Treatment of Iraqi collapsible soil using encased stone columns

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ABSTRACT

Stone columns are widely used globally due to their versatility and relative wide applicability to treat different soil and foundation situations but much of the research undertaken to date has focused on their use in soft soils. In countries like Iraq the use of stone columns is still limited from a practical point of view, chiefly as many other soil conditions are commonly encountered. These include collapsible soils: soils that are prone to relatively rapid volume compressions (through collapse of metastable fabrics) that occur due to the action of load and/or increases in water content. Recent work has opened up the possibility to use stone columns in these soils by the use of encasement, thereby overcoming the impact of loss of lateral support when collapse occurs. Area of potential will be discussed; why stone columns could be beneficial for use in Iraq and how employing them as an alternative to conventional ground improvement techniques in number of Iraqi projects would be cost saving and has other benefits. Also, a review of soil conditions in Iraq will be presented and focusing how to treat collapsible soil by encasing the individual stone column by geofabrics illustrating the scope for developing a reliable design approach which suits Iraqi soils. An evidence of their potential applicability in Iraqi soils will be presented. Moreover, the installation technique, facts regarding failure, factors control the behaviour of encased stone columns, calculation of bearing capacity and settlement and some previous related laboratory work will be reviewed as well as recommendations regarding the proposal work in this field are produced with this paper.

Keywords: Collapsible soils, Iraqi Problematic soils, encased stone columns, Ground improvement

1 INTRODUCTION

Stone columns have been used in Iraq since the 3rd or 2nd century BC with archaeological evidence having been found in the heritage city of Hatra (Al-Jumailyperscomms, 1999). Holes were found filled with uniform pieces of rocks covered with lime as a connecting material. In addition, rock discs with a diameter equal to that of stone column, were seen arranged at different distances along stone column body.

On other hand, raw materials for stone columns such as gravel are readily available and at a low cost, as many new gravel quarries opening to meet the new demand of rapid reconstruction which Iraq is now seeing (e.g. in Kerbala province by (Al-Maimuri et al. 2013). Moreover, Cino stones are abundantly available in the north of Iraq and can be used as a fill material of the granular column as it has been demonstrated by (Al-Obaidy 2000). As a result to all of the above, stone columns have a considerable potential to use in Iraqi sites and using them as alternative to conventional expensive foundation solutions such as raft foundations or reinforced concrete piles could be economically beneficial.

However, installation of stone columns in Iraqi soils at the present time still limited. The reason for that is the majority of ground conditions there are not considered stable for such foundations. As stone columns obtain their load capacity from the confinement mobilized by the surrounding soil (Hughes & Withers 1974). Also, the lateral captivity offered by collapsible soils that lose strength and suffer from sudden collapse on inundation; may not be sufficient. Consequently, the formation of the stone column itself may be not applicable.

Casing the individual stone column with suitable geosynthetic is one of the ideal solutions for solving this limitation (Ayadat & Hanna 2005). This encasement by geofabrics makes stone columns stiffer
and stronger further to the function of drainage that they preserved (Murugesan & Rajagopal 2007). With this increase in investment that Iraq witnessed of civil engineering projects, alternative foundation methods are being explored and these include encased stone columns. This paper provides a brief review of the work had done in Iraq regarding stone columns. Also, it would produce the context of the use of encased granular columns as a suitable ground improvement technique to treat collapsible soils. Highlighting the key challenges and issues that require careful consideration for this approach to work effectively.

2 PREVIOUS RESEARCHES ON STONE COLUMNS IN IRAQ

In Iraqi literature, stone columns were first discussed by (Al-Mosawe et al. 1985) through their study on a series of model tests on soft soil. Later, in the ends of nineteen’s, an intensive research with this area including lab experiments and numerical analysis have been done. The most was to treat soft soils. Further, few field studies were carried out too but on relatively stiff soils (e.g. see Al-Obaidy, 2000).

Although, the above mentioning wide research in this topic, there was no attempt to use granular columns to improve problematic soils that present a number of engineering challenges until 2003. Once (Salih 2003) illustrated how stone columns stabilized with asphalt and lime are considered as a successful technique for controlling the collapsibility of gypseous soils. But the wetting process in this research included soaking the soil surface only. So other sources of inundation such as rising groundwater table level have not been considered.

Moreover, the effect of soil mineralogy on the bearing capacity and the corresponding settlement was studied by (Mandhour 2007). She performed her laboratory tests on samples collected from three parts of the country (west, centre, and south) all of them from the unstable shelf area. Her findings indicated to a possible use of the granular columns improvement technique, but the researcher produced her recommendation for performing similar tests under controlled inundation conditions as inclusion water to the samples have not been considered.

To sum up, much research have been done to treat soft soils by this remedy. However, little research focused on treatment for collapsible soil in which water inclusion was not ideally represented. On the other hand, there are several local publications focused on encased stone columns to improve soft soils. Recent example on that by (Fattah & Majeed 2012) in which finite element analysis had been employed to study a geogrid encased stone columns that are assumed to be supported by a soft clay layer.

3 SOIL CONDITIONS IN IRAQ

(Buringh 1960) outlined the main features of soil conditions in Iraq according to the geomorphological regions: the Mountains and foothill region, the Mesopotamian plain, and the Deserts (see Fig. 1) showing a variety of soil type and groundwater table level crosswise the country. There are five main problematic soils could be recognized as following:

- Loess: thin loess deposits are found on parts of Iraq. Example, the southern edge of Lower Jezira Plain, which locates within Al-Ramadi Province on the left bank of the Euphrates River, see Fig. 2. (Yahia 1971). It should be noted that all studies related to loess have been performed from agricultural and geological points of view. While there is a crucial need to study the loess from civil engineering standpoint as the construction projects extend across the country.

- Sand dunes: large areas of Iraq are very arid and are affected by wind erosion and formation and movement of sand dunes, particularly in the middle and south of the country (Al-Taie 1984). Sand dunes affect many infrastructures within Iraq, e.g. the delay in completion of the Highway No. 1 between Diwaniyah and Hilla (in the south as shown in Fig. 2). The presence of which was a major obstacle for the construction (Sissakian et al. 2011).

- Expansive soil: in spite of many published papers, confirmed the exits of swelling soil in middle and north of Iraq and some in the south. The most affected area with expansive clay is concentrated on the west. Example on damage include the residential area of Akashat Mine (near Rutbah in the west where tens of houses suffer from severe damage due to swelling clays (Sissakian et al. 2011).

- Sabkha soil: the collapse potential of saline soils is principally related to the dissolution of salts. Most of the valleys of Tigris and Euphrates about 72000 km², contained saline soils, determined mainly in the middle and the south of Iraq (Boumans et al. 1977). Sabkhas are unfavourable areas for construction of any structure; unless special treatments are used, which are often costly. Owing to very shallow water table, which is usually less than 1 m and high sulphate content. In the extreme southern part of Iraq, all roads and other infrastructures are suffering from the effect of the high percentage of salt in the subsurface, which acts as a highly corrosive agent (Sissakian et al. 2011).

- Gypseous soils: gypsum presented in the soil causes an apparent cementation when the soil is dry. nevertheless, the inclusion of the water resulting dissolution and often leading serious collapse (Razouki et al., 1994). In Iraq, the percentage of gypsum content varies from 10% to 70%, with about a third of the land covered with gypseous soil. In areas where the annual rainfall exceeds 350mm, the gypsum content typically ranges between 3-10%. In arid regions (with
less than 250mm of rainfall annually) the gypsum percentage typically exceeds 50% (Ismael 1994)).

The long-term soaking has a considerable effect on the behaviour of such soils. The soaking could affect the shear strength parameters in expressions of cohesion and angle of internal friction over time as illustrated by (Razouki et al. 2007). Also, (Salih 2013) confirmed this fact as he noticed that under water pressure and axial stress by the end of the test which last 60 days, there are small increases in strain but with no failure. However, over long time periods of 166 and 238 days a notable failure has occurred.

Many researchers investigated the effect of leaching and gypsum content on the behaviour of gypseous soil such as (Al-Mufty 1997), (Al-Busoda 1999), and (Namiq & Nashat 2011). Further, many improvements techniques have been employed to treat gypseous soils such as using some additives (Fattah et al. 2013), increasing compaction ((Razouki et al. 2012). However, using granular columns was restricted to the few previous examples mentioned in section two.

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**Fig. 1.** Map of physographic regions in Iraq (taken from (Buringh 1960)).

**Fig. 2.** Map of Iraqi large cities (taken from google, page: http://www.globalsecurity.org/military/world/iraq/maps-admin.htm, accessed on 28/11/2014).

### 4 ENCASED STONE COLUMNS

Early examples of encased stone columns were introduced by (Van Impe & Silence 1986). Case histories indicated a successful performance in the presence of this technique in soft soils. Examples are given by (Alexiew et al. 2005) in Europe, and by (de Mello et al. 2008) in South America. Moreover, (Raithel et al. 2008) presented work from across Europe where encased stone columns have been used successfully.

However, little field research on encased stone column to treat problematic soils had been done to date. Of the few examples available (Araujo et al. 2009) investigated the behaviour of geotextile and geogrid encased columns in porous collapsible fine-grained soil by means of field load tests. They concluded that encasing the sand column increased load capacity and water injection at the column top caused soil collapse, influencing the behaviour of the columns overall. These authors reported the need for satisfactory bearing capacity of the soil at the column base.

(Ayadat 1990) was one of the first to introduce the encasement to treat collapsible soil. The treated soil was a mixture gap-graded, consisted of 78% concrete sand, 10% Leighton buzzard sand (less than 90 µm), and 12% speswhitekaolin clay). According to his study, introduction the geotextile reinforcement to the sand column has contributed of increasing the ultimate bearing capacity of the sand column in proportion to the stiffness of the geotextile used. Also, an obvious decrease in settlement had been noticed. Later (Ayadat et al. 2008) discussed the failure process of the stone column inserted in collapsible soil after wetting. They
reported that the stone columns have failed to strengthen a loose fill that displays collapse behaviour through the loss of the lateral confinement of the fill.

The bulk of the research to date has investigated the behaviour of encased columns in clay or sandy soils. Little research in which there is a referring to the potential of using this technique in treating collapsible soil with a percentage of 5%. However, the share of the actual work done on collapsible soil was just 2.5%, which is small indeed. The pie chart in Fig. 3 illustrates these statistical percentages.

It is worth noting that column encasement has negligible effect for a column undergoing elastic deformations and begins to be functional only after column yielding occurs. Using stiff encasements to the granular columns is recommended under moderate loads because for high applied loads, where the encasement reaches its tensile strength it does not provide any further improvement. (Castro and Sagaseta, 2011).

4.3 Ultimate bearing capacity

Fig. 4 shows the unit cell model for an encased stone column installed in a collapsible soil soaked with water from the bottom (in case of rising ground water level). The ultimate vertical stress in this case can be computed from three components as the following:

\[
\sigma_{v1} = k_p (k_1 c_u + \sigma_{r01})
\]  
\[
\sigma_{r01} = k_0 (p + \gamma h_1) / 2
\]  

where \(\sigma_{v1}\) : vertical stress of the top layer of soil, \(k_p\) : Rankine passive pressure coefficient of the column, \(k_1\) : coefficient of the soil, \(c_u\) : effective radial stress from surface to the water level and it is determined as described in the following equation:

\[
\sigma_{r01} = k_0 \left( p + \gamma h_1 \right) / 2
\]
So, the vertical stress corresponding to the depth of the inundation will be governed by the following equation

$$\sigma_{v2}=k_2(cu+\sigma_{v2}) \quad (3)$$

where $\sigma_{v2}$: vertical stress of the bottom layer of soil, $k_2$: coefficient $=f(cp)$ where $cp$: collapse potential of the soil,

$$\sigma_{v2}=k_0(p+\gamma h_i+\frac{\gamma h_i^2}{2}) \quad (4)$$

and $\sigma_{v2}$: is the effective radial stress of the soaked layer where $h_i$: height of the bottom layer of soil.

3. The encasement effect: according to Castro & Sagaseta (2011), in the vertical direction, the unit cell is compressed, and the encasement can only take tension because it is a flexible membrane. So, the encasement works only in the radial direction. As a result to maintain equilibrium and compatibility conditions, the radial encasement pressure can be calculated from the following equation:

$$\sigma_{encasement} = \frac{T_A}{r_c^2} \quad (5)$$

where $\sigma_{encasement}$: the radial encasement pressure, $T$: tensile stiffness, $r_c$: the radial displacement, and $r_c$: radius of stone column. By adding equation (5) to the term corresponding to lateral stress of soil in equations. (1) and (3) and by substituting $k_1=4$ and $k_2$ as a function to collapse potential, the general equation to calculate bearing capacity for encapsulated stone column inserted in collapsible soil can be written thus:

$$\sigma_{v1}=k_p\left(4cu+\sigma_{v1}\right)+\left(k_2(cp)cu+\sigma_{v2}\right)+\frac{T_A}{r_c^2} \quad (6)$$

4.4 Settlement

The settlement of untreated collapsible soaked soil($\Delta_{unt}$) could be calculated as a result of two components; the load ($\delta_{load}$) and the water injection($\delta_{water}$) as shown by the following equation (see, Murthy 2007):

$$\Delta_{unt}=\delta_{load}+\delta_{water} \quad (7)$$

$$=\frac{h}{T+e_0}(\Delta e_n+\Delta e_c) \quad (8)$$

where $h$: depth of the submerged collapsible soil, $e_0$: initial void ratio, $\Delta_n$: change in void ratio as result to load $\Delta p$ (corresponding to e-logp curve without wetting), and $\Delta_c$: change in void ratio as result to wetting (corresponding to e-logp curve in case of soaking). $\Delta_n$ and $\Delta_c$ in equation (6) can be gained from the adjusted water content curve for normally consolidated soil presented by (Clemence & Finbarr 1981) as when the soil has collapsed it will behave as a normally consolidated (Maswoswe 1985). After the treatment by encased stone column, the total settlement $\Delta_{total}$ will reduce as described in the following equation:

$$\Delta_{total} = \Delta_{unt} * S.R.R \quad (9)$$

where $S.R.R.$: Settlement Reduction Ratio according to (Priebe 1995) is considered to calculate as follow:

$$S.R.R=1/(1+\alpha(R-1)) \quad (10)$$

where $\alpha$: area replacement ratio, the ratio between the stone column to that of the composite cell of the column and surrounding soil. $R$: the ratio of the stiffness of stone columns material ($E_s$) to the stiffness of the soil ($E_c$). Here as the column is encapsulated, the geofabric stiffness ($E_{encasement}$) should take into consideration and add to the stiffness of the column fill material and as such R yields from the equation below:

$$R=\left(\frac{E_c+E_{encasement}}{E_s}\right) \quad (11)$$

By Substituting equation (11) into equation (10) and then, equations (8) and (10) into equation (9) the total settlement of collapsible soil could be obtained from:

$$\Delta_{total} = \frac{h}{T+e_0}(\Delta e_n+\Delta e_c) * 1/1+\alpha(\left(\frac{E_c+E_{encasement}}{E_s}\right)-1) \quad (12)$$

5 CONCLUSIONS

Nowadays, the use of stone columns in ground improvement for Iraqi locations has not been considered. However, recent work has demonstrated the potential for the use of encased stone columns as a means to treat potentially collapsible soils, many examples of which are found across Iraq. Key findings from this review are:

1. Additional lateral confinement produced from the encasement as described in the equation (6), showing the level of improved bearing capacity achievable.

2. Iraqi soils can be treated through encased stone columns as soils have with similar collapsibility have been showed to be treated successfully through increases the load capacity and reductions in settlements.

6 RECOMMENDATIONS

Further investigations are required to study the performance in such soils to develop a reliable model that simulates Iraqi soil conditions whilst accounting for the effects of water inclusion over a long time period, including as a result to existence of soluble salts which be time dependent.

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