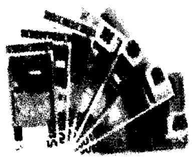
Hogeschool van Utrecht

Hogeschool van Utrecht

Graduation Thesis

Design of the East Ring Road



Tutor and Teacher 1: **Ir. Frans van Heerden.**
Teacher2: **Ir. Pieter van Valen.**

Student:
Mr. M.A .Ashraf.
Student Id: 1199564.
.il.com

Preface

Begin with the name of the Lord Almighty, who has blessed us with a lot of things which might even we don't deserve. Indeed He is most merciful. I am very great full to Him, to give me courage and knowledge which help me to finish my Final Thesis in a good manner.

Beside a lot of motivation from my family, there were many people who help me to finish my that final part of studies. First of all I would like to thank to the **Mr. Pieter Van Valen** for his personal help and guidance which finally help me to finish that project on time. I have found him very humble person and I was very lucky to have him, to supervise Design of East Ring Road. I have learned a lot from him about the design standards which are being practiced in Holland.

To accomplish the part of project, I am very thankful to my fellow student **Tommy Anwar**, who helped me to accomplish my Project. Beside Him I would like to thank to the library personals of the Hogeschool Van Utrecht, to assist me in finding the required books.

There were many other people who were a source of a lot of motivation & help; especially **Mr. Nicos** from Frederick Institute of Technology, Cyprus & **Mr. René Camerik** from Rijkwaterstaat.

"Success is to be measured not so much by the position
that
one has reached in life
but
as by the obstacles
which he has overcome"

May Lord bless us all.

M.Adnan Ashraf.

Table of Content

Table of Content

Topic **Page**

Table of Content

Introduction :

Roads are used for the transfer of people, goods and material thus permitting economic activity. Highway Engineering is the process of providing a suitable network to satisfy the needs of an economically sophisticated society. Rapid growing economy & globalization are the reason, which needs the fast mobility of people & goods from one point to another. These are the main reasons which push forward the need of Extension of Schiphol Airport, as Amsterdam is already been developed to its limits, hence Government start looking for some good suitable place which should serve as the extension of the Schiphol Airport.

These necessities give birth to the idea of the Island in the Markermeer, naming Meerland. In order to make the mobilization of people & goods on the Island, there will be networks of Road links. I have selected the Design of the East Ring Road as my graduation Project. See the **Figure 1**, map of Meerland, on next page for the location of the East Ring Road.

There will be a lot of advantages by the compilation of that road project as this Island will be developed as the Financial Center of The Netherlands, because of the main facilities like Airport will be on that Island. The function of this road will be to enable cars, passenger trucks and heavy loaded trucks to move easily from Flevo International Airport (FIV), the proposed name of Airport, to the other areas on that Island vise versa. There will be a need to design an appropriate road that will meet the traffic demand since the new airport (FIV) is going to be constructed on this new Island.

Beside that there will be a lot of benefits, some of them will be:

- After the completion of the reclamation project, it will contain 700 million cubic meters of water, with the possibility of deepening which will result in increase of water capacity of 580 million cubic.
- There will be a new airport of 20 km2, which will result in 84 million passengers per year.
- A new Natural Forest of 20 km2.
- Plant for wind energy, which will meet the energy requirements of Meerland.
- Urban district named New Amsterdam, with the capacity of accommodating around 650,000 inhabitants.
- Fast speed rail which will be linked to all EU countries.
- Tremendous growth in Dutch economy results in many job opportunities.

<u>Map of Meerland.</u>

Introduction:

Geometric Design of highways refers to the design of the visible dimensions of such features as Horizontal and Vertical alignments, Cross sections, intersections & other highway features like bicycle and pedestrian features. The main objective of geometric design is to produce a highway with safe, efficient and economic traffic operations while maintaing esthetic and environmental quality.

Design Process:

The design process of a proposed highway involves preliminary location study, environmental impact evaluation and final design. This process normally relies on a team of professionals including engineers, planners, economists, ecologists and lawyers. Such a team may have responsible addressing social, environmental, land use and community issues associated with highway development.

Project Proposal:

After a detailed locational studies like analyzing available ground data, feasible routes & most important Environmental evaluation, the final design is established. This includes detailed drawings of the selected route, final geometric design, drainage facilities etc.

Fundamentals of Geometric Design:

Geometric design comprises of many Fundamentals and concepts. The main important are as:

(a) Highway Types:

Highways are usually classified into different classes, it is necessary for the communication among the engineers, administrators, and the general public. The functional classification system facilities grouping roads that require the same quality of design, maintenance and operation. The system also facilitates the logical assignment of responsibility among different jurisdictions and its structure of design guidelines is readily understood.

According to the AASHTO, the highway functional classes, adopted separately for urban and rural areas, are locals, collectors and arterials. Each of them defined as:

(I) Access Roads.

(II) Collector Roads.

(III) Arterial Roads.

According to the standards set by the AASHTO, access roads are classified as the roads which have the low volumes of traffics; normally they are single road operational. Normally these roads are served as the links between the rural roads.

Beside that Collector Roads are those which are build, which have the medium volume of traffic, as compare to Access and Collector Roads, arterial roads are those which have a volume of traffic, these are multi lanes and serve as the connection between the big cities, provinces etc. Normally Arterial roads are called as Expressways, Motorways.

For that project an **Arterial Road** will be designed.

(b) Speed:

* Design Speed

Design speed is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design feature of the highway governs. A design speed selected for this project will establish criteria for several design elements including horizontal and vertical curvature, superelevation and sight distance. The chosen design speed to be **100 km/h**. The speed relates to the drivers comfort and is not the speed at which a vehicle will lose control.

* Low Speed

For geometric design purposes, low speed is defined as 70 km/h or less.

* High Speed

For geometric design purposes, high speed is defined as greater than 70 km/h.

* Average Running Speed

Running speed is the average speed of a vehicle over a specified section of highway. It is equal to the distance traveled divided by the running time (the time the vehicle is in motion). The average running speed is the distance summation for all vehicles divided by running time summation for all vehicles.

* Operating Speed

Operating speed as defined by AASHTO is the highest overall speed at which a driver can safely travel a given highway under favorable weather condition and prevailing traffic condition while at no time exceeding the design speed.

(c) Design Year:

This highway is design to accommodate the traffic volume expected to occur within the life of the facility under reasonable maintenance. This involves projecting the traffic condition for a selected future year. The following will apply:

- The roadway design will be based on a 10-year projection of traffic volume. Life cycle analysis for pavement types may exceed this period.
- The design year is measured from the expected completion date of construction.
- Traffic volume in this road will be relatively high. Thus there is need to provide a road with high geometric standards.
- The requirements for wide carriage, flat gradients and full overtaking sight distance may therefore be appropriate.

(d) Traffic Volume Control:

With relation to the volume of traffic using the road, the passenger car is adopted as the standard unit and vehicles are assessed in terms of passenger car units (PCU). The classification of vehicles in PCU's is shown in table below. This classification is for the road that exists in heavy populated cities of the world and it is assumed to be same for the East Ring Road.

This traffic volume will not be the loading used in the pavement design. These values are used to determine the road width only

Type of Vehicle	Rural	Urban
Private cars, motor cycle combinations, taxis and light private goods vehicles up to 1.5 tone unladen	1	1
Motorcycles (solo), scooters and mopeds	1	0,75
Goods vehicles over 1.5 tone unladen weight	3	2

Tab: Traffic volume in urban cities.

(e) Average Daily Traffic (ADT) :

According to the studies based on Rijkwaterstaat, who are responsible for the feasibility studies for that reclaimed land, it is proposed that the Daily Hourly Traffic Volume (DHV), will be **1665 PCU/h**. This figure is for the East Ring Road which will be two lane dual carriageways.

Normally this value is being calculated by the formula as fellow, as the project is related to the Geometric Design so there will be no detail for the calculation:

$$DHV = ADT \times K \text{ or } DHV = AADT \times K.$$

With that DHV, the ADT will be calculated as:

$$ADT = \frac{DHV}{K}$$

$$ADT = \frac{1665}{0.15} = 11100.$$

According to the Data collected from the College Highway Engineering text book, this Table is developed for the Geometric design of East Ring Road.

Road function	**Design class**	**Traffic flow (ADT)**	**Surface type**	**Carriage way (m)**	**Shoulder (m)**	**Maximum gradient (%)**	**Terrain**	**Design speed (km/h)**
Arterial	A	5000-15000	Paved	7.0	3.25	7- 8	Level	100

Design of East Ring Road

CHAPTER No 1.

GEOMETRIC DESIGN

Introduction to Geometric Design

The geometric design of roads refers to the design of the visible dimensions of the roadway. The aim of geometric design is to provide for the safe, efficient and economical movement of all types of traffic. The design process is aided by the use of geometric road design standards which have proven to provide acceptable design. The majority of material in this module will deal with Horizontal & Vertical alignment design. The practice of good road design involves judgment as well as calculation. It involves comprises between conflicting goals. Experience assists the designer to arrive at an appropriate compromise that cannot be met by simply applying a set of mathematical rules. The designer's aim should be to produce an appropriate design for the specific problem being addressed, while retaining a reasonable overall level of uniformity within the road network.

Factors Influencing the Choice of Design Standard

Three reasonably distinct stages may be identified in the development of a nation's road system:

- Stage 1: Basic Network – establishment of links – main criteria is that roads must be trafficable – geometric design standards relatively unimportant.
- Stage 2: Increasing Capacity – improving the road's ability to carry increasing volumes of traffic – geometric standards assume greater importance.
- Stage 3: Quality of Service – building safety, efficiency and convenience into the network – alignment and cross sectional standards important.

The majority of the World wide road networks are a mixture of increasing the network's capacity and improving the quality of service, i.e. stages 2 and 3.

Observation suggests that there are effectively three speed ranges that roads can be classified into:

- **High Speed Roads.** Drivers will expect to be able to maintain a high travel speed, and the design must therefore be able to provide for this expectation along the entire length. The road will therefore be designed for speed of 100kph or more.
- **Intermediate Speed Roads.** For roads designed for speeds of less than 100kph, the speed adopted by drivers will vary along the alignment in accordance with driver perception and the control of road features such as horizontal curves. The variation in travel speed must be considered in the design of individual road elements. Provided the standard provided is in keeping with driver expectations a safe and adequate alignment will result.
- **Low Speed Roads.** Low speed roads (less than abut 60 kph) are only used when difficult terrain and costs prevent the provision of better facilities. In

these areas drivers will generally be more alert, and lower standards are both expected and acceptable.

Consideration of a nation's stage of development and the role of driver expectancy in regard to speed therefore help in determining what is an appropriate road design standard for a specific situation. A number of other factors can be identified as influencing the choice of design standard, and these include:

- **Financial Level** - Design standards must somehow be related to the overall availability of finance to construct, operate and maintain the whole of the road network.
- **Terrain** - Research indicates that terrain is one of the factors which influence driver expectation in regard to speed. Terrain also has a significant effect on costs, particularly the cost of adopting high design standards.
- **Traffic Volume** - The volume of traffic to be carried by a road can be considered as the design loading which the designer must satisfy. Design is generally carried out for some future design year, say 20 years hence.
- **Traffic Composition** - The proportion of heavy commercial vehicles in the traffic stream influences the structural design of the pavement, as well as the design of geometric elements such as grades.
- Safety - Whatever the design standard, safety is a major goal of road design.
- **Environment** - Environmental impacts need to be considered in all major engineering construction works and must be seen as an essential part of the design process.

Locational Design

One of the most crucial and important parts of the design process is the location of the road. The location procedure is an iterative process in which engineering, land use, economic, environmental and social factors are taken into account. The location of a large facility, such as a freeway, would probably involve a multi-disciplinary team of professionals. Several approximate locations are initially selected based on preliminary information and data. Possible choices are then narrowed down, usually with the help of additional information. The ultimate aim is to determine a 'best' route from a balance of cost and user benefit, taking into account socioeconomic and environmental impacts.

Speed Parameters

To produce a logical basis for the selection of speeds for geometric design it is necessary to define three speed parameters:

- **Desired Speed** – the operating speed a driver will adopt in non-constrained conditions e.g. on straights or large radius curves. A desired speed is largely a function of terrain and the overall geometric standard of the road.
- **Speed Environment** – describes a characteristic of a section of road which is reasonably consistent in terrain and geometric standard. It is numerically the

desired speed of the 85th percentile driver over that road section. It can be measured on existing roads but must be estimated for new roads.

- **Design Speed** – applies to individual geometric elements. It is the speed that a driver can negotiate a road element (e.g. curve or grade) without exposing himself to undue hazard. It must be a speed that is unlikely to be exceeded by most drivers.

Geometric design is mainly consist of the;

- **Horizontal Alignment.**
- **Vertical Alignment.**

Horizontal Alignment

The horizontal alignment of a road is a plan view of the road projected onto a horizontal plane. It is the view of the road that would be obtained flying above it. The horizontal alignment is usually a series of straights (tangents) and circular curves joined by transition curves. Where long, large radius circular curves are used instead of straights the alignment is known as curvilinear alignment. This type of alignment may be used where the terrain is suitable (e.g. flat inland areas) to reduce driver headlight glare and to improve the driver's perception of the speed of an approaching vehicle.

GENERAL CONTROLS

The design of horizontal alignment involves, to a large extent, complying with specific limiting criteria. These include minimum radii, superelevation rates and sight distance. In addition, the designer should adhere to general design principles and controls which will determine the overall safety of the facility and will enhance the aesthetic appearance of the highway. These general controls include:

1. **Consistency.** Alignment should be consistent. Avoid sharp curves at the ends of long tangents and sudden changes from gentle to sharply curving alignment.

2. **Directional.** Alignment should be as directional as practical and consistent with physical and economic constraints. On divided highways a flowing line that conforms generally to the natural contours is preferable to one with long tangents that slash through the terrain. Directional alignment can be achieved by using the smallest practical central angles.

3. **Use of Minimum Radii.** The use of minimum radii should be avoided if practical.

4. **High Fills**. Avoid sharp curves on long, high fills. Under these conditions, it is difficult for drivers to perceive the extent of horizontal curvature.

5. **Alignment Reversals**. Avoid abrupt reversals in alignment ("S" or reverse curves). Provide a sufficient tangent distance between the curves to ensure proper superelevation transitions for both curves.

6. **Broken-Back Curvature**. Avoid where practical. This arrangement is not aesthetically pleasing, violates driver expectancy and creates undesirable superelevation development requirements.

7. **Compound Curves**. Avoid the use of compound curves on highway mainline. These may "fool" the driver when judging the sharpness of a horizontal curve.

8- **Coordination with Natural/Man-Made Features**. The horizontal alignment should be properly coordinated with the natural topography, available right-of-way, utilities, roadside development and natural/man-made drainage patterns.

9. **Environmental Impacts**. Horizontal alignment should be properly coordinated with environmental impacts (e.g., encroachment onto wetlands).

10. **Intersections**. Horizontal alignment through intersections may present special problems (e.g., intersection sight distance, superelevation development). See Chapter Twenty-eight in the Montana Traffic Engineering Manual for the design of intersections at-grade.

11. **Coordination with Vertical Alignment**. Chapter Ten discusses general design principles for the coordination between horizontal and vertical alignment.

12. **Visibility**. Design the roadway so that the driver has a clear view of the alignment

The basic components of the Horizontal Alignment are as under;

A- **Horizontal Curves.**

B- **Super Elevation.**

C- **Horizontal Sign Distance.**

D- **Computation of Horizontal Curve.**

CHAPTER No 2.

Horizontal Alignment

A- Horizontal Curves; -

There are the following types of the curves usually used;

1. **Simple Curves.** These are continuous arcs of constant radius which achieve the necessary highway deflection without an entering or exiting transition.

2. **Compound Curves.** These are a series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other.

3. **Spiral Curves.** These are curvature arrangements used to transition between a tangent section and a simple curve which are consistent with the transitional characteristics of vehicular turning paths. When moving from the tangent to the simple curve, the sharpness of the spiral curve gradually increases from a radius of infinity to the radius of the simple curve.

4. **Reverse Curves**. These are two simple curves with deflections in opposite directions which are joined by a common point or a relatively short tangent distance.

5. **Broken-Back Curves**. Broken-back curves are two closely spaced horizontal curves with deflections in the same direction and a short intervening tangent.

A1 Calculation of Curve Radius

As the vehicle traverses a circular curve it is subjected to internal forces which must be balanced by Centripetal Forces associated with the circular path. For a given radius and speed a set of forces is required to keep the vehicle in its path. The radius can be expressed by the following formula:

$$R = \frac{V^2}{127\,(e + f)}$$

Where:

e = Super-elevation slope in decimal
f = Side friction factor, decimal
R = Curve radius in meter
V = Velocity in kilometer per hour

A2 Minimum Radius:

The following table (A2.a) present the Minimum radii (R).To define (R) , a maximum superelevation rate (e) must be selected as with the side friction factor(f)

Design Speed, V (km/h)	e_{max}	f_{max}	Minimum Radii, R_{min} (m)
30	8.0%	0.17	30
40	8.0%	0.17	50
50	8.0%	0.16	80
60	8.0%	0.15	125
70	8.0%	0.14	175
80	8.0%	0.14	230
90	8.0%	0.13	305
100	8.0%	0.12	395
110	8.0%	0.11	500

Note: R_{min} is rounded to the nearest 5 m increment.

So as per the Design speed we can get the Minimum Radius of the Curve.

A3 Minimum Length of Curve :

Short horizontal curves may provide the driver with the appearance of a kink in the alignment. To improve the aesthetics of the highway, the designer should lengthen short curves, if practical, even if not necessary for engineering reasons. The following guidance should be used to establish minimum curve lengths for deflection angles (Δ) of 5° or less:

Generally, use of the following criteria results in the greatest curve length.

The length of the curve in meters = 3 * V, where "V" is the design speed in Km/h.

For example if the Design speed is 100Km/h, then in that case the Length of the curve should be around 300 meters i.e. (100 * 3).That result give a reasonable and safe length of the curve.

B- Super Elevation;

Superelevation is the amount of the cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of the vehicle traversing the curve. The following figure B.1 clearly gives the idea about the superelevation.

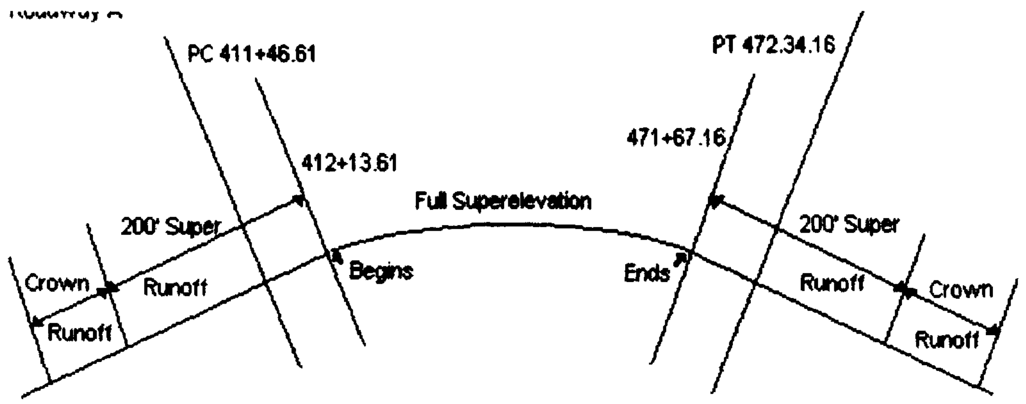


Fig B.1 gives the idea about the superelevation on a curve.

B1 Maximum superelevation rate;

The selection of a maximum superelevation "e_{max}" depends upon several factors. These includes;

- Urban/Rural location.
- Climatic Conditions.

The maximum value of superelevation is normally set at 8%, however it can also be applied in the range of 7 to 10 %, according to the above mentioned factors.

B2 Superelevation Transition;

the superelevation transition length is the distance required to transition the roadway from a normal crown section to the full design superelevation. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length (L).

Please see **the Figure B2.1 & B2.2** on the next page .

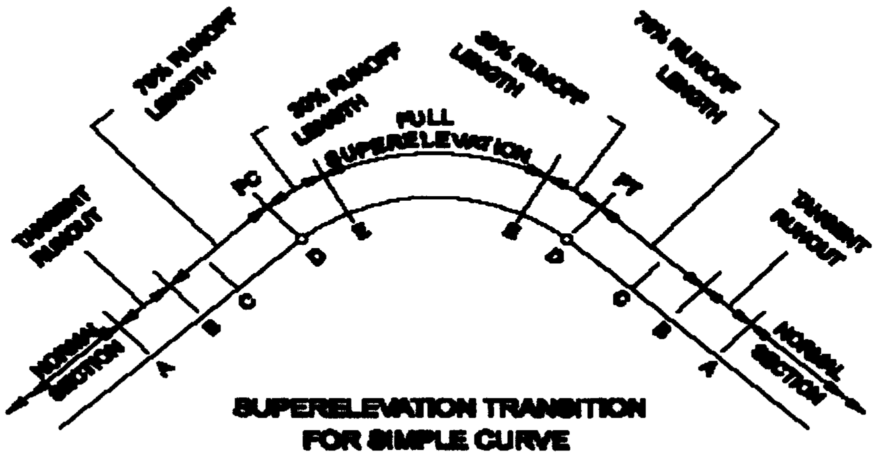


Fig B2.1. cross section views (i.e., A, B, C, D and E) of superelevation development. C is the first (or last) point at which the cross section is at a uniform slope.

The terms used in the above figure are ;

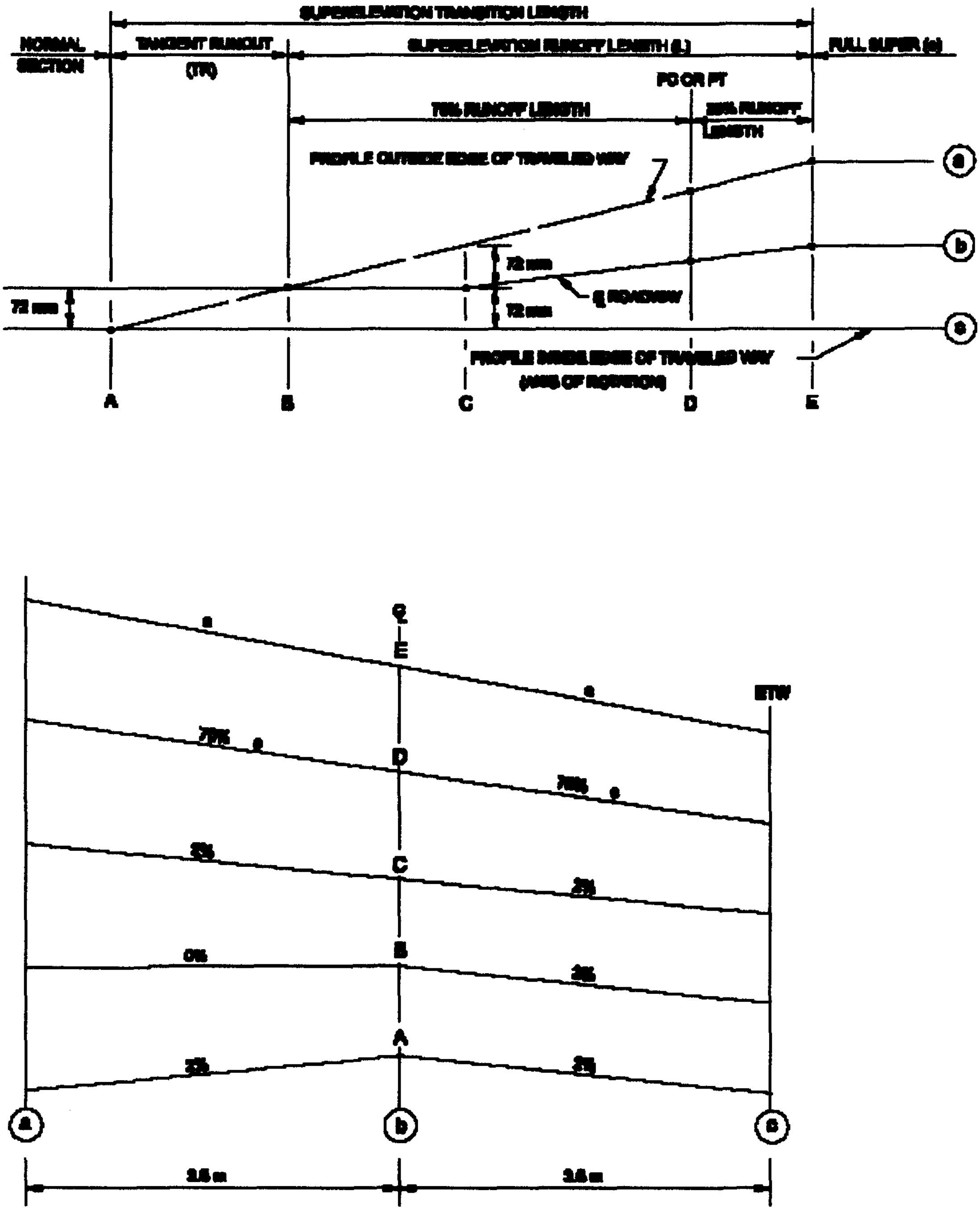
a- <u>Tangent Runout (TR).</u>

Tangent runout is the distance needed to transition the roadway from a normal crown section to a point where the adverse cross slope of the outside lane or lanes is removed (i.e., the outside lane(s) is level).

b. <u>Superelevation Runoff (L).</u>

Superelevation runoff is the distance needed to transition the cross slope from the end of the tangent runout (adverse cross slope removed) to a section that is sloped at the design superelevation rate.

Fig B2.2



<u>**Fig. B2.2** Illustration of superelevation development with the axes of rotation about the centerline.</u>

C- Horizontal Sight Distance;

C1- Sight Obstruction;

Sight obstructions on the inside of a horizontal curve are defined as obstacles which interfere with the line of sight on a continuous basis. These include walls, cut slopes, wooded areas, buildings and high farm crops. In general, point obstacles such as traffic signs and utility poles are not considered sight obstructions on the inside of horizontal curves. The designer must examine each curve individually to determine whether it is necessary to remove an obstruction or to adjust the horizontal alignment to obtain the required sight distance. For more clarification see **Fig C1.1**,

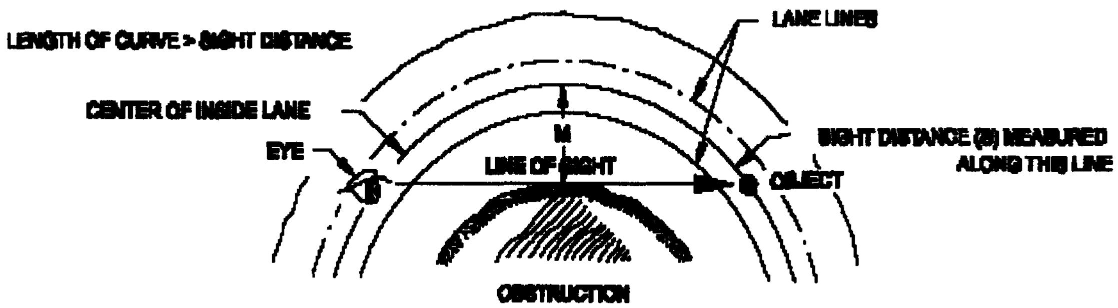


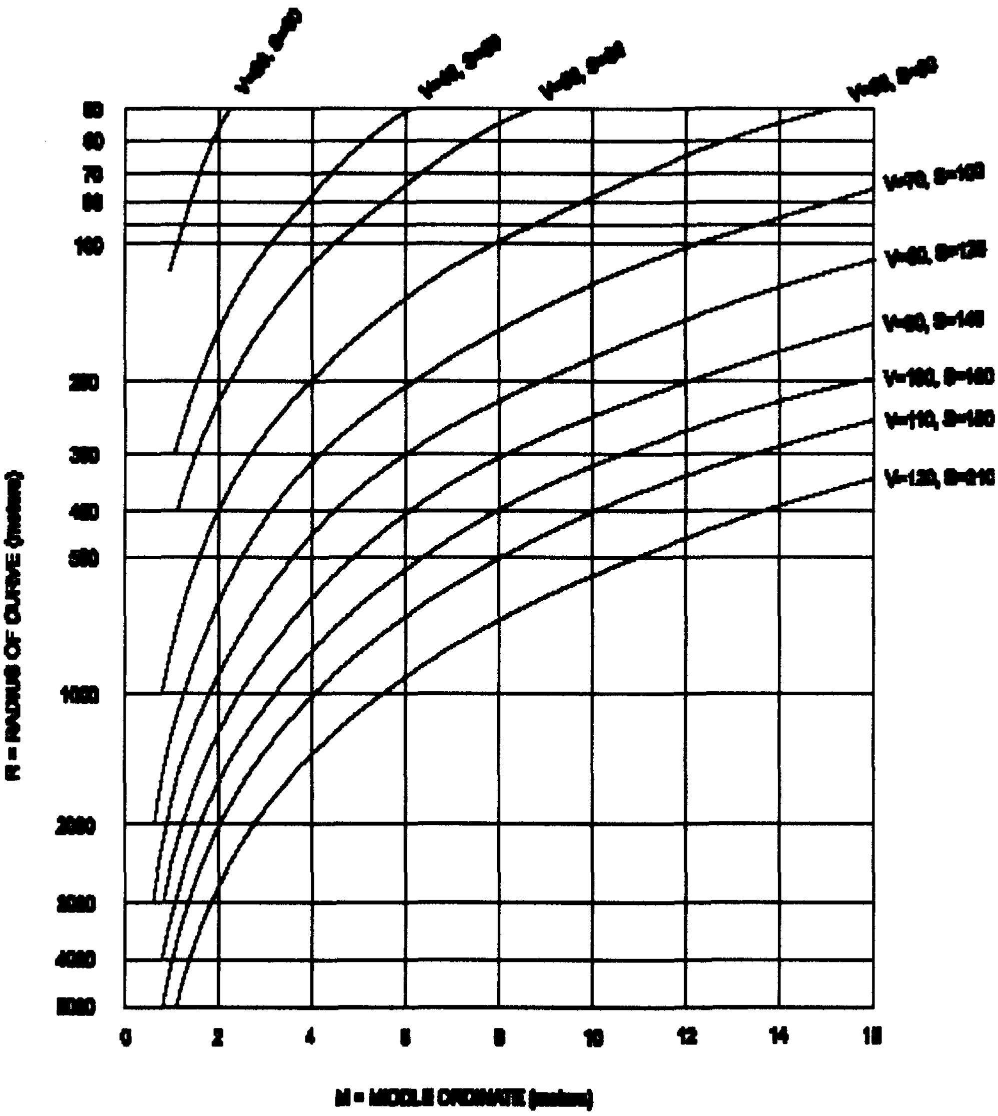
Fig C1.1 Sight Obstruction Illustration 1

C2- Calculation of Sight Obstruction Distance;

The required radius of the curve is dependent on the distance of the obstruction from the center-line and the sight distance as shown above in the **Fig C1.1**, and that can also be derived from the relationship;

Formula

Also see the **Graph C2.1** on next page showing the Sight Distance with Different speed



SIGHT DISTANCE AT HORIZONTAL CURVES
(Minimum SSD)

<u>**Graph C2.1** showing Sight distance with the combination of Radius of curve and Design speed.</u>

C3- Longitudinal Barriers

Longitudinal barriers (e.g., bridge rails, guardrail) can cause sight distance restrictions at horizontal curves, because barriers are placed relatively close to the traveled way (often 3 m or less) and because their height is greater than 600 mm. The designer should check the line of sight over a barrier along a horizontal curve and attempt to locate the barrier such that it does not block the line of sight. The following should also be considered:

- **Superelevation.**
  - A super elevated roadway will elevate the driver eye and improve the line of sight over the barrier.
- **Grades.**
  - The line of sight over a barrier may be improved for a driver on an upgrade and lessened on a downgrade.
- **Barrier Height.**
  - The higher the barrier, the more obstructive it will be to the line of sight.
- **Object Height.**
  - Because of the typical heights of barriers, there may be many sites where the barrier blocks visibility to a 150 mm object but does not block the view of a 460 mm object, the typical height of vehicular taillights. This observation provides some perspective to the potential safety problem at the site.

Each barrier location on a horizontal curve will require an individual analysis to determine its impacts on the line of sight. The designer must determine the elevation of the driver eye, the elevation of the object (150 mm above the pavement surface) and the elevation of the barrier where the line of sight intercepts the barrier run. If the barrier does block the line of sight to a 150 mm object, the designer should consider relocating the barrier or revising the horizontal alignment.

D- Computation of Horizontal Curve;

Horizontal curves are used to transition changes in alignment at angle points in the straight portions in alignments. An angle point, P1 is the point of Intersection and the change in alignment is defined by the deflection angle. See Figs D1.1 & D1.2.

D1- Definition of Curve:

The curve is chosen by setting the value for one of the elements of the curve. The most common elements are either the radius "R," of the Degree of the curve "D".The degree of the curve is the central angle that subtends either 100 meters of arc or 100ft of arc depending on the used units. For more explanation see Figs D1.1 , D1.2 & D1.3.

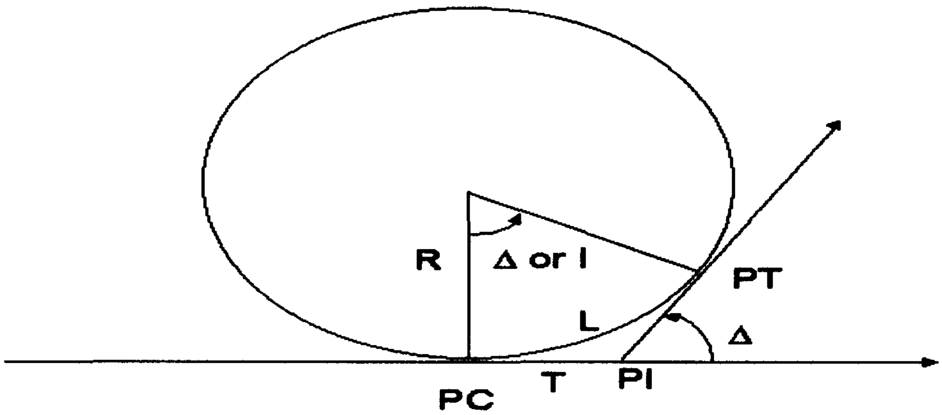
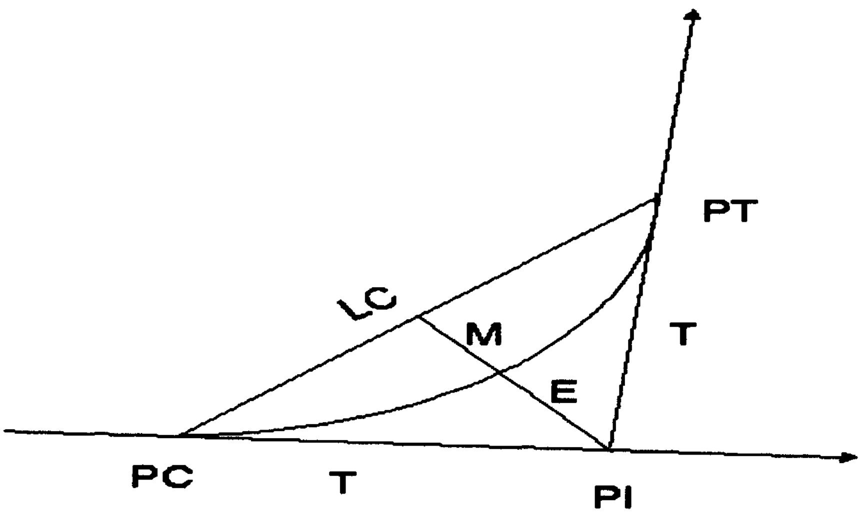


Fig D1. 1 Elements of Curve.



D1. 1 Elements of Curve.

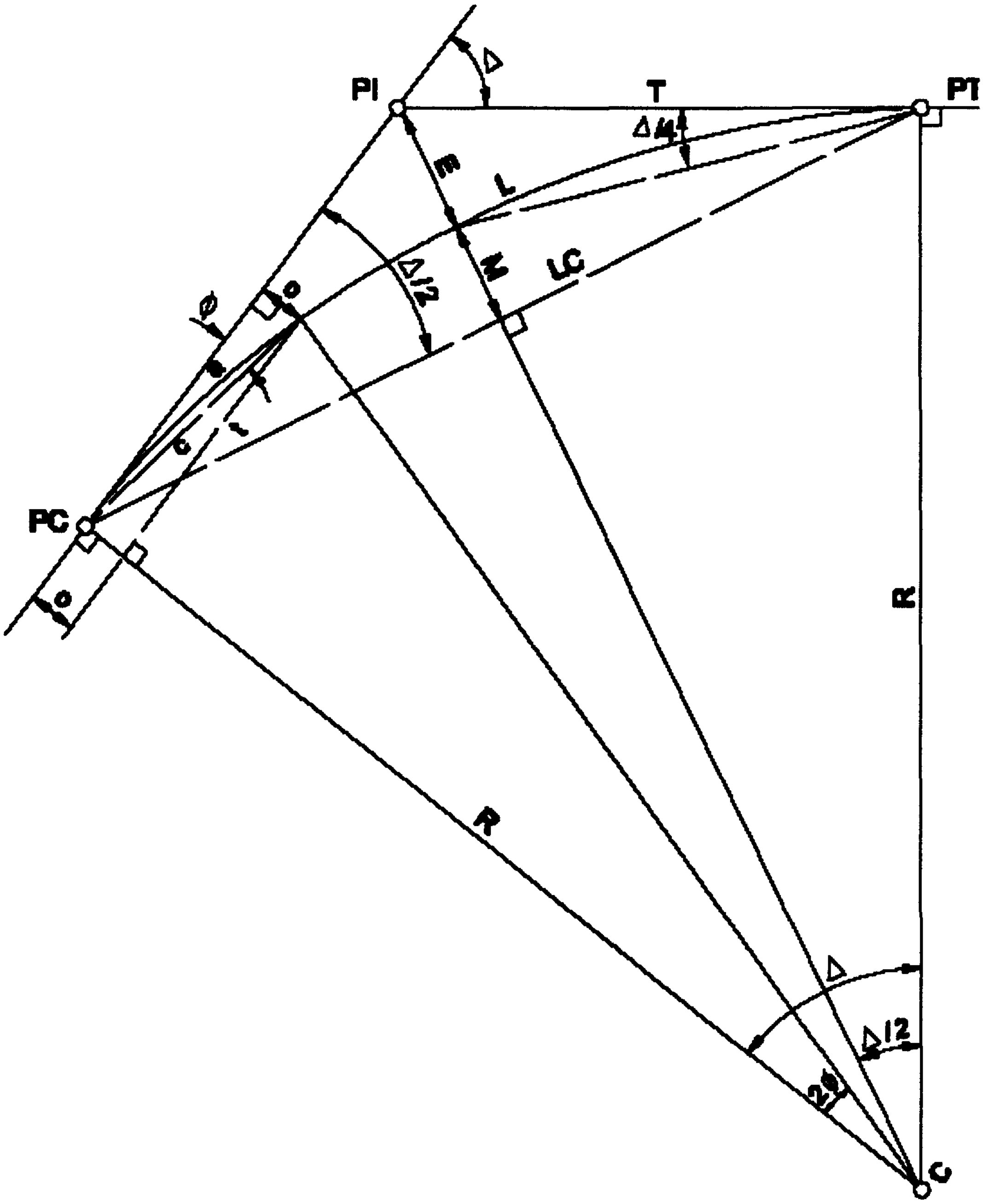


Fig D1.3 Elements of Circular Curve.

Please see the Curve Symbols on next Page.

D2- Curve Symbols:

Δ	=	Deflection angle, degrees
T	=	Tangent distance, m. T = distance from PC to PI or distance from PI t
L	=	Length of curve, m. L = distance from PC to PT along curve
R	=	Radius of curvature, m
E	=	External distance (PI to mid-point of curve), m
C	=	Intersection of radii at center of circular arc
LC	=	Length of long chord (PC to PT), m
M	=	Middle ordinate (mid-point of arc to mid-point of long chord), m
a	=	Length of arc to any point on a curve, m
c	=	Length of chord from PC to any point on curve, m
φ	=	Deflection angle from tangent to any point on curve, degrees
t	=	Distance along tangent from PC to any point on curve, m
o	=	Tangent offset to any point on curve, m

D3- Curve Formulas and Abbreviations:

$$T = R(\tan(\Delta/2)) = R\frac{\sin(\Delta/2)}{\cos(\Delta/2)}$$

$$L = \frac{\Delta}{360}2\pi R$$

$$E = \frac{R}{\cos(\Delta/2)} - R = T\tan(\Delta/4)$$

$$LC = 2R(\sin(\Delta/2)) = 2T(\cos\Delta/2)$$

$$M = R(1-\cos(\Delta/2)) = E\cos(\Delta/2)$$

$$a = \frac{(200\varphi)(2\pi R)}{100(360)} = \frac{(\varphi)(\pi R)}{90}$$

$$c = 2R\left(\sin\frac{(100)(360a)}{(200)(2\pi R)}\right) = 2R(\sin\frac{90a}{\pi R})$$

$$\varphi = \frac{90a}{(\varphi)(\pi R)}$$

$$\cos\varphi = (R-o)/2R$$

$$t = R\sin 2\varphi = (c)\cos\varphi$$

$$o = (c)\sin\varphi$$

$$o = R - \sqrt{R^2 - t^2}$$

$$o = R - (R\cos 2\varphi)$$

$$o = R(1-\cos 2\varphi)$$

$$\pi = 3.141592654$$

CIRCULAR CURVE ABBREVIATIONS

PC	=	Point of Curvature (Beginning of Curve)
PT	=	Point of Tangency (End of Curve)
PI	=	Point of Intersection of Tangents
PRC	=	Point of Reverse Curvature
PCC	=	Point of Compound Curvature

LOCATING THE PC AND PT

Station PC = Station PI – T
Station PT = Station PC + L
Stations are in 100 meters. For example, Sta 13+54.86 means 1354.86 meters from Sta 0+00.

D4- Calculation of Curve:

Here I am taking just one imaginary point (PI 22+34.58) where we have to lay put the Circular Curve, Radius the 1300 m & deflection angle $\Delta = 7°00'00''$.
So the main elements of the curve will be calculated as:

Calculation:-

For calculation of Curve Elements and Stations we will use the Formulas described on the previous page.

1. $T = R(\tan(\Delta/2)) = 1300(\tan(7/2))$

   $T = 79.5144m$

   $T = 79.51m$ (rounded value)

2. $L = \frac{\Delta}{360} 2\pi R = \frac{7}{360}(2\pi)(1300)$

   $L = 158.82496m$

   $L = 158.82m$ (rounded value)

3. $E = \frac{R}{\cos(\Delta/2)} - R = \frac{1300}{\cos(7/2)} - 1300$

   $E = 2.4292m$

   $E = 2.43m$ (rounded value)

4. $LC = 2R(\sin(\Delta/2)) = (2)(1300)(\sin 7/2))$

   $LC = 158.7262m$

   $LC = 158.73m$ (rounded value)

5. $M = R(1 - \cos(\Delta/2)) = 1300(1 - \cos(7/2))$

   $M = 2.4247m$

   $M = 2.42m$ (rounded value)

6. Stations are as follows:

   Station PC = Station PI - T = 22 + 34.58 - 79.51 = 21 + 55.07
   Station PT = Station PC + L = 21 + 55.07 + 158.82 = 23 + 13.89

So after getting these values, we can easily lay out the curve. The calculation of Simple/Circular curve is very simple as the Radius of the Curve remains same and it gives more comfortability to the Driver while passing through.

CHAPTER No 3.

Vertical Alignment

Vertical Alignment:

The highway vertical alignment plays a significant role in a highway's safety, aesthetics and project costs. Chapter 3 "Horizontal Alignment Design " provides numerical criteria for various vertical alignment elements. This chapter provides additional guidance on these and other vertical alignment elements, including laying out a profile grade line, maximum and minimum allowable grades, critical lengths of grade, climbing lanes, vertical curves.

A- Design Principles & Procedures:

A1- <u>General Controls for Vertical Alignment :</u>

The design of vertical alignment involves, to a large extent, complying with specific limiting criteria. These include maximum and minimum grades, sight distance at vertical curves and vertical clearances. In addition, the designer should adhere to certain general design principles and controls which will determine the overall safety of the facility and will enhance the aesthetic appearance of the highway. These design principles for vertical alignment include:

1. <u>Consistency</u>. Use a smooth grade line with gradual changes, consistent with the type of highway and character of terrain, rather than a line with numerous breaks and short lengths of tangent grades.

2. <u>Environmental Impacts</u>. Vertical alignment should be properly coordinated with environmental impacts (e.g., encroachment onto wetlands). The Engineering Bureau within the Environmental Services Office is responsible for evaluating environmental impacts.

3. <u>Long Grades</u>. On a long ascending grade, it is preferable to place the steepest grade at the bottom and flatten the grade near the top.

4. <u>Intersections</u>. Maintain moderate grades through intersections to facilitate turning movements. See Chapter Thirteen for specific information on vertical alignment through intersections.

5. <u>Roller Coaster</u>. Avoid using a "roller-coaster" type of profile. They may be proposed in the interest of economy, but they are aesthetically undesirable and may be hazardous.

6. <u>Broken-Back Curvature</u>. Avoid "broken-back" grade lines (two crest or sag vertical curves separated by a 150 m or less tangent section). One long vertical curve is more desirable.

7. <u>Coordination with Natural/Man-Made Features</u>. The vertical alignment should be properly coordinated with the natural topography, available right-of-way, utilities, roadside development and natural/man-made drainage patterns.

A2- Co-ordination of Horizontal & Vertical Alignment :

Horizontal and vertical alignment should not be designed separately, especially for projects on new alignment. Their importance demands that the designer carefully evaluate the interdependence of these two highway design features. This will enhance highway safety and improve the facility's operation. The following should be considered in the coordination of horizontal and vertical alignment:

1. Balance.

Curvature and grades should be in proper balance. Maximum horizontal curvature with flat grades or flat curvature with maximum grades does not achieve this desired balance. A compromise between the two extremes produces the best design relative to safety, capacity, ease and uniformity of operations and a pleasing appearance.

2. Coordination.

Vertical curvature superimposed upon horizontal curvature (i.e., vertical and horizontal P.I.'s at approximately the same stations) generally results in a more pleasing appearance and reduces the number of sight distance restrictions. Successive changes in profile not in combination with the horizontal curvature may result in a series of humps visible to the driver for some distance, which may produce an unattractive design. However, under some circumstances, superimposing the horizontal and vertical alignment must be tempered.

3. Crest Vertical Curves.

Sharp horizontal curvature should not be introduced at or near the top of pronounced crest vertical curves. This is undesirable because the driver cannot perceive the horizontal change in alignment, especially at night when headlight beams project straight ahead into space. This problem can be avoided if the horizontal curvature leads the vertical curvature or by using design values which exceed the desirable.

4. Sag Vertical Curves.

Sharp horizontal curves should not be introduced at or near the low point of pronounced sag vertical curves or at the bottom of steep vertical grades. Because visibility to the road ahead is foreshortened, only flat horizontal curvature will avoid an undesirable, distorted appearance. At the bottom of long grades, vehicular speeds often are higher, particularly for trucks, and erratic operations may occur, especially at night.

5. Passing Sight Distance.

In some cases, the need for frequent passing opportunities and a higher percentage of passing sight distance may supersede the desirability of combining horizontal and vertical alignment. In these cases, it may be necessary to provide long tangent sections to secure sufficient passing sight distance.

6. Intersections.

At intersections, horizontal and vertical alignment should be as flat as practical to provide designs which produce sufficient sight distance and gradients for vehicles to slow or stop.

7. Divided Highways.

On divided facilities with wide medians, it is frequently advantageous to provide independent alignments for the two 1-way roadways. Where traffic justifies a divided facility, a superior design with minimal additional cost generally can result from the use of independent alignments.

8. Residential Areas.

Design the alignment to minimize nuisance factors to neighbourhoods. Minor adjustment to the horizontal or vertical alignment may increase the buffer zone between the highway and residential areas.

9. Aesthetics.

Design the alignment to enhance attractive scenic views of rivers, rock formations, parks, golf courses, etc. The highway should head into rather than away from those views that are considered to be aesthetically pleasing. The highway should fall towards those features of interest at a low elevation and rise toward those features which are best seen from below or in silhouette against the sky.

B- Grades :

B1- Maximum Grades:

Criteria for maximum grades based on functional classification, urban/rural location, type of terrain, and in some cases, design speed. The maximum grades should be used only where absolutely necessary. Where practical, use grades flatter than the maximum. The desired maximum grade for freeways is 3% but the higher values shown in the **Table B1.1** (next page) may be used if the conditions make that necessary.

The use of the maximum grades shown in the table for lengths in excess of 150 m should be avoided unless environmental or economic impacts are prohibitive. These long maximum grades shall be fully justified in the appropriate project reports.

TYPE OF ROADWAY		TYPE OF TYPOGRAPHY	DESIGN SPEED (km/h)									
			30	40	50	60	70	80	90	100	110	120
COLLECTOR	RURAL[1]	LEVEL	7	7	7	7	7	6	6	5	4	NA
		ROLLING	10	10	9	8	8	7	7	6	5	NA
		MOUNTAINOUS	12	11	10	10	10	9	9	8	6	NA
	URBAN	LEVEL	9	9	9	9	8	7	7	6	5	NA
		ROLLING	12	12	11	10	9	8	8	7	6	NA
		MOUNTAINOUS	14	13	12	12	11	10	10	9	7	NA
ARTERIAL	RURAL	LEVEL	NA	NA	NA	5	5	4	4	3	3	3
		ROLLING	NA	NA	NA	6	6	5	5	4	4	4
		MOUNTAINOUS	NA	NA	NA	8	7	7	6	6	5	5
	URBAN	LEVEL	NA	NA	8	7	6	6	5	5	NA	NA
		ROLLING	NA	NA	9	8	7	7	6	6	NA	NA
		MOUNTAINOUS	NA	NA	11	10	9	9	8	8	NA	NA
FREEWAY[2]	RURAL & URBAN	LEVEL	NA	NA	NA	NA	NA	4	4	3	3	3
		ROLLING	NA	NA	NA	NA	NA	5	5	4	4	4
		MOUNTAINOUS	NA	NA	NA	NA	NA	6	6	6	5	NA

[1] On one way down grades, and on low volume rural collectors, grades may be as high as 2% steeper than those shown.
[2] The desired maximum grade for freeways is 3%.

<u>**Table B1.1**: Maximum values for short grades(less than 150m long).</u>

B2- <u>Minimum Grades:</u>

Flat grades are acceptable on non-curbed pavements with sufficient cross slope to drain the surface. On curbed pavements it is desirable to use a minimum grade **of 0.35%** on concrete and bituminous pavements and **0.5%** on other pavements. These will help facilitate surface drainage and prevent pounding if the proper cross slopes are provided.

B3- <u>Critical Length of Grade:</u>

Maximum grade alone is not a complete design control. The length of grade will determine the truck speed reduction on an ascending grade. At some point the reduction becomes unreasonable because of its adverse impact on highway safety, operating speeds, and capacity. The critical length of grade can be determined from **Figure B3.1.** This graph is based on an average of 180 kg/kW of rated engine power. For general design purposes the 15 km/h speed reduction curve should be used. A study of the accident involvement rate on grades has indicated that the rate increases significantly for speed reductions above this amount. If the planned length exceeds the critical length, an analysis considering accident history, traffic volumes, capacity, percent trucks, and construction costs must be made to assess the need for a climbing lane.

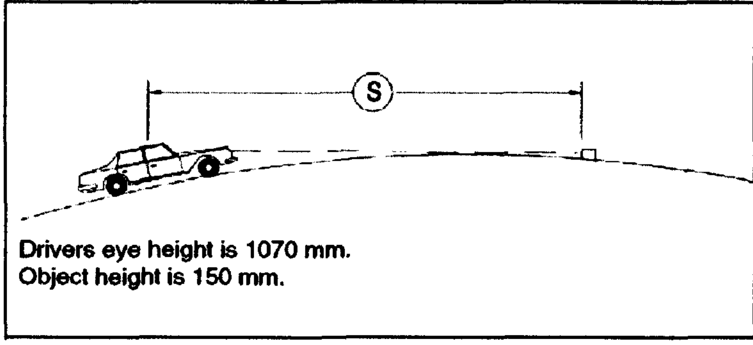
C - Stopping sight distance:

Where an object off the pavement such as a bridge, pier, building, cut slope, or natural growth restricts sight distance, the minimum radius of curvature is determined by the stopping sight distance.

C1- Stopping sight distance on Crest Vertical Curves:

By these figures we can calculate Stopping sight distance. **Fig C1.1 & Fig C1.2.**

Stopping Sight Distance on Crest Vertical Curves



L = Curve Length (meters)

A = Algebraic Grade Difference (%)

S = Sight Distance (meters)

V = Design Speed for "S" in km/h

K = Distance in meters required to achieve a 1% change in grade. K value as shown on graph is valid when S < L.

Fig C1. 1 Stopping Sight Distance

For the Calculation that formula is used,

When S > L	When S < L
$L = 2S - 405/A$	$L = AS^2/405$

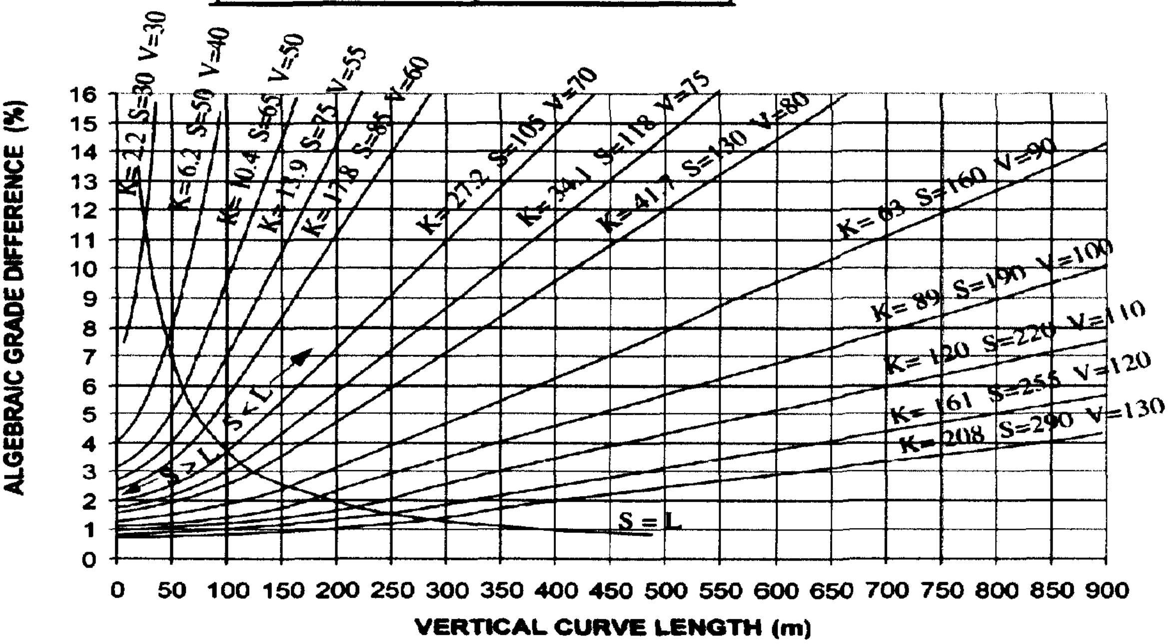
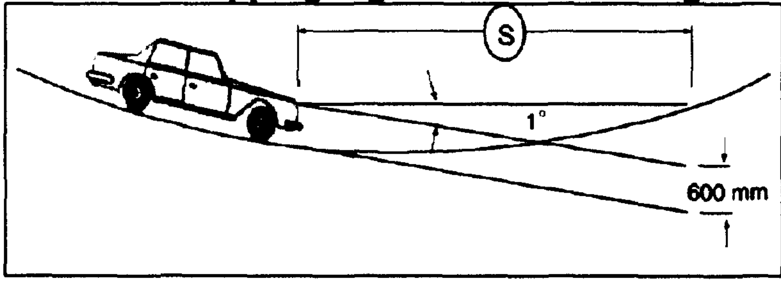


Fig C1. 2 Graph for Vertical Curve Length.

C2- Stopping sight distance on Sag Vertical Curves:

Following are the Figures by which we can calculate the stopping sight distance on Sag Vertical Curves. **Fig C2.1 & Fig C2.2.**

Stopping Sight Distance on Sag Vertical Curves



L = Curve Length (meters)
A = Algebraic Grade Difference (%)
S = Sight Distance (meters)
V = Design Speed for "S" in km/h
K = Distance in meters required to achieve a 1% change in grade. K value as shown on graph is valid when S < L.

Fig C2. 1 Stopping Sight Distance on Sag Vertical Curves.

For Calculation that Formulation is used:

When S > L	When S < L
$L = 2S - (122 + 3.5S)/A$	$L = AS^2/(122 + 3.5S)$

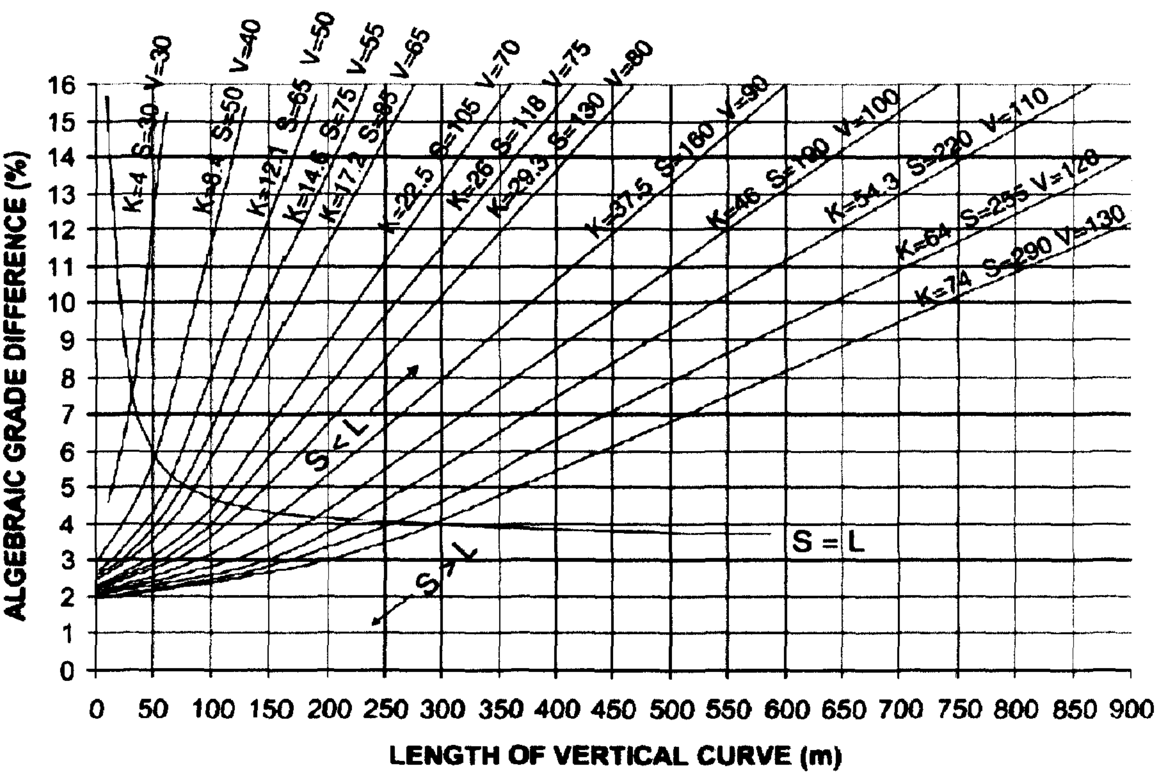


Fig C2. 2 Graph for Length of curve

D- Vertical Curves :

In addition to horizontal curves that go to the right or left, roads also have vertical curves that go up or down. Vertical curves at a crest or the top of a hill are called summit curves, or oververticals. Vertical curves at the bottom of a hill or dip are called sag curves, or underverticals.

According to the AASHTO "Vertical curves should be simple in application and should result in a design that is safe, comfortable in operation, pleasing in appearance, and adequate for drainage (as Vertical curves used in Highway design are Parabolic not circular. There is a Uniform rate of change of grade throughout the curve)".

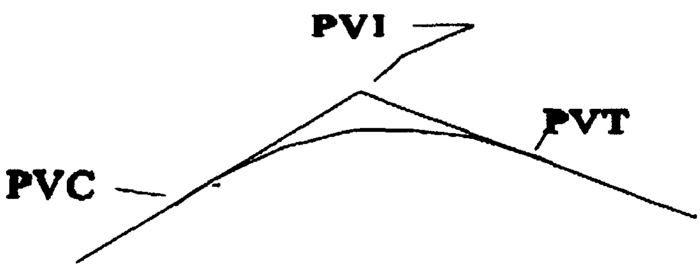
In order to describe this topic we need to understand some of the terms used.

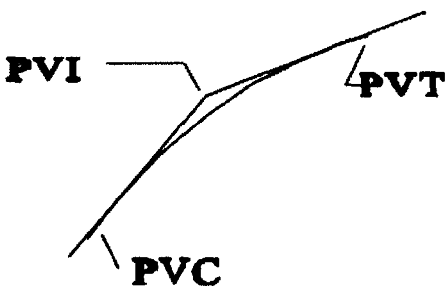
No	NYSDOT / AASHTO Terminology	Definition
1-	**PVI / VPI** (vertical point of Intersection)	Theoretical location where intersecting grades would intersect if they were not a vertical curve introduced. Generally described as Station and Elevation.
2-	**PVC / VPC** (vertical point of Curvature)	Location where the Vertical Curve begins (as one proceeds in an up-station direction).
3-	**PVT / VPT** (Point of Vertical Tangency)	Location where the Vertical Curves ends (as one proceeds in an up-station direction).

D1- <u>Types of Vertical Curves:</u>

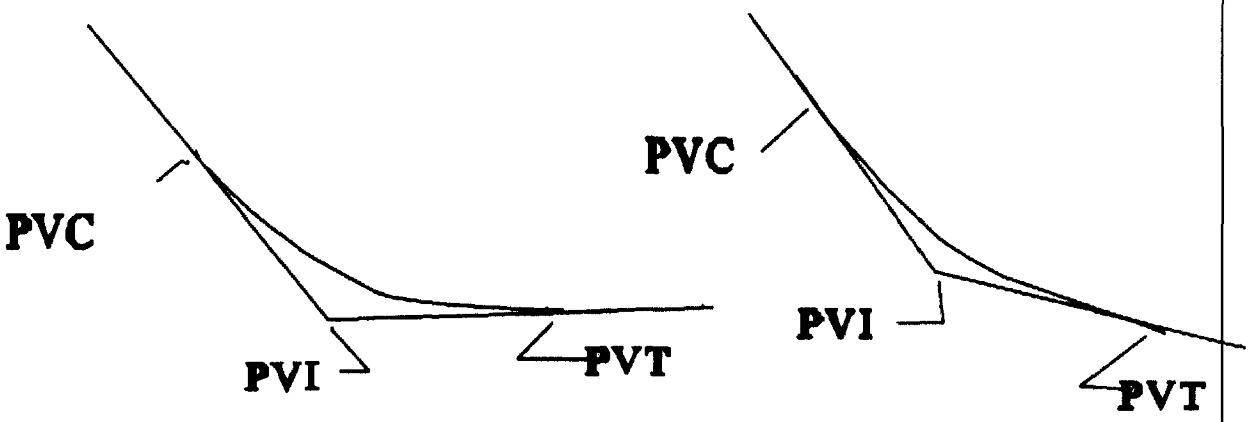
A vertical curve falls into two categories:

D1.1- Crest Vertical Curves:





D1.2- Sag Vertical Curves:



D1.1- Crest Vertical Curves:

Crest Vertical curves are in the shape of Parabola. The basic equations for determining the minimum length of a crest vertical curve are:

$$L = \frac{AS^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

(Equation 1).

$$L = KA$$

(Equation 2).

Where:

L	=	length of vertical curve, m.
A	=	algebraic difference between the two tangent grades, %.
S	=	sight distance, m.
h_1	=	height of eye above road surface, m.
h_2	=	height of object above road surface, m.
K	=	horizontal distance needed to produce a 1 % change in gradient.

The length of the crest vertical curve will depend upon "A" for the specific curve and upon the selected sight distance, height of eye and height of object.

For design purposes, the calculated length of curve based on the rounded K-value should be rounded up to the next highest 20 m increment. The principal control in the design of crest vertical curves is to ensure that, at a minimum, stopping sight distance (SSD) is available throughout the curve. **Figure D1.1** presents the K-values for stopping sight distance.

DESIGN SPEED (km/h)	ROUNDED SSD FOR DESIGN(1) (m)		CALCULATED K-VALUES(2) ($K=S^2/404$)		K-VALUES ROUNDED FOR DESIGN(2)	
	Desirable	Minimum	Desirable	Minimum	Desirable	Minimum
30	30	30	2.2	2.2	3	3
40	50	50	6.2	6.2	7	7
50	70	60	12.1	8.9	13	9
60	90	80	20.1	15.8	21	16
70	120	100	35.6	24.8	36	25
80	140	120	48.5	35.6	49	36
90	170	140	71.5	48.5	72	49
100	210	160	109.2	63.4	110	64
110	250	180	154.7	80.2	155	81
120	290	210	208.2	109.2	209	110

Fig D1.1 "K" values for Crest vertical curves.

Note:-

1- K- Values are calculated using rounded stopping sight distances, eye height of 1.070 m and Object height of 0.150 m.

D1.1.2 -"K"value

The following discusses the application of K-values:

(a)- Passenger Cars (Level Grade):

Fig D1.1 presents minimum and desirable K-values for passenger cars. These are calculated by assuming $h_1 = 1.070$ m, $h_2 = 0.150$ m and $S = SSD_{minimum}$ or $SSD_{desirable}$ in the basic equation for crest vertical curves **(Equation 1).** The minimum values represent the lowest acceptable sight distance on a facility. However, the designer should provide a design in which the K-values meet the $SSD_{desirable}$.

(b)- Minimum Length:

For aesthetics, the suggested minimum length of a crest vertical curve on a rural highway is 300 m. For small values of A, the calculated curve lengths may actually be zero. However, angle points are not allowed on rural highways. Therefore, the minimum length of curve is based on **Equation 3.**

$$\mathbf{L_{min} = 0.6\,V} \qquad \textbf{(Equation 3).}$$

Where:

L_{min} = minimum length of vertical curve, m

V = design speed, Km/h

If the design speed is 100 Km/h, then Minimum length will be **60 Meters.**

(c)- Passing Sight Distance (PSD):

At some locations, it may be desirable to provide passing sight distance in the design of crest vertical curves. See the Graph below:

No	Design Speed (Km/h)	Minimum passing sight distance for Design (m)
1	50	350
2	60	400
3	70	490
4	80	550
5	90	615
6	100	675
7	110	150

Graph for minimum PSD on Crest vertical Curves.

(d)- Drainage:

Drainage should be considered in the design of crest vertical curves where curbed sections are used. Drainage problems should not be experienced if the vertical curvature is sharp enough so that a minimum longitudinal grade of at least 0.3% is reached at a point about 15 m from either side of the apex. To ensure that this objective is achieved, the length of the vertical curve should be based upon a K-value of 50 or less. For crest vertical curves on curbed sections where this K-value is exceeded, the drainage design should be more carefully evaluated near the apex.

D1.2- Sag Vertical Curves:

Sag Vertical Curves also in parabolic shape as like the Crest Vertical Curves. Typically they are designed to allow the vehicular headlights to illuminate the road way surface (i.e., the height of object = 0.0m) for a given distance "S'. These assumptions yield the following basic equations for determining the minimum length of sag vertical curves:

$$L = \frac{AS^2}{200h_3 + 3.5S}$$ **(Equation 4)**

$$L = KA$$ **(Equation 5)**

L = length of vertical curve, m

A = algebraic difference between the two tangent grades, %

S = sight distance, m

h_3 = height of headlights above pavement surface, m

K = horizontal distance needed to produce a 1 % change in gradient

The length of the sag vertical curve will depend upon "A" for the specific curve and upon the selected sight distance and headlight height. For design purposes, the calculated length of curve based on the rounded K-value should be rounded up to the next highest 20 m increment. See **Graph D1.2.1:**

DESIGN SPEED (km/h)	ROUNDED SSD FOR DESIGN[1] (m)		CALCULATED K-VALUES[2] ($K=S^2/(122+3.5S)$)		K-VALUES ROUNDED FOR DESIGN[2]	
	Desirable	Minimum	Desirable	Minimum	Desirable	Minimum
30	30	30	4.0	4.0	4	4
40	50	50	8.4	8.4	9	9
50	70	60	13.4	10.8	14	11
60	90	80	18.5	15.9	19	16
70	120	100	26.6	21.2	27	22
80	140	120	32.0	26.6	33	27
90	170	140	40.3	32.0	41	33
100	210	160	51.5	37.5	52	38
110	250	180	62.7	43.1	63	44
120	290	210	74.0	51.5	74	52

Graph D1.2.1 "k" values for sag vertical curves.

The principal control in the design of sag vertical curves is to ensure that, at a minimum, stopping sight distance (SSD) is available for headlight illumination throughout the curve. The design assumes that there is a 1° upward divergence of the light beam from the longitudinal axis of the headlights. See the **Graph D1.2.1** on previous page "K" values for stopping sight distance. The following discusses the application of "K" values:

(a) Passenger Cars:

Graph D1.2.1, presents minimum and desirable K-values for passenger cars. These are calculated by assuming $h_3 = 0.600$ m and $S = SSD_{minimum}$ or $SSD_{desirable}$ in the basic equation for sag vertical curves **(Equation 4).** The minimum values represent the lowest acceptable sight distance on a facility. However, the designer should provide a design in which the K-values meet $SSD_{desirable}$.

(b) Minimum Length:

For most sag vertical curves, the minimum length of curve should be based on **Equation 3,** (i.e., $L_{min} = 0.6$ V).

(c) Drainage:

Drainage should be considered in the design of sag vertical curves where curbed sections are used. Drainage problems are minimized if the sag vertical curve is sharp enough so that a minimum longitudinal grade of at least 0.3% is reached at a point about 15 m from either side of the low point. To achieve this objective, the length of the vertical curve should be based upon a K-value of 50 or less. For sag vertical curves on curbed sections where this K-value is exceeded, the drainage design should be more carefully evaluated near the low point. For example, it may be necessary to install flanking inlets on either side of the low point.

E- Computation of Vertical Curves:

The following will apply to the mathematical design of vertical curves:

1. Definitions. **Figure E.1** presents the common terms and definitions used in vertical curve computations.

2. Measurements. All measurements for vertical curves are made on the horizontal or vertical plane, not along the profile grade. With the simple parabolic curve, the vertical offsets from the tangent vary as the square of the horizontal distance from the VPC or VPT. Elevations along the curve are calculated as proportions of the vertical offset at the point of vertical intersection (VPI). The necessary formulas for computing the vertical curve are shown in **Figure E.2.**

3. Unsymmetrical Vertical Curve. Occasionally, it is necessary to use an unsymmetrical vertical curve to obtain clearance on a structure or to meet other field conditions. This curve is similar to the parabolic vertical curve, except the curve does not vary symmetrically about the VPI.

4. Vertical Curve Through Fixed Point. A vertical highway curve often must be designed to pass through an established point. For example, it may be necessary to tie into an existing transverse road or to clear existing structure.

ELEMENT	ABBREVIATION	DEFINITION
Vertical Point of Curvature	VPC	The point at which a tangent grade ends and the vertical curve begins.
Vertical Point of Tangency	VPT	The point at which the vertical curve ends and the tangent grade begins.
Vertical Point of Intersection	VPI	The point where the extension of two tangent grades intersect.
Grade	G_1, G_2	The rate of slope between two adjacent VPI's expressed as a percent. The numerical value for percent of grade is the vertical rise or fall in meters for each 100 m of horizontal distance. Upgrades in the direction of stationing are identified as plus (+). Downgrades are identified as minus (-).
External Distance	M	The vertical distance (offset) between the VPI and the roadway surface along the vertical curve.
Algebraic Difference in Grade	A	The value of A is determined by the deflection in percent between two tangent grades (G_2 - G_1).
Length of Vertical Curve	L	The horizontal distance in meters from the VPC to the VPT.
Tangent Elevation	Tan. Elev.	The elevation on the tangent line between the VPC and VPI and the VPI and VPT.
Elevation on Vertical Curve	Curve Elev.	The elevation of the vertical curve at any given point along the curve.
Horizontal Distance	X	Horizontal distance measured from the VPC or VPT to any point on the vertical curve, in meters.
Tangent Offset	Z	Vertical distance from the tangent line to any point on the vertical curve, in meters.
Low/High Point	X_T	The station at the high point for crest curves or the low point for sag curves.
Symmetrical Curve	—	The VPI is located at mid-point between VPC and VPT stationing.
Unsymmetrical Curve	—	The VPI is not located at mid-point between VPC and VPT stationing.

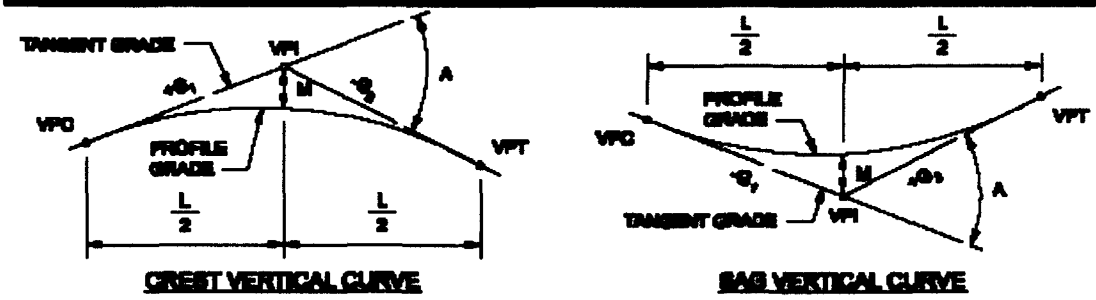
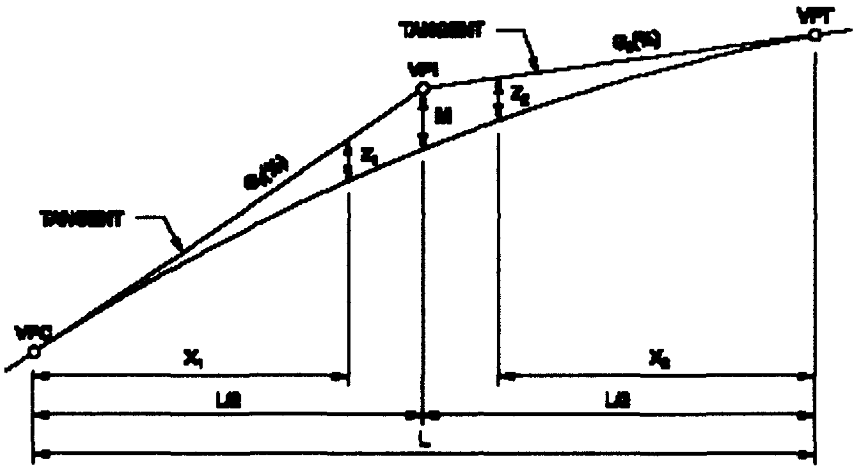


Fig E.1 Vertical Curves Definitions

Fig E.2 Symmetrical Vertical Curves Calculations:



M = External distance, m
Z = Any tangent offset, m
L = Horizontal length of vertical curve, m
X = Horizontal distance from VPC or VPT to any ordinate "Z," m
G_1 & G_2 = Rates of grade, expressed algebraically, percent

NOTE: ALL EXPRESSIONS TO BE CALCULATED ALGEBRAICALLY
(Use algebraic signs of grades; grades in percent.)

1. Elevations of VPC and VPI:

$$ELEV.OF\ VPC = ELEV.VPI - G_1\left(\frac{L}{200}\right)$$

$$ELEV.OF\ VPT = ELEV.VPI + G_2\left(\frac{L}{200}\right)$$

2. For the elevation of any point "X" on the vertical curve:

$$CURVE\ ELEV. = TAN\ ELEV. + Z$$

Where:

Left of VPI (X_1 measured from VPC):

(a) $TAN.ELEV. = VPC\ ELEV. + G_1\left(\frac{X_1}{100}\right)$

(b) $Z_1 = X_1^2\frac{(G_2 - G_1)}{200L}$

Right of VPI (X_2 measured from VPT):

(a) $TAN\ ELEV. = VPT\ ELEV. - G_2\left(\frac{X_2}{100}\right)$

(b) $Z_2 = X_2^2\frac{(G_2 - G_1)}{200L}$

3. Calculating high or low point in the vertical curve:

(a) To determine distance "X_T" from VPC: $X_T = \frac{LG_1}{G_1 - G_2}$

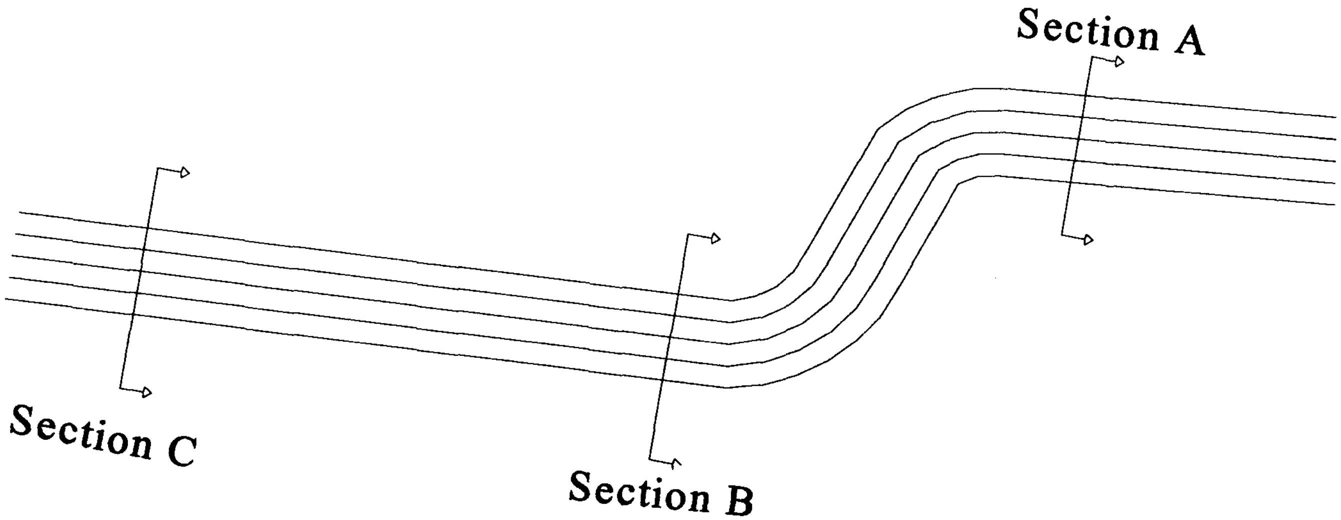
(b) To determine high or low point stationing: $VPC\ Sta. + X_T$

(c) To determine high or low point elevation on the vertical curve:

$$ELEV._{HIGH\ OR\ LOW\ POINT} = ELEV\ VPC - \frac{LG_1^2}{(G_2 - G_1)200}$$

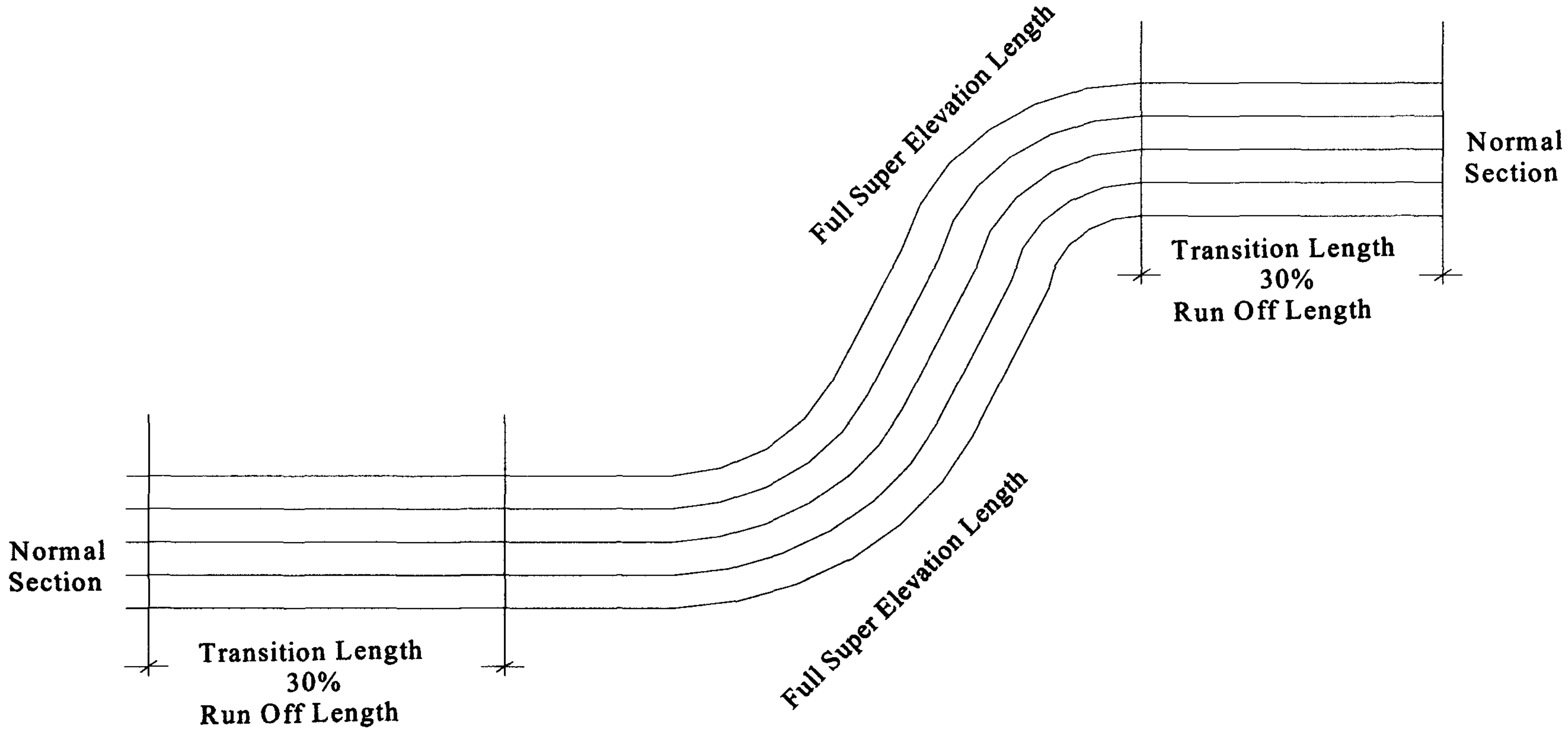
CHAPTER No 4.

Road Cross-Sectional Drawings.



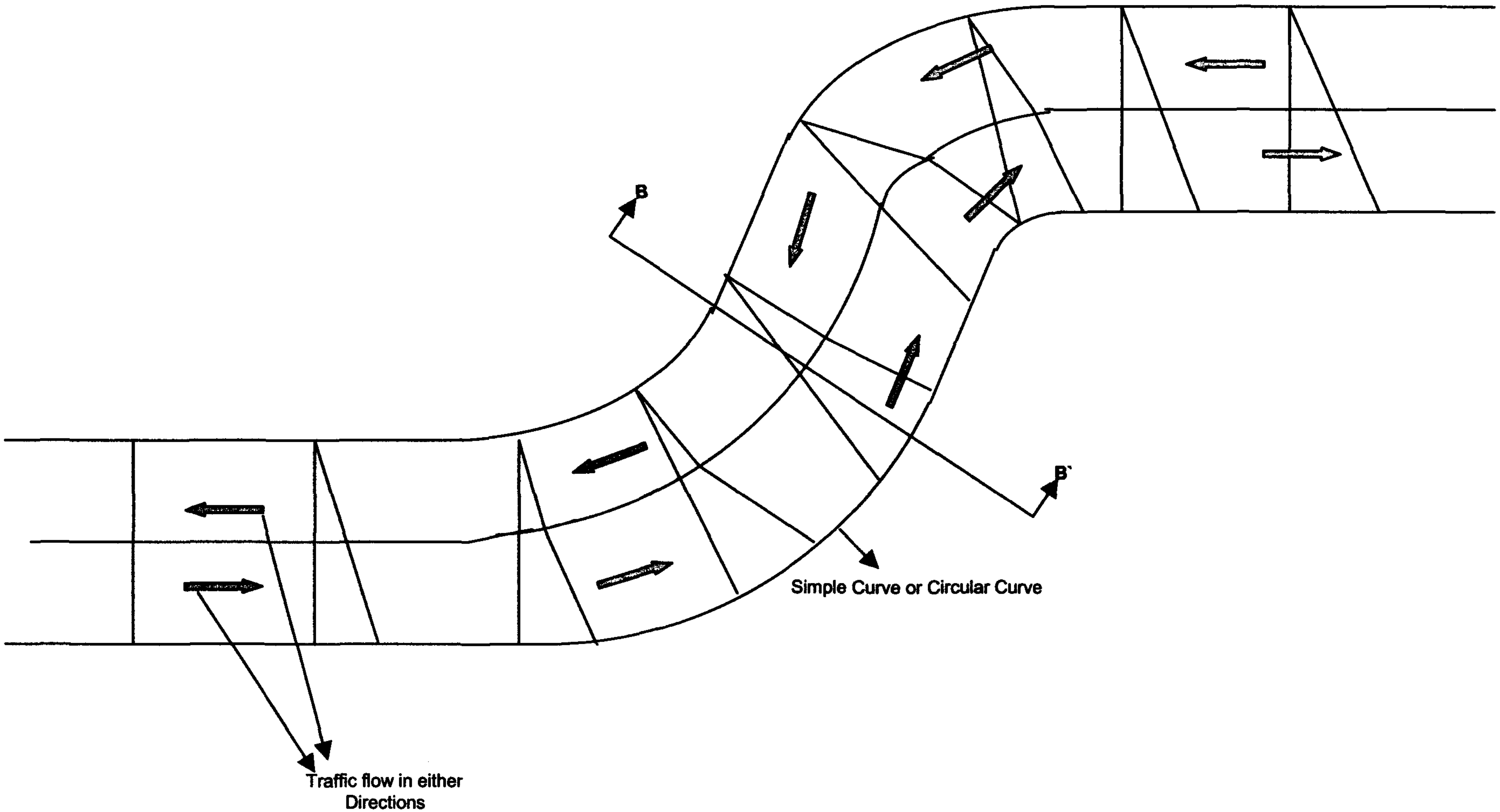
Typical Road Section

Hogeschool Van Utrecht
Typical Road Section
Tutor: Mr.Pieter Van Valen

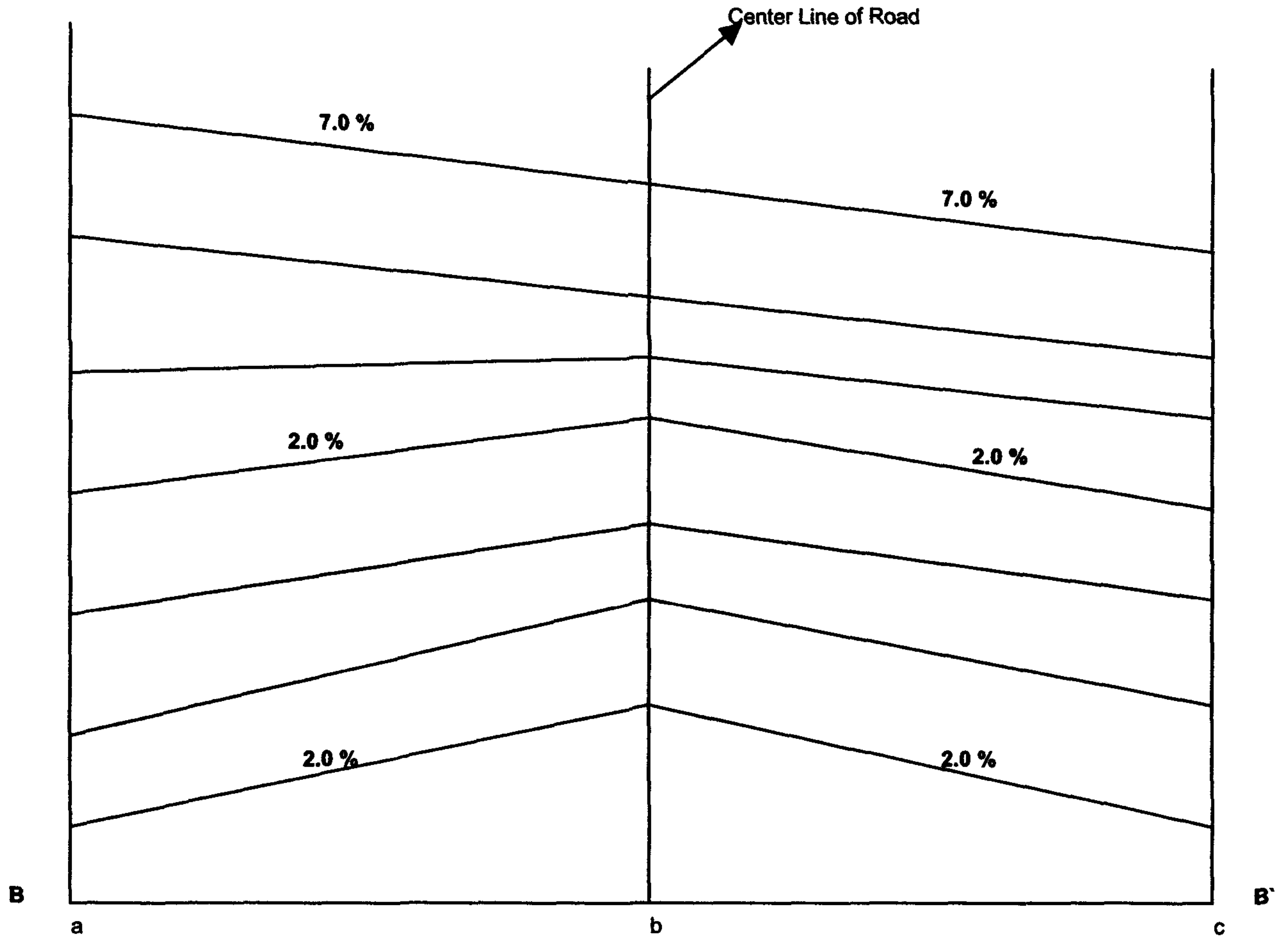


Detailed View of Section B

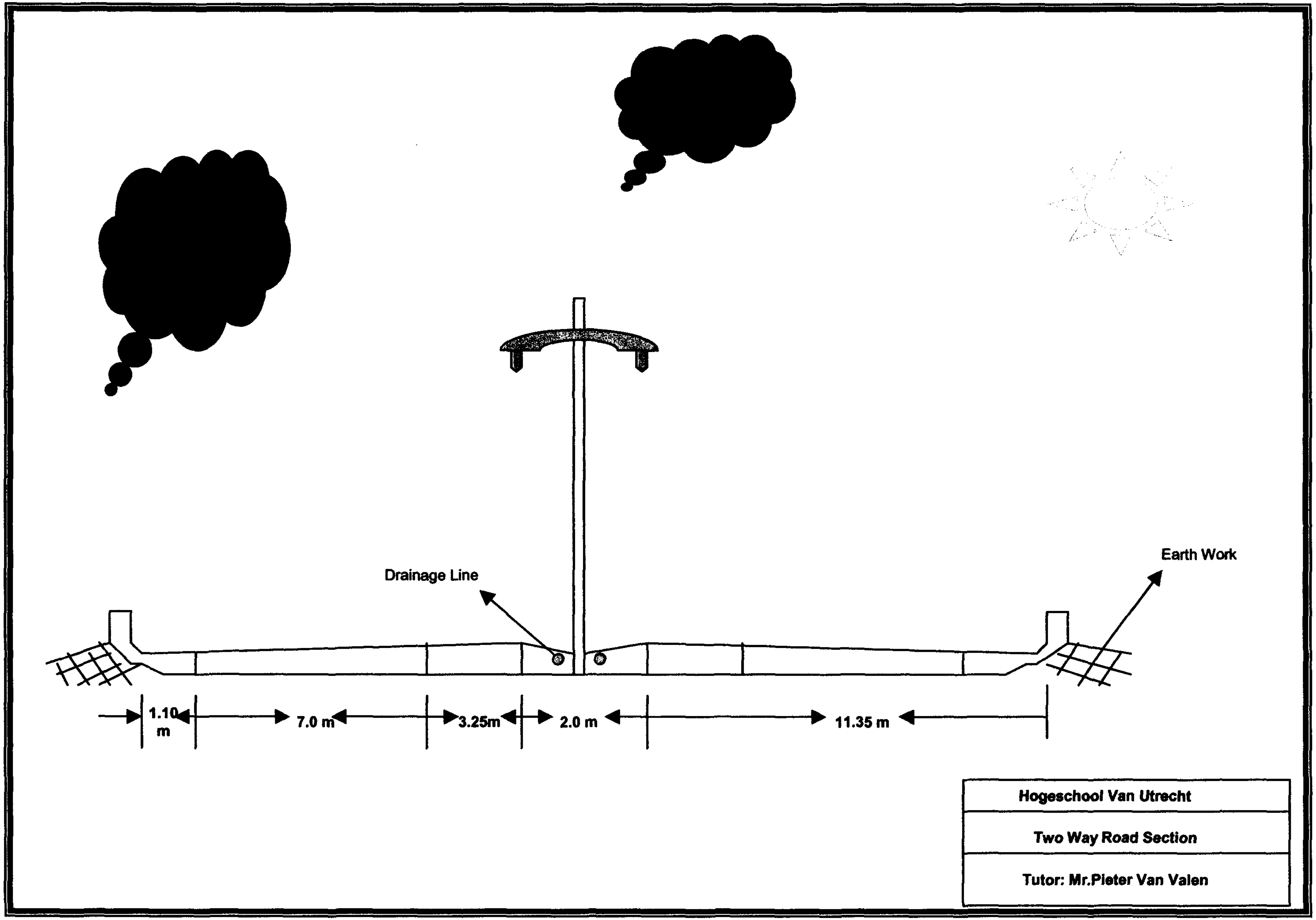
Hogeschool Van Utrecht
Detailed view of Section B
Tutor: Mr.Pieter Van Valen



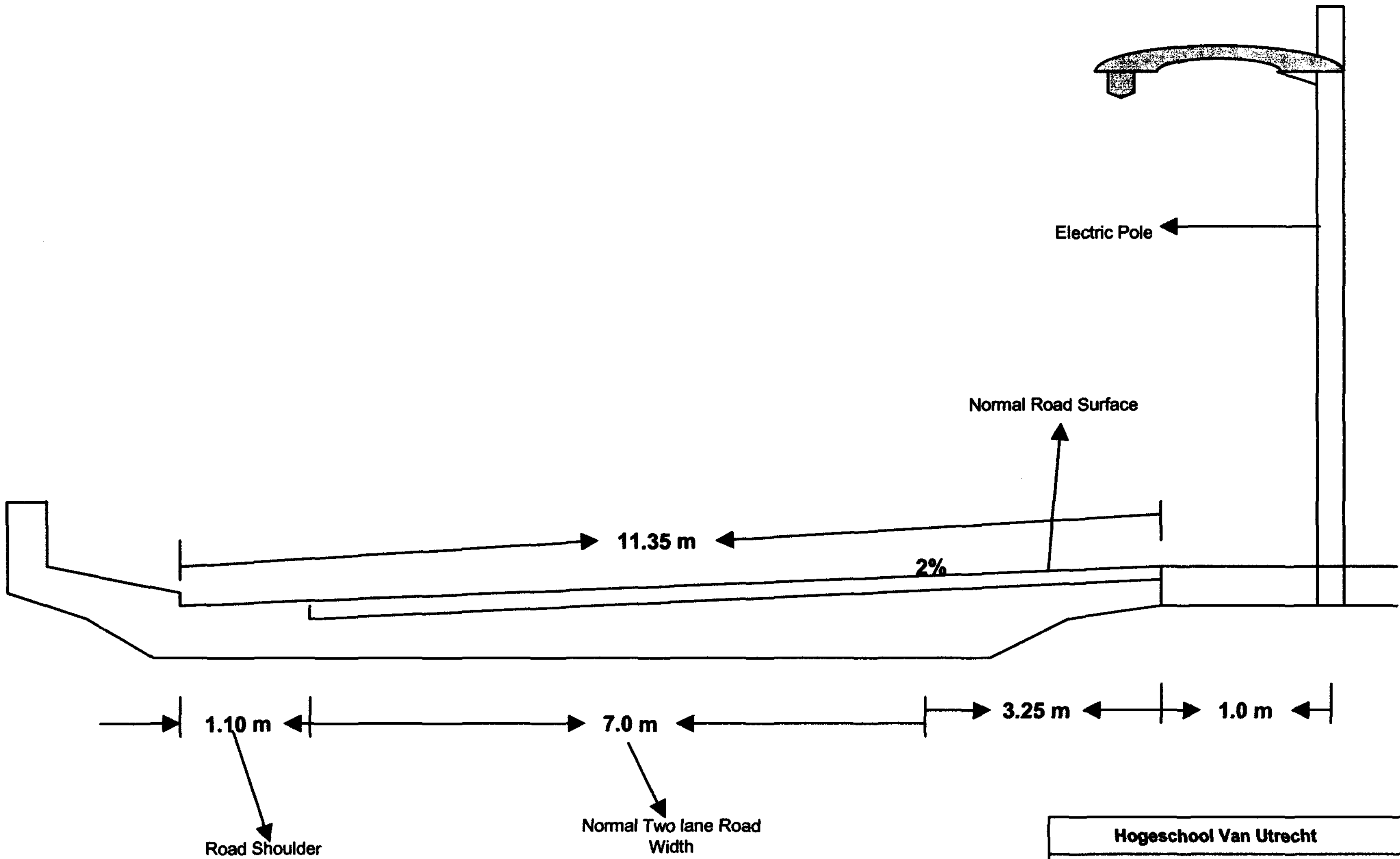
Hogeschool Van Utrecht
Elevation Transition on Section B
Tutor: Mr.Pieter Van Valen



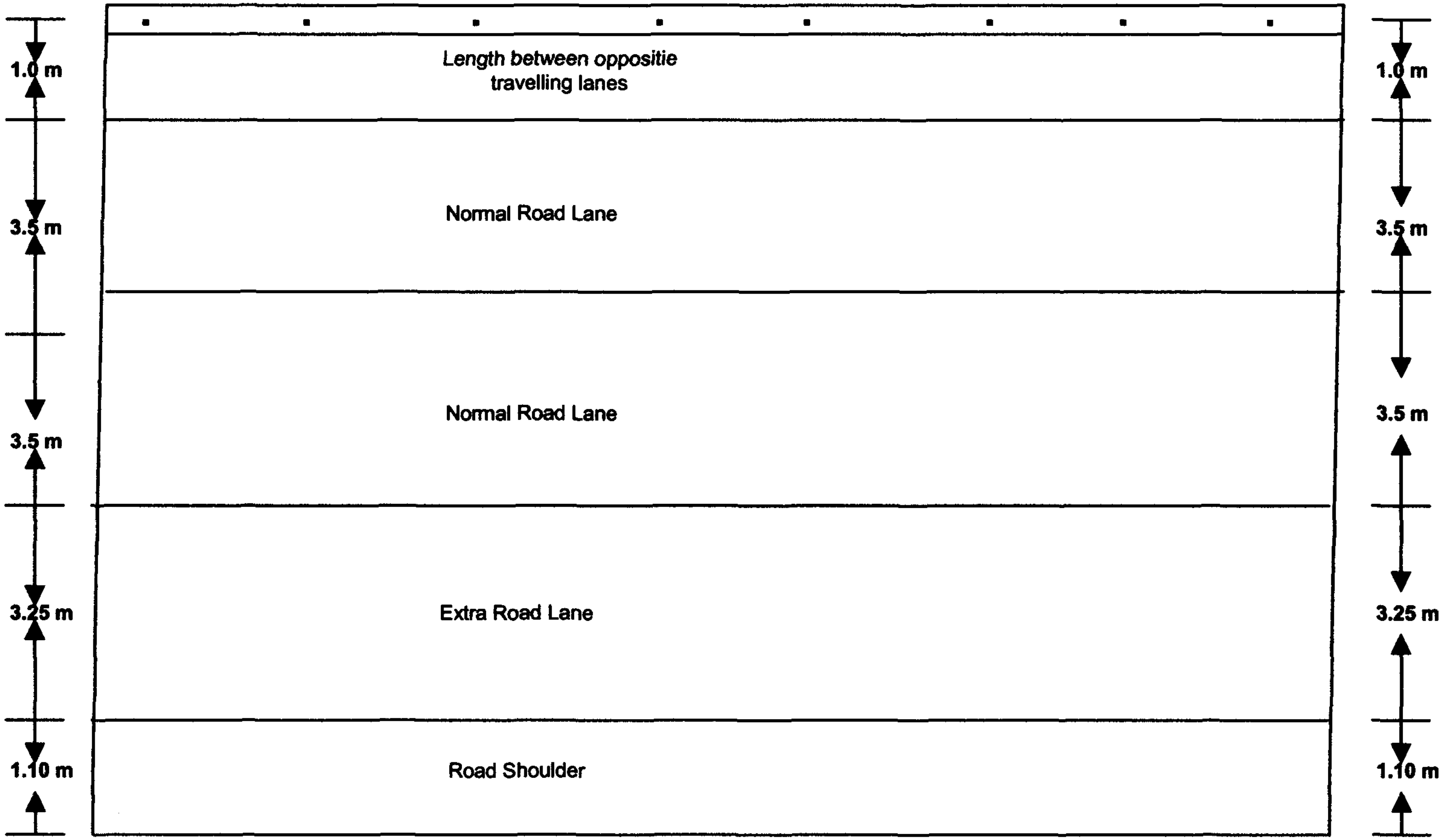
Hogeschool Van Utrecht
Curve Transition on Road Turn
Tutor: Mr.Pieter Van Valen



Drainage Line
Earth Work
1.10 m
7.0 m
3.25m
2.0 m
11.35 m
Hogeschool Van Utrecht
Two Way Road Section
Tutor: Mr.Pieter Van Valen



Hogeschool Van Utrecht
One way detail Section
Tutor: Mr.Pieter Van Valen



Hogeschool Van Utrecht
Road Plan
Tutor: Mr.Pieter Van Valen

CHAPTER No 5.

Pavement Design

INTRODUCTION:

Pavements are designed and constructed to provide durable all-weather traveling surfaces for safe and speedy movement of people and goods with an acceptable level of comfort for users. These functional requirements of pavements are achieved through careful considerations in the following aspects during the design and the construction phases:

- Selection of Pavement Type.
- Selection of Material to be used for various pavement layers and treatment of sub grade soils.
- Structural thickness design for pavement layers.
- Subsurface drainage design for pavement system.
- Surface drainage and geometric design.
- Ridability of pavement surface.

Pavement design procedures are classified here in Conventional or Equivalent single axel load (EASL) based. Design of pavement is based on set standards by AASHTO, which are widely respected and practiced all over the world.

Beside these above mentioned considerations, the current field conditions are also very important and should be keep in consideration while design procedure. Proper field conditions normally comprising of:

- Ground Cover (Grass cover, vegetation etc).
- Natural Slopes.
- Soil Density.
- Moisture content.
- Soil consistency (soft, hard).
- Natural soil strength (CBR Ratio).

- Ground water Level.

Design Motivation:

For that project i will design Conventional Cement Concrete (PCC) Pavement.

Normally in Holland Asphalt pavement are constructed. There are many reasonable points upon which I have decided to design PCC pavement. Among these motivations some are:

- As this project will be build on the Island between Almere and Lelystad.According to the proposed plan for that Island, the Island will reclaimed by Sand. As the sand has more load bearing capability so PCC pavement can be build.
- There will be less settlement.
- PCC pavement has long life as compare to Asphalt pavement.
- Construction cost will be very reasonable as compare to Asphalt Pavement because of the less cost on foundation building.
- Maintenance cost will be very less.
- As this pavement will be used for heavy transportation, PCC can bear heavy load more easily and deformation chances will be less.

These all motivations are based on the studies by Rijkwaterstad and the information material that I get from Hogeschool as for reference for the project conditions.

Conventional Pavement Design (PCC):

Conventional pavement design is based on both the amount of traffic and the percentage of trucks. See the Table, which gives the pavement thickness that should be used according to concerned Traffic volumes. Normally Conventional Portland Cement

Concrete (PCC) pavements are constructed with **5.5 meter** long length, unreinforced slabs.

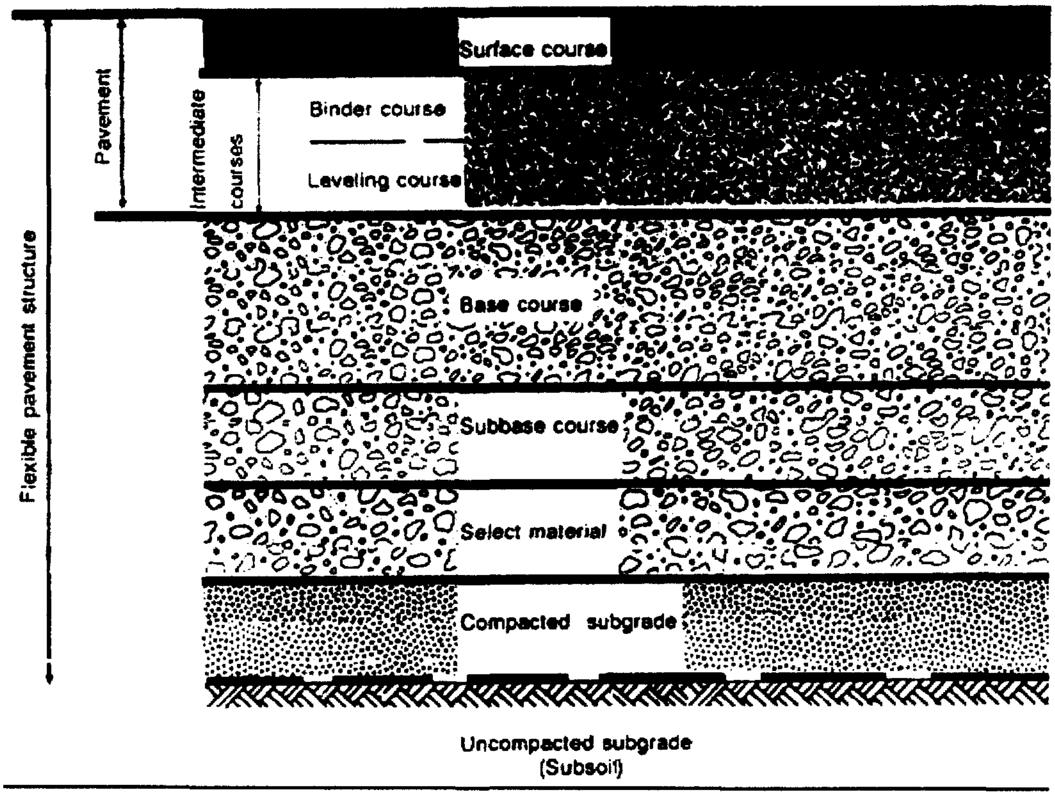


Fig-1 Typical Pavement structure.

Conventional Pavement Design (PCC) Procedures:

There are the following design procedures for the PCC pavements:

- The first main thing in the Design procedure is to get the Annual Daily Traffic (AADT) & Percentage of the Trucks. These can be self calculated like the way described in Geometric design of Road. It followed the same pattern of calculation. Beside that it is also possible to get the values from the office of Highway Department of Regional Planning Office.

- Determine the minimum pavement thickness.
- Determine the shoulder design.
- Determine the drainage design.

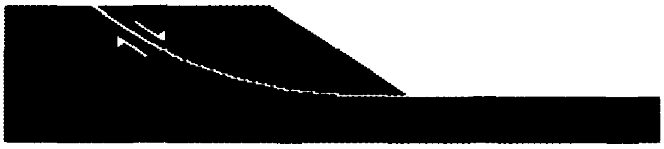
Conventional Pavement Design (PCC) Consideration:

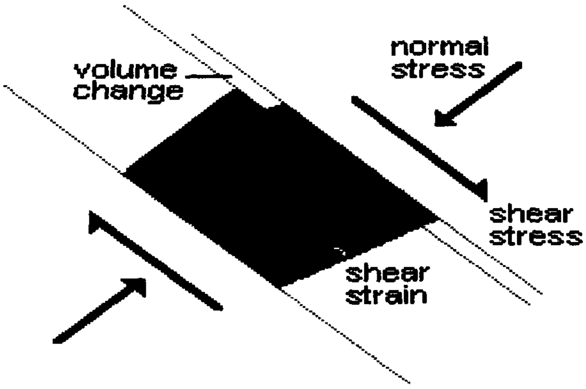
Following are main design considerations for PCC pavements, those should be taken into account while design procedure.

(a) Soil Strength:

Near any geotechnical construction (e.g. slopes, excavations, tunnels and foundations) there will be both mean and normal stresses and shear stresses. The mean or normal stresses cause volume change due to compression or consolidation.

The shear stresses prevent collapse and help to support the geotechnical structure. Shear stress may cause volume change.





Failure will occur when the shear stress exceeds the limiting shear stress (strength). Usually CBR test is conducted to find out the bearing capacity of soil.CBR is determined by a standardized penetration shear test.Noramlly field tests are conducted on base course, sub base and subgrade materials.

(b) Soil Behaviour:

Soil has to be compacted in order to improve its load bearing capacity. High soil strength is usually associated with high degree of compaction. In saturated soil volume changes can only occur as drainage occurs and as effective stresses change. In unsaturated soils volume change is due to changes in water and air volume; both of which can change without change in effective stress. Usually these are terms which are named as the soil behaviour:

1- **Compaction**: in which air is expelled, can occur due to vibration (e.g. from traffic, machinery, piling, etc.); also, loosely-placed fill can compact under its own weight.

2- **Shrinking and swelling** can occur in some clay near the surface due to climatic changes (shrinking in summer, swelling in winter).

3- **Creep** occurs in some clay soils due to gradual changes in fabric.

(c) Base & Subgrade compaction:

CBR tests are usually conducted on remolded samples. However, where existing similar construction is available, conduct CBR tests on material in place when it has attained its maximum expected water content or on undisturbed, soaked samples. The procedure for selecting test values described in the section on subgrades also applies to select and subbase materials. In order to be used as a select or subbase, the material must comply with the requirements indicated in **Table 1**(next page), including CBR value, gradation, and Atterberg limits. If a material meets the requirements for gradation and

Atterberg limits for the next higher design CBR category, but the material's CBR value does not meet the maximum design CBR for that category, assign the material design a CBR value equal to the measured CBR results. For example, a material with a measured CBR value of 37, which meets the gradation and Atterberg limit requirements for a CBR 40 subbase, should be used as a CBR 37 subbase. Conversely, if the material failed to meet the CBR 40 subbase requirements (gradation and Atterberg limits) but met the CBR 30 subbase requirements, it would be used as a CBR 30 subbase rather than a CBR 37.

Some natural materials develop satisfactory CBR values but do not meet the gradation requirements in **Table 1**. These materials may be used as select or subbase materials, as appropriate, if supported by adequate inplace CBR tests on construction projects using the materials that have been in service for several years.

The CBR test is not applicable for use in evaluating materials stabilized with chemical admixtures. These chemically stabilized soils must be assigned an equipment CBR value based on the type of admixture and method of application. Ratings as high as 100 can be assigned to these materials when proper construction procedures are followed.

Pavement compaction 98 - 100% CE 55

Base course (CBR 80 - 100) Airfield
(CBR 50 - 100) Road
Compaction 100 - 105% CE 55 (Soil)
98 - 100% CE 55 (Asphalt)

Subbase course (CBR 20 - 50) Airfield or roads
Compaction usually 100 - 105% CE 55

SELECT MATERIAL
Subgrade CBR < Select CBR < 20
Cohesive compaction 90 - 95% CE 55
Cohesionless compaction 95 - 100% CE 55

COMPACTED SUBGRADE
Cohesive compaction 90 -95% CE 55
Cohesionless compaction 95 - 100% CE 55

Uncompacted subgrade
(Subsoil)

Table 1- Typical Pavement Structure. 1

Conventional Pavement Design (PCC) Thickness:

ESAL-based pavement design is based on the *American Association of State Highway and Transportation Officials (AASHTO).* Equivalent single axle loads (ESAL) are used for determining pavement thickness and the design relies on using a treated open graded permeable base layer with continuous edge drains in the pavement structure to provide positive drainage. The key input variable in the ESAL-based design process is the anticipated amount of heavy truck traffic. The truck traffic is measured and converted to a number of 80 kN ESALs. See **Table 2,** which provides the steps for calculating ESALs using available traffic data.

Table 2 provides a reasonable methodology in designing for adequate structural capacity of the pavement structure.

Annual Average Daily Traffic AADT[1]	Percent Trucks	Subbase Course (all Pavements)	Portland Cement Concrete Pavement
Over 10,000 Vehicles	10 % or more	300 mm	250 mm
	less than 10 %		
6,000 to 10,000	10 % or more	300 mm	225 mm
	less than 10 %		
4,000 to 5,999	All	300 mm	Not Applicable
Under 4,000 Vehicles	All	300 mm	Not Applicable

Table-2 Conventional pavement thickness guide

Conventional Pavement Design (PCC) Features:

ESAL based pavement is designed to be a long lasting, low maintenance, smooth riding pavement system. Major component differences compared to conventional pavement design accounts for increase life as follows:

- Thicker PCC pavement slabs (up to 325 mm thick).
- Thicker pavement sub base course(s) (up to 900 mm thick).
- Locating the longitudinal joint between shoulders and driving lane 0.6 m outside of the travel lane.
- Subsurface pavement drainage via a 100 mm thick treated permeable base with continuous edge drains outleting approximately every 75 m.
- Subbase is considered impermeable, so water drains through permeable base layer and does not penetrate subbase.

Conventional Pavement Design (PCC) Calculation:

ESALs or 80 KN Equivalent Single Axel Loads, is an important input parameter for the pavement thickness design tables. Traffic on pavement structure includes numerous types of vehicles with varying weights and axel configuration. Please see **Table-3**.The anticipated traffic damage over pavements entire design life from all load combinations must be converted to a fixed traffic factor or ESAL.

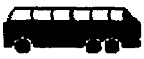
Vehicle classifications			Typical wear factor
	Buses and Coaches	PSV	1.3
	2 axle rigid	OGV1	0.34
	3 axle rigid		1.7
	3 axle articulated		1.65
	4 axle rigid	OGV2	3.0
	4 axle articulated		2.6
	5 axle or more		3.5

Table-3 Vehicle Classification chart:

ESALs are a measurement of load repetitions which accumulate and cause pavement damage. The pavement thickness is design for the projected number of EASLs over the pavements design life. ESALs calculated for PCC pavement are Not the same as those calculated for HMA pavement due to the Truck frequency factor.EASLs calculated for rigid pavement are about **40%** greater than EASLs calculated for the flexible pavement.

Calculation Inputs:

According to the AASHTO, the main input parameters for pavement design are as:

(a) Design Life:

As defined by AASHTO, this is the initial performance period of the pavement structure in years. The design life is the useful life of the pavement structure and the drainage system after which time the pavement may need total reconstruction from the sub base up. The Design life for that project will be **30 to 35** years. The design life based on with increase in:

1- Annual Truck weight Growth Rate = 0.5%.
2- Annual Truck Volume Growth Rate = 2.0%.
3- Percent Truck in Design Lane = 1 lane = 100.

(b) Initial AADT:

This will be 24-hr two way vehicle count in all lanes for the pavement structure when opened to traffic. Choose highest AADT value provided in the Highway sufficiency ratings with in the project limits.

(c) Percent Heavy Trucks:

This percentage is assumed to be remain constant over the design life unless other information is available, such as a proposed a new truck route or a new business requiring a lot of trucking, in which case the percentage should be modified.

(d) Percent Truck in Design Direction and Design Lane:

Percent Truck in Design Direction is a directional distribution factor applied to the two-way AADT to account for any variations 50 %, but in special cases where one direction of travel has either larger traffic or heavier vehicles, this factor may be increase. Beside that Percent Truck in Design Lane is a lane distribution factor which accounts for the percentage of trucks in the design lane. See **Table-4**.

No of Lanes in Each Direction	Percentage of Trucks in Design Lane
1	100
2	80-100
3	60-80
4	50-75

Table-4 Percent Trucks in Design Lane.

(e) Truck Equivalency Factor (ESALs/Truck):

This is the weighted average factor which represents the number of 80-kN ESAL applications caused by a single passage of an average heavy vehicle. Equivalency factors may vary by as much as a factor of 2, depending on local industry, highway classification and pavement type. According to AASHTO, value for ESALs/Truck is:

Vehicle Classification	Flexible Pavement	Rigid Pavement (PCC)
4 – 13	1.35	1.85

(f) Annual Truck Volume Growth Rate:

Expressed as a percentage, this is used to specify the anticipated growth rate of the truck traffic volume compounded over a pavement design life. Typical values are between **0 %** till **2 %**. These growth rates are calculated every year based on the previous **15** years of traffic volume.

(g) Annual Truck Weight Growth Rate:

The annual truck weight growth is a factor which accounts for the increase in truck weight over time. It is expressed as a percentage and typically rages from **0 %** till 4 **%** per year. A high growth rate can cause dramatic increase of EASLs over the life of the pavement structure.

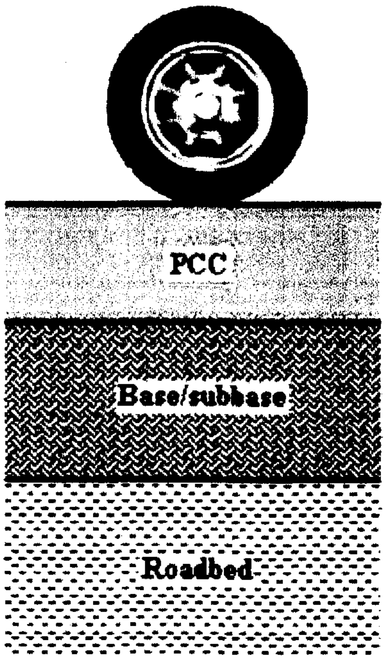
PCC Pavement Driving Lane Width & Length:

The recommended driving lane slab width is **3.5 m,** which mount to a standard lane plus of **3.25m** & with shoulder length of **1.1m**. For a two lane pavement, both lanes should be of **3.5 m** slab width. The joint at the pavement edge, between the driving lane and shoulder, deteriotes quicker than the other joints, since traffic runs close to or over the joint. The width of slab spread the load over a larger area and moves the pavement edge on to shoulder, reducing the stresses and thus the distress at the edge of pavement. So the pavement edges must be thicker.

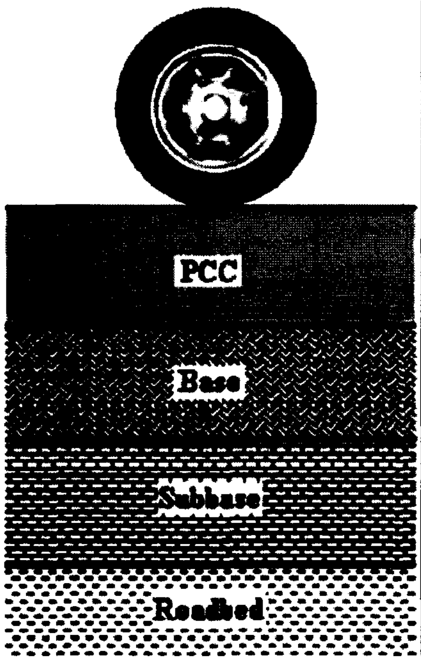
The typical slab length will be **5.5 m,** but in some cases this may be reduced to a minimum of **3.5 m** to satisfy site conditions such as utilities or interruptions in the pavement. In some cases the slab aspect ratio (width/length), the maximum slab width and length both can be **5.5 m**.

Typical Load Combinations & Distribution:

There are two possibilities with respect to the Foundation of the PCC pavement. As we have sand as the ground material, it is advisable to go for the **Option No-1** same compare to the **Option No-2.** Please see **Fig-2** for load distribution case.



Option-1



Option-2

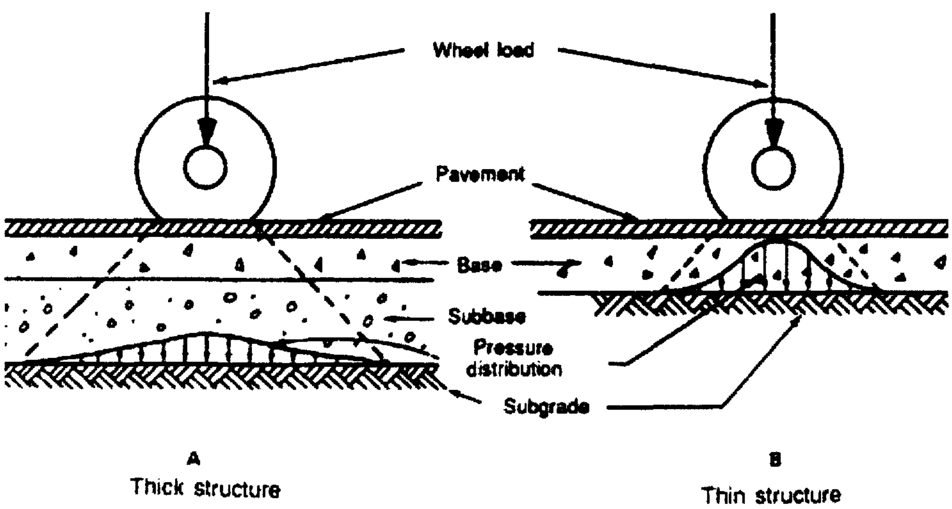
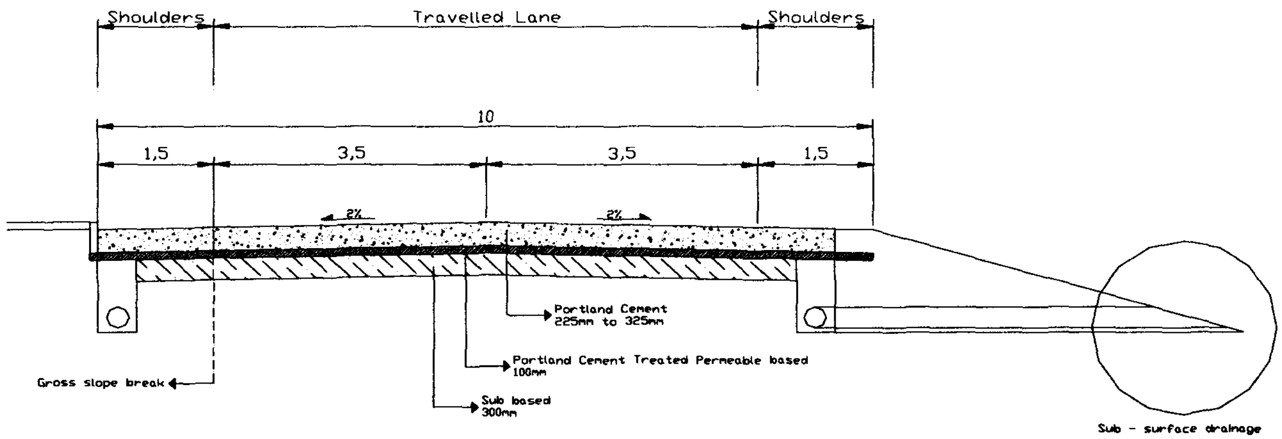


Fig-2 Load Distribution case in two foundation cases



Typical PCC Pavement Section

East Ring Road Project	
Pavement Cross Section	
Tutor 1	Tutor 2
Frans van Heerden	Pieter van Valen

Design Summary;

Basic Features:

Some of the basic features of the East Ring road will be as follows, which is only proposed according to the future needs and suitability. The design speed will be 100 Km/h and minimum speed of 60 Km/h.

1 - Design Year:

East Ring road will be designed as design year of 10.Which means that all the data which will be used for the design will be start from 10 years ahead, from the date of the construction begins. It is so to minimize the error in the studies conducted about the estimation of the Traffic load. The design life will be **30 to 40** years.

2 - Lanes:

East Ring Road will be designed as the four lanes **(04).** The two roads will be used in either direction. Usually in Holland the criteria to determine the number of lanes is as follow;

1 Truck = 3 PAE or PCU (Passenger Car Unit).

1 Car = 1 PAE or PCU (Passenger Car Unit).

1 Motor Cycle = 0.5 PAE or PCU (Passenger Car Unit).

Normally road of 1 lane the PAE values are as follow;

1 Lane road = 1600 PAE.

As the density of the Traffic will be high so according to the Two(02) lanes rule, the capacity will be as;

2 Lane road = 3200 PAE.

3 - Extra width lane:

For that project extra width of lane,**3.25 m** is recommended, it is so because to cope with the sudden increase in traffic load & also in case of maintenance or accident the two lanes in one direction can be used in both direction.

Geometrical Design Summary for East Ring Road;

Here is the some design features of the proposed design of the East Ring Road, comprise of 30 Km length, a straight stretch with one bend. The Road is designed according to the set standards of the **AASHTO,** which are widely respected and used.

1 - Road Classification;

According to the nature of use of the East Ring Road, the main things in determination of Road classification we as;

- Road function Arterial Type. (Please see report for explanation).
- Design class "A".
- Surface Type Paved.
- Road with level terrain.

2 - Road Features;

The main features which were being determined according to the AASHTO standard were as under;

- Standard 1 lane width of 3.5.meters.
- Side slope of 2 %.
- Shoulder length of 1.10 meters.
- Extra width lane of 3.25 meters.
- Distance between lanes of 2 meters.(lanes to and come).
- Total length of one side 11.35 meters without lane distance.

3 - Geometrical Design;

The summary of the Geometric Design as briefly explained in the detailed report is as ;(please turn over to next page)

* Vertical Alignment;

  - Maximum grades for freeway is 3 %.
  - Minimum grades of 0.35 %.
  - Stopping sight distance on crest vertical curve 190 meters.
  - Stopping sight distance on sag vertical curve 190 meters.
  - Minimum length of crest vertical curve will be 60 meters.
  - Passing sight distance of 675 meters.

* Horizontal Alignment;

  - Simple curve is recommended. It is so because simple curve is comprised of the continuous radius without variation which results in more safety and comfortability.
  - Minimum recommended radius is 395 meters.
  - Maximum Super Elevation rate is 8%. The maximum rate will be applied of the curve,inorder to short the length of the super elevation and on the normal way it will vary from 5 to 7 % according to the varying conditions.
  - Side friction ratio of 1.2.
  - Length of curve will be 300 meters.
  - Sight Obstruction distance will be 160 meters.

Design summary of the Pavement :

The main things in relation to the design of the Pavment were as;

- Design life will be 30 to 35 years.
- PCC pavement. (Please see the detail report for motivation).
- Design process and strategy will be same as of Road, as described in detail in the report about the Deisgn of road.
- Slab of 5.5 meters length will be used.
- Driving lane slab width of 3.5 meters.
- Standard lane plus of 3.25 meters.
- Shoulder of 1.1 meters.
- PCC slab thickness of 325 mm.
- Pavement sub base course of 900 mm thickness.
- Drainage outleting approximately on every 75 meters.
- Annual truck weight growth of 0.5 %.
- Annual truck volume growth of 2 %.
- Percentage of truck in design lane will be 40 to 60.
- Truck Equivalency Factor (ESALs/Truck) will be 1.85.

Reference and Guidance:

For satisfactory completion of that project, following assistance and literature source will be used:

Personal Guidance;

I will look forward for help from my following honorable Teachers and friend,

Ir. Frans Van Heeeden.	Hogeschool Van Utrecht.
Ir. Pieter van Valen.	Hogeschool Van Utrecht.
Ir. René Camerik.	Rijkswaterstaat.
Ari Saptono Brotoaji	TU Delft.

Books;

For the completion of the Project, I have used many books, but mainly I have used these below mentioned Books.

* Highway and Railway Engineering (1 & 2), Faculteit Natuur en Techniek. Hogeschool Van Utrecht.
* Civil Engineering Hand Book, L.S Blake.
* Civil Engineering Hand Book, H.S Khanna.

TU Delft;

I am very thankful to **Mr. René** and **Ari**, who is studying at the TU Delft, for helping me with my Sub topic related to the Engineering Policy and Analysis. The information which I get from them in shape to discussion and information material helps me a lot to make my work to a good level.

World Wide Web (www):

There were the following web links which were being used to get the guidance and precious information, which were:

www.icivilengineer.com

http://www.usace.army.mil/inet/usace-docs

www.construction-pm.com

http://www.dot.ca.gov

http://www.vsmlc.com/converter.html

www.**aashto**.org

www.transportation1.org

www.normas.com

www.safety.fhwa.dot.gov

www.fhwa.dot.gov/ve

http://www.ucalgary.ca

http://www.globalsecurity.org

http://www.bb.fnt.hvu.nl/