Jurnal Komposit: Jurnal Ilmu-ilmu Teknik Sipil
Vol. 9 No. 2 (2025) pp. 457 – 464
DOI: https://doi.org/10.32832/komposit.v9i2.17343

ISSN: 2615-3513
e-ISSN: 2655-934X

The Influence of Subgrade CBR Value and Concrete Quality on Rigid Pavement Thickness (Case Study: Simpang Village, Berbak to Muara Sabak)

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ABSTRACT

Roads are the primary infrastructure for land transportation, facilitating traffic from one place to another. The road from Simpang Village, Berbak to Muara Sabak, in the Muara Sabak Timur District, Tanjung Jabung Timur Regency, faces a significant issue with low California Bearing Ratio (CBR) values of the subgrade soil. These low CBR values can lead to instability and deformation of the subgrade, ultimately damaging the rigid pavement built upon it. This study aims to evaluate the influence of subgrade CBR values and concrete quality on the thickness of rigid pavement for the road from Simpang village, Berbak to Muara Sabak. The research employs a quantitative approach using the AASHTO 1993 method. The results indicate that subgrade CBR values and concrete quality significantly affect the thickness of rigid pavement. Higher CBR values allow for a reduction in concrete slab thickness, while higher concrete quality increases the modulus of elasticity and flexural strength of the concrete, enabling a reduction in slab thickness. However, the influence of CBR values is more significant than that of concrete quality, particularly at higher concrete grades.In conclusion, improving subgrade CBR values is more effective in reducing rigid pavement thickness than solely enhancing concrete quality. Further economic analysis is recommended to evaluate the most cost-effective combination of concrete quality and subgrade CBR values, considering both construction and long-term maintenance costs.

Key words: *Road, rigid pavement, California Bearing Ratio (CBR), concrete quality, AASHTO 1993*

Submitted:	Reviewed:	Revised	Published:
July 30th, 2024	October 11th, 2024	January 5th, 2025	August 1st, 2025

INTRODUCTION

Roads are the primary infrastructure for land transportation, facilitating traffic from one place to another. Road pavement planning continues to develop alongside advancements in technology and science. The most commonly used types of pavement are composite, rigid (concrete), and flexible (asphalt). Determining the structure's load-bearing capacity is the primary goal of rigid pavement planning. Rigid concrete pavement has a high modulus of elasticity (Pasaribu & Simanullang, 2021). This allows the load to be distributed evenly over a wide soil area, enabling the concrete slab to provide most of the pavement structure's capacity. In contrast, flexible pavement derives its strength from the subbase and the deep surface layers (Akbar & Wesli, 2016).

Subgrade soil with a low CBR value tends to be less stable and prone to deformation, which can ultimately cause damage to the rigid pavement built on it (Kumar et al., 2021). Selecting a concrete quality that matches the existing subgrade conditions is necessary to address this issue. Regarding the road from Simpang village, Berbak to Simpang Muara Sabak, there are issues related to the low CBR value of the subgrade soil. This raises concerns about the performance of the existing rigid pavement, especially given that the concrete used may not be suitable for the subgrade conditions.

Therefore, an in-depth study is needed to examine the influence of the subgrade CBR value and concrete quality on the optimal thickness of the rigid pavement for the road. This research identifies and evaluates the impact of two main factors: the California Bearing Ratio (CBR) value of the subgrade soil and the concrete quality on the thickness of rigid pavement slabs (Mayadhita, 2019). The CBR value of the subgrade is used to assess the soil's load-bearing capacity, which serves as the foundation for the pavement. Meanwhile, concrete quality affects the strength and durability of the pavement slab under loads and environmental conditions (Suhelmidawati et al., 2021). Thus, this study aims to determine the influence of the subgrade CBR value and concrete quality on rigid pavement thickness.

RESEARCH METHOD

This study employs a quantitative approach using the AASHTO 1993 method to determine the influence of the subgrade CBR value and concrete quality on the thickness of rigid pavement (Case Study: Simpang village, Berbak to Simpang Ma. Sabak Road).

Research location

The location of this research is the Simpang Village, Berbak to Muara Sabak Road, in the Muara Sabak Timur District, Tanjung Jabung Timur Regency. (**Figure 1**).

Figure 1. Research Location

Flowchart and Methodology

This study employs a quantitative approach using the AASHTO 1993. The overview of the research flows is presented in **Figure 2**. Data on subgrade soil, particularly CBR values (**Table 1**), and rainfall data from the BPS Provinsi Jambi (Badan Pusat Statistik Provinsi Jambi, 2018) are collected and analyzed using the AASHTO 1993 method to determine the optimal rigid pavement thickness. The analysis focuses on traffic volume, subgrade characteristics, and material quality to ensure accurate pavement design.

Table 1. CBR Values

STA	CBR Value
26+000	1,460%
26+200	1,869%
26+400	3,671%
26+600	1,992%
26+800	1,561%
27+000	1,450%
27+100	1,696%

(Source: Dinas PUPR Provinsi Jambi, 2023)

The concrete grades used in this study are K-200 and K-250, representing low-grade concrete (for working floors), and K-300, K-350, K-400, and K-450, representing medium-grade concrete for pavement, to assess their impact on the thickness of rigid pavement (Kementerian Pekerjaan Umum Dan Perumahan Rakyat Direktorat Jenderal Bina Marga, 2020).

Technical Data

1. Road Width: 7 m
2. Shoulder Width: 1 m (varies)
3. Number of Lanes: 2 lanes
4. Number of Directions: 2 directions
5. Lane Width: 2 × 3.5 m

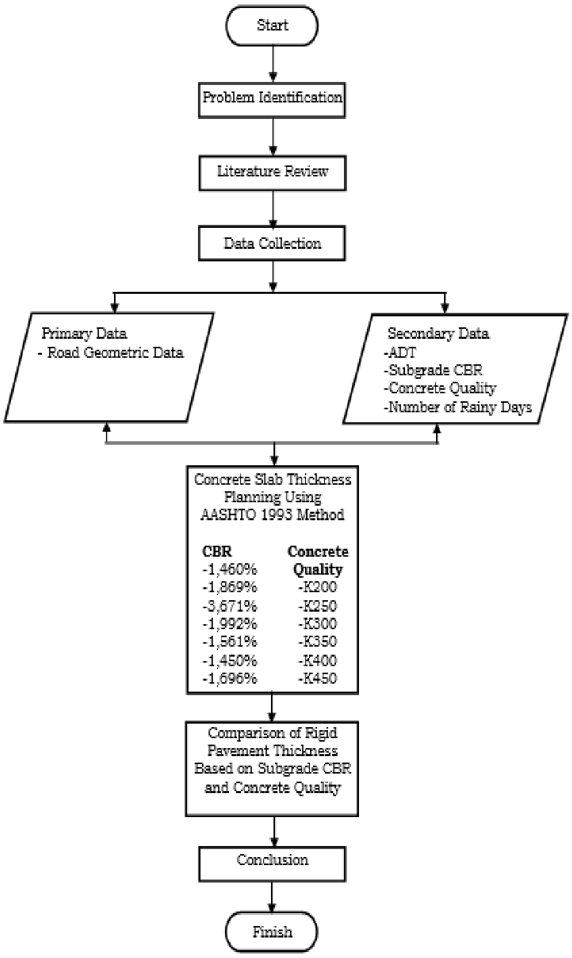

Figure 2. Flowchart

RESULT AND DISCUSSION

Traffic Analysis

The design life for the Simpang, Berbak to Muara Sabak Road is set at 40 years old. The directional distribution factor (DD) typically ranges from 0.3 to 0.7, with 0.5 commonly used. For a road with two lanes, the lane distribution factor (DL) ranges from 80 to 100, and a value of 80 (0.8) is used (AASHTO, 1993). **Equation 1** estimated daily traffic for a specific year based on secondary data. The results of the estimation are shown in **Table 2**. The estimation was then extended to 2030 for the research purposes. According to Bina Marga, the Vehicle Damage Factor (VDF) values can be determined as listed in **Table 3**.

$$LHR_n = LHR_0 + (1 + i)^n \quad \text{.... (1)}$$

Determining Equivalent Single Axle Load (ESAL)

The formula to calculate ESAL is:

$$W18 = \sum LHRj \times VDFj \times DD \times DL \times 365 \quad \text{...(2)}$$

The cumulative ESAL over 40 years is calculated to be 29.777.187.

Table 2. Daily Traffic 2024

Vehicle			2014	2024
			3,5%	3,5%
Sedan, Jeep, st. Wagon	2	1,1	390	524
Pick-up, Van	3	1,1	469	630
2-axle Truck (L), Micro Truck	4	1,2L	322	433
Mini Bus	5a	1,2	99	133
Large Bus	5b	1,2	5	7
2-axle Truck (H)	6	1,2H	554	745
3-axle Truck	7a	1,22	63	85
4-axle Trailer	7b	1,2+2,2	1	1
Semi-trailer Truck	7c	1,22+2,2	39	52

Table 3. Vehicle Damage Factor

Category	Vehicle Type	*VDF*
2	Sedan, Jeep, Station Wagon	0,0005
3	Pick-up, Van	0,2174
4	2-axle Truck (L), Micro Truck, Obstruction Vehicle	0,2174
5a	Mini Bus	0,2174
5b	Large Bus	0,3006
6	2-axle Truck (H)	2,4159
7a	3-axle Truck	2,7461
7b	4-axle Trailer, Articulated Truck	3,9083
7c	Semi-trailer Truck	4,1718

(Sumber: Direktorat Jenderal Bina Marga, 2017)

Determining Reliability (R)

The reliability (R) is between 75% and 95% for a rural collector road, with R set at 95%. Therefore, the ZR value is -1.645. The overall standard deviation is chosen based on local conditions, with AASHTO (1993) recommending a standard deviation (So) between 0.30 and 0.40 for rigid pavements.

Determining Serviceability

AASHTO (1993) recommends an initial serviceability index (Po) 4.5. Since this is a low-traffic road, the final serviceability index (Pt) is 2.0. The total loss of serviceability is a critical parameter for road condition evaluation:

$$\Delta PSI = P_0 - P_t \quad \text{…(3)}$$
$$\Delta PSI = 4{,}5 - 2$$
$$\Delta PSI = 2{,}5$$

Determining Drainage Coefficient (CD)

The drainage coefficient (CD) ranges from 70% to 95% for asphalt or concrete roads. With an average rainfall frequency (Tj) of 3 hours per day and an average of 207 rainy days per year (Badan Pusat Statistik Provinsi Jambi, 2018), the drainage coefficient is calculated as:

$$P = \frac{T_j T_h}{8760} \times (1 - C) \times 100 \quad \text{…(4)}$$
$$P = \frac{3 \times 207}{8760} \times (1 - 0.7) \times 100$$
$$P = 2{,}31\%$$

For good quality drainage with 2.31% water exposure, the CD is taken as 1.10.

Determining Load Transfer Coefficient (J)

For a Jointed Reinforced Concrete Pavement (JRCP), the load transfer coefficient (J) ranges from 2.5 to 3.1, with a value of 2.8 used.

Determining Effective Subgrade Reaction Modulus (k)

The resilient modulus is calculated using the formula:

$$MR = 1500 \times CBR \quad \text{…(5)}$$
$$MR = 1500 \times 1{,}45\%$$
$$MR = 2175\ psi$$
$$k = \frac{MR}{19.4}$$
$$k = \frac{2175}{19{,}4}$$
$$k = 112{,}113\ pci$$

For fine-grained/natural subgrade materials, the value of LS is chosen as 3. Based on the graph, % effective subgrade reaction modulus for a CBR of 1.45% (k = 112.113 and LS = 3) is 8.

Determining Concrete Elasticity Modulus (Ec) and Flexural Strength

For one sample of concrete quality K-200:

$$Ec = 57000\sqrt{f'c} \quad \text{…(6)}$$
$$Ec = 57000\sqrt{2844}$$
$$Ec = 3.039.762$$
$$Sc' = 43{,}5\left(\frac{Ec}{10^6} \times 48{,}58\right) \quad \text{…(7)}$$
$$Sc' = 43{,}5\left(\frac{3.039.762}{10^6} \times 48{,}58\right)$$
$$Sc' = 620\ psi$$

Determining Concrete Slab Thickness

The required Log_{10} W_{18} value is used as a reference standard. The calculated Log_{10} W_{18} should equal or exceed the required Log_{10} W_{18}, which is acquired by substituting all the variables that have been aforementioned before into Equation 8.

$$\log_{10} W_{10} = Z_R + S_0 + 7{,}35\log_{10}(D+1) - 0{,}66 + \frac{\log_{10}\left(\frac{\Delta Psi}{4{,}5-1{,}5}\right)}{1+\frac{1{,}6424\times10^7}{(D+1)^{4{,}86}}} + (4{,}22 - 0{,}32pt) \times \log_{10} \frac{Sc'Cd\left(D^{0{,}7}-1{,}132\right)}{2156{,}63J\left[D^{0{,}75}-\frac{10{,}42}{\left(\frac{EC}{K}\right)^{0{,}25}}\right]} \quad \ldots(8)$$

The estimated slab thickness is 27 cm or 11,417 inches. The final check shows:

Log_{10} W_{18}	≥	Need Log_{10} W_{18}	
7,490	≥	7,474	**(OK)**

The results for all calculations using every variation of CBR and concrete quality are shown in **Table 4** to **Table 10**. The recap of Concrete Slab Thickness Variation by CBR Value and Concrete Quality is shown in **Table 11**.

Table 4. Thickness of Concrete Slab for CBR 1,45%

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
1,45%	K-200	112,113	3039762	621	27	7,474	7,490	OK
1,45%	K-250	112,113	3398558	636	27	7,474	7,515	OK
1,45%	K-300	112,113	3722934	650	27	7,474	7,538	OK
1,45%	K-350	112,113	4021228	663	27	7,474	7,560	OK
1,45%	K-400	112,113		676	27	7,474	7,580	OK
1,45%	K-450	112,113	4559644	687	26	7,474	7,492	OK

Table 5. Thickness of Concrete Slab for CBR 1.46%

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
1,46%	K-200	112,887	3039762	621	27	7,474	7,491	OK
1,46%	K-250	112,887	3398558	636	27	7,474	7,516	OK
1,46%	K-300	112,887	3722934	650	27	7,474	7,539	OK
1,46%	K-350	112,887	4021228	663	27	7,474	7,561	OK
1,46%	K-400	112,887	4298873	676	26	7,474	7,474	OK
1,46%	K-450	112,887	4559644	687	26	7,474	7,493	OK

Table 6. Thickness of Concrete Slab for CBR 1,56%.

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
1,56%	K-200	120,696	3039762	621	27	7,474	7,499	OK
1,56%	K-250	120,696	3398558	636	27	7,474	7,555	OK
1,56%	K-300	120,696	3722934	650	27	7,474	7,577	OK
1,56%	K-350	120,696	4021228	663	26	7,474	7,492	OK
1,56%	K-400	120,696	4298873	676	26	7,474	7,512	OK
1,56%	K-450	120,696	4559644	687	26	7,474	7,530	OK

Table 7. Thickness of Concrete Slab for CBR 1,696%.

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
1,696%	K-200	131,134	3039762	621	27	7,474	7,499	OK
1,696%	K-250	131,134	3398558	636	27	7,474	7,555	OK
1,696%	K-300	131,134	3722934	650	27	7,474	7,577	OK
1,696%	K-350	131,134	4021228	663	26	7,474	7,492	OK
1,696%	K-400	131,134	4298873	676	26	7,474	7,512	OK

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1,696%	K-450	131,134	4559644	687	26	7,474	7,530	OK

Table 8. Thickness of Concrete Slab for CBR 1,869%.

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
1,869%	K-200	144,510	3039762	621	27	7,474	7,510	OK
1,869%	K-250	144,510	3398558	636	27	7,474	7,534	OK
1,869%	K-300	144,510	3722934	650	27	7,474	7,557	OK
1,869%	K-350	144,510	4021228	663	27	7,474	7,578	OK
1,869%	K-400	144,510	4298873	676	26	7,474	7,491	OK
1,869%	K-450	144,510	4559644	687	26	7,474	7,510	OK

Table 9. Thickness of Concrete Slab for CBR 1,992%.

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
1,992%	K-200	144,510	3039762	621	27	7,474	7,523	OK
1,992%	K-250	144,510	3398558	636	27	7,474	7,547	OK
1,992%	K-300	144,510	3722934	650	27	7,474	7,569	OK
1,992%	K-350	144,510	4021228	663	26	7,474	7,484	OK
1,992%	K-400	144,510	4298873	676	26	7,474	7,503	OK
1,992%	K-450	144,510	4559644	687	26	7,474	7,522	OK

Table 10. Thickness of Concrete Slab for CBR 3,671%.

CBR	Concrete Quality (MPa)	k (pci)	Ec	Sc' (psi)	D (cm)	Need Log10 W18	Log 10 W18	Status
3,671%	K-200	283,840	3039762	621	26	7,474	7,526	OK
3,671%	**K-250**	**283,840**	**3398558**	**636**	**26**	**7,474**	**7,545**	**OK**
3,671%	K-300	283,840	3722934	650	26	7,474	7,564	OK
3,671%	K-350	283,840	4021228	663	25	7,474	7,476	OK
3,671%	K-400	283,840	4298873	676	25	7,474	7,493	OK
3,671%	K-450	283,840	4559644	687	25	7,474	7,509	OK

Table 11. Recap of Concrete Slab Thickness Variation by CBR Value and Concrete Quality.

STA	CBR Value	K-200	K-250	K-300	K-350	K-400	K-450
27+000	1,450%	27 cm	27 cm	27 cm	27 cm	27 cm	26 cm
26+000	1,460%	27 cm	27 cm	27 cm	27 cm	26 cm	26 cm
26+800	1,561%	27 cm	27 cm	27 cm	26 cm	26 cm	26 cm
27+100	1,696%	27 cm	27 cm	27 cm	26 cm	26 cm	26 cm
26+200	1,869%	27 cm	27 cm	27 cm	26 cm	26 cm	26 cm
26+600	1,992%	27 cm	27 cm	27 cm	26 cm	26 cm	26 cm
26+400	3,671%	26 cm	26 cm	26 cm	25 cm	25 cm	25 cm

Discussion

In this study, the variables examined are limited to the subgrade CBR value and concrete quality, while other values such as design life (40 years), cumulative traffic, lean concrete (K-175 with a thickness of 10 cm) (Dinas PUPR Provinsi Jambi Bidang Bina Marga, 2016), and other parameters are kept constant. According to the data in **Figure 3**, for concrete grades K-200 to K-300, low CBR values (less than 1.992%) do not significantly affect the pavement thickness. However, CBR values significantly impact the pavement thickness for higher concrete grades (K-350 to K-450). The efficiency of increasing concrete quality is evident from CBR values of 1.450% to 1.460% for K-400 and K-450 and from CBR values of 1.561% to 1.992% for K-300 to K-350.

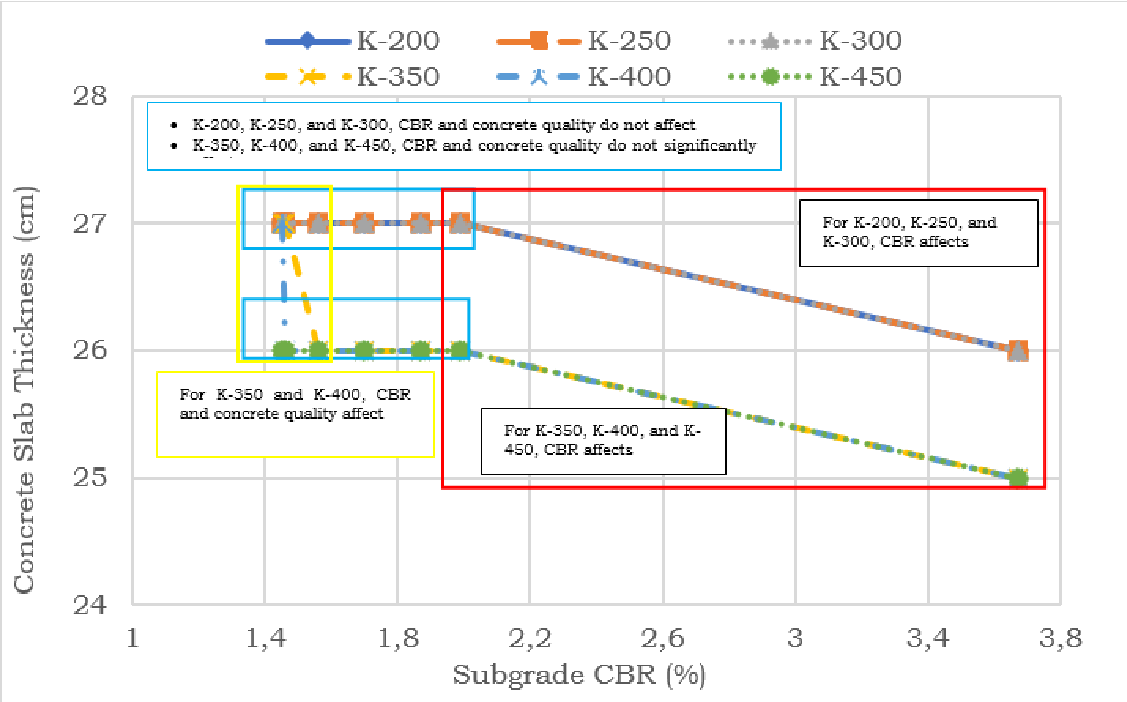

Figure 3. Comparison of Rigid Pavement Thickness Based on Subgrade CBR and Concrete Quality

Conversely, the efficiency of increasing CBR is noticeable for K-200 to K-300 at CBR 3.671% and for K-350 and above, ranging from CBR 1.561% to 1.992%.

Thus, implementing rigid pavement to improve the subgrade CBR value can provide more cost-effective and performance-efficient solutions. This is supported by research by Suhelmidawati et al. (2021), which indicates that increasing the subgrade CBR value through soil stabilization with cement is cheaper than using high-quality concrete in the pavement layer, potentially saving about 10% to 20% in costs. Similarly, research by Amakye et al. (2022) supports this, concluding that the thickness of rigid pavement can be reduced by strengthening the subgrade material with cement. Thus, soil stabilization with 20% cement results in a much more economical design than using high-quality cement for concrete slab work. Similar result can be achieved using fly ash as filler material (Insan et al., 2019; Taqwa & Irfan, 2020). This study uses actual CBR data from tests on the Simpang/Berbak-Simpang Ma. The Sabak Road project led to a disproportion in the CBR value range. This range causes more significant variation in the recommended pavement thickness, especially when the subgrade CBR value is low, indicating weaker soil that requires thicker pavement to support the load.

If the CBR value is low, the rigid pavement should be thicker. Although high-quality concrete can provide better strength, the low CBR value of the subgrade necessitates a concrete structure designed to compensate for the soil's insufficient load-bearing capacity, resulting in increased pavement thickness (Amakye et al., 2022). Conversely, if the CBR value is high but the concrete quality is low, the pavement thickness will be thinner than required.

Based on the results of the calculations and analysis that have been carried out, the recommended pavement thickness for the Simpang/Berbak Village Road construction project to Muara Sabak Junction is 26 cm. This thickness is determined based on the average value of the calculated pavement, taking into account the stability and bearing capacity requirements of the road. The recommended concrete compressive strength to be used is 32.1 MPa or equivalent to K-350 concrete quality. The use of this concrete grade is expected to provide optimal strength and durability against traffic loads and environmental conditions, thus ensuring a longer road service life and more reliable performance.

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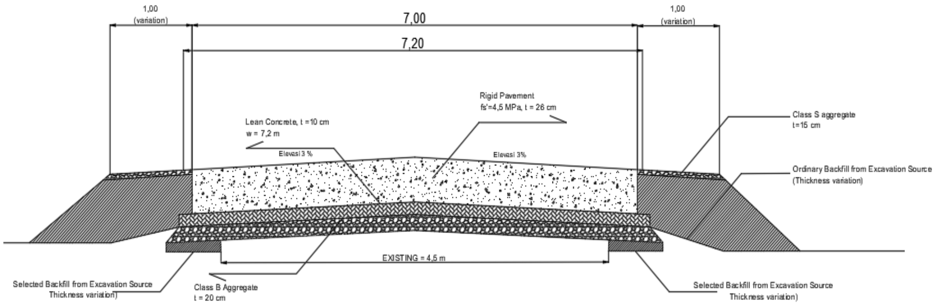

Figure 4. The Recommended Pavement Thickness

In both scenarios, having a high CBR value is generally better, as a firm subgrade can support greater loads, providing higher stability and reduced deformation. It can offer sufficient strength with appropriate thickness adjustments when combined with medium-quality concrete. These results highlight the significance of using CBR values as an essential parameter in pavement design. The significant impact of the subgrade CBR value can be explained by the considerable variation in subgrade strength, especially when low CBR values indicate weaker soil that requires thicker pavement to ensure stability and long-term performance. However, it should be emphasized that this study is case-based and cannot be generalized, as the results are empirically calculated rather than based on direct testing, thus only meeting existing standards.

CONCLUSION

Based on the study regarding the effect of subgrade CBR values and concrete quality on the thickness of rigid pavement at Simpang village, Berbak to Muara Sabak, it can be concluded that the subgrade CBR value affects the effective subgrade modulus; as the CBR value increases, the thickness of the concrete slab can be reduced. The influence of CBR on the thickness of the concrete slab is more significant than the influence of concrete quality when the concrete quality is high. Secondly, concrete quality affects the modulus of elasticity and flexural strength of the concrete; as the concrete quality increases, the thickness of the concrete slab can be reduced. However, concrete quality only significantly affects the slab thickness if the subgrade CBR value is low. If the CBR value is low, improving concrete quality can reduce the thickness of the pavement, as high-quality concrete can compensate for the lack of subgrade support. Conversely, if the concrete quality is low, despite good subgrade support, the concrete structure becomes prone to cracking or failure and requires additional thickness to provide adequate strength.

If the goal is to use the thinnest possible concrete slab in certain conditions, focusing on improving the subgrade strength (increasing the CBR value) rather than just improving concrete quality is better. Further economic analysis is also recommended regarding using different concrete qualities and varying subgrade CBR values. Considering construction and long-term maintenance costs, this study can provide better guidance in selecting the most cost-effective combination of concrete quality and subgrade CBR values.

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