International Journal of Sustainable Building, Infrastructure and Environment (IJOSBIE)
Vol. 7, No. 2, October 2026, pp. 43-52
ISSN: 2716-4829 DOI: https://doi.org/10.26877/ijosbie.v7i2.1114

Structural Design of Concrete Pavement Using the MDPJ 2024 Method on Kraguman Kidul Road, Klaten Regency

Kharis Lutfi*, Slamet Budirahardjo, Agustina Wardani, Qurrota A'yun

Faculty of Engineering and Informatics, Universitas PGRI Semarang, Jl. Sidodadi-Timur No.24 Semarang, Central Java 50232, Indonesia

*22640063@upgris.ac.id

Abstract. Traffic volume surges and axle overloading cause premature damage to flexible pavements on Kraguman Kidul Road, Klaten Regency, necessitating a rigid pavement solution. This study designs a concrete pavement structure using the mechanistic-empirical Manual Desain Perkerasan Jalan (MDPJ) 2024 method for a 500-meter segment with a 40-year design life, using traffic surveys and Dynamic Cone Penetrometer testing that showed a subgrade CBR of 2.44%. To withstand a cumulative load of 9×10^6 JSKN, the design determines a concrete slab thickness of 22 cm (f'c 40 MPa) with a 12.5 cm lean concrete subbase, 20 cm Class A aggregate, 20 cm Class C aggregate, and 60 cm selected embankment. Transverse joints use Ø33 mm dowels (30 cm spacing), and longitudinal joints use D16 mm tie bars (60 cm spacing). This conservative design effectively prevents premature structural failures on soft subgrades under heavy traffic.

Keywords: construction budget, dynamic cone penetrometer, Kraguman Kidul Road, MDPJ 2024, rigid pavement

1. Introduction

Road networks represent vital infrastructure indispensable for regional economic development, distribution logistics, and public mobility, requiring rigorous design standards to ensure long-term safety and structural reliability [1], [2]. Rapid regional expansion and economic development inevitably trigger a substantial surge in traffic volume and the prevalence of heavy commercial vehicles operating under overloaded conditions, which drastically accelerates the structural degradation of road networks. On conventional flexible pavements, these excessive and repetitive axle loads manifest as severe premature surface distresses, including widespread alligator cracking, localized depressions, and frequent patching, all of which significantly deteriorate traffic safety and increase vehicle operating costs [3]. To address these structural deficiencies, rigid pavement (cement concrete pavement) serves as a superior alternative for strategic corridors owing to its high flexural rigidity, uniform load distribution over the subgrade, extended design life, and minimal maintenance expenditures throughout its operational lifespan [4].

© 2026 The Author(s). International Journal of Sustainable Building, Infrastructure and Environment (IJOSBIE) are published under the terms of the Creative Commons Attribution-ShareAlike (CC BY-SA 4.0). Authors retain the copyright to their work. Users may read, copy and distribute the work in any medium provided the authors and the journal are appropriately credited

2. Methods

The design stages begin with a comprehensive literature review of various reference books, scientific journals, and related technical standards to establish a solid theoretical framework for rigid pavement structural design. Through this literature study, the planning parameters and technical specifications mandated by the latest regulations are thoroughly reviewed to ensure the accuracy and reliability of the computational process. The systematic workflow of these research and engineering design stages is comprehensively illustrated in the flowchart presented in Figure 1.

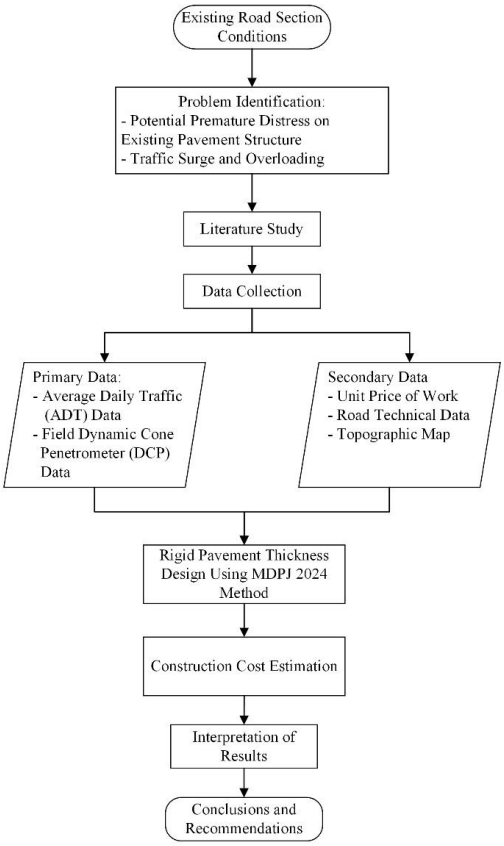


Figure 1. Research methodology

The subsequent stage involves data collection, which is categorized into primary and secondary data. Primary data are gathered directly through on-site traffic volume surveys—specifically Average Daily Traffic (ADT / LHR)—and field geotechnical testing using the Dynamic Cone Penetrometer (DCP) [5] on Kraguman Kidul Road, Klaten Regency. Meanwhile, secondary data are compiled from relevant authorized institutions to complete the modeling variables required for the structural analysis.

The next phase encompasses field data analysis and the technical engineering design of the concrete slab thickness utilizing the 2024 Road Pavement Design Manual (Manual Desain Perkerasan Jalan / MDPJ 2024) method. The step-by-step procedure of the MDPJ 2024 design method is systematically outlined in the flowchart shown in Figure 2. In this stage, the effective subgrade bearing capacity is determined, and the cumulative axle load repetitions of commercial vehicles are projected to evaluate the structural thickness boundaries that are safe from both fatigue and erosion failure risks.

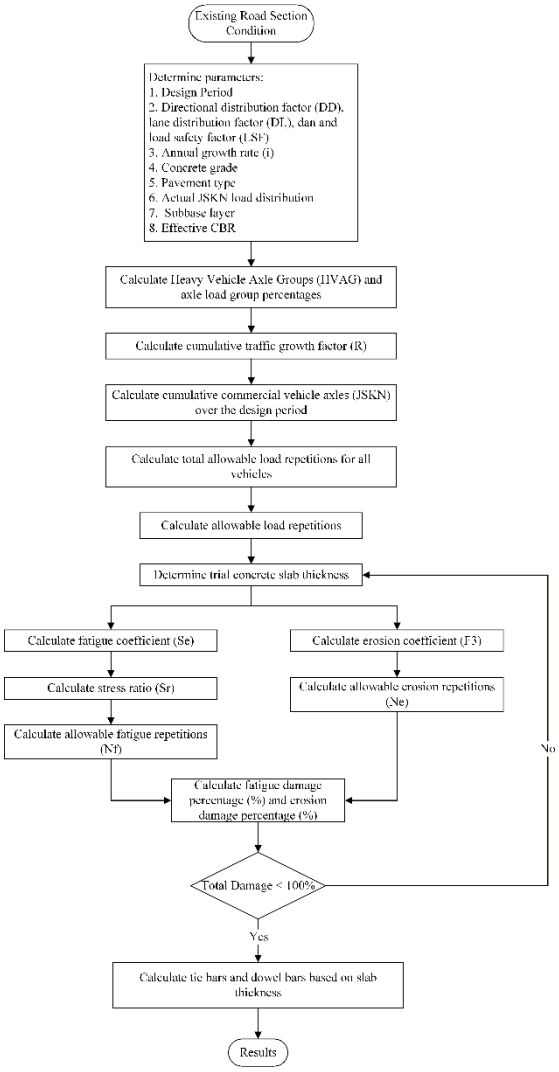


Figure 2. Procedure of the MDPJ 2024 design method

The final stage of this design process involves evaluating the initial capital investment by compiling a detailed construction cost estimate (Rencana Anggaran Biaya / RAB) and formulating conclusions and recommendations. The physical construction budget is calculated based on the exact material volumes derived from the final structural design, while the conclusions and recommendations are structured to provide robust and highly applicable technical guidance for direct field implementation.

3. Results and Discussion

3.1. Based on the MDPJ 2024 method

Based on the MDPJ 2024 guidelines, Table 1 presents the breakdown of vehicle categories, axle layouts, axle groups, and vehicle numbers sourced from the 2026 ADT data [6].

Table 1. Vehicle group classification

Vehicle Group	Vehicle Type	Axle Configuration	Axle Group	Vehicle Count
1	Motorcycle and 3-wheel vehicles	1.1	2	5331

Vehicle Group	Vehicle Type	Axle Configuration	Axle Group	Vehicle Count
2	Light vehicles - sedan, jeep, and station wagon	1.1	2	489
3	Light vehicles - medium public transport	1.1	2	0
4	Light vehicles - pick up, micro truck	1.1	2	275
5A	Small bus	1.1	2	8
5B	Large bus	1.2	2	2
6A	2-axle truck - light	1.1	2	20
6B	2-axle truck - medium	1.2	2	506
7A2	3-axle heavy truck	1.22	2	4
7B	4-axle heavy truck	1.2+2.2	4	0
7C	5-axle heavy truck	1.22-22	5	0

Next, ADT data restricted to vehicles weighing at least 5 tons is converted into JSKN using the axle configuration table provided in the guidelines, with the results summarized in Table 2.

Table 2. Conversion results to JSKN

Vehicle Group	ADT	HVAG	$JSKN_{JK}$	STRT	STRG	STdRT	STrRG	SQdRG
5B	506	4	2	2	2	-	-	-
6A	4	40	2	40	-	-	-	-
6B	0	1012	2	506	506	-	-	-
7A2	0	8	2	4	-	-	4	-
7B	506	0	4	-	0	0	-	-
7C	4	0	5	0	-	-	0	-
Total	532	1064	-	552	508	0	4	0
Percentage		100%	-	51.88%	47.74%	0.00%	0.38%	0.00%

Next, for two-way roads, a direction distribution factor (DD) of 0.5 and a lane distribution factor (DL) of 100% are used, taken from the table of provisions according to the single-lane condition in each direction. With 365 days in a year, a growth factor (R) of 48.89, and a daily JSKN value of 1,064, the total cumulative JSKN is calculated using the formula in Equation 1.

$$JSKN = (\Sigma\ LHR_{JK} \times JSKN_{JK}) \times 365 \times DD \times DL \times R \quad (1)$$

The calculation yields a result of 9,492,755.98 or equivalent to 9×10^6 JSKN. The type of rigid pavement structure used is jointed plain concrete pavement (JPCP) with a slab thickness of 220 mm (22 cm), designed using concrete with f'c 40 MPa (flexural strength fcf = 4.74 MPa), exceeding the minimum requirement of 4.5 MPa, and equipped with concrete shoulders. The bearing capacity of each layer consists of existing subgrade soil with a CBR of 2.44%, supported by a 600 mm thick selected embankment layer for subgrade improvement, a 200 mm Class C aggregate foundation layer, and a 200 mm Class A aggregate foundation layer. Additionally, the structural design incorporates a lean concrete lower foundation layer (BK) with a thickness of 125 mm, as per the specifications in the guidelines [6]–[8]. Based on the graph and the thickness of the lower foundation layer (Figure 3), the Effective Subgrade CBR value is determined to be 24%.

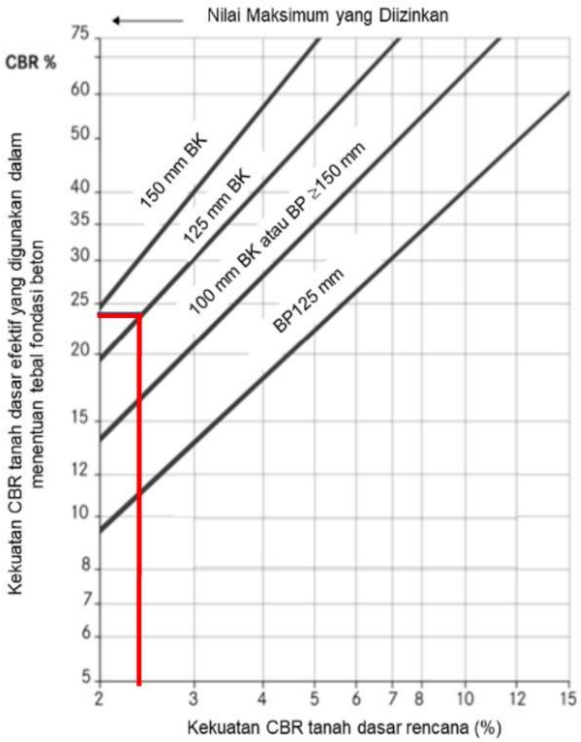


Figure 3. Effective Subgrade CBR chart

Furthermore, using the Effective Subgrade CBR value of 24% and the slab thickness of 220 mm, fatigue and erosion analyses were performed for each axle load group. The detailed calculation results for the STRT, STRG, STdRT, STdRG, and STrRG groups are presented in Table 3 to Table 7.

Table 3. Fatigue and erosion factor calculation results STRT

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
10	12				
20	24	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
30	36	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
40	48	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
50	60	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
60	72	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
70	84	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
80	96	*UNLIMITED*	0.00%	5.017×10^{7}	0.14%
90	108	*UNLIMITED*	0.00%	5.967×10^{6}	0.32%
100	120	10749207.23	0.04%	1.972×10^{6}	0.20%
110	132	579969.06	0.08%	8.910×10^{5}	0.06%
Total			**0.122%**		**0.715%**

Table 4. Fatigue and erosion factor calculation results STRG

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
20	24	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
30	36	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
40	48	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
50	60	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
60	72	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
70	84	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
80	96	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
90	108	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
100	120	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
110	132	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
120	144	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
130	156	2335825.63	5.98%	3.555×10^{14}	0.00%
140	168	394434.63	15.28%	3.555×10^{14}	0.00%
150	180	125997.01	16.19%	3.555×10^{14}	0.00%
160	192	48446.53	7.48%	3.555×10^{14}	0.00%
170	204	18693.01	31.52%	3.555×10^{14}	0.00%
180	216	7236.92	18.79%	3.555×10^{14}	0.00%
Total			**95.237%**		**0.000%**

Table 5. Fatigue and erosion factor calculation results STdRT

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
40	48	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
50	60				
60	72				
70	84				
80	96	*UNLIMITED*	0.00%	8.982×10^{6}	0.00%
90	108	*UNLIMITED*	0.00%	2.338×10^{6}	0.00%
100	120	*UNLIMITED*	0.00%	9.500×10^{5}	0.00%
110	132	*UNLIMITED*	0.00%	4.716×10^{5}	0.00%
120	144	*UNLIMITED*	0.00%	2.630×10^{5}	0.00%
130	156	*UNLIMITED*	0.00%	1.585×10^{5}	0.00%
140	168	*UNLIMITED*	0.00%	1.010×10^{5}	0.00%
150	180	*UNLIMITED*	0.00%	6.709×10^{4}	0.00%
160	192	*UNLIMITED*	0.00%	4.611×10^{4}	0.00%
170	204				
180	216	*UNLIMITED*	0.00%	2.353×10^{4}	0.00%
190	228	*UNLIMITED*	0.00%	1.734×10^{4}	0.00%
Total			**0.000%**		**0.000%**

Table 6. Fatigue and erosion factor calculation results STdRG

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
50	60	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
60	72	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
70	84	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
80	96	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
90	108	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
100	120	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
110	132	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
120	144	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
130	156	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
140	168	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
150	180	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
160	192	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
170	204	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
180	216	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
190	228	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
200	240	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
210	252	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
220	264	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
230	276	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
240	288	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
250	300	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
260	312	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
270	324	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
280	336	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
290	348	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
300	360	9853802.17	0.01%	3.555×10^{14}	0.00%
310	372	2796392.98	0.27%	3.555×10^{14}	0.00%
320	384	1130865.44	0.00%	3.555×10^{14}	0.00%
330	396	557663.90	0.00%	3.555×10^{14}	0.00%
340	408	312253.49	0.00%	3.555×10^{14}	0.00%
350	420	190995.80	0.00%	3.555×10^{14}	0.00%
360	432				
370	444	83666.62	0.01%	3.555×10^{14}	0.00%
380	456				
390	468				
400	480	25371.10	0.03%	3.555×10^{14}	0.00%
Total			**0.324%**		**0.000%**

Table 7. Fatigue and erosion factor calculation results STrRG

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
120	144	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
130	156	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
140	168	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
150	180	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
160	192	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
170	204	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
180	216	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
190	228	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
200	240	*UNLIMITED*	0.00%	3.555×10^{14}	0.00%
210	252	*UNLIMITED*	0.00%	9.007×10^{7}	0.00%
220	264	*UNLIMITED*	0.00%	2.420×10^{7}	0.00%
230	276	*UNLIMITED*	0.00%	1.093×10^{7}	0.00%
240	288	*UNLIMITED*	0.00%	6.073×10^{6}	0.00%

Axle Group Load (kN)	L_{sf}	Allowable Repetitions (Fatigue)	Fatigue	Allowable Repetitions (Erosion)	Erosion
250	300	*UNLIMITED*	0.00%	3.783×10^{6}	0.00%
260	312	*UNLIMITED*	0.00%	2.534×10^{6}	0.00%
270	324	*UNLIMITED*	0.00%	1.786×10^{6}	0.00%
280	336	*UNLIMITED*	0.00%	1.307×10^{6}	0.00%
290	348	*UNLIMITED*	0.00%	9.846×10^{5}	0.00%
300	360	*UNLIMITED*	0.00%	7.592×10^{5}	0.00%
310	372	*UNLIMITED*	0.00%	5.966×10^{5}	0.00%
320	384	*UNLIMITED*	0.00%	4.764×10^{5}	0.00%
330	396	*UNLIMITED*	0.00%	3.855×10^{5}	0.00%
340	408	*UNLIMITED*	0.00%	3.156×10^{5}	0.00%
350	420	*UNLIMITED*	0.00%	2.610×10^{5}	0.00%
360	432	*UNLIMITED*	0.00%	2.178×10^{5}	0.00%
370	444	*UNLIMITED*	0.00%	1.832×10^{5}	0.00%
380	456				
390	468	*UNLIMITED*	0.00%	1.323×10^{5}	0.00%
400	480	*UNLIMITED*	0.00%	1.135×10^{5}	0.00%
Total			**0.000%**		**0.000%**

Fatigue and erosion damage percentages were calculated using a concrete slab thickness of 220 mm, yielding total accumulated damage values of 95.682% for fatigue and 0.715% for erosion (Table 8). Since both values were below the maximum allowable limit of 100%, the proposed slab thickness was confirmed to be structurally safe and fulfilled the design criteria.

Table 8. Accumulation of fatigue and erosion damage percentages

Failure Aspect	Percentage
Fatigue	95.682%
Erosion	0.715%

Based on the analysis results, the appropriate concrete thickness to withstand traffic loads in the rigid pavement design using the MDPJ 2024 method was determined to be 220 mm (22 cm), with a total accumulated fatigue factor of 95.682% and an erosion factor of 0.715%. The concrete pavement is designed as a jointed plain concrete pavement (JPCP) with a lane width of 3 meters. The dowels used are plain steel bars (BjTP 280) with a diameter of Ø33 mm, a length of 45 cm, and a spacing of 30 cm between dowels, in accordance with the guidelines. Meanwhile, the tie bars use deformed/threaded steel bars (BjTS 420A) with a diameter of D16 mm and a length of 70 cm, installed at a spacing of 60 cm [6], [9].

3.2. Construction cost estimation / unit price analysis

The physical construction cost estimation (Rencana Anggaran Biaya / RAB) for the rigid pavement design using the Manual Desain Perkerasan Jalan (MDPJ) 2024 method was calculated based on the Bill of Quantities (BOQ) and the Unit Price Analysis (AHSP) of Bina Marga Central Java Province (2025 edition) for Klaten Regency [10]. The scope covers a 500-meter road length (STA 0+000 to STA 0+500). The total physical construction budget required for the MDPJ 2024 design is IDR 8,827,143,793.00 (including 12% Value Added Tax / PPN). This budget accommodates the multi-layer foundation structure, which includes 600 mm subgrade improvement with selected embankment, 200 mm Class C aggregate base course, 200 mm Class A aggregate base course, 125 mm Lean Concrete (BK) subbase, 220 mm f'c 40 MPa concrete slab, and integrated precast U-ditch drainage. The detailed summary of the cost breakdown is presented in Table 9.

Table 9. Construction cost recapitulation

No.	Work Item Description	Total Price (IDR)
1	General Works (Pekerjaan Umum)	64,500,000.00
2	Earthworks (Pekerjaan Tanah)	784,196,060.00
3	Granular & Concrete Pavement Works (Pekerjaan Perkerasan Berbutir & Beton Semen)	5,352,259,343.00
4	Drainage Works (Pekerjaan Drainase)	1,591,233,332.00
5	Miscellaneous Works (Pekerjaan Lain-Lain)	89,189,651.00
A.	Subtotal (Including Overhead & Profit)	7,881,378,387.00
B.	Value Added Tax (PPN) = 12% × (A)	945,765,406.00
C.	**TOTAL CONSTRUCTION COST = (A) + (B)**	**8,827,143,793.00**

4. Conclusion

The structural design of rigid pavement using the 2024 Road Pavement Design Manual (Manual Desain Perkerasan Jalan / MDPJ 2024) on Kraguman Kidul Road, Klaten Regency (STA 0+000 to STA 0+500) successfully establishes an optimal engineering solution for soft subgrade conditions (design CBR of 2.44%) under heavy traffic loads of 9×10^6 JSKN over a 40-year design period. To ensure long-term structural reliability, the recommended pavement structure comprises a 220 mm (22 cm) thick Jointed Plain Concrete Pavement (JPCP) slab using f'c 40 MPa (flexural strength fcf = 4.74 MPa), supported by a multi-layered foundation consisting of a 125 mm Lean Concrete (BK) subbase, a 200 mm Class A aggregate base, a 200 mm Class C aggregate layer, and a 600 mm selected embankment layer for subgrade stabilization. The joint design specifies plain steel dowels (Ø33 mm, 45 cm length, 30 cm spacing, BjTP 280) for transverse joints and deformed tie bars (D16, 70 cm length, 60 cm spacing, BjTS 420A) for longitudinal joints. Structural adequacy is validated by accumulated fatigue damage (95.682%) and erosion damage (0.715%), both of which remain strictly below the maximum allowable threshold of 100%. Based on the 2025 Unit Price Analysis (AHSP) of Bina Marga Central Java Province for Klaten Regency, the total physical construction cost for this 500-meter section is estimated at IDR 8,827,143,793.00 (including 12% VAT). To guarantee optimal performance during implementation, strict field supervision is strongly recommended during the 600 mm subgrade excavation and backfilling process to ensure uniform density and prevent differential settlement. Furthermore, precision in horizontal alignment and lubrication of dowel bars during joint installation must be strictly enforced to maintain uninhibited thermal expansion and contraction. For future research, conducting a comprehensive Life Cycle Cost Analysis (LCCA) is suggested to evaluate whether the initial capital investment of the conservative MDPJ 2024 design is economically offset by reduced maintenance expenditures over the 40-year service life [11].

Declaration of AI and AI assisted technologies in the writing process

During the preparation of this work the author(s) used google translate in order to translate from Indonesian to English. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Acknowledgements

The authors express their sincere gratitude to the Department of Civil Engineering, Faculty of Engineering and Informatics, Universitas PGRI Semarang, for providing the necessary academic facilities and technical support throughout this research. Special thanks are expressed to the field survey assistants who contributed to the execution of the Dynamic Cone Penetrometer (DCP) testing and traffic volume surveys on Kraguman Kidul Road.

References

[1] Pemerintah Republik Indonesia, *Undang-Undang Republik Indonesia Nomor 38 Tahun 2004 tentang Jalan*. Indonesia, 2004.

[2] Pemerintah Republik Indonesia, *Peraturan Pemerintah Republik Indonesia Nomor 34 Tahun 2006 tentang Jalan*. Lembaran Negara Republik Indonesia Tahun 2006 Nomor 86, 2006.

[3] G. Nugroho, V. G. Saputra, A. Wardani, and S. Budirahardjo, "Analysis of road surface distress using Pavement Condition Index (PCI) and Bina Marga method (Case study: Jalan KH. Abdurahman Wahid, STA. 0+000–STA. 1+950, Wonosobo Subdistrict)," *International Journal of Sustainable Building, Infrastructure and Environment (IJOSBIE)*, vol. 6, no. 2, 2025. https://doi.org/10.26877/ijosbie.v6i2.25079

[4] H. C. Hardiyatmo, *Perancangan Perkerasan Jalan & Penyelidikan Tanah*. Yogyakarta, Indonesia: Gadjah Mada University Press, 2015.

[5] Kementerian Pekerjaan Umum Republik Indonesia, "Surat Edaran Menteri Pekerjaan Umum tentang Pemberlakukan Pedoman Cara Uji California Bearing Ratio (CBR) dengan Dynamic Cone Penetrometer (DCP)," Kementerian Pekerjaan Umum Republik Indonesia, Jakarta, 2010.

[6] Direktorat Jenderal Bina Marga, *Manual Desain Perkerasan Jalan 2024*. Jakarta, Indonesia, 2024.

[7] Direktorat Jenderal Bina Marga, "Spesifikasi Umum Bina Marga 2018 untuk Pekerjaan Konstruksi Jalan dan Jembatan (Revisi 2)," Kementerian Pekerjaan Umum dan Perumahan Rakyat, Jakarta, 2020.

[8] Kementerian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, *Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 5 Tahun 2023 tentang Persyaratan Teknis Jalan dan Perencanaan Teknis Jalan*. Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2023.

[9] Badan Standardisasi Nasional, "Perancangan Perkerasan Beton Semen," Badan Standardisasi Nasional (BSN), Jakarta, 2017.

[10] Dinas Pekerjaan Umum Bina Marga dan Cipta Karya Provinsi Jawa Tengah, "Harga Satuan Pekerjaan (HSP) Konstruksi Bina Marga - MAS PETRUK Edisi Ke-II Tahun 2025," Balai Jasa Konstruksi Provinsi Jawa Tengah. Accessed: Jun. 12, 2026. [Online]. Available: https://maspetruk.dpubinmarcipka.jatengprov.go.id/harga_satuan/hspk_binamarga

[11] F. H. Administration, "Life-cycle cost analysis in pavement design," U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., USA, 1998.