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Redesign of Rigid Pavement Based on Subgrade Bearing Capacity Evaluation

Yanyan Agustian[1], Anjar Muhammad Budiman[2], Asep Setiawan[3]
Universitas Widyatama Bandung, Indonesia
Email: yanyan.agustian@widyatama.ac.id

KEYWORDS
Bearing capacity, Rigid pavement, Soil stabilization.

ABSTRACT
The Rancacili Road in the Rancasari District of Bandung City frequently suffers from damage due to its strategic importance. To address this issue, this study aims to redesign the pavement by replacing the subgrade soil composition and upgrading the surface layer with rigid pavement. The research objectives include assessing the subgrade bearing capacity, analyzing the impact of subgrade stabilization, and evaluating the causes of road damage. The methodology involves field and laboratory tests. Field tests include Dynamic Cone Penetrometer (DCP) tests and traffic data observations. Laboratory tests encompass physical and mechanical soil tests. Soil samples were collected from the field, and various mixtures of soil, concrete sand, and cement were used. Stabilization tests were conducted with mixtures containing 75% soil and varying percentages of sand and cement. The results indicate that the variation 5 mixture, consisting of 75% soil and 25% cement, significantly enhances the subgrade bearing capacity, increasing from an existing value of 4.186 to 8.18. In addition to soil stabilization using cement, the redesign includes implementing rigid pavement. Using AASHTO 1993 methods, the recommended concrete thickness is 274 mm. This redesign aims to improve the durability and performance of the Rancacili Road.

1. INTRODUCTION

A pavement is composed of multiple layers of processed materials placed on top of the natural soil subgrade. Its main purpose is to distribute vehicle loads to the subgrade effectively. The pavement must offer a riding surface with good quality, adequate skid resistance, suitable light reflection properties, and minimal noise pollution. The primary goal is to ensure that the stresses transmitted by wheel loads are sufficiently minimized to avoid surpassing the subgrade's bearing capacity (Jichkar, 2021). Two types of pavements are generally recognized for serving this purpose: flexible pavements and rigid pavements. This chapter provides an overview of rigid pavement, including its layers, functions, and common failures. Rigid pavements consist of a Portland Cement Concrete (PCC) surface course. Due to the high modulus of elasticity of the PCC material, these pavements are significantly "stiffer" than flexible pavements. Additionally, rigid pavements can include reinforcing steel, which is typically used to reduce or eliminate joints (Setiawan et al., 2020).

The Rancacili Road in the Rancasari District of Bandung City is heavily used by large trucks transporting goods. Based on field surveys conducted by researchers, it is found that this road has an existing condition of a single lane with two-way traffic (1/2 U) and a width of 4 meters. Each year, the Rancacili Road frequently suffers from damage. Given its strategic importance, it is essential to undertake maintenance and improvements. This includes redesigning the road by replacing the subgrade soil composition and upgrading the surface layer with rigid pavement.

Since the main purpose of a pavement structure is to distribute the repetitive loads from vehicle traffic to the subgrade, having information about traffic volume and the composition of heavy goods vehicles is crucial in the design process. Therefore, in most design methods, the choice of pavement construction is based on the anticipated number of vehicles that will use the pavement during its intended service life, as well as their total and axle weights (Bayraktarova et al., 2023).

The objectives of this Final Project research are to determine the subgrade bearing capacity condition of Rancacili Road in the Rancasari District, Bandung City, and to assess the impact of subgrade stabilization on this road. Additionally, the research aims to evaluate the causes of road damage on Rancacili Road based on subgrade bearing capacity and to provide solutions for addressing these road damage issues.

2. METHOD

The research method used in this study is a quantitative approach to design the thickness of rigid pavement. Quantitative research is based on positivist philosophy and is used to study specific populations or samples(Sugiyono, 2010). Data collection is done using research instruments, and data analysis is quantitative or statistical, with the aim of testing predetermined hypotheses. Additionally, a causal comparative method is used to compare the planned thickness of rigid pavement using the Bina Marga 2017 method and the AASHTO 1993 method with existing conditions. Causal comparative research focuses on the relationship between dependent and independent variables, with data collected after a fact or event has occurred (Narbuko & Achmadi, 2021; Agustian et al., 2024).

The data collection for subgrade bearing capacity using the Dynamic Cone Penetrometer (DCP) involves field data acquisition (Sarifah et al., 2024). Testing is conducted at intervals of approximately 100 meters. The procedure includes lifting the hammer and dropping it (first blow) while reading the ruler, which indicates the penetration depth of the DCP rod. The CBR test was conducted at the Widyatama Soil Mechanics Laboratory, using soil samples taken from the Rancacili road section in the Rancasari District of Bandung City. The laboratory CBR testing was carried out by mixing the soil samples at a specific moisture content (i.e., at the optimum moisture content determined from compaction testing). The soil samples, mixed with sand or cement, were compacted using a tamper rod. A traffic survey was conducted at a single point along the Rancacili road section in Rancasari District, Bandung City. The data collection was performed from 07:00 to 09:00 and from 16:00 to 18:00 on Monday and Saturday. The counts were categorized every 15 minutes, with each type of vehicle passing the survey location being recorded.

The data collection method used both primary and secondary data. Primary data were obtained from field studies through direct observation, while secondary data were sourced from the Citarum River Basin Authority. Both sets of data were then analyzed using the AASHTO 1993 method to compare them with the existing rigid pavement conditions.

3. RESULT AND DISCUSSION

Existing Road Conditions

Rancacili Road, located in the Rancasari District of Bandung City, is categorized as an urban road. This road section serves as a connector road and is heavily used by motor vehicles such as motorcycles, private cars, trucks, and others, which can lead to damage on the rigid pavement surface. The road condition in the Rancacili area shows signs of cracks and potholes, necessitating actions to ensure the safety and comfort of road users traveling through this area. Repairs can be carried out by improving the base pavement structure of the road. Fig.1. is the typical cross section of Rancacili Road.

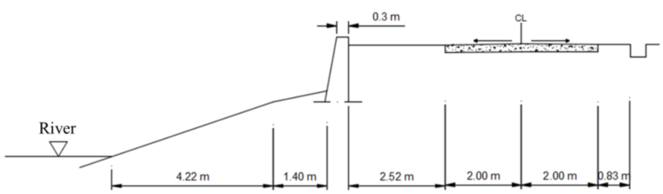

Fig. 1. Typical cross section of Road of Rancacili

The road damage conditions on the Rancacili road section in Rancasari District, Bandung City, are identified as follows:

1. Longitudinal cracking
   It is widely recognized that Portland Cement Concrete (PCC) slabs often develop longitudinal cracks when transverse tensile stresses surpass the slab's tensile strength (Yang et al., 2020). Research has shown that these longitudinal cracks arise from a combination of factors, including fluctuations in temperature and moisture gradients, the geometry of the slab, jointing techniques (such as timing and depth of saw cuts, and dowel alignment), vibrations, and the support provided by underlying layers.
2. Joint Seal Defects
   Joint seal damage refers to any condition that permits the accumulation of soil or rocks within the joints or allows substantial water infiltration(Lee & Stoffels, 2003). The buildup of incompressible materials restricts slab expansion, potentially leading to buckling, cracking, or spalling.

Daily Traffic

The daily traffic data for the Rancacili road section in Rancasari District, Bandung City, was obtained from field surveys. This data serves as load input in the design planning for rigid pavement thickness, which will be discussed in this chapter. The daily traffic data is presented in the table below:

Table 1. Daily traffic data

Category	Vehicle Type	Number of Vehicle
1	Motorcycles, Scooters, Three-Wheeled Vehicles	8165
2	Sedans, Jeeps, Station Wagons	472
3	Minivans, Pickups, Suburbans, Kombis, Mini Buses	256
4	Pickups, Micro Trucks, Delivery Vans	172
5a	Small Buses	-
5b	Large Buses	-
6a.2	Light Trucks (2 Axles)	35
6b.1.2	Medium Trucks (2 Axles)	20
7a1	Three-Axle Trucks	5
7b	Trailer Trucks	-
7c1	Semi-Trailer Trucks	-

Soil Investigations

The carrying capacity of the soil is measured using the DCP (Dynamic Cone Penetrometer) tool. This DCP tool is used to determine the CBR (California Bearing Ratio) value of a direct soil layer in the field. The results of the CBR value are then correlated into the soil bearing capacity value using the equation 1 and 2 (Sukirman, 1992) . The results of the DCP test analysis of the Rancacili road section, Rancasari District, Bandung City, obtained an average

CBR of 6.78%, a maximum CBR of 9.48% in segment number 2 and a minimum CBR of 3.50% in segment number 3. The CBR value that can be represented to be used as the basis for pavement planning needs to be analyzed.

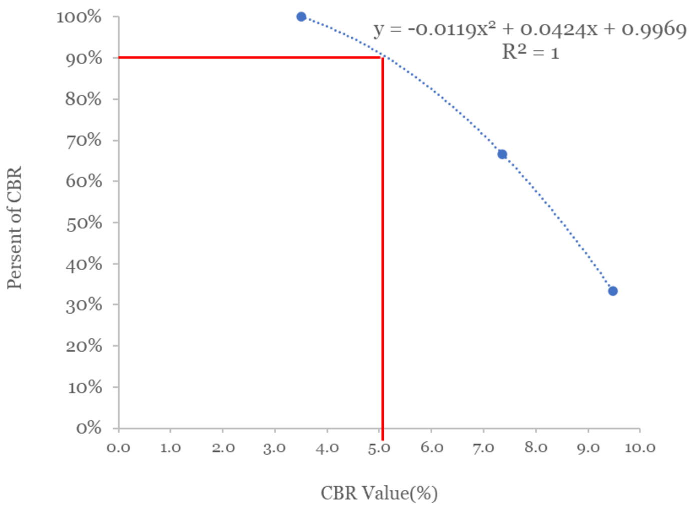

Fig.2 Recapitulation of the Results of the 3-point CBR Reading

The calculation above gives a 90% CBR value of 5.15%. The results of the field CBR value from the DCP test on Jalan Rancacili, Rancasari District, Bandung City are then correlated to obtain the SBC (Soil Bearing Capacity) value, with the following calculation:

$$CBR < 10\ then, SBC = 1.71428571 + (1.89228309 \text{ x } \ln(\text{CBR})) \quad (1)$$

$$CBR \geq 10\ then, SBC = 1.64285714 + (1.89228309 \text{ x } \ln(\text{CBR})) \quad (2)$$

From the results of the correlation calculation between the CBR values, the DDT value on Jalan Rancacili, Rancasari District, Bandung City was obtained as 4,186.

Soil Properties

Data on the condition of the ground soil was taken from the soil sample of Jalan Rancili in the form of disturbed soil samples. In this study, concrete sand and three-wheeled cement samples were also used as a comparison in determining the subgrade soil mixture. In addition, it is also used as a method to improve the soil stabilization of the bottom soil on the Rancacili Road section. Soil properties testing aims to determine the physical properties and mechanical properties of soil. Testing the physical properties of this soil is in the form of: testing moisture content, specific gravity (G_s), soil volume weight, soil grain distribution, atterberg limit. Testing of soil mechanical properties in the form of: standard testing of proctor, and CBR. The resume of the soil properties is illustrated in Tabel 2.

Tabel 2. Resume of soil properties

No	Property	Hasil		
		Location 1	Location 2	Location 3
1	Water contens (w) %	19.32	21.04	20.74
2	Spesifci gravity (G_s)	2.56	2.27	2.27
3	Degree of saturation(S_r) %	66.24	72.17	76.65
4	Porosity (n)	42.75	39.82	38.05
5	Void ration (e)	0.75	0.66	0.61
6	Shrinkage Limit (SL) %	24.23	23.47	26.81
7	Plasticity Limit (PL) %	37.14	34.78	35.29
8	Liquid Limit (LL) %	39.87	43.07	45.98
9	Plasticity Index (PI) %	2.72	8.29	10.68

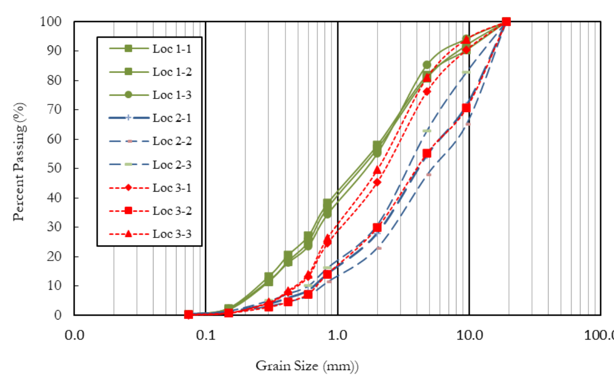

Fig.3 Grain size distribution from samples taken from three different locations

From the grain size distribution graph Fig. 3 above, it can be observed that the results from the three sampling locations do not differ significantly. The soil classification system used in this research is the Unified Classification System (UCS). Based on the grain size analysis testing, the soil classification follows the UCS system (Engr. Yasser M. S. Almadhoun, 2015).

Tabel 3. Soil Classification

No	Location	Parameter (%)				Soil Type
		F_{200}	C_u	C_C	*GF*	
1.	Loc 1	0.34 < 5	9 ≥ 6	3 ≤ 3	14.7 < 15	SW (Well-graded Sand)
2.	Loc 2	0.39 < 5	7 ≥ 6	3 ≤ 3	37.1 > 15	SW (Well-graded Gravelly sand)
3.	Loc 3	0.22 < 5	6 ≥ 6	2 ≤ 3	19.1 > 15	SW (Well-graded Gravelly sand)

Soil Mechanical Properties

To determine the relationship between moisture content and maximum dry density, a soil compaction test (Proctor test) is conducted. The test conducted is the standard Proctor test. The results of the Proctor test provide the optimum moisture content and maximum dry density, which are then applied in the CBR test. This soil compaction test using the standard Proctor method can be observed in the figure. The data from the Proctor test results for the five sample variations and the standard Proctor graph are shown in Fig. 1 below.

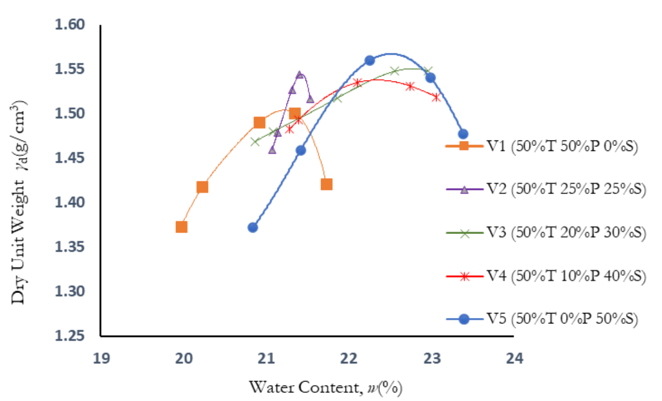

Fig. 3. Compaction test result. T is Soil, P is sand cement and S is Portland cement.

To determine the bearing capacity of the soil layer that will be used as the subgrade (base layer) for road construction, a CBR (California Bearing Ratio) test is conducted. There are two types of CBR tests performed in the laboratory: unsoaked and soaked tests. This study utilizes the unsoaked CBR test because the research involves dry conditions or the need to evaluate soil strength under the worst-case scenario. The test uses a mixture of Rancacili Road soil, sand, and portland cement.

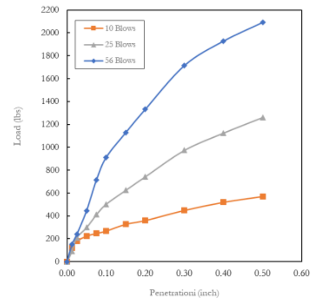

Fig 4. Relationship between penetration and pressure in CBR testing for 10, 25, and 56 blows with a mixture of 75% soil, 0% sand, and 25% cement

The results of the CBR testing on the soil mixture from Rancacili Road in Rancasari District, using sand and Portland cement with CBR values at 10, 25, and 56 blows, indicate that adding sand and Portland cement produces varying CBR values. The optimum CBR value was achieved in mixture which contained 75% soil, 0% sand, and 25% cement. This result shows that a 75% soil and 25% cement mix (with no sand) reached the optimal composition, where the soil and cement bond and interlock effectively, resulting in a maximum CBR value of 30.40%. This optimal composition can improve the existing CBR value. This value is higher than the existing CBR value of Rancasari Road in Rancacili District, meaning that the 75% soil and 25% cement mixture could be used to stabilize the subgrade of Rancasari Road. The graph above demonstrates that the number of blows, or compaction energy applied to the soil, sand, and cement mixture, affects the CBR value. The more blows applied, the higher the CBR value. The highest compaction level, as shown in the graph, is achieved at 56 blows.

Road Redesign based on AASHTO 1993 Method

Based on the survey conducted, the calculation of W_{18} can be determined using the formula below:

$$W_{18} = \sum_{N1}^{Nn} AADTj \; x \; VDFj \; x \; DD \; x \; DL \; x \; 365 \quad (3)$$

In traffic data surveys, W_{18} represents the design equivalent single axle load (ESAL) over the pavement's design life. Specifically, it denotes the total number of 18,000-pound (approximately 8,164 kg) single axle load applications that the pavement is expected to withstand throughout its service life. This parameter is crucial in pavement design, as it helps engineers determine the structural requirements based on expected traffic loads.

Tabel 4 Calculation results of W_{18}

Type of Vehicle	AADT	Weight	EAL	DD	DL	W18'	GF	18ESAL
Passenger cars and other light vehicles	1305	2	0.00235	0.5	1	1120.36	115.064	64456.51
6A.2	6	9	0.3839	0.5	1	840.75	115.064	48369.9786
6B.1.2	3	8.3	0.06369	0.5	1	69.74	115.064	4012.2711
7A.1	1	18.2	0.54781	0.5	1	199.95	115.064	11503.6205
					Total 18ESAL			128342.38

where:
DD: Directional Distribution for rigid pavement, typically between 0.3-0.7, set at 0.5
DL: Lane Distribution for two-way traffic, generally between 80%-100%, set at 90%
VDF: Vehicle Damage Factor

From the calculation results in the table above, the W18 value for one year is 128,342 ESAL. The traffic used for the rigid pavement thickness design is the cumulative traffic over the design life. Using formula:

$$W_t = W_{18} \; x \; \frac{(1+g)^n - 1}{g} \quad (4)$$

Thus, the cumulative traffic value over the design life is obtained as 1.73E+12 ESAL.

Tabel 5. Resume of the calculation results

No	Parameter Item	Value
1	Cumulative traffic volume over the design life	1.73E+12 ESAL
2	Subgrade reaction modulus	398 pci
3	Concrete modulus elasticity	4412624.729 psi
4	Reliability	90% (-1.282)
5	Serviceability	Initial : 4.5 Terminal : 2.5 Loss : 2
6	Drainage	Good
7	Plate thickness	274 mm
8	Rebar	
	longitudinal reinforcement	383.6 mm²/m
	transverse reinforcement	383.6 mm²/m

Based on the calculation results using the AASHTO method, the concrete slab thickness obtained is 275 mm. Below is the design plan for the rigid pavement on Rancacili Road, Rancasari District, Bandung City.

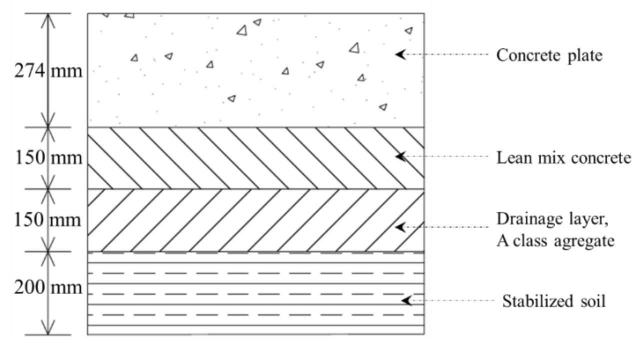

Fig. 5 Design of Rigid Pavement for Rancacili Road in Rancasari District using the AASHTO 1993 Method

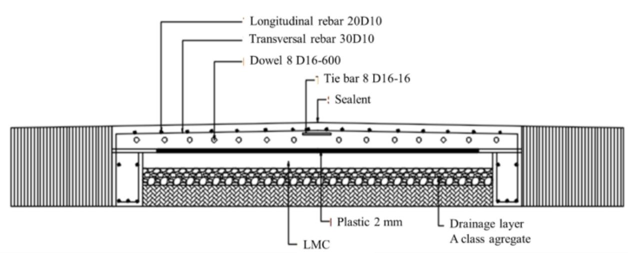

Fig. 6 Cross section design of Rigid Pavement for Rancacili Road in Rancasari District

Based on the AASHTO 1993 calculation results, the required slab thickness is 274 mm, while the existing slab thickness on the Rancacili road section in Rancasari District is 200 mm. This indicates that the current rigid pavement design is not safe according to AASHTO 1993 standards, and the calculated AASHTO thickness is superior to the existing thickness. The optimum subgrade composition was achieved with a mixture of 75% soil, 0% sand, and 25% cement, yielding a CBR value of 30.40% and a soil bearing capacity of 8.18. These results are significantly better than the existing conditions on Rancacili Road in Rancasari District, making this composition a viable solution or recommendation for improvements to this road section.

4. CONCLUSION

From this study, several conclusions can be drawn:

1. Subgrade Condition: The subgrade condition on Rancacili Road, Rancasari District, Bandung City, is not adequate for supporting the current traffic load. This is indicated by a low subgrade bearing capacity, as demonstrated by the field and laboratory tests.
2. Subgrade Improvement: Stabilizing the subgrade using a mix of 75%, 0% sand, and 25% cement significantly improves the bearing capacity. This treatment increases the existing California Bearing Ratio (CBR) value from 5.15% to 30.40% and the Dynamic Cone Penetrometer (DCP) test value to 8.18.
3. Rigid Pavement Design: Implementing a rigid pavement design is an effective solution for the road. Replacing the surface layer with a concrete slab of 274 mm using the AASHTO 1993 method, along with a 125 mm lean concrete base and a stabilized subgrade, can effectively distribute the load and enhance the durability of the road.
4. Subgrade Material Composition: Changing the subgrade material composition to 75% soil, 0% sand, and 25% cement significantly improves the road's structural integrity. This new composition shows a marked improvement in both CBR and DCP test results, suggesting it as an effective and efficient solution for subgrade stabilization.

In summary, the study highlights the importance of proper subgrade stabilization and the benefits of using rigid pavement to extend the lifespan and performance of the road under heavy traffic conditions. These findings provide valuable recommendations for the improvement and maintenance of Rancacili Road in Rancasari District, Bandung City.

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