Study on the Application and Material Properties of Lime-soil Compaction Pile Modified by Steel slag

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Abstract: Relying on the test section of composite foundation with rigid-flexible and long-short piles in Xingheng expressway first phase project, the lime-soil compaction pile modified by steel slag was proposed to strengthen lake-phase soft soil with material properties analysis of steel slag. The modified characteristics, capacity and water resistance capability of the lime-soil compaction pile modified by steel slag were researched by series of mechanical tests. The construction effect and bearing capacity of lime-soil compaction pile modified by steel slag were evaluated by the static load tests and heavy dynamic penetration tests, which will provide technical reference for the further application of lime-soil compaction pile modified by steel slag.

1. Introduction

Steel slag is the remnants mixture produced by smelting steel of high temperature. Generally by pouring on liquid steel slag, pouring water to the hot steel slag and being stuffy it in batches, then flipping the steel slag, finally the steel slag will be produced by the process of crushing, screening and magnetic separation the steel slag[1]. The major mineral components of steel slag consist of C_3S,C_2S,C_2F,CFS,RO(solid solutions of Mg^{2+},Fe^{2+},Mn^{2+}), f-MgO,f-CaO,C_3MS_2, $FeO{\cdot}Al_2O_3$.C_3S, C_2S make it have good hydraulic and gelatinization and the activity of steel slag is also determined by C_3S,C_2S. Meanwhile, with the increasing of steel slag alkalinity, the activity of steel slag will be increased too. The f-MgO and f-CaO in the steel slag have dense crystalline and its hydration expansion is slowly. After its hydration, $Ca(OH)_2$ and $Mg(OH)_2$ will be produced and the volume of steel slag will be expanded. It will cause the strength of the steel slag decreased and steel slag cracking. And the steel slag will be instable [2]. Steel slag is concerned by the engineering sector because of its potential active properties. And it is gradually used in engineering. For example, inorganic stable binding material is mixed with the steel slag with lime, fly ash, cement and others, which are widely used in the cushion and structural layer in road embankment. It is also used as aggregate to asphalt mixing materials to pave pavement layers. In such applications, the generally use longer age steel slag to minimize its instability. It can also replace gravel to mix with cement, fly ash, then, add a certain percentage of water to form a low-strength concrete. Using cement and fly ash steel slag piles (CFS pile) formed by vibration immersed tube method to deal with soft ground has good application effects [3]. And the use of the steel slag as the compaction pile material to deal with soft ground also shows good treatment effect [4, 5].

The first-period project of Xing-Heng highway, including Zaoyuan interoperability hub segment and the southern Hengshui beltway segment, total length is 18.684 km. The project has crossed the lacustrine soft soil area of Hengshui Lake. Foundation soil has such feature as high porosity, water rate,

large compression and low carrying capacity. To satisfy the design requirements of carrying capacity and settlement of subgrade, we need to process the soft ground. Considering the shortcomings, limited of lime-soil compaction pile processing range [6] and the poor applicability in large moisture soft ground, and based on the characteristics of steel slag material, we put forward that we can make a pile by mixing a certain proportion of steel slag with lime-soil material to process this soft ground, in order to improve the strength of the pile and the applicability of it. It has been studied through a large number of laboratory tests to analyze of lime-soil compaction pile modified by steel slag, which is a pile of new material, and we selected ZK2+030- ZK2+407 mileage segment as the test section to analyze and evaluate the effects of its application.

2. The analysis of modified features

The modified features of lime-soil material modified by steel slag are mainly reflected in two aspects: physical and chemical effects.

2.1 Physical effects

Steel slag particles are bigger than soil particles and are well-graded. By incorporating a certain percentage of steel slag in lime-soil material, we can modify the grain composition of pile material; to make the pile easily compacted. At the same time, because of the steel slag particles' rude surface, the mechanical bite force among pile material particles and the early strength of the pile are improved.

The incorporation of steel slag in pile material can improve the optimum moisture content of it. It makes the pile material also can be best compacted at higher moisture content. According to the common proportion of lime-soil in engineering, I conducted a mixture ratio design of steel slag and lime soil material. And through a lot of compaction test I studied the improved properties of steel slag and lime-soil.

We design to use the additive method selecting 12 groups of steel slag and lime-soil mass ratio. The soil material used in compaction test is the drying soil that drilled in site within the test section. We used the lime of above national quality standard level 3. The content of Effective CaO and MgO is no less than 55%. The steel slag and lime-soil material should be fully digested before mixing. Particle size is less than 2 mm. We used the activity steel slag of the age of no more than 3 months and the particle size of not more than 19 mm. We used light I-2 type compaction method to compact it.

By the compaction test of different mixing ratio of steel slag and lime-soil material, we obtain the optimum water content ratio of each mixing material shown in figure 1. According to the data, the moisture content of the lime-soil material mixed with steel slag has been significantly improved. The overall increase rate is 2% to 4%. Also, the most obvious raise of optimum water content is mixing with the rate of 30 steel slags to the lime-soil material, which is 4.2%. Moreover, when the mixing steel slag increased in the proportion of 35, the optimal moisture content will decrease.

2.2 Chemistry effects

The strength of lime-soil compaction pile is mainly from the crystallization hardening of $Ca(OH)_2$ produced by digested lime and the hydraulically settable cementing material produced by the calcium silicate and aluminium silicate generated by active silica and alumina in the soil when effected by volcanic ash. The incorporation of steel slag improved the content of silicon oxide and aluminium, promoted the formation of calcium silicate, aluminium and other ingredients and increased hydration, thus, the strength of the pile material would be improved. Steel slag contains a small amount f-CaO and f-CaO, which react with water to generate Ca(OH)2. So the volume will swell. The f-CaO in the steel slag can absorb the moisture of the pile material and improve the consolidation characteristics of pile material.

3. Mixing strength test

To determine under which proportion, steel slag lime soil materials' strength is the largest, according to the above 12 kinds of mixing ratio to make parts respectively, conduct a large number of

unconfined compressive strength test, analyze the best mixing ratio of steel slag, lime and soil. Mainly measure different materials' strength under different age, such as 7d, 28 d, 90 d, to analyze the change rule of the lime-soil compaction piles modified by steel slag with the change of age, and then determine the best mixing ratio under which strength increase most with the increase of age. Lime-soil materials without steel slag under the ratio of lime: soil: steel slag are 7:100:0, 9:100:0, 11:100:0, to be the strength improvement control group. According to the standard [7] to conduct the parts, curing and unconfined compressive strength test, test specimen's size select Φ 150×150, test instrument use YZM-2 computer roadbed material strength test system [8].

Test get the rule of different ratio of specimen strength change under different proportion of lime soil with the change of age, as shown in Fig. 1, Fig.2, Fig.3, by three figure can be seen that:

(1)With the increase of age, different ratio of specimen strength shows different degrees of increase, in the age of 7 d~28 d, dust proportion is 8:100, different ratio of specimen strength increase the maximum, on the contrary, in the age of 28 d~90 d, this different ratio of specimen strength increase the minimum.

(2)In the different ages, the intensity of specimen under fixed lime-soil ratio shows the trend of first increases and then decreases with the increase of steel slag adding amount, but almost much higher than the lime soil without lime soil, and material strength get the biggest when steel slag adding amount is 30, also gradually increased more, with the increase of age.

(3)In the age of 7d, the intensity of specimen get biggest under the ratio of 7:100:30, which is 1 696.58 kPa, compare with the lime soil without lime soil, the intensity increased 83.59%; in the age of 28d, the intensity of specimen get biggest under the ratio of 9:100:30, which is 2 944.58 kPa, compare with the lime soil without lime soil, the intensity increased 48.16%; in the age of 90 d, the intensity of specimen get biggest under the ratio of 11:100:30, which is 3 965.66 kPa, compare with the lime soil without lime soil, the intensity increased 51.13%, at the same time, the intensity of specimen get biggest under the ratio of 9:100:30, which is 3 819 kPa, compare with the lime soil without lime soil, the intensity increased 49.85%. All of this shows that, with the increase of age, high lime soil ratio test specimen do further reaction, make the intensity much higher.

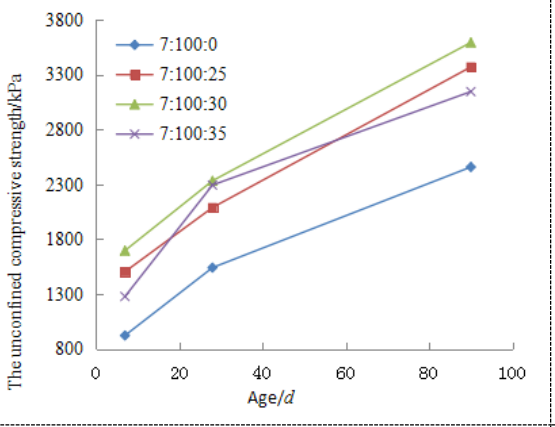

Figure 1. Change curve of different ratio of the specimen's strength under the lime soil ratio of 7:100 change with the increase of age.

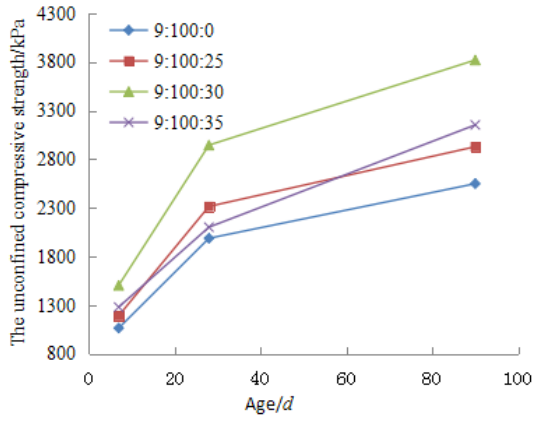

Figure 2. Change curve of different ratio of the specimen's strength under the lime soil ratio of 9:100 change with the increase of age.

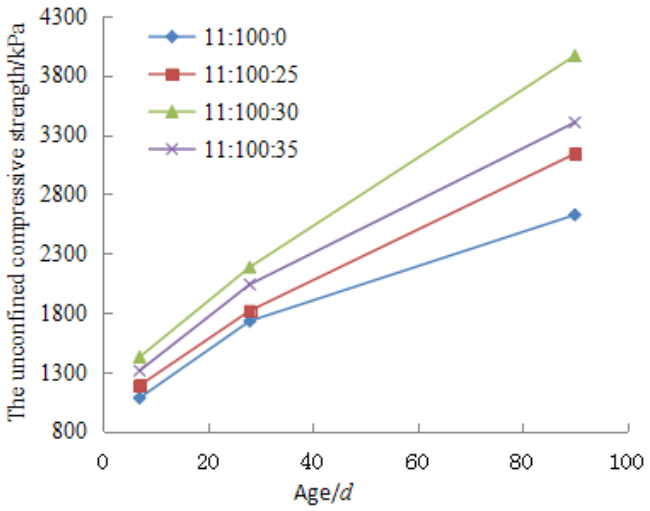

Figure 3. Change curve of different ratio of the specimen's strength under the lime soil ratio of 11:100 change with the increase of age.

4. Water Resistance Test

Based on the mix ratio test and construction conditions, select lime: soil: steel slag as 9:100:30 as construction mix proportioning to do the on-site construction. In order to further study the material properties of this new type of pile in the proportion mentioned to make parts, the experimental study on the water resistance of the material is necessary. Content of experiment design is as follows:

Select the lime-soil in a proportion of 9 to 100 as control group, each of the mix ratio of specimen is divided into six groups, each group of 6 specimen, a total of 72 specimens, for 7 d standard curing, and then put them in the water tank respectively soak in 1 d, 3 d, 5 d, 7 d, 11 d, 22 d, the water more than at the top of the specimens more than 25 mm. Select specimen which could satisfy the requirement of immersion time, carries them on the unconfined compressive strength test, get the rules that the strength of specimens change under different mixing proportion with the change of immersion time as shown in Fig.4.

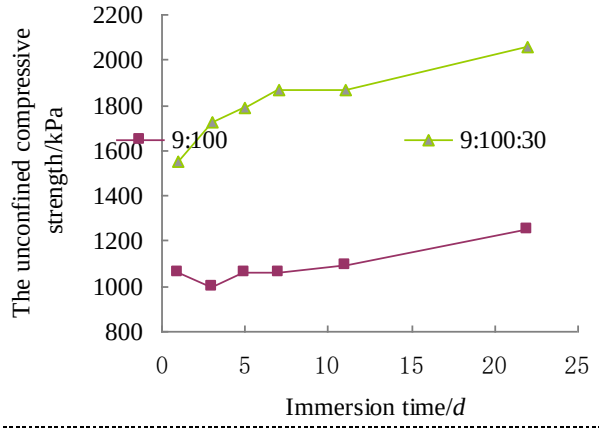

Figure 4. The law of compressive strength of the specimens under different mixing proportion change with the change of immersion time.

Fig.4 illustrates that, with the increase of immersion time, strength of Steel slag- lime soil specimen in a proportion of 9:100:30 showed varying degrees of growth, Steel slag- lime soil specimen's strength which soaking 22d is 2055.27 kPa, strength growth of the lime-soil in a proportion of 9 to 100 is not obvious, and the strength of Steel slag- lime soil specimen is much higher than the lime-soil specimen. Compared the strength of steel slag have immersion time for 22 d with the strength of the

specimen with the age of 28 d, the strength of the soaking specimens decrease rate of 30.2%, and the intensity of lime soil specimen reduced rate of 37.05%, which means that, add a certain percentage of steel slag, dust material by hydration, coagulation, crystallization and a series of reaction, make the steel slag, lime, soil particle cementing into a whole, not only improve the strength of pile material, but also makes the pile material's water stability improved.

5. The research the applied effect

In order to study the application effect of the lime-soil compaction piles modified by steel slag, the construction effect and bearing capacity of lime-soil compaction pile modified by steel slag was evaluated by the static load tests a heavy dynamic penetration tests. Design parameters of the lime-soil compaction piles modified by steel slag in test section are: effective pile length is 8 m, whole diameter is 400mm, compaction pile diameter after processing ≥450 mm, the unconfined compressive strength of Pile R28≥1 MPa.

5.1 Static load test

The lime-soil compaction piles modified by steel slag in test section is in total of 5693, do the static load test according to the design requirements for 0.2% detection rate on the bearing capacity of single pile, the single pile bearing capacity *Q* - *s* curve as shown in Fig.5.

According to the specification of determination method of the single pile ultimate bearing capacity, make sure the single pile ultimate bearing capacity of the lime-soil compaction piles modified by steel slag is 320 kN, in another word, that is 1630 kPa, bearing capacity satisfy the design requirements.

5.2 Heavy dynamic penetration test

Through the heavy dynamic penetration test for pile body in pile length range, analyze the pile quality of the lime-soil compaction piles modified by steel slag.N63.5 shows first increases and then decreases trend, and touch the biggest in 6.5m, N63.5 is 33, and then N63.5 decreases, get the lowest in 13. According to the reduction formula of allowable bearing capacity value and heavy hammer dynamic number in Hunan highway roadbed penetration test: Y=35.96X+23.8, to do rough conversion of the allowable bearing capacity value, most of single pile's allowable bearing capacity value in pile length range is above 700 kPa, shows good effect of pile-forming.

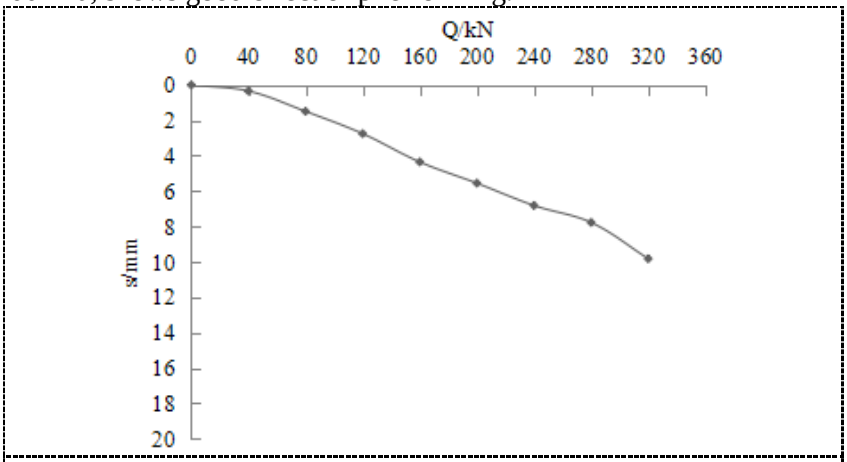

Figure 5. *Q* - *s* curve of the single lime-soil compaction piles modified by steel slag's static load test.

6. Conclusions

In this paper, by means of mechanism analysis and experimental study of the lime-soil compaction piles modified by steel slag, get the following conclusions:

Steel slag on the amelioration of lime soil materials is mainly used for two aspects, which are physical function and chemical processes.

Incorporation of steel slag in steel slag lime soil material makes unconfined compressive strength improved significantly, with the increase of the steel slag adding amount. Also, it increase in the trend of first increases and then decreases, under different ratio of lime soil, material strength get the biggest when steel slag adding amount is 30. With the increasing age, different ratio of material strength shows different degree of increase. It is compared with lime soil materials contains no steel slag, when steel slag adding amount get 30, steel slag lime soil material's strength increase in the range of 49.85%~83.59% in different age, which shows nice strength properties.

With the increase of immersion time, strength of Steel slag- lime soil specimen in a proportion of 9:100:30 showed varying degrees of growth. Steel slag- lime soil specimen's strength which is soaking 22d is 2055.27 kPa, and the strength of steel slag- lime soil specimen is much higher.

Applying the lime-soil compaction piles modified by steel slag to strengthening lake-phase soft soil foundation, pile body shows nice bearing capacity characteristics and the effect of pile-forming, which can make the conclusion that applying the lime-soil compaction piles modified by steel slag to handling high water content of soft soil foundation is feasible.

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