Bearing Capacity of Granular Piles (Stone Columns): a critical review

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Abstract:

Stone columns (SCs) are widely used as an effective technique to enhance the engineering performance of poor soils. The process enhancement of soils using stone columns is accomplished by the consolidated acceleration of weak soils through shortened drainage paths, increasing the load bearing capability and decreasing the settlement by addition of robust granulated materials. Despite the existence of several methods for assessing the bearing capacity of reinforced soils, predicting the behaviour of stone columns is prone to peculiar challenges that require comprehensive analysis. Therefore, this paper reviews previously published literature of developments connected to granular columns. It also includes various efforts to analyse and model weak treated grounds comprised of partially or fully penetrated, single or collections of granular columns. The paper also compares the differences between the most common design methods for assessing the bearing capacity of stone columns. Finally, the review will guide engineers on the procedures and considerations to apply during system design.

Keywords:

Bearing Capacity, Granular Piles, Stone Column, Failure Mechanism.

1. Introduction :

The scarcity of suitable construction sites typically requires engineers to make modifications based on the technical requirements of each project [1]. The use of stone columns is an environmentally friendly approach selected from a vast array of ground improvement techniques. As a result, the use of SCs to improve the ground has become more prominent due to its relative economic advantages over conventional piling methods for less sensitive structural settlements [2]. The technique is typically utilized to increase the ground bearing capacity while decreasing the total and differential settlements of the loaded ground. Furthermore, the installation of the SCs improves the *in-situ* stress conditions [3, 4]. The creation of columns using compacted granulated materials affects the liquefaction potential and the consolidation rate of the treated ground are affected since the columns will act as vertical drains [5, 6 & 7].

Generally, the design of reinforced ground-based SCs is typically performed in two major stages. To begin with, the ultimate bearing capacity is evaluated. Next, the supportability evaluation is executed primarily on the lasting drained settlement because it is typically more critical. For the SCs design, geotechnical engineers are required to rely on either knowledge or analysis techniques such as finite element method (FEM). This typically safeguards the stability against failure and controls the deformation of the subsoil within the permissible limits [8]. So far, efforts have been made by various researchers to evaluate the performance of treated ground through analytical and experimental studies, which will be presented in this review.

During the past four decades, numerous research works in the literature have examined the behaviour of SC treated grounds through numerical analysis, experimental, and field load tests. For instance, Ref. [9] investigated the behaviour of granular piles by varying the densities and proportions of sand and gravel on soft Bangkok clay. The results showed that higher ultimate pile capacity was observed when the pure gravel was used with increasing density and internal angle of friction of the granulated materials. The contribution of end bearing for different values of columns length ratio (L/D) was investigated by Ref. [10]. The authors observed that the end bearing load was only 13 % of the applied load for L/D = 2.5 but negligible when L/D values exceeded 10.

The column critical length was also investigated by other several researchers [e.g., 11, 12]. The findings revealed that the critical lengths of the SCs ranged between 4 and 6 times the diameter of the column indicating the column length did not deliver additional bearing capacity. Therefore, an area replacement ratio of 25% or more is required for any considerable enhancement in bearing capacity for the SC treated ground [13]. According to Ref. [14], the load carrying capacity of a group of SCs was developed as the diameter and the stiffness of the columns was enhanced.

This occurred where the internal friction angle of the SCs exerted the greatest influence. In general, the columns typically act as load-bearing components that accommodate a large portion of the load from superstructures and transmits it through side friction or to a competent deep layer. However, the load capacities of granular filled columns greatly depend on the filling strength and the stress restrained in the adjacent soil.

Nevertheless, the columns and soils synergise to share the load applied thereby providing shear resistance to avoid sliding.

Despite the technological advances in the construction of columns, it is still challenging to accurately predict the bearing capacity of SCs [15]. Therefore, this paper seeks to enhance the understanding of the performance of SCs, along with its failure mechanisms and conventional design methods for examining the bearing capacity.

Furthermore, a brief comparison between selected theoretical methods of assessment will be highlighted.

2. Failure Mechanism

In practice, SCs are constructed on a firm layer beneath a soft soil (end bearing column) or embedded inside a soft layer of soil (floating columns). However, the end bearing columns are reportedly more practical than the floating variant. However, to ensure optimum application of SCs, the various failure mechanisms of the system require understanding to detect the sources of failure in either individual or grouped columns. The failure modes depend mainly on the following parameters:

- SCs geometries and type (End-bearing or Free Floating),
- Loading on columns,
- Passive resistance of the surrounding soil.

2.1 Failure mode of single column:

Since the foundation's bearing capacity resting on the SC is mainly dependent on the column failure mechanism, numerous research in the past have been mainly dedicated to the failure modes of columns that are isolated. Typically, short, floating columns with slenderness ratios below 3 are prone to failure due to toe plunging as also observed in the small piles of stiff clay from soft to medium stiff [5]. However, the failure mode for an extended SC of toe resistance and acceptable shaft to avoid punching is called bulging. This occurrence is governed by the critical lateral pressure of confinement and the surrounding soil's shear strength. Figure 1 provides the mechanism of failure for a single SC in a homogeneous soft ground as described in Ref. [5]. The Figures 1.a and b show the area of long SC with firm support (denoted by dash-lines) where it is most likely to have an internal bulging effect. In the case where a rigid SC is assumed (Figure 1.c), the main criteria that control the failure are bearing capacity failures typically denoted by stress and strain bulbs that simply follow the Terzaghi and Meyerhof analysis. In addition, when a short floating SC embedded in soft soil is considered (Figure 1.d) bulging may occur particularly for a column length below 2-3 times the diameter the column, which is already unstable due to the end bearing failure [16].

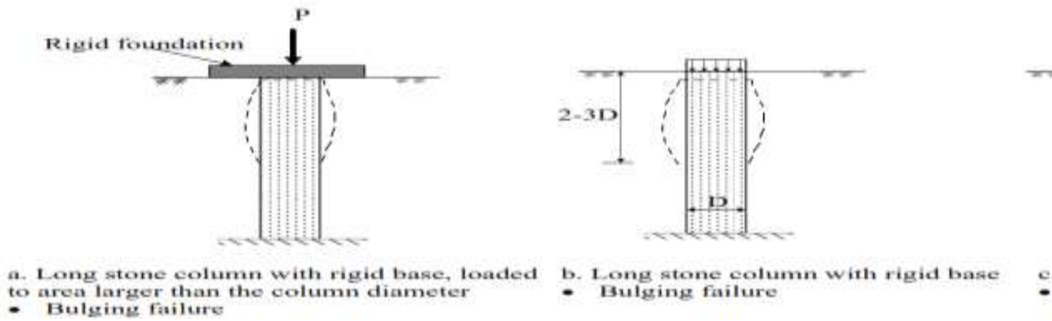


Figure 1. Failure mechanisms of a single stone column in a homogeneous soft layer [5]

Ref. [17] stated that the depth of the bulging zone of the SC was affected mainly by column diameter rather than the depth ratio and soil strength. This conclusion in agreement with Ref. [18] who reported that the degree of bulging is largely dependent on the strength of the in situ clay. Besides, the bulging depth was approximately four times the column diameter [11, 19]. In recent studies, Ref. [15] investigated the failure mode o a single SC through 3-D numerical analysis. The results indicated that bulging independently and in combination with plunging are the two principal failure modes typically observed in a single SC.

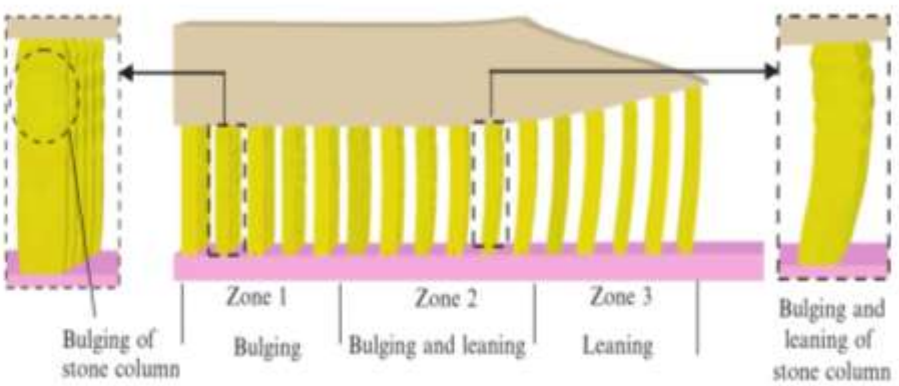
Overall, an isolated SC contained in a weak subsoil deposit experiences different modes of failure such as bulging [11], general shear failure [20] and sliding [21]. When the column's length exceeds its critical length and regardless of whether it ends in bearing or floating, it will fail by bulging g [5, 19]. However, when the column length is shorter than the critical length, the failure mode is general shear particularly if its bearing ends on a rigid base or punching if it is a floating column. Furthermore, particular attention should be paid when very weak organic clay layers with limited thickness are present where the local bulging failure is likely to occur [5].

2.2 Failure mode of stone columns group:

The mode of failure of SCs group has been investigated by a number of researchers (e.g. 22, 23). In general, the studies indicated that SCs constructed in groups showed different failure behaviour compared to isolated columns. In groups, each column can interact and restrain the expansion of the neighbouring column leading to increased bearing capacity. Ref. [22] investigated the capacity of grouped SCs. The results demonstrated that the failure pattern of bulging proposed by

Ref. [11] was non-existent throughout the interaction testing of the group columns. Furthermore, the mechanism of shear-failure for the joined columns or soil system was similar to the collapsing design observed in the reinforced mass of soil. Ref. [13] also examined the behaviour of SCs groups using finite-element analysis which yielded results that verified the group interaction findings reported in Ref. [22]. In addition, the numerical modelling showed by Ref. [24] on ground reinforced SCs confirmed Hu's inference regarding the failure mechanism.

Ref. [25] examined the mechanism of load transfer from the SCs to the adjacent soils. The results indicated that the distortion of the SCs, as specified in the 2D strip model, is comparable to the baseline 3D result (Figure 2). Hence, the SCs can be generally classified into three zones namely: Zone (1) away from the fill where columns undergo vertical deformation by "bulging"; Zone (2) directly behind the top of the fill where columns experience deformation either vertically or horizontally by "bulging" and "bending"; lastly Zone (3) below the fill where columns primarily experience leaning.



Overall, in the SC groups, the central column deforms or bulges uniformly, while the others at the edge column bulge away from the neighbouring columns [23]. Therefore, neglecting the surrounding columns contribution in a group will produce an untrue load carrying behaviour of SC reinforced foundation [5].

3. Bearing Capacity of Stone Column:

In spite of progress in construction and engineering, confidence in the methodologies of SCs for estimating the precision of bearing ability of SC supported foundation remains unsatisfactorily. Therefore, the regulation for estimating the bearing capacity for experts is lacking [26]. In addition, Ref. [27] indicated that the performance of SCs has not been entirely addressed by methodical and numerical methods. Therefore, several techniques have been proposed by several researchers to forecast the bearing capacity of a foundation resting on granular columns. The fundamentals of these methods are typically based on cylindrical cavity expansion [28], classical plasticity theory [29], analytical methods (e.g., 5, 30], and experimental methods (e.g., 8, 31].

Ref. [29] noted that there was no exact mathematical method to predict the bearing capacity of cohesive soils treated by SCs. This is ascribed to the dilation that occurs inside the column and the resulting lateral stress to the surrounding soil, which can be resisted by passive pressure. Ref. [29] hypothesized that the column will behave as if it is in a triaxial chamber, hence the measure of improvement in the bearing capacity will be governed by the lateral support from the surrounded clay to the column and the friction angle. Furthermore, the SC is supported by the lateral confining stress

(σ_3) which is typically considered as the critical passive resistance, since the surrounding soil can mobilize as the SC bulges outwards against the soil. Meanwhile, the column is assumed to be in a failed condition so that the final vertical stress of the column (σ_1) can be taken as identical to the coefficient of the passive pressure of the SC, ($k_{p,c}$) multiplied by the lateral confining stress. Ref. [29] was among the first scientists to study the mechanisms and explain the load transfer phenomenon of SCs. Hence, the Bell's formula was suggested to estimate the passive resistance which is set as:

$$\sigma_r = \gamma z k_{p,s} + 2c_u\sqrt{k_{p,s}} \qquad (1)$$

Where: γ_s is the unit weight of soil; z is the average bulge depth; $k_{p,s}$ is the passive pressure coefficient of soil $= \frac{1+\sin\varphi_s}{1-\sin\varphi_s}$, where φ_s is the internal friction angle of soil and c_u is the undrained shear strength of soil. In the following sections additional details of the bearing capacity along with the estimated approaches of isolated and group of columns will be presented.

3.1 Bearing capacity of a single stone column:

Numerous studies have investigated the bearing capacity of an isolated column through several approaches, which are typically classified into three categories. by Ref. [32]. The first approach considers the state of stress, whereas, in the second, a mechanism of failure was joined with a state of stress. The third method considers the mechanism of failure.

In the earliest studies, Ref. [11] adopted the principle of elasto-plasticity to demonstrate the total confinement pressure accessible to the expanding cylindrical cavity is in the clay substrate. This was based primarily on the maximum radial reaction of the soil against the bulging. Therefore, the untrained conditions are expressed in the following equation:

$$\sigma_{3,ult} = \sigma_{ro} + k_p . c_u \quad (2)$$

Where: k_p is column cavity expansion factor and σ_{ro} is the total lateral stress. In order to yield the ultimate minor principal effective stress, Ref. [11] assumed $(k_p = 4)$ as a result of drainage within the column;

$$\sigma_{3,ult} = \sigma_{ro} + 4c_u \; and \; \sigma'_{3,ult} = \sigma'_{ro} + 4c_u \quad (3)$$

Consequently, the definitive vertical stress which a column can bear at its critical state (lateral bulging) is expressed as:

$$q_{ult} = [\sigma'_{ro} + 4c_u].[\frac{1+\sin\varphi_c}{1-\sin\varphi_c}] \quad (4)$$

Where: σ'_{ro} is the original radial effective stress. Due to its simplicity, Eq (4) is generally used in practice today to estimate the load bearing capacity of SCs in cohesive soils. Furthermore, Refs. [29,33] recommended that the bearing capacity of a single SC can be determined, the portion of cohesive (c_u) due to passive earth pressure must be integrated to Hughes's equation;

$$q_{ult} = [\sigma'_{ro} + 4c_u].\frac{1+\sin\varphi_c}{1-\sin\varphi_c} + 2c_u\sqrt{\frac{1+\sin\varphi_c}{1-\sin\varphi_c}} \quad (5)$$

In the same framework of granular columns, Ref. [30] suggested a simple technique to determine the critical bearing capacity of an isolated SC surrounded by saturated soft soil under undrained condition based on the axisymmetric model illustrated in Figure 3. The method reflects a passive shear failure from the column to the nearby soil based on the following assumptions: (1) there is a negligible boundary between the column and the soil, (2) lack of circumferential stress exists, (3) lack of volume changes for a single SC in the cohesive ground. Therefore, the lateral stress that can be mobilised in an SC by the surrounding cohesive soil is given by:

$$\sigma_r = \left(\Delta\sigma_s + \frac{2c_u}{\sin 2\Psi}\right).(1 + \frac{\tan \Psi_p}{\tan \Psi}) \quad (6)$$

Where: $\Delta\sigma_s$ is the vertical stress on the soil; Ψ is the failure plane angle within the soil and Ψ_p is the passive failure planar angle in the column $[\Psi_p = (45 + \frac{\varphi_c}{2})]$.

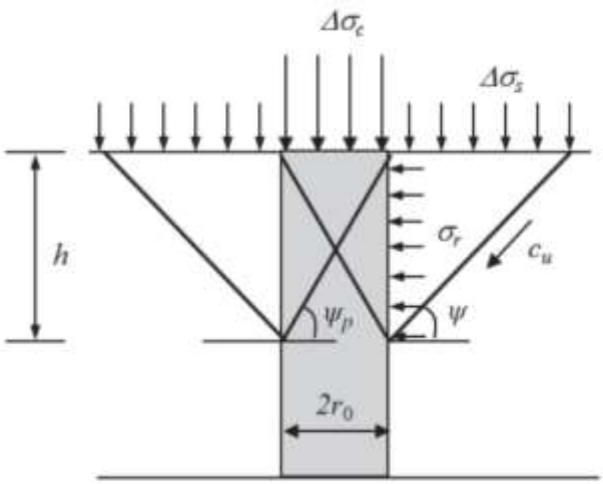


Figure 3. Failure mode of a single column *[30]*

From practice, the internal angles of friction of SCs are typically between 35° and 45° [29]. Therefore, at if φ_c is presumed to be 38° (a typical value), thus Ψ = 61 then the bearing capacity of the isolated stone column will be:

$$q_{ult,c} = 20.75c_u \tag{7}$$

Based on Vesic's theory of cavity expansion, Ref. [5] proposed a basic equation to compute the ultimate bearing capacity of a single column by proposing a bearing capacity factor $\overline{N}_c$ and applying the shear undrained strength of the nearby soil.

$$q_{ult} = c_u\overline{N}_c \tag{8}$$

Although the $\overline{N}_c$ calculation is based on Vesic's theory, it assumes E values between $5c_u$ and $10c_u$ (as recommended by Ref. [5]). By comparing with field measurements, the authors suggested that the value of $\overline{N}_c$, should be selected semi-empirically. The values appear to normally range from 10 to 22 subject to the soil compressibility. The authors suggested an $\overline{N}_c$ value of 22 for soils with a high initial stiffness including non-organic soft to stiff clays and silts. However, a value of $\overline{N}_c$of 18 was selected for soils with low stiffness like organic soils and clays with plasticity index above 30. However, the study by Ref. [34] proposed values of 25 to 30 for vibro-replacement columns, including 45 to 50 for cased, rammed SCs, and 40 for uncased, rammed SCs.

Based on existing lateral expanded cavity studies, a simple formula was proposed by Ref. [35] to approximate the critical bearing capacity of an isolated stone column fitted in cohesive soft clay. The ultimate bearing capacity was examined by joining a stress state with a mechanism of failure for lateral extension in a cylindrical cavity that replicates the SC installed in a purely cohesive soft soil.

$$q_u = k_{p,c}[p_0 + c_u[1 + \frac{2}{1+k}\ln(\frac{E_c}{3(0.1812k + 0.1408)^{k-1}c_u})]] \quad (9)$$

Where: p_0 is the initial horizontal stress at rest calculated (at depths equivalent to two column diameters); E_c is the Young's modulus of column material; and k is column compressibility coefficient which is contingent on the dilation angle, denoted as ψ, and is written as: $k = \frac{1-\sin\psi}{1+\sin\psi}$.

In the year 2018, Ref. [15] predicted the formula for ultimate bearing capacity that accounts for the undrained shear strength of the surrounding soil and the angle of friction for the SC:

$$q_{ult} = (\varphi_c - 15)c_u + 50 \quad (10)$$

In summary, the load bearing capability of a specific granular column is a multifaceted problem involving the relations amongst the constituent granular column materials and the adjoining soil. So far, the exact mathematical solution to estimate the ultimate bearing capacity is still lacking [4].

3.2 Bearing capacity of stone columns group:

The bearing capacity of SCs group has been traditionally modelled by assuming a laterally infinite distribution of idealized cell units comprising a single column and a branch area of the soil matrix. Hence, Ref. [5] adopted the unit cell concept to represent a finite group of columns and to determine the bearing capacity of the SCs group. The authors presumed that the bearing capacity of a strip and square footing resting on a group of columns could be computed by adjusting Ref [36] theory of local shear failure for a homogeneous soil. The authors assumed that mobilizing the peak shear strength within the columns and adjacent soil occurs concurrently as illustrated in Fig. 4. According to the outlined hypotheses, the average shear strength parameters for estimating the resistance along the presumed failure surface were determined by Ref. [5];

$$\varphi_{avg} = \tan^{-1}[\frac{n.A_s}{1+(n-1).A_s}.\tan\varphi_c] \qquad (11)$$

$$q_{ult} = (\varphi_c - 15)c_u + 50 \qquad (12)$$

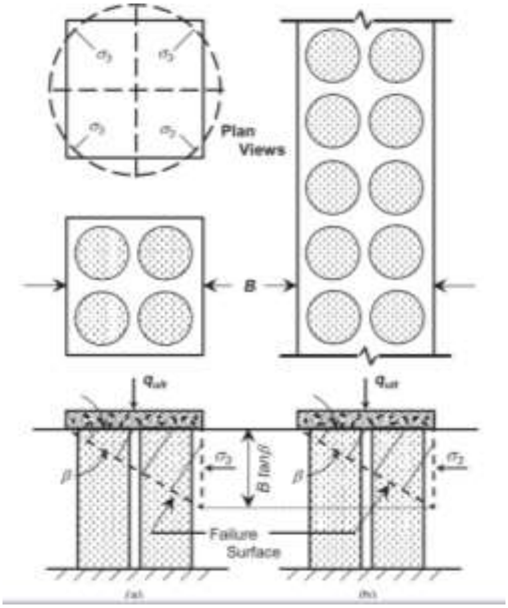


Figure 4 Failure surface for (a) square footing and (b) strip footing modification (Ref. [5] modification)

Next, the classic theory of earth pressure was applied to approximate the confining stress counteracting the triangular mass failure directly beneath the strip foundation [5].

$$\sigma_3 = 0.5B.\gamma.\tan[45 + \frac{\phi_{avg}}{2}] + 2c_u \qquad (13)$$

Furthermore, Ref. [5] computed the stress confinement for square footings that oppose the failure wedge by considering the footprint as a circle and using the cylindrical cavity expansion theory of Ref. [30]. Furthermore, Ref. [5] recommended adopting a lower rigidity index [I_r] boundary and a shear modulus to shear strength ratio of 3.79 (equivalent to $E_s = 11c_u$) for implementing the Ref. [30] theory of cavity expansion.The bearing capacity of SCs group could be calculated as:

$$q_{ult,group} = \sigma_3 . \tan^2[45 + \frac{\varphi_{avg}}{2}] + 2c_{u,avg} . \tan[45 + \frac{\varphi_{avg}}{2}] \quad (14)$$

Figure 5 presents a diagram by Ref. [37] that shows the proportional load of the columns (*m*) based on the ratio of area replacement (A/A_c), and the friction angle of column material(φ_c). This method was developed to predict the bearing capacity of a footing on the SCs group according to the general shear failure and the homogeneous equivalent composite.

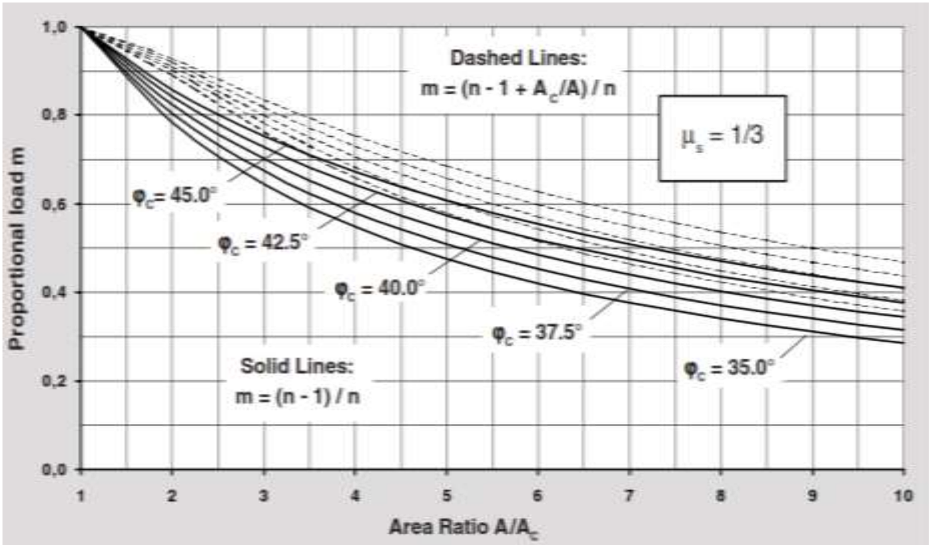


Figure 5. Proportional load on stone columns [37]

Ref. [38] established a systematic model for the example of a group of SCs subjected to general shear failure in soft soil. The model is robust enough to estimate the critical bearing capability of the reinforced ground. In theory, the model founded on the limit-equilibrium technique and the concept of a reinforced soil with composite properties. Hence, the system's final bearing capacity can be computed as follows:

$$q_u = \frac{1}{2}\gamma_{comp} B N_\gamma + q N_q + c_{comp} N_c \qquad (15)$$

$$\gamma_{comp} = A_s \gamma_s + (1 - A_s)\gamma_c \qquad (16)$$

$$c_{comp} = A_s c_{u,s} + (1 - A_s) c_{u,c} \qquad (17)$$

Where the produced bearing-capacity factors denoted by N_γ, N_q *and* N_c were grouped, investigated, and presented as design charts for γ_{comp}/γ_c and c_{comp}/c_c which are typically from 1 to 2 and 0.2 to 0.8, respectively. However, these span a wide spectrum of applied cases in which γ_{comp} and c_{comp} are the unit weight and cohesion shearing resistance of the corresponding soil and column (or composite) system. Lastly, the terms $c_{u,c}$ and $c_{u,s}$ are the cohesions for the material (stone) column and soil, respectively. Besides, a good agreement was obtained the ultimate bearing capacity predicted based on proposed theory was correlated with laboratory test outcomes and available statistical data for the case of a group of stone columns mounted on soft soil.

Furthermore, Ref. [39], developed a formula to predict the bearing capacity of floating SCs group mounted on clays of different undrained shear strengths (between 4 kPa and 25 kPa), different column diameters d and length ratios L/d. The formula was obtained by executing statistical analysis using SPSS (Statistical Package for the Social Sciences) program based on their empirical work and previous studies data.

$$q_{ult} = 15.34c_u^{0.401}\, A_s^{0.266}\, N_s^{0.084}\, (\frac{L}{d})^{0.526} \tag{18}$$

Where: N_s is the No. of stone columns.

The equation included the most control bearing capacity parameters such as area ratio and undrained shear strength. Based on the assessment between the measured bearing capacity and predicted values of this formula, the equation was robust for appraising the bearing capacity of single and groups of SCs.

Next, the bearing capacity of soft clay reinforced with SCs was successfully calculated using the Morgenstern-Price method of slices [40]. The study predicted the ultimate bearing capacity of the soil reinforced with a group of SCs based on an analytical model utilizing the slices technique.

The soil inside the failure zone was separated into slices so that the limit equilibrium technique could be adopted for analysis. Furthermore, the shear forces and passive earth pressure on the boundaries for each slice were deduced. The smallest inter-slice force coefficients were determined by applying the failure plane in circular mode. However, the surface of failure was deduced by trial and error to assess the minimum safety factor. Lastly, the foundation load was increased until the factor of safety of one was obtained to determine the ultimate bearing capacity.

Ref. [41] optimized the column diameters and lengths that influence the load carry capacity and settlement of soft clay using response surface methodology (RSM). About twelve of the randomized trials were designed with variations in SC diameter and length. The data was analysed and investigated to obtain the first-order response surface model equations using Design Expert software. Similarly, RSM was adopted to produce the response surface plots, which useful for comprehending the link between each factor and its response. Therefore, two examined factors showed positive significant effects on the settlement and the load-bearing capacity. Lastly, the model revealed a significant link between the increment and a decrease in the load-bearing capacity selected in factorial terms as given by the following equations:

$$q_{ult}(\mathrm{N}) = 2147.32 - 15.51\mathrm{d} - 0.078\mathrm{L} + 0.96\,\mathrm{d}^2 - 1.69 \times 10^{-3}\mathrm{L}^2 - 7.52 \times 10^{-3}\mathrm{d.L} \quad (19)$$

Where: *d* is column diameter (mm), and *L* is column length (mm).

However, the RSM model is only an approximation since it does not include all the potential external factors that could influence the design.

Nonetheless, numerous researchers have tried to categorise and forecast the behaviour of SC treated soil. One of the most realistic, theoretical foundations for vibro-column techniques extensively adopted is the approach by Ref. [10]. Since SCs always work together in a foundation, the reliability of the assumption that each column in a group will behave in the same way as a single isolated column on its own [10] is questionable [22]. Consequently, there is still a gap in this design term, for researchers to investigate in the future.

4. Example of ultimate load prediction:

An end bearing SC of 0.8 m diameter with a 1.6 m centre-to-centre spacing have been proposed and designed to support a foundation resting on saturated soft clay soil with column length up to 6 m. In the SC design, the following parameters were listed (Table 1):

Table 1:
Value of stone column and soil parameters adopted

Selected Parameter	nit	one column	Soft clay
Friction angle		8	1
Undrained shear strength	Pa		15, 20, 28, 35 & 40
Young's module	Pa	0	2
Unit weight	N/m^3	2	16
Poisson's ratio		.333	0.4
Dilacety angle			0

The bearing capacity of an SC has been estimated in this example using various selected approaches previously mentioned with the findings summarised in Figure 6. It can be observed that there is a large range of probable ultimate bearing capacities when diverse methods are applied. This range was 54% and 40% for undrained strength 15 kPa and 40 kPa, respectively. However, this could create large uncertainties or confusion for design engineers during the assessment. Moreover, the approach adopted by Ref. [11] tends to predict lower values for column capacity whereas the Ref. [35] formula generates the maximum load capacity of SC. For the same elemental properties, much closer methods observed in the literature. For example, the Ref. [34], and the Ref. [5] methods are both derived from the cylindrical cavity expansion theory and the Refs. [31, 15] approach.

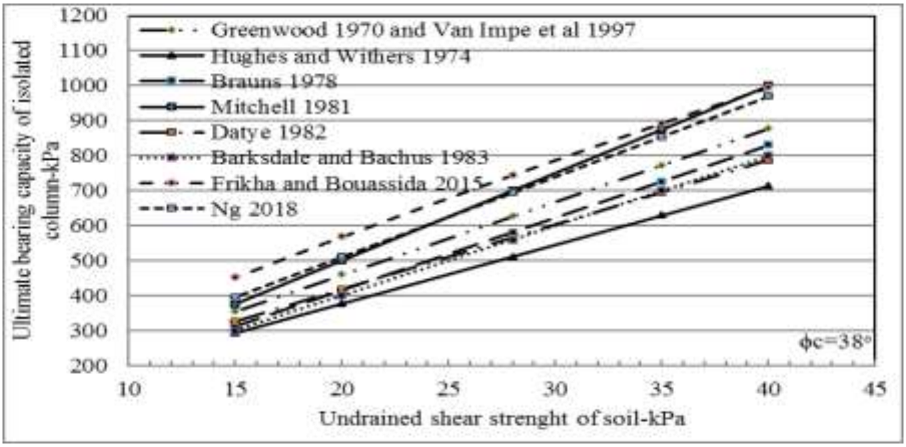


Figure 6. Comparison of methods for predicting the bearing capacity of an SC

5. Conclusion:

Stone columns play a key role in the area of ground improvement. However, the column design is still largely empirical and past experience shows that practice plays an important role in the design technique. Specific conclusions based on the critical review of the available literature on SCs are as follows:

- Many attempts based on numerical modelling, mathematical analysis, along with small and full-scale testing have been conducted to understand and predict the behaviour of SCs.
- Most researchers have proved that single SC deforms by bulging into the sub-soil strata and dispenses the stresses

at the upper portion of the soil profile rather than transmitting the stresses into a deeper layer. However, a group of SCs and the adjoining soil may fail by overall, local, or punching shear mechanism. This is subject to the ground geometry and strength parameters of both SC and surrounding soil.

- The accurate load-carrying mechanism of the formed system is complex and so far, no exact design formulas to assess the SC bearing capacity are available, which needs more investigations to predict it.

قدرة تحمل الأوتاد الحبيبية (الأعمدة الحجرية): مراجعة نقدية

مريـم جابـر

الملخص:

تستخدم الأعمدة الحجرية على نطاق واسع كتقنية فعالة عزيز الأداء الهندسي للتربة الضعيفة، يتم إنجاز عملية تحسين التربة باستخدام الأعمدة الحجرية من خلال زيادة سرعة التصلب للتربة الضعيفة وذلك بخلق مسارات الصرف القصيرة و زيادة قدرة التحمل و تقليل الهبوط وذلك عن طريق إضافة مواد حبيبية قوية للتربة، على الرغم من وجود العديد من الطرق لتقييم قدرة تحمل التربة المعززة فإن التنبؤ بسلوك الأعمدة الحجرية عرضة للتحديات الغريبة و التي تتطلب تحليلاً شاملاً، لذلك فإن هذه الورقة تستعرض المنشورات السابقة للتطورات المتعلقة بالأعمدة الحبيبية، كما تتضمن جهود مختلفة لتحليل و نمذجة التربة الضعيفة المعالجة شاملاٌ: \

الاختراق الجزئي و الكلي، و كذلك سلوك العمود حين يكون منفرداً أو ضمن مجموعة من الأعمدة الحبيبية، تقارن الدراسة ايضاً الاختلافات بين أساليب التصميم الأكثر شيوعاً لتقييم قدرة تحمل الأعمدة الحجرية، أخيراً المراجعة ستوجه المهندسين للإجراءات و الاعتبارات اللازم تطبيقها أثناء تصميم النظام.

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