Experimental Study on Behavior of Soft Clay Strengthened by Geogrid Encased Stone Columns

Mohammed Y. Fattah
Professor
University of Technology
Haifaa A. Ali
Lecture
University of Baghdad \Iraq

Abstract

Treatment of soft unsaturated soil using stone columns provides the most satisfactory results in terms of bearing improvement and settlement reduction under monotonic loading conditions, as compared to the untreated soil.

The present work deals with improvement of soft clay by single stone column under circular foundation 10 cm in diameter. The evaluation of that method is based on the amount of increase in bearing capacity and the reduction in settlement as compared to the untreated soil. The proposed method of treatment of soft clay requires determination of the affecting factors, the method is illustrated by using geogrid reinforced stone columns at different diameters (3, 5 and 7) cm of different lengths (1/3, 1/2 and 1) the model sample height (40 cm .)

It was concluded that the variation of IF (influence factor) was found between 3 and 88 % depending on the ratio of D/L, L (where D is the diameter of stone column and L is the length of embedded stone column) and the stiffness of geogrid. The stone column's length has a greater influence on settlement reduction and bearing capacity improvement than its diameter. The geogrid stiffness and pattern affects considerably the stone column's efficiency, as the geogrdid stiffness increases, the influence factor increases too. The settlement influence factor for encased stone columns is decreased by about 60 to 75% when the stone column diameter is increased from 3 to 7 cm.

Keywords: Soft clay, stone column, encased geogrid improvement.

1-Introduction

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Regardless of the purpose for stabilization desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of the project, [4.[

A series of laboratory tests on the geosynthetic encased stone columns performed to investigate the behavior of single and group of geosynthetic encased stone columns. The tests were performed on single and group of stone columns with and without geosynthetic encasement in a large scale model test tank. It was found that the geosynthetic encasement more effect by the stiffness of the stone column and the confining pressure of stone column, [14].

The present work deals with improvement of soft clay by single stone column under circular foundation 10 cm in diameter. The evaluation of that method is based on the amount of increase in bearing capacity and the reduction in settlement as compared to the untreated soil. The proposed method of treatment of soft clay requires determination of the affecting factors, the method is illustrated by using geogrid reinforced stone columns at different diameters (3, 5 and 7) cm of different lengths (1/3, 1/2 and 1) the model sample height (40 cm).

2. Experimental Work

Soil samples were collected from a depth of 30 cm below the ground surface of a site in Al-Jadirea in Baghdad city. The samples obtained were subjected to routine laboratory tests to determine their properties.

These tests include:

1. Grain size distribution (sieve analysis and hydrometer test).
2. Atterberg limits (liquid and plastic limits).
3. Compaction test.
4. Specific gravity.

According to the standard specification ASTM D4318-03, [3];. The sample was subjected to Atterberg limit tests in the laboratory, the results show that the soil sample has Atterberg limits as given in Table 1. According to the unified soil classification system, the soil is organic and organic silty clay with low plasticity CL.

The physical properties of the test soil samples conducted in the present work are particle-size distribution (ASTM D422); liquid and plastic limits (ASTM D4318); specific gravity (ASTM D 854-00) and the maximum dry density and optimum moisture content (ASTM D698). The results of these tests are given in Table.1.

2.1 Physical properties for stone column material

The natural calcium carbonate, $CaCo_3$ (limestone), crushed stone was used as a backfill material. The size of the crushed stone was chosen in accordance with the guidelines suggested, 15; where the particle size is about (1/6 to 1/7) of the diameter of stone columns. The minimum particle size is 4mm and the maximum particle size is 10 mm.

2.2 Geogrid reinforcement

The geogrids used are polymer meshes commercially known as Netlon CE 121(G1) and Tensar SS2 geogrid (G3). The plastic mesh has the engineering properties shown in Table 2 as provided by the manufacturing company. Fig. 1 shows the geogrid reinforcement used.

2.3 Model Tests

Large scale model tests were prepared for experimental work. Load tests were programmed to be incorporated using the frame of compression machine. These tests were carried out on single column. All the experimental work was carried out at the Soil Mechanics Laboratory of the Civil Engineering Department of the University Baghdad. The setup for laboratory tests consisted of circular tank, jack to apply pressure, electronic load reader, gage to read the settlement, electrical oven, holder, stands and extensions, footing, and soil model, see Figs. 2 and 3.

Each 20 kg of soil sample was mixed with enough quantity of water to get the desired consistency. The wet soil was kept inside tightened polythen bags for a period of two days. This period was sufficient to get uniform moisture content. After that, the soil was placed in three layers inside a steel container a circular tank of size 500 mm in height and 400 mm in diameter before that the sides of the container were coated with silicone grease to minimize the friction effect. After the placement of each layer, it was pressed gently with a wooden tamper of size (75×75mm) in order to remove entrapped air. After completing each layer, the top surface was scraped, leveled and compressed by steel sheet (390) mm in diameter loaded from axial loading system to reach the bed of soil and left for a period of two days to regain part of its strength.

The optimum water content amount that was obtained from the compaction test was added to the dry soil sample and then the soil was placed inside a circular tank of size 500 mm in height and 400 mm in diameter. Granite stone chips were used for the formation of stone columns. At the beginning of the tests, the footing plate was located in the center of tank. Load tests were carried out on single stone columns with various lengths (L = 400 mm, 133 mm, 200 mm) and various diameters (D = 30 mm, 50 mm, 70 mm). The position of the stone column to be constructed was properly marked in the center of the model and hollow steel tube was used to drive a hole inside of the soil model downwards until reaching the required depth, then the tube was slowly withdrawn and twisted during the lifting process in order to prepare the place of the stone column.

Table 1. Physical properties of testing soil sample.

Property	G_s	LL %	PL %	PI %	Fines %	Coarse %	$\gamma_{dry,max}$ kN/m^3	ω_{opt} %
Value	2.7	34	23	11	68.22	31.78	15.5	20

Table 2: Engineering properties of geogrid used.

a- Physical, chemical and biological properties for all geogrid used.

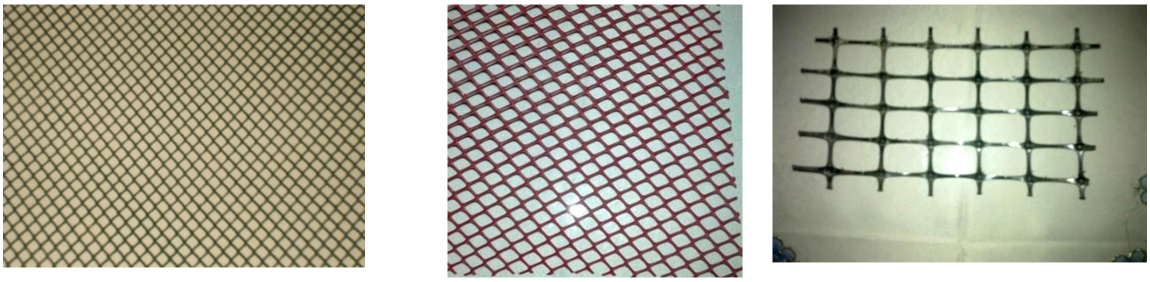
Property	Test method	Data
Structure		Extruded geogrid
Mesh type		Square
Standard color		Blake
Polymer type		$HDPE_2$
Packing		Rolls
Chemical resistance		The produce is inert to all chemicals naturally found in soils and water
Biological resistance		The produce is not affected by micro or genesis
Sunlight resistance		The addition of suitable stabilizers limits the attack from UV light. The material can be expected to have a life of over 5 years when exposed, without a loose of more than 20% of the product strength in a temperature climate
Temperature Stability		The material is stable within a temperature range of -60C^o to 100 C^o, but with a reduced strength at elevated temperature
UV stabilizer	ASTM D1603	Added with color

b- Dimensional properties

Property	Test Method	Unit	Data for geogrid No.1	Data for geogrid No.2	Data for geogrid No.3
Aperture size	ISO 9864	mm×mm	8×6	5×4	40×28
Mass per unit area	ISO 9864	g / m^2	730	100	300
Roll width	ISO 9864	m	2	2	4
Roll length	ISO 9864	m	20	20	50

c- Technical properties

Property	Test Method	Unit	Data for geogrid No.1	Data for geogrid No.2	Data for geogrid No.3
Tensile strength at 2 %	ISO10319	kN/m	5.1	3	6
Tensile strength at 5 %	ISO 10319	kN/m	9.1	8	16.4
Peak tensile strength	ISO10319	kN/m	16.0	12	17.5
Yield point Elongation	ISO10319	%	20	8	12



Geogrid (1) | Geogrid No. (2) | Geogrid (3)

Fig. 1: Geogrid reinforcement

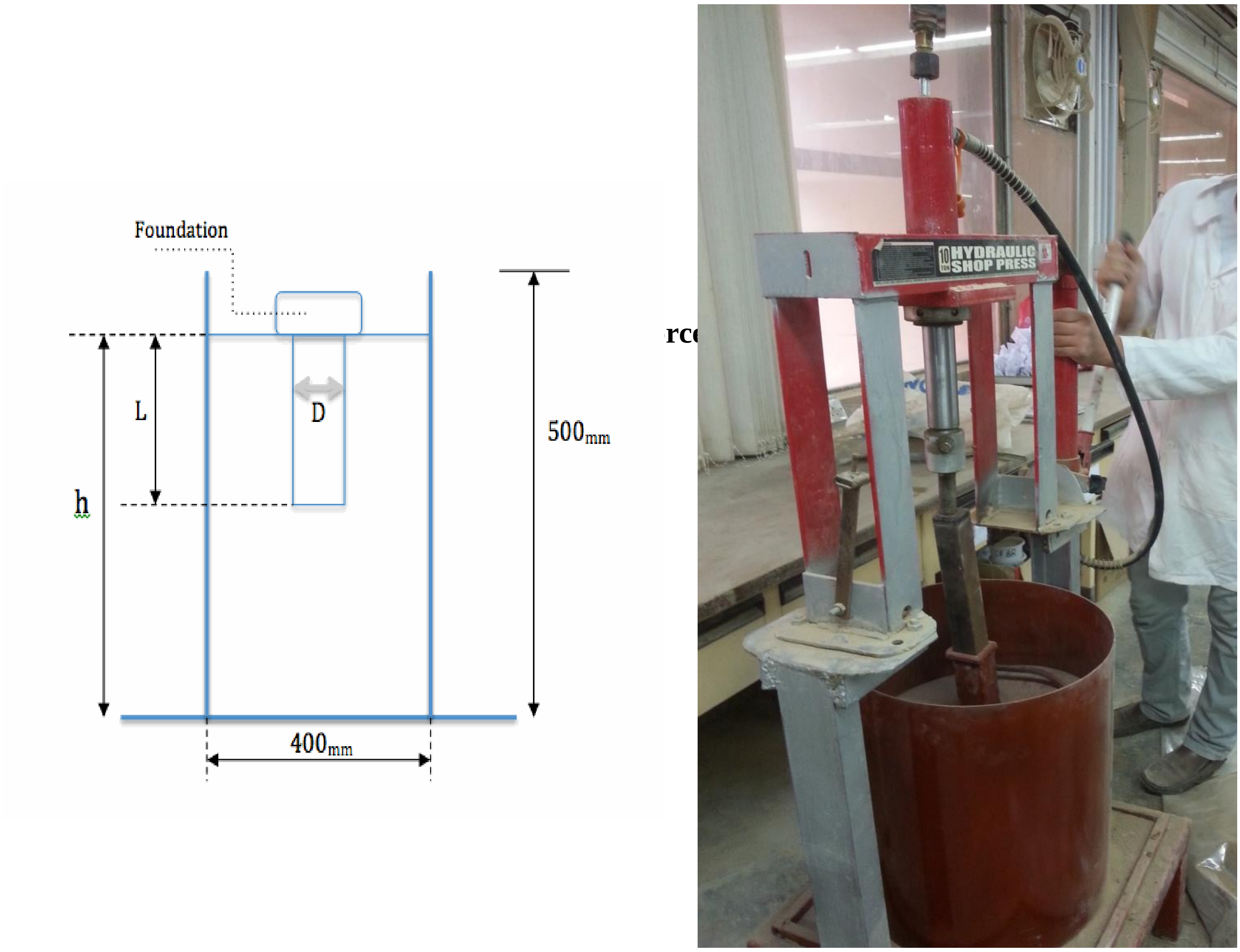


Fig.2 Sketch and View for large scale model.

(S-Beam load cell No. SSL300)	Hydraulic juke piston	Digital weighing indicator (No. 4010)

Fig. (3) Parts of loading pressure system.

3. Results and Dissection

The variable effects such as diameter of stone column, length of embedded column in soft soil, the effect of the ratio D/L and the stiffness of geogrid which is used as a material to decrease the effect of bulging reduction in granular column, were investigated in the experimental work.

To show the validity of treatment method in improving the strength of soft soil by geogird encased granular columns, Figures 4 to 27 are drawn, the results can be summarized in Tables 3 to 6.

From the loading test results, Figures 4 to 27 show the significant effect of the treatment on strength of the soft soil by reduction of settlement under loading for all values of variables at any loading state.

The ratio D/L was found to have a great effect when connecting with variation of embedded stone column encased with geogrid or without encasement. This effect can be shown in results Figures or Tables 3 to 6.

The Influence Factor (IF) which is defined in equation 1 can be used to reflect the agreement results and show the effect of D/L on increasing the beneficial effect of the method and the suitability for each variable.

$$IF = \frac{S_t - S_u}{S_u} \times 100 \qquad \text{.................(1)}$$

where:

S_t: settlement for treated sample at any loading stage, and

S_u: settlement for untreated sample at the same load stage.

Tables 3 to 6 summarize the results of experimental work and the variation of IF was found between 3 and 88 % depending on the ratio of D/L, L and the stiffness of geogrid.

The effect of the stiffness of geogrid in reduction of the effect of bulging in granular stone is found in Figures 4 to 27 as reduction in the total value of settlement when comparison is made between two states; the first is ordinary stone column and the stone column encased by geogrid at any stiffness.

To investigate the behavior of reinforced stone column under loading, the loading test is chosen to represent the behavior and the stress-settlement curves can be shown in Figures 19 to 27. Stress-settlement curves of geogrid encased stone columns have the same initial rating curve under light loading and then have a high rating curve under high level of loading. The difference between each case depends on the stiffness of reinforcement geogrid that is used for this treatment, D/L ratio and the depth of embedment of stone column encased by geogrid.

The efficiency of the treatment method is noticed in Tables 3 to 6 at for each case and for any variable such as diameter of stone column, the depth of location of reinforced stone column and the stiffness of geogrid materials.

It can be noticed that the stone column's length has a greater influence on settlement reduction and bearing capacity improvement than its diameter.

The geogrid stiffness and pattern affects considerably the stone column's efficiency, as the geogrdid stiffness increases, the influence factor increases too.

The results of the geogrid encased stone columns have a more improvement for bearing pressure as compared with ordinary stone columns. This behavior is attributed to the load transfer mechanism, the stress is transferred to the stone columns expressing these peak values then it is gradually transferred to the surrounding soil implied by the drop in the improvement ratio. The results have a good agreement with results from laboratory tests in references [10, 14, and 15]. They found that using geogrid material have a more effect on bearing capacity of stone columns.

The efficiency of geogrid encased stone columns as compared with ordinary stone columns is also pronounced in models. These results are in agreement with the results of references [7, 8, 9, and 17] who indicated a clear reduction in column vertical settlement when encased stone columns are used. The settlement influence factor for encased stone columns is decreased by about 60 to 75% when the stone column diameter is increased from 3 to 7 cm.

There is an increase in bearing ratio at the early stages of applying the load in the case of ordinary and geogrid encased stone columns, and then the value of bearing ratio was increased with increase of the settlement ratio. This behavior may be attributed to the beginning of loss of interlocking between the stone particles and the geogrid or attributed to the increase of lateral deformation of the column with increase of the load; this observation is in close agreement with the results presented by references, [12, 14 and

16]; who found that encasing stone columns with geogrids resulted in an increase of load carrying capacity.

4. Conclusions:

1. The variation of IF was found between 3 and 88 % depending on the ratio of D/L, L and the stiffness of geogrid.
2. The stone column's length has a greater influence on settlement reduction and bearing capacity improvement than its diameter.
3. The geogrid stiffness and pattern affects considerably the stone column's efficiency, as the geogrdid stiffness increases, the influence factor increases too.
4. The settlement influence factor for encased stone columns is decreased by about 60 to 75% when the stone column diameter is increased from 3 to 7 cm.

5. List of symbols and abbreviations:

IF : The influence factor
D : Diameter of stone column
L : Length of stone column
L.L : Liquid limit (%)
P.L : Plasticity limit (%)
P.I : Plasticity index (%)
Gs: Specific gravity
γdry max. : Maximum dry unit weight.
ωopt. : Optimum water content.

St: settlement for treated sample at any loading stage, and
Su: settlement for untreated sample at the same load stage.

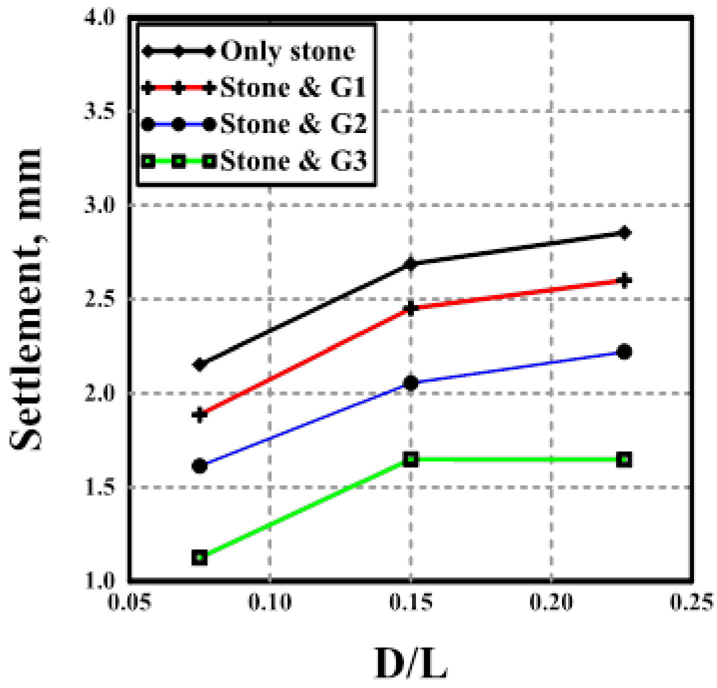


Fig. 4: D/L ratio with settlement for a sample having a diameter 3 cm under a load of 50 kN.

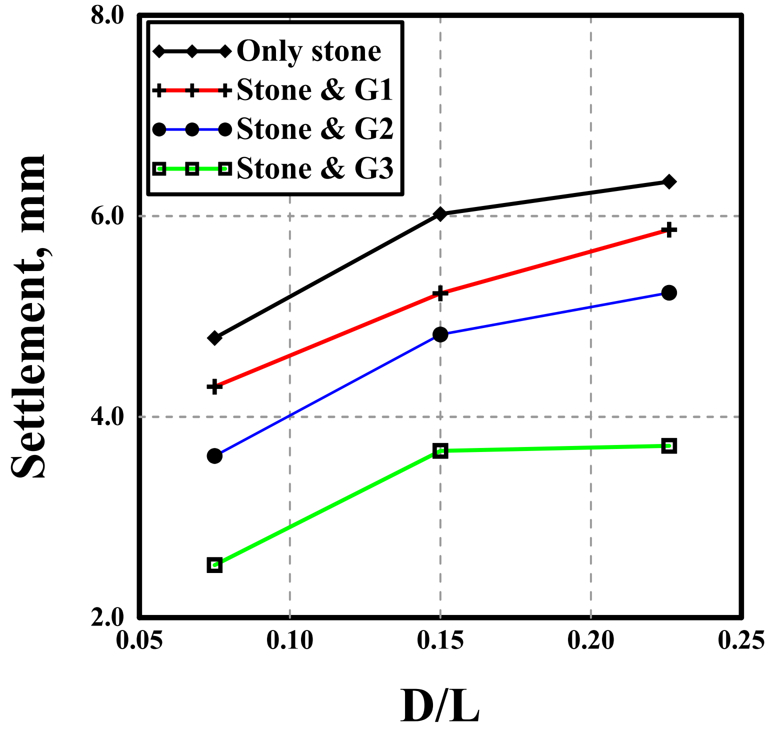


Fig. 5: D/L ratio with settlement for a sample having a diameter 3 cm under a load of 100 kN.

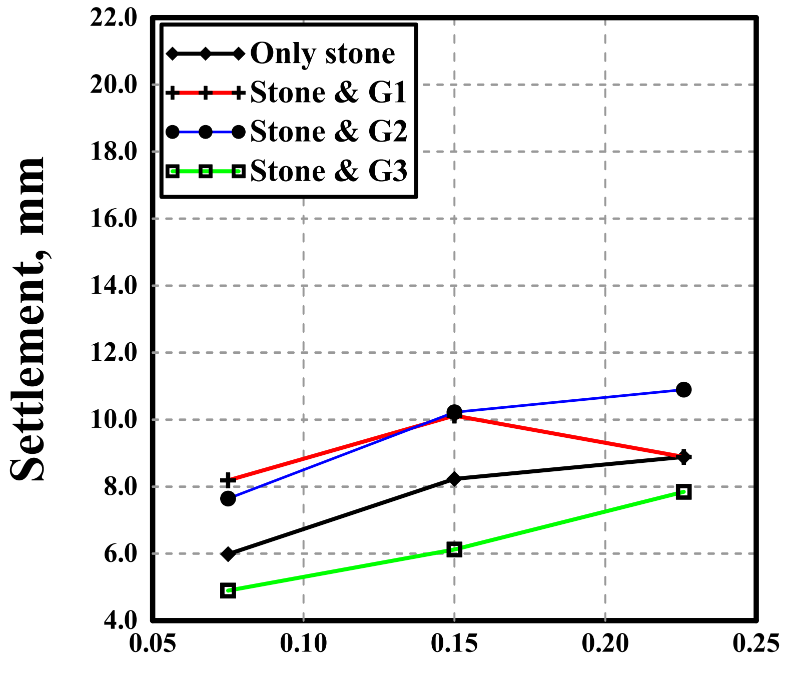


Fig. 6: D/L ratio with settlement for a sample having a diameter 3 cm under a load of 200 kN.

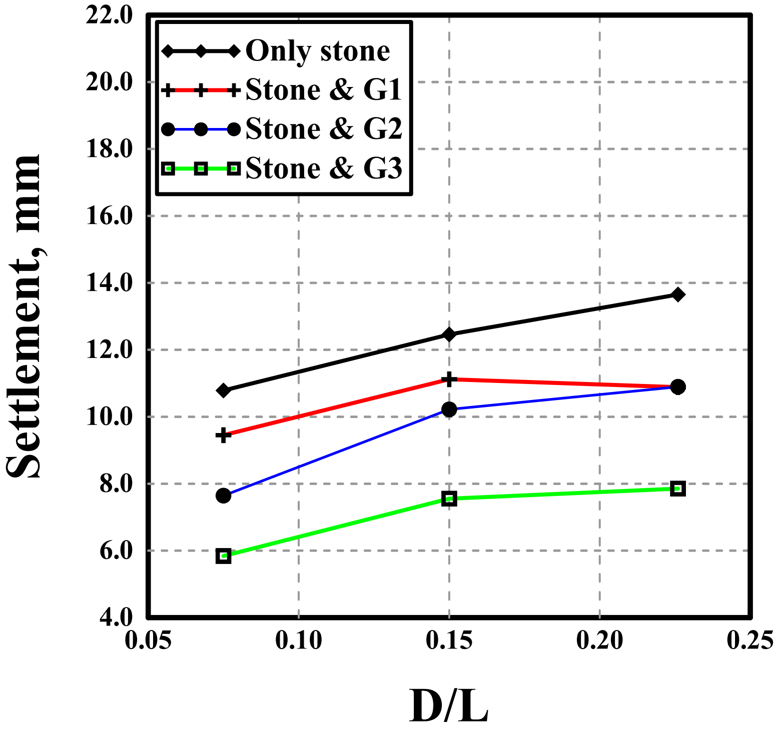


Fig. 7: D/L ratio with settlement for a sample having a diameter 3 cm under a load of 400 kN.

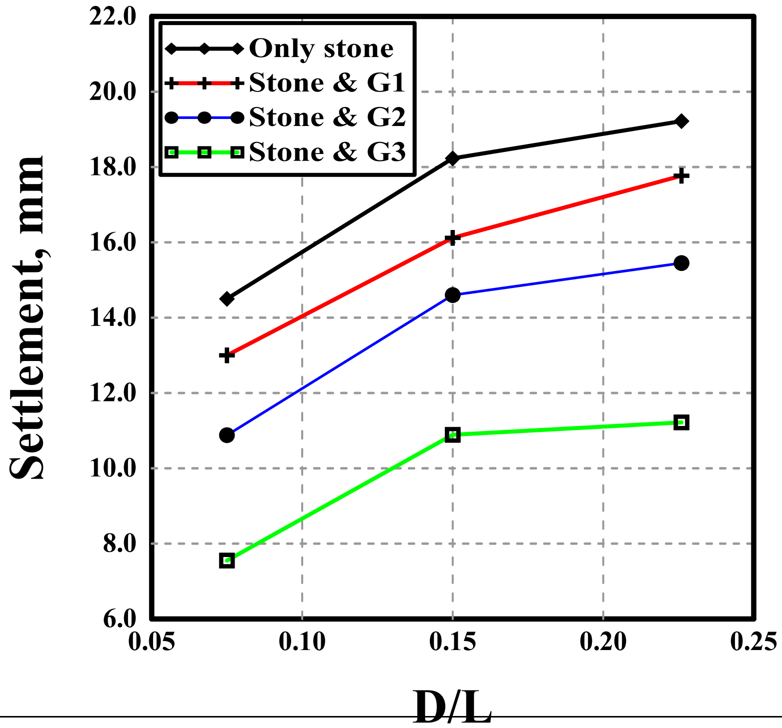


Fig. 8: D/L ratio with settlement for a sample having a diameter 3 cm under a load of 600 kN.

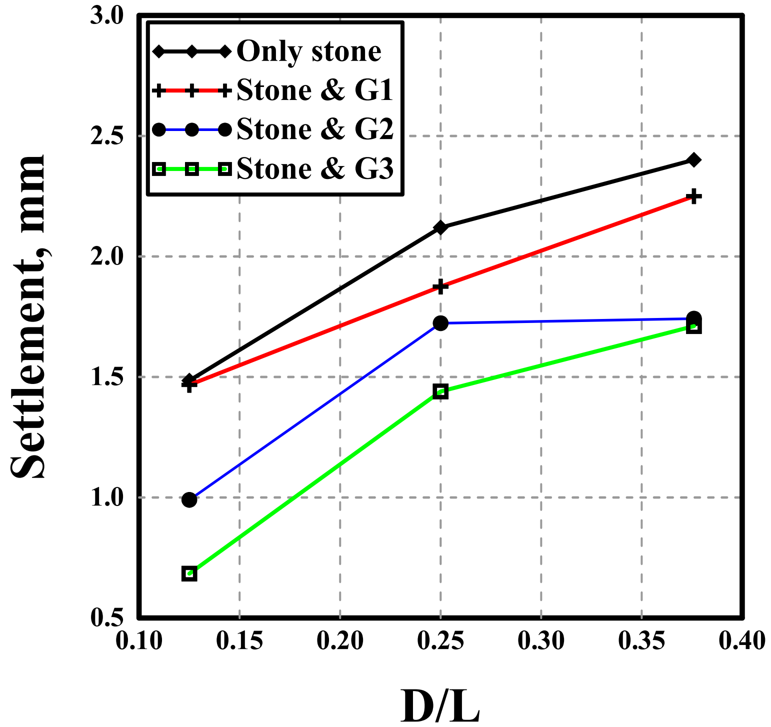


Fig. 9: D/L ratio with settlement for a sample having a diameter 5 cm under a load of 50 kN.

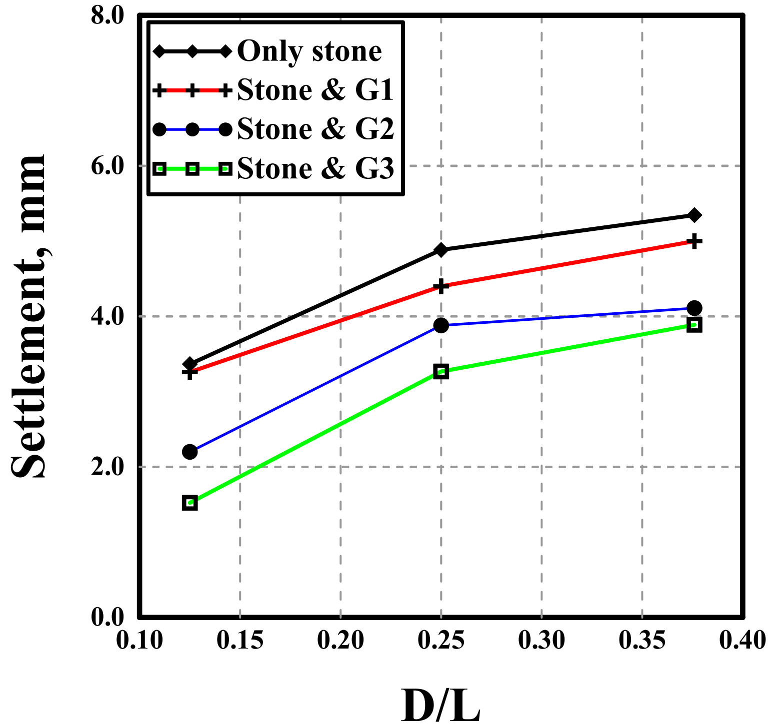


Fig. 10: D/L ratio with settlement for a sample having a diameter 5 cm under a load of 100 kN.

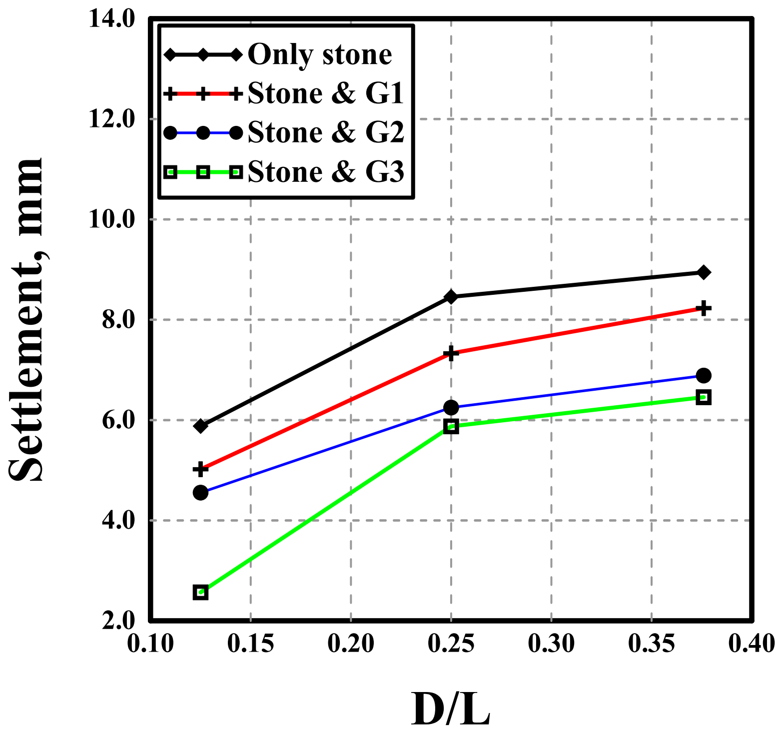


Fig. 11: D/L ratio with settlement for a sample having a diameter 5cm under a load of 200 kN.

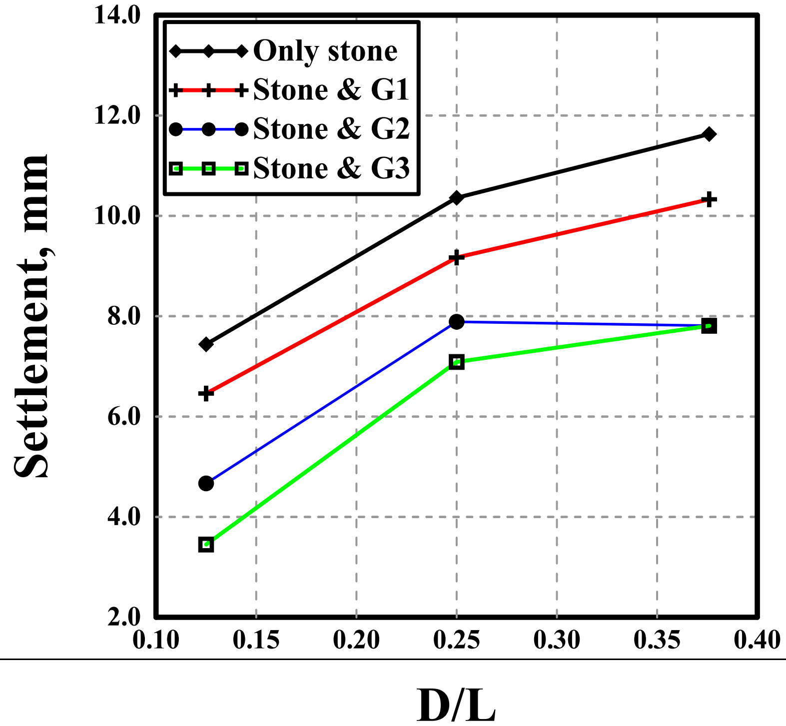


Fig. 12: D/L ratio with settlement for a sample having a diameter 5 cm under a load 400 kN.

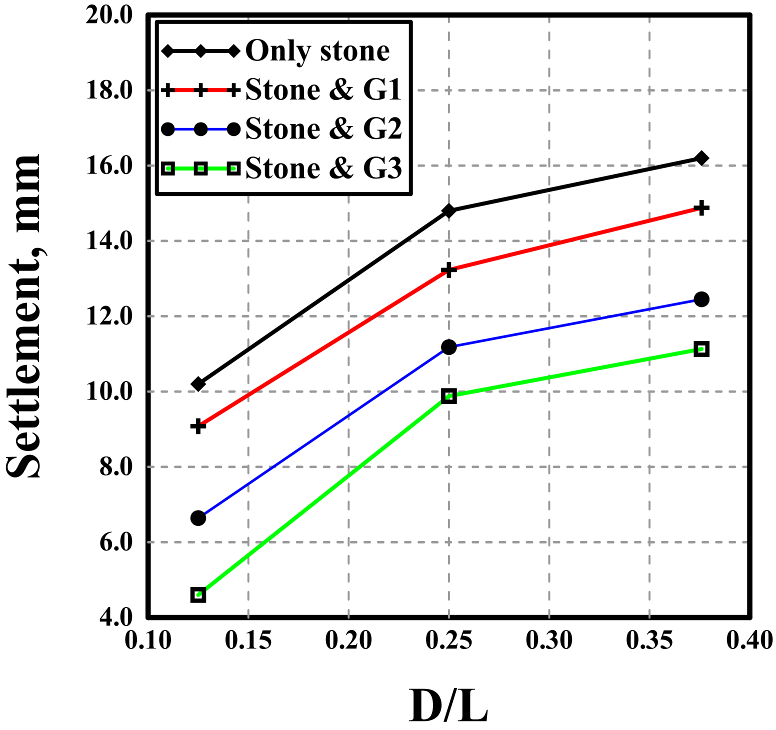


Fig. 13: D/L ratio with settlement for a sample having a diameter 5 cm under a load 600 kN.

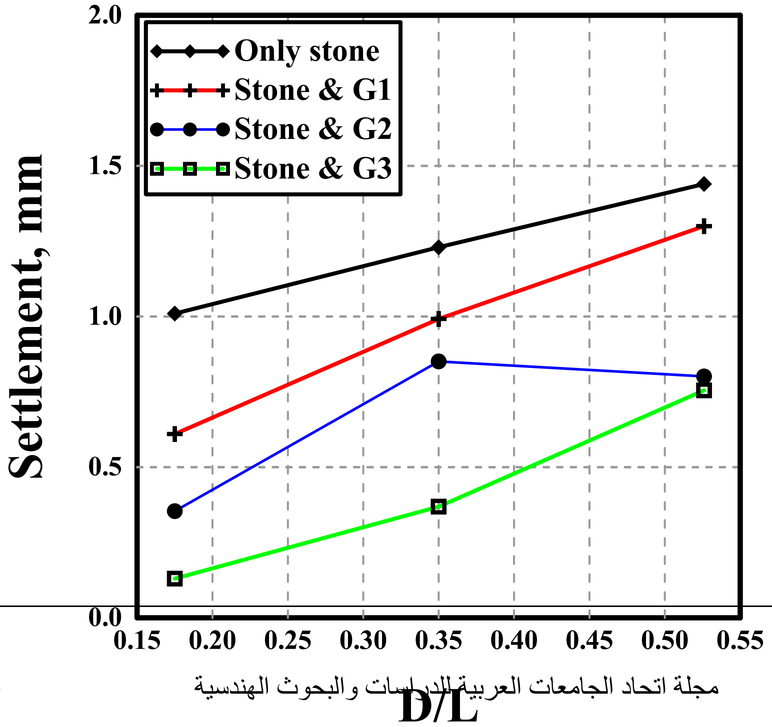


Fig. 14: D/L ratio with settlement for a sample having a diameter 7 cm under a load 50 kN.

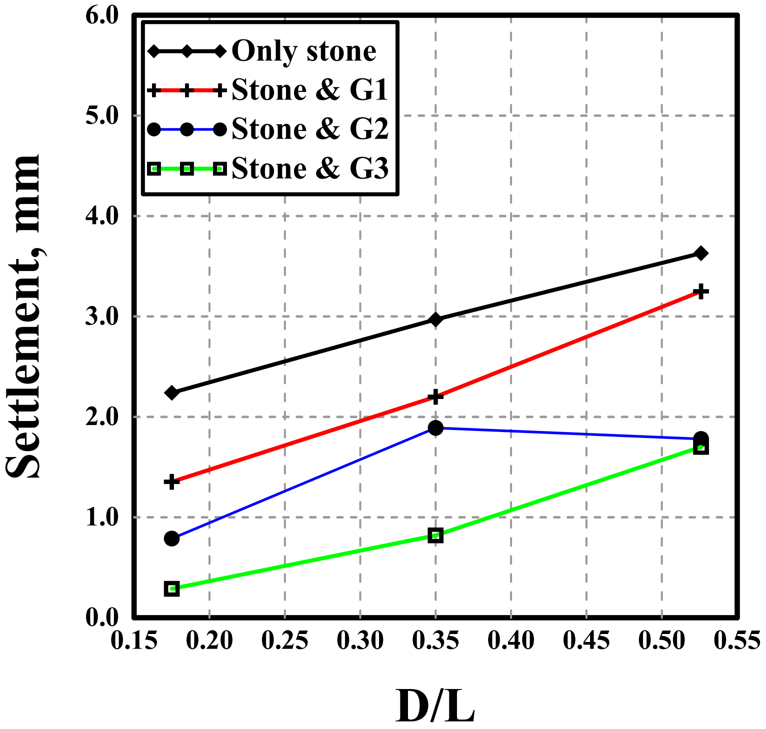


Fig. 15: D/L ratio with settlement for a sample having a diameter 7 cm under a load 100 kN.

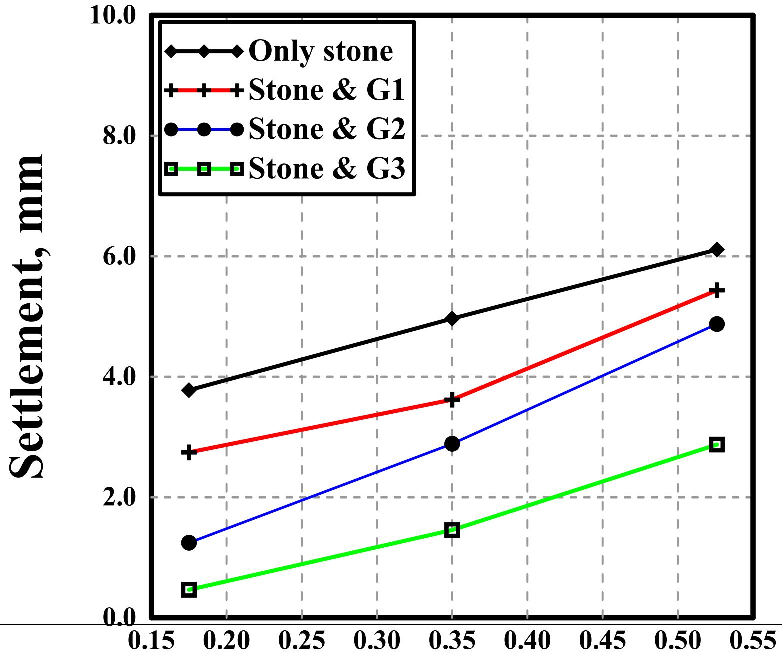


Fig. 16: D/L ratio with settlement for a sample having a diameter 7 cm under a load 200 kN.

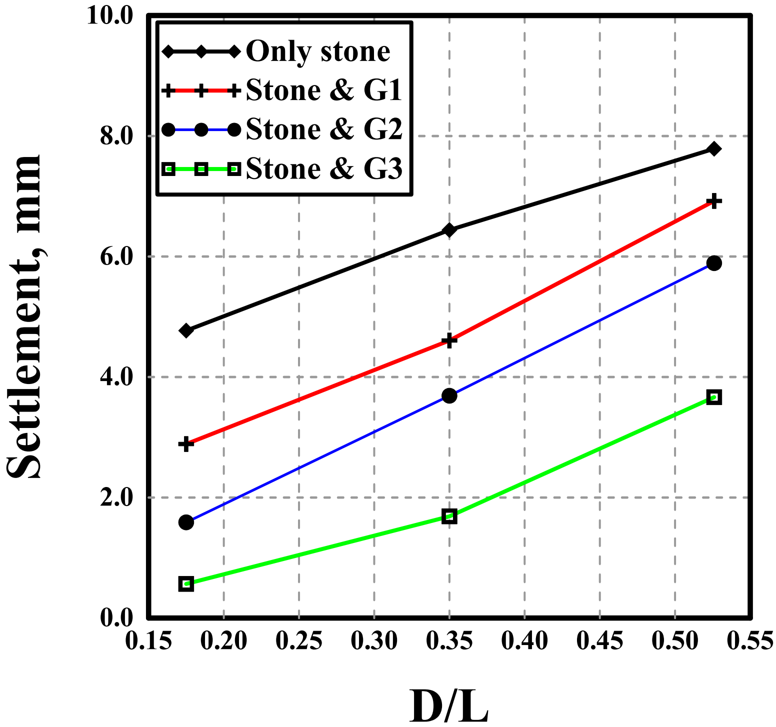


Fig. 17: D/L ratio with settlement for a sample having a diameter 7 cm under a load 400 kN.

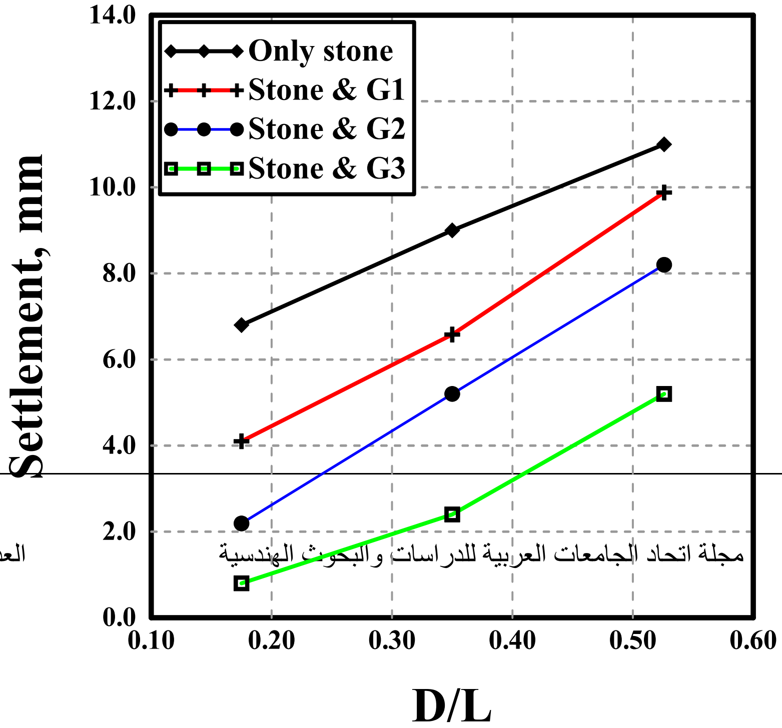


Fig. 18: D/L ratio with settlement for a sample having a diameter 7 cm under a load 600 kN.

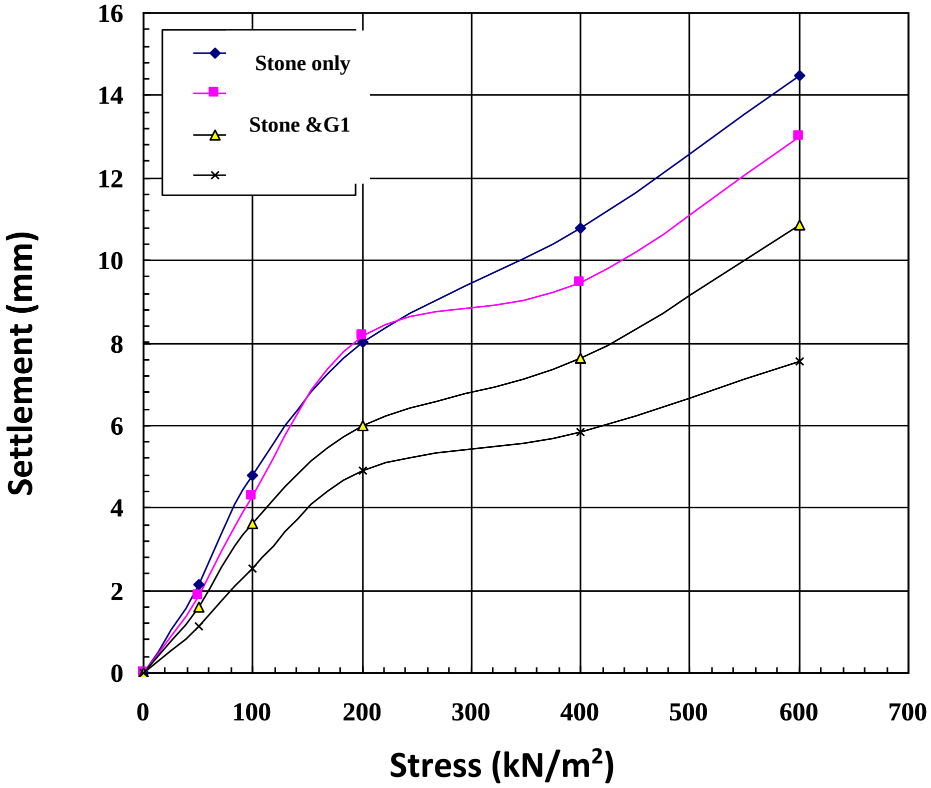


Fig. 19: Stress-settlement for sample having a diameter of 3 cm and D/L=0.075.

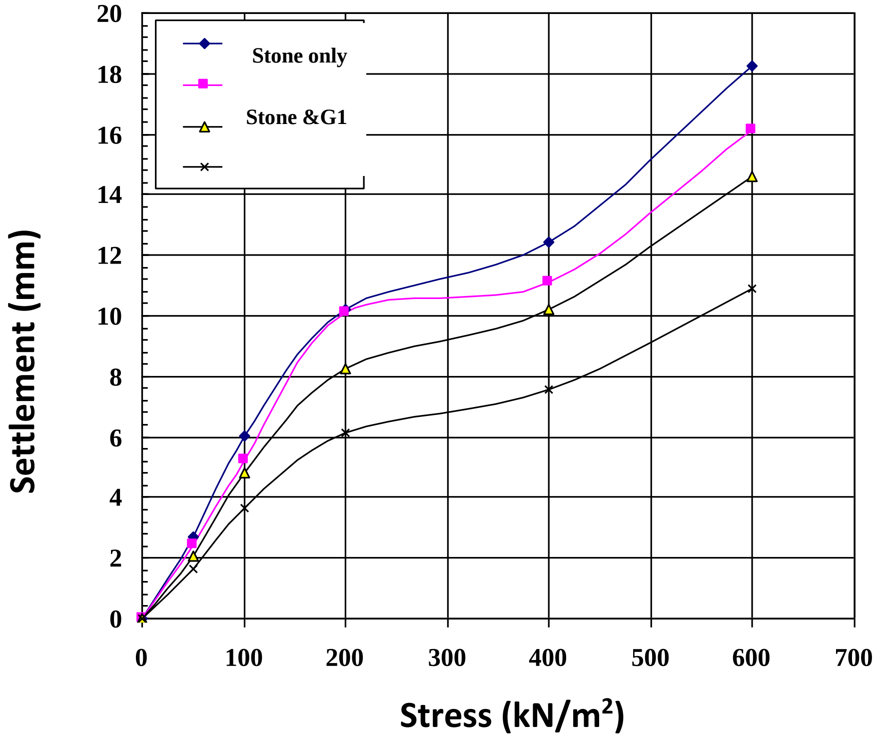


Fig. 20: Stress-settlement for sample having a diameter of 3 cm and D/L=0.15.

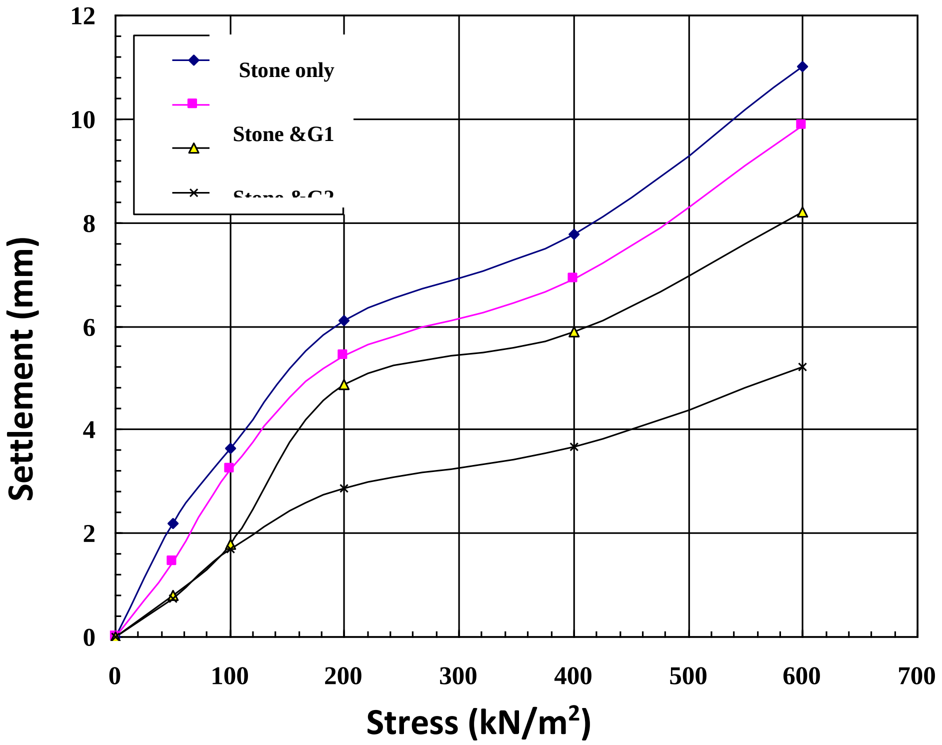


Fig. 21: Stress-settlement for sample having a diameter of 3 cm and D/L=0.526.

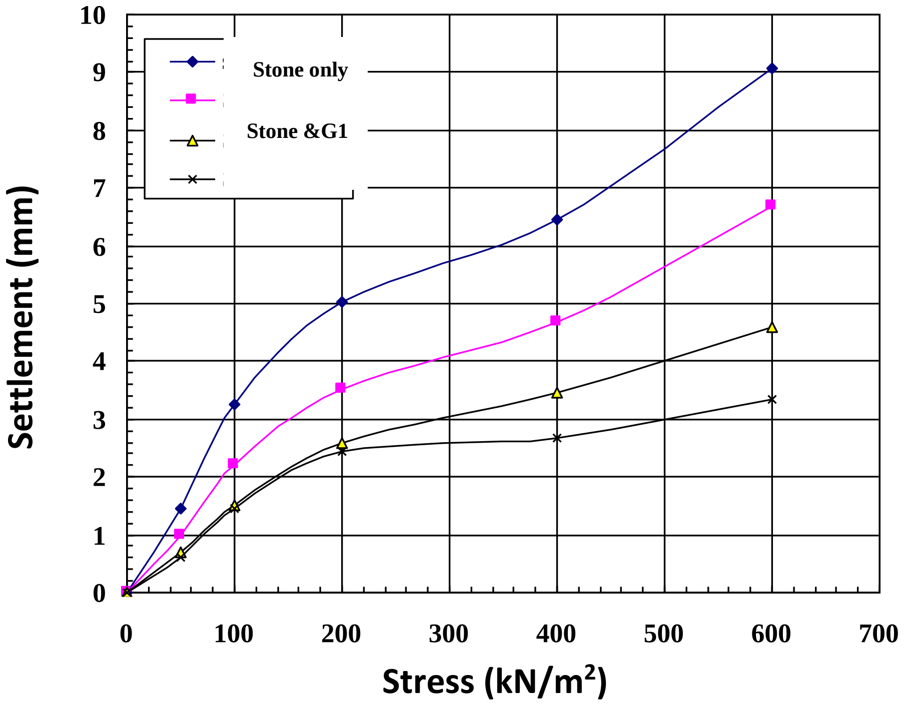


Fig. 22: Stress-settlement for sample having a diameter of 5 cm and D/L=0.125.

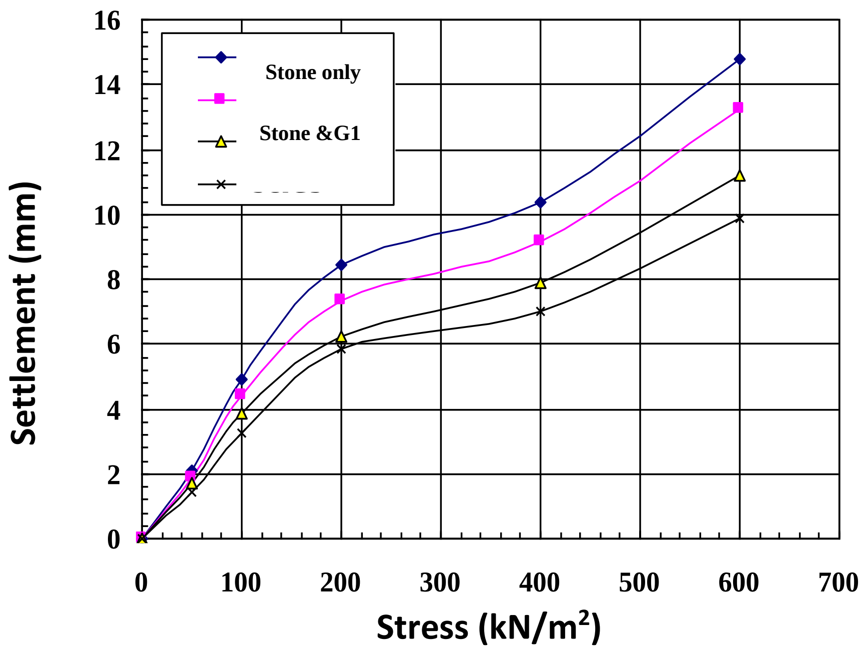


Fig. 23: Stress-settlement for sample having a diameter of 5 cm and D/L=0.25.

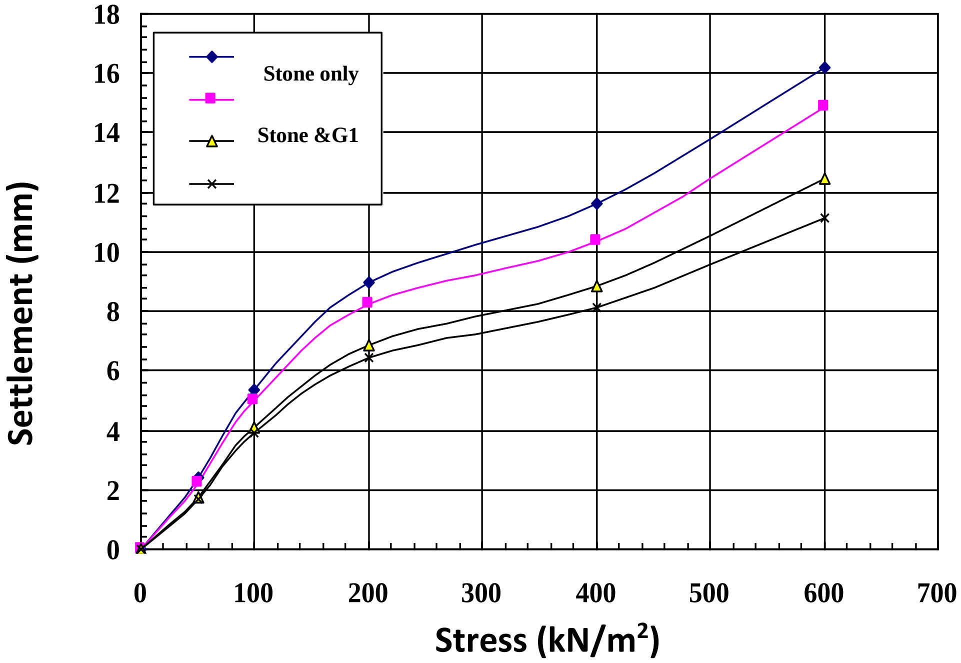


Fig. 24: Stress-settlement for sample having a diameter of 5 cm and D/L=0.376.

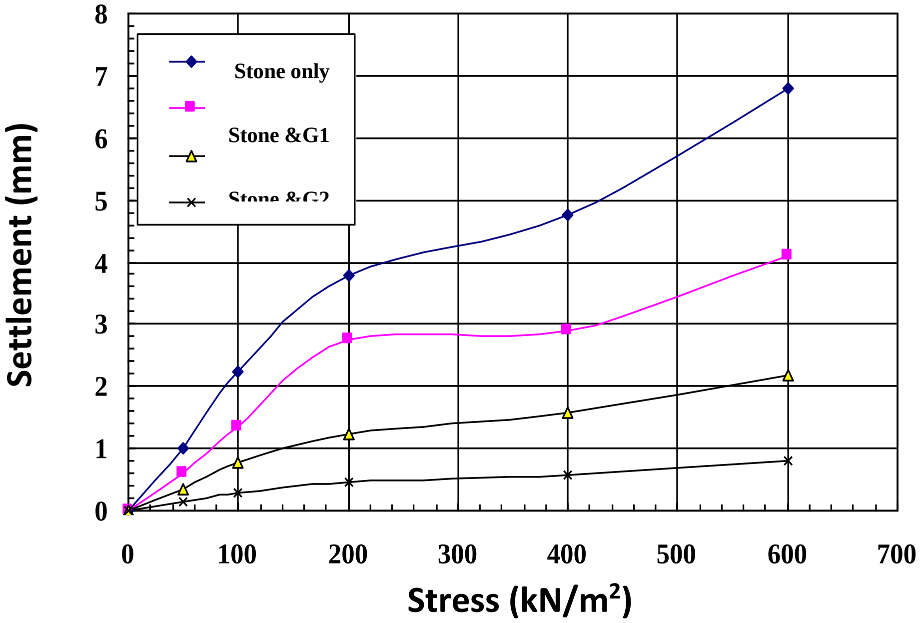


Fig. 25: Stress-settlement for sample having a diameter of 7 cm and D/L=0.175.

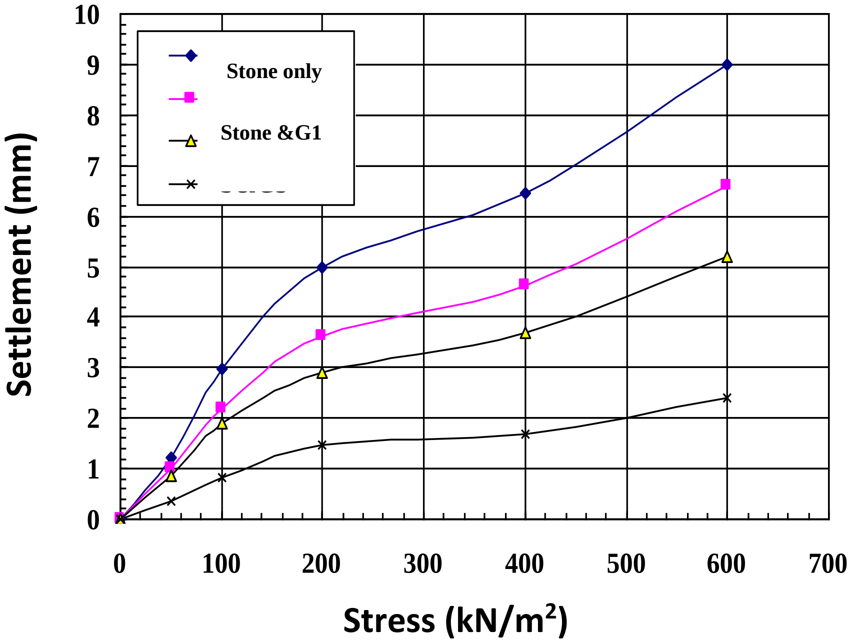


Fig. 26: Stress-settlement for sample having a diameter of 7 cm and D/L=0.35.

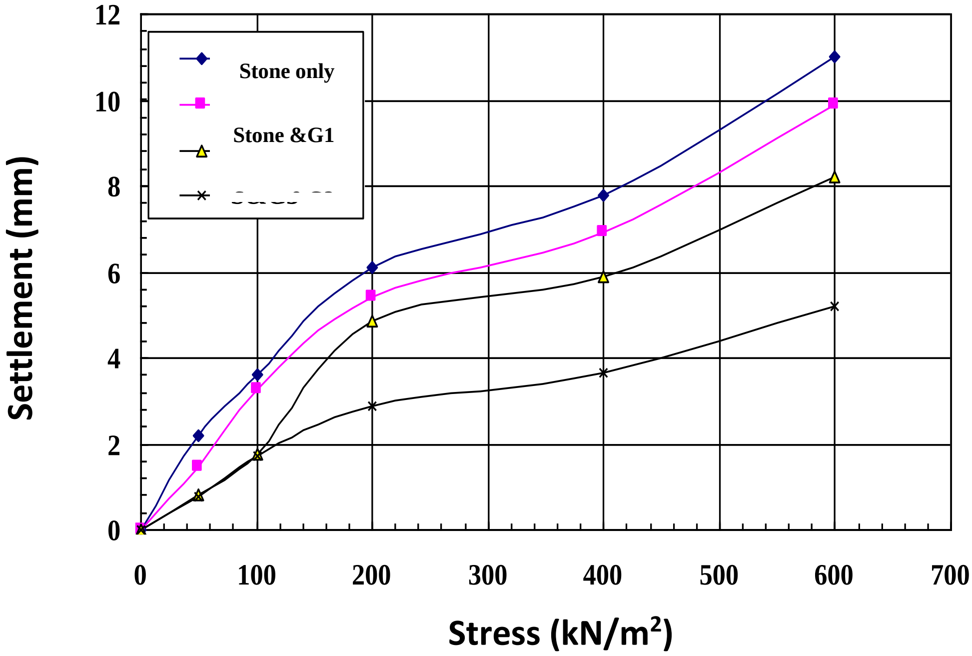


Fig. 27: Stress-settlement for sample having a diameter of 7 cm and D/L=0.526.

Table 3: Variation of IF with D/L for Treatment Methods at Load =100 kPa

L (cm)	D (cm)	D/L	IF (%) Stone &G1	IF (%) Stone &G2	IF (%) Stone &G3
40	3	0.075	12	29	46
20	3	0.150	11	18	39
13.3	3	0.526	11	24	53
40	5	0.125	28	47	59
20	5	0.250	12	24	32
13.3	5	0.376	11	24	30
40	7	0.175	34	67	88
20	7	0.350	29	43	74
13.3	7	0.526	11	24	86

Table 4: Variation of IF with D/L for Treatment Methods at Load =200 kPa.

L (cm)	D (cm)	D/L	IF (%) Stone &G1	IF (%) Stone &G2	IF (%) Stone &G3
40	3	0.075	3	25	39
20	3	0.150	4	20	40
13.3	3	0.526	11	24	53
40	5	0.125	30	49	52
20	5	0.250	13	26	31
13.3	5	0.376	8	23	28
40	7	0.175	27	67	88
20	7	0.350	27	42	71
13.3	7	0.526	11	26	53

Table 5: Variation of IF with D/L for Treatment Methods at Load =400 kPa.

L (cm)	D (cm)	D/L	IF (%) Stone &G1	IF (%) Stone &G2	IF (%) Stone &G3
40	3	0.075	12	29	46
20	3	0.150	11	18	39
13.3	3	0.526	11	24	53
40	5	0.125	28	47	59
20	5	0.250	12	24	32
13.3	5	0.376	11	24	30
40	7	0.175	34	67	88
20	7	0.350	29	43	74
13.3	7	0.526	11	24	86

Table 6: Variation of IF with D/L for Treatment Methods at Load =600 kPa

L (cm)	D (cm)	D/L	IF (%) Stone &G1	IF (%) Stone &G2	IF (%) Stone &G3
40	3	0.075	10	25	48
20	3	0.150	12	20	40
13.3	3	0.526	10	26	53
40	5	0.125	25	49	63
20	5	0.250	11	25	33
13.3	5	0.376	8	23	31
40	7	0.175	40	68	88
20	7	0.350	27	42	73
13.3	7	0.526	10	26	53

References

1. ASTM, D422 (2003),"Standard Test Method for Particle-Size Analysis of Soils", Soil and Rock (I), Vol. 04.08.
2. ASTM, D1557(2003),"Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))", Soil and Rock (I), Vol. 04.08.
3. ASTM, D4318 (2003), "Standard Test Method forLiquid Limit, Plastic Limit, and Plasticity Index of Soils", Soil and Rock (I), Vol. 04.08.
4. Barksdale, R.D. and Bachus, H.G. (1983), "Design and Construction of Stone Columns", Dept. of Transpiration, Federal Highway Administration Report, USA report No. FHWA/RD 83/026.
5. Brand, E.W. and Brenner, R.P., (1981), "Soft Clay Engineering", Elsevier Scientific Publishing company, Amsterdam, pp. 778.
6. Deb, K., Chandra, S. and Basudhra, P.K., (2007)," Response of Multilayer Geosynthetic-Reinforced Bed Resting on Soft Soil with Stone Columns", Computers and Geotechnics 35, pp. 323-330 available online at www.sciencedirect.com.
7. Fattah M. Y. and Majeed, Q.G. (2012), "Finite Element Analysis of Geogrid Encased Stone Columns" Geotechnicaland Geological Engineering Journal,Vol. 30, pp. 713–726.
8. Gniel, J. and Bouazza, A. (2008), "Numerical Modeling of Small-Scale GeogridEncased Sand Column Tests", Proceedings of the Second International Workshop on Geotechnics of Soft Soils, Scotland, pp.143-149.
9. Gniel, J., Bouazza, A.(2009), "Improvement of Soft Soils Using Geogrid Encased Stone Columns", Geotextiles and GeomembranesVol.27, pp. 167–175.
10. Gniel, J., Bouazza, A. (2010), "Construction of Geogrid Encased Stone Columns- A New Proposal Based on Laboratory Testing", Geotextiles and Geomembranes,Vol.28, pp. 108–118.
11. Greenwood, D.A. and Kirsch, K., (1983), “Specialist Ground Treatment by vibratory and dynamic methods –State of Art”, Advances in Piling and Ground Treatment for Foundations, Institution of Civil Engineers, London, England, pp 17-45. (Cited
12. Malarvizhi, S.N. and Ilamparuthi, K. (2004), "Load Versus Settlement of Clay-Bed Stabilized with Stone and Reinforced Stone Columns",

Proceedings of the 3rd Asian Regional Conference on Geosynthetics, GEOASIA, Seoul, Korea, pp. 322-329.
13. Malarvizhi, S.N. and Ilamparuthi, K. (2006), "Modeling of Geogrid Encased Stone Column", Proceedings of the 2nd International Congress on Computational Mechanics and Simulation (ICCMS-06), IIT Guwahati, India, pp. 1- 8.
14. Murugesan, S. and Rajagopal, K. (2010), "Studies on the Behavior of Single and Group of Geosynthetic Encased Stone Columns", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 136, No.1, pp. 129-139.
15. Nayak, N.V., (1983) " Recent Advances in Ground Improvements by Stone Column", Proceedings of Indian Geotechnical Conference, Madras, IGC-83.
16. Sharma, R.S., Kumar, B.P. and Nagendra, G. (2004), "Compressive Load Response of Granular Piles Reinforced with Geogrids", Canadian Geotechnical Journal, Vol. 41, No. 1, pp. 187-192.
17. Wu, C. S., Hong, Y.S. (2008), "The Behavior of a Laminated Reinforced Granular Column". Geotextiles and GeomembranesVol.26, pp. 302–316

دراسة عملية عن تصرف الاعمدة الحجرية المقيدة بالمشبكات المطاطية لتحسين خصائص التربة الضعيفة

محمد يوسف فتاح
قسم البناء والانشاءات/الجامعة التكنولوجية
هيفاء عبد الرسول علي
قسم المدني /جامعة **بغداد**
بغداد / العراق

الخلاصة:

ان معالجة التربة الضعيفة باستخدام أعمدة حجرية غير المشبعة توفر نتائج مرضية للغاية من حيث تحمل تحسين التربة والحد من الهبوط المتوقع تحت ظروف التحميل الدوري، بالمقارنة مع التربة غير المعالجة.

ويتناول العمل الحالي تحسين الطين الضعيفة بواسطة عمود حجر واحد تحت اساس دائري 10 سم في القطر. ويستند تقييم هذه الطريقة على مقدار الزيادة في قدرة التحمل وخفض في الهبوط المتوقع بالمقارنة مع التربة غير المعالجة. الطريقة المقترحة للعلاج من التربة الطينية الضعيفة يتطلب تحديد العوامل المؤثرة، ويتضح الأسلوب باستخدام شبكة مطاطية ذات خصائص هندسية عززت بها الأعمدة الحجرية في أقطار مختلفة (3 و 5 و 7) سم من أطوال مختلفة (3/1، 2/1 و 1) ارتفاع عينة نموذجية (40 سم).

من خلال النتائج العملية وجد أن الاختلاف ما بين 3 و 88٪ اعتمادا على نسبة L / D، L وصلابة من شبكة المطاطية. طول عمود الحجر له تأثير أكبر على الحد من الهبوط المتوقع وتحسين قدرة التحمل من قطرها. صلابة الشبكة المطاطية المقيدة ذو تأثير إلى حد كبير كفاءة العمود حجر، كما يزيد مقدار التحسين اعتمادا على خصائص الشبكة المطاطية المستخدمة، عامل التأثير يزيد وظيفة عامل التأثير تسوية للأعمدة الحجر المغطى وانخفضت بنحو 60-75٪ عند زيادة قطر عمود الحجر من 3 إلى 7 سم.

الكلمات المفتاحية : التربة الضعيفة، الاعمدة الحجرية، التحسين بالتقيد بواسطة المشبكات المطاطية.