

CHAPTER II

THEORETICAL REVIEW

2.1. Road Classification

When constructing roads, two main pavement types are commonly used: flexible pavement and rigid pavement (Bina Marga, 2024). Flexible pavement consists of multiple layers—including asphalt surface, binder, base, and subbase—that work together to distribute loads gradually and accommodate slight deformations, making it suitable for most road types due to its cost-effectiveness and ease of repair. In contrast, rigid pavement uses concrete slabs with high stiffness to spread loads over a broader area, offering greater durability and strength for heavy traffic but with higher initial costs. The selection between these methods depends on factors such as traffic load, soil conditions, climate, and construction budget.

The new type of pavement design consists of:

1. Pavement on the original ground surface.
2. Pavement on embankments.
3. Pavement of the excavation.

a) Flexible Pavement on Original Soil Surface (At Grade)

Flexible pavement is a common road structure composed of multiple layers, each with specific roles to ensure durability, load distribution, and surface performance (Bina Marga, 2024). These layers typically include a surface course, binder course, base, and subbase, all resting on the natural subgrade or a treated foundation if necessary. The surface layer resists weather and traffic wear, while the layers beneath it work together to distribute loads and improve drainage. The illustration below presents a cross-sectional view of flexible pavement constructed on natural soil, detailing the sequence of layers from the top surface down to the foundation. It shown in Figure 2.1.



Figure 2.1. Flexible Pavement on Original Soil Surface (Bina Marga, 2024)

b) Flexible Pavement in Embankments

Flexible pavement on embankments is composed of several layers that work together to provide strength and durability (Bina Marga, 2024). The surface and binder courses, made of asphalt concrete, ensure a smooth and weather-resistant surface while distributing loads to the base. The base and sub-base layers, built from crushed stone or granular materials, support the upper layers and aid drainage. Below them, compacted embankment fill raises the road to the desired level and adds stability, resting on the subgrade, which acts as the foundation. The Figure 2.2. shows the typical structure of flexible pavement on embankments.

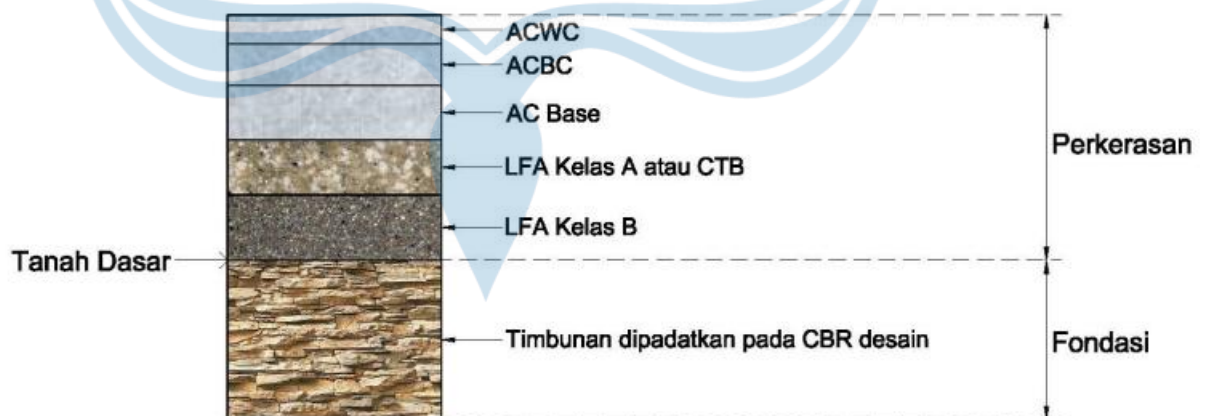


Figure 2.2. Flexible Pavement in Embankments (Bina Marga, 2024)

c) Flexible Pavement in Excavations

Flexible pavement in excavations is constructed below the natural ground level and follows a layered system designed to maintain performance and structural integrity under constrained conditions (Bina Marga, 2024). The surface course, made of quality

asphalt concrete, provides a smooth and weather-resistant top layer. This is supported by a binder course with coarser asphalt to enhance structural strength and distribute loads. Below that, the base and subbase layers, composed of crushed stone or granular materials, continue the load distribution and facilitate drainage. The pavement structure is built within an excavated section, where the surrounding soil acts as a natural retaining boundary, while the subgrade at the bottom remains the foundation for the entire structure. The diagram below shows the typical arrangement of flexible pavement within excavated areas. The Figure 2.3. below shows the typical structure of flexible pavement on embankments.

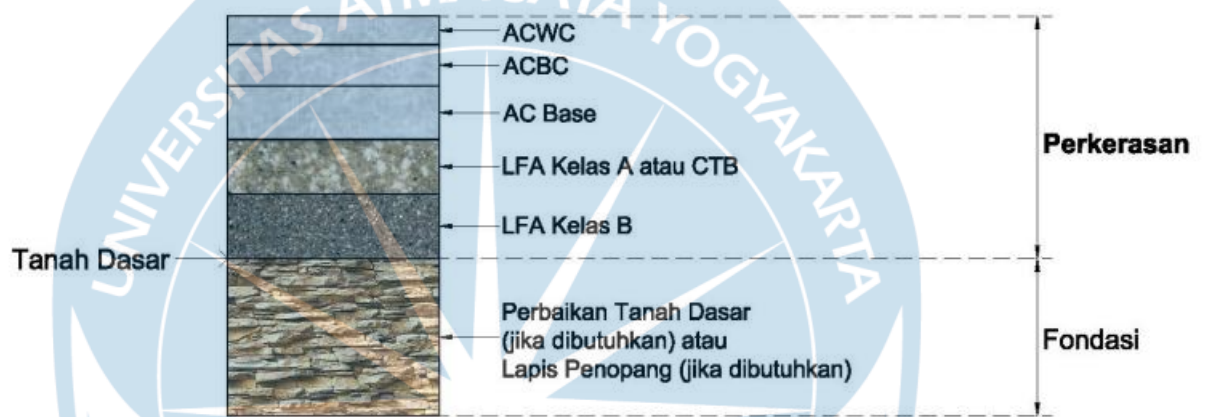


Figure 2.3. Flexible Pavement in Excavations (Bina Marga, 2024)

d) Rigid Pavement on Original Soil Surface (At Grade)

Rigid pavement on original soil surface (at grade) consists of a concrete slab placed over supporting layers that ensure strength, stability, and durability (Bina Marga, 2024). The concrete slab, made of Portland cement concrete, serves as the primary structural layer, capable of distributing loads over a wide area due to its rigidity. Beneath it, the base course, composed of materials like crushed stone or treated asphalt, provides essential support and helps with drainage. An optional subbase layer may be added to further aid in load distribution and moisture control, depending on the strength of the base. At the bottom lies the subgrade, the native soil that forms the foundation of the pavement system. The illustration below depicts the typical configuration of rigid pavement constructed at grade. The illustration below presents a cross-sectional view of flexible pavement constructed on natural soil, detailing the sequence of layers from the top surface down to the foundation. It shown in Figure 2.4.



Figure 2.4. Rigid Pavement on Original Soil Surface (Bina Marga, 2024)

e) Rigid Pavement in Embankments

Rigid pavement on embankments features a Portland cement concrete slab as the main structural layer, designed to distribute loads efficiently and withstand heavy traffic (Bina Marga, 2024). Beneath it, the base course—made of crushed stone or treated materials—provides support and aids drainage. An optional subbase layer may be added for additional load distribution and moisture control. These layers rest on compacted embankment fill, which elevates the roadbed, supported by a prepared subgrade at the bottom. The Figure 2.5. illustrates this structural configuration of rigid pavement built on embankments.

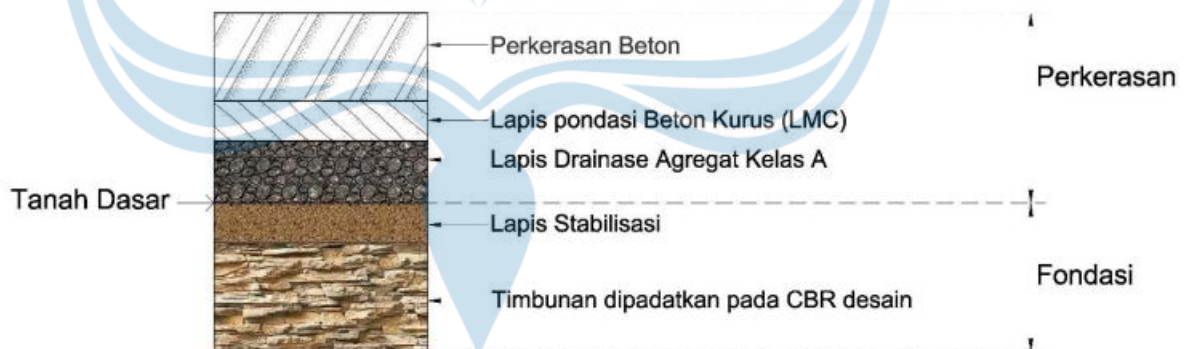


Figure 2.5. Rigid Pavement in Embankments (Bina Marga, 2024)

f) Rigid Pavement in Excavations

Rigid pavement in excavations involves placing a concrete slab—made of Portland cement concrete—as the main structural layer to carry and distribute loads over a broad area (Bina Marga, 2024). Below it, the base course of crushed stone or treated materials provides strong support and assists with drainage. An optional subbase layer, using granular materials, may be added for further load distribution and moisture control, depending on the strength of the base. At the lowest level lies the subgrade, which is the

prepared soil at the bottom of the excavation and serves as the foundational support. If we look closely to the Figure 2.6., it shows the more detailed info with illustration and narrative.

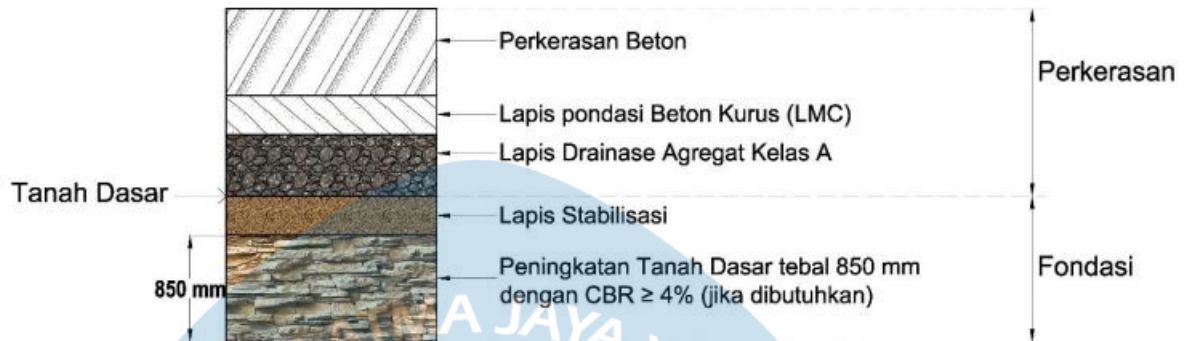


Figure 2.6. Rigid Pavement in Excavations (Bina Marga, 2024)

2.1.1. Classification According to Road Function

Classification According to Road Function refers to how roads are categorized based on the role they play within a transportation network (Bina Marga, 2021). This classification helps in determining design standards, pavement structures, and traffic management strategies. Road functions include:

- a. Arterial roads: these are primarily used for long-distance travel, have high average vehicle speeds, effectively few entries, and connect many cities.
- b. Collector roads: these are often used for medium-distance driving, have a limited number of entrances, and have moderate vehicle speeds.
- c. Local roads: these are often used for short-distance travel, have an unlimited number of entries, and normally have modest vehicle speeds.

2.1.2. Classification According to Road Terrain

Classification According to Road Terrain refers to how roads are categorized based on the topographical conditions of the land they traverse (Bina Marga, 2021). This classification is important because terrain significantly influences road design, construction costs, alignment geometry, drainage, and safety considerations. Road terrain is categorized based on the slope conditions perpendicular to contour lines, as measured in Table 2.1.

Table 2.1. Classification Criteria for Terrain (Bina Marga, 2021)

Types of Terrain	Notation	Terrain Slope
Flat	D	<3
Hilly	B	3-25
Mountainous	G	<25

2.1.3. Classification According to Road Class

Classification According to Road Class refers to the categorization of roads based on their administrative status, construction standards, and role in supporting national, regional, or local connectivity (Bina Marga, 2021). This classification helps define the hierarchy of road infrastructure and guides decisions on design, maintenance, and funding priorities. Road groups based on road class relate to the road's ability to withstand traffic loads expressed in terms of the Maximum Single Axle Load (MSAL) in tons, as shown in Table 2.2.

Table 2.2. Classification According to Road Class (Bina Marga, 2021)

Road Class	Function of The Road	Maximum Vehicle Dimension (m)			Maximum Permitted Axle Load (Ton)
		Width	Length	Height	
Class 1	Arterial, Collector	≤2,55	≤18,0	≤4,2	10
Class 2	Arterial, Collector,	≤2,55	≤12,0	≤4,2	8
Class 3	Local, and Environment	≤2,2	≤9,0	≤3,5	8
Special Class	Arterial	>2,55	>18,0	≤4,2	>10

2.1.4. Classification According to Road Development Authority

Classification According to Road Development Authority refers to the categorization of roads based on the government or institutional body responsible for their planning, construction, and maintenance. This classification ensures that road development and management are organized and executed according to jurisdictional responsibilities, funding sources, and strategic importance. The classification of roads according to their development authority, as per Government Regulation No. 26/1985,

includes National Roads, Provincial Roads, District/City Roads, Village Roads, and Special Roads.

1. National Roads

National roads are broadly categorized into three main groups based on their function and importance. The first category includes primary arterial roads, which serve as the main corridors for long-distance travel and high-volume traffic between major cities and economic centres. The second group comprises primary collector roads, which connect smaller towns and regions to the arterial network, facilitating regional access and mobility. The third category encompasses roads of strategic value, which may not carry high traffic volumes but play a vital role in supporting national interests—such as enhancing national integration, promoting access to remote or underdeveloped areas, and strengthening defence and security. These classifications help prioritize infrastructure development to meet both economic and strategic goals.

2. Provincial Roads

Provincial highways are collector roadways that link the provincial capital with the capitals of the province's districts or cities, as defined by Government Regulation No. 34, Article 26 (b) of 2006. Primary collector highways that link district/city capitals can also be considered provincial routes. Except for national highways, all other province key roads serve the Jakarta Special Capital Region.

3. District/City Roads

District governments are responsible for managing district or city roads, which serve vital local transportation functions. These include primary collector roads that are not directly connected to provincial or national highways, ensuring internal connectivity within the district. Additionally, principal local roads play an essential role in linking district capitals to sub-district capitals, village centres to district capitals, and villages to sub-district hubs. The classification also includes secondary urban roads that facilitate movement within city areas but do not fall under provincial or national jurisdiction. Finally, the main district roads form the backbone of district-level infrastructure, supporting both mobility and regional development.

4. Village Roads

Village roads are public thoroughfares that link several locations and/or communities within a village. In rural locations, village roads also function as main local roads that aren't considered district roads. These roads are essential for facilitating daily activities such as access to farms, markets, schools, and health facilities. Often developed

and maintained by the village government or through community-based initiatives, village roads play a critical role in supporting rural livelihoods and ensuring connectivity to broader regional networks. Their quality and accessibility can significantly impact the economic and social development of rural areas.

5. Special Roads

Special roads are roads constructed by institutions, businesses, individuals, or community groups for their specific purposes. These roads are typically built to serve private or limited-access functions, such as industrial zones, plantation areas, mining sites, housing complexes, or tourism facilities. While they are not part of the public road network, they play an important role in supporting specific economic activities and internal logistics. The design, maintenance, and usage regulations of special roads are usually determined by the entity responsible for their construction, although they may still be subject to certain government standards or oversight when intersecting with public infrastructure.

2.2. Road Segments

A road segment refers to a stretch of road with uniform characteristics, and segment boundaries mark significant changes in these characteristics (Bina Marga, 1997). Each segment is assessed individually, and if there are multiple geometric options observed for a segment, each is assigned a specific code and documented in separate data input forms (UR-1 and UR-2). Additionally, separate analysis forms (UR-3) are utilized for each scenario. If different time periods are being analysed, a unique code must be assigned to each scenario, and separate data inputs and analyses should be conducted.

1. Traffic Lane

The traffic lane, also known as the carriageway or travelled way, is the portion of the road used for vehicle movement. It often consists of multiple lanes that accommodate the flow of vehicles in one or more directions. Within the traffic lane, vehicle lanes are designated paths that allow two or more wheeled vehicles to pass in a single direction.

The number of lanes required is determined by:

- The anticipated traffic volume
- The desired level of service

At curves, the cross slope of the road is carefully designed to meet both drainage requirements and to counteract centrifugal force, ensuring safety and comfort.

2. Road Shoulder

The road shoulder is the area immediately adjacent to the traffic lane and plays a vital role in ensuring road functionality and safety. It acts as a support zone for the main carriageway and provides space for vehicles in emergency situations or when stopped temporarily. Beyond its practical use, it also contributes to the structural stability of the pavement edge.

The main functions of the shoulder include serving as a temporary stopping area, offering space for emergency vehicles like ambulances, improving driver comfort, and providing an area to pull over in emergencies without obstructing traffic flow.

There are generally two types of road shoulders based on their structure and material. Comfortable shoulders are typically used on low-grade or rural roads, made from unbound materials such as compacted soil or gravel, and often covered with grass. These are designed for light use, such as accommodating small vehicles stopping briefly. Reinforced shoulders, on the other hand, are made from water-resistant materials combined with binders, like asphalt-treated base, and are strong enough to support frequent or heavier vehicle loads.

In terms of dimensions, the minimum width of the shoulder varies depending on the road classification and terrain:

- Class II C roads in hilly areas: minimum of 1 meter.
- Class I roads in hilly terrain: minimum of 3 meters.
- Class I roads connecting hilly regions: at least 1 meter, adjusted to local topography.

For Class I roads, reducing the shoulder width is not recommended. Instead, a soft shoulder extension of at least 2 meters beyond the edge of the hard shoulder should be provided to maintain safety and accessibility.

The slope (tilt) of the shoulder is also carefully designed. It must ensure adequate drainage, allowing surface water to flow away from the road structure. At the same time, the slope should not be too steep, as this could endanger vehicles that need to stop or re-enter the main lane. A balance is maintained between drainage efficiency and vehicle safety, especially on high-speed or high-traffic roads.

The detailed illustration of road shoulder can be obtained in Figure 2.7.

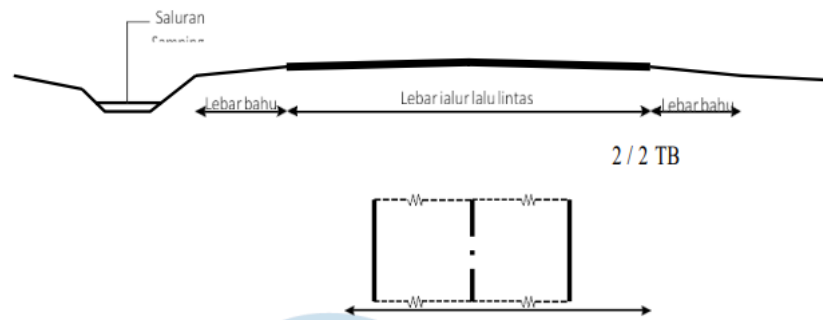


Figure 2.7. Road Shoulder (Bina Marga, 1997)

Roads are divided into three categories, according to Peraturan Pemerintah Nomor 34 Tahun 2006 tentang Jalan (Pemerintah Republik Indonesia, 2006) addressing roads: road usage space (rumaja), road ownership space (rumija), and road monitoring space (ruwasja).

2.2.1. Road Use Space (Rumaja)

The Road Use Space, or Rumaja, refers to the portion of land directly utilized for road construction and transportation activity. This includes the carriageway (traffic lanes), shoulders, medians, and drainage channels, which together form the main road body. At the edge of this zone is the road threshold, which serves to protect the structural integrity of the road. This space is crucial for accommodating vehicle movement and maintaining functional road performance.

2.2.2. Road Ownership Space (Rumija)

The Road Ownership Space, or Rumija, is the area that extends beyond the road use zone. It is demarcated by boundary markers and reserved for future road development needs, utility placement, or road widening. Although not actively used for traffic, this space remains under the ownership of the road authority and ensures that the road system can adapt safely to future expansions or upgrades without land acquisition delays.

2.2.3. Road Monitoring Space

The Road Monitoring Space, or Ruwasja, lies outside the road ownership boundary and is under surveillance to ensure it does not disrupt the safety and function of the roadway. Authorities monitor this space to prevent visual obstructions, unauthorized constructions, or other activities that could endanger drivers or degrade road utility. In cases where the Rumija is inadequate, some temporary or auxiliary road structures may be allowed in this space, provided they do not hinder visibility or operational safety.

The components of a road can be described as follows in Figure 2.8.



Figure 2.8. Road Space

2.3. Geometric Design Parameter

Based on "UU No 2 Tahun 2022 Tentang PERUBAHAN KEDUA ATAS UNDANG-UNDANG NO 38 TAHUN 2004 TENTANG JALAN" (Presiden Republik Indonesia, 2022), Road maintenance is carried out based on the principle of: safety and comfort, efficiency and effectiveness, transparency and accountability, and participatory involvement. While according to "PP No 34 Tahun 2006 Tentang JALAN" (Pemerintah Republik Indonesia, 2006), the geometric parameters of roads include planned vehicles, planned speed, gradients, curves, and cross slopes.

2.3.1. Planned Vehicles

Planned vehicles refer to specific types of vehicles chosen as design references in road and highway geometric planning (Bina Marga, 2021). These vehicles are selected based on their technical dimensions—such as length, width, height, and turning radius—and their operational characteristics, including acceleration, braking, and maneuverability. By using planned vehicles as a standard, engineers ensure that the roadway design (such as lane width, curve radius, intersection layout, and parking space dimensions) can safely and efficiently accommodate the movements of those vehicles, thereby enhancing overall traffic safety and performance. This reference is outlined in Table 2.3.

Table 2.3. Vehicle Planning (Bina Marga, 2021)

Category Vehicle Plan	Vehicle Dimension (cm)			Protrusion (cm)		Turn Radius (cm)		Protrusion Radius (cm)
	Height	Width	Long	Front	Rear	Min	Max	
Small	130	210	580	90	150	420	730	780
Medium	410	260	1210	210	240	740	1280	1410
Big	410	260	2100	120	90	290	1400	1370

2.3.2. Planned Speed

Planned speed (V_r) on a road segment is the chosen speed used as the foundation for geometric road design, enabling cars to go safely and pleasantly in clear weather. (Bina Marga, 2004)

For intercity road planning, the value of V_r is determined based on road classification and terrain as follows in Table 2.4.

Table 2.4. Planning Speed (Bina Marga, 2004)

Road Function	Design Speed (V_d = km/h)		
	Flat	Hilly	Mountainous
Arterial	80-120	70-110	60-100
Collector	40-80	30-70	20-60
Local	40-80	30-70	20-60

2.3.3. Traffic Volume

An estimate of the daily traffic volume at the conclusion of the traffic planning year, expressed in passenger cars per day, is the average daily traffic volume (ADT) (Badan Standardisasi Nasional, 2017). Furthermore, throughout the traffic planning year, the number of passenger automobiles per hour is used to express traffic at peak hours.

a. Passenger Car Unit (PCU)

A "passenger car" is a standardized unit used in traffic engineering to represent vehicle traffic based on a typical automobile's characteristics. This unit allows engineers and planners to analyse traffic flow more uniformly by converting different types of vehicles (e.g., buses, trucks, motorcycles) into equivalent numbers of passenger cars. For example, due to their larger size and different handling characteristics, a heavy truck may be considered equivalent to two or more passenger cars. This concept is essential for road

capacity analysis, intersection design, and level of service evaluations in transportation planning. Table 2.5. show more detailed information of unit in each vehicle.

Table 2.5. Traffic Volume (Badan Standardisasi Nasional, 2017)

Vehicle Types	Passenger Car Unit (PCU)
Bicycle	0.5
Passenger Car/Motorcycle	1.0
Light Truck	2.0
Medium Truck	2.5
Heavy Truck	3.0
Bus	3.0
Non-Motorized Vehicle	7.0

b. Passenger Car Equivalent (PCE)

Due to the diversity of vehicle types in traffic—ranging from motorcycles and passenger cars to heavy trucks and buses—a standard measurement unit called the Passenger Car Equivalent (PCE) is used to simplify traffic analysis. This unit allows different vehicles to be expressed in terms of their impact relative to a typical passenger car, which is assigned a value of 1.0. Larger or slower vehicles, such as trucks or buses, are given higher PCE values because they occupy more road space and affect traffic flow differently. Using PCE ensures more accurate planning, modelling, and evaluation of road capacity and performance under mixed traffic conditions. In can be seen in Table 2.6.

Table 2.6. Passenger Car Equivalent (Badan Standardisasi Nasional, 2017)

Vehicle Types	Flat/Hilly	Mountainous
Sedan, Jeep, Station Wagon	1.0	1.0
Pick-up, Small Bus, Small Truck	1.2-2.4	1.9-3.5
Large Bus and Truck	1.2-5.0	2.2-6.0

The commonly used traffic volume units for quantity and lane width are:

- The average number of cars that use one lane of traffic over a 24-hour period is known as the Annual Average Daily Traffic (AADT), and it is derived from data collected over the course of a full year.

$$AADT = \frac{\text{Total traffic volume in 1 year}}{365 \text{ days}}$$

- Average Daily Traffic (ADT) is the result of dividing the total number of vehicles observed during the monitoring period by the duration of the observation.

$$ADT = \frac{\text{Total traffic volume during observation}}{\text{Duration of observation}}$$

2.4. Alignment Election

In the process of selecting the most appropriate road alignment, it is essential to consider multiple criteria that affect the technical, environmental, and economic feasibility of the alternatives. The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that enables planners and engineers to structure complex decisions based on both qualitative and quantitative factors (Saaty, 1980). By comparing alternatives pairwise with respect to various criteria, AHP helps derive priority values that reflect the relative importance of each option. This method includes consistency checks to ensure the reliability of judgments, making it a valuable tool in infrastructure planning and alignment selection.

2.4.1. Fundamental Scale of Pairwise Comparison

In the Analytic Hierarchy Process (AHP), the relative importance between two elements is expressed using a numerical scale known as the fundamental scale of pairwise comparison. This scale, developed by Saaty, assigns intensity values ranging from 1 to 9 to quantify how much more important one element is over another. The Table 2.7 explains the meaning of each intensity value.

Table 2.7. Matrix Comparison (Saaty, 1980)

Intensity of Interest	Information
1	Both elements are equally important.
3	One element is slightly more important than the other.
5	One element is clearly more important than the other.
7	One element is strongly more important than the other.
9	One element is absolutely more important than the other.
2, 4, 6, 8	Intermediate values between the two adjacent levels of importance above.

2.4.2. Random Consistency Index

The Random Consistency Index (RI) is used in the Analytic Hierarchy Process (AHP) to evaluate the logical consistency of pairwise comparison matrices. It represents the average consistency index of randomly generated matrices and varies depending on the matrix size (n). The RI values for different matrix sizes are shown in the Table 2.8.

Table 2.8. Random Consistency Index (Saaty, 1980)

n (Matrix Size)	RI Value
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

2.4.3. Consistency Ratio (CR) Formula

To evaluate the consistency of the pairwise comparison, follow these steps:

1. Calculate the Principal Eigenvalue ($\lambda_{\max}$):
 - Multiply the pairwise matrix by the priority vector, then divide the result by the priority vector elementwise and take the average.

2. Calculate Consistency Index (CI):

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

3. Calculate Consistency Ratio (CR):

$$CR = \frac{CI}{RI}$$

- If $CR < 0.1$, the matrix is considered acceptably consistent.
- If $CR \geq 0.1$, the pairwise comparisons may need to be revised.

2.5. Horizontal Alignment

2.5.1. Introduction

Horizontal alignment is the arrangement of elements along a horizontal line, commonly applied in areas like design, typography, and engineering (Bina Marga, 2021). In visual design, horizontal alignment helps maintain order, clarity, and balance, ensuring that text or objects are placed in a way that looks neat and is easy to read or interpret. This alignment is especially important in layouts and formatting where consistency enhances the overall appearance and function.

There are three main types of horizontal alignment:

- Left alignment: Text or objects are lined up along the left edge, creating a straight left margin and a rough or uneven right margin.

- Centre alignment: Text or objects are positioned in the centre, producing equal or nearly equal spacing on both sides.
- Right alignment: Text or objects are aligned to the right edge, resulting in a straight right margin and an uneven left side.

2.5.2. Formula and Factor

When a vehicle travels along a curved or circular path, it is subjected to centrifugal force, which tends to push it outward from the center of the curve (Bina Marga, 2021). To maintain stability and prevent skidding, this outward force must be balanced by the inward components—specifically, the gravitational component due to road superelevation (the banking of the road surface) and the lateral friction between the tires and the pavement. These forces work together to keep the vehicle safely on its path. The fundamental relationship of these forces acting on a vehicle in a curve is illustrated in Figure 2.9.

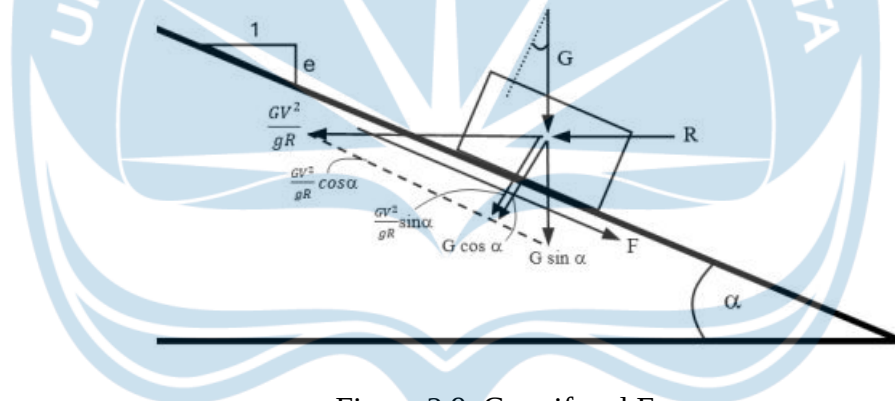


Figure 2.9. Centrifugal Force

- $\frac{GV^2}{gR}$: centrifugal force (k)
 V : velocity (m/s)
 R : radius of curvature (m)
 g : gravitational acceleration (m/s)
 F : lateral friction force
 Fmt : coefficient of lateral friction
 α : superelevation angle

The forces acting on a vehicle are shown in Figure 2.9.

$$\frac{GV^2}{gR} \cos \alpha = G \sin \alpha + F$$

$$= G \sin\alpha + f \, m t \left(G \cos\alpha + \frac{G V^2}{g R} \sin\alpha \right)$$

The value of α is small $\rightarrow \cos \alpha = 1$, very small and can be ignored

$\sin\alpha = \tan\alpha$: $\sin\alpha$ equals $\tan\alpha$, thus

$$\frac{V^2}{gR} = \tan\alpha + f \, m t + \frac{f \, m t \, V^2}{gR} \tan\alpha$$

$\tan\alpha$ is represented by the lateral slope of superelevation e , so:

$$\frac{V^2}{gR} = e + f \, m t \quad g = 32 \, \text{ft/s}^2 \quad \frac{V^2}{15R} = e + f \, m t$$

If the speed is given in km/h and $g = 9.81 \, \text{m/s}^2$:

$$\frac{V^2}{127R} = e + f \, m t$$

2.5.3. Degree of Curvature (D)

The radius and degree of curvature of a horizontal curve can be used to express it. In the metric system, the central angle that happens with an arc of 25 meters is the degree of curvature, but in the English system, it is the centre angle that occurs with an arc of 100 feet.

2.5.4. Side Friction Factor

The side friction coefficient is influenced by several interrelated factors. One of the primary determinants is vehicle speed, as higher speeds typically reduce the available friction due to decreased contact time and increased centrifugal force. The type and condition of tires also play a crucial role; tires with better tread and proper inflation provide more grip, while worn or inappropriate tires reduce the frictional resistance. Additionally, the road surface along with its texture and maintenance condition, directly affects the friction level. Lastly, weather conditions such as rain, snow, or ice significantly lower the side friction coefficient by creating slippery surfaces that hinder tire grip. Understanding these factors is essential in road design and safety analysis.

For safety concerns, curves cannot be built using the greatest side friction coefficient. In planning, the following factors define the maximum side friction coefficient:

1. Centrifugal force causing discomfort and prompting the driver to slow down.
2. Uncomfortable feeling of speed due to centrifugal force can be clearly defined and accepted as control in determining the side friction coefficient.

2.4.5. Maximum Superelevation

For a specific speed, determining the maximum superelevation and assuming the maximum friction factor is necessary to establish the minimum radius. Superelevation, or the banking of a roadway curve, is influenced by several factors such as weather conditions, field conditions (whether flat or mountainous), the type of area (rural or urban), and the presence of frequent slow-moving vehicles that cause unpredictable traffic operations. Taking these parameters into account, the maximum superelevation for open or rural areas is generally set at 0.12, although in some cases, values up to 0.13 may be used. This higher superelevation benefits fast-moving vehicles by improving stability on curves; however, it can create challenges in terms of road construction, maintenance, and may pose risks to slow-moving vehicles.

On the other hand, lower superelevation values are applied in areas with heavy traffic, particularly near urban centers, major intersections, or locations with a high frequency of turning or crossing movements, where vehicles tend to move at lower speeds. The presence of traffic signs in such areas further necessitates reduced speeds and thus justifies using lower superelevation values—typically around 0.06.

According to AASHTO guidelines, several standard superelevation rates are proposed, namely 0.06, 0.08, 0.10, and 0.12, allowing for flexibility in road design. For each group of curve radii, the minimum radius and corresponding superelevation for larger curves can be calculated, enabling safer and more efficient geometric alignment across varying traffic and environmental conditions.

2.4.6. Maximum Degree of Curvature

A limiting number for a design speed that is established by the maximum superelevation and maximum side friction factor is the maximum degree of curvature, also known as the minimum radius. It is also crucial to attain superelevation on bigger radius; using a lower radius for this design speed will provide a superelevation larger than the designated limit.

2.4.7. Superelevation

For each design speed environment, the usable superelevation must be determined in curve designing. The smallest radius is found by using the extreme values from various settings, whose superelevation is dictated by useful features. The maximum superelevation varies according on the state of the road.

Zero superelevation on straight roadways represents another extreme circumstance. Superelevation for radii between extremes and for a certain design speed should be rationally calculated between the side friction factor and superelevation.

Four techniques of curve distribution may be used to get the distribution of e (superelevation) and f (side friction factor) for curved surfaces with a given design speed.

- a. Superelevation is directly proportional to the degree of curvature, so there is a straight-line relationship between $D=0$ and $D = \text{maximum}$.
- b. Superelevation is designed so that vehicles traveling at the design speed can balance all centrifugal forces by superelevation on curves up to maximum E . Maximum E is used on sharper curves.
- c. Like method 2, speed is based on the average running speed.
- d. Superelevation at a price between methods 1 and 3, as shown by the curved line.

2.4.8. Sharp Curves Without Superelevation

The minimum cross-slope inclination is determined by drainage requirements. Regarding road type and amount of rainfall, acceptable tolerances are typically:

- a. ± 0.008 for high-class rigid concrete pavement,
- b. 0.02 for low-class flexible pavement.

Superelevation > 0.02 and a straight-line inclination throughout the pavement are essential for steeper bends. Curvature is provided by a limit of 0.02 for design speeds ranging from 30 mph to 80 mph , with sections of 2.5% curvature.

2.4.9. Influence of Grade

When driving on rural roads with long or steep hills, vehicles tend to travel faster downhill due to gravitational acceleration, while uphill movement is generally slower and more controlled. This difference in speed must be carefully considered in road design, particularly when curves are involved. Higher downhill speeds increase the centrifugal force acting on vehicles during turns, which can raise the risk of skidding or losing control if the road's superelevation is not adequately designed. To address this, adjustments in superelevation may be required on downhill curves to safely counterbalance the lateral forces. Proper planning ensures safer vehicle handling in both directions, enhances driver control, and reduces accident risks, especially in areas with sharp turns or adverse weather conditions.

2.4.10. Spiral Curves

Every vehicle that enters or exits a horizontal circular curve will travel a transitional track. The driver's actions, superelevation radius, and speed all affect the

route. Drivers can change lanes within the typical lane width restrictions when travelling at slow speeds and wide radius. A transitional curve between a straight line and a circular curve is necessary because it is impractical to maintain a steady regular lane width at high speeds and steep turns.

Transitional curves in horizontal alignment have the following benefits:

- a. When cars enter and depart circular curves, centrifugal forces can gently grow and drop thanks to well-designed transitional curves that offer an easy-to-follow track. This lessens the possibility of straying from the course.
- b. Slope attainment is possible due to the transitional curve's length. Without a transition, the attained superelevation is transferred from the normal cross-slope to the straight portion, usually in part across the curve.
- c. Spirals are a very useful tool for roads to prevent end of circular bends and surface fractures. For the creation of optimal road alignments, spirals are necessary.

The definition states that the length measured along the spiral is directly proportionate to the degree of curvature at each point on the spiral.

2.6. Vertical Alignment

Vertical alignment refers to the positioning of elements along a vertical axis and plays a crucial role in design, typography, and layout by creating visual balance and organization within a composition (Bina Marga, 2021). It ensures that elements are arranged in a harmonious and aesthetically pleasing manner. In design and typography, vertical alignment is commonly used to align text or other design components along a vertical line or within a defined vertical space. There are three main types of vertical alignment typically used to achieve this effect. It can be divided into these categories:

- Top alignment: This alignment positions the elements or text at the top of the vertical space or container. It creates a straight top edge and may result in empty space or gaps below the elements.
- Centre alignment: Also known as vertical centre alignment, this aligns the elements or text to the middle of the vertical space or container. It creates equal or near-equal spacing above and below the elements, resulting in a centred appearance.
- Bottom alignment: This alignment positions the elements or text at the bottom of the vertical space or container. It creates a straight bottom edge and may result in empty space or gaps above the elements.

2.6.1. Features of Vehicle Performance on Grades

All passenger cars can typically drive on gradients between 7% and 8% without experiencing any appreciable changes from flat parts. Based on observations, passenger cars are not significantly affected by a 3% slope in comparison to flat roads. For trucks, the gradient has a greater influence than for passenger cars at the same slope.

2.6.2. Grade Limits for Planning

Maximum grades are established by considering a variety of variables, such as the link between speed and distance travelled for a particular vehicle. The highest gradient with an 80-mph design speed is 3%. Depending on the geography, the allowable gradient for a 30-mph design speed varies from 5% to 12%.

Table 2.9. Grade Limits for Planning (AAHSTO, 2001)

Maximum Length of Straight Sections								
Topography Types	30	40	50	60	65	70	75	80
Flat	6	5	4	3	3	3	3	3
Hilly	7	6	5	4	4	4	4	4
Mountainous	9	8	7	6	6	6	-	-

2.6.3. Critical Length of a Grade for Design

In road design, it is critical to consider the duration or length of a specific grade, especially on steep inclines or declines, as it directly affects vehicle performance and safety. The critical length of a grade refers to the distance over which a vehicle, typically a truck, experiences a 15 mph (24 km/h) reduction in speed because of gravity and engine power limitations. This concept is important for identifying when additional measures are needed to maintain safe and efficient traffic flow, particularly in areas with long, steep grades.

2.6.4. Vertical Curve

To ensure a smooth and safe transition between two distinct grades in a roadway, a vertical curve is used. This curve provides a gradual change in slope, enhancing driver comfort, vehicle control, and overall road safety. Properly designed vertical curves eliminate sudden grade changes that could cause discomfort or visibility issues, particularly at high speeds. The curve should be gentle enough to maintain adequate sight distance, especially for stopping or passing, while also accommodating drainage and structural considerations. Ultimately, a well-planned vertical curve contributes to a safer and more user-friendly roadway design.

2.6.5. Properties of Vertical Curves

A road's length is measured horizontally, and its slope is calculated approximately using the vertical-to-horizontal ratio, which may be streamlined by utilising the vertical axis that is centred at the Vertical Point of Intersection (VPI). A constant grade change gives a $\Delta L/800$ distance from the VPI, where:

Δ = Algebraic change in grade as a percentage

L = Horizontal length of the vertical curve

2.6.6. Types of Vertical Curves

In the context of vertical curves, the terms convex and concave are used to describe the shape of the curve as it transitions between two different gradients. A convex curve, also known as a crest curve, bends upward like the top of a hill and is formed when an ascending grade meets a descending grade. This type of curve can limit a driver's line of sight, making the provision of adequate sight distance a critical design factor. On the other hand, a concave curve, also known as a sag curve, bends downward like the bottom of a valley and is formed when a descending grade meets an ascending grade. Sag curves are typically easier for drivers to navigate visually during the day, but at night they rely on headlight beams for visibility, which makes the curve's design important for ensuring safe stopping sight distance. Both types must be designed carefully to ensure smooth transitions, comfort, and safety for road users. It shown in Figure 2.10 about convex curve and concave curve.

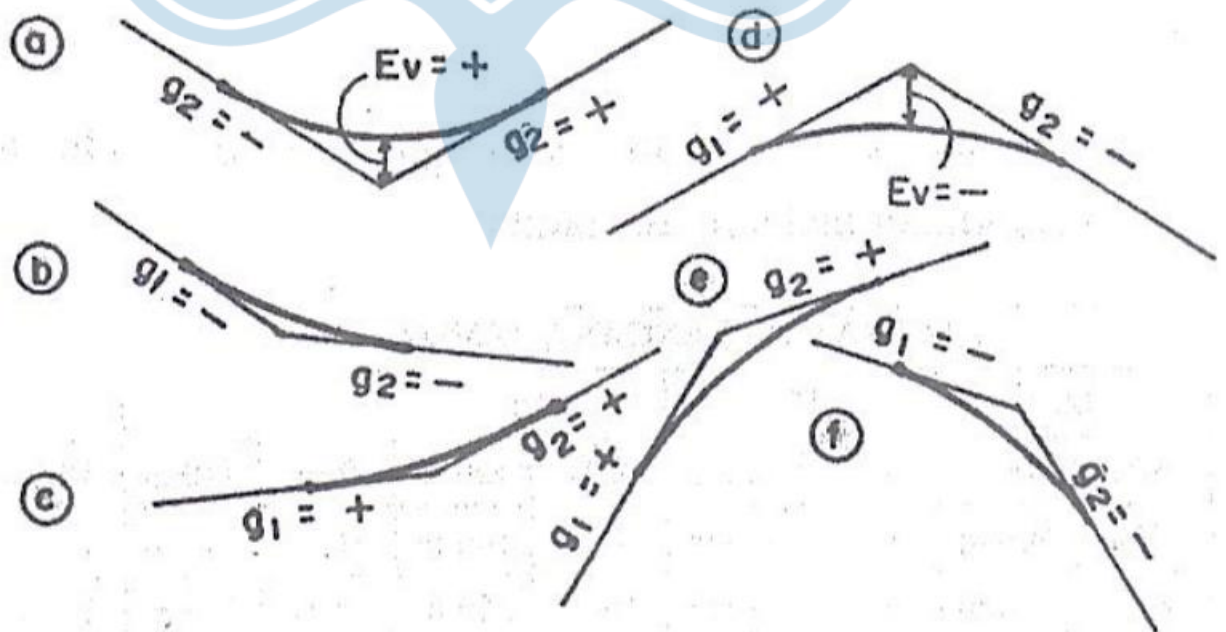
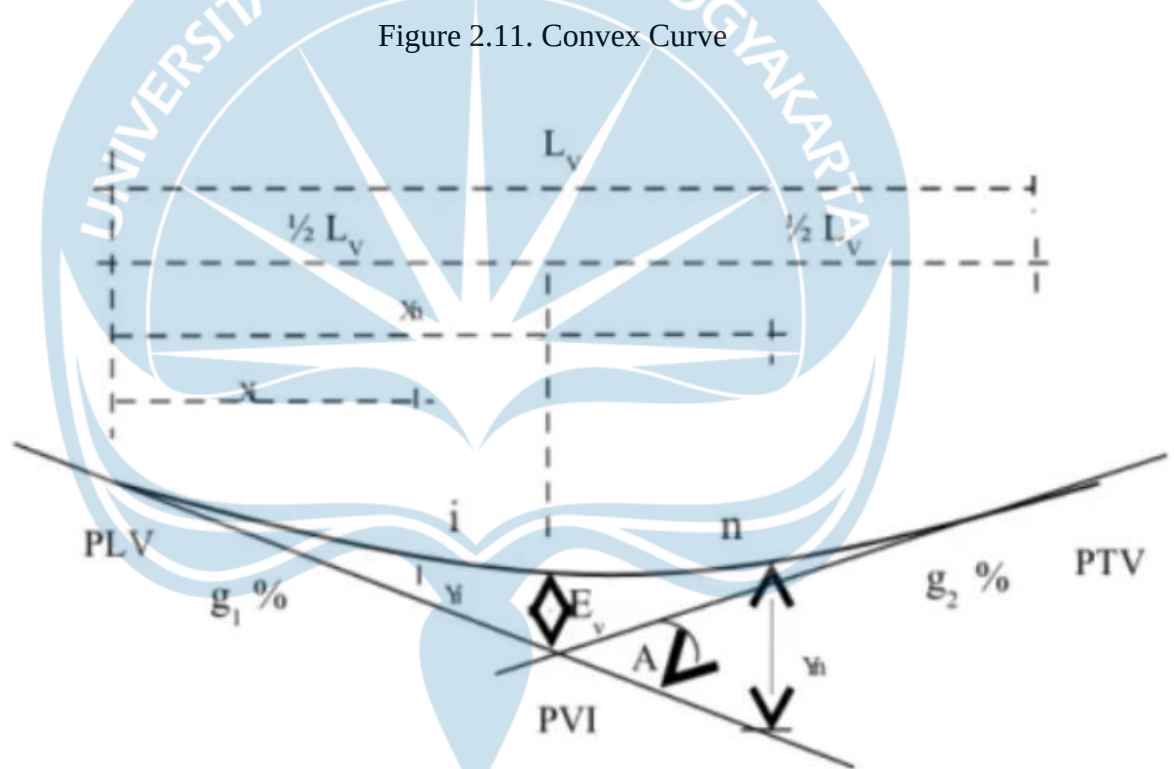
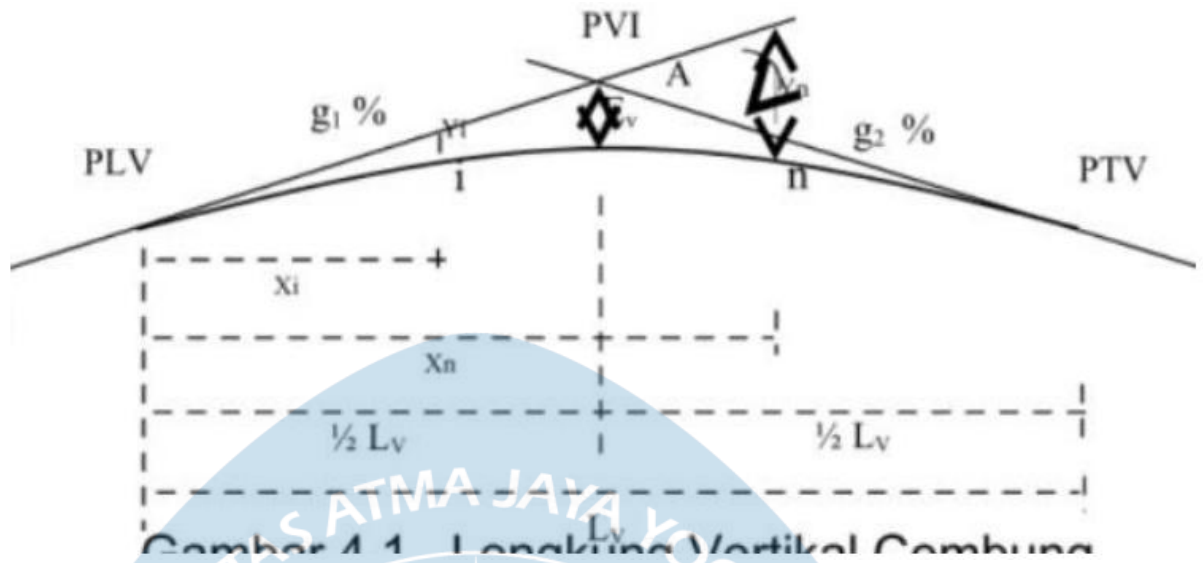


Figure 2.10. Types of Convex Curve and Concave Curve



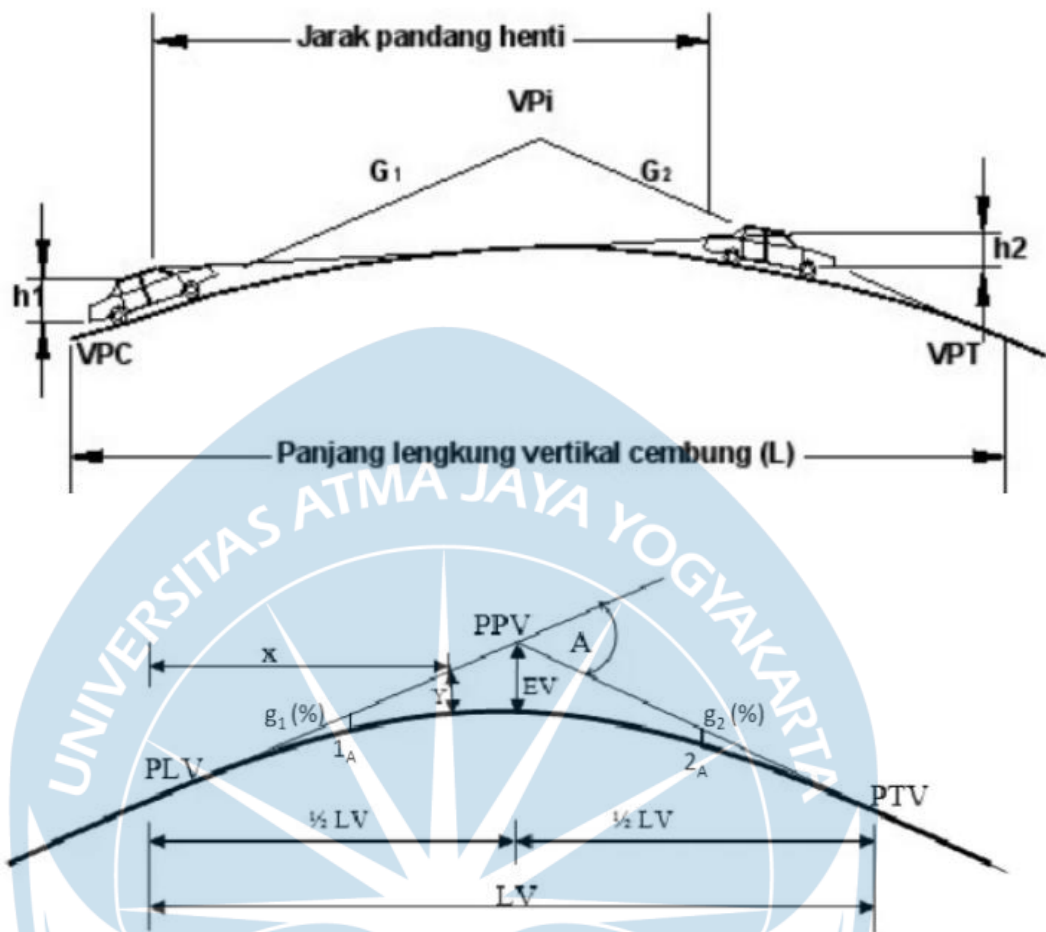


Figure 2.13. Vertical Curve

2.6.7. Parabolic Curve Equation

The phrase "parabolic curve equation" describes an equation that is used to calculate a road's curvature in vertical alignment such that it forms a parabola, or an appropriate curve based on the requirements and field circumstances at hand.

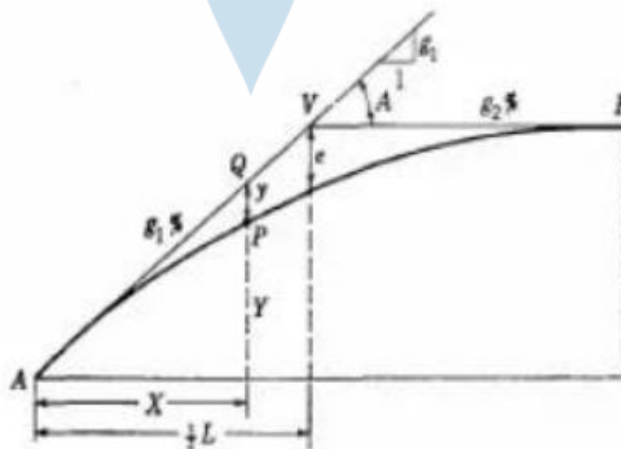


Figure 2.14. Parabolic Curve

2.7. Soil Work

Soil work, also known as soil engineering or geotechnical engineering, involves the study and analysis of soil properties, behavior, and its interaction with structures (Hardiyatmo, 2019). It focuses on understanding the physical, mechanical, and chemical characteristics of soil to provide recommendations for construction, foundation design, and earthwork projects. Soil work plays a crucial role in various engineering disciplines, including civil engineering, geotechnical engineering, and construction engineering.

2.7.1. Soil Work Specifications

To finish the contract job, this labour entails digging, moving, discarding, or storing dirt, pebbles, or other debris from the road.

Types of excavation work:

1. **Common Excavation:** This refers to any excavation that isn't classified as asphalt pavement, rock, structural, or material source excavation.
2. **Rock excavation:** includes extracting rock fragments that have a volume of one cubic metre or greater. This excludes excavation that can be completed with a single ripper hauled by a tractor with a maximum net horsepower of 180 hp and a weight of up to 15 tonnes.
3. **Structural Excavation:** Consists of excavation within the designated work limitations in all types of soil. Structural excavation excludes any excavation that is categorised as common or rock excavation.
4. **Asphalt Pavement Excavation:** This process entails removing outdated pavement and discarding the materials used to create it.

Steps for Excavation:

1. Excavation must adhere to the specified slope, lines, and elevations.
2. Excavation work should cause minimal disruption to materials beneath and outside the excavation boundaries.
3. If material at the subgrade or foundation is loose, soft, contaminated, or unsuitable, it must be entirely removed and replaced with suitable fill.
4. If hard stone, rock layers, or difficult-to-remove material is encountered in the subgrade for pavement or road shoulders, or at the bottom of pipeline trenches or structural foundations, it should be excavated 15 cm deeper to achieve a uniform surface. Sharp protruding stones on the surface must be removed, and all stone fragments larger than 15 cm in diameter must be disposed of. The required excavation profile should be achieved by backfilling with suitable material and compacting it.

5. Explosives for rock demolition should only be used if it's impractical to use air pressure tools or a single-tooth hydraulic ripper.
6. The contractor must provide blast protection mesh to safeguard people, buildings, and work during excavation.
7. Rock excavation should be performed carefully to ensure that cut edges are left safe and as even as possible. Loose or overhanging stones can pose hazards to the work or individuals and must be removed.

2.7.2. Embankment Work

In embankment construction, soil or other granular materials must be properly provided, transported, spread, and compacted to ensure the stability and integrity of the structure (Hardiyatmo, 2019). This process requires careful planning and execution to achieve the desired strength and durability. When working on embankments, several important factors must be considered, including the selection of suitable fill material, moisture content control, layer thickness during placement, and the method and degree of compaction. Additionally, the foundation soil must be adequately prepared to support the load, and drainage must be managed to prevent water accumulation that could weaken the embankment. Proper attention to these aspects is essential for ensuring a safe, long-lasting embankment that performs well under traffic and environmental conditions.:

a. Selected Fill Material

Embankment fill materials must comply with SNI 03-1744-1989, requiring a minimum CBR of 10% after 4 days of soaking (Badan Standardisasi Nasional, 2012). Suitable materials include sand, gravel, or other clean granular soils with a Plasticity Index not exceeding 6%. Where higher shear strength is needed well-graded rock or gravelly clay may be used.

b. Ordinary Fill Material

High plasticity soils are generally not recommended for use in ordinary embankment fill due to their poor strength and stability. If their use is unavoidable, they should be limited to the base of the fill or placed in non-load-bearing areas. Moreover, such soils should not be used within 30 cm of the pavement base or roadside base material to avoid compromising structural integrity. According to SNI 03-1744-1989 (Badan Standardisasi Nasional, 2012), ordinary fill materials should have a minimum CBR of 6% after 4 days of soaking to ensure adequate performance.

c. Compaction of Embankment

Proper compaction is essential in embankment construction to ensure stability and prevent settlement. Each layer must be compacted using suitable equipment, with soil moisture maintained between 3% below and 1% above the optimum moisture content. For rock embankments, a 20 cm layer of well-graded material, free of stones larger than 5 cm, should be used to fill voids between rocks. Before placing the next layer, density testing must be conducted to ensure adequate compaction. Compaction should begin at the outer edge and move toward the centre of the roadway. When working around pipes or concrete drainage structures, care must be taken to maintain similar elevation on both sides. In cases where material can only be placed on one side of structures such as abutments, piers, or retaining walls, over-compaction near these structures should be avoided to prevent structural displacement or damage.

d. Spreading of Embankment

Embankment construction should begin on a properly prepared surface, with soil spread in uniform layers that comply with specified thickness tolerances after compaction. Typically, embankment soil is taken directly from its source and placed during clear weather to ensure optimal workability. Following the installation of pipes or other structures, backfilling must be carried out promptly and systematically. For areas around concrete retaining structures or stone masonry, a curing period of at least 14 days is required before backfilling. In road widening projects, the slope of the existing embankment must first be cleared of vegetation, and the new embankment should be constructed by placing horizontal layers up to the subgrade elevation, ensuring the widened section is quickly made usable.

2.8. Pavement Design

According to book “Perancangan Perkerasan Jalan dan Penyelidikan Tanah” (Hardiyatmo, 2019) defines flexible pavement as a spread and compacted mixture of crushed stone, sand, filler, and asphalt. The pavement must be able to bend to take up weight and then return to its original location beside the subgrade. The foundation of flexible pavement design is the elasticity concept and practical expertise. We may assess the stresses in each layer of pavement to prevent permanent deflection by applying theory elasticity.

2.8.1. Methodology and Fundamentals

The mechanistic-empirical approach to pavement design involves a mechanistic examination of pavement structures by analysing the mechanical properties of materials. Key input parameters include wheel load, pavement structure, and the mechanical

characteristics of the materials involved. The output focuses on how the pavement responds to wheel loads, particularly in terms of strain, deflection, and stress. This methodology enables the prediction of pavement performance by incorporating both field observations and laboratory test data, with particular attention to fatigue cracking and permanent deformation. This combined approach is referred to as empirical mechanistic.

2.8.2. Benefits of Mechanistic Approaches

Mechanistic methods offer several advantages in pavement analysis. They allow for analytical evaluation of vehicle load effects on pavement performance, enabling more accurate predictions compared to empirical methods. These approaches also facilitate the assessment of novel materials, as their mechanical properties can be used directly in the performance evaluation. Additionally, mechanistic models account for the influence of environmental and climatic conditions on material behaviour, offering a more realistic representation of in-service pavement performance. They are also effective in evaluating damage modes, such as long-term deformation and fatigue cracking, which are critical to pavement durability.

2.8.3. Model of Pavement Structure

In mechanistic pavement design, the pavement is modeled as a multilayer structure, where material behaviors vary depending on their composition. Unbound granular materials are often modeled as anisotropic, while bound materials (like asphalt or concrete) are treated as isotropic and linearly elastic. Key parameters used in modeling include Poisson's ratio (μ) and elastic modulus (E) for isotropic and anisotropic materials. For cross-anisotropic materials, five elastic constants— E_v , E_h , μ_{vh} , μ_{hh} , and shear modulus—are required to define their behavior accurately. In the case of particulate materials, non-linear behavior is approximated by modeling multiple layers with varying modulus values.

2.8.4. Crucial Stress in Pavement Function

Two primary stress responses are crucial for pavement performance. First, vertical compressive strain at the subgrade surface must be minimized to avoid permanent deformation or rutting. Second, horizontal tensile strain at the bottom of the bound layer (such as asphalt) must be controlled to limit fatigue damage and cracking. To link these critical strains with long-term pavement performance, a transfer function model is used, connecting strain measurements to the accumulated damage from traffic loads, including both permanent deformation and fatigue cracking. Although it is possible to use the actual

traffic load spectrum in the analysis, it is more common and practical to express traffic loading in terms of Standard Equivalent Single Axle Load (ESA) for design purposes.

2.8.5. Flexible Pavement Design Procedure Using Empirical Mechanistic Methods

The flexible pavement design procedure using empirical mechanistic methods provides a more accurate and adaptive approach by considering variations in traffic loading, material behaviour, and environmental influences on pavement performance. This method integrates engineering mechanics with empirical data, allowing designers to predict how pavements will respond over time under real-world conditions. The following steps outline the standard procedure for designing flexible pavements with asphalt mixtures:

1. Determine the Plan Age – Establish the design life of the pavement, which influences traffic load estimation and structural requirements.
2. Determine ESA4 and/or ESA5 – Calculate the cumulative equivalent standard axle loads (ESA4 for 4-wheeled and ESA5 for 5-axle vehicles) based on the selected plan age.
3. Determine Pavement Type – Choose the pavement type by considering economic factors, including initial construction cost and long-term maintenance.
4. Identify Uniform Subgrade Segments – Divide the route into segments with uniform subgrade bearing capacity to ensure consistent design across varying soil conditions.
5. Determine Pavement Foundation Structure – Design the foundation layers (e.g., subbase and base) suitable for the identified subgrade.
6. Select Pavement Layer Thickness – Use Design Chart 3 or other suitable design charts to select layer thicknesses that satisfy the expected loading and performance requirements.
7. Assess Pavement Edge Strength – Ensure the pavement edge has adequate bearing capacity, particularly in areas without shoulders or adjacent support.
8. Evaluate Shoulder Sealing Needs – Determine whether shoulder sealing is needed to protect pavement edges and improve performance.
9. Repeat for Each Segment – Apply steps 5 through 9 to each segment with different subgrade characteristics.

2.9. Soil Investigation

When planning to build a structure, soil is one of the most important aspects to consider because it is part of the foundation to support the structure above it (Hardiyatmo,

2014). Soil investigation is the process of obtaining data from the soil of the project site. The interpretation of the result will provide the important information about the geotechnical and geological soil to design the foundation, slope stability, road making, and others.

A comprehensive soil investigation is essential in any geotechnical project to understand the subsurface conditions and ensure safe and cost-effective foundation design. Soil condition refers to the physical and mechanical properties of the soil at the project site, including factors such as moisture content, density, consistency, shear strength, and bearing capacity. These characteristics influence the soil's behavior under structural loads and environmental changes. Observations from field tests—such as SPT (Standard Penetration Test) and CPT (Cone Penetration Test)—along with laboratory tests on soil samples, help define these conditions accurately (Hardiyatmo, 2018).

Based on the results of these investigations, soils are then classified using standardized systems such as the Unified Soil Classification System (USCS) or the AASHTO classification system. These systems categorize soils into groups like gravel, sand, silt, clay, or organic soils, depending on grain size distribution and plasticity characteristics. For instance, well-graded sands are labelled as SW under USCS, while high-plasticity clays are classified as CH (AAHSTO, 2001). This classification provides engineers with essential information on how the soil will perform under different loading and environmental conditions, guiding decisions on foundation type, depth, and the need for soil improvement or replacement.

2.9.1. Cone Penetration Test

Cone Penetration Test (CPT) is a geotechnical in-site test method used to determine subgrade soil conditions without drilling boreholes (Badan Standardisasi Nasional, 2008). CPT provides essential information about the soil strength, bearing capacity, and ground stratification necessary in road pavement design by selecting appropriate pavement layers and ensuring the structural integrity. The CPT equipment is driven into the ground hydraulically, reading continuously tip resistance (q_c) and sleeve friction (f_s) with depth.

In highway design, especially in soft or variable ground, CPT information helps the engineer determine potential weak spots and decide on the subgrade and base thickness and rigidity needed. The technique is particularly valuable as it yields real-time, high-resolution data, and is therefore a valuable tool for assessing site-specific soil response and minimizing construction risk.

There are some technical drawings of Cone Penetration Test (CPT) equipment components, specifically the CPT cone and friction sleeve used for soil investigation. In the figure below, the left side illustrates the external dimensions, while the right side presents a cross-sectional view showing internal construction.

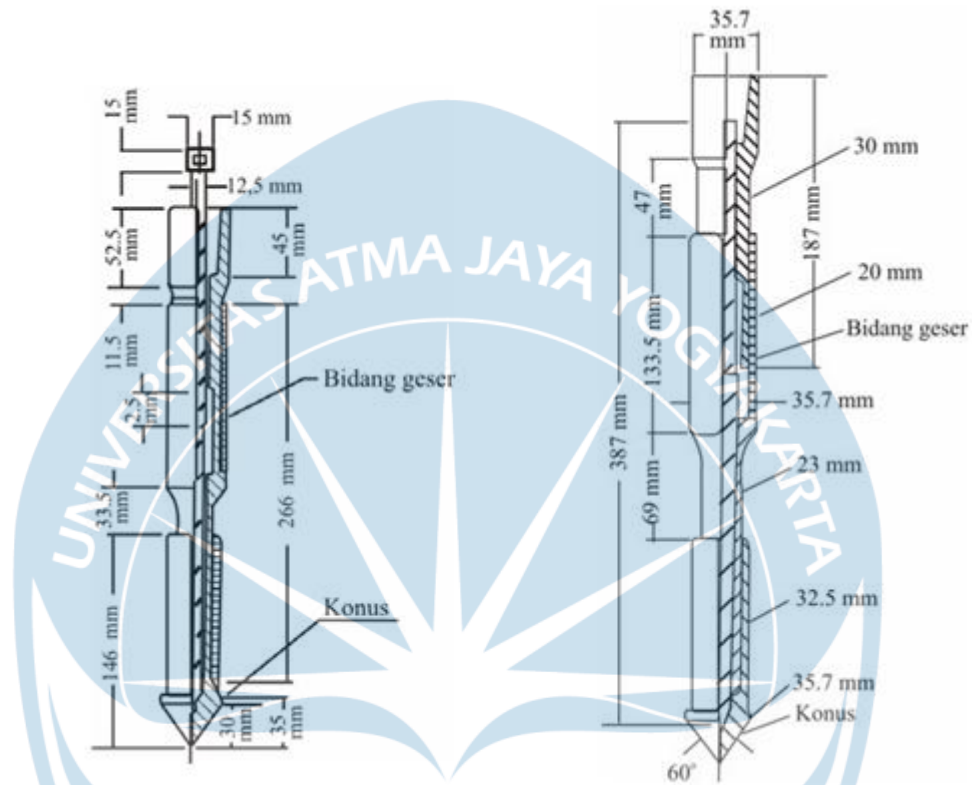


Figure 2.15. Double Cone Details (Badan Standardisasi Nasional, 2008)

Based on the Figure 2.15, the components include:

- The cone tip (conus) at the bottom, typically with a 60° apex angle, used to penetrate soil and measure tip resistance.
- The friction sleeve (sliding plane), located above the cone, designed to measure sleeve friction along the soil layer.
- Dimensions are precisely given, such as the cone diameter (35.7 mm), the sleeve length (266 mm), and other features like the sleeve diameter (35.7 mm) and various thicknesses and lengths of the structural elements.

2.9.2. Standard Penetration Test

Standard Penetration Test (SPT) is a widespread in-situ test for the evaluation of the relative density of coarse-grained soils and fine-grained soil consistency (Badan Standardisasi Nasional, 2008). The test entailed driving a split-barrel sampler to a location at the bottom of a borehole using the aid of a 63.5 kg (140 lb) fall hammer from a 760

mm (30 inches) drop. The number of blows used to drive the sampler the last 30 cm out of a total of 45 cm of penetration is utilized as the SPT N-value. The N-value is a significant geotechnical engineering parameter and is commonly used in approximating soil bearing capacity, liquefaction, and foundation design parameters.

The obtained raw N-value of the field test is normally corrected against numerous factors affecting the energy efficiency of the hammer, overburden pressure, diameter of the borehole, rod length, and conditions of groundwater. All the corrections are applied to standardize data to obtain better accuracy and reliability. SPT remains a simple test in geotechnical exploration and is mentioned in various international standards such as ASTM D1586 and Indonesian National Standards (SNI). Despite its empirical beginnings, the SPT has been enjoyed for being easy, cheap, and for the rich amounts of historical data there are to be used in soil behaviour study and foundation design.

The figure 2.16 illustrates the detailed design of the Standard Penetration Test (SPT) split-spoon sampler, which is commonly used in geotechnical investigations to assess subsurface soil conditions. The drawing shows two configurations of the sampler: one with a flat base and the other with a pointed tip, both of which are used depending on soil type and testing requirements. Key components such as the coupling head, barrel (split tube), and shoe are depicted with precise measurements, serving as a reference for equipment fabrication or verification. The SPT sampler is driven into the ground to collect disturbed soil samples, and the design shown here ensures compliance with standard dimensions to maintain consistency and reliability in field testing.

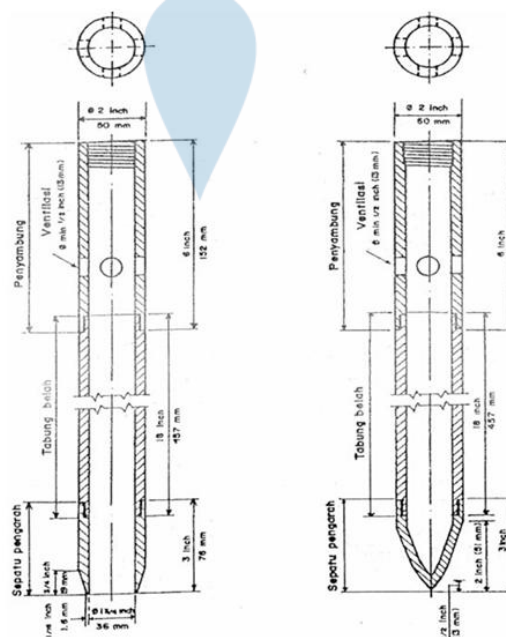


Figure 2.16. Split Tube Sampling Tool (Badan Standardisasi Nasional, 2008)

The energy ratio (Ef) in the Standard Penetration Test (SPT) is a critical parameter that reflects the efficiency of energy transfer from the hammer to the sampler during testing. This ratio significantly affects the resulting N-value, which is used to estimate soil strength and consistency. Variations in equipment, testing procedures, and operator technique can lead to inconsistent energy delivery, potentially impacting the accuracy of the test results. Therefore, measuring and correcting for Ef ensures that SPT data are standardized and comparable across different locations and projects. In this study, consideration of the Ef value is essential to validate the reliability of the SPT results and to ensure they align well with the corresponding CPT data and soil classifications. It shown in Table 2.11.

Table 2.10. Hammer Efficiency for SPT (Hardiyatmo, 2014)

Country	Hammer type	Release mechanism	Hammer efficiency (Ef)
Argentina	Donut	Cathead	0.45
Brazil	Pin weight	Hand release	0.72
China	Automatic	Trip	0.60
	Donut	Hand release	0.55
	Donut	Cathead	0.50
Columbia	Donut	Cathead	0.50
Japan	Donut	Tombi Trigger	0.78 – 0.85
	Donut	2 turns on cathead + special release	0.65 – 0.67
England	automatic	trip	0.55 – 0.60
America	safe	2 turns on cathead	0.45
	Donut	2 turns on cathead	0.43
Venezuela	Donut	Cathead	0.43

The previous table contains the data used to find the hammer efficiency factor. Next table contains the information for the C_b , C_s , C_r coefficient.

Table 2.11. SPT Coefficient Table (Hardiyatmo, 2014)

Faktor	Variation	Correction
Drill hole diameter (Cb)	65 – 115 mm	1.00
	150 mm	1.05
	200 mm	1.15
Sample tube (Cs)	standard	1.00
	Without liner	1.20
Drill pipe length (Cr)	3 – 4 m	0.75
	4 – 6 m	0.85
	6 – 10 m	0.95
	>10 m	1.00

2.10. Soil Settlement

Soil settlement refers to the vertical displacement of the ground surface caused by the compression of soil layers under loading, such as from embankments, foundations, or other structures (Hardiyatmo, 2018). This phenomenon is a critical concern in geotechnical engineering because excessive or uneven settlement can lead to structural damage or serviceability issues. Settlement typically occurs in two main stages: immediate settlement, which happens directly after loading and is usually associated with elastic deformation in granular or partially saturated cohesive soils; and consolidation settlement, which develops over time as pore water is gradually expelled from saturated cohesive soils under sustained loading. The nature, magnitude, and duration of settlement depend on various factors including soil type, loading intensity, drainage conditions, and soil compressibility, all of which must be carefully evaluated during design and construction planning. Settlement divided into 2 types, it's immediate settlement and consolidation settlement.

2.10.1. Immediate Settlement

Immediate settlement happens rapidly after loading and is typically associated with elastic deformation in granular or partially saturated cohesive soils. There are so many formulas to calculate immediate settlement. Two of the most common are Janbu Method (1956) and De Beer and Martens Method (1957).

The Janbu Method estimates settlement with the formula:

$$S_i = \mu_1 \mu_0 \frac{qB}{E} \text{ (for } \mu = 0.5 \text{)}$$

Where:

S_i = immediate Settlement (cm)

μ_1 = correction factor for upper soil layer thickness

μ_0 = correction factor for foundation depth

q = Net foundation pressure (kN/m²)

B = Foundation width for square and diameter for circle foundation (m)

E = Elastic modulus (kN/m²)

For this formula, we also need to determine the value of μ_1 and μ_0 from the following graph:

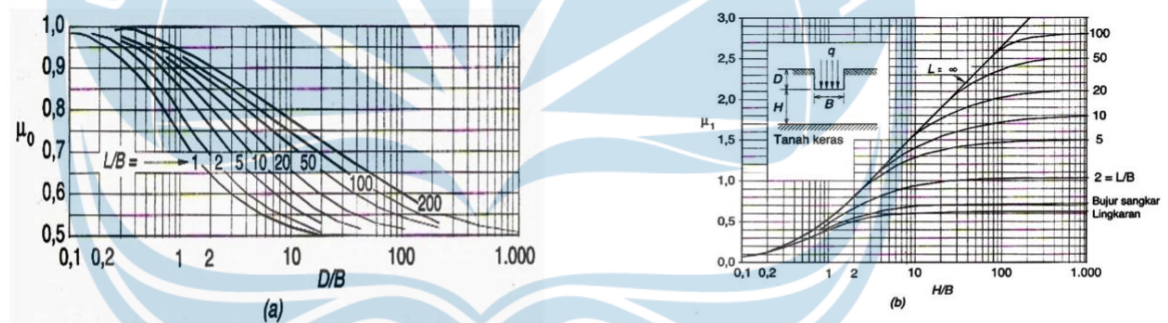


Figure 2.17. Diagram of μ_1 and μ_0 (Hardiyatmo, 2018)

Meanwhile, the De Beer and Martens Method is simpler because it not using any table or diagram for calculation. Besides, this is the formula:

$$S_i = \frac{H}{C} \ln \frac{p_o' + \Delta p}{p_o'}$$

Where:

S_i = immediate settlement (cm)

H = thickness of the layer (m)

C = constant of compressibility soil $C = \frac{1.5 + \Delta p}{p_o'}$

p_o' = effective overburden pressure

Δp = change in pressure

2.10.2. Consolidation Settlement

Consolidation settlement is a time lag vertical settlement of the soil caused by loading of saturated fine-grained soils (silts and clays) by an embankment or a structure. Instantaneous settlement is caused by sudden occurrence due to elastic deformation, while consolidation settlement is gradual and is governed by the drainage of the excess pore water from the soil voids.

When a weight is put on a saturated soil layer, the pore water initially resists the imposed stress. Over time, however, the excess pore water is lost and the effective stress in the soil framework increases, so the soil particles are pushed closer together. That displacement of particles leads to a reduction in volume—consolidation. The formula to find the consolidation is as follows.

$$S_c = \frac{C_c H_c}{1 + e_0} \log \frac{\sigma'_o + \Delta \sigma'}{\sigma'_o}$$

Where:

S_c = Consolidation Settlement

C_c = Compression index

H_c = contact depth (m)

e_0 = pore number

p_0' = effective overburden pressure (kN/m²)

Δp = change in pressure

There are various ways to find compression index, depending on the type of the soil so these are the listed table:

Table 2.12. Correlations for Compression Index (Das & Sobhan, 2016)

Formula	reference	Applicable soil
$C_c = 0.0007 (LL - 7)$	Skempton (1944)	Remolded clays
$C_c = 0.01 w_N$		Chicago clays
$C_c = 1.15(e_0 - 0.27)$	Nishida (1956)	All clays

Formula	reference	Applicable soil
$C_c = 0.30(e_o - 0.27)$	Hough (1957)	Inorganic cohesive soils: silt, silty clay, clay
$C_c = 0.0115 w_N$		Organic soils, peats, organic silt, clay
$C_c = 0.0046 (LL - 9)$		Brazilian clays
$C_c = 0.75(e_o - 0.5)$		Soils with low plasticity
$C_c = 0.208e_o + 0.0083$		Chicago clays
$C_c = 0.156e_o + 0.0107$		All clays

2.11. Soil Bearing Capacity

Soil bearing capacity is the maximum unit area load that may be sustained by the soil without shearing failure or excessive settlement. Estimation of bearing capacity is essential to foundation design for both structural safety and sustainability. Two fundamental approaches are used to determine the bearing capacity of soil: analytical methods and empirical methods.

2.11.1. Analytical Method

Analytical methods estimate soil bearing capacity using theoretical formulas derived from principles of soil mechanics, particularly based on limit equilibrium and plasticity theories. For this project, we use Terzaghi and Hansen Method.

a. Terzaghi Bearing Capacity

The Terzaghi calculation method focuses on the soil shear strength components with these considering factors: cohesion, effective stress, and the angle of internal friction. There is also some assumption need to make when using Terzaghi such as a shallow foundation where width is greater than depth, no sliding between foundation and soil, homogenous soil, no applied moments, and uniform surcharge.

The Terzaghi method uses the following formula:

$$q_u = c' \cdot N_c' + D_f \gamma N_q' + 0.5 \cdot \gamma \cdot B \cdot N_\gamma'$$

Where:

c = Cohesion of the drained soil (kPa)

γ = Unit weight of the soil (kN/m³)

D_f = Depth of the Foundation (in this project using 2 m)

B = Width of footing (m)

For the loose layer of soil or weak, due to the friction of the foundation to the ground there will be a major decline before a major failure on the balance of the soil below. This condition is called local shear failure and on this condition the formula for Terzaghi bearing capacity must be reduced.

$C' = 2/3 c$ = soil cohesion on local shear failure

$\tan \phi' = 2/3 \tan \phi$ = friction degree on local shear failure

The factor used to calculate the bearing capacity is N_c' , N_q' , N_γ' . For non-cohesive soil, it can use these guides:

local shear failure happens when $\phi < 29^\circ$

general shear failure happens when $\phi > 38^\circ$

The value of N_c' , N_q' , N_γ' are obtained from the following table:

Table 2.13. Terzaghi Bearing Capacity Factor (Hardiyatmo, 2018)

Friction Angle ($^\circ$)	Local Shear Value		
	N_c'	N_q'	N_γ'
0	5.70	1.00	0.00
1	5.90	1.07	0.01
2	6.10	1.14	0.02
3	6.30	1.20	0.04
4	6.51	1.30	0.06
5	6.74	1.39	0.07
6	6.97	1.49	0.10
7	7.22	1.59	0.13
8	7.47	1.70	0.16
9	7.74	1.82	0.20
10	8.02	1.94	0.24
11	8.32	2.08	0.30
12	8.63	2.22	0.35
13	8.96	2.38	0.42
14	9.31	2.55	0.48

Friction Angle (°)	Local Shear Value		
	N_c'	N_q'	N_γ'
15	9.67	2.73	0.57
16	10.06	2.92	0.67
17	10.47	3.13	0.76
18	10.90	3.36	0.88
19	11.36	3.61	1.03
20	11.85	3.88	1.12
21	12.37	4.17	1.35
22	12.92	4.48	1.55
23	13.51	4.82	1.74
24	14.14	5.20	1.97
25	14.80	5.60	2.25
26	15.53	6.05	2.59
27	16.30	6.54	2.88
28	17.13	7.07	3.29
29	18.03	7.66	3.76
30	18.99	8.31	4.39
31	20.03	9.03	4.83
32	21.16	9.82	3.51
33	22.39	10.69	6.32
34	23.72	11.67	7.22
35	25.18	12.75	8.35
36	26.77	13.97	9.41
37	28.51	15.32	10.90
38	30.43	16.85	12.75
39	32.53	18.56	14.71
40	34.87	20.50	17.22
41	37.45	22.70	19.75
42	40.33	25.21	22.50
43	43.54	28.06	26.25
44	47.13	31.34	30.40

Friction Angle (°)	Local Shear Value		
	N _c '	N _q '	N _γ '
45	31.17	35.11	36.00
46	55.73	39.48	41.70
47	60.91	44.54	49.30
48	66.80	50.46	59.25
49	73.55	57.41	71.45
50	81.31	65.60	85.75

b. Hansen Bearing capacity

The Hansen method is an extension of Meyerhof calculation that also calculate the tilting of the base foundation which is more suited on this road design with formula for foundation on slopes. Hansen also derived a new formula for bearing capacity factor N_γ. For the soil $\phi > 0$ Hansen method uses the following formula:

$$qu = \frac{Qu}{B'L'} = s_c d_c i_c g_c c N_c + s_q d_q i_q b_q g_q p_o N_q + s_\gamma d_\gamma i_\gamma b_\gamma g_\gamma 0.5 B' \gamma N_\gamma$$

Below is formula tables used to determine the value of each factor used in Hansen method.

Table 2.14. Depth Factor (Hardiyatmo, 2018)

Depth Factor	Value	Description
d _c	1 + 0.4 (D/B)	
d _q	1 + 2 (D/B) tg ϕ (1-sin ϕ) °	When (D/B)>1, then change it to arc tg (D/B)
d _γ	1	

Table 2.15. Load Slope Factor (Hardiyatmo, 2018)

Load Slope Factor	Value	Description
i _c	$i_q - \frac{(1 - i_q)}{N_q - 1}$	
i _q	$[1 - \frac{0.5H}{V + A'c} ctg\phi]^5 \geq 0$	

Load Slope Factor	Value	Description
i_γ	$[1 - \frac{0.7H}{V + A'c \operatorname{ctg}\phi}]^5 \geq 0$	For horizontal base
	$[1 - \frac{(0.7 - \alpha^\circ/450)H}{V + A'c \operatorname{ctg}\phi}]^5 \geq 0$	For sloping base limit: $H \leq c. A' + V \operatorname{tg} \delta$

Table 2.16. Foundation Shape Factor (Hardiyatmo, 2018)

Shape Factor	Load Direction		
	Perpendicular Base	Tilted with width (B)	Tilted with length (L)
s_c	$1 + \left(\frac{B'}{L'}\right)\left(\frac{Nq}{Nc}\right)$	$1 + \left(\frac{B'}{L'}\right)\left(\frac{Nq}{Nc}\right)i_{cB}$	$1 + \left(\frac{B'}{L'}\right)\left(\frac{Nq}{Nc}\right)i_{cL}$
$s_{c'}$	$0.2 (B'/L')$	$0.2 (B'/L')i_{cB}$	$0.2 (B'/L')i_{cL}$
s_q	$1 + (B'/L')\sin\phi$	$1 + (B'i_{qB}/L')\sin\phi$	$1 + (L'i_{qL}/B')\sin\phi$
s_γ	$1 - 0.4 (B'/L') \geq 0.6$	$1 - 0.4(B'i_{\gamma B}/L'i_{\gamma L}) \geq 0.6$	$1 - 0.4(L'i_{\gamma L}/B'i_{\gamma B}) \geq 0.6$

Table 2.17. Base Slope Factor (Hardiyatmo, 2018)

Base Slope Factor	Value	Description
b_c	$1 - \frac{\alpha^\circ}{147^\circ}$	$\alpha = \text{slope degree of the base}$
$b_{c'}$	$\frac{\alpha^\circ}{147^\circ}$	
b_q	$e^{-2\alpha \operatorname{tg}\phi}$	
b_γ	$e^{-2.7\alpha \operatorname{tg}\phi}$	

Table 2.18. Surface Slope Factor (Hardiyatmo, 2018)

Surface Slope Factor	Value	Description
g_c	$1 - \frac{\beta^\circ}{147^\circ}$	

Surface Slope Factor	Value	Description
g_c'	$\frac{\beta^\circ}{147^\circ}$	α = slope degree of the surface $\alpha + \beta \leq 90^\circ$
$g_c = g_\gamma$	$(1 - 0.5 \operatorname{tg} \beta)^5$	

Table 2.19. Hansen Bearing Capacity Factor (Hardiyatmo, 2018)

Friction Angle (°)	Shear Value		
	N_c'	N_q'	N_γ'
0	5.14	1.00	0.00
1	5.38	1.09	0.00
2	5.63	1.20	0.01
3	5.90	1.31	0.02
4	6.19	1.43	0.05
5	6.49	1.57	0.07
6	6.81	1.72	0.11
7	7.16	1.88	0.16
8	7.53	2.06	0.22
9	7.92	2.25	0.30
10	8.35	2.47	0.39
11	8.80	2.71	0.50
12	9.28	2.97	0.63
13	9.81	3.26	0.78
14	10.37	3.59	0.97
15	10.98	3.94	1.18
16	11.63	4.34	1.43
17	12.34	4.77	1.73
18	13.10	5.26	2.08
19	13.93	5.80	2.48
20	14.83	6.40	2.95
21	15.82	7.07	3.50

Friction Angle (°)	Shear Value		
	N_c'	N_q'	N_γ'
22	16.88	7.82	4.13
23	18.05	8.66	4.88
24	19.32	9.60	5.75
25	20.72	10.66	6.76
26	22.25	11.85	7.94
27	23.94	13.20	9.32
28	25.80	14.72	10.94
29	27.86	16.44	12.84
30	30.14	18.40	15.07
31	32.67	20.63	17.69
32	35.49	23.18	20.79
33	38.64	26.09	24.44
34	42.16	29.44	28.77
35	46.12	33.30	33.92
36	50.59	37.75	40.05
37	55.63	42.92	47.38
38	61.35	48.93	56.17
39	67.87	55.96	66.76
40	75.31	64.20	79.54
41	83.86	73.90	95.05
42	93.71	85.38	113.96
43	105.11	99.02	137.10
44	118.37	115.31	165.58
45	133.88	134.88	200.81
46	152.10	158.51	244.65
47	173.64	187.21	299.52
48	199.26	222.31	368.67
49	229.93	265.51	456.40
50	266.89	319.07	568.57

2.11.2. Empirical Method

Empirical methods rely on field test results and observe correlations, rather than purely theoretical calculations. These methods are especially practical for preliminary design or when subsurface conditions are well-known. Common empirical approaches include:

- CPT-based Correlations: Cone Penetration Test (CPT) results, particularly the cone resistance is used with empirical formulas to estimate the allowable bearing pressure.
- SPT-based Correlations: Bearing capacity is estimated from Standard Penetration Test (SPT) N-values using empirical charts and equations.

a. CPT Empirical Method

The Cone Penetration Test (CPT) is an in-situ testing method that measures the cone resistance (q_c) of soil as a steel cone is pushed into the ground at a constant rate. This resistance reflects the strength and stiffness of the soil, particularly useful in granular and fine-grained soils. Based on Meyerhof (1956), the ultimate bearing capacity (Q_u) of a shallow foundation can be estimated from CPT data using the following formula:

$$Q_u = \frac{q_c}{50} \left(\frac{B+0.3}{B} \right)^2 \quad (\text{for } B > 1.2\text{m})$$

This empirical relationship provides a quick and efficient way to estimate bearing capacity using direct measurements from the subsurface, making it especially advantageous in sandy or layered soils where traditional sampling is difficult.

b. SPT Empirical Method

The Standard Penetration Test (SPT) is another common in-situ method used to evaluate soil properties by driving a split-spoon sampler into the soil and counting the number of blows required to penetrate a specified depth. The resulting N-value reflects the soil's density and strength, which can be correlated to bearing capacity. According to Meyerhof (1956), the empirical formula for estimating bearing capacity from SPT data is:

$$Q_u = 8N \left(\frac{B+0.3}{B} \right)^2 \quad (\text{for } B > 1.2\text{m})$$

This method is particularly useful in cohesive soils or mixed profiles where SPT results are readily available and well-understood. The equation includes a scale factor that adjusts for footing width, improving its accuracy for wider foundations.

2.12. Slope Stability

Slope stability is one of the crucial factors in soil investigation especially on this road design project as slope failures can cause considerable damage especially on mountainous road. The soil stability analysis focuses on calculating the safety factor that follows the parameter below.

Table 2.20. Safety Factor Criteria (Hardiyatmo, 2018)

Safety Factor	Stability Classification	Description
FS > 1.5	Stable	Only major disruption can cause instability
1.25 < FS < 1.5	Medium stability	Medium disruption can cause instability
1 < FS < 1.25	Slight stability	Minor disruption can cause instability
FS < 1	Not stable	A slope stability fix is needed

In slope stability analysis, the critical height refers to the maximum height of a slope that can be constructed without the need for additional reinforcement, while still maintaining an acceptable Factor of Safety (FoS)—commonly taken as 1.5 for static conditions. The critical height is typically determined by a formula from Culman, in which the slope height is varied while keeping other parameters constant (e.g., soil strength, slope angle, groundwater conditions). The process involves adjusting the slope height until the resulting FoS approaches the threshold value. This approach provides a practical limit for safe slope construction based on existing soil properties, geometry, and loading conditions, ensuring both stability and cost-efficiency in earthwork design. This is the formula:

$$H_{cr} = \frac{4c}{\gamma} \left[\frac{\sin\beta \cos\phi}{1 - \cos(\beta - \phi)} \right]$$

Y = Unit Weight (kN/m³)

Φ = Internal Friction Angle (°)

C = Cohesion (kPa)

β = Slope Angle (°)

If the $H_{cr} > H_{max}$, so the slope will be safe from landslide.