

# Study on Road Performance Parameters and Field Test of Solidified Waste Soil

Shihu Gao<sup>1</sup>, Jing Wu<sup>2</sup>, Xin Peng<sup>3</sup>

<sup>1</sup>Wenzhou Polytechnic, Wenzhou 325035, China

<sup>2</sup>Wenzhou Vocational College of Science and Technology, Wenzhou 325035, China

<sup>3</sup>Sichuan City Solid Waste Energy and Building Materials Conversion Technology Engineering Research Center, Chengdu University, Chengdu 610000, China

## Abstract

**In the construction of subgrade filling, a lot of high quality fillers is needed to control the settlement under traffic loading. However, under the theme of environmental protection, the filling materials are becoming harder to obtain. At the same time, there will be a lot of waste soil in the river construction, waste soil treatment is also a big problem. Based on this, this paper uses the waste soil solidification treatment as the subgrade filler to solve the above problems. In order to verify the feasibility of solidified soil as subgrade filler, indoor compaction test with different solidified soil filling curing time, multiple groups of curing agent ratio, CBR strength test of solidified soil with different filling curing time and resilience modulus test were carried out. The field test of solidified soil subgrade filling and mixed soil and stone filling is also carried out. During the filling process, the settlement value and earth pressure value on both sides of the subgrade and the position of the center line of the subgrade are monitored. The results show that the optimum water content is 19% when the maximum compaction degree can be obtained after 7 days of curing. When the waste soil with 65% water content is added with 9% cement and 2% slag powder, the maximum CBR value is 36.4%, which is the best dosage of curing agent, and fully meets the strength requirements of the filling. In addition, the CBR value of solidified soil is significantly increased with the increase of the curing time. When the curing time of solidified soil is 7d under the best dosage, the design value of the resilience modulus of solidified soil is 56MPa, which fully meets the requirements of the resilience modulus of asphalt roadbed filler. Field test shows that solidified soil as subgrade filling has good feasibility, compared with mixed soil and stone filling subgrade, solidified soil filling subgrade shows better integrity and light quality, and has better filling effect.**

## Keywords

**Solidified Soil; Compaction Test; CBR Test; Resilience Modulus Test; Field Subgrade Filling Test.**

## 1. Introduction

In the construction of high-grade highway, on the one hand, due to the particularity of the project, in the process of embankment filling takes a lot of high quality filling, most of these high quality filling from the stone or river channel sand mining, which not only consume large amounts of natural resources, also bring huge costs for engineering, on the other hand, in the construction projects tend to produce a large number of buildings in the construction waste such as: drilling pile, shield tunnel construction carried out from the waste slurry or river dredging silt [1, 2, 3], these wastes are often transported and stacked, not only occupy a large amount of land resources, and transportation will also produce a certain amount of extra costs,

these treatment methods are not economic, not environmental protection. In this case, in-situ solidification technology shows its advantages.

In-situ solidification technology refers to the green environmental protection technology that uses professional and supporting machinery and equipment to use single or mixed curing agent to improve bad soil[4]. In-situ solidification technology was first used in Japan, Europe and other countries, and has obtained good practical and economic benefits in practical projects [5]. Existing studies have shown that it is feasible for the soil mixed with curing agent to serve as a support structure and load transfer platform and pavement [6, 7, 8, 9, 10], because the soil mixed with an appropriate amount of curing agent can greatly improve its shear and compressive strength under certain curing conditions [11, 12, 13, 14, 15]. Many scholars have studied the influencing factors of solidified soil strength and found that the dosage of curing agent, water content, curing time, porosity and organic matter content of undisturbed soil, etc. [16, 17, 18, 19, 20] are closely related to the strength of solidified soil, but they mainly depend on the water-cement ratio and the content of curing agent. At present, in-situ solidification technology is most widely used in engineering to improve the defective foundation on site, so that it can meet the requirements of construction. Chen et.al [21] conducted shallow solidified treatment on the soft soil to form a double-layer foundation. After curing, the plate load test on the foundation found that the bearing capacity of the foundation after curing fully met the requirements of construction machinery entering the site. Wang et.al[22] combined in -situ solidification technology with prefabricated piles to form composite foundation to strengthen the foundation. Some scholars also explored the state of soil-cement under transverse stress. Faro et.al[23] tested the ring breaking mechanism of the hard shell layer as a load transfer platform when it contacted the pile under the action of lateral force. The application of the above soil solidification technology is to solidify the bad soil in the site as a whole, so as to form the integral board with certain shear and compressive strength, which is used as a part of the foundation structure, but the solidified soil is rarely used as the subgrade filler. At present, a large number of scholars have verified that the addition of external curing agent can significantly improve the properties of the original soil, and can be used as building materials. In the current environment where it is difficult to obtain fillers and waste slurry is piled up at will, the waste slurry is improved by using in-situ solidification technology and innovatively used as subgrade fillers, so as to realize the reuse of waste and solve the problem of difficult to obtain high-quality fillers.

Since the properties of solidified soil as subgrade filler are very different from those of previous soil-stone mixed filler, it is necessary to further study solidified soil. In this study, indoor mechanical parameters of solidified soil were tested to explore the basic properties of solidified soil, CBR, resilience modulus and other road parameters, so as to guide the field filling test of solidified soil filled subgrade. Rolling combination test was carried out at the scene at the same time, the solidified soil layered filling subgrade fill it and soil-stone mixture filling rolling forming rolling forming scale test of the subgrade, the degree of compaction test, as well as to the construction in the process of filling subgrade soil pressure, settlement changes at the bottom of the monitoring, the comprehensive evaluation of solidified soil subgrade filler filling effect, It provides reference for the application of solidified soil as subgrade filler in engineering.

## 2. Materials and Methods

### 2.1. Test Procedure

The parameter mechanical tests for indoor solidified soil road were carried out. Firstly, the compaction tests were carried out on solidified soil with different curing time, and the maximum dry density of solidified soil with the best curing time and the optimum water content corresponding to the maximum dry density of solidified soil were obtained. Then, the solidified

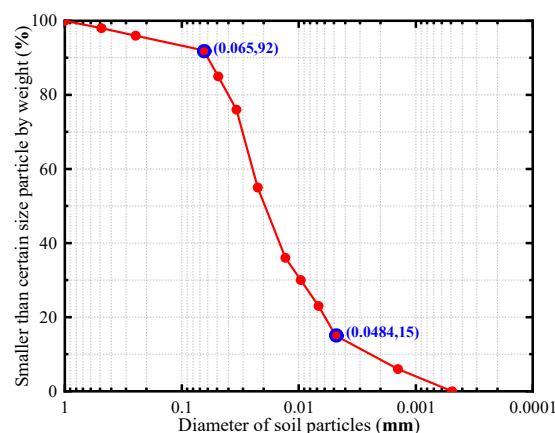
soil mixed with different admixtures was prepared to the optimal water content, and the CBR test was carried out to compare the influences of different curing time and different ratio of curing agent on the CBR strength of solidified soil, and finally the optimal curing agent content of waste soil with fixed water content was obtained. Finally, according to the first two groups of tests obtained the best curing time, the best ratio of solidified soil to carry out the resilience modulus test, to obtain the solidified soil's resilience modulus value, and according to the requirements of the code to modify the value of resilience modulus, to obtain the design value of resilience modulus, and compared with the code requirements of the filler resilience modulus, further verify the feasibility of solidified soil as a subgrade filler. The obtained solidified soil parameters are used as the design parameters of field solidified soil subgrade filler.

### 2.2. Test Material

The slurry used in the indoor test was river dredging waste slurry. The soil samples were collected on site and brought back to the laboratory for determination. The natural water content of the undisturbed soil was as high as 65%. The basic physical properties of waste slurry are shown in table 1. The particle analysis test of waste mud was carried out by laser particle size analyzer to determine the particle distribution of the slurry. It was determined that most of the soil particles in waste slurry were composed of fine soil particles ( $D_{92} = 0.065\text{mm} < 0.075\text{mm}$ ), and the clay content was more than 15% ( $D_{15} = 0.0484\text{mm} < 0.005\text{mm}$ ). The detailed distribution of soil particles in waste slurry is shown in figure 1. The additive used for curing soil was cement (P.042.5) and slag powder (S95) mixed curing agent. P.042.5 denotes ordinary Portland cement with a compressive strength of 42.5MPa, and S95 denotes the activity index of slag powder greater than 95% for 28 days.

**Table 1.** Physical properties of waste slurry

property	Value
Water content (%)	65
Liquid limit (%)	67
Plasticity limit (%)	20
Wet weight (g/cm <sup>3</sup> )	1.66
Void ratio	1.38
Specific gravity	2.62
Plasticity index	47
Liquid index	0.96
Organic matter content (%)	5.8



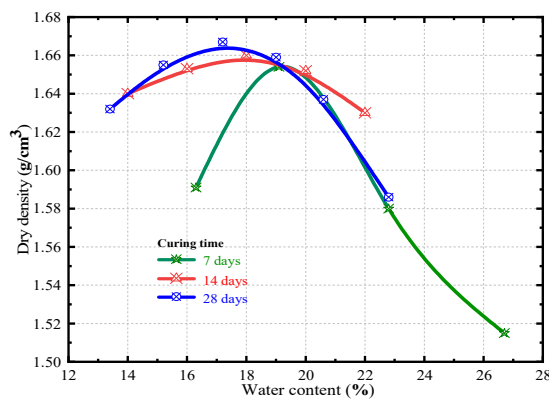
**Fig 1.** Particle size distribution of waste slurry

### 2.3. Compaction Test

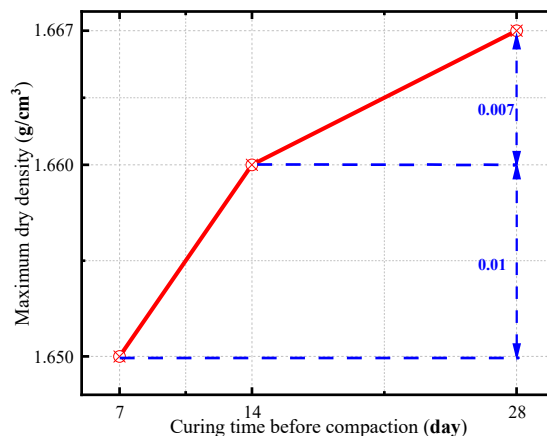
After completely drying the undisturbed soil, it is broken. The large soil particles were screened by a square sieve with a pore size of 4.75mm, and the remaining soil particles and powders were mixed with water to obtain soil samples with different water content. The soil sample was sealed with plastic film for one day, and then the curing agent of the same ratio and type was mixed with the soil sample and thoroughly stirred. The soil sample was cured, and the curing time was recorded as 7d, 14d, and 28d. Finally, laboratory compaction tests were carried out on three kinds of solidified soils with different curing time, and the compaction tests were carried out in full accordance with the test procedures [24]. The inner diameter of the test barrel used in the test is 15.2cm, the height is 12cm, and the volume is 2177cm<sup>3</sup>. The main technical parameters of compaction test are shown in table 2. The results of compaction test are shown in fig. 2 and 3.

**Table 2.** Technical parameters of compaction test

Hammer mass (kg)	Diameter of hammering surface (cm)	Falling height (cm)	Number of hammering layers	Number of blows per layer	Average unit compaction work (J)	Allowable maximum nominal particle size (mm)
4.5	5.0	45	3	98	2.677	37.5



**Fig 2.** Compaction characteristic curve of solidified soil with different curing time.



**Fig 3.** Relation curve between curing time and maximum dry density of solidified soil.

The solidified soil with different water content was treated with curing, and then the compaction test was carried out. As can be seen from fig. 2, the curve of variation law between water content and dry density shows that the water content corresponding to the maximum dry density is the optimal water content. The optimal water content of solidified soil is 19%, 18%, and 17% when the curing time is 7d, 14d, and 28d. When the water content of solidified

soil reaches the optimal water content, the best compaction effect can be obtained. In the longitudinal direction, we know: when the water content of solidified soil is about 18%, the longer the time of compaction of solidified soil is, the greater the dry density of the soil after compaction is obtained when the same compaction method is used. However, it is found that this law does not apply with the increase of the water content of solidified soil. In addition, the curing agent can react more fully with the water in the soil with the extension of the curing time. However, as can be seen from the curve in the figure, the change of its dry density shows the opposite trend when the water content is high, indicating that the optimal water content of solidified soil samples is also corresponding to the optimal dosage of external curing agent. Figure 3 shows the change curve of maximum dry density corresponding to different time of compaction. According to the figure, the maximum dry density of solidified soil increased by 0.01g/cm<sup>3</sup> from 7d to 14d, and the dry density of solidified soil increased by 0.007g /cm<sup>3</sup> from 14d to 28d, indicating that the applied curing agent did not react completely at 14d and 28d. Therefore, the maximum dry density increases at a similar rate. It can be seen from the test results that the compaction degree is higher when the curing time is 7 days than when the curing time is 14 days and 28 days.

## 2.4. CBR Test

To mix different admixture content in indoor laboratory strength of solidified soil in the CBR test, with subgrade CBR can effectively response the water stability and strength of the size of the whole, can be used as the basis for determining dosage of admixture, the experiment of three different curing agent content of solidified soil in the CBR test, to determine the best proportion of curing agent. The ratio of curing agent is: (1) 5% cement +2% slag powder, (2) 7% cement +2% slag powder, (3) 9% cement +2% slag powder, the percentage is the ratio of admixture quality and undisturbed soil quality, the total ratio of admixture is: 7%, 9%, 11%. As the maximum dry density of solidified soil with 7d of curing was used to calculate the compaction degree of solidified soil subgrade on site, according to the results obtained in the previous section, the water content corresponding to the optimal dry density obtained with 7d of curing was 19%, so the water content of solidified soil was adjusted to 19% in the CBR test. Indoor CBR test is shown in table 3 and figure 4.

**Table 3.** CBR of solidified soil with different proportions.

Detailed proportioning	5% Cement +2% Slag powder	7% Cement +2% Slag powder	9% Cement +2% Slag powder
Total proportioning	7%	9%	11%
Compactness (%)	100	100	100
Soaking expansion (%)	0.10	0.09	0.07
CBR (%)	3.60	18.5	36.4
	<b>Before compaction</b>		
Curing time (day)	7	7	7
Water content (%)	18.8	19.0	19.1
	<b>After compaction</b>		
Wet density (g/cm <sup>3</sup> )	1.96	1.96	1.97
Dry density (g/cm <sup>3</sup> )	1.65	1.65	1.65

The CBR test can reflect the strength of the filler after immersion in water and its ability to resist local deformation, as shown in table 3. The comparison of the swelling amount after immersion in water with different admixtures shows that: When the amount of curing agent increases, the swelling amount after influent gradually decreases. As the admixture reacts with water to form a large number of cementing compounds, the properties of soil can be enhanced and the shrinkage or swelling of soil can be reduced [25]. Obviously, this effect will be amplified under the action of more curing agents to better reduce the swelling amount of soil. Figure 4 shows the change curve of the relationship between the total amount of admixture and CBR value. It

can be intuitively found that the CBR value of solidified soil increased approximately linearly with the increase of the amount of curing agent. Linear fitting of the curve can obtain the linear relationship equation of the strength value of admixture and CBR value:  $y=8.2x-54.3$ , Where, the square of the correlation coefficient is:  $R^2=0.997$ . According to this equation, the corresponding relationship between the total admixture content and the CBR value of solidified soil can be predicted. When the total admixture content reaches 7%, the CBR value of the cured soil is 3.6%. According to the relevant standards [26], the CBR value of the road bed should not be less than 8%. Considering the complexity and economy of site construction, 11% is considered as the best admixture content. At the same time, the relationship between different compaction time of solidified soil and CBR was also studied, as shown in table 4 and figure 5.

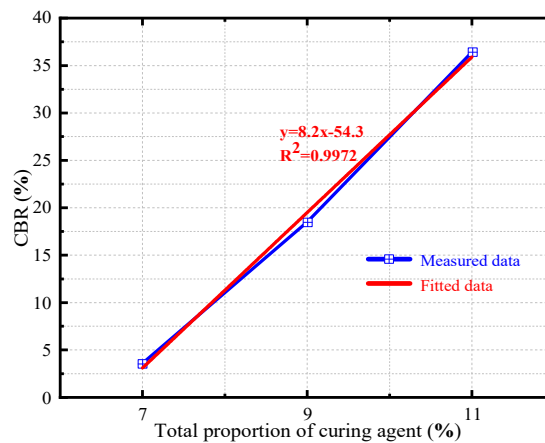


Fig 4. Relationship curve between different curing agent proportioning and CBR.

Table 4. CBR table of 11% proportion solidified soil.

Detailed proportioning	5% Cement +2% Slag powder	7% Cement +2% Slag powder	9% Cement +2% Slag powder
Total proportioning	11%	11%	11%
Compactness (%)	100	100	99
Soaking expansion (%)	0.07	0.05	0.04
CBR (%)	36.40	45.00	54.70
<b>Before compaction</b>			
Curing time (day)	7	14	28
Water content (%)	19.10	18.70	20.00
<b>After compaction</b>			
Wet density (g/cm <sup>3</sup> )	1.97	1.96	1.96
Dry density (g/cm <sup>3</sup> )	1.65	1.65	1.63

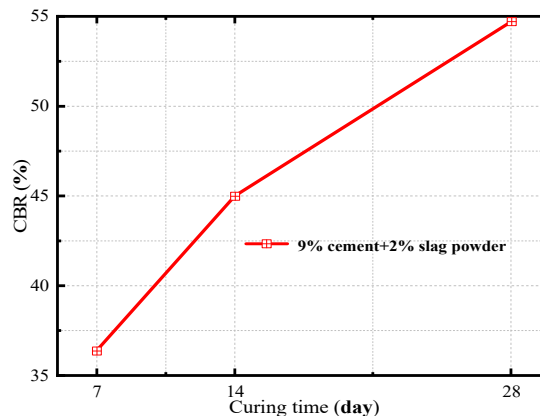
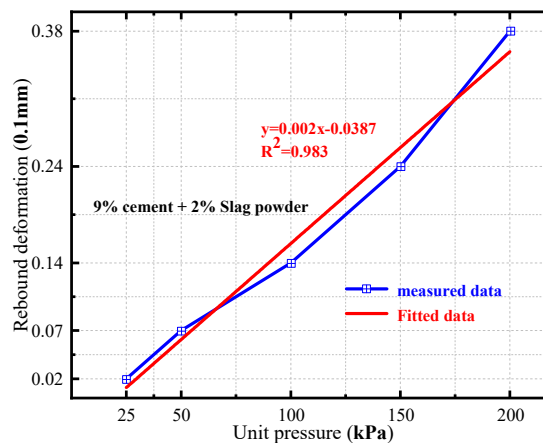


Fig 5. Variation law of CBR value of 11% solidified soil with curing time.

It can be seen from the test results that, with the increase of the time of solidified soil compaction, the admixture gets more adequate reaction and strengthens the interaction between cementing material and soil particles, which is manifested as the decrease of the water-immersion swelling of solidified soil and the significant increase of the CBR Data displayed in the plus additive ratio of the total was 11% of the 7d curing time has been able to meet the performance requirements of the stabilized soil as subgrade filling, and in the curing time to 28 d strength CBR value as high as 54.7% is 7 d time strength of solidified soil CBR value of 1.5 times, shows a longer curing time for subgrade filling of stabilized soil is obviously more useful.

### 2.5. Resilience Modulus Test

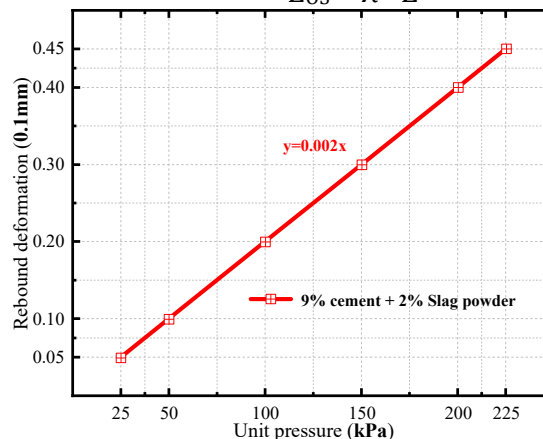
The indoor load plate method is used to resilience modulus of subgrade filling test, the test of solidified soil and curing agent content is: 9% cement + 2% Slag powder, admixture total ratio was 11%, the curing agent and undisturbed soil mixing after mixing solidified soil water content to 19%, after curing 7d indoor material loading plate test, the load of 50 mm diameter steel plate size. The test results are shown in fig.6.



**Fig 6.** Relation curve between unit pressure and rebound deformation.

Three groups of indoor load plate parallel tests were carried out, and the typical test results are shown in figure 6. After calculation, the average measured resilience modulus in the room is 173.93MPa, and the resilience modulus value represents the ability of subgrade to resist deformation under upper load to a certain extent. When the same upper load is applied to the subgrade, the larger the resilience modulus of the subgrade, the smaller the vertical deformation of the subgrade. According to the asphalt pavement design code [26], the indoor measured elastic modulus value E is modified as follows.

$$E_{0S} = \lambda \cdot E$$



**Fig 7.** Relation curve between unit pressure and rebound deformation after modification.

According to the size of the load plate used in the test, the size constraint correction coefficient  $\lambda$  is evaluated,  $\lambda=0.78$ , and the unit pressure and resilience deformation curve after correction is shown in fig.7.

After calculation and correction, the average Eos of the resilience modulus is 135.67MPa, so the design value of the resilience modulus is:

$$E_{OD} = Z \cdot E_{os} / K$$

Where Z is the reduction coefficient when considering the guarantee rate, and the value of the expressway is 0.66. K is the comprehensive influence coefficient considering the adverse season and the dry and wet subgrade type, and the subgrade type is considered as medium wet type, so the value is 1.6. Therefore, the design value EOD is 56MPa, which is greater than the requirement of 30MPa resilience modulus of asphalt subgrade [26]. Through the laboratory load plate test, it is verified that when the curing soil admixture is 2% cement +9% slag powder and the water content is 19%, it can meet the resilience modulus requirements of the subgrade filler after seven days of curing.

### 3. Field Subgrade Filling Test

When in-situ solidified soil is used as subgrade filling, it needs to meet not only the requirement of filling CBR but also the requirement of compaction degree after filling. Therefore, the loose laying coefficient of solidified soil, the number of rolling times of roller and the combination mode of rolling are studied before the field subgrade filling test. After meeting the requirements of compaction degree, the tests of layered filling and rolling forming subgrade with solidified soil and layered filling and rolling forming subgrade and soil and stone mixture layered filling and roller forming subgrade were carried out on site, and the settlement and base pressure of the two kinds of subgrade after filling and compaction were monitored. Finally, the effect of solidified soil as subgrade filler was analyzed.

#### 3.1. Coefficient of Loose Paving

**Table 5.** Determination of loose paving coefficient of subgrade filled with solidified soil.

Number of compaction layers	Roller tonnage (t)	Loose paving thickness (cm)	Compacted thickness (cm)	Coefficient of loose paving
The first layer	22	30	25	1.20
The second layer	22	40	33	1.20
The third layer	22	50	41	1.20
The fourth layer	22	40	33	1.20
The fifth layer	22	30	25	1.20
The sixth layer	22	40	33	1.20
The seventh layer	22	40	33	1.20

The ratio of the loose paving thickness of the solidified soil filler to the thickness when the compaction degree is achieved is the loose paving coefficient. The test of the loose paving coefficient was carried out on site. Before soil filling, the measured point position is determined, and the elevation of the point position at this time is recorded as H0. After that, the tilled solidified soil filler will be transferred to the subgrade. Then, the elevation of the marked point position after flattening is recorded, and the elevation is recorded as H1.  $H_s = H1 - H0$ . After that, the compaction of the loose solidified soil filler is rolled to ensure that the compaction degree after rolling meets the requirements of the specification. At this time, the height of the compaction filler H2 after rolling is recorded, the compaction thickness is:  $H_y = H2 - H0$ , the coefficient of loose paving is the thickness of loose paving divided by the thickness of compaction. The calculated coefficient of loose paving of each marker point is averaged to

obtain the coefficient of loose paving of solidified soil filled subgrade. Multi-layer filling test is carried out on site to determine that the coefficient of loose paving of different fillers is 1.2 when the thickness of loose paving of different fillers reaches 93% compaction degree.

The soil layers with different thickness of loose paving were rolled, and the compaction degree of each soil layer was tested by sand filling method after the compaction was completed. The test results showed that the compaction degree of each soil layer was not less than 93% after the compaction treatment of subgrade filling soil layer on site, which met the minimum requirement of embankment compaction degree in the code. When the loose paving thickness is the same as the rolling compaction combination, the compaction degree of the subgrade filler can be effectively improved by increasing the number of rolling compaction times. Under the rolling compaction combination of the 6th and 7th layers, the compaction degree of the subgrade soil layer reaches 96%, which can fully meet the requirements of the subgrade filler.

### 3.2. Comparative Test of Subgrade Filling Effect

The field test is based on the north connection project of Hangzhou Bay Bridge. The designed road speed is 120km/h, the subgrade width is 34.5m, and the slurry is mostly distributed in the site. In-situ curing method is adopted for foundation treatment, and the treatment depth is 2.2m. In order to study the solidified soil subgrade filler filling effect, the experiments of filling subgrade with solidified soil filler and soil and stone mixed filler were carried out on site, in three places in the subgrade construction pile number corresponds in the transverse section of road on both sides and shoulder embedment earth pressure box to test after completion of subgrade filling process and filling subgrade soil pressure at the bottom of the change, respectively is: K25+855, K25+875 and K25+895, while placing settlement plates at adjacent locations to observe the filling process and the settlement changes at the bottom of the subgrade after the completion of filling. Site specific arrangement as shown in figure 8, 9, 10, in front of the subgrade filling, construction waste pulp inside the venue first curing process and curing agent ratio for 2% cement + 9% slag powder, in solidified soil on the in-situ curing after even mixing material processing, after three days of curing, the in-situ solidified soil is dug out for curing treatment, The water content of the solidified soil is regulated after seven days of stacking the material. After adjusting the water content to 19%, the solidified soil filling can be transported to the subgrade. According to the thickness of loose paving and the soil layer, the appropriate rolling combination method can be selected for filling and rolling to meet the requirements of the prescribed compaction degree of each soil layer.

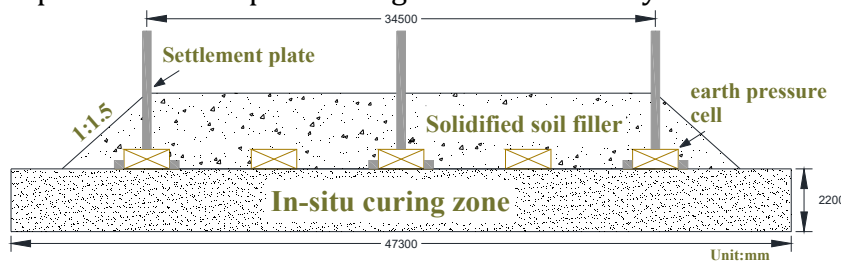


Fig 8. Solidified soil fills the subgrade.

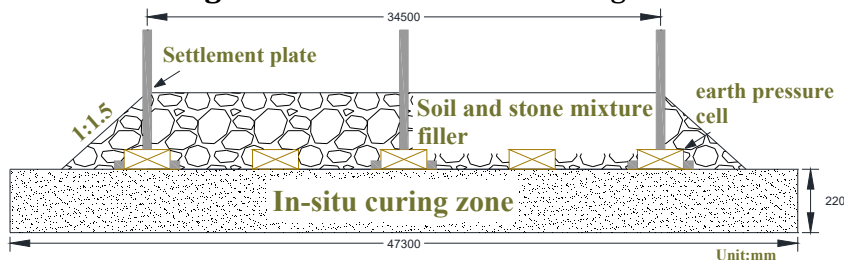


Fig 9. Soil and stone mixture fill the subgrade.

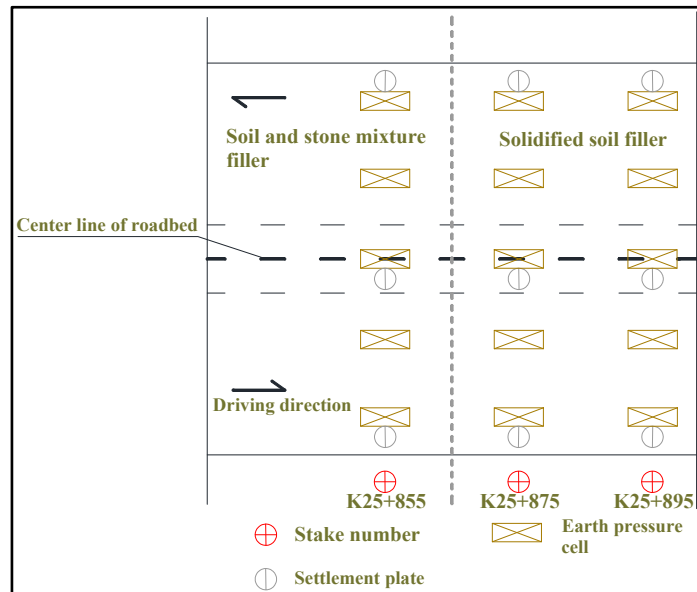


Fig 10. Layout plan of monitoring points.

### 3.3. Analysis of Subgrade Filling Monitoring Results

The site mainly monitors the earth pressure and settlement at the bottom of the subgrade during and after the subgrade filling. Subgrade filling is divided into four soil layers, which are the upper and lower embankment and the upper and lower roadbed filling. The design thickness of each structure layer is 300mm for the roadbed, 500mm for the lower roadbed, 700mm for the upper embankment and 1000mm for the lower embankment. According to the compactness requirement of highway asphalt pavement design code [26], each structure layer selects rolling combination mode to roll the soil layer. When the road is designed for extra heavy and extremely heavy traffic load, the compaction degree of the upper and lower roadbed is not less than 96%, the upper embankment is not less than 94%, and the lower embankment is not less than 93%. After the compaction of each structural soil layer is completed, the compaction degree of the soil layer is tested. When the compaction degree meets the requirements, the rolling of the next soil layer can be carried out. The embankment filling process and the load, settlement and time relationship after the filling and rolling are shown in figure 11, 12 and 13.

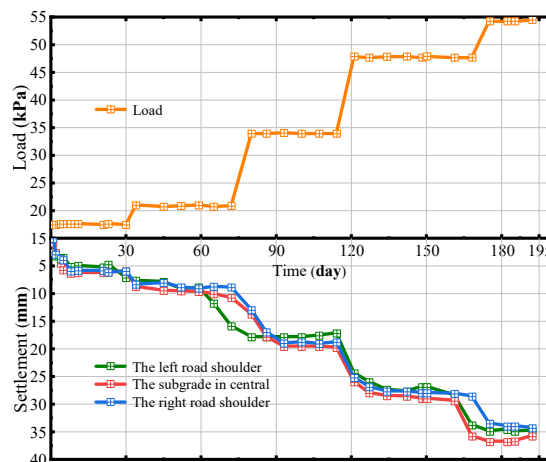


Fig 11. K25+855 load, settlement and time relation curve

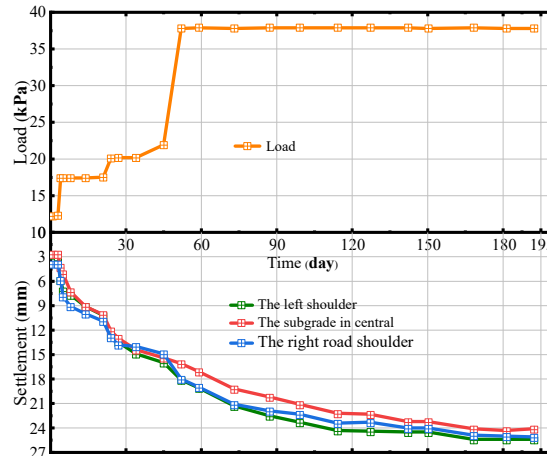


Fig 12. K25+875 load, settlement and time relation curve.

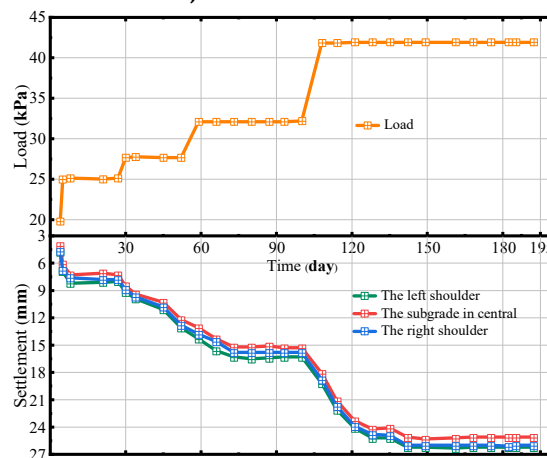


Fig 13. K25+895 load, settlement and time relation curve

The monitoring data of soil pressure and settlement of subgrade filling show that the subgrade is filled with either solidified soil or mixed soil and stone filling. In the whole process of filling, the increasing rate of settlement never exceeds the warning value of 10~15mm/d, and the change of settlement in the process of filling is consistent with the deformation law of soil, showing good stability.

When the subgrade is filled and rolled to the design elevation. The average earth pressure at the bottom of the embankment filled with mixed soil and stone filling is higher than that of the embankment filled with solid soil filling. This is because the density of the mixed soil and stone filler is relatively large. When rolling to the same height, the average earth pressure at the bottom of the embankment filled with the mixed soil and stone filler is higher than that of the solidified soil filler. Whether it's on the shoulder or in the center of the subgrade, when the subgrade filled with solidified soil filling reaches the same height in filling and rolling, the bottom settlement of the subgrade is smaller than that of the subgrade filled with soil and stone mixed filling, which is also caused by the high weight of the soil and rock mixed filler. Therefore, by comparing the two different filling methods of subgrade, due to the difference in the weight of the materials, the subgrade filled with solidified soil filling and mixed soil-stone filling can bear higher upper load. after the subgrade compaction in each filling compaction stage, most load by crushed stone and gravel between contact is passed to the foundation, thus showed a surge in the settlement of change trend, because of the stabilized soil filling single species, and under the action of adding curing agent, The bond between soil particles increases the integrity of the subgrade after rolling, and the load applied at each filling stage can be more evenly transferred to the foundation, showing a more moderate settlement growth change.

Therefore, it is feasible to use engineering waste slurry solidified as subgrade filler, and it has a better filling effect than the soil and stone mixed filler.

## 4. Conclusion

In the environment where it is difficult to obtain high-quality fillers and it is difficult to treat engineering waste slurry, this study solidifies engineering waste slurry and uses solidified soil as subgrade fillers. Since solidified soil is different from the previous subgrade fillers, it is necessary to conduct laboratory road parameter test and analyze its feasibility as subgrade fillers. In addition, the field tests of filling roadbed with mixed soil and stone filler and solidified soil fillers were carried out, and the following conclusions were drawn:

1. According to the laboratory compaction test of solidified soil with different curing time, it is found that the maximum compaction degree can be obtained when the curing time of solidified soil is 7 days, the optimal water content is 19%, and the corresponding maximum dry density is 1.65g/cm<sup>3</sup>.
2. Multiple groups of curing agent dosage and different curing time of solidified soil were carried out indoor CBR tests, and it was found that the best curing agent dosage was 9% cement +2% slag powder, and the maximum CBR value could be obtained at this time, the corresponding CBR value was 36.4%, which could meet the strength requirements of the road bed filler. Moreover, when the curing agent dosage was fixed, with the increase of the curing time, The CBR value of solidified soil was also significantly increased. The design value of resilience modulus of solidified soil filler determined by indoor bearing plate test is 56MPa, which meets the requirement of resilience modulus of asphalt pavement facing roadbed.
3. Through the field spreading and rolling test, the solidified soil with the total ratio of admixture of 11% (9% cement +2% slag powder) was obtained, and the loose paving coefficient was 1.2, and the corresponding rolling combination under different compaction requirements was determined. When the thickness of loose paving is 300-40mm, if the soil compaction degree is more than 93%, the rolling combination sequence is as follows: one static compaction, one weak vibration, two strong vibration, and finally one static compaction, and the rolling sequence is repeated at least five times. In order to obtain higher soil compaction, it is necessary to increase the number of strong vibration and the total rolling.
4. The experiments of embankment filling with solidified soil and mixed soil and stone were carried out in the field. It is found that the solidified soil filled subgrade after rolling can be used as subgrade filler completely. Through comparative analysis, it is found that the embankment filled with solidified soil has the advantage of lightening compared with the embankment filled with soil and stone, which can increase the bearing capacity of the foundation. Compared with the embankment filled with soil and stone, the embankment filled with solidified soil has better integrity and better filling effect.

## Acknowledgments

**Funding:** The work presented in this paper was supported by the Supported by Sichuan City Solid Waste Energy and Building Materials Conversion Technology Engineering Research Center, Chengdu University(Grant No.GF2022YB003);the Major project of Wenzhou Polytechnic (Grant No .WZY2022010).

## References

- [1] Cui, Y. L., Pan, F. R., Zhang, B. B., Wang, X. Q., & Diao, H. G. (2022). Laboratory test of waste mud treated by the flocculation-vacuum-curing integrated method. *Construction and Building Materials*, 328, 127086.

- [2] Zhang, C., Chen, K., Yang, J., Fu, J., Wang, S., & Xie, Y. (2022). Reuse of Discharged Soil from Slurry Shield Tunnel Construction as Synchronous Grouting Material. *Journal of Construction Engineering and Management*, 148(2), 04021193.
- [3] Cui, W., Liu, D., Song, H. F., & Pu, G. J. (2019). Development and experimental study on environmental slurry for slurry shield tunneling. *Construction and Building Materials*, 216, 416-423.
- [4] Wang, Y., Hu, Z., Chen, Y., & Xiao, H. (2020). Two-dimensional parametric study of an embankment on clay improved by an artificial crust composite foundation. *Advances in Civil Engineering*, 2020.
- [5] Jelusic, N., & Leppänen, M. (2003). Mass stabilization of organic soils and soft clay. In *Grouting and Ground Treatment* (pp. 552-561).
- [6] Chian, S. C., Chim, Y. Q., & Wong, J. W. (2017). Influence of sand impurities in cement-treated clays. *Géotechnique*, 67(1), 31-41.
- [7] Wang, Y., Chen, Y., Qiao, W., Zuo, D., Hu, Z., & Feng, Q. (2018). Road engineering field tests on an artificial crust layer combined with pre-stressed pipe piles over soft ground. *Soil Mechanics and Foundation Engineering*, 54(6), 402-408.
- [8] Do, D. H., & Pham, T. A. (2018). Investigation of performance of soil-cement pile in support of foundation systems for high-rise buildings. *Civil Engineering Journal*, 4(2), 266.
- [9] Wu, Y., Zhang, K., Fu, L., Liu, J., & He, J. (2019). Performance of cement–soil pile composite foundation with lateral constraint. *Arabian Journal for Science and Engineering*, 44(5), 4693-4702.
- [10] Mengue, E., Mroueh, H., Lancelot, L., & Eko, R. M. (2017). Mechanical improvement of a fine-grained lateritic soil treated with cement for use in road construction. *Journal of Materials in Civil Engineering*, 29(11), 04017206.
- [11] Shen, Y. S., Tang, Y., Yin, J., Li, M. P., & Wen, T. (2021). An experimental investigation on strength characteristics of fiber-reinforced clayey soil treated with lime or cement. *Construction and Building Materials*, 294, 123537.
- [12] Li, J., Qian, J., & He, C. (2022). Experimental analysis of cement-treated red sandstone coarse-grained soil and its microstructural evolution. *Case Studies in Construction Materials*, 17, e01535.
- [13] Zhao, Y., Chen, X., Wen, T., Wang, P., & Li, W. (2022). Experimental investigations of hydraulic and mechanical properties of granite residual soil improved with cement addition. *Construction and Building Materials*, 318, 126016.
- [14] Li, N., Zhu, Q., Wang, W., Song, F., An, D., & Yan, H. (2019). Compression characteristics and microscopic mechanism of coastal soil modified with cement and fly ash. *Materials*, 12(19), 3182.
- [15] Hata, T., Saracho, A. C., GuhaRay, A., & Haigh, S. K. (2022). Strength characterization of cohesionless soil treated with cement and polyvinyl alcohol. *Soils and Foundations*, 62(6), 101238.
- [16] Pham, T. A., Koseki, J., & Dias, D. (2021). Optimum material ratio for improving the performance of cement-mixed soils. *Transportation Geotechnics*, 28, 100544.
- [17] Chen, H., Zhang, J., & Yan, H. (2013). Quantitative evaluation of microstructure characteristics of cement consolidated soil. *Bulletin of Engineering Geology and the Environment*, 72(2), 233-236.
- [18] Yang, J., Dong, M., Sun, T., & Wang, M. (2019). Forecast formula for strength of cement-treated clay. *Soils and Foundations*, 59(4), 920-929.
- [19] Wang, F., Li, K., & Liu, Y. (2022). Optimal water-cement ratio of cement-stabilized soil. *Construction and Building Materials*, 320, 126211.
- [20] Wang, S., Guo, S., Gao, X., Zhang, P., & Li, G. (2022). Effects of cement content and soil texture on strength, hydraulic, and microstructural characteristics of cement-stabilized composite soils. *Bulletin of Engineering Geology and the Environment*, 81(7), 1-16.
- [21] Chen, Y., Gao, S., Chen, L., Chen, G., & Chen, J. (2019). Laboratory and field test study on the improvement of marine clay slurry by in-situ solidification. *Marine Georesources & Geotechnology*, 37(6), 695-703.
- [22] Wang, Y., Chen, Y., Qiao, W., Zuo, D., Hu, Z., & Feng, Q. (2018). Road engineering field tests on an artificial crust layer combined with pre-stressed pipe piles over soft ground. *Soil Mechanics and Foundation Engineering*, 54(6), 402-408.

- [23] Faro, V. P., Consoli, N. C., Schnaid, F., Thomé, A., & da Silva Lopes, L. (2015). Field tests on laterally loaded rigid piles in cement treated soils. *Journal of Geotechnical and Geoenvironmental Engineering*, 141(6), 06015003.
- [24] Research Institute of Highway Science, Ministry of Communications. (2007). Code of Geotechnical Test for Highway :JTG E40-2007. People's Communications Publishing House.
- [25] Madhyannapu, R. S., Puppala, A. J., Nazarian, S., & Yuan, D. (2010). Quality assessment and quality control of deep soil mixing construction for stabilizing expansive subsoils. *Journal of geotechnical and geoenvironmental engineering*, 136(1), 119-128.