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ENHANCEMENT OF BEARING CAPACITY OF SOFT SOIL USING GEOSYNTHETICS

*Md Lokman Hossain[1], Hossain Md Shahin[2], Teruo Nakai[3]

[1]Office of the Chief Engineer, Bangladesh University of Professionals, Dhaka, Bangladesh
[2]Department of Civil and Environmental Engineering, Islamic University of Technology, Bangladesh
[3]Geo-Research Institute, Emeritus Professor at Nagoya Institute of Technology, Nagoya, Japan

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ABSTRACT: In many situations, conventional foundation systems could not be chosen in soft soil due to the low bearing capacity. In such a case, ground improvement or reinforcing of the ground is necessary to obtain the required bearing capacity. This paper deals with the use of geosynthetics to reinforce the ground for reducing ground deformation and increasing bearing capacity of the ground. This research is mainly focused on the soft clay soil which is more problematic than the sandy soils with respect to the building foundation of infrastructures. Here, numerical analysis has been carried out with the finite element method, using the elastoplastic sub loading t_{ij} model. Bearing capacities for different over consolidation ratios (OCRs)and changing the depth of the reinforcement are compared. Bearing capacity is also checked replacing the soft clay with granular soil in between the foundation and reinforcement. It is found that reinforcement increases the bearing capacity of the soft clay and the increment of the bearing capacity depends on the depth of the reinforcement, OCR and improved area of the ground underneath the foundation.

Keywords: Bearing Capacity, Geosynthetics, Finite Element Method, Soft Clay

1. INTRODUCTION

The vast areas of Bangladesh are composed of very soft to soft fine-grained soil materials of recent origin. Subsoil's of South-West coastal districts consist of fine-grained soil deposits predominantly with peat and muck. As the soil is composed of organic substances, it is soft and compressible. Thus soil exhibits huge total, and differential settlement and engineers are facing difficulties in addressing the issue of geotechnical engineering-related problems such as bearing capacity failure and slope stability. The general foundation system is not suitable in this kind of soft soil due to environmental constraints and because of their expensive and time-consuming nature. For the construction in very soft soil, excavation and replacement was a common method in the past. But this is expensive and not always practical. This research focuses on using geosynthetics to reinforce the ground for increasing6 the bearing capacity and reducing ground deformation. In recent years, many researchers used base reinforcement technique as a solution to increase the bearing capacity of soft ground using the tensile strength of the reinforcement ([1], [2], [3], [4], [5], [6], and [7]. Reinforcement can withstand tensile forces acting upon the soils from the upper surcharge.

The benefit of geosynthetics reinforcement for ground improvement has been confirmed in field-scale experiments on square footings [8]. It was found that a significant increase in bearing capacity can be achieved by using geosynthetics in the foundation systems at the academic and residential buildings constructed at Khulna Medical College [9], which is located at the South-West region of Bangladesh. In the same region, at Khulna University, the foundation for the four-story academic building-I was constructed over mat by replacing top soft ground and peat layer whereas academic building-II was constructed on floating foundation resulting in settlement of 700 mm and 19 mm, respectively [10].It was found that fixed edges of the reinforcing members with the ground are more effective than that of the free edges of the reinforcement [7] which was also proven during a tremor of the Great East Japan Earthquake on March 11, 2011.

In this study, numerical analyses were performed with the finite element program FEMtij-2D using the elastoplastic sub loading t_{ij} model ([11] and [12]). The validity of the model has already been verified in previous research ([6] and [7]). This model can describe the typical stress deformation and strength characteristics of soils, such as the influence of the intermediate principal stress, stress path dependency of plastic flow and the density and/or confining pressure.

2. OUTLINE OF NUMERICAL ANALYSES AND TEST PATTERNS

Two-dimensional finite element analyses are carried out with FEMtij-2D program which is developed in Nagoya Institute of Technology. Fig. 1 represents a typical mesh used in the numerical analyses. The left and right boundaries of the finite element model are kept fixed in the horizontal direction and free in the vertical direction. The bottom boundary of the model is kept fixed in both horizontal and vertical directions. Isoperimetric four-nodded elements are used for soil elements, and elastic beam elements are used to simulate reinforcements. The frictional behavior between the reinforcement and soil, and the foundation/ground is modeled employing the elastoplastic joint element[13]. The friction angle between foundation and soil is δ=15°. Fig. 2 refers to the reinforcement set up. Here, D depicts the depth of the reinforcement and L represents the length of the reinforcement. In this study, the length of the reinforcement is kept constant which is 14.4 m, and the width of the foundation (B) is 12.0 m. The edges of the reinforcement are kept fixed with the ground considering the same movement of the nodes of the reinforcement and soil. Three depths of the reinforcement are considered to find the effective depth for getting maximum benefit, D/B= 0.05, 0.10, and 0.20. Bearing capacity is also checked replacing the soft clay with granular soil in between the foundation and reinforcement for all D/B. The material parameters of granular soil are listed in Table 2. The tensile strength of the reinforcement is 1340 kN/m^2. Four different over consolidation ratios, OCR = 1.0, 2.0, 4.0, and 8.0 are considered to check the interaction of ground stiffness and reinforcement.

In the numerical analyses, the elastoplastic sub loading t_{ij} model ([11] and [12]) is used. This model can describe typical stress deformation and strength characteristics of soils such as the influence of intermediate principal stress, the influence of stress path, the dependency of plastic flow and the influence of density and/or confining pressure. The parameters of the clay soil are listed in Table 1. The parameters are fundamentally the same as those of the Cam clay model, except for the parameter a, which is responsible for the influence of the density and the confining pressure. The parameter β represents the shape of the yield surface. The parameters can easily be obtained from traditional laboratory tests.

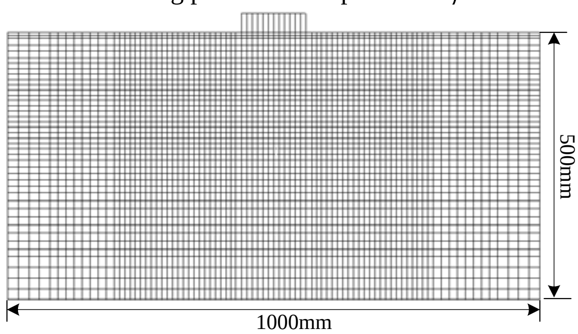

Fig.1 A typical mesh for finite element analysis

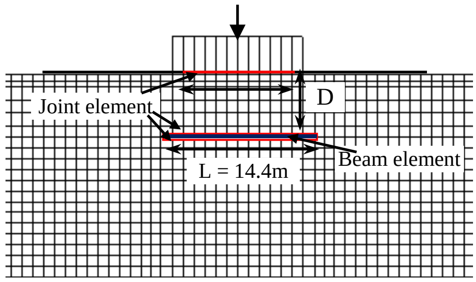

Fig.2Explanation of reinforcement setup

Table 1 Material parameters of clay soil

Parameters	Notations	Value
Compressive Index	λ	0.1039
Swelling Index	κ	0.0099
Void ratio at atmospheric pressure (98 kPa)	N	0.922
Critical state stress ratio	R_{cs}	3.2
Poisson's ratio	ν_e	0.2
The shape of the yield surface	β	1.5
Influence of density	a	500

Table 2 Material parameters of granular soil

Parameters	Notations	Value
Compressive Index	λ	0.040
Swelling Index	κ	0.0045
Void ratio at atmospheric pressure (98 kPa)	N	1.10
Critical state stress ratio	R_{cs}	2.0
Poisson's ratio	ν_e	0.2
The shape of the yield surface	β	1.5
Influence of density	a	200

3. RESULTS AND DISCUSSIONS

3.1 Effect of the Depth of Reinforcement

Fig.3 illustrates the normalized displacement which is normalized by maximum applied displacement curves for the ground at OCR=1.

For OCR=1.0 at the lower value of normalized displacement, bearing capacity is found more for reinforcement at D/B=0.05 but at higher value it is found more for reinforcement at D/B=0.20.Fig.4 depicts the normalized displacement curves for the ground at OCR=4.0. For OCR=4.0, at a lower value of normalized displacement, the bearing capacity is found more for reinforcement at D/B=0.

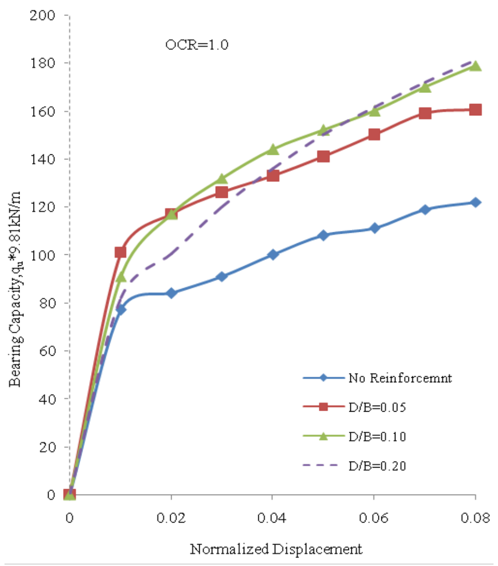

Fig.3 Relation of Bearing Capacity with Normalized Displacement at OCR=1.0

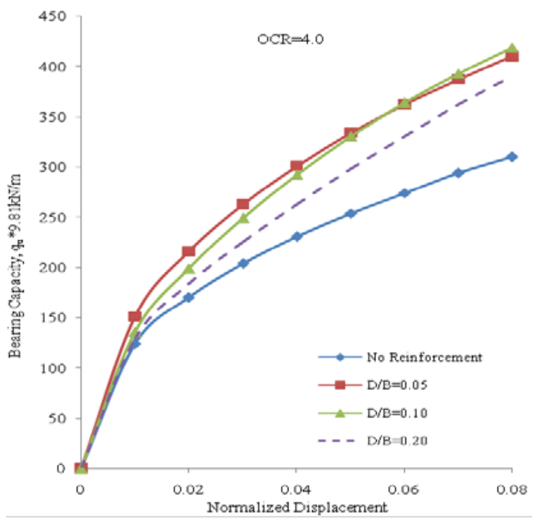

Fig.4 Relation of bearing capacity with normalized displacement at OCR=4.0

Fig.5 shows a percentage of increase in bearing capacity with respect to the ground without reinforcement against normalized displacement for OCR=1.0. The vertical axis represents percentage increment in bearing capacity, whereas, abscissa illustrates normalized-displacement. For normalized-displacement of ground reinforced at D/B= 0.05, there is a declining trend in the percentage of increase in bearing capacity but for ground reinforced at D/B=0.20there exists a sharp positive trend.

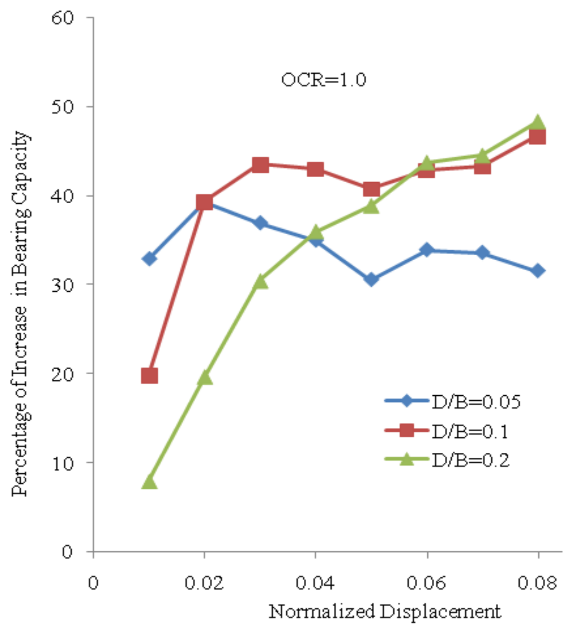

Fig.5 Relation of % of the increase in bearing capacity with respect to no-reinforcement against normalized displacement at OCR=1.0

Fig.6 represents the percentage increase in bearing capacity with respect to the ground without reinforcement against normalized displacement for the ground at OCR=4. Vertical axis illustrates percentage increase in bearing capacity with respect to bearing capacity of ground without reinforcement whereas abscissa depicts normalized displacement.

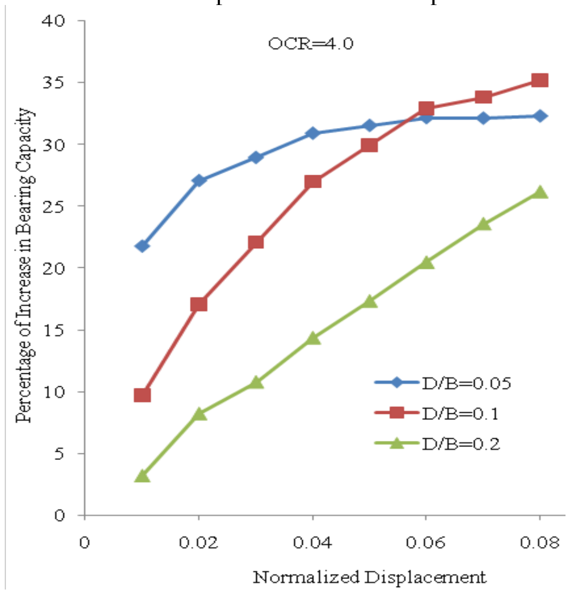

Fig.6 Relation of percentage increment in bearing capacity with respect to no-reinforcement against normalized displacement at OCR=4.0

It is found that initially rate of increment in bearing capacity for ground reinforced at D/B=0.05 increases more compare to other positions of reinforcement, but at higher value of displacement reinforcement placed at D/B=0.10 is more effective than other cases.

3.2 Effect of Ground Conditions

Fig.7 depicts bearing capacity against normalized displacement for different OCRs value when reinforcement is placed at D/B=0.05. The vertical axis represents bearing capacity whereas abscissa shows normalized displacement. It is seen in the figures, bearing capacity is the lowest for OCR=1 whereas it is maximum in case of OCR=8 for the same displacement.

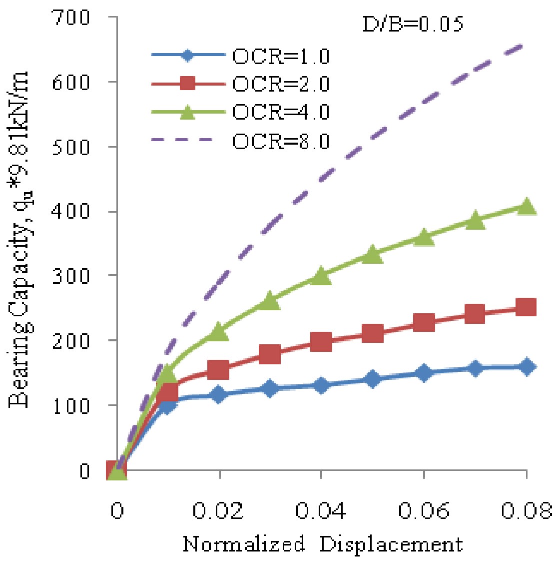

Fig.7 Relation of bearing capacity with respect to normalized displacement at different OCRs

Fig.8 represents bearing capacity against displacement for different OCRs value when reinforcement is placed at D/B=0.1. The vertical axis depicts bearing capacity whereas abscissa shows normalized displacement. Bearing capacity is the lowest for OCR=1 whereas it is the maximum in case of OCR=8 for the same displacement. Though increasing rate of bearing capacity trends to be similar but there is a slight increase in bearing capacity from that of the ground reinforced at D/B=0.05.

Fig.9 illustrates bearing capacity against normalized displacement for different OCRs value when reinforcement is placed at D/B=0.2. Vertical axis shows bearing capacity whereas abscissa represents displacement. Here the line with the diamond box describes bearing capacity at OCR=1. It is found that bearing capacity is the lowest for OCR=1 whereas it is maximum in case of OCR=8.

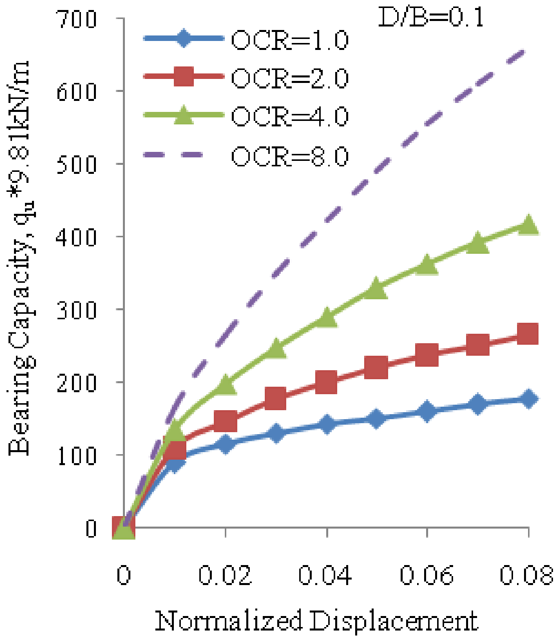

Fig.8 Relation of bearing capacity with respect to normalized displacement at different OCRs

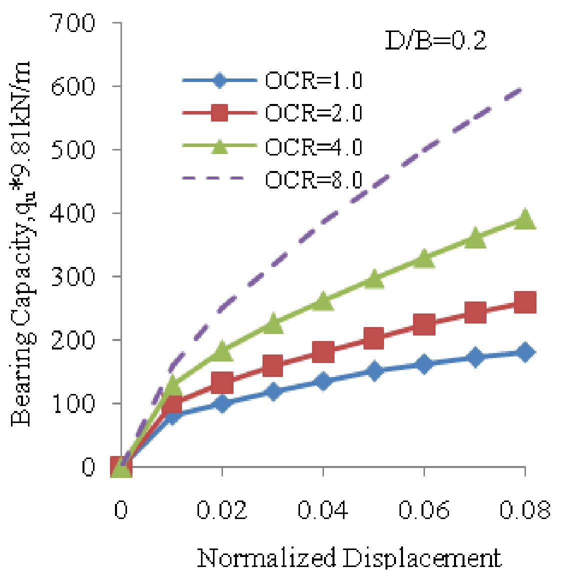

Fig.9 Relation of bearing capacity with respect to normalized displacement at different OCR

3.3Effect of Ground Improvement

Fig.10 illustrates bearing capacity against normalized displacement for OCR=1 with different situations for ground reinforcement (D/B=0.1) and improvement. The vertical axis shows bearing capacity of ground whereas abscissa represents normalized displacement. There was gradual increase in bearing capacity from the ground without improvement to subsequent improvement & reinforcement. Again for same OCR value bearing capacity found more when reinforcement is at D/B=0.1 than that of D/B=0.05(By comparing Fig.12 & Fig.13). If other conditions remain same then bearing capacity increases with the increased value of OCR.

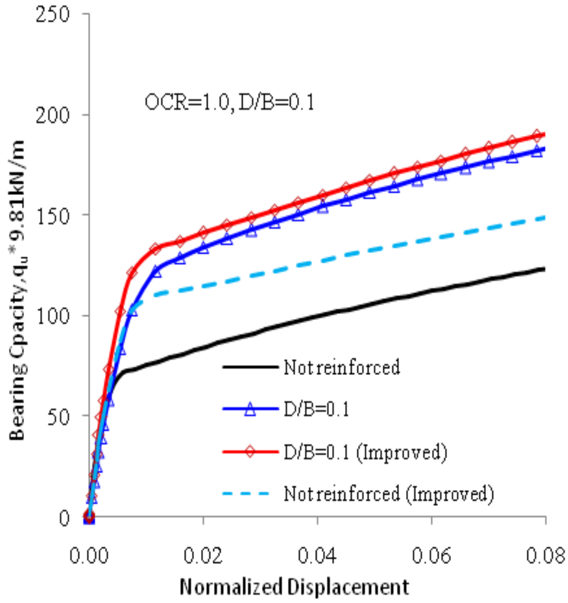

Fig.10 Effect of Ground Improvement with & without Reinforcement at OCR=1.0

Fig.11 shows bearing capacity against normalized displacement for OCR=4.0 with different situations of ground reinforcement (D/B=0.05) and improvement. The vertical axis represents bearing capacity of ground whereas abscissa describes normalized displacement.Fig.12 depicts the bearing capacity against normalized displacement at OCR=1.0 for ground improvement & reinforcement at different locations. Fig.13 depicts the bearing capacity against normalized displacement at OCR=4.0 for ground improvement and reinforcement at different locations. There was gradual increase in bearing capacity from ground without improvement to subsequent improvement & reinforcement. Bearing capacity has increased substantially once reinforcement has been placed from D/B=0.05 to D/B=0.1. In addition, bearing capacity has also increased as the OCR value has changed from OCR=1.0 to OCR=4.0.

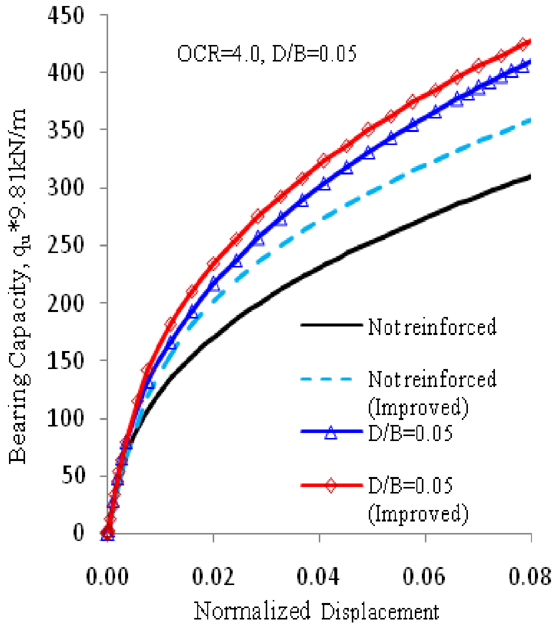

Fig.11 Effect of Ground Improvement with & without Reinforcement at OCR=4.0

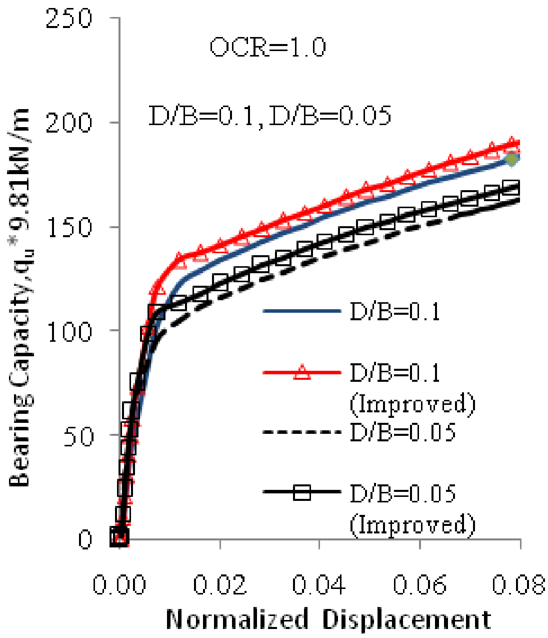

Fig.12 Effect of Different Locations of Ground Improvement & Reinforcement at OCR=1.0

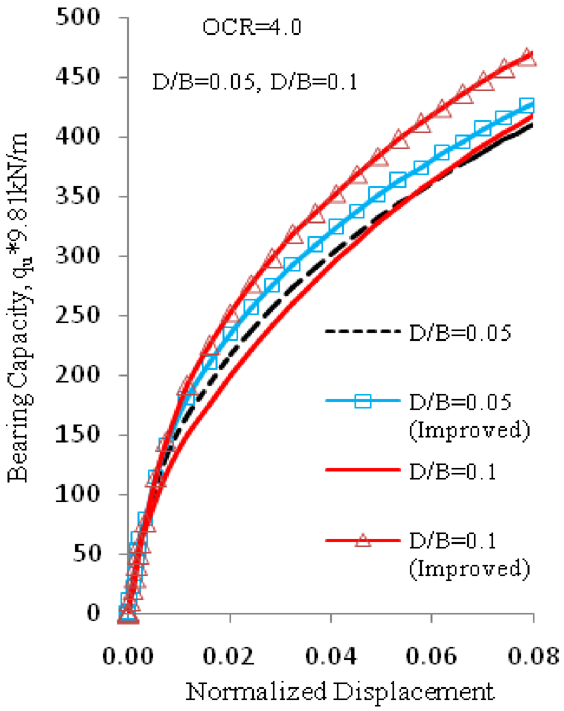

Fig.13 Effect of Different Locations of Ground Improvement & Reinforcement at OCR=4.0

4. CONCLUSION

From the analyses presented in this paper, it can be concluded that,

a. The bearing capacity of clay soil improves with the increase of OCR.
b. For the same OCR, bearing capacity of clay improves with the improvement of the soil underneath the footing.
c. Bearing capacity further increases with the introduction of reinforcement like geotextile below the footing.
d. Optimum result due to the reinforcement of clay soil underneath the footing is found at around D/B=0.1.
e. Bearing capacity of soft ground substantially increases applying both geotextile and improvement in between the geotextile as observed in all simulations.
f. The position of the reinforcements relative to the foundation is an important factor for increasing the bearing capacity. The simulation can give a guideline on the area which should be improved depending on the ground condition.

In the South-West region of Bangladesh, the technique discussed can be used to build low-rise buildings at cheaper costs.

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