Investigation of Factors Influencing the Confining Effect of HDPE Pipes through Analytical and Model Studies

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***Abstract*—The scarcity of land with good marginal properties leads to the construction of buildings on available land. For the safety of the structures, it is necessary to improve the property of the soil by adopting suitable ground improvement technique. The methods of ground improvement technique adopted depends on the soil to be tested, availability of materials required for improving the soil and economic viability. The foundations for the residential buildings in paddy fields and marshy lands with water table near the ground level, are constructed in the dense or medium dense sand layers which are confined with well rings beneath the foundation. HDPE pipes can be used as a substitute for well rings there by making cost effective. In the present investigation the various factors which influences the pressure versus settlemnt behaviour of a model circular footing on medium dense sand which is confined with HDPE pipes is studied in detail through plate load tests. In order to validate the test results model of the confined footing was developed using FEM package PLAXIS and analysed and compared with the experimental results obtained from plate load test. The model developed is good in agreement to the prototype.**

Keywords:Plaxis,confinement,HDPE pipes,soil improvement

I. INTRODUCTION

Every civil engineering structures, whether it is a building , a bridge, or a dam is founded on or below the surface of the earth. The behaviour of structures depends on the properties of the soil on which they are constructed. For structures to be safe and sound , they are to be built on good soils. The dearth of good construction sites has resulted in more and more industries coming up on low lying/ filled up/ marshy land. Thus engineers are often left with no other choice but to render such unsuitable land suitable for construction. Normally shallow foundations are adopted for structures if the soil close to the ground surface possessess sufficient bearing pressure and if the settlement is within permissible limits. However, where top soil is soft or loose, the loads from the structure will have to be transferred to a deeper, firm stratum. In such situations, deep foundations are the obvious choice. But the use of deep foundations may not always be possible and many a times be uneconomical. In such cases, ground improvement technique is essentially needed to provide adequate soil properties.

The construction of residential buildings in paddy fields, marshy lands or in filled up areas are very common in most of the cities of Kerala. In most of these locations especially in paddy fields, dense or medium dense sand layer is available at shallow depths of about 0.5 to 2.0m and the water table is available at or near the ground level. In these locations well rings are effectively used to tranfer the load coming over to soil.

Several investigators have reported significant effects of soil confinemnt by using vertical confinement to increase the bearing capacity of supporting soils. Verma et al. (1990) studied the influence of model footing on sand subgrades reinforced with galvanized rods placed vertically. The use of vertical reinforcement along with horizontal reinforcement was investigated as well (Dash et al. 2001 b). Swaaf and Nazeer (2005) studied the effect of confinement on bearing capacity of sand using (UPVC) confining cylinders. Bearing capacity increases with the introduction of these cylinders and there by reducing the settlement. Reshma (2007) studied the effect of soil confinement using PCC well rings. It was observed that PCC well rings can be effectively used for confining. Also observed that failure occurred due to the cracking of the top well ring due to the hoop stress developed in the soil. Ambili (2008) studied the effect of using soil confinement using RCC well rings. Bearing capacity was increased by the introduction of RCC well rings. Rajeev Gupta et al. (2009) conducted study on the bearing capacity and settlement of footing resting on loose silty sands confined with steel confining cells. Results indicates a significant improvement in the response of the footing. Dash (2010) conducted study on the influence of relative density of foundation soil on the performance improvement of geocell reinforcement.

Inorder to investigate the effect of using HDPE pipes as a confining material, a series of model plate load tests were conducted on weak sand. Inorder to validate the test results, an attempt has been made to study the effectiveness of vertical reinforcement in sand using finite element package PLAXIS .

II. LABORATORY TESTING PROGRAMME

The main objective of the investigation is to study the performance of HDPE pipes on improving the load carrying capacity of medium dense sand bed. Initially plate load test was conducted on the prepared sand bed without any confinement and then with HDPE pipes as confinement.

A. Test Materials

(i) Soil

The soil used for the study was dry sea sand. Various tests were performed in order to determine the basic and index properties on the soil as per IS. The properties of the soil are given in Table 1. Grain size distribution characteristics is shown in Fig. 1. The soil is classified as poorly graded soil (SP) as per (IS :1498 -1970).

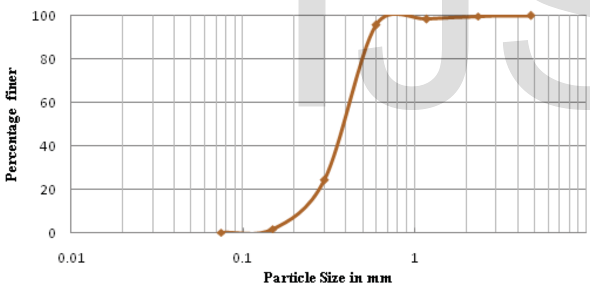

Fig. 1. Particle Size Distribution

(ii) Confining Cells

The confining cells used for the study were made up of High Density Polymer Ethylene (HDPE) pipes. Cells with different diameter and heights were used for the study. The used diameters were 90, 105, and 180mm. The thickness of the cylinder wall is 3mm. UPVC is produced from the polymerization of a vinyl chloride monomer with certain additives including heat stabilizers and lubricants.

Table 1 Properties of sea sand

Specific Gravity	2.7
Υ_{max} (kN/m^3)	18.502
Υ_{min} (kN/m^3)	15.79
e_{max}	0.709
e_{min}	0.459
Effective Size D_{10} (mm)	0.23
Uniformity Coefficient C_u	2.206
Coefficient of Curvature C_c	1.144

Its actual strength for any situation depends on the wall thickness uniformity, the rate of loading, and the temperature of plastic materials. Properties of HDPE pipes as given by the manufacturer are shown in Table 2.

Table 2 Properties of HDPE pipes

Specific Gravity	ASTM D792	1.40	-
Tensile Strength	ASTM D638	52	10^3 kPa
Modulus of Elasticity	ASTM D638	28	10^5 kPa
Compressive Strength	ASTM D695	66	10^5 kPa
Water adsorption @25^0 C for 24hrs	ASTM D570	0.05	%

(iii) Model Tank and Footing

3 series of model tests were conducted in a test tank having dimension of 600mmx600mmx500mm. The loading system is mounted by a horizontal standard I steel beam supported on columns. Load is applied by means of hydraulic jack. A circular steel plate of diameter 90mm and 20mm in thickness was used as the model footing. A rough base condition was achieved by fixing a thin layer of sand on the base of the model footing with glue. The footing was loaded by a hand operated hydraulic jack supported against a reaction frame. The definition sketch of the problem in the present study is shown in Figure 2

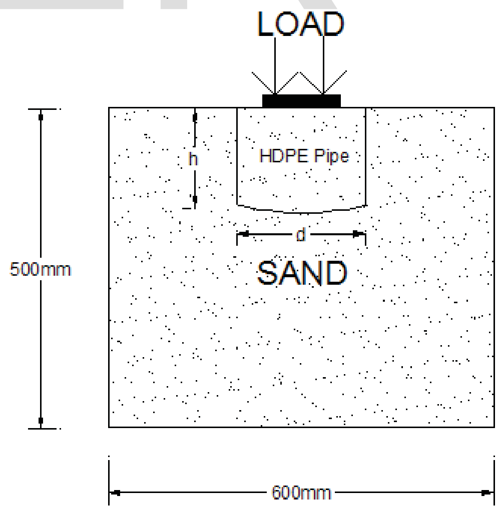

Fig. 2 Line sketch of plate load test

B. Experimental Setup

(i) Preparation of Test Bed

In order to set up a sample, the sample was poured in tank using raining technique (Khing et al. 1993), in which sand is allowed to rain through air at a controlled discharge rate and height of fall, to achieve uniform densities. A series of test were carried out to check the relative density obtained and uniformity of the sand samples by using three molds placed at different locations in the test box. After pouring, each mold was carefully excavated and the density of sample calculated. At the prescribed depth, the raining of sand was temporarily stopped and the pipe was placed in the centre of the tank. Then again the sand was filled using the rainfall technique upto the top of the tank

The raining technique adopted in this study provided a uniform relative density of approximately 50% with a unit weight of 17.04 kN/m^3. A series of direct shear tests were performed at the same relative density of the sand and the estimated internal friction angle was approximately 41^0.

(ii) Testing Procedure

The surface of the sand bed was leveled after filling upto the top of the tank. The footing was placed on the centre of the tank, such that the load from the loading jack was transferred concentrically to the footing. The footing was loaded in small increments. The magnitude of the load applied to the footing was recorded with the help of a sensitive proving ring placed between the hydraulic jack and the reaction beam. Each load increment was maintained constant until the rate of settlement was less then 0.01mm/hr. Settlement of the model footing was measured by two sensitive dial gauges of least count 0.01mm located on each side of the centre line of the footing. The dial gauges were mounted on a rigid steel channel section by means of magnetic bases. Figure 3 shows the test setup for model plate load test. The settlements reported are the average of the two dial gauge readings, which were nearly identical.

In all the experiments, the loading was continued until failure. Before starting each plate load test, the sand in the tank was fully emptied and was then replaced by sand raining technique as described earlier. All the experiments were repeated to verify the consistency of the test data.

Fig. 3 Test Setup

(iii) Test Variables

Three different series of experiments were conducted by varying the parameters such as diameter and height of confining cylinders. The sequence of model tests is given in Table 3.

Table 3 Details of Parametric Study

Test series	Constant parameters	Variable parameters
A(Without confinement)		
B	$\frac{h}{D} = 0.5$	$\frac{d}{D} = 1, 1.67, 2$
C	$\frac{h}{D} = 1.0$	$\frac{d}{D} = 1, 1.67, 2$

III.RESULTS

The load-settlement relationship and the ultimate bearing capacity of the footing with and without confinement were obtained. The bearing capacity improvement due to the soil confinement is represented using a nondimensional factor, called the bearing capacity ratio (BCR). This factor is defined as the ratio of the footing ultimate load with soil confinement to the footing ultimate load in tests without confinement. The footing settlement is also expressed in non dimensional form in terms of the footing diameter (D) as the ratio (S/D)%.

Typical variations of bearing pressure with footing settlement ratios (S/D) with and without soil confinement for different heights and diameters are shown in Figure 4, Figure 5. The bearing capacity values at a settlement corresponding to 10% of the size of the plate were taken for comparison. It can be seen that the installation of confining cylinders appreciably improves the bearing capacity of the footing as well as the stiffness of the foundation bed.

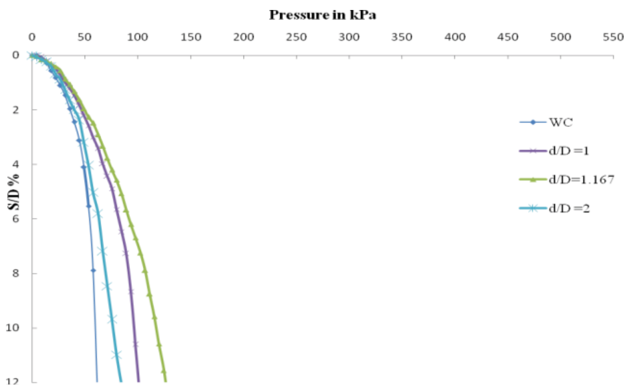

Fig. 4 Variation of bearing pressure with settlement ratio (S/D) for (h/D) =0.5

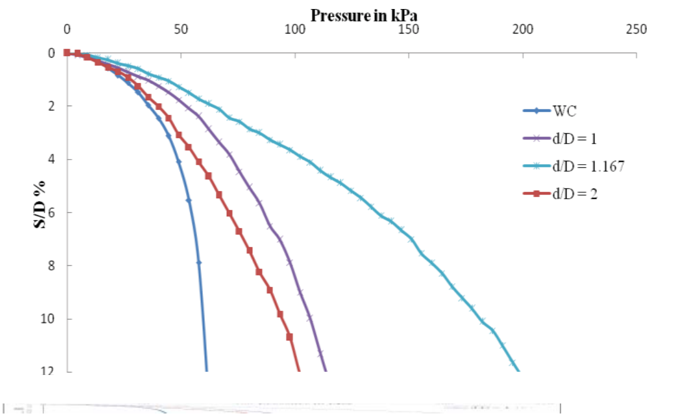

Fig. 5 Variation of bearing pressure with settlement ratio (S/D) for (h/D) =1.0

A. Effect of Cell Diameter

To study the influence of cylinder diameter on the footing behavior, 3 cells with diameters of 90, 105 & 180 mm were used. Figure 6 shows the variation of BCR with normalized cylinder diameter for different cylinder heights with a footing diameter of 90mm. A significant increase in the bearing capacity of the model footing supported on confined sand with the increase of normalized cell diameter d/D is observed until a specific value of d/D after which the BCR decreases with an increase in the d/D ratio. From the Fig. it is clear that using soil confinement could result in an improvement in bearing capacity as high as 5 times more than that without soil confinement.

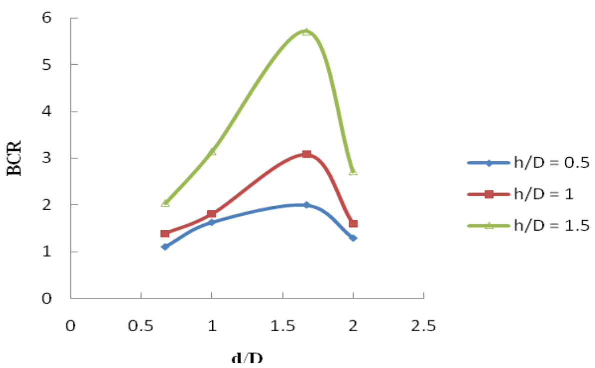

Fig. 6 Variation of BCR with normalized cell diameter (d/D)

From the graph it is clear that the best benefit of soil confinement could be obtained with a (d/D) ratio between 1.0 to 2.0 with the maximum improvement in the bearing capacity at a ratio of about 1.2 for different heights of confining cells. The increase in bearing capacity is due to the fact that, when the footing is loaded such confinements resists the lateral displacements of soil particles underneath the footing and confines the soil leading to a significant decrease in the vertical settlement and increase in bearing capacity.

B. Effect of Cell Height

The effect of cell height on the footing response were investigated by carried out test on confining cylinders with three different heights for each cell diameter. The variation of BCR with normalized cell height (h/D) is shown in Figure 7 for different normalized cell diameters (d/D).

From the graph it is clear that there is greater improvement in BCR with increase in height. Thus increase in cell height leads to the enlargement in the surface area of the cylinder-model footing leading to a higher bearing capacity load. From the results the greatest benefit of cell confinement can be obtained at a h/D ratio of about 1.5. That is bearing capacity ratio increases by more than 5 times than that with unconfined case. It is due to the fact that by increasing the height of the cellular supports, the surface area increases and the failure plane moves in downward direction.

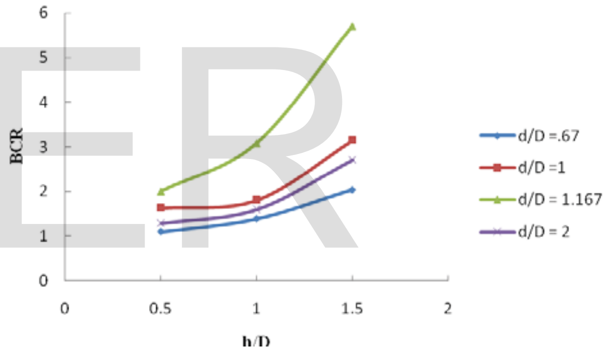

Fig. 7 Variation of BCR with normalized cell height (h/D)

IV MODEL STUDY

A model study was conducted using PLAXIS V 8.1, a finite element software for soil and rock analysis. The structure as a whole is analyzed using 2D model in PLAXIS V 8.1. The material model of HDPE pipes and steel plates was linear elastic and material type was non-porous. The material model and material type used for soils was Mohr-Coulomb model and drained respectively. Interface was considered throughout the element using 5-noded line element. 15 noded triangular elements were chosen for the present study. The axis-symmetry case was considered in the present study. In all these cases the effect of water table was not taken into consideration, since the sand taken was in dry condition. The behaviour was noted and presented in terms of pressure versus S/D.

Seven models were considered for the analysis. To create the boundary condition the standard fixity option was chosen and as a result a full fixity at the base of the geometry and roller condition at the vertical sides is attained. In order to simulate the behaviour of the soil, a suitable soil model and suitable parameters must be assigned to the geometry. The creation of material data sets is generally done after the input of boundary conditions.

When the geometry model is complete, the finite element model (or mesh) can be generated. PLAXIS allows for a fully automatic mesh generation procedure, in which the geometry is divided into elements of the basic element type and compatible structural elements, if applicable. The genereation process is based on a robust triangulation principle that searches for optimized triangles and which results in an unstructured mesh. In addition to mesh generation, a tranformation of input data (properties, boundary conditions, material sets etc.) from the geometry modelt o finite element mesh.

Once the mesh has been generated, the finite element model is complete. Before starting the calculation, the initial conditions must be generated, which comprise of initial ground water condition, the initial geometry configuration and the initial effective stress state. The sand layer in the current footing project is dry, so there is no need to enter ground water conditions. The analysis does however, require the generation of initial effective stresses by means of the K_0 - procedure.

Table 4 Material Properties

Type of material	Properties of material	
Sand	Material model	Mohr-Coulomb
	Type of material	Drained
	Unsaturated unit weight	17.04 kN/m^3
	Young's Modulus	25500 kN/m^2
	Poisson 's ratio	0.3
	Cohesion	1 kN/m^2
	Fristion angle	41^0
Pipe	Material model	Linear Elastic
	Type of material	Non porous
	Unsaturated unit weight	9.7 kN/m^3
	Young's Modulus	2.8 x 10^6 kN/m^2
	Poisson's ratio	0.46

A. Models developed for the analysis

The models for test wit and without confinement are shown in Figure 8, Figure 9. The tank is filled with sand of uniform density. Steel plate is placed, over which the load is applied.

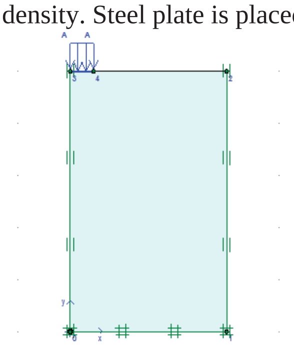

Fig. 8 Model for without Confinement

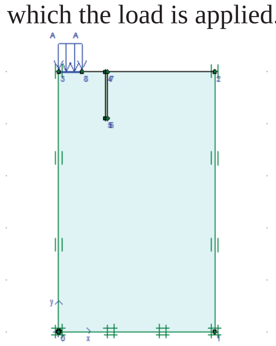

Fig. 9 Model for confinement with h/D =1

B. Test Result

The results of Finite Element Analysis using Plaxis, shows that the load carrying capacity of pipe having a d/D ratio of 1.2 is greater than other d/D ratio's. Also the load carrying capacity increases with increase in h/D ratio.

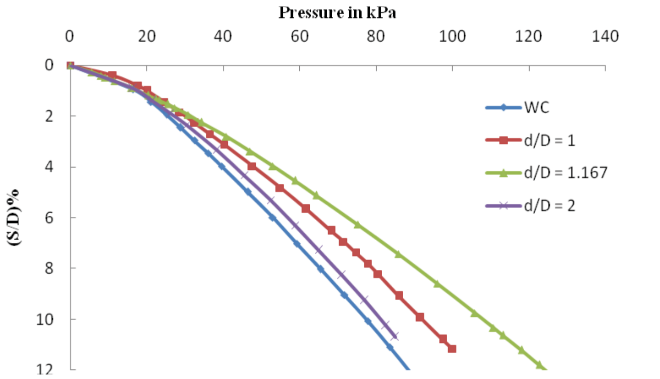

Fig. 10 Variation of bearing pressure with settlement ratio (S/D) for (h/D) =0.5 from model analysis

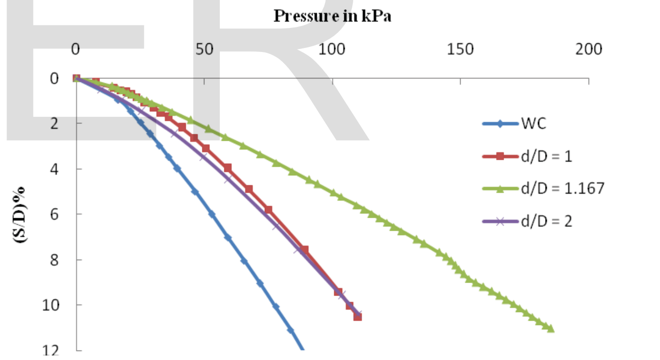

Fig. 11 Variation of bearing pressure with settlement ratio (S/D) for (h/D) =0.5 from model analysis

C. Validition of the model

The footing with pipes was modelled using axisymmetric model and accuracy of model was confirmed by validating it with experimental results. It can be seen that the load settlement graph for the model and prototype coincide. The results are shown in Figure 12, Figure 13, Figure 14. Thus the model developed is in good agreement to that of prototype.

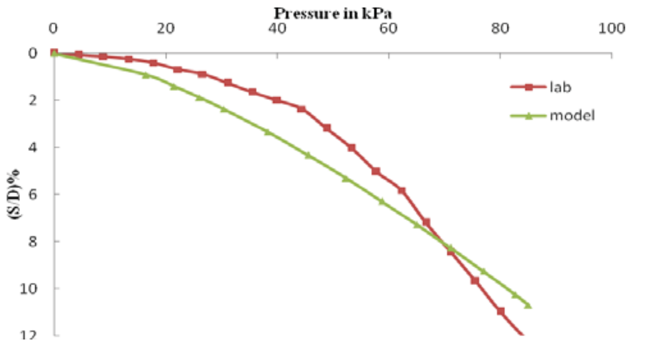

Fig. 12 Variation of bearing pressure with settlement ratio (S/D) from lab and model analysis for without confinement

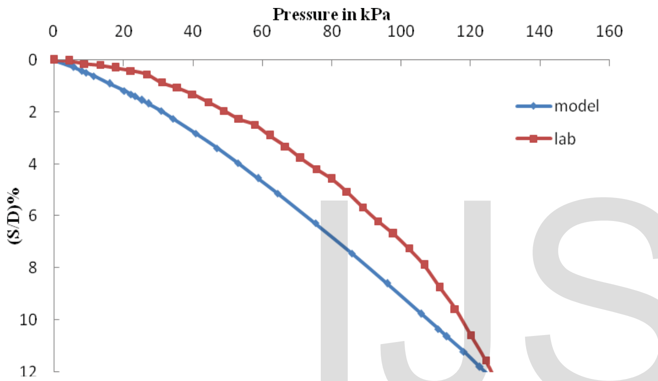

Fig. 13 Variation of bearing pressure with settlement ratio (S/D) for h/D=0.5 and d/D =1.167 from lab and model analysis for without confinement

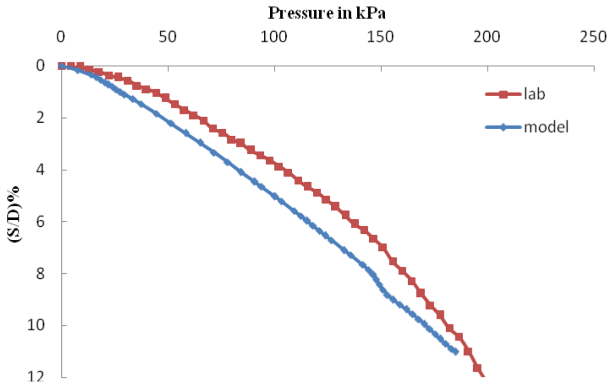

Fig. 14 Variation of bearing pressure with settlement ratio (S/D) for h/D=1.0 and d/D =1.167 from lab and model analysis for without confinement

CONCLUSIONS

The objective of this paper is to study the effect of lateral confinement on the behaviour of shallow foundations. Based on the experimental test results, the following conclusion can be drawn.

(1) The models developed using PLAXIS is in good agreement with the laboratory study.

(2) Soil confinement has a significant influence on improving the bearing capacity of circular footing resting on poorly graded soil.

(3) The ultimate bearing capacity was found to increase by a factor of 5 as compared to unreinforced case in medium dense sand.

(4) Improvement in ultimate bearing capacity depends on the d/D (cell diameter/footing diameter) and h/D (cell height/footing diameter). The optimum ratio is about d/D = 1.2, beyond which the improvement decreases as the ratio increases.

(5) Increasing the height of the confining cell, results in increasing the surface area of the cell–model footing, which transfers footing loads to deeper depths and leads to improvement in the BCR.

(6) For small diameters of cells relative to footing size (d/ 1.0), the cell soil footing settle all together, i.e. they act as one unit.

(7) For large diameter cells relative to footing size (d/D > 1.0), the footing only settles, while the cell remains unaffected.

(8) From the analysis of the model the optimum load bearing capacity is obtained for a d/D ratio of 1.2. It is about 5 times greater than that of unconfined case.

NOTATIONS

The following symbols are used in this paper.

D = footing diameter
d = pipe diameter
h = pipe height
S = footing settlement
BCR = Bearing Capacity Ratio

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