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The Behavior of Dredged Soil-Shredded Rubber Embankment Stabilized with Natural Minerals as a Road Foundation Layer

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Abstract

Recently, geotechnical studies have been conducted more progressively to utilize dredged soil. The inclusion of shredded rubber (SR) and natural minerals (NM) to stabilize dredged soil (DS) has become an exciting issue in the geotechnical field. This technique can be a promising environmental innovation for the future. This study aimed to investigate the unconfined compressive strength (UCS), California bearing ratio (CBR), and embankment performance under the strip footing test. The UCS sample was prepared using shredded rubber with a proportion of 2% and 3% and natural minerals with a proportion of 3%, 6%, 9%, and 12% from the dry weight of the soil. Whereas for the CBR samples (both in un-soaked and soaked conditions) were also prepared with a proportion of 2% and 3% shredded rubber and 6% and 9% natural minerals from the dry weight of the soil as well. The strip footing test was conducted in small-scale laboratory tests to evaluate the performance of stabilized dredged soil embankments. The applied load test was gradually increased until the embankment collapsed. The results showed that adding shredded rubber and natural minerals could increase the UCS value by 3–4 times and the CBR value by 2–3 times. Furthermore, 84% and 116% efficient results were obtained in the strip footing test for the 7 and 14 days of curing, respectively. Therefore, the utilization of dredged soil stabilized with SR and NM can be considered for use as a road foundation layer.

Keywords: Dredged Soil; Shredded Rubber; Natural Minerals; Road Foundation Layer.

1. Introduction

Over the past few decades, the problems caused by dredged soil from the bottom of the river channel, reservoirs, or swampy areas have caused health and environmental problems [1]. This problem can be a challenge for geotechnical engineers contributing to the construction field. One suggestion that can be given is to utilize this dredged soil as a backfill for highway construction. Proper handling of dredged soil is critical to preventing environmental contamination in the future [2]. Previous studies have reported that dredged soils have poor geotechnical properties to utilize as backfill directly. It happens due to their limited bearing capacity, high moisture content, high porosity ratio, uniformity of fine soil particles, and poor permeability [3, 4]. In order to find a solution to this problem, soil stabilization techniques can be used to treat and reuse dredged soil. Soil stabilization methods are considered to improve the geotechnical properties of dredged soil before use. Mixing the soil with cement, lime, fly ash, bottom ash, bacteria, pozzolan, and zeolite are some of the soil stabilization techniques to optimize the geotechnical characteristics of dredged soil [5–10].

Common soil stabilization using cement, lime, or combustion residue has several limitations, such as its high cost and limited availability of materials. Previous studies have also reported that cement and lime as chemical stabilization materials can seriously impact the environment and human health. Cement and lime production is estimated to cause the release of 5-7% CO_2 and harmful dust into the atmosphere during the production process [11]. Besides releasing

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CO_2, cement production processes also release SO_2, NO_2, and other gases that contribute to the greenhouse effect and acid pollution. From an economic aspect, this cement production process also requires high production costs [12]. Therefore, it is urgent to pursue soil improvement research utilizing natural minerals as a new, environmentally friendly, and low-cost breakthrough.

Stabilized dredged soils are prone to cracking due to desiccation. These cracks can cause water to infiltrate the soil, triggering the separation of soil particles bonding. These cracks can trigger the reduction of the soil's long-term bearing capacity and shear strength [13]. Therefore, several researchers reported and proposed that fiber inclusion can improve soil geotechnical properties, mainly shear strength, flexural characteristics, and bearing capacity parameters, and also reduce the crack intensity factor (CIF) [13–17].

Hence, this research aims to present the current state-of-the-art soil stabilization techniques, focusing on innovative approaches in terms of using natural minerals and shredded rubber. The study also discusses the significant factors that affect the sensitivity of soil stabilization properties, such as soil classification, mixing proportion, mechanical properties, and the role of curing time during soil stabilization. Hopefully, this research can provide more insight into the latest developments in soil stabilization and contribute to developing environmentally friendly engineering in the geotechnics field and recycled materials.

2. Literature Review

Significant sedimentation in some reservoirs has been widely reported in countries such as China, Russia, the United States, Iran, Taiwan, France, North Africa, Algeria, and Sudan [18, 19]. This condition has prompted dredging activities in those areas. However, as a result, these dredging activities produce an abundance of dredged soil material that tends to be an environmental issue. Dredged soil (DS) is a material derived from dredging activities in wet areas [20], such as waterways, rivers, estuaries, swamps, and reservoir beds. Dredging, especially of reservoir beds, is implemented to preserve the storage capacity and service life of the reservoir. However, dredged soils have poor mechanical behavior and tend to be treated as waste [21].

The feasibility of using dredged materials taken from several dams as fill material has been conducted in Taiwan [22]. Park (2016) stated that the dredged soil is slightly acidic with a pH of 4.25-5.39 and an Electrical Conductivity (EC) value of 83.3-265.0 μS/cm. It is also stated that the X-RF test results show that the chemical element content is minimally enriched, and the heavy metal content is below the required standard. In addition, for the dredged soil's mechanical properties, the maximum dry density (MDD) values were 16.0-16.3 kN/m^3; the coefficient of permeability ranged from 8.7×10^{-7} to 6.3×10^{-6} cm/sec. The shear strength parameter, namely cohesion (C), was 14.8-44.9 kN/m^2, and the internal shear angle (ϕ) reached 22.2°-23.5°.

Zoubir et al. (2013) investigated the impact of adding lime (L) and natural pozzolana (NP) to dredged soil taken from the Oued el Fodda reservoir. The tests involved 4% and 8% lime and 10% and 20% natural pozzolana at several days of curing. The results showed that there was an improvement in the basic properties. It also found a reduction in the plasticity index (PI) value and an enhancement of soil mechanical properties, namely an increase in the UCS value by five times, an improvement in the shear strength parameters, as well as significant changes in cohesion value (c) and the internal shear angle (ϕ) both in the mixture with a composition of 20NP + 8L.

Yu et al. [23] also investigated the effect of several curing periods by adding FA at 10%, 20%, and 30% to the dredged soil. The results indicated that adding FA can reduce the PI and LL values. It was also found that there was an increase in MDD value and a decrease in OMC in FA-stabilized dredged soil. The UCS value of the stabilized soil increased 1.5–3 times compared to the original soil, and the CBR of the stabilized soil was also found to increase. Jan and Mir (2018) reported that OPC inclusion proved to be very effective in improving the mechanical parameters of dredged soil. The UCS value increased to 15 times at the optimum 12% OPC addition proportion. Mohr-Coulomb parameters were seen to improve. Soil consistency conditions increased from soft to dense, and also, the Scanning Electron Microscope (SEM) analysis showed that internal binding of particles due to cementation reactions occurred. The flocculation phenomenon occurred along with the reduction of grain voids due to the formation of larger and more brittle particles. Jamsawang et al. (2021) presented recent research results related to stabilizing dredged soil with a proportion of 1-5% OPC and 5–20% FA at a longer curing period, such as 60 and 120 days. The results show that adding 10% FA to various OPC compositions gives the best UCS and CBR values. It also stated that the curing period has a significant increase in effect. The reaction of OPC + FA was confirmed to produce calcium silicate hydrate (CSH) by SEM.

Several researchers also presented their research results related to the involvement of fiber materials to improve soil mechanical properties, including shear strength and CBR parameters [24-27]. The use of tire rubber shredded fibers will strengthen and enhance the mechanical properties, especially the soil's shear and flexural strength. Bayat et al. conducted a study involving waste tire fibers with a proportion of 0.25%-1.0% to the sand with a Relative Density (RD) of 50% - 90% [28]. This study revealed an escalation in Bearing Capacity Ratio (BCR) ranging from 1.22-2.05 times, followed by a decrease in the Settlement Reduction Factor (SRF) value of 0.4-0.84. The optimal proportion obtained was 0.75% of waste tire fiber content. It confirmed that using rubber fibers increases the load capacity of the sand embankment. Other research results show that adding waste tire fibers can increase the shear parameter value of silty sand [29]. Bayat et al. (2019) researched by adding waste tire fibers 0.4%, 0.8%, and 1.2% with four variations in fiber length into silty sand to test the value of shear parameters [28]. The results showed increased internal shear angle (ϕ) in materials reinforced with waste tire fibers. The results show that adding 0.8% waste tire fibers is the optimum proportion of the mixture.

Based on the literature review above, a research gap in soil stabilization can be filled by combining stabilization efforts by utilizing shredded rubber fibers as reinforcement material and natural minerals as pozzolanic stabilization material to improve the geotechnical characteristics of the soil. It is hoped that this research can present/propose a new type of composite embankment that is expected to make a valuable contribution to the development of geotechnical engineering that is environmentally friendly and sustainable for the benefit of human life.

3. Materials and Methods

3.1. Materials

This research involved three main types of materials, namely (i) dredged soil from the reservoir; (ii) shredded rubber from waste tires; and (iii) natural pozzolanic minerals (Figure 1). The DS used in this study is soil derived from dredged sedimentary deposits at the bottom of the Bilibili reservoir, South Sulawesi Province, Indonesia. The DS is light brown, finely textured, and Specific Gravity (Gs) 2.66. The sieve analysis shows that the grain size of this DS material is 88% passing the #200 sieve, whereas 85% is in the silt fraction, and the remaining 3% is in the clay fraction (Figure 2). A plasticity properties test was conducted to assess the soil consistency. The results show that the liquid limit (LL) is 39%, and the plasticity index (PL) is 7%. According to the Unified Soil Classification System (USCS), this dredged soil is categorized as silt with low plasticity (ML) [30]. The complete results of the DS material properties tests are presented in Table 1. The shredded rubber (SR) used in this study is the waste of a vehicle tire retreading factory. The waste was taken randomly, filtered through no 4 (4.75 mm opening), and retained no 10 (2 mm opening). The SR used is 10-25 mm long, 1-3 mm wide, and 0.2-1.0 mm thick. Generally, the specifications of these shredded rubber are Gs 1.15-1.21; Young's modulus ranges from 1.2-5.1 MPa; Unit weight (γ) ranges from 5.1-5.4 kN/m^3 [31].

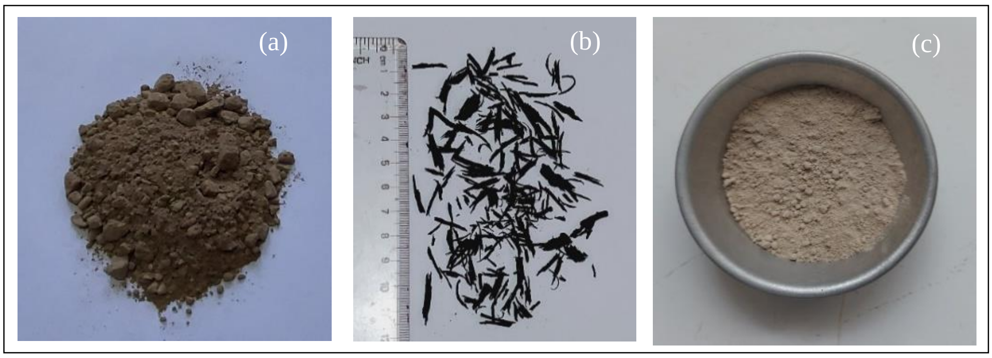


Figure 1. Research material (a) dredged soil; (b) shredded rubber; (c) natural minerals

Table 1. Basic properties of DS material

Soil Characteristics	Value	Unit	Standard
Specific gravity	2,66	-	ASTM D854-02 [32]
Sieve analysis			ASTM C136/C136M-06 [33]
Sand	12	%	
Silt	85	%	
Clay	3	%	
Atterberg test			ASTM 4318-10e1 [34]
Liquid limit	39	%	
Plastic limit	32	%	
Plasticity index	7	%	
Shrinkage limit	30	%	
Compaction characteristic			ASTM D698-07 [35]
MDD	14.1	kN/m^3	
OMC	25	%	
Soil classification	ML	USCS	ASTM D2487-06 [30]

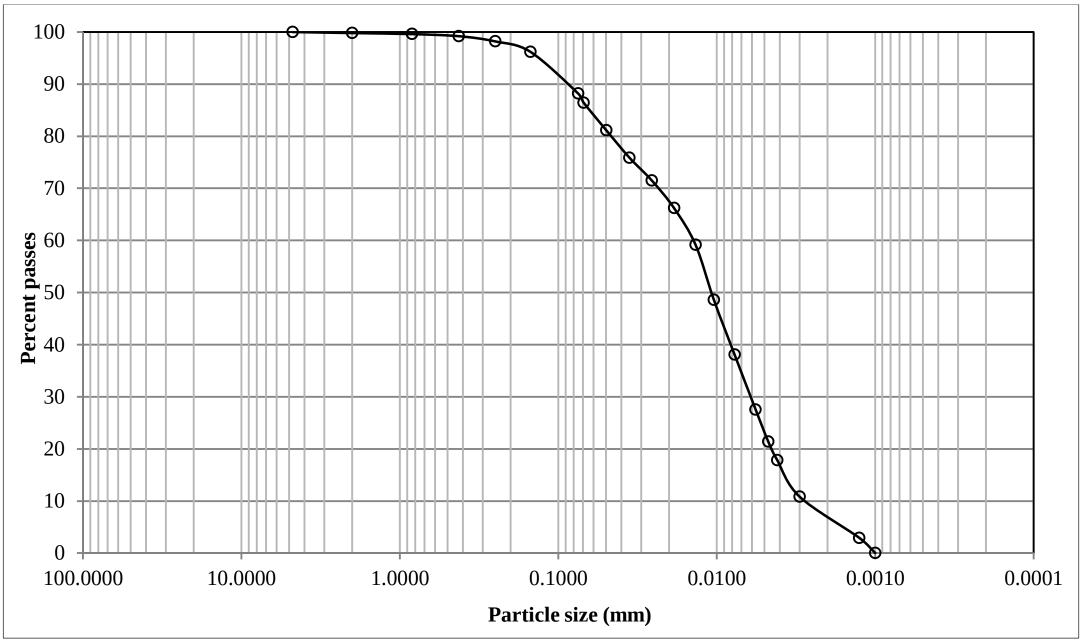


Figure 2. Distribution curve of DS material grain size analysis

NM was collected from the quarry site in Gorontalo Province, Indonesia. X-ray fluorescence (XRF) spectrometry test was conducted to identify the chemical compound content of the NM. The results are exposed in Table 2. NM, which acts as a stabilizing material, is composed of a crystalline material containing silica, alumina, and ferric oxide and has a Gs of 2.69. The NM was finely crushed and screened through a #200 (0.075 mm) sieve. This material is classified as class N natural pozzolan based on ASTM C618 [36].

Table 2. Characteristics of natural minerals

Characteristics		Value	Unit
Basic	Specific gravity	2.69	-
	Particle grain size	0.075	mm
	Color	light cream	-
	Water content	0.65	%
Chemical compound	SiO_2	81.35	%
	Al_2O_3	6.85	%
	Fe_2O_3	4.93	%
	CaO	3.76	%
	K_2O	2.02	%
	others	1.09	%

3.2. Methods

All testing procedures for basic and mechanical properties of untreated and treated soil, such as density, UCS, and CBR, refer to the American Society for Testing and Materials (ASTM) standards [34-38]. In the UCS and CBR tests, the proportion of SR involved was 2% and 3% of dry weight. The percentage of SR used was 2% and 3% of the dry weight of the soil. Meanwhile, 3%, 6%, 9%, and 12% were added for NM. Water is added to the soil mix according to the OMC condition composition obtained from the standard proctor compaction test results. 7, 14, and 28 days of curing were applied to obtain a pozzolanic reaction. Remolded test samples were prepared for UCS test samples in a cylindrical shape with 5 cm in diameter and 10 cm in height with a compaction energy of 600 kJ/m3 according to ASTM D698-07. The UCS sample was tested using an automatic compression testing machine with a 2 mm/min uniform compression rate. Furthermore, the CBR sample will be prepared dan tested under unsoaked and soaked conditions. It will follow the procedure in accordance with ASTM D1883-14. All UCS and CBR testing data will be analyzed and presented as explanatory descriptions and images (see Figures 8 to 13).

With an Occupied understanding of the mechanical behavior of reinforced embankments, a strip footing test model will be conducted to analyze the stabilized dredged soil embankment performance. This embankment model uses a proportion of 2% SR and 9% NM, which was determined based on the optimum results of UCS and CBR tests at several compositions (see Figures 8 and 12). The stabilized DS embankment will be compared with sand-gravel embankment as a standard embankment for road foundation. The physical model was made in an experimental box 150 cm long, 60 cm wide, and 80 cm high. The strip footing used was 20 cm in diameter to simulate the diameter of the vehicle tire contact area on the road. The design of the experimental box was determined based on the dimensions of the strip footing load and the area affected by the deformation (Figure 3). In order to avoid the effect of sidewall friction, plexiglass acrylic and painted walls were applied to the experimental box.

All embankment layer model was divided into a 50 cm high subgrade backfill layer and a 20 cm high subbase backfill layer (as the standard thickness of the road subbase) placed above the subgrade layer. The physical model test was conducted three times. All embankments in the physical test model applied the maximum density (MDD) with optimum moisture content (OMC) obtained from the element model testing. In this model test stage, the magnitude of vertical deformation and the applied load were measured continuously (Figures 5 and 6).

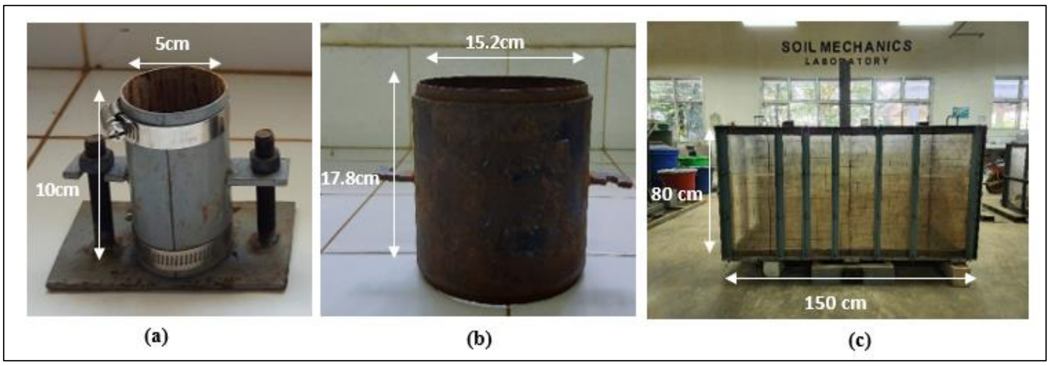


Figure 3. Research equipment: (a) UCS mold; (b) CBR mold; (c) experimental box

Figure 4, shows the flowchart of the research methodology through which the objectives of this study were achieved.

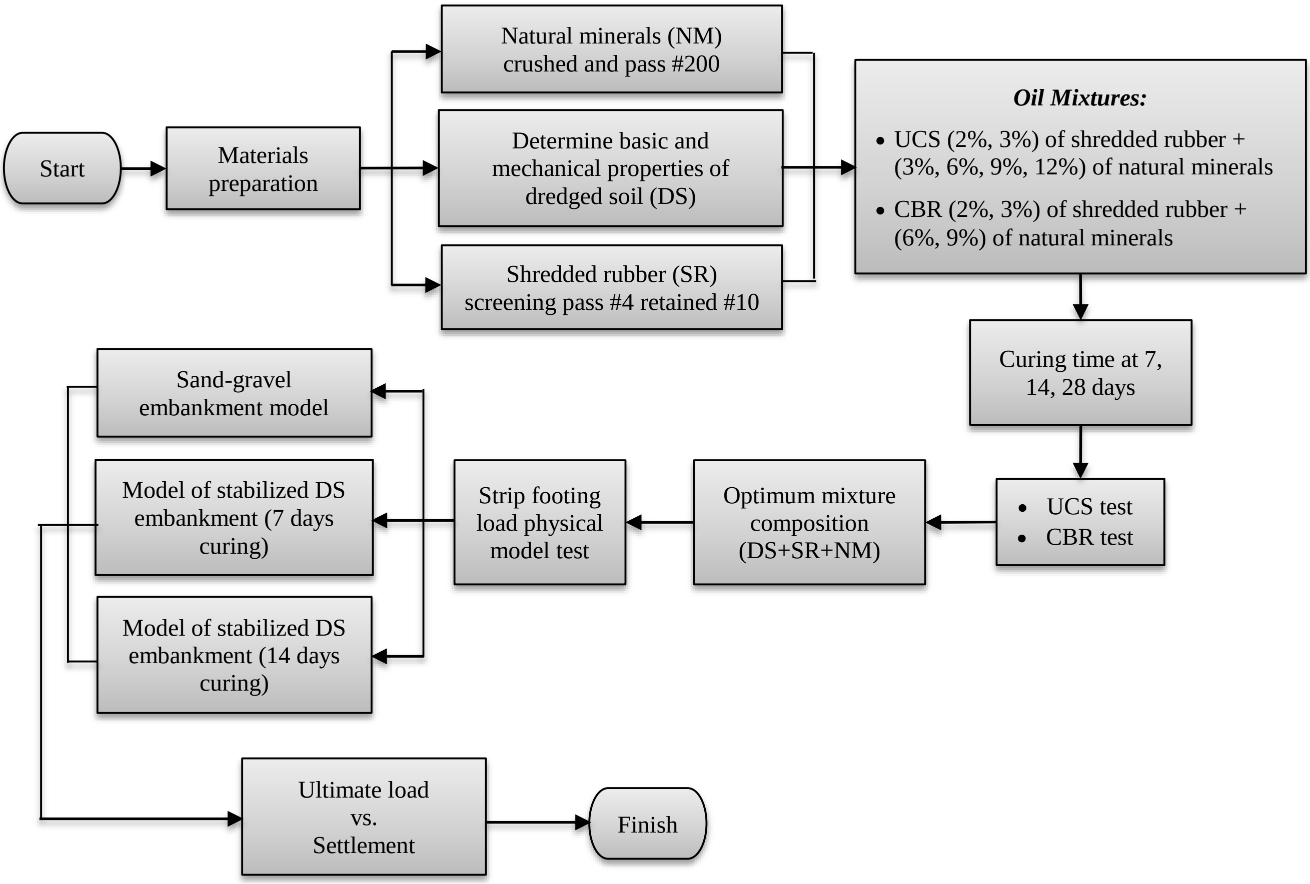


Figure 4. Experimental program

The strip footing test procedure was started by testing the bearing capacity of the subgrade layer according to the Dynamic Cone Penetrometer (DCP) [39] test procedure to ensure a minimum CBR value of 6%. Furthermore, the sand-gravel embankment model that has been made was tested by giving the strip footing load. The loading process was performed until the subbase layer collapsed following the test procedure in ASTM [40]. Previous studies terminated the loading stage after a large settlement, usually at least 20 mm [41]. The settlement due to the given loading was measured using a dial indicator. Observations in this test were made by recording using a recording camera. The graph of the relationship between the settlement value and the amount of static load applied will be used to indicate the performance of the three embankment models tested.

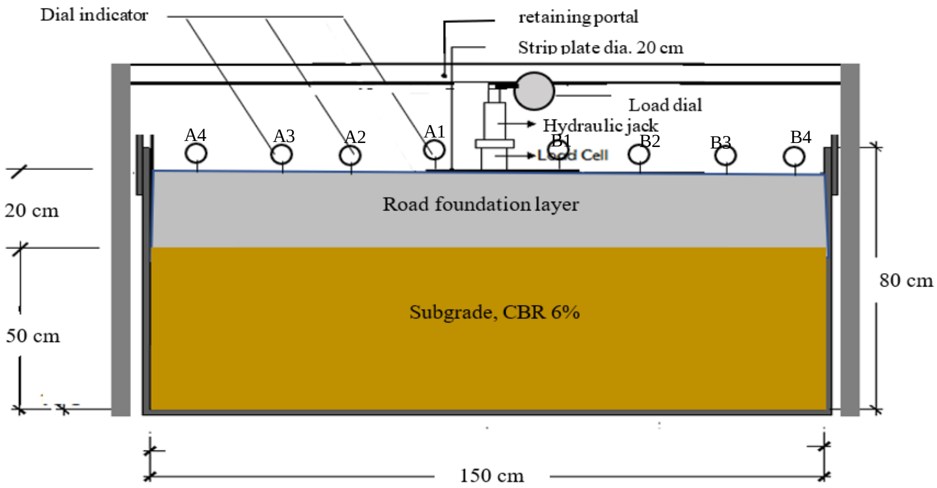


Figure 5. Physical test model schematic

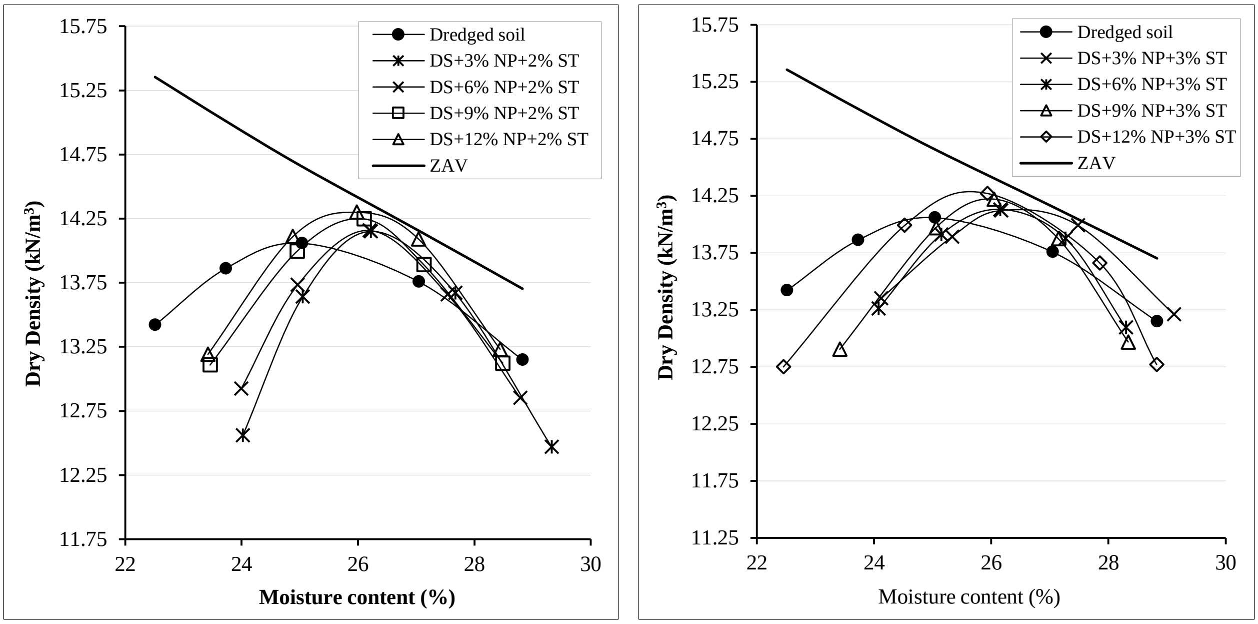
Figure 6. Model building (a) camera recorder; (b) load cell; (c) dial indicator; (d) magnetic stand; (e) load indicator

4. Results and Discussion

4.1. Compaction Test

The soil compaction technique is an approach to increase soil density by squeezing solid particles more tightly and reducing air volume. During the compaction phase, the density of the compacted unit is determined by the rate and technique of energizing as well as material characteristics such as gradation, particle shape, grain size, plasticity, and water content. The soil density is an important property in recognizing soil characteristics. Primarily this will relate to the ability of the soil to support loads, permeability, stability, and settlement that can occur if this soil is used as fill or foundation [42].

The test results indicated that the material properties, such as soil density and water content, were increased with the addition of SR and NM. The MDD increase was 0.4-1.7% for both 2% and 3% SR addition. The increase in MDD of stabilized soil can occur as the addition of fine-grained NM can enlarge the effective surface area of NM. Therefore, the large effective surface area of NM can make the cation exchange reaction can occur more optimally. In addition, flocculation-agglomeration reactions also occur in soil stabilized with materials that have pozzolanic properties, causing the soil to become denser. Similar properties are found in other references related to cohesive soils stabilized with pozzolanic materials [43, 44]. At the same time, the increase in OMC occurred by 3.6-4.7%. This increase in OMC occurs because the involvement of SR enlarges soil pores so that the soil requires more additional water. At the same time, there is also an increase in the surface water adsorption process caused by the addition of fine pozzolanic particles. Other researchers also reported this phenomenon [45].



(a) (b)

Figure 7. Compaction curve of stabilized dredged soil: (a) 2% SR; (b) 3% SR

4.2. Unconfined Compressive Strength (UCS)

The effect of adding shredded rubber and pozzolanic minerals has an impact on increasing the UCS value of the stabilized dredged soil. It can be seen that the addition of these additives increases the UCS value of the dredged soil by 3-4 times compared to the UCS of the original soil (see Figure 8). This increase occurred at all curing periods 7, 14, and 28 days. The increasing UCS value is caused by the pozzolanic reaction, which results in a bonding effect between particles in the soil as well as reinforcement of the soil interface due to the addition of fibers in the form of rubber shreds into the dredged soil sample. The results obtained in the UCS properties test of this dredged soil are similar to the results obtained by other researchers who conducted similar studies [6, 15, 46].

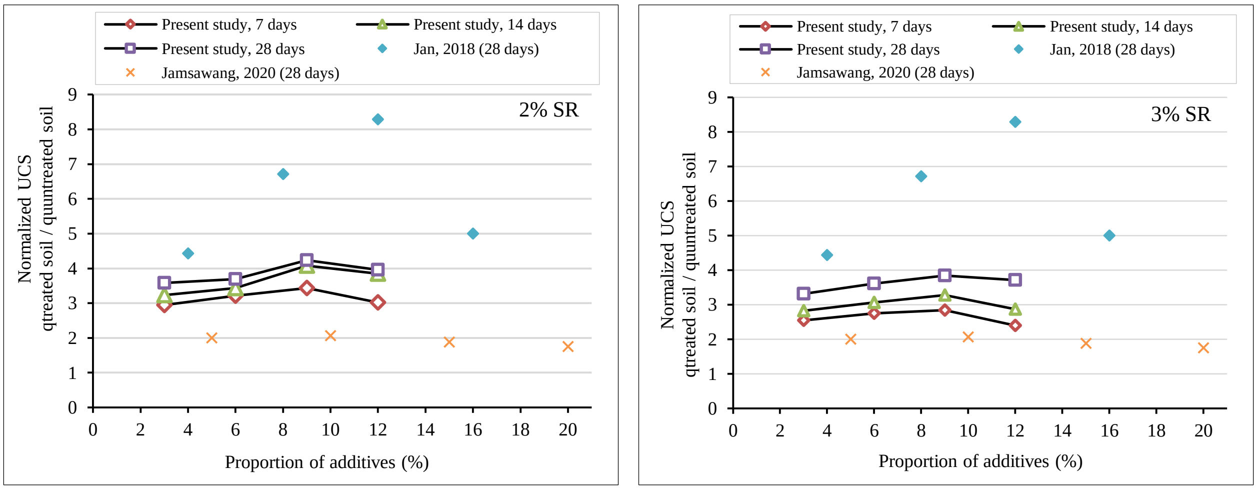


Figure 8. Normalized UCS value 2% SR (left) and 3% SR (right)

Adding shredded rubber composition from 2% to 3% causes a slight decrease in the compressive strength value. It was also reported by other researchers, who stated that increasing the proportion of SR will decrease the mechanical properties of the soil, especially in terms of its bearing capacity. It occurs because adding more SR fibers will weaken the bond between particles due to the involvement of rubber fibers in the interface conditions of soil grains [47]. In addition, if we look at the graph in Figure 8, it can be seen that the DS+SR+NM composition has an optimum value, which is at the proportion of 9% NM, both at the addition of 2% and 3% shredded rubber. Other research also found similar results [5, 6], where adding additives can produce the maximum UCS value in dredged soil stabilization.

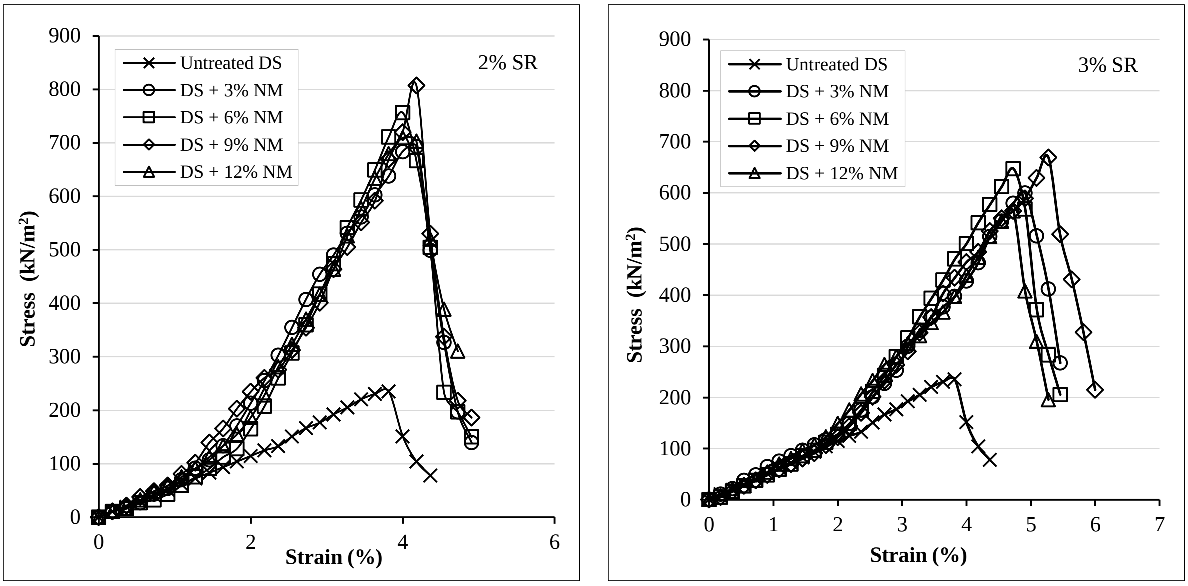


Figure 9. Stabilized DS stress-strain relationship with 2% SR (left) and 3% SR (right) at 7 days of curing

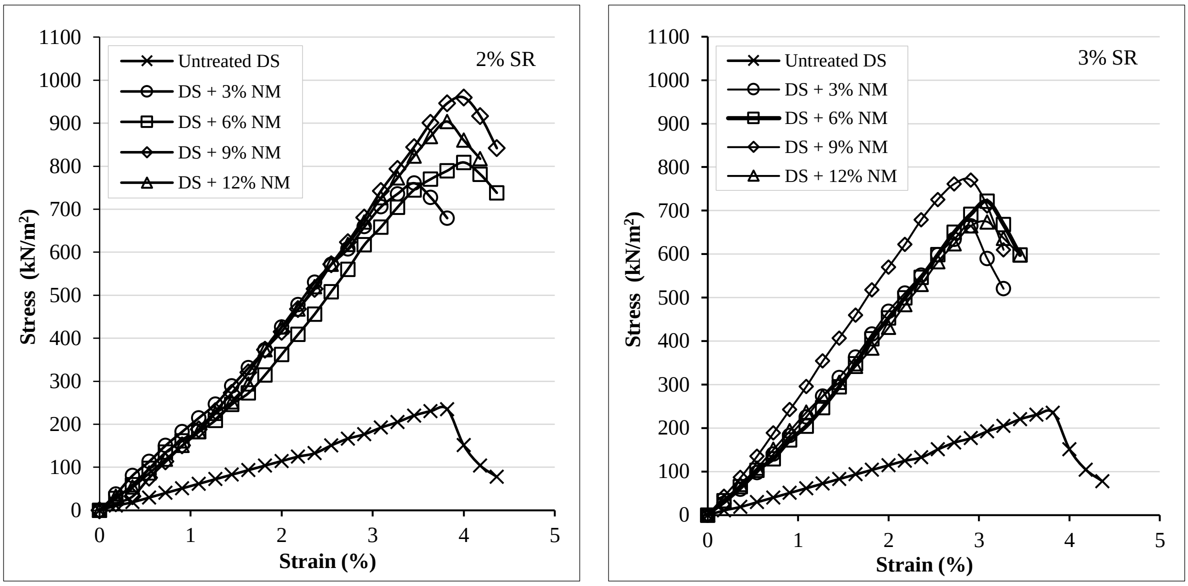


Figure 10. Stabilized DS stress-strain relationship with 2% SR (left) and 3% SR (right) at 14 days of curing

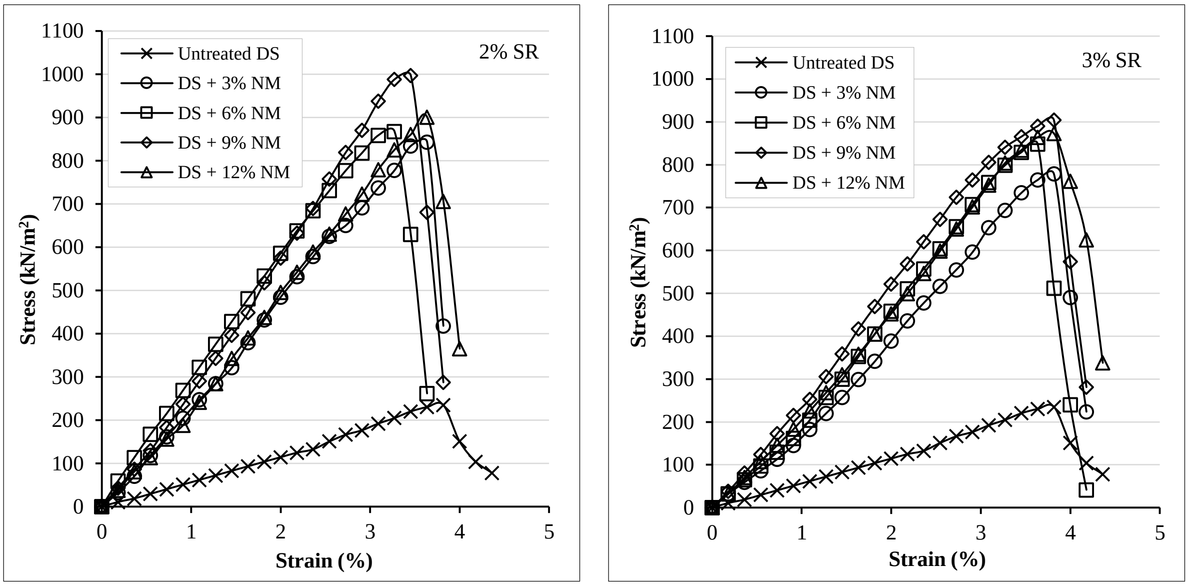
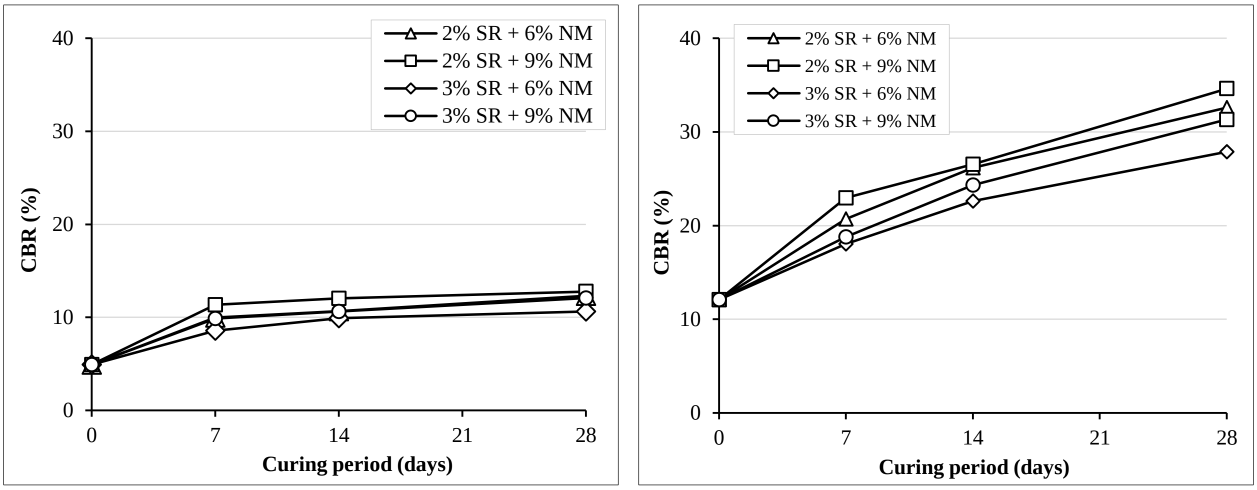


Figure 11. Stabilized DS stress-strain relationship with 2% SR (left) and 3% SR (right) at 28 days of curing

Meanwhile, based on the stress-strain relationship graph, it can be seen that the stabilization effort caused an increase in the secant elasticity modulus of the soil by 3-5 times as the curing time increases. It means the stabilized dredged soil was getting brittle compared to the un-stabilized. It is in line with the condition of the pozzolanic reaction effect, which causes an increase in the compressive strength of the soil [22]. The stress-strain relationship of the UCS test results is presented in Figure 9 to 11.

4.3. California Bearing Ration (CBR)

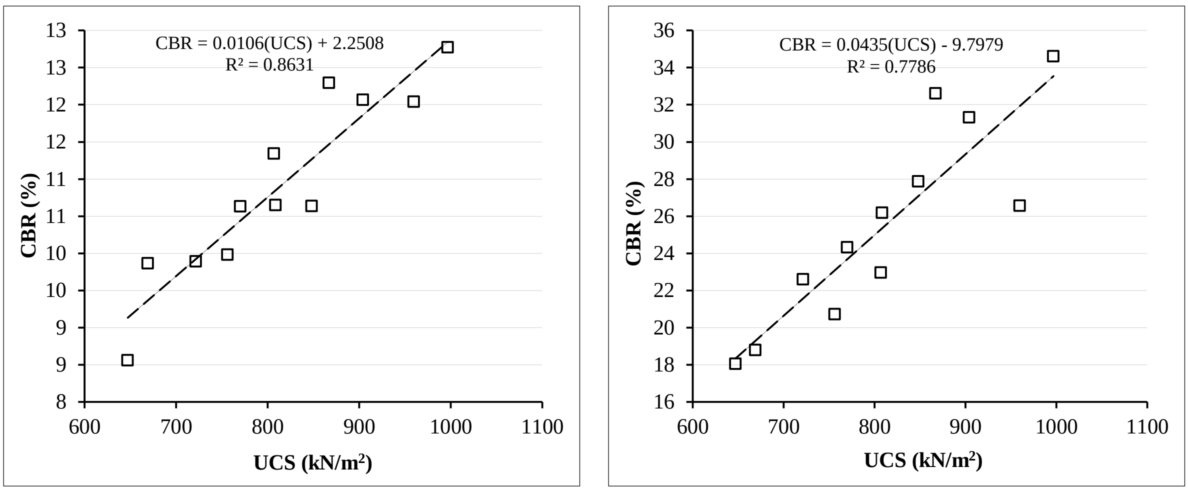
The CBR values of the dredged soil stabilized with SR and NM, both in the soaked and un-soaked state, are presented in Figure 12. In general, it can be seen that there is a satisfactory increase in the CBR value of the treated soil compared to the CBR value of untreated soil. This increase is in line with the increase in SR and NM involvement. However, it is observed that the CBR value slightly decreases when the amount of SR is added to the stabilized soil. The increase in CBR value of treated soil reaches 2-3 times the CBR value of untreated soil. Similar to the increase in UCS value previously described, the increase in CBR value is also caused by the involvement of pozzolanic binder material in the stabilization soil mixture [8]. In addition to the very fine grain size factor of the binder involved in the soil pores, the curing time factor also plays an essential role in increasing the CBR value. The curing time provides an opportunity for the pozzolana reaction to occur so that it correlates with the increase in the bearing capacity of this soil [18]. Results with similar mechanical properties were also found by other researchers who showed an increase in CBR values due to adding FA as a pozzolanic additive [6]. Figure 12 also shows differences in the CBR values of soaked and un-soaked conditions. When referring to the soaked CBR value, this dredged soil can be used as a road subgrade layer with excellent quality (above 10% CBR). Meanwhile, if we look at the un-soaked CBR value, the stabilized dredged soil can be used as a subbase layer in the pavement foundation (above CBR 20%). It all meets the requirements as stated in the Indonesian national standard regulations for road pavements [48].



(a) (b)

Figure 12. CBR value of stabilized soil: (a) soaked, (b) un-soaked

The relationship between the mechanical properties of the stabilized soil is presented in Figure 13.



(a) (b)

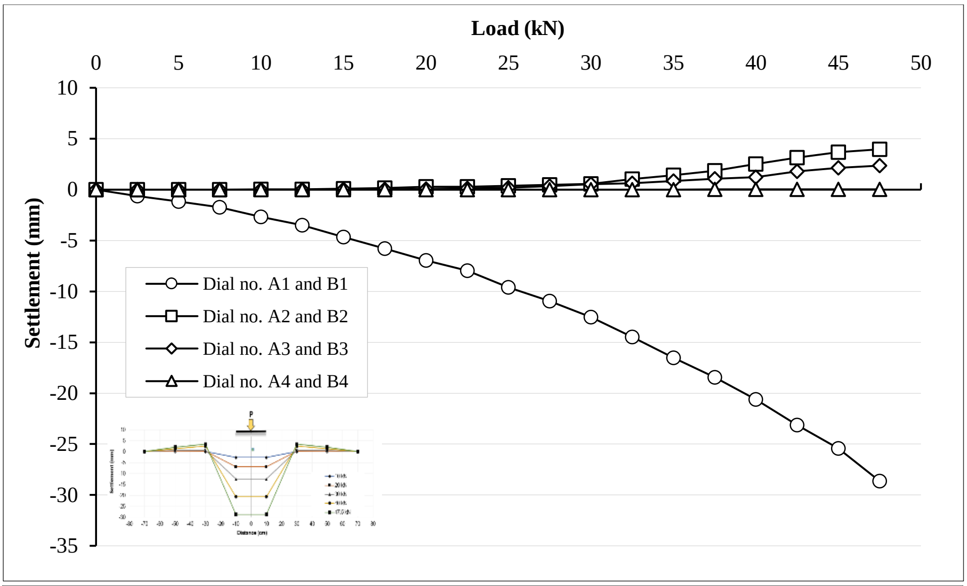
Figure 13. CBR vs UCS mechanical properties relationship: (a) soaked, (b) un-soaked

The relationship between these parameters is presented as a positive linear relationship. A positive correlation indicates that the two parameters move in the same direction. It indicates that the stabilization effect on the mechanical properties of CBR and UCS have similar behavior. The strong relationship is illustrated in the graph in Figure 13. The value of the relationship has an R^2 above 0.75. A positive correlation relationship between parameters is also suggested by other researchers [6].

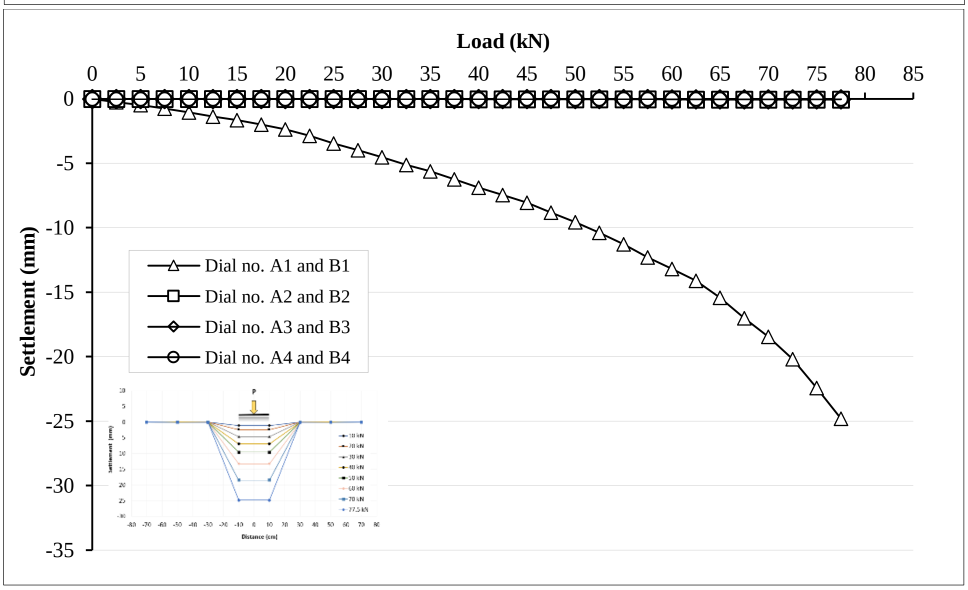
4.4. Strip Footing Test

Strip footing tests are conducted to test the performance of road foundation layers under static loads. The tests were conducted in three schemes. The first test scheme was to test the standard sand-gravel subbase embankment. This standard sand-gravel embankment has a minimum CBR value of 20%, following the required standard [48]. The second and third test schemes were dredged soil embankment models stabilized with SR and NM. The composition of the strip footing test model was determined based on the stabilized soil sample element test that had been conducted previously. The element test's previous results showed that the mixing composition of 2% SR + 9% NM met the technical criteria to be used as the desired foundation layer embankment (subbase). The curing period was 7 days for the second test model and 14 days for the third test model. Determining the curing period on this model is based on the previous properties test, which stated that after 14 days, the mechanical properties do not significantly increase [41]. Moreover, at the field application level, construction project engineers need a shorter time to complete their projects to achieve the given targets.

The settlement measurement was performed by installing dial indicator devices (A1-A4 and B1-B4) along the centerline of the longitudinal direction of the embankment (see Figure 5). The strip footing device was placed in the center of the embankment such that the loading condition was symmetrical in all directions of the test embankment. The test results are presented as a load-settlement relationship graph in Figure 14.



(a)



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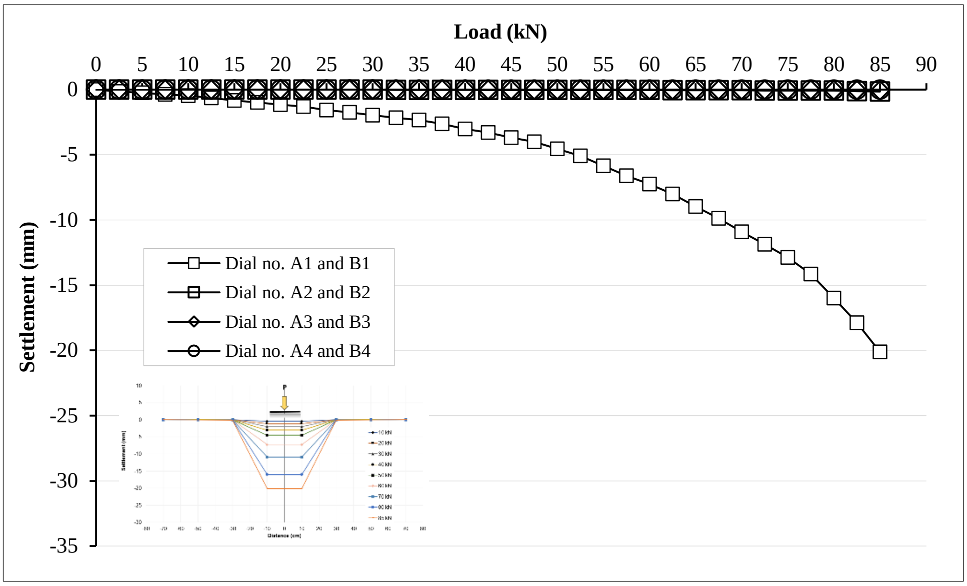

(c)

Figure 14. Load-settlement behavior of embankment (a) san-gravel; (b) DS stabilized 7 days; (c) DS stabilized with 14 days

The sand-gravel embankment shows considerable settlement at maximum loading. The settlement at points A1 and B1 was 28.64 mm at a loading of 47.5 kN (see Figure 14-a). While at points A2-A4 and B2-B4, an upward deformation decreases slowly toward the test container's edge. The shear failure character of the embankment causes this observed deformation. Other researchers also found the same phenomenon [41]. Furthermore, the second and third model tests also found a settlement. However, the settlement values in the second and third models are smaller than in the first, namely 24.8 mm at a loading of 77.5 kN and 20.12 mm at a loading of 85 kN, respectively (see Figures 14-b and 14-c). A different phenomenon is seen in the second and third models compared to the first model: there is no significant upward deformation. It was attributed to the effect of the inclusion of shredded rubber in the embankment mix. The addition of the shredded rubber fiber increases the shear strength of the embankment.

Figure 15 shows a comparison of the settlement value that occurs in the three models tested. It can be seen that the embankment can provide satisfactory performance. The performance of the stabilized embankments conducted in this study was measured by comparing the vertical load-bearing capacity of each embankment at a 20 mm settlement. As shown in Figure 16, the results show that the DS embankment stabilized at 14 days of curing provides 116% better performance and 84% better performance than the DS embankment stabilized at 7 days.

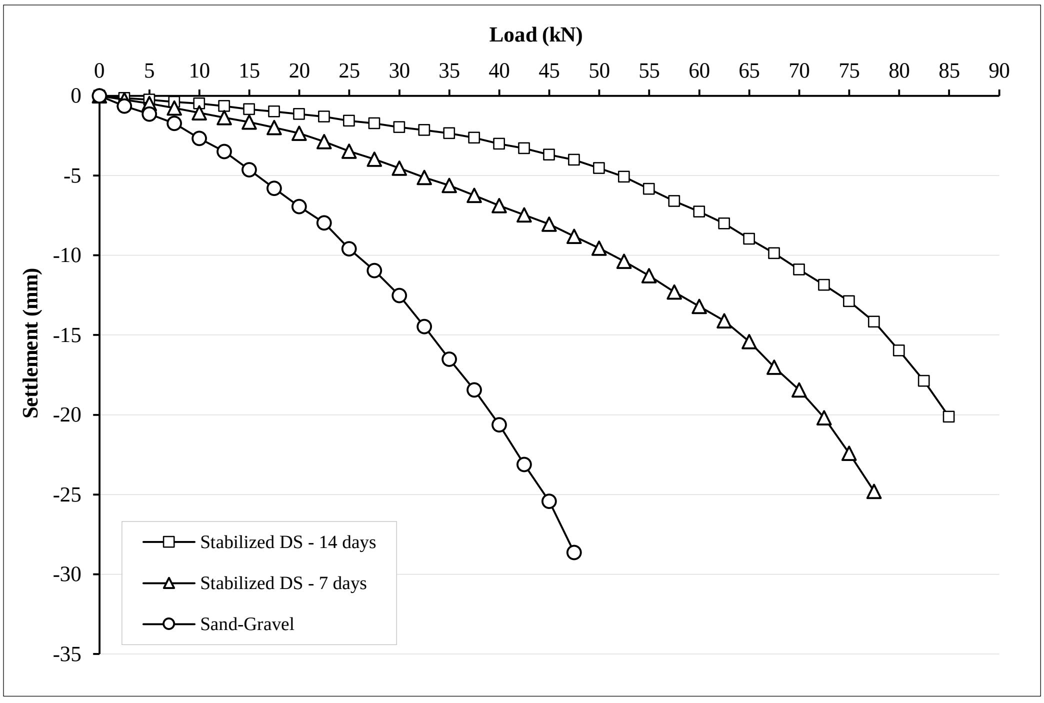

Figure 15. Comparison of settlement in strip footing test

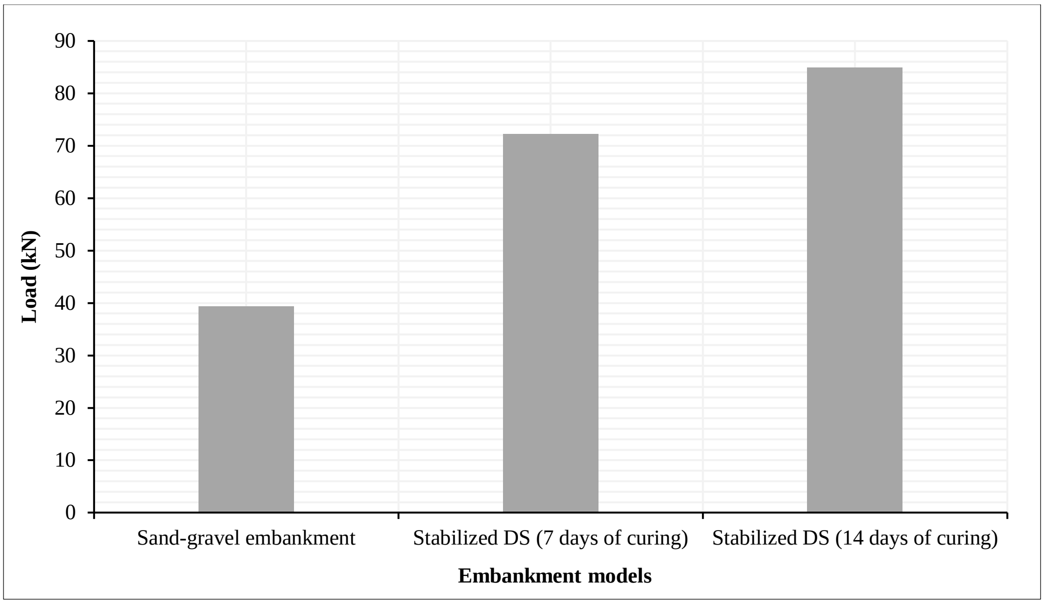

Figure 16. Histogram of road sub-base foundation layer embankment performance

5. Conclusion

The results of this study prove that the inclusion of shredded rubber (SR) and natural minerals (NM) has a satisfactory effect on improving the mechanical behavior of dredged soil. Adding SR and NM to the dredged soil has been shown to increase the UCS and CBR values of the dredged soil in line with the additional curing period. The UCS value of the stabilized dredged soil increased by 3–4 times compared to the un-stabilized soil. At the same time, the CBR value increased by 2-3 times for both unsoaked and soaked conditions. The increase in mechanical values is believed to occur due to the flocculation-agglomeration process from the cementation reaction of natural minerals and the addition of shredded rubber. As a result, the dredged soil becomes stiffer but still has enough ductile behavior. The optimum result for mixture proportion by adding 9% NM provides good insight that this addition has good economic value due to the relatively small addition.

Strip footing tests on SR and NM stabilized dredged soil showed satisfactory results. The test results showed increased bearing capacity of the soil embankment as the road foundation layer. The phenomenon of reduced settlement characterizes it due to static loading. In addition, it can also be proven that there is no shear failure in the stabilized dredged soil embankment due to the effect of adding rubber fibers. The increase in shear strength characteristic is caused by the rubber fiber inclusions that provide additional strength that functions as a "bridging effect" on the embankment. The performance of the SR and NM stabilized dredged soil embankments was 84% and 116% at 7 and 14 days of curing, respectively.

6. Declarations

6.1. Author Contributions

Conceptualization, K.A.U. and T.H.; methodology, K.A.U.; software, K.A.U.; validation, T.H., A.B.M., and A.A.; formal analysis, K.A.U.; investigation, K.A.U.; resources, K.A.U.; data curation, K.A.U.; writing—original draft preparation, K.A.U.; writing—review and editing, K.A.U. and T.H.; visualization, K.A.U.; supervision, T.H., A.B.M., and A.A.; project administration, K.A.U.; funding acquisition, K.A.U. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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