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GEOMETRIC DESIGN, FLEXIBLE PAVEMENT, DRAINAGE DIMENSIONS, AND COST ESTIMATION FOR THE MEREK-SIDIKALANG ROAD WIDENING

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Abstract

The Merek-Sidikalang road section is a national primary arterial road connecting North Sumatra to Aceh. Its current condition fails to meet the minimum width standards set by the Directorate General of Highways (Bina Marga), characterized by inconsistent road widths ("jumping segments") and a damaged drainage system. This study aims to design the horizontal geometric alignment, determine the thickness of the flexible pavement, calculate drainage channel dimensions, and develop a Budget Plan (RAB) for the Merek-Sidikalang road section—specifically from STA 9+950 to STA 14+290 (a total length of 2.047 km, divided into five segments). The design methodology adheres to the 2021 Road Geometric Design Guidelines (PDGJ) for horizontal alignment, the 2024 Road Pavement Design Manual (MDPJ) for flexible pavement, the 2021 Road Drainage Design Guidelines (PDDJ) for drainage dimensions, and the 2026 Unit Price Analysis for Construction Works (AHSP) for cost estimation, utilizing secondary data from relevant authorities. The design results in a Class III primary arterial road with a pavement width of 2x3 meters and a design speed of 20–40 km/h, incorporating 19 horizontal curves (consisting of "Full Circle" and "Spiral-Circle-Spiral" types). The flexible pavement structure—designed for a 20-year service life with a subgrade CBR value of 4.095%—comprises a 400 mm AC-WC layer, a 650 mm AC-BC layer, a 200 mm Class A base course, a 150 mm Class B base course, and a 200 mm granular selected embankment layer. A trapezoidal drainage channel is designed to accommodate a discharge of 0.0510 m^3/s, with a base width of 0.113 m and a total channel height of 0.597 m. The total budget required for construction amounts to IDR 17,455,360,947 (including 10% VAT), or approximately IDR 7,703,160.17 per meter.

Keywords: Horizontal Alignment, Road Drainage, Road Widening, Flexible Pavement, Budget Plan.

INTRODUCTION

The Merek-Sidikalang road connects Merek and Sidikalang and forms part of the national road network serving North Sumatra and the western corridor toward Aceh. The 14.3 km road is managed by the North Sumatra National Road Implementation Agency (BBPJN). Its regional role includes passenger movements, goods distribution, and access between surrounding districts. Within this corridor, road improvement has produced discontinuous widths because some sections have been widened while others retain the previous cross-section. The resulting variation makes the remaining sections an identifiable priority for coordinated technical planning.

Field observations identified five sections that had not been widened, with a combined length of 2,047 m. Their respective lengths were 640, 272, 125, 250, and 760 m. These sections were separated by previously widened stretches, so the intervention area was not a single continuous road segment. The recorded existing widths were approximately 6.5 m in the unwidened sections and 8.5 m in the widened sections. This condition requires attention to the connections between existing and proposed road elements as well as the horizontal alignment within the selected sections. Widening on curves also requires consideration of vehicle movements and geometric transitions, rather than applying an identical cross-section throughout the corridor.

Drainage conditions provided a second reason for reviewing the road design. Existing stone-masonry drains were obstructed by landslide material, branches, leaves, and vegetation, while some sections had sustained physical damage. These observations indicate that drainage provision and maintenance are relevant to the proposed widening works. Drainage design must consider the contributing area, rainfall, runoff, and channel geometry so that surface

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water can be conveyed through the roadside system. The national drainage guidance provides the hydrological and hydraulic basis for this component of road planning (Direktorat Jenderal Bina Marga, 2021a).

The study therefore addresses four connected design tasks: horizontal alignment, flexible pavement thickness for the additional road width, roadside drainage dimensions, and construction cost estimation. Geometric design follows the 2021 Road Geometric Design Guidelines, pavement design uses the 2024 Road Pavement Design Manual, and drainage design follows the 2021 Road Drainage Design Guidelines (Direktorat Jenderal Bina Marga, 2021a, 2021b, 2024). The cost estimate combines the calculated quantities with the unit-price analysis used for the 2026 planning basis. These outputs are intended to support planning for the remaining widening and drainage works. Vertical alignment is outside the scope and is assumed to follow existing conditions. The study consequently presents an engineering design case study rather than an assessment of completed construction or observed improvements in road performance.

LITERATURE REVIEW

Road widening studies show that pavement design is an important component of improvement planning, although the breadth of the analysis differs between cases. Anisarida and Sopian (2023) examined widening on the Ciomas-Mandalawangi road and determined a flexible pavement structure for a 20-year design life. Anisarida and Handayani (2023) considered the Gunung Sari-Mancak-Anyer road, where the existing width motivated a widening proposal supported by pavement calculations. Their study used a 10-year design life. These cases establish the relevance of traffic demand, subgrade support, and pavement composition to widening projects. Their numerical thicknesses cannot be transferred directly to another road without considering the corresponding design inputs.

Other studies have considered geometric, pavement, drainage, and cost requirements together. Azizah et al. (2022) developed a redesign for the Kertajaga-Cidolog road that included horizontal and vertical alignment, flexible pavement, drainage, and a construction budget. Ainnisa and Buana (2021) examined the South Coast road in Bakung, Blitar, using geometric and pavement planning alongside roadside drainage design. Their work illustrates how the selected alignment and cross-section are related to terrain and other project requirements. Munthe (2022) likewise combined geometric design, pavement thickness, drainage dimensions, and cost estimation for the Bangun Purba-Tiga Juhar road. These studies provide relevant examples of integrated road planning, but they concern different corridors, lengths, terrain conditions, and design assumptions.

The reviewed studies also used different editions of Indonesian road-planning guidance. The earlier integrated applications included the 1997 interurban geometric design procedure and earlier pavement and drainage methods. The present study applies PDGJ 2021, MDPJ 2024, and PDDJ 2021 to the selected Merek-Sidikalang sections. This distinction concerns the technical basis and local application of the design. It does not establish that the resulting design is superior to the earlier cases. A comparison of absolute costs, curve counts, or pavement thicknesses would require comparable traffic, subgrade, topographic, and pricing assumptions.

For horizontal alignment, the principal design relationships involve road classification, design speed, curve radius, superelevation, and transition length. These parameters must be considered together when selecting full-circle and spiral-circle-spiral curves (Direktorat Jenderal Bina Marga, 2021b). For the additional pavement width, the design basis includes the service period, traffic loading, vehicle damage factors, directional and lane distribution, and the California Bearing Ratio of the subgrade. The pavement manual links these inputs to the selection of the foundation and pavement structure (Direktorat Jenderal Bina Marga, 2024). The analysis therefore needs to distinguish between the surveyed road conditions, the adopted planning assumptions, and the resulting layer arrangement.

Drainage and cost estimation complete the design framework. Rainfall analysis establishes the design input for runoff calculations, while the contributing area and runoff coefficient determine the discharge to be conveyed. Hydraulic calculations then relate that discharge to channel dimensions and flow conditions (Direktorat Jenderal Bina Marga, 2021a). The resulting geometry, pavement layers, and drainage dimensions also determine work quantities and influence the estimated budget. For Merek-Sidikalang, the specific planning problem is the coordination of these components across five separated unwidened sections. The contribution is a documented application of the selected design procedures to this local condition, with the scope restricted to the remaining widening and drainage works.

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METHOD

Study design and intervention boundaries

The research used an engineering design case-study approach. Its unit of analysis was the remaining widening work on the Merek-Sidikalang road, together with the associated roadside drainage. The investigation combined the identification of existing conditions with calculations for the proposed road elements. The principal outputs were a horizontal-curve arrangement, a pavement-layer configuration, a drainage section, and a construction cost schedule.

The intervention boundaries were identified by station, conventionally written as STA followed by chainage in kilometres and metres. The five selected sections are presented in Table 1. Their combined length represents the sum of the unwidened sections; it does not represent the distance between the first and last station. Existing widened sections between these locations were relevant to continuity of the road layout but were not included in the stated 2,047 m intervention inventory. The design retained the existing vertical alignment, while pavement analysis was directed at the additional road width.

Table 1. Locations of the five unwidened sections

Section	Start station	End station	Length (m)	Target curve labels
1	9+950	10+590	640	PI1-PI6
2	11+000	11+272	272	PI10-PI11
3	11+430	11+555	125	PI12
4	12+100	12+350	250	PI15-PI19
5	13+430	14+190	760	PI22-PI26
Total			**2,047**	**19 curves**

Source: field-condition inventory and the selected-section summary. Curve labels follow the design calculation schedule.

Data collection and processing

Primary information comprised field observations, station mapping, measurements of existing cross-sections, and photographic documentation of road and drain conditions. A measuring tape and mobile phone supported this work. Secondary information consisted of topography, traffic counts, California Bearing Ratio (CBR) data, rainfall records, and basic construction prices. The traffic data were described as continuous 24-hour counts over seven days. They were supplied by BBPJN North Sumatra, together with the subgrade and basic-price data. The rainfall information was attributed to BMKG North Sumatra, using the Sitinjo station as the nearby observation source.

Table 2. Data sources and their roles in the design

Data	Source or acquisition method	Use in analysis
Existing road and drainage	Field observation, tape measurement, and photographs	Identify unwidened stations, cross-sections, and drainage obstructions
Topographic information	Google Earth and Global Mapper	Establish route coordinates and terrain context
Traffic and CBR	BBPJN North Sumatra	Adopt traffic-loading and subgrade design inputs
Rainfall, 2016-2025	BMKG North Sumatra; Sitinjo station	Develop the drainage rainfall and discharge inputs
Basic prices and work items	BBPJN data and the adopted 2026 unit-price analysis	Prepare quantities and the construction estimate

Excel was used to organize input data and perform the engineering calculations, while AutoCAD supported the preparation of geometric and construction drawings. The work proceeded from the inventory of existing conditions to geometric design, pavement selection, drainage analysis, and quantity-based costing. Each calculation depended on its own input records, but the outputs had to be coordinated because changes in width, layer thickness,

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and channel dimensions affect the quantities of excavation, materials, and associated works. Numerical outputs are presented with the precision reported in the calculation records.

Horizontal alignment procedure

The horizontal alignment procedure followed the framework of PDGJ 2021 (Direktorat Jenderal Bina Marga, 2021b). Road classification, terrain, design speed, lane width, normal crossfall, and maximum superelevation formed the initial criteria. Route coordinates were used to determine changes in direction and deflection angles. Full-circle (FC) and spiral-circle-spiral (SCS) arrangements were then considered using curve radius, transition length, and the available tangent lengths. Vertical-curve design was excluded in accordance with the stated study boundaries.

The minimum-radius relationship used in the design is expressed in Equation (1). It connects design speed with the combined contributions of superelevation and lateral friction. The speed in this expression is in kilometres per hour, the radius is in metres, and both superelevation and the friction factor are dimensionless. The selected radius was then used in the detailed curve calculations; it was not derived from the road width alone.

$$R_{min} = \frac{{V_d}^2}{127(e_{max} + f_{max})} \quad (1)$$

The calculation sequence also addressed the transition between normal crossfall and superelevation, curve length, tangent distance, and additional width associated with turning vehicles. A city transit bus was the design vehicle in the worked widening examples, with a reported body width of 2.50 m, wheelbase parameter of 7.70 m, and front-overhang parameter of 2.00 m. The results summarize the adopted curve geometry. Individual transition-length and widening checks remain subject to reconciliation where the recorded intermediate expressions are inconsistent.

Flexible pavement and subgrade procedure

The flexible pavement procedure used MDPJ 2024 (Direktorat Jenderal Bina Marga, 2024). The surface and granular layers were assessed for a 20-year design period, while the foundation assessment used a 40-year period. The adopted annual traffic-growth rate was 4.83%, with a directional distribution factor of 0.50 and a lane distribution factor of 1.00 for the single lane in each direction. Vehicle damage factors were selected from the values used for Aceh and North Sumatra. The method distinguishes the number of vehicles from their equivalent structural loading.

For a constant annual growth assumption, the cumulative traffic-growth factor is represented by Equation (2). In this expression, the growth rate is entered as a decimal and the period is measured in years. Equation (3) summarizes the conversion of classified average daily traffic into cumulative equivalent standard axles. The vehicle damage factor is specific to the vehicle class and the axle-equivalency exponent used in the design.

$$F_N = \frac{(1+i)^N - 1}{i} \quad (2)$$

$$CESA = 365\, D_D\, D_L\, F_N \sum_j (LHR_j\, VDF_j) \quad (3)$$

The design records distinguish traffic-loading columns labeled "factual" and "normal" and separate periods within the overall design life. Their stated final CESA5 values were used as adopted design inputs in the pavement selection. Those values are distinguished from an independently reproduced loading estimate because several projected traffic entries and the aggregation of the loading columns are inconsistent. Retaining this distinction preserves the documented pavement-selection basis without implying that all intermediate traffic calculations have been verified.

Subgrade support was derived from the supplied dynamic cone penetrometer-based CBR data. The 20 field values were adjusted using the recorded correction factor of 0.90 and sorted in ascending order. The characteristic CBR was selected using the percentile procedure applied in the calculation: at the tenth-percentile index of two, the second and third ordered values were averaged. This characteristic value informed the foundation improvement thickness, while the 20-year loading input informed the asphalt and granular-layer selection. Aggregate foundation layers were selected to maintain compatibility with the detailed engineering design for the previously widened sections.

Drainage analysis procedure

Drainage analysis followed the hydrological and hydraulic sequence described in PDDJ 2021 (Direktorat Jenderal Bina Marga, 2021a). A representative 250 m roadside reach was selected with an outlet associated with an existing cross-drainage location. The contributing strip comprised a 3.0 m asphalt width, a 1.2 m shoulder, and a 3.3 m adjoining area. Runoff coefficients were assigned to these surface categories. The area-weighted coefficient was

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obtained using Equation (4), and the rational method in Equation (5) related rainfall intensity and contributing area to design discharge.

$$C_w = \frac{\sum_j C_j A_j}{\sum_j A_j} \quad (4)$$

$$Q = 0.278\, C_w\, I\, A_c \quad (5)$$

In Equation (5), rainfall intensity is expressed in millimetres per hour and catchment area in square kilometres. The coefficient 0.278 converts these units to cubic metres per second. The rainfall procedure used a 50-year return period and a normal-distribution calculation, followed by the intensity selected from the design curve at the reported concentration time. The drainage analysis contains two different annual rainfall series, which are displayed separately in the results to make the basis of the reported discharge transparent.

A trapezoidal stone-masonry channel was considered. The hydraulic section was described using bottom width, water depth, side slope, freeboard, wetted perimeter, and hydraulic radius. The Manning relationship is summarized in Equation (6), where channel capacity depends on the actual longitudinal slope as well as the section geometry and roughness. The reported dimensions and allowable-velocity check are therefore presented as preliminary design outputs. A check of permissible velocity alone does not establish that the selected section conveys the design discharge at the surveyed slope.

$$Q_c = \frac{1}{n_M} A_w R_h^{2/3} S^{1/2} \quad (6)$$

Quantity measurement and cost estimation

The cost estimate was prepared from work quantities and the 2026 unit-price analysis adopted for the study. Work items covered mobilization, drainage excavation, stone masonry, removal of existing pavement materials, selected fill, aggregate foundation layers, asphalt works, and thermoplastic road markings. Material, labour, and equipment components were incorporated through the applicable item rates. Equation (7) expresses the basic summation of quantities multiplied by their respective unit prices.

$$\text{Cost} = \sum_j q_j\, p_j \quad (7)$$

Quantities were obtained from the cross-sectional areas, lengths, application rates, and material densities specified in the design calculations. Earthworks, masonry, and aggregate quantities were expressed volumetrically, asphalt quantities by mass, prime and tack coats by volume, and road markings by area. The reported estimate then added a 10% value-added tax allowance. This percentage is retained as an assumption of the original estimate. The costing length of 2,266 m is reported separately from the 2,047 m field inventory because their difference is not resolved in the design records.

RESULTS AND DISCUSSION

Existing conditions and adopted geometric criteria

The five unwidened sections exhibited the discontinuous improvement pattern that motivated the study. The intervention lengths ranged from 125 m to 760 m, with already widened sections between them. Consequently, the proposed works require coordination at multiple interfaces with existing construction. The observed drainage obstructions also demonstrate that the road problem includes the condition of the roadside water-conveyance system. The findings support addressing the road cross-section and drainage together.

The adopted technical criteria are summarized in Table 3. The road was treated as a Class III primary arterial route in hilly terrain, with a two-lane, two-way undivided configuration. Each traffic lane was 3.0 m wide, giving a nominal carriageway width of 6.0 m; the shoulder width was 1.20 m. These dimensions describe individual cross-sectional components and should not be equated directly with the field inventory of overall road widths. The design-speed range used in the calculations was 20-40 km/h.

Table 3. Geometric criteria adopted in the design

Parameter	Adopted value
Road function and class	Primary arterial; Class III
Terrain	Hilly
Road configuration	Two lanes, two directions, undivided
Design speed	20-40 km/h
Traffic-lane width	3.00 m per lane
Shoulder width	1.20 m

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Parameter	Adopted value
Normal pavement crossfall	2%
Maximum superelevation	8%
Vertical alignment	Existing alignment retained
Pavement design period	20 years

Source: geometric criteria in the detailed design. Values are reported as adopted inputs, without asserting approval of departures from road-function requirements.

The design criteria summarize the inputs used in the calculations, but they do not by themselves establish compliance with every requirement for the stated road function. In particular, the combination of primary arterial classification, constrained design speeds, and available cross-sectional space requires a documented engineering review. The study did not include a separate road-safety audit or a detailed reassessment of the functional classification. These boundaries are relevant when translating the design into a construction proposal.

Horizontal curves within the selected sections

Nineteen curves were associated with the five selected sections. Table 4 reproduces their deflection angles, design speeds, selected radii, and curve types from the calculation schedule. The selected radii range from 10.00 m to 70.00 m. The schedule assigns SCS geometry to 17 curves and FC geometry to two curves, PI11 and PI18. This count concerns the selected intervention sections and does not represent every curve listed elsewhere along the wider corridor.

Table 4. Adopted curve parameters for the 19 curves in the selected sections

Curve	Deflection (°)	Speed (km/h)	Radius (m)	Type
PI1	78.29	30.00	30.00	SCS
PI2	95.15	20.00	10.00	SCS
PI3	135.53	20.00	15.00	SCS
PI4	99.90	30.00	35.00	SCS
PI5	109.30	30.00	25.00	SCS
PI6	43.14	20.00	15.00	SCS
PI10	108.13	40.00	47.00	SCS
PI11	63.57	20.00	40.00	FC
PI12	105.97	30.00	35.00	SCS
PI15	93.89	40.00	50.00	SCS
PI16	69.01	40.00	50.00	SCS
PI17	63.78	40.00	55.00	SCS
PI18	64.85	30.00	50.00	FC
PI19	76.72	30.00	25.00	SCS
PI22	38.46	40.00	70.00	SCS
PI23	83.51	30.00	41.00	SCS
PI24	56.09	30.00	23.00	SCS
PI25	56.93	40.00	58.00	SCS
PI26	44.68	40.00	70.00	SCS

FC = full circle; SCS = spiral-circle-spiral. Labels and values follow the curve calculation schedule, which uses a different labeling sequence from part of the coordinate inventory.

The worked SCS example at PI1 uses a deflection angle of 78.29°, a design speed of 30 km/h, and a selected radius of 30.00 m. Its reported transition length is 17.00 m, circular-arc length is 23.99 m, and total curve length is

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57.99 m. The associated calculation gives a tangent distance of 33.221 m and additional curve width of 0.575 m. These values illustrate the combination of curvature, transitions, and vehicle-width considerations in the proposed widening. The FC example labeled PI11 uses a 20 km/h design speed, a 40.00 m radius, and a deflection angle rounded to 63.57°. The calculation reports a tangent length of 24.78 m and an external distance of 7.056 m. Its reported extra width is 0.33 m. The supporting threshold comparison for this extra width is inconsistent in the design record, so the value should be retained as a reported calculation rather than a verified instruction to widen the curve. Curve labels, transition criteria, and turning-width checks require consistent treatment in the final drawings.

These results demonstrate how a common set of design criteria produces different geometric arrangements across the selected sections. They do not establish a uniform operating speed for the completed route. Road geometry, transition lengths, driver visibility, and the connection to adjacent sections must be reviewed together. This interpretation is consistent with the integrated planning approach used by Azizah et al. (2022) and Munthe (2022), while recognizing that the present study excludes vertical-alignment redesign.

Traffic input and characteristic subgrade strength

Table 5 presents the nonzero vehicle-class entries in the 2025 average daily traffic inventory. Vehicle class 2 has the largest recorded count, followed by classes 1, 4, and 3. The pavement analysis nevertheless depends on the vehicle damage factors and cumulative axle loading, so the largest traffic count does not automatically identify the largest contribution to structural demand. The original class codes are retained because the supplied traffic schedule is the basis of the load calculation.

Table 5. Nonzero entries in the 2025 classified average daily traffic inventory

Vehicle class	Vehicles per day	Vehicle class	Vehicles per day
1	891	5B	8
2	1,443	6A	11
3	243	6B	181
4	333	7A2	87
5A	4	7C2A	2

Other listed vehicle classes have zero counts. Source: classified traffic inventory supplied for the study.

The pavement selection adopts a 20-year CESA5 value of 2,042,395.11, and the foundation selection adopts a 40-year value of 6,222,487.59. These are the final design values stated in the calculation narrative. Differences between some projected class counts and the tabulated loading totals prevent their interpretation as independently reproduced totals. The pavement structure below therefore represents the structure selected under those stated inputs; confirmation of the traffic-loading aggregation is necessary before fixing the design for implementation.

The corrected CBR values are presented in Table 6. They range from 3.42% to 8.28%, with a reported mean of 5.418%. The tenth-percentile calculation averages the second and third ordered observations, 3.96% and 4.23%, producing a characteristic CBR of 4.095%. This value is supported directly by the ordered data and the percentile rule used in the study. It describes the adopted design subgrade and is not interchangeable with the mean of all observations.

Table 6. Ordered corrected CBR observations used in the percentile calculation

Rank	CBR (%)	Rank	CBR (%)
1	3.42	11	5.13
2	3.96	12	5.40
3	4.23	13	5.49
4	4.32	14	5.58
5	4.32	15	5.76
6	4.50	16	6.12
7	4.50	17	7.20
8	4.59	18	7.65
9	4.86	19	8.10

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Rank	CBR (%)	Rank	CBR (%)
10	4.95	20	8.28

Characteristic CBR = (3.96 + 4.23)/2 = 4.095%, following the percentile procedure applied in the design.

The low characteristic value explains why the design includes subgrade improvement rather than placing the selected pavement layers directly on an unimproved foundation. The 200 mm selected-fill layer was chosen using the adopted foundation traffic loading and a characteristic CBR below 5%. The records pool CBR observations from several stations along the corridor, including stations beyond some individual widening sections. Their spatial coverage should therefore be checked before treating every widening location as having identical support conditions.

Selected flexible pavement structure

The detailed pavement result consists of an asphalt surface over aggregate foundation layers and selected fill, as shown in Image 1. The design uses 40 mm of Asphalt Concrete-Wearing Course (AC-WC), 65 mm of Asphalt Concrete-Binder Course (AC-BC), 200 mm of Class A aggregate, 150 mm of Class B aggregate, and 200 mm of selected fill. The asphalt thicknesses are consistent between the detailed layer schedule, the pavement drawing, and the thicknesses used in the quantity calculations.

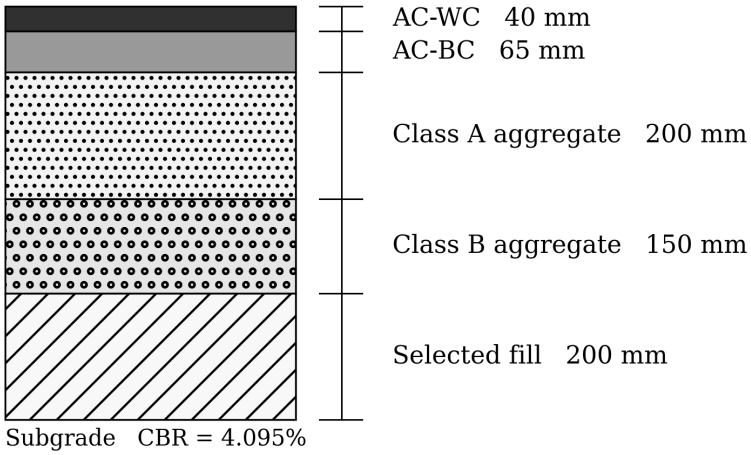


Image 1. Pavement-layer arrangement adapted from the detailed design

The choice of aggregate foundation layers was linked to the existing detailed engineering design for sections that had already been widened. It also reflected the construction and maintenance considerations discussed in the study. Aggregate layers were preferred to a cement-treated base in the selected solution because of compatibility with those existing sections and the intended work sequence. The analysis did not include a separate comparative life-cycle cost model, so this choice should be understood as the adopted design rationale rather than a demonstrated economic optimum.

For the widening works, continuity with the adjacent pavement is a practical design issue. The selected layers must be considered together with the existing road level, edge support, shoulder details, and drainage arrangement. The study determines the proposed layer thicknesses but does not report construction trials, laboratory performance of the final asphalt mix, or monitoring after installation. The resulting configuration is therefore a design specification conditional on the adopted load and subgrade inputs, rather than evidence of achieved pavement performance.

Rainfall inputs and preliminary drainage section

The drainage design addresses the observed obstruction and deterioration of the existing stone-masonry drains. For the representative 250 m reach, the asphalt, shoulder, and adjoining areas contribute 750, 300, and 825 m², respectively. The adopted runoff coefficients are 0.70, 0.70, and 0.30. The calculation reports an average coefficient of 0.524 and a concentration time of 5.960 minutes. These inputs were used with a 50-year return period to select the design intensity.

The annual rainfall values displayed in the initial rainfall table differ from the values entered in the subsequent frequency-analysis table. Both series are shown in Table 7 because the distinction materially affects the interpretation of the reported drainage output. The frequency-analysis series gives a reported mean of 56.6 mm and standard deviation of 24.98978 mm. Using the frequency factor of 2.05, the calculation obtains 107.829 mm for the

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50-year rainfall value. The intensity subsequently read from the design curve is 187 mm/h; rainfall depth and rainfall intensity have different units and are retained separately here.

Table 7. Annual rainfall entries appearing in the drainage calculation records

Year	Initial rainfall table (mm)	Frequency-analysis input (mm)
2016	181.1	95
2017	189.5	95
2018	242.4	72
2019	164.5	32
2020	118.0	73
2021	64.0	33
2022	67.0	36
2023	90.0	44
2024	61.5	38
2025	69.9	48

Source: the two rainfall tables in the drainage calculations. Their discrepancy remains unresolved; neither series is replaced with assumed observations.

Using the reported intensity and contributing area, the design records a discharge of 0.0510 m^3/s. A trapezoidal stone-masonry section is proposed with a 0.113 m bottom width, 0.136 m water depth, and side slopes of 1 horizontal to 1 vertical. The listed freeboard is 0.261 m and the masonry thickness is 0.20 m. The reported total outer depth of 0.597 m includes the water depth, freeboard, and base thickness. Table 8 separates these quantities so that the flow depth is not confused with the full construction depth.

Table 8. Reported drainage parameters and preliminary channel dimensions

Parameter	Value
Representative reach length	250 m
Return period	50 years
Adopted rainfall intensity	187 mm/h
Reported design discharge	0.0510 m^3/s
Channel material and shape	Stone masonry; trapezoidal
Bottom width	0.113 m
Water depth	0.136 m
Side slope	1 horizontal : 1 vertical
Freeboard	0.261 m
Masonry thickness	0.20 m
Total outer depth	0.597 m
Manning roughness coefficient	0.017
Reported field longitudinal slope	0.8%

The section dimensions are reported design outputs. Capacity at the field slope requires confirmation before construction.

The hydraulic interpretation is subject to a separate limitation. The calculation uses an allowable velocity of 1.5 m/s, a wetted area of approximately 0.034 m^2, and a hydraulic radius of approximately 0.068 m. It then compares the field slope of 0.8% with an allowable slope of approximately 2.33%. This comparison addresses the adopted upper velocity criterion but does not demonstrate that the design discharge can be conveyed by the selected section at the field slope. Hydraulic capacity must be recomputed using the section geometry, roughness, and surveyed longitudinal gradient together.

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The preliminary section is also only one part of the drainage system. The observed blockages were associated with sediment, fallen material, vegetation, and local damage. A completed design therefore needs to retain usable outlets and provide a practical basis for inspection and cleaning. This requirement follows directly from the observed condition and the integrated drainage approach in PDDJ 2021 (Direktorat Jenderal Bina Marga, 2021a).

Construction quantities and reported budget

The construction estimate groups the works into the divisions shown in Table 9. Asphalt pavement accounts for the largest reported division value, followed by granular pavement, earthworks and geosynthetics, and drainage. The estimate also includes mobilization and thermoplastic road markings. These categories reflect the interdependence of the selected pavement and drainage solutions: the section dimensions determine material volumes, while the proposed road layout contributes to the extent of excavation and surfacing.

Table 9. Reported construction budget by work division

Division	Description	Reported amount (IDR)
1	General works	31,418,612
2	Drainage	1,497,866,444
3	Earthworks and geosynthetics	1,753,747,438
5	Granular pavement	4,198,809,859
6	Asphalt pavement	8,110,563,130
9	Dayworks and miscellaneous works	276,104,470
	Reported subtotal	15,868,509,952
	Tax allowance used in the estimate (10%)	1,586,850,995
	Reported total	17,455,360,947

Source: cost recapitulation. Values are retained as reported; minor rounding and the inconsistency in the earthworks subtotal require reconciliation.

The detailed quantity schedule includes 1,211.70 m³ of drainage excavation and 734.92 m³ of stone masonry. The pavement-related quantities include 4,051.61 m³ of selected fill, 3,904.32 m³ of Class A aggregate, and 2,991.12 m³ of Class B aggregate. Asphalt quantities are reported as approximately 1,755.33 tonnes of AC-WC and 2,871.05 tonnes of AC-BC. Prime coat and tack coat quantities are 7,713.46 and 2,868.76 litres, respectively. These are schedule quantities and should be checked against the final drawings before procurement.

The reported total is IDR 17,455,360,947, including the original 10% tax allowance. The associated unit estimate of IDR 7,703,160.17 per metre is based on a costing length of 2,266 m. That denominator differs from the 2,047 m total in the field inventory. The cost per metre therefore describes the estimate on its own recorded quantity basis, not a verified unit cost for the five inventoried sections. Applying it to the shorter length without a revised quantity take-off would obscure the difference between the two scopes.

The budget also contains an internal difference between the displayed earthworks item amounts and their division subtotal. As a result, the division recapitulation is reported as an estimate requiring reconciliation. It is not presented as an audited bill of quantities or a confirmed contract value. The recommended follow-up in the study is to compare the published basic prices with prices obtained from material suppliers around the project location. This would improve the local relevance of the estimate after the physical quantities have been aligned with the agreed work limits.

Integration of the design components and limitations

The principal contribution of the study is the coordination of four engineering components for a road that has been widened unevenly. The curve schedule identifies local geometric requirements, the pavement arrangement links structural design to traffic and subgrade assumptions, the drainage analysis identifies a preliminary section, and the cost schedule translates the proposed works into expenditure categories. This organization is relevant to the five separated intervention sections because each section connects with previously improved construction. It also provides a clear basis for checking whether a later change in one component has been reflected in the others.

The results should be interpreted at the level supported by the investigation. The field work identifies conditions and intervention locations, while most design inputs come from institutional records and the adopted

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technical manuals. No post-construction outcomes, travel-time measurements, crash analysis, or economic-benefit evaluation were reported. The study can consequently support design development, but it cannot demonstrate the magnitude of operational improvements resulting from the proposed works. Its comparison with earlier studies concerns planning scope and methods rather than controlled performance differences.

Several matters require resolution before implementation. The intervention inventory and costing length must use the same agreed station limits. The projected traffic entries, directional distribution, and final CESA aggregation must be reconciled. The annual rainfall series and concentration-time calculation must be checked against the station records, followed by a hydraulic capacity calculation at the measured slope. Curve labels and intermediate geometric checks must also match the final layout. Finally, the quantities and division subtotals must be recalculated consistently with those drawings. These limitations concern the internal consistency of the existing design records and are not replaced by assumed input data.

CONCLUSION

The study developed a coordinated design for the remaining widening and drainage works on five Merek-Sidikalang road sections totaling 2,047 m. The selected sections contain 19 horizontal curves with adopted speeds of 20-40 km/h; the curve schedule identifies 17 SCS curves and two FC curves. The nominal carriageway comprises two 3.0 m traffic lanes, with a 1.20 m shoulder specified in the design criteria. The analysis is limited to horizontal alignment and retains the existing vertical condition.

Under the stated 20-year traffic-loading input and a characteristic CBR of 4.095%, the detailed pavement arrangement consists of 40 mm AC-WC, 65 mm AC-BC, 200 mm Class A aggregate, 150 mm Class B aggregate, and 200 mm selected fill. The drainage analysis reports a design discharge of 0.0510 m^3/s and a preliminary trapezoidal stone-masonry section with a 0.113 m bottom width, 0.136 m water depth, and 0.261 m freeboard. Its capacity must be confirmed using reconciled rainfall inputs and the surveyed longitudinal slope.

The reported construction estimate is IDR 17,455,360,947, including the estimate's 10% tax allowance, and is calculated on a recorded costing length of 2,266 m. Agreement between this length, the intervention inventory, and the work quantities is required before the budget is used for implementation. Further work should confirm the geometric and traffic calculations, verify the drainage inputs and capacity, and update quantities and local material prices. The study provides a documented planning basis, with the identified inconsistencies defining the next steps in design verification.

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