

# Introduction to Geometric Design

## Lecture Notes in Transportation Systems Engineering

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### 1 Overview

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The emphasis of the geometric design is to address the requirement of the driver and the vehicle such as safety, comfort, efficiency, etc. The features

normally considered are the cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection. The design of these features is to a great extent influenced by driver behavior and psychology, vehicle characteristics, traffic characteristics such as speed and volume. Proper geometric design will help in the reduction of accidents and their severity. Therefore, the objective of geometric design is to provide optimum efficiency in traffic operation and maximum safety at reasonable cost. The planning cannot be done stage wise in this case like that of a pavement, but has to be done well in advance. The main components that will be discussed are:

1. Factors affecting the geometric design,
2. Highway alignment, road classification,
3. Pavement surface characteristics,
4. Cross-section elements including cross slope, various widths of roads and features in the road margins.
5. Sight distance elements including cross slope, various widths and features in the road margins.
6. Horizontal alignment which includes features like super elevation, transition curve, extra widening and set back distance.
7. Vertical alignment and its components like gradient, sight distance and design of length of curves.
8. Intersection features like layout, capacity, etc.

## 2 Factors affecting geometric design

A number of factors affect the geometric design and they are discussed in detail in the following sections.

### 2.1 Design speed

Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves.

Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.

Design speed is defined as the highest continuous speed at which individual vehicles can travel with safety on the highway when weather conditions are conducive. Design speed is different from the legal speed limit which is the speed limit imposed to curb a common tendency of drivers to travel beyond an accepted safe speed. Design speed is also different from the desired speed which is the maximum speed at which a driver would travel when unconstrained by either traffic or local geometry.

Since there are wide variations in the speed adopted by different drivers, and by different types of vehicles, design speed should be selected such that it satisfy nearly all drivers. At the same time, a higher design speed has cascading effect in other geometric designs and thereby cost escalation. Therefore, an 85th percentile design speed is normally adopted. This speed is defined as that speed which is greater than the speed of 85% of drivers. In some countries this is as high as 95 to 98 percentile speed.

## 2.2 Topography

The next important factor that affects the geometric design is the topography. It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multiform with the gradient and the terrain. Therefore, geometric design standards are different for different terrain to keep the cost of construction and time of construction under control. This is characterized by sharper curves and steeper gradients.

## 2.3 Other factors

In addition to design speed and topography, there are various other factors that affect the geometric design and they are briefly discussed below:

1. **Vehicle:** :The dimensions, weight of the axle and operating characteristics of a vehicle influence the design aspects such as width of the pavement, radii of the curve, clearances, parking geometrics etc. A *design vehicle* which has standard weight, dimensions and operating characteristics are used to establish highway

design controls to accommodate vehicles of a designated type.

2. **Human:** The important human factors that influence geometric design are the physical, mental and psychological characteristics of the driver and pedestrians like the reaction time.
3. **Traffic:** It will be uneconomical to design the road for peak traffic flow. Therefore a reasonable value of traffic volume is selected as the design hourly volume which is determined from the various traffic data collected. The geometric design is thus based on this design volume, capacity etc.
4. **Environmental:** Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.
5. **Economy:** The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.
6. **Others:** Geometric design should be such that the aesthetics of the region is not affected.

We will discuss on alignment, classification and factors affecting GD.

### 3 Road classification

The roads can be classified in many ways. The classification based on speed and accessibility is the most generic one. Note that as the accessibility of road increases, the speed reduces. (See figure 1). Accordingly, the roads can be classified as follows in the order of increased accessibility and reduced speeds.

1. **Freeways:** Freeways are access-controlled divided highways. Most freeways are four lanes, two lanes each direction, but many freeways widen to incorporate more lanes as they enter urban areas. Access is controlled through the use of interchanges, and the type of interchange depends upon the kind of intersecting road way (rural roads, another freeway etc.)
2. **Expressways:** They are superior type of highways and are designed for high speeds ( 120 km/hr is common), high traffic volume and safety. They are generally

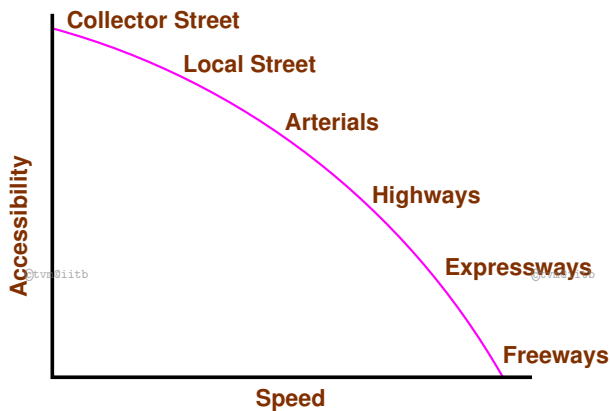


Figure 1: Speed vs accessibility

provided with grade separations at intersections. Parking, loading and unloading of goods and pedestrian traffic is not allowed on expressways.

3. **Highways:** They represent the superior type of roads in the country. Highways are of two types - rural highways and urban highways. Rural highways are those passing through rural areas (villages) and urban highways are those passing through large cities and towns, ie. urban areas.
4. **Arterials:** It is a general term denoting a street primarily meant for through traffic usually on a continuous route. They are generally divided highways with fully or partially controlled access. Parking, loading and unloading activities are usually restricted and regulated. Pedestrians are allowed to cross only at intersections/designated pedestrian crossings.
5. **Local streets :** A local street is the one which is primarily intended for access to residence, business or abutting property. It does not normally carry large volume of traffic and also it allows unrestricted parking and pedestrian movements.
6. **Collector streets:** These are streets intended for collecting and distributing traffic to and from local streets and also for providing access to arterial streets. Normally full access is provided on these streets . There are few parking restrictions except during peak hours.

## 3.1 Nagpur classification

In Nagpur road classification, all roads were classified into five categories as National highways, State highways, Major district roads, Other district roads and village roads.

### 3.1.1 National highways

1. They are main highways running through the length and breadth of India connecting major ports , foreign highways, capitals of large states and large industrial and tourist centers including roads required for strategic movements.
2. It was recommended by Jayakar committee that the National highways should be the frame on which the entire road communication should be based.
3. All the national highways are assigned the respective numbers.
4. For e.g. the highway connecting Delhi-Ambala-Amritsar is denoted as NH-1 (Delhi-Amritsar), where as a bifurcation of this highway beyond Fullundar to Srinagar and Uri is denoted as NH-1A.
5. They are constructed and maintained by CPWD.
6. The total length of National highway in the country is 58,112 Kms, and constitute about 2% of total road networks of India and carry 40% of total traffic.

### 3.1.2 State highways

1. They are the arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within the state
2. They also serve as main arteries to and from district roads.
3. Total length of all SH in the country is 1,37,119 Kms.

### 3.1.3 Major district roads

1. Important roads with in a district serving areas of production and markets , connecting those with each other or with the major highways.
2. India has a total of 4,70,000 kms of MDR.

### 3.1.4 Other district roads

1. Roads serving rural areas of production and providing them with outlet to market centers or other important roads like MDR or SH.

### 3.1.5 Village roads

1. They are roads connecting villages or group of villages with each other or to the nearest road of a higher category like ODR or MDR.
2. India has 26,50,000 kms of ODR+VR out of the total 33,15,231 kms of all type of roads.

## 3.2 Modern-Lucknow classification

The roads in the country were classified into 3 classes:

### 3.2.1 Primary roads

1. Expressways
2. National highways

### 3.2.2 Secondary roads

1. State highways
2. Major district roads

### 3.2.3 Tertiary roads

1. Other district roads
2. Village roads

## 3.3 Roads classification criteria

Apart from the classification given by the different plans, roads were also classified based on some other criteria. They are given in detail below.

### 3.3.1 Based on usage

This classification is based on whether the roads can be used during different seasons of the year.

1. All-weather roads: Those roads which are negotiable during all weathers, except at major river crossings where interruption of traffic is permissible up to a certain extent are called all weather roads.
2. Fair-weather roads: Roads which are negotiable only during fair weather are called fair weather roads.

### 3.3.2 Based on carriage way

This classification is based on the type of the carriage way or the road pavement.

1. Paved roads with hards surface : If they are provided with a hard pavement course such roads are called paved roads.(eg: stones, Water bound macadam (WBM), Bituminous macadam (BM), concrete roads)
2. Unpaved roads: Roads which are not provided with a hard course of atleast a WBM layer they is called unpaved roads. Thus earth and gravel roads come under this category.

### 3.3.3 Based on pavement surface

Based on the type of pavement surfacing provided, they are classified as surfaced and unsurfaced roads.

1. Surfaced roads (BM, concrete): Roads which are provided with a bituminous or cement concreting surface are called surfaced roads.
2. Unsurfaced roads (soil/gravel): Roads which are not provided with a bituminous or cement concreting surface are called unsurfaced roads.

### 3.3.4 Other criteria

Roads may also be classified based on the traffic volume in that road, load transported through that road, or location and function of that road.

1. Traffic volume : Based on the traffic volume, they are classified as heavy, medium and light traffic roads. These terms are relative and so the limits under each class may be expressed as vehicles per day.
2. Load transported : Based on the load carried by these roads, they can be classified as class I, class II, etc. or class A, class B etc. and the limits may be expressed as tonnes per day.
3. Location and function : The classification based on location and function should be a more acceptable classification since they may be defined clearly. Classification of roads by Nagpur Road plan is based on the location and function which we had seen earlier.

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## 4 Highway alignment

Once the necessity of the highway is assessed, the next process is deciding the alignment. The highway alignment can be either horizontal or vertical and they are described in detail in the following sections.

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### 4.1 Alignment

The position or the layout of the central line of the highway on the ground is called the alignment. Horizontal alignment includes straight and curved paths. Vertical alignment includes level and gradients. Alignment decision is important because a bad alignment will enhance the construction, maintenance and vehicle operating costs. Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structures by the roadside.

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### 4.2 Requirements

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The requirements of an ideal alignment are

1. The alignment between two terminal stations should be short and as far as possible be straight, but due to some practical considerations deviations may be needed.

2. The alignment should be easy to construct and maintain. It should be easy for the operation of vehicles. So to the maximum extent easy gradients and curves should be provided.
3. It should be safe both from the construction and operating point of view especially at slopes, embankments, and cutting. It should have safe geometric features.
4. The alignment should be economical and it can be considered so only when the initial cost, maintenance cost, and operating cost are minimum.

### 4.3 Factors controlling alignment

We have seen the requirements of an alignment. But it is not always possible to satisfy all these requirements. Hence we have to make a judicial choice considering all the factors.

The various factors that control the alignment are as follows:

1. **Obligatory points:** These are the control points governing the highway alignment. These points are classified into two categories. Points through which it should pass and points through which it should not pass. Some of the examples are:
  - (a) **bridge site:** The bridge can be located only where the river has straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and skew crossing should be avoided as possible. Thus to locate a bridge the highway alignment may be changed.
  - (b) **mountain:** While the alignment passes through a mountain, the various alternatives are to either construct a tunnel or to go round the hills. The suitability of the alternative depends on factors like topography, site conditions and construction and operation cost.
  - (c) **intermediate town:** The alignment may be slightly deviated to connect an intermediate town or village nearby.

These were some of the obligatory points through which the alignment should pass. Coming to the second category, that is the points through which the alignment should not pass are:

- (a) religious places: These have been protected by the law from being acquired for any purpose. Therefore, these points should be avoided while aligning.
  - (b) very costly structures: Acquiring such structures means heavy compensation which would result in an increase in initial cost. So the alignment may be deviated not to pass through that point.
  - (c) lakes/ponds etc: The presence of a lake or pond on the alignment path would also necessitate deviation of the alignment.
2. Traffic: The alignment should suit the traffic requirements. Based on the origin-destination data of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc.
3. Geometric design: Geometric design factors such as gradient, radius of curve, sight distance etc. also govern the alignment of the highway. To keep the radius of curve minimum, it may be required to change the alignment. The alignments should be finalized such that the obstructions to visibility do not restrict the minimum requirements of sight distance. The design standards vary with the class of road and the terrain and accordingly the highway should be aligned.
4. Economy: The alignment finalised should be economical. All the three costs i.e. construction, maintenance, and operating cost should be minimum. The construction cost can be decreased much if it is possible to maintain a balance between cutting and filling. Also try to avoid very high embankments and very deep cuttings as the construction cost will be very higher in these cases.
5. Other considerations : various other factors that govern the alignment are drainage considerations, political factors and monotony.
- (a) Drainage:
  - (b) Political: If a foreign territory comes across a straight alignment, we will have to deviate the alignment around the foreign land.
  - (c) Monotony: For a flat terrain it is possible to provide a straight alignment, but it will be monotonous for driving. Hence a slight bend may be provided after a few kilometres of straight road to keep the driver alert by breaking the monotony.

- (d) Hydrological (rainfall/water table): The pavement should be as high above the water table as possible, so that saturation/submergence and subsequent damage to subgrade are avoided.

## 4.4 Special consideration for hilly areas

Alignment through hilly areas is slightly different from aligning through a flat terrain. For the purpose of efficient and safe operation of vehicles through a hilly terrain special care should be taken while aligning the highway. Some of the special considerations for highway alignment through a hilly terrain is discussed below.

1. Stability of the slopes: for hilly areas, the road should be aligned through the side of the hill that is stable. The common problem with hilly areas is that of landslides. Excessive cutting and filling for road constructions give way to steepening of slopes which in turn will affect the stability.
2. Hill side drainage: Adequate drainage facility should be provided across the road. Attempts should be made to align the roads in such a way where the number of cross drainage structures required are minimum. This will reduce the construction cost.
3. Special geometric standards: The geometric standards followed in hilly areas are different from those in flat terrain. The alignment chosen should enable the ruling gradient to be attained in minimum of the length, minimizing steep gradient, hairpin bends and needless rise and fall.
4. Ineffective rise and fall : Efforts should be made to keep the ineffective rise and excessive fall minimum.

## 5 Summary

This lecture covers a brief history of highway engineering, highlighting the developments of road construction. Significant among them are Roman, French, and British roads. British road construction practice developed by Macadam is the most scientific and the present day roads follows this pattern. The highway development and classification of Indian roads are also discussed. The major classes of roads include National

Highway, State highway, District roads, and Village roads. Finally, issues in highway alignment are discussed.

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