Royal Government of Bhutan
Ministry of Works & Human Settlement
Department of Roads
Thimphu

Road Survey & Design Manual

First Edition **June 2005**

Foreword

The "Road Survey & Design Manual" in its present garb has been prepared and produced by the Department of Roads, (DoR) through its own in-house capacity. This Road Survey & Design Manual is made more user friendly and more practical than the previous one that was published in 1988. It is intended to serve as a guide for the Design Engineers & Planners at the Head Quarter as well as those who are involved in the route alignment survey and construction in the field.

The field design for improvement of blind curves is a special feature of this manual. It is expected that the procedure and methods of field design described in Chapter 4 will help the field engineers to carryout the field design with full confidence.

A Technical Standard Committee had been formed in 2004 in the Department with Roads Director, Mr. Phuntsho Wangdi as the Chairman. The Technical Standard Committee is responsible for publishing technical manuals and standards of which this publication is one of the Technical Standard Committee's first modest contribution. The following are the members of the Technical Standard Committee:

Phuntsho Wangdi	Director	Chairman
Kunzang Wangdi	Superintending Engineer	Coordinator
Pravat Rai	Assistant Engineer	Member
Karma Wangdi	Assistant Engineer	Member
Karma Tenzin	Assistant Engineer	Member
Tougay Choedup	Assistant Engineer	Member

This manual is a living document and will be subjected to reviews and refinements from time to time both in terms of its contents and quality of presentation.

We would like to dedicate this manual to the theme **"Towards Quality Infrastructure"** being pursued by the Ministry & DoR.

Thimphu
Date : June 2005

Phuntsho Wangdi
Director
Department of Roads

Acknowledgement

I would like to gratefully acknowledge our Director Mr. Phuntsho Wangdi for his conception and initializing to write this Road Survey & Design Manual to be used by the Head Quarter and Field Engineers of the Department of Roads and beyond with his vision to provide smoother driving comfort for the travelers.

I would like to thank the Superintending Engineers of the Department of Roads Mr. Kunzang Wangdi, Mr. Tshering Wangdi and Mr. M.N. Lamichaney for their painstaking efforts in editing and providing necessary corrections and would also thank the staff of the Survey & Design Division for providing necessary help when required.

The support and financial assistance given by EFRC Support Project in publishing this manual is also gratefully acknowledged, without which the publication of this manual would have been delayed.

Karma Tenzin
Member
Technical Standard Committee
Department of Roads

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1.0 INTRODUCTION

Geometric design of road in Bhutan's terrain characterized by steep mountains and deep gorges presents special challenges. Factors such as weak geology, varying topography and climatic conditions and environmental requirements dictate the choice of road alignment. Therefore multidisciplinary involvement is necessary particularly in the feasibility study stage. The various phases of activities involving survey, investigation and geometric design of road are briefly described in the following sections.

2.0 SURVEY

2.1 Feasibility Study

Sequence of Survey and Survey Methods

Upon the identification of the project by the competent authority and the scope and geometric standards of the work is defined feasibility study is carried out to determine the most preferred alignment. The feasibility study includes

1. Desktop Study based on topo map.
2. Ground Reconnaissance Survey
3. Geo-Technical Study
4. Environmental Assessment and
5. Selection of optimal alignment

2.2 Desktop Survey

The desktop survey is done on 1:50000 scale topographical (topo) maps produced by the Survey of Bhutan. The topo map provides a fairly good information on settlements, rivers, terrain, and land use etc, with contour intervals of 20 or 40 meters. This study is usually done at the Head Quarter by the Survey & Design Division. Large scale topo maps (say of the area of 1:25000) would be more useful.

Scanned Topo Sheets are all available in JPG format to be used in PhotoShop software.

The following equipment are required for carrying out the desktop study.

a) Computer (Pentium 4 and above)
b) A0 Plotter
c) Photoshop software
d) Run-mat/Planimeter

An improved version of desktop study is being explored using Arc GIS making use of Arial photographs to create Digital Elevation Model.

2.3 Reconnaissance Survey

The various route corridors or alternative alignments are identified in the desktop study phase considering the terrain conditions and the merits of each alternative alignment.

The reconnaissance team should comprise of the following:

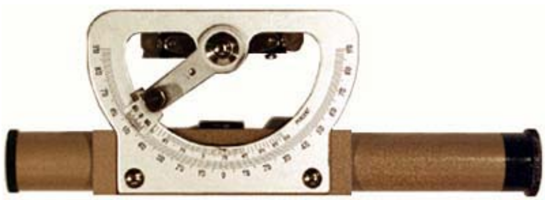
a) S.E/E.E/A.E - Team Leader
b) Representative from the Engg. Cell of the Concerned Dzongkhag
c) Representative from the concerned Field Division, DoR
d) Engineer involved in the desktop study
e) Representative from Geo-Tech Unit, S&D
f) Representative from Environment Unit, S&D
g) Representative from the Bridge Division
h) Surveyor
i) Local interpreter from the study area

The Team should be equipped with the following:

a) Desktop study map
b) Altimeter

c) Measuring Tape
d) Digital Camera
e) Camping equipment etc.
f) Clinometer
g) Hand held GPS
h) Disto Meter
i) Binocular

Altimeter



Clinometer

2.4 Geotechnical Study

There is a general belief that the level of investment being made at present for geotechnical studies is not adequate. More investment needs to be made for geotechnical studies in order to ensure that the selected road alignments are safe and stable while ensuring that the construction is reasonably economical. Geotechnical assessment is a specialized job which involves evaluation of slope stability, slope stabilization and hazard mapping.

2.5 Environment Assessment

Environment assessment (EA) also forms a part of the feasibility study. EA ensures that the negative impacts on the environment due to road construction are minimal.

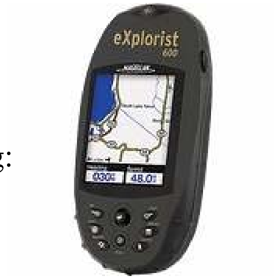
2.6 Detail Survey

This is the most important part of engineering survey. The detail survey consists of two parts, namely (i) ghat tracing which is done using a ghat tracer or clinometer to fix the rough center line of the alignment and (ii) detail topo-graphical survey.

The survey team should consist of the following:

a) Team Leader (Surveyor)
b) Member (Surveyor)
c) Survey Field Assistant
d) Labourers as required

The team should be equipped with the following:



GPS


Total Station (TPS1200)


Laptop computer


Digital Camera

1) Total Station
2) Digital Camera
3) Laptop
4) Generator
5) Camping Gears
6) Geocomp software
7) Calculator
8) Measuring Tape


Typical Survey Camp

The procedures for downloading of survey data from the Total Station into the Geocomp Software currently being used by the Survey & Design Division is described below.

Steps for using TC1101

1. Setup the Instrument (Centering & Leveling)
2. Go to **Meas job management** and press ↵
   Select **F2 (New)**, and enter job name
   Eg, 191901↵ where first four digits are job number and last two are version number.
   Then press **F1(CONT)**, twice.
3. Go to **Data job management** ↵
   Select the same file by, ↑ ↓ and press **F1(CONT)**
4. Go to Configuration ↵
   Select **01. Instrument Config.** ↵
   Select **05. Display and Record** ↵
   Make sure,
   Displ. Mask is S&D
   Coord. Seq. is E/N as in Dmask
   REC Mask is S&D
   Then press **F1 (CONT)**
   F1 (BACK)
   F1 (BACK)
5. Then Press **F5(SETUP)**
   Check if Meas job/ Data job/ Displ. Mask/ REC Mask
   Are correct, and then press **F1(STN)**
   Station ID : Should be 1
   Then Enter
   Inst Ht., Stn. East, Stn. North, Stn. Elev.
   Then press **F4(Set Hz)**
   And set the Instrument to North and then press **F4(Hz=0)**
   Then press **F1(CONT)**
6. Then Press CODE and enter the following:
   Code - **5**
   Info1 - **Station number** (eg. 00300001)

003 = Station Entity
00 = String
001 = Station Number

Info2 - **Instrument Height**, (in mm)
Info3 - **Target Height**, (in mm)
And then press **F1(REC)**

7. Then make the **point Id as 2** and start detail Survey.
8. When Detail survey is over, then sight to the New Station.
   Then Press **CODE** and enter the following:
   Code - **6**
   Info1 - **1430** (Height of Next Station)
   Press **F1(REC), and change the Refl. Height to the same height but in meter**
   Then press **CODE** and enter the following
   Code - **10**
   Info1 - **00300002** (Where 003 is Station Entity
   00 is String
   002 is Station Number)
   Then press **F1(ALL)**
   Please Note the point number of the station.
9. Setup at the new station, (centering and leveling)
   Then Press **F5(STN)**
   Then press **F4(QSET)**
   Then on the screen:
   For Station Id : Input the number you have noted. (Pt.No. for Stn.)
   Back. Id : In put the point Id for back station.(Pt. No. for back Stn)
   Enter Stn. East, Stn. North. & Stn. Elev.
   For Station 1. and sight to back station and press
   F2(DIST)
   Then press **F4(CONT)**, **Twice**.
   Then press **F2(DIST)** to check the East/North/RL

10. Then Press CODE and enter the following:

    Code - **5**

    Info1 - **Station number** (eg. 00300002)

    003 = Station Entity

    00 = String

    002 = Station Number

    Info2 - **Instrument Height**, (in mm)

    Info3 - **Target Height**, (in mm)

    And then press **F1(REC)**

    Then start the detail survey.

The Code to be used are as follows:

Code 5 → Instrument Point (New)

Code 6(BM) → Prism Ht. change

Code 10(BM) → Measurement to New Station

Code 14(AM) → Three Point Arc

Code 15(AM) → Feature Code (Entity number & String)

Code 16(AM) → Extra Description

Code 19(AM) → Circle feature (Enter radius in mm)

For eg. Tree can be taken as Code 15, 20100 (20100 is entity & string)

Code 19, 100 (100 is radius of tree in mm)

Code 16, 20500 (20500 is entity & String)

Code 19, 20000 (20000 is radius of spread in mm)

Code 20(AM) → Close of String

For eg. Building(60101) Code 20, 60101

Please note that (BM) means Before Measurement and (AM) After Measurement.

Steps for using TC1700

1. Setup the Instrument (Centering & Leveling)
2. Press **F5(SETUP)**

   Make sure that the following are listed:

   User templ. : User 4

Rec. device : 1 Memory Card
Meas. file : 1 √ FILE01.GSI
Data file : 1 √ FILE01.GSI

3. Then press **F5(STN)**
   And enter the following:
   Station no. : **1** (This is point number)
   Inst. Height : **1.450** m (in meters)
   Stn. Easting : **10000** m (Easting)
   Stn. Northing : **10000** m (Northing)
   Stn. Elev. : **100** m (Elevation or RL)
   Then press **F4(Hzθ)** Sight to North and enter the bearing
   Then press **F3(REC)**
4. Go to press **F6(MEAS)** Make sure the point number is 2
5. Then Press CODE and enter the following:
   Code - **5**
   Info1 - **Station number** (eg. 00300001)
   003 = Station Entity
   00 = String
   001=Station Number
   Info2 - **Instrument Height**, (in mm)
   Info3 - **Target Height**, (in mm)
   And then press **F3(REC)**
6. Then make the **point Id as 2** and start detail Survey.
7. When Detail survey is over, then sight to the New Station.
   Then Press **CODE** and enter the following:
   Code - **6**
   Info1 - **1430** (Height of Next Station)
   Then press **F3(REC), Change the Refl. Height to the same height but in meter**
   Then Press **CODE** and enter the following:
   Code - **10**
   Info1 - **00300002** (Where 003 is Station Entity
   00 is String
   002 is Station Number)
   Then press **F1(ALL)**

Please Note the point number of the station.

8. Setup at the new station, (centering and leveling)
   Then Press **F5(STN)**
   Then press **F4(QSET)**
   Then on the screen:
   For Station Id : Input the number you have noted. (Pt. No. for Stn.)
   Back. Id : In put the point Id for back station.(Pt. No. for back Stn)
   Enter Stn. East, Stn. North. & Stn. Elev. For Station 1. and sight to back station and press
   F2(DIST)
   Then press **(CONT)**, **Twice**.
   Then press **F2(DIST)** to check the East/North/RL
9. Then Press CODE and enter the following:
   Code - **5**
   Info1 - **Station number** (eg. 00300002)
   003 = Station Entity
   00 = String
   002 = Station Number
   Info2 - **Instrument Height**, (in mm)
   Info3 - **Target Height**, (in mm)
   And then press **F1(REC)**
   Then start the detail survey.

The Code to be used are as follows:

Code 5	→	**Instrument Point (New)**
Code 6(BM)	→	**Prism Ht. change**
Code 10(BM)	→	**Measurement to New Station**
Code 14(AM)	→	**Three Point Arc**
Code 15(AM)	→	**Feature Code (Entity number & String)**
Code 16(AM)	→	**Extra Description**
Code 19(AM)	→	**Circle feature (Enter radius in mm)**

For eg. Tree can be taken as	Code 15, 20100 (20100 is entity & string) Code 19, 100 (100 is radius of tree in mm) Code 16, 20200 (20200 is entity & String) Code 19, 2000 (2000 is radius of spread in mm)
Code 20(AM) →	**Close of String**
For eg. Building(60101)	Code 20, 60101

Please note that (BM) means Before Measurement and (AM) After Measurement.

Steps for using TC605L

1. Set up the instrument (Centering & leveling).
2. Then press **MENU** and with ↓ and ↑ keys point to **1. Set Hz** and press **Enter** key. Sight to North or any other R/O and enter the bearing. **ENTR to hold** and when properly sighted **ENTR to release**.
3. The press **CODE** and enter the following.
   Cod: **5**
   In1: **Station number** (e.g. 00300001)
   003 = Station entity
   00 = String
   001 = Station number
   In2: **Instrument height** (in mm)
   In3: **Target height** (in mm)
   Then press **ENTR.**
   ENTR.
4. Make sure that the **Pt**. No. is 1 and start the detail survey.
5. When detail survey is over, sight to the new (foresight) station. Then press **CODE** and enter the following.
   Cod: **6**
   In1: **Height of next (foresight) station in mm**.
   Press **ENTR.**
   ENTR.

Change the reflector height to the same height but in meter by pressing PTNR and entering the height in meter against 'hr' using keys ↓ and ↑.
Then press **CODE** and enter the following.
Code: **10**
In1: **Next (foresight) station** e.g. 00300002
003 = station entity
00 = string
002 = Station number

ENTR
ENTR
Then make sure that the instrument is properly sighted to next (foresight) station (in this case station number 00300002) and press **ALL.**

6. Set up at the new station (centering & leveling).
7. Follow step number 3 (with proper station number, instrument height and target height) for station number 2.
8. **Change the reflector height to the same height but in meter by pressing PTNR and entering the height in meter against 'hr' using ↓ and ↑ keys.** Then press **CODE** and enter the following.
   Code: 7
   In1: Back sight station e.g. 00300001
   003 = station entity
   00 = string
   001 = station number

   ENTR
   ENTR
   Then make sure that the instrument is properly sighted to back sight station No. 1 and press **ALL**. Then carry on with the detail survey.

The CODES to be used are as follows.
Code 5 (BM) - **New instrument point (new set up)**
Code 6 (BM) - **Prism/target height change**

Code 7 (BM) - **Measurement to back sight station**
Code 10 (BM) - **Measurement to foresight station**
Code 14 (AM) - **Three point arc**
Code 15 (AM) - **Feature code (entity number and string)**
Code 16 (AM) - **Extra description**
Code 19 (AM) - **Circle feature (enter radius in mm)**

For e.g. tree can be taken as Code 15, 20100 (201 = entity, 00 = string)
Code 19, 100 (100 = radius of tree in mm)
Code 16, 20500 (205 = entity, 00 = string)
Code 19, 20000 (20000 = radius of spread in mm)

Code 20 (AM) - **Close of string**

For e.g. building (60301) Code 20, 60301

BM = Before measurement AM = After measurement

3.0 BATTER PEGGING SETTING OUT THE ROAD ALIGNMENT

Background

The setting out of batter pegs is being carried out by the Survey and Design Division. Considerable time and resources are have to be dedicated for fixing the batter pegs for construction. More often for various reasons, there is a time gap between the fixing of better pegs on the ground and start of the formation cutting works. Past experiences have shown that during this interim period the batter pegs often get displaced or lost requiring re-fixing. Sparing the services of surveyors from Survey and Design Division is often not possible firstly because of the distant work sites and secondly because of the shortage of surveyors.

To offload some of the activities of the Survey & Design Division, the engineers of Field Divisions have now been trained on batter pegging survey. This is expected to have the following advantages.

- The Field engineers will not have to depend on the services of the surveyors from Survey and Design Division.
- The Field engineers can fix/re-fix the lost/displaced/missing pegs whenever requested at their own convenience.
- The Field Division can plan the batter pegging survey in tune with the pace of construction. It is expected to shorten the time gap between batter pegging survey and formation cutting works.
- Being conversant with the work of batter pegging the Field engineers will be in a better position to implement the construction work in a more expeditions manner.

3.1 Batter pegging survey

This exercise is implemented to physically impose the road design on the ground to carry out the construction works. In other words, it is the positioning of the design on the ground. It is important to realize that setting out or batter pegging is a very important job. Due importance has to be given for setting out better pegs otherwise it will result in errors, causing delays which leave construction machinery and plant idle.

The following information generated in the design are required to carry out the batter pegging survey.

3.2 Station Co-ordinate listing sheet (List A)

This list provides the co-ordinates and the height (x,y,z positions) of each survey stations. The table below is one such list generated in design.

Point	Easting	Northing	Height	Description	
1	50000.000	20000.000	100.000	00300001	0001
45	49976.283	19980.733	103.278	00300002	0054
85	**49935.130**	**19946.191**	**100.764**	**00300003**	**0106**
140	49952.858	19909.461	101.280	00300004	0174

For example in the station co-ordinate list shown above, station number 3 has co-ordinates of 49935.130 E (Easting) and 19946.191 N (Northing) and a height (reduced level) of 100.764 m.

3.3 Center-line Co-ordinate listing sheet (List B)

The list shows the co-ordinates and the heights of design center-line in each chainage. The table below illustrates the same.

Point	Easting	Northing	Height	Description		
466	49990.537	19983.821	100.518	Ch	0.000	0.00
473	49990.315	19983.545	100.506	Ch	0.355	0.00
480	49982.037	19979.115	100.166	Ch	10.000	0.00
487	49973.815	19981.431	99.859	Ch	18.734	0.00

494	49972.975	19982.054	99.822	Ch	19.780	0.00
501	49972.797	19982.184	99.814	Ch	20.000	0.00
509	**49963.392**	**19984.994**	**99.477**	**Ch**	**30.000**	**0.00**
518	49958.331	19983.880	99.353	Ch	35.208	0.00

In the center-line co-ordinate list shown above, chainage 30 has co-ordinates of 49963.392 E, 19984.994 N and a height of 99.477 m.

3.4 Batter co-ordinate listing sheet (List C)

It provides the co-ordinates, heights and the offsets of the design batters from the design center-line in each chainage. Here minus (-) sign indicates towards the left of centerline and plus (+) sign indicates towards the right of the centerline.

Point	Easting	Northing	Height	Description		
463	49992.689	19982.090	100.428	Ch	0.000	-2.76
469	49987.534	19986.237	100.645	Ch	0.000	3.85
470	49993.365	19981.091	100.396	Ch	0.355	-3.91
476	49987.293	19985.977	100.681	Ch	0.355	3.87
477	**49982.568**	**19973.198**	**100.344**	**Ch**	**10.000**	**-5.94**
483	**49981.583**	**19984.172**	**102.739**	**Ch**	**10.000**	**5.07**
484	49970.817	19977.391	98.276	Ch	18.734	-5.03

In the batter list shown above, batter at chainage 10 with 49982.568 E, 19973.198 N and a height 100.344 m has an offset of 5.94 m towards the left of the center-line. Similarly, the batter at chainage 10 with 49981.583 E, 19984.172 N and a height 102.739 m has an offset of 5.07 m towards the right of the center-line.

3.5 Station to station set out listing sheet (List E)

It shows the horizontal bearing, horizontal distance and height difference of one station from the other station. Here minus (-) sign indicates that the other station sighted is at a lower elevation than the station you are positioned at. Likewise, the (+) sign indicates otherwise.

Scale Fac 1.0	Bearing	Horiz dist	Diff in Ht	Description	
1 to 45	230°54'35"	30.557	3.278	00300002	0054
45 to 1	50°54'35"	30.557	-3.278	00300001	0001
85 to 140	154°14'05"	40.785	0.516	00300004	0174
140 to 85	334°14'05"	40.785	-0.516	00300003	0106
140 to 168	**211°19'36"**	**33.482**	**-1.462**	**00300005**	**0206**
168 to 140	31°19'36"	33.482	1.462	00300004	0174
214 to 232	284°24'30"	33.437	3.462	00300007	0281
232 to 214	104°24'30"	33.437	-3.462	00300006	0259

We know from station co-ordinate listing sheet (List A) that point 140 is station number 4 and point 168 is station number 5. The above setout list shows that the horizontal bearing of station 4 to 5 is 211° 19’ 36’’ and they are 33.482 m distant apart horizontally. Station 5 is at a lower elevation (of 1.462 m) than station 4.

3.6 Station to center-line set out listing sheet (List F)

It shows the horizontal bearing, horizontal distance and height difference from the particular station to that particular chainage of centerline. Here minus (-) sign indicates that the design center-line is at a lower elevation than the station and the (+) sign indicates that design center-line is at a higher elevation than the station.

Scale Fac 1.0	Bearing	Horiz dist	Diff in Ht	Description		
1 to 466	210°19'23"	18.743	0.518	Ch	0.000	0.00
1 to 473	210°28'48"	19.094	0.505	Ch	0.355	0.00
1 to 480	220°41'55"	27.547	0.166	Ch	10.000	0.00
1 to 487	234°39'28"	32.101	-0.141	Ch	18.734	0.00
1 to 494	236°24'50"	32.441	-0.178	Ch	19.780	0.0
1 to 501	**236°46'41"**	**32.518**	**-0.186**	**Ch**	**20.000**	**0.00**

From station co-ordinate listing sheet (List A), we know point 1 is station number 1 and from center-line co-ordinate listing sheet (List B), point 501 is center-line chainage 20. So, the horizontal bearing from station 1 to chainage 20 is 236° 46’ 41’’ with a horizontal distance of 32.518 m between them. Design center-line 20 is at a lower elevation of 0.186 m than station 1.

3.7 Station to batter set out listing sheet (List G)

It shows the horizontal bearing, horizontal distance and height difference from the particular station to that particular design batter. In column 4 (diff in ht) minus (-) sign indicates that the design batter is at that particular chainage is at a lower elevation than the elevation of the station and the (+) sign indicates that design batter is at a higher elevation than the elevation of the station. In column 6 minus (-) sign indicates the offset of the design batter is at that particular chainage is towards the left side of the center-line and (+) sign indicates that batter offset is towards the right side of the center-line. °

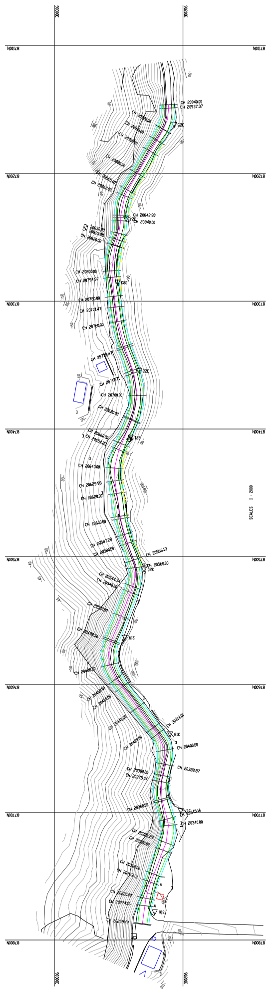
Scale Fac 1.0	Bearing	Horiz dist	Diff in Ht	Description		
1 to 463	202°12'22"	19.345	0.428	Ch	0.000	-2.76
1 to 469	222°10'13"	18.569	0.645	Ch	0.000	3.85
1 to 470	199°20'03"	20.040	0.396	Ch	0.355	-3.91
1 to 476	222°10'55"	18.924	0.681	Ch	0.355	3.87
1 to 477	**213°02'26"**	**31.972**	**0.344**	**Ch**	**10.000**	**-5.94**
1 to 483	**229°19'26"**	**24.283**	**2.739**	**Ch**	**10.000**	**5.07**

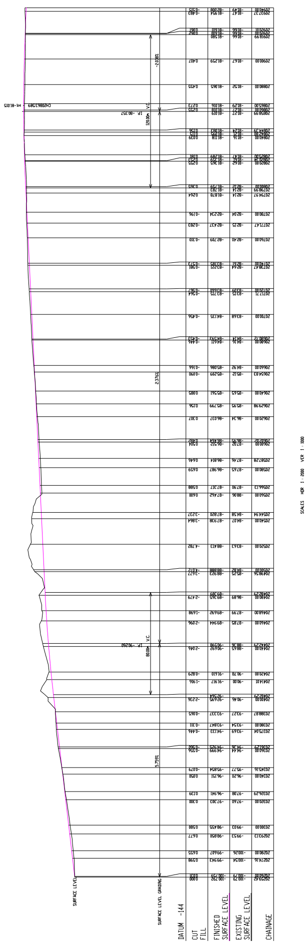
We find out from station co-ordinate listing sheet (List A) that point 1 is station number 1 and from batter co-ordinate listing sheet (List C) that points 477 and 483 are left and right batters at chainage 10 with left offset and right offsets from center-line of 5.94 m and 5.07 m respectively. The above setout data indicates that the bearing from station 1 to left batter (point 477) at chainage 10 is 213° 02’ 26’’ with a horizontal distance of 31.972 m between them and the batter point is 0.344 m higher than the station point. Similarly, the bearing from station 1 to right batter (point 483) at chainage 10 is 229° 19’ 26’’ with a horizontal distance of 24.283 m between them and the batter level is 2.739 m above the station.

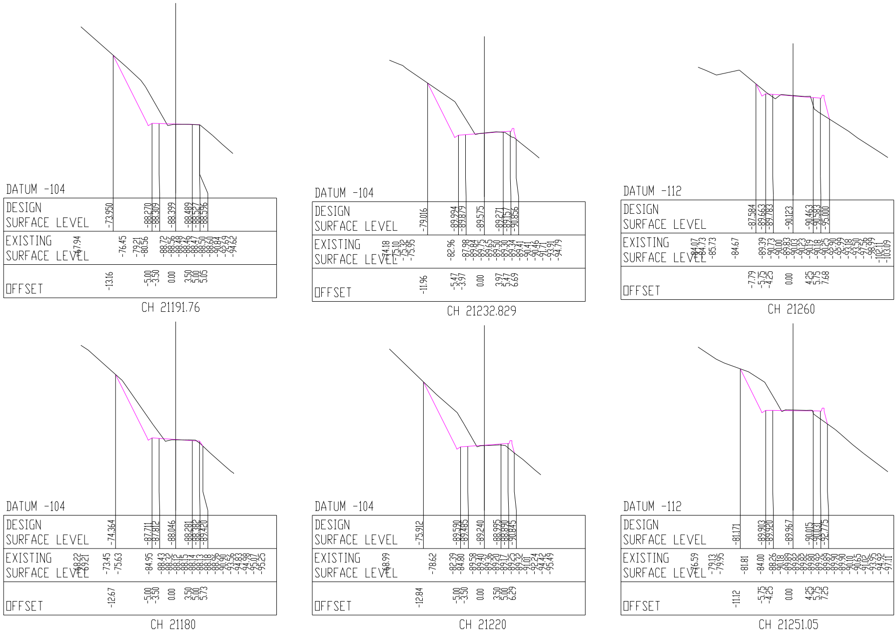
3.8 Design drawings

The design drawings comprise of the plan, longitudinal section and cross section of design. The plan shows the horizontal alignment of the road (center-line, pavement edge, shoulder edges, etc.). The longitudinal section shows the vertical alignment of the road (vertical curves, road grades, design and existing surface levels, cut and fill at each chainage along the center-line). The cross section drawings show the cross section at each chainage with the design and existing levels and offsets from the center-line.

The typical plan, L-section and cross sections of a design are as given below.

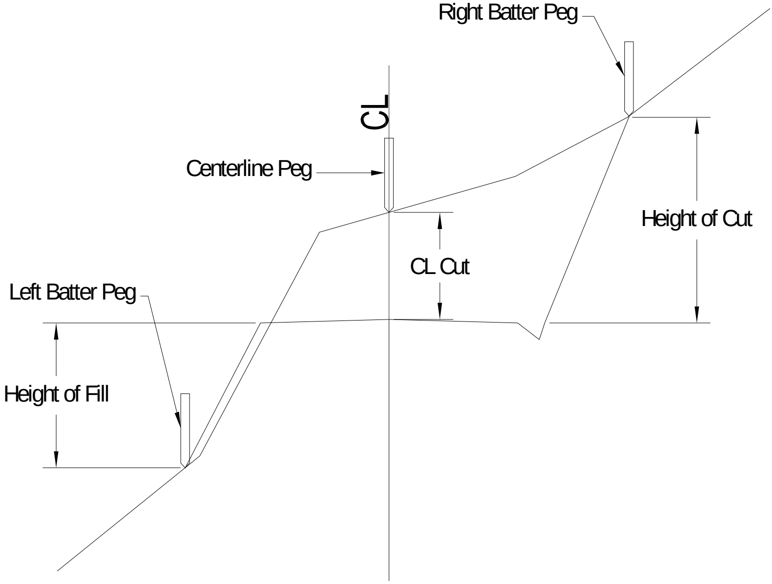






The information described above is used to provide the following information on the setout pegs.

1. Chainage
2. Height of Cut or Fill
3. Slope (if possible)
4. Offset from the center-line (in case of batter)



Typical setout of road design on the ground
Fig 1

The above diagram (Fig 1) shows the pegs to be fixed at the site at each cross section. The pegs should be fixed at 20 m interval on straight sections and at 5m on the curve sections (especially at the hairpin bends).

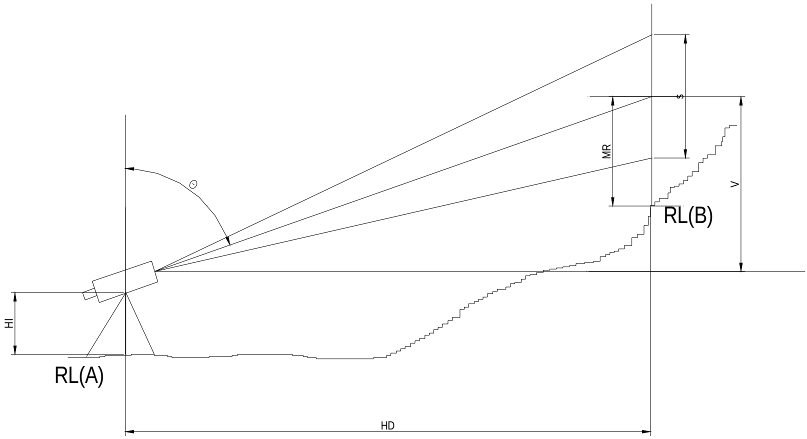
This job can be done by using a simple Theodolite or the Total Station. Of the two, Total Station provides a better and faster result.

Normally, with the type of information available above, the batter fixing can be done in two way using 1)co-ordinates (Easting, Northing), or 2) the bearings. With Total Stations, batter pegging can be carried with both methods. However, in the case of theodolite it is easier and convenient to conduct with bearings.

Generally, the following batter slopes are recommended for various soil classifications.

Hard rock	1V: 0.12H
Soft rock	1V: 0.25H
Hard soil	1V: 0.50H
Ordinary soil	1V: 1H

A brief description on the use of theodolite to obtain the distances and levels is explained below.



Where HD = Horizontal distance

θ = Observed vertical angle (zenith angle)

MR = Middle wire Reading

S = Stadia intercept

HI = Height of Instrument

Formulas to find HD, VD, RL(A) & RL(B) by theodolite

$HD = 100 * S * Sin^2 \theta$

$VD = 50 * S * Sin\ 2\theta$

To find the RL at (B) with RL at (A) known

RL(B) = RL(A) + HI + V –MR

If the position of B is at a lower level than A, the value of V will be negative, so take negative sign for V in the formula.

RL(B) = RL(A) + HI - V – MR

3.9 Worked out example

Assume the two stations 1 and 2 are known. It is a must to know the locations of at least two stations visible from each other. If the person carrying out the batter pegging was not involved during the detail survey, a help of the plan is taken to locate out the stations.

We will start at station number 1 and carry out the setting out from there. Center and level the theodolite at station number 1. Measure the height of the instrument. Place your staff vertically on the top of the station number 2. Now from station to station setout list, you know the horizontal bearing of station 1 to 2 is 230° 54’ 35’’. Sight the theodolite onto the staff placed over station number 2 and set the horizontal bearing to 230° 54’ 35’’.

Now to fix the center-line of say, chainage 10 follow the following steps.
You know from station to centre-line setout list that the horizontal bearing from station 1 to chainage 10 is 220° 41’ 55’’ and the horizontal distance them is 27.547 m with chainage 10 higher by 0.166 m. Rotate the theodolite and fix it at 220° 41’ 55’’ Hz. That is the direction at which the design center-line chainage 10 is located. Having fixed the theodolite at this HZ bearing, sight the staff along this line of sight and obtain the readings θ and S. Using the horizontal distance formula given above, calculate the HD. Depending upon whether the distance is lesser or greater than 27.547 m, move the staff either back or forth as the case may be till you obtain a HD of 27.547 m. The location where the HD is 27.547 m is the position of center-line of chainage 10. Peg this point. Now from the L-section, you will find that the height of cut at this chainage is 1.534 m (Existing level – design level). Provide the following information on the peg.

1. Centre-line (CL)
2. Chainage (CH 10)
3. Height of cut or fill (C 1.534 m) or if it is fill, the letter F is used

Likewise, you can follow the same steps to locate the left and right batters at chainage 10. You will notice that batter on the left of the centre-line has 213° 02’ 26’’ Hz with horizontal distance of 31.972 m and offset from centre-line is 5.94 m and the right batter has 229° 19’ 26’’ Hz with horizontal distance of 24.283 m and offset from centre-line is 5.07 m. You will find from the cross section at chainage 10 that the height of the cut at the right batter is 2.656 m (Design level at the batter point – design level at the shoulder/drain edge = 102.739 – 100.083 = 2.656 m). Similarly, the height of cut at the left is 0 m (100.344 – 100.344 = 0 m). The batter slopes can be leveled accordingly depending upon the classification of soil or as provided by the Survey and Design Division. Provide the following information on the batter pegs.

Right batter peg

1. Batter Peg (BP)
2. Chainage (CH 10)
3. Offset (O/S 5.07 m)
4. Height of cut or fill (C 2.656 m)
5. Slope (if possible)

Left batter peg

1. Batter Peg (BP)
2. Chainage (CH 10)
3. Offset (O/S 5.94 m)
4. Height of cut or fill (C or F 0 m)
5. Slope (if possible)

The design data will contain the following:

1. Station Co-ordinate listing sheet
2. Centre line Co-ordinate listing sheet
3. Batter Co-ordinate listing sheet
4. Station to Station Set-Out listing sheet
5. Station to Centre line set-out listing sheet
6. Station to Batter setout listing sheet
7. Design Drawings

4.0 FIELD DESIGN PROCEDURE ON BLIND CURVE IMPROVEMENT

Most of the length of hill roads have to be laid on curves, some of which are very sharp which pose risks to road users. Blind curve improvement is one of the important goals of the Department of Roads for achieving the long term policy of reducing travel time, to minimize road user cost and to enhance the safety of road users.

Blind curves are those curves on which the available sight distance is less than that required for the vehicle to come to a halt before colliding. By and large, minimum sight distance is essential from the safety point of view and should be ensured regardless of any other consideration. Normally a blind curve needs to be improved by way of cutting the hillside.

The Pavement Design Unit of S&D has developed a simple and practical field design method for blind curve improvement. This method which is based on the theory of stopping sight distance had been tested once at Rabuna under Field Division (FD) Lobeysa and FD Tashigang. It was found that this method though quite laborious is fairly reliable and may therefore be adopted until other improved methods can be developed.

4.1 Sight Distance

The safe and efficient movement and operation of vehicular traffic on roads which depends on the longest distance a driver can see in front of him at any instance, is termed as ***sight distance***. It is imperative that for safe driving, certain minimum sight distance shall be required. Generally three types of sight distances are commonly provided. They are:

i) Safe stopping sight distance
ii) Safe passing sight distance
iii) Safe sight distance at intersections

All the above sight distances depend on the ***reaction time*** of the driver i.e. the time required to avoid dangerous situation by way of accelerating, decelerating or stopping of the vehicle and most important of all, the reaction time depends on the speed of the vehicle. The total reaction time is basically generated from the famous ***PIEV theory***.

P = Perception time; time required for transmission of the sensation to the brain.
I = Intellection; formation of new thoughts and ideas.
E = Emotion; result of intellection like fear or anger based on the situation.
V = Volition; the actual act of taking decision to produce action.
The total time required for PIEV is called reaction time. This could vary from ***0.5 seconds for simple situations to 4 seconds for complex situations***. The reaction time depends on conditions of driver and environment i.e. his habits, skills, judgment and environmental conditions like climate, season, weather, time of day and influence of alcohol etc. ***However a total reaction time of 2.5 seconds is recommended by IRC.***
This manual, deals only with Safe Stopping Sight Distance which will be the basis for design of blind curve improvement

4.1.1 Safe stopping sight distance

The distance required by a driver to bring the vehicle to a stop before meeting a stationary object on his way is called safe stopping sight distance. This will be equal to the sum of distance traveled during the reaction time (sometimes called lag distance) and the braking distance which is the distance required to bring the vehicle to a stop after the brakes have been applied.

4.1.2 Safe Stopping Sight Distance Analysis.

Stopping sight distance = lag distance + braking distance
Lag distance ***(LD)***
Let v = speed of the vehicle in m/s

t = total reaction time in seconds

$\therefore$ Lag distance (LD) = $v\,t$ meters

When speed is expressed in Km/h

$$LD = \frac{V * 1000}{60 * 60} t$$

= 0.278 Vt meters

Braking distance ***(BD)***

The vehicle of mass m in motion at speed v m/s possess kinetic energy = ½ $\boldsymbol{mv^2}$

The change in kinetic energy to bring the vehicle to a stop is equal to the weight of the vehicle (W) multiplied by braking distance (d) and lateral friction (f) between the tyre and the pavement.

$$\frac{1}{2} mv^2 = \frac{1}{2}\frac{W}{g} v^2 = Wfd$$

$$\frac{Wv^2}{2g} = Wfd$$

$$d = \frac{v^2}{2gf}$$

When speed is expressed in Km/h and gravity g is taken as 9.81 m/s^2

$$d = \frac{v^2}{254 f}$$

Hence stopping sight distance (SSD) = LD + BD

$$d = 0.278Vt + \frac{V^2}{254 f}$$

Where V = speed in Km/h

t = reaction time in seconds

f = coefficient of friction (refer table 8.1)

When the vehicle is on slope, we have to consider the component of gravity in terms of gradient i.e. n vertical to 100 horizontal. The vertical component helps in stopping the vehicle when it is going up and tends to push while it is going down. Therefore the stopping sight distance is modified as

$$d = 0.278Vt + \frac{V^2}{254(f \pm n)}$$

Where d = stopping sight distance in meters
V = speed in Km/h
f = coefficient of friction (refer table 8.1)
n = gradient in % (+n when the vehicle is going up and –n for down)

Since the stopping sight distance (d) with –n value gives higher sight distance, we will always use

$$d = 0.278Vt + \frac{V^2}{254(f - n)}$$ for the field design of blind curves.

The gradient (n) of can be checked by any leveling instrument or theodolite.

For example
R_L of point A (instrument point) = 100m
R_L of point B (staff point) = 101m
Horizontal distance between A to B = 20 m

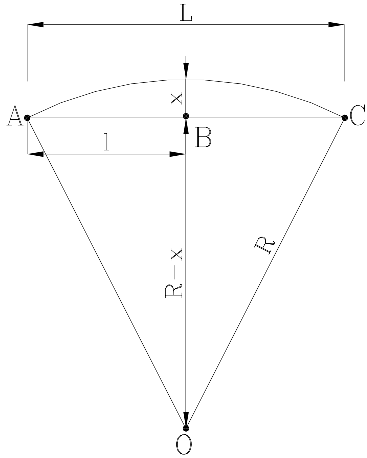
$\therefore$ Gradient at A of B = $\left(\frac{101-100}{20}\right)$

$= \frac{1}{20}$

Or $\frac{1}{20} * 100 = 5\%$ ------------------(I)

4.2 Design Speed On Curves

In order to find out the design speed on curves, we should determine the radius and super elevation of the curve. The radius of the curve can be determined by Chord and Offset method.



Let L = length of the chord of any length

l = L/2

x = offset distance

R = Radius of the curvature

∴ from Δle ABO

$$R^2 = l^2 + (R - x)$$

$$R^2 = l^2 + R^2 + x^2 - 2Rx$$

$$2Rx = l^2 + x^2$$

$$R = \left(\frac{l^2 + x^2}{2x}\right)$$

The super elevation at the curve can be measured in a manner similar to that for checking the road gradient but along the transverse section of the road. The design speed can be computed with the relationship.

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

$V = \sqrt{(e + f) * (127 * R)}$ ------------------------ (II)

Where e = Super elevation in %
f = Coefficient or side friction = 0.15
V = Speed in Km/h
R = Radius in m

The design speed based on radius of curvature can be calculated with the help of equation (II) or can be directly read off from the graph in Fig 2.

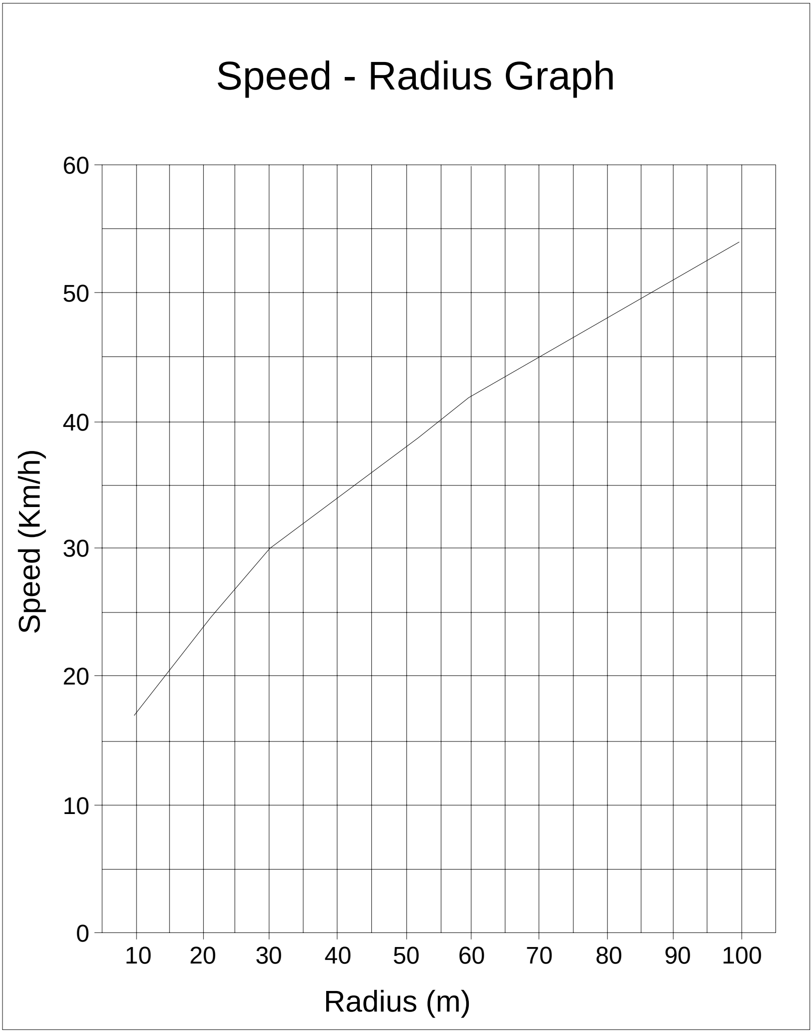


Fig 2.

Knowing the speed (V), the required sight distance for various road gradients can be calculated with the help of equation (I) or can be read off from the following graph, in Fig 3. If widening/cutting becomes uneconomical it would be better to opt for box cutting or through cut.

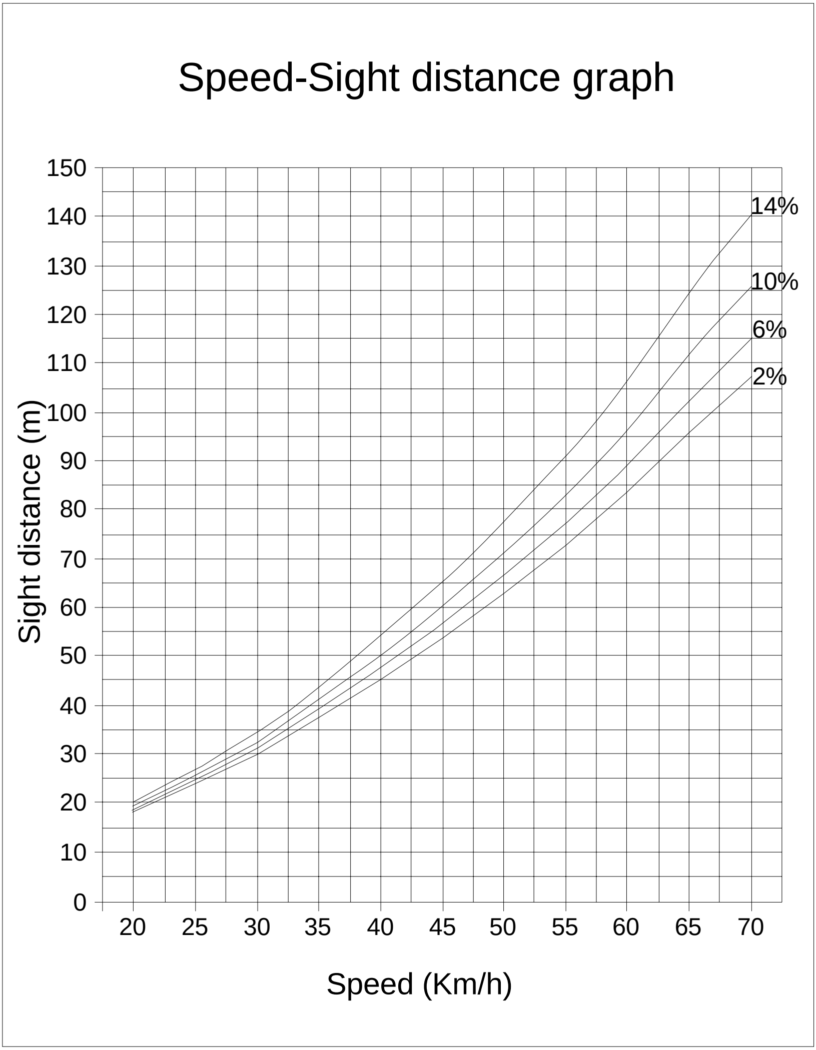

Speed-Sight distance graph
Sight distance (m)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
20
25
30
35
40
45
50
55
60
65
70
Speed (Km/h)
14%
10%
6%
2%

Fig 3

4.3 Steps To Fix The Pegs/Cutting Point

Instruments required

1. Theodolite (if possible with diagonal eye piece)
2. Leveling staff (4m)
3. 30 m measuring tape
4. Scientific calculator
5. Scale, protractor graduated in degrees
6. Graph sheets, pencil and erasers.
7. Planimeter

Step 1

Identify the horizontal curve required for widening

Step 2

Determine the radius of the curve as explained earlier

Step 3

Select the instrument point, preferably at the crest of a curve, so that both the road approaches of the curve are visible. Set the instrument on the selected point. Measure the height of the instrument.

Step 4

Determine the gradient of the steepest section of the road near the curve area. Similarly find out the maximum super elevation of the curve.

Step 5

Plot both edges of the road by the method explained below.

Select a reference point (any sharp point). You may also create the reference point by fixing a peg at a suitable location. Bisect the reference point and adjust the horizontal angle approximately to 0° 0’0”. Pick up all the required road edge points by reading from the staff.

For this the following observations are to be recorded in the format (A) attached.

Horizontal angle
Vertical angle
Top wire reading (T)
Middle wire reading (M)
Bottom wire reading (B)

Step 6
Complete all the calculations as outlined in format (A)

Step 7
Plot the instrument point and all the road edge points on the graph sheet with the help of horizontal angle and distance calculated in format (A). Plot reference line as well. Find out the existing sight distance from the graph and mark it by a straight line (Centre to centre of road).

Step 8
Measure the existing sight distance of the curve by tape. The result can be compared with the sight distance obtained from the graph. See Fig (A) for consistency.

Step 9
Calculate the required sight distance by using equation (I) or it can be obtained directly from the graph for a given gradient.

Step 10. See fig (A)
With the help of a scale, fit the required sight distance on the graph parallel to the existing sight distance i.e. towards the hill side where cutting is required. With the mid point of required sight distance line as tangent, draw a free hand curve or by using radius template if available. On the free hand drawn curve, identify the peg points at an interval of desired spacing. See 1 to 5 as shown in Fig (A).

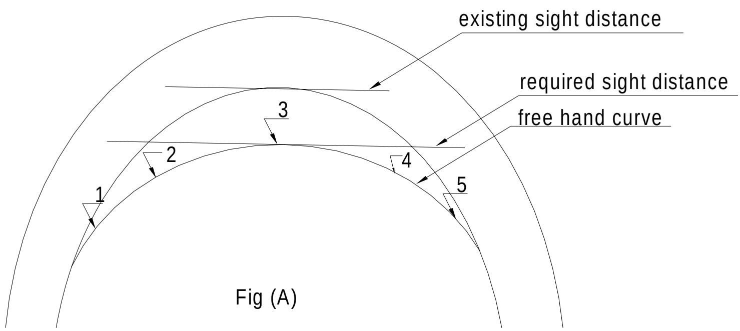


Fig (A)

Step 11

Measure the distance of all the peg points from the instrument point and horizontal angles with respect to the reference line. Note down all the measurements.

Example:

Let the distance and horizontal angle of peg point 1 be 45m and 45° 0'0" respectively. Re-sight the theodolite to reference point and adjust the horizontal angle to 0° 0'0" if required. Rotate the instrument to required angle (for this case 45° 0'0"). Direct the staff man along that line of sight and find out the required distance (in this case 45m) by using trigonometric formula given in format (A). Similarly fix all the pegs temporarily.

Plotting of Cross-Sections

It is advisable to plot the cross section against each peg that is fixed temporarily. Stepping method is recommended for this work. With the help of a pole and tape, measure the x and y distances as shown below. Note down these values in format (B)

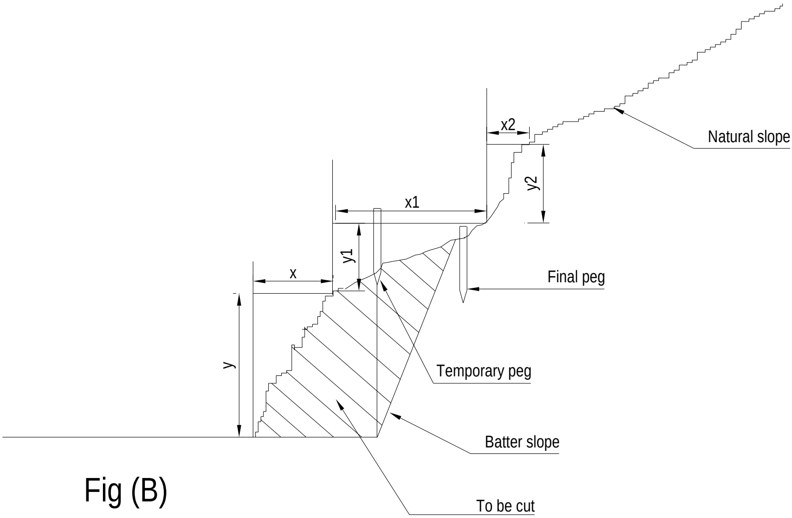


Fig (B)

Stepping method for all the pegs should depict the existing slope surface, well beyond temporary pegs. For a particular cross-section, plot the existing surface and temporary peg point with the values of x and y. Draw a vertical line down through the temporary peg and extend the road level line to meet the vertical line. (Refer Figure B). The section enclosed by the vertical line, extended road level line and existing surface is to be cut which is without batter slope.
Provide the batter slope as per soil classification
Recommended batter slopes

Hard rock	1V: 0.12H
Soft rock	1V: 0.25H
Hard soil	1V: 0.50H
Ordinary soil	1V: 1H

After batter slopes are incorporated, final peg point can be determined. Measure either the slope or the horizontal distance between the temporary peg and the final peg point on the graph. Shift all the temporary peg points to final peg points to the hillside as per requirement.

Earth work quantities

The earthwork volume may be computed by end average area method, which is given by

$$V = \left(\frac{A1 + A2}{2}\right) * L$$

Where V = Volume of earth (m^3)
A1 = Area of 1^{st} cross-section (m^2)
A2 = Area of 2^{nd} cross-section (m^3)
L = Length between A1 & A2 in (m)

Note: Areas of cross-sections can be determined by planimeter or by other suitable methods. Excess earthwork for provision of super elevation can also be incorporated in cross sections by maintaining a super elevation of 8% transversely.

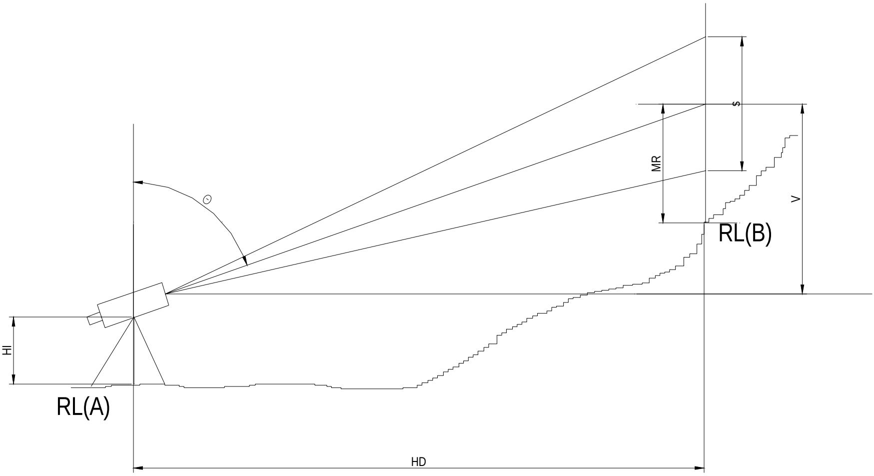
Format (A)
Name of Road:
Location :
Date :

STN #	Pt	Hoz. Angle	Vert. Angle (θ)	Top (T) Staff	Mid. (M) Staff	Bot. (B) Staff	S=(T-B)	Hor. Dist $100 x S x Sin^2\theta$

Cross-Section Point: **FORMAT (B)**

Step No.	**X**	**Y**	**Remarks**

Some useful trigonometric formulas



Where HD = Horizontal distance
θ = Observed vertical angle (zenith angle)
MR = Middle wire Reading
S = Stadia intercept
HI = Height of Instrument

Formulas to find HD,V,RL(A) & RL(B) by theodolite

$HD = 100 * S * Sin^2 \theta$

$V = 50 * S * Sin\ 2\theta$

To find the RL at (B) with RL at (A) known

RL(B) = RL(A) + HI + V –MR

If the position of B is at lower level than A, the value of V will be negative, so take negative sign for V in the formula.

Table 8.1

Speed Km/h	20	25	30	40	50	60	65	80	100
Friction coefficient	0.40	0.40	0.40	0.38	0.37	0.36	0.35	0.35	0.35

5.0 GEOMETRIC DESIGN

General

Geometric design on hill roads has to be carefully done to align the road to provide comfort and safety. The following parameters have to be considered for design.

1. Classification of Road
2. Design Speed
3. Horizontal Alignment
4. Formation & Cross Section
5. Sight Distance
6. Super elevation
7. Vertical Alignment
8. Grade

Environment friendly approaches have been adopted in the geometric design through optimization of cut and fill involved in the earthworks. Environment friendly road design aptly demonstrates that a slight shift of the centerline to the valley side can result in substantial reduction of earthworks and height of hill side cut.

5.1 Classification of Road

The roads in Bhutan are classified as follows:

- i) Express Way
- ii) National Highway
- iii) Dzongkhag Road
- iv) Feeder Road
- v) Forest Road
- vi) Farm Road
- vii) Urban Road

The Urban Road is further sub-divided into the following:

- a) Primary Road
- b) Secondary Road
- c) Access Road
- d) Other Road

The classification and standards of urban roads can be found in the URBAN ROADS STANDARDS 2002 published by the Standard & Quality Control Authority.

5.1.1 Terrain Classification

1)	Plain	-	0 to 10º
2)	Rolling	-	10ºto 25º
3)	Mountainous	-	25º to 60º
4)	Steep	-	Greater than 60º

5.2 Design Speed

While driving along a road the drivers drive at a certain speed at which they feel that they can overcome any possible obstruction. The speed at which a driver feels most comfortable is considered as the design speed.

The class of the road and the terrain influence the design speed for the particular section of the road. The following design speeds are recommended to be used for design.

Class of Road	Minimum Design Speed KM/Hr. for Terrain Type (Minimum Curve Radius in meter)			
	Plain	Rolling	Mountainous	Steep
Express way	80 (280)	70 (200)	60 (120)	50 (75)
National Highway	80 (280)	70 (200)	60 (120)	50 (75)
Dzongkhag Road	70 (200)	60 (120)	50 (75)	40 (45)
Feeder Road	50 (75)	40 (45)	30 (25)	20 (15)

5.3 Horizontal Alignment

The horizontal alignment of a road comprises of usually a series of straight and circular curves connected by the transition curves.
The radius of the curve is determined by the formula given below.

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

Where	e	=	super-elevation
	f	=	Coefficient of side friction
	V	=	Speed in Km/Hr.
	R	=	Radius in meter

The maximum super-elevation of 0.08 (8%) may be adopted in the steep sections and 0.07 (7%) in flat section.
The maximum value of the coefficient of side friction varies from 0.19 at 20 to 40 Km/hr., down to 0.12 at 100 km/hr.

$$(\deg ree) = COS^{-1}\frac{(R-m)}{(R-n)}$$

	D	=	2Θ (R – n) Where Θ is the radians
Where	D	=	The sight distance measured around the curve between two points n meters on the inside of the pavement centerline.
	R	=	the radius of the pavement centerline
	m	=	the offset distance from the pavement centerline to the line of sight obstruction
	n	=	the distance from the pavement centerline to the centre of the inside lane
	Θ	=	Half the angle subtended by the line of sight

The minimum radius of horizontal curves to the design speed is as follows

Sl. #	Design Speed Km/Hr.	Radius
1	20	15
2	30	25
3	40	45
4	50	75
5	60	120
6	70	200
7	80	280

5.4 Formation & Cross Section

5.4.1 Formation

The width of the pavement and formation is determined by the lane width which depends on:

- The dimension of the vehicle
- Speed of travel
- Traffic volume
- Width of shoulder

The desirable minimum width is 3.5 m and this is adopted as the standard width for the single lane and for two lanes the minimum width is 3.0 m for one lane.

The shoulder is measured from the pavement edge to the end of the usable formation. Wide shoulders have the following advantages:

- Space is available for vehicle to stand clear of the pavement.
- Space is available to avoid colliding with other vehicles and to regain control of vehicle.
- In cuttings on curves a wide shoulder gives a longer sight distance.
- The shoulder can be used for widening the road without cutting in future to widen the road

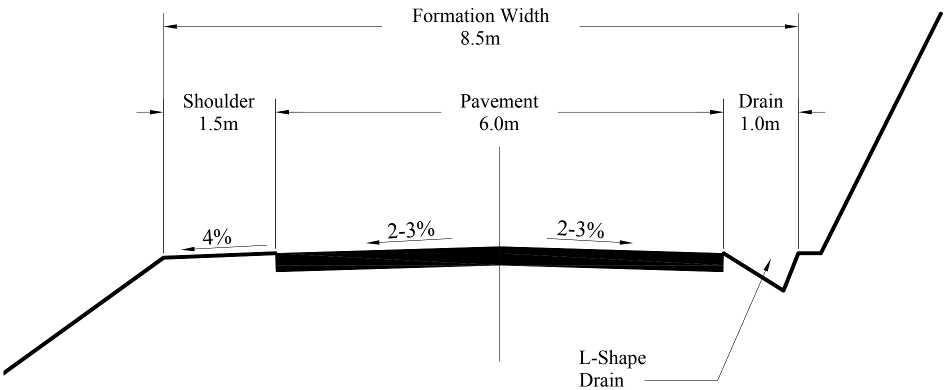
ROAD CLASS (Design traffic volume)		DESIGN FORMATION
National Highway (Double Lane)	Pavement Shoulder Drain (On hill side) Formation	6.0 1.5 X 1 1.0 8.5
National Highway (Single Lane)	Pavement Shoulder Drain (On hill side) Formation	3.5 1.5 X 2 1.0 7.5
Dzongkhag Road (Single Lane)	Pavement Shoulder Drain (On hill side) Formation	3.5 1.0 X 2 0.6 6.1
Feeder Road (Single Lane)	Pavement Shoulder Drain (On hill side) Formation	3.5 0.5 X 2 0.6 5.1

- Forest Road – Refer Forest Road Manual published by EFRC-SP
- Farm Road – Refer Farm Road & Power Tiller Track Manual published by EFRC-SP
- Urban Road – Refer URBAN ROADS STANDARDS 2002 published by the SQCA.

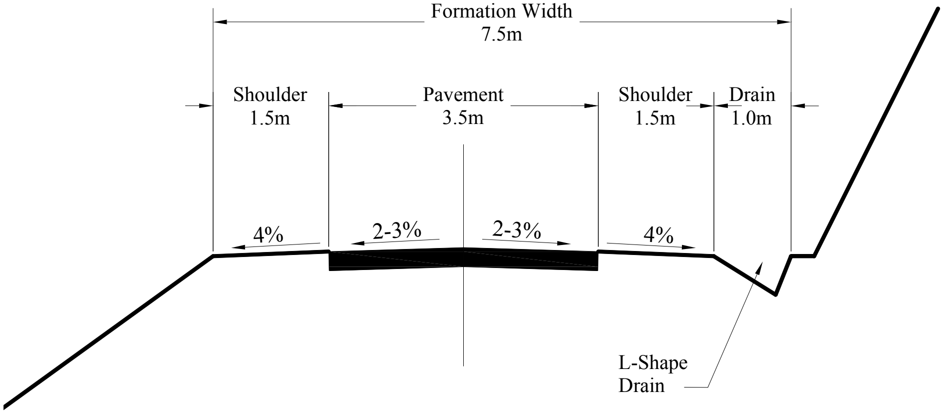
5.4.2 Cross Section

Crossfall is the slope of the surface of the formation/carriageway measured at right angle to the horizontal alignment. The crossfall is required to drain out the surface water from the carriageway.

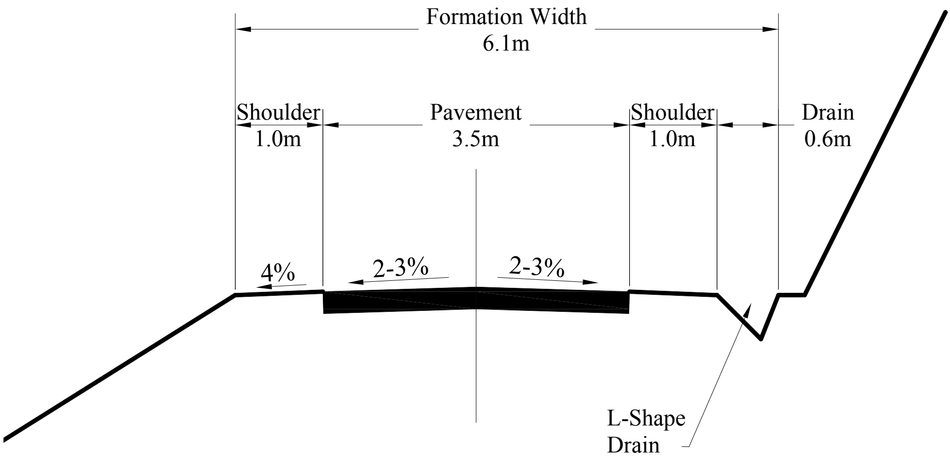
MATERIAL SURFACE TYPE	PAVEMENT CROSSFALL	SHOULDER CROSSFALL
Earth, Loam	5 %	6 %
Gravel, Waterbound Macadam	3 - 4 %	5 %
Bitumen seal coat	2.5 - 3 %	4 %
Dense bituminous premix or ridge pavement	2 – 3 %	3 %



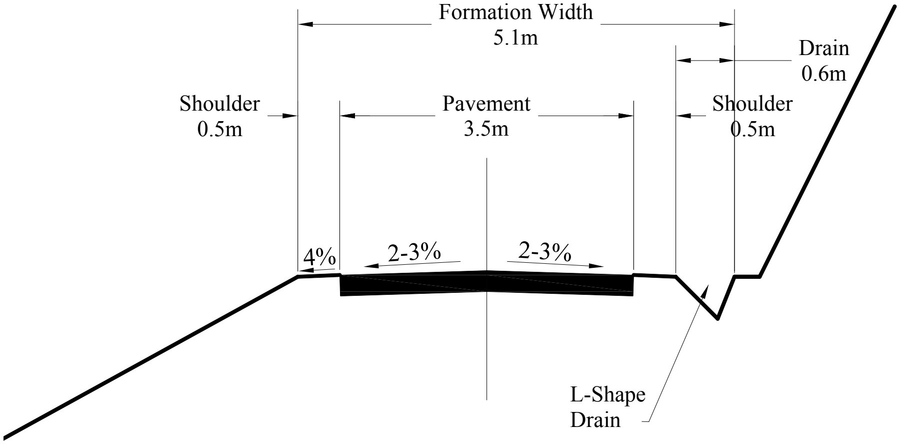
National Highway (Double Lane)



National Highway (Single Lane)



Dzongkhag Road (Single Lane)



Feeder Road (Single Lane)

5.5 Sight Distance

Sight distance is the distance at which the driver of a vehicle can see an object of specified height on the road ahead of him. The following constants have been adopted for sight distance.

• Total reaction time	2.5 seconds
• Height of vehicle oncoming	1.15 m
• Height of object on road	200 mm
• Height of headlamps above road	750 mm
• Beam of headlight	one degree upward from grade of road

5.5.1 Stopping sight distance

Stopping sight distance provides stopping distance for a driver approaching the object on the road. The stopping distance can be calculated using the formula.

$$Ds = 0.7V + \frac{V^2}{245f}$$

Where

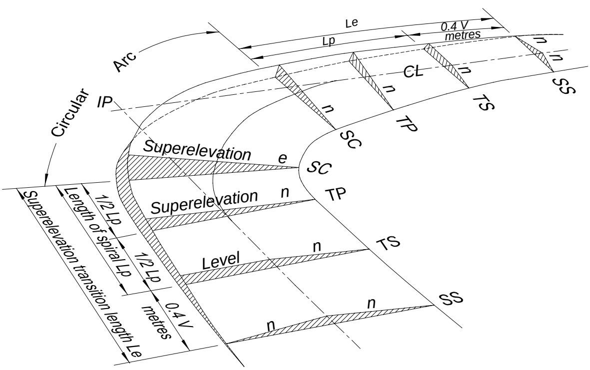
Ds	=	Stopping distance (m)
V	=	Speed of vehicle (Km/Hour)
F	=	Coefficient of friction

The following table shows stopping distance (rounded up) value against the speed and the coefficient.

DESIGN SPEED Km/Hr.	Coefficient of Friction	Stopping Distance (m)
20	0.56	15
30	0.54	25
40	0.52	40
50	0.50	60
60	0.47	80
70	0.45	100
80	0.43	120

5.6 Super-Elevation

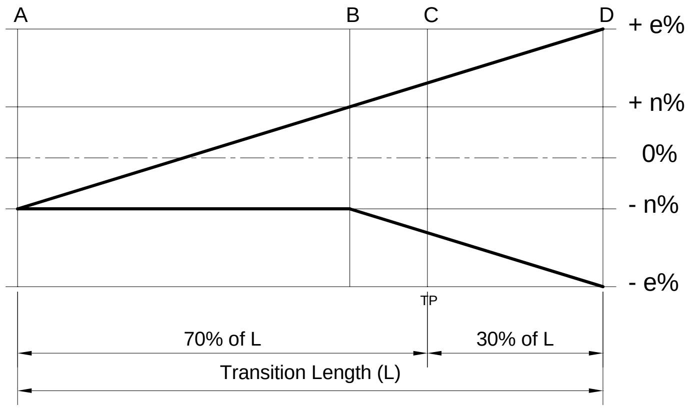
The figure shows the method of development of super elevation and horizontal curve transitions. It also shows the positioning of transitions.



LEGEND

IP	Point of intersection of the main tangents
TS	Tangent Spiral, common point of tangent and spiral
TP	Tangent point, common point of tangent and Circular curve
SS	Start of super-elevation transition
SC	Spiral curve, common point of spiral and circular curve
Lp	Length of spiral between TS and SC
La	Length of super-elevation transition
n	Norma pavement crossfall – tangent of angle
e	Pavement super-elevation – tangent of angle
V	Design speed (Km/Hr.)

The super-elevation transition commences at the point SS, 0.4V m from the TS along the straight, and ends at the point SC. The pavement crossfall on the outer lane changes uniformly from normal, n, sloping towards the outside shoulder of the curve, to a super-elevation n (the same crossfall as the normal section) sloping towards the inside shoulder of the curve, over the distance of 0.4V + Lp, from SS. For the remainder of the transition the crossfall changes uniformly on both traffic lanes to the maximum value e as calculated. We can use the figure below to calculate the location also.



The locations of the points for super-elevation are as follows:

A	=	Location of normal crossfall – (-n%, -n%)
B	=	Location straight crossfall - (-n%, +n%)
C	=	Tangent Point
D	=	Location of full super-elevation – (-e%, +e%)
AC	=	70% of L

$$AB = \frac{2n}{e+n} * L$$

Where n = normal crossfall

e = maximum super-elevation

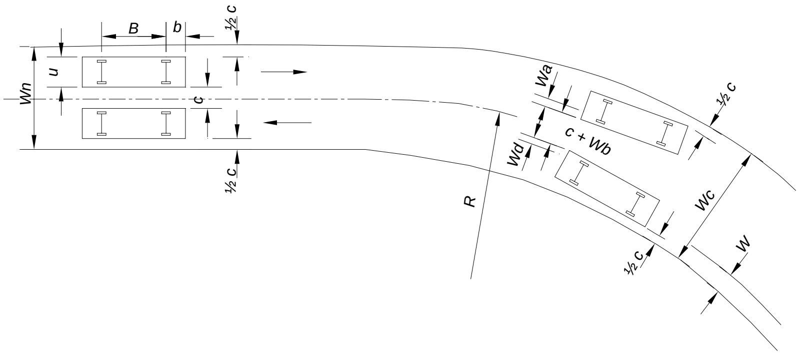
$$BD = \frac{e-n}{e+n} * L$$

L = Transition length

The calculation for this chainage points can be tedious, so a Qbasic programme has been developed by the Survey & Design Division called:

a) Urban.Bas for urban roads
b) Double.Bas for National Highway Double Lane.
c) Highway.Bas for National Highway Single Lane
d) Dzongkhag.Bas for Dzongkhag Roads
e) Feeder.Bas for Feeder Roads

5.6.1 Widening



BASIC FORMULA

Wa = $R-(R^2-B^2)^{½}$
Wb = $VR^{-1/2}$
Wd = $(R^2 + b[2B + b])^{½} - R$
Wc = $2Wa + Wd + Wb + 0.002c + 2u$
= $R - 2(R^2 - B^2)^{1/2} + (R^2 + b[2B + b])^{1/2} + VR^{-1/2} + 0.002c + 2u - Wn$
W = Wc – Wn

Where

W = widening for two lane pavement on curve (m)
Wa = distance rear wheels track inside front wheels on curve (m)
Wb = extra width allowance for difficulty of driving on curves (m)
Wc = width of two lane pavement on curve (m)
Wd = additional width of front overhang of vehicle on curve (m)

Wn	= width of two lane pavement on tangent (m)
B	= Wheelbase of vehicle (m)
R	= radius of center line of two lane pavement (m)
V	= design speed for curve radius (Km/hr.)
b	= front overhang of vehicle (m)
u	= track width of vehicle on tangent, outside to outside of tyres (m)
c	= lateral clearance between vehicles in adjacent lanes (mm)

5.7 Vertical Alignment

a) The longitudinal section of a road consists of straights (grade) joined by curves. The curves are known as vertical curves and are provided to smoothen the junction between two grades and to increase the sight distance. The convex vertical curves are known as summits or crests and the concave vertical curves are called sags.

The length of the summit vertical curve for a given sight distance required is given by the formula:

$$L = 2D - \frac{200}{A}(\sqrt{h1} + \sqrt{h2})^2$$

And where length of the curve is greater than sight distance required is given by the formula:

$$L = \frac{D^2 A}{200(\sqrt{h1} + \sqrt{h2})^2}$$

Where	L	=	length of vertical curve (m)
	D	=	sight distance (m)
	A	=	algebraic difference in grade (percent)
	h1	=	height of eye above road (1.15 m)
	h2	=	Height of the object above the road
		=	1.15 m if it is another vehicle
		=	0.2 m if it is an object on the ground

The length of the summit vertical curves for stopping and for overtaking sight distance are shown in Fig 5.7.1.1 and Fig 5.7.1.2

b) The length of the sag curve is given by
The length of the curve if less then the sight distance

$$L = 2D - \frac{150 + 3.5D}{A} (meter)$$

Where length of curve is greater than sight distance

$$L = \frac{AD^2}{150 + 3.5D} (meter)$$

Sag curve designed for headlight sight distance are satisfactory for riding comfort. For calculation of length the formula is

$$L = \frac{V^2 A}{1300a}$$

Where V = Speed (km/h)

A = algebraic change of grade (%)
a = radial acceleration (m/s) usually taken as 0.1g or say 1 m/s)

The length of the sag vertical curve length is also given in Fig 5.7.1.3

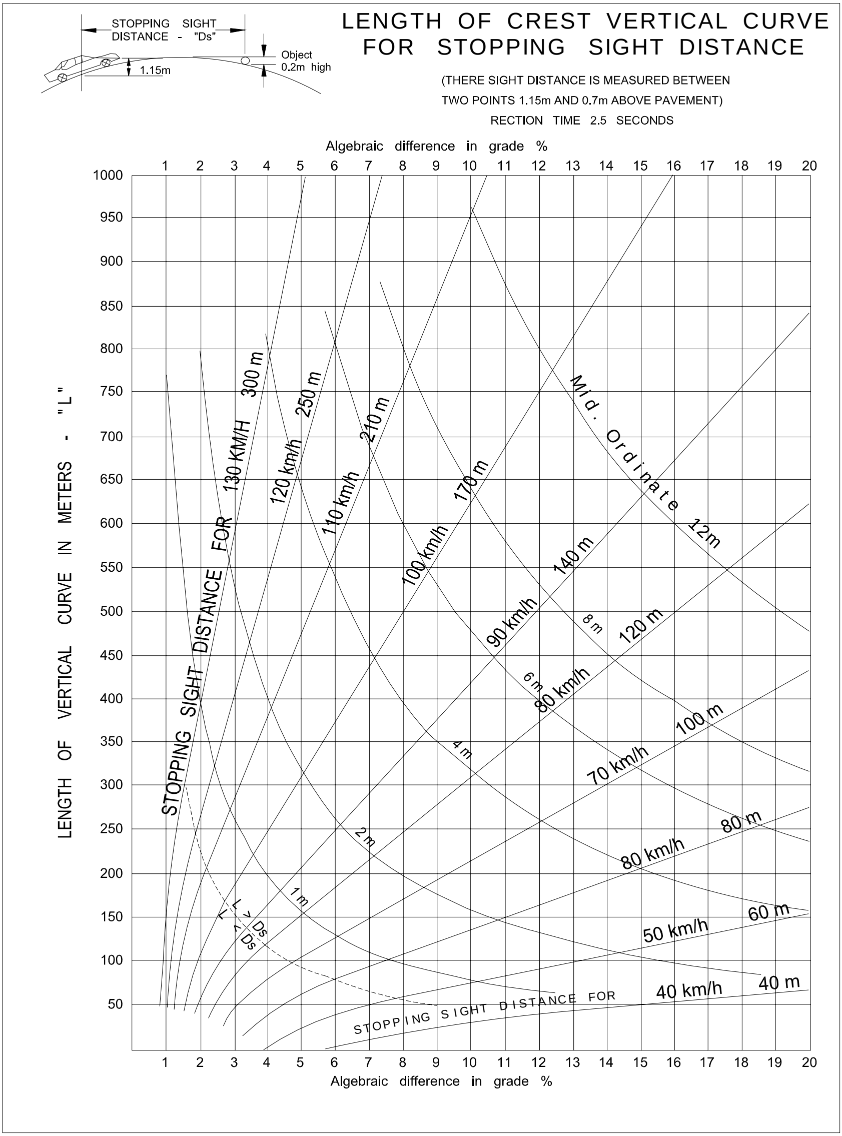

STOPPING SIGHT DISTANCE - "Ds"
Object 0.2m high
1.15m
LENGTH OF CREST VERTICAL CURVE FOR STOPPING SIGHT DISTANCE
(THERE SIGHT DISTANCE IS MEASURED BETWEEN TWO POINTS 1.15m AND 0.7m ABOVE PAVEMENT)
RECTION TIME 2.5 SECONDS
Algebraic difference in grade %
LENGTH OF VERTICAL CURVE IN METERS - "L"
STOPPING SIGHT DISTANCE FOR 130 KM/H
120 km/h
110 km/h
100 km/h
90 km/h
80 km/h
70 km/h
80 km/h
50 km/h
40 km/h
300 m
250 m
210 m
170 m
140 m
120 m
100 m
80 m
60 m
40 m
Mid. Ordinate 12m
8 m
6 m
4 m
2 m
1 m
L > Ds
L < Ds
STOPPING SIGHT DISTANCE FOR

Fig 5.7.1.1

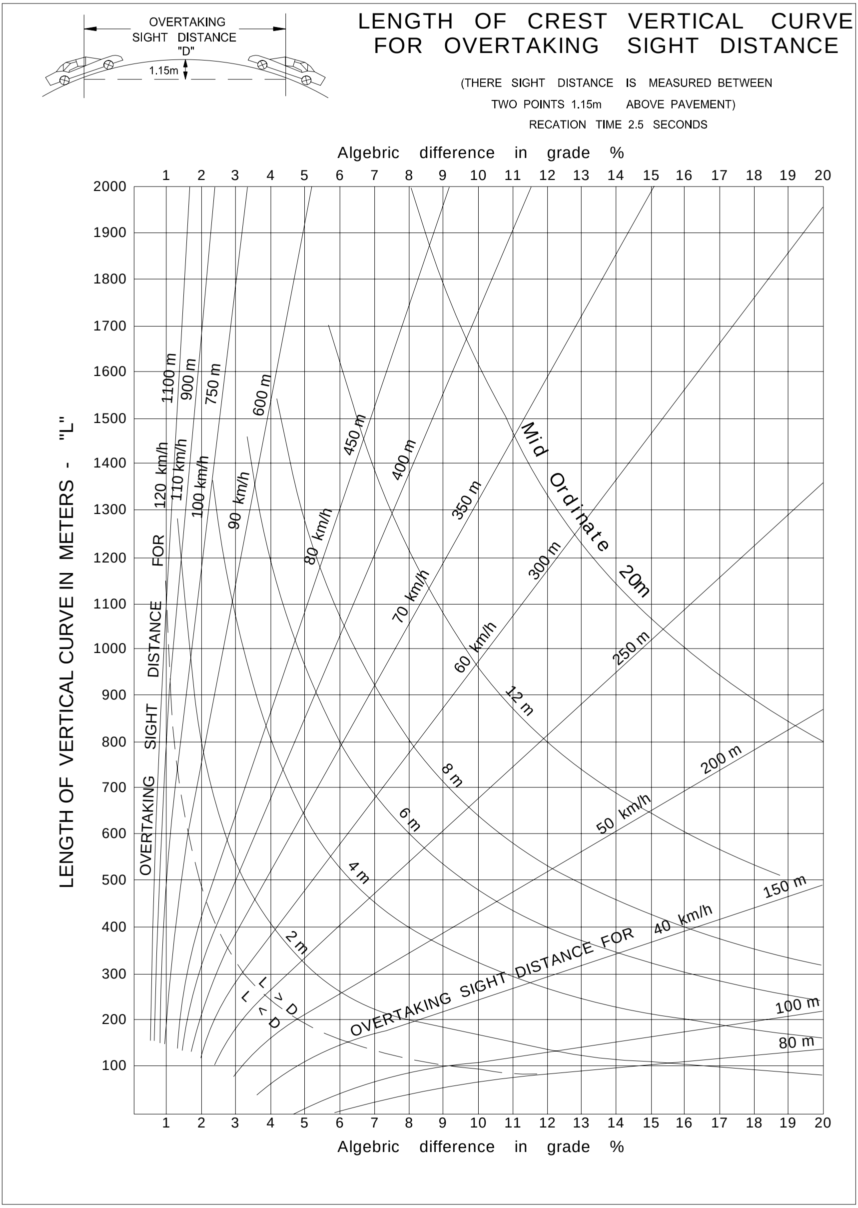

OVERTAKING
SIGHT DISTANCE
"D"
1.15m
LENGTH OF CREST VERTICAL CURVE
FOR OVERTAKING SIGHT DISTANCE
(THERE SIGHT DISTANCE IS MEASURED BETWEEN
TWO POINTS 1.15m ABOVE PAVEMENT)
RECATION TIME 2.5 SECONDS
Algebric difference in grade %
LENGTH OF VERTICAL CURVE IN METERS - "L"
OVERTAKING SIGHT DISTANCE FOR
120 km/h
110 km/h
100 km/h
90 km/h
80 km/h
70 km/h
60 km/h
50 km/h
40 km/h
1100 m
900 m
750 m
600 m
450 m
400 m
350 m
300 m
250 m
200 m
150 m
100 m
80 m
Mid Ordinate
20m
12 m
8 m
6 m
4 m
2 m
L > D
L < D
OVERTAKING SIGHT DISTANCE FOR

Fig 5.7.1.2

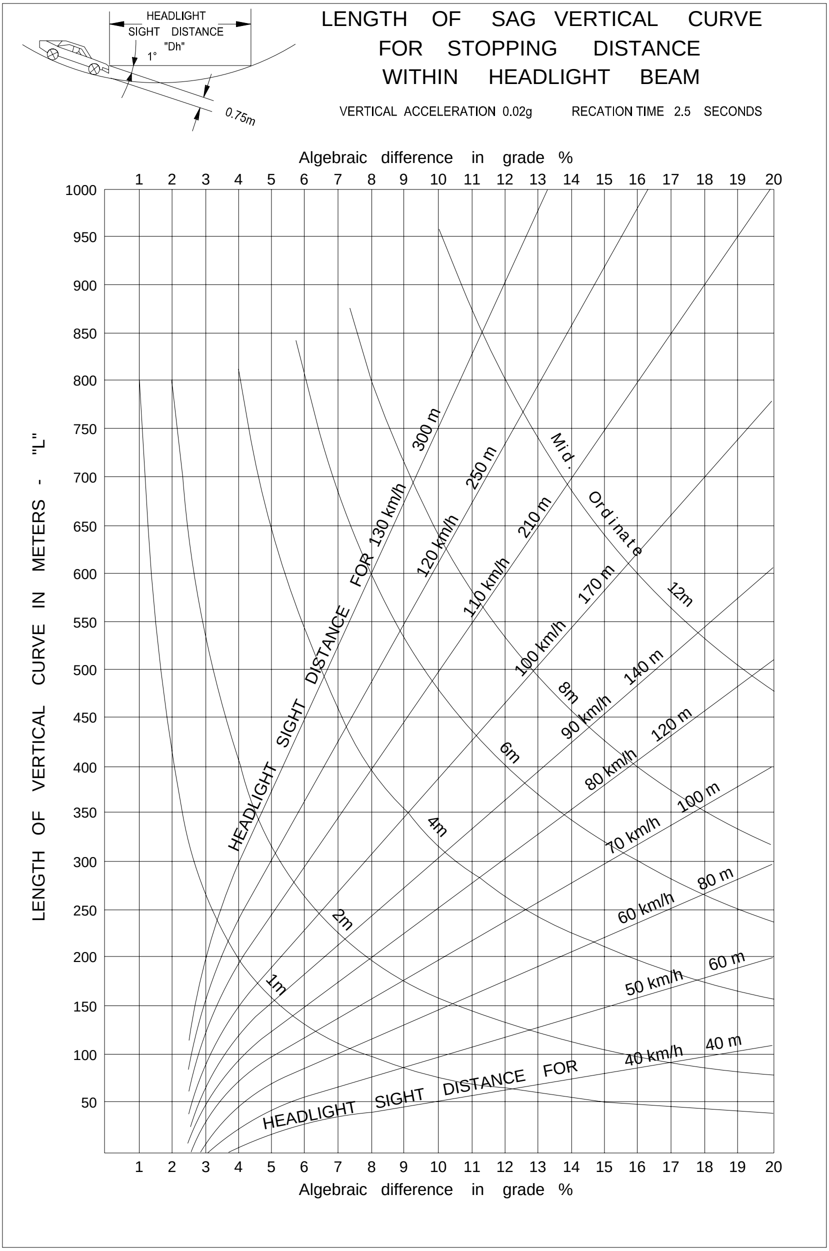

HEADLIGHT SIGHT DISTANCE "Dh"
1°
0.75m
LENGTH OF SAG VERTICAL CURVE
FOR STOPPING DISTANCE
WITHIN HEADLIGHT BEAM
VERTICAL ACCELERATION 0.02g
RECATION TIME 2.5 SECONDS
Algebraic difference in grade %
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
1000 950 900 850 800 750 700 650 600 550 500 450 400 350 300 250 200 150 100 50
LENGTH OF VERTICAL CURVE IN METERS - "L"
HEADLIGHT SIGHT DISTANCE FOR 130 km/h
120 km/h
110 km/h
100 km/h
90 km/h
80 km/h
70 km/h
60 km/h
50 km/h
40 km/h
HEADLIGHT SIGHT DISTANCE FOR
300 m
250 m
210 m
170 m
140 m
120 m
100 m
80 m
60 m
40 m
Mid. Ordinate
12m
8m
6m
4m
2m
1m
Algebraic difference in grade %

Fig 5.7.1.3

5.8 Grade

General maximum grades for each design speed are the steepest grades that the majority of cars can travel in a high gear without loss of speed up hill and without gain downhill. It varies with the design speed and with the terrain also.

The following table shows the length and the value of maximum grade.

Design Speed Km/hr.	General Maximum Grade (%)	Absolute Maximum Grade (%)	Allowable Length of Grade Steeper than General Maximum	
20 - 40	10	*	-	-
50	7	9	8	500
			9	350
60	7	9	8	900
			9	600
70 - 80	7	9	8	1000
			9	700

Note: No absolute maximum grade is shown for design speeds of 20 to 40km/h as in some circumstances a length of very steep grade may be necessary. The length of grade steeper than 10 % should be kept as short as possible.

HORIZONTAL CURVE DESIGN DATA

Radius	Speed	Super-elevation	Sight Distance		Transition Super elevation	Widening		SD offset	
			Stop-ping	Over-taking		Single lane	Double lane	Stop-ping	Double stopping
(m)	(Km/h)	(%)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
15	20	8	15	-	20	0.9	1.8	5	15
25	30	8	25	110	30	0.6	1.8	5	16
40								3	11
45	40	8	40	140	45	0.6	1.5	5	17
70								3	12
75	50	8	60	200	60	-	1.2	5	20
110									14
120	60	7	80	300	70	-	0.9	6	23
160								5	17
200								4	14
240								3	12
260	80	7	120	450	80	-	0.6	7	29
300								6	24
400								5	18
500								4	15

SD - Sight Distance

5.9 Road Design Procedure

The following steps are required to complete a road design. They are pointers only and not an exhaustive treatment of each step. This Step is for GEOCOMP Software only.

STEP 1 INITIAL DTM

Obtain edited DTM for surveyors.

STEP 2 PLOT DTM

Using SDS 93, plot plan including contours, string lines, labeled grid etc.

STEP 3 HORIZONTAL ALIGNMENT

Hand plot trial alignment on plan including curves

STEP 4 INTERSECTION POINTS
Scale coordinates of IP's

STEP 5 HORIZONTAL ALIGNMENT
Create the horizontal alignment using SDS 84

STEP 6 EXTRACT FROM DTM
Use RDP 400 and RDP 401 to extract the Cross Section and the Longitudinal Section from the DTM.

STEP 7 DESIGN TEMPLETES
RDP 410 – create main and side templates to include super-elevation and widening. This File is already created so you can skip this step. The file name is 000101.CES

STEP 8 VERTICAL ALIGNMENT
RDP 412 – create vertical alignment along the Longitudinal Section extracted from DTM.

STEP 9 TEMPLETE FITTING FILE
RDP 412 – Use chainage from horizontal alignment to fit the templates with the help of a QBasic program to fit the templates to the chainage, you should print the horizontal alignment file *.TRN.

STEP 10 FIT TEMPLATES
RDP 415 – Use the template fitting file to the vertical alignment to form the combined cross section.

STEP 11 PLOT CROSS SECTION
RDP 492 & PU 4 – Plot the cross sections in draft from without detail boxes.

STEP 12 REVIEW

Check cross section plots and make adjustments where necessary. Both vertically and horizontally. Go back and repeat design procedures until you are satisfied with the design.
To change vertically go back to step 8 and to change horizontally go back to step 3.

STEP 13 EDIT CROSS SECTION

RDP 421 – Edit batter slopes, drains etc. until satisfied with all the cross sections.

STEP 14 CUT AND FILL INTERSECTION POINTS

RDP 470 – to trim off excess design surface and defines the design/natural intersections.

STEP 15 QUANTITIES

Plot earth work quantities using RDP 471

STEP 16 PLOT FILES

Create cross section & Longitudinal Section using RDP 492 and RDP 493

STEP 17 PLAN PLOT

To create the plan plot file go to SDS and use SDS 93

STEP 18 SET OUT PRINTING

Import the design cross section to the plan and print out the Co-ordinates using SDS 26, and the setout using SDS 41. The following should be printed:

a) Station Co-ordinates
b) Centerline Co-ordinates
c) Batter Co-ordinates
d) Station to station setout
e) Station to Centerline setout
f) Station to Batter setout

STEP 19 DXF FILES

Convert all the plot files to DXF format

STEP 20 AUTOCAD

Create a presentable plot file using AutoCAD by importing the DXF files

STEP 21 FINAL PLOTING

Once you have a presentable plot files plot it out in the required paper size to be handed over to the site Engineers.

Terminology

Altimeter: is an instrument which measures vertical distance with respect to a reference level.

Batter Pegging: This is a peg fixed at the site to guide the construction team to cut or fill to bring the road level to the design level at the construction stage.

Carriageway: is the portion of the road designed and constructed for use of vehicular traffic.

Clinometer: is a very simple instrument for measuring vertical angles at relatively fair accuracy.

Crossfall: is the fall at right angles to an alignment given to the surface of any part of a road. It may be expressed as ratio of vertical to horizontal or equivalent percentage.

Cut and fill: is a term used to describe any section of earth work which is partly in cutting and partly in filling.

Drain: is a conduit or channel, either artificial or natural, for carrying of surplus ground water or surface water.

Dzongkhag Road: is a road connecting two Dzongkhags

Embankment: is an earth work raised above the natural ground by the deposition of material to support construction at a higher level.

Exceptional grade: is the gradient steeper than the limiting gradient which may be used in short length only in extra-ordinary situations.

Feeder Road: is a road that takes off from a highway or Dzongkhag road to connect small villages or community centre.

Formation Width: is the finished width of earth work in fill or cut.

Formation width: is the finished width of earth work in fill or cut. And is the total sum of carriageway width and shoulder plus the drain exclusive of parapets.

Grade/Gradient: is the rate of rise or fall with respect to the horizontal along the length of a road expressed as percentage or as a ratio or in degrees.

Hairpin bend/Zigs: is a bend in alignment resulting in reversal of direction of flow of traffic. A bend may be reversing road direction on same face of hill slope.

Highway: is a road connection two main business centre and connecting Dzongkhags/Village in between.

Horizontal curve: is the curve in plan to change the direction of the center line of a road.

Limiting grade: is the gradient steeper than the ruling grade which may be used in short length where keeping within the ruling gradient is not possible.

Passing Place: is an area provided on the side of the road at convenient locations to facilitate crossing of vehicles approaching from the opposite direction and toe aside a disabled vehicles so that it does not obstruct traffic

Reconnaissance: is a preliminary and usually rapid, examination or survey of a region in reference to its natural features, other local conditions to determine the location of a proposed highway or other roads.

Ruling grade: is a gradient which in the normal course must never be exceeded in any part of a road.

Sight distance: is the distance along the road surface at which a driver has visibility of objects, (stationary or moving) at a specified height, above the carriageway.

Super-elevation: is the inward tilt or transverse inclination given to the section of a carriageway on a horizontal curve to reduce the effects of centrifugal force and a moving vehicle. Super-elevation is generally expressed as a slope or percentage.

Total Station: A land survey instrument that combines the angle-measuring capabilities of a transit with electronic distance measurement.

Transition Curve: is the curve whose curvature goes on changing at a certain rate from one radius to another radius for giving smooth change of direction of road.

Transition Length: is the centerline length along a curve, radius of which goes on changing at a certain rate of change of acceleration.

Vertical curve: is a curve in the longitudinal section of a road to provide for easy and safe change of gradient.

Abbreviation

A.E	Assistant Engineer
AM	After Measurement
BM	Before Measurement
BP	Batter Peg
C&D	Cardio & Davies
CH	Chainage
CL	Centerline
Config	Configure
CONT	Continue
Coord	Coordinate
Displ	Display
DIST	Distance
DoR	Department or Roads
DTM	Digital Terrain Model
E.E	Executive Engineer
E/N	Easting/Northing
EA	Environment Assessment
EFRC	Environment Friendly Road Construction
Engg	Engineering
ENTR	Enter/Return
FD	Field Division
Geo-Tech	Geotechnical
HD	Horizontal Distance

Hz	Horizontal
J.E	Junior Engineer
Meas	Measurement
O/S	Offset
Pt	Point
PU	Perspective Utility
PWD	Public Works Department
QSTN	Quick Station
RDP	Road Design Package
REC	Record
Refl	Reflector
RL	Reduce Level
S&D	Survey & Design Division
S.E	Superintending Engineer
SDS	Spatial Data System
Seq	Sequence
SMEC	Snowy Mountains Engineering Corporation
SP	Support Program
SQCA	Standard Quality Control Authority
STN	Station
Topo	Topographical

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2. Road Design Manual by SMEC for PWD, Bhutan – 1988
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4. Tougay Choedup – Field Design Manual for Blind Curve Improvement
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