Eng. & Tech. Journal, Vol. 31,Part (A), No.20, 2013

1st International Conference for Geotechnical Engineering and Transportation ICGTE in2415/4/2013

A Comparative Study between Piled-Raft and Two Soil Improvement Techniques

Dr. Maki Jafar M. Al-Waily
Al-Musaib Technical Institute
Ala'a Ali S. Al-Ta'ai
Al-Musaib Technical Institute
Suad Mohammed H. Al-Janabi
Al-Musaib Technical Institute

ABSTRACT

This investigational study was directed to establish the correlation between piled raft foundation and two soil improvement techniques, stone columns and lime columns to evaluate the bearing improvement ratio BCR for the soft clay soil with three values of undrained shear strength, 8 kPa,10 kPa and 12 kPa. The 12 model tests was conducted in the present work, three models of untreated soil, three models of soil with piled raft, three models of soil treated with stone columns and three models of soil treated with lime columns. The container used in experimental works was made of steel with plane area of 500 mm * 500 mm and 500mm in height. The thickness of soil sample inside the container was 400 mm.

The study showed that the piled raft was more efficient in the bearing capacity improvement than the two soil improvement techniques. The bearing improvement ratio were 3.39, 3.27 and 2.78 in the three model tests of piled-raft for three samples of soil, respectively, while the lime columns provided the lowest values of the bearing improvement ratio were 1.64, 1.67 and 1.8 respectively.

Keywords: Piled-Raft, Improvement Techniques, Comparison Study, Soil

دراسة مقارنة بين الأساس الحصيري المدعم بالركائز وبين اثنين من تقنيات تحسين التربة

الخلاصة

وجهت هذه الدراسة الاستكشافية لتحديد علاقة بين الاساس الحصيري المدعم بالركائز وبين تقنيتين من تقنيات تحسين التربة وهما الاعمدة الحجرية واعمدة النورة لتقييم نسبة تحسين التحمل BCR لتربة طينية رخوة مع ثلاث قيم لمقاومة القص غير المبزولة وهي 8 kPa و 10 kPa و 12 kPa. تم اجراء اثنا عشر نموذج فحص في هذا العمل توزعت بواقع ثلاثة نماذج لتربة غير معالجة وثلاثة نماذج لتربة مع الاساس الحصيري المدعم بالركائز وثلاثة لتربة مع عمود حجري وثلاثة لتربة مع عمود نورة. لقد استخدمت حاوية مصنوعة من الفولاذ بابعاد 500 mm * 500 mm في المساحة و 500 mm في الارتفاع, علما بان سمك نموذج التربة داخل الحاوية كان يساوي 400 mm.

لقد بينت هذه الدراسة بان الأساس الحصيري المدعم بالركائز كان أكثر كفاءة في تحسين قابلية التحمل من تقنيتي تحسين التربة حيث أعطى قيما لنسبة تحسين التحمل BCR تساوي 3.39 و

3.27 و 2.78 في نماذج الفحوصات الثلاثة للاساس الحصيري المدعم بالركائز لثلاث نماذج من التربة على التوالي, بينما اعطت اعمدة النورة اقل لنسبة تحسين التحمل BCR وهي 1.64 و 1.67 و 1.8 لنفس نماذج التربة على التوالي.

INTRODUCTION

The Piled Raft Approach

In the past few years, there has been an increasing recognition that the use of piles to reduce raft settlements and differential settlements can lead to considerable economy without compromising the safety and performance of the foundation. Such a foundation makes use of both the raft and the piles, and is referred to there as a pile-enhanced raft or a piled raft. Technical CommitteeTC18 of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) has focussed its efforts since 1994 towards piled raft foundations, and has collected considerable information on case histories and methods of analysis and design.[1]

Piled raft on soft soil ground is an economical foundation system where the bearing capacity of the raft is taken into consideration in supporting the loads from superstructures. The friction piles in a raft system are located strategically to enhance the bearing capacity of the raft and also to control settlement, especially different settlement and hence, these piles are commonly known as “Settlement reducing piles”. Therefore, piled raft is technically competent foundation system and offers significant savings in terms of overall foundation cost as compared to conventional piled foundation. This is because conventional piled foundation usually ignores the contribution of the raft and assumes the loads are supported entirely by piles.[2]

The foundation concept of piled rafts differs from traditional foundation design, where the loads are assumed to be carried either by the raft or by the piles , considering the safety factors in each case. Several methods of analyzing piled rafts have been developed. Three broad classes of analysis method have been identified [3]:

1. Simplified calculation methods
2. Approximate computer-based methods
3. More rigorous computer-based methods

The interaction between the raft and the piles depend on the foundation design. Four different approaches are defined in , where the latter three is in the scope of piled raft foundation [4]:

- The conventional approach, where the piles are designed for the entire load.
- Creep piling, in which the piles operate at 70-80% of their capacity, i.e. at the load where creep, typically, starts to occur. The piles are further used to limit the contact pressure below the pre consolidation pressure.
- Differential settlement control, where the bearing capacity of the raft is sufficient but piles are added strategically to reduce differential settlements.
- Settlement reducing, an extreme version of creep piling, in which the piles operate at 100% of their ultimate load capacity. The main purpose is to reduce settlement, Rather than increasing the ultimate load capacity. But the ultimate load capacity is, of course, increased as well.

The Stone Column Approach

Stone column technique is used extensively as soil improvement to undertake constructions in weak soils. The stone columns essentially increase the bearing capacity of loose cohesionless soils. In cohesive soils, along with the increase of bearing capacity, the stone column is also considerably reduced the total settlement beside the stone column act as drainage to accelerate the rate of consolidation of the residual settlement.

Stone columns in compressive loads fail in different modes, such as bulging [5], general shear failure [6], and sliding [7]. A long stone column having a length greater than its critical length (i.e., about 4 times the diameter of the column) fails by bulging irrespective of whether it is end bearing or floating [8]. Many of the researchers have developed theoretical solutions for estimating bearing capacity and settlement of reinforced foundations by stone columns [6,7and 9]. A homogenization assumption (improved soil is assumed as a homogeneous material with equivalent properties) to estimate the ultimate bearing capacity and settlement is presented by [10].

The Lime Column Approach

Lime and lime cement columns are installed using the deep soil mixing technique, in which a hardening binder such as lime, cement or a mixture of lime and cement is mixed with the soil using mixing tools. This technique was developed and put into practice in the middle of 1970's independently in Sweden and Japan. It is distinguished between dry mixing and wet mixing. In dry mixing a mixing tool is penetrated to the desired depth after which during retrieval a dry binder (usually a lime cement mixture) is injected into the soft soil using compressed air. This binder is mixed with the soil . Since no water is added, the soil should have a water content of at least 20%. In wet mixing generally a cement slurry is added to the soil mechanically.[11]

This method produces both a consolidation and strength gain effect on the treated soil, without additional loading, via lateral expansion of the lime columns as they absorb water from the soft soil. These lime columns have the following effects on the adjacent soil:

a. Consolidation / dewatering effect

Quick lime, CaO, absorbs water from the surrounding ground, causing the lime to swell and form slaked lime (Ca(OH)2) as per the following chemical reaction:[12]

	CaO +	H_2O →	$Ca(OH)_2$	+ 15.6 Kcal/mol
Molecular weight	56	18	74	[280 Kcal/kg]
Specific gravity	3.3	1	2.2	
Weight ratio	1	0.32	1.32	(absorption ratio 1.3 times)
Apparent volume	1	1.06	2.0	(swelling ratio 2 times)

Lime-cement columns are used to stabilize soft soils. It is commonly used in road and railway embankments to reduce settlements and improve the stability. It also reduces vibrations that can arise from railways. Lime-cement columns can be made with two different methods; the dry-mixing method and the modified dry-mixing method. The dry mixing method is most frequently used in some countries. In this method no water is added, instead water in the soil is consumed for the Process. Therefore this method only can be used in soils with relatively high water content, e.g. in clay and silt. [13].

The present paper investigate the behavior of stone column, lime column and piled raft under compression state oriented mainly towards the determination the bearing improvement ratio BRC.

Testing equipment

Figure (1) shows details of the complete set up which consist mainly of loading frame, steel container, and the following accessories.

1-Four dial gauges (with capacity of 50 mm and accuracy of 0.01 mm) to measure the settlement of soil with (raft, piled raft, raft with stone column and raft with lime column).

2-Container of a box shape with plane of 500 mm * 500 mm and 500 mm in height, made of steel plate (6 mm in thickness) to carry out the tests on the models.

3-The circular plate with diameter of 75 mm and 6 mm in thickness was used as raft foundation.

4-The plate loads with various shapes (circular, square and rectangular) are used to apply load on foundation.

Materials used

six basic materials used for this study are clay, stones, gravel, sand, lime and cement having the following properties:

The soil used in the tests are brought from the vicinity of Al-Musayyab technical institute in Babylon .The soil consists of 13% sand, 35% silt, and 52% clay with liquid limit equal to 44% plastic limit of 22%. The Maximum dry unit weight of soil sample was 18 kN/m^3. The soil was classified as (CL) Symbol according to unified soil classification system. The tests were carried on a pile, stone and lime columns of the same dimensions (30 mm in diameter and 300 mm in height). A Sulphate Resisting Portland cement, natural gravel and sand were used in this investigation for constructing the pile model. The natural calcium carbonate crushed stone was used as a backfill material for constructing the stone column, with particle size varying from 1 mm to 10 mm . A commercial hydrated lime was used in this investigation to make lime column .

Preparation of the bed of soil

- Prior to the preparation of the bed of soil a relationship between the water content and the undrained shear strength of the soil ranged between 8 kPa and 12 kPa was obtained.
- The undrained shear strength of the soil is tested by unconfined compression machine.
- The conditional soil was mixed with enough quality of water to get the desired shear strength.
- The soil was placed in layers inside the steel container and each layers was tamped with a special tamping hammer.
- The final thickness of each layers was about 50 mm.
- The procedure continued until the final thickness of the bed of soil was 400 mm.
- After the completion of the preparation of the bed of soil, it was covered tightly with nylon sheets and left five days curing period.

Construction of Pile, stone and Lime columns

- At the end of curing period, the top of the soil bed was levelled and divided into four zones. One zone was left for raft foundation only.
- A pile with diameter of 30 mm and length of 300 mm (i.e. length to diameter or (L/D) ratio equal to 10) was inserted in the centre of piled raft zone.
- The plastic pipe with external diameter equal to 30, was pushed vertically to the depth of 300 mm to make the hole of stone column. The previous process was repeated for lime column.
- The plastic pipe was then slowly withdrawn and twisted during the lifting process.

- The soil was removed from the tube by hand auger, and samples of the soil at different depths were taken for water content measurement,(1) see Figure (2).
- The crushed stone or lime was poured into the hole in layers and each layer was compacted gently using (10 mm) in diameter steel rod.
- The unit weight of the compacted crushed stone was 18 kN/m^3 and initial unit weight of lime column was 7 kN/m^3.The whole bed of clay was covered with a nylon sheet and protected from any lose of moisture and left for a period of five days .
- The temperature was measured daily along the period.

Model testing procedure

- At The end of the five days period, the footing assembly was placed in position so that the centre of the footing coincides with the centre for each four zone (raft, piled raft, raft with stone column and raft with lime column) .
- Plate load were then placed centrally on the upper part of loading disk .
- Each plate load was left for (2.5 min) .
- The dial gauge readings of the settlement were recorded at the end of the period for each plate load in the four model tests.
- The placing of plate load continued until total pressure reached approximately 60 kPa on raft foundation only and 105 kPa for other three foundation (piled raft, raft on stone column and raft on lime column).
- Following that the final load is held constant for 96 hours for recording the settlement for each model test, (2) see Figure **(**1).
- **Presentation And Discussion**
- It can be used the formula suggested by [14] to get the effects of pile-raft and the two soil improvement techniques (stone and lime columns) on bearing capacity of soil. This formula is generally expressed in terms of non-dimensional parameter called bearing capacity ratio, BCR. The bearing capacity ratio can be expressed with respect to the ultimate bearing capacity or allowable bearing capacity at a given settlement level of the foundation. In present work , the bearing capacity ratio, BCR can be defined as,

$$BCR = \frac{q_R}{q} \qquad \text{... (1)}$$

Where:

q_R, q= load per unit area on the foundation at a settlement level, equal to 10% of footing diameter with and without pile, stone column and lime column respectively.

The model tests were divided into three groups, differ among them in the value of the undrained shear strength of soil sample. The values of undarined shear strength are 8 kPa, 10 kPa and 12 kPa respectively. Each of the three group included four model tests, untreated soil or raft only, soil with raft and pile or piled-raft, soil with raft and stone column and soil with raft and lime column.

Figures (3, 4 and 5) show the relation between the bearing capacity ratio, BCR, represents the ratio of load of raft with pile or stone column or lime column to the load on the raft only and the settlement ratio, S/D where the S, represents the settlement of the footing and the D, represents the diameter of the foundation for three values of undarined shear strength of soil. All three groups exhibited the same behavior of maximum values of bearing capacity ratio, BCR at the initial value of S/D . When S/D exceed 0.08 at the soil having shear strength of 8 kPa or S/D= 0.07

in the soil of shear strength 10 kPa or S/D=0.05 in the soil with cu= 12 kPa the BCR values reached constant values and continued up to the end of the test.

Among all the improvement techniques the use of piled raft provided the most efficient increasing in bearing capacity ratio i.e. the highest value of BCR as shown in Table (2).

It can be noticed from the Table (2) that the value of BCR is decreased with increasing the shear strength of surrounding soil for soil with piled raft i.e. The impact of the use of this technique seems clear in soils with low shear strength than others. It is worth mentioning that the behavior soil treated with lime column in contrary way. While the manner of soil treated with stone columns is not entirely clear. In general, the change in the value of the bearing capacity ratio, BCR was slight in three model tests of stone columns and lime columns. There is a clear difference in the results of BCR appears between piled-raft and both soil improvement techniques, stone column and lime column. This difference decreases with increasing settlement ratio, S/D, then the difference become constant about the settlement ratio, S/D= 0.1.

The greatest value of the bearing capacity ratio is achieved when using the pile-raft technique. This behavior is related to that the stiffness of concrete used in pile is lager the crushed stone and lime.

The bearing improvement ratio were 3.39, 3.27 and 2.78 in the three model tests of piled-raft, while the lime columns provided the lowest values of the bearing improvement ratio were 1.64, 1.67 and 1.8.

Figures (3 to 5) and Tables (3 to 5) show the relationship between stresses settlement ratio, S/D versus time when the stress is held constant for 96 hours after the end of the loading tests. These Figures showed the identical global trend that the rapid settlement ratio is occurred immediately when the holding of final stress constant up to 10 hour, especially through early two hours of holding . At this point the settlement reached to peak value in the all model tests. The value of S/D reaches a plateau at the end of 48 hours in the model tests of (piled raft, stone column and lime column) but the settlement in the model test of raft is continued to the 72 hours. These Figures indicates that the using of pile under raft and using the soil improvements technique lead to clear reduction in the long term settlement of the soil.

CONCLUSIONS

The results revealed that the bearing capacity ratio BCR achieved by piled raft, raft with stone column and raft with lime column are 3.39, 2.13 and 1.64 respectively in the soil having the shear strength equal to 8 kPa .The value of bearing capacity ratio ,BCR is decreased with increasing the shear strength of surrounding soil to the 10 kPa and 12 kPa. The using of stone column techniques provided the higher values of BCR than the lime column technique.

REFERENCES

[1].Poulos, H.G., " Methods of Analysis of Piled Raft Foundations"- report prepared on behalf of technical committee tc18 on piled foundations-(ISSMGE),2001.

[2].Tan, Y.C and Chow, C. M." Design of Piled raft Foundation in Soft Soil". Internet website, 2004

[3].Rabiei, Meisam, "Parametric Study for Piled Raft Foundations", EJGE Vol. 14, Bund. A, 2009.

[4].Ryltenius, André.," FEM Modelling of Piled Raft Foundations in Two and Three Dimensions" ,Master thesis , Geotechnical Engineering, LTH, Lund University.

[5].Hughes, J. M. O., & Withers, N. J., (1974), "Reinforcing of soft cohesive soils with stone columns", Ground engineering, Vol. 7, No. 3, May 1974, pp. 42 – 49.

[6].Madhav, M. R., and Vitkar, P. P.(1978), "Strip footing on weak clay stabilized with a granular trench or pile." Can. Geotech. J., 15(4), 605–609.

[7].Aboshi, H., Ichimoto, E., Enoki, M. & Harada, K., (1979), "The compozer: a method to improve characteristics of soft clays by inclusion of large diameter sand columns", proceedings International Conference on soil reinforcement; Reinf. Earth and other techniques, Vol. 1, Paris, pp. 211 – 216.

[8].Indian Standards (IS), (2003), "Indian standard code of practice for de-sign and construction for ground improvement-guidelines. Part 1: Stone columns." IS 15284 (Part 1), New Delhi, India.

[9].Greenwood, D. A., (1970), "Mechanical improvement of soils below ground surface", Proceedings Ground Engineering Conference, Institution of Civil Engineers, June 1970.

[10].Jellali, B., Bouassida, M., and De Buhan, P., "A homogenization method for estimating the bearing capacity of soils reinforced bystone columns." Int. J. Numer. Analyt. Meth. Geomech. ,29(10),(2005),Pp989–1004.

[11].Kempfert, H. G. "Ground improvement methods with special emphasis on column-type techniques", Int. Workshop on Geotechnics of Soft Soils, 2003.

[12].Wong, P. K., "Ground Improvement Case Studies Chemical Lime Piles and Dynamic Replacement". from website:(http://www.docstoc.com/docs/32209733/ground-improvement-case-studies-chemical-lime-piles-a...], (2004).

[13].Andersson, C. and Karlström, B., "Installation Effects of Lime-Cement Columns", Master of Science Thesis In The Master's Programme Geo And Water Engineering-Chalmers University Of Technology, 2010.

[14].Das, B. M; Omer, M. T. and Shin, E. C., "Development on the Bearing Capacity of Shallow Foundations on Geogrid-Reinforced Soil- A Review", Proceedings of the International Conference on Geotechnical Engineering, Soil Exploration, Testing and Foundation Design, the University of Sharjah, (2004), pp.k20- 46.

[15].Ambily, A. P. and Gandhi, S. R., "Behavior of Stone Columns Based on Experimental and FEM Analysis", Journal of Geotechnical and Geoenvironmental Engineering © Asce / April 2007,Pp 405-415

Table (2) Summary of Bearing Capacity ratio, BCR.

Type of foundation	cu	Bearing Capacity Ratio, BCR
Piled Raft Piled with stone column Piled with lime column	cu=8 kPa	3.39 2.13 1.64
Piled Raft Piled with stone column Piled with lime column	cu=10 kPa	3.27 2.19 1.67
Piled Raft Piled with stone column Piled with lime column	cu= 12 kpa	2.78 2.14 1.80

Table (2) Variation of settlement ratio with time in soil of cu= 8 kPa.

Time	Raft		Piled raft		Stone column		Lime column	
Hour	q/cu	S/D	q/cu	S/D	q/cu	S/D	q/cu	S/D
0	7.524	0.214	21.011	0.071	13.327	0.186	12.849	0.243
5	7.524	0.305	21.011	0.213	13.327	0.190	12.849	0.253
10	7.524	0.319	21.011	0.215	13.327	0.194	12.849	0.255
24	7.524	0.349	21.011	0.223	13.327	0.200	12.849	0.257
48	7.524	0.379	21.011	0.230	13.327	0.207	12.849	0.262
72	7.524	0.423	21.011	0.241	13.327	0.214	12.849	0.264
96	7.524	0.432	21.011	0.244	13.327	0.221	12.849	0.269

Table (3) Variation of settlement ratio with time in soil of cu= 10 kPa.

Time	Raft		Piled raft		Stone column		Lime column	
Hour	q/cu	S/D	q/cu	S/D	q/cu	S/D	q/cu	S/D
0.000	7.040	0.196	16.809	0.143	12.753	0.179	11.095	0.179
5.000	7.040	0.232	16.809	0.157	12.753	0.191	11.095	0.207
10.000	7.040	0.237	16.809	0.161	12.753	0.196	11.095	0.212
24.000	7.040	0.249	16.809	0.168	12.753	0.203	11.095	0.215
48.000	7.040	0.278	16.809	0.174	12.753	0.209	11.095	0.219
72.000	7.040	0.321	16.809	0.184	12.753	0.215	11.095	0.222
96.000	7.040	0.374	16.809	0.187	12.753	0.220	11.095	0.226

Table (4) Variation of settlement ratio with time in soil of cu= 12 kPa.

Time	Raft		Piled raft		Stone column		Lime column	
Hour	q/cu	S/D	q/cu	S/D	q/cu	S/D	q/cu	S/D
0.000	6.717	0.171	8.927	0.125	11.478	0.131	8.502	0.140
5.000	6.717	0.264	8.927	0.140	11.478	0.154	8.502	0.165
10.000	6.717	0.279	8.927	0.148	11.478	0.168	8.502	0.170
24.000	6.717	0.286	8.927	0.154	11.478	0.179	8.502	0.176
48.000	6.717	0.300	8.927	0.163	11.478	0.187	8.502	0.180
72.000	6.717	0.316	8.927	0.173	11.478	0.191	8.502	0.182
96.000	6.717	0.329	8.927	0.178	11.478	0.196	8.502	0.186

q: represents the applied stress

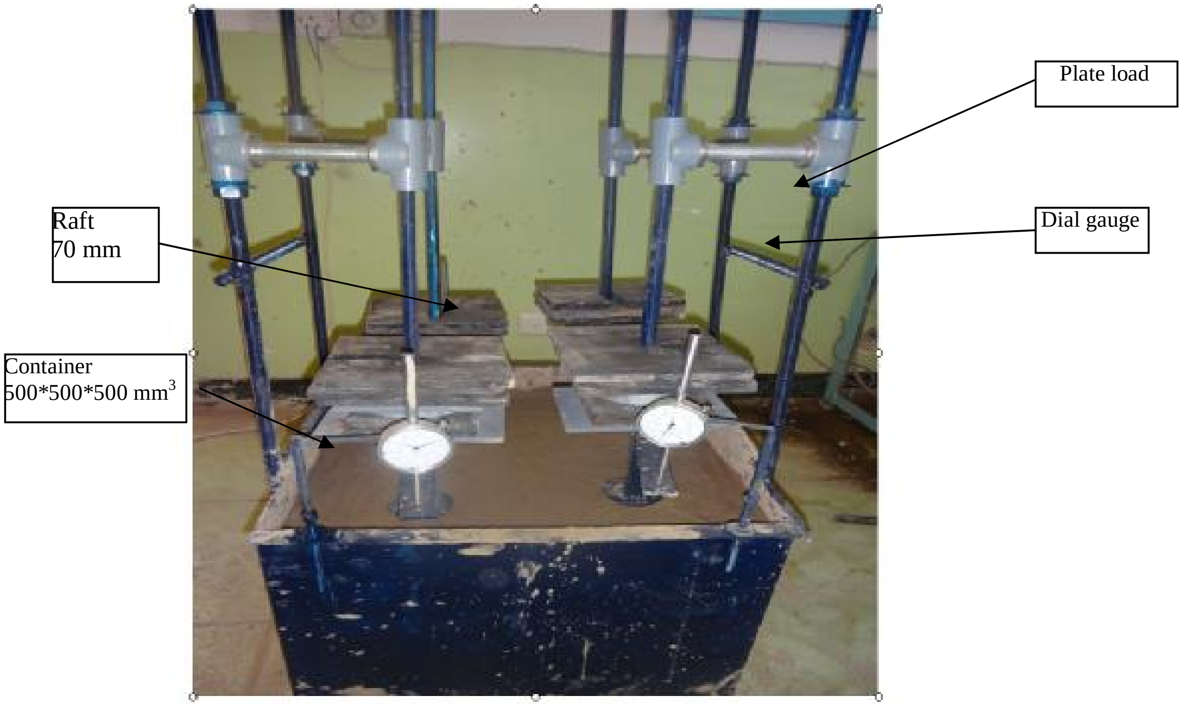

Figure (1) Experimental set-up.

a): Pouring of lime

b): Make the hole of the stone column

c): Pouring of crush stone

d): Pile model

e): Piled raft, stone column and lime column models

e): Fixation of accessories

Figure (2a to 2f) Installation of piled raft, stone column and lime column.

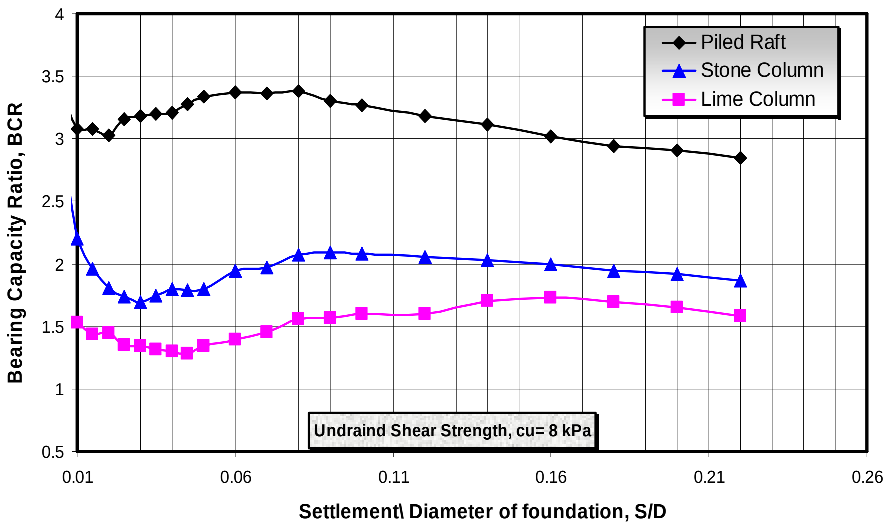

Figure (3) BCR versus S/D for soil of cu = 8 kPa.

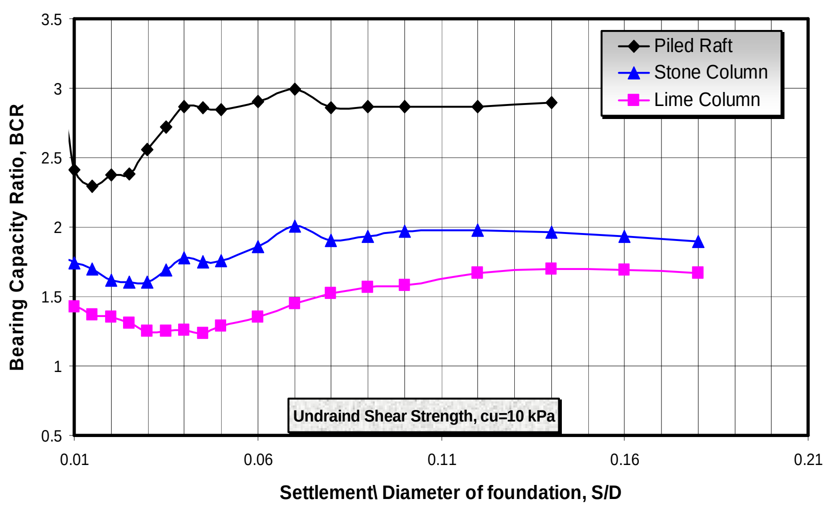

Figure (4) BCR versus S/D for soil of cu = 10 kPa.

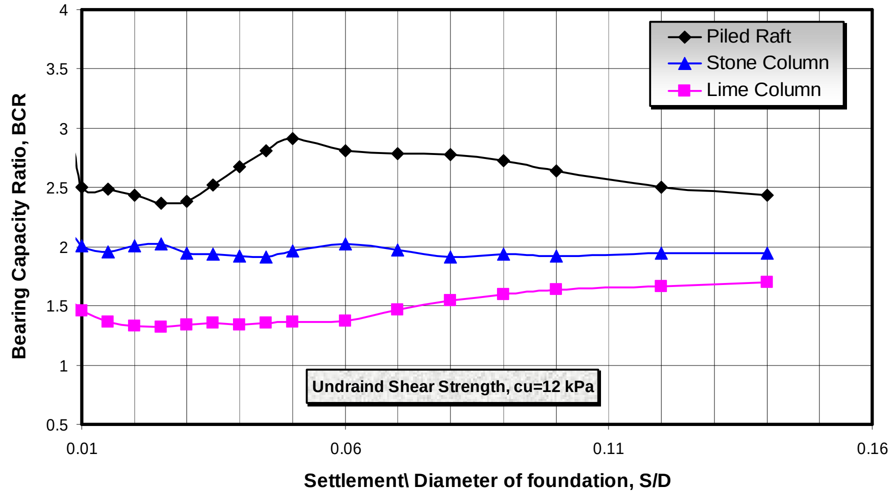

Figure (5) BCR versus S/D for soil of cu = 12 kPa.

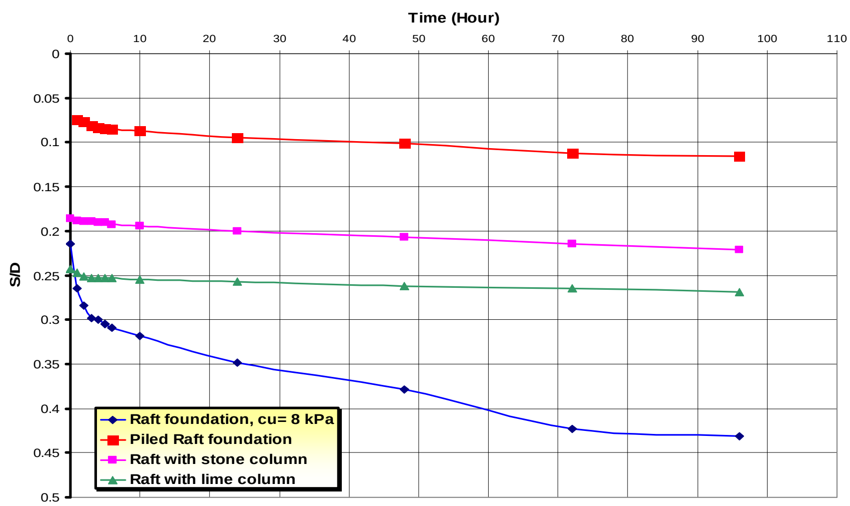

Figure (6) S/D versus time for the raft, piled raft, raft with stone Column and raftwith lime column Pile, cu = 8 kPa.

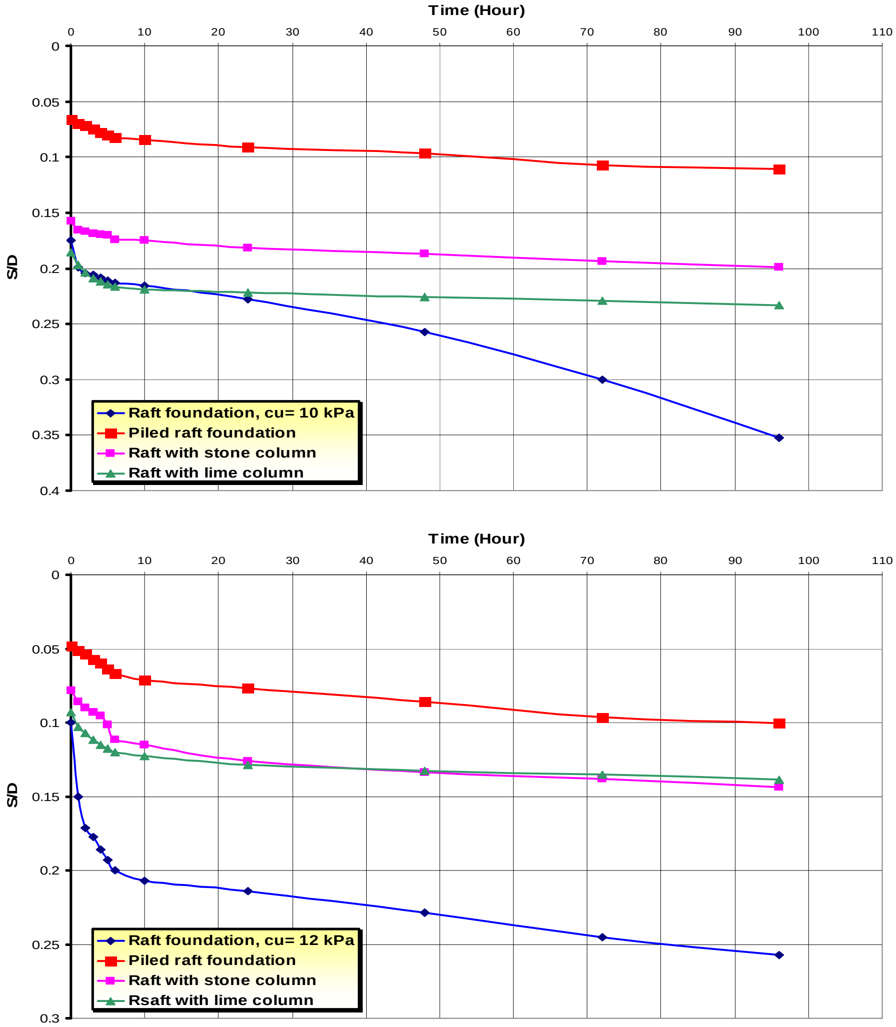

Figure (7) S/D versus time for the raft, piled raft, raft with stone Column and raft with lime column Pile, cu = 10 kPa.