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Using of Stones in Building the Foundations

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ABSTRACT
The problem of this study is that the building of foundation by stones at the present time leads to develop cracks in the superstructure. Therefore, the solutions and the right manner were suggested for building the stone in the small and big structures. This paper studies using and properties of stones in building of foundations, that the stone is rigid and stiff in the same time very cheap for building, especially in the regions wealthy with stone. The models were taken for analyzing, firstly experimentally in the field site and secondly by Plaxis Program using the Finite Elements with the same properties of the soil and calculate the vertical displacement, vertical strain, factor of safety and bearing capacity. It can be concluded that the using of the reinforced columns in the small foundation in addition to the beam and stones will reduce the vertical displacement and strain to lower values, maintain high value of bearing capacity and increase the factor of safety that makes the structure becomes safer. Also for the big structures like bridges another models were used with higher loadings and the same above parameters were calculated, the stone with special requirements approved to improve and treat the soil parameters even for the big structures.

أستخدام الحجر في بناء ألاسس

الكلمات المفتاحية
ميكانيك الصخور، هندسة الاسس، قابلية تحمل التربة، برنامج **Plaxis**

الخلاصة
المشكله من هذه الدراسة هي انه في الوقت الراهن البناء بواسطة الحجر يؤدي الى حدوث تشققات في المنشأ. لذلك، الحلول والاسلوب الصحيح في البناء قد اقترح في هذا البحث بالنسبة للمنشاءات الصغيرة والكبيرة. يهتم هذا البحث بدراسة استخدام وخواص الحجر في بناء الاسس، لكون الحجر قوي وصلد وفي نفس الوقت رخيص في البناء، خصوصا في المناطق الغنية به. قد تم اخذ موديلات للدراسة، الاول كان عملي في الواقع الحقلي، وبقية الموديلات تم تحليلها بواسطة برنامج بلاكسز للعناصر المتناهية بنفس الخواص والمحددات وتم حساب الازاحة العمودية، المطاوعة العمودية، عامل الامان وقابلية تحمل التربة. من الدراسة تم استنتاج انه باستخدام الاعمدة الخرسانية في الاسس الصغيرة اضافة الى العتب الكونكريتي والحجر سوف يؤدي الى تقليل الازاحة العمودية والمطاوعة، الحصول على قابلية تحمل تربة عالية وزيادة عامل الامان مما يجعل المنشأ اكثر أمانا. اضافة الى في حالة المنشاءات الكبيرة مثل الجسور قد تم استخدام موديلات اخرى مع احمال أكبر ونفس المحددات السابقة قد حسبت، لذا فانه الحجر وبمتطلبات محددة يمكن ان يحسن ويعالج خواص التربة حتى في المنشات الكبيرة.

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Introduction

The using of stone as a foundation in small building is common in many countries because of the low prices of the stone, especially in the countries with many lands of stone which have low amount of Gypsum [1, 2].

The reinforced concrete used in the foundations is expensive [3], therefore, other solutions must be found for small buildings which cannot bear high values of loads. Using the stone in building the foundation with a suitable way does not lead to cracks or soil collapse [4].

The building of foundation by stone means to replace the stone instead of the reinforced concrete or bricks to raise the foundation to the suitable level before putting the reinforced or normal concrete beam above the stone. The mortar of building the stone is the cement and sand with a ratio of 1:3 and sometimes the clay with water [5].

The stone is also used for building the foundation of big structures by replacing the weak soil with different sizes of crushed stones and improving the bearing capacity of the foundation [6]. There are other benefits for the stone like in manufacturing of the cement, paving the river side's, building the fences of the parks and gardens, etc [7].

Deflection of Stone Foundation in the Experimental Work

Two models were selected for this study and conducted as shown in the Figures 1 and 2. The first behavior of the concrete is elastic which provides a movement for concrete due to the effect of loading, this movement of the stone foundation comes from the rearrangement of the stone pieces because of the loads coming from the superstructure constructed above the foundation. Therefore, the concrete beam above the stone will move also with a similar manner [1]. The deflection in the concrete beam above the stone will affect on the structure above the foundation which leading to make cracks in the walls and may be in the concrete of the structure [4].

Analyzing by plaxis program of finite elements

The Case of Low Loading

By using Plaxis Program for analyzing two models to study the effect of using the stone in the foundation and the treatment by adding reinforced concrete columns as following:

- **First model:** A foundation consists of concrete beam and stone with applied load 100 kN/m^2 as shown in Figure 1
- **Second model:** A foundation consists of concrete beam,

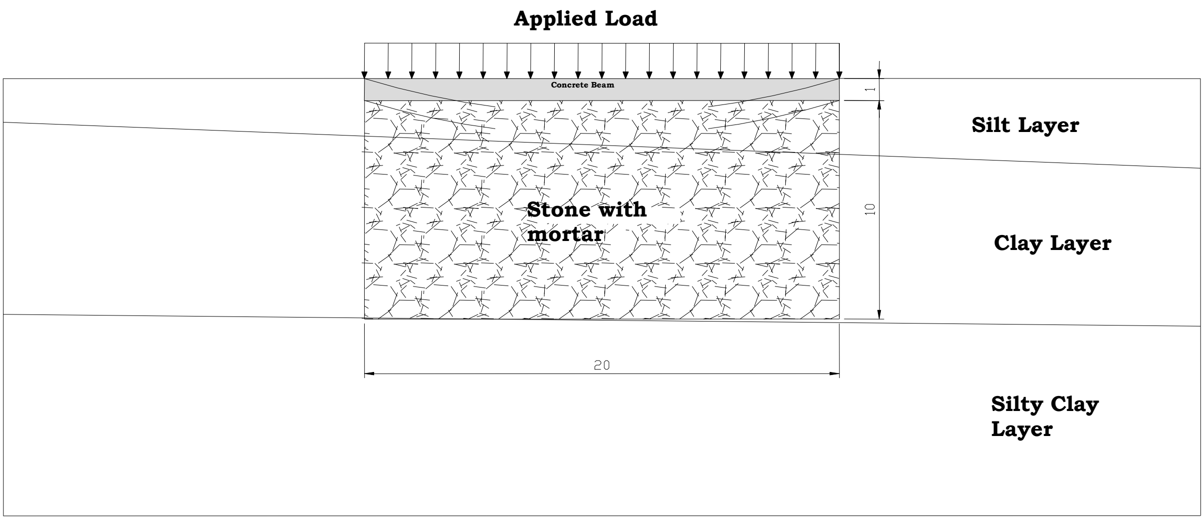


Figure 1: The deflection happened in the stone foundation consisting of stones and reinforced concrete beam only

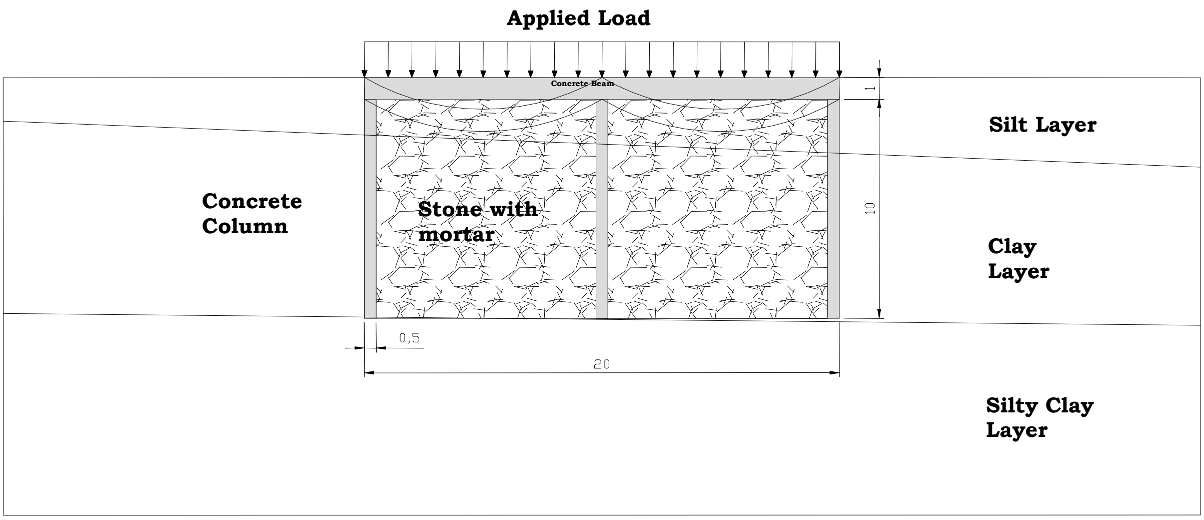


Figure 2: The deflection happened in the rock foundation consisting of pieces of rocks, reinforced concrete beam and columns

columns and stone with applied load 100kN/m^2 as shown in Figure 2.

The Plaxis Program of finite elements is used to analyze the two above models with the same dimensions of foundation and properties of the soil and materials, Mohr-Coulomb with undrained condition is assumed [8]. Ground water level is 2m under the N.G.L (normal ground level).

Length of the foundation beam is 20m, width is 1m and thickness is 1m. Depth of reinforced column is 10m, width is 50cm; distributed load is 100kN/m^2.

Table 1 shows the properties of the soil and materials used for construction the model. The data were taken from a proposed project depending on the soil investigations. After analyzing the two above models and calculate the vertical displacements and vertical strain for each model by using Plaxis program of finite elements as shown in the Figures from 3 to 8. It can be seen the effect of using the concrete columns with stone to reduce the settlement and modify all the soil parameters.

The results of the numerical analysis can be summarized of the two models in Table 2.

Table 2 shows that the using of reinforced concrete column with the stone in the foundation will reduce the values of vertical displacement and vertical strain, increase the values of factor of safety; therefore, it will avoid the structure from the effect of cracks and collapse of the soil.

Figure 7 shows the comparison for vertical displacements between the two models, while Figure 8 shows the comparison of the factor of safety for the two models, which indicate the safety and suitability of using the reinforcing columns to improve the characteristics of the structure, in spite of that the values of the vertical displacements for both model is considered high compared with allowable settlement according to Skempton and McDonald (1956) limitations for maximum settlement and maximum angular distortion [9]. We should mention also that the settlement calculations were taken at middle point of the foundation base, the minus signs means the deflection to down.

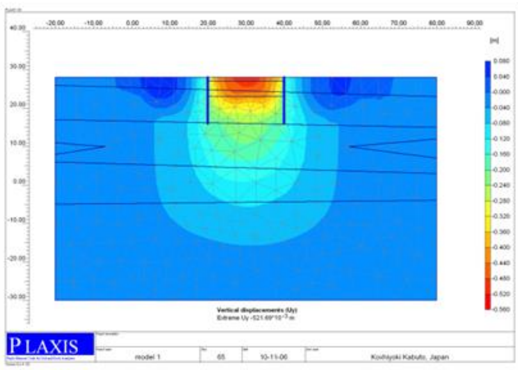
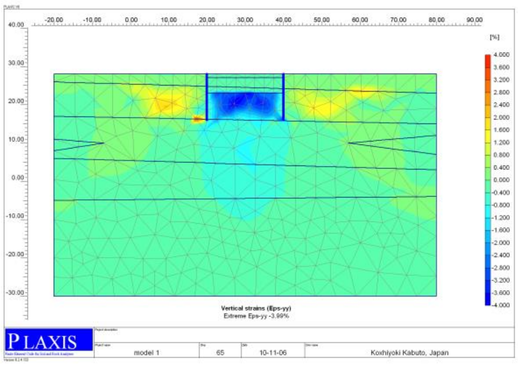


Figure 3. The vertical displacement (Uy) in meters for all the layers of the model (1).



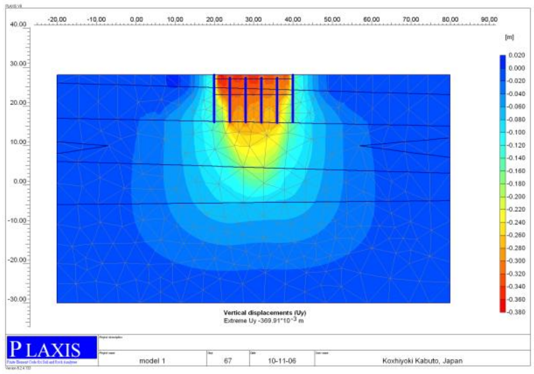


Figure 5. The vertical displacements (Uy) in meters for all the layers of the model (2).

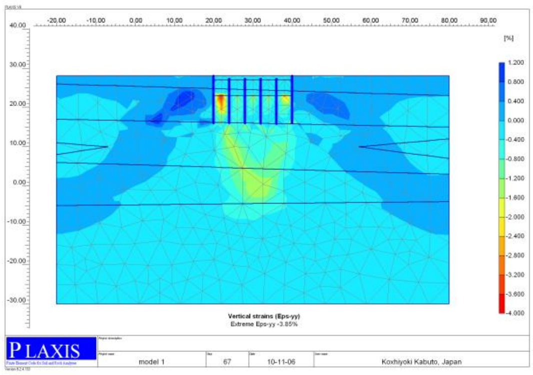


Figure 6. The vertical strain for all the layers of the model (2).

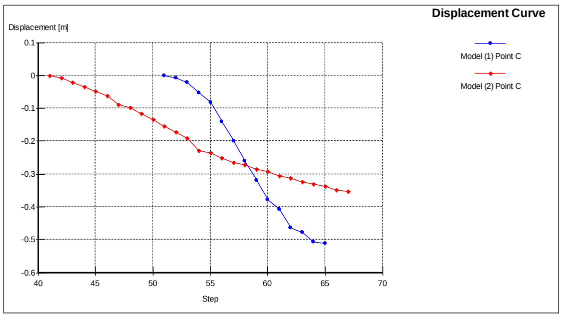


Figure 7. The Displacement curves for the models (1) and (2).

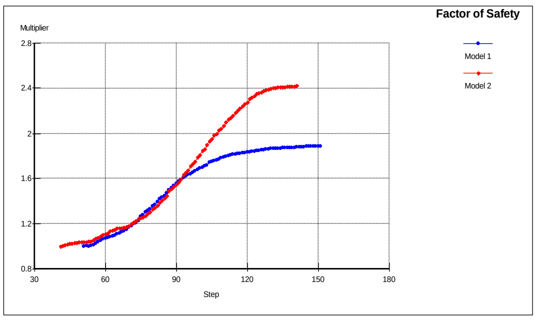


Figure 8. The factor of safety for the models (1) and (2).

The Case of High Loading

Two models with the same requirements in the previous section were analyzed by using Plaxis program but for big structure like bridge and higher loadings as following:

- Length of pile cap is 20m, width is 2.5m and thickness is 2.5m.
- Depth of piles is 24m, massive circular pile with diameter is 1.5m, spacing between piles is 5.5m, pile end distance is 1.75m, number of piles is 4
- Third model: is a foundation consists of pile cap and piles with applied load 240kN/m^2.
- Fourth model: is a foundation consists of pile cap, piles and stone with applied load 240kN/m^2.

The data of the soil investigations in Table 1 used for the two above models. Mohr-Coulomb with undrained condition is assumed. The properties of the piles and pile cap material are shown in Table 3.

After analyzing the two above models, the settlement for each model by using Plaxis Program for Finite Elements is shown in the Figures from 9 to 12. It can be seen the effect of using the stone with the piles to reduce the settlement and modify all the soil parameters.

The results of the numerical analysis of the two models can be summarized in Table 4.

Table 4 shows that the results of the fourth model are modified by reducing the values of vertical displacement and vertical strain through the treatment by replacement the soil with stone to depth equal to 15m, which means that the safety in the fourth model becomes more than that of the third model and gives more agreement for this treatment.

Calculating of bearing capacity

The ultimate load-bearing capacity of group piles can be calculated for the case of high loading by the following formula [10]:

$$\sum Q_u = L_g B_g c_u N_c + \sum 2(L_g + B_g)\, c_u \Delta L \qquad (1)$$

Where:

Q_u = Ultimate load-bearing capacity of group piles.
L_g = (number of piles in x-direction – 1) × spacing between piles + 2× (thickness of pile cap/2).
B_g = (number of piles in y-direction – 1) × spacing between piles + 2× (thickness of pile cap/2).
c_u = Undrained cohesion of the soil at the pile tip.
ΔL = Length of the pile.
N_c = Bearing capacity factor, from (Figure 7.9) [10].

Third Model

L_g = (4 – 1) × 5.5 + 2(2.5/2) = 19 m
B_g = (1 – 1) × 0.0 + 2(2.5/2) = 2.5 m
N_c = 7.5, maximum cohesion = 60kN/m^2
Q_u = 19×2.5×60×7.5+2(19+2.5)×60×24
= 83295kN.

Fourth Model

The value of c_u is taken equal to the cohesion of the stone equal to 500kN/m^2, therefore:

Q_u = 19×2.5×500×7.5+2(19+2.5)×500×24
= 694125kN > 83295kN. OK

As shown from the above calculations that the replacement of the soil with stone will increase the ultimate load-bearing capacity of the group piles. Therefore the value of the ultimate load-bearing capacity of the group piles is more than the applied load, indicating that the bearing capacity of the pile group is sufficient.

Table (1): The Strength Parameters and Properties of The Soil With the Depths of Bore Holes.

Soil Layer	Soil Type	γ (kN/m^3)	$γ_s$ (kN/m^3)	k (m/min)	ν	G (MPa)	c (kPa)	φ (°)	$R_{inter.}$
1	Silt	19	20.3	0.864	0.29	50	7	20	0.87
2	Clay	16	17	8.64E-4	0.35	6	15	15	0.85
3	Silty Clay	18	18.5	8.64E-4	0.32	6.2	25	22.5	0.82
4	Fine Sand	19.6	21	0.864	0.28	58	5	37	0.86
5	Silty Clay	21	21.3	8.64E-4	0.30	7.8	34	30	0.8
6	Clay	19	19.3	8.64E-4	0.35	5	45	32	0.85
7	Silty Clay	18.5	19	8.64E-4	0.35	5	60	34	0.78
8	Stone with mortar	24	24	Non-porous	0.25	10000	500	36	0.89

Notes: γ = Natural Unit Weight; $γ_s$ = Saturated Unit Weight; *k* = Coefficient of Permeability; ν = Poisson Ratio; *G* = Shear Modulus; *c* = Cohesion; φ = Friction Angle; $R_{inter.}$ = Interface Reduction Factor. The shear modulus and strength parameters for the stone taken from references [8].

Table (2): Results of The Numerical Analysis for Models (1) And (2)

First Model	Total vertical displacement	- 52.169 cm
	Vertical strain	- 3.99 %
	Factor of safety	1.9
Second Model	Total vertical displacement	- 36.991 cm
	Vertical strain	- 3.85 %
	Factor of safety	2.4

Table(3): Material Parameters For Pile Foundation

Item	Unit Weight (kN/m^3)	Poisson's Ratio	Shear Modulus (GPa)
Pile Cap	24	0.15	28
Pile	25	0.10	30

Table 4. Results of The Numerical Analysis for Models (3) and (4)

Third Model	Vertical displacement	- 39.72 cm
	Vertical strain	- 4.53 %
Fourth Model	Vertical displacement	- 8.821 cm
	Vertical strain	1.32 %

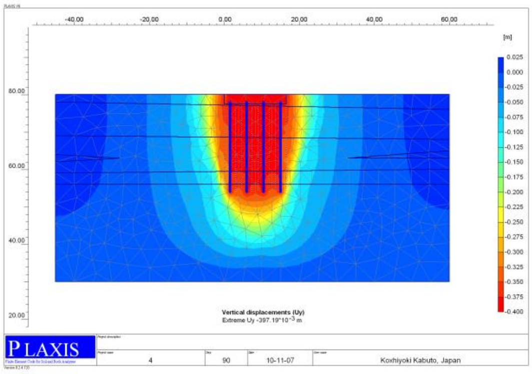


Figure 9. The vertical displacements (Uy) in meterts for all the layers of the model (3) of high loading.

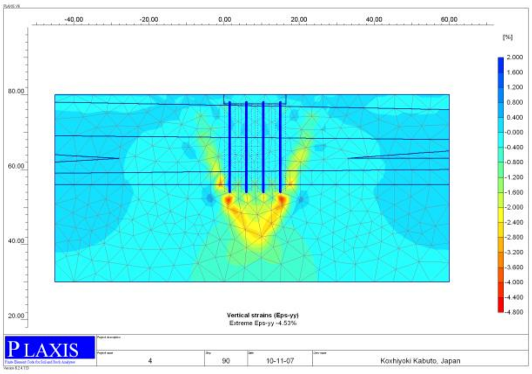


Figure 10. The vertical strain for all the layers of the model (3) of high loading.

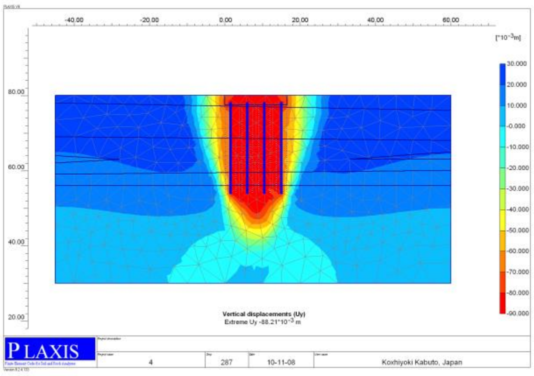


Figure 11. The vertical displacements (Uy) in meters for all the layers of the model (4) of high loading.

Conclusions

- There are many types of stones used for building, manufacturing of cement, paving of the rivers, soil replacement, etc. In the present time we can use them in building the foundations for small and big structures.
- The processes used of building with stones in the foundation leading to cracks and structural failure because of the movement and rearrangement of pieces of stones due to loads coming from the superstructure.
- The stones used in the foundations building should not contain large amounts of gypsum, because it leads for piping (collapse) due to the effect of water coming from ground water or rain etc.
- Using the reinforced columns in the small foundations with the stone and beam leads to reduce the vertical displacement to small value and reducing the effect of deflection and cracks to 70% and 22% respectively.
- The vertical strain will be decreased for the foundation treated with stone.
- The factor of safety will be increased for the foundation treated with stone.
- The bearing capacity becomes high by using the stones in addition to the beam (or pile cap) and concrete columns (or pile) in the foundation.

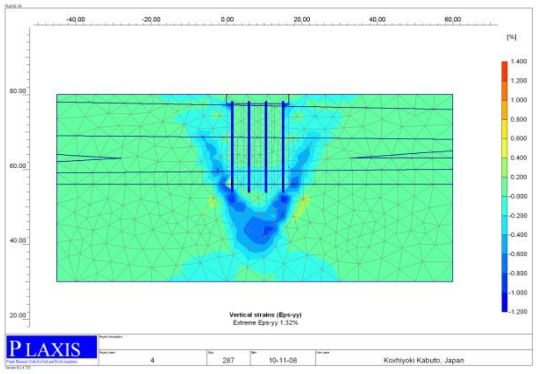


Figure 12. The vertical strain for all the layers of the model (4) of high loading.

Recommendations

- The stone used for building the foundations must be rigid with high strength and having a little amount of gypsum.
- To avoid the cracks in the structures due to the movement and rearrangement of the pieces of stones in the foundation, we must use reinforced concrete columns and beams for small structures, and using stone instead of the weak soil for big structures.
- When the weak soil is replaced by stone, the stone should be as a crushed stone with different sizes to reduce the voids between the pieces of the stones.
- For the purpose of replacement of the weak soil with stone in the deep excavation, the excavation sides should be supported with a suitable sheet piles to protect the soil to not be collapsed.

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