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Improved performance of soft clay foundations using stone columns and geocell-sand mattress

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ABSTRACT

A series of experiments have been carried out to develop an understanding of the performance improvement of soft clay foundation beds using stone column-geocell sand mattress as reinforcement. It is found that with the provision of stone columns, of adequate length and spacing, about three fold increases in bearing capacity can be achieved. While with geocell-sand mattress it is about seven times that of the unreinforced clay. But if combined together, the stone column-geocell mattress composite reinforcement, can improve the bearing capacity of soft clay bed as high as by ten fold. The optimum length and spacing of stone columns giving maximum performance improvement are, respectively, 5 times and 2.5 times of their diameter. The critical height of geocell mattress can be taken equal to the diameter of the footing, beyond which, further increase in bearing capacity of the composite foundation bed is marginal.

1. Introduction

Rapid urbanisation and growth of infrastructure, in the present days, has resulted in dramatically increased demand for land space. This has compelled the building industry to improve the soft soil grounds which otherwise are unsuitable for construction activities. Amongst the various ground improvement techniques used, stone columns and geosynthetic reinforcement are probably the most popular ones. This is primarily due to their simplicity, ease of construction and overall economy that finds favour with the practicing engineers.

A stone column is a column of stones, made through opening up a vertical cylindrical hole in the soft clay bed and subsequently filling it up with compacted stone aggregates. Due to higher strength and stiffness, the stone columns sustain larger proportion of the applied load, than their soft soil counterpart, leading to significant performance improvement of foundation beds (Hughes and Withers, 1974; Juran and Guermazi, 1988; Christoulas et al., 2000, Wood et al., 2000, McKelvey et al., 2004, Ambily and Gandhi, 2007; Black et al., 2007, Cimentada et al., 2011, Dash and Bora, 2013). Moreover, being highly permeable the stone columns act as vertical drains facilitating consolidation of the soft clay around and thereby improving the long term performance of the foundation system.

Geocell reinforcement is a latest development in the avenues of geosynthetics. It is a three dimensional, polymeric, honeycomb like structure of cells interconnected at joints that the reinforcing mechanism is primarily through all-round confinement of soils. Besides, geocells intercept the potential failure planes and their rigidity forces them deeper into the foundation soil. This induces a higher surcharge loading on the failure plane, giving rise to increased load carrying capacity (Webster and Watkins, 1977; Bush et al., 1990; Cowland and Wong, 1993; Dash et al., 2001, 2003a, 2003b, 2004; Zhou and Wen, 2008; Sireesh et al., 2009; Leshchinsky and Ling, 2013; Tanyu et al., 2013).

Review of literature shows that geocell-sand mattress and stone columns are effective means of performance improvement of soft clay foundations. Their individual applications though have been intensely studied, but combined application of both has remained unexplored. It is expected that the geocell-sand mattress with stone columns underneath shall further enhance the load carrying capacity of the foundation system. Moreover, a cushion of sand is generally provided over the stone columns for the purpose of drainage. Limited research reported in the literature indicates that this sand layer when reinforced with planar geosynthetics can noticeably improve the bearing capacity of the foundation system (Deb et al., 2007, Abdullah and Edil, 2007; Deb et al., 2011). Arulrajah et al. (2009) have reported the use of a geogrid-soil platform over stone columns in the construction of high speed railway embankments in Malaysia. In this arrangement the reinforced soil cushion serves as a flexible raft over the stone columns, similar to that of a

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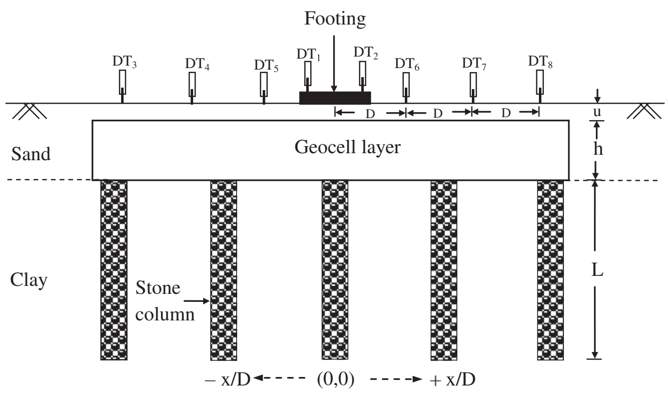

Fig. 1. Schematic diagram of test configuration.

piled raft system leading to improved load capacity. However, geocell is a superior form of reinforcement over the planar one (Dash et al., 2004; Madhavi and Vidya, 2007; Latha and Somwanshi, 2009). This is mostly due to its three dimensional confining structure that prevents lateral spreading of soil. Therefore, the sand cushion over the stone columns if reinforced with geocells is expected to produce enhanced performance improvement. These aspects are studied herein through a series of laboratory-scale model tests. The results have been analysed in developing an understanding of the behaviour of clay foundations reinforced with the stone column-geocell mattress composite system.

2. Details of model tests

2.1. Planning of experiments

Schematic sketch of a typical test configuration is shown in Fig. 1. The stone columns were left floating in the clay bed. This was to simulate the situation commonly encountered in coastal areas wherein soft clay deposits extend over very large depths that the stone columns are generally terminated in the clay itself. The columns were placed in triangular pattern at a regular spacing, S (Fig. 2). In all the tests, diameter of stone columns (d_{sc}) was kept constant as 100 mm.

Geocells were formed in chevron pattern (Fig. 3) as it gives better performance improvement over the diamond pattern (Dash et al., 2001). Diameter of geocells (d_{gc}), taken as equivalent diameter of geocell pocket opening, was kept constant as $0.8D$ throughout (D, diameter of footing). The geocell mattresses were placed at a constant depth (u) of $0.1D$ from the base of the footing, which was found to be the optimum location giving maximum performance improvement (Dash et al., 2008).

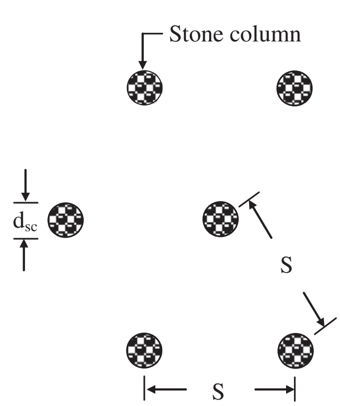

Fig. 2. Layout of stone columns.

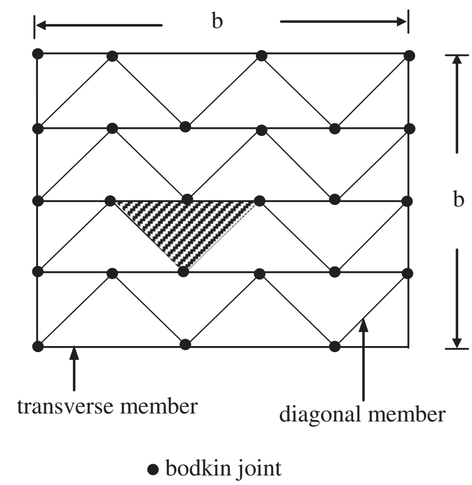

Fig. 3. Geocell system in chevron pattern: plan view.

In total twelve series of model load tests were conducted the details of which are presented in Table 1. Within each series, only one parameter was varied. This was to understand the influence of this particular parameter on the overall behaviour of the foundation system, while the others were kept constant. Tests in series 1 were performed on unreinforced clay beds. Series 2 and 3 consisted of testing the stone column reinforced clay beds, wherein, the influence of length (L) and spacing (S) of the columns were studied. In all these tests there was no sand cushion over the clay beds. The effect of height of geocell-sand mattress (h) was studied under series 4. Subsequently, tests in series 5–12 were designed to

Table 1
Details of model tests.

Test series	Type of reinforcement	Details of parameters investigated
1	Unreinforced clay bed with c_u of 5 kPa	
2	SC	Variable parameter: $L/d_{sc} = 1, 3, 5, 7$ Constant parameter: $S/d_{sc} = 2.5$
3	SC	Variable parameter: $S/d_{sc} = 1.5, 2.5, 3.5$ Constant parameter: $L/d_{sc} = 5$
4	GC	Variable parameter: $h/D = 0.53, 0.9, 1.1, 1.6$ Constant parameter: $d_{gc}/D = 0.8$, $b/D = 6$
5	GC + SC	Variable parameter: $L/d_{sc} = 1, 3, 5, 7$ Constant parameter: $h/D = 0.53$, $d_{gc}/D = 0.8$, $b/D = 6$, $S/d_{sc} = 2.5$
6	GC + SC	Variable parameter: $L/d_{sc} = 1, 3, 5, 7$ Constant parameter: $h/D = 0.9$, $d_{gc}/D = 0.8$, $b/D = 6$, $S/d_{sc} = 2.5$
7	GC + SC	Variable parameter: $L/d_{sc} = 1, 3, 5, 7$ Constant parameter: $h/D = 1.1$, $d_{gc}/D = 0.8$, $b/D = 6$, $S/d_{sc} = 2.5$
8	GC + SC	Variable parameter: $L/d_{sc} = 1, 3, 5, 7$ Constant parameter: $h/D = 1.6$, $d_{gc}/D = 0.8$, $b/D = 6$, $S/d_{sc} = 2.5$
9	GC + SC	Variable parameter: $S/d_{sc} = 1.5, 2.5, 3.5$ Constant parameter: $h/D = 0.53$, $d_{gc}/D = 0.8$, $b/D = 6$, $L/d_{sc} = 5$
10	GC + SC	Variable parameter: $S/d_{sc} = 1.5, 2.5, 3.5$ Constant parameter: $h/D = 0.9$, $d_{gc}/D = 0.8$, $b/D = 6$, $L/d_{sc} = 5$
11	GC + SC	Variable parameter: $S/d_{sc} = 1.5, 2.5, 3.5$ Constant parameter: $h/D = 1.1$, $d_{gc}/D = 0.8$, $b/D = 6$, $L/d_{sc} = 5$
12	GC + SC	Variable parameter: $S/d_{sc} = 1.5, 2.5, 3.5$ Constant parameter: $h/D = 1.6$, $d_{gc}/D = 0.8$, $b/D = 6$, $L/d_{sc} = 5$

Note: SC: Stone columns, GC: Geocell-sand mattress.