2 over almost the whole foundation area and the maximum was 85 kN/m^2. The soil pressure was 75 kN/m^2 in Case 3 and maximum was 82 kN/m^2 (Fig. 8). Case 4 shows that the maximum pressure was 81 kN/m^2 and the pressure distributed to the foundation was about 71 kN/m^2. The base pressure is higher than what is it in the soil. The raft type is a suitable chose for Basra soil conditions.

6. Conclusions

In view of the results obtained using STAAD Pro V8i software on the same educational building in three different sites in Iraq having different soil conditions, it was concluded that:

(1) The base pressure on soil under the whole foundation of the building in Mosul was low. For this region, it is possible to use raft foundation or another type, which will be suitable and more economical;

(2) Baghdad region soil is less in its hardness compared with that in Mosul. The analysis of the building shows that base pressure under the right part of the building foundation was higher than the left part. This leads to more than one choice. The first is using two types of foundations, raft type for the left part and continuous type for the right part. The second is to build the complete foundation as raft type;

(3) The base pressure in Basra region is very high for the whole area under the foundation. Raft type is suitable to be used for Basra soil.

The results imply that Iraqi engineers should use new design style for the buildings. Modern systems should be adopted depending on using different materials such as cold formed steel, pre cast, wood and thermistor bricks. Local materials are recommended to be used. This will decrease the loads of the building transmitted to the soil. Special code is to be used for construction and design in Iraq. Such code should include all the modern requirements for construction and design according to type of soil, geological and environmental conditions of Iraq.

References

[1] J.E. Bowles, Foundation Analysis and Design, 5th ed., McGraw-Hill Companies, ISBN 0-07-912247-7, Singapore, 1997.

[2] L.C. Reese, W.M. Eisenhower, S.T. Wang, Analysis and Design of Shallow and Deep Foundation, John Wiley & Sons Inc., Hoboken, New Jersey, 2006.

[3] P. Buringh, Soils and Soil Conditions, in: H. Veenman, N.V. Zonen (Eds.), Iraqi Ministry of Agriculture, Wageningen, Iraq, 1960.

[4] S.Z. Jassim, J.C. Goff, Geology of Iraq, 1st ed., Dolin, Hlavi, ISBN 80-7028-287-8, Prague, Czech Republic, 2006.

[5] Z.A. Stephan, Food and Agriculture Organization of the United Nations, Iraq, www.fao.org (accessed Jan. 1, 2013).

[6] B.K. Ramiah, R.A. Ovanessian, Engineering Properties of Subsoil's in Baghdad Area, Scientific Research Council, Baghdad, Iraq, 1982.

[7] Chapter 4: Design Loads for Permanent Foundations, https://portal.hud.gov (accessed Jan. 1, 2013).

[8] D.P. Coduto, Foundation Design Principles and Practices, 2nd ed., Prentice-Hill Inc., ISBN 0-13-589706-8, USA, 2001.

[9] B.M. Das, Principles of Foundation Engineering, 2nd ed., Brooks/Cole Publishing Company, ISBN 0-534-20646-8, California, USA, 1999.

[10] N.S.V. Kameswara Rao, Foundation Design Theory and Practice, John Wiley & Sons (Asia) Pte. Ltd., ISBN 978-0-470-82534-1, Singapore, 2011.

[11] Computers and Structures Inc. Website, www.csiberkeley.com (accessed Jan. 1, 2013).

[12] D.G. Lee, H.S. Kim, M.H. Chun, Efficient seismic analysis of high rise building structures with the effect of floor slabs, Engineering Structures 24 (2002) 613-623.

[13] A. Mwafy, A. Elnashai, R. Sigbjörnsson, A. Salama, Significance of severe distant and moderate close earthquakes on design and behaviour of tall buildings, the structural design of tall and special buildings, Struct. Design Tall Spec. Build 15 (2006) 391-416.

[14] C.S. Mohd, Finite element analysis on flush end plate connection using LUSAS software, A Project Report Submitted in Partial Fulfilment of the Requirement for the Award of the Degree of Master of Engineering (Civil-Structure), University of Technology Malaysia, Malaysia, 2006.

[15] A.V. Asha, Dynamic Analysis of Multistorey Frame, Submission of Project Report, Dept. of Civil Eng. Nit Rourkela, National Institute of Technology Rourkela, https://ethesis.nitrkl.ac.in (accessed Jan. 1, 2013).

[16] R.P. Clarke, Staad Basics-Notes on the Effective Use of STAAD-Pro REL 3.1- for Structural Analysis, 2003, FOR STRUCTURAL ANALYIS-, http://richardpclarke.tripod.com (accessed Jan. 1, 2013).

[17] T. Subramani, D. Ponnuvel, Seismic and stability analysis of gravity dams using STAAD Pro, International Journal of Engineering Research and Development 1 (5) (2012)

44-54.
[18] A.K.M. Anwarul Islam, Performance of AASHTO girder bridges under blast loading, A Dissertation Submitted to the Department of Civil Engineering in Partial Fulfilment of the Requirements for the Degree of Doctor Philosophy, Degree Awarded, Florida State University, USA, 2005.
[19] STAAD Pro V8i Website, www.staadpro.com (accessed Jan. 1, 2013).
[20] ACI Committee 318-08, Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, USA, 2008.

Paper V

Engineering, 2014, 6, 292-303
Published Online May 2014 in SciRes. http://www.scirp.org/journal/eng
http://dx.doi.org/10.4236/eng.2014.66033

Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i

Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson

Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden
Email: entidhar.altaie@ltu.se, nadhir.alansari@ltu.se, Sven.Knutsson@ltu.se

Received 28 February 2014; revised 28 March 2014; accepted 4 April 2014

Abstract

Most of Iraqi soil is classified as Quaternary deposits, especially in the Mesopotamian plain and tributaries of the River Tigris. Soil varies from north to south of Iraq. These differences in soil affected the process to select the suitable type of foundation. This research is to study the effect of bearing capacity on shallow foundations in different regions of Iraq. Seventy nine samples were collected from 23 boreholes at three different locations (Mosul at the North, Baghdad at the middle and Basrah at the south of Iraq). The samples were collected at varying depth between 1 to 24 m. They were subjected to the following testes: Atterberg limits, sieve and hydrometers, consolidation, direct shear, unconfined compression and the filed (SPT test). The values of the bearing capacity parameters (ϕ and c) were obtained from the above tests. The results obtained were used in the application of the general equation of the bearing capacity. Then, the model of a building was designed (two floors, with mat foundation type) using STAAD Pro software. The average values of bearing capacity in each region were applied in the program (Mosul = 177 KPa, Baghdad = 125 KPa and Basrah = 84 KPa). In addition, the worst bearing capacity values were also used for the three regions (Mosul = 77 KPa, Baghdad = 68 KPa and Basrah = 24 KPa). The results obtained from the average and worst bearing capacity indicated that for Mosul, we could use shallow foundation (spread and mat used if there was basement) for different areas and for buildings with many stories. For Baghdad region, shallow foundation was more suitable for building not higher than five stories. Finally, for Basrah region, shallow foundations were an appropriate selection, but for most areas deep foundation was the right choice.

Keywords

Bearing Capacity, Soil, STAAD Pro., Laboratory Tests and Foundation

1. Introduction

It is important to have good feedback about the project site, because soil nature is heterogeneous [1]. All mate-

How to cite this paper: Al-Taie, E., *et al.* (2014) Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i. *Engineering*, **6**, 292-303. http://dx.doi.org/10.4236/eng.2014.66033

rials used in building are artificial materials. They are produced according to the international standards or codes, such as steel, concrete, etc. When structural engineers start to design a structure, the properties of these materials, are well known for them from text books. For soil however, site investigations and laboratory tests are required. In addition, information about the geology of the site will help the designer. Therefore, tests and identifications for soil and rocks must be done at each new site before conducting any analysis [2]. Foundation is the most important part which connects the superstructure with ground. Foundations are divided into two categories: shallow foundations and deep foundation (**Figure 1**).

Spread foundations are mostly used in medium and small size structures, on moderate to good soil site conditions. Raft foundations are often used for larger structures when the soil has differential settlement problems and the foundations are to be under the ground water table. The contact pressure between the lower face of the shallow foundation and the implied soils is the bearing pressure [2]-[4]. The stress distribution that influences the stress zone under the foundation is to be considered for both shallow foundations and deep foundations. **Figure 2** shows the theoretical vertical stress distribution under a square footing and pile foundation on the ground surface.

The influence depth of soil under foundation depends on its width [1]. The bearing capacity of soil for any site can be determined from the soil tests (field and laboratory tests). The laboratory tests that define the shear strength (bearing capacity parameters) are: direct shear, unconfined and Triaxial. Field tests are: Standard Penetration Test (SPT), Cone Penetration Test (CPT) and van shear [3]. An educational building was previously designed and analyzed using STAAD Pro.V8i software [5]. The building model was applied for three sites in different regions of Iraq (Mosul, Baghdad and Basrah). Due to the different geology and soil types in Iraq. The bearing capacity used in that analysis was obtained from engineering departments at the universities in those sites [5]. In this research soil samples were collected from different sites of the three regions of Iraq and analyzed. Thereafter, defining the best type of foundation for each region, the calculated bearing capacities from Mosul, Baghdad and Basrah regions were supplied to the STAAD Pro software model to find out the best suitable foundation for each site.

2. Methodology

2.1. Nature of Iraqi Soil

The Quaternary period (including Pleistocene and Holocene ages) affected the formation and nature of soil in Iraq. During this period, many processes took place that caused some erosion in the mountains and hills. Terraces have been formed along the Tigris and Euphrates Rivers and their tributaries as a result of changing climate. Rivers and wind filled up the Mesopotamian plain with fine texture sediments. Moreover, secondary gypsum crest has been formed and covered large areas of the deserts and the Mesopotamian plain. Almost all the soil of center and southern parts of Iraq became saline due to the natural conditions and the shallow level of ground water. Due to repeated flooding and irrigation practices, layers of mud accumulated on the original soil. As a result, most of the basin areas of the rivers are of silty soil [6]. Quaternary sediments are covering nearly 30% of the Iraqi surface area as it can be noticed on the geological map (**Figure 3**). They are important for the human activities and engineering works [6] [7].

2.2. Study Area

Three areas were tested. They are:

1-Mosul: This city is located north of Iraq (**Figure 4**). The nature of soil in Mosul region includes different types. Clayey (expansive type) covers most of the regions of Mosul city. Furthermore, alluvium sediments are usually located near the banks of Tigris River, and primary gypsum is located in west part of Mosul [9]-[13].

2-Baghdad: This city is the capital of Iraq. It is located in the central part of the country in the middle Mesopotamian plain (**Figure 4**). The area is covered by accumulation of the deposits brought by the two rivers (Tigris and Euphrates). The area was occupied by humans since the dawn of civilization. Early human activities affected the soil formations because they were depending mainly on agriculture, irrigation and farm practices. These activities made numerous changes in the soil characteristics from one place to another. Over the years, soil became a sequential stratum from alluvial and sand sediment [6]. The changing course of the river caused changes in the flood plain of the river and thus changing the sequences of the deposited layers. These changes gave the soil at Baghdad unexpected and misleading characteristics. Moreover, the soil is saline because of the

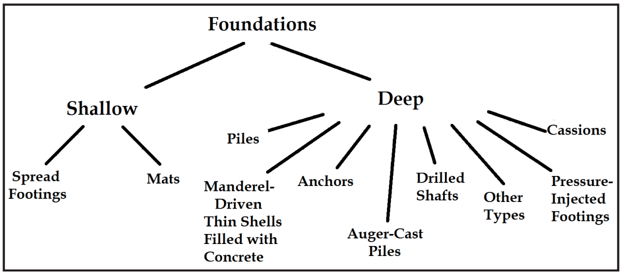


Figure 1. Classification of foundations [2].

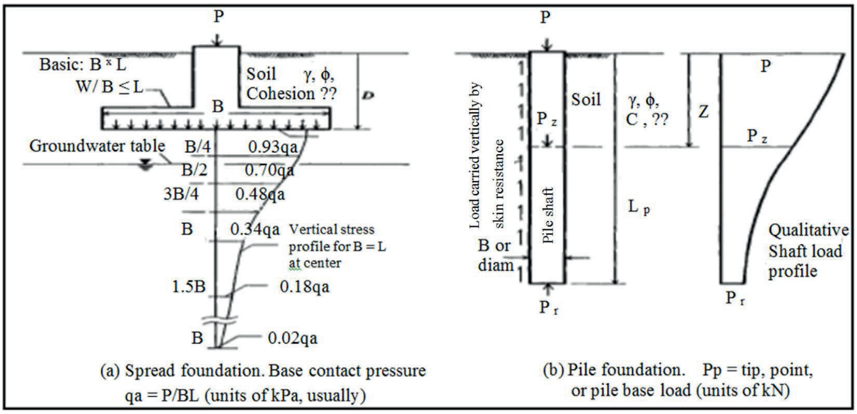


Figure 2. The theoretical vertical stress distribution under a square footing and pile [1].

arid climate [6]. Based on the nature of Baghdad, soils are mostly of fluvial origin (clayey and silty) with some gypsiferous soil, and sand.

3-Basrah: Basrah region (south of Iraq) is located in the lower part of the Mesopotamian plain (**Figure 4**). The stratification of Basra's soil is of irregular nature and consists of different strata and lenses as a result of the depositions of the Tigris and Euphrates Rivers through geological history of the area.

Quaternary sediment consisting of lacustrine, deltaic, fluviatile and Aeolian sediment replaced each other both vertically and horizontally. In the upper part of this region, the soil consists of layers that their surfaces are naturally consolidated, which are a mixture of sediment of fluvial flood and aeolian deposits. Deep soil layer (between 20 - 30 m) consists of very dense sand laminated with hard clay (Dibdibba deposits) representing high bearing capacity layers for heavy structures. While the upper part of Basrah area is useful for shallow foundations [14]-[16] Soil of Basrah is characterized by its fine particles fundamentally clay and silt [17].

2.3. Data Collection

The data were aggregated from subsurface soil investigation of 23 sites distributed all around the three regions of Iraq (Mosul, Baghdad and Basrah) as shown in **Figure 4**. These involve 9 boreholes drilling to depths of (3 - 10) meters in Mosul, 5 boreholes drilled to a depth of (10 - 13) meters in Baghdad and 9 boreholes drilled to depths of (10 - 24) meters in Basrah. The samples collected from ground drilling were undisturbed, disturbed and SPT.

2.4. Laboratory Tests

1) The collected samples were tested for the ID tests (Identification and Description of subsoil conditions) are

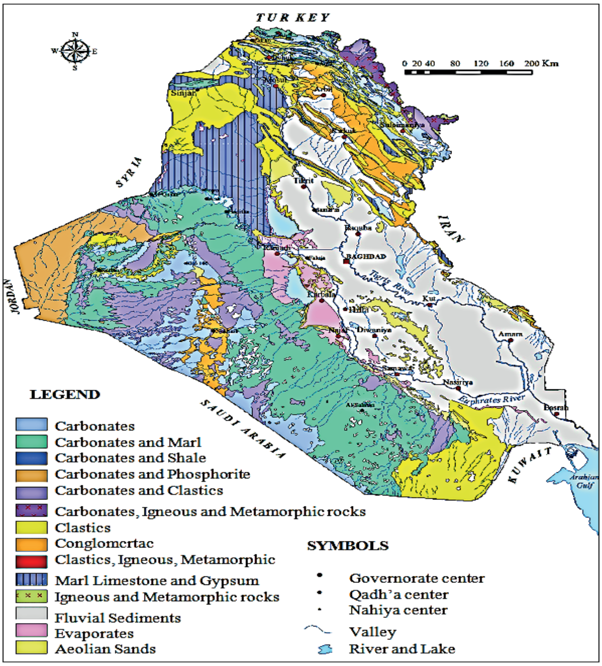


Figure 3. Geological map of Iraq [8].

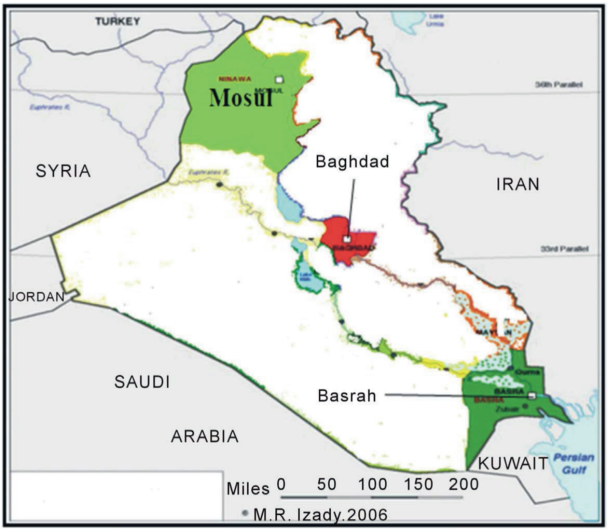


Figure 4. Locations of Mosul, Baghdad & Basrah sites.

the Atterberg limits to obtain the liquid limit (LL), the plastic limit (PL) and the different between the LL and the PL of soil is defined as the plastic index (PI).

To find the plastic limit, soil sample soil about 100 - 250 g passed through sieve No. 40. Water was added to the soil and mixed to the form of uniformed paste. A part of the paste was placed in casagrande cup and the surface was smoothed using spatula. After that a groove was made along the center line of soil in the cup using grooving tool. By returning the crank of the casagrande device, the two sides of the soil began to flow toward the center. The moisture sample was placed in cane and weighted. The above procedures were repeated for three to four times for each sample. Then putted the canes in the oven for 24 hours, and weighted the sample to calculate the plastic limit. This was performed according to ASTM D 4318-Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

2) To classify the soil samples, sieving and hydrometer tests were performed. The sieve analysis was per-formed by using 500 g of each sample. The sample was sieved using sieves numbers 4, 10, 20, 40, 60, 140 and 200. Then, the stacks of sieves were placed onto shaker for 10 - 15 minutes. Then, weighted of the sample for each sieve was retained and calculations of the percent of soil size was calculated. The size distribution of the small soil fractions was performed using the hydrometer method.

3) To find the strength parameters angle of internal fraction (ϕ) and the cohesion (C) Strength tests in-cluding direct shear, and unconfined compression tests were conducted. The test was performed on three or four specimens from undisturbed soil sample. The sample was placed in a shear box. A confining stress was applied vertically to the specimen. The load applied and horizontal and vertical dial gauges attached to the shear box were measuring the displacement during the test. After that, load was applied to the top half of shear box, and readings of both gauges were recorded until the spacemen failed. Then calculations were done to obtain the values of cohesion c and angle of friction ϕ.

4) Consolidation test was performed to obtain the three important parameters required for calculating the settlement. They are the compression index (Cc), the swelling index (Cs) and preconsolidation p Undisturbed sample used in this test. Soil specimens were trimmed in a dimension suitable to the consolidation ring using saw wire. Then, porous stone was put on the base of consolidometer under the soil specimen and on the top of it. Water was added to the consolidometer to keep the soil saturated and placed in the loading device. The loads applied to the specimen. Reading were taking for the added loads (1/4, ½, 1, 2, 4, 8, 16 Kg). Finally, eo, cs, pc, and cc were calculated pressure (Pc).

5) All the above tests were performed according to the procedures given by ASTM, AASHTO and BS.

2.5. Calculations

The calculation had been done to find the ultimate bearing capacity following the Hansen (general) Equations (1) and (2):

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qNqsqdqiqgqbq + 0.5\gamma BN\gamma s\gamma d\gamma i\gamma g\gamma b\gamma$$

where:

q_{ult} = the ultimate bearing capacity
c = the cohesion of soil
q = the effective stress at the level of the bottom of foundation
γ = the unit weight of soil
B = the foundation width
N_c, N_q, N_γ = bearing capacity factors
s_c, s_q, s_γ = shape factors
d_c, d_q, d_γ = depth factors
i_c, i_q, i_γ = load inclination factors
g_c, g_q, g_γ = ground inclination factors
b_c, b_q, b_γ = base inclination factors

N_c, N_q, N_γ the values of these factors were taken from especial tables. The other factors were calculated using the following equations [3]:

Shape factors:
k = D/B for D/B ≤ 1
s_c = 1.0 + Nq. B/Nc. L
s_q = 1.0 + B/L sinϕ ………… for all ϕ
sγ = 1.0 – 0.4 B/L, ………… B/L ≥ 0.6

Depth factors:
$d_c = 1.0 + 0.4k$
$d_q = 1.0 + 2\tan\phi\,(1-\sin\phi)2k$
$d\gamma = 1.0$
Moreover, in some locations; the bearing capacity was calculated from unconfined compression test. This test can be used to obtain (cu) values, depending on the measurement of unconfined compression strength (qu). Thus, [18]:

$$C_u = 1/2 q_u$$

where:
Cu = cohesion strength; qu = unconfined compression

Furthermore, the bearing capacity of soil for few sites was determined using the standard penetration test (SPT). The method used to define empirical values for relative density (Dr), unit weight (γ_{wet}), angle of internal friction (ϕ) and undrained compressive strength (q_u) as shown in **Table 1** & **Table 2**, [19].

2.6. Results

The results of the laboratory tests, including Atterberg limits, direct shear, unconfined and consolidation tests are given in **Table 3**. The tests were done for different sites in Mosul, Baghdad and Basrah. The purpose was to identify soil properties and described the soil types. Then from these values could obtain the strength of soils. Later, used these results to calculate the value of bearing capacity. In **Table 4**, the calculations performed for the average and worst bearing capacity for each site are tabulated.

2.7. Model of the Study

Modeling is a method that was used during the last 40 years by designers, architects and engineers. Many programs and softwares had been available and were used by structural and foundation engineers in design and analysis. STAAD Pro.v8i program is one of these softwares and was chosen to be used in this research for the design and analysis of the building model.

The program is computer software for structure and foundation design and analysis developed originally by international research engineers in Yorba Linda, CA. It was firstly, used for educational purposes for civil and structural engineers by Iowa state university. Then, Bently system adopted the program and developed to be used in the analysis and design for different constructions work such as structural, foundations, bridges, dams, etc., [20]. STAAD Pro program is the most popular designing software used because of its easy interface use, offering finite element, nature versatile at solve any type of problem, and collecting different codes [21].

The general procedures for the design and analysis in STAAD Pro as follow [22]:

- Drawing the geometry of the model.
- Adding the properties for beams, columns, slabs and foundations.
- Specifying the materials.
- Adding the loads (dead, live and combination).
- Analyzing the model.

Results obtained from the program are of different types, depending on the aim of the analysis. In this research, the analysis requires the base pressure of the building on the soil beneath it. Wherefore, the results were presented inform of contour. The colors of the contours reflect the value of the distribution of the bearing pressure under the foundation. The violet, pink, blue and green colors indicating that the bearing pressure is low to medium. Yellow and red colors indicating that the bearing pressure is high or exceeds the limit value.

The model used for this study was a building with two stories (ground & 1st flower). Mat foundation was suggested for the building with dimensions of 25 × 60 meters. The method of design and analysis of the building model was performed using STAAD Pro.v8i Program. The dead and the live loads values used in the design were 53.5 KN/m^2 and 8 KN/m^2 respectively for Mosul, Baghdad and Basrah. While, the outcomes from the calculations which depend on the field and laboratory tests were used to obtain the value of the bearing capacity. The value of a safety factor used was 3; design was according to ACI code [23]. The results of the design of a building model in STAAD Pro, Program and analysis are shown in **Figures 5-10**.

Figure 5 and **Figure 6** show the effect of the bearing pressure on the soil that supports the foundation of the

Table 1. Consistency of clay and SPT number [3].

Standard penetration number, N_{60}	Consistency	Unconfined compression strength, q_u (KN/m^2)
0 - 2	Very soft	0 - 25
2 - 5	Soft	25 - 50
5 - 10	Medium stiff	50 - 100
10 - 20	Stiff	100 - 200
20 - 30	Very Stiff	200 - 400
>30	Hard	>400

Table 2. Empirical values for Dr, ϕ & γ_{wet} of granular soils based on SPT at 6m depth & normally consolidated [1].

Description	Very loose	Loose	Medium	Dense	Very dense
Relative density D_r	0	0.15	0.35	0.65	0.85
SPT N' Fine Medium coarse	1 - 2 2 - 3 3 - 6	3 - 6 4 - 7 5 - 9	7 - 15 8 - 20 10 - 25	16 - 30 21 - 40 26 - 45	? >40 >45
Φ Fine Medium coarse	26 - 28 27 - 28 28 - 30	28 - 30 30 - 32 30 - 34	30 - 34 32 - 36 33 - 40	33 - 38 36 - 42 40 - 50	<50
$\gamma_{wet,}$ KN/m^3	11 - 16*	14 - 18	17 - 20	17 - 22	20-23

Table 3. Results from laboratory tests.

Parameters obtained from tests	Location		
	Mosul	Baghdad	Basrah
Liquid limit (L.L) %	43 - 54	34 - 53	37 - 45.6
Plastic limit (P.L) %	22 - 26	19 - 30	21.33 - 31.9
Plastic index (P.I) %	17 - 30	15 - 29	11 - 18
Unit weight (γ) KN/m^3	15.7 - 19.7	14.4 - 20.31	15.1 - 20.1
Cohesion (C) KPa	0 - 40	-	0 - 4
Angle of internal friction (ϕ)°	15 - 28	-	33 - 31
Initial void ratio (e_o)	0.558 - 0.767	0.647 - 0.769	0.72 - 0.90
Compression index (C_c)	0.065 - 0.28	0.156 - 0.22	0.186 - 0.267
Swelling index (C_s)	0.011 - 0.156	0.010 - 0.054	0.028 - 0.090
Preconsolidation pressure (P_c) KPa	70 - 150	95 - 165	90 - 135
Unconfined compression strength (q_u) KPa	-	76 - 370.6	24 - 125.1

Table 4. Results of calculated bearing capacity values.

Locations	Capacity values (KPa)	
	Average	Worst
Mosul	177	77
Baghdad	125	68
Basrah	84	24

building for Mosul region.

The bearing pressure in **Figure 5** is the average bearing capacity value. It is not distributed evenly and is subjected to concentric vertical loads. The colors in the figure give the indication of the amount of bearing pressure on soil. The yellow and red colors indicate that the pressure in this zone is in a critical state. These zones are very restricted and do not affect the soil beneath the foundation.

Figure 6 show the distribution of the bearing pressure under the foundation, when worst bearing capacity values were used at Mosul region. The red and yellow zones in the figure does not cover large portion that can

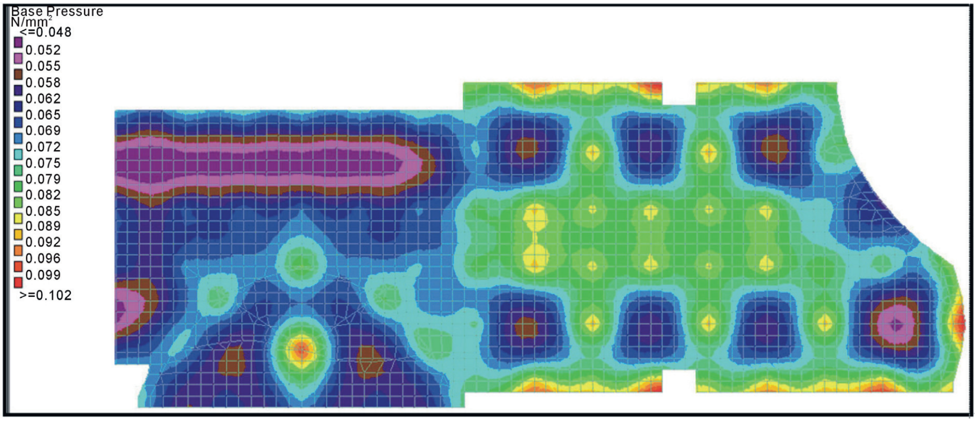


Figure 5. Base pressure distribution using the average value of bearing capacity at Mosul.

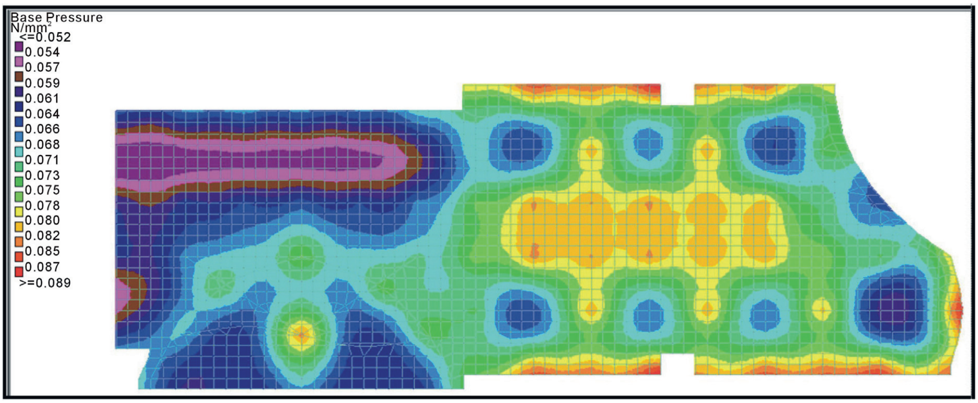


Figure 6. Base pressure distribution using the worst value of bearing capacity at Mosul.

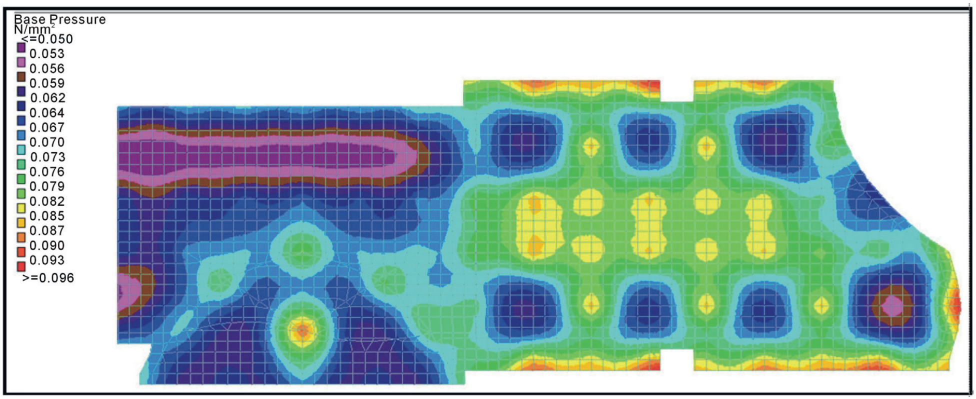


Figure 7. Base pressure distribution using average value of bearing capacity at Baghdad.

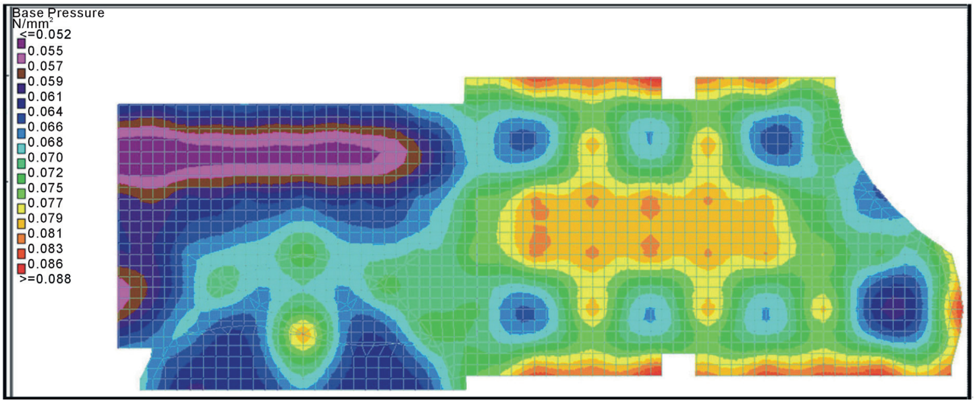


Figure 8. Base pressure distribution using the worst value of bearing capacity at Bagdad.

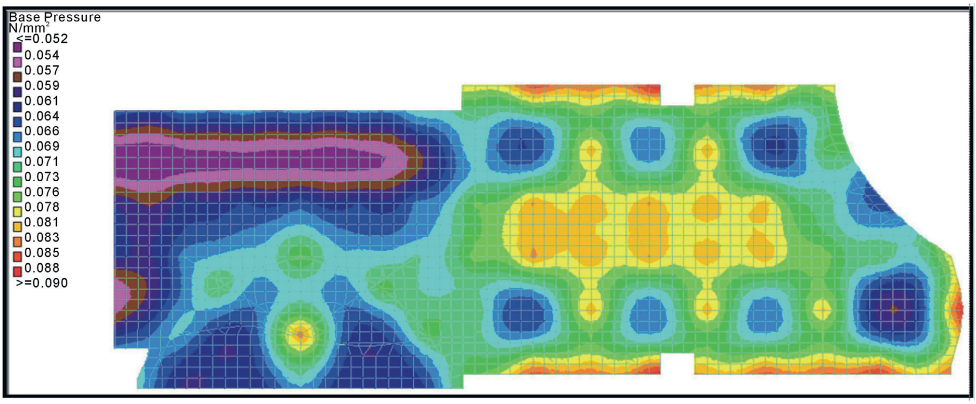


Figure 9. Base pressure distribution using the average value of bearing capacity at Basrah.

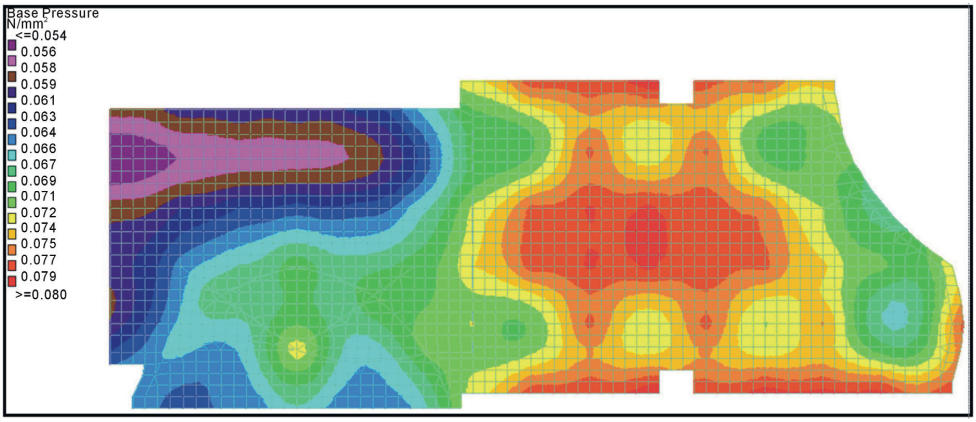


Figure 10. Base pressure distribution using the worst value of bearing capacity at Basrah.

affect the soil under the foundation.

Figure 7 and **Figure 8** show the effects of the bearing pressure on the soil that supports the foundation of the building at Baghdad region. As mentioned above, the bearing pressure under the foundation when using average bearing capacity values is not equally distributed (**Figure 7**). The yellow and red zones are covering small area that does not cause concern for the building.

Figure 8 show the distribution of the base pressure when using the worst bearing capacity values at Baghdad region. The red and yellow zones are large enough to affect the foundation but do not cause failure in the foundation. Therefore, we can consider the building is in safe mode.

The contours of **Figure 9** show the distribution of the bearing pressure beneath the foundation when using the average value of bearing capacity at Basrah. The red and yellow zones appear in the figure are of moderate sizes, and they do not affect the soil beneath the building.

Figure 10 show the distribution of bearing pressure when the worst bearing capacity values are used at Basrah region. The figure includes many red and yellow zones. These zones are affecting soil under the foundation.

3. Discussion

The results obtained from the program showed that the bearing pressure under the foundation of the building model for Mosul region for the average value was 102 KPa; this value is less than the calculated value (177 KPa). The worst value shown by the contour lines was 89 KPa. This value was restricted in small areas and had no effect on the foundation. Most of the areas under the foundation had a pressure value of 75 KPa. While, in the previous work done by Al-Taie, *et al*., (2013) [5] for the same building model using STAAD Pro Program and for one site in Mosul, the results showed that the value of the bearing pressure under the foundation was 73 KPa, and in few areas was 115 KPa. These values had no effect on the foundation and it did not reach the calculated value (300 KPa). For this site, continuous or strip type foundation should be chosen. This will be more economical. As shown in **Table 5**.

In Baghdad region, the bearing pressure for the average value was unevenly distributed under the foundation (the range of value was 82 to 96 KPa), but it did not exceed the calculated bearing capacity (125 KPa).

The worst value of the bearing pressure under the foundation (68 KPa), was equal to the value calculated. However, in some few areas under the foundation, the value of the bearing pressure was 88 KPa, which exceeded the calculated value and had no effect on the foundation. Previous work [5] of the bearing pressure under the foundation for one site in Baghdad showed two values. One was lower than the calculated bearing pressure (68 KPa) and occupied half of the area under foundation.

The other value of the bearing pressure was 77 KPa which exceeded the calculated value 70 KPa. Therefore, the suitable choice of the foundation type for the area with the bearing capacity value less than the calculated value is strip or continuous foundation type. While for the area with high bearing capacity value, raft foundation is recommended.

For Basrah region, the result of the average bearing capacity value indicated that the bearing pressure was (78 KPa) and did not reach the calculated value (84 KPa). The result for the worst bearing capacity value showed that it exceeded the calculated value for whole the area under foundation. The calculated and the measured values of the bearing pressure were 24 KPa and 72 KPa, respectively. Whereas, the previous work in Basrah for one site (Al-Taie, *et al*., 2013) showed that the bearing pressure under the foundation (71 KPa) was almost near the calculated value (50 KPa) of the bearing capacity. Therefore, raft foundation is recommended.

Table 5 shows the comparison between the current and previous work executed by Al-Taie *et al*. (2013). The value of the bearing capacity in the previous work for one site in each region of the three were higher than the worst value for the current work except for Mosul region. The average and worst values of bearing capacity are less than the previous work that was done by Al-Taie *et al*. (2013). Soil investigations specify the bearing capacity of the soil at a specific site so that suitable dimensions and type of foundation for the building can be considered. If the value of the bearing capacity is low, then the foundation dimensions should be large, and vice versa.

4. Conclusions

Seventy nine soil samples were collected from three different sites in Iraq (Mosul, Baghdad and Basrah) to investigate their effect on the foundation of the buildings. The results of the tests were used in a hypothetical

Table 5. Comparison of the values of bearing capacity at three sites in Iraq from current and previous work [5].

	Current work			Previous work (Al-Taie *et al.*, 2013)	
Location	Bearing capacity KPa Avg.	worst	Suggestions	Bearing capacity KPa	Suggestions
Mosul	177	77	Use shallow foundation (continues, spread and mat is to be used if the basement is required)	300	Any type of shallow foundation
Baghdad	125	68	Shallow foundation (spread and mat) is suitable in use in some parts of Baghdad region for buildings with not more than five floors	70	Mixed 2 kinds of foundation (raft and continuous)
Basrah	84	24	The mat foundation is the suitable type for low buildings	50	Raft foundation

building and analyzed by STAAD Pro.v8i model. Soil in Mosul region includes many types such as clayey (expansive clayey), gypsum and silty clay. The results indicated that the bearing pressure under the foundation was lower than that calculated. Similar results were obtained when using the relatively worse bearing pressure values. Therefore, we can use shallow foundation (continues; spread and mat can be used if there was a basement) in Mosul area. These types of foundations can be used for buildings with many floors.

The soil in Baghdad region is of fluvial nature. The calculation of the bearing capacity gave high values in some parts of this region. These values seem to be normal since the soil layers in this region represent the accumulation of fluvial sediment. The results showed that the value of the average bearing pressure did not exceed the value calculated. This suggests that shallow foundation (spread and mat) is suitable to be used in some parts of Baghdad region for buildings with not more than five floors. When worse bearing pressure values were used, it was beyond the calculated bearing pressure which means that the mat foundation is suitable for these areas too.

In Basrah region the soil has irregular nature and consists of different strata as a result of the deposition of sediments by the Tigris and Euphrates Rivers. Basrah soil can be divided into three zones. The first zone depth values from 0.5 - 4 m. It is hard silty clay soil. The second which is zone 5 - 19 m deep is cohesive soil, and the third zone 20 - 30 m deep is Cohesionless soil. The average bearing pressure was not exceeding the calculated value. Therefore, the mat foundation is the suitable type for low buildings (not more than three stores). When the worse bearing pressure values are used, it was evident that in most of the area under the foundation, it was higher than the calculated value. The suggestion for this area is deep foundation (piles). Therefore, shallow foundation is not the right choice.

The comparison of the results of this work and previous theoretical work for the same areas gave similar results.

Acknowledgements

All works of field and laboratory tests were done by the support of the Ministry of Higher Education and Scientific Research/Iraq. University of Mosul and Basrah, college of Engineering, Department of civil engineer greatly helped in sampling and laboratory testing. Especial thanks for Dr. Moataz Al-Obeydi and Dr. Qutayba Al-Saffar from University of Mosul for all their help and support. Great thanks for both engineers Abdul Hassan and Alaa from University of Basrah for all their support.

References

[1] Bowles, J.E. (1996) Foundation Analysis and Design. 5th Edition, McGraw-Hill Companies, Inc., Singapore.

[2] Coduto, D.P. (2001) Foundation Design: Principle and Practices. 2nd Edition, Prentice Hall, Upper Saddle River.

[3] Das, B.M. (2000) Fundamentals of Geotechnical Engineering. Brooks/Cole, Pacific Grove.

[4] Das, B.M. (2011) Principle of Geotechnical Engineering. 7th Edition, Cengage Learning, Stamford.

[5] Al-Taie, E., Al-Ansari, N, Knutsson, S. and Saad, T.E. (2013) Foundation Assessment in Different Parts of Iraq Using STAAD Pro v8i. *Journal of Civil Engineering and Architecture*, **7**, 273-281.

[6] Buringh, P. (1960) Soils and Soil Condition in Iraq. Ministry of Agriculture, Baghdad.

[7] Jassim, S.Z. and Goff, J.J.C. (2006) The Geology of Iraq. Dolin, Hlvanf.

[8] Sissakian, V.K. (2000) Geological Map of Iraq. 3rd Edition, State Company of Geological Survey and Mining, Baghdad.

[9] Al-Saoudi, N., Al-Khafaji, A. and Al-Mosawi, M. (2013) Challenging Problems of Gypseous Soils in Iraq. *Proceedings of the* 18*th International Conference on Soil Mechanics and Geotechnical Engineering*, Paris, 479-482.

[10] Khattab, S.A.A., Al-Juari, K.A.K. and Al-Kiki, I.M.A. (2008) Strength, Durability and Hydraulic Properties of Clayey Soil Stabilized with Lime and Industrial Waste Lime. *Al-Rafidain Engineering*, **16**, 102-116.

[11] Khattab, S.A.A. and Al-Omary, A.M.A. (2009) Effect of Disturbance and Gypsum Content on Soil Water Characteristic Curve. 2*nd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering*, Near East University, Nicosia, North Cyprus, 28-30 May 2009, 426-433.

[12] Al-Juari, K.A.K. (2009) Volume Change Measurement of Collapsible Soil Stabilized with Lime and Wasit Lime. *Tikrit Journal of Engineering Sciences*, **16**, 38-54.

[13] Khattab, S.I.A., Abed, R.S. and Al-Imam, B.M.A.A. (2013) Analyzing Some Geotechnical Properties of Soils to Predict the Swelling Potential in the Left Side of Mosul City Using GIS Methods. *International Journal of Chemical*, *Environmental & Biological Sciences* (*IJCEBS*), **1**, 2320-4087.

[14] Karim, H.H., Ali, H.Z. and Hamdullah, A.H. (2010) Digitally Processed Geophysical Data Sets for Identification of Geological Features in Southern Iraq. *Engineer & Technology Journal*, **28**, 236-252.

[15] Mahmood, R. and Albadran, A.A. (2002) Geotechnical Classification and Distribution of the Quaternary Deposits in Basrah City, South of Iraq. *Iraqi Journal of Earth Sciences*, **1**, 6-16.

[16] Kadhim, M.M., Al-Saoudi, N.K.S. and Ziboon, A.R.T. (2013) Digital Geotechnical Maps of Basrah City Using Geographical Information Systems Technique. *Engineering & Technology Journal*, **31**, 599-617.

[17] Al-Taie, M.A.J., Ali, A.M. and Albdran, B.N. (2009) Improvement of Selected Parts of Basrah Governorate Soil Using Resorcinol Resin. *Basrah Journal of Sciences* (*C*), **27**, 1-16.

[18] Gunaratne, M. (2012) The Foundation Engineering Handbook. Taylor & Francis Group, New York.

[19] Mohammed, A.H., Yahya, A.Y. and Ahmed, B.A. (2012) Database for Baghdad Soil Using GIS Techniques. *Journal of Engineering*, **18**, 1307-1324.

[20] Subramani, T., Ponnuvel, D. and Deans, D. (2012) Seismic and Stability Analysis of Gravity Dams Using Staad PRO. *International Journal of Engineering Research and Development*, **1**, 44-45.

[21] Bhattacharjee, B. and Nagender, A.S.V. (2007) Computer Aided Analysis and Design of Multi-Storeyed Buildings. BSc. Thesis, National Institute of Technology Roukela, Roukela.

[22] Bentley, (2011) Staad Pro & Staad Foundation Software. http://www.staadpro.com

[23] ACI Committee 318-08 (2008) Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary. American Concrete Institute, Farmington Hills.

Paper VI

Engineering, 2014, 6, 610-632
Published Online September 2014 in SciRes. http://www.scirp.org/journal/eng
http://dx.doi.org/10.4236/eng.2014.610062

The Need to Develop a Building Code for Iraq

Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson

Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden
Email: Entidhar.altaie@ltu.se, nadhir.alansari@ltu.se, Sven.Knutsson@ltu.se

Received 20 July 2014; revised 20 August 2014; accepted 29 August 2014

Abstract

Building Code is a legal document that provides a minimum level of safety and health for the constructions to make the public live in safe buildings. People recognize the importance of constructing the buildings in safe conditions, since the dawn of civilization. Many countries around the world were facing different kind of disasters such as fires, earthquakes, etc. These disasters made builders develop methods for safe construction to avoid any disaster. Later, these developments became codes and standards. Since the middle of the last century many countries established its local codes. This research represented a review of the importance of the codes with a short history for them. Furthermore, reviews for some national codes (Egyptian, Syrian and Arabia Saudi) were done as well as comparison between load's correction factors, geotechnical requirements and materials used in concrete. Most of the national codes were highly based on the ACI, British and Germany codes and standards. In addition, a review and comparison were presented for International codes (American (ACI) and European (EC)) through a case study. EC code is becoming more common for the world. Eurocode gives more flexibility to the user to employ their own standards (national annex). To find the best suitable foundation design to be used in Iraq and the differences when using the American and European codes, a building model was designed and analyzed using STAAD Pro., and SAFE softwares for three locations (Mosul, Baghdad and Basrah). The combination loads used in the two softwares were for ACI and EC codes. Results obtained were very similar. The type of foundation to be chosen for Mosul location is spread or continuous. For Baghdad location the suitable type is raft and for Basrah the choice is raft and piles. In view of the fact that Iraq has no national code, engineers and designers were depending on the ACI and British codes and standards. It is very important to have an Iraqi code because it will improve the quality and safety of the design and construction of buildings as well as its economic value.

Keywords

Codes, ACI, Standards, Loads, Eurocode, Correction Factors, SAFE Software, Bearing Pressure

How to cite this paper: Al-Taie, E., Al-Ansari, N. and Knutsson, S. (2014) The Need to Develop a Building Code for Iraq. *Engineering*, **6**, 610-632. http://dx.doi.org/10.4236/eng.2014.610062

1. Introduction

A code is a document covering a system of laws. Code of building is a document containing standardized requirements which specify the minimum acceptable limit of safety for buildings and non-buildings. These codes are based on the experience of engineers, experimental work and specific conditions and behavior. They are protecting the buildings against various risks like fire, structural collapse and amenity issues like ventilation, lighting, dampness, sound insulation and sanitation. Moreover, codes are significant tools for achieving society's goals such as sustainability and energy efficiency. Moreover, codes are significant tools for achieving society's goals such as sustainability and energy efficiency, addressing all the aspects of construction such as: safe exits, electrical, plumbing, seismic design, structural integrity and correct use of the construction materials. Building codes classify structures by applying and using various standards, as an example, schools and office buildings are in separate occupancy categories with various performance requirements [1] [2]. Codes have two categories which are safety codes and standards, and the product standards [3].

A comparative work was made by Shkoukani, 1993, between Eurocode (EC2) and American Concrete Institute (ACI), for the design and analysis of a reinforced concrete rectangular cross-section with tension reinforcement. The results he obtained showed that the moment calculated by elastic analysis and partial safety factors used for loads and materials in EC2 code were smaller than those used in the ACI code. While, the amount of shear reinforcement which was calculated using the ACI code was smaller than the one calculated using EC2 code [4]. Jawad [5], did a comparison of the design requirements (loading and materials) of the structural building ACI 318M-02, BS8110:1985, and Eurocode 2, 1992 codes. The comparison included the strength design requirements of constructional elements for safety provisions, flexural design, shear design and column design. He studied some numerical examples using the three codes. He recommended the EC2 because it was more liberal in strength design and partial factors of safety than the ACI code [5]. A comparison of seismic provisions of three seismic design codes, the American (IBC 2009 and ACI318-08M), Eurocode 8 (EC8) and The National Structural Code of the Philippines (NSCP 2010) codes was presented by Landingin, *et al*., (2013). Regular and irregular reinforced concrete frames were analyzed and compared for four types of storey building. Equivalent lateral force analysis response and spectrum analysis were also performed using SAP2000 software package. Five representative columns for each reinforce column (RC) frame structure were analyzed. Using EC8 the results of column axial load-bending moment interaction diagrams, were found to be conservative when compared to the NSCP 2010 and IBC 2009. The design and analysis of ordinary RC residential buildings with specific irregularity using EN8 provisions were considered to be safer, and therefore they were recommended in the conclusion by Landingin, *et al*. (2013) [6].

A review and comparison will be presented for different types of national (Egyptian, Syrian and Saudi Arabia) and international (American and European) codes in this paper. Furthermore, Iraq does not have a national building code. For this reason an attempt had been carried out to find the best suitable foundation to be used in different parts of Iraq. To achieve this goal a building model was designed and analyzed using STAAD Pro., and SAFE software for three locations (Mosul, Baghdad and Basrah) in Iraq. The study would summarize the geotechnical requirements, the principal design requirements and materials used in concrete for all codes. Comparison was done using both ACI and EC codes to choose the suitable type of foundation for each location. Furthermore, part of this paper would be devoted to focusing on the suggested Iraqi Building code.

History of Building Codes

First code was written by King Hammurabi (3000 BC) during early civilization in Babel. Articles 228, 229, 230, 231, 232, and 233 of the code were specified the rules of payment and the punishments to the builders (If they cause any harmful or damages for persons who lived in the new building or in case the building was not properly constructed). These rules were representing the starting of safety requirements in the built environment [7].

Emperor Nero developed master plan for idealized Roman city after burning in 64 ADs, because the constructions of Roma public buildings were of bad construction quality. In addition, the distances between buildings were cramped and they had poor sanitation. After burning, the constructions were done according to the master plan of Nero; principles regarding fire resistance and sanitation [7].

Fires broke out near the Tower of London's city in 1666 ADs, because the city was crowded with tightly spaced buildings and raw sewage flowing through open drains. Parliament started writing what is known as London Building Act for two years after that fire. The documents established the regulations for the buildings of London's city only [7].

Chicago city faced huge fire for two days during 1871 ADs. More than a quarter of the city buildings were destroyed. For that reason, most of the insurance companies threatened to leave unless developments should be done to the regulations of buildings. In 1875, rules for regulations of buildings and fire prevention were enacted [7]. On April 18, 1906, an earthquake hit San Francisco city and left it in ruins. Some parts of the city were destroyed by the fires that broke out after the earthquake. The scientific community was gathered to observe what had happened and they formed the building code organizations that still exist today. Organizations since then had been studied various structures after each earthquake to check their ability to withstand the events [3] [7]. In view of these disasters the regulations of constructions were improved and collected in code.

2. Review of Codes

2.1. National Codes

Most of the countries have their own national building codes. They are usually adopted and developed by governmental building institutes. Most of the codes depend on the international codes because the standards used in such codes fulfill the building requirements in many countries. Reviews for some of the different national codes in the Middle East region are given below.

2.1.1. Egyptian Codes

The first code in Egypt was published in 1956 [8]. It was dedicated for the reinforce concrete only. The government adopted the code in 1964, and established Housing and Building National Research Center (HBRC), to lead the research to develop the building's design and materials used, to enact the codes [8]. In addition, it was the responsibility of that center to issue and develop the codes and specifications related to the construction industry. In 1980, the first copy of the code was printed and published. It included topics on concrete structures, soil mechanics, foundations and electrical connections for buildings. HBRC published various codes and technical specifications (**Figure 1**). Codes were improved every five years [8]. Egyptian codes specified the minimum requirements for design and construction of the buildings to provide safety and efficiency. They included the basics for design, and implementation of buildings, and material's specifications. Moreover, they include inspections and quality control. The aim of the code is to provide safety requirements to the buildings without causing any damages, collapse and distortions [9]. Egyptian code is composed of nine portions, with four annexes (**Figure 1**). Most of the Egyptian standards for the construction field are now harmonizing with the

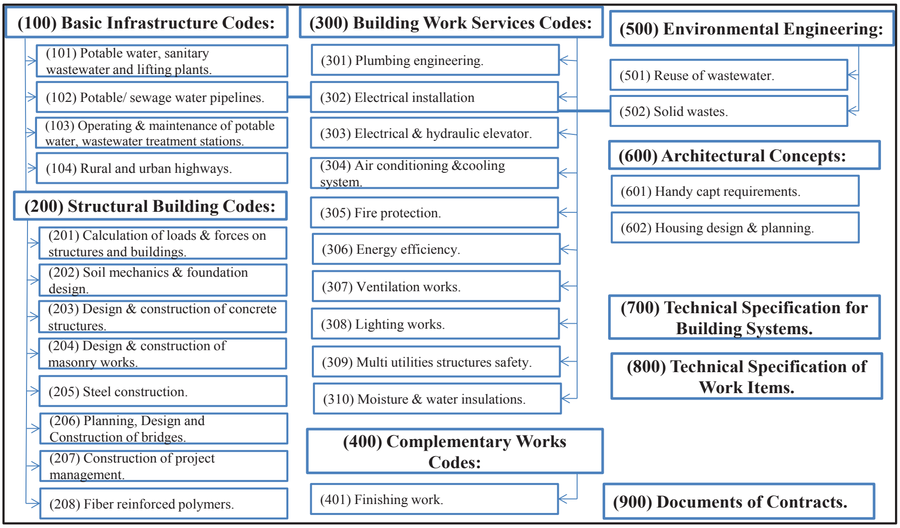


Figure 1. Egyptian code for building & construction [8].

International European standards (ENV), in particular the seismic code. The codes are usually including all the criteria needed for engineering works [8].

1) Geotechnical requirements

The geotechnical requirements are very important for the designers to define the appropriate and efficient foundations to be chosen for any construction for a suitable type of soil. Soils or rocks are materials that have no fixed properties like other engineering materials. Properties of the soils and rocks can be defined by collecting samples from the site and preform different types of tests on them to classify and define the soil properties.

Structural building codes 200 (**Figure 1**) is that part covers the structural building requirements. It has eight sub-portions. Soil mechanics and foundation design is sub-portion (202/3). It defines and explains the Geotechnical requirements (202) are: Site investigations (202-1); Laboratory tests (202-2); Shallow foundations (202-3); Deep foundation (202-4); Foundations in problematic soil (202-5); Foundations facing vibrations & dynamics loads (202-6); Retaining walls (202-7); Stability of slopes (202-8); Earthworks & dewatering (202-9) and Foundations on rocks (202-10). All the geotechnical and engineering information, details and requirements for soil, rocks, site studies (topographic, geomorphology, hydrology), field tests and basic and safe requirements for foundations design(shallow and deep) are given in these portions [9].

2) Loads requirements for design (201)

These requirements exist in part 201(Structural building codes 200). The factors of safety (correction factors) for dead, live, wind and earthquake loads which are used for ultimate strength limit values are shown in **Table 1** [10].

3) Materials (203)

The materials that are used in concrete are presented in the sub-portion design and construction of concrete structures 203. These materials are reinforcement, cement, aggregates, water and admixtures. Furthermore, it specifies the rate of components according to the types and working conditions of the concrete. The materials are taken according to the Egyptian standards (ES). Specifying all types of cement to be used in concrete and testing (chemical, mechanical and natural) are tabulated in ES (4756-1/2006; 583/2005; 3071, 3072/1996; 474/1994; 2421/1993; 2149/1992; 2149/1992; 1658/1988). Water to be used in mixing of concrete should be clean and without any harmful materials such as oils, acids, organic maters and salts. The admixtures should not affect the bearing of concrete with time and should be conforming to ES 1899/1990. Steel Reinforcement: All types of steel reinforcement such as: bars, wires and welded plain wire which are to be used with the concrete are defined and should be conforming to ES 262/2000. The tensile test for the reinforcement should conform to ES 76/2001. Moreover, method of storage, and physical and mechanical property's tests, concrete and aggregates tests, were included in the code [10].

2.1.2. Syrian Code

Implementation of the buildings in Syrian used to depend on the experiences of engineers, before 1974. Syrian engineers association published rules to be followed in design of structural buildings and stone bearing walls, for the first time in 1974 [11]. However, designers were depending on the foreign codes because the rules were not enough for design work. Later, in 1977, Arab engineers union issued the Arab building code for design and implementation of reinforced concrete structures and it was adopted by the Syrian government. After that, Syrian engineers association issued many national codes which were adopted by the government (1992 1st edition issued; 1995 2nd edition issued with some developments; 1996, 1997 and 2000) [11]. Different appendixes issued for earthquake. Furthermore, evaluation and rehabilitation for the existing buildings and 2004 Last edition issued [11]. The code and its appendixes provided designers and engineer a good assistance and support in their work. In 2004 edition the code included all the details needed in modern constructions and software used for

Table 1. Loads factors and the alternative [10].

Ultimate strength	Dead load	Live load	Wind load	Seismic load	Notes
U	1.4	1.6	-	-	
U	1.5	1.5	-	-	*When L load not more than 75% from the standing loads*
U	0.8 * 1.4	0.8 * 1.6	0.8 * 1.6	0.8 * 1.6	
U alternative	0.9	-	1.3	1.3	

analysis and design. Syrian code was developed every few years where new requirements were added such as earthquakes [12]. Syrian code had fourteen appendixes; each one specifies a requirement of different type for construction, as follows:

1. *Loads.*
2. *Earthquake.*
3. *Drawings and details.*
4. *Evaluate and rehabilitation the existing buildings.*
5. *Foundations.*
6. *Retaining walls.*
7. *Tanks.*
8. *Precast and prestressed concrete structures.*
9. *Composite sections.*
10. *Bridges and floating bridges.*
11. *Minarets, chimneys and cooling towers in industrial facilities.*
12. *Flexor ceilings and crustaceans.*
13. *Bases of machineries.*
14. *Silos and hoppers.*

In 2006, Syrian thermal insulation code was issued to decrease the energy used in the buildings, protecting the environment [13]. Furthermore, to provide minimum rules and judgments to be followed through the design and implementations of reinforce concrete, materials for buildings and tests methods. The purpose of the code is establishing investment and operation requirements for buildings [12].

1) Geotechnical requirements

Site investigations, soil description and identification are the main requirements in any building design. The geotechnical requirements are part of *foundation's appendix No.*5**.** The Appendix, defined all the conditions and recommendations to be followed in the design and implementation. Moreover, it addresses all types of foundations (shallow and deep foundations), loads affecting the foundations and the materials used such as: normal concrete, reinforce concrete, etc. It has defined the requirements of durability and permanence for foundations against collapse and unbalances, and the limits of total and differential settlement. The topics of the appendix are (*Materials properties*; *Evaluation of loads*; *How to determine safety requirements and stresses distribution on soil beneath foundations*; *How to determine a soil modulus of elasticity beneath foundations*; *Distribution of soil reaction beneath foundations*; *Distribution of soil reaction beneath foundations*; *Distribution of soil reaction beneath foundations*; *Classification of foundations and the state of used*; *Steps of how to choose foundations*; *General requirement for design of foundations*; *Base general requirements in stresses calculations on soil and foundation's analysis*; *Foundations design and Foundations for machines* [14]. All field tests in Syrian code are based on finding the soil modulus of elasticity beneath the foundations. The geotechnical reports should be prepared by specialist engineers in geotechnical works. Nothing mentioned about the laboratory tests and procedures. The standards to be followed in the tests were not sited as well [14].

2) Loads requirement for design

The loads affect buildings or any constructions to be considered in the design are dead, live, wind and earthquake loads. The correction factors used to define the ultimate load's values are shown in the following equations [15]:

$$U = 1.5G + 1.8P \qquad \text{General situation}$$

$$U = 0.8\left[1.5G + 1.8P + 1.8W\right] \qquad \text{For wind effect}$$

$$U = 0.8\left[1.5G + 1.8P + 1.8\left(1.1S\right)\right] \qquad \text{For earthquake effect}$$

$$U = 0.8\left[1.5G + 1.8P + 1.5T\right] \qquad \text{For settlement or creep or change in climate effect}$$

The alternative factors used to calculate the ultimate loads used are:

$$U = 0.9G + 1.4W$$

$$U = 0.9G + 1.8E$$

$$U = 0.9G + 1.4W + 1.4E$$

where: *U is the ultimate load*, *G is a dead load*, *P is a live load*, *W is a wind load*, *S is an earthquake load*, *E is earth pressure and T is creep or settlement or weather change.*

3) Materials

All materials properties depend on local or international standards mentioned in the code [14]:

The types of cement used are Portland (normal, rapid solidification, white, etc.). Cement must follow the standards that are specified in the term of the project. Usually, aggregate are taken from deserts or riverbeds or sea beaches or from crushed rocks. The aggregate grains must be solid, hard and clean and their strength must be greater than double the strength value for concrete. Water used in concrete mixture and cleaning aggregate must be clean and empty from harmful materials such as oil, acids and salts, which will affect the concrete or reinforcement. Rate of soluble chlorides and sulfate salt are ≤0.5 g/letter and ≤0.3 g/letter respectively. Drinking water is suitable to be used, while sea water is not allowed to be used. Admixtures must have not harmful effect on the concrete and steel reinforcement. Concrete mixed with admixtures must not change the mechanical properties values of the concrete. Steel reinforcement: Different types of reinforcements are usually used with concrete. Their types, mechanical properties and diameters are defined in the code.

2.1.3. Saudi Building Code (SBC)

Saudi Building Code (SBC) is a set of legal, technical and administrative regulations and requirements that specify minimum standards of construction for building to ensure public health and safety. In 2000, a national committee in Saudi Arab study a number of codes to choose a base code for the Saudi buildings. International Building Code (IBC) was chosen and permission from International Code Council (ICC) was taken to include any or all part from IBC codes and standards in the SBC code [16].

The code took into consideration the cultural and social environment, the climatic and natural conditions, and soil types and material's properties in the Kingdom. First edition of the code was published in 2007. It included thirteen portions of requirements (**Table 2**). The purpose of the Saudi Building Code (SBC) it is to provide public safety and health, sustainability and environmental protection [16].

1) Structural-soil and foundations (SBC 303)

The geotechnical requirements and minimum requirements for footing and foundation systems in areas not subjected to water pressure by wave and wind action or scour are included in this code. The topics contained in the code are: *Site investigations*; *Excavation grading & fill*; *Allowable load bearing values of soil*; *Spread footing*; *Foundation walls*; *Retaining walls*; *Combined footings and mats*; *Design for expansive soils*; *Design for collapsible soils*; *Design for sabkha soils*; *Design for vibratory loads*; *Dampproofing and waterproofing*; *General requirements for pier & pile foundations*; *Driven pile foundations*; *Cast-in-place concrete pile foundations and Pier's foundations* [16].

Table 2. Parts of the Saudi building code [16].

No.	Portion name	Code based on
201	Architectural requirement	The International Building Code (IBC)
301	Structural-load & Forces	American Society of Civil Engineers, through Structural Engineering Institute (SEI/ASCE)
302	Structural-testing & Inspection	ICC code in addition to American Concrete Institute (ACI) materials
303	Structural-foundation & Soil	ICC code in addition to American Concrete Institute (ACI) materials
304	Structural-concrete structures	ICC code in addition to American Concrete Institute (ACI) materials
305	Structural-masonry structures	ICC code in addition to American Concrete Institute (ACI) materials
306	Structural-steel structures	ICC code in addition to American Institute of Steel Construction Inc. (AISC)
401	Electrical	The standards of the Saudi Arabian Standards Organization (SASO) which in turn based on the International Electro technical standards IEC (Electrical Installations of Buildings)
501	Mechanical	International Mechanical Code (IMC)
601	Energy conservation	International Energy Conservation Code (IECC)
701	Sanitary	International Plumbing Code (IPC)
801	Fire protection	International Fire Code (IFC)
901	Existing buildings	American Society of Civil Engineers, through Structural Engineering Institute (SEI/ASCE)

The code also clarifies the cases that do not need site investigations such as: load on foundation less than 50 kPa, unexpected Problematic soil beneath the foundation, unavailable vibration or dynamic load on the building and unsuspected cavities beneath the foundations of the building.

In addition, all the requirements are to be specified, sampling must be done from different types of soils (expansive, collapse, and sabkha kind). All laboratory tests should be done according to ASTM standards. Furthermore, the code defined the settlement limits for different types of soil and foundations [16].

2) Loads requirements (301)

The Saudi Building Code provides minimum load requirements in the design of buildings and other structures. The loads and appropriate load combinations were developed to be used together. Basic combination loads were used as shown in **Table 3** [16].

3) Materials (304)

All materials used in concrete must be quality specified, and are as follow [16]:

Cement: Each type of cement specification such as Portland cement is specified by (ASTM C150); blended hydraulic cement is specified by (ASTM C595M) and expansive hydraulic cement specified by (ASTM C845). Aggregates must have the following specifications: concrete aggregates and lightweight aggregates for structural concrete according to (ASTM C33) and (ASTM C330) respectively. Water used in mixing concrete must be clean and free from oils, alkalis, acids, salts, organic materials, or other substances deleterious to concrete or reinforcement. The mixing water should be prepared and tested in accordance with (ASTM C109). Specification for air-entraining admixtures for concrete must conform to (ASTM C260). Chemical admixtures for concrete specification must conform to (ASTM C494) or the specification for chemical admixtures used in producing flowing concrete is conforming to (ASTM C1017). Fly ash or other pozzolans used as admixtures must conform to the specification of (ASTM C618). While, specification for ground granulated blast-furnace Slag for use in concrete and mortars must conform to (ASTM C989). Specification for Silica fume used as an admixture must conform to (ASTM C1240). Steel reinforcement: The types of deformed reinforcing bars for concrete using are deformed and plain billet-steel bars specification must conform to (ASTM A615M), and Low-alloy steel deformation and plain bars with specifications that conform to (ASTM A706M). While, the plain reinforcement types are: plain bars for spiral reinforcement. It should conform to the specifications of (ASTM A615M; or ASTM A706M) and plain wire for spiral reinforcement must conform to the specification of (ASTM A82).

Egyptian, Syrian, and Saudi Arabian codes impose loads safety factors related to designing assumption and inaccuracy of calculation, constructional inaccuracies, and possible unusual load increases [5]:

Design load = characteristic load × partial load factor of safety

As shown in **Table 4**, the Egyptian and SEC codes are using the same safety factors. These codes are dependent on the American code, while, Syrian code has other factors of safety related to Germany's standards.

Table 3. Load combinations and alternatives equations [16].

Combining loads using allowable stress design	Combining factored loads design
$D + L$	$1.4\,(D + F)$
$D + H + F + L + T$	$1.2\,(D + F + T) + 1.6\,(L + H) + 0.5\,(L_r \text{ or } R)$
$D + H + F + (L_r \text{ or } R)$	$1.2D + 1.6\,(L_r \text{ or } R) + (f_1 L \text{ or } 0.8W)$
$D + H + F + 0.75\,(L + T) + 0.75\,(L_r \text{ or } R)$	$1.2D + 1.6W + f_1 L + 0.5\,(L_r \text{ or } R)$
$D + H + F + (W \text{ or } 0.7E)$	$1.2D + 1.0E + f_1 L$
$D + H + F + 0.75\,(W \text{ or } 0.7\,E) + 0.75\,L + 0.75\,(L_r \text{ or } R)$	$0.9D + 1.6W + 1.6H$
$0.6D + W + H$	$0.9D + 1.0E + 1.6H$
$0.6D + 0.7E + H$	
The alternative basic load combinations	Special case
$D + L + (L_r \text{ or } R)$	
$D + L + 1.3\,W$	
$D + L + 1.3\,W$	$1.4\,(D + F + T) + 1.7\,(L + H) + 0.5\,(L_r \text{ or } R)$... *for concrete structure and masonry construction*
$D + L + 1.3W/2$	
$D + L + E/1.4$	
$0.9D + E/1.4$	

Where: *D*: *Dead load*; *L*: *Live load*; *E*: *Earthquake load*; *W*: *Wind load*; *R*: *Rain load*; *T*: *Self-straining force*; *H*: *Load due to lateral earth pressure, ground water pressure, or pressure of bulk materials*; *F*: *Load due to fluids with well-defined pressures and maximum heights*; L_r: *Roof live load*; f_1 = 1.0 *for areas occupied as places of public assembly, for live loads in excess of* 0.5 kN/m^2, *and for parking garage, live load*; f_1 = 0.5 *for other live loads.*

Table 4. Comparison between national codes for strength design requirements for geotechnical requirements and materials.

Code/requirements	Egyptian	Syrian	Saudi Arabian Code
Dead load	1.4	1.5	1.4
Live load	1.6	1.8	1.6
Combinations load	D = 0.8; L = 1.3	D = 0.8; L = 1.4	D = 1.2; L = 1.6
Geotechnical works	– All requirements and details for laboratory and field tests. – Foundations design details and requirements depending on Egyptian and ACI code.	– All requirements and details for laboratory and field tests. – Foundations design details and requirements depending on Syrian and Germany standards.	– All requirements and details for laboratory and field tests. – Foundations design details and requirements depending on ASTM standards and IBC.
Materials	Materials are defined according to Egyptian standards.	Materials are defined according to Syrian standards.	Materials are defined according to ASTM standards.

2.2. International Codes

International codes are available and are used in most of the countries around the world. The most widely used are the American (ACI) and the European (EC) codes. Local country codes usually rely on one of these codes.

2.2.1. American Codes

United States of America issued two international codes, International Building Code (IBC) and Building code requirements for structural concrete and commentary (ACI-318) [17]. The paper will present preface for the IBC, and will focus in details on the ACI-318.

1) IBC code

First code in United States was authored in 1700's AD. George Washington and Thomas Jefferson encouraged the development of constructions arrangements to prepare minimum standards to ensure safety and health. First code developed in United States was in 1905 by the Fire Underwriters Association [18]. They planned to make it national code and were focusing on the safety of the buildings and people inside them. The code was called National Building Code and it aimed on safety of people (fire alarms, isolation of hazards and fire exits). Since 1900, there were three models of building codes to be used in the United States, and developed by three regional code groups [19]:

- Building Official Code Administrators International, Inc. (BOCA). This code was used on the east coast and throughout the Midwest of the United States.
- International Conference of Building Officials (ICBO). This code was covered the west coast of the United States.
- Southern Building Code Congress International, Inc. (SBCCI). The code was used in the southeastern of the United States.

The codes were effective and responsive to the local regulatory needs. In 1994, the three national groups combined their efforts and formed the International Code Council (ICC) and developed non limitation's code. First issue of the International Building Code (IBC) was in 1997. The final edition of the International Building Code of (IBC) was issued in 2000, and made development of previous codes. The National Fire Protection Association (NFPA) initially joined ICC in a collective effort to develop the International Fire Code (IFC) [19].

The code's references were taken from the previous codes. Furthermore, including the following International codes: International Plumbing, International Mechanical, National Electric, and various National Fire Protection Association standards codes [18] [19]. The code is comprehensive for all types of buildings and constructions; and for all types of materials used in constructions.

2) ACI 318 (Building code requirements for structural concrete and commentary)

Code is a document collecting many practice standards provided to the architects and engineers [20]. History of any organization represents a reflection of the ideals and acts of organized groups within it. These activities were a revision to meet changed conditions and have formed the American Concrete Institute (ACI). The history of ACI is closely tied with the history of concrete technology developments [21] [22].

1904: The joint committee on reinforced concrete was established and produced several drafts for concrete code.

1905: National association of cement users become ACI.

1909-1914: ACI committee 318 was established to develop a concrete code and it published a concrete design code.

1930: ACI 318 requirements became the only document in the USA dealing with concrete design.

1963: ACI 318-63 issued documents for both Working Stress Design (WSD) and Ultimate Strength Design (USD) requirements.

1971: ACI 318-71 issued containing USD and WSD as appendixes, ACI 318 was meant Building Code Requirements for Reinforced Concrete.

1989: Names of the code were changed to the Building Code Requirements for Structural Concrete.

2002: Issues of the code made procedure known as the unified design procedure and the previous requirements became the appendix B. The WSD was taken out from ACI 318 [21] [22]:

ACI 318 is the basic document for concrete building's design in USA, and it covers design materials and structural construction concrete. Furthermore, it specifies the resistance factors, the design resistance and the load factors. The code was adopted by the IBC and become legal. Every three to four years, ACI 318 code is updated according to the development in the field of engineering. The code covers both reinforcing and prestressing steel and precast and prestressed concrete. Additionally, the resistance factors are increased by 10% - 15% during the last thirty years [23]. ACI code cover twenty three topics that deals with design and implement of concrete, with six appendixes presenting all the requirements needed, as [24]:

- *General requirements.*
- *Inspection.*
- *Materials.*
- *Durability requirements.*
- *Concrete quality, mixing and placing.*
- *Formwork, embedment and construction joints.*
- *Details of reinforcement.*
- *Analysis and design—general considerations.*
- *Strength and serviceability requirements.*
- *Flexure and axial loads.*
- *Shear and torsion.*
- *Development and splices of reinforcement.*
- *Two-way slab systems.*
- *Walls.*
- *Footings.*
- *Precast concrete.*
- *Composite concrete flexural members.*
- *Prestressed concrete.*
- *Shells and folded plate members.*
- *Strength evaluation of existing structures.*
- *Earthquake-resistant structures.*
- *Structural plain concrete.*

- *Appendix A*: *Strut and tie models.*
- *Appendix B*: *Alternative provisions for reinforce and prestressed concrete flexural and compression members.*
- *Appendix C*: *Alternative load and strength reduction factors.*
- *Appendix D*: *Anchoring to be concrete.*
- *Appendix E*: *Steel reinforcement information.*
- *Appendix F*: *Equivalence between SI-metric, MKS-metric and U.S. customary units of nonhomogeneous equations in the code.*

(1) Geotechnical requirements

Geotechnical requirements are taken from IBC code, soils and foundations portion, because ACI does not give these requirements. All the useful requirements to define the structure and identify the soils are presented in this part. Furthermore, the types of foundations that should be chosen in the design for a suitable type of soil are also presented. The portion contains the followings topics [25]:

- *Geotechnical investigations* (1803): Classification and identification of soil are conforming to ASTM D2487, ASTM D4318, ASTM D422 and ASTM D4829 standards respectively.
- *Excavation*, *grading and fill* (1804): They are defined according to ASTM D1557 standards and the Controlled Low-Strength Material (CLSM).
- *Dampproofing and waterproofing* (1085): The requirements of the story of above a grade plane, under floor spaces, follow the requirements of FEMA/FIA-TB-11. Ground water control, Dampproofing the mortar used comply with ASTM C887.
- *Presumptive load-bearing values of soil* (1806): It concerns determining the load combinations, presumptive load-bearing values and lateral load resistance.
- *Foundation walls*, *retaining walls and embedded posts and poles* (1807): Masonry foundation walls with reinforcement and the concrete masonry comply with ASTM C90. While, clay masonry comply with ASTM C62 or ASTM C216.
- *Foundations* (1808): The criteria for foundation design, design for expansive soils, slab-on-ground foundation, stabilization, and foundation on or adjacent to slopes, pools, and concrete foundations are presented in this section.
- *Shallow foundation* (1809): All requirements for design and construction for shallow foundations (such as supporting soils, stepped footings, depth and width of footings, frost protection and location of footings) are listed. Moreover, plain concrete footings, masonry-unit footings, steel grillage footings, timber footings, and footing seismic ties are also listed.
- *Deep foundations* (1810): The analyses and design details and installations of deep foundations are given. These details include geotechnical investigation, use of existing deep foundation elements, and special type of deep foundations. The analysis of lateral support, stability, settlement, seismic design, and group effects are also stated. Design conditions, composite elements, driven piles, helical piles, casings, materials (concrete, seismic hooks, pre-stressing steel) should conform to ASTM A416. While, allowable axial load and load tests should be conforming to ASTM D1143 or ASTM D4945. Allowable frictional resistance, uplift capacity of single deep foundation element, uplift capacity of grouped deep foundation element, load bearing capacity, and allowable lateral load are given. Dimensions of deep foundation elements such as precast, cast-in-place or grouted-in-place, cased, uncased, micropiles, steel, H-piles, steel pipes and tubes and helical piles are also tabulated. Moreover, Cast-in-place deep foundations: design cracking moment, required reinforcement, placement of reinforcement, seismic reinforcement and materials should conform to ASTM A615 Grade 60 or 75 or ASTM A722 Grade 150 and heaved elements, enlarged base cast-in-place elements, hollow-stem angered cast-in-place element, socketed drilled shafts, micro-piles, helical piles, and special inspection, all the details of implementation are listed in section 1810 [25].

In addition, it is present the types of tests and the equipment and its calibrations. Some of these (as mention above) requirements follow the American Society for Testing and Materials (ASTM) [25].

(2) Strength and serviceability requirements

The demand is considered as the strength required, while the supply as the strength furnished. The required strength (U) could be expressed under the forms of design loads or their related moments, forces and shears. For dead, live, wind and other loads the ACI code specifies design requirements, shears and moments be obtained from service loads by using the following relations [24] [26]:

$$U = 1.2D + 1.6L$$

$$U = 0.75(1.2D + 1.6L) + (1.0W \text{ or } 1.0E)$$ for resisting wind load or effect of earthquake load

$$U = 0.9D + (1.0W \text{ or } 1.0E)$$

$$U = 1.4D + 1.7L + 1.7H$$ for lateral loads

$$U = 0.75(1.4W + 1.7L + 1.7L)$$ for temperature change

$$U = 1.4(D + T)$$

where: *D = Dead load.*

L = Live load.

W = Wind load.

H = Loads due to weight and pressure of soil, water in soil or other materials.

E = Load effects due to earthquake.
T = Cumulative effect of temperature, creep, shrinkage, differential settlement and Shrinkage-compensating concrete.

The above relations are basics and important for any design for different constructions.

(3) Materials

Testing must be done to any materials used in concrete constructions to define if the materials are of the specified quality. Materials are [24]:

- Cement: Different types of cement are used in buildings (such as Portland, blended hydraulic, expansive hydraulic, hydraulic, flash and natural pozzolan, slag and silica fume). All types of cement must conform to the relevant specifications of ASTM C150, ASTM C595, ASTM C845, ASTM C1157, ASTM C618, ASTM C989 and ASTM C1240 respectively [24].
- Aggregates added to cement to produce concrete of adequate strength and durability. Aggregates are conformed to each of the following specifications: normal weight (ASTM C33) or lightweight (ASTM C330). Coarse aggregate must have maximum size due to one of the following: 1/5 the narrowest dimension between sides of forms, or 1/3 the depth of slabs, or 3/4 the minimum clear spacing between individual reinforcing wires or bars, bundled tendons, bundles of bars, or ducts [24].
- Water used in mixing concrete must conform to (ASTM C1602). Drinking water is also suitable to be used for mixing concrete. Water has excessive impurities that may not affect the setting time, volume stability and concrete strength and may cause corrosion of reinforcement. Water use in mixing concrete must have limited quantities for sulfates, chlorides, solids and alkalis [24].
- Admixtures that are used to reduce water and time setting modifications must conform to (ASTM C494). Types of admixture are air-entraining (must conform to ASTM C260), flowing concrete (must conform to ASTM C1017) and expansive cement use in concrete (must conform to ASTM C845) [24].
- Steel reinforcement includes deformed and plain reinforcements. Deformed reinforcement bars have different types such as: Carbon steel conforms to ASTM A615; Low-alloy steel conforms to ASTM A706; Stainless steel conforms to ASTM A955 and Roll steel and axel steel conforms to ASTM A996. While, plain reinforcement types are plain bars for spiral reinforcement must conform to (ASTM A615, A706, A955, or A1035); plain wire for spiral reinforcement must conform to (ASTM A1064), and headed studs and its assemblies must conform to (ASTM A1044) [24].

2.2.2. European Code (Eurocode)

Eurocodes are tools for safety of buildings and reliability enhancement. The objectives of Eurocodes are to improve civil engineering works and compliance of building, putting a framework to harmonize the technical specifications for construction products and being the basis for specifying contracts.

Since 1971 until 1990 the code committee was working to obtain a draft of technical documents set as international inquiry. During the period 1990-2006, the European committee for Standardization (CEN) has converted the first Eurocodes into provisional European standards (EN Vs), and then into European standards (EN). From 2007, until now, the Eurocodes are in a continuous evaluation process [27]. Eurocode structure includes 58 documents of standards, as shown in **Figure 2** [28].

Each part of the Eurocodes has a symbol and number to explain the purpose of the standard as shown in **Figure 3**.

European code is based on philosophy of limit–states, including both criteria of serviceability and strength. They are called resistance and load factors design. Moreover, the code includes the reduction factors of material strength. The uses of load factors are to increase the working loads.

1) Geotechnical requirements (EC7)

The requirements for the geotechnical design to be considered are as follows [31]:

- Nature and size of the structure with any special requirements.
- Conditions of its surroundings such as: neighboring structures, traffic, utilities, vegetation, hazardous chemicals, etc.
- Ground conditions and groundwater situation.
- Regional seismicity.
- Influence of the environment like hydrology, surface water, and seasonal changes of moisture.

Eurocode for geotechnical design is divided into three parts: ENV 1997-1, ENV 1997-2, and ENV 1997-3.

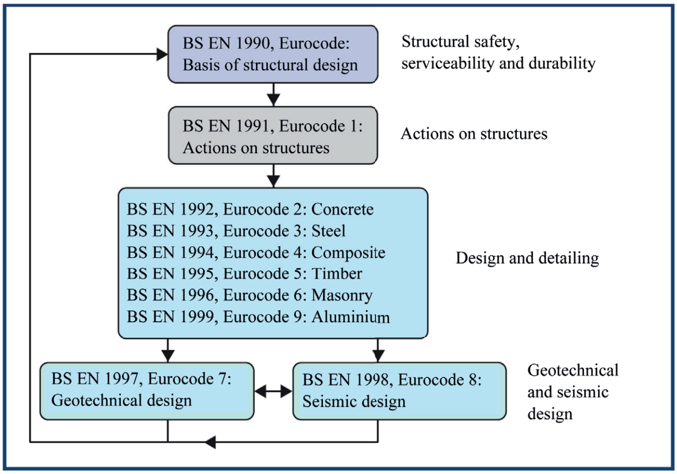


Figure 2. Eurocodes structural [29].

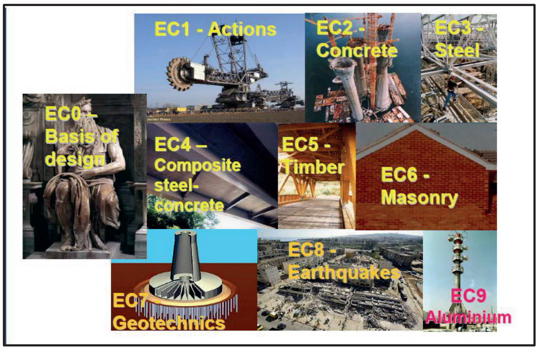


Figure 3. The Eurocode family [30]. EC0—*Basis of design*; EC1—*Actions*; EC2—*Concrete*; EC3—*Steel*; EC4—*Composite*; EC5—*Timber*; EC6—*Masonry*; EC7—*Geotechnical design*; EC8—*Earthquakes*; EC9—*Aluminum*.

A. ENV 1997-1 (Geotechnical designed code): It is includes nine sections, the topics of these sections are: *General*; *Basis of Geotechnical Design*; *Geotechnical Data*; *Supervision of Construction*, *Monitoring and Maintenance*; *Fill*, *Dewatering*, *Ground Improvement and Reinforcement*; *Spread Foundations*; *Pile Foundations*; *Retaining Structures*; *Embankments and Slopes*.

Three categories are important, when establishing geotechnical design requirements, they are the following [31]:

1. *Category* 1: The procedure is adequate only if there is no excavation under the water table. Structures are simple and based on experience and qualitative geotechnical investigations.

2. *Category* 2: Conventional types of structures and foundations are covered. Require quantitative geotechnical data and analysis to ensure that the fundamental requirements will be satisfied. Routine procedures for field and laboratory testing, design and execution may be used. Types of structures complying with geotechnical category are spread and raft foundations; piled foundations; walls and other structures retaining or supporting soil or water; excavations and ground anchors and other tie-back systems; bridge's piers and abutments and embankments and earthworks; tunnels in hard, non-fractured rock and not subjected to special water tightness or other requirements.

3. *Category* 3: This category includes structures or parts of structures, which are not following the limits of Geotechnical category (1 and 2). Structures involve abnormal risks, unusual or exceptionally difficult ground or loading conditions and those in highly seismic areas.

B. ENV 1997-2 (Design assisted by laboratory testing): It is determined primarily for geotechnical projects of category 2 (which is explained above). It also covers all the requirements for all laboratory tests such as classification, identification and description of soils; chemical testing; strength testing; Compaction and Permeability testing, etc. Furthermore, it includes classification, swelling and strength tests for rock's material. Furthermore, it includes classification, swelling and strength tests for rock's material as well as calibration for tests equipment's and all detailed information on tests and methods [32].

C. ENV 1997-3 (Design assisted by field testing): The third part of the geotechnical code explains the field testes principles and application rules. Field tests for soil and rocks, including Cone penetration and piezcone tests CPT (U), Pressuremeter test (PMT), Standard penetration test (SPT), Dynamic probing test (DP), Weight sounding test (WST), Field vane test (FVT), Flat dilatometer test (DMT), Rock dilatometer test (RDT), Plate loading test (PLT) and Groundwater measurements in soils and rock. Moreover, it explains the ways of sampling soil and rocks.

The three subjects of design, laboratory and field tests are related to each other as shown in **Figure 4** [33].

2) Basis of structural design

Eurocode EN1990 is explains the requirements and principles for safety, durability and serviceability for structures. The basic requirements of a structure are influences (serviceability) and actions (resistance, durability) are suitable for design purpose. The code includes *normative part*, and *informative part* which is for information purposes. The structural Eurocodes design is based on two limit states. They are the ultimate limit, and the serviceability limit states. The ultimate limit state requirements are subdivided into five broad categories as shown in **Table 5**. Each category has set of partial factors' values that are connected to each other's and must be added in corresponding design calculations, as shown in **Figure 5** [34] [35]:

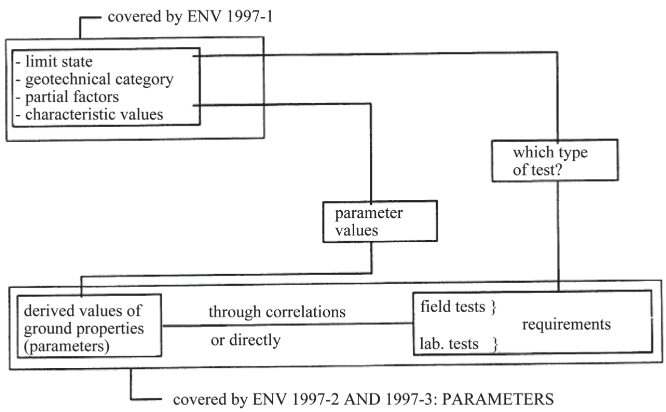


Figure 4. The link between ENV 1997-1 & ENV 1997-2 and 3.

Table 5. The categories of ultimate limit state [34].

Categories	Symbols	Description
Equilibrium	EQU	Loss of equilibrium of the structure or the ground.
Strength	STR	Excessive deformation or internal failure of the structure or structural elements, including piles, footings, walls, basement, etc.
Geotechnical	GEO	Failure or excessive deformation of the ground.
Uplift	UPL	Loss of equilibrium of the structure or the ground due to uplift by water pressure or other vertical actions.
Hydraulic heave	HYD	Failure by internal erosion and piping in the ground caused by hydraulic gradients.

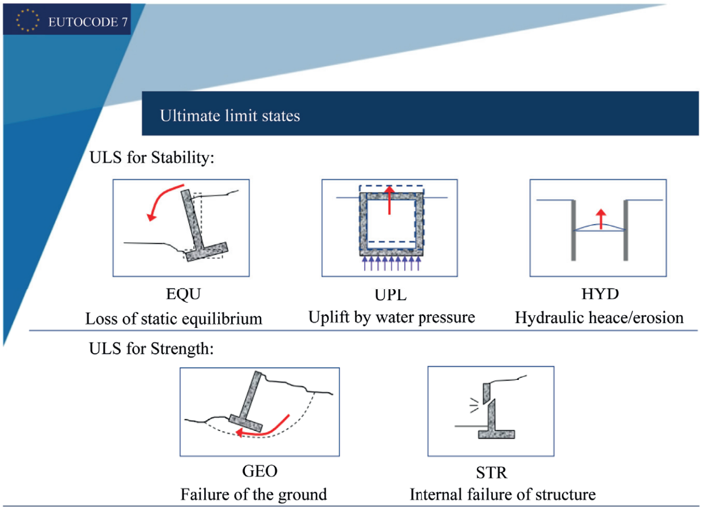


Figure 5. Ultimate limit states [35].

The calculations steps in foundation design are carried out according to STR and GEO are actions, materials and resistance. However, the dead and live loads in Eurocode have other names. The dead loads become permanent actions while the live loads become imposed actions, including snow, wind, etc. Load combinations called combinations of actions. EN 1991 is a part that explains the actions (permanent and imposed) on structures [36]. Part of the values that are related to safety matters in the Eurocode should be decided by the National Annex. The National Annex contains the information about the parameters left open in the Eurocode for national choice, which known as Nationally Determined Parameters (NDPs). These parameters are related to geographical or climatic conditions such as snow map or wind map or way of life. Therefore, different levels of protection may prevail at a local or regional level. The actions in Eurocodes are classified as [37]:

1. *Variation in time*: *Divided into permanent G*, *variable Q*, *and accidental A*.
2. *Origin*: *They are direct* (*e.g. forces*), *and indirect* (*e.g. temperature*).
3. *Spatial variation are fixed* (*e.g. self-weight*), *and free* (*e.g. predeformation*).
4. *Nature and/or structural response*: *They are static*, *and dynamic.*

EN 1997 covers two approaches for determining the combination of actions for STR ultimate limit state. For the first approach the following equation is to be used:

$$\sum_{j\geq 1}\gamma_{G,j}G_{K,j}+\gamma_p P+\gamma_{Q,1}Q_{K,1}+\sum_{i\geq 1}\gamma_{Q,1}\Psi_{0,i}Q_{K,I} \tag{1}$$

For the second approach is using the following equations are to be used:

$$\sum_{j\geq 1}\gamma_{G,j}G_{K,j}+\gamma_p P+\gamma_{Q,1}\Psi_{0,1}Q_{K,1}+\sum_{i\geq 1}\gamma_{Q,i}\Psi_{0,i}Q_{K,I} \tag{2}$$

$$\sum_{j\geq 1}\xi_j\gamma_{G,j}G_{K,j}+\gamma_p P+\gamma_{Q,1}Q_{K,1}+\sum_{i\geq 1}\gamma_{Q,i}\Psi_{0,i}Q_{K,I} \tag{3}$$

where: $\sum$ = Implied "the combined effect of".
Ψ_o = A combination factor.
ξ = A reduction factor for unfavorable permanent actions G.
γ_G = A partial factor for permanent actions.
γ_p = A partial factor for prestressing actions.
γ_Q = A partial factor for variable actions.
P = Represents actions due to prestressing.

The partial and combination factors values can be taken from the National Annex of EN 1997. Eurocode gives three approaches (DA1, DA2, and DA3) for determining the loads (**Table 6**). Using of these approaches depends on many factors related to loads or actions **A**, material's properties **M**, and resistance of soils **R**. These approaches are used to determine GEO & STR Ultimate Limit States as shows in **Table 6**.

Future of Eurocodes can be summarized [38]:

- New materials and/or techniques such as glass, carbon fibers and fiber reinforced polymers (FRP).
- New concepts and/or requirements. Basic works requirements are Mechanical resistance and stability, Safety in case of fire, Hygiene, health and the environment, Safety in use, Protection against noise, Energy economy and heat retention, and Sustainable use of natural resources (durability and recyclability of the construction work).
- New societal needs (assessment of existing structures).

3) Materials

Materials used in concrete must be suitable and not harmful ingredients. These materials are [39] [40]:

- Cement: General suitability establishing for common cement conforming to EN 197-1. Sulphate resisting Portland cement conforming to BS 4027:1996. Fly ash for concrete conforming to I.S. EN 450-1:2005.
- Aggregates must conform to EN 12620:2002. Maximum aggregates size usually limited to 20 mm, but they are depending on the particular application. Other types of aggregates called semi-inert such as filler aggregate conforming to EN 12620 and pigments conforming to EN 12878. Other types of aggregate like pozzolanic or latent hydraulic are established for fly ash, silica fume, and ground granulated blast furnace slag are conforming to EN 450; prEN 13263 and BS 6699:1992.
- Water: Water use for mixing and recycled from concrete production should conform to EN 1008:2002.
- Admixtures use must conform to EN 934-2:2000 (including Annex A).
- Reinforcing steel: The requirements for the properties of the reinforcement should conform to EN10080.

ACI code and Eurocode impose safety factor's loads as shown in **Table 7**.

3. Case Study

To find the best suitable foundation design to be used in Iraq and the differences when using the American and European codes, a Building model was designed and analyzed using STAAD Pro., and SAFE softwares for three locations (Mosul, Baghdad and Basrah). The combination loads used in the two softwares were for ACI and EC codes. The design of the building and foundation was done according to ACI and EC in the both softwares. The bearing capacities used in the softwares were obtained from field and laboratory tests done in three locations (Mosul southern, Baghdad in middle and Basrah in southern) of Iraq [41]. Results obtained from the two softwares are shown in **Table 8**. **Figures 6-9** show the bearing pressure distribution under the foundation for Baghdad location as an example.

Table 6. Equations given in Eurocode 7 for combining partial factors [34].

DA1 – for most situations
DA1.C1: A1 "+" M1 "+" R1
DA1.C2: A2 "+" M2 "+" R1
DA1 – for piles and anchors
DA1.C1: A1 "+" M1 "+" R1
DA1.C2: A2 "+" (M1 or M2) "+" R4
DA2 A1 "+" M1 "+" R2
DA3 (A1 or A2**) "+" M2 "+" R3*

*On structural actions; **On geotechnical actions.

Table 7. Comparison between international codes for strength design requirements.

Code/requirements	ACI	Eurocode (EC)
Dead load	1.2	1.35
Live load	1.6	1.5
Combination load	0.9; 1.6	0.7; 0.5

Table 8. Comparison between results using ACI and EC for bearing pressure in STAAD Pro. and SAFE softwares.

Results \ Locations	Mosul Northern of Iraq	Baghdad Middle of Iraq	Basrah Southern of Iraq
Average Base pressure from STAAD Pro., software using ACI code	99	87	81
Worst Base pressure from STAAD Pro., software using ACI code	75	90	77
Average Base pressure from STAAD Pro., software using EC code	102	111	100
Worst Base pressure from STAAD Pro., software using EC code	107	95	109
Average Base pressure from SAFE software using ACI code	100	95	81
Worst Base pressure from SAFE software using ACI code	92	79	96
Average Base pressure from SAFE software using EC code	110	100	90
Worst Base pressure from SAFE software using EC code	100	90	108

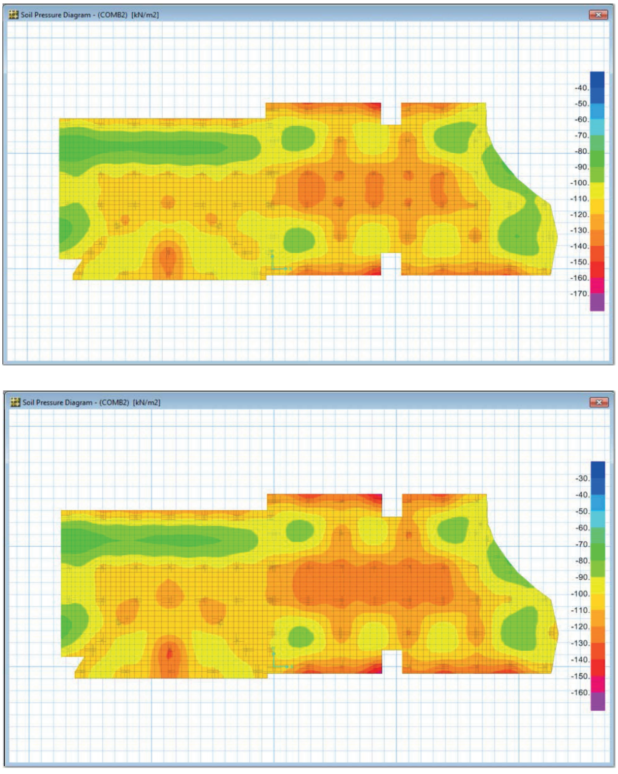


Figure 6. Bearing pressure distribution for average bearing capacity value from SAFE software for ACI and EC codes.

In all cases the design was done by used ACI and EC codes. The base pressure values under the foundation obtained from the two softwares for the two codes were very close. The foundation to be chosen according to the results tabulated in **Table 8**, for Mosul locations is spread or continuous depending on the both codes. In Baghdad locations the type of foundation to be chosen is spread and raft for the both codes. While, for Basrah locations the type of foundation to be chosen is raft and pile using both codes.

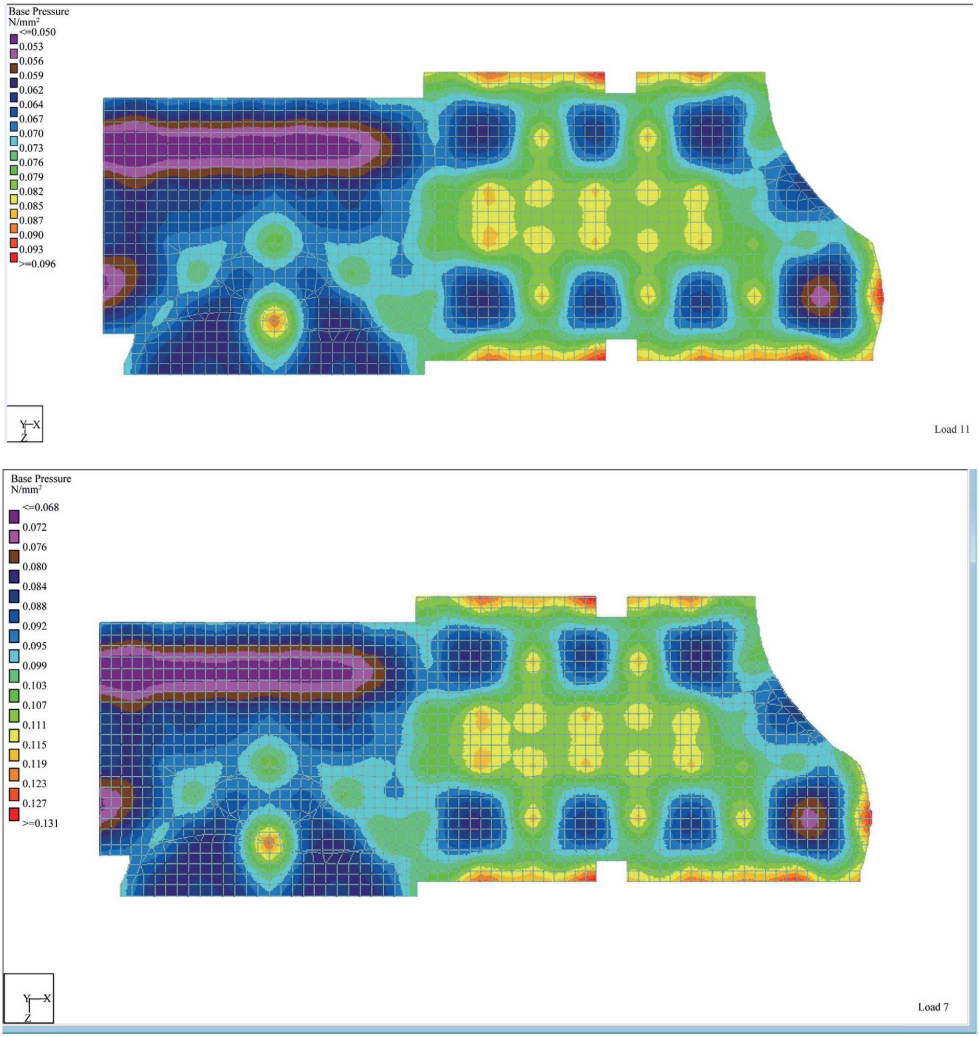


Figure 7. Bearing pressure distribution for average bearing capacity value from STAAD Pro. software for ACI and EC codes.

4. Suggested Code for IRAQ

In the eighties of the last century, an Iraqi code was suggested by the committee of Iraqi code/Ministry of planning. The code was based on the American and British codes. It was covering only the design and implementation of reinforce concrete constructions. In 1987, the code was suggested to be used optionally for two years [42]. The government did not adopt the code legally to be used. For that reason, Iraqi designers and engineers did not use the code, and were depending on ACI and British codes in their works for the last forty years [42]. In 2013, the Ministry of Construction and Housing adopted the Arabic codes. These codes are issued by the Council of Arab Ministers of Housing; during this year (2014), the Iraqi ministries started to adopt these codes in their buildings works. The codes includes ten parts for the soil investigations and foundation's design only, with other parts for different construction works such as structural steel and concrete, electrical, mechanical, etc. [43].

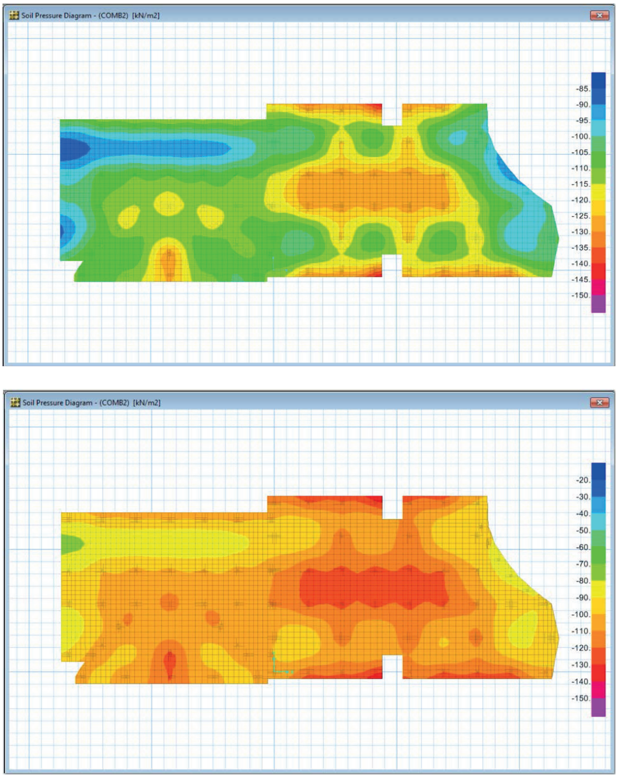


Figure 8. Bearing pressure distribution for worst bearing capacity value from SAFE software for ACI and EC codes.

4.1. Importance of Establishing Iraqi Code

The code is important to provide a requirement for safety and healthy buildings for the public. Moreover, codes present requirements to enhance the durability for existing buildings and implementing them in economic and high quality way.

The code should be cover all the requirements needed in the design and implementation of any construction such as buildings, bridges, dams, etc. Furthermore, it should cover the geotechnical requirements. These requirements are an important part in the code to ensure that the constructed of buildings will be implemented in a safe and suitable site. The code is to ensure safe, durable and economical buildings in different regions of Iraq. It is also important to make sure that the designers and engineers will cover the following points:

1. To choose the suitable design for a given site based on soil properties such as bearing capacity, shear strength, etc.
2. To perform suitable dimensions of foundation (depth & width) for a given load.
3. Selecting most suitable type of foundation based on building loads and type of soil.
4. Specifying a suitable mixture of concrete excavations (percent of gravel, sand, and cement).
5. Designing the most economical building based on unit price of materials used in construction (steel and concrete).

4.2. Outline Concerning Geotechnical Engineering Part of the Suggested Code for Iraq

Code is a legal document, which present all the requirements that should be considered during the design, con-

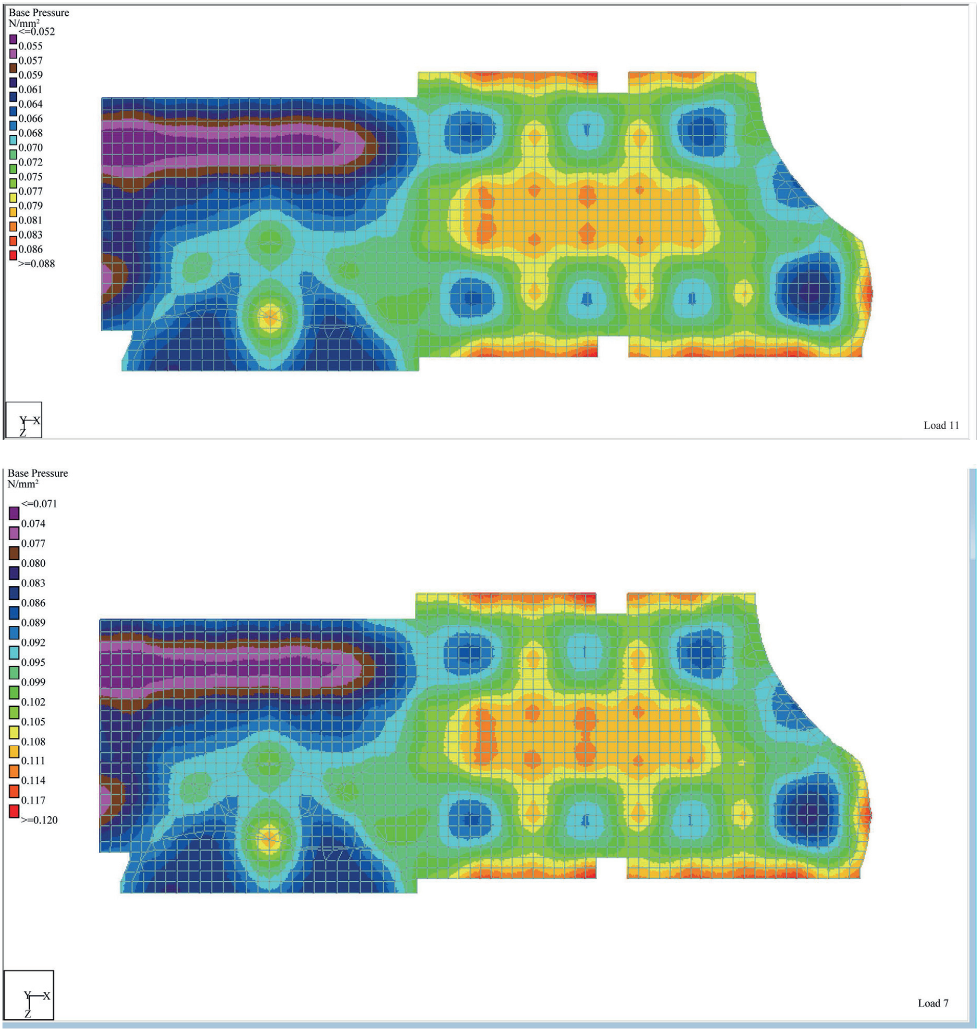


Figure 9. Bearing pressure distribution for worst bearing capacity value from STAAD Pro. software for ACI and EC codes.

struction, and maintenance of buildings. Soil is the most important factors that should be considered for the design for any construction. Defining soil properties is the main step in the design procedure of any structure. To present the basics of building code for Iraq, the following requirements should be considered:

1. Soil survey should be conducted for different regions of Iraq. This includes field tests and collecting, reviewing of the literature.
2. Based on the geology and soil properties, Iraq can be divided into three zones (north, middle, and south).
3. Exiting information about the soil in Iraq (e.g. Buringh, 1960) indicates that there are different types. It is suggested that in each zone suggested in 2 above different samples are to be collected and tested.
4. Field and laboratory tests are required for both disturbed and undisturbed soil samples. These tests are to identify important soil properties that can affect the foundation. **Table 9** below shows the required soil tests and the type of soil sample (disturbed or undisturbed) [44] [45].

Table 9. Types of tests to identify soil properties [44] [45].

Type of test	Sample type	Test location
Physical test: w/c γ_t, γ_d G_s	Disturbed	Laboratory
Atterberg limits: liquid limit, plastic limit	Disturbed	Laboratory
Grain size: sieve analysis, hydrometer	Disturbed	Laboratory
Chemical tests: total soluble salt, SO_3 salt, organic matters, gypsum, chloride	Disturbed	Laboratory
Swelling test	Undisturbed	Laboratory
Collapse test (CP%)	Undisturbed	Laboratory
Consolidation test (C_c, C_s, P_c)	Undisturbed	Laboratory
Unconfined compression test (C, ϕ)	Undisturbed	Laboratory
Direct shear test (C, ϕ)	Undisturbed	Laboratory
Triaxial shear test (C, ϕ)	Undisturbed	Laboratory
Van shear test	Undisturbed	Field
Standard penetration test (SPT)	Disturbed	Field

5. General soil map for the main regions of Iraq to be prepared that can be used as a guide to identify the soil types and different properties of soil. This will help in foundation's design of different buildings at the studied sites.

5. Discussion

Building codes are legal laws and standards to provide minimum requirements for health, safety and welfare to the public. The historical review presented different disasters and accidents that made the codes existed in different countries. Hammurabi code was the first to put regulations for safe constructions.

Most of the codes which were defined and used in the Arabic countries depend on British and Germany's standards, or American codes.

Saudi Arabian had its own code since (2008). It is one of the best National codes. The code includes all the requirements for the design and construction of modern buildings and materials. It also, includes requirements for the existing buildings. All these requirements were depending on the international building code (IBC) and American concrete institute (ACI). It includes some national requirements such as type of Saudi soil and local maps for earthquake. Furthermore, it collects requirements of modern buildings and materials.

International codes (ACI and Eurocode) cover all the requirements in details. Eurocode is better because it covers all the requirements for design and constructions for different types of building modern materials as well as the ordinary materials (concrete, steel, wood, etc.). Moreover, it contains national annex (national determined parameters NDPs).

Eurocodes became known since 1990. Before that, many countries around the world were familiar with British code and standards, but now they are part of the EC. Now, eighteen European countries adopted the Eurocodes to be used in the design and implementation instead of their national code. EC using three approaches in the design. These are: materials properties, action loads, and soil resistance. Later, Some Arabic countries tried to harmonize their code with EC codes like Egypt. EC codes have adopted new materials and techniques. European countries gave flexibility to use local national standards to obtain suitable and economical buildings.

There is no special code in Iraq for the design and construction of building. For that reason, engineers and designers are depending on different codes and standards such as American and/or British. In the case study, both the ACI and EC codes were used for the building model design and analysis by two softwares (STAAD Pro. and SAFE). The results obtained from the two softwares for the bearing pressure for three locations in Iraq shown in **Table 7** were almost the same for both codes. According to the results obtained, spread or continuous are recommended for Mosul locations. Spread and raft foundation is recommended for Baghdad locations, while raft and pile is recommended for Basrah locations.

6. Conclusions

The first code that defined the regulations for safe of buildings in the history was Hammurabi code. Saudi Arabian code is the best national code within the Middle East because it includes all the requirements for the design and construction of modern buildings and materials as well as the requirements needed for the existing buildings. Moreover, it includes especial parts for Saudi conditions such as soil and earthquake maps.

Eurocode covers all the requirements for design and constructions for different types of building and modern materials as well as the ordinary materials (concrete, steel, wood, etc.). Furthermore, it contains national annex-national determined parameters NDPs. For these reasons the Eurocode is the best international code. Also, the code includes the British code and standards which are familiar to many countries around the world.

According to the case study performed on Iraq, the designers are recommended to use either ACI or Eurocode. In the designed model, both codes (ACI and EC codes) were used for determining the bearing pressure for three locations (Mosul, Baghdad and Basrah) in Iraq. The results show that the values of bearing pressure in the both codes are similar. Moreover, the type of foundation to be chosen for Mosul location is spread or continuous. For Baghdad location the suitable type is raft while for Basrah location the choice is raft and piles. It is believed that Iraqi Government should establish its own code to provide minimum requirements for the safety and economy for the buildings that suites the local environment in Iraq.

References

[1] Natural Hazard Mitigation Insights (2005) The Benefits of Statewide Building Codes. A Publication of the Institute for Business & Home Safety. http://scd.hawaii.gov/HazMitPlan/chapter_6_appK.pdf

[2] Building Code (2013) Chapter 14. http://www.co.ozaukee.wi.us/DocumentCenter/Home/view/315

[3] Cote, A.E. and Grant, C.C. (2008) Codes and Standards for the Built Environment. Chapter 3, Section 1, 51-66. http://www.nfpa.org/~/media/files/forms%20and%20premiums/fire%20protection%20handbook/codesfph.pdf

[4] Shkoukani, H.T. (1993) General Rules for Design of Reinforced Concrete Structures According to EUROCODE No.2 Comparative with the ACI. *The First Palestinian Engineering Conference*, Nablus, November 1993, 239-255. http://scholar.najah.edu/sites/default/files/conference-paper/general-rules-design-reinforced-concrete-structures-according-eurocode-no2-comparative-aci-code.pdf

[5] Jawad, A.A.H. (2006) Strength Design Requirements of ACI-318M-02 Code, BS8110, and Eurocode 2 for Structural Concrete: A Comparative Study. *Journal of Engineering and Development*, **10**, 136-150.

[6] Landingin, J., Rodirigues, H., Varum, H., Arede, A. and Costa, A. (2013) Comparative Analysis of RC Irregular Buildings Designed According to Different Seismic Design Codes. *The Open Construction and Building Technology Journal*, **7**, 221-229. http://dx.doi.org/10.2174/1874836801307010221

[7] Yeager, M. (2013) History of Building Codes, Buyer's Choice Home Inspection, Thoroughness and Accuracy Matters. www.buyerschoiceinspections.com/history-of-building-codes

[8] Salama, A.E. (2006) Egyptian Codes for Design and Construction of Buildings. *Building the Future in the Euro-Mediterranean Area*, *Workshop*, 27-29 November 2006, Varese. http://elsa.jrc.ec.europa.eu/eurocodes2006/pdf/pres210.pdf

[9] The Standing Committee of the Egyptian Code (2001) Egyptian Code for the Design and Implementation of Concrete Structures. Housing & Building National Research Center, Al Tjaria Press, Cairo.

[10] The Standing Committee of the Egyptian Code (2007) Egyptian Code/ for Soil Mechanics and Design and Implementation of the Foundations. Housing & Building National Research Center, Al Tjaria press, Cairo.

[11] Nassif, S.I. (2011) Evaluating the Values of Some Factors and Seismic Requirements. Given by the Seismic Syrian Code, Damascus University, College of Civil Engineer. http://www.geocities.ws/mazen_alhalabi/Naseef.pdf

[12] Syrian Engineers Union (2004) Syrian Arab Code for the Design and Implementation of Reinforced Concrete Structures. 3rd Edition, Engineers Union, Damascus.

[13] NERC (2007) Building Thermal Insulation Code in Syria. Engineers Union, Damascus.

[14] Syrian Engineers Union (2008) Appendix 5 for the Syrian Arab Code for Foundations, Implementation of Reinforced Concrete Structures-Loads on Buildings. Engineers Union, Damascus.

[15] Syrian Engineers Union (2006) Appendix 1 for the Syrian Arab Code for the Design and Implementation of Reinforced Concrete Structures-Loads on Buildings. Engineers Union, Damascus.

[16] Saudi Building Code National Committee (2007) Saudi Building Code. 1st Edition, Saudi Arabia. http://faculty.ksu.edu.sa/ashuraim/Documents/SBC306C_FEB_2008_FINAL.pdf

[17] Ghosh, S.K. (2013) The Concrete Provisions of the 2012 IBC and ACI318-11. *Building Safety Journal*, 31-35. http://www.skghoshassociates.com/sk_publication/Ghosh_article_Feb_BSJ.pdf

[18] FEMA (2001) What Is a Building Code. Federal Emergency Management Agency & Central United States for Earthquake Consortium. www.cusec.org/publications/mitigation/whatearebuildingcodes.pdf

[19] McFann, G.J. (2013) The History of Building Codes. TPREIA. www.tpreia.com/historyofcodes.html

[20] ACI Committee 318-08 (2008) Building Code Requirements for Structural Concrete and Commentary. American Concrete Institute, Farmington Hills.

[21] American Concrete Institute (2013) History of ACI. www.concrete.org/historyofACI/ACI.pdf

[22] Stehly, R. (2009) ACI 318-08, Requirements for Structural Concrete. http://www.concrete.org/Chapters/GetChapterDocument.aspx?DocID=53344

[23] Nowak, A.S. and Rakoczy, A.M. (2007) Reliability-Based Calibration of Design Code for Concrete Structures (ACI 318). University of Nebraska-Lincoln. www.ibracon.org.br/eventos/54cbc/cobertura/ACIcalib10-10-12.pdf

[24] ACI Committee (2011) Building Code Requirements for Structural Concrete and Commentary. American Concrete Institute, Farmington Hills. www.concrete.org210.42.35.80/G2S/ewebeditor/uploadfile/20110806224616634.pdf

[25] International Code Council (2012) 2009 International Building Code. First Printing, Dallas. https://law.resource.org/pub/us/code/ibr/icc.ibc.2009.pdf

[26] Assakkaf, I. (2002) Rectangular R/C Concrete Beams: Tension Steel Only, Introduction to Structural Design. Department of Civil and Environmental Engineering, University of Maryland, College Park. www.assakkaf.com/courses/ENCE355/Luctures/part1/chapter2a.pdf

[27] Calgaro, J.A. (2006) The Eurocodes History and Present. Workshop of Building the Future in the Euro-Mediterranean Area, 27-29 November 2006, Varese. http://elsa.jrc.ec.europa.eu/eurocodes2006/pdf/pres090.pdf

[28] SSBond, A. and Harries, A. (2008) Decoding Eurocode 7—Basis of Structural Design. Taylor & Francis, London. www.decodingeurocode7.com

[29] Bound, A.J., Brooker, O., Harris, A.J., *et al*. (2006) How to Design Concrete Structures Using Eurocode 2. The Concrete Center, Michael Burbridge Ltd., Maidenhead. http://www.civilworx.com/Pdfs/How%20to%20design%20concrete%20structures%20using%20Eurocode%202.pdf

[30] Calgaro, J.A. (2008) Eurocodes a Tool for Building Safety and Reliability Assessment. EU-Russia Cooperation on Standardization for Construction, Moscow. http://eurocodes.jrc.ec.europa.eu/doc/Moscow08/Moscow08_9_Calgaro2.pdf

[31] European Committee for Standardization, NVE 1997-1 (1999) Geotechnical Design-Part1: General Rules. CEN National Members, Brussels.

[32] European Committee for Standardization, NVE 1997-3 (1999) Geotechnical Design—Part 2: Design Assisted by Field Testing. CEN National Members, Brussels.

[33] European Committee for Standardization, NVE 1997-3 (1999) Geotechnical Design—Part 3: Design Assisted by Field Testing. CEN National Members, Brussels.

[34] Orr, T. (2010) The Concepts of Eurocode 7 for Harmonized Geotechnical Design in Europe. Trinity College, Dublin. http://doktoranci.pwr.wroc.pl/pliki/pokl/orr1.pdf

[35] Smith, I. (2013) Retaining Walls and Geotechnical Design to Eurocode 7. Edinburgh Napier University. www.ice.org.uk/../retaining-walls-and-geotechnicaldesign-to-eurocde

[36] NSC (2008) Loads and ULS Load Combinations to the Eurocodes. www.steelconstruction.com/wp/wp-content/uploads/digi/0803NSCmar08/index.html/30/

[37] Formichi, P. (2008) Eurocode 1-Actions on Building Structures. EU-Russia Cooperation on Standardization for Construction, Moscow. http://eurocodes.jrc.ec.europa.eu/doc/Moscow08/Moscow08-9-Formichi.pdf

[38] Calgaro, J.A. (2008) The Eurocodes General Overview—Past, Present and Future. EU-Russia Cooperation on Standardization for Construction, Moscow. www.setra.equipement.gouv.fr

[39] EFNARC (2002) Specification and Guidelines for Self-Compacting Concrete. Association House, Farnham. www.efnarc.org

[40] European Committee for Standardization ENV 1992-1-1 (2004) Eurocode 2: Design of Concrete Structures-Part 1-1: General Rules and Rules for Buildings. CEN national Members, Cairo.

[41] Al-Taie, E., Al-Ansari, N. and Knutsson, S. (2014) Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i. *Engineering*, **6**, 292-303. http://dx.doi.org/10.4236/eng.2014.66033

[42] Code Committee (1987) Iraqi Building Code Requirements for Reinforced/ CODE 1/87. 1st Edition, Concrete Building Research Center, Scientific Research Council, Ishbeelia Press, Baghdad.

[43] Council of Ministries of Housing and Construction Arabs (2003) United Arab Codes for the Design and Implementation of Buildings, League of Arab States. House of the Republic of Journalism, Cairo.

[44] Lambe, T.W. (1951) Soil Testing for Engineers. John Wiley & Sons, Inc., New York.

[45] Das, B.M. (2009) Soil Machines Laboratory Manual. 7th Edition, Oxford University Press, New York.

Paper VII

Journal of Earth Sciences and Geotechnical Engineering, vol. 4, no. 4, 2014, 35-52
ISSN: 1792-9040 (print), 1792-9660 (online)
Scienpress Ltd, 2014

Bearing Capacity Affecting the Design of Shallow Foundation in Various Regions of Iraq Using SAP200 & SAFE softwares

Entidhar Al-Taie[1], Nadhir Al-Ansari[2], Tarek Edrees Saaed[3] and Sven Knutsson[4]

Abstract

Bearing pressure is the load per unit area along the foundation bottom. The value of bearing pressure can be obtained from soil exploration. In this research, three sites in Iraq were tested (Mosul at north, Baghdad at middle and Basrah at south) for the best type of foundation to be chosen. Seventy nine samples were taken from twenty three boreholes drilled to a depth ranging from 1to 24m, from various sites for the three sites. Samples were tested for their size; Atterberg limits; direct shear; unconfined compression; consolidation and SPT tests. The results showed that the nature of soil in Mosul was generally were silty clay to clay (in some areas silt or sand) with high to very high plasticity. In Baghdad, it was loam clay, silty clay, and in some areas silt. Its plasticity range was medium to high and non-plastic in few sites. For Basrah, the soil type was clay loam and in many places was sand or silt. The value of plasticity was medium. The average and the worst values of bearing capacity were: 177KN/m^2 and 77KN/m^2 for Mosul; 125 KN/m^2 and 68 KN/m^2 for Baghdad; and 84KN/m^2 and 24 KN/m^2 for Basrah. These values were used in a computer model (SAP2000 and SAFE softwares) to find the best suitable foundation in each site. The model suggests that spread or continuous and raft (if basement is used for building with many floors) are suitable for Mosul. For Baghdad, spread and raft type of foundations are suitable. While, for Basrah, raft foundation type are to be used in some areas where building should be less than three floors and for other areas, deep foundation (piles or pier) can only to be used.

Keywords: Base pressure, soil, bearing capacity, SAFE program, SPT tests.

[1]Lulea University of Technology, 97187 Lulea, Sweden.
[2]Lulea University of Technology, 97187 Lulea, Sweden.
[3]Lulea University of Technology, 97187 Lulea, Sweden.
[4]Lulea University of Technology, 97187 Lulea, Sweden.

1 Introduction

The interface between foundation and soil supports is defined by the most essential parameter which is the bearing pressure. It is the contact force per unit area along the bottom of the foundation [1]. The force acting between the foundation and the soil must be equal to the integral of the bearing pressure over the base area of shallow foundation. Bearing pressure is not necessarily distributed equally. Filed measurements and analytical studies mention that many factors define the actual distribution of the bearing pressure such as eccentricity of the added load; volume of the applied moment (if any); foundation structural rigidity; the soil stress-strain properties and bottom roughness of the foundation. Bearing pressure distribution along the shallow foundations base makes foundation exposure to concentric vertical loads [1] (Figure 1).

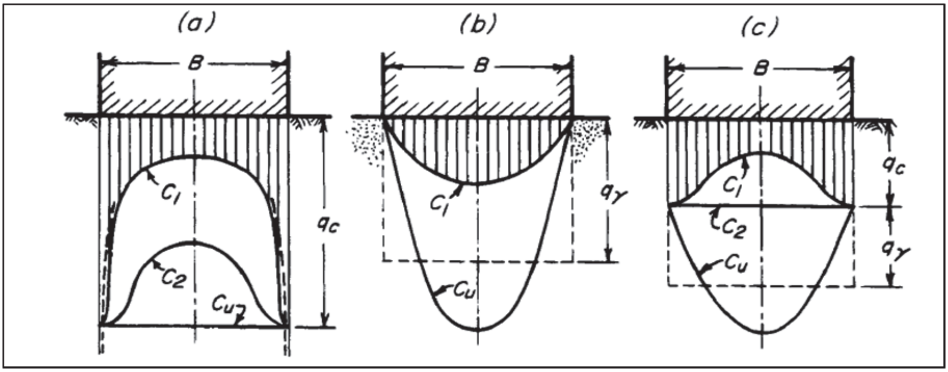


Figure 1: Distribution of contact pressure on base of smooth rigid footing supported by (a) Real, elastic material; (b) Cohesionless soil; (c) soil having intermediate characteristics.

Curve c_u refers to contact pressure at the loading of footing to ultimate value [2].
Generally, each structure (such as buildings, dams, bridges, towers, etc.) has two parts; the part above the ground level which is referred to as the superstructure; while, the lower part is the foundations supported by soil below. Soil is also a foundation for the structure and affords the entire load coming from above. For that, soil should be defined before any design process, starting with site investigations to define the types and properties (mechanicals and chemicals) of the soil [3 and 4]. Soil is non-homogeneous material. It does not have a unique stress-strain relationship and its behavior is affected by pressure, time, environment, and many other parameters. Soil below the ground level cannot prototype its behavior because it cannot be seen entirety and must be estimated through small samples taken from random locations [4]. Soil properties in each location are defined by various methods such as geology of the area, topography, and soil exploration (disturbed and undisturbed sampling) or the geotechnical soil properties and nature of soil layers for any project site. The aim of these tests is not only to define the soil types and properties. The aim is to define the bearing capacity parameters (angle of internal friction **φ**; cohesion **c**) that will specify the allowable stress to prevent shear failure in soil because soil is considered as heterogeneous material. Moreover, the tests of soil will define the active zone. Active zone is the soil layers which are near the ground level and its water content state in continuous change depending on evaporation and wetting [5].

Bearing capacity of soil under foundations depends on different factors such as shear strength, cohesion; unit weight of soil, etc. Foundation design must achieve two criteria. It should be safe against overall shear failure and don't exceed the allowable settlement of the soil that supports it [6]. Figure 2, shows the relationship between the allowable bearing capacity and the width of foundation.
Earlier work done by Al-Taie et al. (2013) was included the use of a hypothetical building model designed and analyzed by STAAD Pro. program for three locations (Mosul, Baghdad and Basrah) in Iraq. The work was done to find the best type of foundation to be used in each location.

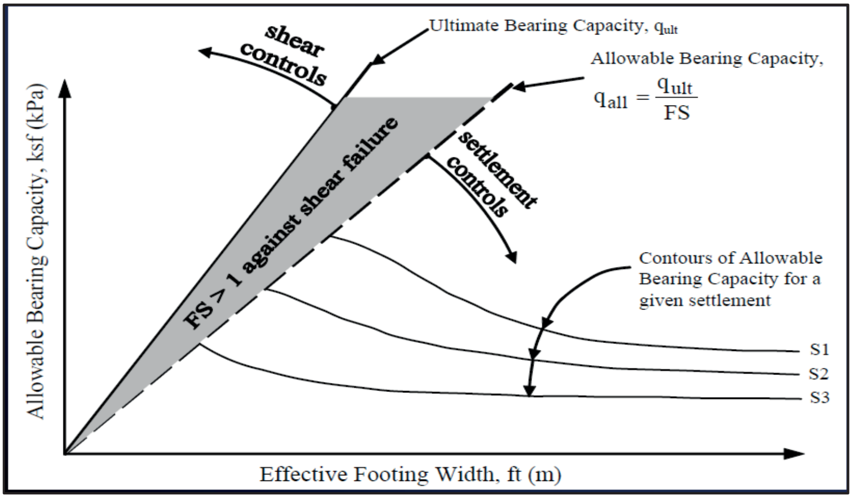


Figure 2: Relation between the allowable bearing capacity and the width of foundation [7].

In this research, a design and analysis of building model using SAP2000 and SAFE programs for three regions (Mosul in the north, Baghdad in the middle and Basrah in south of Iraq) had been undertaken. The bearing capacity used in the design will be calculated using general bearing capacity equation by Hansen [8], and the parameters used in the equation were taken from soil samples at different locations in the three regions of Iraq. Samples were tested in the field and laboratory to obtain the shear parameters. This was used to determine the best type of foundation to be chosen for the three regions.

2 Methodology

2.1 Soil Exploration

Soil exploration was carried out through samples collected from the three different regions of Iraq. The soil nature of these locations can be summarized as follows:

2.1.1 Mosul region

Mosul soils include different types (figure 3). Some of these types can cause engineering problems (collapse, swelling, soluble in gypsum, volumetric change; etc.). Large parts of Mosul area are covered with clay of different colors (light brown, reddish brown and light green). This clay belongs to the lower Fars Formation (Middle Miocene) and has been deposited in a closed basin. Most of the clay soil of Mosul is an expansive clayey type that had affected several buildings in the center of Mosul city. The buildings in the city were normal and their foundation is within the active zone (0.5 - 7.0 m). The volumetric change into soil of the active zone is due to the change of its water content, which causes the swelling of soil [5; 9 and 10].

2.1.2 Baghdad region

This region is part of the Mesopotamia plain and characterized by great variations in the land use and high population density (figure 4). Quaternary sediments covering the Mesopotamia plain are of Pleistocene to Holocene in age. Its thickness varies from few meters up to 180m. Flood plain deposits are of fluvial nature brought by the Tigris and Euphrates Rivers. The prevalent component of soil in this region is silt and clay [11 and 12].

2.1.3 Basrah region

This region is part of the Lower Mesopotamian basin where Quaternary sediments are deposited (figure 5). Basrah region can be classified into two parts. The eastern part, constitute surficial fine-grained deposits and its thickness is 14m. While, the western part is characterized by coarse-grained sediments that are part of an alluvial fan and sandy Dibdiba Formation deposits. The sediments of Dibdiba Formation gradually changed from marine to river sediments. The upper parts are characterized by hard clay followed by very dense sandy layers having significant bearing capacity. In general, the ground surface of Basrah city is flat and its soil consist of silt and clay with little amount of sand. The sediments at depth 1-18.5 m are clayey silt, while the sediment at depth 21m are sandy silt and at 24m depth are sand [13 and 14].

2.1.4 Sampling

Disturbed and undisturbed samples were taken from nine boreholes in different locations in Mosul region northern Iraq, (figure 3).Three to four samples were taken from each borehole drilled to depth 3- 10m.

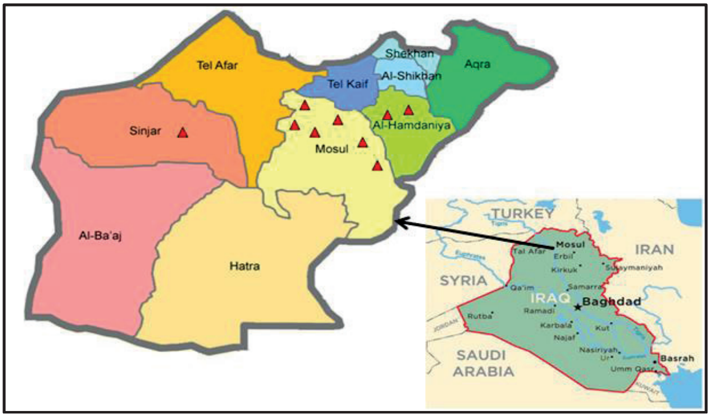


Figure 3: Mosul region northern Iraq map.

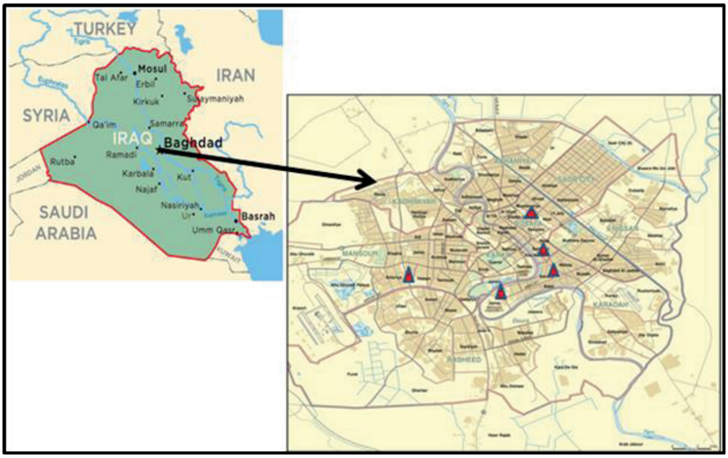


Figure 4: Baghdad region center Iraq map.

At Baghdad, samples were collected from five (figure 4). Three samples were taken from each borehole drilled to a depth of 10 - 13m.

In Basrah, samples were taken from nine boreholes in different locations (figure 5). Three to four samples were taken from each borehole drilled to a depth of 10-24 m.

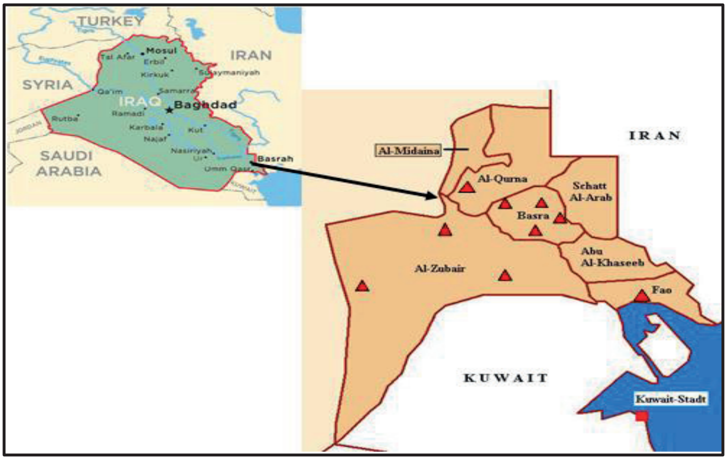


Figure 5: Basrah region in southern Iraq map.

2.2 Samples Tests

Field and laboratory tests were performed on the samples collected from the three Mosul, Baghdad, and Basrah. The purpose of these tests was to classify and define the mechanical properties of subsoil. All tests were done according to ASTM, AASHTO and BS standards [15 and 16] as follows:

- Sieving was performed using sieve numbers 4, 10, 20, 40, 60, 140 and 200 to classify the subsoil for each sample taken from different locations. The outcome was to find out the soil grains size distribution. Hydrometer grain size analysis was used for the part of soil particles which were finer than sieve No.200.
- Atterberg limits were used for the identification and description of subsoil conditions (ID). The test was done to obtain the liquid (LL), and plastic (LP) limits. The difference between them is the plastic index (PI).
- Strength parameters were obtained from two types of tests. The direct shear and the unconfined compression tests. The samples used for these tests should be undisturbed type. Finally, the results were cohesion (c), the angle of internal friction (ϕ^o) of soil and undrained compressive strength (q_u).
- Consolidation soil test was performed for undisturbed samples to obtain compression index (C_c), swelling index (C_s), pressure (P), and the preconsolidation pressure (P_c).

2.3 Calculations of the Bearing Capacity

The calculations of ultimate bearing capacity (q_{ult}) were performed using Hansen general equation [6] depending on the parameters obtained from the direct shear test:

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma \quad (1)$$

where: c: cohesion of soil, kPa.
q: effective stress at the bottom level of foundation, kPa.
B: width of foundation, m.

γ: unit weight of soil, *KN/m³*.
N_c, N_q, N_γ: bearing capacity factors, (their values can take from especial tables).
S_c, S_q, S_γ: shape factors.
d_c, d_q, d_γ: depth factors.
i_c, i_q, i_γ: load inclination factors.
g_c, g_q, g_γ: ground inclination factors.
b_c, b_q, b_γ: base inclination factors.
The depth and shape factors values can be calculated from the following equations:

$$K = D/_B \ldots\ldots.For\ D/_B \leq 1$$

Equations for calculated depth factors are:

$$d_c = 1.0 + 0.4k$$
$$d_q = 1.0 + 2tan\emptyset(1 - sin\emptyset)2k$$
$$d_\gamma = 1.0$$

Equations for calculated shape factors

$$S_c = 1.0 + N_q.B/_{N_c}.L$$
$$S_q = 1.0 + B/_L\,sin\emptyset \ldots\ldots\ldots for\ all\ \emptyset$$
$$S_\gamma = 1.0 - 0.4\,B/_L \ldots\ldots\ldots for\ B/_L\ \geq 0.6$$

In some locations in Baghdad and Basrah the calculations of ultimate bearing capacity depended on the unconfined compression strength (q_u) obtained from unconfined compression test and was used to calculate the undrained cohesion (C_u) as follow [17]:

$$c_u = \frac{1}{2}q_u \qquad (2)$$

Standard penetration test (SPT) was used in some locations in Basrah to calculate the bearing capacity value. Numbers of blows identify the compression strength (q_u) value depending on the correlation as shown in table 1. This correlation is quite useful when according to the soil conditions [18].

Table 1: Relationship between N_{cor} and q_u [18].

Consistency	$\mathbf{N_{cor}}$	$\mathbf{q_u}$ **, KPa**
Very Soft	0-2	<25
Soft	2-4	25-50
Medium	4-8	50-100
Stiff	8-15	100-200
Very Stiff	15-30	200-400
Hard	> 30	>400

Where: $\mathbf{q_u}$ is the unconfined compressive strength.
$\mathbf{N_{cor}}$ is the correction blow of SPT.

2.4 Results

The results of field and laboratory tests and the calculations of bearing capacity for Mosul, Baghdad, and Basrah are shown in table 2.

- Atterberg limits results included the LL, PL, and PI for different locations in the three regions. The results showed that the soil in Mosul region is between silty clay to clay with high to very high plasticity and in some areas contain sand or silt. In Baghdad region, the results showed that the soil is loam clay and silty clay, and in some areas contain silt. Range of plasticity was between medium to high and non-plastic in few sites. For Basrah region, the value of plasticity was medium and the soil type is clay loam and in many places it contains silt or sand.
- The strength parameters values for angle of internal friction **φ**, cohesion of soil **c,** and undrained compressive strength $\mathbf{q_u}$ were obtained from direct shear and unconfined compression tests.

Table 2: Results obtained from field and laboratory tests.

Parameters obtained from field and laboratory tests	Locations		
	Mosul	Baghdad	Basrah
Atterberg Limits:			
Liquid limit(L.L)	43-54	34-53	37-45.6
Plastic limit (P.L) %	22-26	19-30	21.33-31.9
Plastic index (P.I) %	17-30	15-29	11-18
Unit weight (γ) KN/m^3	15.7-19.7	14.4-20.31	15-20
Direct shear test:			
Angle of internal friction	15-28	-	31-33
Cohesion (C) KPa	0-40	-	0-4
Consolidation test:			
Initial void ratio (e_o)	0.558-0.767	0.647-0.769	0.72-0.90
Compression index	0.065-0.28	0.156-0.22	0.186-0.267
Swelling index (C_s)	0.11-0.156	0.010-0.054	0.028-0.090
Preconsolidation pressure (P_c) KPa	70-150	95-165	90-135
Unconfined test:			
unconfined compression strength (q_u) KPa	-	76-370.6	24-125
SPT test: q_u KPa	-	-	24

- Using the consolidation test, the initial void ratio $\mathbf{e_o}$, compression index $\mathbf{C_c}$, swelling index $\mathbf{C_s}$, and preconsolidation pressure $\mathbf{P_c}$ were obtained. These values were used to calculate the settlement.
- In some locations in Basrah, SPT test was used to obtain the $\mathbf{q_u}$ value.
- Bearing capacity values were obtained using the general bearing capacity equation. The results are shown in figures 6, 7 and 8 for Mosul, Baghdad, and Basrah respectively.

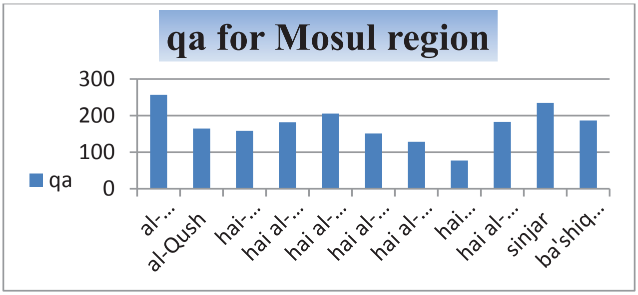


Figure 6: Results of Bearing Capacity for Mosul.

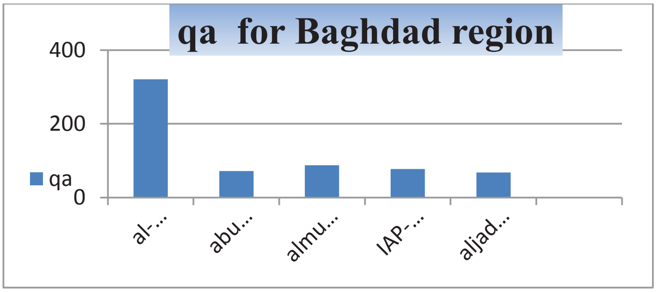


Figure 7: Results of Bearing Capacity for Baghdad

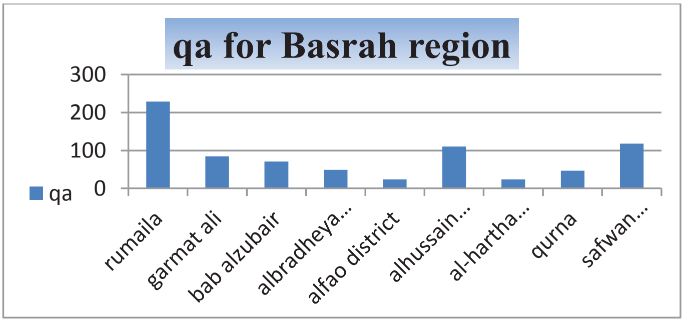


Figure 8: Results of Bearing Capacity for Basrah.

2.5 Computer modeling

The model of study was designed and analyzed using two computer programs. These programs were SAP2000 (Structural Analysis Program, version 16) and SAFE (Slab Analysis Finite Element) software for structural and foundation design and analysis. SAP2000 is a program used to design general structures such as buildings, dams, towers, stadium; etc. It has advantages such as powerful and completely integrated design program for concrete, steel, cold formed steel, and aluminum. The concrete design for frame members includes the calculation of the amount of reinforcing steel required. The program includes a wide variety of national and international design codes. Moreover, It has unlimited analysis capabilities, time-history, a complete range of finite elements analysis options and static nonlinear analysis. The program has a capability of export and import for other popular drafting and design programs as well [19 and 20]. SAFE is finite element software. It has many capabilities such as strong graphic tools for drawing various shapes and patterns, system of mesh generator, different load combinations are created, and the capability of presenting the loading states by 3D animation. The variety of outputs given by the software can be used to study the behavior of loads and deformations. SAFE is a sophisticated program for concrete slab\ beam and basement\ foundation systems. Moreover, the program has the capability to import and export models and design from other programs [21 and 22]. General steps were used in the design and analysis of any structure and foundation using SAP2000 and SAFE, are as follow [23]:

- Creating a model or modifying it, which numerically defines the geometry, loading, properties, and analysis parameters for the structure.
- Executing an analysis of the model.
- Reviewing the results of the analysis.
- Checking and optimizing the design of the model.
- Mouse over diagram shown instantaneous values.

The results to be obtained from both programs are of different types depending on the case studied or the problem to be solved.

In this study a building model was designed and the structure of the building was analyzed using SAP2000 software. The structure was of two floors of 25*60m dimensions with 3m as the height for each floor.

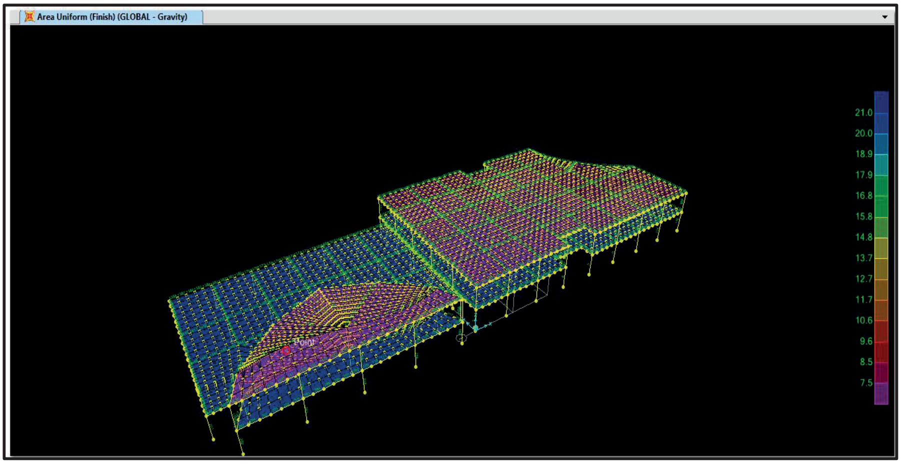


Figure 9: The structure of the building in SAP2000 program.

The model was loaded with dead and live loads of 29.5 KN/m^2 and 8 KN/m^2 respectively. ACI code was used in the design [24]. The model was analyzed to check the deformations for the columns and slabs (figure 9).

The structure model was exported to SAFE software with all loads on each column. In SAFE program, the raft foundation for the building was designed. The design parameters used were the dead load 25 KN/m^2, as well as the live load. The load combination was used according to ACI code [24] as follows:

$$1.2DL + 1.6LL \tag{3}$$

Where: DL is the dead load.
LL is the live load.

The building model was applied in the three regions (Mosul, Baghdad, and Basrah). The calculated bearing capacity (in section 2.3) for each location was used twice. The first using the average value and then the worst values. The results obtained from the program were illustrated in figures 10 to 15.
The results of the average bearing capacity values for Mosul are shown in figure 10. It indicates that the base pressure under the foundation ranges from 70 to110 KN/m^2. These values were less than the calculated value (177KN/m^2).

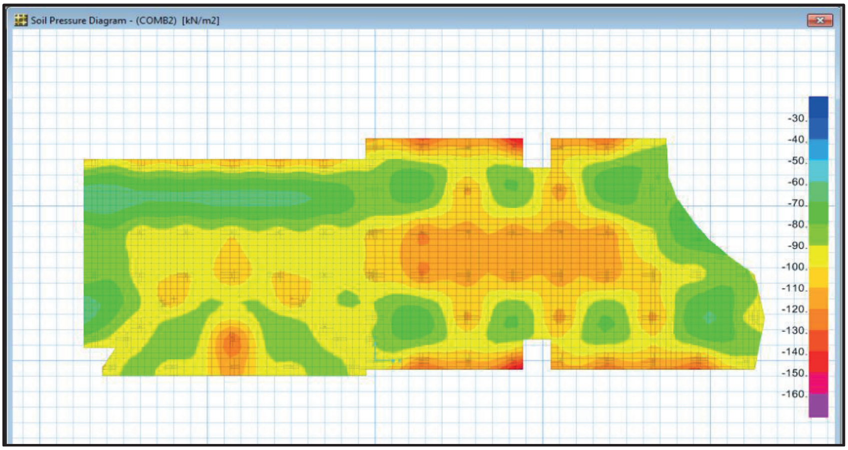


Figure 10: Average bearing capacity obtained distribution of base pressure for Mosul.

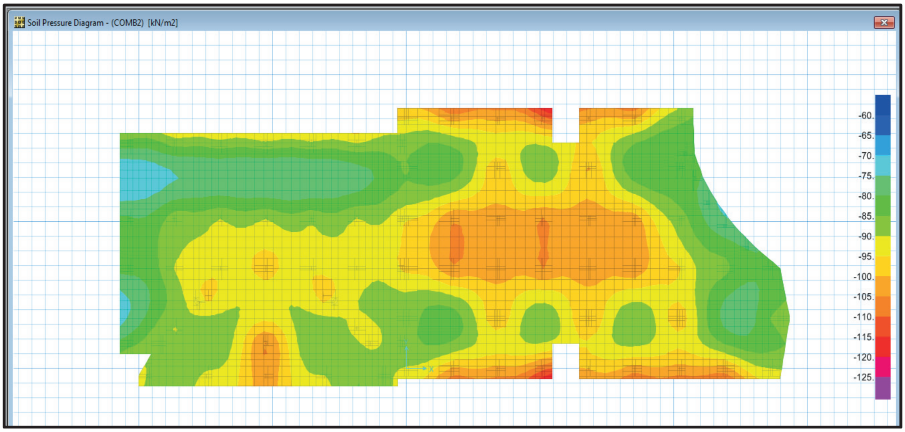


Figure 11: Worst bearing capacity obtained distribution of base pressure for Mosul.

The worst value of bearing capacity used for Mosul region is shown in figure 11. The range of base pressure under the foundation was from 70 to 95KN/m^2. These values were close to the calculated value.

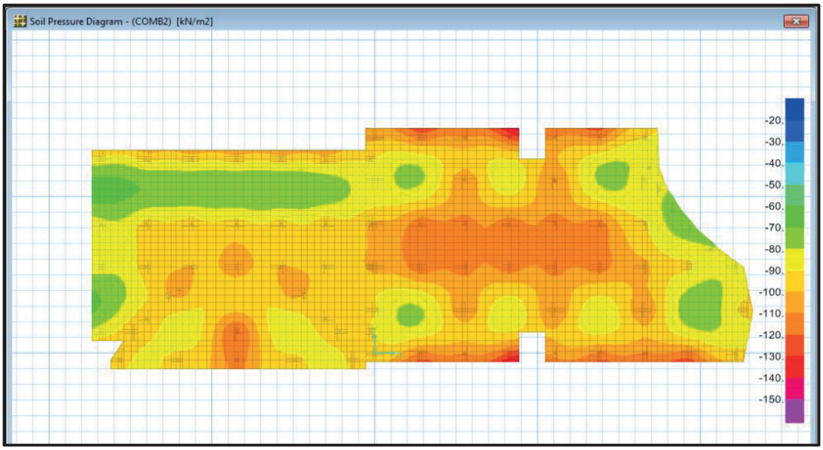


Figure 12: Average bearing capacity obtained distribution of base pressure for Baghdad**.**

Figures 12 and 13 show the distribution of base pressure under the foundation using the average (125KN/m^2) and worst (68 KN/m^2) values of calculated bearing capacity for Baghdad region. The range of base pressure under foundation was 70-100 KN/m^2 for average value, and between 65-96 KN/m^2 for worst value. In both cases, the base pressure was less than or within the calculated value of bearing capacity.

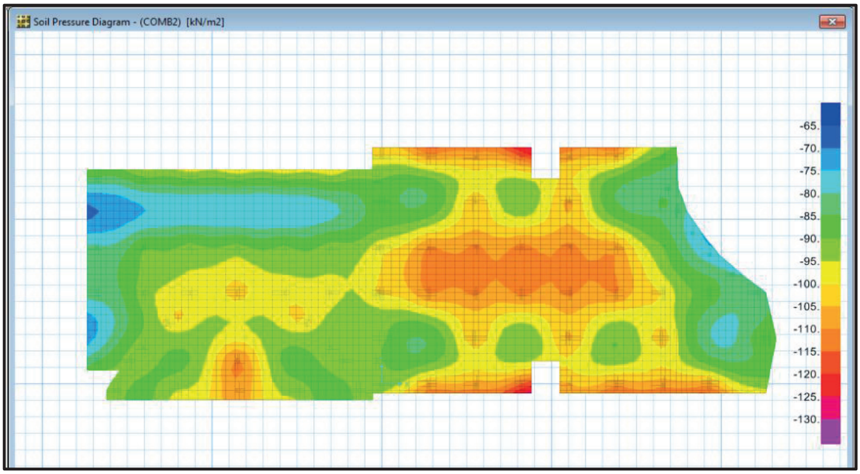


Figure 13: Worst bearing capacity obtained distribution of base pressure for Baghdad.

For Basrah region, figure 14 shows that the base pressure distribution for average value of calculated bearing capacity was 84 KN/m^2. The range for the base pressure under foundation was 70-95 KN/m^2, which is close to the calculated value of bearing capacity.

Furthermore, figure 15 shows the distribution of base pressure for the worst calculated bearing capacity (24 KN/m^2). The value of the base pressure under the foundation was between 72 -100KN/m^2.

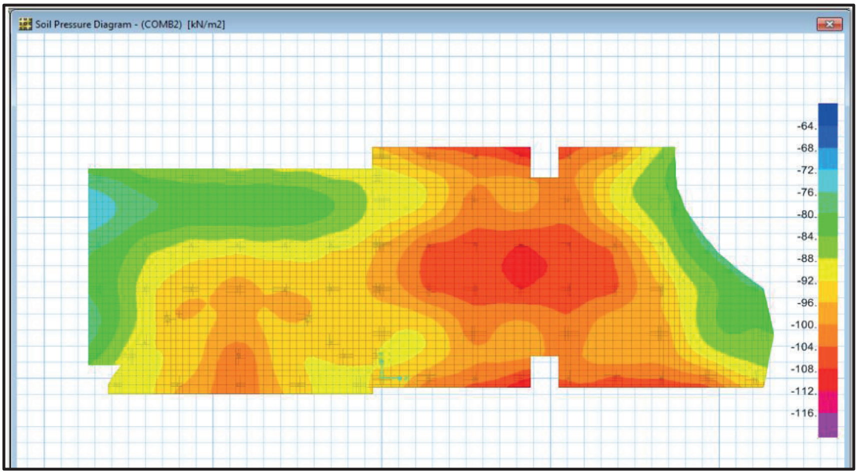


Figure 14: Average bearing capacity obtained distribution of base pressure for Basrah.

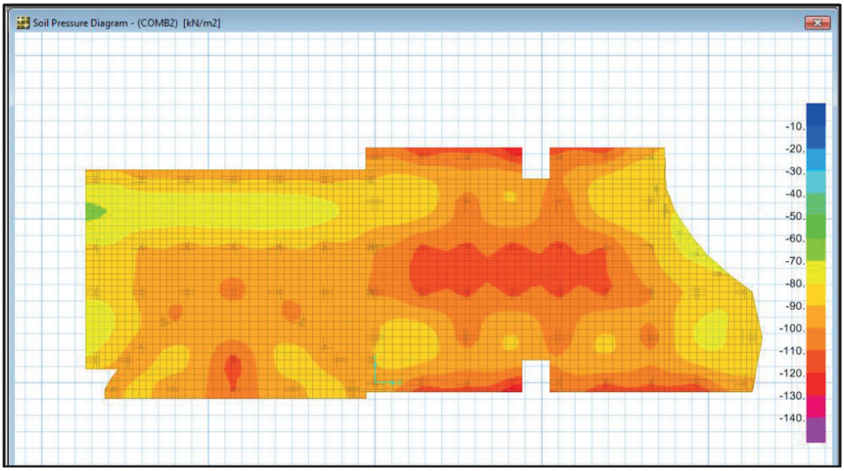


Figure 15: Worst bearing capacity obtained distribution of base pressure for Basrah.

3 Discussion

In this research, the purpose of the case study was to define the soil pressure under foundation for different locations (Mosul, Baghdad, and Basrah in Iraq). Usually, SAFE program gives the results of soil pressure in two directions: tension (positive) and compression (negative). The results were only negative, which means that the effect of tension was zero (legend of the values of base pressure tabulated in the right side of figures 10-15).

The results obtained for Mosul region (figure 10), were values of the base pressure distributed under the foundation for the average value of calculated bearing capacity. The maximum value of the base pressure was 100 KN/m^2, which was less than the calculated bearing capacity value (177 KN/m^2). It is significant that the best type of foundation should be chosen. While, the maximum value of base pressure shown in figure 11, for the worst value of calculated bearing capacity was 92 KN/m^2 for some areas under the foundation. These values will not affect the foundation, although it is beyond the calculated value of bearing capacity (77KN/m^2). In the previous work done by Al-Taie, et al. (2014)[25] for the same building model using the same data, but the design and analysis was done using STADD Pro *vi8* program for Mosul region, the results showed the maximum value of the base pressure under the foundation was 99 KN/m^2 for the average calculated value of the bearing capacity (177KN/m^2). The result was less than the calculated value as shown in figures 16 and 17. While, the maximum value of the base pressure under the foundation was 75 KN/m^2 for the worst value of the calculated bearing capacity. The result value was less than the calculated (table 3). The recommendation (in the previous work) for Mosul region was to use continuous or spread type of foundation and raft type if a basement is required for buildings with many floors. While, the suggestion depended on the results obtained from SAFE program, the best type of foundation is spread or continuous for buildings with many floors, and raft type foundation if basement is to be used. Earlier work [26] for Mosul location indicated that continuous type of foundation is recommended.

The base pressure under foundation (figure 12), for Baghdad region was for the average value of calculated bearing capacity (125KN/m^2). The maximum value of base pressure shown under the foundation was 95 KN/m^2. This value was less than the calculated value. Figure 13, shows that the base pressure under foundation for worst value of calculated bearing capacity was 68 KN/m^2. The result for the value of the maximum base pressure was 90KN/m^2. It was higher than the calculated value. While, in the previous work [25] for the same building model showed that the maximum value of base pressure under foundation was 87 KN/m^2, for the average of calculated bearing capacity 125 KN/m^2 value. The maximum value of the base pressure was 79 KN/m^2 for the worst value of the calculated bearing capacity. This value was higher than the calculated value (68 KN/m^2), as shown in figures 16 and 17. Spread or raft foundation type for such areas are recommended using the average value of bearing capacity, and only raft foundation type is the suitable for the area with worst value of bearing capacity [25]. According to SAFE program, continuous or raft foundation type are recommended for buildings not higher than five floors. For areas with worst bearing capacity value raft or mat foundation is recommended (table 3). Previous work [26] suggested raft type of foundation for Baghdad.

Table 3: comparison of the results obtained of current and previous works.

Location	**Method used**	**Average bearing capacity (KN/m^2)**	**Worst bearing capacity (KN/m^2)**	**Foundation to be used**
Mosul	Calculated	177	77	Shallow type
	STAAD Pro.	99	75	Continuous or spread type, & raft type for basement.
	SAFE	100	92	Continuous or spread type, & raft type for basement.
Baghdad	Calculated	125	68	Shallow type
	STAAD Pro	87	90	Spread or raft type.
	SAFE	95	79	Spread or raft type.
Basrah	Calculated	84	24	Shallow and deep type
	STAAD Pro	81	77	Raft and pile types.
	SAFE	81	96	Raft and pile types.

Figure 14, for Basrah region shows that the maximum value of base pressure (81 KN/m^2) for the average calculated bearing capacity (84 KN/m^2). Figure 15 show that the value of the maximum base pressure (96 KN/m^2) for the worst value of calculated bearing capacity (68 KN/m^2). Previous work [25] showed that the maximum value of base pressure under foundation was 81 KN/m^2, for the average calculated value of bearing capacity 84 KN/ m^2. While, the maximum value of the base pressure obtained from STAAD Pro program was 77 KN/ m^2, for the worst value of the calculated bearing capacity 24 KN/m^2 (figures 16 and 17). The raft foundation was the type of foundation recommended for the average value of bearing capacity [25]. The piles were the best type of foundation recommended for the worst value of the bearing capacity. The suggestions according to the results obtained from the current work, is that areas with a high value of bearing capacity, raft type is recommended for building not high than three floors. The areas with low values of bearing capacity the deep foundation type is the suitable one. Al-Taie et al. [26], suggested raft foundation for Basrah.

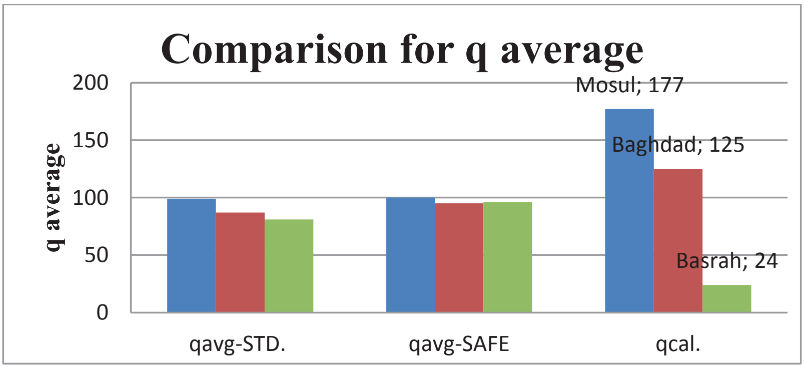


Figure 16: The results of q average values from STAAD Pro., SAFE programs and calculations.

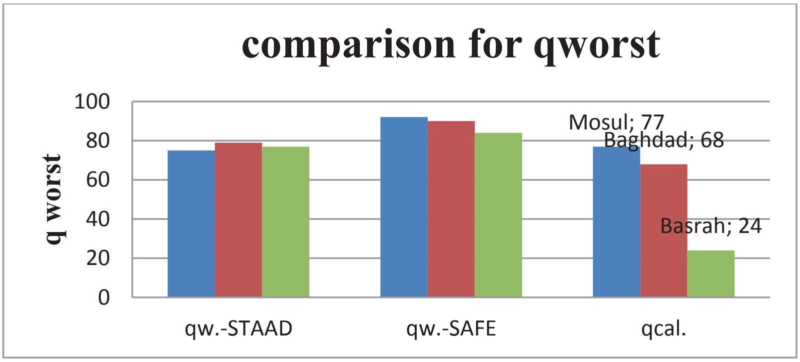


Figure 17: The results of q worst values from STAAD Pro., SAFE programs and calculations.

4 Conclusions

- Exploration for soil in northern (Mosul), middle (Baghdad) and southern (Basrah) parts of Iraq. Was carried out to find the best suitable foundation to be used in these areas. Field and laboratory tests were performed on seventy nine samples collected from these areas. The results indicated that the soil in Mosul had high to very high plasticity and its type was silty clay and clay, while, in some areas it was sand or silt. In Baghdad, the results showed that the soil had medium to high plasticity and non-plastic in few sites. Soil type was loam clay, silty clay and in some area silt. Plasticity of soil in Basrah region was medium and the soil type was clay loam and in many places it was silt or sand.
- Model of building was designed and analyzed using SAP2000 program specialist for structure and SAFE program specialist for foundation, depending on the calculated bearing capacities for different locations in the three regions of Iraq. The effect of loads (dead and live) on each column in the structure was transported to SAFE program. The results showed that the contours for the base pressure distribution under the foundation is more accurate and more realistic compared to results from STAAD Pro program.
- The results obtained from the programs, for Mosul region showed that the value for base pressure under foundation was lower than the average calculated bearing capacity in the whole area. The same results were obtained when using the worst value for bearing capacity as well. For that, the best type of foundation recommended for Mosul region is spread or continuous type for buildings with many floors and raft type foundation if basement is to be used.

In Baghdad region the value obtained for the base pressure under foundation did not exceed the average value of calculated bearing capacity. This makes the choice of continuous or raft foundation type is more suitable for buildings with not more than four to five floors in some locations of Baghdad. While, the results of the base pressure value were close to the worst calculated value of bearing capacity. The suitable choice for such areas is the raft or mat foundation.

Results for Basrah region showed that the suitable type of foundation for the average value of bearing capacity is the raft type for the normal building with not more than three

floors. This type was chosen because the value of the base pressure was less than the calculated value. The value of the base pressure obtained using worst calculated value for bearing capacity was higher. In such a case, deep foundation (piles or drilled shafts) type is recommended.
The comparison of the results obtained from this research and the previous one (using STAAD Pro program) for the same building and areas, gave the same suggestions for the type of foundation to be used in the three regions (Mosul, Baghdad, and Basrah) due to the fact that, the values of base pressure obtained from STAAD Pro and SAP2000, SAFE programs were convergent with each other. These differences were related to the finite element technique used in each program. Moreover, the value of base pressure in any area under the foundation in SAFE program can be obtained directly from the contour.

References

[1] D**.** P**.** Coduto, *Foundation Design: principles and practices*, 2nd edition, printed by Prentice-Hall, Inc., New Jersey, 2001.
[2] K. Terzaghi, R. B. Peck and G. Mesri, *Soil Mechanics in Engineering Practice*, 3rd, John Wiley & Sons, Inc., New York, 1996.
[3] B. M. Das, *Shallow Foundation: bearing capacity and settlement*, 2nd edition, press Taylor & Francis group, New York, 2009.
[4] N. S. V. Kameswara Rao, *Foundation Design theory and practice*, John Wiley & Sons (Asia) Pte Ltd, Singapore, 2011.
[5] B. M. A. A. Al-Imam, Primary Study to Execution and Testing Geotechnical Model Based on GIS Technique in the Left Side of Mosul City, *PhD thesis*, College of Engineering, University of Mosul, 2013
[6] B. M. Das, *Principles of Foundation Engineers*, 7TH edition, Cengage learning, Stamford, 2011.
[7] J. Riseborough and S. Tysl, LRFD implementation of shallow spread footing for bridge structures, *Contech engineering solution*, 2010. www.conteches.com .
[8] J. B. Hansen and S. Inan, Bulletin No. 28, *geoteknisk institute*, Copenhagen, 1970.
[9] M. O. Al-Ashou, Expansive properties of the clay in Mosul area, *M.Sc. thesis*, College of Engineering, University of Mosul, 1977.
[10] A. H. T. Al-Zubaydi, Effect of Wetting and Drying Cycles on Swell/Collapse Behaviour and Cracks of Fine–Grained Soils, *Tikrit Journal of Engineering Sciences*, **18**(4), (2011), 71-79.
[11] S. M. Ali, Hydrogeological Environmental Assessment of Baghdad Area, *PhD thesis*, University of Baghdad, College of Science, 2012.
[12] S. F. A. Fouad and V. K. Sissakian, Tectonic and Structural Evolution of the Mesopotamia Plain, *Journal of Iraqi Bill. Geological and Mining*, Special Issue (Geology of the Mesopotamia Plain), No.4**,** (2011), 33-46.
[13] W. R. Muttashar, F. K. Al-Amari and M. A. A. Al-Hussein, Geotechnical analysis for types of surficial fine-grained Soils at eastern side of Basra region, Southern Iraq, *Journal of University of Thi-Qar*, **7**(2), (2012), 1-11.
[14] M. H. A. Al-Jabberi, Sedimentological and environmental aspects of subsurface Basrah sediments-south Iraq, *Mesopotamian Journal of Marine Science*, **25**(2), (2010),176-187. www.iasj.net .
[15] T. W. Lambe, *Soil Testing for engineers*, John Wiley & sons Inc., 1951.

[16] B. M. Das, *Soil Mechanics Laboratory Manual*, 7th edition, OXFORD University press, New York, 2009.
[17] M. B. Das, *Principle of Geotechnical Engineering*, 7th edition, Cengage learning, Stamford, 2010.
[18] V. N. S. Murthy, *Geotechnical Engineering: Principles and practices of soil mechanics and foundation engineering*, Marcel Dekker Inc., New York, 2002.
[19] K. Soni Priya, T. Durgabhavani, K. Mounika, M. Nageswari and P. Poluraju, Non-Linear Pushover Analysis of Flat slab Building by using SAP2000, *International Journal of Recent Technology and Engineering (IJRTE)*, **1**(1), (2012), 29-33.
[20] M. Y. Abdulwahid, I. A. Al-Qasem and I. Arman, Determination of load transfer in reinforced concrete solid slabs by finite element computer analysis, *Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, **8**(3), (2013), 01-07. www.iosrjournals.org
[21] A. Hassani and A. Jamshidi, Modelling and structural design of a concrete block pavement system, *8th International Conference on Concrete Block Paving*, San Francisco, California, (2006), 389-398.
[22] M. A. Alashorafa, Modifications of Conventional Rigid and Flexible Methods for Mat Foundation Design, *M.Sc. thesis*, Islamic University of Gaza, Faculty of Engineering **,** 2008.
[23] Computers and Structures, Inc., *CSI Analysis Reference Manual*, Berkley, California, 2013. https://docs.csiamerica.com.
[24] ACI committee 318-08, *Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary*, American Concrete Institute, Farmington Hills, 2008.
[25] E. Al-Taie, N. Al-Ansari and S. Knutsson, (2014), Effect of bearing capacity on designing foundations in Iraq using STAAD Pro-v8i, *Engineering*, **6**,(2014) 292-303; http://dx.doi.org/10.4236/eng.2014.66033.
[26] E. Al-Taie, N. Al-Ansari, S. Knutsson and T. E. Saad, Foundation Assessment in different parts of Iraq using STDDA Prov*8i*, *journal of civil Engineering and Architecture*, **7**(3), (2013), 273-281.

Paper VIII

Engineering, 2015, 7, 379-386
Published Online July 2015 in SciRes. http://www.scirp.org/journal/eng
http://dx.doi.org/10.4236/eng.2015.77034

Estimation of Settlement under Shallow Foundation for Different Regions in Iraq Using SAFE Software

Entidhar Al-Taie[1,2], Nadhir Al-Ansari[2], Sven Knutsson[2]

[1]Reconstruction and Projects Department, Minister of Higher Education and Scientific Research, Baghdad, Iraq
[2]Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden
Email: Entidhar.altaie@ltu.se, nadhir.alansari@ltu.se, Sven.Knutsson@ltu.se

Received 9 June 2015; accepted 11 July 2015; published 14 July 2015

Abstract

Foundation design must satisfy limited values of settlement. Settlement is an essential criterion in the design process of shallow foundations. To calculate the settlement under different types of shallow foundations, 79 samples were taken from twenty-three sites distributed in three regions: Mosul, Baghdad and Basrah in the northern, central and southern parts of Iraq. Field and laboratory tests were performed to obtain the strength parameters to calculate the bearing capacity. The results obtained for the bearing capacity were used in SAFE software. The software was used to design and analyze the foundation and to calculate the settlements under two types of foundations (raft and continuous) for the three regions. Average and minimum values of bearing capacity were used. The software used subgrade reaction modules values for the design and analysis. According to the results, the suitable, safe and economical type of foundation to be used in Mosul, Baghdad and Basrah regions for the average value of bearing capacity is the continuous type for the first two regions while the raft type is recommended for Basrah region. In case that the minimum bearing capacity values are used, raft foundation is recommended for Mosul and Baghdad. While deep foundation is the suitable type of foundation for Basrah region.

Keywords

Raft Foundation, Silt, Clay, Settlement, SAFE

1. Introduction

The design of foundations must satisfy limiting values of the settlement. Settlement is an essential criterion in

How to cite this paper: Al-Taie, E., Al-Ansari, N. and Knutsson, S. (2015) Estimation of Settlement under Shallow Foundation for Different Regions in Iraq Using SAFE Software. *Engineering*, **7**, 379-386. http://dx.doi.org/10.4236/eng.2015.77034

the design process of shallow foundations. Settlement prediction is a major concern for designers. The two major criteria which control the design of shallow foundations on cohesion and cohesionless soils are the settlement and the bearing capacity of the soil beneath the foundation. Settlement usually controls the design process more than bearing capacity, especially when the width of foundation (B) exceeds 1 meter. Estimation of settlement of shallow foundations on soil facing problem related to uncertainty associated with the factors which affect the value of the settlement. These factors are: the history of the stress-strain of the soil, the distribution of applied stresses, the effect of soil compressibility, and the difficulty in obtaining undisturbed samples of cohesionless soil [1]. There are three types of settlements: uniform settlement, tilt and non-uniform settlement (**Figure 1**). Uniform settlement will not cause any damages in the structure but damages can be noticed in the drainage or at interface with utilities.

The most problematic settlement is the non-uniform type because it leads to structural distortions such as cracking of beams, slabs, etc. If the cracks appear in every floor of the structure it is due to foundation movement. Whilst, tilting is a problem with rigid and lean structures such as soils, tanks and towers [3].

Total excessive or differential settlements are sometimes related to unexpected consolidation. The stress-strain behaviour of soil is nonlinear from very small strains; it may have controlling influence on the scale and shape of the distribution of displacement of structure on soil. For that, design approach must be simple that can be related to collapse limits and successfully serviceable to the real nature of the soil [4]. Settlement is usually estimated depending on field test such as standard penetration test (SPT) and cone penetration test (CPT). Laboratory test is also used to obtain settlement values such as oedometer and triaxial tests. Another method for estimating settlement is computer modelling which depends on finite element analysis.

The aim of the research is to calculate the settlement of different sites in three locations, Mosul, Baghdad and Basrah in the northern, central and southern parts of Iraq respectively. SAFE software was used to calculate settlement under two types of foundations to choose the best type for each site.

2. Study Area

The study was conducted Mosul (9 sites), Baghdad (5 sites) and Basrah (9 sites) at the northern, central and southern parts of Iraq (**Figure 2**).

2.1. Mosul Location

Mosul is located at northern part of Iraq. The area is characterised by extensive plains and anticlines. Near the Tigris River there are three levels of accumulated terraces of alluvial soils. Most of the soil in the area is of moderate expansive type. Flat areas between the anticlines are covered by sheet run-off sediments which include clay, sand, silt, and sometimes coated by scattered gravels [5] [6].

2.2. Baghdad Location

Baghdad is located at the northern part of Mesopotamian plain. The area is characterized by sediments of flat laying alluvium due to flood of the two rivers (Tigris and Euphrates). Quaternary sediments soil (thickness more than 80 m) covers the area, which include levee silts, clay and some sand. The main features of this area are the salinity and shallow ground water table between 1 to 5 m [7].

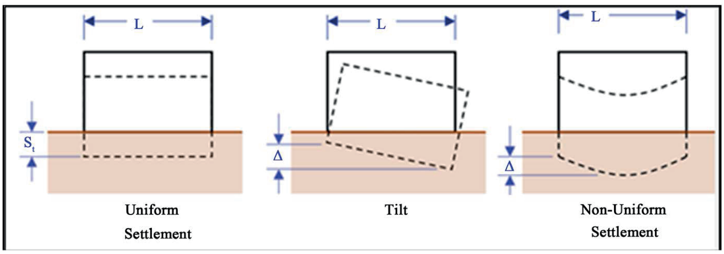


Figure 1. Types of settlement in soil [2].

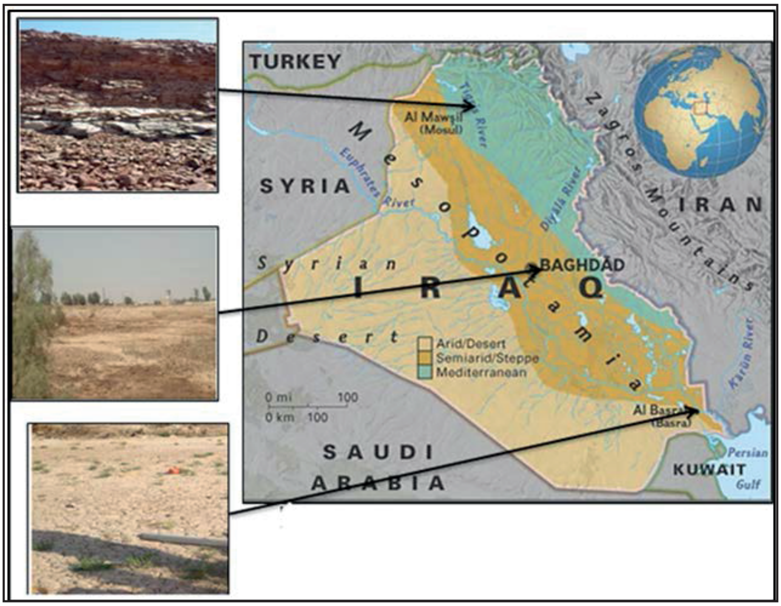


Figure 2. Locations of Mosul, Baghdad and Basrah map and soil type.

2.3. Basrah Location

Basrah is located at the southern part of Iraq. The soil of the area is about 250 m thick of flat thick quaternary sediment. The area represents the lower part of Mesopotamian plain. Its soil is of deltaic and river sediments type characterized by distinct change and exchange facies horizontally and vertically. The soil of the area is a combination of silt and mud river spate and wind sediments. These deposits are economically important as raw materials for the building and construction industries [8] [9].

3. Experimental Work

Soil investigations included field and laboratory tests. Field work includes drilling twenty three boreholes in different sites for the three locations (Mosul, Baghdad and Basrah) of Iraq. Seventy nine samples were collected (disturbed and undisturbed). Furthermore, standard penetration test (SPT) also performed in some of the sites. Laboratory tests conducted on the collected samples from sites included different types of tests. All the tests were done according to ASTM, AASHTO and BS as follow:

- Physical tests including, natural moisture content, unit weight and specific gravity.
- Sieve and hydrometer analysis.
- Atterberg limits (liquid limit LL and plastic limit PL to obtain plastic index PI).
- Shear tests (direct shear strength and unconfined compression).
- Consolidation test to obtain the compression index (C_c), swelling index (C_s) and preconsolidation pressures (P_c).

The results obtained from shear tests to determine the shear strength were the angle of internal friction (ϕ), the cohesion (C) and unconfined compression (q_u) [10]. These parameters were used to calculate bearing capacity value for each site using the general equation [11].

4. SAFE Modelling

Computation of settlement in this paper was done using SAFE software. SAFE software is a finite element tool used to design and analyze foundations, slab, mat and basement. It has powerful modelling tools with an intuitive graphical interface. Design is integrated with modelling and the analysis is based on a chosen design code calculation. SAFE software can be used as a standalone programme or can import complete design, analysis and detailing of concrete floor plates created in SAP 2000 or ETABS. The SAFE software gives a variety of outputs that can be used to study the behavior of loads and deformations [12] [13].

The principle of the software is the ability to compute a plate displacements and resultant stresses with an acceptable degree of accuracy in order to ensure a safe and economical design. Modelling the soil is difficult method because soil has very complex nature. Winkler foundation model is the principle of the analysis of the foundation used in the software to obtain the results of displacement under foundation [14].

The geometry of model of study was raft foundation of (25*60) m used for different regions (Mosul, Baghdad, and Basrah) in Iraq. The used data in the software which were based on the calculated bearing capacities as shown in **Table 1**, and the soil subgrade reaction modulus (Ks).The combination loads (dead and live) were used according to ACI code [10]. The type of finite element used in the software was shell type where the mesh was generated automatically.

5. Results and Discussions

SAFE software was used to estimate settlement values. SAFE software analyzed the raft and continuous foundations depending on the subgrade reaction of the soil under the foundation for each site in the three regions. The results were illustrated in the form of contours as follows:

The displacement under foundation for the average value of bearing capacity in Mosul region is shown in **Figure 3** for both raft and continuous types; the displacement value was 5.2 mm and 6 mm respectively. For the minimum value of bearing capacity, the displacement under raft and continuous foundation are show in **Figure 4**. The value of the displacement is 11 mm and 14 mm for raft and continuous types respectively.

Whilst, for Baghdad region, the displacement value distributed under raft and continuous foundations for the average value of bearing capacity was 8.4 mm and 8.8 mm respectively as shown in **Figure 5**. For the minimum bearing capacity value the displacement was 13.5 mm under raft type and 16 mm under continuous type (**Figure 6**).

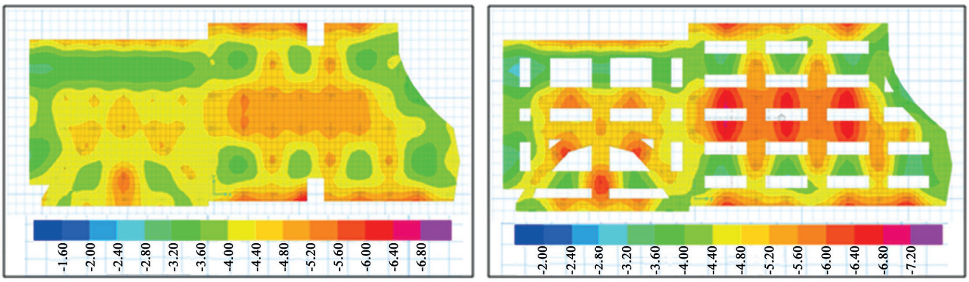


Figure 3. Displacement under raft and continuous foundation for average value of bearing capacity in Mosul region.

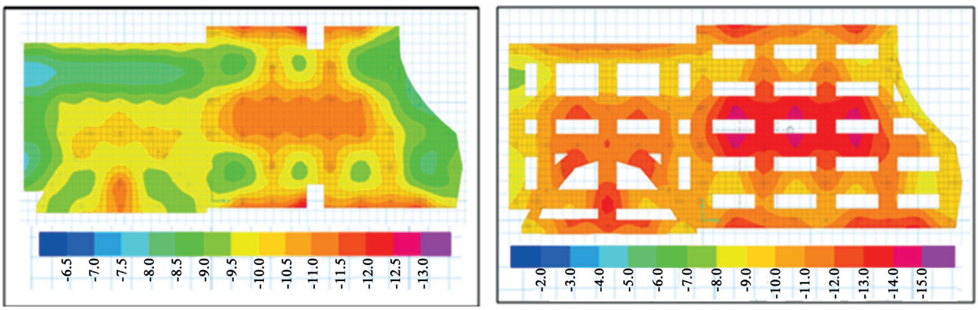


Figure 4. Displacement under raft and continuous foundation for minimum value of bearing capacity in Mosul region.

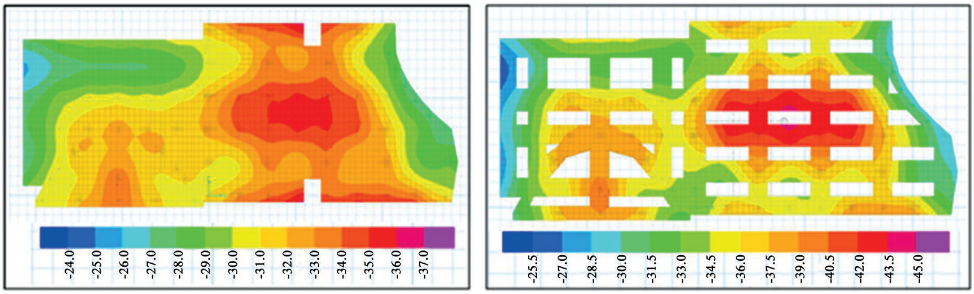


Figure 5. Displacement under raft and continuous foundation for average value of bearing capacity in Baghdad region.

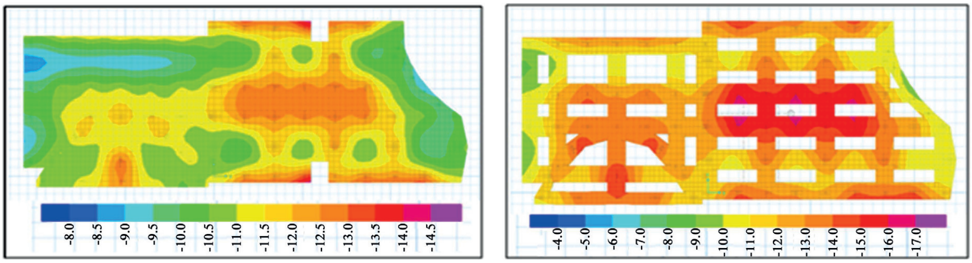


Figure 6. Displacement under raft and continuous foundation for minimum value of bearing capacity in Baghdad region.

Table 1. Bearing capacity for the three locations.

Subgrade reaction modulus, kN\m^3	Mosul	Baghdad	Basrah
Average value	21,240	15,000	10,080
Minimum value	9240	8160	2880

For Basra region, the analysis done for the average and minimum baring capacity values and for the raft and continuous type are shown in **Figure 7** and **Figure 8** respectively. The value of the displacement for the average value under raft type was 10.5 mm and under continuous type was 13 mm. Whilst the displacement for minimum value under raft type was 36 mm and under continuous type was 42 mm.

SAFE software showed that the results for the settlements of soil under the foundation depended only on the subgrade reaction modules for the soil. The settlement obtained from the software was distributed horizontally. The behaviour of all soil layers cannot be seen because the software show only the results of top soil layer which is in contact with the foundation.

The settlement values for Mosul region: The contour for settlement under raft and continuous in **Figure 3** shows that the values of the settlement are nearly close to each other for both types of foundations (raft = 5.2 mm; continuous = 6 mm). Both types of foundation can be used in such areas. According to the cost of implementation where the total volume of raft and continuous foundations were equal to 955 m^3 and 248 m^3 respectively. Then the continuous type is relatively more appropriate. The results for the minimum bearing value for both types of foundations indicated that the values of settlement were 13.5 mm and 15 mm respectively (**Figure 4**). The contours for raft type showed that most of the settlement values distributed under foundation are 10.5 mm (with minor exceptions where few areas had the value of 13 mm) .While, the contour under the continuous foundation showed that most of the area had a value of 15 mm. For that, raft type for such area is relatively more suitable and safe. **Figure 9** illustrate settlement values for both types of foundations.

The settlement values for Baghdad region: The contour of settlement (**Figure 5**) under raft and continuous foundations for average bearing capacity values in Baghdad region give almost similar values (8.8 mm). For such areas, continuous type is the best because it is safe and economical. Whilst, the results for settlement under

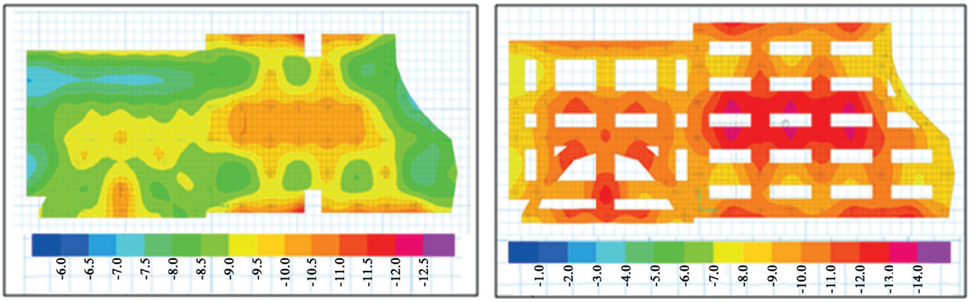


Figure 7. Displacement under raft and continuous foundation for average value of bearing capacity in Basrah region.

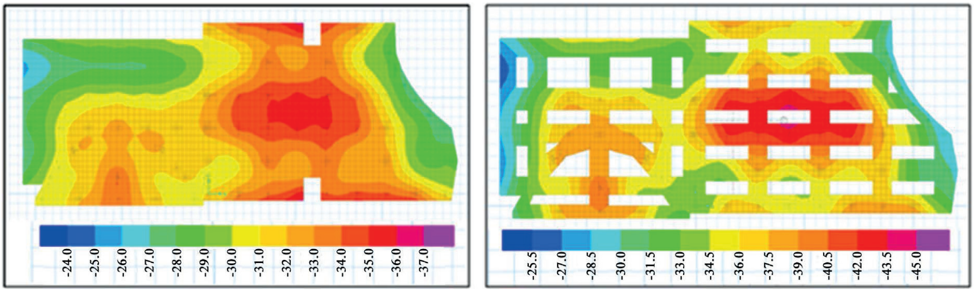


Figure 8. Displacement under raft and continuous foundation for minimum value of bearing capacity in Basrah region.

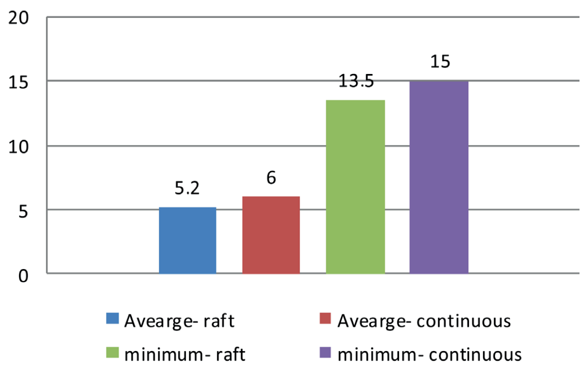


Figure 9. Settlement values under raft and continuous foundation for Mosul region.

raft and continuous foundations (**Figure 6** and **Figure 10**) for minimum bearing capacity value showed that most of the area has values of 11.5 mm (few areas with 13 mm) and16 mm respectively. For such area; the suitable type of foundation to be used is raft.

The settlement values for Basra region: The results in **Figure 7** show that the settlement under raft foundation in most of the area is equal to 9.5 mm with few areas have 11.5 mm value. But the settlement value for most areas under continuous foundation is equal to 13 mm. Therefore, for such areas, the suitable type is the raft. While the results of settlement under both types (raft and continuous) of foundation in **Figure 8** and **Figure 11** show that for the whole area has values of 36 and 42 mm respectively. The suitable type of foundation to be used is deep type.

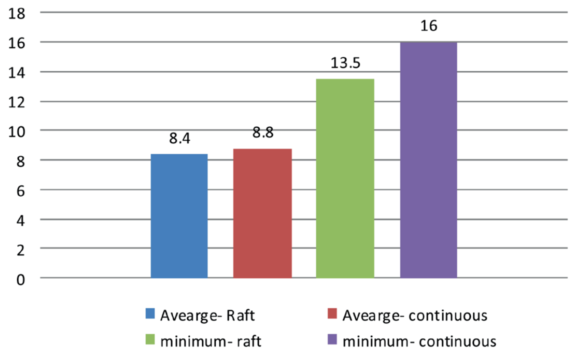


Figure 10. Settlement values under raft and continuous foundation for Baghdad region.

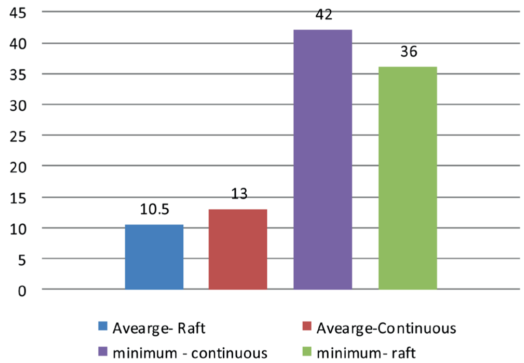


Figure 11. Settlement values under raft and continuous foundation for Basrah region.

6. Conclusion

SAFE software was applied on a hypothetical building on three regions in Iraq (Mosul, Baghdad and Basrah at the northern, central and southern parts of Iraq) to find out the most suitable foundation required in each region. According to the results, the suitable, safe and economical type of foundation to be used in Mosul, Baghdad and Basrah regions for the average value of bearing capacity is the continuous type for the first two regions while the raft type is recommended for Basrah region. In case that the minimum bearing capacity values are used, raft foundation is recommended for Mosul and Baghdad. While deep foundation is the suitable type of foundation for Basrah region. These results are satisfying the designer's requirements because the contour clarifies the displacements and cracking analysis.

References

[1] Shahin, M.A., Jaksa, M.B. and Maier, H.R. (2000) Predicting the Settlement of Shallow Foundations on Cohesionless Soils Using Back-Propagation Neural Networks. *Research Report* No. R 167, University of Adelaide, Adelaide.

[2] The CITADEL (2010) CIVL410 Geotechnical Engineering II-Shallow Foundations. http://cee.citadel.edu/civl410/CIVL410/Course_Materials_files/CIVL410%20Shallow%20Foundation%20-%20Settlement.pdf

[3] Salgado, R. (2013) Settlement and Serviceability, Piling Engineering. https://engineering.purdue.edu/COFFEE/courses/CE597PilingEngineering/2013Fall/lectures/Piling%20Engineering%20-%20Lecture%2003.pdf

[4] Osman, A.S. and Bolton, M.D. (2004) A New Approach to the Estimation of Undrained Settlement of Shallow Foundations on Soft Clay. Engineering Practice and Performance of Soft Deposits, IS-OSAKA, 93-98.

[5] Buringh, P. (1960) Soils and Soil Condition in Iraq. Ministry of Agriculture, Baghdad.

[6] Jassim, S.Z. and Goff, J.C. (2006) Geology of Iraq. Dolin, Prague and Moravian Museum, Brno.

[7] Al-Taie, E., Al-Ansari, N., Knutsson, S. and Saaed, T.E. (2013) Foundation Assessment in Different Parts of Iraq Using STAAD Pro V8i. *Journal of Civil Engineering and Architecture*, **7**, 273-281.

[8] Mahmood, R.A., Al-Marsomy, A.H. and Mohammad Ali, A.A. (2011) Study of Gypsum Content of Soils at Selected Sites in Basrah Governorate South of Iraq for Engineering Purposes. *Journal of Basrah Researches* (*Sciences*), **37**, 10-21.

[9] Muttashar, W.R. (2010) Some Geotechnical Soil Properties of Western Bank of Khor Al-Zubair Channel Coast at Khor Al-Zubair Port Location, Southern Basrah, Iraq. *Mesopotamian Journal and Marian Science*, **25**, 124-133.

[10] Al-Taie, E., Al-Ansari, N., Saaed, T.E. and Knutsson, S. (2014) Bearing Capacity Affecting the Design of Shallow Foundation in Various Regions of Iraq Using SAP200 & SAFE Softwares. *Journal of Earth Sciences and Geotechnical Engineering*, **4**, 35-52.

[11] Das, M.B. (2010) Principle of Geotechnical Engineering. 7th Edition, Cengage Learning, Stamford.

[12] Key Features and Terminology (2009) SAFE Design of Slabs, Beams and Foundations Reinforced and Post-Tensioned concrete. Computers & Structures, Inc., Berkeley.

[13] Computers and Structures, Inc. (2013) CSI Analysis Reference Manual. Berkley, California. https://docs.csiamerica.com

[14] Rajpurohit, V.K., Gore, N.G. and Sayagavi, V.G. (2014) Analysis of Structure Supported on Elastic Foundation. *International Journal of Engineering and Advanced Technology* (*IJEAT*), **4**, 1-6.

Paper IX

Evaluation of Foundation Settlement under Various Added Loads in Different locations of Iraq Using Finite Element

Entidhar Al-Taie[1], Nadhir Al-Ansari, Sven Knutsson

Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology, 97187 Lulea, Sweden

Entidhar.altaie@ltu.se, nadhir.alansari@ltu.se, Sven.Knutsson@ltu.se

Abstract

Settlement is an important criterion in the design of the foundations. It is classifying into immediate (or elastic) settlement and consolidated settlement (primary and secondary). The factors that affect the shallow foundation settlement are the applied loads, soil stiffness, and width, depth, and shape of foundation. Calculations of settlement depend on the parameters of soil which can be obtained from field and laboratory tests. Field and laboratory tests conducted for twenty three sites in three different regions in Iraq (Mosul, Baghdad, and Basrah). In this research field and laboratory tests results adopted for two sites from each region depended on the maximum and minimum bearing capacity values. Settlement for each site was calculated using numerical calculations and PLAXIS software under different added loads. The results of settlements beneath the foundation were competing for the sites with maximum value of bearing capacity in Mosul; Baghdad and Basrah. Also, the comparison conducted for sites of minimum bearing capacity value and the results showed different settlement values of each site. The change of settlement values under different loads were linearly in the six sites using numerical calculations. While, the settlement values obtained from PLAXIS software for sites with maximum bearing capacity value showed that Mosul site had the highest value due to the type of soil layers and the difference models of soil used in the software. Basrah site had a settlement value higher than Baghdad site due to the soil layers of sand type only. PLAXIS results for sites with minimum bearing capacity showed that for Basrah site the soil collapsed under last two values of load and the settlement value was very high. While, the settlement values for Mosul and Baghdad sites were close to each other due to their locations near the Tigris river bank. Therefore, soil in some locations and under some added loads needed to be improved before the implementation of any constructions.

Key words: Settlement, foundation, field test, cohesion soil, PLAXIS, consolidation, overconsoildation soil.

1. Introduction

Settlement is an important criterion in the design of the foundations. Foundation settlement must be estimated carefully to ensure stability of buildings, towers, bridges, and any high cost structures. The main reason for the settlement occurrence is the compressive deformation of the soil. According to [*Liu*, *et al 2008*] settlement is classifying as (Figure 1):

[1] Reconstruction and Projects Department, Minister of Higher Education and Scientific Research, Iraq.

- **Immediate (or elastic) settlement:** It takes place rapidly after adding loads without any change in the moisture content and volume.
- **Consolidation:** This type includes two phases:
  1. **Primary phase:** This phase is a consolidation settlement results from the change of volume due to water extrusion from soil voids. It occurs in saturated cohesive soils and the change happens slow and takes place over a long period of time.
  2. **Secondary phase**: This phase is compression settlements which consider as a plastic adjustment observe in saturated cohesive soils. It is an extra deformation of soil occurs due to constant add loads.

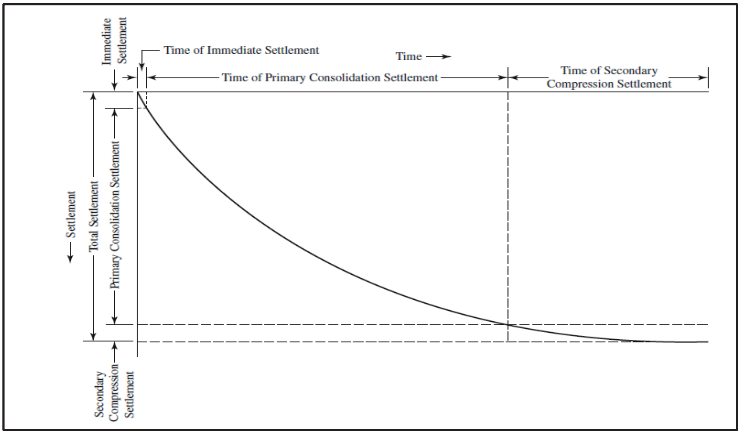


Figure 1: Time-Settlement relation (immediate settlement, consolidation, and secondary compression settlement), [*Liu, et al, 2008*].

The major factors affect shallow foundation settlements are: applied loads, soil stiffness, width, depth, and shape of foundation [*Bowles, 1996; Shahriar, et al., 2013*].

Foundation settlement (immediate, consolidation) are estimated depending on the calculating stresses in the mass of the soil related to foundation pressure. The settlements and stresses distribution and their values in soil are calculating with the assumption that soil model is homogeneous, isotropic, and linearly elastic and playing an important role in the foundations design [*Al-Ramthan, 2012*].

Immediate settlement usually estimates according to elastic theory, which assumes that the soil may behave elastically under stresses at any point in soil mass. There are usually three types of methods to calculating the elastic settlement [*Murthy, 2002; Das, 2015*]:

Empirical methods: They are depending on observation settlement of structure and full scale prototypes. They are depending on correlations of the results from the standard tests in situ such as the cone penetration test (CPT) and the standard penetration test (SPT). Moreover, they contain steps improved by Terzaghi and Peck (1948, 1967), Meyerhof (1956, 1965), DeBeer and Martens (1957), Hough (1969), Peck and Bazaraa (1969), and Burland and Burbidge (1985) [*Das, 2015*].

Semi-Empirical methods: They based on the integration of the theoretical studies and the field observations. The methods contain steps outlined by Schmertmann (1970), Schmertmann et al. (1978), Briaud (2007), and Akbas and Kulhawy (2009) [*Das, 2015*].

Theoretical relationship methods: They are relating to the theory of elasticity. The settlement calculations depend on the modulus of elasticity (E_s) [*Das, 2015*].

The consolidated settlement is estimating from the consolidation test (Triaxial or oedometer). These tests are the way of estimating the magnitude and time of consolidation to obtain settlement for normally consolidated and overconsolidated cohesive soils [*Liu, et al, 2008, Smith, et al, 1998*].

The objective of this paper is evaluating shallow foundation settlement under different added loads in the three regions of Iraq (Mosul northern, Baghdad central, and Basrah southern parts). The evaluations were conducted using numerical calculations and finite elements (PLAXIS 2D) models. The work was conducted by collecting samples from different sites in the three regions of Iraq. And evaluate the behaviour of soil layers under the different added loads.

2. **Study area**

The study area located in Mosul northern, Baghdad central, and Basrah southern parts of Iraq (Figure 2) due to the variation in geology and soil formation [*Jassim, et al, 2006*].

- *Mosul region* situated in the northern part of Iraq. It is occupying part of the foothill zone and north part in Al-Jazira zone (Figure 2). Most of Mosul areas are covering by clay soil, which is moderately to highly expansive type. On the Tigris River banks deposits of soil consist of clay, silt and sand as a result of repeated flooding. The western part of Mosul region contained soil of gypsum, limestone and sandstone types. The ground water table depth in Mosul region is about 20m but in some places it is about 3m depth [*Jassim and Goff, 2006; Al-Taie, et al, 2015*].

- *Baghdad region* is the capital of Iraq, situated in the upper of the Mesopotamian plain (Figure 2). Quaternary sediments cover the area; these sediments are accumulating as result of the recurrence of the two rivers floods. Soils of Baghdad are of silty clay; silty clay loam and silt loam and have low salinity. Soils are of fine sandy and silty type along the streams. The depth of ground water in Baghdad region is between 1.2 to 8 m [*Ali, 2012, Al-Taie, et al., 2014*].

- *Basrah region* situated in the lower part of Mesopotamian plain southern of Iraq. The sediments of this plain are related to the Quaternary period. Multi-sources of sediments have been classified as fluvial, deltaic and marine. These sediments are of economic value because they used in constructions. Most of the sediments of fluvial type and composed of sand, silt and clay. They are the source of gravels, sands and clays. Tigris and Euphrates Rivers were the main sources of these sediments and they contain carbonates and gypsum grains. The ground water table in Basrah region is less than 1m to less than 5m [*Al-Baidhany, et al, 2005; Almutury, et al, 2008*].

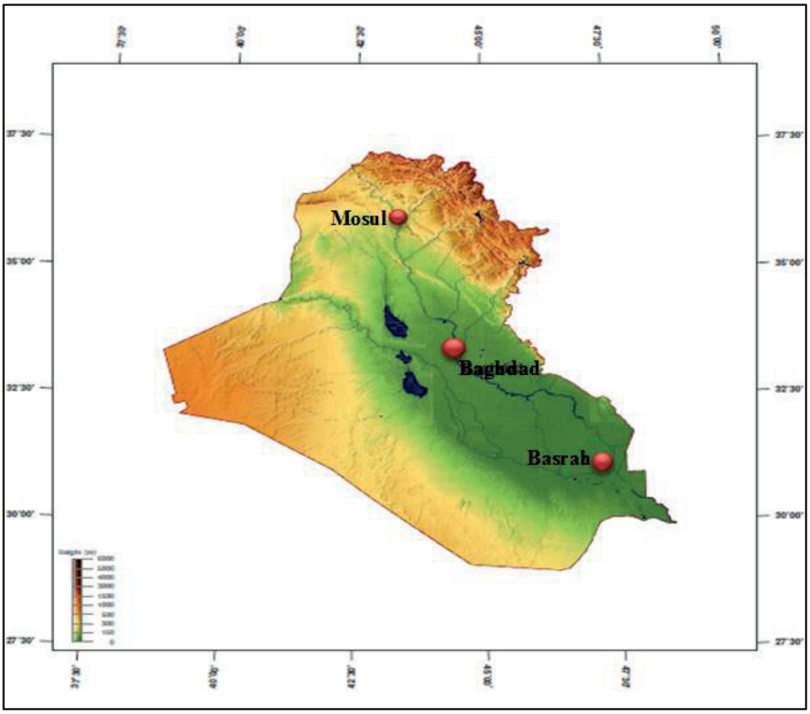


Figure 2: Map of the locations of the study area in Iraq.

3. Methodology

3.1 Soil investigations: Samples were taking from the three regions of Iraq (Mosul, Baghdad, and Basrah). Boreholes drilled to different depth ranges between 3m to 24 m depend on depth of dense material, to obtained disturbed and undisturbed samples from all sites. Table 1 show the number, the depth and the location for each sample from six sites were selected and had been used in this research.

Table 1: Location, number and depth of samples in the three regions.

Region	Location	No. of samples	Depth (m)
Mosul	Al-Hamedat	3	1, 2, 3
	Al-Rashidia	3	1,2, 4
Baghdad	Al-Karada	4	2, 4, 8, 13
	Al-Jadrea	4	2, 4, 8, 13
Basrah	Al-Rumaila	3	1, 5, 10
	Al-Hartha	4	2, 6, 13, 24

3.2 Laboratory tests: Different types of tests conducted for these samples to define the soil classification and mechanical properties. The tests are: physical test, index properties (Atterberg limits and grain size), shear strength test (direct shear and unconfined compression), and consolidation test.

Two sites selected from each region (Mosul, Baghdad, and Basrah) depended on the bearing capacity value (maximum and minimum) obtained from the field and laboratory tests [*Al-Taie, et al, 2014*].

3.3 Computations of settlements: Computations of soil settlement under different added loads for the three regions of Iraq conducted and explained in the following sections:

3.3.1 Numerical calculations: The analytical calculations were conducted based on the oedometer tests for cohesion soil layers. While, for cohesionless soil layers the immediate settlement calculations were conducted based on the SPT field tests:

A. The calculations of consolidated settlement are depending on a plot of the void ratio (e) against (log scale) effective pressure (σ'), which is obtaining from oedometer test [*Das, 2010; Murthy, 2002*]. The results of these tests are shown in figures (3-5).

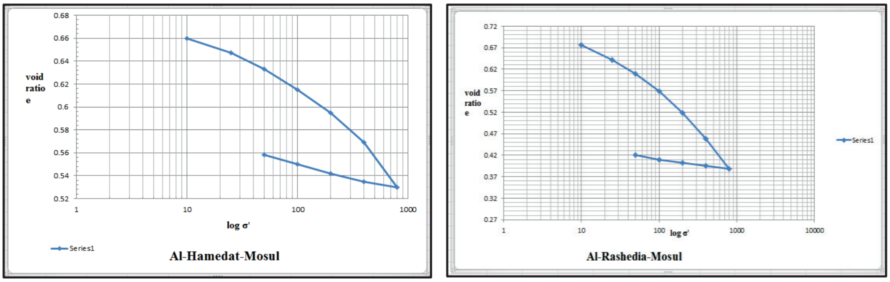


Figure 3: Plot of void ratio (e) vs. effective pressure (σ') for Mosul sites.

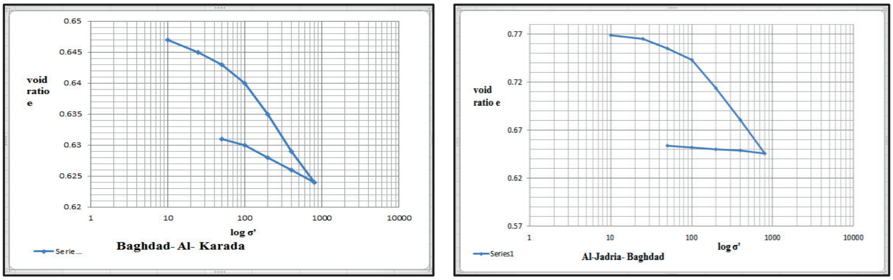


Figure 4: Plot of void ratio (e) vs. effective pressure (σ') for Baghdad sites.

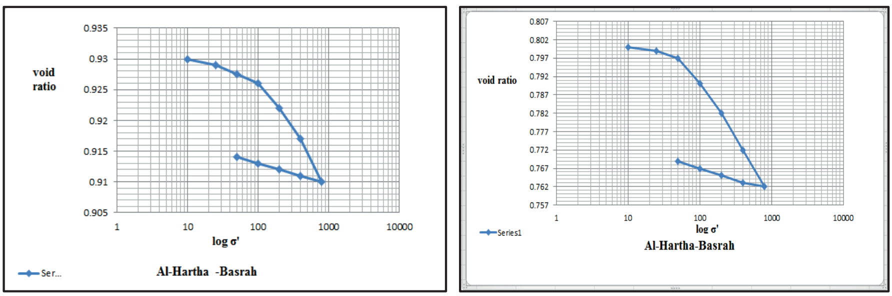


Figure 5: Plot of void ratio (e) vs. effective pressure (σ') for Basrah sites.

From curves shown in figures 3, 4 and 5: the compression index $\mathbf{C_c}$, swelling index $\mathbf{C_s}$, and void ratio **e** values were obtaining. Boussinesq equation used to determine the effective stress at the corner of rectangular foundation **Δσ'** (KPa) for the different layers of soil mass of 75m depth. The following equation used to calculate the normal consolidated cohesion soil [*Liu, et al, 2008*]:

$$S_c = \frac{C_c}{1+e_o} H \log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.1$$

Where: S_c = consolidated settlement (mm).

H = thickness of soil layer (m).

For overconsolidated cohesion soil the following equations used [*Liu, et. al, 2008*]:

$$S_c = \frac{C_s}{1+e_o} H \log\left(\frac{\sigma'_o+\Delta\sigma'}{\sigma'_o}\right) \ldots\ldots\ldots. for\ \sigma'_o + \Delta\sigma' \leq \sigma'_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

$$S_c = \frac{C_s H}{1+e_o} \log\frac{\sigma'_c}{\sigma'_o} + \frac{C_c H}{1+e_o} \log\left(\frac{\sigma'_o + \Delta\sigma'}{\sigma'_c}\right) \ldots\ldots\ldots\ldots for\ \sigma'_o + \Delta\sigma' > \sigma'_c \ldots\ldots\ldots\ldots..3$$

B. The immediate or elastic settlement for cohesionless soil layers carried out using the following formula which depends on Standard Penetration Test (SPT). This test was performed in the fields. The calculations assumed that the foundation is flexible [*Bowles, 1996; Akpila, 2014; Brahma, et al,2010*]:

$$S_e = q_o B \frac{1-\mu'}{E_s} I_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where: S_e = immediate settlement for flexible foundation (mm).

μ = Poisson's ratio.

I_s = influence factor.

B = width of foundation (m).

q_o = applied pressure (kPa).

E_s = Young's Modulus of Elasticity (kPa).

The immediate settlement of a rigid foundation estimated according to the following formula [Bowles, 1996]:

$$S_{e(rigid)} = 0.93 S_{e(flexible)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.5$$

The Young's modulus of elasticity of soil obtained from the following equation [*Bowles, 1996*]:

$$E_s = 500(N + 15) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where: N = the value of blows of SPT test.

The influence factor calculated from the following formula:

$$I_s = I_1 + \left(\frac{1-2\mu}{1-\mu}\right) I_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.7$$

Where: $I_1 = \frac{L}{B} = m$, and $I_2 = \frac{H}{B} = n$ and m, n can be estimated from tables [*Bowles, 1996*].
Poisson ratio of soil (**μ**) calculated according to the following relation [*Akpila, 2014*]:

$$\mu = \frac{1 - sin\,\emptyset}{2 - sin\emptyset} \qquad \dots \mathbf{8}$$

All the calculations were done for the six sites under different loads of values 56; 63.5; 68; 75 and 93 kPa. Theses loads present the dead and live load for buildings with two, three and four stories, respectively.

1.3.2. PLAXIS modelling: The finite element method is the most used method for analysis in engineering works. PLAXIS 2D software is a finite element tool which is used for geotechnical works. In view of the fact that soil is a material which behaves differently under loading, unloading and reloading [*Bajad, et al, 2012; Ahmed, et al, 2014*]. PLAXIS 2D software used in this research to simulate the soil behaviour under raft foundation for different sites and loads. The finite element soil geometry model adopted for the analysis of raft foundation of (25*60) m, and the added loads (dead and live loads) used were 56; 63.5; 68; 75 and 93 kPa. The same foundation and loads used in the six sites in the three Iraqi regions (Mosul, Baghdad and Basrah) with different soil conditions. Depending on the results obtained from oedometer and SPT tests for each region the analysis was performed. The models for soils used in the software were Harding soil (HS) for the cohesion soil and Mohr-Coulomb (MC) model for cohesionless soil. The parameters that were used for the soil in the software for each site were obtained from the field and laboratory tests as shown in table 2. After the creation of the geometry of the two-dimensional (2D) model the mesh were generated automatically [*material models, 2012*].

Table 2: Soil parameters used for the two models at different locations.

Soil parameters	**Mosul Region**		**Baghdad Region**		**Basrah Region**	
	Hamedat	**Rashidia**	**Karada**	**Jadrea**	**Rumaila**	**Hartha**
Material model	HS	HS & MC	HS & MC	HS & MC	MC	HS & MC
Unsaturated weight (γ_{unsat}), kN/m^3	19	19, 20	20,21, 19	18	15, 18.7, 20	18.6, 19, 19
Saturated weight (γ_{sat}), kN/m^3	20	23, 24	20, 21,19	19, 20	17.55, 18.7, 19.66	23, 23.4, 25
Compression index (**C_c**)	0.126	0.21	0.0156 0.109	0.108	-	0.191, 0.224
Swelling index (**C_s**)	0.019	0.022	0.054 0.027	0.0067	-	0.029, 0.027
Initial void ratio (**e**)	0.650	0.647	0.647 0.455	0.741	-	0.8, 0.93
Modulus of elasticity (**E**), kN/m^2	-	32500	32166.7	32500	26833 32500	32500
Passion's ratio (**μ**)	-	0.35	0.35	0.37	0.31, 0.28, 0.26	0.36

Cohesion (C), kN/m^2	40	0	185.3	38	4, 2,0	12
Friction angle (ϕ^o)	20	28	-	-	33, 38, 41	26
Dilatancy angle (ψ^o)	-	-	-	-	3, 8, 11	0

4. Results and Discussions

Estimation of settlement under foundation for different loads conducted using numerical calculations and PLAXIS software. The equation used in the numerical calculation was the Boussinesq equation for the purpose of the calculated settlement in each layer of soil. Equations 1, 2 and 3 used to calculate the consolidation settlements for cohesion soil layers. The immediate settlement was calculated using equations 4, 5, 6, 7 and 8 for cohesionless soil layers. The Hardening Soil (HS) model was used in PLAXIS for cohesion soil layers. And Mohr-Coulomb (MC) model was used for the cohesionless soil layers. All the results were obtained from the two methods as following:

4.1. Numerical Results: The results obtained from numerical calculations were performed by dividing mass of soil into layers. The data depended on the field and laboratory tests and the groundwater level was taking into consideration through the calculations of σ_o' for each layer. The numerical calculations conducted for the mass of soil with 75m depth in all sites. The results based on the field and laboratory tests. The settlement values obtained from numerical calculations showed the increases linearly and related to the bearing capacity value of each site. The results of the calculated settlement for the six sites were shown in Figures 6 and 7. The results shown in Figure 6 for the sites with maximum bearing capacity value, the settlement values for Al-Rumaila (Basrah) were less than the other two sites due to the soil type of sand. While, for Al-Hamedat (Mosul) the values of settlement were high due to the soil type of clay with high compressibility.

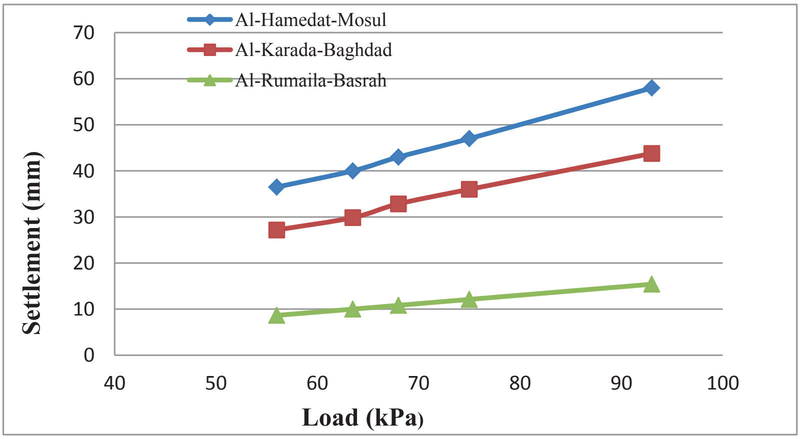


Figure 6: Settlement obtained from Numerical calculations for sites with maximum bearing capacity value for the three regions.

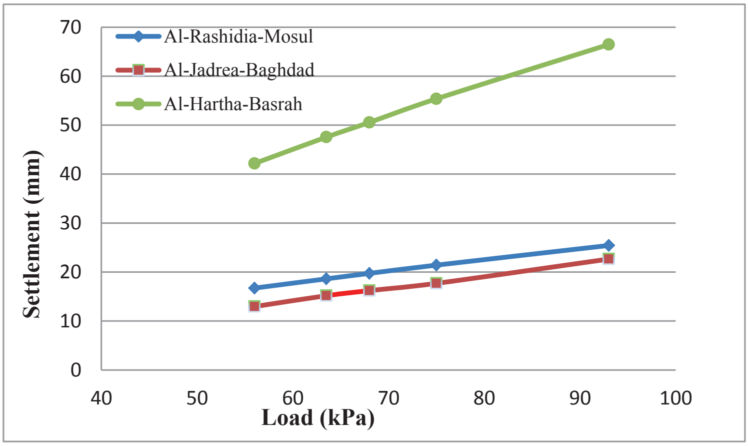


Figure 7: Settlement obtained from Numerical calculations for sites with minimum bearing capacity values for the three regions.

The results shown in Figure7 were for the sites with minimum bearing capacity value. For Al-Hartha site (Basrah) had the high settlement values due to the loose layer of soil (soft sandy silt to medium silty sand). While for the two sites Al-Rashidia and Al-Jadrea (Mosul and Baghdad, respectively) the settlement values were close to each other due to the both sites were sited on the bank of Tigris River.

4.2. PLAXIS results: The same soil properties and type of foundation used in the numerical calculations also used for PLAXIS model. The data used in the programme shown in table 2. The settlement calculations conducted for different types of soil layers in the different sites under the raft foundation. PLAXIS software used to obtain the values of settlement in each site under different added loads (56; 63.5; 68; 75 and 93) kPa.

Figure 8 shows results obtained from PLAXIS software for Al-Hamedat and Al-Rashidia sites of Mosul region. The settlement values for Al-Hamedat with maximum bearing capacity were less than settlement values for Al-Rashidia with minimum bearing capacity but the last value of settlement changed not linearly at Al-Hamedat. For Al-Rashidia the settlement value was linearly change.

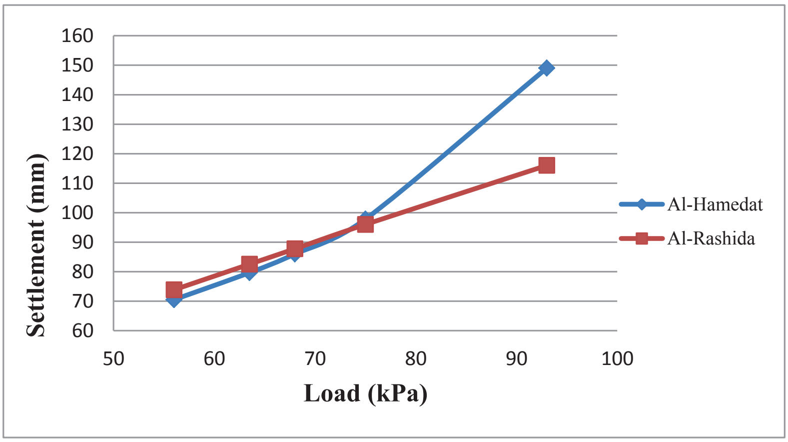


Figure 8: Settlement values for Al-Hamedat and Al-Rashidia sites in Mosul region.

Figure 9 illustrated the results extracted from PLAXIS software for Al-Krada and Al-Jadrea sites in Baghdad region. The settlement values for Al-Krada were less due to the high value of bearing capacity. An Al-Jadrea site had high settlement values due the low value of bearing capacity.

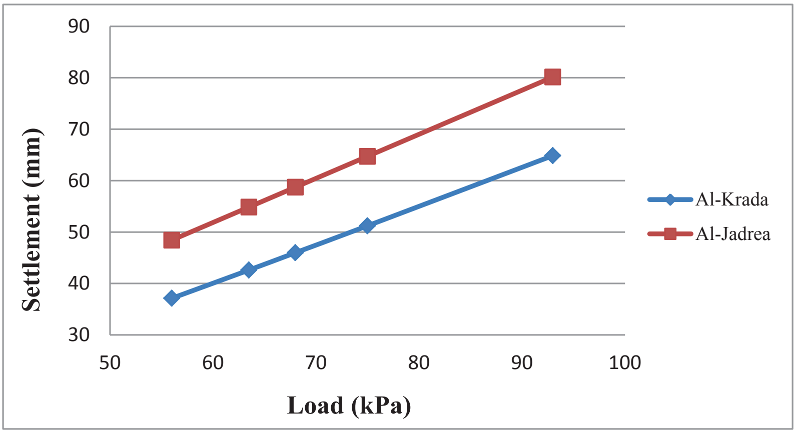


Figure 9: Settlement values for Al-Karada and Al-Jadrea sites in Baghdad region.

Whilst, the results obtained from PLAXIS software for Basrah region (Al-Rumaila and Al-Hartha) illustrated in figure10. The settlement values for Al-Rumaila site increased linearly with low values due to the type of soil layers of sand only and the high bearing capacity value. The settlement values for Al-Hartha site showed very high values and the last two points showed that the soil give high settlement values under the heavy loads. The reason for that is the loose of soil layers and low value of bearing capacity.

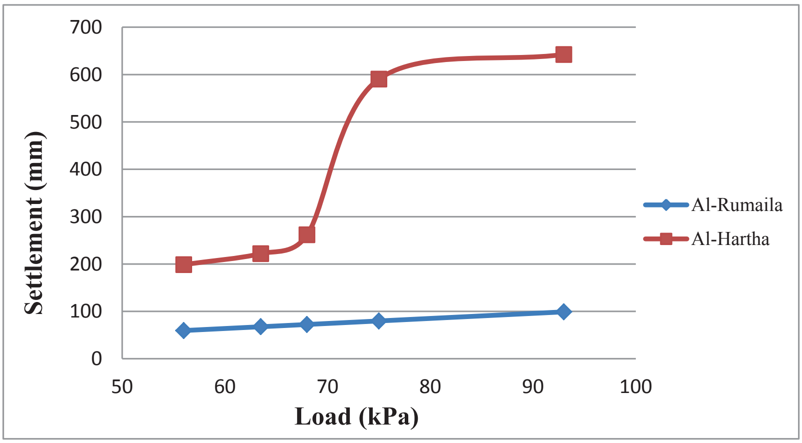


Figure 10: Settlement values for Al-Rumaila and Al-Hartha site in Basra region.

All the sites in the three regions were consisting of soil layers of cohesion and cohesionless type except two sites. Al-Hamedat (Mosul region) which was completely consisting of cohesion soil (brown clay) and Al-Rumaila (Basrah region) was completely consisting of cohesionless soil (sand). Also, the differences in layers of the soil obtained various behaviours under the added loads.

The results obtained from the PLAXIS software were depended on the elastic- plastic behaviour of the soil layers under different added loads. The level of groundwater was stated in the model of each site. Soil parameters which obtained from the experimental tests (field and laboratory) used in the software. The settlement values were affected according to the water content and grain size of the soil that is change depending on the geology and climatic of the locations. The models of soil used in the software were: Hardening soil (HS) and Mohr Coulomb (MC). HS model depends on the stiffness parameter of the soil obtained from the oedometer tests. MC model depends mainly on the elastic parameters are the Modulus of elasticity and the Poison's ratio of the soil. The results presented in Figures 8 show differences in the settlement for the both sites in Mosul region under different added loads due to the different types of soil layers (clay, silty clay and sand). Figure 9 the results were parallel to each other related to the similarity of soil layers types (silty clay, silty sand, sandy silt and sand). For Basrah sites the results shown in Figure 10 were different also due to the soil layers types which is for the lower line the soil type was only sand. The other site was containing silty clay, silty sand and sand of loose soil layers and they collapsed under heavy loads.

Figures 11 and 12 showed the comparison between the settlement values obtained from PLAXIS software for the different sites in the three regions. The comparison show that the values of settlements in figure 11 for Mosul site is the highest value due to the soil layers of clay type with high compressibility. Whilst, Basrah site has a settlement value higher than Baghdad site due to the soil layers of sand type only.

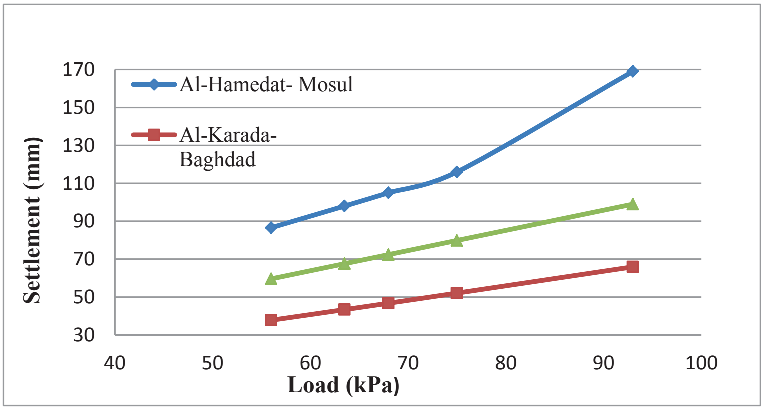


Figure 11: The comparison for PLAXIS results for the maximum bearing capacity values in the three regions.

Figure 12 showed the compressibility of soil for Mosul and Baghdad sites are very close to each other due to their position near the bank of Tigris River. For Basrah site the compressibility of soil very high and the soil has high settlement value under the last two values of loads due to the loose soil layers of low bearing capacity.

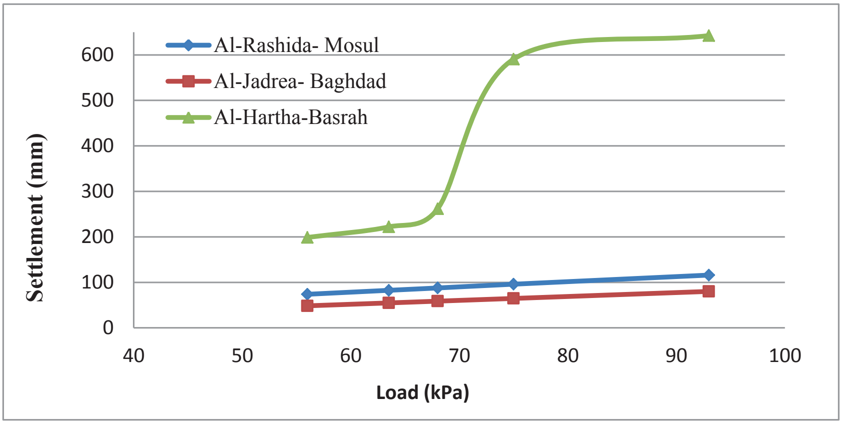


Figure 12: The comparison for PLAXIS results for the min. bearing capacity values in the three regions.

The results obtained from PLAXIS for the Mosul region for the second site was less than the first site for different reasons. That caused by the difference of the soil layers types and the soil models used for the first site which was HS. While for the second site, both HS and MC models were used. Figure 13 show the behaviour of HS, MC models in comparison with the real response of soil. The curves show that the behaviour of MC model is linear; while the HS model behaves non-linearly which is nearly similar to the behaviour of the real soil [*Ehsan, 2013*].

For Baghdad region, results were convergence because the soil types are nearly the same (silty clay and sand). In addition, the results obtained from PLAXIS software were nearly close values because of the convergence in soil types and the models used (HS and MC) for the two sites. While, the results obtained from PLAXIS software for the first site of Basrah region were low values due to the sand soil layers. The settlement values for the second site were very high due to the loose of the soil layers.

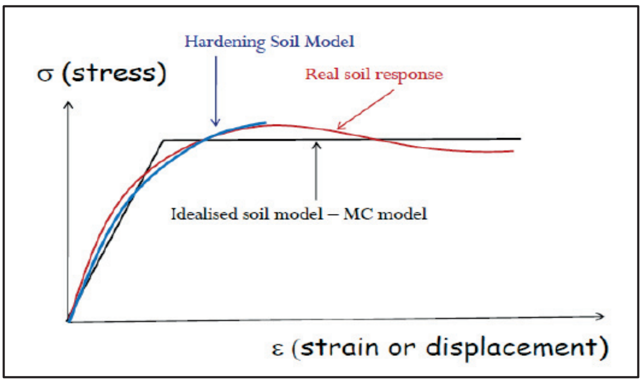


Figure 13: HS, MC and reail soil response comparsions [*Ehsan, 2013*].

5. Conclusions

Numerical and finite element (PLAXIS) methods are means depending on the field and the laboratory tests. They used to estimate the settlement values beneath foundation for different added loads. The results obtained from the numerical calculations for the six sites in the three regions and under different loads were increases linearly. The difference of settlement values were depending on the soil layers types and the level of the ground water also the bearing capacity values. PLAXIS models were an approximation of the reality. The results obtained from PLAXIS software showed the approximate real behaviour for the soil under different loads. The software was using soil parameters of stiffness and strength, depending on the elastic theory and clarifies the elastic- plastic behaviour of the soil layers. PLAXIS results were explaining that soil in some sites of the three regions needed to be improved before implementation of any buildings. Finally, for the numerical calculations the changes of settlement values under different loads were linearly in the six sites but not show the realistic behaviour of the soil. Whilst, PLAXIS software results of settlement values under different loads were not linearly for some sites depending on the layers type and compressibility of soil and ground water level. Also, it shows almost the realistic behaviour of the soil under load. PLAXIS software is a good tool must be used to explain the deformation and soil behaviour under different loads.

References

- Ahmed, M.; Mohamed, M.H.; Mallick, J. and Hasan, M. A. (2014), 3D-Analysis of Soil-Foundation-Structure Interaction in Layered Soil, Open Journal of Civil Engineering, Vol. 4, pp 373-385.

- Ail, S. M. (2012), Hydrogeological Environmental Assessment of Baghdad Area, PhD thesis, College of Science, University of Baghdad, Iraq.

- Akpila, S. B. (2014), bearing capacity and settlement response of raft foundation on sand using standard penetration test method, SENRA Academic Publishers, British Columbia, Canadian journal of pure & applied sciences, Vol. 8, No. 1, pp. 2769-2774.

- Almutury, W. Gh. And Al-Asadi, M. M. (2008), Tectonostratigraphic History of Mesopotamian Passive Margin during Mesozoic and Cenozoic, South Iraq, Journal of Kirkuk University, vol.3, No. 1, pp 31-50.

- Al-Ramthan, A. Q. O. (2012), Using Matlab with Quadrilateral Finite Elements in Analysis of Multi-layered Nonhomogeneous Soils under Strip Footing, Research Journal of Applied Sciences, Engineering and Technology, vol. 4, No. 7, pp 717-723.

- Al-Taie, E.; Al-Ansari, N. ; Saaed, T. E. and Knutsson, S. (2014), Bearing Capacity Affecting the Design of Shallow Foundation in Various Regions of Iraq Using SAP200 & SAFE softwares, Journal of Earth Sciences and Geotechnical Engineering, Vol. 4, No. 4, pp 35-52.

- Al-Taie, E.; Al-Ansari, N. and Knutson, S. (2014), Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i, Engineering, vol.6, pp 292-303.

- Bajad, S. P. and Sahu, R. B. (2012), An experimental Investigation on Interference of piled Rafts in Soft Soil, civil and environmental research journal, India, Vol. 2, No. 2, pp 49-59 www.iiste.org.

- Bowles, J. E. (1996), Foundation Analysis and Design, 5th edition, the McGraw-Hill companies, Inc., USA.
- Brahma, P. and Mukherjee, S.P. (2010), A realistic way to obtain equivalent Young's Modulus of layered soil, Indian geotechnical conference, GEOtredz, IGS Mumbai chapter & IIT Bombay, December 16-18.

- Das, B. M. (2015), Elastic settlement of shallow foundations on granular soil: a critical review, http://gle.wisc.edu/wp-content/uploads/2013/07/Elastic-Settlement-Shallow-Foundations_A-Critical-Review-2.pdf.

- Das, M. B. (2010), Principle of Geotechnical Engineering, 7th edition, Cengage learning, Stamford, USA.

- Ehsan, R. (2013), A study of geotechnical constitutive models used in PLAXIS 2D, ICE G&S Papers Competition, http://www.ice.org.uk/ICE_Web_Portal/media/southeast/Competitions/Raisa-Ehsan-past-paper.pdf .

- Jassim, S. Z. and Goff, J. C. (2006), Geology of Iraq, 1st edition, published by Dolin, Prague and Moravian Museum, Brno, printed in the Czech Republic.

- Kattab, S. A.; Abd, R. S. and Abdulla, B. M. A. (2013), Spatial analysis of some geotechnical properties for the left side of Mosul city using GIS system, Tikrit Journal of Science and Engineering, vol. 20, No. 2, pp 12-17.

- Liu, C. and Evett, J. B. (2008), Soils and Foundations, 7th edition, Pearson prentice Hall, USA.

- Mahmoud, R. A. and Daham, H. A. (2012), expansive Characteristics for surface soils in selected areas of Alfaw city of Basra province / south Iraq, Basra science journal, vol. 2B, No. 38, pp 1-8.

- Murthy, V.N.S. (2002), Geotechnical Engineering: Principles and practices of soil mechanics and foundation engineering, Marcel Dekker Inc., New York, USA.

- PLAXIS Version 2012.02 (2012) Material Manual, Delft University of Technology & PLAXIS, The Netherlands, A. A. Balkema, PUBLISHERS. http://www.plaxis.nl/.

- Shahriar, M. A.; Sivakugan, N.; Urquhart, A.;Tapiolas M. and Das, B. M. (2013), A study on the influence of ground water level on foundation settlement in cohesionless soil, the 18th International conference on soil mechanics and geotechnical engineering, Paris.

- Smith, G. N. and Smith, Ian G. N. (1998), Elements of soil mechanics, 7th edition, Blackwell science, Great Britain.

Paper X

Engineering, 2015, 7, 668-675
Published Online October 2015 in SciRes. http://www.scirp.org/journal/eng
http://dx.doi.org/10.4236/eng.2015.710058

Effect of Material Used in Concrete Mixture on the Foundation Stresses on Soil

Entidhar Al-Taie, Nadhir Al-Ansari, Sven Knutsson

Department of Civil, Environment and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden
Email: Entidhar.altaie@ltu.se, Nadhir.alansari@ltu.se, Sven.Knutsson@ltu.se

Received 23 September 2015; accepted 27 October 2015; published 30 October 2015

Abstract

Sustainable design, green architecture and sustainable construction are new methods for design and construction that are employed for environmental and economic challenges. Clay and bricks proved as sustainable building materials. In this paper, crush brick in the concrete mixture instead of normal coarse aggregate will be used. STAAD Prov8i software was applied for the designed of a hypothetical building in different sites of the three locations in Iraq (Mosul at the north, Baghdad at the center and Basrah at the south). The input model data used in the software were depending on the field and laboratory tests done for twenty three sites in the three locations of Iraq. Concrete properties values were used in the software for concrete mixture with crushed bricks. The results values of base pressure obtained from the software were low for the three locations. The maximum values of base pressure under the foundation for both the average and the minimum bearing capacity values for Mosul region for the normal strength concrete and air-entrained were (94, 84) kPa and (91, 82) kPa respectively, for Baghdad region were (89, 82) kPa and (86, 81) kPa respectively. Finally, for Basrah, the results for the base pressure were (84, 77) kPa and (82, 76) kPa, respectively. The results values of the base pressure were less for all locations compared with the base pressure values obtained from a previous work for the same locations. The use of crushed brick as aggregate in the concrete mixture is economical due to its availability as local material and it is durable materials with low weight.

Keywords

Crush Brick, Sustainable Material, Base Pressure, STAAD Prov8*i* Software, Mud

1. Introduction

Sustainable design, green architecture and sustainable construction are new methods for design and construction

How to cite this paper: Al-Taie, E., Al-Ansari, N. and Knutsson, S. (2015) Effect of Material Used in Concrete Mixture on the Foundation Stresses on Soil. *Engineering*, **7**, 668-675. http://dx.doi.org/10.4236/eng.2015.710058

used for environmental and economic challenges (**Figure 1**). The new buildings are designed and implemented using methods and techniques that contribute to reduction of the impact on the environment and at the same time lead to lower costs and, in particular, cost of operation and maintenance. In the twentieth century, Iraqi constructions started to be influenced by modern trends in planning and architecture. They formed the modern environment but are not characterized by sustainability, due to the mismatch between the goals of urban and the natural reality. Urban growths ignored the various environmental and humanitarian factors when planning new buildings. One of the most sustainable city planning standards must be environmental compatibility and taking into account the technology and renewable energy resources. This has to be the goal in the new urban communities in Arab cities, especially in the desert areas [1]. Many sustainable materials can be used in new cities such as brick, recycling of waste materials, steel structural framing, glass and cladding, etc.

Iraqis from ancient eras used mud in their building and architecture because Mesopotamian soil is muddy and fertile. They used it in different methodologies according to the natureand the function of the building. They used it either in its pure form or by mixing it with other materials such as straw. Also they used it as raw bricks in different ways either for the whole building or parts of it and for the finishing parts such as roofing for instancebable [2].

Now a day, concrete becomes the most widely used construction material. Concrete is a mixture of cement, aggregates (coarse such as stone and fine such as sand) and water. Many researchers studied the effect of replacing natural coarse aggregate by crushed clay bricks on the properties of concrete. Abib, *et al.* [3] has worked on replacing a portion of cement in concrete by clay fired at a temperature of 800˚C to 900˚C. A waste of crushed bricks of 5% has been added to help not only to improve the tensile and the compression, but also to support a better rheological behavior in terms of fluidity and stability, with a low heat of hydration.

Dey, *et al.* [4] worked was due to the leakage in coarse aggregates in some parts of India for which only stone aggregate were used, as a result, the cost of construction raised up. Researchers worked to check the feasibility of using brick aggregates made from locally material mixed with standard concrete (M25 to M55). The major problem faced the researcher was the high water absorption (12% to 20% by mass) of brick aggregates. An experimental work had been made to suggest a realistic solution. Various strength parameters, fire resistance and workability of brick aggregates concrete were checked. The results showed that concrete could be mixed with crushed brick aggregates. The concrete have heat resistance up to 6000˚C.

Bhanbhro, *et al.* [5] studied and evaluated the basic properties of concrete derived from local recycled bricks from Nawabshah city, Pakistan. The results obtained reduced the density up to 16% as compared to regular concrete. Concrete compressive strength obtained using recycled aggregates was 23.2%, 34% and 37% less compared with concrete using regular aggregates for 7, 14 and 28 days of curing period respectively.

Kallak [6] studied the feasibility of used crushed bricks instead of the coarse aggregate (gravel) in concrete. The results obtained from the use of the crushed bricks reduced the strength of concrete. Moreover, the percentage of water to cement ratio increased as well.

Rekha [7] checked the suitability of using low grade recycled aggregates for concrete production. The experiments were performed to find out the effects of high temperatures on the properties of a standard recycled brick aggregates (concrete mix with 25% of crushed clay bricks as a coarse aggregate) and granite aggregate. The two type of aggregates used in the concrete mixture were subjected to temperatures ranging from 100˚C to at an interval of 1000˚C for three hours. The results gave that the concrete mixed with crushed clay bricks performed better than concrete mixed with granite aggregate.

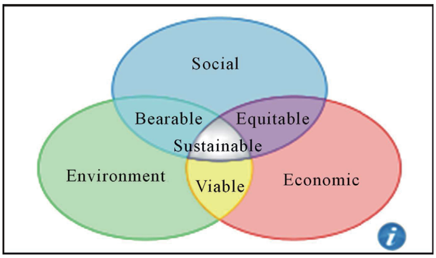


Figure 1. Sustainability plan.

This paper will presented the effect of using crush brick in the concrete mixture as coarse aggregate on the stresses of the foundation on the soil. Design and analysis for a hypothetical building of two stories built using concrete mixed with crush brick was used and analyzed using STAAD Pro*v*8*i* software. The design and the analysis of the building obtained for three locations at Mosul, Baghdad and Basrah at the northern, centeral and southern parts of Iraq. Compressive strength and density of concrete used in the software depending on the results obtained by [8].

2. Methodology

2.1. STAAD Pro*v*8*i* Modelling

STAAD. Pro*v*8*i* is integrated and comprehensive finite element analysis and design software. It is used as a tool for achieving the analysis and design of wide variety types of structures. Three basic activities are to be carried out to achieve the goal. These are: model generation; the calculations to obtain the analytical results and finally, result inquest is to be all facilitated by tools contained in the graphical environment of the software [9]. It is originally developed in Yorba Linda, CA by research engineers international. The software supports several steel, concrete and timber design codes. It can make use of various forms of analysis and use also various forms of dynamic analysis [10]. Moreover, the software is supporting standards of several countries. The procedure of using the software includes modeling the structure, applying properties, specifications, loads and load combinations. Also, it is an effective tool for the three dimensional model analysis and multi-material designs [11]. STAAD. Pro features are a powerful analysis and design engines, visualization tools, user friendly interface, provides an efficient, fast, easy to use and accurate platform for analyzing and designing structures. Various Loads can be used in the software such as Dead load, Live load, Earthquake loads and their suitable combinations [12]. In this work, a hypothetical building of two stories with raft foundation of 25 × 60 m dimensions was designed and analyzed. The dead and live loads used were 53.5 KN/m^2 and 8 KN/m^2 respectively for the three locations (Mosul, Baghdad and Basrah). The design was according to ACI code [13].

Material properties used in the software depended on the tests conducted for concrete mixture using crushed new clay brick as coarse aggregate [8]. Materials used were: ordinary Portland cement (BSI2000a, b; ASTM 1994), fine aggregate, four types of clay bricks and granite. The experimental procedure was designed for concrete mixtures for each of the four new brick aggregates and the granite aggregate. The crushed bricks had been submerged in a bucket of water for a period of 30 min. The aggregate was towelled dried to remove any excess water on the surface of the crush brick [8]. The crushed new brick absorption had values between 6.2% and 12.4% by weight in relation to the material in its dry state. The experiments were performed for five phases to study if the new crushed brick aggregate could be used as a coarse aggregate to produce concrete of a higher strength, normal strength, air-entrained, with varying water/cement ratios, increased workability, concrete without pre-wetting aggregate, and admixtures [8]. The results obtained from all the mixtures phases were for the concrete density of 28 days. Also, Concrete compressive strength obtained for 7, 14, 28 days for all phases. Moreover, the results were obtained for concretes produced with granite as a coarse aggregate. The compressive strength of the new bricks before crushed down into a coarse aggregate, were measured for comparison with the compressive strength of the concrete made with such bricks as aggregates [8]. In this paper the magnitudes of compressive strength and density of concrete for 28 days were used in the software.

2.2. Study Area

Three locations were chosen for the work: Mosul, Baghdad and Basrah (**Figure 2**). These locations have different geological nature.

2.2.1. Mosul Region

This region cover part of the foothill zone and the north part of Al-Jezira desert (**Figure 2**). The region is characterized by its anticlines. Clay soil is covering most of Mosul area and most of the clay is of moderately to highly expansive potentials. Recent sediments include sand; mud and gravel are deposited by Tigris River in addition to deposits of clay soil resulting from weathering processes. As a result of repeated flooding of the Tigris River, deposits consist of clay, silt and sand. Most of soil of the western part of this region (which is part of Jezira zone) is undisturbed Miocene and Pliocene limestone, sandstone, and gypsum [14]-[16].

2.2.2. Baghdad Region

It is located in the central part of Iraq in the upper Mesopotamian zone (**Figure 2**). The land of this region is used extensively since the dawn of civilization till now because of the high population density. The old inhabitants were depending mainly on the agricultural practices. These practices affected the formations of soil having different sequential layers from place to another over the years. Quaternary flood plain sediments cover the area. These deposits are brought by the Tigris and Euphrates rivers. The main component of soil is silt with some clay and sand [17] [18].

2.2.3. Basrah Region

It is located in the southern part of Iraq in the low parts of Mesopotamian plain. The surface of the region is flat and covered by Quaternary fluvial deposits of the Tigris and Euphrates rivers and marsh/lacustrine sediments of southern part of the region. In some area of Basrah region, such as Al-Fao, it is covered with 5 m thick of highly expansive clay [19] [20].

3. Calculations

The design and analysis of a hypothetical building was prepared using STAAD Prov8*i* software for the average and minimum bearing capacity for the three regions (Mosul, Baghdad and Basrah) of Iraq. The results of compressive strength (f'_c) of normal concrete and air-entrained concrete were 37.6 and 52.5 N/mm^2 respectively. While, the density of the normal concrete and air-entrained concrete the concrete were 21.58 and 21.25 kg/m^3 respectively using crush bricks as aggregates in the mixture [8].

The relationship between elastic modulus of concrete and compressive strength was defined as in the ACI code (ACI-318) as follows [21]:

$$E_c = 4734\sqrt{f'_c}\ . \tag{1}$$

The results of calculating modules of elasticity of concrete (E_c) are given in **Table 1**:

Table 1. Results of modules of elasticity of concrete.

Compressive strength of normal concrete (N/mm^2) f'_c	Modules of elasticity of concrete E_c	Compressive strength of air-entrained concrete (N/mm^2) f'_c	Modules of elasticity of concrete E_c
37.6	2.902	2.125	2.9179

Figure 2. Study areas locations on Iraq Map.

The values of the density of concrete and the values of modules of elasticity for both normal strength and air-entrained concrete (from **Table 1**) were used in STAAD Pro software. These values applied for the three locations (Mosul, Baghdad and Basrah) of Iraq.

4. Results and Discussion

The input model data used in the software were depending on the field and laboratory tests done for twenty three sites in the three locations (Mosul, Baghdad and Basrah).

The concrete properties used in software were those obtained by Khalaf (2006). The values of density and modules of elasticity (E_c) for concrete were used for both normal strength and air-entrained concrete in STAAD Pro software. The analysis was carried out for the three regions (Mosul, Baghdad and Basrah) in Iraq and for the average and minimum values of bearing capacity for each region. **Figures 3-5** and **Figure 6** show the results of base pressure under foundation for Mosul locations as an example.

The results for the values of base pressure under foundation for the three locations and for the two types (normal strength and air-entrained) of concrete were lower than that when using standard concrete. This is due to the low density of the concrete mixed with the crush brick for the two types. The density of the standard concrete (according to ACI code) is 2400 kg/m^3. Whilst, the density of concrete used in the software according to ACI code was 235,616 kg/m^3 when using crush brick the concrete density is 8% - 13% less [8]. The base pressure under the foundation in **Figures 3-6** are tabulated in **Table 2** for the three locations of Iraq.

Comparing these results of the base pressure for the three locations with previous work done by [13] using standard concrete, the base pressure values obtained in the previous work [13] were higher than the values obtained in this work as shown in **Table 3**. This is due to the fact that the density of the concrete mixed with crush brick is lower than that in the case of standard concrete. This type of concrete can be useful to be used in choosing the foundation type when there is problem in the soil of the site. It will also reduce the costs of the constructions due to availability of the brick as a local material.

Table 2. Base pressure values for new mixing concrete for the three locations.

Locations		Base pressure value for normal strength (kPa)	Base pressure value for air-entrained (kPa)
Mosul	Average bearing capacity	80	78
	Minimum bearing capacity	77	76
Baghdad	Average bearing capacity	82	77
	Minimum bearing capacity	79	75
Basrah	Average bearing capacity	82	77
	Minimum bearing capacity	77	76

Table 3. Comparison between using standard concrete and new concrete.

Locations		Maximum base pressure value for standard concrete (kPa)	Maximum base pressure value for normal strength (kPa)	Maximum base pressure value for air-entrained (kPa)
Mosul	Average bearing capacity	102	94	91
	Minimum bearing capacity	89	84	82
Baghdad	Average bearing capacity	96	89	86
	Minimum bearing capacity	88	82	81
Basrah	Average bearing capacity	90	84	82
	Minimum bearing capacity	80	77	76

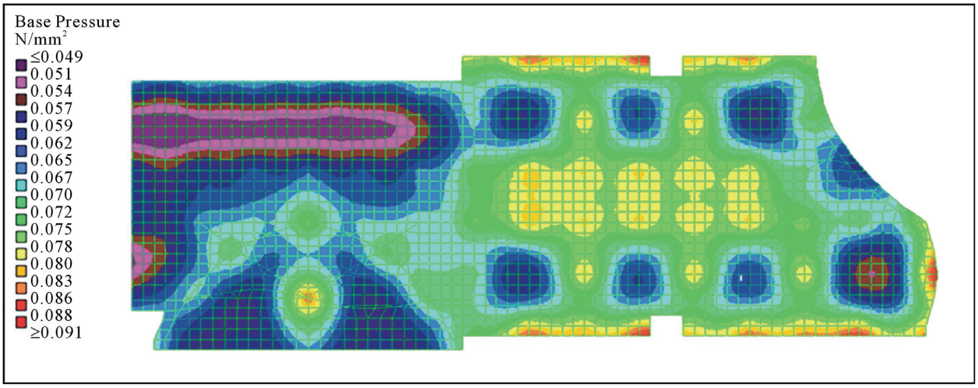


Figure 3. Base pressure distribution using concrete with crush brick as aggregates for air-entrained for Mosul (average value).

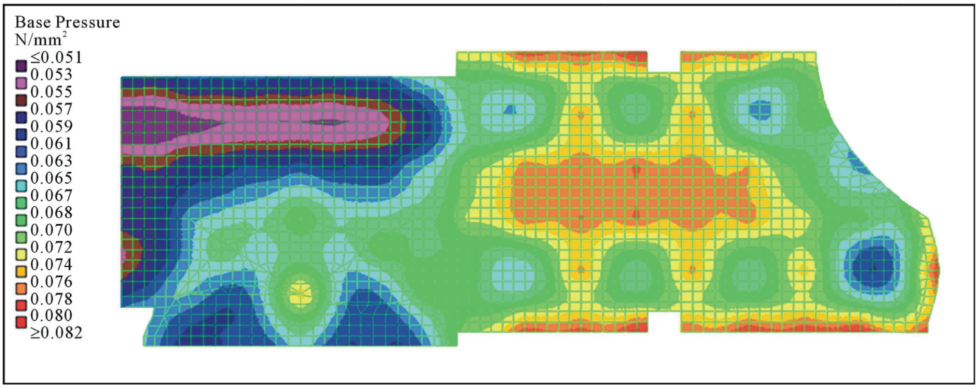


Figure 4. Base pressure distribution using concrete with crush brick as aggregates for air-entrained for Mosul (minimum value).

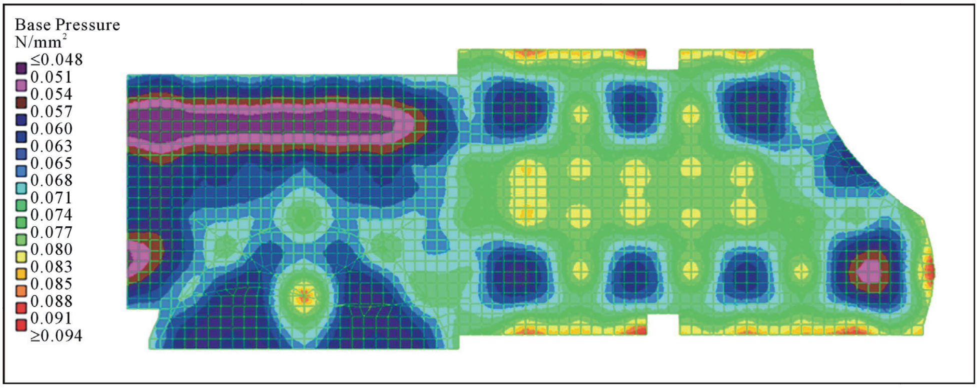


Figure 5. Base pressure distribution using concrete with crush brick as aggregates for normal strength for Mosul (average value).

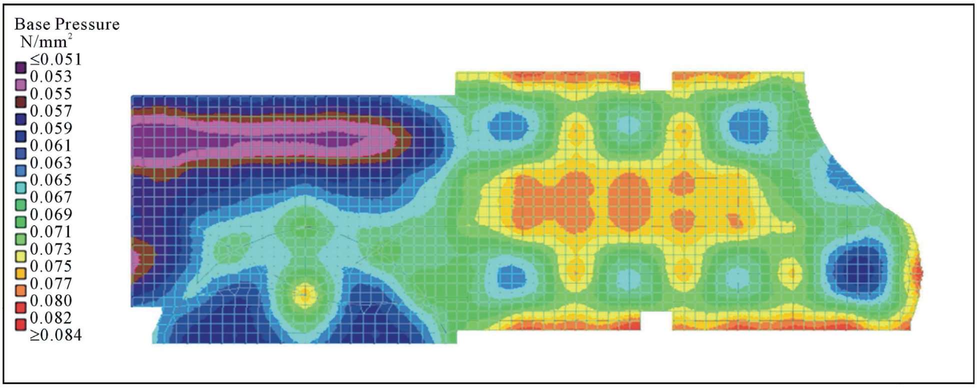


Figure 6. Base pressure distribution using concrete with crush brick as aggregates for normal strength for Mosul (minimum value).

5. Conclusions

Brick is a local sustainable material because clay has been proved as sustainable building materials. The use of crush brick as aggregate in concrete mixture gives lower concrete density relative to the standard concrete. This result is reflected on the stresses (dead loads) of the building on the soil beneath the foundation. Moreover, the size and type of foundation can be reduced and changed, which reduces the costs of buildings.

STAAD Prov8*i* software used to design and analysis a hypothetical building in the three regions of Iraq (Mosul, Baghdad and Basrah). The results showed that the base pressure under the foundation was less compared with the previous work for all locations using standard concrete. Use of crush brick is economical due to it is availability as local material, durability and low prices.

References

[1] Kamel, M.S. (2010) Cities Constructions towards a Better Future. *First Arabic Construction Conference*, The League of Arab States, 23-26 December 2010, Cairo.

[2] Abdul Razzaq, N.K. (2012) Planning and Design Characteristics of the Buildings and Settlements of Mud in Iraq. *Journal of Planned and Development*, **25**, 93-111.

[3] Abib, Z.E., Gaher-Abib, H. and Kharchi, F. (2013) Effect of Clay Fines on the Behavior of Self-Compacting Concrete. *Engineering*, **5**, 213-218. http://www.scirp.org/journal/eng

[4] Dey, G. and Pal, J. (2013) Use of Brick Aggregate in Standard Concrete and Its Performance in Elevated Temperature. *IACSIT International Journal of Engineering and Technology*, **5**, 523-526. http://dx.doi.org/10.7763/IJET.2013.V5.610

[5] Bhanbhro, R., Memon, I., Ansari, A., Shah, A. and Memon, B.A. (2014) Properties Evaluation of Concrete Using Local Used Bricks as Coarse Aggregate. *Engineering*, **6**, 211-216. http://www.scirp.org/journal/eng

[6] Kallak, F.S. (2009) Use of Crushed Bricks as Coarse Aggregate in Concrete. *Tikrit Journal of Engineering Sciences*, **16**, 64-69.

[7] Rekha, K. and Potharaju, M. (2015) Residual Compressive Strength of Recycled Brick Aggregate Concrete at High Temperatures. *International Journal of Emerging Technology and Advanced Engineering*, **5**, 159-164.

[8] Khalaf, F.M. (2006) Using Crushed Clay Brick as Coarse Aggregate in Concrete. *Journal of Materials in Civil Engineering*, **18**, 518-526.

[9] Arya, U., Hussain, A. and Khan, W. (2014) Wind Analysis of Building Frames on Sloping Ground. *International Journal of Scientific and Research Publications*, **4**, 1-7.

[10] Subramani, T. and Ponnuvel, D. (2012) Seismic and Stability Analysis of Gravity Dams Using Staad PRO. *International Journal of Engineering Research and Development*, **1**, 44-54.

[11] Meera, C.M. (213) Pre-Engineered Building Design of an Industrial Warehouse. *International Journal of Engineering Sciences & Emerging Technologies*, **5**, 75-82.

[12] Thakur, A. and Singh, A. (2014) Comparative Analysis of a Multi Storied Residential Building with a without Shear

Wall Using STADD Pro. *International Journal of Recent Research Aspects*, **1**, 54-57.

[13] Al-Taie, E., Al-Ansari, N. and Knutsson, S. (2014) Effect of Bearing Capacity on Designing Foundations in Iraq Using STAAD Pro-v8i. *Engineering*, **6**, 292-303. http://dx.doi.org/10.4236/eng.2014.66033

[14] Al-Juboury, A.I., Ghazal, M.M. and Mccann, T. (2009) Detrital Chromian Spinels from Miocene and Holocene Sediments of Northern Iraq: Provenance Implications. *Journal of Geosciences*, **54**, 289-300.

[15] Kattab, S.A., Abd, R.S. and Abdulla, B.M.A. (2013) Spatial Analysis of Some Geotechnical Properties for the Left Side of Mosul City Using GIS System. *Tikrit Journal of Science and Engineering*, **20**, 12-17.

[16] Al-Dewachi, B.M. (2005) Origin of Caves in Quaternary Fluvial Deposits at the Left Side of Mosul City-Iraq. *Iraqi Journal of Earth Science*, **5**, 58-67.

[17] Ail, S.M. (2012) Hydrogeological Environmental Assessment of Baghdad Area. Ph.D. Thesis, College of Science, University of Baghdad, Iraq.

[18] Al-Taie, E., Al-Ansari, N. and Knutsson, S. (2014) Bearing Capacity Affecting the Design of Shallow Foundation in Various Regions of Iraq Using SAP200 & SAFE Softwares. *Journal of Earth Sciences and Geotechnical Engineering*, **4**, 35-52.

[19] Mahmoud, R.A. and Daham, H.A. (2012) expansive Characteristics for Surface Soils in Selected Areas of Alfaw City of Basra Province/South Iraq. *Basra Science Journal*, **2B**, 1-8.

[20] Almutury, W.Gh. and Al-Asadi, M.M. (2008) Tectonostratigraphic History of Mesopotamian Passive Margin during Mesozoic and Cenozoic, South Iraq. *Journal of Kirkuk University*, **3**, 31-50.

[21] Anbuvelan, K. and Subramanian, K. (2014) An Empirical Relationship between Modulus of Elasticity, Modulus of Rupture and Compressive Strength of M60 Concrete Containing Metakaolin. *Research Journal of Applied Sciences, Engineering and Technology*, **8**, 1294-1298.