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ABSTRACT

This paper is concerned with the performance of Rammed Aggregate Pier in soft ground at a selected site of South-West region of Bangladesh. The ground at the site consists of soft fine-grained soil up to great depth with a layer of organic soils at 4.5 to 9m depth from the existing ground surface. The Rammed Aggregate Piers (RAPs) were installed with locally fabricated equipments. Rammed Aggregate Pier of cylindrical shape having 0.75m diameter and 3.4m length were installed manually in three arrangements as single, double and group. A uniform mixture of local sand and brick aggregates at the proportion of 1:2 was used as the granular materials maintaining saturated surface dry condition. The granular materials were poured into the excavated hole in layers and hence compacted adequately by using a hammer of 108kg and a free fall height of 600mm. Load tests on full-size isolated square footing of 1.68x1.68m resting at a depth of 0.75m from the existing ground surface were conducted on both the natural and improved ground by using the method similar to pile load test. The result shows that the ultimate bearing capacity of footing resting on single, double and group RAP treated ground can be increased by 1.5, 1.8 and 1.96 times, respectively, comparing to that of natural ground. Field investigation reveals that the RAPs made-up of locally available granular materials and installation technique can be used successfully as a suitable ground improvement method to improve the bearing capacity of such soft ground.

INTRODUCTION

Ground improvement has become a common foundation practice to tackle the adverse situations arises from poor ground conditions. Among the various ground improvement techniques, columnar inclusion such as stone columns, granular piles, sand compaction piles, etc is the most versatile and cost effective option (Alamgir 1996). Rammed aggregate pier system, named as geopier, had been developed in the 1980’s in the United States and more recently in Asia and Europe, for supporting of lightly to heavily loaded structures and highway and railway embankments (Lawton and Fox 1994 and Lawton et. al. 1994). Rammed Aggregate Pier is constructed by drilling out a volume of compressible soil to create a cavity and then ramming selected aggregate into the cavity in thin lifts using a patented beveled tamper. The ramming action causes the aggregate to compact vertically as well as to push laterally against the matrix soil, thereby increasing the horizontal stress in the matrix soil and reducing the compressibility of the matrix soil between the elements. The RAP foundation system is one of the few soil improvement method that can safely carry significant lateral and up lift forces and has been successfully used on hundreds project sites both the poor and unsuitable soils as well as fair to good soils. Rammed Aggregate Pier is installed by creating holes in the ground by augering or excavation, and filling the cavities with granular materials, which are compacted using high energy impact temper (Lawton 1999). Some practical application of geopier can be obtained in Wissmann and Fox (2000) Wissmann et al. (2000) and Wissmann et al. (2001).

Soft fine-grained soil with significant organic content dominates the sub-soil in Bangladesh, which often creates problem to the geotechnical engineers to select suitable economic foundations for structures due to low shear strength and high compressibility (Alamgir et al. 2001). Recently some ground improvement techniques including granular columns have been employed successfully in this region. The performance of geotextile-reinforced footing, sand compaction piles, stone columns and granular piles have also been studied in this region at field level (Haque 2000, Zaher 2000, Alamgir and Zaher 2001, Haque et al. 2001 and Sobhan 2001). This study has been undertaken to depict the applicability of Rammed Aggregate Pier in such sub-soil conditions. However, acknowledging the reality, instead of standard practices, locally available granular materials and installation technique have been used for the construction of Rammed Aggregate Pier. Local sand and brick aggregates mixtures were compacted in layer using a hammer of 108 kg in a manually formed borehole of 750mm dia and 3.4m length. This type RAPs was installed in single, double and group pattern.

The performance of RAP improved ground was established by conducting load test on full-size footing resting on such ground. Total four load tests were conducted for same sized footing of 1.68mx1.68m placed on untreated, single-RAP, double-RAP and group-RAP ground. The field results reveal that the ultimate bearing of the square footing in this site placing at a depth of 0.75m can be increased by 1.5, 1.8 and 1.96 times, respectively, for single, double and group Rammed Aggregate Pier treated ground compared with natural ground.

CONSTRUCTION OF RAMMED AGGREGATE PIER

The sub-soil condition of KUET campus at Khulna, Bangladesh in which RAPs were installed and the installation method are described in the followings sections. Locally available granular materials and the manual labor intensive installation technique are employed. To obtain a vivid picture about the effectiveness of Rammed Aggregate Pier, three different arrangementsnumber of Rammed Aggregate Pier under the same sized footing are considered.

Location of Project Site

The investigation site is located at the KUET campus, Khulna i.e. south-west part of Bangladesh. The KUET campus is situated 12 km. from Khulna city center and to the 1 km. west of Khulna-Jessore highway. The campus map of KUET, location of investigated site at the campus map and the map of Bangladesh is shown in the Fig. 1.

Sub-Soil Condition

The general sub-soil condition in the south-western part is similar to that of KUET campus. Standard penetration test associated with related field and laboratory tests was conducted to characterize the sub-soil conditions up to 20m depth from the existing ground surface as presented at Table 1. The sub-soil at the top 0 to 3m consists of a layer of fine sand of loose to medium relative density, after that a thin layer of clay exists which is followed by a thick organic clay layer of soft consistency at a depth of 4.5 to 9m. Beyond this layer, the sub-soil is encountered as silty clay of soft consistency till the final depth of boring. The field test shows that the N-value remains almost uniform at a range of 4 to 5 throughout the depth. Alamgir and Zaher (2001) reveals almost similar sub-soil profile in another location about 250m apart at KUET campus,

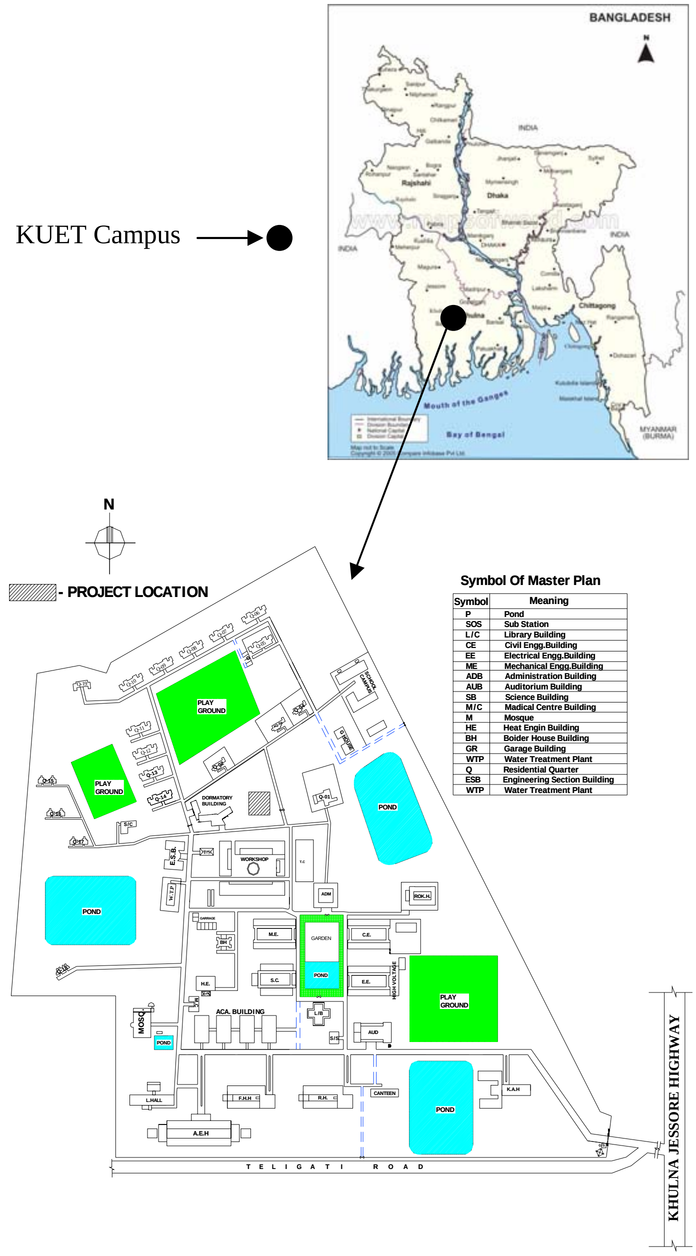


Fig. 1. Location map of KUET campus, Khulna in Bangladesh.

where field investigations were conducted to established the performance of stone columns and sand compaction piles as installed using both the dry-displacement (Zaher 2000) and wet-replacement (Sobhan 2001) methods. The special feature of this sub-soil profile is the presence of a thick organic soil layer at a depth of 4.5m.

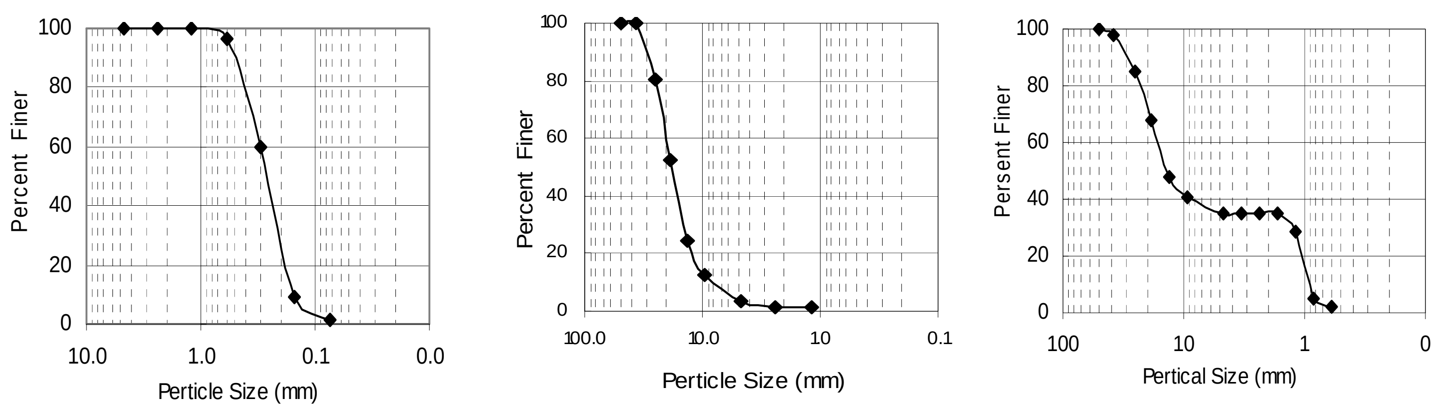
Table 1. Geotechnical engineering properties of the site at KUET campus in Khulna, Bangladesh.

Note: w=Water content, W_l= Liquid limit, Wp=Plastic limit, γ=Unit weight, G_s=Specific gravity, e_0=Initial void ratio, C_c=Compression index, s_u=Undrained shear strength. Average values of various parameters are provided here.

Depth (m)	Soil stratification	w (%)	Physical properties						Compressibility properties		Shear strength properties	
			W_l (%)	Wp (%)	Ip	γ kN/m^3	G_s	Organic contents (%)	e_0	Cc	s_u (kPa)	N Value
1-1.5	Silty sand	-	-	-	-	-	-	1.49	-	-	-	8
1.5-3		-	-	-	-	-	-	3.44	-	-	-	5
3-4.5	Clay	48.20	53.20	21.21	31.99	16.92	2.78	10.01	1.15	0.66	20	5
4.5-6	Organic clay	74.65	81.50	47.27	34.23	13.88	2.59	12.70	5.22	1.80	28	3
6-7.5		167.56	255.0	177.42	77.58	10.59	2.10	31.75	1.35	0.65	30	9
7.5-9		63.63	44.80	34.41	10.39	13.42	2.68	7.76	1.73	0.55	35	4
9-10.5	Silty clay	50.12	39.10	28.07	11.03	17.10	2.75	6.46	1.06	0.35	18	4
10.5-12		44.72	40.00	32.71	7.29	16.85	2.52	7.22	1.36	0.37	11	4
12-13.5		55.58	32.50	31.30	1.2	16.12	2.15	5.59	0.76	0.25	9	5
13.5-15		51.52	36.40	32.46	3.94	-	-	6.49	-	-	-	5
15-16.5		54.32	39.00	35.29	3.71	-	-	4.89	-	-	-	6
16.5-18		55.21	32.30	31.11	1.19	-	-	3.52	-	-	-	5
18-19.5		53.25	37.00	30.34	6.66	-	-	3.74	-	-	-	8

Materials of Rammed Aggregate Pier

In this investigation, considering the practical situation of availability of construction techniques and materials in Bangladesh, RAPs were installed completely manually using replacement method. Granular materials (Cu=11.89 and Cc= 0.20) consisting of 2:1 mixture of brick aggregates (Cu= 2.86 and Cc=1.49) and local sand (Cu=1.76, Cc=.78 and FM=1.26) as shown in Fig. 2 was used as the constituent materials of RAP. Here, Cu is coefficient of uniformity, Cc is the coefficient of curvature and FM is the fineness modulus.



(a) Local sand *(b) Brick aggregates* *(c) Mixed granular materials*

Fig. 2. Grain size distribution curve of used granular materials.

Installation of Rammed Aggregate Pier

To install columnar inclusions (stone columns, granular piles, sand compaction piles, cement column, RAPs, etc.) several methods ranging from conventional labor intensive to well-equipped have been practiced throughout the world. The choice of installation techniques primarily depends on the sub-soil condition, required degree of improvement, availability of installation equipments and finally cost involvement. In Bangladesh, appropriate equipments are not readily available and hence practiced. For sand compaction piles installation generally operated manually through dry displacement method, has been practiced. Sylhet sand and local sand are usually used as granular materials to construct sand piles of an average diameter of 200mm of varying length. Compaction is done by a dropping hammer of weight ranging from 100 to 500kg.

In this investigation, the boreholes of 0.75m diameter and 3.4m long were excavated manually using locally available ground digging tools and the side of boreholes were retained by using locally made burned clay ring of 750mm diameter, 150mm length and 10mm thickness, which were placed as the excavation proceeds. After the completion of boreholes, designated granular materials were placed in layer and hence compacted to get the required density, nearly equivalent to that of obtained in standard proctor test for the same materials. The installation procedure of RAP is briefly described in the followings and also in Fig. 3 in a schematic diagram. However for more details reference can be made as Hossain (2007).

Step1. Manually excavate a borehole of 750mm diameter till the depth of 4.15m measured from the existing ground surface. Burned clay ring of about 750mm dia and 150mm length were placed to protect the borehole collapse as the excavation proceeds.

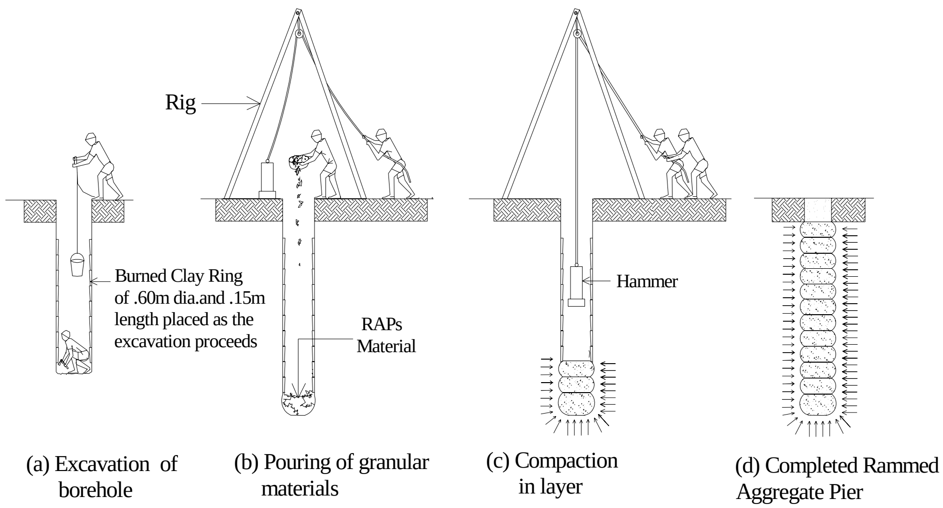


Fig. 3. Schematic diagram of installation process of RAP used in this study

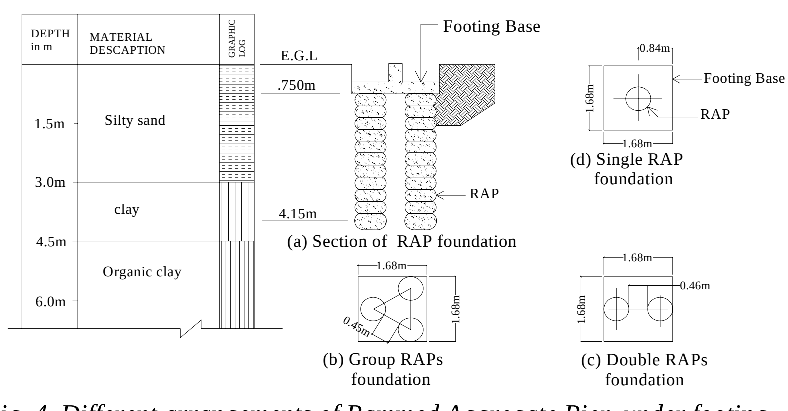


Fig. 4. Different arrangements of Rammed Aggregate Pier under footing.

Step2. After the completion of borehole the properly mixed granular materials were placed at the bottom and sufficiently compacted with a hammer of 200mm diameter, 650mm length and 108kg weight to make a bottom plug. For having a wider area the hammer has an enlarged head of 325mm diameter. The tripod stand with rope-pulley system (locally made for SPT) was used here for the free fall of hammer and hence to densify the granular materials.

Step3. After the making of bottom plug, granular materials were placed in layers (initial thickness of 350mm) and hence compacted properly by dropping the hammer ensuring the same height of freefall (about 600mm) as designated to obtain pre-set compaction . Total 40 number of hammer drops were provided in each layer and hence obtained a compacted layer of 250mm thickness.

Step4. Step 3 was then repeated and continued till the RAP reached the ground surface to have a compacted RAP.

In this investigation, to depict the effectiveness of Rammed Aggregate Pier under footing at various arrangements, RAP of same properties in terms of diameter, length and stiffness were installed in single, double and group pattern. Same spacing was used for the double and group RAPs as 1110mm center to center. The schematic diagrams of RAP arrangements are shown in Fig. 4.

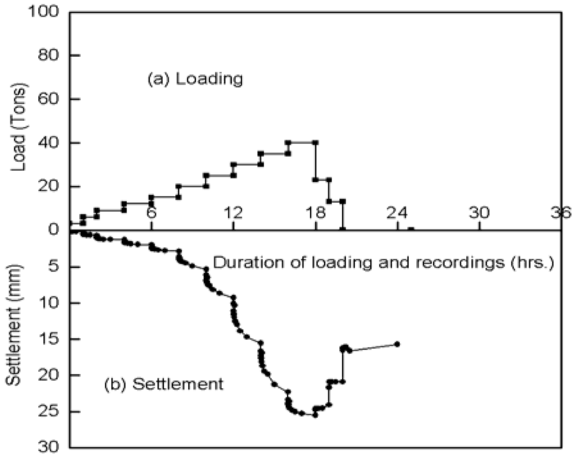
FULL-SIZE FOOTING LOAD TEST

Most reliable method of obtaining ultimate bearing capacity at a site is to perform a load test on a full-size footing, which is not usually done since an enormous load would have to be applied, which eventually leads to high cost (Bowles 1997). The usual practice is to perform plate load test to avoid cost and related involvements. Despite the problems with full-sized square footing load test, in this study, the bearing capacity of the improved ground was measured through load tests on full-size footing of 1.68mx1.68m placing on the both of natural and improved grounds at a depth of 750 mm measured from the existing ground surface. Sufficient dead load, more than the estimated capacity of footing based on the ground conditions, was placed on the ground at a platform and hence transfers through hydraulic jack to the top of column (300x300mm) sectioned constructed at middle of the footing. The settlement is measured by two deformation dial gauge mounted from a position not effected by the settlement of the footing. Typical load arrangement and transfer of load is shown in Figs. 5 and 6. Each load increment is one-eights of the estimated capacity. However, load increments were continued till the settlement was reached to 25mm. At each level of load increment, the readings were continued till the rate of settlement less than 0.25mm per hour and rebound readings were also recorded at four steps. The measurement systems are very similar to that of follow in standard pile load and plate load test. Typical load-settlement-time diagram is shown in Fig. 7.

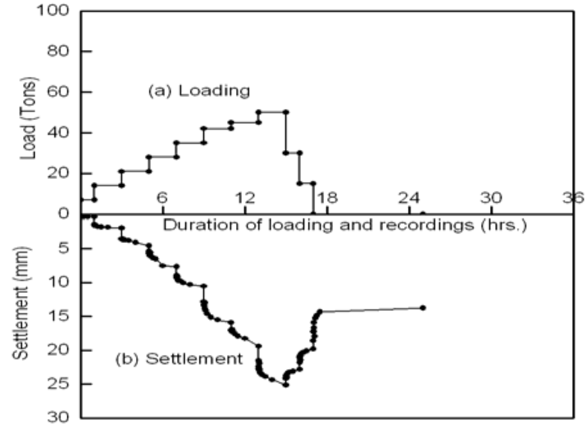
Fig. 5. Set up of load arrangement for footing load test.

Fig. 6. Full scale footing load test arrangement

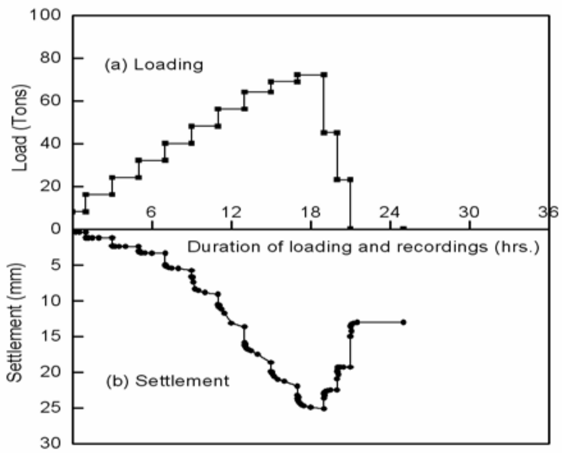
In natural ground, the load intensity on the footing was increased up to 139.64kN/m^2 with an equal load increment of 10.50kN/m^2. Similarly, load intensities on the footing resting on single, double, and group RAPs treated ground were increased to 174.56 at an interval of 24.44kN/m^2, 251.36 at an interval of 27.93kN/m^{2}and 279.29kN/m^2 at an interval of 34.91kN/m^2, respectively, as shown in Figs. 7(a), (b), (c) and (d).



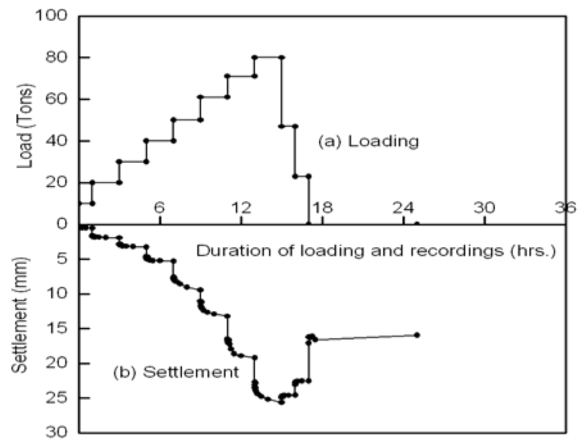
(a) Load-settlement-time response of natural ground.



(b) Load-settlement-time response of single RAP treated ground.



(c) Load-settlement-time response of double RAPs treated ground.



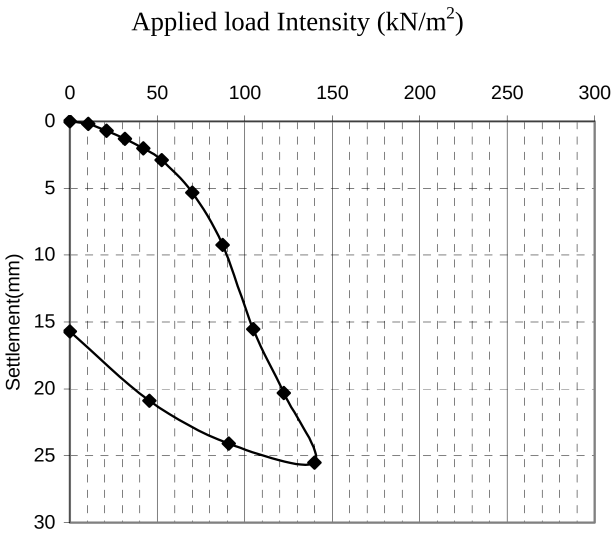
(d) Load-settlement-time response of group RAPs treated ground.

Fig. 7. Load-settlement-time response untreated and RAPs treated ground obtained from full-scale footing load test.

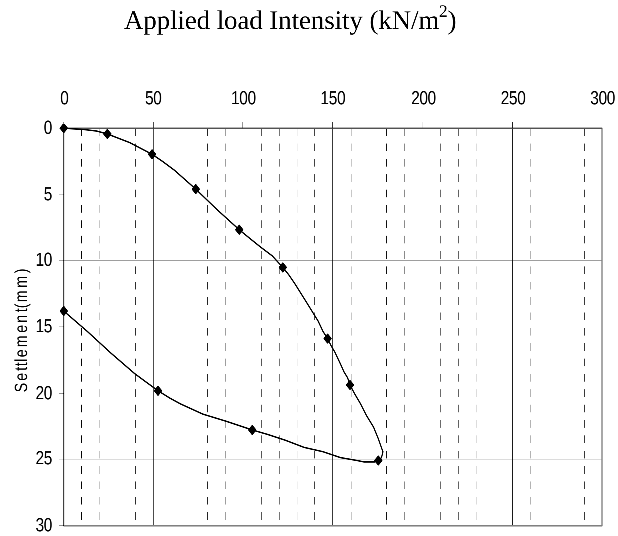
RESULTS AND DISCUSSION

The load-settlement curves as measured from full-size footing load tests are shown in Fig. 8 for both the natural and improved ground. The load settlement response of natural ground is shown in Fig.8(a), while the settlement response in single, double and group RAPs improved ground are shown in Figs. 8(b), (c) and (d). In all these curves both the loading and unloading responses are illustrated as measured from loading tests. From these figures, it can be seen that the settlement increases with the increase of applied load almost in the similar fashion. The gross settlement curves for all the conditions are shown in Fig. 9 and the comparison of ultimate bearing capacities as measured corresponding to the settlement of 25mm is given in Table 2.

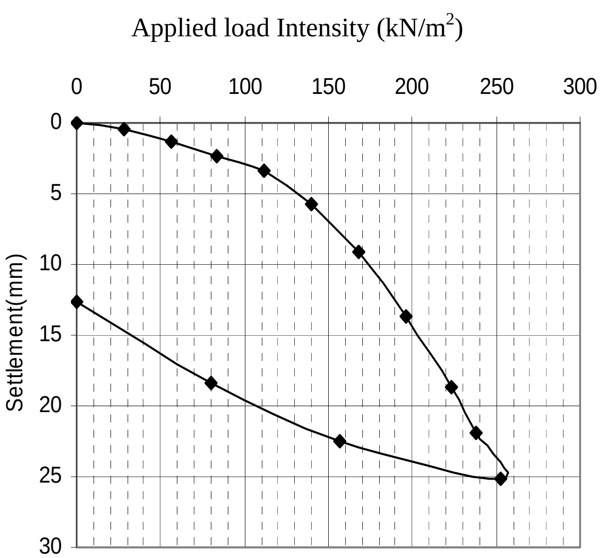
The figures reveal that the ultimate bearing capacity of footing in the same site has increased significantly due to the installation of RAPs. From the load test results, it can be seen that the ultimate bearing capacity on the natural ground is 141kPa, while the values are 177, 254 and 277kPa for the single, double and group RAPs treated ground, respectively. The result shows that the bearing capacity of single, double and group RAPs treated ground have increased to 1.5, 1.8 and 1.96 times compared to that of untreated ground. The load intensity of double and group RAPs treated ground is respectively, 1.48 and 1.56 times higher than that of single RAP treated ground. The result also reveals that group RAPs improved ground yields nearly equal increase of ultimate bearing capacity with that of double-RAPs improved ground having same spacing of RAPs. This finding depicts that under a square footing resting on double RAPs improved ground yields better results than the other two counterparts.



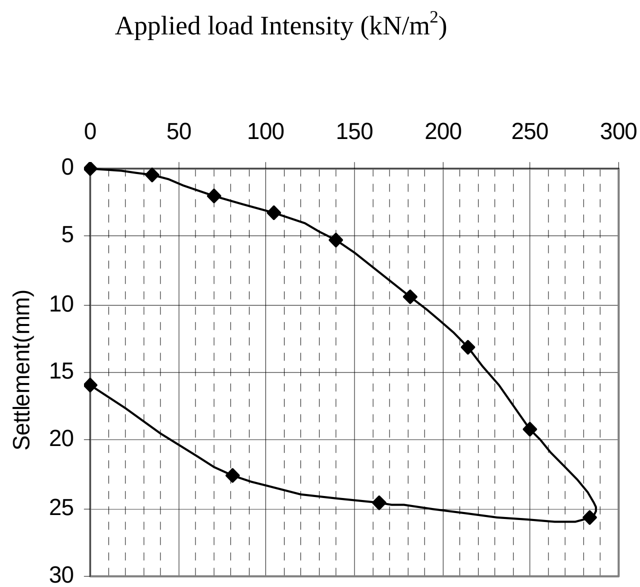
(a) Natural ground



(b) Single RAP improved ground



(c) Double RAP improved ground



(d) Group RAP improved ground

Fig.8. Load versus settlement curve on both the natural and improved ground.

Applied load Intensity (kN/m2)

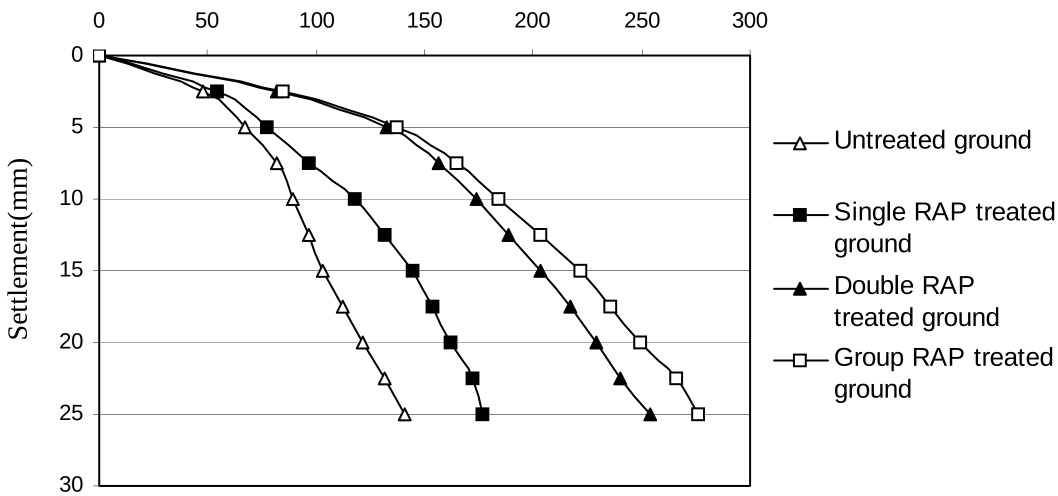


Fig. 9. Load-settlement response of footing resting on both the natural and RAPs improved ground.

Table 2. Degree of improvement of RAPs improved groun

Ground condition	Ultimate bearing capacity, q_{ult} (kN/m^2)	Degree of improvement (ratio of ultimate bearing capacity of improved ground and natural ground)
Natural ground	141	1
Single RAPs improved ground	177	1.25
Double RAPs improved ground	254	1.8
Group RAPs improved ground	277	1.96

CONCLUSION

Based on this study the following conclusions can be made:

(i) The field experience during the installation of Rammed Aggregate Pier depicts that the installation techniques based on locally available equipments and practices required very close monitoring and precaution in case of double and group Rammed Aggregate Pier arrangements.

(ii) Proper mixing, moisture content and pouring of granular materials are required to ensure the stiffness of Rammed Aggregate Pier. The layer thickness of granular material, dropping height, number and placement of hammer are to be maintained properly through close field monitoring to achieve the designated stiffness of the Rammed Aggregate Pier.

(iii) The results reveals that the bearing capacity of footing resting on Rammed Aggregate Pier improved ground has increased significantly than that of resting on the natural ground.

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