Chapter 7
Investigation on Resource Utilization of Saline Sludge to Roadbed Material

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Abstract The resource utilization of sediment can fully tap the potential application value of sediment and provide new materials which is instrumental in save resources. In this study, resource utilization of saline sludge from Binhai Port in Yancheng City to roadbed material was investigated and a complete technical route was proposed. The roadbed material strength of 3% (lime): 3% (Portland cement): 94% (sample) with curing agent could achieve 3.69–4.05 MPa and meet the strength requirements of road subbase, which were higher than that of roadbed material strength of 5% (Portland cement): 95% (sample) without curing agent. The leached salinity of roadbed material was less than 1.04 PSU according to PSS-78, which was about 1/10 of the original sludge. A protection measure was proposed to lead salt water to drainage ditch and prevent leached salinity into farmland. The results of this study can provide valuable reference for resource utilization of sludge, especially for saline sludge.

Keywords Saline sludge · Resource utilization · Roadbed material · Leached saltwater control

7.1 Introduction

As an important part of water body, sediment is the mixture of clay, sand, organic matter and minerals deposited at the river bed under the action of water transmission and after long-term physical, chemical and biological interaction (Sun et al. 2018). Therefore, the sediment is rich in a large amount of nutrients. At the same time, it is the

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reservoir of a variety of pollutants (Singh et al. 1997). The pollutants accumulated by it can be used as a secondary pollution source to directly or indirectly poison benthos or overlying aquatic organisms (Kara et al. 2017; Sin et al. 2001), and enter the food chain and affect human health through biological enrichment and other processes. Therefore, dredging engineering plays an important role in eliminating endogenous pollution. Due to the large amount of sediment with high moisture content and complex composition produced in the process of sediment dredging, it will bring serious secondary pollution to the ecological environment (Huang et al. 2021; Qureshi et al. 2021). As a result, it is very necessary to make resource utilization of the dredged sediment.

The traditional sediment landfill method is easy to cause secondary environmental pollution and is not conducive to the resource utilization. The resource utilization of sediment can fully tap the potential application value of sediment and provide new materials, which mainly includes two directions, including land use and building use. Land use refers to the application of dredged sediment to farmland, forest land, grassland, wetland, municipal greening, seedling substrate and seriously disturbed land restoration and reconstruction. For example, the dredged sediment were applied to improve dune sand in Oman (Juan José et al. 2020), strawberry cultivation from marine (Zhao et al. 2022). The construction utilization is mainly through the modification of sediment, which is used for brick making, carbonized ceramsite, road subgrade and so on. For example, the dredged sediment were used to produce porous lightweight aggregate (ceramsite) from lake (Amar et al. 2021), supplementary cementitious material (Frar et al. 2014), fired brick from Tangier and Larache port (Mezencevova et al. 2013) and Savannah Harbor (Chen et al. 2021), synthesize zeolite for removing Cd(II).

In this study, it is investigated that the dredged sediment from coastal port is tried to prepare subgrade materials, which not only can reduce the impact of saline sludge stacking on the environment, but also obtaining considerable economic benefits.

7.2 Sample Collection and Analysis

7.2.1 Study Area

The project is located between the Haidi Road and the Dongxing Road near the Binhai Harbor with area of 1.07 km^2 and stacked volume of 6.54 million square. The sludge produced by the excavation and dredged for the port's construction has been stored in a semi dry state, as shown in Fig. 7.1. Unfortunately, farmland is distributed around the site and threatened by saltwater seepage during the rainy season. Therefore, it is necessarily to conduct a research on resource utilization of saline sludge to roadbed material, which could provide shelter belts for farmland.

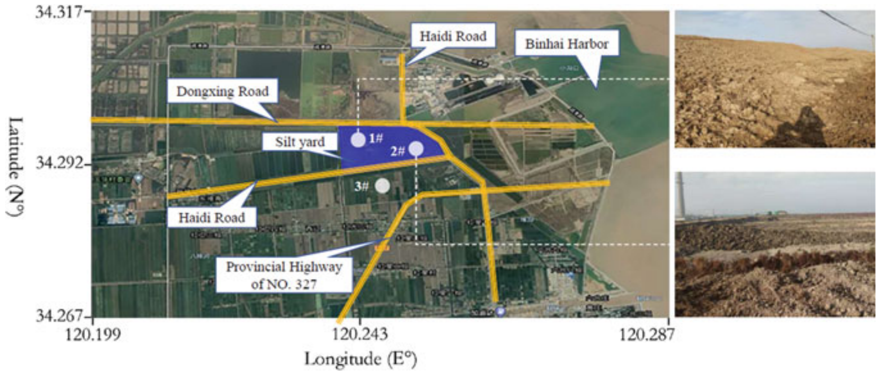

Fig. 7.1 The study area

7.2.2 Sample Collection

In order to understand the sediment characteristics, three samples were collected as shown in Fig. 7.1, among which two samples (1# and 2#) were collected at surface and with depth of 1 m, respectively; one sample (3#) was collected from the farmland with depth of 0.5 m.

7.2.3 Sample Analysis

For preparation of subgrade materials, two key indicators of mass moisture content and total salt content (TSC) were analyzed (Tab. 7.1). The mass moisture content was tested according to National Environmental Protection Standards of the People's Republic of China called "Soil-Determination of Dry Matter and Water Content-Gravimetric Method (HJ 613-2011)". The TSC was tested according to the Forestry Industry Standard of the People's Republic of China called "Analysis Methods of Water Soluble Salts of Forest Soil (LY/T 1251-1999)".

(1) The mass moisture content.

The mass moisture content (MMC) could be calculated by Eq. 1.

Table 7.1 The MMC and TSC of the collected samples

Number of samples	Depth (m)	Mass moisture content (%)	Total salt content (g/kg)
1#	0.0	10.5	10.2
	1.0	31.8	12.1
2#	0.0	15.5	11.5
	1.0	21.7	11.4
3#	0.5	34.2	0.66

$$\omega_{H_2O} = \frac{m_{w2} - m_{w3}}{m_{w3} - m_{w1}} \times 100 \quad (7.1)$$

where ω_{H_2O} is the mass moisture content (%); m_{w1} is the container mass (g); m_{w2} is the total mass of container and fresh soil (g); m_{w3} is total mass of container and dry soil (g).

(2) Test method of the total salt content.

The total salt content could be calculated by Eq. 2.

$$S = \frac{m_{s2} - m_{s1}}{m_s} \times 1000 \quad (7.2)$$

where m_s is the dry soil mass equivalent to 50 ml of leaching solution (g); m_{s1} is the mass of glass evaporating vessel (g); m_{s2} the total mass of salt and glass evaporating vessel (g).

After long-term natural drying, the surface sludge is drier than that with depth of 1.0 m. The mass moisture content are between 10.5–31.8%, which doesn't have to go through dehydration. The total salt content are between 10.2 g/kg and 12.1 g/kg, which are up to 17–20 times the salinity of farmland and causes serious environmental threat.

7.3 Roadbed Material Preparation

7.3.1 Sample Handling

The fresh sludge sample with particle size less than 5 mm was collected by dry sieving and dried by infrared drying oven until the mass moisture content lower than 12%. Afterwards, five sludge samples with different mass moisture content were obtained by add water, of which the mass moisture content was 14%, 16%, 18%, 20% and 22%, respectively. The relationship between mass moisture content (ω_{H_2O}) and dry density (ρ_{dry}) could be obtained (Fig. 7.2), from which the optimum moisture content was 17% and the maximum dry density is 1.8 g/cm^2.

7.3.2 Roadbed Material Preparation

The sludge sample was aired until the mass moisture content lower than the optimum moisture content, which was mixed with quicklime powder (3% of the sample mass) evenly and seal and stew for 72 h. Afterwards, the sludge sample was mixed with self-developed curing agent and Portland cement to make roadbed material. There were four experimental schemes, as shown in Table 7.2. For every scheme, six subsamples

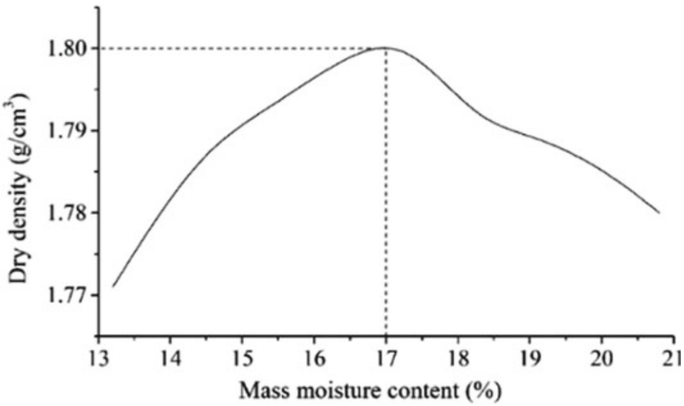

Fig. 7.2 The relationship between MMC and dry density

were made with mass moisture content of about 17%, which were sealed and cured at temperature of 25 °C for 6 days, soaked in water for 24 h on the 7th day, and then tested for 7 d unconfined strength, as shown in Fig. 7.3.

Table 7.2 Experimental schemes of sample mixed with additive

Schemes	Material proportioning	Curing agent content	Mould size
1	5% (Portland cement): 95% (sample)	0.02% (about 110 ml/t)	Φ50mm* 50 mm
2		0.03% (about 167 ml/t)	
3	3% (lime): 3% (Portland cement): 94% (sample)	0.02% (about 110 ml/t)	
4		0.03% (about 167 ml/t)	

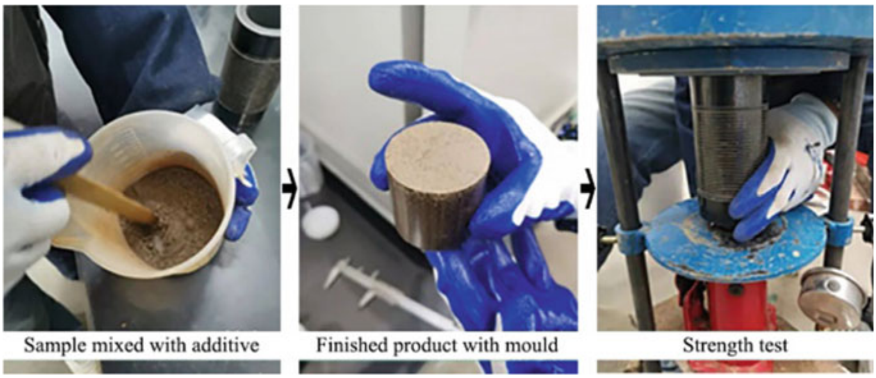

Fig. 7.3 The produce of sample preparation and testing

7.3.3 Roadbed Material Strength Test

Therefore, the experimental results of roadbed material could be achieved according to "Test Methods of Soils for Highway Engineering (JTG3430-2020)", as shown in Table 7.3. The average water absorption for schemes 1–4 were between 1.52–1.88%, which were all lower than 2% and meet the compaction standard. The 7 d unconfined strength could be 2.46–2.62 MPa for scheme 1 and scheme 2, which were 3.69–4.05 MPa for scheme 3 and scheme 4. Compared with scheme 1 and scheme 2, the strength of scheme 3 and scheme 4 were higher benefiting from the curing agent addition. The strength of roadbed material is appropriate to road subbase, which can replace the conventional materials.

7.4 Salinity Control Measures

It is necessary to consider the situation of salinity leaching when the roadbed materials are applied to actual project. Therefore, a test was conducted to evaluate the salinity leaching concentration according to the National standards of the people's Republic of China called "The Specification for Marine Monitoring-Part 4: Seawater Analysis".

Table 7.3 The water absorption and strength of subsamples

Schemes	Curing agent content	Detection index	Subsamples						Average
			①	②	③	④	⑤	⑥	
1	0.02%	Water absorption (%)	2.19	1.51	1.88	1.91	1.91	1.87	1.88
		Strength (MPa)	2.44	2.46	2.58	2.36	2.46	2.46	2.46
2	0.03%	Water absorption (%)	1.77	1.67	1.63	1.74	1.51	1.58	1.65
		Strength (MPa)	2.82	2.87	2.62	2.46	2.46	2.47	2.62
3	0.02%	Water absorption (%)	1.51	1.68	1.57	1.64	1.71	1.56	1.61
		Strength (MPa)	3.77	3.69	3.71	3.70	3.66	3.62	3.69
4	0.03%	Water absorption (%)	1.43	1.53	1.52	1.57	1.43	1.62	1.52
		Strength (MPa)	4.19	3.95	4.02	3.90	4.38	3.87	4.05

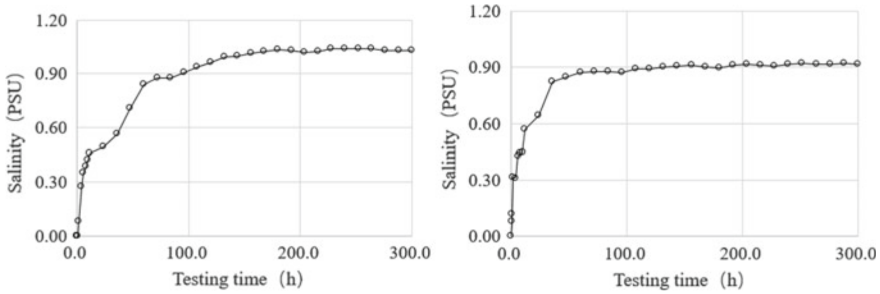

Fig. 7.4 The practical salinity value of two roadbed material samples according to PSS-78

7.4.1 Salinity Leaching Test

Firstly, the roadbed material was put into a beaker with volume of 2 L with ultra-pure water according to the ration of 1 kg produce to 2 L ultra-pure water. The salinity was determined by Portable Multi Parameter Measuring Instrument (WTW Multi 3630, Germany), as shown in Fig. 7.4. The salinity value was converted from conductivity according to PSS-78 (Practical Salinity Standard 1978). The salinity for two roadbed material samples were less than 1.04 PSU and 0.92 PSU. Though the roadbed material preparation process has reduce the salt ion release effectively, the leached salinity were slightly higher than that of farmland (0.66 g/kg).

7.4.2 Salinity Protection Measure

In view of this, a salinity protection measures was proposed to protect the farmland (Fig. 7.5). It need to set anti-seepage geo-membrane under the subgrade material and slopes on both sides of the road. The salinity water would be lead to the drainage ditch and collected. Besides, salt tolerant vegetation would be planted on slopes on both sides of the road for using leached saltwater.

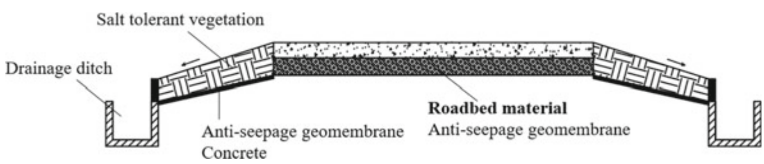

Fig. 7.5 A road structure for prevent leached saltwater

7.5 Conclusion

In the present study, a complete technical route that the saline sludge was used to preparation roadbed material has been proposed based on laboratory test. From the previous investigation, the following conclusions can be concluded.

The total salt content of saline sludge are between 10.2 g/kg and 12.1 g/kg, which are up to 17–20 times the salinity of farmland and causes serious environmental threat. The optimum moisture content and the maximum dry density of the saline sludge were 17% and 1.8 g/cm^2, respectively.

The average water absorption for schemes 1–4 were all lower than 2% and meet the compaction standard. The 7 d unconfined strength of roadbed material could be 2.46–2.62 MPa for 5% (Portland cement): 95% (sample) without curing agent, which were 3.69–4.05 MPa for 3% (lime): 3% (Portland cement): 94% (sample) with curing agent.

The leached salinity of roadbed material can be reduced to 0.92–1.04 PSU, which was slightly higher than that of farmland. Therefore, a protection measure was necessary to prevent the leached salinity into farmland.

Above all, resource utilization of saline sludge to roadbed material is feasible, which still needs further study if the roadbed material will be used to actual project.

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