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Analysis of subgrade repair using lime by modeling in the field for design of the foundation foundation of the rigid pavement micro pole

Moch. Fajar Rahmadhoni[1], Agus Tugas Sudjianto[1]✉, Aji Suraji[1], M. Cakrawala[1]
[1] *University Of Widya Gama Malang*

agustugas@widyagama.ac.id*

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Abstract

The subgrade is an important component in the road pavement structure because it functions as the main lining of the traffic load. However, the condition of the land on Jl. North Baruk III, Kedung Baruk, Surabaya, tends to be less stable because it is dominated by soil types such as soft sauce, plastic clay, and loose -grained soils that have low carrying capacity. This study aims to evaluate subgrade improvement using chemical stabilization methods with a mixture of dolomite lime of 6%, as well as analyzing its impact on the value of density, CBR, and carrying capacity of micro pole foundations. The method used is laboratory experiments and field modeling. The results showed that the addition of lime 6% increased the value of soil density from 95.84% to 99.70% (an increase of 4.03%), the CBR value from 2.53% to 4.09% (an increase of 61.66%), and the carrying capacity of the foundation of micro pole from 27.84 kN to 38.66 KN (increased 38.87%). Thus, the combination of lime stabilization and the utilization of micro pole effectively increases the carrying capacity and stability of the subgrade to support the rigid pavement construction.

Keywords: subgrade repair, dolomite lime, CBR, compaction, micro pole foundation, rigid pavement

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INTRODUCTION

Subgrade is the lowest layer in the road pavement structure that functions as the main support for the traffic load which is passed on from the pavement layer above it[1]. The quality and stability of the subgrade greatly affects the structural performance and age of road services. In the area of Jl. Baruk Utara III, Kedung Baruk, Rungkut District, Surabaya, soil conditions are dominated by soft silt, plastic clays, and loose -grained soils that have low carrying capacity. This type of soil has the potential to cause problems such as early cracks, uneven degrees, to failure of road structures[2].

Efforts to improve the quality of subgrade can be carried out through chemical stabilization methods, one of which is by adding dolomite lime into land granules the optimum mixture of dolomite lime for soil stabilization is 6%[3]. In addition, the use of micropile foundations (micropiles) can also be a soil strengthening solution from the mechanical aspect[4]. By combining chemical stabilization methods and foundation strengthening, it is hoped that an increase in the carrying capacity and the stability of subgrade more effectively.

This study aims to evaluate the effectiveness of stabilization of the increase in the carrying capacity of the foundation of micro pole as the basis of the rigid road pavement structure. Modeling is carried out directly in the field with a foundation dimension of 1.2m × 1.2m × 0.6 m, and test[5].

Several previous studies have investigated various soil stabilization approaches for problematic subgrade conditions. Domestically, Sudjianto et al. (2025) [3] confirmed that quicklime addition to expansive soil in East Java significantly reduced the plasticity index and improved CBR, consistent with findings in the present study. Research on soft alluvial soils in Indonesian urban areas has also demonstrated that lime dosages between 4% and 8% can effectively improve compaction characteristics, although the optimal dosage is highly site-specific. In the international context, Ahmed et al. (2024) [1] reported that recycled concrete aggregate (RCA) and fly ash as subgrade stabilizers increased CBR values by up to 78.5%, demonstrating the comparable effectiveness of industrial by-product-based stabilization relative to conventional lime treatment. Ewa et al. (2023) [2] showed that a combination of limestone dust and sugarcane bagasse ash improved CBR by 50%–78.5% and unconfined compressive strength by 23.8%–38.1% in subgrade soils, indicating that multi-component stabilizers may provide superior results in certain conditions. These comparisons highlight that while dolomite lime stabilization is an established and effective method, alternative or complementary stabilizers such as fly ash, cement kiln dust, and industrial by-products offer similar or potentially greater improvements depending on soil type and environmental context. The primary limitation of this study is its focus on a fixed lime dosage (6%) without systematic exploration of dosage variations or alternative binders. Future work may include a comparative analysis between dolomite lime and other agents (e.g., Portland cement or class C fly ash) to determine the most technically and economically optimal stabilization strategy for soft silt-dominant soils in the Surabaya region.

METHOD

This study applied an experimental approach through field modeling to evaluate the effect of soil stabilization with dolomite lime on the characteristics of subgrade[6]. This study includes a subgrade layer on Jl. Baruk Utara III, Kedung Baruk, Rungkut District, Surabaya. The sample was taken purposively by selecting the soil that reflects the dominant conditions, namely soft silt, plastic clay, and loaded soil which generally has a low carrying capacity[7].

The instrumentation used includes a sandcone test tool to measure the degree of field density, a field CBR test tool to test the carrying capacity of vertical loads, as well as auxiliary equipment such as horse stamper for compaction process. The stabilization material in the form of dolomite lime is added by 6% of the dry weight of the soil, based on the optimum levels obtained from the initial study. Calculation of the carrying capacity of the foundation of micro pole is done analytically using the approach[8] and [9], by entering the parameter of the field test results as the main input.

The implementation procedure begins with taking land from the location, followed by mixing dolomite lime according to the specified levels. The soil mixture is then put into a mold measuring 1.2 m × 1.2 m × 0.6 m as a foundation scale simulation. After the compaction process, a sandcone test is performed to measure density, followed by a field CBR test. The parameters of the test results are the basis for calculating the carrying capacity of micro pole. The entire series of activities, ranging from location preparation to data analysis.

Data are analyzed descriptively-quantitatively by comparing the value of density, CBR, and carrying capacity of the foundation of micro pole before and after stabilization. To guarantee the validity and reliability of the results, each test is carried out three times at different locations, and the average value is used as the final result. All tests follow the standards[10],[11],and[12], as well as the applicable geotechnical technical procedures. Equipment calibration is carried out before implementation to ensure data accuracy.

This method has a limited scope to the use of one dolomite lime (6%) and application on the field modeling scale. In addition, the calculation of the carrying capacity of micro pole foundations is done analytically, not through the actual load test in the field, so the results need to be interpreted contextually. Thus, the experimental procedures and designs used have been prepared to enable replication by other researchers in a similar context.

The analytical bearing capacity calculation of the micro pile foundation in this study follows the general formula $Qu = Qb + Qs - Wp$, where Qu is the ultimate bearing capacity, Qb is the ultimate end resistance, Qs is the ultimate skin friction resistance, and Wp is the weight of the pile. Several key assumptions were applied in this model: (1) the micro pile is modeled as a short rigid pile with a uniform cross-section of 2.5 cm diameter and embedded length of 60 cm corresponding to the field model dimensions; (2) the soil is assumed to behave as a homogeneous cohesive medium over the depth of embedment, with cohesion (c) values derived from the DCP-to-CBR correlation and the CBR-to-bearing capacity conversion; (3) the end resistance Qb is calculated using the net unit end bearing pressure $qb = 9c$ (for cohesive soil), applied to the base area of the pile; (4) the skin friction Qs is computed from the perimeter of the pile multiplied by the embedded depth and the unit skin friction $fs = \alpha \cdot c$, where α is the adhesion factor (taken as 0.5 for soft to medium cohesive soils per Hardiyatmo [8]); and (5) the pile weight Wp is calculated based on the assumed concrete unit weight of 24 kN/m^3. The field test parameters integrated into the model include the average DCP penetration rate (mm/blow), which is converted to cone resistance qc using the empirical relationship $qc = 37.5/DCP$, and subsequently transformed to CBR using the DCP-CBR correlation. The CBR value is then used to estimate the undrained shear strength (cu) through the relationship $cu \approx CBR / 10$ (in kg/cm^2), enabling computation of the bearing capacity components. This sequential integration of field data into the analytical model ensures that the results directly reflect in-situ soil conditions.

RESULT AND DISCUSSION

This study was conducted through two main stages, namely testing in laboratories and direct testing in the field, with the aim of evaluating changes in the characteristics of subgrade before and after repairs using dolomite lime as material stabilization. The main focus of this evaluation is the value of California Bearing Ratio (CBR) and soil density, which is an important indicator in assessing the carrying capacity and stability of the land on traffic loads. Pengujian laboratorium dilakukan untuk menentukan parameter dasar tanah seperti uji sifat fisis tanah. Furthermore, field testing is carried out by the CBR Field and DCP (Dynamic Cone Penetrometer) test method to obtain the actual data performance of soil that has been stabilized. The results of the two stages of the test are expected to provide a comprehensive picture of the extent of the effect of dolomite lime mixing on increasing carrying capacity and soil density. With this approach, a comprehensive understanding of the effectiveness of soil stabilization, both in terms of mechanical laboratories and actual responses in the field, which can be used as a basis for technical considerations in the work of repairing subgrade on the rigid road pavement project.

1. Laboratory Test

In this laboratory test only tests the physical properties of the soil. Testing the physical properties of the original soil in the 0% mixture and 6% include testing water content, specific gravity, content weight, liquid limit, and plasticity limit. Can be seen data from the results of testing the physical properties of soft sauce soil as in Table 1.

Table 1 Test of Soil Physical Properties

No	Properties		Land Building Baruk Surabaya	
			0%	6%
1	Water content		59,14	36,94
2	Specific gravity		2,17	2,08
3	Volumetanah weight	ɤb (gr/cm³)	1,44	1,48
		ɤd (gr/cm³)	1,19	1,29
4	Atterbeg limit	Liquid limit (%)	55,82	47,30
		Plastic limit (%)	50	44,44
		Plasticity index (%)	5,82	2,86
5	Classification	Sistem Unified	OL	
		Sistem AASHTO	A-4	

The test results above the stabilization of the Surabaya Baruk Building with 6% dolomite lime showed significant improvements to the physical properties of the soil. The water content drops from 59.14% to 36.94%, indicating an effective lime binding free water. The value of dry volume weight increases from 1.19 gr/cm^3 to 1.29 gr/cm^3, showing an increase in density due to the pozolanic reaction which strengthens the soil structure. The plasticity index also decreased dramatically, from 5.82% to 2.86%, indicating the soil to be more stable and less plastic. Decreased liquid and plastic boundaries emphasize that the soil stabilization is more easily compacted and does not easily change volume. Although the soil classification remains in the OL group (USCS) and A-4 (AASHTO), a decrease in plastic properties and increasing density shows that dolomite lime can significantly improve the quality of subgrade to support road construction.

2. Field Test

a. Sandcone

Sandcone is a test to check the level of soil density In the field with the main material of sand as a reference that is clean, hard, and does not have a binder, so it can flow without any obstacles[13]. Through this test, it can be seen that the dry density of the soil at the test site, which is then compared with the maximum dry density of the results of laboratory testing to evaluate the success rate of compaction. Through this test, it can be seen that the dry mass of the soil at the test site, which is then compared with the maximum dry density of laboratory test results to evaluate the success rate of compaction for the problem of soft sauce sandcone data with a mixture of 0% lime and 6% can be seen in Table 2 and 3.

Table 2. Mixed soil sandcone test 0%

No.	Description	Unit	Point 1
I	**Sand contents (lab)**		
1	Bottle weight + funnel	gr	661,00
2	Bottle weight + funnel + water	gr	5525,00
3	Volume of the contents of the bottle	gr	4864,00
4	Bottle weight + funnel + sand	gr	8020,00
5	The weight of the sand	gr/cc	1,51
6	Bottle weight + funnel + remaining sand	gr	6668,00
7	The weight of the sand in the funnel	gr	1352,00
II	**Land density (lap)**		
1	Bottle weight	gr	136,00
2	Funnel weight	gr	525,00
3	Bottle weight + sand	gr	6594,00
4	Sand weight	gr	6458,00
5	Bottle weight + funnel + sand	gr	7119,00
6	Bottle weight + funnel + remaining sand	gr	1857,00
7	The weight of the sand in the funnel and the hole	gr	5262,00
8	The weight of the sand in the hole	gr	3910,00
9	Hole volume	gr	2584,35
10	Soil weight weight	gr/cc	2,50
11	Wet soil weight	gr	1789,00
12	Wet soil contents	gr	0,69
13	Water content	%	22,22
14	The weight of the field of the field	gr/cc	0,566
15	Laboratory soil weight weight	gr/cc	0,591
16	The degree of soil density	%	95,84

Table 3. 6% Mixed Soil Sandcone Test

No.	Description	Unit	Point 1
I	**Sand contents (lab)**		
1	Bottle weight + funnel	gr	661,00
2	Bottle weight + funnel + water	gr	5625,00
3	Volume of the contents of the bottle	gr	4964,00
4	Bottle weight + funnel + sand	gr	8023,00
5	The weight of the sand	gr/cc	1,48
6	Bottle weight + funnel + remaining sand	gr	6651,00
7	The weight of the sand in the funnel	gr	1372,00
II	**Land density (lap)**		
1	Bottle weight	gr	136,00
2	Funnel weight	gr	525,00
3	Bottle weight + sand	gr	6622,00
4	Sand weight	gr	6486,00
5	Bottle weight + funnel + sand	gr	7147,00
6	Bottle weight + funnel + remaining sand	gr	1890,00
7	The weight of the sand in the funnel and the hole	gr	5257,00
8	The weight of the sand in the hole	gr	3885,00
9	Hole volume	gr	2619,55
10	Soil weight weight	gr/cc	2,48
11	Wet soil weight	gr	1897,00
12	Wet soil contents	gr	0,72
13	Water content	%	20,19
14	The weight of the field of the field	gr/cc	0,603
15	Laboratory soil weight weight	gr/cc	0,604
16	The degree of soil density	%	99,70

Based on the data obtained based on the results of testing water content from the soil sample taken at the sandcone testing location in soft lanau soil with a mixture of lime 0% and 6% obtained water content of 22.22% 20.19%. This shows the addition of lime can reduce soil water content. While the γd max value in soft lanau soil with a mixture of lime 0% and 6% with a value of 0.591g/cm^3 and 0.604g/cm^3. γd Max describes the maximum capacity of the soil to be compacted on the optimum water content.

The weight of the dry soil in the field is calculated based on the results of the sandcone testing, which shows the ability of the soil in the field to achieve a certain density. The γd lap value in soft silt soil with a mixture of lime 0% and 6% is 0.566 kN/m^3 and 0.603 kN/m^3. The degree of density is the ratio between the weight of the dry soil and the maximum weight of the contents of the dry soil. The test results show the degree of degree of degree in the 0% mixture and 6% are 95.84% and 99.70%, this indicates that the compaction process has been carried out well and according to technical specifications. A degree of compaction of 95.84% (0% lime) indicates that the original soil achieved adequate but marginal compaction relative to the laboratory Proctor maximum. After the addition of 6% dolomite lime, the degree of compaction increased to 99.70%, approaching the theoretical 100% Proctor density. This significant improvement of 4.03 percentage points (4.03%) reflects the pozzolanic and cation exchange reactions between lime and clay minerals, which alter the soil's plasticity and particle aggregation, thereby facilitating more efficient compaction under the same energy input. The reduction in water content from 22.22% to 20.19% also contributed to the improved compaction, as the lime absorbed free pore water, shifting the soil closer to its optimum moisture content. According to technical specifications for subgrade compaction on rigid pavement projects in Indonesia (SNI 2828:2011), a minimum degree of compaction of 95% is required; thus, both conditions satisfy this threshold, while the stabilized condition provides a greater safety margin. The improvement in field dry unit weight (γd lap) from 0.566 to 0.603 kN/m^3 further confirms the enhanced densification of the soil matrix following lime treatment.

b. CBR Field

CBR Field is a testing method to determine the carrying capacity and strength of the land in the field[14]. Field CBR is defined as the ratio between the stress of penetration of a pavement of pavement and stress in penetration of standard materials at the same depth and penetration speed, expressed in the form of percent[15]. This test is carried out to find out how much influence the addition of lime on the value of the soil CBR, which is the main indicator in assessing the carrying capacity of the subgrade [16]. The data on the results of the field CBR testing on Lanau soil with a mixture of lime 0% and 6% for CBR test data are displayed in Table 4 and Table 5, as well as the following calculations:

Table 4. Mixed Field CBR Test 0%

Penetration			
Time (minutes)	Decrease (inch)	Reading Dial (DIV)	Load (LBS)
0,25	0,0125	3	32,48
0,5	0,0250	4	43,31
1	0,0500	6	64,97
1,5	0,0750	6	64,97
2	0,1000	7	75,79
3	0,1500	9	97,45
4	0,2000	10	108,28
6	0,3000	12	129,93

Table 5. 6% Mixed Field CBR Test

Penetration			
Time (minutes)	Decrease (inch)	Reading Dial (DIV)	Load (LBS)
0,25	0,0125	1	10,83
0,5	0,0250	2	21,66
1	0,0500	4	43,31
1,5	0,0750	9	97,45
2	0,1000	11	119,11
3	0,1500	15	162,42
4	0,2000	17	184,07
6	0,3000	20	216,56
8	0,4000	22	238,21

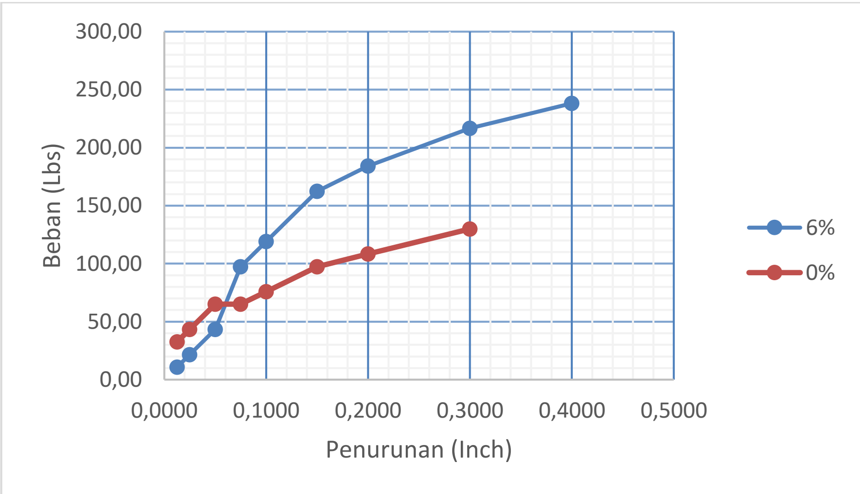

Figure 1. CBR Testing Graph

Figure 1 is taken a decrease in 0.1 inch and 0.2 inch. The CBR value on each blow is taken by the largest value between a decrease of 0.1 inch and 0.2 inch. In the test the original soil or soft soil with a 0% lime mixture shows the CBR value of 2.53%, which is classified in the soil classification with low carrying capacity (Poor Subgrade Material) based on AASHTO standards and Manual Development Marga. After stabilization using a 6%lime mixture, the CBR value increased to 4.03%. This increase reflects the improvement of micro and macro soil structure due to lime reaction, although there is an increase in the value of CBR but is still classified as CBR with low carrying capacity according to[17].

The CBR values before and after stabilization are summarized as follows: at 0.1-inch (2.54 mm) penetration, the unstabilized soil recorded a load of 75.79 lbs, yielding a CBR of 2.53%, while the lime-stabilized soil recorded 119.11 lbs, yielding a CBR of approximately 3.97%. At 0.2-inch (5.08 mm) penetration, the unstabilized soil recorded 108.28 lbs (CBR = 2.41%), and the stabilized soil recorded 184.07 lbs (CBR = 4.09%). The governing CBR value for each condition is taken as the maximum of the two penetration depths, resulting in CBR values of 2.53% (0% lime) and 4.09% (6% lime), representing an absolute increase of 1.56% and a relative increase of 61.66%. Although both values remain within the "Poor Subgrade Material" category per AASHTO M145 classification (CBR < 7%), the improvement is technically significant because it directly increases the design subgrade bearing capacity (CBR design) used in pavement thickness calculations. In the context of rigid pavement design per Pt T-14-2003, a CBR increase from 2.53% to 4.09% can reduce the required subbase thickness by approximately 10–15%, contributing to cost efficiency. The moderate CBR level remaining after stabilization with a single lime dosage further supports the rationale for employing micro pile foundations as a supplementary mechanical strengthening measure, as discussed in the following section.

c. DCP (Dynamic Cone Peneumeter)

The DCP tool is used to determine the CBR value and measure the level of strength and consistency of the soil directly in the field through the speed of metal cone penetration into the ground due to a standard load blow[18]. However, in this study the DCP tool was used as a correlation conversion between the resistance of the QC cone and the DCP scale value can be approached with a departure function in order to calculate the carrying capacity of the foundation[19]. For the correlation between the resistance of the QC cone and the DCP scale value is presented in Table 6 and Table 7.

Table 6. Mixture Correlation 0%

Point	DCP (mm/mash)	qc	Qb (kN)
1	39,17	1,303	1,420
2	34,12	1,531	
3	32,59	1,615	
4	41,10	1,232	

Correlation testing between DCP, QC, and QB is carried out to evaluate the effect of the addition of dolomite lime on the strength of the soil subgrade. The results in the 0% mixture show that the DCP value ranges from 32.59 to 41.10 mm/mashed and QC between 1,232-1,615, reflecting a fairly uniform natural soil condition. After the addition of dolomite lime of 6%, the DCP value becomes more varied (33.57–52.37 mm/mash) and QC is in the range of 0.929-1,560. Some points have increased the QC value, signifying the improvement of soil strength. However, high DCP variations indicate that mixing and compacting have not been evenly distributed in all test points. In general, a consistent relationship between DCP and QC, where the lower DCP value is associated with a higher QC value. This shows that the addition of dolomite lime can increase the carrying capacity of the soil, although its effectiveness is very dependent on the distribution of materials and the quality of compaction.

Table 7. Mixed Correlation 0%

Point	DCP (mm/mash)	qc	Qb (Kn)
1	37,62	1,366	
2	39,79	1,280	
3	37,73	1,361	
4	38,50	1,330	
5	38,33	1,337	
6	45,76	1,087	
7	42,74	1,177	
8	52,37	0,929	1,296
9	43,84	1,143	
10	45,83	1,085	
11	34,81	1,495	
12	39,33	1,297	
13	36,54	1,413	
14	33,57	1,560	
15	37,62	1,366	
16	34,52	1,510	

d. Micro Pole Carrying Capacity

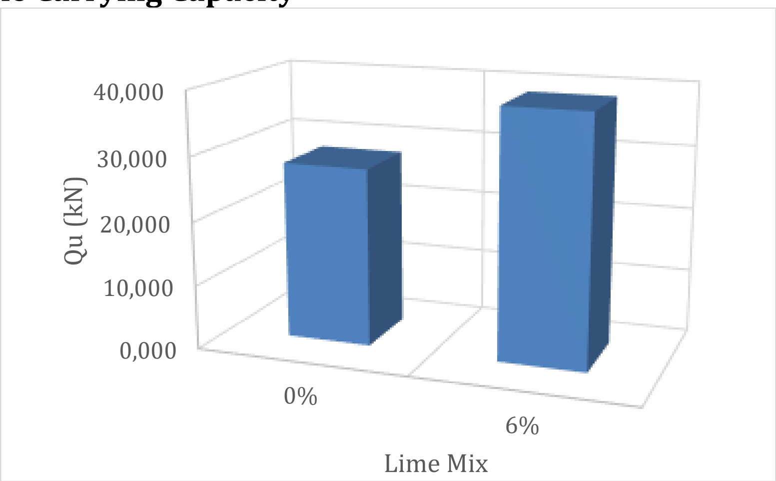

Figure 2. Graph of Micro Pole Foundation carrying capacity

The carrying capacity of the foundation is the ability of the foundation in holding loads on it, both vertically (axial) and lateral [20]. In the type of micropile (micropile), this capacity is obtained through a combination of the compressive force at the end of the pole that rests on the lining of the hard soil and the frictional force between the pole wall and the surrounding soil[8] presented in the following formula:

$Qu = Qb + Qs - Wp$

Where, Qu is Ultimit Carrying Capacity (kN), Qb is Ultimit end resistance (kN), Qs is Ultitmit friction resistance (kN) and Wp is Pole weight (kN).

Figure 2 There is an increase in the carrying capacity of micro pole in the soil resulting from this stabilization occurs through two main mechanisms. Increased value of adhesion and cohesion between the surface of the pole and the soil as a result of increasing bonding strength between particles and adhesion to the surface of the pole. Increased lateral shear resistance and ultimit end resistance makes the ultimit carrying capacity increase from the 0% lime mixture with a carrying capacity of 27.838 kN increase after the soil is mixed with 6% lime to 38.656 kN. Thus the mixing of soft sauce soil with lime can improve the mechanism of interaction between the soil to the pole, which causes an increase in the carrying capacity of the foundation of micro pole as a whole.

CONCLUSION

Based on the results of the research and discussion that has been carried out, the following conclusions can be drawn::

1. The value of density in the soil of Kedung Baruk mixed with 6% lime shows the increase in the density. The original soil has a density value of 95.84%, while it is mixed with 6%lime by 99.70%, so this density value has increased by 4.03%.
2. CBR Value of Kedung Baruk soil with a mixture of lime 6% shows an increase in CBR NIKAI. The original soil has a CBR value of 2.53%, while it is mixed with 6% lime to 4.09%, so the addition of 6% lime increases the CBR value by 61.66%.
3. The carrying capacity of the foundation of the Micro Pole of Kedung Baruk with a mixture of lime 6% has increased. The original soil has a carrying capacity of 27.84 kN while the carrying capacity of the soil mixed with 6% lime has a carrying capacity of 38.66 kN. So, the carrying capacity of the land of Kedung Baruk mixed with 6% lime experienced an increase in carrying capacity of 38.87%.

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