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Laboratory Model Study for Granular Pile with Various Backfill Materials

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Abstract-In this work, laboratory experiments have been carried out to study the bearing capacity ratio which is defined as ratio of the bearing capacity of treated soil with granular pile to the bearing capacity of untreated soil at a given settlement for the foundation. A laboratory setup was used electronic load cell to measure the applied load to the soil-granular pile system and used the displacement transducer to measure the settlement. Granular piles made of crushed stone or gravel or sand with a diameter of 50 mm were installed in very soft clays having undrained shear strength ranging between 13 and 21 kPa. Two ratios of the length to diameter were tried, namely 5.2 and 4. The experimental tests showed that the granular pile using crushed stone as backfill material provided a highest bearing capacity ratio equal to 1.6 and 1.5 for the soil having a shear strength = 13 kPa at the two ratios of length to diameter respectively.

Index Terms— Granular pile, backfill materials, various, laboratory model

I. INTRODUCTION

Stone columns (Granular piles) were first employed in Europe in the 1830’s and have been used there extensively since the late 1950’s. The practice was adopted in the US since the early 1970’s. The results of in-situ soil tests performed before and after sand pile installation have shown that soil density can be significantly increased [1].

Installation of sand piles densifies loose deposits. It provides a reinforcing effect, increases the horizontal effective stress and acts as a vertical drain. The use of the sand columns (Granular piles) have been identified in different applications of geotechnical engineering such as the reduction in settlements of structures, reduction in earthquake induced liquefaction potential, increased bearing capacity of the foundation and improved stability of slopes.

Granular piles have also proven useful in providing drainage and reducing the potential for buildup of excess pore water pressure [2].

Granular piles are used to support structures overlying both very soft to firm cohesive soils and also loose silty sands having greater than about 15 percent fines [3].

Ref. [4] carried out a laboratory model test with unreinforced granular piles(stone columns) in soft soil of cu = 5.0 kPa to 10.0 kPa, revealed on average bearing improvement ratio for single granular pile of 1.25, 1.5 and 1.7 for area replacement ratios of 1.6%, 3.8% and 6.5% respectively.

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Ref. [5], presented a recent theoretical formulation based on a lateral expanded cavity study for estimating the bearing capacity of an isolated stone column (granular pile) installed in purely cohesive soft clay. The soft soil is modeled as an elastoplastic medium governed by a thin dilatant zone around the pile and the exterior zone where plastic volume variation is neglected. The calibration of the proposed model has been carried out by comparing analytical predictions of bearing capacity with recorded measurements on full scale isolated granular pile models. The reliability of the model proposed has been verified, with respect to previous contributions.

Ref. [6] carried out a parametric study and they found that the important increase in strength of (stone column) granular pile occurs when it is encased by geogrid for (length/diameter) L/D = 5.2 while in case of L/D = 4, a slight increase in the bearing improvement ratio at the early stages of applying the load is obtained and then the value of (q/cu) for both ordinary and encased granular piles is the same.

II. MATERIAL PROPERTY VALUES OF GRANULAR PILES

Under widespread load, a group of granular piles deforms much more than a group of rigid piles and the surrounding soil is subject to compression as the granular pile deforms laterally. As a result, the relative stiffness and strength of the granular piles can change significantly as load is applied and the granular pile deforms [7].

The granular material of a granular piles is often assumed to have an internal angle of friction value between 35 and 45 degrees and a cohesion value equal to zero. However, Ref.[8] state that a friction angle of 38 degrees is now thought to be low, and they recommend values up to 50 degrees. The modulus of elasticity, or Young’s modulus, of the granular pile material is often assumed to be 4,400 – 10,200 psi (30,000 – 70,000 kPa) [9].

Ref. [10] and [11] performed finite element analyses assuming that the ratio of modulus values between the granular pile and soft compressible clays is about 10 to 40. However, [3] indicated that the modular ratio value is more likely to be between 40 and 100. In either case, granular piles are inherently non homogenous and the Young’s Modulus of the granular pile will increase with depth and loading [12].

III. EXPERIMENTAL WORK

The model tests were carried out in a test tank of size, 240 mm * 240 mm * 265 mm.. The load tests were carried out using Multispeed frame of the Unconfined test machine consisted mainly of electronic load cell with a capacity of (50 kN) to measure the applied load, displacement transducer (50 mm) to measure the settlement and 5 channel digital unit to read the load and the settlement.

The test tank and the loading frame and accessories were shown in fig. 1,. Load test was carried out on single granular piles with a diameter of 50 mm and three various ranged sizes of the following backfill material:

Crush stone of size varying from 1 to 12 mm

Gravel with sizes ranged from 2.32 to 11.2 mm

Sand with range of sizes of (0.125-4.76)

The test was conducted in very soft to soft clay soil with two shear strength 13 kPa and 21 kPa as classified in BS 8004:1986 [13].

Mild steel of 100 mm in diameter is used as footing plate, were placed over a granular pile and this granular pile supported plate were loaded during the load test.

A. Soil Used

Soil samples were collected from depths of 0.50 m to 2.00 m from the ground surface of a site north of Babylon in Iraq. The soil was subjected to routine laboratory tests to determine its properties. These tests include:

1- Grain size distribution (sieve analysis and hydrometer tests) according to ASTM D422 specifications [14].

2-Atterberg limits (liquid and plastic limits) according to ASTM D423 and D424 specifications [14].

The test results show that the soil consists of 13% sand, 35 % silt, and 52 % clay. According to the unified soil classification system, the soil is inorganic sandy silty clay designated as (CL). Table (I) shows the physical properties of the soil.

B. Preparation of The Soil Used

The soil used in experimental test was mixed with specified quality of water to get the preferred shear strength that varied from 13 to 21 kPa . The soil was packed carefully in layers of thickness of about 40 mm or in six layers to reach the final height of 260 mm and after the placement of each layer; it was pushed lightly to remove the entrapped air. As the soil bed was formed conforming to very soft to soft, there was no difficulty in forming a homogeneous soil bed. The uniformity in the soil bed was checked by measuring the density at various stages of the soil bed formation and typical formation and a typical density of soil was 18.50 kN/m3. The soil sample is left for 24 hours before carrying out the tests.

C. Installation of the granular pile

The position of the granular pile to be constructed was property marked in the center of the mould(test tank) of the tests and the hollow PVC tube, with diameters of 50mm, coated with petroleum jelly was inserted vertically to the required fully penetrated depth 26 mm at length to diameter of granular pile(L/D) equal to 5.2 and partially penetrated depth 20 mm at (L/D) equal 4 after that the soil inside the PVC tube was removed by auger with diameter of 30 mm . Then the tube was slowly withdrawn and twisted during the lifting process. At the end the crush stone or gravel or sand was filled the hole and compacted to gain the density about 18 kN/m3 [fig. 2,].

D. Testing Program

Fourteen experimental tests were conducted as follows

1-Seven model tests for soil having shear strength, cu=13 kPa, included the following cases.

a- Single model test for untreated soil

b- Six model tests for soil treated with granular piles of 50 in diameter, with three specific materials of backfills (stone or gravel or sand)

2- Seven model tests for soil having shear strength, cu= 21 kPa , included the same model tests in the previous item 1.

TABLE I PHYSICAL PROPERTIES OF THE TREATED SOIL

Property	Value
Liquid limit (LL)	44%
Plastic limit (PL)	22%
Plasticity index (PI)	22%
Specific gravity (GS)	2.71
% Passing sieve No. 200	87%
Sand content	13%
Silt content	35%
Clay content < 0.005 mm	52%
Maximum dry unit weight kN/m3	18.5
Symbol according to Unified Soil Classification System	CL

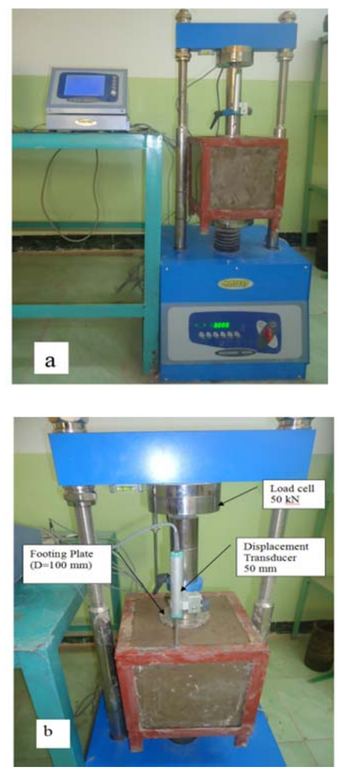


Fig. 1.a and 1.b: The Loading frame and the accessories

E. Model Testing Procedure

According to the testing program the model tests were carried out by the next steps:

At the beginning of the tests, the footing plate was located in the center of electronic load cell. In purpose of measuring the applied load on footing and the settlement, the electronic load cell and the displacement transducer were connected to five channels unit. Then the displacement transducer was placed on the one outer edge of the test mould to measure the settlements of the plate. After that the loads were applied by multispeed loading machine in increments of 50 Newtons. Then the displacement transducer readings were recorded for each load increment, the incremental load was stopped when the final settlement reached 40 millimeters. The loading test were performed for untreated soil only for comparison purposes. Figures (3) present the granular pile model after the completion of the test.

IV. PRESENTATION OF RESULTS AND DISCUSSION

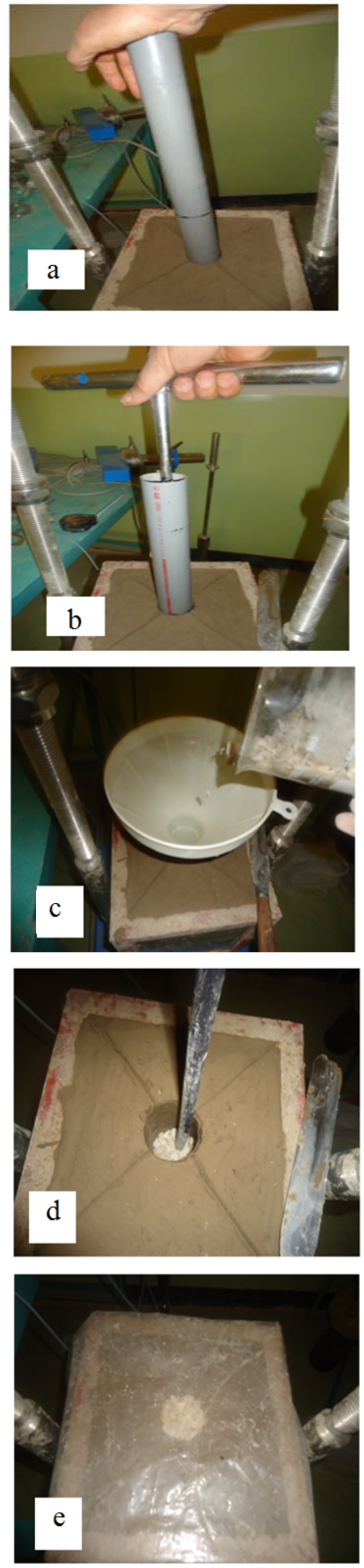
There are many approaches proposed to define the ultimate bearing capacity and failure of granular pile. The Terzaghi (1947) proposal is adopted in the present work, where failure was defined as the load corresponding to 10% of the model footing width (or pile diameter). Also this proposal is adopted by [15].

Figures (4 and 5) relate the bearing ratio (q/cu) with the deformation ratio (S/B) for untreated soil and soil treated with granular (stone, gravel and sand) piles having (L/D) ratio of 5.2 and 4, respectively. The surrounding soil was prepared at the undrained shear strength of (cu=13 kPa and 21 kPa), respectively.

These models were tested 24 hours after preparation. The figures demonstrate that the granular pile especially in the late bearing ratios shows significant difference in the behaviour corresponding to (S/B) ratio. It can be attributed this behavior to that the granular piles are stiffer than the surrounding soil. Since the granular pile is stiffer than the soil, it carries a larger proportion of the load. As consolidation progresses, additional load transfer to the granular pile occurs until an equilibrium condition is reached [16].

The figures also indicate that when the shear strength of the soil decreases, the effect of granular pile becomes more visible and a clear increase in (q/cu) ratio is noticed. The reason for this action is that the calculation of stresses is dependent on the stress applied to the soil replaced from the zone of granular pile only, disregarding the stress applied to the soil surrounding the pile. Thus the effect of improvement seemed clearly in the treated soil of low shear strength.

The bearing improvement (created / quntreated) ratio achieved by granular piles is presented briefly in the table (II). It can be noticed from (qtreated / quntreated) in table (II) that the bearing improvement ratio (qtreated / quntreated) ranges from 1.11 to 1.60 for the soil having (cu = 13 kPa) treated with granular(gravel) pile with (L/D = 4) and with granular (stone) pile of (L/D = 5.2) respectively at S/B=10% . The ratio (qtreated / quntreated) ranges from 1.06 to 1.41 for soil having (cu = 21 kPa) treated with granular(gravel) pile of (L/D = 4) and with granular (stone) pile of (L/D = 5.2), respectively .



Fig, 2-a to 2-e. Installation of the granular material (stone) pile, L/D = 4

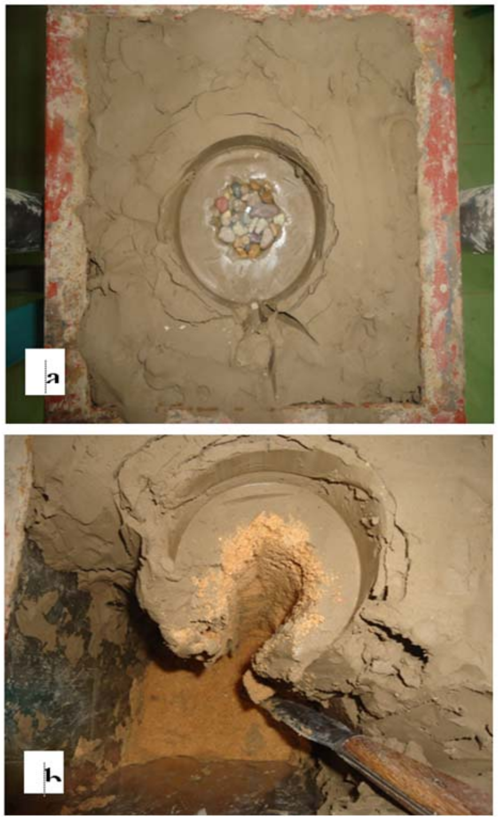


Fig. 3. Granular pile model after the completion of the test
a) granular (gravel) pile b) granular(sand) pile

It can be seen from figures (4) and (5) that the shape of the load-settlement in the case of local shear failure [17], reveals that the treated and untreated clays showed local shear failure in spite of improvement by stone columns.

It can be concluded from the previous values in the table (II) that the bearing improvement ratio is increased with increasing the length to diameter of granular pile (L/D) by a percentage ranges between (5%) and (11%) in soil of cu=13 kPa and by percentage ranges between (5%) and (20%) in soil of cu= 21kPa.

It can be seen from the table (II) that the bearing improvement ratio achieved by granular piles with backfill of crushed stone is higher than other the backfill materials such as gravel and sand, also the granular pile of gravel backfill exhibits the lowest value of (qtreated / quntreated) ratio. It can interpreted the high values of bearing ratio of crushed stone that the stiffens of crushed stone is higher than the gravel or sand.

TABLE II BEARING IMPROVEMENT RATIO FOR THE SOIL TREATED WITH GRANULAR PILE.

Shear strength	**Crushed stone**		**Gravel**		**Sand**	
	L/D		**L/D**		**L/D**	
	5.2	**4**	**5.2**	**4**	**5.2**	**4**
cu=13 kPa	1.60	1.50	1.24	1.11	1.30	1.24
cu= 21 kPa	1.41	1.18	1.18	1.06	1.24	1.17

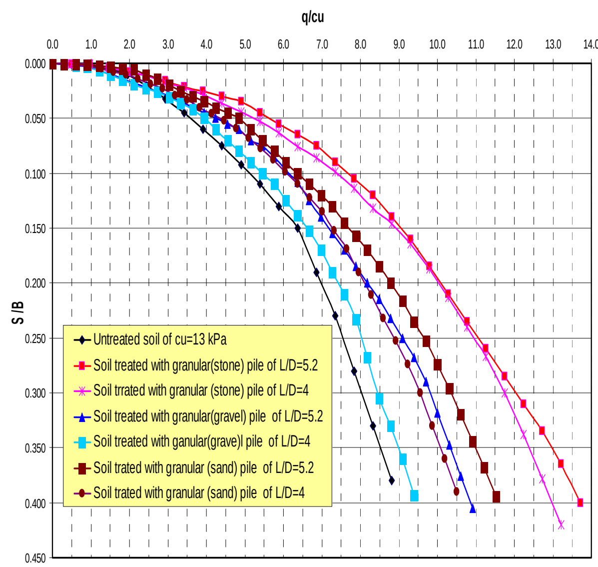


Fig. 4. q/cu versus S/B for the soil treated with granular (stone, gravel and sand) Pile, cu = 13 kPa, L/D= 5.2 and 4.

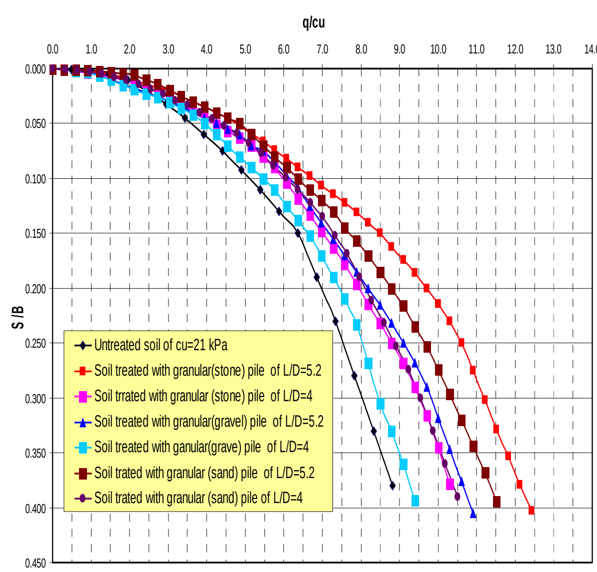


Fig. 5. q/cu versus S/B for the soil treated with granular (stone, gravel and sand) pile, cu = 21 kPa, L/D= 5.2 and 4.

IV. DEFINITIONS OF BEARING CAPACITY RATIO

The beneficial effects of treated soil by granular pile for increasing the bearing capacity are 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 [18].

Fig. 6, shows the general nature of the load settlement curves of a foundation with or without treatment. Based on this concept, the bearing capacity ratio can be defined as,

$$BCR_u = \frac{q_{u(R)}}{q_u} \qquad (1)$$

And $$BCR_s = \frac{q_R}{q} \qquad (2)$$

Where:

BCRu = bearing capacity ratio with respect to the ultimate load.

BCRs= bearing capacity ratio at a given settlement, s, for the foundation.

q_R, q= load per unit area on the foundation (at a settlement level $s \leq su$) with and without treatment, respectively.

$q_{u(R)}$, q= ultimate bearing capacity with and without treatment respectively.

s_u =Settlement of the foundation on the untreated soil at ultimate load.

The BCRs values are the same as those of the bearing improvement ratios summarized in table (II). Table (III) shows the values of BCRu calculated for all model tests. In this case, the failure load is considered to be at the last point in the load-settlement curve as shown in "fig. 6,"

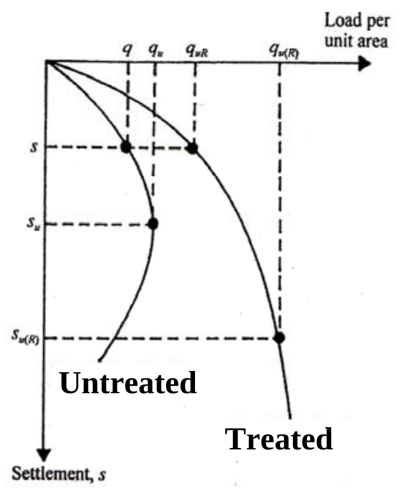


Fig. 6. General nature of the load- settlement curves for untreated and treated soil supporting a foundation (after Das et al., 2004).

TABLE III SUMMARY OF THE BEARING CAPACITY RATIO WITH RESPECT TO ULTIMATE BEARING CAPACITY RATIO (BCR_U) FROM VARIOUS MODEL TESTS.

Shear strength	**Crushed stone**		**Gravel**		**Sand**	
	L/D		**L/D**		**L/D**	
	5.2	**4**	**5.2**	**4**	**5.2**	**4**
cu=13 kPa	1.56	1.50	1.14	1.07	1.27	1.23
cu= 21 kPa	1.37	1.13	1.20	1.03	1.27	1.16

Fig. 7 and Fig. 8 show the value of (BCRs / BCRu) for all model test of soil treated with granular pile.

These figures illustrate that the (BCRs / BCRu) ratio decrees slightly with increasing of shear strength in soil treated with single granular pile. In general the shear strength of (13 kPa) present the largest value of (BCRs / BCRu).. The values of (BCRs / BCRu) ranged between (1.01 to 1.09) in six model tests of soil having cu=13 kPa and it ranged between 0.96 to 1.02 in all model tests of soil of cu=21 kpa . This means that the criterion adopted in the definition of failure (10% of the diameter of the footing) is successfully accepted.

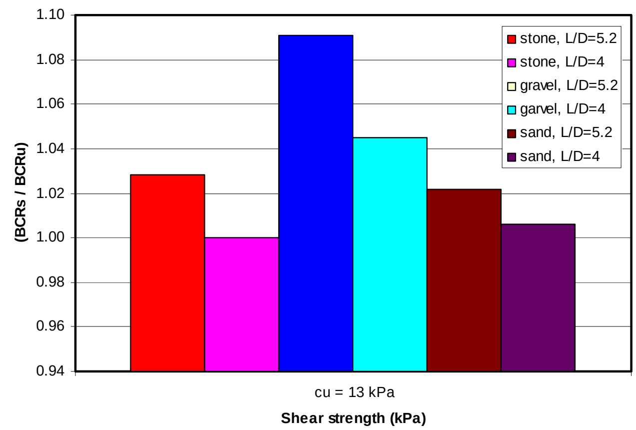


Fig. 7. (BCRs / BCRu) for six model tests of granular pile, cu = 13 kPa

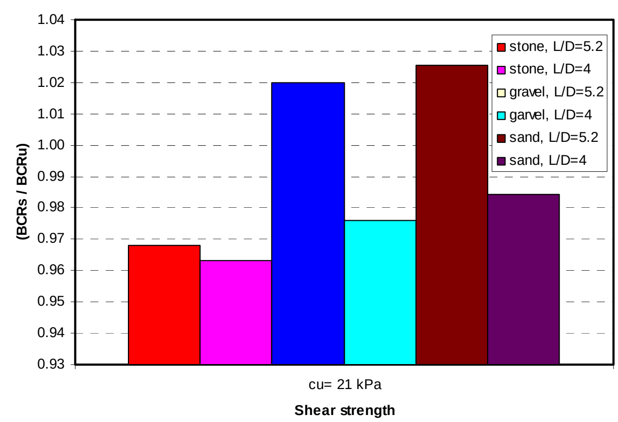


Fig. 8. (BCRs / BCRu) for six model tests of granular pile, cu = 21 kPa

V. CONCLUSIONS

1) The maximum value of bearing improvement ratio is 1.60 at (L/D) =5.2 in the soil of shear strength (cu=13 kPa) treated with a granular pile using the crushed stone as backfill material. The minimum value of bearing improvement ratio is 1.06 in the soil of cu= 21 kPa treated with a granular pile of gravel backfill material at (L/D) = 4.0.
2) The bearing improvement ratio increases with increasing (L/D) ratio form 4 to 5.2 by a percentage ranges between (5%) to (11%) for soil having shear strength, cu=13 kPa , and by percentage ranges between (5%) and (20%) in soil of cu= 21 kPa .
3) The bearing improvement ratio decreases with increasing shear strength of soil treated with granular pile.
4) the soil treated with granular pile of sand backfill material exhibits higher values of the bearing improvement ratio than granular pile of gravel.
5) The values of (BCRs / BCRu) ranged between (0.96 to 1.09) in all model tests of granular pile. This means that the criterion adopted in the definition of failure (10% of the diameter of the footing) is successfully accepted.

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