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Behavior of Single Franki Pile in Gypseous Soil

A Thesis Submitted to the Council of the College of Engineering, University of Diyala in Partial Fulfillment of the Requirements of the Degree of Master of Science in Civil Engineering

by
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Dedicated to

My beloved mother who always
Supports me,
My dear father who always encourages and
stands beside me,
My dearest sister and brothers
Thanks for being supportive and patient with
me

Acknowledgments

All praise for Al-Mighty Allah, without Allah's kindness I can't complete this work alone.

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Last but not least, I would like to express my deep gratitude to my dear family for being patient with me all the time and helping me whenever I need. Thanks for their endless love that helped me to move on especially in the hard days.

ABSTRACT

Deep foundations such as piles are adopted in case of weak soil or when the type of soil in the site is not able to resist the external loadings from superstructure or collapsible soil. Therefore, using pile to resist the load as friction resistance or construct pile to reach the hard layer passing the weak soil.

Gypseuos soil is defined as that soil which contains calcium sulphates in sufficient quantity Such soil make big problems in the super-structure in case of becoming wet due to the dissolving of pypum salts that causes large settlements and sudden failure because of decrease in strength capacity of the soil.

One of the most significant piles foundations is Franki pile that is used in cases of need for high capacity, cast in situ and cost-wise where granular soil types of external loads that the pile can sustain such as compression and tension on the design of pile and on the real behavior of soil-structure interaction.

This study focuses on studying the behavior of a single bored Franki pile in gypseous soils in dry and soaking conditions to examine the effect of increasing the diameter bulbous base on the ultimate bearing capacity of pile where the increments ratio of   bulb diameter to shaft diameter of pile $(D_{bulb}/d_{pile}) were$(1.5,2 and 2.5) in the three samples of gypseous soil with three different gypsum contents (S1=30%, S2=46%, S3=66%) and comparing the results with normal pile with a shaft diameter (d=1cm).

The study also studies the effect of slenderness ratio (L/d) (20, and 25) on pile with highest bearing resistance in dry and soaking conditions. The soaking time term is 24 hours.

The test results illustrate that the load bearing of pile increases with increasing (D_{bulb}/d_{pile}) in S1, S2 and S3 for dry and soaking conditions. Increasing the slenderness ratio (L/d) (20, 25) led to increasing pile load bearing for highest load bearing$(D_{bulb}/d_{pile})(2.5)$. The highest reduction due to the presence of water in pile bearing load is for pile with $(D_{bulb}/d_{pile})(2.5)$ in three samples of soil (85.3% for S1, 88% for S2 and 89.1%) respectively.

COMMITTEE DECISION

We certify that we have read the thesis entitled **(Behavior of Franki Pile in Gypseous Soil)** and we have examined the student **(Amani Mizher Zeadan)** in its content and what is related with it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

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Scientific Amendment

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Different types of foundations are adopted under super-structural buildings to transfer the loadings into the soil layers. Many types of soil underneath the foundations relay on soil properties, mechanical properties, particle size and others. The main function of pile foundation is to transfer the applied loading to the deep soil layer. The pile foundation is adopted in many projects due to weak soil layers under the natural ground level, increased stability especially in high buildings, heavy external loadings and when the water table is near the ground surface.

One of the most significant piles foundations is Franki pile that is used in cases of need of high capacity, cast in situ, cost wise, and there is no need for excavation or dewatering in granular soil.

Gypseous soil can be defined as that soil which contains calcium sulphates in sufficient quantity. Gypseous soil causes big problems in the super-structure when becoming wet due to dissolvent of gypsum that causes large settlements and sudden failure because of decrease in strength capacity of the soil.

2.2 Types of piles

Pile is defined as deep foundation that is used in cases when traditional shallow foundations are not possible. The classification of pile foundation is based on its functions as bearing, friction or both. It can also be is classified as materials such as concrete, precast, steel and composite in case of permanent case, also in shape like circular or square such as precast pile and the methodology of setup such as cast in situ or driven.

The main functions of piles are to withstand the gravity and lateral loadings, control of ground movement and to prevent settlement. The pile selection type relies on different parameters such as soil conditions, super-structural loadings, cost-wise, site conditions and pile type availability in market.

Piles are adopted to resist the up lift and lateral loadings in addition to compression loads. Piles have also the advantage of controlling the ground movements. In case of less soil cohesion, piles compact this type of soil and then enhance it to reduce soil settlement.

There are different parameters that effect the pile type selection such as soil conditions, loads transfer from super-structure to the foundation, cost effects and the availability of piles in the local markets.

2.3 Piles setup

The methods of pile setup affect pile capacity. Different studies dealt with and described the methodology of piles installations. The driven pile gave more capacity than other piles such as bored piles (Meyerhof, 1976), while (Ropert, 1997), declared that there are no differences in pile capacities.

Pile capacity embedded in sand soil gave more strength capacity than driven pile (Wang, 2009). Different methods were applied in situ to install the driven pile as by dropping weight that is preoperational with pile capacity, vibration, jack or boring. In case of bored pile, the machine bore the hole and then the required reinforcement insert base on the design and then concrete fills the overall hole.

2.4 Franki pile

Franki pile is defined as a driven pile that is casted in site concrete displacement pile with an enlarged base in dry concrete and a cylindrical shaft. The benefit of such pile was classified as optimal geotechnical solution for different types of soil, especially for weak soil. The general technical specifications of Franki pile are; the cross sectional area at the base is equal to twice of the pile sectional area, in which the pile diameter is up to 609 mm. The maximum allowable capacity of pile is around 2250 kN and the pile shaft is filled by dry concrete. Franki pile has excellent tensile and compressive strength capacity. (Tomlinson, and Woodward, 2015).

2.5 Pile capacity

Different methods were available to estimate the strength capacity of piles. Experimental test is the best approach to expect the pile capacity as under real conditions. Some exact and empirical formula were also adopted by design engineering to predict the pile capacity.

Pile strength capacity under the effect of compression load is applied as static load Fellenius (2009), the estimated formula is as follows:

$$P_t = P_b + P_s \qquad \ldots\ldots\ldots\ldots\ldots \qquad (2.1)$$

In which, P_t is the total pile capacity, P_b is the bearing pile capacity and $P_s$is the skin pile capacity. The strength of pile capacity relies on the base area of the pile and bearing capacity underneath the bottom face of the pile in case of bearing load. Another parameter that influences pile capacity is the skin friction that depends on the surface area of the pile and the skin friction parameter. In case of Franki pile, the strength capacity, due to its powerful driving method during installation, can penetrate stiff soils and reach large depths. Because of the explosive dry concrete plug, the soil improved around the surrounding surface of the pile makes increases the bearing capacity.

The failure load in case of Franki pile depends on many parameters such as soil properties surrounding the pile, volume of bubble and compressive strength of concrete. The best way to determine the Franki pile capacity is in-situ test by applying static load and recording the settlement for each step load. Load – settlement curve is then drawn and the average of three blows will be counted so that the pile capacity is determined .Prakash and Sharma (1990).

The Franki pile is designed for a characteristic action as the axial pile resistance in which) several techniques have been developed for the design of Franki piles. In this study, the empirical relationship of Nordlund (1982) was used to assess the allowable pile end bearing capacity, (Qb) all, utilizing available pile driving records, through:

$$(\boldsymbol{Q_p})_{\boldsymbol{all}} = \boldsymbol{W} * \boldsymbol{H} * \frac{\boldsymbol{N} * (\boldsymbol{V})^{\frac{2}{3}}}{\boldsymbol{K}} \quad \dots\dots\dots\dots\dots \quad (\mathbf{2.2})$$

Where: (Qp)all is the allowable pile tip capacity with a factor of safety W is the hammer weight used for pile base formation (lb);H is the drop height of the used hammer (ft.); N is the number of blows needed to ram concrete into the ground ;V is the bulk volume of the base (ft3); and K is a factor that depends on soil type.

The ultimate friction resistance along the pile shaft can be assessed through:

$$\boldsymbol{Q_f} = \boldsymbol{C_a} * \boldsymbol{P} * \boldsymbol{L} \qquad \dots\dots\dots\dots\dots \quad (\mathbf{2.3})$$

Where: Ca is the adhesion resistance between the soil and pile material; P is the pile perimeter; and L is the pile embedment depth.

2.6 Construction methodology of Franki pile

The methodology steps to install Franki pile start from levelling the tube at position in which the water-tight gravel plug is placed in the bottom to prevent the soil or water to enter inside the tube. The second step is bottom drive on the plug by hammer to compress the strata of the soil. Then inserting dry concrete inside the tube after exploding the plug. This is followed by the setup and placing the main reinforcement inside the tube before finishing the dry concrete operation. After that, completing the concrete operation and then withdrawing and recovery of the derived tube therefore the construction of Franki piles usually passes through three stages (Prakash and Sharma 1990):

1. Driving a steel casing to the pile foundation depth;
2. Construction of the concrete base (bulb); and
3. Shaft construction.

Figure (2.1) explain the steps of franki pile construction:

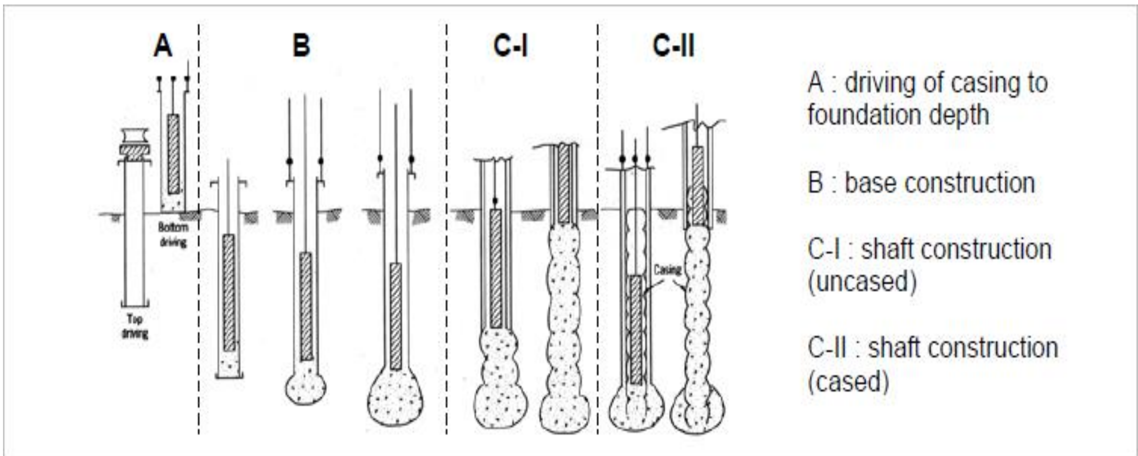


plate (2.1) details of construction of Franki piles. (modified from Prakash and Sharma 1990

2.7 Franki pile test

The full behavior and test methodology of Franki pile in situ as full scale prototype. The load as tensile or compressive loads was applied and the settlements are recorded for each load step. Load settlements curve was drawn for each pile test or cycle. The soil at the bulb is known so that the volume of the bulb and the average progress of the last three blows can predict the limit load of the pile on the spot of the pile driving. (Prakash and Sharma ,1990)

2.8 Gypseous Soils

There are studies specifying the gypseous soil classifications, such as:

1. Jennings and Knight (1975), and ASTM who determine the problem severity depends on the C.P% and Ie %. Value depends on the results of odometer test, and value of collapse potential earned:

Table (2.1) Degree of Collapse by Two Methods (Al-Lamy, 2008)

Jennings and Knight, 1975		ASTM (D 5333-2003) standard	
Problem Severity	C.P%, Jennings and Knight (1975)	Severity problem	Ie %, ASTM D5333 (2003)
Non	0-1	Non	0
Moderate	1- 5	Slight	0.1-2
Trouble	5-10	Moderate	2.1-6
Sever	10-20	Moderately Sever	6.1-10
Very Sever Trouble	>20	Sever	>10

2. Van Alphen and Romero (1971) who express the phrase “Gypsiferous soils” which is a soil with gypsum component more than 2%.

3. Saaed and Khorshid (1989) who express that Gypseous soils are soils with gypsum component more than 6%.

4. Boyadgiev and Verheye (1996) who show that when the gypsum component is more than 15%, the soil composition of soil will be unstable.

5. Nashat (1990) proposes that when the soil included 3% or more of gypsum content, it is called gypseous soil, and proposes the classification of gypseous soil as shown in table (2.2).

Table (2.2) Classification of gypsum soil by Nashat (1990)

Gypsum content (%)	Classification
0 – 10	Slightly
10 – 25	Moderately
25–50	Highly
>50	Gypcrete

2.9 Gypseous Soil Distribution in Iraq

Al Barazanji (1973) specified the allocation of gypseous in Iraq; gypseous soils spread on a large area of Iraq in at about 12.2% of the total area of Iraq, as shown in Fig. (2.1) and (2.2). Al-Barzanji (1986), Nashat (1990), Ismael (1993), Al-Mufty (1997) and Al-Obaidi (2003 and 2014)

In Iraq, the gypsous soil is spread in the northwestern, southwestern and western areas forming about (20% to 30%) of the Iraqi total area.

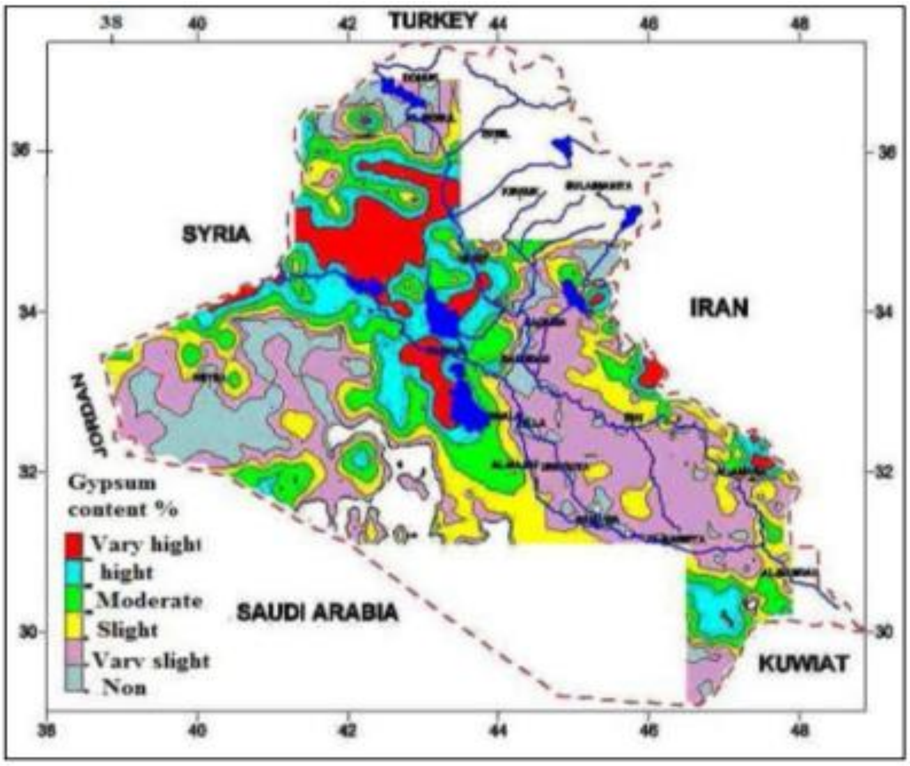


Figure (2.1) Distribution of Gypseous Soils in Iraq, at depth (250-1500) (Alkaabi, 2007).

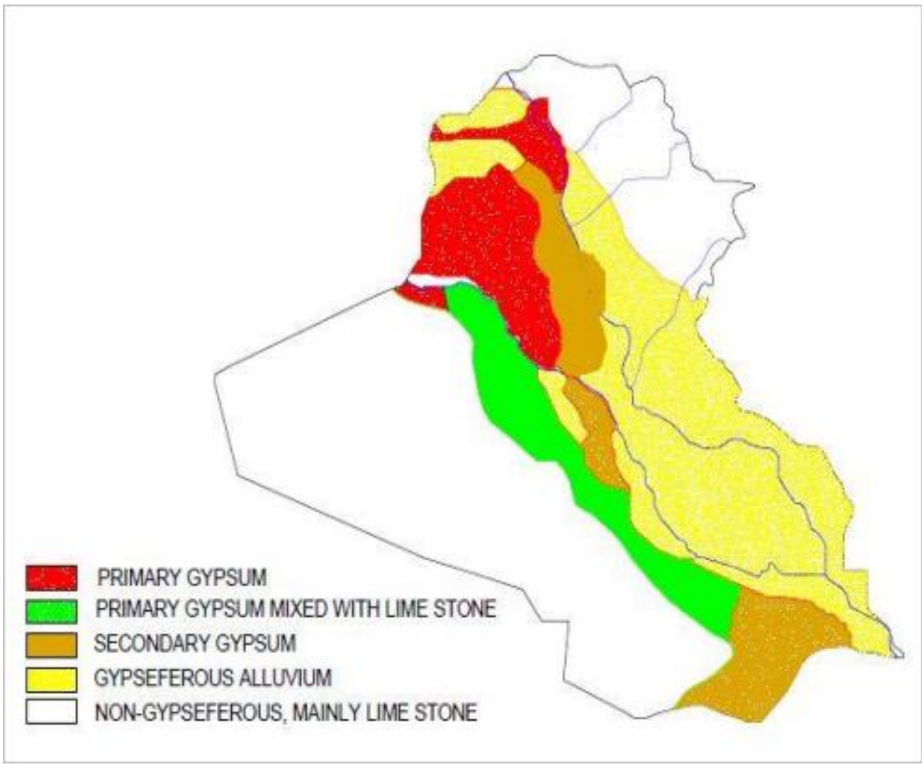


Figure (2.2)Distribution of gypsum in Iraq (after Buringh, 1960)

2.10 Collapse Mechanism

The ingrates of collapsing soil are silt, sand, or any other material presented in the honeycomb shape established in plate (2.2). Besides that, these materials are tied by water in tension and small amount of clay or another binding. (Dudley, 1970),(Barden et al., 1973).

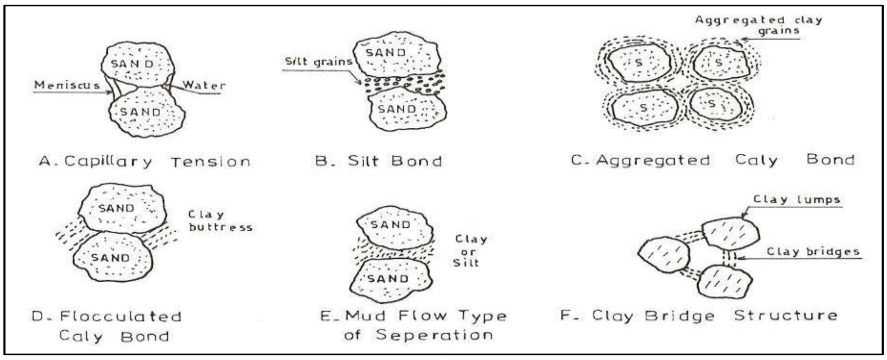
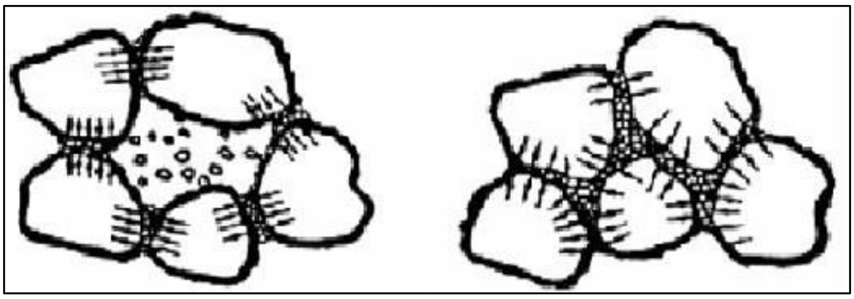


Plate (2.2) Structure of Collapsible Soil (Clemence and Finbarr, 1981).

Plate (2.3) shows the weak arrangement of particles that are collected and linked by brittle bonds, such as the bonds of water atoms, clay or calcium carbonate. When the soil remains dry, the high capacity of soil which makes the soil support large weight is due to these bonds. But, these bonds are destroyed when the soil is flooded with water, resulting in sudden collapse of soil.



(a) (b)

Plate (2.3) Structure of The Collapsible Soils **(a)** Loaded Structure Before Soaking, **(b)**After Soaking. (Houston, et al., 1988).

2.11 Collapsibility of gypsum soil

The collapse of soil can be defined, according to ASTM D 5333-03, as the drop that happens in the height of soil confined after being exposed to water at a constant perpendicular stress. As mentioned above, the gypseous soils have a high resistance to stress in case of dryness, but these soils become weak when they are watered or flooded causing many structural problems such as sudden failure to the structures which are built on due to the dissolving of gypsum salts and losing bonds between the soil particle which forms an opening through the soil.

Several studies described collapsibility of gypsum soil Petrokhin and Boldyrev (1978) calculated the amount of gypseous soil collapsibility in field by using plate load method. In this study, they found that collapse occurs in gypseous sand soil due to the presence of water and the value of collapse settlement is 50% of the settlement of plate used in the study.

Al-Mohammadi, et al. (1987) dealt with the gypsiferous soils behavior the results of this study specified that the value of collapse potential can be suspended due to some factors related to gypseous soil structure like void ratio, equal distribution of stress, type of gypseous and the grain size rounded.

Seleam (1988) and Nashat (1990) showed that the amount of potential for gypseous soils exposed to constant stress 200 kPa increases with the increase of gypsum content for the soil collapse.

Seleam (1988) illustrated that the gypseous sandy soil with collapse potential (0.7- 4.4) is considered a moderate collapse due to gypsum content, also the gypseous soil had same collapse potential (13%) in both cases of leaching and flooding which leads to dissolving problems. These problems happen as a result of water flow through the soil (leaching process) which causes dissolution and broke the bond in the soil structure.

Al-Nouri and Al-Qaissy (1990) conducted numerous experimental tests on cohesive soil with different quantity of gypsum content ranging from low, medium, to high gypsferios content. Those experimental tests showed that when the content of gypsum ranges from moderate to high, it causes decrease in the collapse potential.

Basma and Tuncer (1992) showed that the value of the collapse ability decreases with the increase in the saturation degree.

Nashat, et al. (2001) concluded that soaking of dry or partially saturated soil with water leads to failure in the gypseous soil, and also showed other parameters effecting on soil collapsibility like pressure of water used in soaking process, initial water content, void ratio, gypsum content and time of constant loads.

Al-Saoudi and Al-Sheikha (2001) remarks the value of collapse earned from leaching process is more than that which was earned from soaking, particularly in case of high hydraulic gradient.

The value of collapse which happens in the soil mass depends on many factors, like soil type, the gypsum content, the value of stress at soaking, water content for soil, compaction degree, and the presence of clay (Ayadat and Hanna, 2007).

2.12 <u>Behavior of Gypseous soil under soaking cases</u>

Mikheev, et al. (1977) referred to the notion that compressibility of gypsum soil in field depends on plate load test when the soil is exposed to static load in wet condition.The result of soils settlement are ranging from (76%-91%) of settlement of plate due to dissolution of gypsum content.

Petrukhin and Boldyrev (1978) illustrated the influence of water inundating (in two cases short and long term) on gypsum soil.The result showed that the long term flooding made a settlement of gypseous soil more than in short term flooding due to the removal of gypsum content, as well as the settlement amount related to some parameters such as soil type, gypsum content and relative amount of salt leaching.

Akili and Torrance (1981) explained that rain filtration causes the dissolution of the cementing bond i.e., calcium carbonate and gypsum. The dissolution produced a lack in the soil strength suddenly.

Clemence and Finbarr (1981) showed that the collapsible soil misses the strength which links between the soils particles as result of water presence.

Barazanji (1984) dealt with the infiltration characteristics of gypseous soil in Al-Jazira inundating project and also explained that the infiltration rate increases with the increase of gypsum quantity in soil.

Al-Kuzaie (1985) specified that dissolving gypsum and the soluble salt gypsum removal along with the removal of other soluble salts causes a reduction in the value of parameter shear strength (C,Ø) Therefore, reducing the linked shear strength.

Al Mohammadi, et al., (1987) showed that gypsum soil turned to soft state that led to a sudden collapse in the structure build on these types of soil in case of presence of water where the last leads to dissolve the links between particles of soil.

Subhi (1987); Razouki, et al., (1994) illustrated that remove of gypsum content produce dissolution of the gypsum with water leads to produce caves and/or sudden settlements, hastening flows and leading then to weakness in foundation.

Sirwan, et al., (1989); and Razuki, et al., (1994) specified that water presence produces reduction in Ø.

Nashat (1990) investigated the properties and behavior of gypseous soil from three areas in Iraq (Baiji, Tellafer, and Al-Dor). The results specified a reduction in shear strength and sudden value of settlement due to soaking and leaching.

Al-Mohammadi, et al. (1990) showed that reduction occurs to the shear strength parameters of gypseous soil due to water soaking.

Al-Ani and Seleam (1993) explored the influence of pressure of flood and water content on the geotechnical properties of gypseous soils. The results showed that a rise in water content of gypseous soil leads to decrease potential collapse and hence the reduction of compression index and volumetric strain.

Al-Busoda (1999) and Hussien (2012) investigated about adding water to gypsum soil which lead to sudden settlement in soil as a result of breaking the links which associate the soil particles because of the addition of water.

Al-Dulaimi (2004) and Hussein (2012) specified that wetting the gypsum soil with water led to the reduction in the cohesion of soil as a result of gypsum salt dissolution.

Depending on the results of experimental procedure, Nouaouria, et al. (2008) showed that high pressure floods cause excessive collapse strain.

Therefore, the presence of water and gypsum salt in the soil result in a serious troubles. The gypsum soil affects the foundation of the structure built on this type of soil as a result of dissolution of gypsum salt which causes sudden collapse and that all lead to partial settlement of footing or titling the building.

2.13 Previous studies of piles in gypseous soils

Numbers of researchers have studied the behavior of pile embedded in gypseous soil:

Zakaria (2013) investigated the variations of settlement with time for prototype steel piles embedded in gypsum soil. The adopted methodology was to apply load to the pile up to 70% from the ultimate load pile capacity, the soil was socked for two hours and then it was leached with water for 7 days. Different parameters were considered such as gypsum ratio as 10, 20, 30, 50 and 70 percent and graded sand. The test results showed that the small settlements in case of the percentages of gypsum were less than 20% and the recorded maximum settlement was when the gypsum is 70%. The behavior of the settlements with time looks like S shape. The results of his study are shown in Figure (2.3).

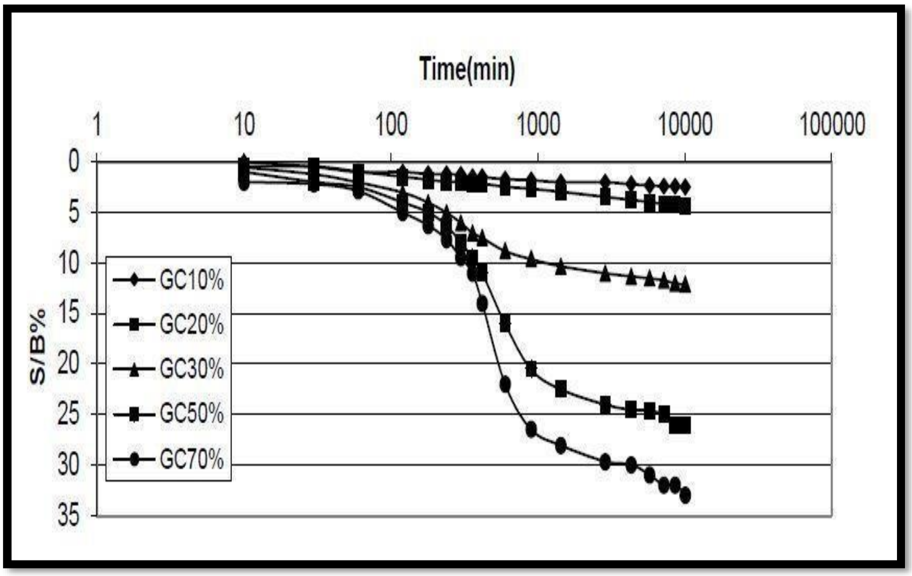


Figure (2.3) Time-S/B% relationships (Zakaria, 2013)

Al-Busoda and Al-Rubaye (2015) looked out to the full capacity of existing reinforced concrete bored pile that was embedded in gypseous soil. The pile was embedded in soil with 42% of gypsum, then axial compression load was applied and the load-settlements were recorded. Different methodologies were adopted to calculate the bearing capacity of the pile. The comparison results indicated that chen's approach for all tests was accepted as results for all prototype steel pile. The drawdown occurring to pile resistance reached to 45%. The amount of final settlement that occurs with gypseous soil (11.02mm) was greater than the final settlement which occurred with pile (9.18mm). The results of their study are shown in Figures (2.4) and (2.5).

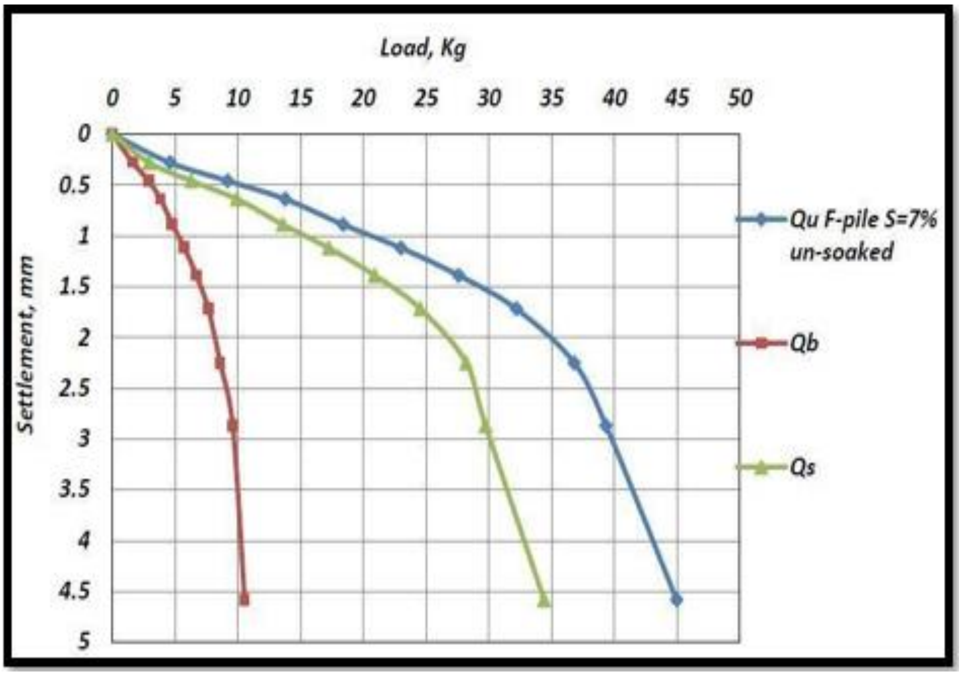


Figure (2.4) Compression load- settlement relationship of pile embedded in gypseous soil in un-soaked case (Al-Busoda and Al- Rubaye, 2015)

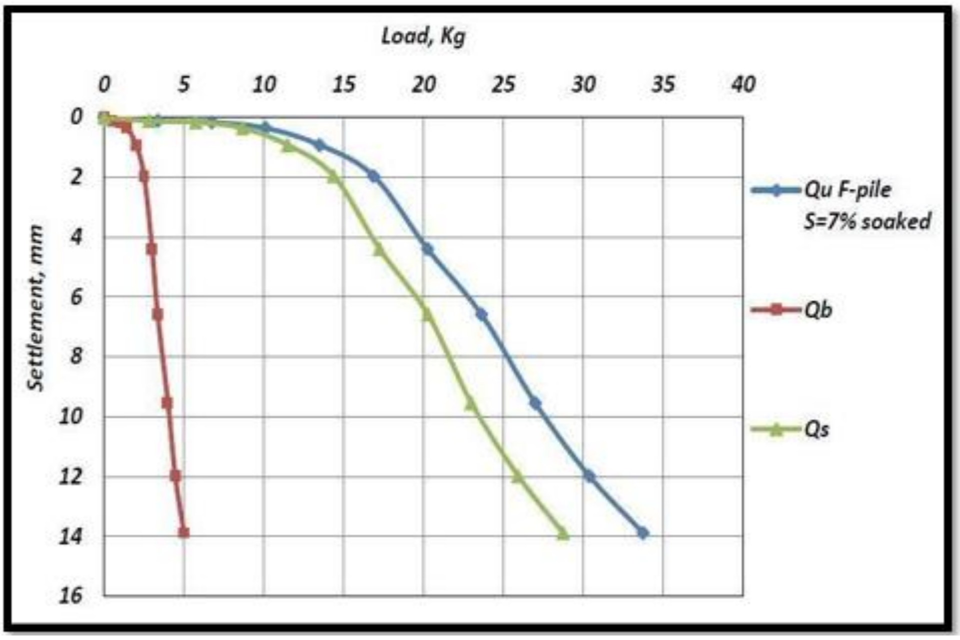


Figure (2.5) Compression load- settlement relationship of pile embedded in gypseous soil in soaked case (Al-Busoda and Al-Rubaye, 2015)

M. R. Mahmood (2017) investigated the behavior of the concrete pile raft embedded in gypseous soil in different conditions such as dryness and socking. Different parameters were taken into account such as pile length, pile configurations grouping such as single, three and six piles, and the contact of pile raft with soil. The small scale prototype was setup inside box with dimensions 600x600x750 mm with pile lengths as 400 and 450 mm with 20 mm in diameter.

The test results indicated that in the case of dry soil, the gypseous soil gave high capacity with some reduced settlements and the pile raft showed more efficiency. The load capacity was enhanced by 16% and 39% and the settlements were reduced by 18% and 45% for single and group piles respectively due to the presence of the bearing layer of dense sand below the gypseous soil as shown in figure (2.6) and (2.7).

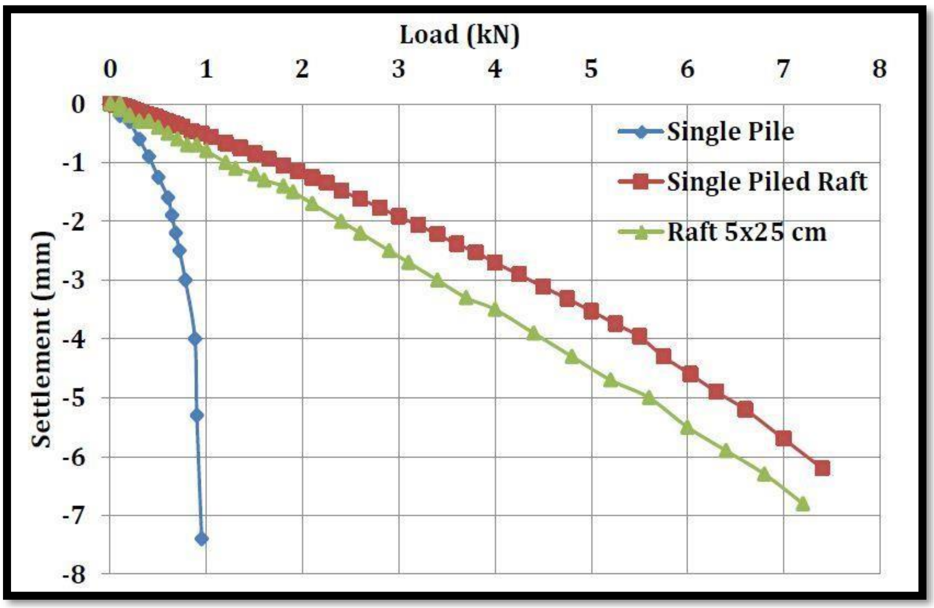


Figure (2.6) Compression load- settlement relationship for raft, single pile and single piled raft in dry case (Mahmood, 2015)

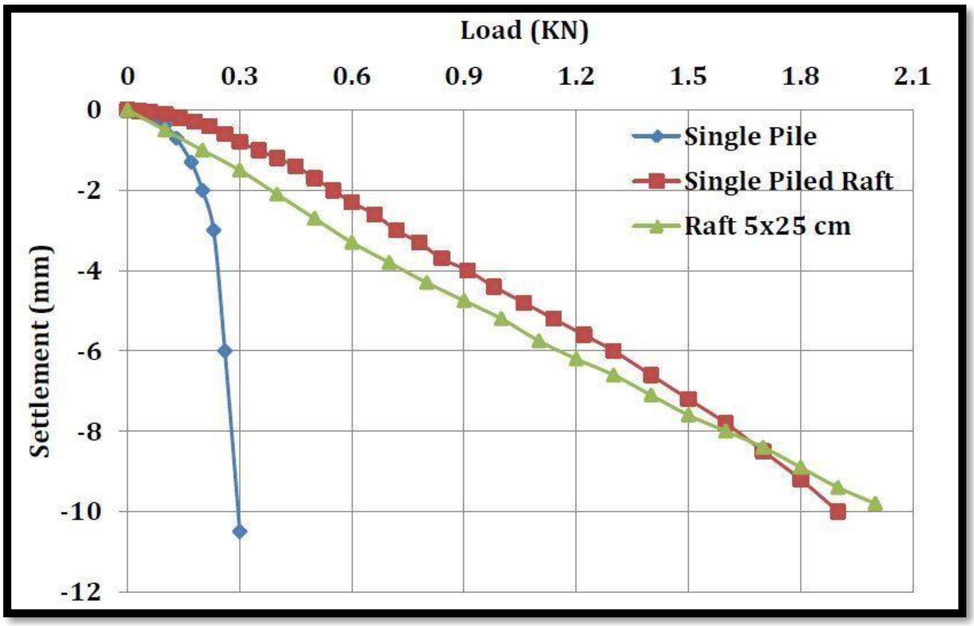


Figure (2.7) Compression load- settlement relationship for raft, single pile and single piles raft in the soaking case (Mahmood, 2015)

Abd-Awn, and Hussein, (2018) investigated the behavior of different piles that were manufactured from different materials such as concrete, steel and timber and embedded in gypsum soil under the effect of tensile loads. The piles were planted in dried and soaked soils. Different parameters were considered such as the presence of gypsum as 30, 46, and 66%, slenderness ratio (length to diameter ratio) such as 10, 15, 20 and 25 and different cross sectional area of piles. The test results showed that when the slenderness ratio increased there was an increase in piles strength capacity. Piles resistance increased with the increase of gypsum content as shown in figure (2.8) and (2.9).

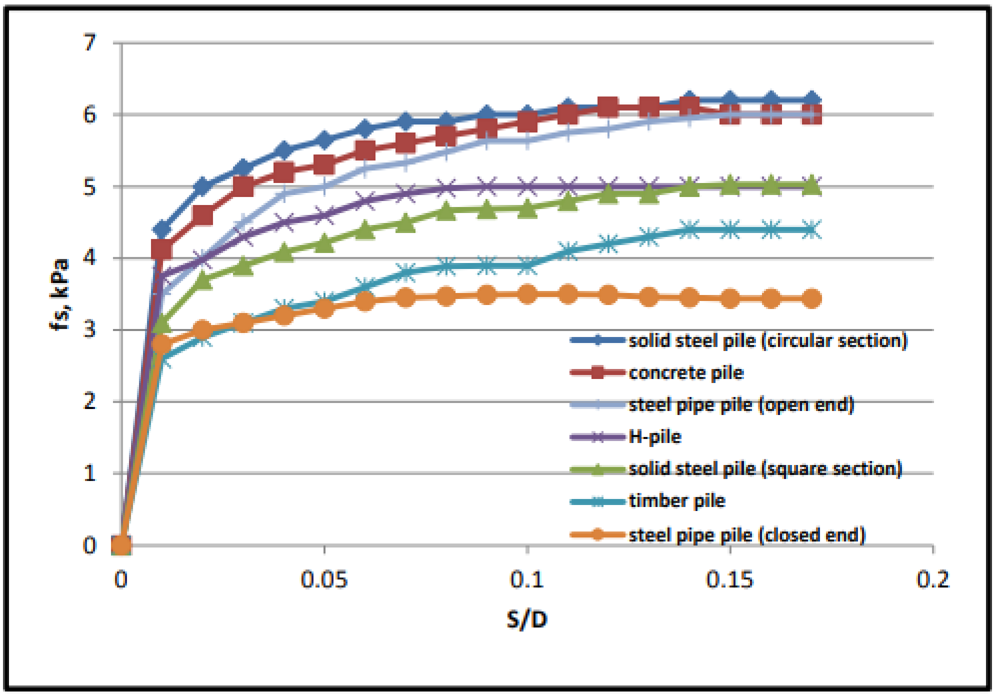


Figure (2.8) relationships between Fs and S/D for different material and cross section of pile at dry case (Qasim ,2018)

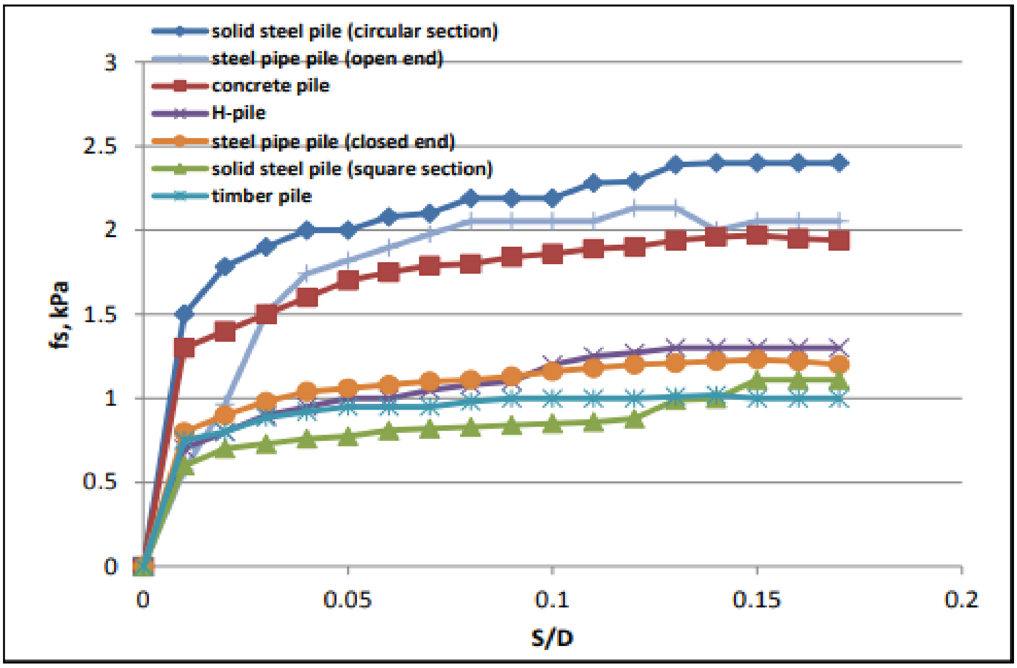


Figure (2.9) Relationships between Fs and S/D for different material and cross section of pile at soaking case (Qasim ,2018)

2.14 Previous studies on Franki piles

Many researchers have investigated the behavior of Franki pile embedded in different soils:

Alkhteeb (2003) discussed existing Franki (base-expanded) pile foundations for mall to examine if these piles can carry additional loads due to build residential units. The Franki pile dimensions were 0.4 m diameters shaft and base volume was ranging from 0.14 m^3 to 0.85 m^3.The program study passed through three stages: evaluation the capacity of Franki pile, using theoretical method then confirmation of the evaluated capacities from pile test program. This study, using pile load tests appear in an increase of the predicted pile capacity of about 60%, which is expected to result in substantial saving during the underpinning of these piles. Table (2.3) show different interpretation methods for load test pile.

Table (2.3) the results of three piles capacities using pile load test interpretation methods (Alkhateeb, 2003)

Method	Test Pile No.1 (KN)	Test Pile No.2 (KN)	Test Pile No. 3 (KN)
De Beer	1440	1430	1620
Butler and Hoy	1690	1836	1820
Mazurkiewicz	1900	2000	2000
Brinch Hansen	1970	1790	2210
Vander Veen	2000	2000	2000
Chin	2000	2000	2500

Pusztai, 2005 explored by experimental tests the behavior of the Franki piles in different soil types. The main goal of the study was to find out the relationship between the pile capacity and the variations of the soil layers. All data were collected from experimental tests, the data were analyzed by statistical analysis and then regression method was adopted to find out the bearing capacity of the Franki pile as a function of variations of soil layers. The analyzed data indicated that the Franki pile can be used only in case of granular soils and the failure which happened under the bulb is smaller than the calculated and measured capacity of board pile as shown in table (2.4).

Table (2.4) verifies the results of some piles to show the difference between the calculated and measured capacity (Pusztai 2005).

Length (m)	Dia. (m)	Soil type	Q calculated	Q measured	Difference= $\frac{Q_{mesured}-Q_{calculated}}{Q_{calculated}} * 100$
9	0.6	gravel	4974	4550	-9%
7	0.6	Sand	5011	4375	-13%
6.5	0.6	clay	3820	4350	14%

Dithinde (2011) evaluated the strength capacity of Franki pile and other different types of piles throughout collected databases from experimental tests by other researchers. All data were drawn and a statistical regression analysis was performed to suggest empirical formula that represented pile capacity for each type. Phoon (2006) recommended normalizing chen hyperbolic equation curve by the interpreted capacity, Qi To develop statistics for the uncertainties in the nonlinear load settlement curves

$$\frac{Q}{Q_i} = \frac{s}{(a'Q_i) + (b'Q_i)s} = \frac{s}{a + bs}$$ **………… (2.4)**

Where: Q_P= predicted capacity; Q_i=interpreted capacity; and a and b = hyperbolic curve-fitting parameters for normalized load-settlement curves

The results from the proposed models indicated that there are some quite differences in the results from those drawn from experimental tests as shown in table (2.5).

Table (2.5) Pile Load Test Data for Driven Piles in Non cohesive Soils (M, Dithinde, 2011)

Shaft Dia. (mm)	base Dia. (mm)	Length (m)	$Ø^o$ base	$Ø^o$ Shaft	S (mm)	Q_P (kN)	Q_i (kN)	a	b
520	760	6	33.6	31.9	15.3	2,564	2,080	3.02	0.80
330	750	6	32.1	26.4	7.5	1,951	1,350	2.57	0.79
410	650	5.8	32.1	33.4	3.6	1,628	2,280	4.56	0.68
410	650	3	38.2	34.5	3.7	1,572	2,200	4.62	0.66
610	800	3	38.2	34.5	8.6	2,380	4,100	8.61	0.57
610	800	3	38.2	34.5	6.8	2,380	3,880	5.98	0.61
520	800	15.6	30.5	31.6	2.03	2,888	1,725	0.67	0.94
611	760	6.4	31.5	31.6	2.8	1,745	3,100	4.65	0.62
520	840	6	34.5	33.7	41.92	4,013	3,400	5.78	0.68

Note: D= shaft diameter; L= pile length; $Ø^o$= friction angle; Q_P= predicted capcity; Q_P=interpreted capacity.

2.15 Summary

All ideas and approaches mentioned above that deal with collapse and failure of soils, gypsum soils, Franki pile and the combination between the behavior and performance of Franki pile in gypsum soil in different percentages are summarized.

Gypseous soil has more capacity when it is dry, whereas it becomes weak when being wet by water. Gypseous soil was classified as a collapsible type of soil because of sudden failure of soil.

Franki piles are suitable for weak soil and have high strength capacity in tension and compression.

In the present work, Franki piles that are embedded in gypsum soil are investigated with different parameters such as pile diameter, length to diameter, pile ratio, soil dryness and soakness and the percentage of gypsum that is concentrated in soil to try to close some gaps in this field.