COMPRESSION AND UPLIFT OF RAMMED AGGREGATE PIERS IN CLAY

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ABSTRACT: Full scale compression and uplift load tests were conducted on 3 Rammed Aggregate Piers in the upper surficial clay fill at the NGES located at the University of Massachusetts – Amherst. The tests were conducted to evaluate the performance of this intermediate foundation system in a fine-grained soil. The field investigation also included measurements of vertical and lateral soil deformation to evaluate the active zone of soil resistance. The results show viable uplift and bearing capacity application for the foundation system in fine grained soils.

INTRODUCTION

In recent years, Rammed Aggregate Piers or Geopier® elements have been used as an intermediate foundation system between conventional shallow spread footings and deep driven or drilled foundations. In places where marginal soils are present near the surface, these foundation elements may provide an economic alternative for foundation support. This type of ground improvement is considered an "intermediate" foundation and has been previously described (e.g., Lawton and Fox 1994; Lawton et. el. 1994; Blackburn and Fassell 1998; Wissmann et al. 2001). Geopier elements have been used as a ground improvement technique in marginal soil conditions to reduce settlements and allow the use of shallow foundations as well as provide uplift resistance against wind and other lateral loads.

An investigation was performed to evaluate the load-displacement behavior of Rammed Aggregate Piers in clay at the NGES. Overall, a total of six uplift and one compression test were conducted. This paper discusses the results of two of the uplift tests and the one compression test.

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RAMMED AGGREGATE PIERS

A Rammed Aggregate Pier or Geopier is conceptually similar to a compacted column of gravel (e.g., Klabena and Mica 1998: Kumar and Ranjan 1999) however this is a proprietary foundation system that uses special equipment for installation. Piers are constructed by drilling an open hole, placing controlled lifts of aggregate stone within the open hole, and compacting the aggregate with a specially designed high energy beveled impact tamper. The first lift of aggregate consists of clean stone and is rammed into the soil to form a bottom bulb below the borehole while imparting lateral and vertical soil stresses (Lawton et al. 1994; White et al. 2000). Additional 0.3 m (1.0 ft.) lifts are then placed and densified with the tamper. The high energy impact ramming action necessary for proper construction pre-stresses and pre-strains the surrounding soil matrix, increasing skin friction and density while reducing settlement (White et al. 2000). This construction sequence is illustrated in Figure 1. According to Wissmann et al. (2001) Rammed Aggregate Piers are typically designed to cover approximately 30 to 40 % of the gross area of the overlying footing element.

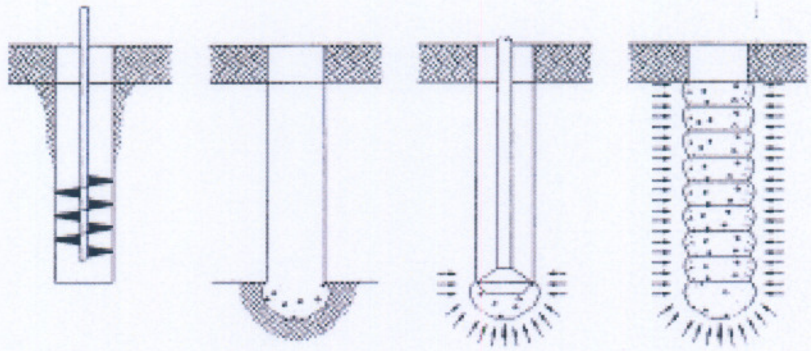

FIG. 1. Geopier Construction Sequence

INVESTIGATION

Site Characteristics

Tests were performed at the National Geotechnical Experimentation Site (NGES) located at the University of Massachusetts – Amherst. The site is situated in a thick deposit of the Connecticut Valley Varved Clay (CVVC). Geotechnical characteristics of the site have been extensively documented (Lutenegger 2000). The site currently consists of two test areas; Area A and Area B. Tests described in this paper were performed at Area B which represents an extension of the original NGES.

Figure 2 shows the soil characteristics and SPT N_{60} values obtained at the site located near the Geopier elements. The upper 2 m (6.6 ft.) consists of a stiff compacted clay fill placed approximately 30 years ago from clay excavated at the adjacent Town of Amherst Wastewater Treatment Plant. Beneath the clay fill the CVVC extends to a depth of about 25 m (82 ft.) and is followed by a deposit of glacial sand and gravel. The upper 3 m (10 ft.) of the CVVC is overconsolidated as a result of desiccation, freezing, etc. The CVVC below a depth of about 8 m (26.2 ft.) is very soft and near normally consolidated. Results of electric Cone Penetrometer Test (CPT) profiles conducted adjacent to the test area are shown in Figure 3. It can be seen that the ground conditions are very similar at all three locations. The upper fill and the clay crust are clearly seen in the CPT profiles. Typically, the water table shows a seasonal fluctuation between 0.5 m (1.6 ft.) and 2.5 m (8.2 ft.) below grade.

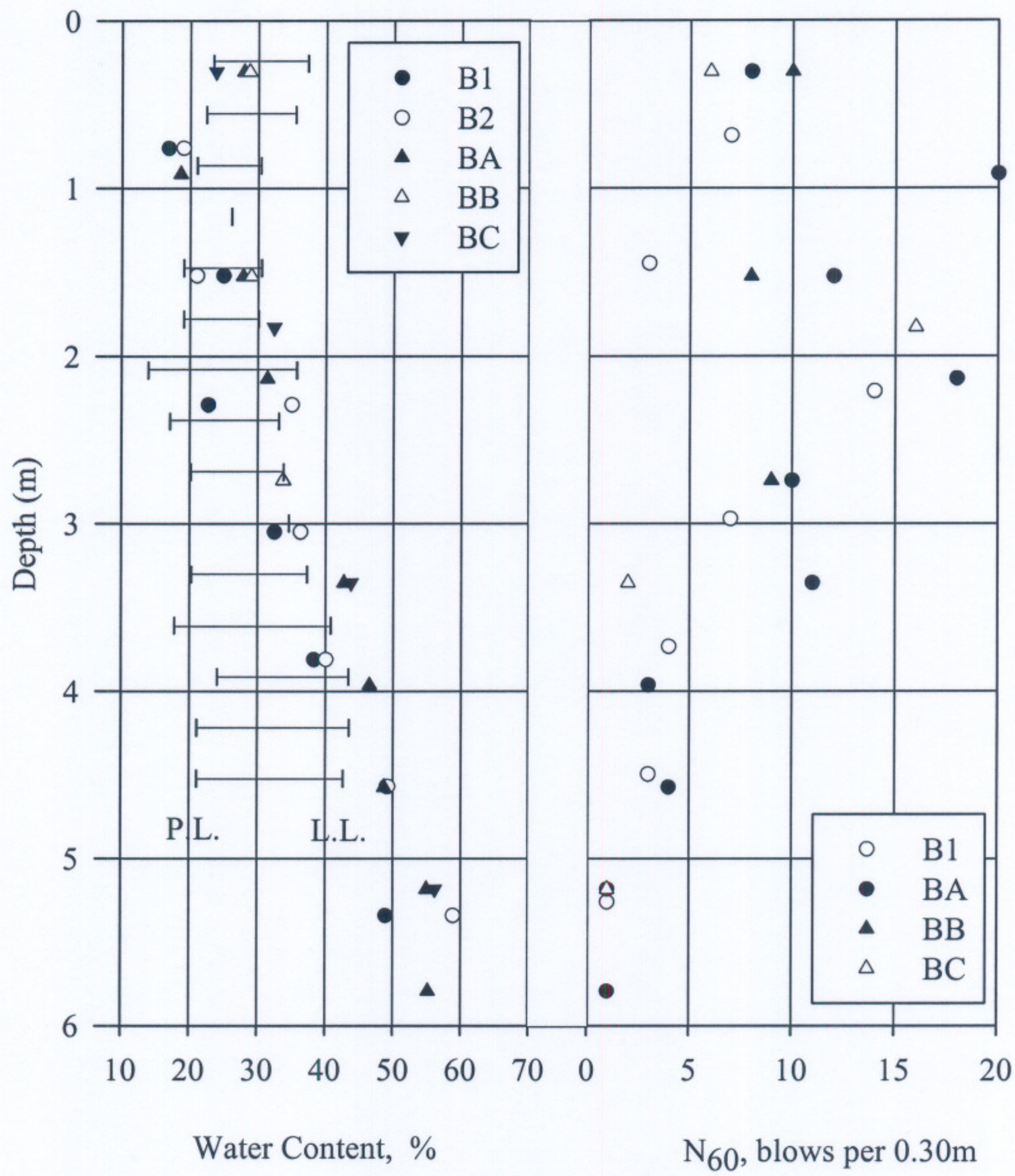

FIG. 2. Soil Characteristics and SPT N_{60} Values, NGES Area B

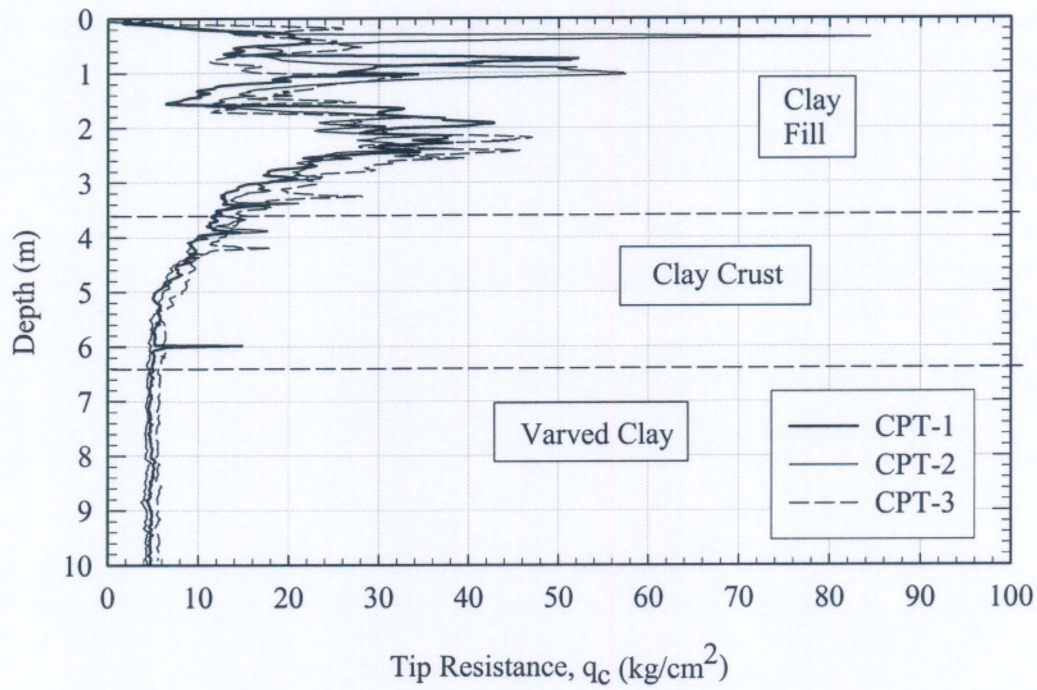

FIG. 3. CPT Profiles Conducted at NGES, Area B

Geopier Construction

Each Geopier for this project was 0.61 m (2 ft.) in diameter by 3.0 m (10 ft.) long. For this project, the Geopier foundation company designed and installed the Geopier elements using the procedure shown in Figure 1. The auger and tamper were operated from a skid steer uniloader; however, in most cases Geopier elements are installed with larger equipment such as a trackhoe. Installation required two laborers, one-day and about 6 metric tons of gravel for all seven Geopier elements.

Construction specific to the Geopier elements to be tested for uplift included the placement of a 0.61 m (2 ft.) long section of 20.3 cm (8 in.) deep channel at the base of each of the piers. Two pieces of threaded rod were then fastened to the channel and extended above ground, serving as the load transfer mechanism during uplift.

Instrumentation

In order to evaluate the active zone of soil resistance, inclinometer casings were installed adjacent to two of the Geopier elements and tell tales were installed.

Uplift Testing

A steel plate or top plate was placed directly on top of the aggregate piers and deflection of the plate was measured during uplift using digital dial gauges attached to an external reference frame. The deflection of the threaded tension rods extending to the base of the pier was also measured during uplift using digital dial gauges attached to an external reference frame.

Inclinometer casing was installed approximately 0.3 m (1.0 ft) away from the edge of one Geopier tested in uplift to a depth of 4.5 m (14.8 ft.). Lateral deflection was monitored over the course of the test using a Slope Indicator Digitilt Sensor and recorded with a Digitilt DataMate.

Compression Testing

For the compression test, a steel plate or top plate was placed directly on top of the aggregate pier to provide a base for applying the load and settlement was measured during loading using a digital dial gauge attached to an external reference frame. Tell tales were installed during construction of the Geopier tested in compression at depths of 1.5 m (5 ft.) and 3.0 m (10 ft.). Tell tale deflection was measured using digital dial gauges attached to an external reference frame.

Inclinometer casing was installed approximately 0.15 m (0.5 ft) and 0.3 m (1.0 ft) away from the edge of the Geopier tested in compression to a depth of 4.5 m (14.8 ft.). Lateral deflection was monitored over the course of the test using a Slope Indicator Digitilt Sensor and recorded with a Digitilt DataMate.

Load Testing

A reaction frame was constructed consisting of a 7.6 m (24.9 ft.) steel I beam supported by 0.15 m x 0.15 m (6 in. x 6 in.) wood cribbing and a 0.91m (3.0 ft.) long section of 0.28 m (0.91 ft.) deep channel. Wood cribbing was placed directly on the surrounding soil at a distance of approximately 3.0 m (10 ft.) from the edge of the Geopier to avoid any influence during testing. Load was applied using a hydraulic jack and pump. Applied load was measured using a load cell with a 1334 kN (300 kips) capacity and a P3500 digital readout. Load was applied initially in increments of approximately 4.5 kN (1 kip) and later in increments of approximately 9 kN (2 kips). Each load increment was held for a period of 15 minutes. The load test setup for a Geopier tested in uplift is shown in Figure 4.

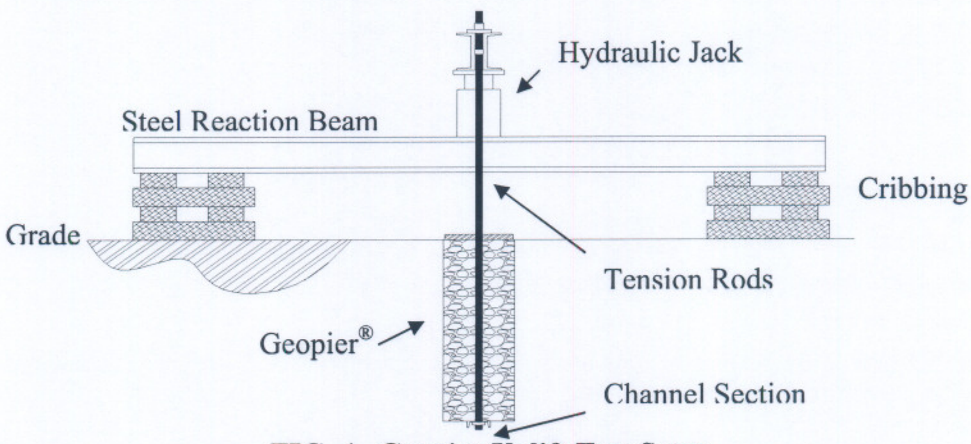

FIG. 4. Geopier Uplift Test Setup

The Geopier tested in compression used four surrounding piers constructed for uplift testing and three I beams placed on cribbing for a reaction system. In turn, while testing the center Geopier in compression, the four surrounding piers were placed in uplift. All five piers were monitored for rod deflection, top plate deflection and applied load as noted in the above mentioned procedures for uplift testing. The load test setup for the Geopier tested in compression is shown in Figure 5.

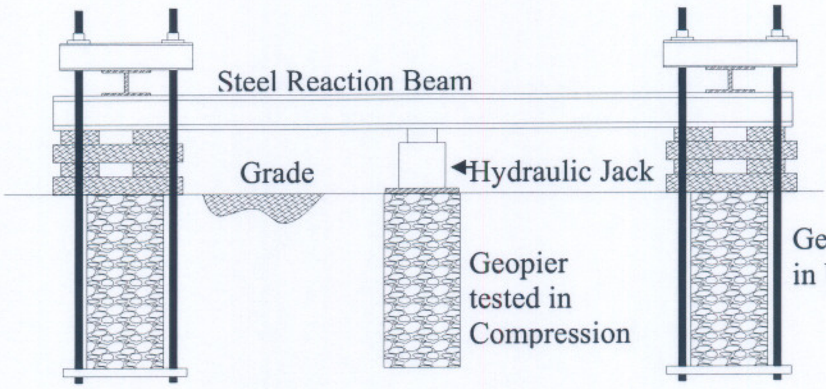

FIG. 5. Geopier Compression Test Setup

RESULTS

Uplift

The deflection of both the tension rods and the top plates of the Geopier elements tested in uplift are shown in Figures 6 and 7. Uplift Test #1 was loaded to a maximum of approximately 130 kN (30 kips) with resulting deflections of approximately 10mm and 85 mm (3.3 in.) for the top plate and tension rods, respectively. Uplift Test #2 was loaded to a maximum of approximately 130 kN (30 kips) with resulting deflections of approximately 30 mm (1.2 in.) and 150 mm (5.90 in.) for the top plate and tension rods, respectively. These results indicate that very little movement of the top of the pier occurred during uplift. This suggests either compression of the Geopier itself (which is unlikely) or failure by lateral bulging.

Lateral deflection at an applied load of 111 kN (25 kips) for Uplift Test #2 is shown in Figure 8. A maximum deflection of 3 mm (0.12 in.) occurred at the base of the Geopier at a depth of 3 m (10 ft.). The majority of the deflection occurred below a depth of 1.5 m (5 ft.) or L/2 with less than 1 mm (0.04 in.) of lateral deflection occurring above this point. These results are consistent with deflection results shown in Figures 7 and 8 and indicate that the pier bulged laterally in the lower meter.

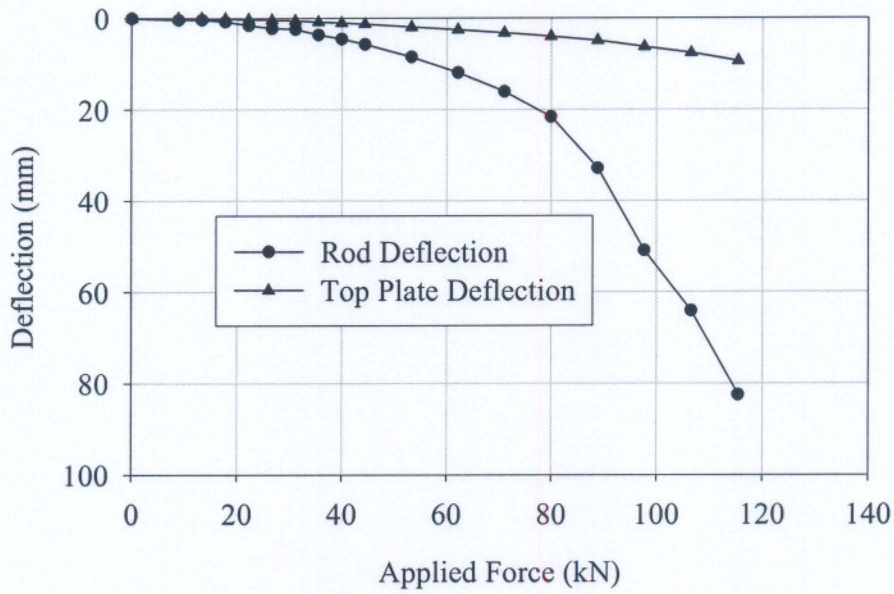

FIG. 6. Load Settlement Curve Uplift Test #1

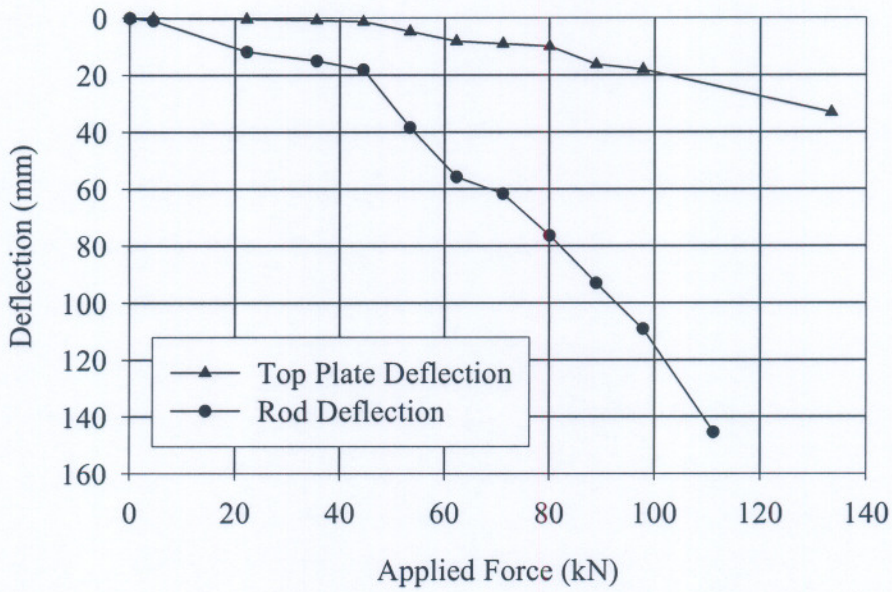

FIG. 7. Load Settlement Curve Uplift Test #2

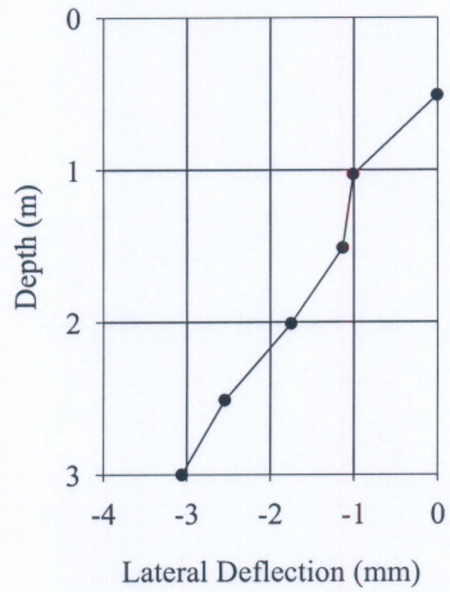

FIG. 8. Lateral Deflection Uplift Test #2

Compression

The settlement curve for the Geopier tested in compression is shown in Figure 9. A maximum settlement of approximately 90 mm (3.5 in.) occurred at an applied load of 311 kN (70 kips).

Soil settlement, as measured by the tell tales, is shown in Figure 10. A maximum settlement of approximately 28 mm (1.1 in.) was recorded at a depth of 1.5 m (5 ft.) or L/2. A maximum settlement of approximately 7 mm (0.28 in.) was recorded at a depth of 3.0 m (10 ft.) or L. Very little settlement of the base or the mid height occurred throughout the loading with essentially no movement until a load of approximately 100 kN (22 kips). This indicates that the pier was bulging laterally in the upper meter.

Lateral deflection at the maximum applied load of 311 kN (70 kips) for the Geopier tested in compression is shown in Figure 11. The S-Inclinometer and N-Inclinometer were placed approximately 0.15 m (0.5 ft.) and 0.3 m (1.0 ft.) away from the edge of the Geopier, respectively. Maximum deflections of 16 mm (0.63 in.) and 22 mm (0.87 in.) occurred at the top of the Geopier for the N-Inclinometer and S-Inclinometer, respectively, with the majority of the lateral deflection occurring in the upper meter (3.3 ft.). This indicates that significant lateral bulging occurred in the upper meter (3.3 ft.).

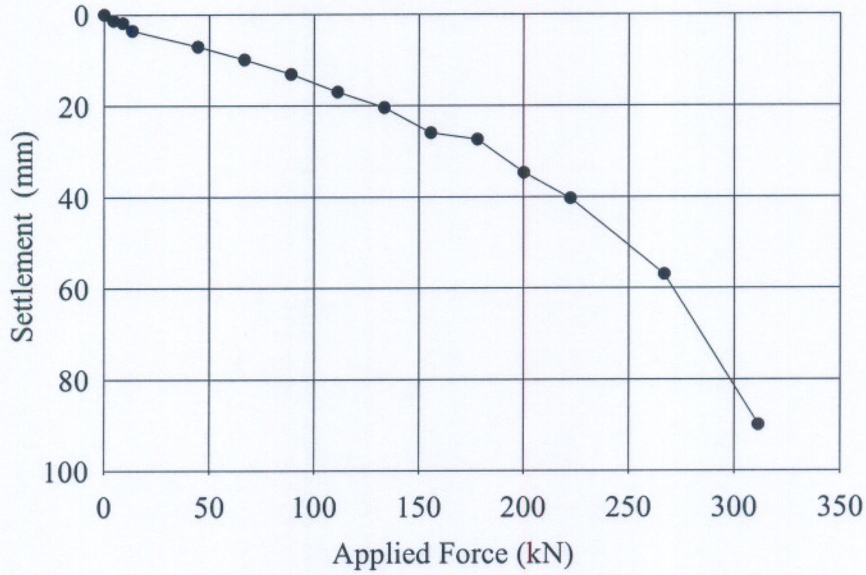

FIG. 9. Load Settlement Curve Compression Test

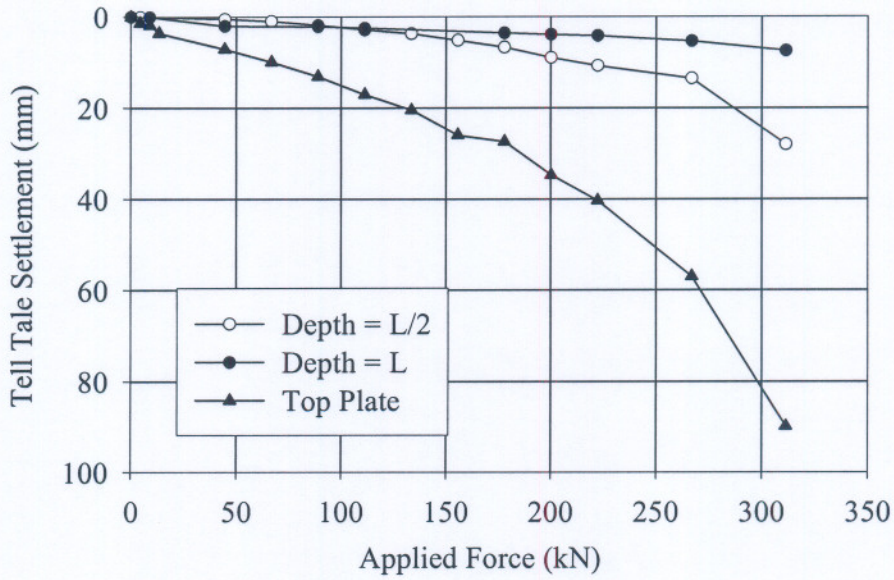

FIG. 10. Tell Tale Settlement Compression Test

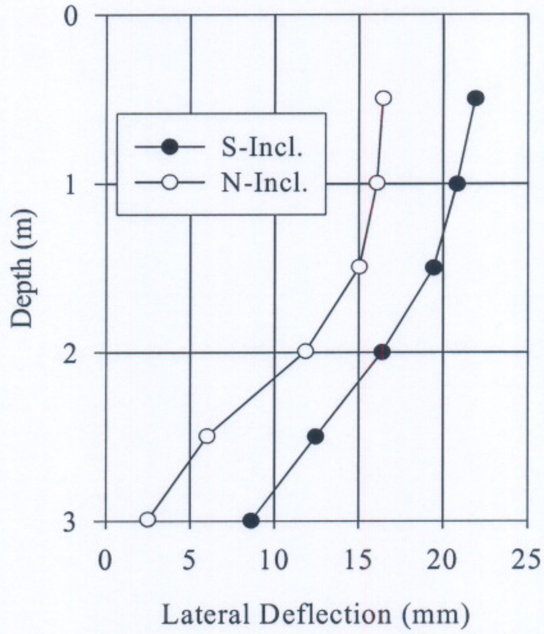

FIG. 11. Lateral Deflection Compression Test

SUMMARY AND CONCLUSIONS

Failure of the Geopier elements in uplift, defined here as the inflection point of the straight line portions of the load/settlement curve, occurred at approximately 80 kN (18 kips). At failure, very little deflection was seen at the top plates with corresponding large deflections in the tension rods. This indicates that for the Geopier elements tested in uplift in this clay, very little load is transferred from the base to the top plate, which remains outside of the active zone of influence.

Failure of the Geopier tested in compression (again defined at the inflection point of the straight line portions of the load/settlement curve) occurred at approximately 266 kN (60 kips). At failure, the tell tale located at a depth of 1.5m (5ft) settled approximately 33% of the top plate settlement as opposed to 10% of the top plate settlement from the tell tale located at the base (3.0 m (10 ft.)) of the Geopier. This indicates that for the Geopier placed in compression, very little load is transferred from the top plate to the base, which remains outside of the active zone of influence.

In both uplift and compression the majority of the lateral deflection occurred within L/2 of the applied load and show failure by lateral bulging. The level of influence with respect to lateral deflection decreases from 0.15m (0.5ft) to 0.3m (1ft) as measured by the N-Inclinometer and S-inclinometer during compression testing. It can also be noted that the lateral active zone of influence extends beyond 0.3m (1ft).

The Geopier elements performed well in both uplift and compression and appear to be very viable for clays. Possible applications include foundation support and/or as a form of ground improvement.

TABLE 1. Geopier Load Test Summary Table

Mode	Test No.	Load at Inflection Point (kN)
Uplift	#1	80
	#2	80
Compression	#1	266

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