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EFFECT OF EPOXY RESIN AND CEMENT AS GROUT ON THE MECHANICAL PROPERTIES OF SILT

*Devi Oktaviana Latif[1], Suraida Nur Kumala[1], Adhitya Yoga Purnama[1], Iman Haryanto[1], Rafa Amatullah Aini[1], Zuhair Hafidz Al Mubarok Kaluku[1]

[1]Department of Civil Engineering, Vocational school, Universitas Gadjah Mada, Indonesia

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ABSTRACT: Grouting is a method or technique that is carried out to improve underground conditions by injecting material that is still in a liquid state, through pressure (it can inject semi-viscous materials) so that the material will fill in all the existing cracks and holes. The main purpose of grouting in this study is to strengthen the soil and increase soil strength. The injection material will enter the soil pores, react with the soil, and harden to form a strong and sturdy bond. The grouting material in this study was applied to filling boreholes in pile foundations when a load is applied, will be held by the frictional resistance between the piles, cement, epoxy paste, and soil. The filling materials for this grouting are soil paste, cement, and epoxy resin which were observed in a laboratory with a tensile test system to see the behavior of increasing soil strength at 7 days, 14 days, and 28 days. Based on the results of laboratory tests carried out, the use of epoxy resin, cement, soil, and water as grouting materials for foundations increases the soil stiffness value expressed in the modulus of elasticity value and increases the soil shear parameter values, namely the values c and φ. The increase in value occurs at the ratio ER/W = 80/180 where with a longer curing time, namely 28 days, the value of shear stress, c and φ and the modulus of elasticity are each 2.3kg/cm^2; 39,520; 12.08 MPa

Keywords: Grouting, Soil strength, Epoxy resin, Soil paste

1. INTRODUCTION

Foundations are underground constructions that function to distribute loads into the ground. In supporting the load above, the behavior of the pile foundation depends on the tip resistance, friction resistance, and the combination of tip resistance and friction resistance. Several factors influence the behavior of piles in supporting loads, namely the type of soil and the way the piles are installed (dried and drilled). In soil located on soft soil types that have a low bearing capacity, the behavior of the pile depends on the frictional resistance of the pile. So, to be able to withstand the load received, the foundation must be extended to a relatively deeper depth. Apart from that, the effect of driving piles in cohesive soil (clay and silt) will usually result in gaps due to driving [1-3], a rise in the surface of the soil around the piles followed by soil consolidation and a temporary decrease in the shear strength of the soil. By applying drilling techniques before installing the foundation, you can avoid an increase in land elevation around the piling location caused by changes in soil volume and vibrations produced by the process of driving piles in silt soil. Therefore, the use of drilling techniques is more advisable. Carrying out drilling before installing the foundation will certainly result in problems, especially the problem of decreasing frictional ability around the pillars, so to increase the frictional ability of the soil around the foundation, additional material is provided using the grouting method. Grouting is a method for increasing the bearing capacity of a foundation by injecting material into the foundation hole with the aim of the injected material improving the properties of the soil. This additional material is expected to increase the frictional resistance value between the foundation and the soil. Research on grouting for increased stability was also tested by Sumiyanto, 2023. Where geopolymer materials are used as soil column injection materials. The results of the study showed that there was a five-fold increase in the value of strong pressure (q_{u}) using geopolymer injection. The additional materials used in this research were a mixture of soil, epoxy (hardener and resin), water, and cement. Epoxy resin has unique characteristics, namely good bonding, high chemical stability and resistance, and improved mechanical properties [5]. Because of its characteristics, epoxy resin is applied as a composite material [6-11], adhesive and coating [12-17], and electronics [18-20]. The use of epoxy as a soil improvement material has been widely recommended by several researchers [21-23] because it is considered significant in increasing the mechanical strength of the soil. Anagnostopoulos, 2015 researched the potential for using epoxy resin for soil stabilization. The results of the research show that adding water to the epoxy resin will reduce the strength value in several research samples, but adding cement to the epoxy resin and water will increase the strength according to the increase in cement content. The resin injection method was also researched by Traylen et al., 2018, who performed a resin injection technique for tin repair to reduce the potential for liquefaction in addition to re-leveling the structure after soil subsidence. Due to the non-intrusive nature of the installation process, it can be used under existing structures to reduce the liquefaction potential. Blake, 2022 research epoxy resin which will be injected as a soil repair method to reduce the potential for liquefaction, namely the melting of soil due to earthquakes. The results obtained were that with resin injection there was an increase in the strength values observed by in situ testing. Research on epoxy resin was also conducted by Latif, 2019, The research carried out was to examine the increase in interface friction between clay and soil given a mixture of epoxy resin and soil. The results of his research showed that there was an increase in interface friction in tensile tests carried out in the laboratory. Apart from that, the use of cement is also an option for improving the mechanical properties of soil in an efficient, cheap, and easy way. In this research, epoxy resin was used as an additional material to improve the mechanical properties of friction resistance. In previous research, researchers have conducted research on friction paste with a mixture composition consisting of cement, soil, and water. Then development is carried out where the mixture composition is added with epoxy resin, cement, soil, and water. The use of this additional material is applied to increase the bearing capacity of the soil, namely the frictional resistance capacity between the pile and the soil. This research also contributes to the pile installation method using the pre-boring method and additional material injection to obtain the mechanical strength of the mixture, the test will be carried out using direct shear. The test objects were observed with different curing time treatments, namely 7 days, 14 days, and 28 days. results of direct shear testing then observed strain stress behavior, soil shear parameters on untreated soils, and treatment soils with epoxy paste with moisture content variations. The next research development is observations related to chemical properties and variations in soil types for mixtures of epoxy resin, cement, soil, and water.

2. RESEARCH SIGNIFICANCE

Research on epoxy resin, cement, and soil materials is part of research on friction paste. Previous research examined the addition of cement paste and soil using the pre-boring method, then the cement paste and soil were inserted into the borehole. Weaknesses from previous research also occurred in the pre-boring method and cement paste was inserted into the drill hole. In this method the calculated total bearing capacity. while an increase in friction resistance capacity is expected. With these conditions, this research was carried out in which materials were added, namely epoxy resin, cement, and soil with variations in the addition of water so that it was hoped that the elastic behavior of the soil and soil strength would increase. Apart from that, this research also provides a different method, namely pre-boring then installing the poles in the drill hole then additional material is added by injection.

3. MATERIAL AND METHODE

3.1 Material Used

The soil material used in this research is disturbed soil originating from Kalimantan. Physically, the grains look smooth, and red in color and become soft when exposed to water. Based on the test results of coarse sieve analysis and hydrometer analysis, the percentage of sand was 11.1%, silt 32.19%, and clay 56.8% with a value of Cu = 55.56 and Cc = 0.2 so the soil sample used was soil. with poor grades. Apart from physical testing, mechanical soil testing was also carried out which is presented in Table 1.

Table 1. Soil Properties

No	Technical Data	unit	Test Result
1	Water Content (w)	%	2.87
2	Specify Gravity (G)		2.68
3	Dry unit Weight	gr/cm^3	1.68
4	Liquid Limit (LL)	%	45
5	Plastic limit (PL)	%	30.16
6	Shrinkage Limit (SL)	%	22.32
7	Plasticity index (PI)	%	14.84
8	Finer No. 200	%	87.6
9	Cohesion (c)	kg/cm^2	0.77
10	Friction angle (φ)	0	8.53

From Table 1, according to the Unified Soil Classification System (USCS), the liquid limit is (LL) = 45% < 50%; and the Plasticity Index (PI) = 14.84% and based on the PI vs LL diagram, the soil is a type of inorganic silt with low plasticity (ML).

Epoxy is a copolymer formed from two different chemicals, namely resin and hardener. When these two compounds are mixed, they produce a very stiff and strong polymer. The polymerization process is called curing. The epoxy mixture reacts by hardening gradually and has a flexible texture and good stickiness. Epoxy is the most widely used type of resin because it has the best quality compared to other types of resin. This type of resin is also the most popular safe when used. The epoxy resin used is a commercial product with the trade name EPOXY ALF. In this study, a resin and hardener ratio of 2:1 was used, and water was added as much as 130 ml, 150 ml, and 180 ml.

3.2 Experimental Procedure

The procedure for manufacturing the material to be injected into the borehole is as follows: mix the soil passed through sieve No. 40 with a variation of the percentage of cement (Portland cement) content from the weight of the soil. The material to be mixed is presented in Fig 1. Then measure the water in a glass measuring 130 ml, 150 ml, and 180 ml according to the composition. Mix the resin and hardener (epoxy) using a spatula/spoon in a ratio of 2:1 so that the total weight is 80 gr. The material is then injected into the borehole analogously on a laboratory scale using Direct Shear testing based on ASTM D 3080-98 standards. Direct shear testing for research specimens used for direct shear testing consists of 3 layers, namely 0.95 cm thick soil, 0.05 cm thick friction paste mixture, and 1 cm thick concrete with a diameter of 6.3 cm. The shear specimen specimens were immediately cured for 7, 14, and 28 days. Illustration of the test object as in Fig 2.

Fig 1. Soil Mixture Material to be Injected into The Borehole

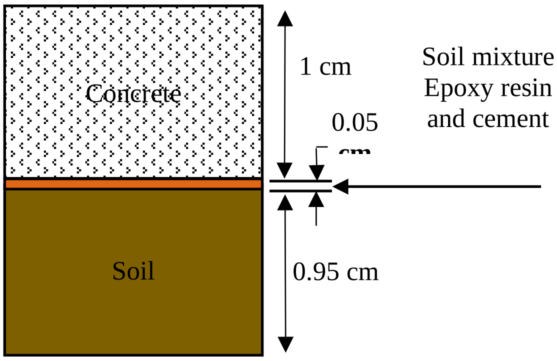


Fig 2. Illustration of Direct Shear Test Sample

After curing, tests were carried out using direct shear test equipment in consolidated undrained conditions. Direct shear testing produces ground displacement data per time interval. Watch reading (dial) on a direct slide device consists of two reading dials, namely the time dial which is carried out starting from 0,15,30 and then constant increments every 30 dial readings. Meanwhile, the reading of the shift dial is carried out simultaneously with the reading of the time dial. The speed used is speed no.3, and the use of speed no. 3 is based on ASTM D 3080 – 03 rules, namely the shift speed is ±1% of the diameter of the test object. According to the tool calibration, speed no. 3 represents a shift speed of 0.60 mm/minute. The loads used are 3.167 kg, 6.334 kg, and 12.714 kg to produce normal stresses approaching 0.99 kg/cm^2, 1.99 kg/cm^2, and 3.99 kg/cm^2 and are adjusted to soil conditions. The direct Shear test was performed on 36 samples whose data are presented in Table 2

4. RESULTS AND DISCUSSION

To obtain the mechanical properties of the soil, a direct shear test was carried out on the existing soil, the soil was mixed with epoxy resin and cement with varying water content with an ER/W ratio of 80/130; 80/150; 80/180 at a curing time of 7,14,28 days. The test results are presented in Fig 3, fig 4, and Fig 5. Figure 3(a) shows the trend of increasing stress values at 7 days of curing time at ER/W 80/130; 80/150; 80/180 1.16 each; 2.06; 2.92 kg/cm^2 or 130.3%; 231.5%; 328% of untreated soil conditions. Figure 3(b) shows the trend of increasing stress values at 14 days of curing time at ER/W 80/130; 80/150; 80/180 1.94 each; 2.8; 3.8 kg/cm^2 or 217.9%; 314.6%; 426.9% of untreated soil conditions. Figure 3(c) shows the trend of increasing stress values at 28 days of curing time at ER/W 80/130; 80/150; 80/180 2.8 each; 3.8; 4.1 kg/cm^2 or 314.6%; 415.7%; 460.7% of untreated soil conditions. Maximum shear stress data of each mixture with curing time are presented in Table 3.

Table 3. Maximum Stress Values for curing 7,14,28 days

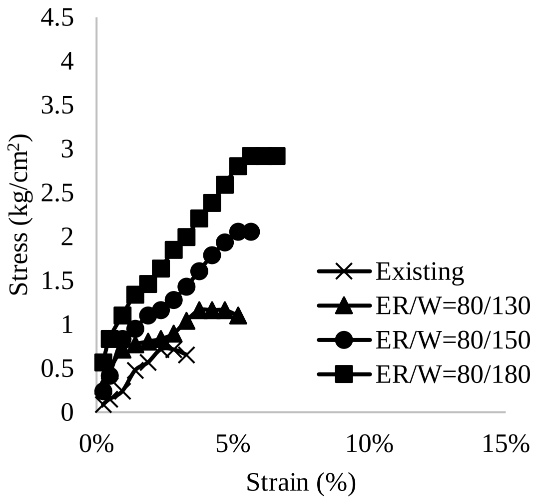
Days	ER/W	Stress (kg/cm^2)
7	Existing	0.66
	80/130,00	1.16
	80/150,00	2.06
	80/180,00	2.92
14	80/130,00	0.81
	Existing	1.93
	80/150,00	2.83
	80/180,00	3.81
28	80/130,00	0.92
	Existing	2.82
	80/150,00	3.72
	80/180,00	4.14

From the graph, the increase in stress at 14 days reached 85% of the strength. The relationship between stress and strain presented in Fig 4 shows an almost linear pattern. the elastic zone extends to the strain ranges of 4%, 4.7%, and 5.1% at ER/W of

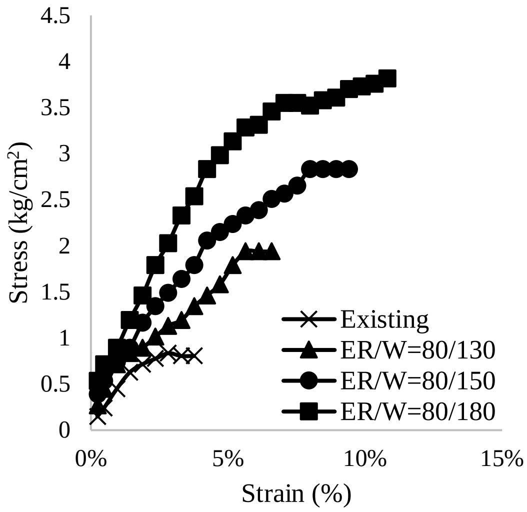
80/130, respectively; 80/150; and 80/180. The linear pattern then continues in the plastic zone. Deformation in the plastic zone occurs up to a certain strain but does not experience failure. This shows the elastoplastic behavior and the strong adhesion that occurs between the mixture of epoxy resin, cement, and silt. The maximum value occurs at the ratio ER/W = 80/150 with a shear stress value of 4.25 (kg/cm^2). Fig 4 and Table 4 show the value of soil shear strength, namely the relationship between normal stress and shear stress, which then draws a failure envelope line on curing days 7, 14, and 28 for conditions ER/W = 80/130; 80/150; 80/180. An increase in the shear value occurred in a mixture with a ratio ER/W= 80/180 and over time of curing the value of the shear parameter increased. This condition can be seen in the graph which shows that as the curing time increases, the failure envelope graph becomes straighter. This indicates an increase in the values of c and φ. The range of c values on days 7,14,28 days respectively while the φ value was. The greater φ value indicates the increase in friction or interface that occurs between soil, epoxy resin paste, cement, and water with concrete.

Table 2. Shear Stress values for untreated soils and variations of treatment soils using resins.

ER/W (gr/gr)	Ring	Shear Stress (kg/cm^2)	Normal Stress (kg/cm^2)	Days
Untread Soil	1	0,75	0,95	7
	2	1,01	1,91	
	3	0,72	3,82	
80/130	1	0,00	0,00	
	2	0,00	0,00	
	3	0,00	0,00	
80/150	1	1,16	0,95	
	2	1,62	1,91	
	3	2,06	3,82	
80/180	1	1,40	0,95	
	2	2,36	1,91	
	3	2,92	3,82	
Untread Soil	1	0,79	0,95	14
	2	1,04	1,91	
	3	0,83	3,82	
80/130	1	1,01	0,95	
	2	1,88	1,91	
	3	1,94	3,82	
80/150	1	1,19	0,95	
	2	2,15	1,91	
	3	2,83	3,82	
80/180	1	1,39	0,95	
	2	2,50	1,91	
	3	3,82	3,82	
Untread Soil	1	0,83	0,95	28
	2	1,16	1,91	
	3	0,95	3,82	
80/130	1	1,04	0,95	
	2	1,85	1,91	
	3	2,83	3,82	
80/150	1	1,36	0,95	
	2	2,21	1,91	
	3	3,73	3,82	
80/180	1	1,97	0,95	
	2	2,50	1,91	
	3	4,25	3,82	



(a)



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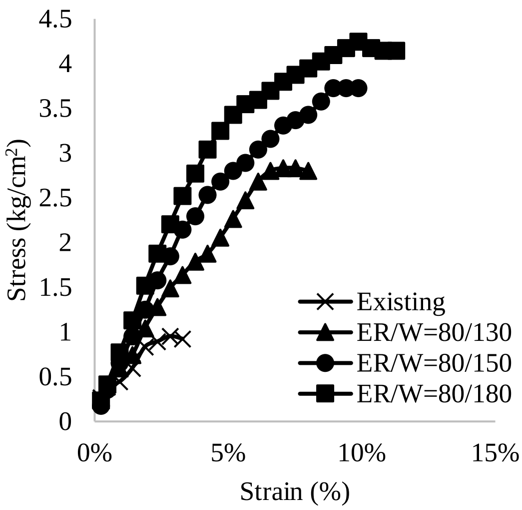
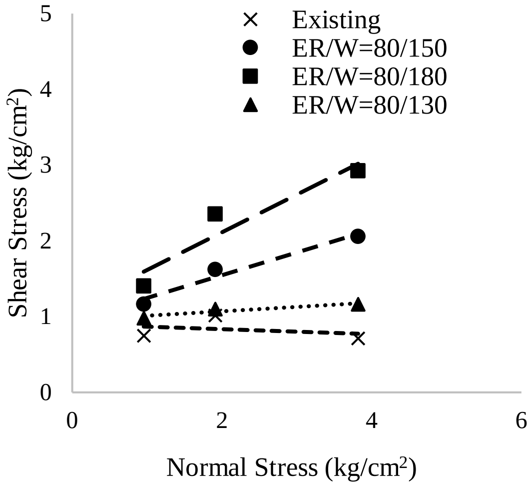
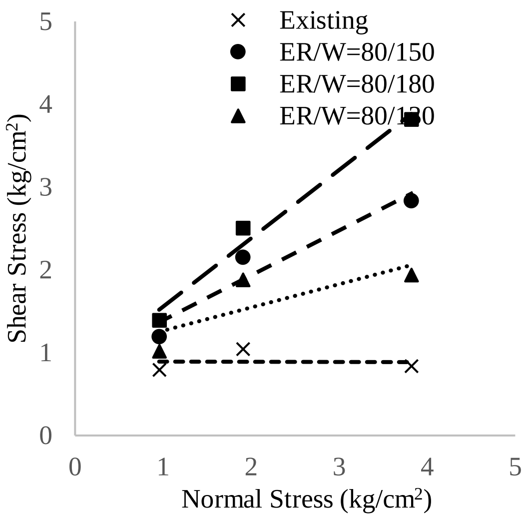


(c)

Fig 3. Typical stress-strain curve of Silt mixes with different ratios ER/W (a) 7 days, (b) 14 days, (c) 28 days



(a)



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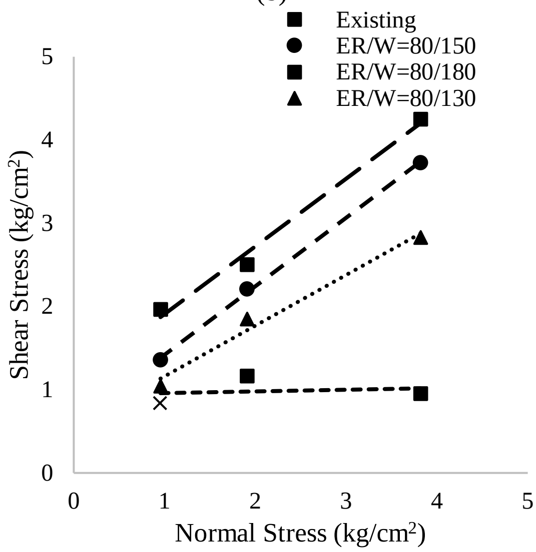

(c)

Fig 4. Failure Envelopes of Silt Mixes with Different Ratios ER/W (a) 7 days, (b) 14 days, (c) 28 days

Table 4. Soil Shear Parameter Values During the Curing Period of 7,14,28 Days

Parameter \ Days	ER/W =80/130			ER/W =80/150			ER/W =80/180		
	7	14	28	7	14	28	7	14	28
C (kg/cm^2)	0,96	0,99	0,55	0,95	0,85	0,59	1,13	0,73	1,1
ϕ (^{0})	3,09	13,50	31,38	16,91	28,37	39,69	26,34	39,52	39,52

Table 5. Modulus of Elasticity Values for curing 7,14,28 days

Days	ER/w	Modulus of Elasticity (MPa)
7	80/130,00	3,91
	80/150,00	5,07
	80/180,00	6,50
14	80/130,00	6,00
	80/150,00	7,50
	80/180,00	9,52
28	80/130,00	8,00
	80/150,00	11,36
	80/180,00	12,08

Fig 5 and Table 5 are soil stiffness values or modulus of elasticity obtained from the stress-strain relationship graph in direct shear testing. The modulus of elasticity is a quantitative measure that shows the level of resistance of a material to deformation when subjected to external force. The deformation in question includes changes in the shape of the object. The greater the elastic modulus of the material, the less likely the material is to deform elastic modulus value of the soil increases with increasing curing time and the highest stiffness value in the ER/W = 80/180 mixture is 12.08 MPa. An increase in the value of shear stress, soil shear parameters, and modulus of elasticity, there is an increase and improvement in the mechanical properties of the soil

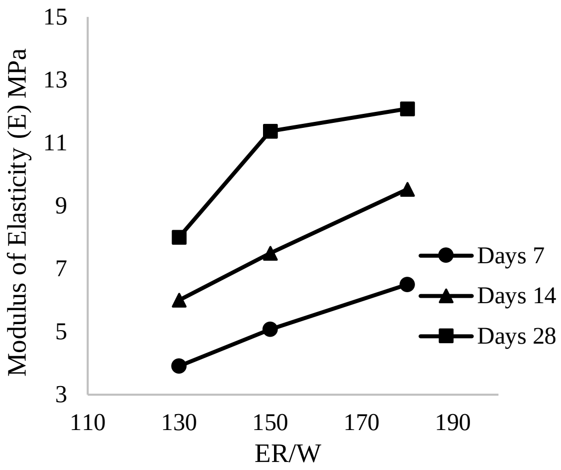

Fig 5. Comparison of the Modulus of Elasticity in Silt mixed with Epoxy resin with variations in ER/W at curing times of 7,14,28 days

5. CONCLUSIONS

Based on the results of laboratory tests carried out, the use of epoxy resin, cement, soil, and water as grouting materials in foundations can improve the mechanical properties of silt soil which is shown in the increase in shear stress values whereby adding epoxy resin, cement, and water the elastic and plastic zones of the soil becomes longer and the soil behavior does not experience collapse. The addition of epoxy resin also increases the soil stiffness value which is expressed in the elastic modulus value and increases the soil shear parameter values, namely c and φ values. The increase in value occurs at the ER/W ratio = 80/180 where with a longer curing time, namely 28 days, the higher the values of shear stress, c and φ and modulus of elasticity, respectively 2.3kg/cm^2; 39.52^0; 12.08 MPa

6. ACKNOWLEDGMENTS

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