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Bearing capacity of stabilized soil with expansive component confined by polyvinyl chloride pipe

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HIGHLIGHTS

- Confined stabilized soil offers high strength and ductility in corrosive environments.
- Expansive component and good confinement stiffness for excellent enhancement.
- Confinement mechanism is different for specimen without and with expansive component.
- Accurate confinement model should consider influence of expansive component.
- Application of the stabilize soil confined by polyvinyl chloride pipe is evaluated.

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ABSTRACT

Confined stabilized soil (CSS) was the composite system that used polyvinyl chloride pipe to confine stabilized soil with the binder consisting of expansive and cementing components, aimed at treating foundation in corrosive environments. Bearing capacities of CSS cylinders were studied considering variations of mass ratio of expansive component and cementing component (E = 0–1.00) and confinement stiffness (K = 0.16–0.52 GPa). Initial lateral strain, stress-strain curve, and failure mode were recorded. Confinement mechanism was analyzed, energy absorption capacity (EAC) was calculated, and confinement model was discussed by comparing experimental values with predictions using 10 widely used models for confined concrete. The application of CSS was also evaluated considering influence of interfacial bonding strength under different loading conditions and integrity of confinement pipe. Results show that CSS offers high compressive strength and ductility, ultimate strength (f'_{cc}) and corresponding axial strain, and EAC are 1.75–4.81, 6.45–25.09, and 65.31–154.64 times the unconfined ones, respectively. High content of expansive component is permitted, which can not only enhance ultimate strength of unconfined stabilized soil (f'_{co}) but make confinement pipe participate in the confinement to the core stabilized soil as soon as the application of axial load, retarding the cracking of core stabilized soil. Effect of E on SER (strength enhancement ratio) of f'_{cc} is dominated by affecting f'_{co}, while SER of f'_{cc} increases with approximately exponential growth with K increasing. Axial stress–strain cures are significantly bilinear, but accurate confinement model should be developed incorporating influence of expansive component. Sufficient interfacial bonding strength can be built in CSS, which further enhances the bearing capacity, while f'_{cc} and EAC are slightly affected by integrity of confinement pipe.

1. Introduction

In infrastructure construction on offshore islands, it was inevitable to deal with soft foundation including treatment of in-situ seabed mucky soil and treatment of reclamation area by sediment reclamation. Since the islands were usually far away from land, which made transportation difficult, materials that need to be transported should be as few as possible. Meanwhile, the durability of foundation treatment must be considered due to risk of the corrosion from salt in the seabed soil [1–3]. Stabilized soil made by mixing soil with binder such as cement, which was a widely used foundation treatment technique in soft soil area [4–7], can make full use of the soil and need not much material transportation, but its bearing capacity and durability were quite limited. Similar problem also retarded the construction in saline soil area [8–10]. For example, salt content of the saline soil around the Qarhan Salt Lake in Qinghai Province of China was even as high

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as 40 wt%. A research done by China Academy of Building Research [11] concluded that all kinds of pile and foundation treatment method containing Portland cement could not be used in the area for severe corrosion caused by the saline soil, although a research showed that the strength of the saline soil stabilized with a binder could increase to 11 MPa and kept stable till the experiment ended in 180 days curing in the saline soil [12]. Stabilized soil pile, such as cement mixing pile, etc., abandoned a little construction waste, which met the nowadays strict limitation to rejection of construction waste for environment protection. But the low bearing capacity and durability limited its application range.

As was known, concrete had also been widely used to treat soft ground because of high bearing capacity. However, natural aggregates of concrete were usually collected by cutting mountains and breaking river gravels, which consumed huge amount of natural resources. Additionally, to solve the erosion problem of concrete, controlled permeability formwork (CPF) were applied [13,14]. CPF could provide a stronger outer concrete layer due to the lower water/binder ratio, less porous and obtained a good protective outer layer of the concrete. However, the concrete was still exposed to those aggressive environments directly. Fiber reinforced polymer (FRP) wraps were also applied to control corrosion of concrete [15,16]. Obviously, FRP confined concrete was of much higher strength and better resistance to the dynamic load. However, as a protective layer against the harmful substance, the elongation at break was the most important parameter, while the composite usually turned to a sudden failure with much lower breaking elongation of FRP (only 2–6%).

The materials with good mechanical property and well corrosion resistance were developed rapidly, like polyvinyl chloride pipe, had been widely used in the civil engineering, due to effective and economical to serve in the corrosive environments [17]. For example, Newman and Stark [18] conducted an ongoing study on the long term performance of a polyvinyl chloride geomembran in northern Minnesota, and data measured over a ten year period suggested that the harsh environment in northern Minnesota appeared to have little effect on the engineering properties measured. In addition, polyvinyl chloride pipe confined concrete [19] was proposed to protect concrete against corrosion, and results of bearing capacity on cylinders with the pipe thickness 3.7–8.5 mm and strength of core concrete 18.20–49.00 MPa, indicated that the ductility and toughness were improved remarkably, while efficiency of confinement was limited.

On the basic of these, confined stabilized soil (CSS) was proposed as a new kind of severe foundation treatment method [20–22], and it was constructed by filling the stabilized soil, which was made by mixing soil with the binder containing high content of expansive component, into polyvinyl chloride pipe fixed in ground. Also, it was supposed that combining lateral confinement with the binder containing expansive component would bring unique effects as follows: 1) Volume expansion produced by expansive components in the binder could reduce voids in the stabilized soil so as to significantly enhance strength of the stabilized soil [23]. Under constraint condition, high content of expansive component could be adopted. 2) Lateral confinement to concrete significantly enhanced the bearing capacity [24–27]. Similar to this, lateral confinement to stabilized soil could also enhance the bearing capacity. 3) Prestress acting on the core concrete further enhanced the bearing capacity [28,29]. According to this principle, prestress to the core stabilized soil could be built due to expansion of expansive component under confinement, which would also enhance the bearing capacity. However, bearing capacity should be investigated at first before the application in practical engineering. Although the fact that numerous studies had been conducted on confined concrete and soils under triaxial compression, whether results of the studies fit CSS was still unconfirmed. It was precisely because that composition and structure of stabilized soil were extremely different from those of concrete and soil particles.

Studies on confined concrete cylinders had concluded that interfacial bonding strength between FRP jacket and concrete core had little effect on bearing capacity [30]. Whereas, for FRP tube encased concrete cylinders, higher interfacial bonding strength resulted in higher cylinder compressive strength and ductility [31]. This was also an issue for CSS especially when stabilized soil contained high content of expansive component.

In this study, bearing capacities of CSS cylinders were investigated considering variations of mass ratio of expansive component and cementing component (E = 0–1.00) and confinement stiffness (K = 0.16–0.52 GPa). Initial lateral strain, stress-strain curve, and failure mode were recorded. Confinement mechanism was analyzed, energy absorption capacity was calculated, and confinement model was discussed by comparing experimental values with predictions using 10 widely used models for confined concrete. The application of CSS was also evaluated considering influence of interfacial bonding strength under different loading conditions and integrity of confinement pipe.

2. Experimental programs

The experimental programs involved the testing of unconfined stabilized soil (USS) cylinders and CSS cylinders, and the binder consisted of expansive component and cementing component. The effect of the following variables on bearing capacities of USS and CSS were examined: 1) mass ratio of expansive component and cementing component (E), and E = 0, 0.64 and 1.00, respectively; and 2) confinement stiffness (K), K was defined by the variation of confinement pipe thickness with 2.7, 4.2, 6.6 and 8.1 mm corresponding value of K = 0.16, 0.25, 0.41 and 0.52 GPa, respectively. It should be pointed out that for CSS, in order to observed bearing capacity of stabilized soil under lateral confinement, only the core stabilized soil was loaded through two 30 mm thick precision cut steel discs with diameter 1 mm smaller than the inner diameter of the pipe (Fig. 1a), and interfacial bonding strength between confinement pipe and the core stabilized soil was eliminated by covering a thin layer of plastic film on inner surface of the pipe which was brushed with oil, separating the core stabilized soil and the pipe before casting stabilized soil. Experimental programs were also designed to examine the application of CSS considering the influence of interfacial bonding strength between confinement pipe and the core stabilized soil under two different loading conditions, and integrity of confinement pipe: 1a) only the core stabilized soil was loaded (Fig. 1a); 1b) both confinement pipe and the core stabilized soil were loaded simultaneously (Fig. 1b); and 2) confinement pipe was divided uniformly into 1, 2, 3 and 4 parts before casting stabilized soil.

In order to ensure only one variable of each experimental program, all specimens were casted with the same binder content by weight, water/binder ratio, and water content of soft soil by weight, which were equal to 15%, 0.5 and 17%, respectively.

Details of the experimental programs are listed in Table 1, where D refers to diameter of the core stabilized soil cylinder, H refers to height of core stabilized soil cylinder, and N refers to number of specimens. The specimens are identified by sets of characters as follows: the letter U denotes the specimen is the kind of unconfined stabilized soil, the letter C donates the specimen is the kind of confined stabilized soil, the letter E with a figure denotes mass ratio of expansive component and cementing component, the letter K with a figure denotes confinement stiffness, the letter B with the figure 0 donates interfacial bonding strength is eliminated, the letter B with the figure1 donates the interfacial bonding strength is existed, the letter L with the letter a denotes only the