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Analysis of the Compaction Quality of Class A Aggregate Foundation Using *the Sand Cone Method* on the Teluk Tapang Port Access Road

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Abstract
This study, entitled *"Analysis of Compaction Quality of Class A Aggregate Base Using the Sand Cone Method on the Teluk Tapang Port Access Road Project"*, aims to evaluate the field compaction quality and its conformity with the applicable technical specifications. The research scope includes field data collection of moisture content and in-situ density on the Class A aggregate base layer at several test points along the access road alignment to Teluk Tapang Port. The method used is the Sand Cone Test in accordance with SNI 03-2827-2011, to determine the in-situ dry density of the compacted layer. The field density values were compared to the laboratory maximum dry density obtained from the Modified Proctor Test, to calculate the degree of compaction (% compaction). The data were analyzed descriptively to observe the relationship between moisture content and compaction level, as well as to evaluate compliance with Bina Marga standards, which require a minimum of 95% compaction for the upper base layer. The results from 60 test points show that the moisture content ranged from 1.32% to 17.7%, with an average of 7.49%, while the compaction percentage ranged from 51.19% to 99.70%, with an average of 86.15%. Evaluation results indicate that 46.7% of the test points achieved compaction above 90%, and only 21.7% met the 95% requirement set by Bina Marga standards. It can be concluded that the compaction quality of the Class A aggregate base layer on this project has not fully met the specified compaction standards, particularly at several stations with moisture content either above or below the optimum level. Therefore, better moisture control and compaction procedures are required to achieve more uniform and compliant results.

Keywords: Sand Cone; Soil Compaction; Moisture Content; Class A Aggregate; Bina Marga Standard

1. Introduction

Quality road infrastructure is a key factor supporting economic development and inter-regional connectivity. The road access development project for Teluk Tapang Port in West Pasaman Regency is an integral part of efforts to streamline logistics and transportation activities.

One of the important elements in road construction is the class A aggregate base layer, which serves to distribute traffic loads evenly to the subgrade, thus ensuring the stability and durability of the road. However, in practice, compaction quality is often affected by various factors, including inconsistent implementation methods and non-ideal soil conditions. [3]

Variations in the compaction process can lead to a decrease in the quality of the foundation, which impacts the durability and safety of the road. To ensure the quality of compaction that meets technical specifications, density testing is carried out using the *Sand Cone method* . This method is widely used in soil density testing due to its accuracy in measuring density in the field and its ability to provide reliable data regarding the density level of the foundation layer. [1 , 2].

This study aims to analyze the compaction quality of class A aggregate foundation layer using the *Sand Cone method* in the Teluk Tapang Port access road construction project at S TA 31+000 to STA 33+950 . In addition, this study also aims to evaluate whether the compaction results meet the technical specifications set out according to the 2021 Bina Marga general specifications. [6]

According to the 2021 Bina Marga specifications, foundation compaction is a vital process in road construction to ensure the stability and resilience of the road to traffic loads. Class A aggregate foundation is used as a base layer that distributes the load evenly to the subgrade. The compaction process aims to increase the material's density to achieve optimal bearing capacity. Various factors such as soil type, humidity, and the equipment used affect compaction results. Substandard compaction can cause road deformation and reduce the road's service life. [2 1 , 2 2] .

Class A aggregate is the primary quality for the layer under the asphalt base. Class A aggregate for the base layer A top The base layer is a layer placed between the base layer and the surface layer. This layer is designed to increase load-bearing capacity by distributing the load over a certain thickness. This layer functions [1 5 , 16]

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a. As part pavement Which withhold latitude from burden wheel and distributes the wheel load to the underlying layers.
b. As layer absorption For layer foundation lower.
c. As placement to part surface

The Indonesian National Standard (SNI) on the method of soil density testing *(sand cone*) in place (field) using a cone tool is SNI 03-2827-2011. The method of testing soil density in the field using a sand cone tool is used to check the field density of the pavement or soil layer, which is compacted using Ottawa sand as a soil density parameter. Sand Ottawa must dry, clean, And hard And No contain binding agent, so that the soil can flow freely. The Ottawa sand used passes through sieve number 10 and remains on sieve number 200. Method This only can used on layer on land about ten to fifteen centimeters.
sand cone test is used to measure soil density in the field and the dry unit weight value can be determined from a comparison of field tests. With laboratory tests for a minimum soil density value of 95% in the soil layer or pavement. has compacted. Testing Which described only involving grains rock and soil, with a diameter of no more than five centimeters. Field density is the dry weight per unit content. This *sand cone* testing , check connection between level water And density example land. Level groundwater is concentration water in land, Which usually shown in the form of a percentage of dry weight. Water content greatly influences the level of compaction that can be achieved by a soil [1 , 2 , 6] .

2. Research methodology

2.1. Research Location

This research will be carried out in the Teluk T apang port access road construction project , which is located in the Jorong Bunga Tanjung area, Aia Bangih village, at S TA 31+000 to STA 33+950, Sungai Beremas District, West Pasaman Regency, West Sumatra. This research is a quantitative descriptive research . which aims to analyze the compaction quality of class A aggregate foundations using the *Sand Cone method* . It describes the level of compaction quality that occurs in the field quantitatively , with describe and analyze the actual conditions of the field density *of the sand cone* test results , then compare them with standard values (e.g. ≥ 95% of the maximum laboratory density). The data used is numerical data from the results of soil water content and density tests. at S TA 31+000 to STA 33+950 in the field [8 , 9] .

The main variable in this study is the density of class A aggregate foundation measured using the *Sand Cone method* . The supporting variables in this study are the type and characteristics of class A aggregate, weather conditions and soil moisture.

2.2 Research Materials and Equipment

The main material used in this study is Class A Aggregate in accordance with the General Bina Marga Specifications 2018 Revision 2 , which includes coarse aggregate (crushed gravel), fine aggregate, and crushed stone filler. The material source is taken from a local quarry that has been approved by the construction service provider and Ottawa sand.
The tools used in this activity are:
1 Set of *Sand Cone Tools* (SNI 03-2827-2011)
2. stationery
3. 1 Set of Compaction Test
4. Camera
5. Laptop
6. Sand Cone
7. *Speedy moisture test*
8. *Safety*

Images of equipment and materials can be seen in figures 2.1 and 2.2.

Figure 2.1 Equipment and materials for *sand cone testing* in the field

Figure 2.2 Equipment and materials for *sand cone testing* in the laboratory

2.3. Field Sample Testing

Test samples were taken purposively *at* five test points along different segments of the access road to the port. Each point represents a Class A aggregate foundation layer compacted to a nominal thickness of 20 cm. Samples were taken after the layer was declared ready for testing by the field supervisor and had not yet been covered by the next layer.
Field density tests were conducted using *the Sand Cone* Method to determine the in-situ dry unit weight. The implementation stages refer to SNI 03-2827-2011 , with the following work procedures:

1. Determining the volume/contents of the sand bottle on *the sand cone test tool*
2. Determining the volume weight of sand on *a sand cone test tool*
3. Determine the weight of sand in the funnel using the *sand cone test tool*
4. Excavation of soil/layers at the location where the density will be tested
5. Determining the density of soil
6. Conducting analysis of the results of *sand cone tests* regarding the calculation of soil density or dry soil volume weight.
7. Take soil samples and then test them again in the laboratory
8. Laboratory compaction testing (Compaction Testing)
9. Determine the degree of soil density by comparing the results of field and laboratory tests.

2.4. Sample Testing in the Laboratory

The soil samples obtained in the field were then tested in the laboratory to determine the water content of the soil, thus determining the maximum dry density in the field. The oven heating process lasted 24 hours at 120 ° C. Five different sample points were taken in this study. for every 25 meters, namely from STA 31+000 to STA 33+000 around the road pavement, with the following work procedures:

1. Determine volume/content bottle sand on tool *test sand cone*
2. Determine heavy volume sand on tool *test sand cone*
3. Determine heavy sand in funnel on tool *test sand cone*
4. Excavation soil/layer on place which will tested its density
5. Determine weight content land
6. Doing analysis from result *sand* testing *cone* about calculation of soil density or dry soil volume weight

In general, the research sequence can be seen in the following flow diagram;

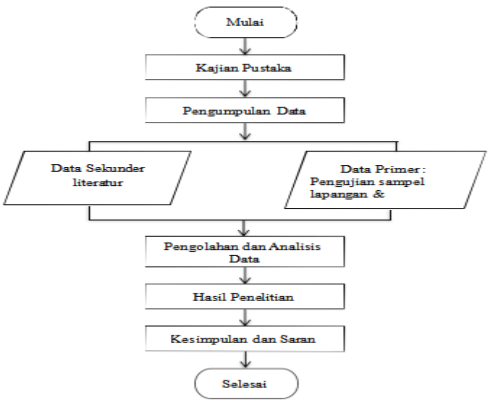

Figure 2.3 Research Flowchart

2.5 Formula used in the research

1. Wet Field Content Weight

$$\gamma_m(\text{field}) = W\_wet\_soil / V\_hole \quad (1)$$

Where:
γ_m(*field*) : Wet field unit weight (g/cm³)
W_wet_soil : Weight of moist soil from the hole (g) V_hole : Volume of the test hole (cm³)

2. Hole Volume

$$V\_hole = W\_sand\_used / \gamma\_sand \quad (2)$$

Where:
V_hole : Volume of hole (cm³) W_sand_used : Weight of dry sand used (g)
γ _sand : Dry unit weight of calibration sand (g/cm³)

3. Water content

$$w = (W\_wet - W\_dry) / W\_dry \times 100\% \quad (3)$$

Where:
w : Water content (%) W_wet : Weight of wet soil sample (g) W_dry : Weight of oven dry soil sample (g)

4. Field Dry Bulk Weight

$$\gamma\_d(\textit{field}) = \gamma_m(\textit{field}) / (1 + (w / 100)) \quad (4)$$

Where:
γ_d(*field*) : Field dry unit weight (g/cm³)
γ_m(*field*) : Field moist unit weight (g/cm³)
w : Water content (%)

5. Degree of Density (*Percent Compaction*)

$$\%K = (\gamma\_d(\textit{field}) / \gamma\_d(\max)) \times 100\% \quad (5)$$

Where:
%K : Degree of density (%)γ_d(*field*) : Field dry unit weight (g/cm³)
γ_d(max) : Maximum dry unit weight of Proctor test results (g/cm³)

3. Results and Discussion

Field density testing using *the Sand Cone* method was conducted along STA 31+000 to STA 33+950 on the Class A aggregate foundation layer of the Teluk Tapang Port Access Road project. One observation point was taken every 50 meters, resulting in a total of 60 test points. The main parameters measured were water content (%) and degree of density (%) , which were compared to the

maximum dry density (MDD) values from laboratory tests.
After the research data obtained in the field and analyzed in the laboratory, the collected data was compiled into a table, so that the density was obtained which was a comparison between the dry density of the soil or material in the field with the maximum dry density obtained from the laboratory test results. Recapitulation of data density calculations from the first point to the fifth point on the Class A/LPA Aggregate Foundation Layer at STA (31+000) to STA (33+950) *Sand Cone* Method on the Teluk Tapang Port Access Road Project can be seen in table 3.1.

The data in Table 3.1 includes water content (%), relative density (%), and a summary of average values. Testing was conducted at every 50-meter observation point to ensure even compaction results in accordance with the 2018 Bina Marga *Highway Material Specification standards* .

The average water content of 7% indicates relatively ideal field conditions, approaching the optimum water content (OMC) from laboratory tests. The average field density of 93.61% indicates that the compaction results are generally close to the minimum specification (95%), but there are still points that do not meet the standard, especially points 1 and 4.

Technically, these density variations can be caused by aggregate size distribution, irregularities in water content during compaction, and the efficiency of the compaction equipment in the field. The graph of the relationship between water content and dry density shows a positive trend up to the optimum point, in line with the basic theory of soil compaction (*compaction curve*).

Table 3. 1Field density

No	Description	Point 1	Point 2	Point 3	Point 4	Point 5	Average	Unit
1	Weight of sand + tools	7213	7017	7020	7212	7032	7098.8	g
2	Waste sand + tools	3212	3510	2922	2930	3215	3157.8	g
3	Weight of sand used	4001	3507	4098	4282	3817	3941	g
4	Weight of sand in the funnel	1473	1473	1473	1473	1473	1473	g
5	Weight of sand in the hole	2528	2034	2625	2809	2344	2468	g
6	Sand content weight	1307	1307	1307	1307	1307	1307	g/cm³
7	Hole volume	1934	1556	1318	1502	1793	1620.6	cm³
8	Wet aggregate weight + cup	637	630	654	640	624	637	g
9	Dry aggregate weight + cup	622	613	636	625	608	620.8	g
10	Cup weight	395	395	395	395	395	395	g
11	Water weight	15	17	18	15	16	16.2	g
12	Dry aggregate weight	227	218	241	230	213	225.8	g
13	Water content	6.61	7.79	7.47	6.52	7.51	7.00	%
14	Aggregate weight in hole	4032	4210	4421	4520	4434	4323.4	g
15	Coarse aggregate weight	1921	1943	1890	1937	1810	1900.2	g
16	Fine aggregate weight	2111	2267	2531	2583	2624	1381.8	g
17	Percentage of coarse aggregate (Pc)	47.64	46.15	41.81	42.85	40.82	43.85	%
18	Percentage of fine aggregate (Pf)	52.36	53.85	57.25	57.15	59.18	56.00	%
19	Specific gravity of coarse aggregate	2,612	2,612	2,612	2,612	2,612	2,612	gr/cc
20	Wet volume weight (ɣwet)	2,085	2,705	3,354	3,009	2,473	2,725	gr/cc
21	Dry weight (ɣdry)	1,956	2,209	2,120	2.124	2,200	2.122	gr/cc
22	Maximum dry density (MDD)	2,096	2,096	2,096	2,096	2,096	2,096	gr/cc
23	Volume weight correction	2,165	2,299	2,726	2,356	2,286	2,366	gr/cc
24	Density percentage	90.35	96.08	95.24	90.15	96.23	**93.61**	%

No	STA	Water content value (%)	Density value (%)
1	31+000	9.74	80.82
2	31+050	3.17	98.92
3	31+100	6.98	98.14
4	31+150	6.4	53.79
5	31+200	10:56	92.31
6	31+250	6.55	84.34
7	31+300	7.45	94.44
8	31+350	17.7	80.03
9	31+400	9.25	78.28
10	31+450	6.4	94.44
11	31+500	9.39	76.20
12	31+550	5.6	80.24
13	31+600	5.75	67.66
14	31+650	6.05	60.75
15	31+700	9.35	94.46
16	31+750	10.87	87.97
17	31+800	9.74	93.94
18	31+850	3.98	89.65
19	31+900	4.34	82.22
20	31+950	4.75	51.19
21	32+000	7.69	83.680
22	32+050	4.19	89.69
23	32+100	2.24	75.53
24	32+150	9.26	86.27
25	32+200	7.11	73.25
26	32+250	7.02	79.50
27	32+300	6.12	95.25
28	32+350	5.22	94.21
29	32+400	10.63	86.06
30	32+450	10.82	78.28
31	32+500	9.62	87.45
32	32+550	3.00	99.70
33	32+600	5.49	83.61
34	32+650	10.73	82.72
35	32+700	9.36	88.59
36	32+750	7.55	96.95
37	32+800	4.55	93.48
38	32+850	3.04	70.51
39	32+900	7.59	81.64
40	32+950	6.73	89.50
41	33+000	4.07	79.16
42	33+050	9.92	88.09
43	33+100	2.14	99.06
44	33+150	1.32	98.63
45	33+200	4.21	94.48
46	33+250	10.17	87.51
47	33+300	3.37	92.68
48	33+350	2.14	80.12
49	33+400	3.22	79.38
50	33+450	6.72	88.26
51	33+500	4.43	81.56
52	33+550	8.22	92.41
53	33+600	7.25	95.23
54	33+650	10.20	95.63
55	33+700	6.22	93.27
56	33+750	6.61	90.35
57	33+800	7.79	96.08
58	33+850	7.47	95.24
59	33+900	6.52	90.15
60	33+950	7.51	96.23

Table 3.2. Water Content and Density Values
According to the SNI 03-2827-2011 requirements, the recommended field density value is 95%. From table 3.2 The results of the tests that have been carried out can be concluded that approximately 46.7% of the test points meet the density requirements of good to very good (≥90%).
However, 23.4% of points were below 80%, indicating the need for repair or re-compaction at those locations. As summarized in Table 3.3 below:

Table 3.3 Density Percentage

Density Category	Density Value Range (%)	Number of Points	Percentage
Very good	≥ 95%	13 points	21.7%
Good	90 – <95%	15 points	25.0%
Currently	80 – <90%	18 points	30.0%
Not enough	70 – <80%	7 points	11.7%
Bad	<70%	7 points	11.7%

Based on the results of field density measurements on Class A aggregate foundation work, the density degree values were grouped into five categories, namely *very good* , *good* , *moderate* , *less* , and *bad* . Of the total test points, it was found that the "moderate" category was the group with the largest number of points, namely 18 points (30.0%) . This finding indicates that most of the test locations have achieved a sufficient level of density, but have not yet met the ideal density standard (≥ 95%) which is generally required for Class A aggregate foundation work.

In the “good” category , there are 15 points (25.0%) , which indicates that a quarter of the total test points have compaction quality that is close to the standard, but still below the minimum limit of the required density level. Meanwhile, the “very good” category has 13 points (21.7%) , which indicates that only about a fifth of the total points actually meet or exceed the technical requirements for compaction (≥ 95%).

Conversely, there were also points in the less than satisfactory category. The "less" category recorded 7 points (11.7%) , while the "bad" category also consisted of 7 points (11.7%) . This number indicates that approximately 23.4% of all compaction points still have density values far below standard and require corrective action or re-compaction to ensure quality meets technical specifications.

Overall, the distribution of density values indicates variations in compaction quality in the field. The proportion of points in the "moderate," "poor," and "poor" categories, which reached approximately 53.4% , indicates that more than half of the locations are still suboptimal and require further attention in the compaction process. Thus, these results emphasize the need for stricter evaluation and control of compaction quality to ensure the stability and bearing capacity of Class A aggregate foundations in the Teluk Tapang Port access road project.

The relationship between soil density and water content in test results can be seen in the following graph:

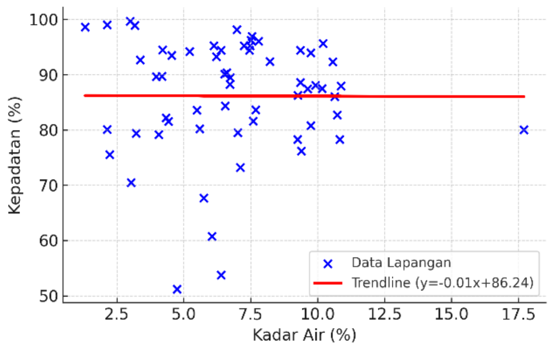

Figure 3.1 Relationship between water content and soil density

The relationship between water content (%) and soil density (%) in the field test results from the graph shows that the higher the water content, the lower the soil density tends to be. This indicates a negative relationship between water content and density, which is in accordance with the theory of soil compaction.
So from the test results it can be concluded that points with low water content (2–5%) generally show high density (90–99%), which can be found at :
STA 32+550 → w = 3.00%, ρ = 99.70%
STA 33+100 → w = 2.14%, ρ = 99.06%
Conversely, points with high water content (>10%) tend to have decreased density , for example:
STA 31+150 → w = 6.4%, ρ = 53.79%
STA 31+350 → w = 17.7%, ρ = 80.03%
According to general earthwork standards (Bina Marga 2018), the minimum density values required are: **95%** of *Modified Proctor* for the top base layer .

4. Conclusion

The average soil density at the research location was 86.15% , still below the minimum standard of 90–95%. The average water content of 7.49% indicates that some of the soil is below or above the optimum water content, affecting density variations.
Field water content control is required to obtain optimal compaction results.
Locations with a density of <80% need to be a priority for field improvements.
Recommended Conducting density testing with a variety of other testing methods such as *Nuclear Density Gauge (* NDG) or *Dynamic Cone Penetration* (DCP) as a comparison to the *Sand Cone method. Comparison* of several methods will provide a more comprehensive picture of the actual density level in the field and further research is also needed to analyze the influence of field factors on density variations.

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