

CHAPTER II

THEORETICAL FRAMEWORK

2.1. Road Classification

According to Law Number 38 of 2004 concerning Roads, a road is a ground transportation infrastructure that includes all parts of the road, including complementary structures and equipment used for traffic, whether on the ground, above the ground, below the ground or in water, and also above water surfaces, except for railways, truck roads, and cable roads.

2.1.1. Classification According to Road Function

According to Bina Marga (1997), road functions include:

- a. Arterial roads: usually for long-distance travel, vehicle speeds on arterial roads are generally high, the number of entrances is efficiently limited, and they typically connect various cities.
- b. Collector roads: usually for medium-distance travel, vehicle speeds on collector roads are moderate, and the number of entrances is restricted.
- c. Local roads: usually for short-distance travel, vehicle speeds on local roads are generally low, and the number of entrances is not limited.

2.1.2. Classification According to Road Terrain

According to Bina Marga (2021), road terrain is categorized based on the slope conditions perpendicular to contour lines, as measured in the table 2.1 below:

Table 2. 1 Classification Criteria: Terrain

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

Source: TPGJAK No 038/T/BM/1997

2.1.3. Classification According to Road Class

According to Bina Marga (2021), 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 the table:

Table 2. 2 Classification according to road class

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

Source: Tata Cara Perencanaan Geometrik Jalan Antar Kota (2021)

2.1.4. Classification According to Road Development Authority

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 can be grouped into three categories:

- Primary arterial roads
- Primary collector roads
- Roads that directly or indirectly have strategic value for national interests, serving regions crucial for national unity and addressing underdeveloped areas.

2. Provincial Roads

According to Government Regulation No. 34 Article 26 (b) of 2006, provincial roads are collector roads that connect the provincial capital with the capitals of districts or cities within the province. Additionally, provincial roads can also include primary collector roads connecting district/city capitals. Other provincial strategic roads are excepted for the Jakarta Special Capital Region, covering all road sections except national roads.

3. District/City Roads

District/City Roads fall under the jurisdiction of the District Government, comprising:

- a. Primary collector roads that are not part of national or provincial roads.
- b. Primary local roads connecting district capitals with sub-district capitals, district capitals with village centres, between sub-district capitals, sub-district capitals with villages, and among villages.
- c. Secondary roads are not classified as provincial or secondary roads within cities.
- d. Strategic district roads.

4. Village Roads

Village Roads are public roads connecting areas and/or settlements within villages. Village roads also serve as primary local roads, not classified as district roads within rural areas.

5. Special Roads

Special Roads are roads constructed by institutions, businesses, individuals, or community groups for their specific purposes.

2.2. Road Components

According to Government Regulation No. 34 of 2006 concerning roads, roads are distinguished into road use space (rumaja), road ownership space (rumija), and road monitoring space (ruwasja).

2.2.1. Road Use Space (Rumaja)

Road use space or rumaja is an area along the road utilised for road construction, consisting of the road body, roadside channels, and its thresholds. The road body includes traffic lanes, medians, and shoulders. The road's threshold is located at the outermost part of the road use space, serving to secure the road's structure.

2.2.2. Road Ownership Space (Rumija)

Road ownership space is a specific strip of land outside the road use space that remains part of the road ownership space, delimited by road ownership boundary markers to fulfil future usage safety requirements.

2.2.3. Road Monitoring Space

Road monitoring space is a specific area outside the road ownership space that is monitored by road authorities to ensure it does not obstruct or impede drivers' visibility or road functions. If the road ownership space is insufficient, this area can be utilized to construct road buildings, provided it does not disrupt road functionality. Failure to use the road monitoring space appropriately can disrupt road functions.

The components of a road can be described as follows:

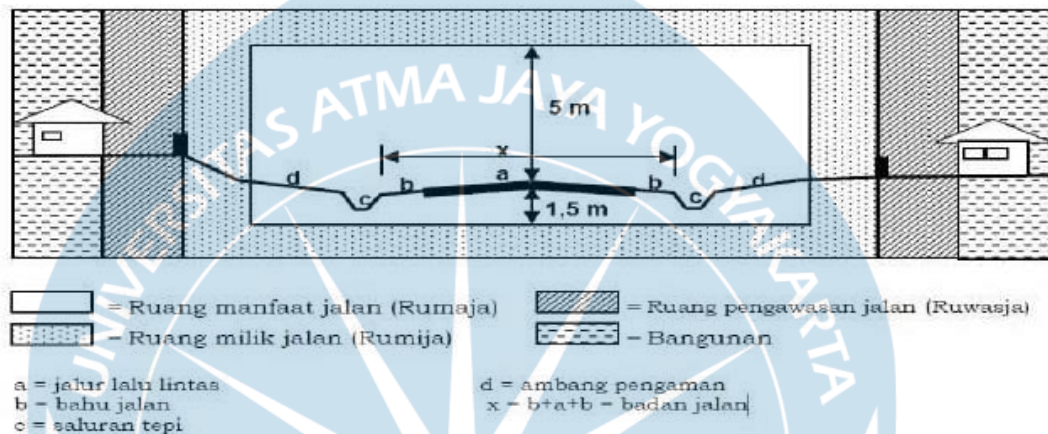


Figure 2. 1 The components of a road

2.3. Geometric Design Parameters

In geometric road design, several planning factors must be understood to determine the level of comfort and safety provided by a geometric road form, such as planned vehicles, planned speed, road volume and capacity, and the level of service provided by the road.

2.3.1. Planned Vehicles

Planned vehicles refer to selected vehicles based on the technical dimensions and operational characteristics used as a reference in geometric planning. This reference is outlined in the following table:

Table 2. 3 Vehicle Planning

Kategori Kendaraan Rencana	Vehicle Dimension (cm)			Protrusion (cm)		Radius Putar (cm)		Radius Tonjolan (cm)
	Tinggi	Lebar	Panjang	Depan	Belakang	Min	Maks	
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

According to Bina Marga (2004), planned speed (V_r) on a road section is the selected speed used as the basis for geometric road design, allowing vehicles to move safely and comfortably under clear weather conditions. For intercity road planning, the value of V_r is determined based on road classification and terrain as follows:

Table 2. 4 Planning Speed

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

Source: Tata Cara Perencanaan Geometrik Antar Kota, Departemen PU, Ditjen Bina Marga 2021

2.3.3. Traffic Volume

The average daily traffic volume (ADT) is an estimate of the daily traffic volume at the end of the traffic planning year, expressed in passenger cars per day. Additionally, traffic during peak hours of the traffic planning year is expressed in passenger cars per hour.

- The unit 'passenger car' refers to a unit of vehicle traffic categorized by vehicle type, dimensions, and maneuvering capability.

Table 2. 5 Traffic Volume

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

Source: *Tata Cara Perencanaan Geometrik Antar Kota, Departemen PU, Ditjen Bina Marga 1997*

b. Passenger Car Equivalent (PCE)

Traffic volume consists of various types of vehicles, thus requiring a conversion factor from different vehicle types to that of a standard passenger car. (Passenger Car Equivalent = 1.0)

Table 2. 6 Passenger Car Equivalent

No	Vehicle Types	Flat/Hilly	Mountainous
1.	Sedan, Jeep, Station Wagon	1.0	1.0
2.	Pick-up, Small Bus, Small Truck	1.2-2.4	1.9-3.5
3.	Large Bus and Truck	1.2-5.0	2,2-6,0

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

- a. Annual Average Daily Traffic (AADT) is the average number of vehicles that pass through one lane of road over a 24-hour period and is obtained from a full year of data.

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

- b. 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. Horizontal alignment

2.4.1. Introduction

Horizontal alignment or road alignment within a road area refers to the projection of the road axis perpendicular to the horizontal plane, consisting of straight and curved lines. In curved line planning, it's important to understand the relationship between the design speed and the curve, as well as their connection with superelevation.

2.4.2. Formula and Factor

When a vehicle traverses a curved path with a circular form, the vehicle is radially pushed outward by centrifugal force, balanced by the vehicle's weight component caused by road superelevation and lateral friction between the tires and road surface. The fundamental formulas for vehicles traversing circular paths are as follows:

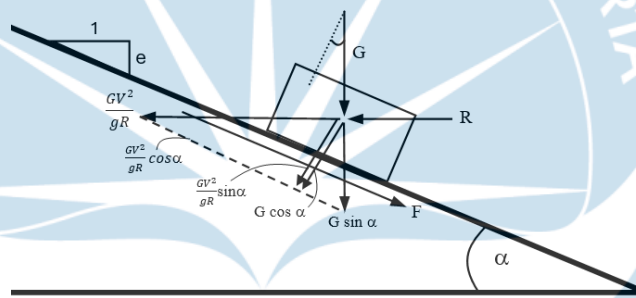


Figure 2. 2 Road Superelevation and Lateral Friction Between The Tires and Road Surface

$\frac{GV^2}{gR}$	: 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 Fig. 1. These forces are in a state of equilibrium.

$$\begin{aligned}\frac{GV^2}{gR} \cos \alpha &= G \sin \alpha + F \\ &= G \sin \alpha + f \, m \, t \, (G \cos \alpha + \frac{GV^2}{gR} \sin \alpha)\end{aligned}$$

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:

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

$$\frac{V^2}{15R} = e + f \, m \, t$$

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

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

2.4.3. Degree of Curvature (D)

A horizontal curve can be expressed by its radius and degree of curvature. The degree of curvature is the central angle that occurs with an arc of 100 feet, while in the metric system, the central angle occurs with an arc of 25 meters.

2.4.4. Side Friction Factor

The side friction coefficient depends on several factors:

1. Vehicle speed.
2. Type and condition of tires.
3. Road surface.
4. Weather conditions.

Curves cannot be designed based on the maximum side friction coefficient due to safety reasons. The parameters that determine the maximum side friction coefficient in planning are:

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.

According to several studies:

1. The side friction factor for high speeds should be smaller than that for lower speeds.
2. Lower values at lower speeds are desired because they often exceed the low design speed.
3. The side friction coefficient used in curve planning is 0.16 at 30 mph – 0.11 at 80 mph.

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.

Maximum superelevation on curves is influenced by several factors:

- a. Weather conditions
- b. Field conditions (flat or mountainous)
- c. Type of area (rural or urban)
- d. Frequent slow-moving vehicles causing unpredictable operations.

Considering these parameters, the maximum superelevation for open/field rural areas is set at 0.12 (maximum value). Using superelevation up to 0.13 is as follows:

1. Benefits fast drivers
2. Poses challenges in road construction, maintenance, and for slow drivers

Lower superelevation is used in:

1. Areas with heavy traffic, like near cities
2. Important intersections where vehicles typically move slowly due to turning or crossing
3. Presence of traffic signs
4. Generally, a value of 0.06 is used.

As proposed by AASHTO, there should be several superelevation rates:

1. 0.06; 0.08; 0.10; and 0.12
2. For each radius group, the minimum radius and superelevation for larger radii can be calculated.

2.4.6. Maximum Degree of Curvature

The maximum degree of curvature or minimum radius is a limiting value for a design speed determined by the maximum superelevation and maximum side friction factor. Using a smaller radius for this design speed will result in a superelevation greater than the specified limit, which is also important to achieve superelevation on larger radii.

2.4.7. Superelevation

In curve planning, it's necessary to determine usable superelevation for each design speed environment. The extreme values from these environments are superelevation determined by practical properties and used to determine the minimum radius. Maximum superelevation varies depending on road conditions. Another extreme condition is zero superelevation on straight roads. Superelevation should be logically determined between the side friction factor and superelevation for radii between extremes and for a specific design speed.

The distribution of e (superelevation) and f (side friction factor) for curved areas with a specific design speed can be achieved using 4 methods of curve distribution. These methods are demonstrated in Figure 3:

- 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 travelling 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. Similar to 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.

On sharper curves, superelevation > 0.02 is required, and a straight-line inclination across the entire pavement is also necessary. A limit of 0.02 provides curvature from areas starting at 2.5% for a 30 mph design speed up to an 80 mph design speed.

2.4.9. Influence of Grade

For rural roads with moderately steep or lengthy grades, drivers tend to run faster downhill compared to uphill. This must be carefully considered in planning, and improvements to superelevation may be necessary.

2.4.10. Spiral Curves

Every vehicle will follow a transitional track when entering or leaving a horizontal circular curve, where the increase or decrease in centrifugal force cannot be abrupt. The path also depends on speed, superelevation radius, and driver action. At low speeds and large radii, drivers can transition within the normal lane width boundaries.

At high speeds and sharp curves, maintaining a constant normal lane width is not feasible, hence the need for a transitional curve between a straight line and a circular curve.

The advantages of transitional curves in horizontal alignment are:

- a. Well-designed transitional curves provide an easy-to-follow track, allowing centrifugal forces to increase and decrease smoothly as vehicles enter and exit circular curves. This reduces the likelihood of deviating from the path.
- b. The length of the transitional curve allows for slope attainment. The transition from normal cross-slope to achieved superelevation is performed without transition, typically partially in the curve and partly in the straight section.
- c. Roads benefit greatly from using spirals to avoid surface breaks and the end of circular curves. Spirals are essential for creating good road alignments.

According to the definition, the degree of curvature at each point on the spiral is directly proportional to the length measured along the spiral.

2.5. Vertical Alignment

2.5.1. Characteristics of Vehicle Operation on Grades

In general, all passenger vehicles can operate on grades of around 7% to 8% without significant differences compared to flat sections. Observations show that a 3% grade has little impact compared to flat roads for passenger vehicles. For the same grade, the effect of grade is more pronounced for trucks than for passenger vehicles.

2.5.2. Grade Limits for Planning

Considering various data, such as the relationship between speed and distance travelled for a specific vehicle, maximum grades are determined. For a design speed of 80 mph, the maximum grade is 3%. For a design speed of 30 mph, the maximum grade ranges from 5% to 12%, depending on the topography.

Table 2. 7 Planning Speed

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	-	-

2.5.3. Critical Length of a Grade for Design

It is important to consider the length of a specific grade. As a guideline, the critical length is often defined as the distance where a reduction of 15 mph from the speed occurs.

2.5.4. Vertical Curve

A vertical curve is used to smoothly transition between two different grades. Vertical curves should be simple to use and result in a safe design.

2.5.5. Properties of Vertical Curves

The length of a road is measured horizontally, and the slope is measured relatively through the ratio of the vertical and horizontal axes, simplified using the vertical axis centred at the Vertical Point of Intersection (VPI). Constant grade changes provide a distance from the VPI of $\Delta L/800$, where:

Δ = Algebraic change in grade as a percentage

L = Horizontal length of the vertical curve

2.5.6. Types of Vertical Curves

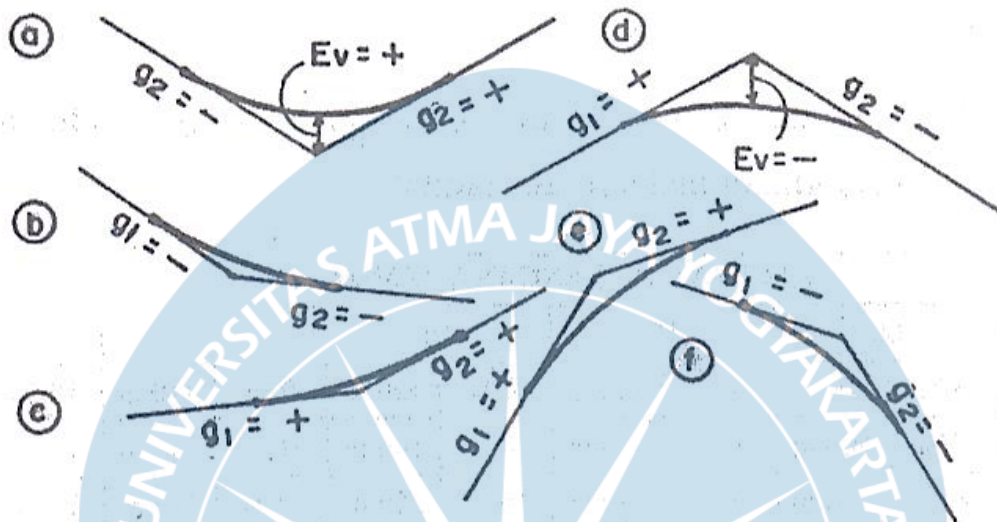


Figure 2. 3 Types of Convex Curve and Concave Curve

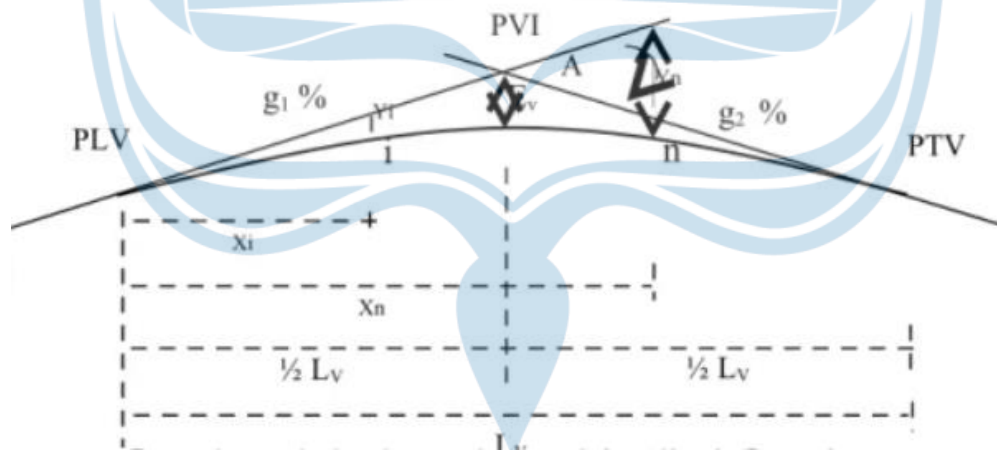


Figure 2. 4 Convex Curve 1

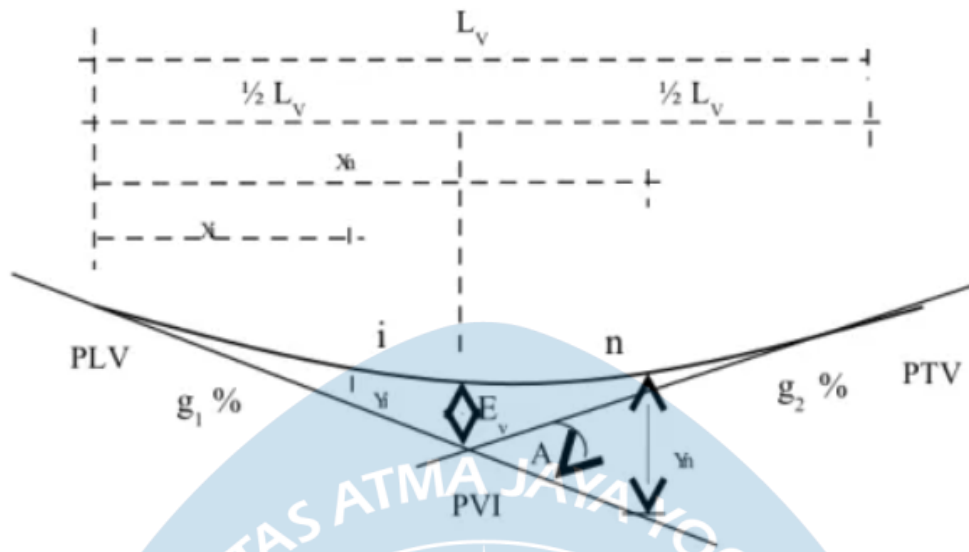


Figure 2. 5 Concave Curve 2

2.5.7. Vertical Convex Curve

Here is the translation of the formula for calculating the minimum length of a convex vertical curve based on sight distance:

$$S < L \quad L = \frac{\Delta S^2}{100((\sqrt{2}h_1 + \sqrt{2}h_2)^2)}$$

$$S > L \quad L = \frac{2S - [200(\sqrt{h_1} + \sqrt{h_2})^2] / \Delta}{1}$$

Where:

L : horizontal length of the vertical curve,

S : sight distance,

Δ : algebraic difference in percentage gradient,

h_1 : driver's eye height,

h_2 : object height

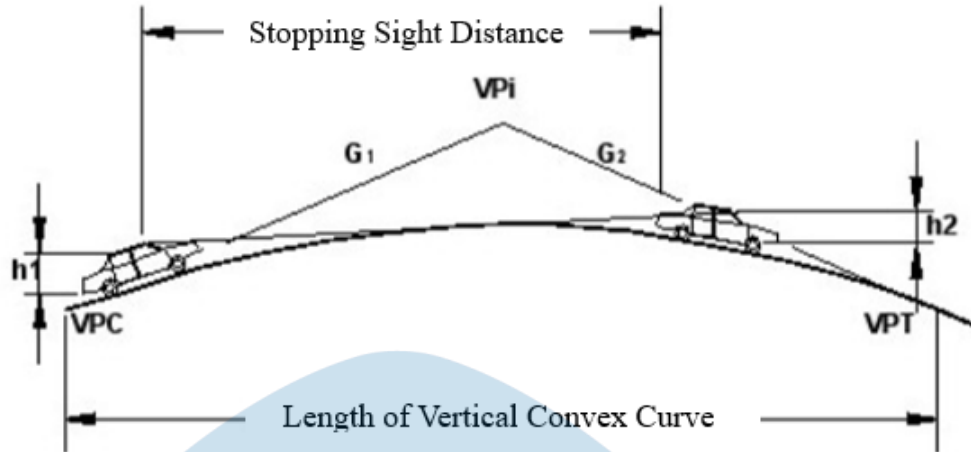


Figure 2. 6 Vertical Convex Curve 1

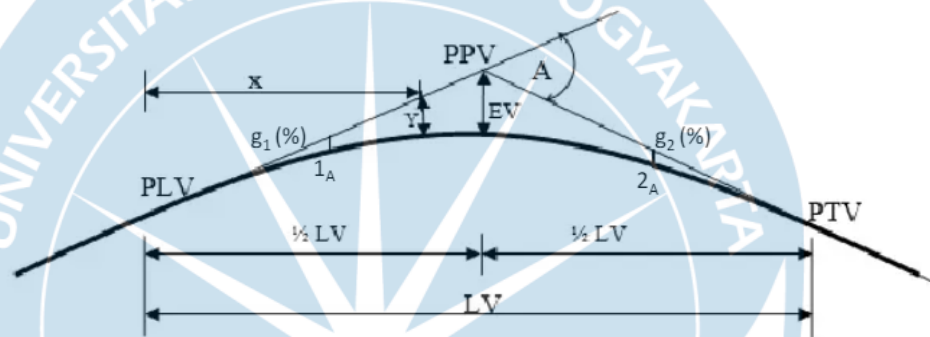


Figure 2. 7 Vertical Convex Curve 2

2.5.8. Parabolic curve equation

The term "parabolic curve equation" refers to an equation used to determine the curvature in the vertical alignment of a road to form a parabola or a suitable curve according to the needs and existing field conditions.

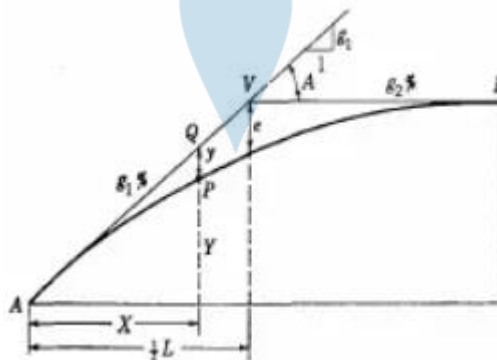


Figure 2. 8 Parabolic Curve

2.6. Earthwork

The road network consists of national roads, provincial roads, district/city roads, village roads, and special roads, all of which are interconnected. Each segment serves its designated function as an arterial, collector, or local road.

As development progresses, the number of vehicles traversing these road sections has rapidly increased, necessitating the enhancement of road capacity. Therefore, it is essential to improve the road's carrying capacity through planning, implementation, and on-site supervision.

2.6.1. Earthwork Specifications

1. Excavation Work

This work includes excavation, handling, disposal, or stockpiling of soil, rocks, or other materials from the road, which are necessary for completing the contract work.

Types of excavation work:

- Common Excavation: Includes all excavation not categorised as rock excavation, structural excavation, material source excavation, or asphalt pavement excavation.
- Rock Excavation: Involves the excavation of rock chunks with a volume of 1 m³ or more. This does not include excavation that can be done with a single ripper pulled by a tractor weighing up to 15 tons and a maximum net horsepower of 180 hp.
- Structural Excavation: Encompasses excavation in all types of soil within the specified work limits. Any excavation classified as common or rock excavation cannot be included in structural excavation.
- Asphalt Pavement Excavation: Involves excavation of old pavement and disposal of asphalt pavement materials.

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.

2.6.2. Embankment Work

This work involves the provision, transportation, spreading, and compaction of soil or granular materials. The following considerations apply to embankment work:

a. Selected Fill Material

- Selected embankment fill must consist of soil or rock that meets the requirements outlined in SNI 03-1744-1989. It should have a California Bearing Ratio (CBR) of at least 10% after 4 days of soaking.
- Selected embankment fill can include sand, gravel, or other clean granular materials with a maximum Plasticity Index of 6%.
- Selected embankment fill used on slopes or in other situations requiring sufficient shear strength may consist of well-graded rock or gravelly clay. The choice of material depends on the slope steepness or the pressure it will bear.

b. Ordinary Fill Material

- Ideally, the ordinary fill should not include high-plasticity soils. If the use of high-plasticity soil is unavoidable, it should only be used at the base of the fill or in areas not requiring high load-bearing or shear strength. Such plastic soil should not be used within 30 cm of the pavement base or roadside base material.
- Ordinary fill material, when tested according to SNI 03-1744-1989, must have a CBR of not less than 6% after 4 days of soaking.

c. Fill Material on Marshy Ground

- Embankment fill material on marshy ground should consist of sand, gravel, or other clean granular materials with a maximum Plasticity Index of 6%.

d. Compaction of Embankment

- After placement and spreading of the embankment, each layer must be compacted using suitable compaction equipment.
- Soil compaction should only be carried out when the moisture content is within 3% below the optimum moisture content to 1% above the optimum moisture content.
- All rock embankment layers should be covered with a layer at least 20 cm thick of well-graded material that does not contain stones larger than 5 cm and can fill the voids between the rocks.
- Each spread layer of embankment must be tested for density before the next layer is laid.
- Compaction should start from the outer edge and move towards the centre of the road.
- When placing embankment material on both sides of pipes or concrete drainage structures, care must be taken to ensure that both sides have nearly the same elevation.
- If embankment material can only be placed on one side of an abutment, wing wall, pier, retaining wall, or culvert headwall, adjacent areas should not be excessively compacted to avoid structural displacement or excessive pressure.

e. Spreading of Embankment

- The embankment must be placed on a prepared surface and spread in even layers that, when compacted, meet the specified layer thickness tolerances.
- Embankment soil is usually directly lifted from the source location to the prepared surface during clear weather and spread.
- Re-filling above pipes and behind structures should be done quickly and systematically after pipe or structure installation. Before backfilling around concrete retaining structures, stone masonry, or stone masonry with mortar, a curing period of no less than 14 days is required.

- If widening the roadbed, the slope of the existing embankment should be prepared by removing all vegetation from the slope surface. The widened embankment should then be spread horizontally, layer by layer, up to the subgrade elevation, which should then be covered promptly to make the widened section usable.

