Introduction

Mobility is a basic human need. Transportation plays a major role in the development of the human civilization.

Strong correlation between the evolution of human settlement and the proximity of transport facilities.

Strong correlation between the quality of transport facilities and standard of living.

Transportationsolution must be analytically based, economically sound, socially credible, environmentally sensitive, practically acceptable and sustainable.

Transportation solution should be safe, rapid, comfortable, convenient, economical, and ecofriendly for both men and material.

Disciplines of Transportation

1. **Transportation Planning**
2. **Geometric Design**
3. **Pavement Design**
4. **Traffic Engineering**
5. **Public transportation**
6. **Financial and economic analysis**
7. **Environmental impact assessment**
8. **Accident analysis and reduction**
9. **Intelligent transport system**

In addition disciplines specific to various modes are railway engineering, port and harbor engineering, and airport engineering.

Factors affecting transportation

- Primary elements, namely the **vehicles, the roadways, and the road users.**
- **Their characteristics affect the performance of the transportation system** and the transportation engineer should have fairly good understanding about them.
- These factors greatly **influence the geometric design as well as design of control facilities.**
- Variant nature of the **driver, vehicle, and roadway** characteristics should be given importance **for the smooth, safe, and efficient performance of traffic in the road.**

Factors affecting transportation

Vehicle Factors

- Design vehicles
- Vehicle dimensions
- Weight, axle configuration etc.
- Turning radius and turning path
- Visibility
- Acceleration characteristics
- Braking performance

Human Factors

- Variability
- Critical characteristics
- Reaction time
- Visual acuity and driving
- Walking
- Other Characteristics

Road factors

- Road surface
- Lighting
- Roughness
- Pavement colors
- Night visibility
- Geometric aspects

TRANSPORTATION PLANNING

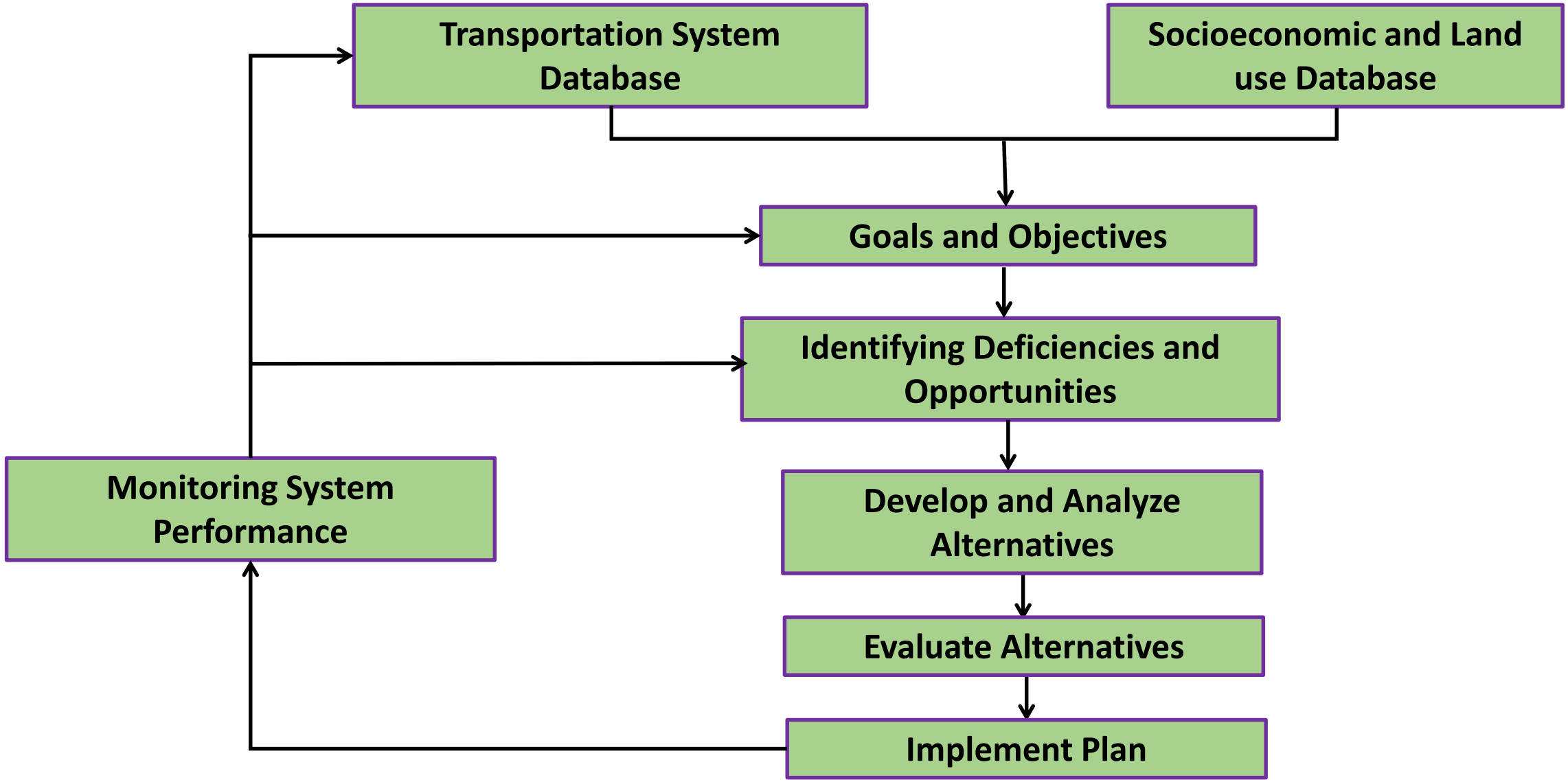
Transportation planning is a process.

It consists of well defined tasks that must be accomplished before the final set of information is presented to those who must decide which course of action is best for an agency, region or community.

It may occur at different level of application

It is a process of producing information that can be used by decision makers to better understand the consequences of different course of action

Basic Elements of Transportation Planning



Tasks for Identifying and Assessing Consequence

- Collect and maintain transportation system data
- Collect and maintain socioeconomic and land use data
- Define goals and objectives
- Identify system deficiencies or Opportunities
- Develop and Analyze alternatives
- Evaluate alternatives
- Implement plan
- Monitor system performance

Transportation Systems Modeling

Transportation planning is concerned with future travel demand and putting in place the facilities and services that will accommodate these demands.

The challenge to transportation planners is to make reliable forecast of travel demands.

Recognized components of future travel demands are:

1. Existing Traffic – to be improved
2. Normal traffic growth – anticipated growth of pop and land use
3. Diverted traffic – new shift from nearby facilities
4. Converted traffic-change of mode
5. Change of destination traffic – different destination
6. Development traffic – due ti improvement of adjacent land
7. Induced traffic – new trip due to improved transportation

Basic Concepts in Transportation Systems Modeling

1. Trip making is a function of land use
2. Trips are made for different purposes
3. Trips are made at different times of the day
4. Travelers often have different options available to them
5. Trips are made to min the level of inconvenience associated with reaching a destination
6. Transportation networks and traffic analysis zones are the basis of system modeling

Social and Environmental Consequences of Highways

Noise Attenuation

- By providing a Buffer Zone
- By modifying the horizontal or vertical alignment
- By providing a noise shield

General Principle of Noise Barrier Design

1. Should be high enough and long enough
2. Should be constructed so as to cast a big sound shadow
3. Should be constructed of a dense materials
4. Should have no air path through or under the barrier
5. Should be made as attractive as possible and blends into the forms of landscape

Air Pollution

- Vehicular emission are prime source
- CO, HC, NOx, SO_2, PM etc

Impacts on Wetlands

Highway Evaluation

Economic studies for highway purposes are done principally for one or more of the following reasons:

1. To determine feasibility of a project
2. To compare alternative locations
3. To evaluate various features of highway design
4. To determine priority of improvement
5. To allocate responsibility for the cost of highway improvemnet among various classes of highway users
6. To compare oproposals for hoghway improvement with proposal for other public projects such as education

Costs of Highway Transportation

1. Highway investment costs
2. Highway maimtenance costs
3. Highway users costs: VOC, TTC, Accdt costs
4. Transit capital costs
5. Transit operating costs
6. Transit users costs

Benefits of Highway Transportation

1. Direct benefits-result from reduction in highway users cost.

Decreased op cost, higher op speed, fewer delays, decreased accdt losses.

2. Indirect benefits- benefits to adjacent property and to the general public

Easier access to market, school, recreational and social facilities
Efficient fire and police protection
Rapid postal delivery
Decreased cost of commodities
Improved national defense
Improved disaster management

Highway Classification

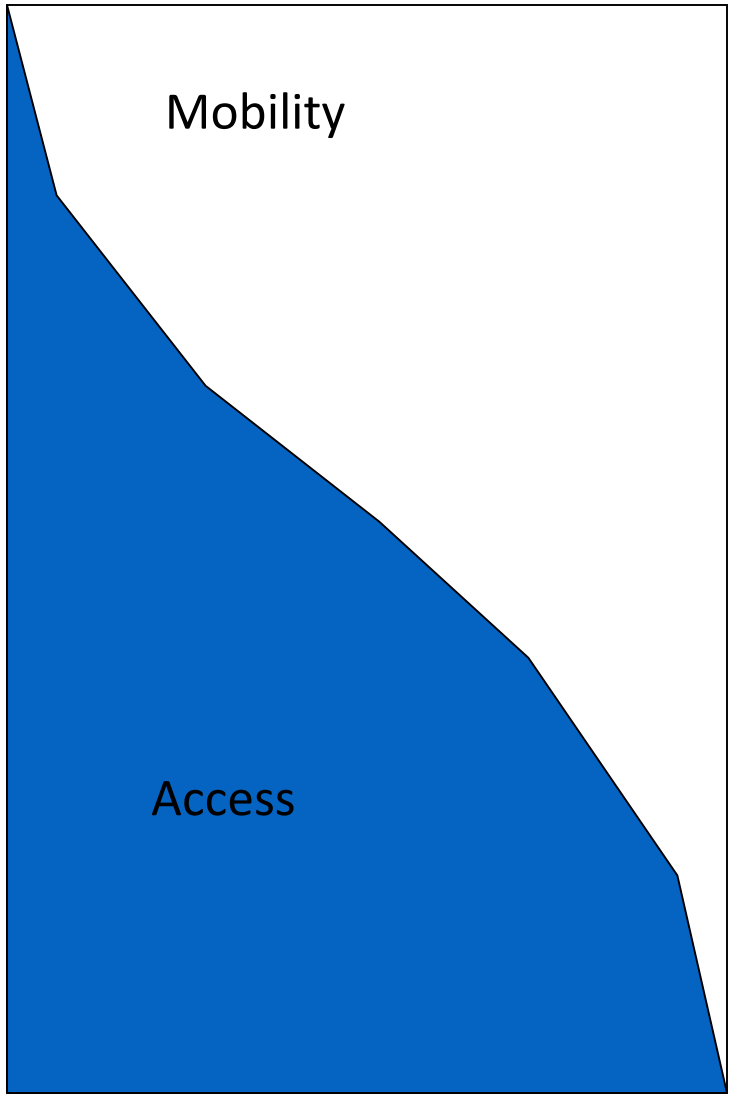
- The classification of highway into different operational system, functional classes or geometric types is necessary among engineers, adminstrators and general public.
- Different classification may be applied for different purposes in different rural and urban areas.

- **Design Types:** Freeways, highways, conventional streets
- **Route Numbering:** Interstate, US routes, State primary, State secondary, county, etc.
- **Administrative Classification:** State federal aid primary and secondary, state primary and secondary
- **Functional Classification:**
  - **Rural Roads**: Principal arterial, Minor arterial, Collector, Local road
  - **Urban Roads**: Principal arterial, Minor arterial street, Collector street, Local street

Main Highway Functions

Mobility = the ability to travel to many different destinations

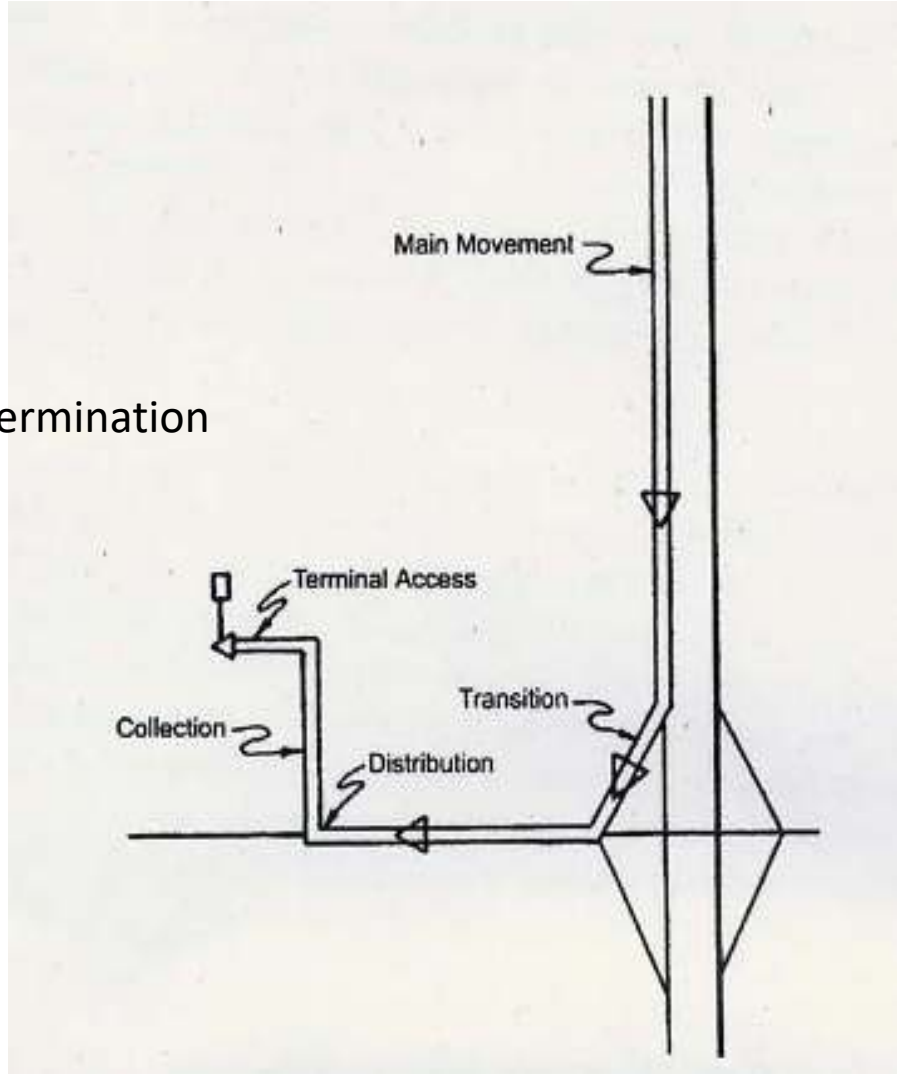
Accessibility = the ability to gain entry to a particular site or area



The Concept of Functional Classification

Hierarchies of Movements and Components: 6 stages

- Main movement,
- Transition,
- Distribution,
- Collection,
- Access, and
- Termination



Classification or Types of Roads

The roads are classified based on many factors as follows.

- Materials
- Location & function
- Traffic volume
- Width
- Economy
- Traffic type
- Rigidity
- Topography

Classification or Types of Roads: Based on Materials

1. Earthen roads
2. Gravel roads
3. Murrum roads
4. Kankar roads
5. WBM roads
6. Bituminous roads
7. Concrete roads

Classification Roads: Based on Location and Function

1. National highways
2. State highways
3. District roads
4. Rural roads or village roads

Based on Traffic Volume

1.Light traffic roads
2.Medium traffic roads
3.High traffic roads

Based on Economy

1.Low-cost roads
2.Medium cost roads
3.High-cost roads

Based on Traffic Type

1.Pedestrian ways
2.Cycle tracks
3.Motorways

Based on Rigidity

1.Flexible roads
2.Rigid roads

Design Controls and Criteria

- Functional classification
- Projected traffic volumes and composition
- Design speed and design vehicle
- Topography
- Available Funding
- Driver performance factors
- Safety
- Politics
- Social and environmental impacts
- Right-of-Way (ROW)
- Costs

Cross-section Elements



Cross-section Elements

Principal elements

- Travel lane
- Shoulders

Marginal elements

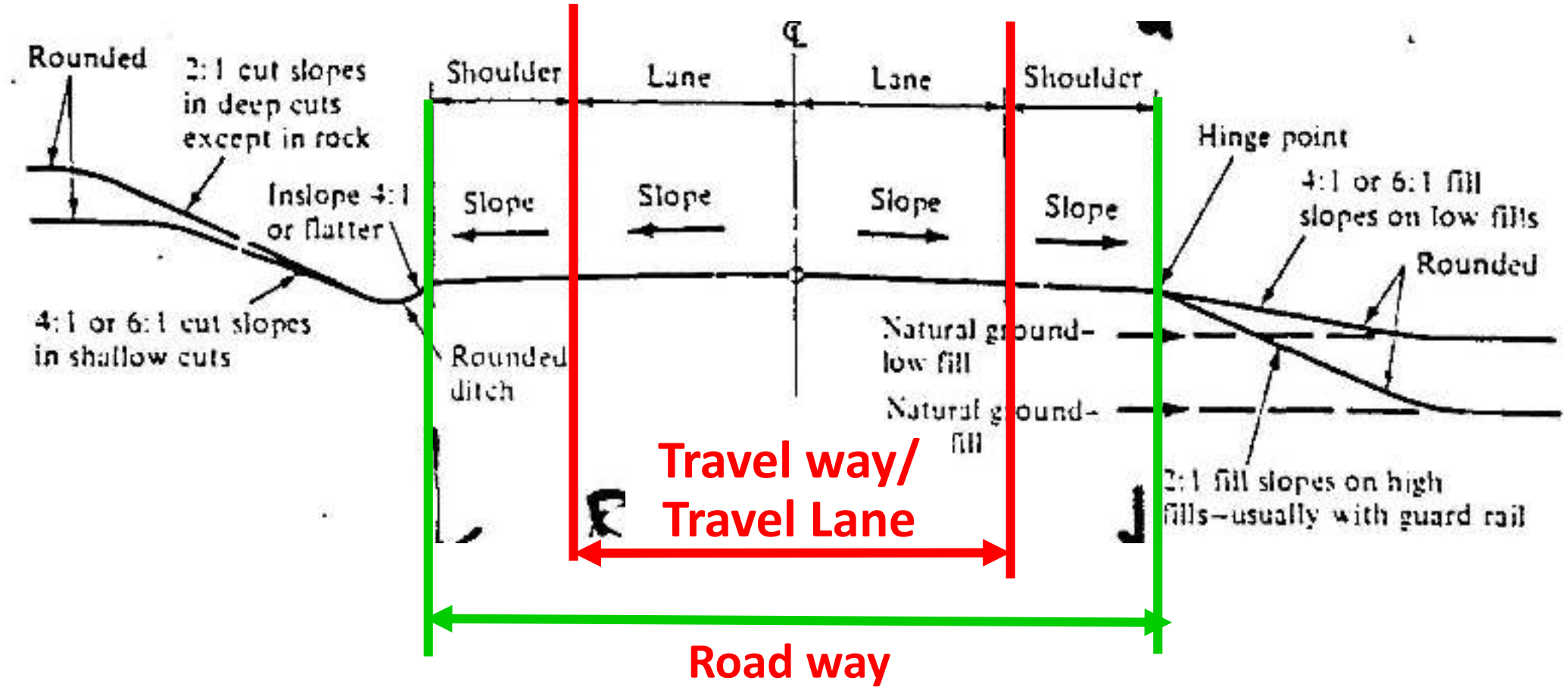
- Median and roadside barriers
- Curbs and gutters
- Guard rails
- Sidewalks
- Cross slopes
- Side slopes
- Right of way

Additional Elements

- Passing Lanes
- Turnouts
- Climbing Lane
- Frontage road/service road
- Bus layby
- Noise barrier
- Street light

- Show in a sketch the different cross sectional element of a tow lane two way highway
- List all cross sectional elements of a two lane two-way highway (principal element, marginal elements and additional elements)

Road way and Travel way



Roadway: The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways.

Traveled Way: The portion of the roadway for the movement of vehicles, exclusive of shoulders.

Cross-section Elements

Lane Width

- ✓The width and number of lanes **should be adequate to accommodate the type and volume of traffic anticipated and the assumed designed speed of the veh**.
- ✓Roads may be of **two lane**, **three lane, multilane undivided, multilane**
- ✓**Four lane highway provide four times capacity of two lane highway**
- ✓Lane width affect **safety, comfort, speed and capacity**
- ✓Generally **10 to13 ft**. Most arterials have 12 ft travel lanes.
- ✓For two –lane, two-way Rural roads, 12 ft is recommended, 10-11 ft acceptable on low speed facilities
- ✓Under unusual and severe constraints, 9 ft acceptable for low-volume roads in rural & suburban areas

- ✓ **Auxiliary lanes at intersections and interchanges (like left turn lanes) should be as wide as poss but not less than 10 ft**, more for long, articulated veh.

Geometric Design standards for Roads & Highway Department, Bangladesh

Table 2.1 Road Cross-Section Standards

Design Type	Design year traffic volume PCU / peak hour (typical MV AADT)	Cross-section widths in metres			Indicative Road Classification
		Crest width	Carriageway (no. of lanes)	Paved shoulders	
1	4500 ঠ 8500 (19,000ঠ36,000)	36.2	2 x 11 (6)	1.8	National
2	2100 - 4500 (7,000 ঠ 19,000)	21.6	2 x 7.3 (4)	1.8	
3	1600 ঠ 2100 (5,000 ঠ 7,000)	16.3	7.3 (2)	1.5	Regional
4	800 ঠ 1600 (1,000 ঠ 5,000)	12.1	6.2 (2)	1.5	
5	400 ঠ 800 (500 ঠ 1,000)	9.8	5.5 (2)	1.2	Feeder
6	<400 (<500)	9.8	3.7 (1)	1.2	

Notes
This is a summary table ঠ refer to Section 4 before using these standards

Table 2.2 Typical Design Speeds

Design Type	Design Speed (km/h)		
	Plain	Rolling	Hilly
1 - 2	80 ঠ100	80	-
3	80	65	50
4	65	50	40
5 - 6	50	40	30

Notes
Terrain: typical cross-slopes
Plain: 0 ঠ 10%
Rolling: 11 ঠ 25%
Hilly: >25%

Table 2.4
Passenger Car Unit (PCU) Values

Vehicle Type	PCU Value
Truck	3.0
Bus	3.0
Minibus	3.0
Utility	1.0
Car	1.0
Baby taxi	0.75
Motorcycle	0.75
Bicycle	0.5
Cycle Rickshaw	2.0
Bullock Cart	4.0

Source: p72, RMSS, Vol. V11A

There are five basic carriageway widths within the six Design Type configurations:

1. **3.7 m wide** - This is the standard single lane carriageway width, and is suitable for the more lightly-trafficked Feeder Roads. Vehicles travelling in opposing directions can pass each other by putting their outer wheels on the shoulder.

2. **5.5 m wide** - This is a minimum width two-lane carriageway. Large vehicles can pass each other at slow speed.

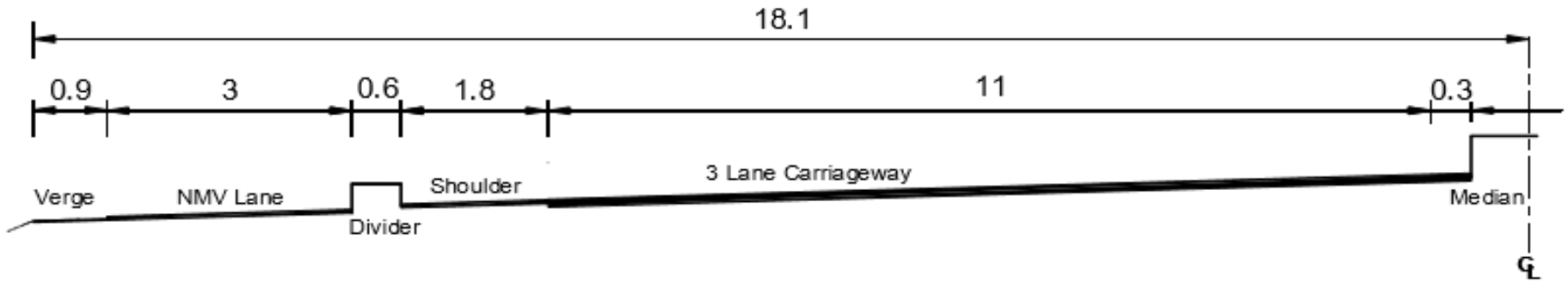
3. **6.2 m wide -** This is the lowest economic cost option for a very wide range of traffic volumes. It allows most vehicles to pass with sufficient clearance to avoid the need to slow down or move aside.

4. **7.3 m wide single** - This is a high standard two-lane single carriageway.

5. **7.3 m wide dual** - This is a high standard carriageway as one half of a dual 2-lane road.

6. **11 m wide dual** - This is a three-lane carriageway as one half of a dual 3-lane road.

Figure 4.2 Design Type 1 Dual 3-lane 11m carriageway



Width of sectional elements (m)	
Crest	36.2
Median	1.0
Carriageway	11.0
Shoulder (L) ð paved	1.8
Shoulder (R) ð paved	0.3
Divider	0.6
NMV lane	3.0
Verge	0.9

Design Capacity
Maximum capacity: 8500 PCU/hr
(assumed NMV/MV ratio of 0.13)

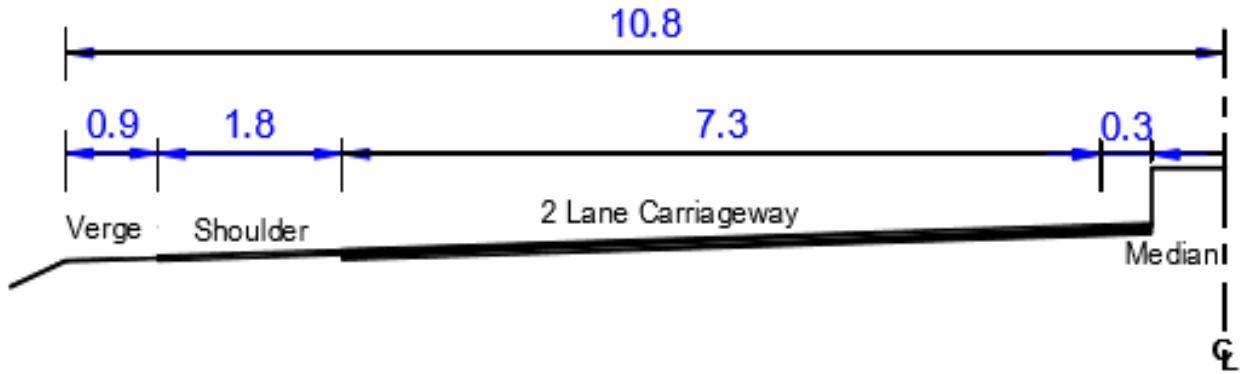
NMV provision

NMVs will use the separate NMV lane. Separation can be achieved in any of the three ways indicated in Figure 4.8. A standard width NMV lane is shown but this may need to be wider if NMV flows are high ð see Section 4.3. Exceptionally the NMV lane may be omitted where it is thought to be feasible to prohibit NMVs from using the road.

Median

See Figure 4.9 for alternative designs.

Figure 4.3 Design Type 2 Dual 2 lane 7.3m carriageway



Width of sectional elements (m)	
Crest	21.6
Median	1.0
Carriageway	7.3
Shoulder (L) ½ paved	1.8
Shoulder (R) ½ paved	0.3
Verge	0.9

Design Capacity

Maximum capacity: 4500 PCU/hr
(assumes that NMVs are either prohibited or are less than 50 PCU/hr)

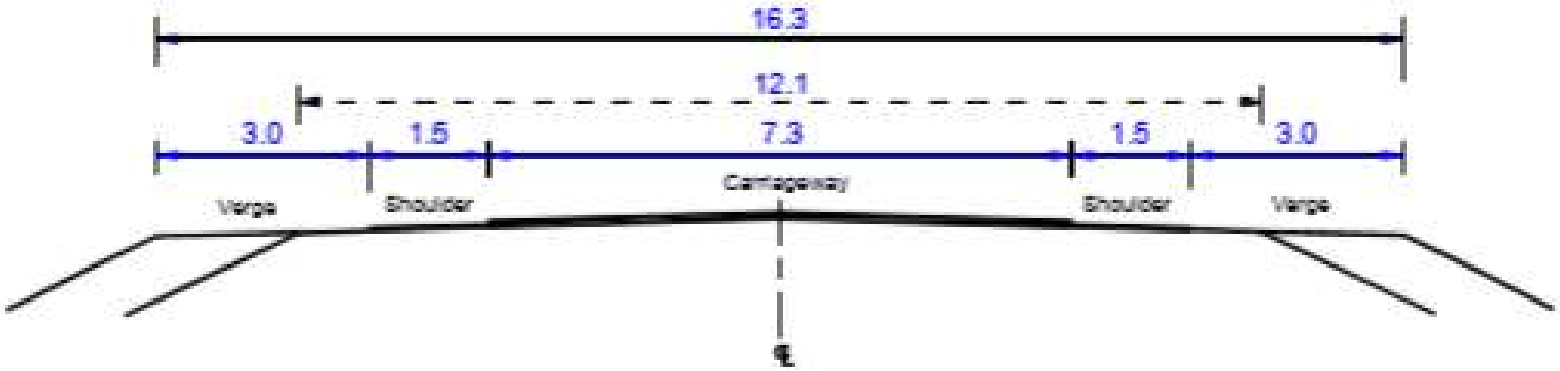
NMV provision

NMVs will use the shoulder. If the Design Year NMV PCU/hour exceeds 50 adopt the Type 2a cross-section which incorporates separate NMV lanes.

Median

See Figure 4.9 for alternative designs.

Figure 4.4 Design Type 3 7.3m carriageway



Width of sectional elements (m)	
Crest	16.3
Carriageway	7.3
Shoulder ÷ paved	1.5
Verge	3.0

Design Capacity
Maximum capacity: 2100 PCU/hr
(assumed NMV/MV ratio of 0.2)

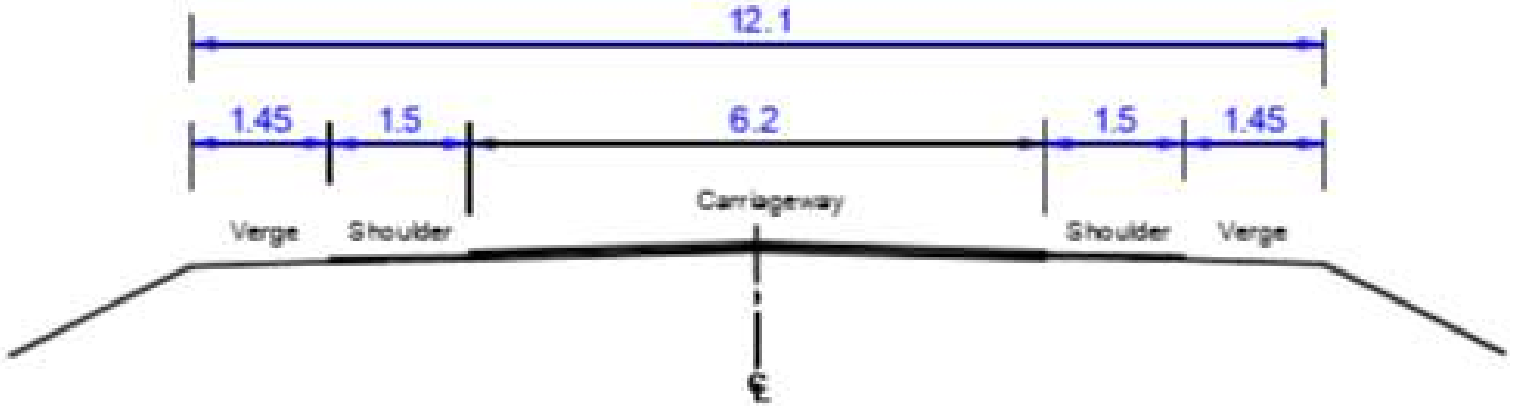
NMV provision

NMVs will use the paved shoulder. Consider providing separate NMV lanes (Type 3a cross-section) if the DY NMV PCU/hr exceeds 400 ÷ see Figure 4.8.

Crest width

The extra-wide embankment permits the future addition of NMV lanes. If it is unlikely that these will ever be needed the verge need only be 0.9m wide, making the crest width 12.1m.

Figure 4.5 Design Type 4 6.2m carriageway



Width of sectional elements (m)		Design Capacity
Crest	12.1	Maximum capacity: 1600 PCU/hr
Carriageway	6.2	(assumed NMV/MV ratio of 0.14)
Shoulder ‡ paved	1.5	
Verge	1.45	

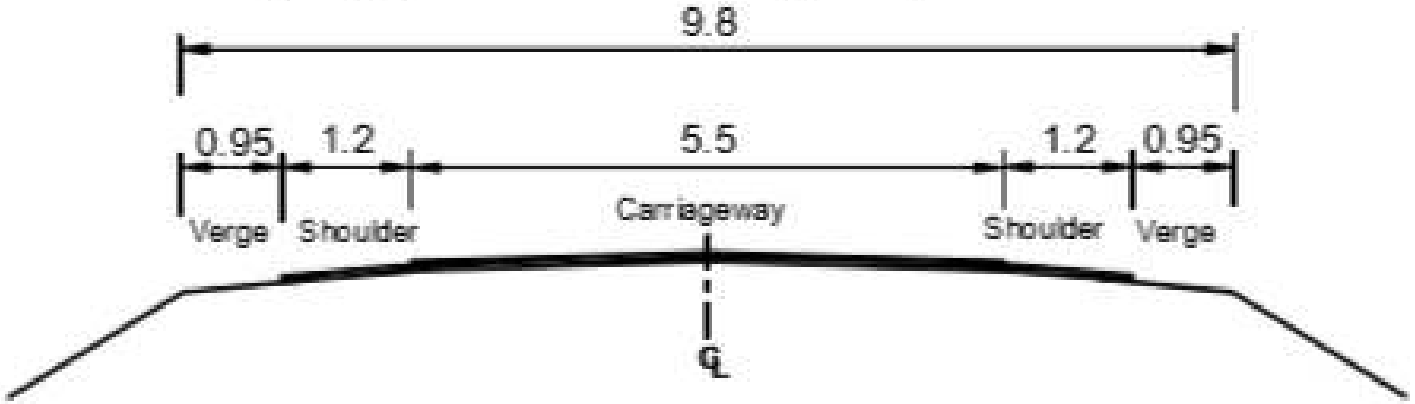
NMV provision

Where DY NMV PCU/hr exceeds 400 consider providing separate NMV lanes (Type 4a cross-section) ‡ see Figure 4.8.

Upgrading

The extra-wide embankment permits upgrading to Type 3 standard.

Figure 4.6 Design Type 5 5.5m carriageway



Width of sectional elements (m)	
Crest	9.8
Carriageway	5.5
Shoulder ½ paved	1.2
Verge	0.95

Design Capacity

Maximum capacity: 800 PCU/hr

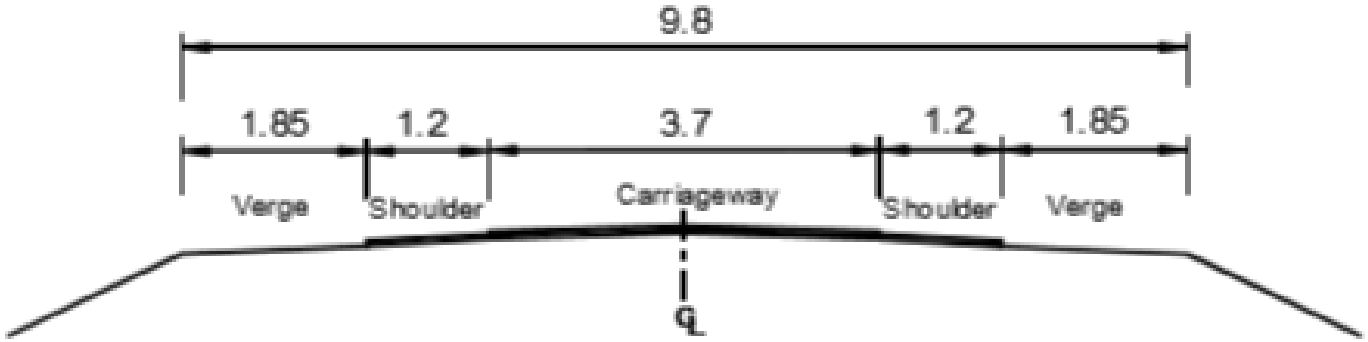
NMV provision

NMVs will use the carriageway and the shoulder, so it is essential that there is no difference in level between the two.

Upgrading

The extra-wide embankment permits upgrading to Type 4 standard.

Figure 4.7 Design Type 6 3.7m single lane carriageway



Width of sectional elements (m)	
Crest	9.8
Carriageway	3.7
Shoulder ± paved	1.2
Verge	1.85

Design Capacity
Maximum capacity: 400 PCU/hr
(assumed NMV/MV ratio of 2.5)

NMV provision
NMVs will use the carriageway and the shoulder, so it is essential that there is no difference in level between the two.

Upgrading
The extra-wide embankment permits upgrading to Type 5 and Type 4 standards.

Capacity
The design capacity of 400 PCU/hr is only achievable with good, well-maintained shoulders and when most of the vehicles are NMVs.

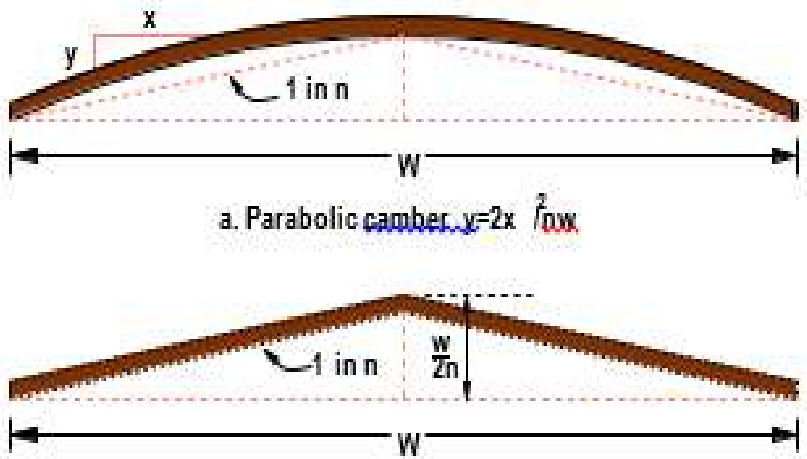
How cross slopes are provided on roadway pavement?

How to ensure surface drain off of rain water?

Camber

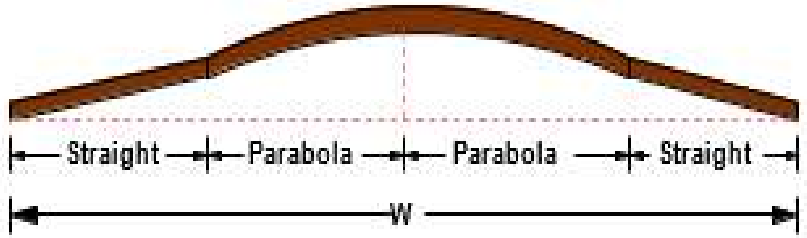
- Camber is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rain water from road surface.
- Too steep slope is undesirable for it will erode the surface.
- Camber is measured in *1 in n* or *n%* and the value depends on the type of pavement surface.

Different types of camber



a. Parabolic camber, $y=2x^2/w$

b. Straight line camber



c. Combination of straight and parabolic camber

The **objectives of providing camber are**:

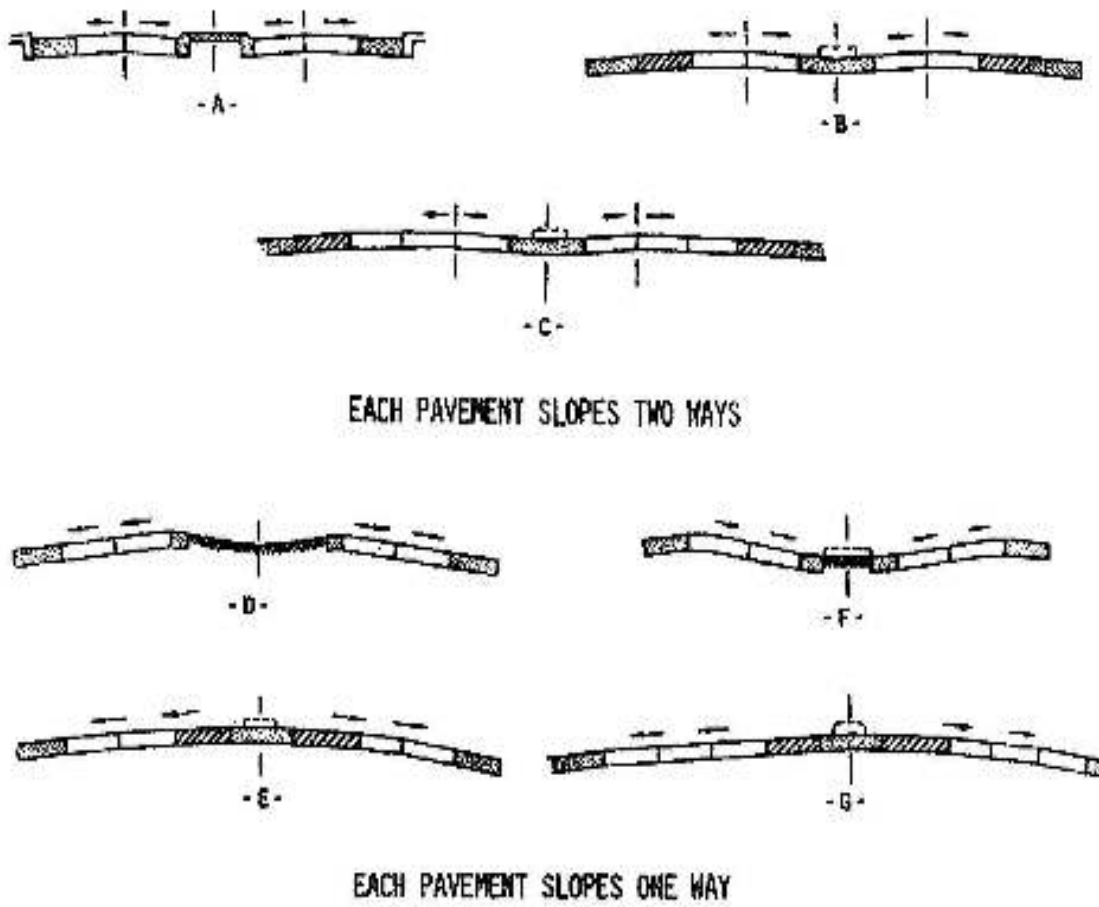
- Surface protection especially for gravel and bituminous roads
- Sub-grade protection by proper drainage
- Quick drying of pavement which in turn increases safety

How cross slopes are provided on roadway pavement?
How to ensure surface drain off of rain water?

Pavements on straight sections of **two-lane and multilane highways without medians are sloped from the middle downward to both sides of the highway.** This **provide a cross slope** (crowned).

The **cross slopes on divided highways** are provided by either :

1. **Crowning the pavement in each direction** *(mainly used in areas with heavy rain and snow)*
   Advantage: quick drain of surface water from traveled roadway during heavy rain storm.
   Disadvantage: more drainage facilities are required such as inlets and underground drains.
2. **Sloping the entire pavement in one direction.**



Shoulders

- **Portion of the rd way contiguous with the traveled way** on either side of the travel way
- May or may not be **surfaced, stabilized or paved**.
- Well designed and properly maintained shoulders are **nec on rural HY with appreciable amount of tfc, on FW and on some types of urban HW**
- It is essentials that shoulder be **flush with the edge of the traveled lane and sloped to facilitate drainage**





Shoulders

Shoulder width

- AASHTO: **10 -12 ft for highways having large number of trucks and high traffic volumes and high speeds**.
- Min width **4 ft w**hen **pedestrians and bicycles are permitted**
- Min **2 ft may be used on** difficult terrain and low tfc volume.

Shoulder Slope

should be **slopped sufficiently to rapidly drain surface water** but not to the extent that veh use would be hazardous

- **Bitumen & concrete-surfaced: 2 to 6%, Gravel/crushed rock: 4 to 6%, Turf: 6 to 8%**

Shoulder Contrast

Color and texture should be different from through tfc lanes. It clearly **defines at ni and inclement weather**, while discouraging the use of shoulder as through lanes

Importance of Shoulders

1. Space for vehicles with problems to park
2. Space for drivers to stop and check maps, etc
3. Space for evasive maneuvers to avoid collisions
4. The sense of openness
5. Help providing required sight distance
6. Increased aesthetics
7. Improved capacity
8. Space for maintenance operations (snow & storage)
9. Lateral clearance for signs and guardrails
10. Discharge storm water away from the edge of pavement
11. Structural support for the pavement
12. Space for pedestrians and bicycles

Shoulders











Sidewalks

- Sidewalks are generally **provided when pedestrian traffic is high along main or high-speed roads in either rural or urban areas**.
- **Necessary on arterials with no shoulders even when pedestrian traffic is low**.
- Should be provided along **both sides of collector streets in urban areas** to provide pedestrian access to schools, parks, shopping centers, and transit stops.
- As a general practice, sidewalks should be constructed along any street or highway not provided with shoulders, even though pedestrian traffic may be light.
- Sidewalks should have all-weather surface to ensure their intended use.
- Sidewalk Min width of (4 ft) in residential areas, and (4 – 8 ft) in commercial areas.

Side walks



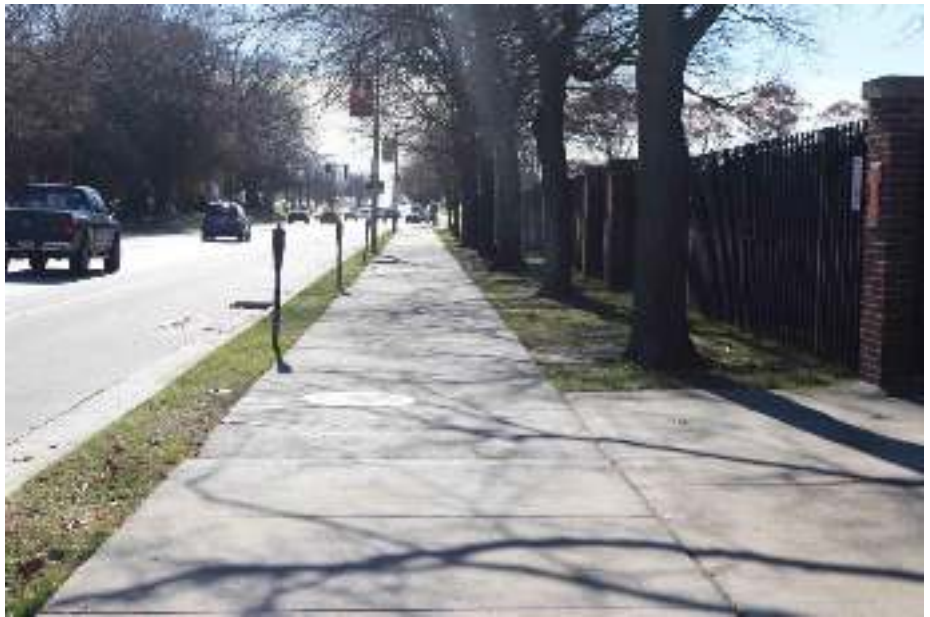




Side walks









Medians

What is it?: Is the section of a divided highway that separates the lanes in opposing directions.





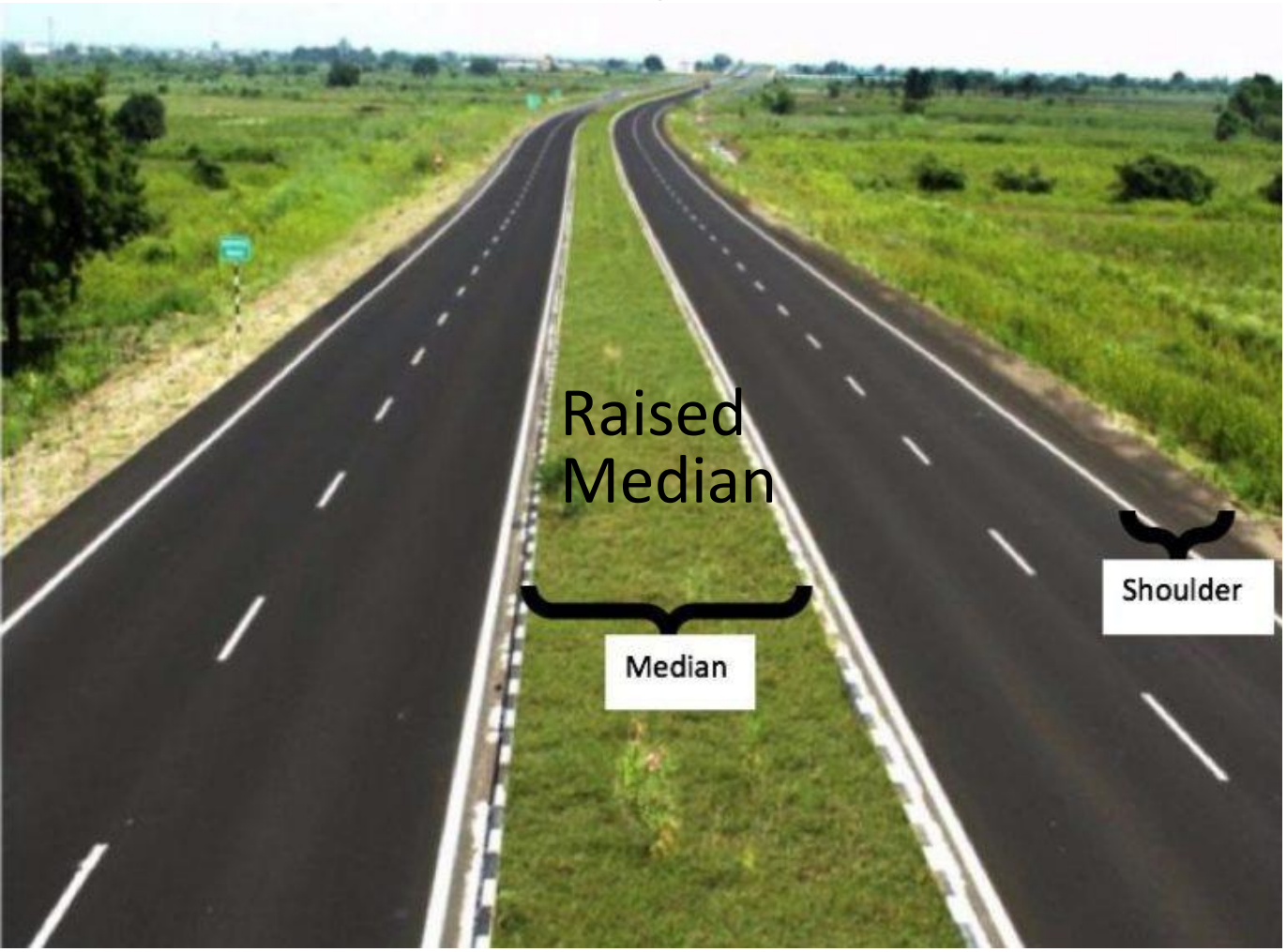
Medians

Median functions:

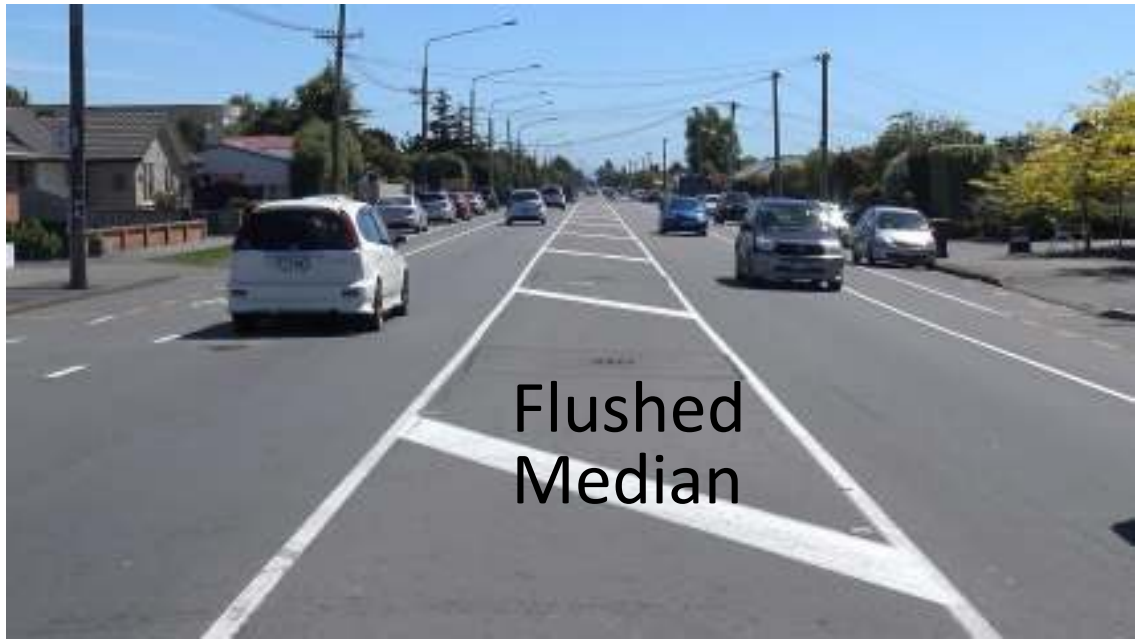
- Provide recovery area for out-of-control vehicles.
- Separating opposing traffic.
- Providing stopping areas during emergencies.
- Providing storage areas for left-turning and U-turning vehicles.
- Providing refuge for pedestrians.
- Reducing the effect of headlight glare.
- Providing temporary lanes and cross-overs during maintenance operations.

Medians Types

1.Raised
2.Flush
3.Depressed







Medians Types

Raised Medians

- used **in urban arterial streets** as they facilitate the control of left turning traffic at intersections by using part of the median width for left-turn only lanes.
- possible loss of control of the vehicle if the median is accidentally struck.
- Prevent headlight graring

Flush Medians

- Commonly used on urban arterials, also on free-ways but with a median barrier.
- Should be crowned to facilitate drainage of surface water.
- flush medians may be used as into two-way left-turn lanes
-

Depressed medians

- Used on freeways.
- More effective in draining surface water.

Cross-section Elements

Medians

Medians Width

- Vary from (**4 - 80 ft) or more.**
- For **4-lane urban freeways** min of **10 ft**.

For **6-lane urban freeways** min of **22- 26** ft.

Median Barriers

Median barriers are longitudinal system used to **prevent an errant vehicle from crossing** the portion of a divided highway separating the traveled ways for traffic in opposing directions.

Used to **shield pedestrians and property** from the traffic stream.

Median and Median Barriers







Drainage structures

1. Ditches
2. Curbs and Gutters
3. Parallel Drainage Structures

   Placed parallel to the flow of traffic.

   Commonly found under the driveway, median crossover, intersecting
   and other travelled ways generally at right angle to the main street c
4. Cross Drainage structures

   Designed to carry water underneath the road way embankment.

   Culvert, Bridges etc



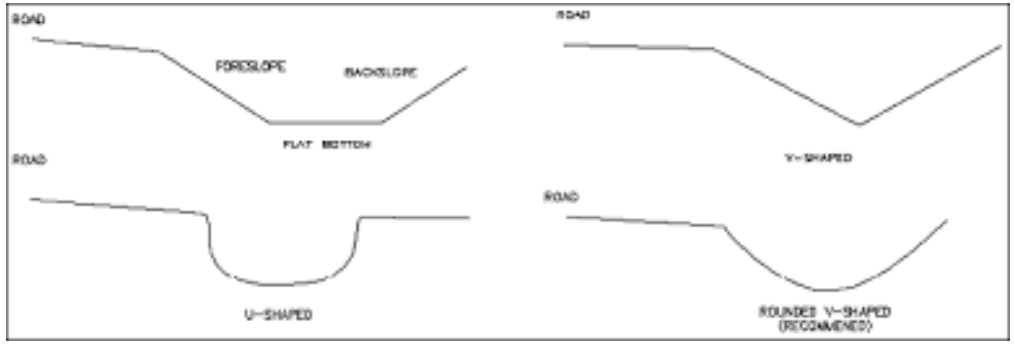


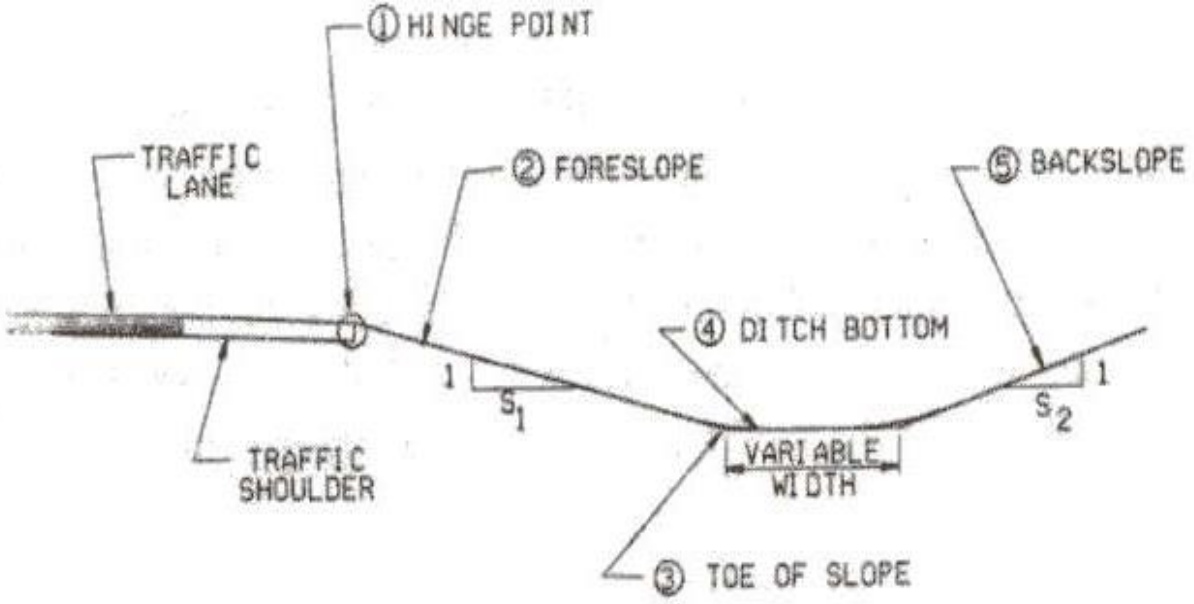




Drainage Structures-Ditches

- The side slope of ditches should be as flat as poss consistent with drainage requirement.
- Preferable the bottom of the ditch should be wide and rounded so as to be traversable by out of con veh.
- Deep narrow ditches need to be shielded by roadside barriers.







Drainage Structure- Curbs and Gutters







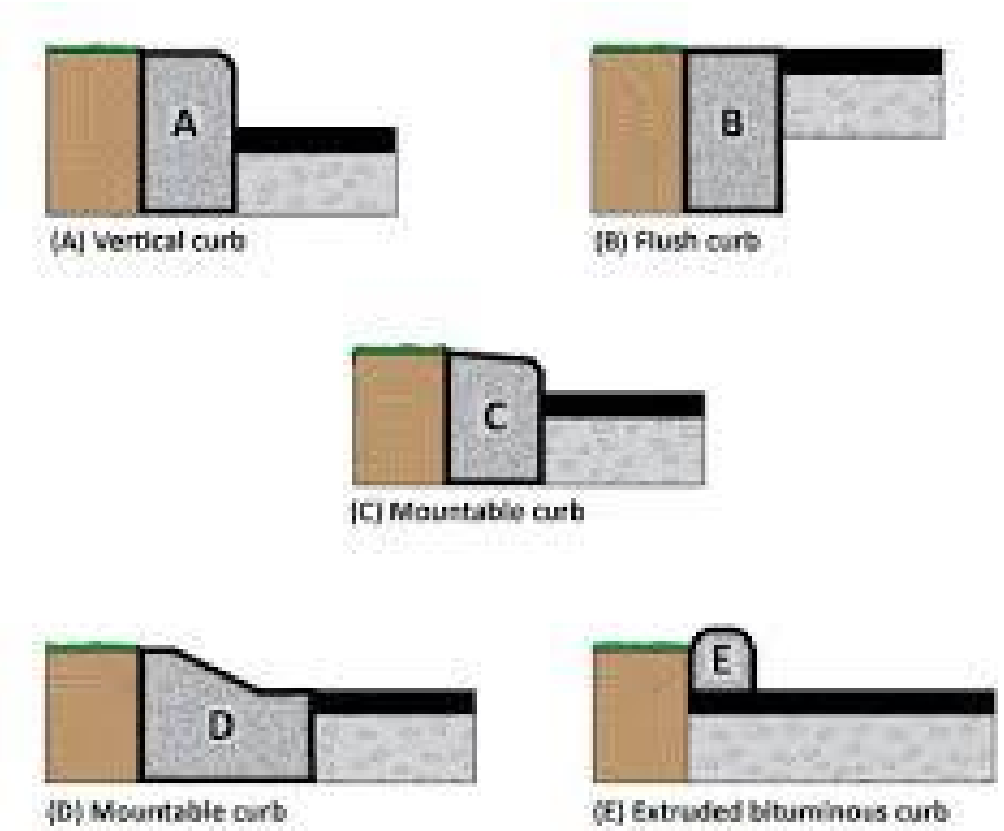




Curbs/Kerbs

Raised structures made of either Portland cement concrete or bituminous concrete that are used mainly on urban highways to :

- Delineate pavement edges and pedestrian walkways.
- indicate the boundary between the carriage way and the shoulder or islands or footpathsControl drainage.
- Improve aesthetics.

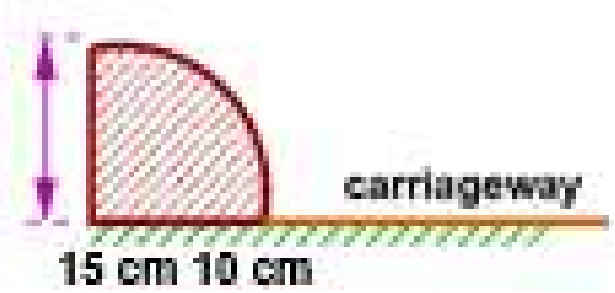


Curbs/Kerbs

Low or mountable kerbs:

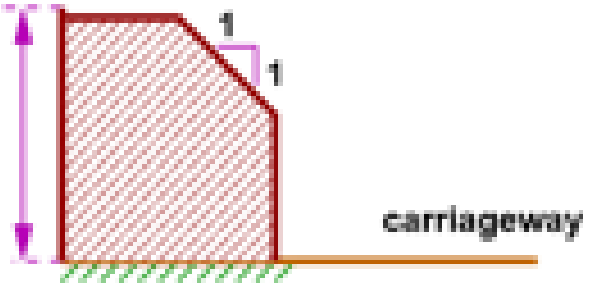
<u>encourage the traffic to remain in the through traffic lanes and also llow the driver to enter the shoulder area with little difficulty</u>.

usually **<u>provided at medians and channelization schemes and also helps in longitudinal drainage</u>**.



Semi-barrier type kerbs:

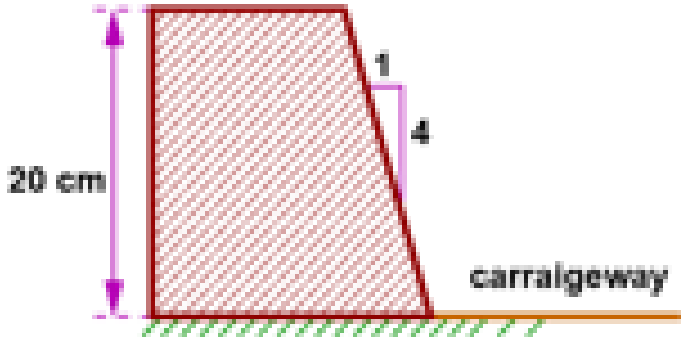
This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.



Curbs/Kerbs

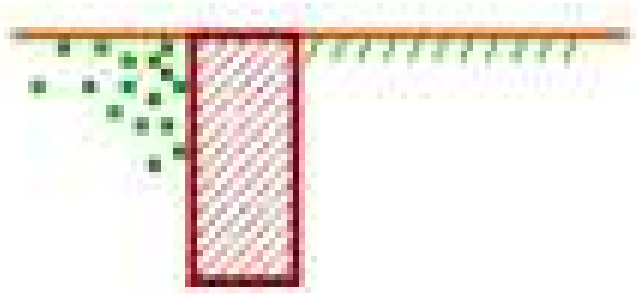
Barrier type kerbs:

designed to discourage vehicles from leaving the pavement
They are provided **when there is considerable amount of pedestrian traffic**.



Submerged kerbs:

They are used in **rural roads**. The kerbs are provided at pavement edges between the pavement edge and shoulders. They **provide lateral confinement and stability to the pavement.**



Gutters

- A **street gutter** is a depression running parallel to a road designed to collect rainwater flowing along the street and divert it into a storm drain. Also known as drainage ditches.
- A gutter alleviates water buildup on a street, allowing pedestrians to pass safely and smoothly
- Çan be designed as V-type sections or as broad, flat, rounded sections







Longitudinal barriers

Purpose: to prevent veh from leaving the roadway and crushing into the roadside obstacle, overturning and crossing into the path of veh travelling in opposite direction.

Roadside Barriers like guard rail

Medians

Bridge Railing

Guard rails

Guard rails are longitudinal barriers whose main function is to prevent vehicles from leaving the roadbed.

Placed on:

- The outside of sharp curves (where there is sudden change in alignment)
- Where greater reduction of speed is nec
- Sections with high fills (embankments > 8 ft)
- Shoulder slopes > 4:1
- Loc with steep banks, deep roadside ditches and other ROW limitations.

Shoulder width to be increased by 2 ft where guard rails are to be used.

Guard Rails



















Right of Way (ROW)

Is the total land area acquired for the construction of the highway.

Its width should be enough to:

- Accommodate all elements of the highway cross section.
- Any planned widening of the highway.
- Any public utility facilities that will be installed along the highway.

In some cases the side slopes may be located outside the ROW on easement areas.

The min. width of ROW for freeway depend on the number of lanes and the existence of frontage roads.

for two-lane urban collectors: (40 – 60 ft)

for two-lane arterials: (min of 84 ft)

for undivided 4-lane arterials: (64 – 108 ft)

for divided arterials: (120 – 300 ft)

Marginal Cross sectional Elements

Footpath, Bike way

- Footpaths are exclusive right of way to pedestrians, especially in urban areas. They are provided for the safety of the pedestrians when both the pedestrian traffic and vehicular traffic is high. Minimum width is 1.5 meter and may be increased based on the traffic. The footpath should be either as smooth as the pavement or more smoother than that to induce the pedestrian to use the footpath.






Marginal Cross sectional Elements

Noise Barrier

Motor vehicles generate traffic noise. Designers should design noise barrier or sound walls to minimize the radiation of noise into noise-sensitive areas along the highway.
Noise reduction designs: depressed highways, sound barriers, natural barriers (trees)










Marginal Cross sectional Elements

Bus-bays

Bus bays are provided by recessing the kerbs for bus stops. They are provided so that they do not obstruct the movement of vehicles in the carriage way. They should be at least 75 meters away from the intersection so that the traffic near the intersections is not affected by the bus-bay.







Marginal Cross sectional Elements

Service roads/Frontage Road

Service roads or frontage roads give access to access controlled highways like freeways and expressways. They run parallel to the highway and will be usually isolated by a separator and access to the highway will be provided only at selected points. These roads are provided to avoid congestion in the expressways and also the speed of the traffic in those lanes is not reduced.





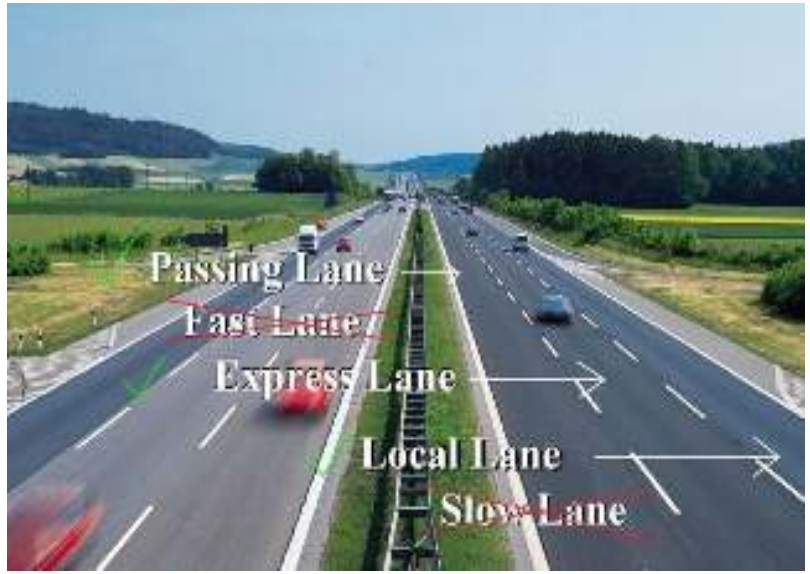
Marginal Cross sectional Elements

Passing Lane

- **A lane added to improve overall traffic operations**, should be long enough, over 0.3 mi. The optimal length is 0.5 to 2 miles
- Provide systematically at regular interval (otherwise inform the drivers well in advance to reduce their frustration)
- A minimum sight distance of 1000 ft is recommended.
- Provide signs to inform drivers.







Marginal Cross sectional Elements

Turnout

- **It is a widened, unobstructed area that allows slow-moving vehicles to pull out of the through lane to give passing opportunities to following vehicles.**
- Minimum = 200 ft, Maximum = 600 ft to avoid for use as a passing lane. It include the entry and exit taper lengths ranging from 50 to 100 ft.
- Available sight distance – at minimum 1000 ft.
- Proper signing and pavement marking essential not to misguide the drives

Marginal Cross sectional Elements

Climbing Lane

A highway section with a climbing lane is not considered a three-lane highway, but a two-lane highway with an added lane.

For low-volume two-lane highways, climbing lanes may not be justified economically. In such cases, vehicle turnouts should be used

Generally climbing lanes should not be considered unless the volume exceeds the service volume of LOS D.

If not warranted now, but may be in the future, then preserve right-of-ways for such additions.

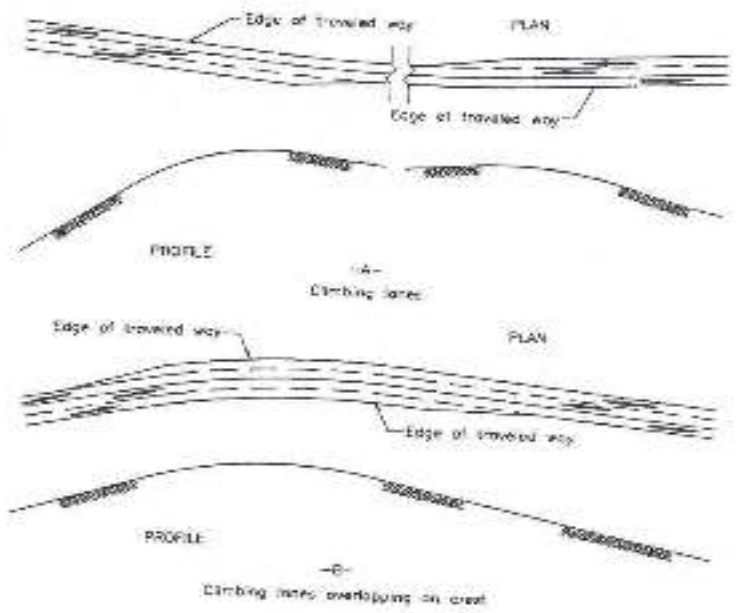


Exhibit 3-61. Climbing Lanes on Two-Lane Highways

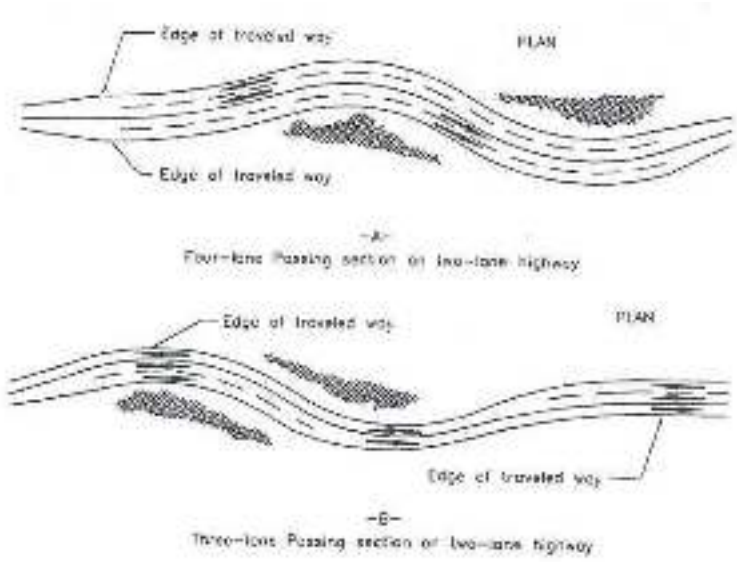


Exhibit 3-63. Passing Lanes Section on Two-Lane Roads

Marginal Cross sectional Elements

Parking lanes

Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving on the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking.







Types of Parking Facilities

On-street / curb parking

- along curb
- Seriously impede tfc flow and contribute to conflicts/ crashes
- short stay
- convenient
- preferable parallel
- charged or free

Off-street parking

- away from curb
- long stay
- may be inconvenient as walking is reqd
- preferably angle
- Types: back street, surface car parks/parking lots, multi storied (self or auto), basement parks

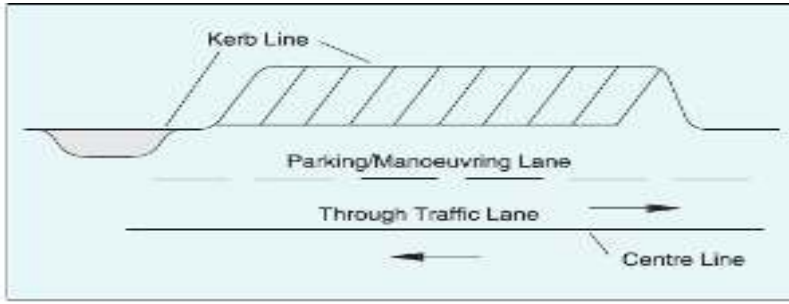
Method of Parking



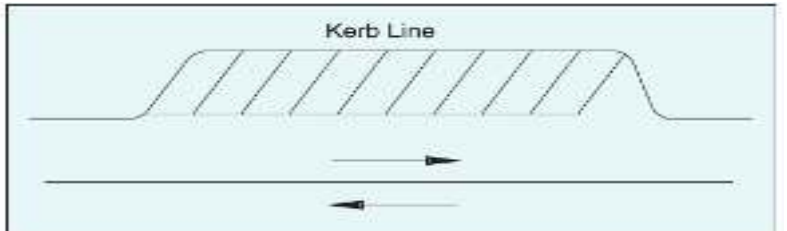
Parallel parking

- Space reqr for parking and unparking maneuvers is least
- Reqr least rdway width but max curb length
- Maneuver is very difficult
- Off side door opening difficult
- Gen recommended for road with narrow width or with high vol of through tfc

Angle Parking



- Space reqr for parking and unparking man increases with angle
- Reqr more rdway width but less curb length
- Maneuver is more convenient or easier
- Usually recommended for off street parking or for exceptionally wider rd or rd with low vol of through tfc



On Street Parking







Street Lighting

Arrangement/Layout

- Single side
- Both sides: staggered or opposite
- Central : one arm or two arms

Recommended arrangement

✓ One side when pavement width <= 30 ft

✓ Both sides staggered for pavement 30 ft > width <= 60 ft

✓ Both sides opposite for pavement width > 60 ft







Street Lighting

Key Loc where Adequate Street Lighting is Necessary

- Where there are high proportion of ped, cyclist or other poorly lit rd users incl animals
- Intersection where both veh and ped flow is high
- Sharp bend, summit curves, tunnels, ped x-ing areas, br sites, level x-ing, other bottlenecks
- Hazardous obj like road humps, channelizing islands etc.

Delay / Congestion Studies

Types of delay

Recurrent delay – occurs periodically at particular place and time

Non-recurrent delay – unpredictable and causes for random events

Causes of delay

Fixed / geometric delay

- Road intersection / signal
- Inconsistent roadway width
- Sharp hor / verticle curves
- Sharp bend, bridges

Operation delay – caused by road side and inter-veh frictions

Other causes-

Negative impacts of Delay / Congestion Studies

- Wasting time of motorists and passengers.
- Inability to forecast travel time accurately, leading to drivers allocating more time to travel and less time on productive activities.
- Wasted fuel increases air pollution owing to increased idling, acceleration and braking.
- Wear and tear on vehicles leading to more frequent repairs and replacements.
- Stressed and frustrated motorists, encouraging road rage and reduced health of motorists leading to accident.
- Emergency vehicles may be interfered traveling to their destinations where they are urgently needed.
- Economic aspec.
- Others

Causes of Accident

1. Distracted Driving.
2. Speeding.
3. Drunk Driving. ...
4. Reckless Driving
5. Weather: Rain, snow, fog, darkness, ice etc.
6. Running Red Lights
7. Running Stop Signs
8. Teenage Drivers.
9. Design Defects:automobile and highway
10. Unsafe Lane Changes
11. Improper Turns
12. Tailgating

Discuss under three groups
Roadway user, Highway environment and Mechanical Failure.

Causes of Accident

1. Distracted Driving

Distracted drivers are the top cause of car accidents in the U.S. today. A distracted driver is a motorist that diverts his or her attention from the road, usually to talk on a cell phone, send a text message or eat food.

2. Speeding

Many drivers ignore the speed limit and drive over the limit. Traveling above the speed limit is an easy way to cause a car accident. The faster you drive, the slower your reaction time will be if you need to prevent an auto accident.

3. Drunk Driving

Driving under the influence of alcohol causes car accidents every day. A drunk driver lose the ability to focus and function properly and its very dangerous when operating a vehicle.

4. Reckless Driving

If you don’t drive carefully, and you may end up in a needless car accident. That’s what often happens to reckless drivers who speed, change lanes too quickly or tailgate before causing a car accident. Reckless drivers are often impatient in traffic so be sure to take extra care around aggressive drivers.

Causes of Accident

5. Rain
Car accidents happen very often in the rain because water creates slick and dangerous surfaces for cars, trucks, and motorcycles and often causes automobiles to spin out of control or skid while braking. To avoid a car accident, drive extra careful when it rains.

6. Running Red Lights
Drivers that run red lights, run the risk of causing wrongful death because they often cause side-impact collisions at high speeds. To avoid a car accident, look both ways for oncoming cars as you approach a green light.

7. Running Stop Signs
Stop signs should never be ignored, but when they are, serious car accidents are often the result. Many rollover accidents and side-impact car accidents result from drivers that run stop signs. You should always look both ways when proceeding through a stop sign.

8. Teenage Drivers
Unfortunately, teenagers aren’t often known for their carefulness. When teen drivers hit the roads they don’t always know what to do and that lack of experience ends up causing car accidents.

Causes of Accident

9. Night Driving
Driving in the daylight can be hazardous, but driving at night nearly doubles the risk of a car accident occurring. When you can't see what's up ahead you don't know what to anticipate as you drive towards it.

10. Design Defects
No product is ever made perfectly, and cars are no different. Automobiles have hundreds of parts, and any of those defective parts can cause a serious car accident.

11. Unsafe Lane Changes
There will always come a time where you need to get over to another lane (i.e. exit from a freeway, get in the correct lane to make a turn, etc.). When drivers don't make safe lane changes properly, it often leads to a car accident.

12. Wrong-Way Driving
You can turn down a street thinking it is a normal right turn, when in actuality, it is a one-way street in the opposite direction. When you go the wrong way, everyone is in danger because as you head towards a car accident.

Causes of Accident

13. Improper Turns
The reason that we have stop lights, turn signals, and lanes designated for moving either right or left as opposed to straight is because when drivers ignore the rules of the road, car accidents are often the result.

14. Tailgating
Many drivers are impatient and reckless, driving so close to another car that they cannot react in time if the car in front of them brakes suddenly.

15. Driving Under the Influence of Drugs
It’s not only alcohol that is dangerous when mixed with drivers on the road. Drugs, both legal and illegal, can impair your ability to fully function as a driver. If your mind isn’t clear and you don’t have complete control over your body, getting behind the wheel can lead to serious car accidents.

17. Snow
Snow’s dangerous mixture of ice and water is a dangerous recipe for car accidents each winter storm.

Causes of Accident

18. Road Rage
By tailgating another driver in anger or speeding past another driver only to pull in front of them and brake, these road “ragers” cause many needless car accidents each year.

19. Potholes
Drivers run the risk of losing control of their car or blowing out a tire when they drive over these potholes. If you see a pothole in your car’s path, you can avoid a car accident by making sure that your tires do not drive over it.

20. Drowsy Driving
Most of the car accidents caused by drowsy driving occur at night. If you find yourself wanting to fall asleep at the wheel, pull over when it’s safe and try to take a quick 30 minute power nap.

21. Tire Blowouts
Most highways are littered with the scattered remains of a tire blowout. Tire blowouts can cause you to lose control of your vehicle, and they are especially dangerous for bigger automobiles like semi-trucks. When encountering a tire blowout, try to maintain control of your vehicle and pull over safely and you will likely avoid a serious car accident.

Causes of Accident

22. Fog
Fog isn't the most common weather occurrence, and that's good news for car accidents statistics. Driving is a skill that requires the ability to see, but fog makes it extremely difficult to see sometimes more than a car length in front of you.

23. Deadly Curves
Many motorists have lost control of their cars along a dangerous curve and lost their lives in a car accident. So when you approach these signs, take head of the posted speed limit and drive cautiously to avoid a car accident.

24. Animal Crossings
While drivers are required to know the rules of the roadway, wild animals do not take driver's education. Wild animals will wade out into the street, and it's up to you to make sure that you don't get into a car accident with them.

25. Street Racing

Accident Studies

Accident Responsible for:

- Road users – drivers and pedestrians (60%)
- Road environment – 30%
- Mech Failure – 10%

Explain different aspect in light of Bangladesh

Use of Accdt Data

- Engineering use
- Enforcement use
- Administrative use
- Educational use

Engineering use

- ✓To justify safety measures and traffic rergulating measures
- ✓Determine adequacy, shape, size and legibility of traffic signs
- ✓To design and plan ped safety facilities
- ✓To implement speed zoning and speed control
- ✓To improve geometric element

Traffic Collision

A **traffic collision**, also known as a motor vehicle **collision** occurs when a vehicle collides with another vehicle, pedestrian, animal, **road** debris, or other stationary obstruction, such as a tree or utility pole.

Traffic collisions may result in injury, death and property damage

Types of Collisions

- **Backup collisions** when a driver reverses the car into an object, person, or other car.
- **Frontal impacts /head on collision**
- **Side impacts / Brush or side swipe** - here the side of one or more vehicles is impacted. These crashes often occur at intersec and parking lots and when two vehicles pass on a multi-lane roadway.
- **Rear end collision-** wherein a vehicle crashes into the vehicle in front of it.
- **Right Angled collision**
- **Right turn collision**
- **Rollovers**

Various Types of Collision



Rear end collision















Head on Collision







Side impacts / Brush or side swipe







Right Angled collision







Parking Studies

Types of Parking Facilities

On-street / curb parking

- along curb
- Seriously impede tfc flow and contribute to conflicts/ crashes
- short stay
- convenient
- preferable parallel
- charged or free

Off-street parking

- away from curb
- long stay
- may be inconvenient as walking is reqd
- preferably angle
- Types: back street, surface car parks/parking lots, multi storied (self or auto), basement parks

Method of Parking

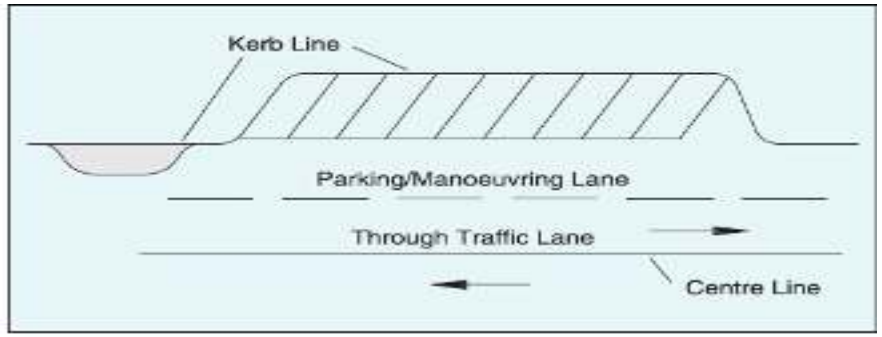
Parallel parking

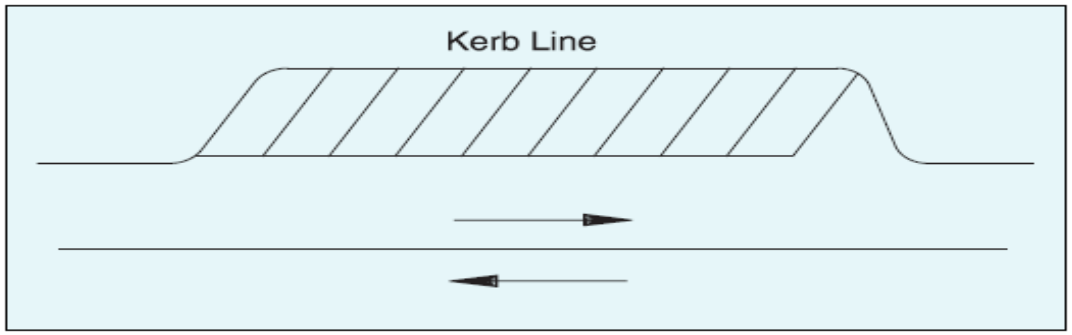
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Angle Parking

- Space reqr for parking and unparking man increases with angle
- Reqr more rdway width but less curb length
- Maneuver is more convenient or easier
- Usually recommended for off street parking or for exceptionally wider rd or rd with low vol of through tfc

Angle parking









Problem with Uncontrolled On Street Parking:

- Reduce roadway capacity and causes congestion and serious economic loss.
- Encourage rd side non-motor activities / rd side friction
- Less efficient use of rd side space
- Loss of revenue
- Make rdway op unsafe and haphazard

Traffic Surveillance

What is it?

Real time tfc con and mgt / enforcement measures

Useful for peak hr and wide area tfc prob

Need remote sensing, replace police petrol

Objective

To provide optimum utilization of all available facilities by monitoring, collecting, integrating etc.

To enforce / detect tfc law breakers

To improve security of public crowded areas or shops

Surveillance Techniques

Manual: Citizen calls, Police petrol

Remote sensing: Detectors / sensors, Using CCTV

Traffic Surveillance

Flow break down?

Is a sudden change of flow condition

It generate shock wave in the saturated tfc stream

The wave propagate and amplified through downstream tfc very quickly

Causes due to non-recurrent events like accdt, mech failure, signal malfunctioning, excess of tfc or congestion etc.

Consequences of Flow break down

Causes temp blockage of road and contribute to non-recurrent congestion

Long queue of veh is built very quickly

Large amount of delay incurred by the travelers at peak period

Since it is an unpredictable real time events, for taking prompt action, continuous surveillance system to detect roadway incidents.

Street Lighting

Key Loc where Adequate Street Lighting is Necessary

- Where there are high proportion of ped, cyclist or other poorly lit rd users incl animals
- Intersection where both veh and ped flow is high
- Sharp bend, summit curves, tunnels, ped x-ing areas, br sites, level x-ing, other bottlenecks
- Hazardous obj like road humps, channelizing islands etc.

Street Lighting

Arrangement/Layout

- Single side
- Both sides: staggered or opposite
- Central : one arm or two arms

Recommended arrangement

- ✓ One side when pavement width <= 30 ft
- ✓ Both sides staggered for pavement 30 ft > width <= 60 ft
- ✓ Both sides opposite for pavement width > 60 ft

SIGHT DISTANCE (SD)

Sight distance is the length of the roadway ahead that is visible to the driver at any time.

Safe highways must be designed to give drivers a sufficient clear vision ahead so that they can:

- ✓ Avoid hitting unexpected obstacles in the road
- ✓ Can pass slower vehicles without danger

Types of sight distances

- Stopping Sight Distance (SSD)
- Passing Sight Distance (PSD)
- Decision Sight Distance (DSD)
- Intersection Sight Distance (ISD)

STOPPING SIGHT DISTANCE (SSD)

Defn.: ***Min dist reqr to stop a veh (traveling at or near the design speed) before it reaches a stationary obj in it's path. Applicable for all the rd way.***

- Sight distance at every point along a highway should be as long as possibl

Reaction Time/ PIEV Time and Distance:

Time interval between seeing, hearing or feeling the existence of an obj or hazard on or along the rd way and the instant of starting to do something in response. **PR dist = vt, where v vel in m/sec.**

Brake reaction time:

Time the object is sighted to the time the brakes are applied. For design a conservative value is used

Combined perception-reaction time and brake reaction time = 2.5 seconds

SSD = ***Sum of Perception reaction dist and braking dist.*** $= v \times t + D_b$

$$= vt + \frac{v^2}{2g(f \pm G)}, \qquad where\ v\ is\ in\ kmph$$

$$= 1.47vt + \frac{v^2}{32(f \pm G)}, \qquad where\ v\ is\ in\ mph\ and\ g = 32.2\ fps^2$$

STOPPING SIGHT DISTANCE (SSD)

The computation of sight distance depends on

- Perception Reaction (PR) time of the driver
- Break Reaction (BR) time of the driver
- Speed of the vehicle
- Efficiency of brakes, tyre, road surface
- Frictional resistance between the tyre and the road
- Gradient of the road, road alignment.
- Size, type of object
- Climate condition

Driver,

Vehicle,

Road,

Climate

Explain the effects of above factors. How they affect?

$$SSD = vt + \frac{v^2}{2g(f \pm G)} = 1.47vt + \frac{v^2}{32(f \pm G)}$$

STOPPING SIGHT DISTANCE (SSD)

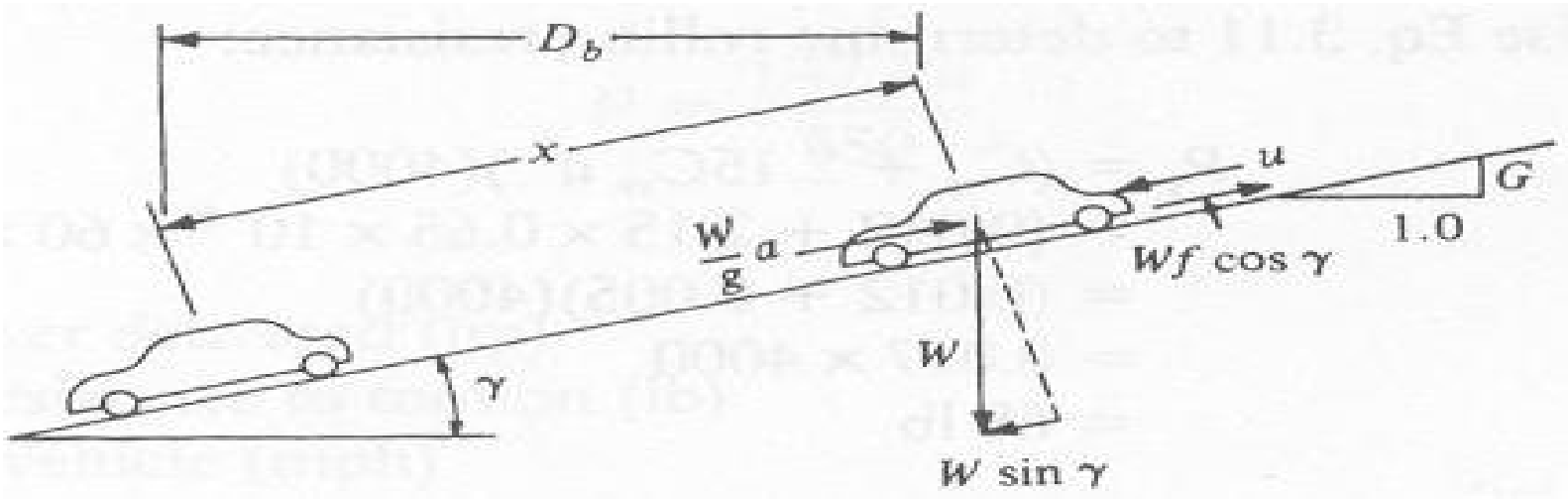
Effect of friction/Climate

- **Wet condition**
- Dry Condition

Effect of Speed

Effect of Grade

- Shorter along up grade
- Longer along down grade



Will you design SSD for car or bus/trucks?

(for passenger cars. Truck drivers' eye heights are much higher and they can see further. Hence, SSDs for just trucks are not used.)

$$SSD = vt + \frac{v^2}{2g(f \pm G)} = 1.47vt + \frac{v^2}{32(f \pm G)}$$

STOPPING SIGHT DISTANCE (SSD)

SSD vs Speed

US Customary				
Design speed (mph)	Brake reaction distance (ft)	Braking distance on level (ft)	Stopping sight distance	
			Calculated (ft)	Design (ft)
15	55.1	21.6	76.7	80
20	73.5	38.4	111.9	115
25	91.9	60.0	151.9	155
30	110.3	86.4	196.7	200
35	128.6	117.6	246.2	250
40	147.0	153.6	300.6	305
45	165.4	194.4	359.8	360
50	183.8	240.0	423.8	425
55	202.1	290.3	492.4	495
60	220.5	345.5	566.0	570
65	238.9	405.5	644.4	645
70	257.3	470.3	727.6	730
75	275.6	539.9	815.5	820
80	294.0	614.3	908.3	910

celeration rate of 3.4 m/s^2 [11.2 ft/s^2] used to determine

SSD w.r.t. Grades

US Customary						
Design speed (mph)	Stopping sight distance (ft)					
	Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %
15	80	82	85	75	74	73
20	116	120	126	109	107	104
25	158	165	173	147	143	140
30	205	215	227	200	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375
55	520	553	593	469	450	433
60	598	638	686	538	515	495
65	682	728	785	612	584	561
70	771	825	891	690	658	631
75	866	927	1003	772	736	704
80	965	1035	1121	859	817	782

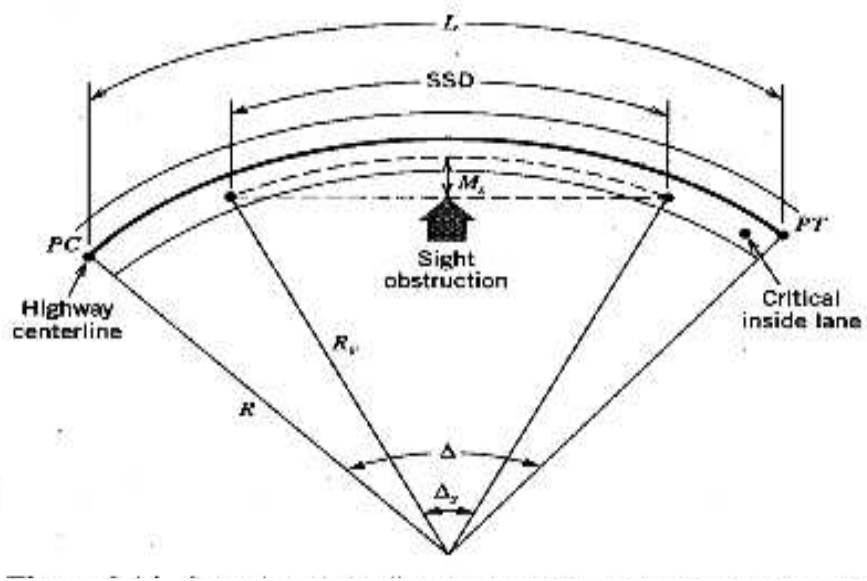
STOPPING SIGHT DISTANCE (SSD)

Low cost improvements for locations with inadequate sight distances

1. Installing reduced speed warning signs
2. Installing 'Limited Sight Distance' warning sign
3. Installing sight distance mirrors

Alternatives designs when SSD is not available due to object alongside of roadway

1. Increase offset to obstruction
2. Increase the radius
3. Reduce design speed



e. Horizontal curve (to see around obstruction):

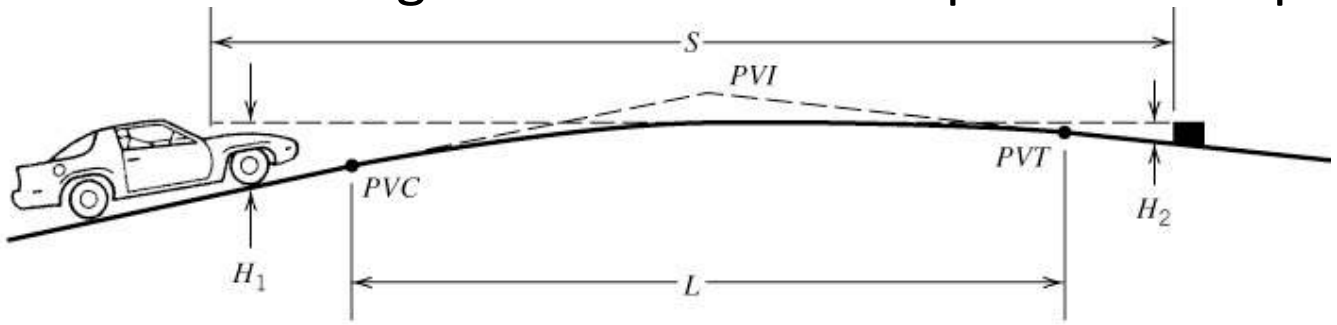
$$M = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right]$$

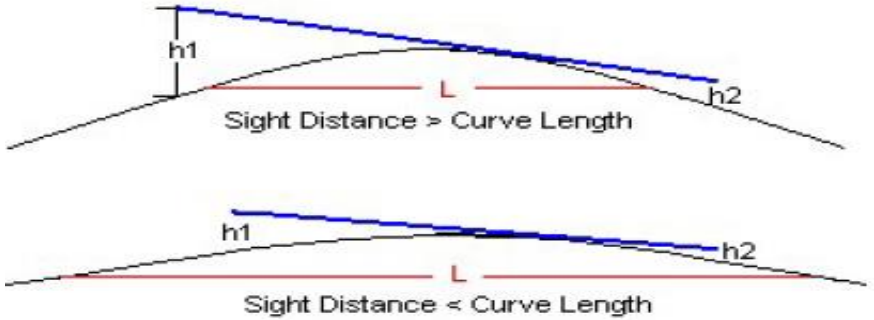
where

R = radius (ft or m)
M = middle ordinate (ft or m),
S = stopping sight distance (ft or m).

SSD for Crest Vertical Curve

- Based on driver eye height above roadway and height of object above roadway surface.
- Minimum length of curve that will provide adequate safety and minimum cost is desired.





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

$$S > L,\ L = 2S - \frac{200(\sqrt{2h_1}+\sqrt{2h_2})^2}{A}$$

Using $h_1 = 3.5\ ft$ and $h_2 = 2ft$, the equations :

$$S > L,\ L = AS^2/2158$$

$$S < L,\ L = 2S - \frac{2158}{A}$$

L = length of vertical curve, in feet

S = sight distance, in feet

A = algebraic difference in percent grade, absolute value

h_1 = height of driver's eye in feet

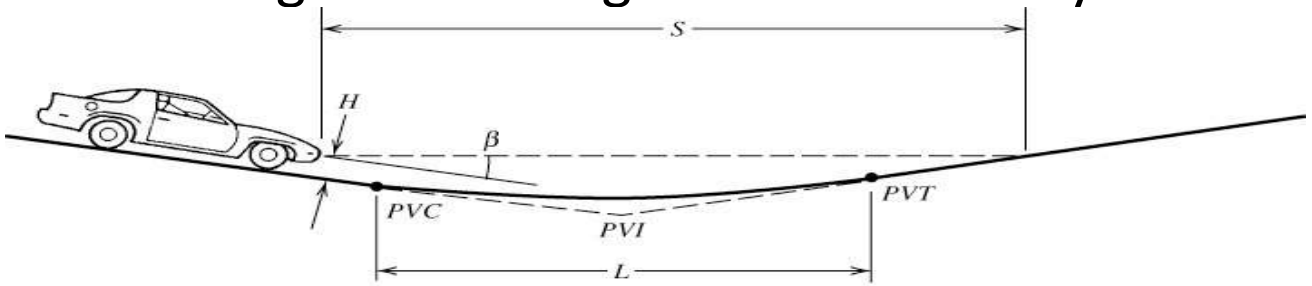
h_2 = height of object in feet

If the passing sight distance required for a vertical curve exceeds the stopping sight distance, to reduce cost, passing may be restricted along the curve

Minimum Curve Length would then = stopping sight distance

SSD for Sag Vertical Curve

- Sight distance is governed by night time conditions.
- Important - height of headlight above roadway and inclined angle of headlight beam.



where:
H = height of headlight above road surface
= inclined angle of headlight beam.

- For sag curves, SD is not physically constrained by the road surface during the day
- At night the SD is limited by the distance and angle of projection of a vehicle's headlights
- Headlights are mounted below a driver's eye height, at a height of 2 feet
- Headlight beam projects ≈1° upward along the vehicle's longitudinal axis

$$S < L,\ L = \frac{AS^2}{400+3.5S}$$

$$S > L,\ L = 2S - \frac{400+3.5S}{A}$$

Where:
L = length of curve, in feet
S = sight (light beam) distance, in feet
A = Algebraic difference in percent grade, absolute value
Using a headlight height of 2 feet and a headlight beam angle of 1°



Problem

A crest vertical curve is to be designed to join a +3% grade with a -3% grade at a section of a two-lane highway. The design speed of the highway is 60 mph. Determine: Minimum length of the curve.

A 1200 ft. equal tangent crest vertical curve is currently designed for 50 mi/hr. A civil engineering student contends that 60 mph is safe in a van because of the higher driver's eye height. If all other design inputs are standard, what must the driver's eye height inthe van be for the student's claim to be valid?

Problem: A sag vertical curve is to be designed to join a -3% grade to a +3% grade. Design speed is 40 mph. Determine: Minimum Length of the curve

A section of highway has vertical and horizontal curves with the same design speed. A vertical curve on this highway connects a +1% and a +3% grade and is 420 ft long. If a horizontal curve on this highway is on a two-lane section with 12-ft lanes, has a central angle of 37 degrees, and has a superelevation of 6%, what is the length of the horizontal curve?

EXAMPLE PROBLEM 4.2 Determine the minimum length of a crest vertical curve between a +0.5% grade and a −1.0% grade for a road with a 100-km/h design speed. The vertical curve must provide 190-m stopping sight distance and meet the California appearance criteria. Round up to the next greatest 20 m interval.

Stopping sight distance criterion:

Assume $S \leq L$

$$L = \frac{AS^2}{200(\sqrt{h_1} + \sqrt{h_2})^2} = \frac{[0.5 - (-1.0)](190^2)}{200(\sqrt{1.070} + \sqrt{0.150})^2} = 134.0 \text{ m}$$

$$134.0 \text{ m} < 190 \text{ m, so } S > L$$

$$L = 2S - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{A} = 2(190) - \frac{200(\sqrt{1.070} + \sqrt{0.150})^2}{[0.5 - (-1.0)]}$$

$$= 380.0 - 269.5 = 110.5 \text{ m}$$

EXAMPLE PROBLEM 4.3 Determine the minimum length of a sag vertical curve between a −0.7% grade and a +0.5% grade for a road with a 110 km/h design speed. The vertical curve must provide 220 m stopping sight distance and meet the California appearance criteria and the AASHTO comfort standard. Round up to the next greatest 20 m interval.

Stopping sight distance criterion:

Assume $S \leq L$

$$L = \frac{AS^2}{120 + 3.5S} = \frac{[0.5 - (-0.7)](220^2)}{120 + 3.5(220)} = 65.3 \text{ m}$$

65.3 m < 220 m, so $S > L$

$$L = 2S - \frac{120 + 3.5S}{A} = 2(220) - \frac{120 + 3.5(220)}{[0.5 - (-0.7)]}$$

$$= 440 - 741.7 = -301.7 \text{ m}$$

Since $L < 0$, no vertical curve is needed to provide stopping sight distance.

Comfort criterion:

$$L = \frac{AV^2}{395} = \frac{[0.5 - (-0.7)](110^2)}{395} = 36.8 \text{ m}$$

An existing vertical curve on a highway connects a +3% grade with -4% grade. If the length of the curve is 250 ft, what is the maximum safe speed on this curve? Assume f = 0.4, PR time 3.0 sec and L> S.

If the speed as determined above is used to design a sag vertical curve, which will join a -3.5% grade to +3% grade, what will be the minimum length of the curve when f and PR time remain same. 5 +5

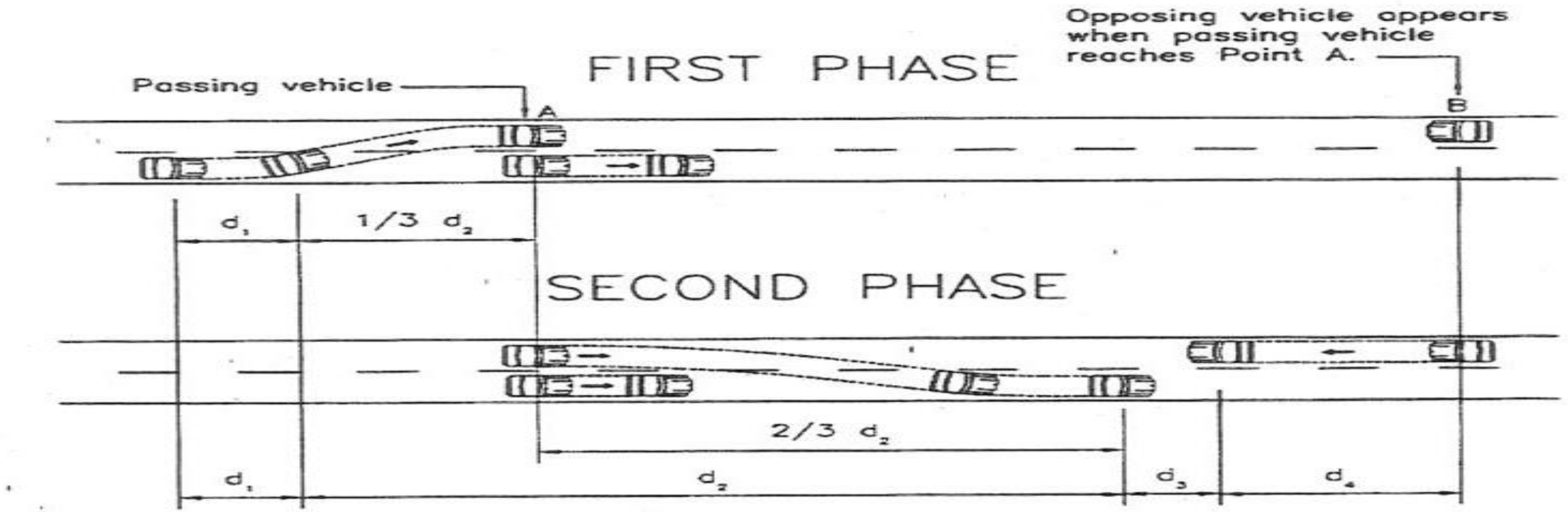
PASSIND SIGHT DISTANCE (PSD)

Defn. *Min dist which enable a veh (a dvr) to overtake and pass another veh on a two lane highway safely and efficiently without interfering the opposing veh. Applicable only on two lane highway.*

Assumptions:

1. PSD is determined for a single veh passing another single veh.
2. Overtaken veh op at uniform speed.
3. Overtaking veh has reduced speed and trails the overtaken veh as it enters a passing sec.
4. When passing sec is reached, dvr reqr a short period of time to perceive the clear passing sec and to react to start his maneuver.
5. Passing is accomplished under delayed start and hurried return in the face of opposing veh.
6. Passing veh accelerates during maneuver and its average speed during the occupancy of opposing lane is 10 mph higher than overtaken veh.
7. When return to own lane there is sufficient clearance dist between it and opposing veh.

Elements of PSD: $d_1+d_2+d_3+d_4$



d_1 = Initial maneuver distance

d_2 = Distance while passing vehicle occupies left lane

d_3 = Clearance length = 110-300 ft

d_4 = Distance traversed by an opposing vehicle = 2/3 of d_2

Elements of PSD

d_1 = Initial maneuver distance

US Customary

$$d_1 = 1.47 t_i \left(v - m + \frac{a t_i}{2} \right) \qquad (3\text{-}6)$$

where:

- t_i = time of initial maneuver, s;
- a = average acceleration, mph/s;
- v = average speed of passing vehicle, mph;
- m = difference in speed of passed vehicle and passing vehicle, mph

d_2 = Distance while passing vehicle occupies left lane

US Customary

$$d_2 = 1.47 v t_2 \qquad (3\text{-}7)$$

where:

- t_2 = time passing vehicle occupies the left lane, s;
- v = average speed of passing vehicle, mph

d_3 = Clearance length = 110-300 ft

d_4 = Distance traversed by an opposing vehicle = 2/3 of d_2

Elements of PSD

Component of passing maneuver	Metric				US Customary			
	Speed range (km/h)				Speed range (mph)			
	50–65	66–80	81–95	96–110	30–40	40–50	50–60	60–70
	Average passing speed (km/h)				Average passing speed (mph)			
	56.2	70.0	84.5	99.8	34.9	43.8	52.6	62.0
Initial maneuver:								
a = average acceleration[a]	2.25	2.30	2.37	2.41	1.40	1.43	1.47	1.50
t_1 = time (sec)[a]	3.6	4.0	4.3	4.5	3.6	4.0	4.3	4.5
d_1 = distance traveled	45	66	89	113	145	216	289	366
Occupation of left lane:								
t_2 = time (sec)[a]	9.3	10.0	10.7	11.3	9.3	10.0	10.7	11.3
d_2 = distance traveled	145	195	251	314	477	643	827	1030
Clearance length:								
d_3 = distance traveled[a]	30	55	75	90	100	180	250	300
Opposing vehicle:								
d_4 = distance traveled	97	130	168	209	318	429	552	687
Total distance, $d_1 + d_2 + d_3 + d_4$	317	446	583	726	1040	1468	1918	2383

[a] For consistent speed relation, observed values adjusted slightly.

Note: In the metric portion of the table, speed values are in km/h, acceleration rates in km/h/s, and distances are in meters. In the U.S. customary portion of the table, speed values are in mph, acceleration rates in mph/sec, and distances are in feet.

Exhibit 3-5. Elements of Safe Passing Sight Distance for Design of Two-Lane Highways

Estimate the total passing sight distance for a two-lane highway for average passing speed of 62 mph. The initial maneuver time is 4.5 sec and average acceleration is 1.50 mph/sec. Consider the time of passing vehicle occupying right lane as 11.3 sec and clearance length as 300 ft.

d_1 = Initial maneuver distance $= 1.47t_1\left(v - m + \frac{at_1}{2}\right)$

$= 1.47 \times 4.5\left(62 - 10 + \frac{1.5 \times 4.5}{2}\right) = 366.31\ ft = 367\ ft$

d_2 = Distance while passing vehicle occupies left lane

$= 1.47vt_2 = 1.47 \times 62 \times 11.3 = 1029.9 = 1030\ ft$

d_3 = Clearance length = 300 ft

d_4 = Distance traversed by opposing vehicle = 2/3 $d_2 = \frac{2}{3} \times 1030 = 686.6 = 687\ ft$

Total PSD $= d_1 + d_2 + d_3 + d_4 = \mathbf{367 + 1030 + 300 + 687 = 2384}\ ft$

PSD

Effect of Grade:

- Up grade greater
- Down grade shorter

INTERSECTION

What Is An Intersection?

- Is an area **shared by two or more roads** whose main **function is to provide for the changes of route direction.**

- May be **simple or complex** depending on the no of roads crossing each other.

- **Overall traffic flow on any highway depends to great extent on the performance of intersection** since they operate at lower capacity than through traffic.

INTERSECTION - *Classification*

1. At Grade intersection
2. Grade separated intersection with ramp that is Interchange
3. Grade separated intersection without ramp







INTERSECTION - *Classification*

Grade separated intersection without ramp







INTERSECTION - *Classification*

Grade separated intersection with ramp that is Interchange





Basic Elements to be considered in intersection design

1. **Human factors** (approach speed, user expectancy, decision and reaction times, etc.
2. **Traffic considerations** (appropriate capacity, distribution of vehicle types and turning movements, **approach speeds**, special treatments for **transit vehicles**, pedestrians, and bicycles)
3. **Physical elements** (abutting properties, traffic movements generated by them, intersection angle, existence and location of traffic control devices, sight distances, specific geometric characteristics)
4. **Economic factors** (cost of improvements, effects of improvements on the values of abutting properties, the effect of improvements on energy consumption
5. **Functional intersection area** (operational intersection area including deceleration and acceleration zones as well as queuing areas)

Objectives of Intersection Design

Main objective:

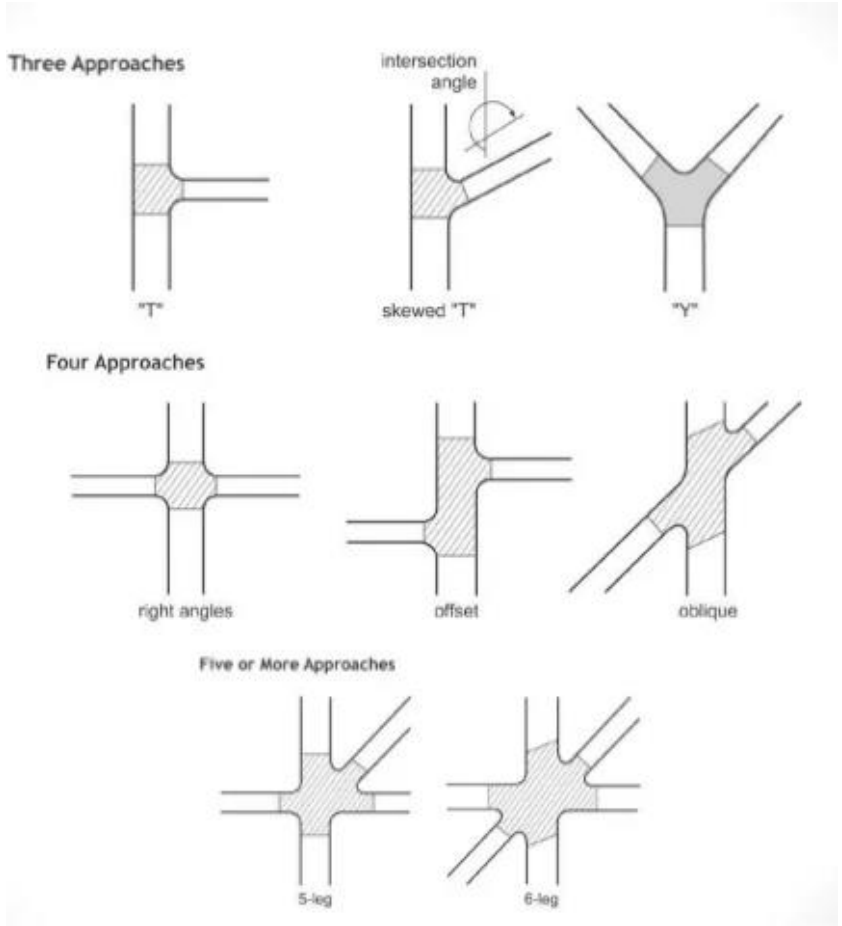
Facilitate the convenience, ease, and comfort of people traversing the intersection while **enhancing the efficient movement** of motor vehicles, buses, trucks, bicycles, and pedestrians.

Need to meet two conflicting objectives:

- **Minimize the severity of potential conflicts** among different streams of traffic and between pedestrians and turning vehicles.
- **Provide for the smooth flow of traffic** across the intersection

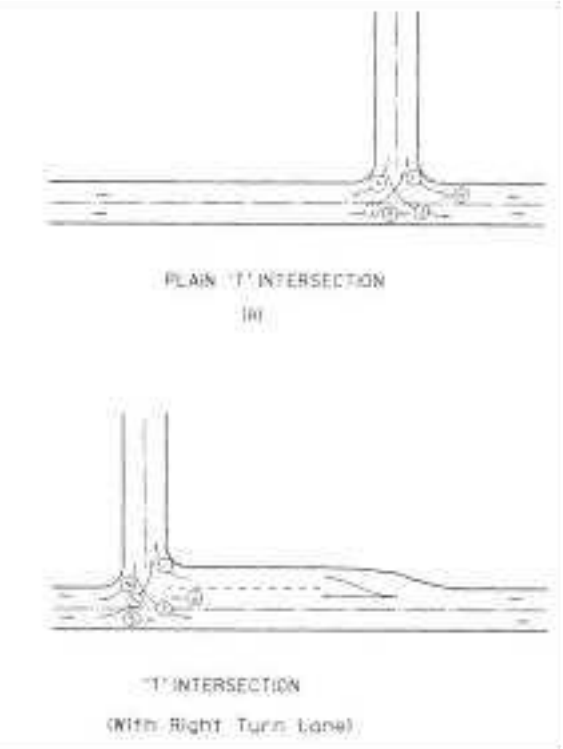
At Grade Intersection

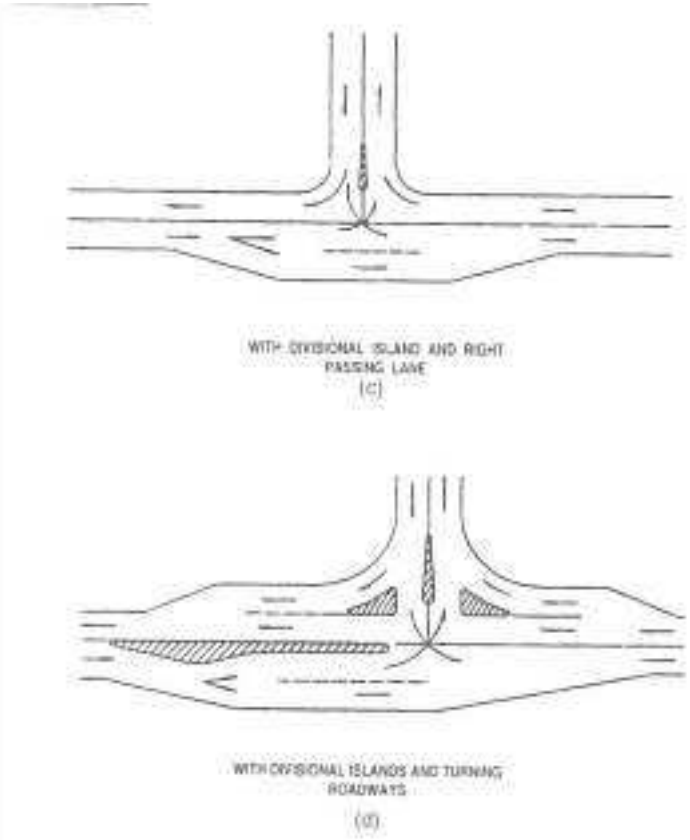
- **All road joins or crosses at the same level**
- **Conflict exist** between intersecting stream of traffic
- Should be designed to provide **adequate turning and crossing mov**, with due consideration to SD, signs, grades and alignments.
- Emphasizes on both **access and mobility function**.
- Types:
  - Three legs (T or Y),
  - Four legs or crossing,
  - multileg and
  - round about intersection.

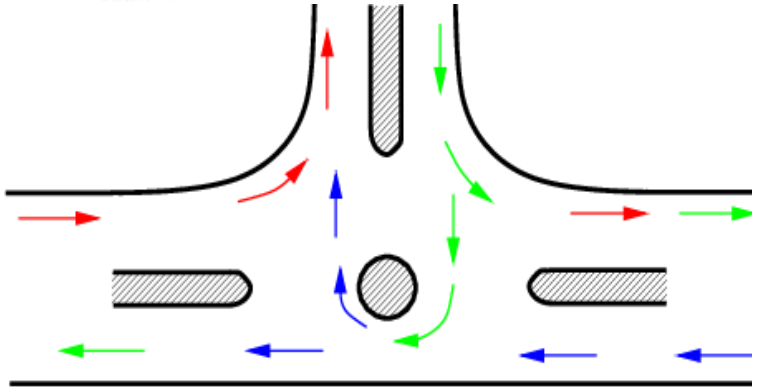


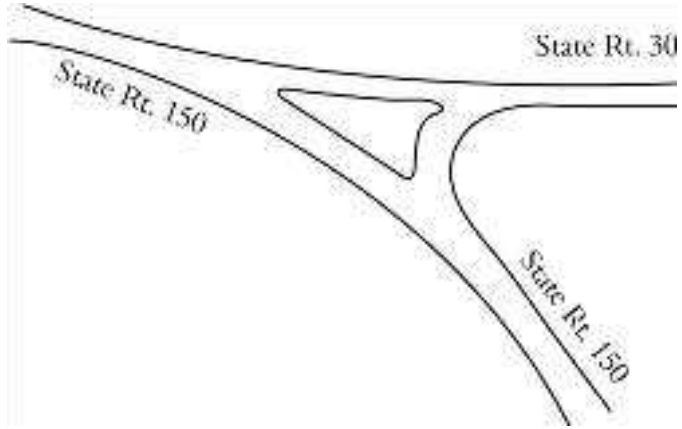
At Grade Intersection - Types

- ***Three legs (T or Y):***
  - ***T Intersection***: Two app to form a continuous line of HW and third app intersect at or nearly at rt angle.
  - ***Y Intersection***: three apps intersect at or nearly at equal angles.





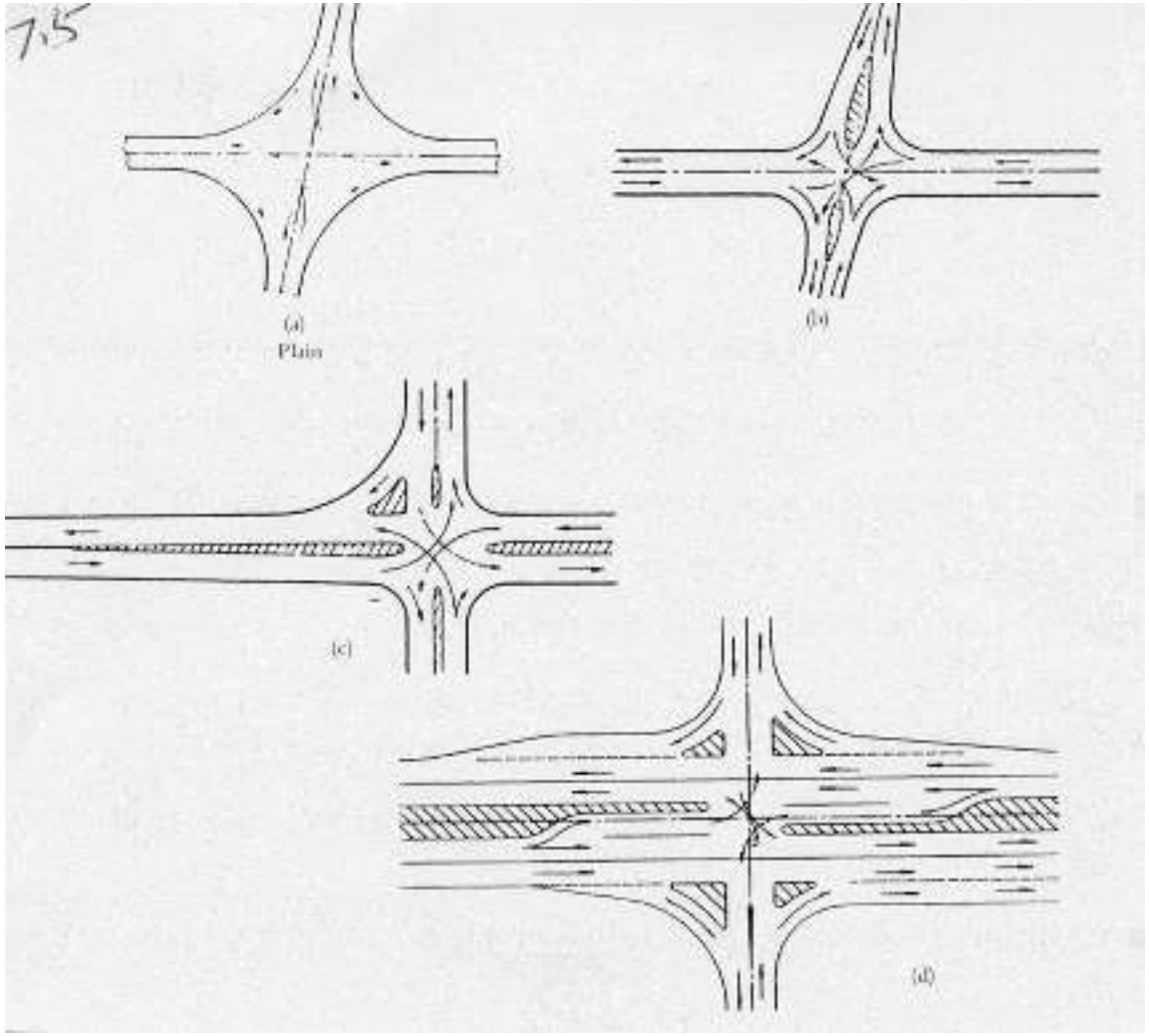




At Grade Intersection - Types

Four or Multileg intersections

Flared Intersection: Additional pavement width or addl tfc lane at intersection area.

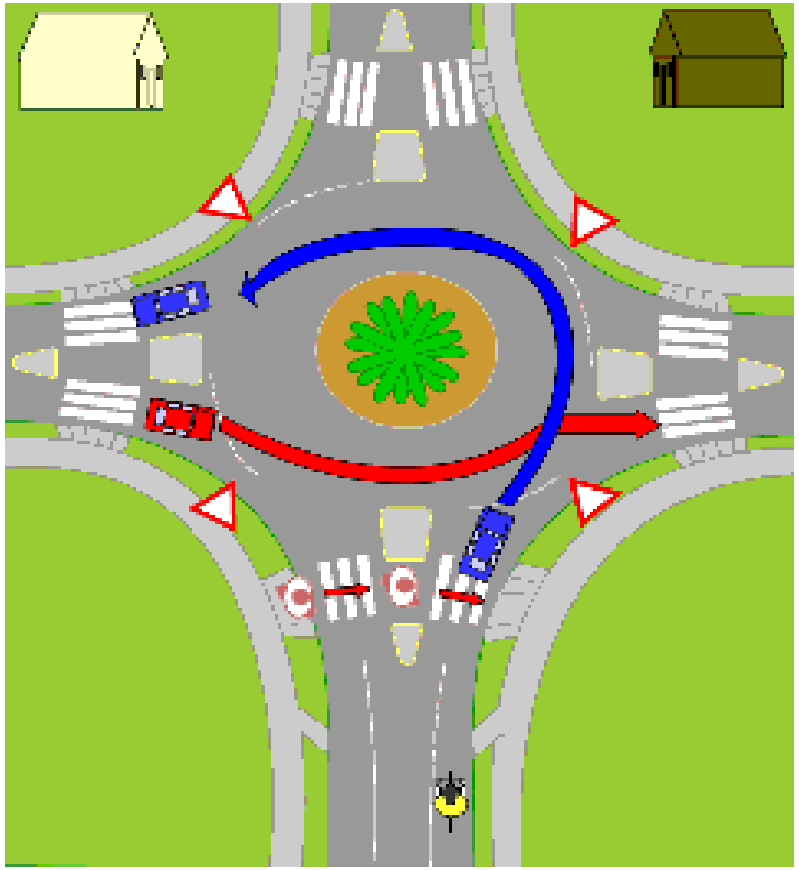




Round about or Rotary Intersection

Roundabout or Rotary intersection is one in which all tfc merges into and emerges from a one-way rd around a central island





Typical markings for roundabouts with one lane

Round about or Rotary Intersection

Advantages:

- Continuous traffic movement at reduced speed, at low vol
- Acidents are less serious (X-ing movement eliminated)
- Simplified design layout (for more than four approaches)
- Cost less than at grade intersection.
- Esthetically appealing
- Function as a traffic calming measure

Disadvantages:

- Can't handle more traffic than an adequately designed canalized layout.
- Definitely NOT for high volume intersections,
- Too many weavings
- Unsatisfactory functioning occurs when two or more legs app design capacity.
- Extensive area is required .
- Channelization is required if large pedestrian traffic is expected.
- It functions at low speed.
- Proper functioning demands for adequate lighting and proper access con, otherwise may cause serious safety hazards.

General Rules for Driving a Roundabout?

Slow down upon approach to the roundabout.

Watch for traffic signs (one way and yield signs).

Yield to pedestrians and bicyclists as you enter and exit the roundabout.

Look to the left for traffic.

Enter when it is safe.

Keep your speed low within the roundabout.

Exit carefully to your destination.

Design Principle of At Grade Intersection

- Design should incorporate the op characteristics of both veh and pedestrian using the intersection.
- Corner radius $\prec$ either turning radius required by design veh or design speed of the rd.
- Should ensure adequate pavement width and approach Sight distance.
- Should not be located at or just beyond the sharp crest vertical curve or sharp hor curve.
- Rd ways or approach should intersect at an angle $\succ$ 30 degree from the normal.
- The design involves:
  - Design of alignment
  - Design of a suitable channeling system
  - Determination of min reqr rd way width for turning when veh mov at > 15 mph.
  - Ensure that the SD are adequate for the type of control at the intersect.
  - SD at an approach of intersection can be improved by : flattering the cut slope, lengthening vertical and hor curves.

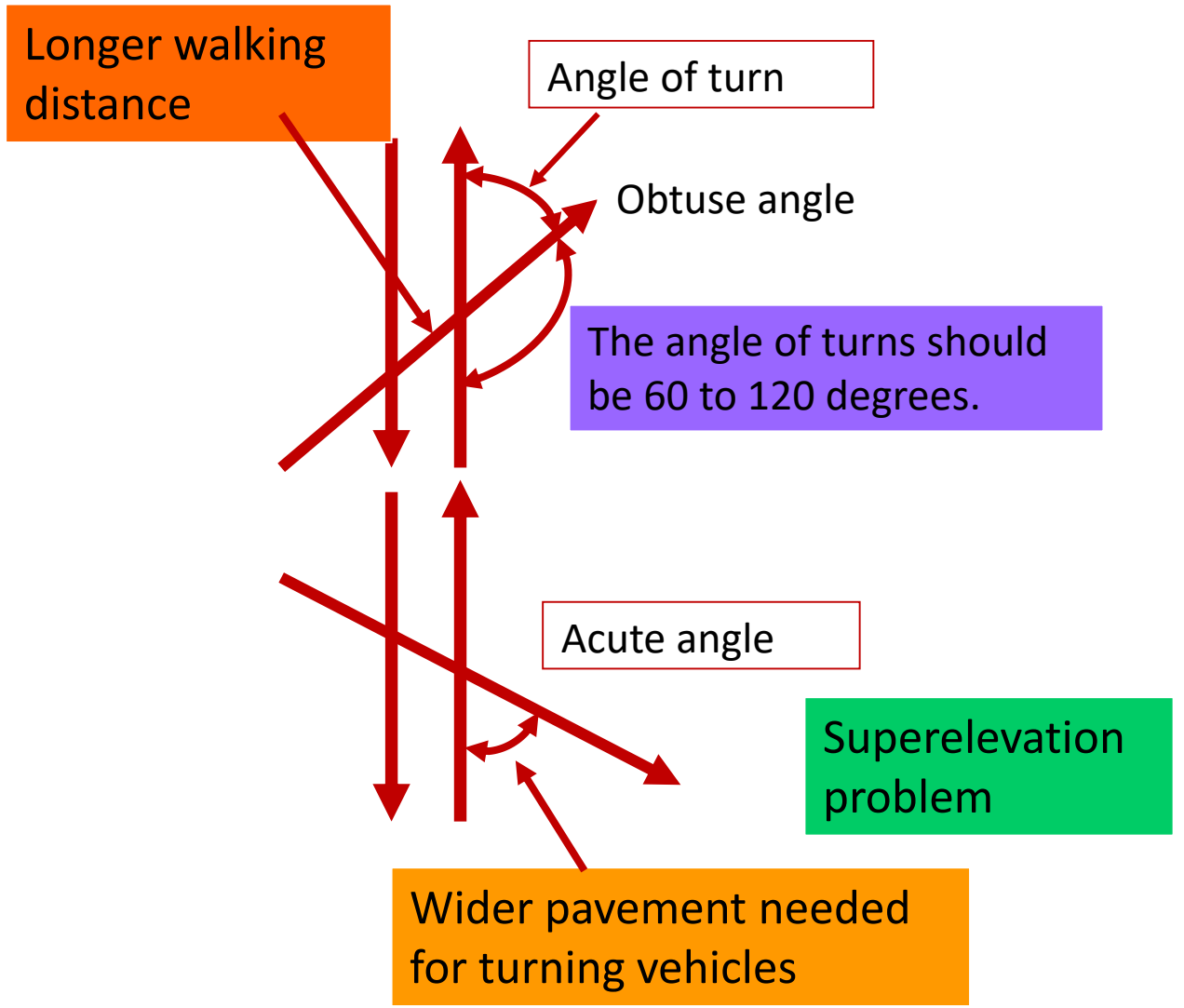
Alignment of At Grade Intersection

Best alignment when intersecting roads **meet at or nearly at right angles**.

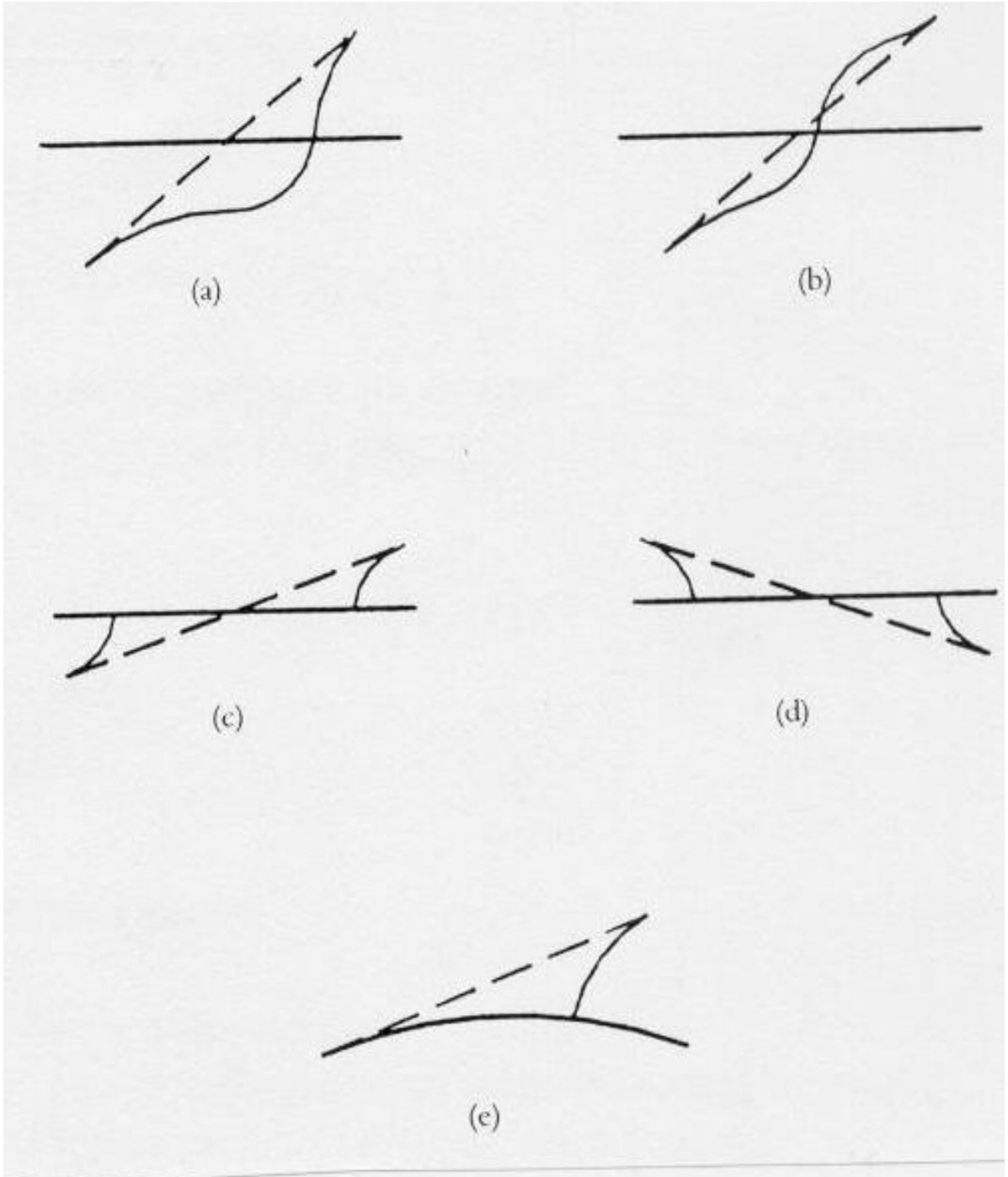
This is **superior to acute angle intersection because:**

- Less road area is reqd for turning
- Lower exposure time for veh Xing main flow
- Minimizes conflict area
- Visibility limitation are not serious i,e suitable SD are aval/ possible to provide
- Speed judgments will be easier.

Possible Method of Alignment

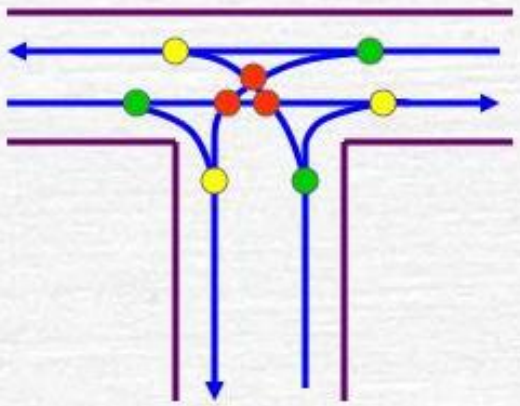


Suggested improvements to intersections with acute “angle” problems



Conflict points at Unsignalized intersection

T intersection



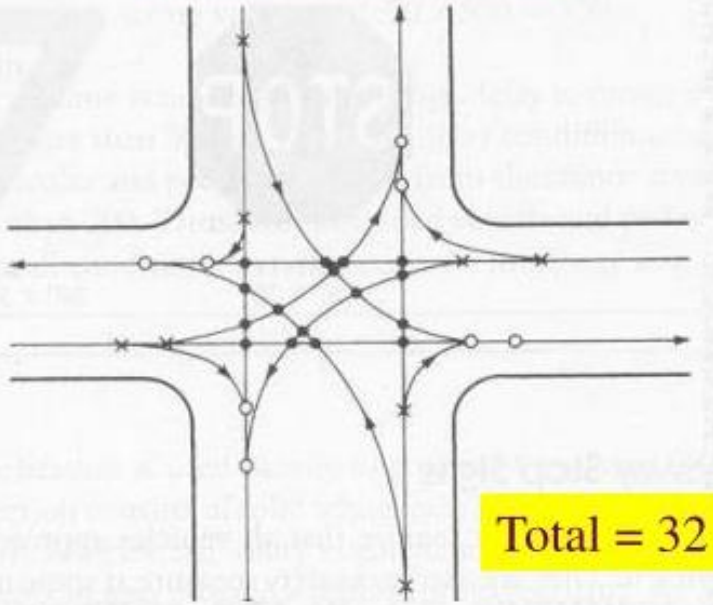
Crossing = 3

Merging = 3

Diverging = 3

Total = 9

4-leg intersection

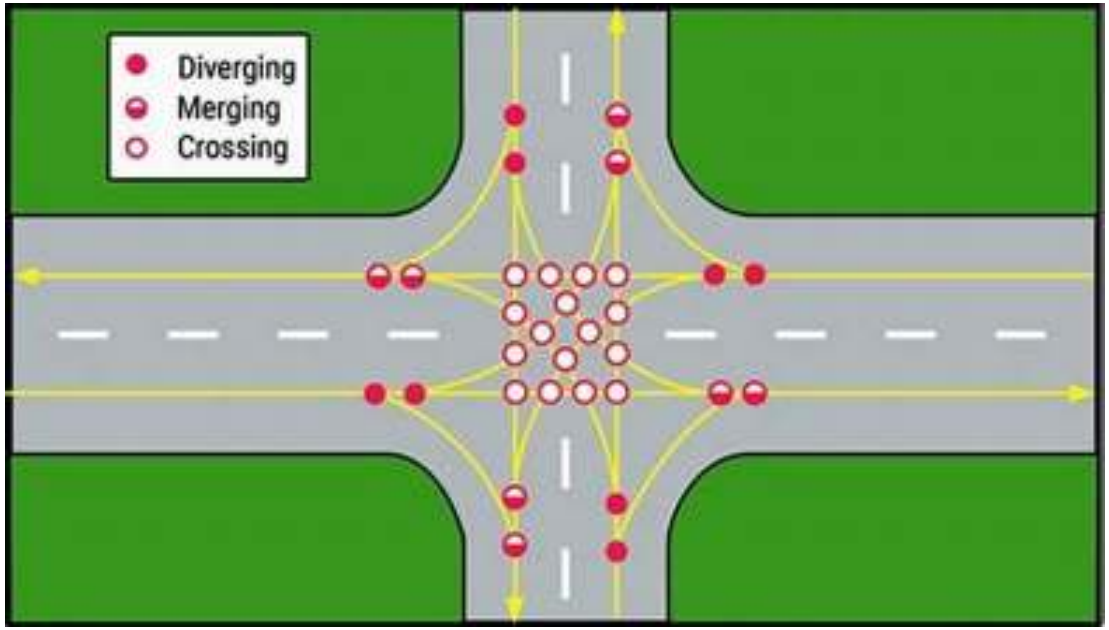


Total = 32

Merging conflict points = 8

Diverging conflict points = 8

Crossing conflict points = 16



Control of at grade intersection

- **No con**
- **Yield con**
- **Stop con**
- **Signalized con**

Yield con Intersection

Minor rd is con by yield sign. SD provided on minor rd must be sufficient for the dvr to see a veh approaching from either the left or rt of the major rd and to be able to stop the veh before reaching the intersecting road way.

Stop con Intersection

Minor rd is con by stop sign. Veh on minor rd must be provided sufficient SD to allow for a safe departure from the stopped position for the three basic maneuver that occur at an intersection. These are crossing the intersection, turning left onto the cross rd and turning the rt on to the cross rd.

Signalized con

The basic principle of signalized intersection is to provide SD that will enable the dvr to see the signal early enough to take the nec action indicated by the signals.

TRAFFIC ISLAND

Is the area between the traffic lanes to regulate the movement of vehicle and serve as a pedestrian refuge.

TRAFFIC ISLAND

Purpose or Objectives: May serve one or more of the fol purposes:

- Separation of conflicts i,e dir the path of the veh.
- Control the merging, diverging and Xing angles.
- Decrease veh wander and conflict areas among veh by reducing the amount of paved area.
- Provide a clear indication of the proper path for different mov.
- Give priority to the predominant mov.
- Provide ped refuge.
- Provide separate storage area for turning veh.
- Provide space for tfc con devices.
- Control prohibited turn.
- Restrict the speed of the veh.

How Formed/ Types of Traffic Island based on Formation

a. Curbed Island: Island Formed by the construction of concrete curbs

- Curb are of two types: Mountable and Barrier or non mountable curbs.
- Because of glare, difficult to see at ni, so fixed sources of light should be provided.
- Preferred in urban HW where Speed is not excessively high

and Ped vol is relatively high.

b. Flushed Island: Island Formed by Pavement Marking

- Marks incl paints, thermoplastic stripping, raised retro reflective markers etc.
- Preferred where:Approach speed are relatively high, Ped tfc is low, Sig or sign need not to be loc on island.

c. Unpaved Island: Island Formed by Pavement Edges

- Used at rural intersection and rural areas where sufficient space are available.

How Formed/ Types of Traffic Island based on Formation

Curbed Island: Island Formed by the construction of concrete curbs





Flushed Island: Island Formed by Pavement Marking





Unpaved Island: Island Formed by Pavement Edges





Types of Traffic Island based on Functional Classification

Channelized Island

- Also known as directional island
- Used mainly to con and dir tfc by indicating the intended route.

Divisional Island

- Mainly to divide opposite or same direction traffic stream.
- Mostly used at undivided HW approaching intersections.
- Particularly advantageous for rightt turning tfc.

Refuge/ Pedestrian Island

- Mainly to provide refuge for pedestrians and wheel chairs Xing the intersec.
- May also be used on wide streets for loading and unloading of transit passengers.

Types of Traffic Island based on Functional Classification

Channelized Island





Divisional Island



Types of Traffic Island based on Functional Classification

Refuge/ Pedestrian Island







Channelization of at grade intersections

- Channelization is the **separation of conflicting tfc mov** into definite paths of travel **by tfc island or pavement markings** to **facilitate the safe and orderly mov of both veh and ped**,

- A properly channelized intersection will result in **increased capacity, decrease conflict and accdts** thus enhance safety and increase dvr confidence.

- An improper Channelization may have opposite effect.

- **Over Channelization should be avoided** as this **creates confusion** and may **lower the op level** than that for an intersection without any Channelization.

Shape and Size of Islands

- Should be large enough to command attention
- Should be visible to dvrs for a sufficient dist to allow appropriate response.
- **Area** at least 75 sft, preferably 100 sft.

- **Sides:** Triangular islands at least 12 ft, preferably 15 ft after rounding corners.
- Elongated or div island 20-25 ft long.
- Median curbed island 100 ft or more, 2-4 ft offset and then gradually to the full width.
- Small (side length near min length), intermediate and large (100 ft >)

- **Width:** at least 4 ft wide, can be reduced to 2 ft when space is limited.
- When signs are to be placed, the width of those to be considered to select the width of islands.

Grade Separated Intersection without Ramp

- Consists of structure that **allow traffic to cross at different level, but not between level (**without a provision for an interchange between levels)**, without interruption**.
- Designed in such a way that at **no point a vehicle has to face traffic from opposite dir**.
- **Often constructed in urban areas** because of high land price and non availability of adequate space.
- **Based on mobility function**.
- May be an over bridge, under pass/tunnels or fly over/ overpass etc

Grade Separated Intersection without Ramp

Adv over At Grade Intersection

- freedom from cross interference
- eliminates conflicts and safety
- minimize delay, saving time
- increasing capacity.

Disadv over At Grade Intersection

- More expensive (reqr very large area and constr of br or ramps etc)
- Drainage problem (under pass)
- Speed reduction (over br) than at grade intersection.

Interchange (Grade Separated Intersection with Ramp)

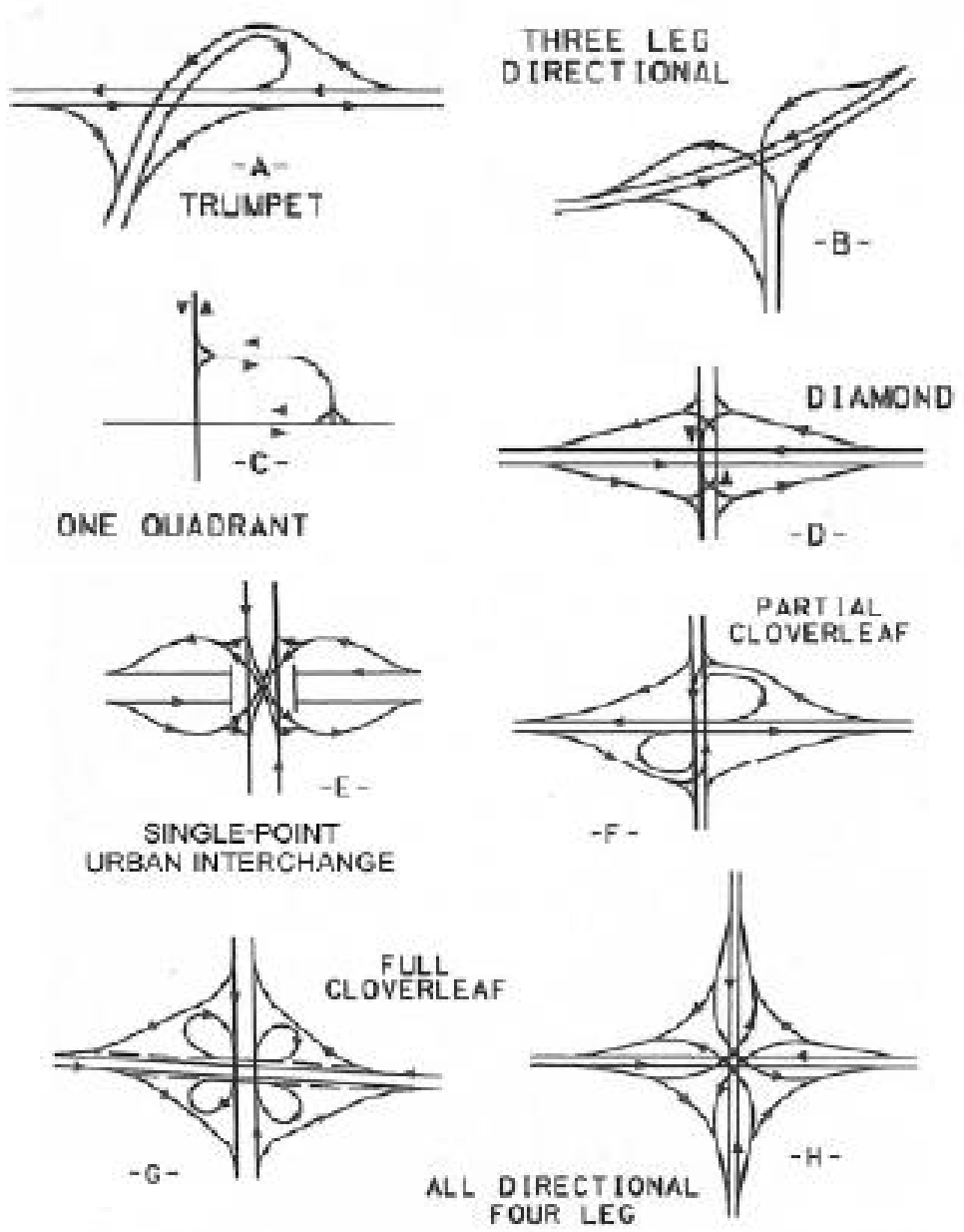
- An interchange is a grade separated intersection with the provision of ramp whereby facility is provided for mov of traffic between two or more rd ways at different level.
- The transfer of traffic from one dir / level to other is provided by the facility known as ramps or access or slip or link rds. They connect two or more legs at an intersection and are generally a one-way rd.
- Usually constructed at open areas where land price is relatively very low.
- Mobility function.

Warrant for Grade Separations and Interchanges

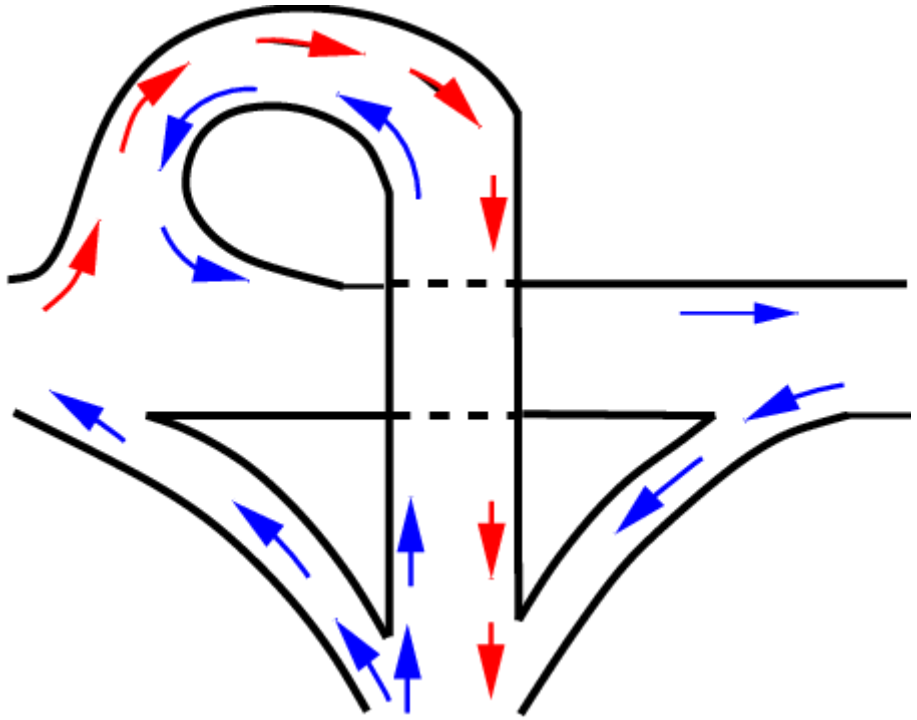
- When sufficient discharge capacity of a junction cannot be achieved by the use of conventional treatments.
- Where congestion and accident records are very high and expected cost savings in delay and accident is significant
- To eliminate bottlenecks and to prevent accidents.
- Where topography does not permit other types of design.
- When traffic on intersecting roads is very high.
- When there is a need to construct expressway to provide high speed and uninterrupted flow.

Common Types of Interchanges

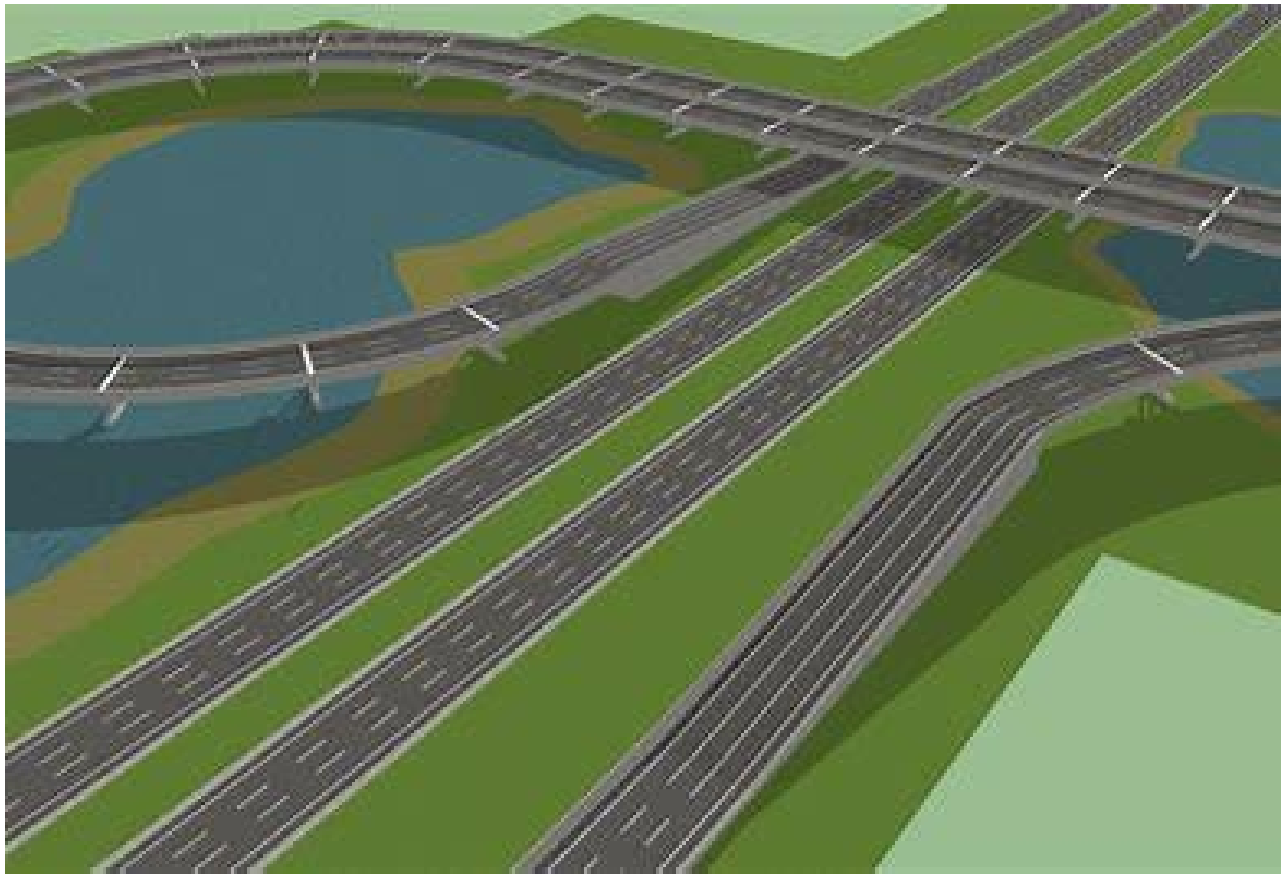
- Three-Leg Designs – (a) and (b)
- Four-Leg Designs
- Ramps in one quadrant (c) – Not Suitable for Freeway Systems
- Diamond Interchange (d)
- SPUI (e)
- Partial Cloverleaf (f)
- Full Cloverleaf (g) – Generates Weaving Maneuvers
- All Directional Four Leg (h)



Three-Leg Interchanges



Trumpet



Four Leg Interchange Designs

- Ramps in One Quadrant
- **Diamond Interchanges**
- SPUI (Single Point Urban Interchange)
- **Full or Partial Cloverleaf**
- Direction and Semi-Direct Connections

Four Leg Interchange – Diamond Type

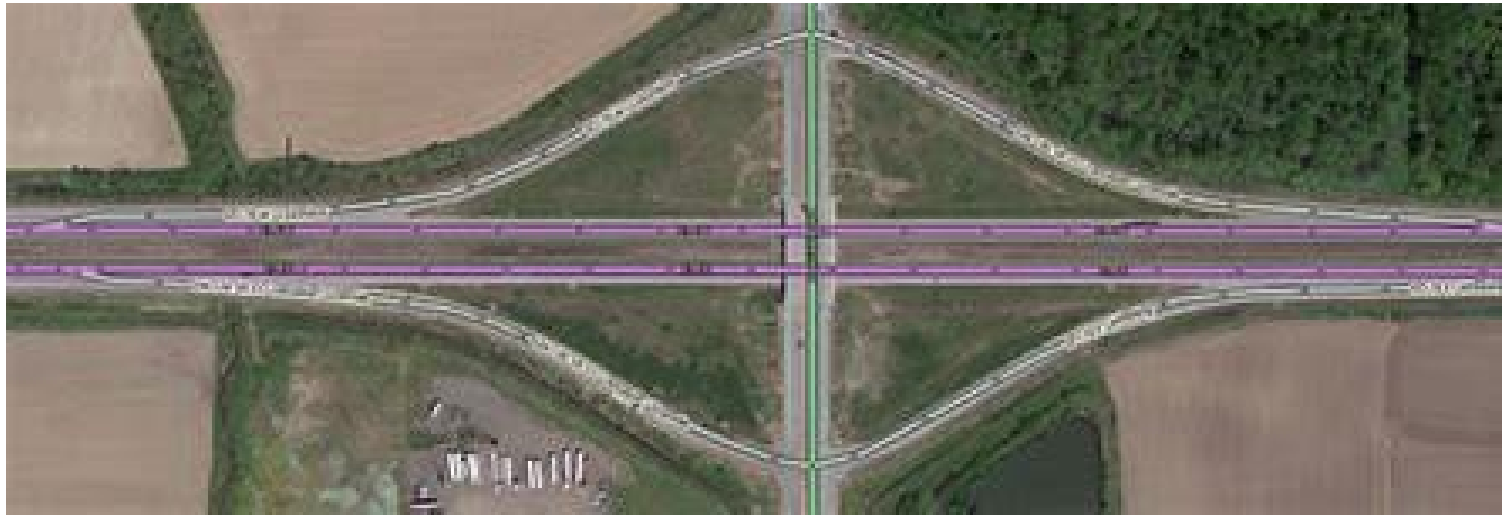




Four Leg Interchange – Diamond Type







Four Leg Interchange – Cloverleafs Type







Partial Cloverleafs

Four-Leg Interchanges: Single Point Urban Interchange (SPUI)

Most recent

- Advantages
  - Narrower ROW
  - Paths of Left Turning vehicles do not intersect
  - Right turn movements are free flow
  - Only one traffic signal is used; lower delay and Greater Capacity
  - Curve radii are flatter; turns made at higher speeds
- Disadvantages
  - High construction costs
  - Overpasses need long bridges to span large intersection below
  - Left-turn movement path is normally quarter of a circle, but in SPUI – half an ellipse

General Causes of tfc Related Problems

External factors (geometric factors)

road intersection/junction
railway crossing
narrow road/br/culverts
inconsistent rdway width
poor turning radius
side friction : *scattered parking, rd side NM activities, frequent access, illegal or improper bus stop / parking, uncoordinated public wk etc.*
poor rdway environment : *poor rd discipline, uncontrolled ped crossing, poor rd surface condition, speed breaker, poor sight dist, poor lighting, poor drainage facilities etc.*

Internal factors

heterogeneous tfc stream
high vol of tfc

Possible Approaches to Solve Tn Prob

- Investment on new highway projects.
- Traffic system management (TSM) which include supply and demand managements

Traffic system management (TSM)

- **Traffic system management (TSM)** is the pseudo science of optimizing output (ensure safety, improve overall roadway capacity and environmental condition) of existing facilities through improved management, improved technology and operation of traffic, vehicles and the roadway, without any significant investments.
- Effective management reduces fuel consumptions, congestions and emissions by idling vehicles.
- **TSM includes both supply side management and demand side management**.

Supply Management Measures

- Supply management measures (managing transportation supply) deals with transportation facilities and operation to improve the roadway capacity, safety and aesthetic.

- Supply management techniques or measures include
  - physical measures
    - Low cost measures
    - Expensive measures
  - regulatory measures and
  - technological measures.

- All these measures can significantly increase the roadway capacity but their implementation need a well planned and well developed road network, corruption free, efficient and committed policy makers and executives and above all healthy financial back up and mass people participation.

Low Cost Physical Supply Management Measures

- ✓ correcting/improving roadway geometry and surface condition
- ✓ channelization
- ✓ flaring
- ✓ exclusive lane marking
- ✓ provision of improved signs
- ✓ introduction of median barrier
- ✓ pedestrian guard rail
- ✓ controlled road crossing,
- ✓ street lighting,
- ✓ improved traffic control system
- ✓ traffic calming measures
- ✓ bus lay by etc.

Expensive Physical Supply Management Measures

- ✓ widening of intersection/ junctions
- ✓ grade separation at junctions/level crossing, segregated transit facilities as elevated bus way, underground rail
- ✓ pedestrianisation /pedestrian mall
- ✓ construction of new links/road
- ✓ construction of off street parking lots
- ✓ construction of terminals etc.

Regulatory Supply Management Measures

- provision of clear ways
- banning right or U turn
- entry restriction for particular vehicle to city center
- access control from side roads
- banning/restricting freight vehicle
- one way operation
- tidal flow operation
- parking control
- use of terminal facilities
- restriction over speed, weight, overtaking
- provision of auto free zone etc.

Technological Supply Management Measures

- Int/automated highway/veh
- Advance tfc info system
  - Dvr- route guidance/navgation system
  - Users- uptodate travel info system
- Advance tfc control and mgt system
  - Use of VMS or dynamic sign
  - Auto surveillance system
  - Active marking/headlight
  - Adaptive tfc signal control

Implementation of various technological measures demands for modern information infrastructure, monitoring system, modern equipment and efficient technical personnel

Transportation Demand Management (TDM)

TDM measures that result in more efficient use of existing roadway capacity can support economic, social and environmental objectives simultaneously, by increasing overall transport system efficiency, reducing congestion and improving access at lower cost to society.

TDM measures consist of restrictive measures and strategic measures.

Restrictive measures

- ✓fiscal measures as road pricing, increasing fuel price/tax
- ✓parking control
- ✓control over vehicle ownership etc.
- ✓***Access control***
- ✓***Turning control***

Strategic measures

- ✓ increasing vehicle occupancy
- ✓ providing improved alternatives modes
- ✓ introducing staggered/ flexible office hours
- ✓ strict land use planning and control
- ✓ introducing one stop services
- ✓ using improved telecommunication and IT facilities
- ✓ introducing IT enabled services etc.
- ✓ Tidal flow operation

Parking Management

Parking to be Prohibited at:

Intersection
Narrow street
Driveway
Ped crossing
Hor curvature and Ver grade
Br and tunnels
Heavy ped concentration areas
Priority locations etc.

Benefits of Parking Control:

Obj of Strict Parking Control:

- ✓ Reduce side frictions
- ✓ Bring rd way discipline and parking culture
- ✓ Use rd space more efficiently and increase productivity
- ✓ Encourage mass public tpt system
- ✓ Encourage use of bicycle
- ✓ Improve safety, reduce congestion

Ways of Parking Control:

- ✓ Parking prohibition policy
- ✓ Parking charge
- ✓ Duration of parking time

Park and Ride facility:

It is traffic control system in which motorists are encouraged /sometimes forced to park their car at selected locations usually at the periphery of the central area and then use the public tpt to travel to their destination and come back again.
It is very effective for large city.
It has potential to make public tpt popular, to rdiuce dmd for parking space, to reduce traffic volume

Problems Caused by Congestion

Increased…

- Travel time
- Travel cost
- Air pollution
- Accident risk



How to Solve?/Options for congestion reduction

- **Construct new roads**
  - Covered in geometric design
  - Not likely to happen on a large scale
- **Reduce Traffic**
  - Travel demand management
  - Alternative transportation
- **Increase existing infrastructure capacity**
  - Uses intelligent transportation systems (ITS)

Linkage of vehicle and transportation infrastructure through ITS infrastructure

Alternative Transport

Increase Existing Infrastructure Capacity

- An alternative to expensive new highway construction is the implementation of strategies that promote more efficient utilization of transportation infrastructures.

- These strategies are known as the **Intelligent Transportation Systems (ITS), which aims to reduce travel time, ease delay and congestion, improve safety, and reduce pollutant emissions**

Intelligent Transport Systems (ITS)

ITS is an emerging transportation system which is comprised of an advanced information and telecommunications network for users, roads and vehicles.

ITS is the integrated application of advanced Technologies using electronics, computers, communications, and advanced sensors.

Intelligent Transport Systems (ITS) intend to add information and communications technology to transport infrastructure and vehicles in an effort to improve:

Safety, reliability, efficiency and quality of means of transport.

Intelligent Transportation Technologies/Infrastructures

- **Wireless communications**
- **Computational technologies**
- **Sensing technologies**
- **Video vehicle detection**
- **Probe & smart vehicles**
- **The incident detection centers**
- Floating car data/floating cellular data
- Inductive loop detection
- **In vehicle information & route guide**

Intelligent Transportation Applications

ITS has wide range of applications as,

1. **Electronic toll collection**
2. **Emergency vehicle notification systems**
3. **Cordon zones with congestion pricing**
4. **Automatic road enforcement**
5. **Collision avoidance systems**
6. **Dynamic Traffic Light Sequence**
7. **Intelligent Vehicle**

Manage and monitor the network traffic flows

Provide information on the state of the network

Fleet management (vehicle location)

- Trucks
- Buses

Monitoring vehicle condition and status

- Trucks
- Buses

Autonomous systems

- Vehicle status
- Intelligent cruise control
- Obstacle detection

Intelligent Transportation Applications

1. **Electronic toll collection (ETC)**

like E-ZPass, that detects and processes tolls electronically.

E-ZPass uses a **vehicle- mounted transponder (**where account information is stored) that is activated by **an antenna on a toll lane**.

The antenna identifies your transponder and reads your account information. The amount of the toll is deducted and you're allowed through.

ETC makes it possible for vehicles to **drive through toll gates at traffic speed, reducing congestion at toll plazas and automating toll collection**.

Intelligent Transportation Applications

2. Emergency vehicle notification systems

The **in-vehicle eCall is an emergency call generated either manually by the vehicle occupants or automatically via activation** of in-vehicle sensors after an accident.

ITS particularly the FCD (Floating Car Data) model can also be used to **provide advance warning to motorists of traffic jams, accidents and other emergency situations**.

This system can then provide **alternative routes or recommendations to motorists so as to avoid congestion and travel delays**.

Intelligent Transportation Applications

3. Cordon zones with congestion pricing:

With the intelligent transportation system, cordon zones can also be enforced where mass transportation systems are available and their use encouraged. Cordon systems make it possible to collect taxes from those entering city areas with high traffic while encouraging the use of Sign indicate the boundary of mass transit. the congestion charge area

Intelligent Transportation Applications

4. Automatic road enforcement

A traffic enforcement camera system, consisting of a **camera and a vehicle-monitoring device**, is used to detect and identify vehicles disobeying a speed limit or some other road legal requirement.

Hot lanes: These are the roads where the speed limit is more than 100 kms./hr. & goes in one track. There are radiators on the sides of the road where if the car goes out of lane, it produces shocks & hence keeps the car on the track.

A traffic enforcement camera system, **consisting of a camera and a vehicle- monitoring device**, is used to **detect and identify** vehicles disobeying a speed limit or some other road legal requirement and automatically **ticket offenders based on the license plate number**. Traffic tickets are sent by mail. For Exam :-

- **Speed cameras** identify speed limit.
- Red light cameras detect vehicles that cross a stop line.
- **Bus lane cameras** identify vehicles traveling in lanes reserved for buses.

Intelligent Transportation Applications

5. Collision Avoidance Systems:

Obstacle Detection Intersection Collision Warning Lane Change assistance Lane Departure Warning

Collision Avoidance Systems …… Road Departure Warning, Rollover Warning, Forward collision Warning, Rear Impact Warning,

6. Traveler Information Service:

Information is Sent to Travelers Generated … Travelers .. Respond

- Delay Traffic Sensor
- Incident Change Route
- Road Aerial Weather surveillance Change
- Next Bus Departure
- Traveler Weather Time Monitoring Times
- Emergency Change Mode Incident Alerts Detection
- Alternate Change Routes Destination Transit Location

Intelligent Transportation Applications

7. Emergency Management Services:

Emergency Management Services are greatly enhanced by traffic control centers that continually monitor roadway conditions. When an incident occurs, the nearest emergency service vehicle is located electronically and dispatched to the scene. Highway managers then alert other drivers of the incident through dynamic message signs. These services reduce response times, help save lives, and reduce the occurrence of secondary incidents.

Benefits of ITS

Time Savings

Better emergency response times and services

Reduced Crashes and Fatalities

Cost Avoidance

Increased Customer Satisfaction

Energy and Environmental Benefits

Decreasing of probability of congestion occurrence

Projected ITS Infrastructure Benefits (1996-2015)

Accident Cost Savings (44%)

Time Savings (41%)

Emissions/Fuel (6%)

Operating Cost Savings (5%)

Agency Cost Savings (4%) Other (< 1%)

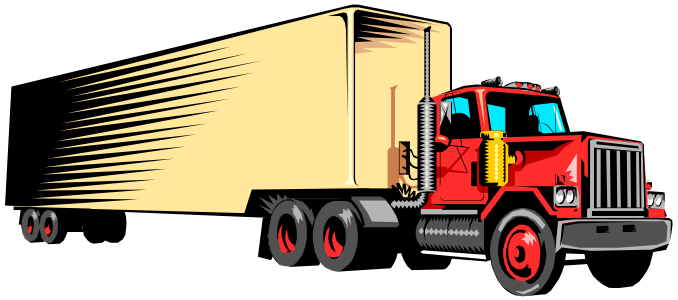
Source : Apogee Report on Global ITS Benefits

Five Primary Functional Areas of ITS

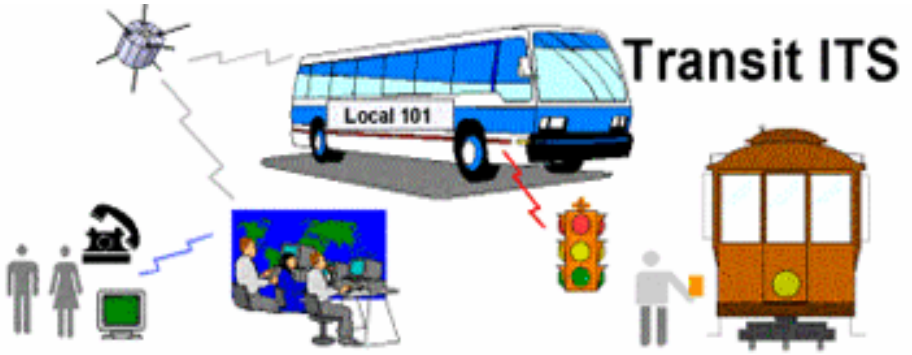
- **Advanced Traffic Management Systems (ATMS)**
- **Advanced Traveler Information Systems (ATIS)**
- **Commercial Vehicle Operations (CVO)**
- **Advanced Public Transportation Systems (APTS)**
- **Advanced Vehicle Control Systems (AVCS)**

Commercial Vehicle Operations

- Apply, pay for and receive permits, registrations, and licenses electronically
- Share of common trucking data across agencies
- Exchange information electronically with roadside enforcement personnel
- Electronic “screening” of trucks for safety or other regulatory violations
- Share information across state lines and with Federal information systems



Advanced Public Transportation Systems



Advanced Vehicle Control Systems



Intelligent Cruise Control (ICC) System



Green Transport

Green transport facilities include eco-friendly methods of travel, such as walking, cycling, electric vehicles (EVs), public transport (buses, trains, metro), and carpooling, all designed to reduce greenhouse gas emissions, pollution, and reliance on fossil fuels.

Types of Green Transport Facilities

- **Electric Vehicles (EVs)**: Cars, bikes, buses, and trucks powered by electricity, which produce zero tailpipe emissions when using renewable energy sources.
- **Public Transportation**: Large-capacity buses, trains, and metros that can be powered by renewable energy or clean fuels, making them a sustainable option for large populations.
- **Bicycles**: A completely emission-free and affordable mode of transportation that also provides health benefits.
- **Walking**: The most basic and eco-friendly form of transport, offering physical activity and zero emissions.
- **Carpooling**: Sharing multi-occupant vehicles to reduce the number of cars on the road, thereby cutting down on traffic and pollution.

Green Transport

Benefits of Green Transport Facilities

- **Climate Change Mitigation**: Significantly reduces global greenhouse gas emissions.
- **Improved Air Quality**: Lowers air pollution by decreasing harmful pollutants and particulate matter.
- **Enhanced Public Health**: Promotes physical activity through walking and cycling, and improves respiratory health by reducing air pollutants.
- **Reduced Congestion**: Makes cities more livable by reducing traffic jams, which waste time and cause economic loss.
- **Sustainable Development**: Contributes to creating cleaner, healthier, and more sustainable urban environments.
- Reduction of Accident rate: severe accident reduction, collision reduction etc.

Walking - Footpath Features

Accessible, safe, comfortable and well-maintained footpaths enhance walking experience and promote walking as a mode of transport for short-distance commuting.

Walkway Design Principles

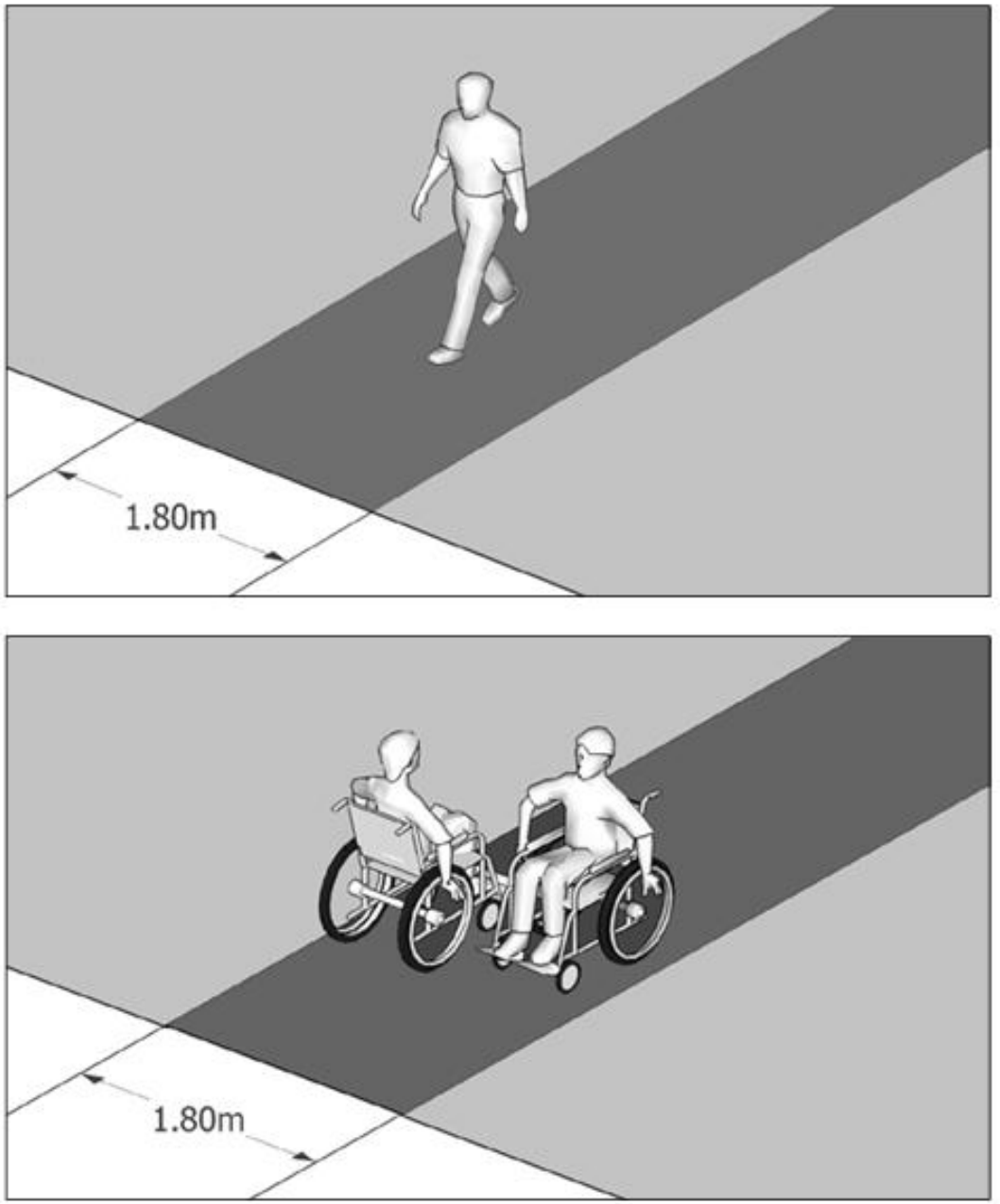
- **Functionality and aesthetics.** A primary consideration is the flow of movement, which should be intuitive and unobstructed. This involves understanding pedestrian behavior and anticipating natural paths.
- **Safety and comfort.** Safety encompasses physical and psychological elements. Adequate lighting; slip-resistant surfaces; gentle curves and slopes enhance safety and comfort.
- **Environmental considerations.** Sustainable practices, like using permeable materials, help manage stormwater runoff and reduce the urban heat island effect. Integrating native vegetation supports local ecosystems, provides shade, and adds aesthetic appeal, benefiting the environment and creating a pleasant user experience.

Footpath Features

Standalone Footpath Width:

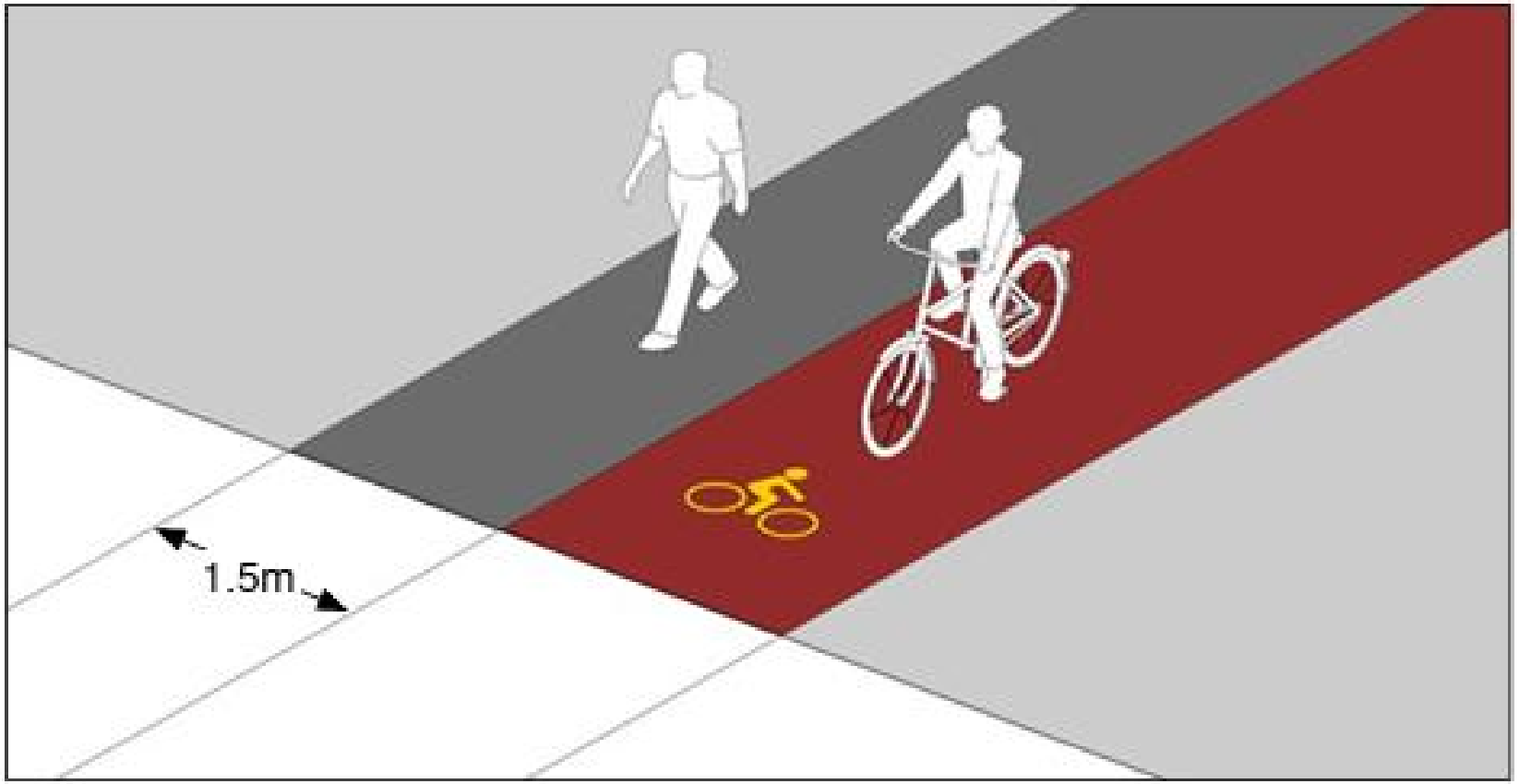
- With the increased use of Pedestrian Mobility Aids (PMAs), (wheelchairs, mobility scooters, etc.) width have been increased from **1.5m to 1.8m**, which is the adequate width for two typical wheelchairs to pass each another
- However, where there are observed or projected high pedestrian volume, footpath widths of **more than 1.8m** would be considered.

Footpath next to Cycling Path: **1.5m** is adopted as the dedicated pedestrian width



ABOVE: Design considerations for 1.8m standalone footpath

Footpath Features



ABOVE: Dimension of footpath is 1.5m when sited next to a cycling path

Footpath Features

Materials:

Concrete is used because of its skid resistant property and durability.

Good levelling and workmanship of floor finishes should be ensured to avoid undulation and protrusions that may result in trips and falls.

Regular maintenance and renewal of footpaths and pavement surfaces is important to ensure a non-slip and level surface.



ABOVE: Typical roadside footpath made with concrete

Footpath Features

Features for Pedestrians with Vision Impairment:

Tactile tiles and kerb ramps are provided at areas near crossings to remind pedestrians, especially pedestrians with vision impairment, to be vigilant while crossing the road



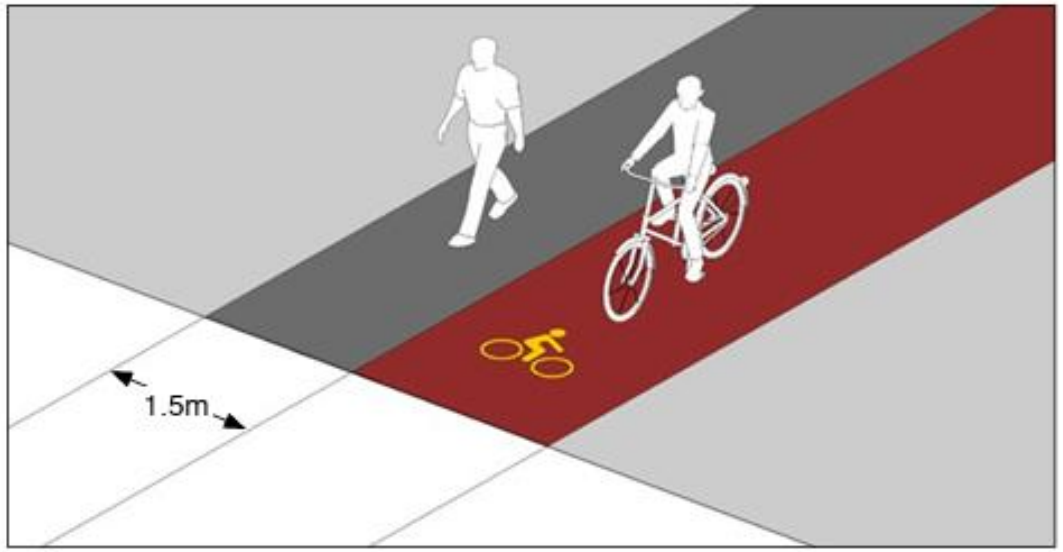
ABOVE: Tactile tile



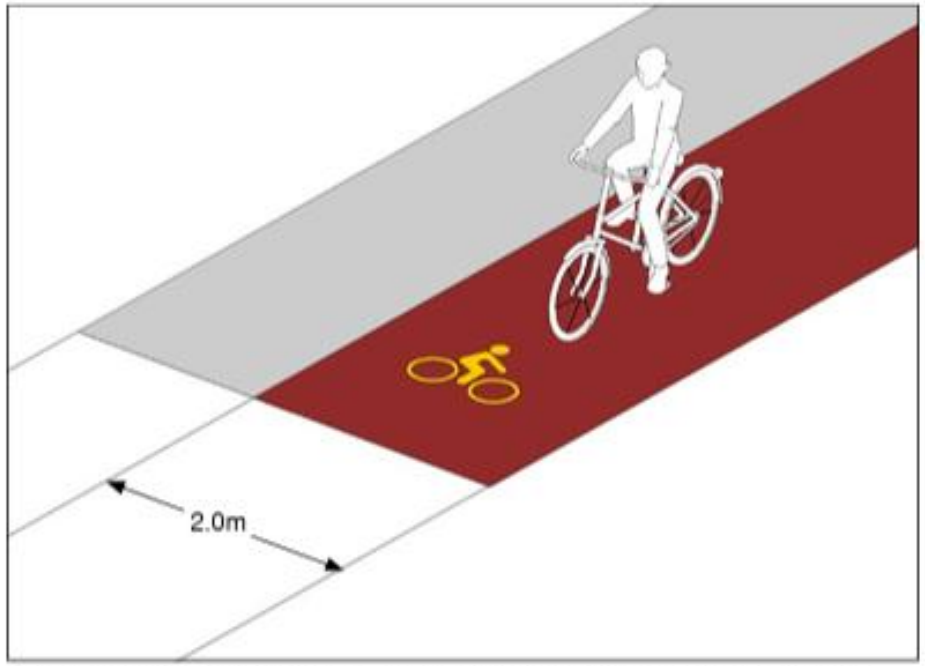
ABOVE: Placement of tactile tiles at crossing

Bike Path/Cycling Path

For safety, cycling paths are designed to be separated from vehicular traffic on a different level. These paths are designed to separate the pedestrians and cyclists to minimize conflict.



ABOVE: Dimension of footpath is 1.5m when sited next to a cycling path



ABOVE: Intra town cycling path requires minimally 2m width for bi directional movements.

Types of Bike path

- **Class I (Multi-Use Trail or Path):** A separated path designed exclusively for bicycles and pedestrians, located off-street and away from vehicle traffic.

- **Class II (Bike Lane or Buffered Bike Lane):** A designated on-street lane for exclusive use by bicyclists, marked by stripes and signage.

- **Class III (Bike Route):** A lower speed roadway where bicycles and motor vehicles share the same lane, indicated by signs or shared lane markings (sharrows).

- **Class IV (Separated Bikeway):** A protected bike lane that is physically separated from vehicle traffic by vertical barriers such as curbs, bollards, or planters.

Types of Bike path







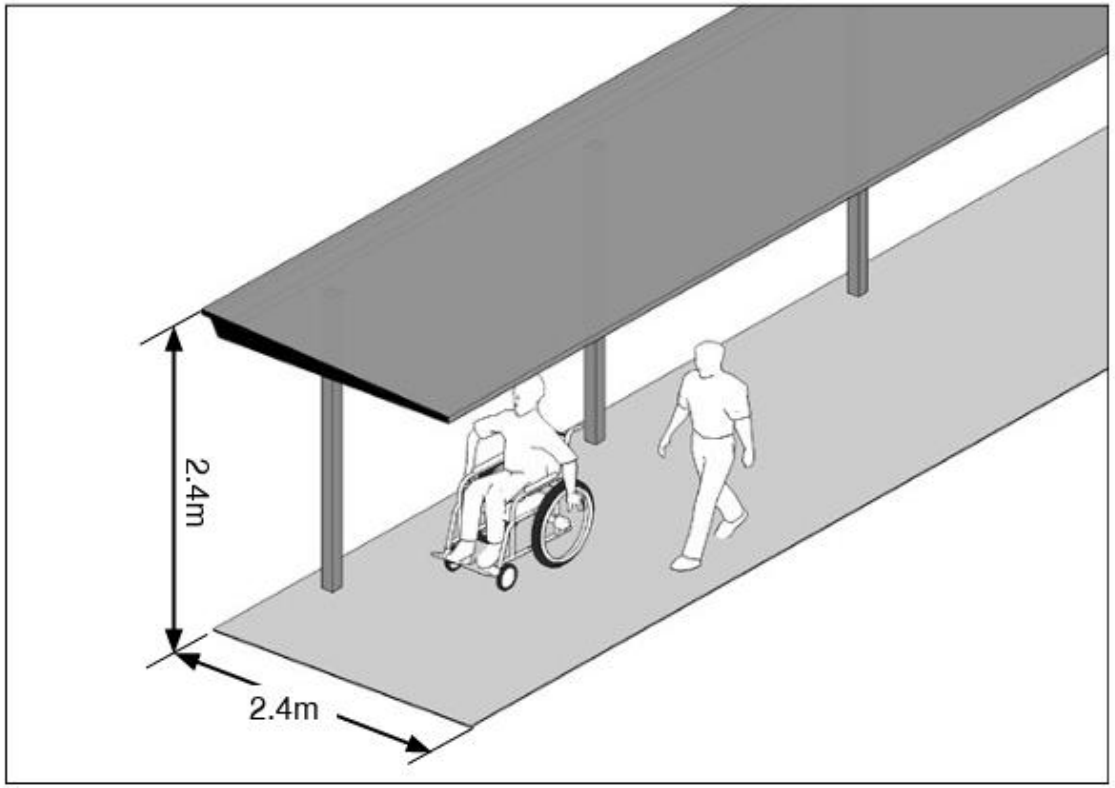


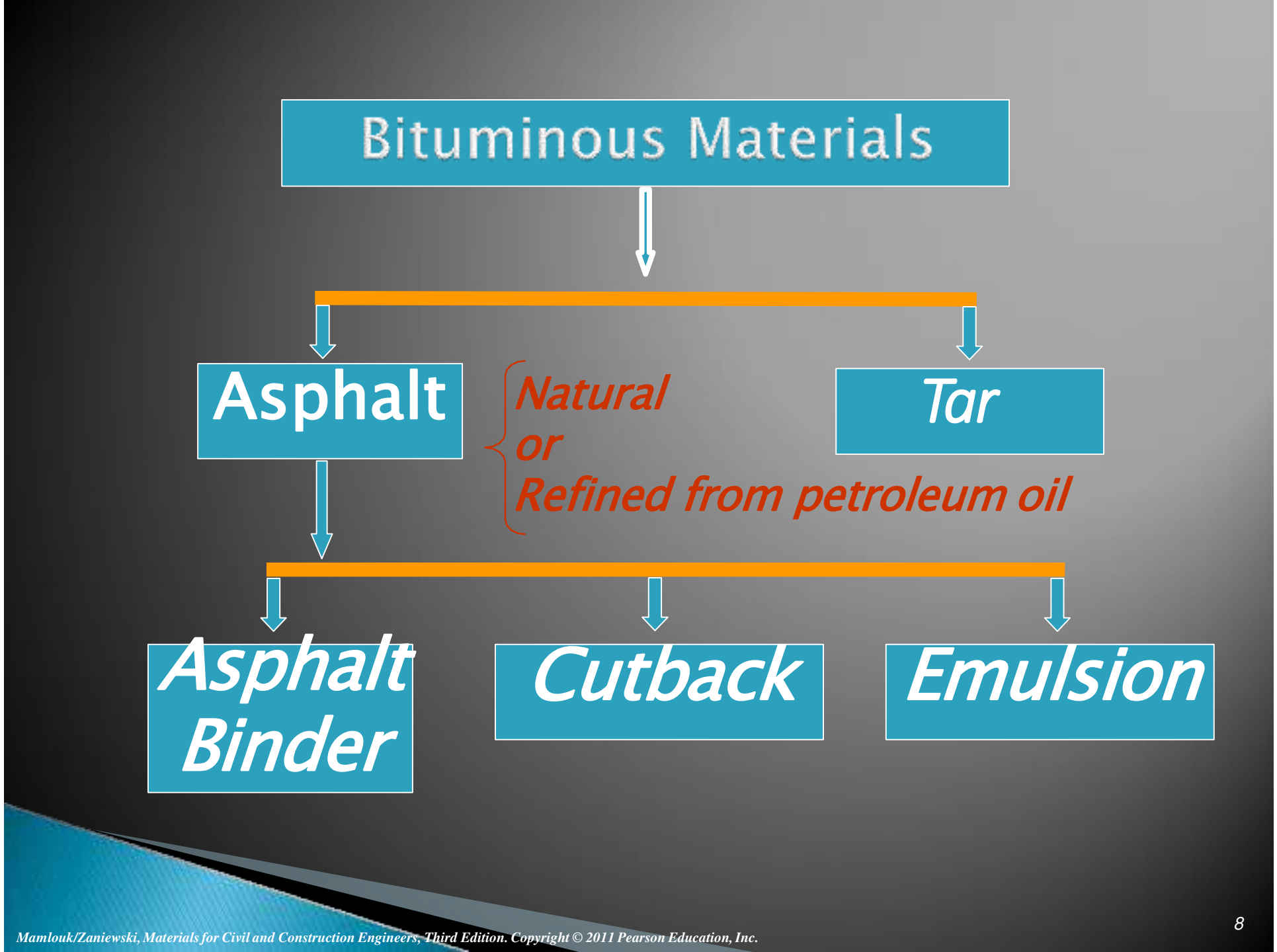


Covered Linkway

Covered linkways are shelters over footpaths to shield pedestrians from the weather while travelling from one place to another.

According to studies, weather protection is often one of the most important factors that affects people's decision to walk. Hence, to promote active mobility, the implementation of covered linkways at key locations is important





Mamlouk/Zaniewski, Materials for Civil and Construction Engineers, Third Edition. Copyright © 2011 Pearson Education, Inc.

What is Asphalt?

"A dark brown to black cementitious material in which the predominating constituents are bitumens which occur in nature or are obtained in petroleum processing **–ASTM**

In *British English*, the word asphalt refers to a mixture of mineral aggregate and bitumen.

In *American English*, bitumen is referred to as 'asphalt' or 'asphalt cement' .

Bituminous Materials

- Asphalt cement and tar are considered bituminous materials.
- Asphalt cement and tar are two distinctly different materials with different origins and different chemical and physical characteristic

Tar is not Asphalt

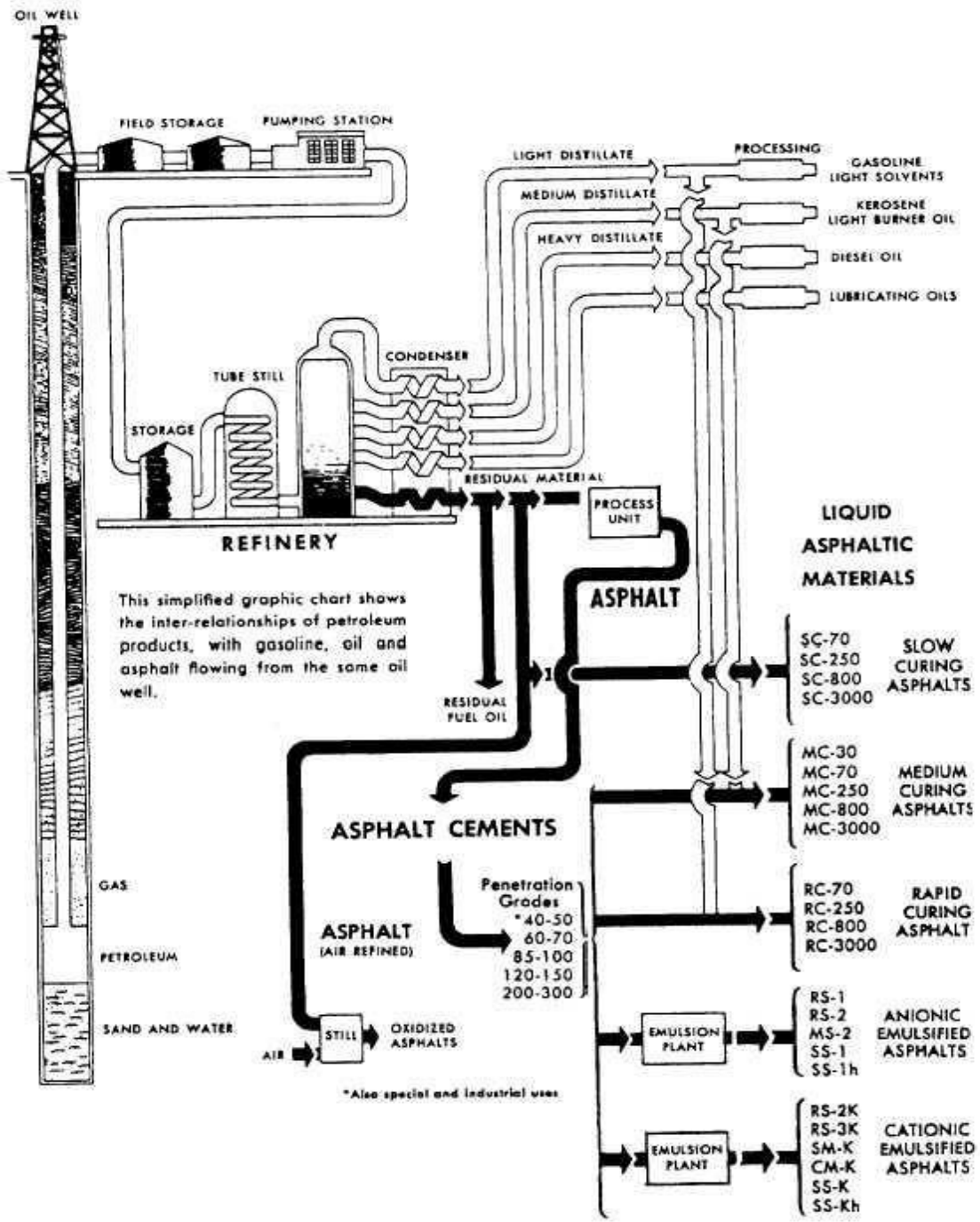
- Asphalt cement is a dark brown to black cementitious materials either it is naturally occurred or produced by petroleum distillation
- Tar however, is primarily manufactured from the destructive distillation of bituminous coal and has a very distinct odor, brown-black in color
- Petroleum asphalt is composed entirely of bitumen, whereas in coal tar bitumen content is relatively low
  - Asphalts will be dissolved in petroleum oils whereas tars will not
  - Therefor tars have been used to seal asphalt concrete surfaces, such as fog seals, to improve the oil resistance of asphalt surfaces

Tar is hardly used in paving. Why?

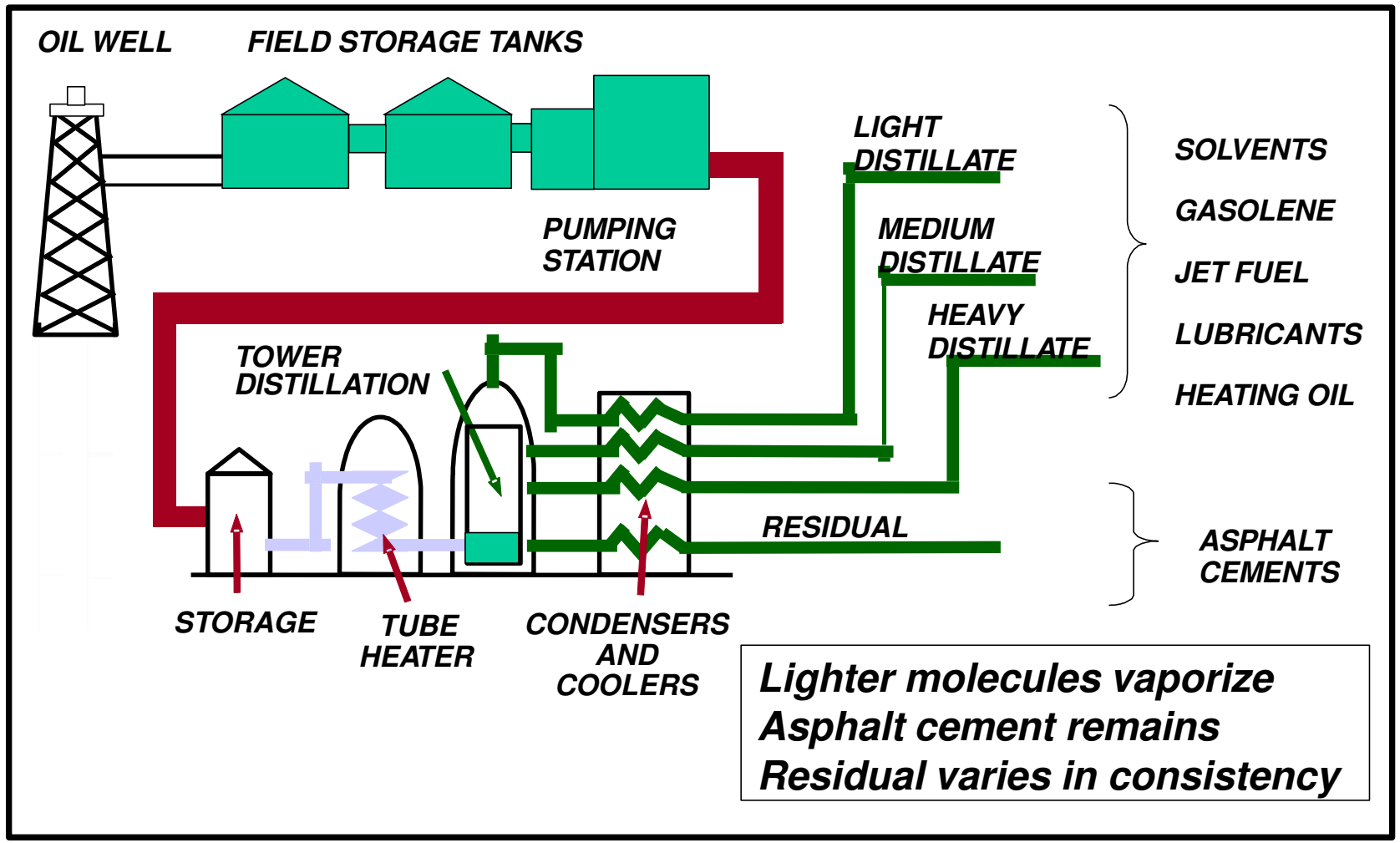
1. Some undesirable physical characteristic such as very high temperature susceptibility
2. Susceptible to weathering
3. Significant health hazards such as severe eye and skin irritation when exposed to its fume

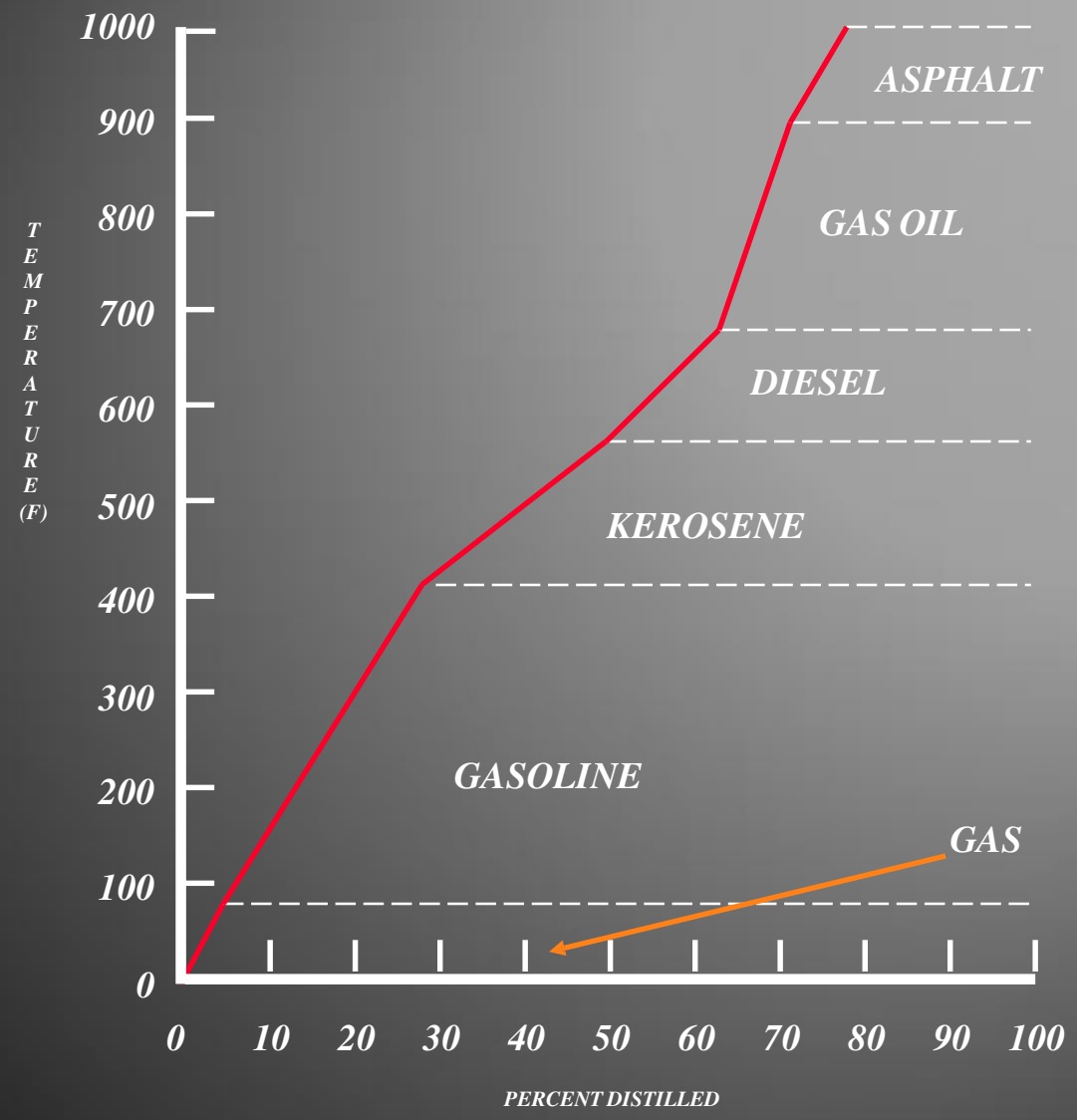
Comparison between Bitumen and Tar

Bitumen	Tar
Adhesion between aggregate and bitumen is less and does not retain well in presence of water	Produced by destructive distillation of coal or wood
Adhesion between aggregate and bitumen is less and does not retain well in presence of water	Adhesion between aggregate and tar is more and retain well in presence of water than bitumen
Weather resisting property is quite good	Has inferior weather resisting property
Less susceptible to temperature	More susceptible to temperature
Cost is high and useful for road construction	Cheaper than bitumen and useful for roofing materials and filler
Setting time is less	Setting time is more
Hardens very slowly	Hardens at much faster rate than bitumen


OIL WELL
FIELD STORAGE
PUMPING STATION
LIGHT DISTILLATE
MEDIUM DISTILLATE
HEAVY DISTILLATE
PROCESSING
GASOLINE
LIGHT SOLVENTS
KEROSENE
LIGHT BURNER OIL
DIESEL OIL
LUBRICATING OILS
CONDENSER
TUBE STILL
STORAGE
RESIDUAL MATERIAL
PROCESS UNIT
REFINERY
This simplified graphic chart shows the inter-relationships of petroleum products, with gasoline, oil and asphalt flowing from the same oil well.
ASPHALT
RESIDUAL FUEL OIL
LIQUID ASPHALTIC MATERIALS
SC-70
SC-250
SC-800
SC-3000
SLOW CURING ASPHALTS
MC-30
MC-70
MC-250
MC-800
MC-3000
MEDIUM CURING ASPHALTS
ASPHALT CEMENTS
Penetration Grades
*40-50
60-70
85-100
120-150
200-300
RC-70
RC-250
RC-800
RC-3000
RAPID CURING ASPHALT
GAS
PETROLEUM
SAND AND WATER
ASPHALT
(AIR REFINED)
STILL
AIR
OXIDIZED ASPHALTS
EMULSION PLANT
RS-1
RS-2
MS-2
SS-1
SS-1h
ANIONIC EMULSIFIED ASPHALTS
EMULSION PLANT
RS-2K
RS-3K
SM-K
CM-K
SS-K
SS-Kh
CATIONIC EMULSIFIED ASPHALTS
*Also special and industrial uses

Refinery Operation




1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (F)
ASPHALT
GAS OIL
DIESEL
KEROSENE
GASOLINE
GAS
0
10
20
30
40
50
60
70
80
90
100
PERCENT DISTILLED

Classification of Asphalt

Asphalt commonly used in flexible pavement construction and can be divided into three (3) general types:

1. Asphalt cement
2. Emulsified asphalt
3. Cutback asphalt

Asphalt Cements

- Asphalt cement is a viscoelastic material
- **The extent to which asphalt cement behaves as a viscous material or elastic material is dependent on the temperature and rate of loading**
- For example, asphalt cement at 60^0C may flow the same amount in 1 hour as it would be at 25^0C in 5 hour

- **At high temperatures under slow loading condition** (slow moving traffic), asphalt cement behaves like a **viscous fluid and flow**
- This is called plastic behavior that may lead to permanent deformation to pavement. It should be noted that aggregates play a significant role in resisting permanent deformation
- **At low temperature and rapid loads (fast moving traffic)**, asphalt cement behaves like **elastic solids**
- **At intermediate temperature**, asphalt cement exhibits **both viscous and elastic behavior**

Emulsified and Cutback Asphalt

Can we pump asphalt without heating?

Can we mix the asphalt with aggregates without by heating?

Yes, there are ways, other than heating to liquefy asphalt for construction operations. **Asphalt can be dissolved in selected petroleum solvents or emulsified agent and water. Asphalt liquefied by these methods is known as cutback asphalt and emulsified asphalt**

For **cutback asphalt,** after completion of construction, the **solvent will evaporate**, leaving the asphalt cement to perform its function

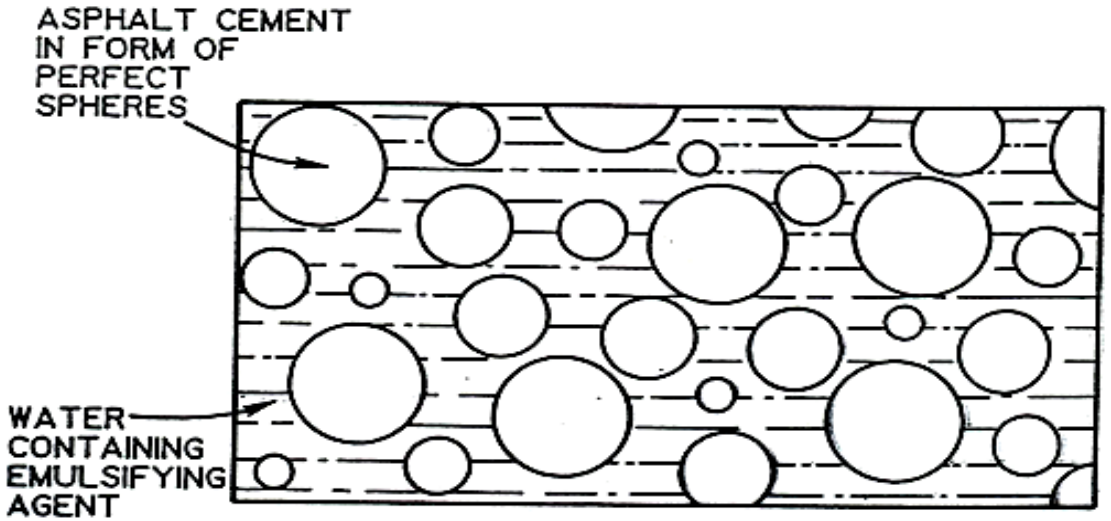
With **emulsified asphalt**, the basic idea is that **water will evaporate, leaving the asphalt cement to perform its function**

In each case asphalt cement is the base material liquefied by emulsifying or cutting back

Bitumen emulsions are ideal binders for hill road construction where heating of bitumen or aggregates are difficult.

Emulsified asphalt

- Emulsified asphalt is a mixture of asphalt cement, water, and emulsifying agent
- **Since the asphalt cement will not dissolve in water, asphalt cement and water exist in separate phases as shown in the following figure:**



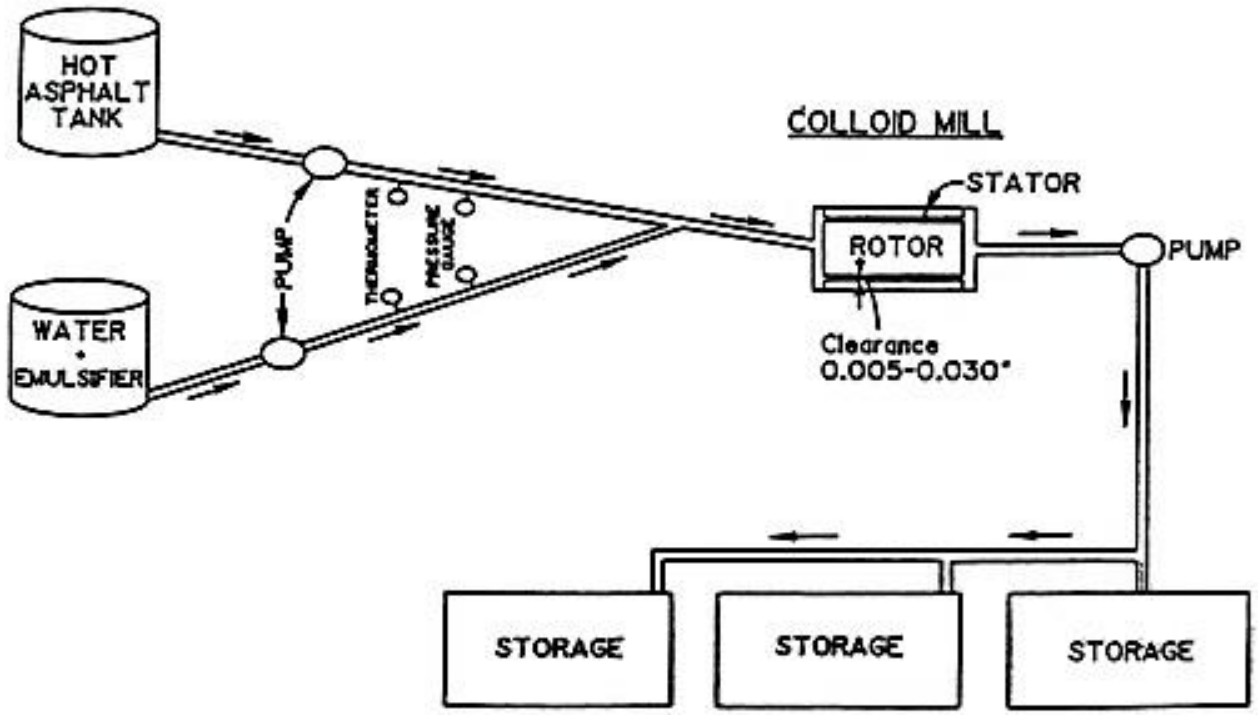
Emulsified Asphalt

- **To mix the asphalt cement with water, an emulsifying agent (usually a type of soap) is added**

Some commonly used emulsifying agents include tragacanth, sodium laurylsulfate, sodium dioctyl sulfosuccinate, and polymers known as the Spans® and Tweens®.

Emulsified asphalt-----contd.

Process of manufacture of emulsified asphalt consists passing the hot asphalt cement and water containing the emulsifying agent under pressure through a colloid mill, as shown in the following



Manufacture of Emulsified Asphalt

- **The colloid mill breaks up the asphalt cement and disperses it, in the form of very fine droplets/globules (5-10 microns and smaller), in the water carrier**
- **The emulsion contains usually 55-75% asphalt cement and up to 3% emulsifying agent, balance being water**

Specifications for Emulsified asphalt

- Two most commonly used types of emulsified asphalts are specified in ASTM D977 and ASTM D2397:
  - Anionic – electro-negatively charged asphalt droplets
  - Cationic – electro-positively charged asphalt droplets
    - Emulsifier gives surface charge to asphalt
    - Opposite charges attract aggregate particles

- Anionic emulsions adhere better to aggregate particles with positive surface charges (e.g., limestone)

- Cationic emulsions adhere better to aggregate particles with negative surface charges (e.g., sandstone, quartz, siliceous gravel). Cationic emulsions also work better with wet aggregates and in colder weather

Three types of bituminous emulsions:

Rapid setting (RS) - used for surface dressing work

Medium setting (MS) - are preferred for premix jobs and patch repairs work

Slow setting (SC) - preferred in rainy season.

Cutback Bitumen/Asphalt

Normal practice is to heat bitumen to reduce its viscosity. In some situations, preference is given to use liquid binders such as cutback bitumen. In cutback bitumen suitable solvent is used to lower the viscosity of the bitumen.

The solvent from the bituminous material will evaporate and the bitumen will bind the aggregate.

Cutback bitumen is used for cold weather bituminous road construction and maintenance.

The distillates used for preparation of cutback bitumen are naphtha, kerosene, diesel oil, and furnace oil.

There are different types of cutback bitumen

Rapid curing (RC) - recommended for surface dressing and patchwork

Medium curing (MC) - recommended for premix with less quantity of fine aggregates

Slow curing (SC) - used for premix with appreciable quantity of fine aggregates.

Emulsified asphalts are increasingly being used in lieu of cutback asphalts for the following reasons:

- **Environmental regulations:** Emulsions are relatively pollution free
- **Loss of high-energy products:** When cutback asphalts cure, the diluents which are high energy, high price products are wasted into atmosphere
- Safety: Emulsions are safe to use
- **Lower application temperature:** Emulsions can be applied at relatively low temperatures saving the fuel costs. Emulsions can also be applied effectively to a damp pavement, whereas dry conditions are required for cutback asphalts

TESTS FOR ASPHALTIC MATERIALS

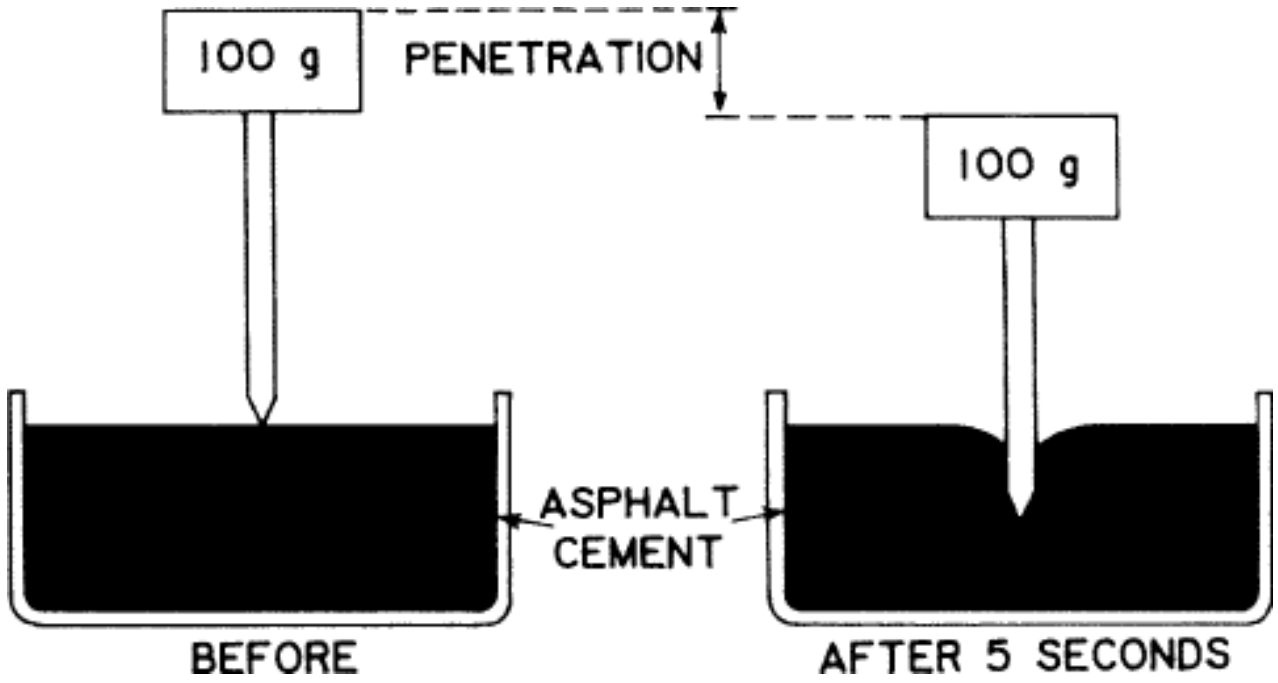
- General
  - Specific gravity
  - Flash point (open cup)
  - Water in petroleum products
- Solubility
  - Solubility of bituminous materials
  - Spot test
- Consistency
  - Specific Viscosity
  - Kinematic viscosity
  - Absolute viscosity
  - Float test
  - Penetration
  - Softening point (ring-and-ball method)
- Ductility
  - Ductility
- Volatility
  - Distillation
  - Loss on heating
  - Thin-film oven test
  - Tests for emulsion

Penetration Test

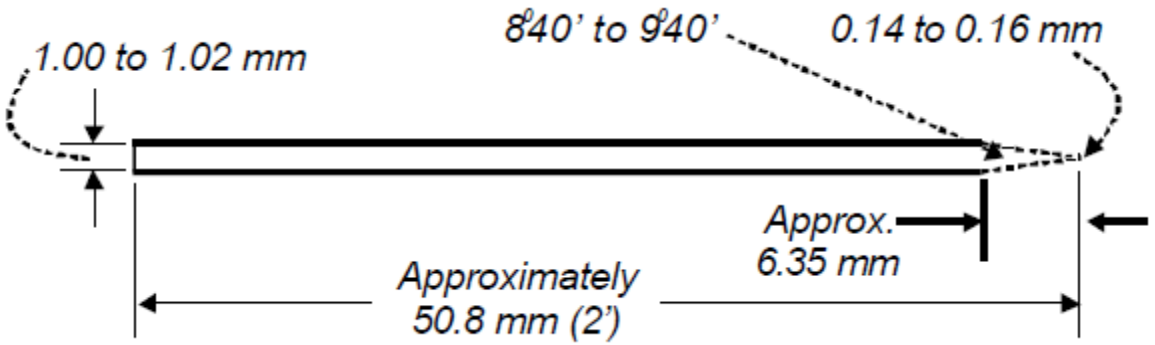
- In this procedure, a needle is typically loaded with a 100 g weight and allowed to penetrate into an asphalt cement sample for 5 sec at 25^0C
- A harder asphalt will have a lower penetration while a softer asphalt cement will have a higher penetration

  - Five penetration grades
    - 40-50 = stiffest
    - 60-70
    - 85-100
    - 120-150
    - 200-300 = softest

Penetration Test (ASTM D5)

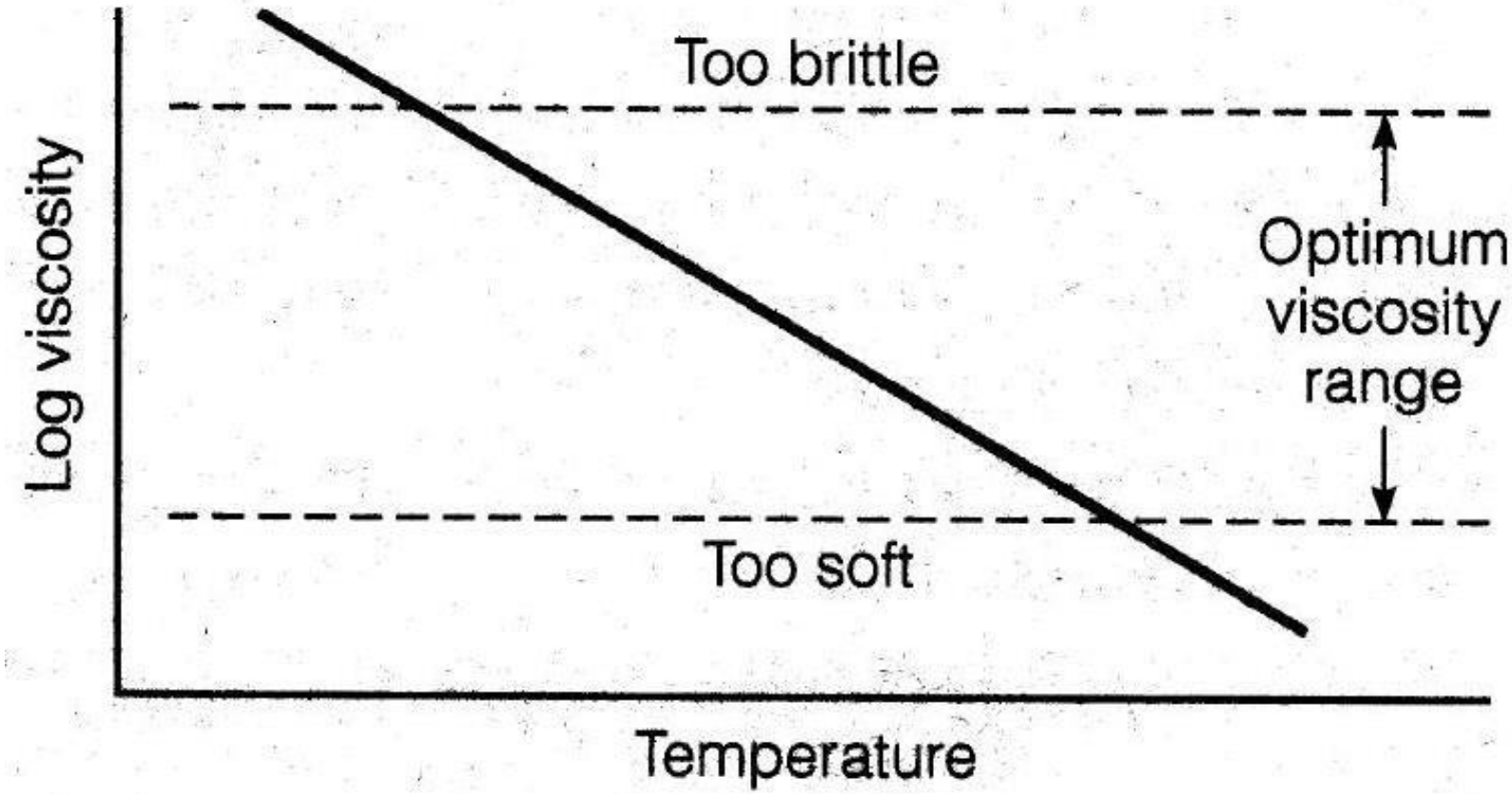






Viscosity

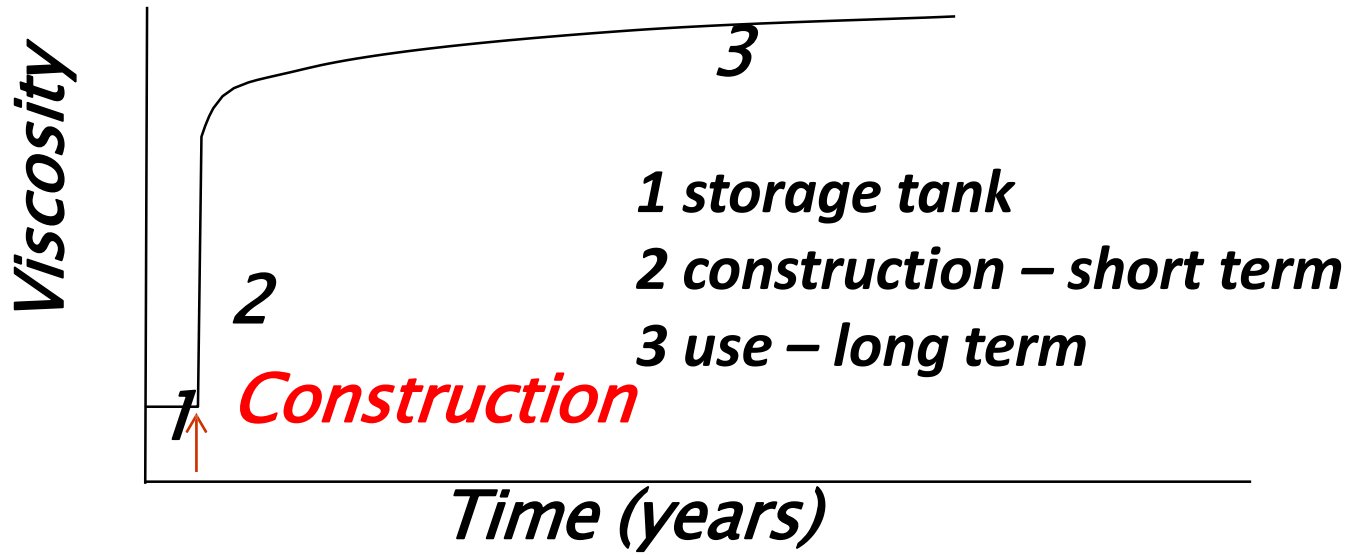
- Viscosity is reverse of fluidity. It is a measure of the resistance to flow
- Higher the viscosity of liquid bitumen, the more nearly it approaches a semi-solid state in consistency
- The bitumen binders of low viscosity, simply lubricate the aggregate particles instead of providing a uniform thin film for binding action
- High viscosity does not allow full compaction and the resulting mix exhibits heterogeneous character and thus low stability values.


Too brittle
Optimum viscosity range
Too soft
Log viscosity
Temperature

Aging Behavior

Aging or hardening is the process under which asphalt becomes harder and brittle due to increase in the viscosity of asphalt caused by:

- the evaporation and oxidation of the lighter, oily constituents during mixing at high temperatures, called "volatilization" (short-term aging or hardening)
- the oxidation of the oils to resins and resins to asphaltenes when used over a period of years (long-term or in-service aging or hardening)



Bituminous mix design

The bituminous mix design aims to determine the **proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical.**

Constituents of a mix

- Coarse aggregates: Offer compressive and shear strength and shows good interlocking properties.
- Fine aggregates: Fills the voids in the coarse aggregate and stiffens the binder.
- Filler: Fills the voids, stiffens the binder and offers permeability

Binder: Fills the voids, cause particle adhesion and gluing and offers impermeability.

Marshall Mix Design

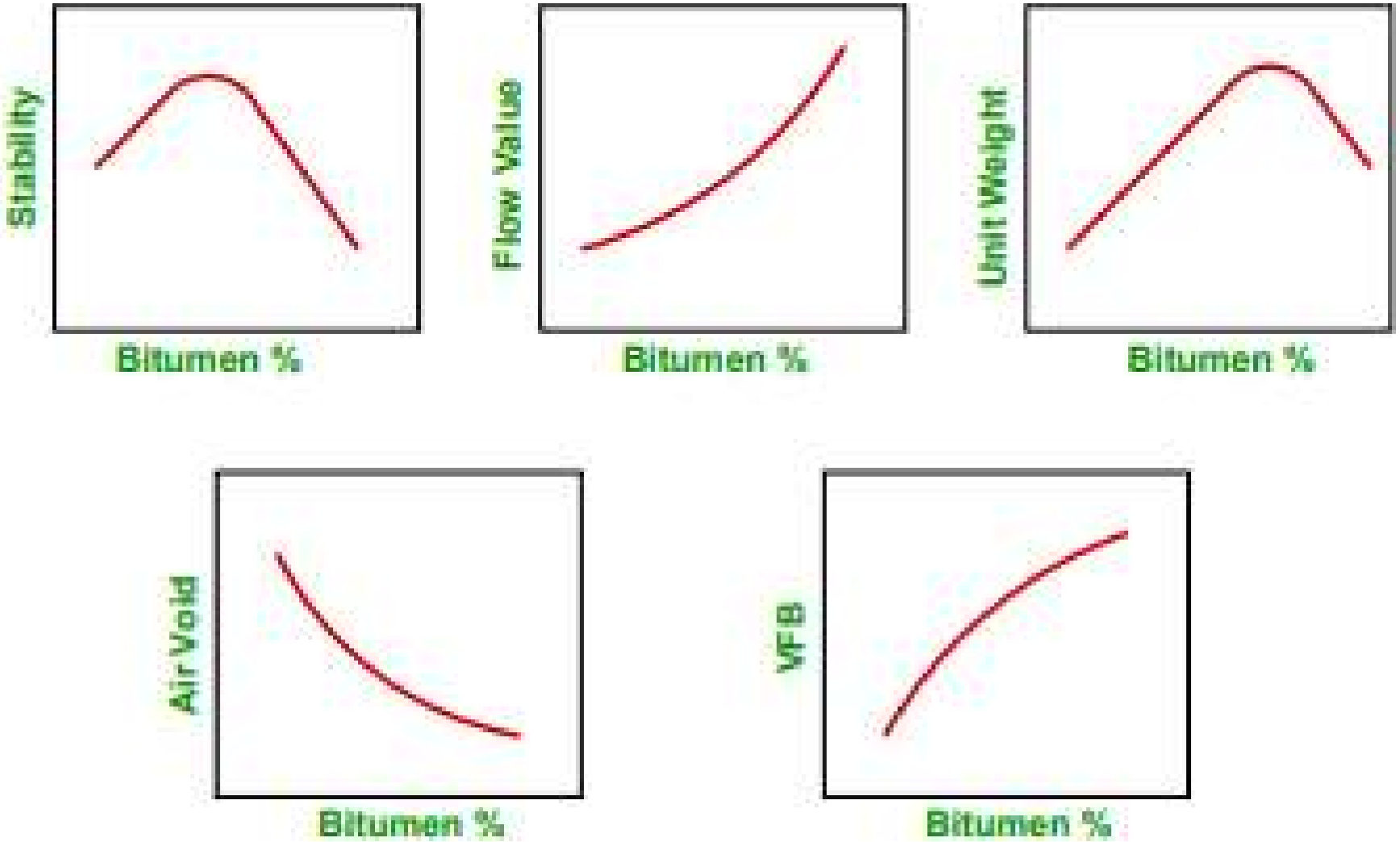
The mix design (wet mix) determines the optimum bitumen content.

Stability and flow test

The stability measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute.

The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.

Marshall Mix Design



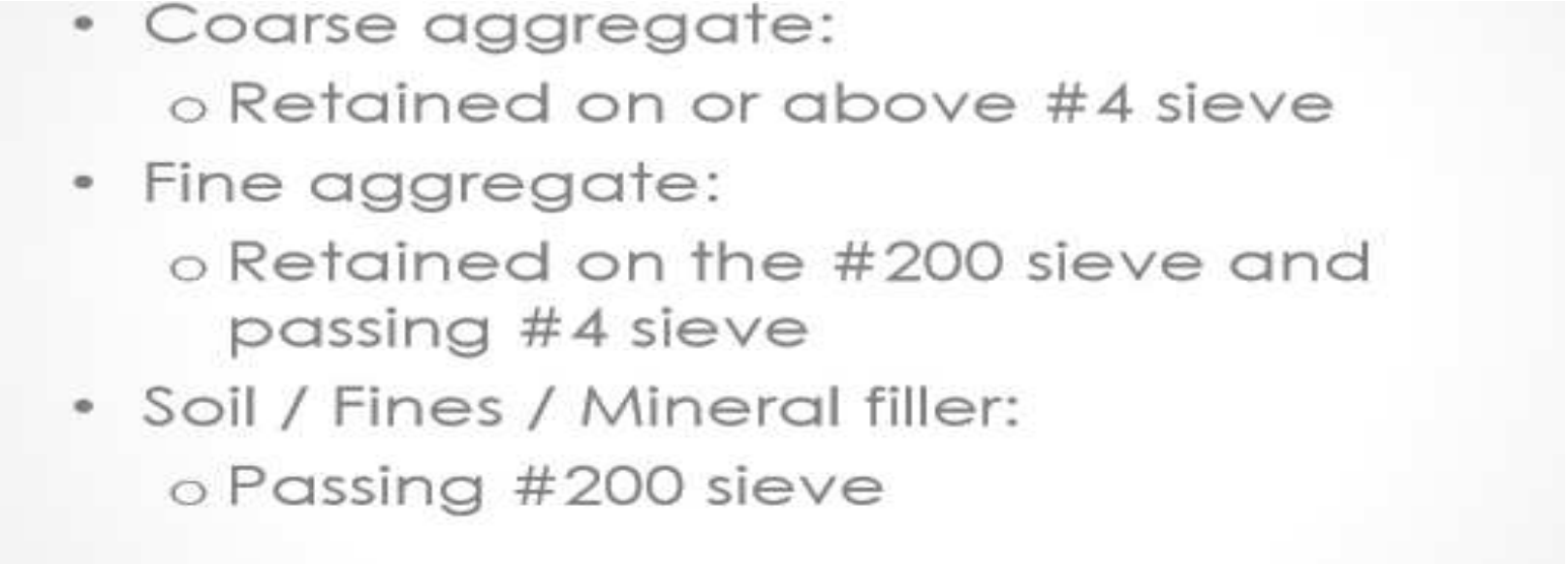
CT 2

1. Give 3 examples of green transport mode. Mention minimum three measures required for encouraging green transport 4
2. What quality of aggregate is tested by LAA test? 2
3. Name the tests for consistency parameter of Bitumen/Asphalt. 3
4. How asphalt cement behave at high, low and moderate temperature? 3
5. Mention the objective of Bitumen mix design. 2
6. Draw the qualitative curves between (a) bitumen (%) vs stability and (b) bitumen (%) vs flow. 6

Definition and Types of Aggregate

Aggregates include sand, gravel, crushed stone, crushed bricks and recycled concrete.

- Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregates serve as reinforcement to add strength to the overall composite materials.
- Aggregates are also used as base material under foundations, roads and railroads.
- **Aggregate Types**:



Coarse Aggregate

- Any type of pavements, either rigid or flexible , coarse aggregate is the prime material used in them
- In case of flexible pavements, coarse aggregates constitute about 90% or even more of the total construction material
- Coarse aggregates bear stresses occurring on road surface and also resists wear and tear due to abrasive action of traffic
- Aggregates are specified according to their size, shape, texture and gradation
- For different thickness and types of aggregates size and gradation are specified differently
- AAASHTO, ASTM, BS have specified grading for highway construction.
- Most of the aggregates are obtained from natural rocks by crushing

Properties of Aggregate

- Particle size and Gradation
- Hardness or resistance to wear
- Durability or resistance to weathering
- Specific gravity and Absorption
- Chemical stability
- Particle shape and surface texture
- Freedom from deleterious particles or substances

Aggregate tests

In order to decide the suitability of the aggregate for use in pavement construction, following tests are carried out:

- Crushing test
- Abrasion test
- Impact test
- Soundness test
- Shape test
- Specific gravity and water absorption test
- Bitumen adhesion test

Properties of Aggregate

Particle size and Gradation

- A key property of aggregates used for highway bases and surfaces is the distribution of particle sizes in the aggregate mix.
- The gradation of aggregates, that is, the blend of particle sizes in the mix affects the density, strength and economy of the pavement structure.
- When particles are to be bounded by a Portland cement or a bituminous binder, a variation in the gradation will change the amount of binder needed to produce a mix of given stability and quality.
- Particle size and gradation also affects workability and permeability of a bituminous mix.
- **A grain size analysis** is used to determine the relative proportions of various particle sizes in an aggregate mix.

Hardness and Resistance to Wear

- Under heavy traffic loads, aggregates in flexible pavement are subjected to continuous slight movements and distortion.
- This action causes different pieces of aggregate to rub and grind against each other.
- Mats used in pavements should be hard and resist wear due to these polishing effects of traffic and the internal abrasive effects of repeated loading.
- ACV, AIV, LAA Test

Durability or Resistance to Weathering

- The aggregates are subjected to physical and chemical action of rain, ground water and other atmospheric impurities.
- So aggregates used in highway construction should be capable to withstand such weathering action.
- Durability and resistance to weathering of aggregates is measured by **soundness test.**
- The test measures the **resistance of aggregates** to disintegration in a saturated solution of sodium or magnesium sulfate. It simulates the weathering of aggregates that occur in nature.
- This property is helpful to prolong the life of pavement.

Specific Gravity

- Specific gravity is a measure of a material's density , in other words, strength and quality. Stones having higher specific gravities are considered **strong**. [limestone SG 2.6 and density 165-170 lb/sft, lead SG 11.0 and density 680-690 lb/sft]
- Specific gravity of a coarse aggregate is calculated by determining the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water.
- Aggregates may contain water-permeable voids(WPV).Two measures of specific gravity of aggregates are used: apparent specific gravity (excluding WPV) and bulk specific gravity(including WPV).

Absorption

- Absorption is a measure of the amount of water that an aggregate can absorb into its pore structure.
- Aggregate absorption is a useful quality because:
  - High values can indicate non-durable aggregate.
  - Absorption can indicate the amount of asphalt binder the aggregate will absorb.
- It is generally desirable to **avoid highly absorptive** aggregate. This is because asphalt binder that is absorbed by the aggregate is not available to coat the aggregate particle surface and is therefore not available for bonding.
- Therefore, highly absorptive aggregates (often specified as over 5 percent absorption) require more asphalt binder to develop the same film thickness as less absorptive aggregates making the resulting mix more expensive.

Particle Shape

Classification	Description
Rounded	Fully water-worn or completely shaped by attrition
Irregular	Naturally irregular or partly shaped by by attrition and having rounded edges
Flakey	Thickness is smaller relative to other two dimensions
Angular	Possessing well defined edges
Elongated	Usually angular, length is larger than other two dimensions
Flakey and elongated	Length considerable larger than thickness

Particle Shape and Surface Texture

- Shape and texture provide guidance about **internal friction** properties (interlocking of particles and surface friction) which resist the movement of aggregates past each other under the action of an imposed load.
- Flaky and elongated particles are **less strong and durable**.
- Rounded particles are have **less interlocking capability** and not preferred in WBM and bituminous road construction.
- Angular particle is **preferred** in bituminous pavement.
- **Rough-textured** aggregates contribute more to the **stability** of a pavement than smooth surface textures.

Chemical Stability of Aggregate

Composition

- Certain Aggregate may be unsuitable for a particular highway construction because of the chemical composition of the aggregate particle
- Limestone consists of calcium carbonate and has a tendency to polish smooth under traffic and therefore is limited to use in low traffic volume.
- Dolostone [sedimentary calcium magnesium carbonate rock] under traffic maintains a higher friction, skid-resistance surface and is used in higher traffic volume locations.

Chemical Stability of Aggregate

Bitumen Adhesion

- In asphalt mixes, certain aggregates that have an excessive affinity for water may contribute film stripping, leading to disintegration of asphalt surfaces.
- 'Hydrophobic' or 'water-hating' aggregates exhibits high degree of resistance to film stripping.
- Opposite is 'hydrophilic' or 'water-loving'.
- Bituminous pavement> bituminous material> thin film> fill void and adhere to aggregate> increase shearing resistance and cohesion.
- Exposed to water> water replace the film.

Chemical Stability of Aggregate

Deleterious Substances

- Aggregates that contain deleterious [harmful] substances react harmfully with the alkalis present in the cement.
- Detrimental alkali-aggregate reactions result in abnormal expansion of the concrete.
- Aggregates used in cement concrete mixes must be free of deleterious substances such as clay lumps, silt and organic impurities.

Other Properties of Aggregates

➢ Good aggregate having sufficient *cementation property*

Test for Road Aggregate

- Los Angeles Abrasion Test (Resistance to wear)
- Aggregate Crushing Value (ACV) Test (Strength or toughness)
- Aggregate Impact Value (AIV) Test (Strength or toughness)
- Soundness Test (Durability)
- Gradation Test (Grain size distribution)
- Unit Weight and Void Test
- Specific Gravity and Water Absorption Test
- Bitumen Affinity or Stripping Test
- Clay Lump Test
- Organic Impurities Test
- Flakiness Index Test (Shape)
- Elongation Index Test (Shape)
- Angularity Number Test (Shape)

BRICK AGGREGATES

Source- Crushed brick

- **Uses- Base , Sub-base courses, Low cost roads, Surface course (for light traffic)**

RHD Specification for CA for Bituminous Mix

S.No.	Name of Test	Testing Procedure	Wearing Course	Base Course
1	Aggregate Crushing Value (ACV) (%)	STP 7.7.1	Less than 25%	Less than 30%
2	Los Angeles Abrasion (LAA) (%)	AASHTO T96	Less than 30%	Less than 35%
3	Water absorption	STP 7.5.4	Not more than 2%	Not more than 2%
4	Soundness	AASHTO T104	Loss in weight (after 5 cycles) with Sodium Sulphate solution- not more than 10%	
5	Coating & Stripping Test	AASHTO T182	Min. 95% retained coating	

When crushed gravel is used, not less than 90% by weight of the particles retained on a 5 mm sieve shall have at least two fractured faces.

The flakiness index as determined in accordance with STP 7.3.1 shall not exceed 30%.

Fine Aggregates (Sand)

General points

- Sand is a naturally occurring granular material composed of finely divided rock and mineral particles.
- Sand is a form of silica.
- Sand grains may be sharp, angular or rounded in shape.

Classification of Sand

- According to source- Pit sand, River Sand and Sea sand
- According to size- Fine sand (passing no. 16 sieve), Moderately coarse sand (passing no. 8 sieve) and Coarse sand (passing no. 4 sieve)

Fine Aggregates (Sand)

Properties of Sand

- Sand should be pure silica.
- Should be free from clay, silt, organic matter and salt.
- Should drain groundwater freely.
- Should not expand or contract with changing moisture content.
- Resist high load without sliding or compacting.

Uses of sand

- Making cement concrete for rigid pavement.
- Stabilized road construction.
- Making bases and sub-bases.
- To fill up the gaps between bricks in brick road.

Roadway alignment

Topo/Terrain Classification:

1. Level terrain – gen curvature are considered
2. Rolling terrain – both grade and curvature are considered
3. Mountainous terrain – grade is most imp consideration

An ideal and most desirable roadway is one that follow existing natural alignment without making considerable adjustment in horizontal and vertical direction.

Alignment should be uniform and consistent to match with driver expectancy

Types of Alignment:

1. Horizontal alignment
2. Vertical alignment

Objective:

1. Comfort
2. Safety

Horizontal Alignment

Elements:
Straight section
Transition curve
Circular Curve
Superelevation
Sight distance
Offset of the roadside objects







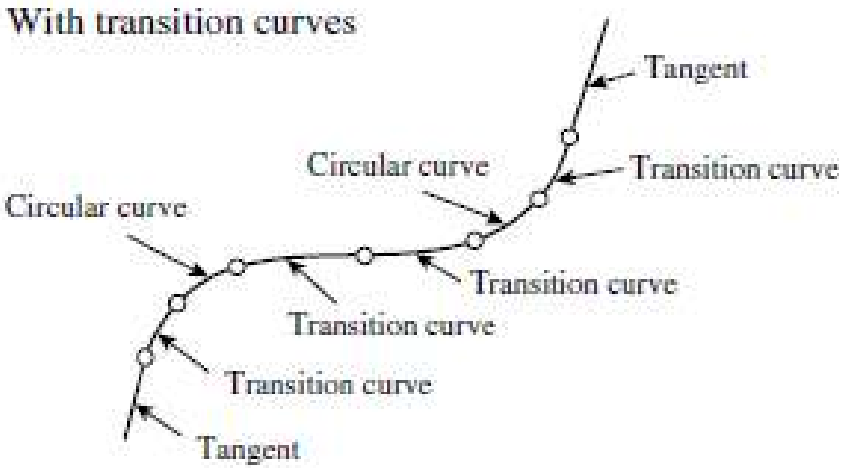
Horizontal alignment

Straight sec or tangent of highway may need to be connected with circular curve with or without the provision of transition curves.

So, we need to design various **elements of curves as well as superelevation**.

Circular curve

- Simple curve
- Reverse curve
- Compound curve
- Spiral curve



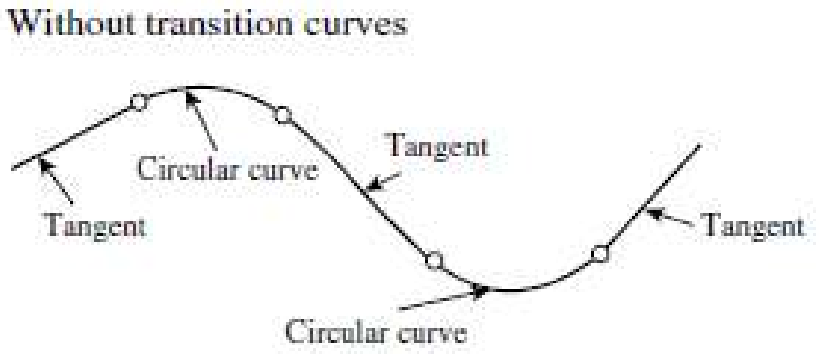


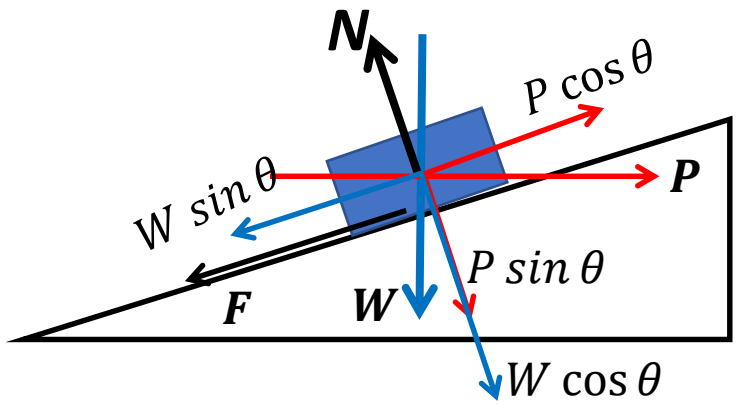
FIGURE 4.11
Horizontal alignments with and without transition curves.

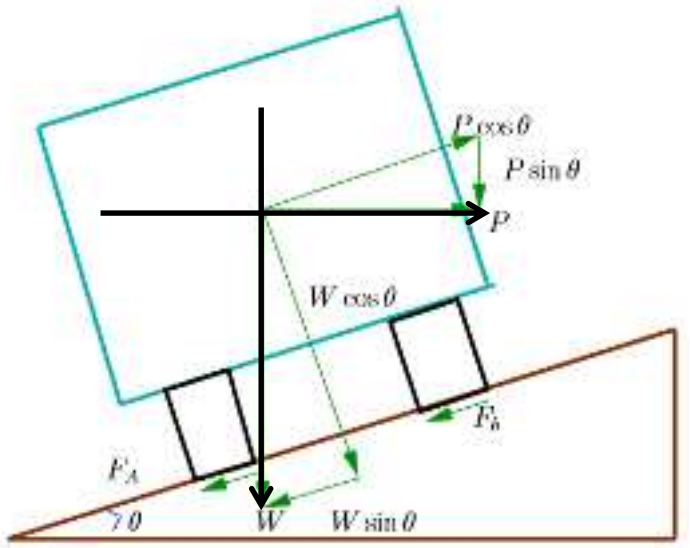
Why superelevation is provided

- To **counteract the effect of centrifugal force** acting on moving vehicle.
- To help a fast moving vehicles to **negotiate a curved path without overturning and skidding**.
- To ensure **smooth and safe movements** of passengers and goods on the road.
- To **prevent damaging effect on the road surface** due to improper distribution of load and thereby to reduce the maintenance cost of road on curve.



Analysis of Superelevation





W = Weight of the vehicle,
v = Speed of the vehicle in m/sec,
g = Acceleration due to gravity in m/sec²,
f = Coefficient of friction,
e = rate of superelevation (tanθ),
F = Frictional force resistance
P = Centrifugal force.

$\sum F_x = 0,\ P\cos\theta = W\sin\theta + F, \qquad P\cos\theta = W\sin\theta + F_A + F_B$

$\sum F_y = 0,\quad N = P\sin\theta + W\cos\theta \quad Again, F = F_A + F_B = fN = f(P\sin\theta + W\cos\theta)$

$Therefore, P\cos\theta = W\sin\theta + f(P\sin\theta + W\cos\theta)$

Or, $P = W\tan\theta + f(P\tan\theta + W)$ [dividing by $\cos\theta$]

Or, $\frac{P}{W} = \tan\theta + f(\frac{P}{W}\tan\theta + 1)$

Or, $\frac{P}{W}(1 - f\tan\theta) = \tan\theta + f \qquad or, \qquad \frac{P}{W} = \frac{\tan\theta + f}{(1 - f\tan\theta)}$

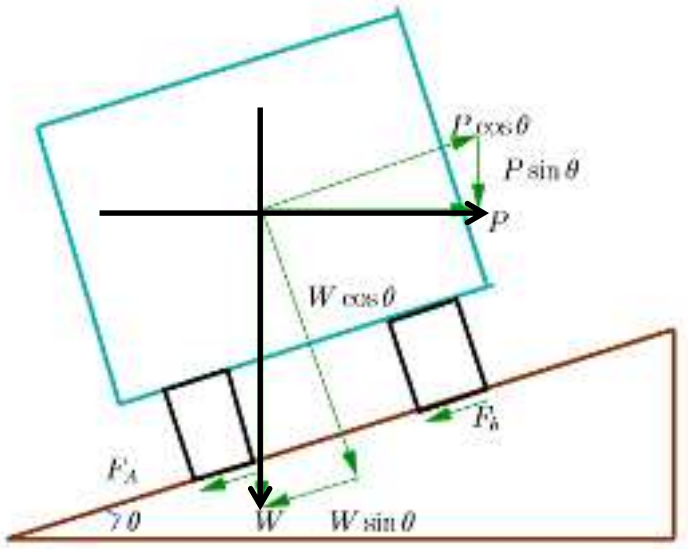


Analysis of Superelevation

$$or, \quad \frac{P}{W} = \frac{tan\,\theta + f}{(1 - f\,tan\,\theta)}$$

neglecting the value of $(1 - f\,tan\,\theta)$

$$tan\,\boldsymbol{\theta} + f = \frac{\boldsymbol{P}}{\boldsymbol{W}}$$



Again, if a vehicle of mass m, travelling at a constant speed v, along a curve of radius R, is subjected to a radial force (centrifugal force), $\boldsymbol{P = m\alpha = m\frac{v^2}{R} = \frac{W}{g}\frac{v^2}{R}}$, **or,** $\boldsymbol{\frac{P}{W} = \frac{v^2}{gR}}$

$tan\,\boldsymbol{\theta} + f = \boldsymbol{\frac{P}{W}}$ **and,** $\boldsymbol{\frac{P}{W} = \frac{v^2}{gR}}$ **Therefore,** $tan\,\boldsymbol{\theta} + f = \boldsymbol{\frac{v^2}{gR}}$

Thus, the centrifugal force is balanced by the sum of the effect of the super elevation and the effect of friction.

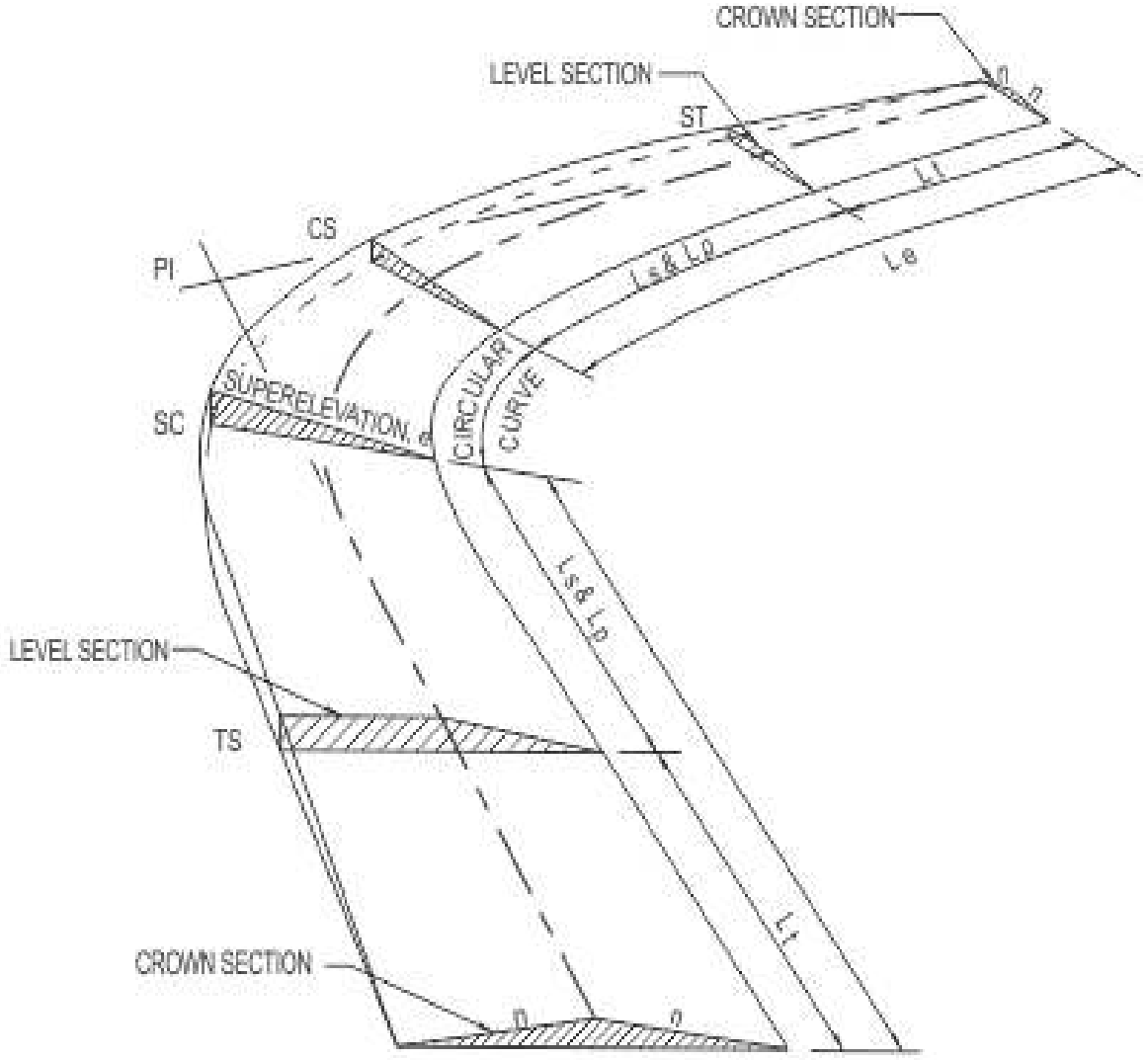
$\boldsymbol{e + f = \frac{v^2}{gR}}$ when the speed of vehicle is in **'m/s'**

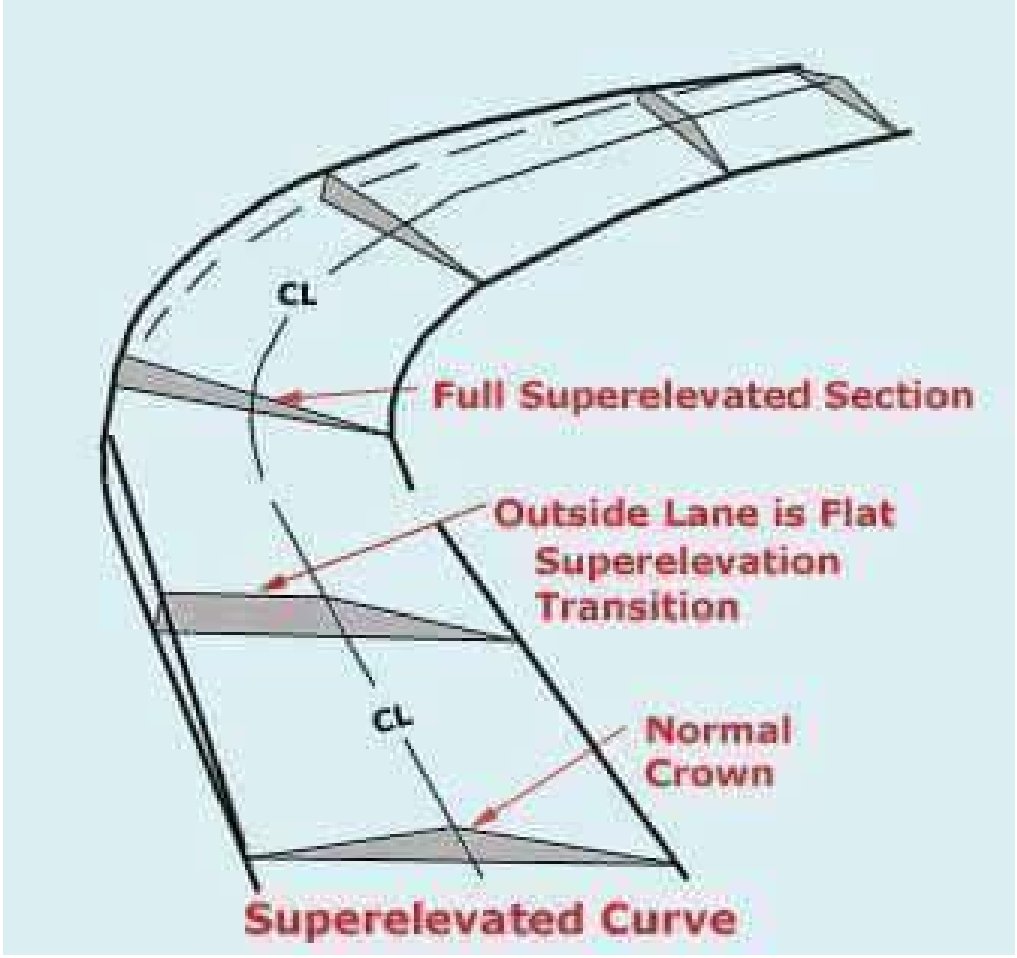
Or, $\boldsymbol{e + f = \frac{V^2}{127R}}$ when speed of vehicle is in **'kmph'**

$$\boldsymbol{e + f = \frac{v^2}{gR} = \frac{(\frac{v}{3.6})^2}{9.81R} = \frac{V^2}{127R}}$$

Superelevation Transition

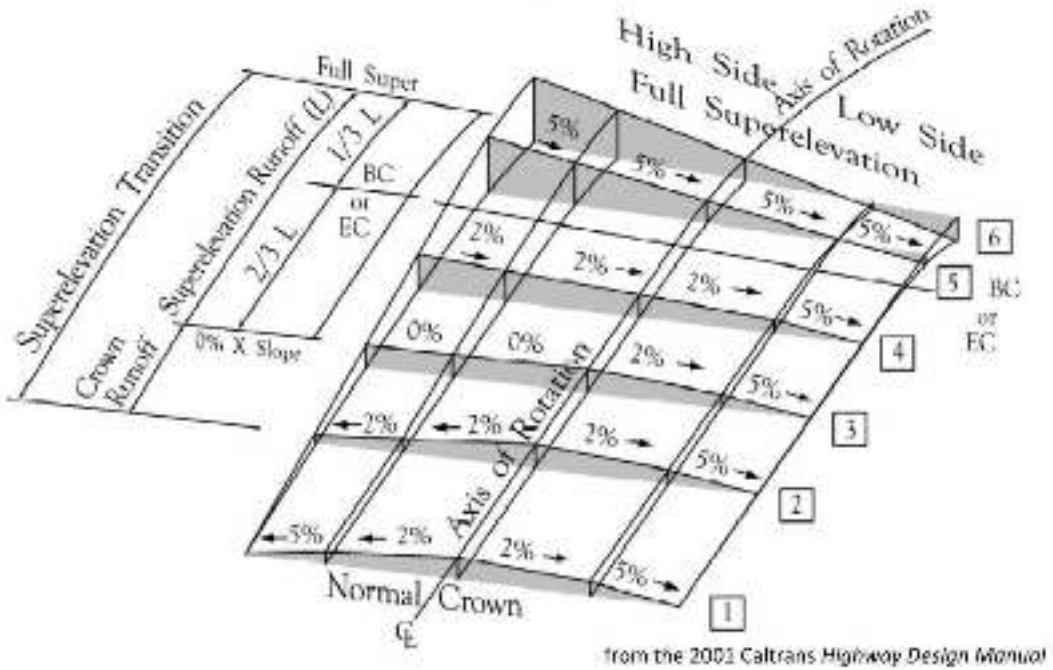
Transitions from crowned sections to superelevation sections should be gradual
Superelevation should be introduced and removed uniformly over the length of the curve



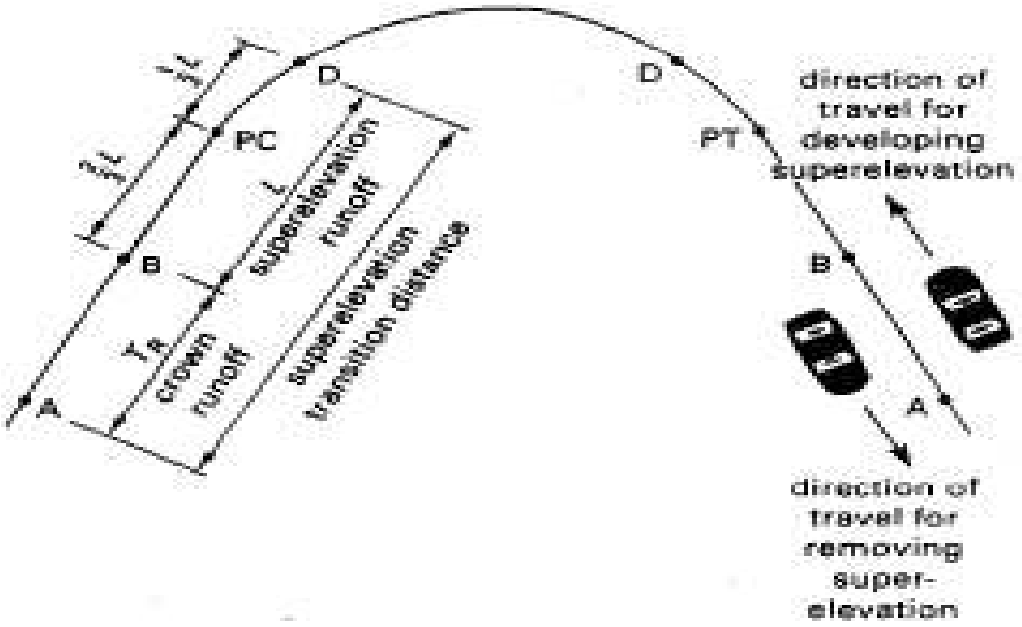


Superelevation Transition

Superelevation runoff: Dist. reqr for accomplishing the transition from a zero percent or flat sec to a fully super elevated sec

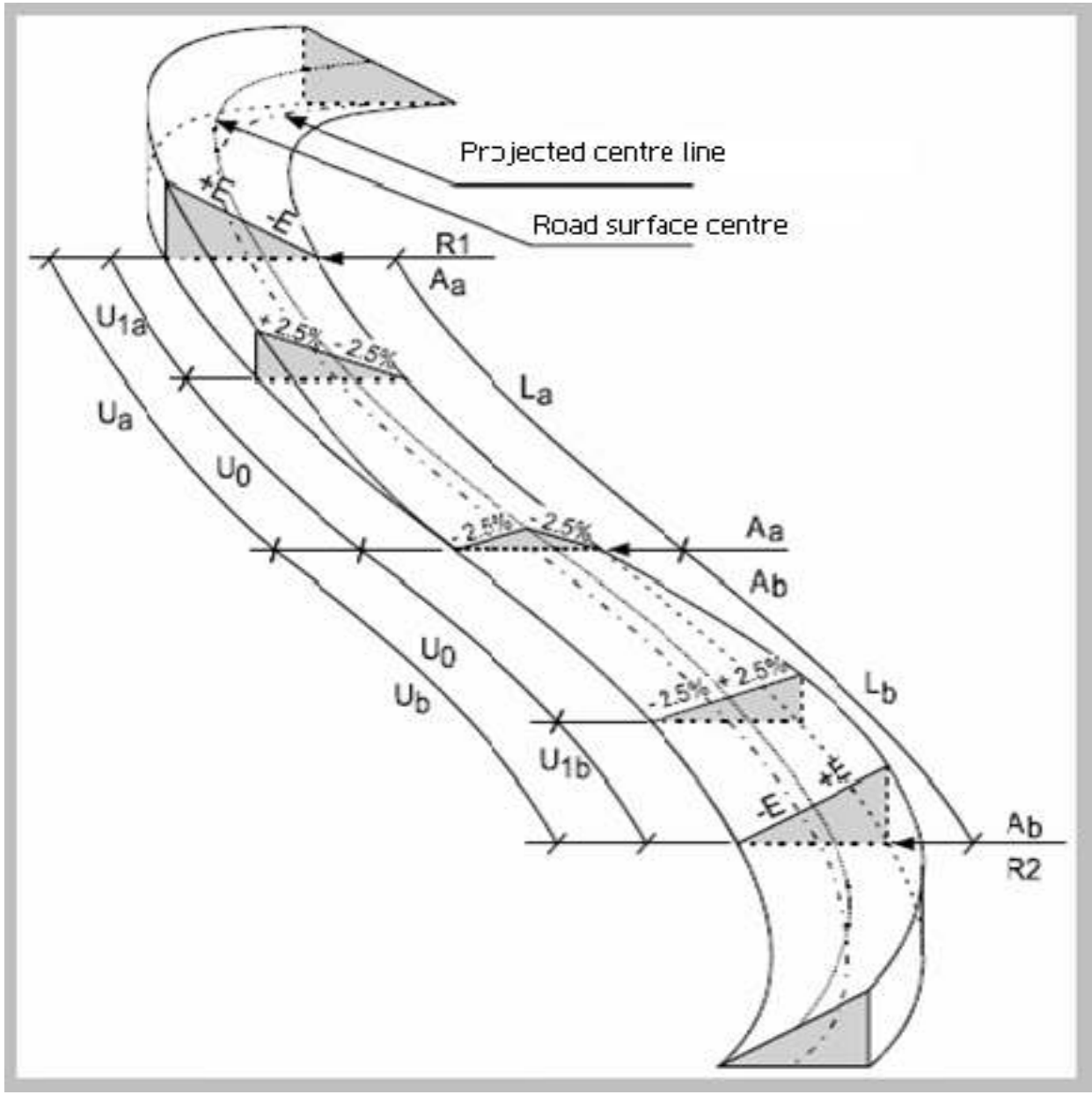


from the 2001 Caltrans *Highway Design Manual*



Tangent Runout: Dist. reqr for accomplishing the transition from adverse cross slope to flat sec or zero percent super elevated sec.

Super elevation Transition Distance



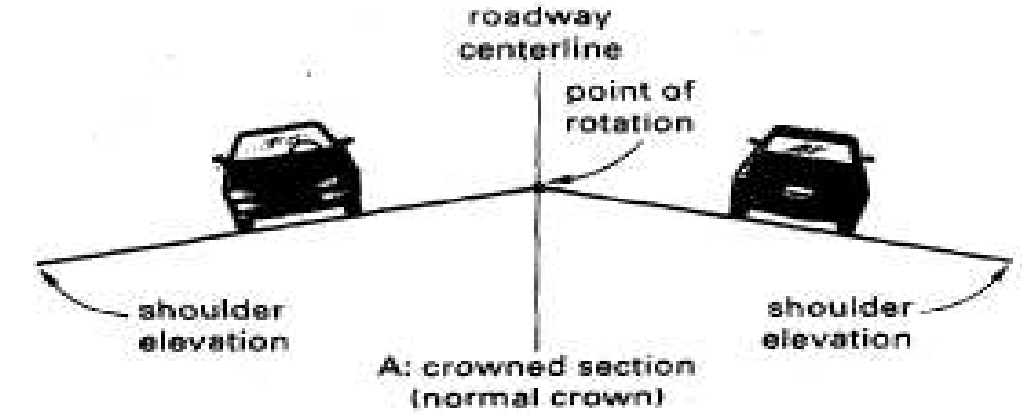
Method of attaining Superelevation

The transition from a tangent, normal crown sec to a curve superelevation sec must be accomplished without any appreciable reduction of speed and in such a manner as to ensure safety and comfort to the occupants.

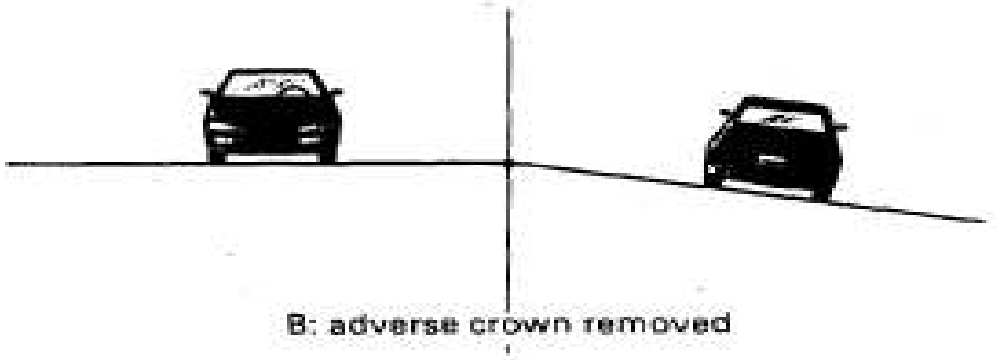
Superelevation is provided in two Steps:

1. Elimination of the crown of the cambered section.
2. Rotation of pavement to attain full superelevation

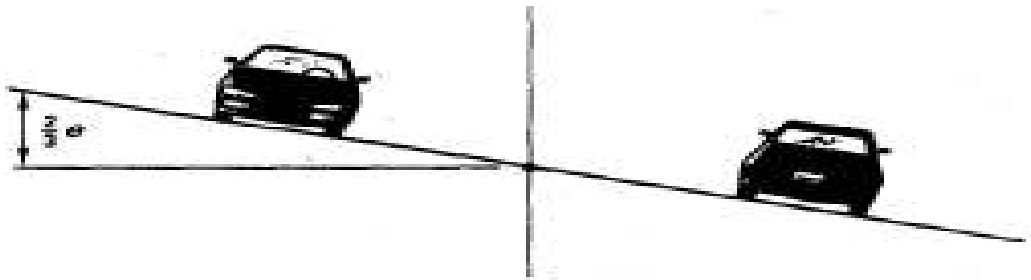
Method of attaining Superelevation



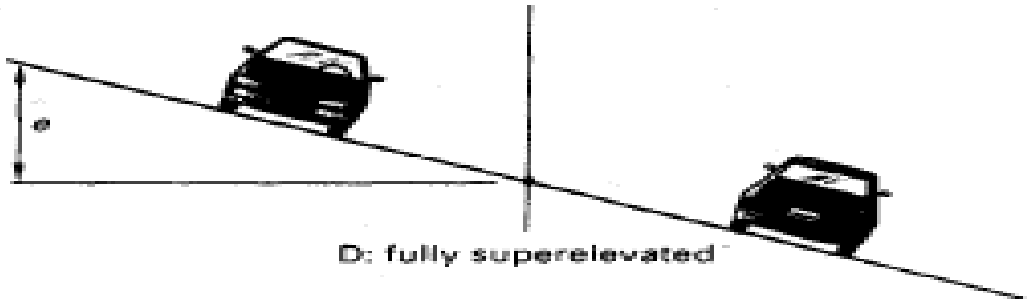
A: crowned section
(normal crown)



B: adverse crown removed



PC: 2/3 of superelevation developed



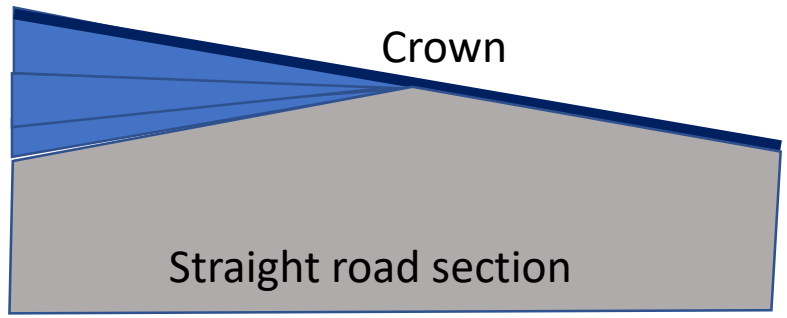
D: fully superelevated

Method of attaining Superelevation

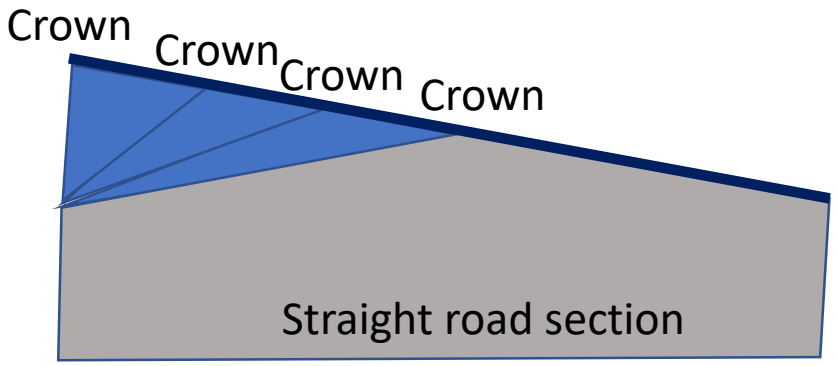
Step 1. Elimination of the Crown of the Cambered Section

In this method, the outer half of the camber is gradually decreased. This may be done by two methods

In the first method, the outer half of the camber is rotated about the crown at the desired rate such that the surface falls on the same plane as the inner half.



In the second method, the crown is progressively shifted outwards. This method is not usually adopted.



Method of attaining Superelevation

Step 2. Rotation of Pavement to attain full Superelevation

A. Revolving Pavement about the Center Line

In this method the surface of the road is **rotated about the center line of the carriageway, gradually lowering the inner edge and rising the upper edge**. The level of the **center line is kept constant**. This method is **widely used**.

B. Revolving Pavement about the Inner Edge

In this method, the surface of the road is **rotated about the inner edge, raising the center and outer edge, inner edge constant.**

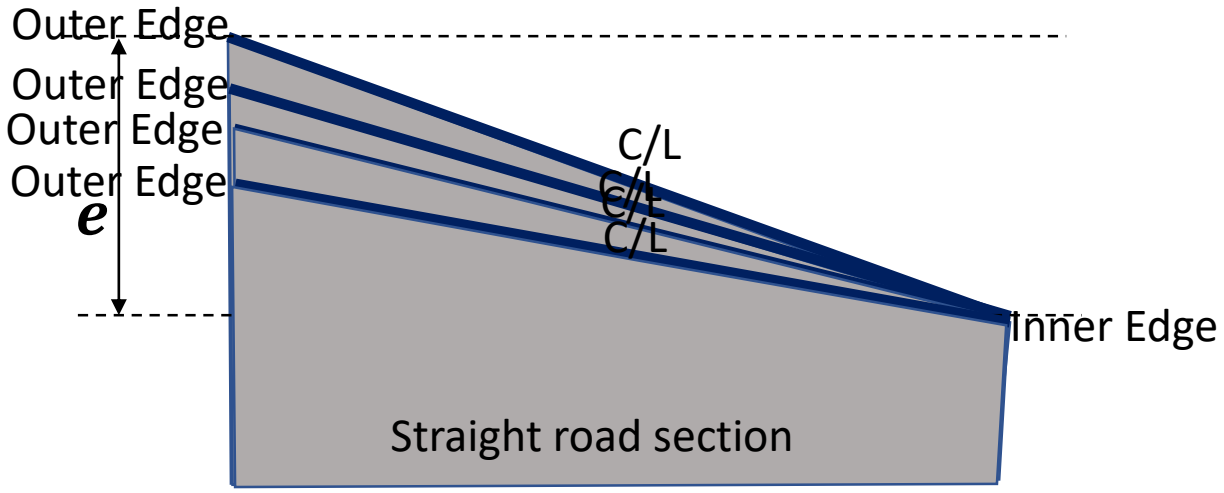
C. Revolving Pavement about the Outer Edge

In this method, the surface of the road is rotated about the outer edge **depressing center and inner edge**, **outer edge constant.**

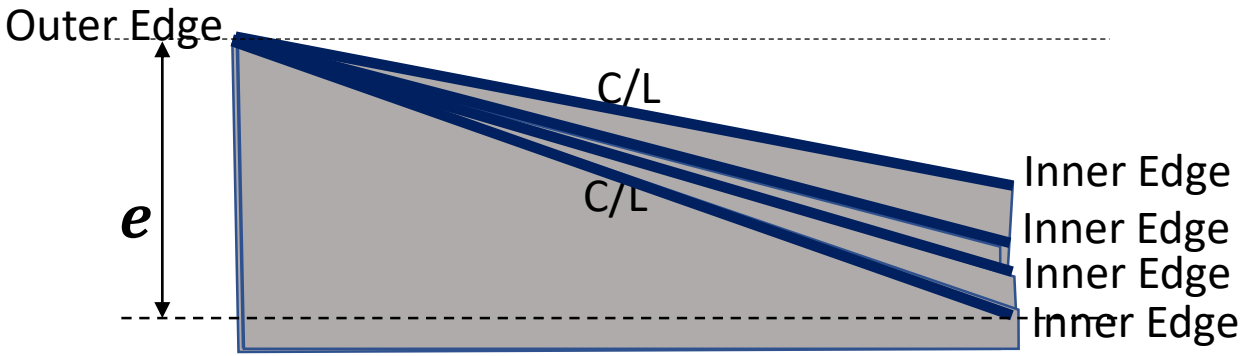
D. Revolving the straight cross slopes travelled way about the outer edge profile

Method of attaining Superelevation

Revolving Pavement about the Inner Edge

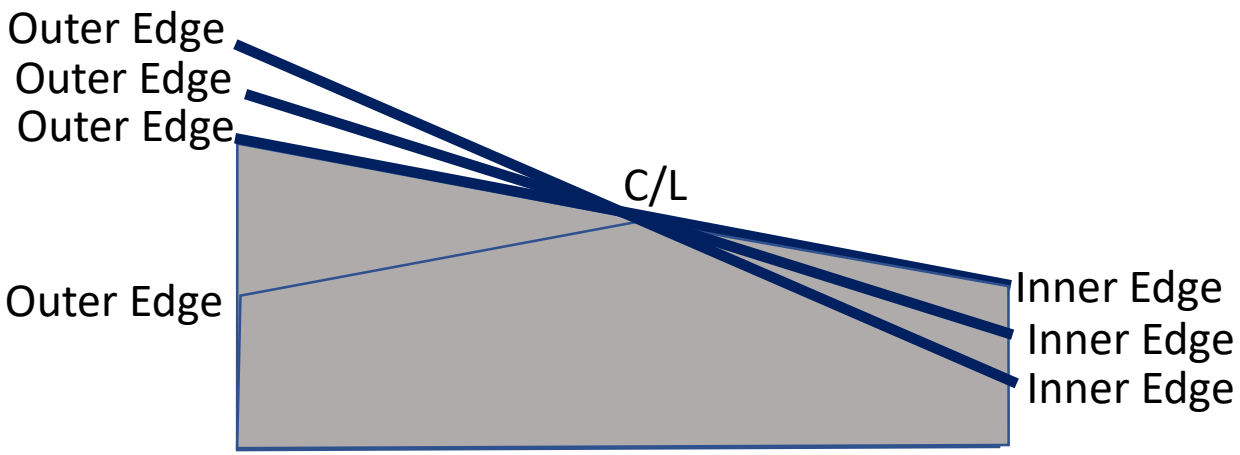


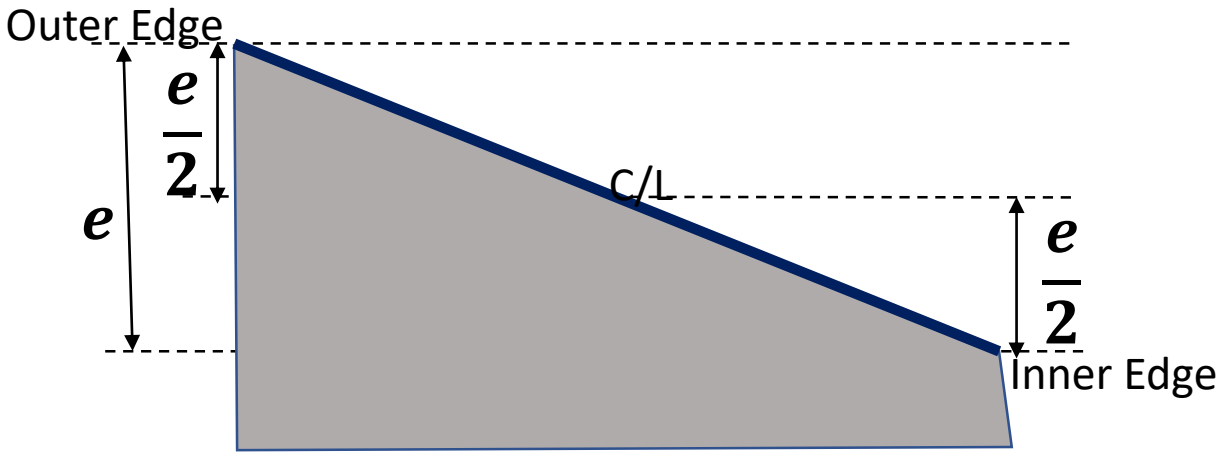
Revolving Pavement about the Outer Edge

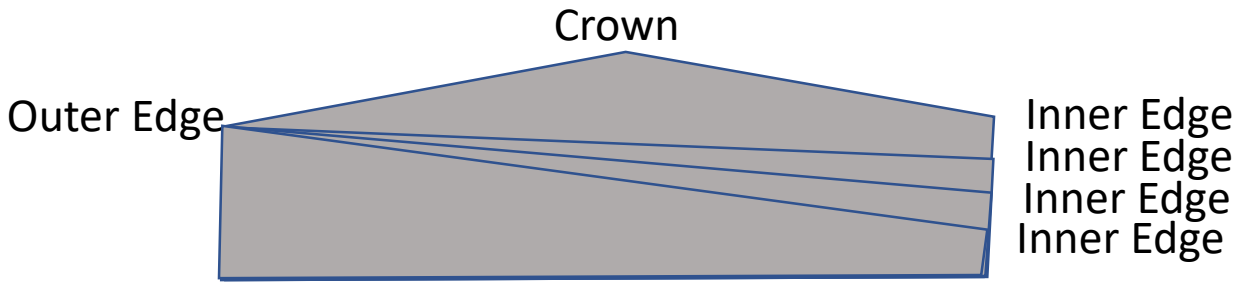


Method of attaining Superelevation

Revolving Pavement about the Center Line





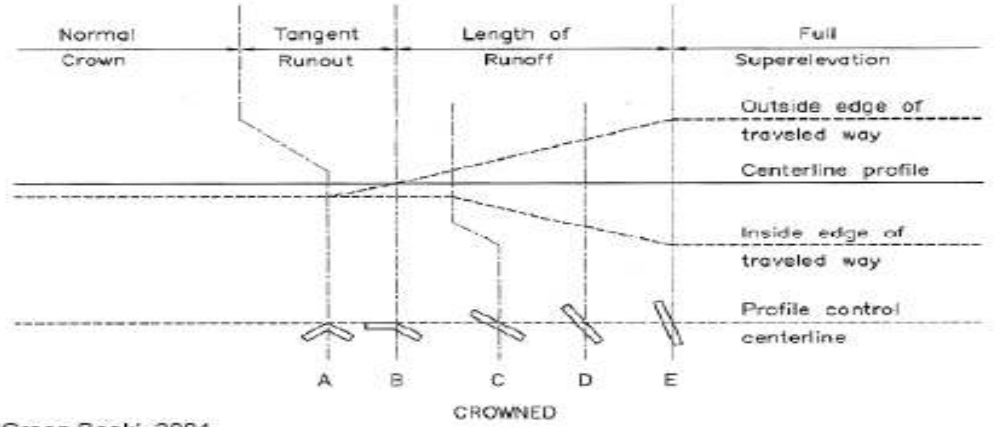


Method of attaining Superelevation

First Method: Most widely used

Change in elevation of the edge is made with less distortion
One-half of the change in elevation is made at each edge

1. Revolving a traveled way with normal cross slopes about the centerline



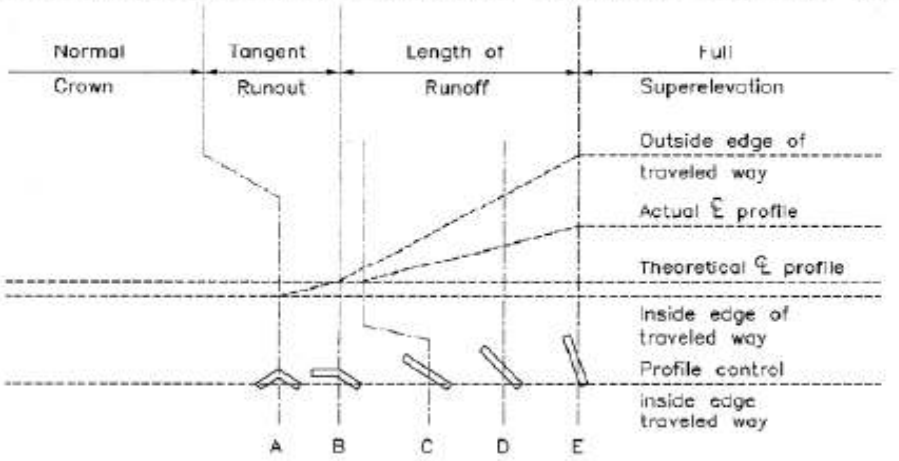
CROWNED
TRAVELED WAY REVOLVED ABOUT CENTERLINE

ASHTO 'Green Book', 2004

Second Method: Preferred when lower edge of profile is control for drainage

One-half of the change in elevation is made by raising the actual centerline profile with respect to the inside-edge profile and the other half by raising the outside-edge profile an equal amount with respect to the actual centerline profile

2. Revolving a traveled way with normal cross slopes about the inside edge profile



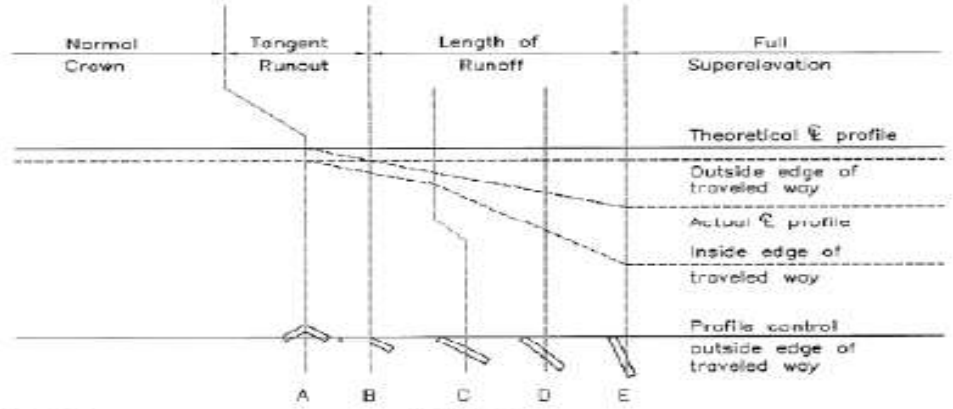
CROWNED
TRAVELED WAY REVOLVED ABOUT INSIDE EDGE

ASHTO 'Green Book', 2004

Method of attaining Superelevation

Third method
Similar to second method, except elevation change is accomplished below the out side edge profile

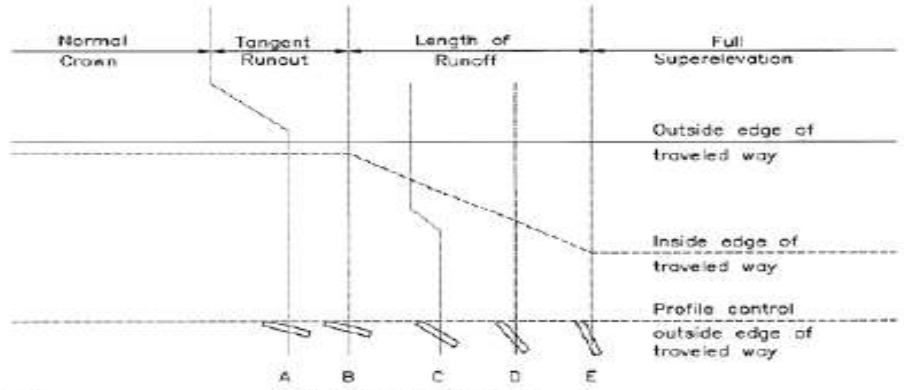
3. Revolving a traveled way with normal cross slopes about the outside edge profile



ASHTO 'Green Book', 2004

Fourth method
used for two-lane one-way roadways where axis of rotation coincides with the edge of traveled way adjacent to the highway median

4. Revolving a straight cross slope traveled way about the outside edge profile



ASHTO 'Green Book', 2004

Super elevation Transition Distance

- Transition curve provides a gradual change from the tangent sec to the circular curve and vise versa.
- Radius of the transition curve/spiral curve varies from infinity at the tangent end to the radius of the circular arc at the end of the spiral
- The min length of the transition is

$L_s = 3.15\ \frac{V^3}{RC}$ **in FPS, L in ft, V in mph, R in ft, C is max rate of change in lateral acceleration (4ft/s³)**

$L_s = 0.0214\ \frac{V^3}{RC}$ **in MKS, L in m, V in km/hr, R in m, C is max rate of change in lateral acceleration (1.2m/s³)**

Properties of Simple Circular Curve

Length of the curve (PC to PT), $L = \frac{2\pi R\Delta}{360}$

Radius of Curve, $R = \frac{5729.58}{D}$

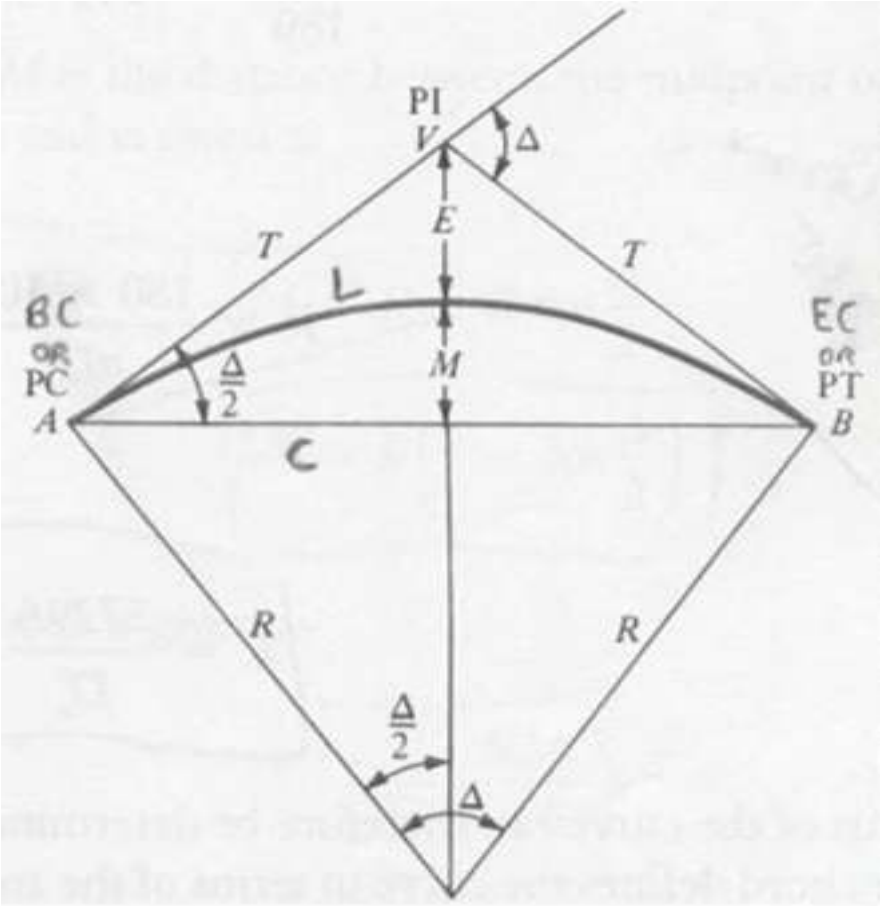
Length of Arc, $l = \frac{100\theta}{D}$

Middle ordinte, $M = R\left(1 - Cos\,\frac{\Delta}{2}\right)$

External distance, $\mathrm{E} = \mathrm{R}\left(\mathrm{Sec}\,\frac{\Delta}{2} - 1\right)$

Chord length, $\mathrm{C} = 2\mathrm{R}\sin\frac{\Delta}{2}$

Tangent length, $T = R\,tan\frac{\Delta}{2}$



Maximum degree of curvature and Minimum Radius

Maximum degree of curvature or Minimum Radius is a limiting value of a curvature for given design speed and is determined from the max rate of superelevation and max allowable side friction factor.

$$R_{min} = \frac{v^2}{15(0.01e_{max}+f_{smax})}$$

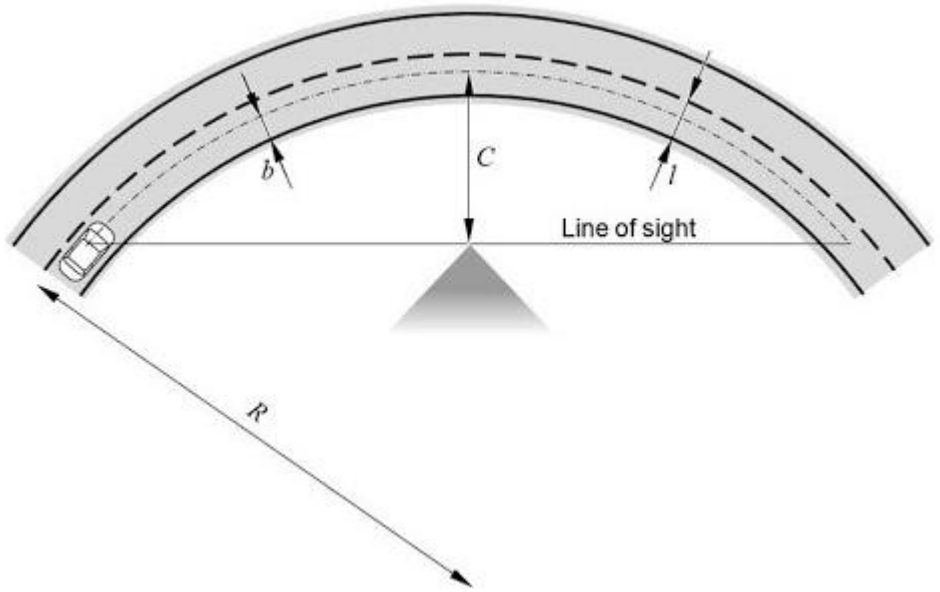
R = Radius of Curve (feet)

V = vehicle speed (mph)

e = tan α = rate of roadway superelevation

fs = coefficient of side friction

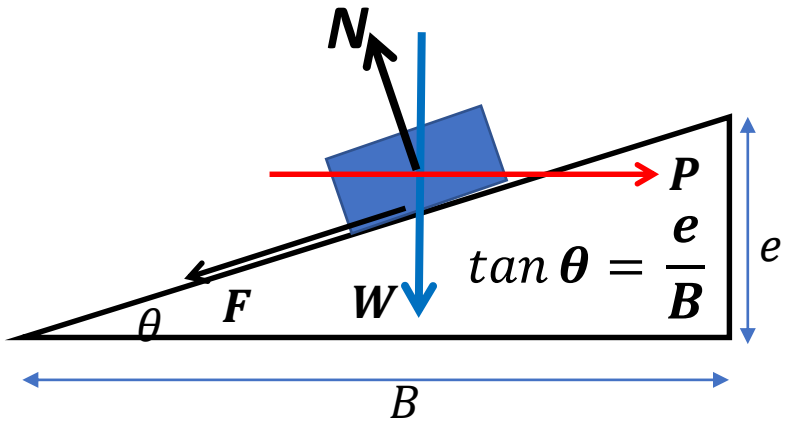
Offset of the Roadside Objects



Widening of Curves

As a veh turns, the rear wh of the veh follow the front wh on shorter radius, and this has the effect of increasing the veh width in relation to the lane width, hence need for additional pavement width. The amount of widening needed varies with

- the width of the pavement on the tangent
- the design speed
- the design veh
- the Horizontal curve radius



$tan\,\boldsymbol{\theta} + f = \dfrac{\boldsymbol{P}}{\boldsymbol{W}}$ and, $\dfrac{\boldsymbol{P}}{\boldsymbol{W}} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$ **Therefore,** $tan\,\boldsymbol{\theta} + f = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$

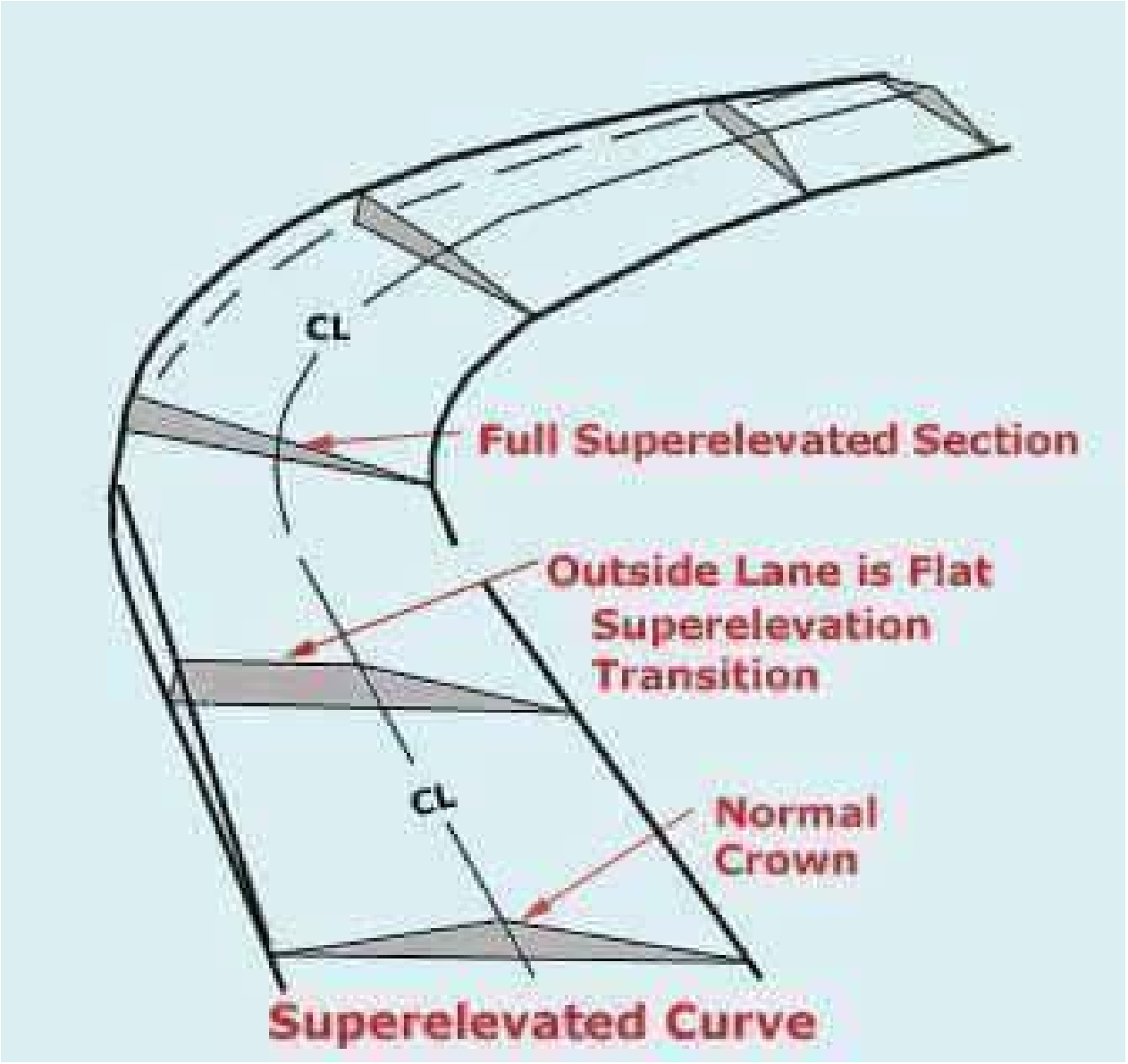
For balancing fully by super elevation, $\tan\boldsymbol{\theta} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$ **For balancing fully by friction,** $\boldsymbol{f} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$

Again, from roadway geometry, $tan\,\theta = \dfrac{e}{B}$ **(when, B road way width and e superelevation**

So, for roadway, $tan\,\boldsymbol{\theta} = \dfrac{\boldsymbol{e}}{\boldsymbol{B}} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$

and for railway, $tan\,\boldsymbol{\theta} = \dfrac{\boldsymbol{e}}{\boldsymbol{G}} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$ **when G is gauge of the railway**

Length of Transition Curve



Length of Transition Curve

Length should be such that the required s.e or cant is provided at a suitable rate.

1. By an arbitrary gradient
2. By the time rate
3. By the rate of change of radial acceleration

Method 1: By an arbitrary gradient

If gradient is 1 in n, then L=ne

Value of n varies from 300 to 1200

$L = ne = nB.\tan\theta = B.v^2/gR$ on road

$L = ne = nG.\tan\theta = G.v^2/gR$ on railways

Method 2: By the time rate

Let e is applied at an arbitrary time rate of r units per sec.

L=length of transition curve in m, v= speed of veh in m/sec, e amount of s.e.

Time taken by a veh to pass over a transition curve = t =L/v sec.

Super elevation attained in this time = t x r cm = r.L/v. So, e= r.L/v

Therefore, L = e.v/r meters

Length of Transition Curve

Method 3: By the rate of change of radial acceleration

In this method length of transition curve is decided on the basis of comfort of passengers. It is experienced that a rate of change of radial acceleration of 1 ft/sec (0.3 m/sec) will pass unnoticed.

If α is the rate of change of radial acceleration in m/sec and t is the time taken to travel over the transition curve having length L, Then acceleration attained in that time is = αt =αL/v sec.

But radial acceleration of a circular curve is v^2/R, so $v^2/R = \alpha L/v$

So $L = v^3/\alpha R$ where v is in m/sec

When α = 0.3 m/sec then $L = V^3/14R$ where V is in kmph

1. **By an arbitrary gradient, $L = ne = \frac{Bv^2}{gR}$**
2. **By the time rate, $L = e.\frac{v}{r}$**
3. **By the rate of change of radial acceleration, $L = \frac{v^3}{\alpha R}$, or $L = \frac{V^3}{14R}$**

Prob: A transition curve is required for a circular curve of 200m radius, the gauge being 1.5 m and max super elevation restricted to 15 cm. The transition is to be designed for a velocity such that no lateral pressure is imposed on the rails and the rate of gain of radial acceleration is 30 cm/sec^3. calculate the required length of the transition curve and the design speed.

$$\tan\theta = \frac{e}{G} = \frac{v^2}{gR}$$

$$\frac{15}{150} = \frac{v^2}{9.81 \times 200}$$

Thus v = 14 m/sec

$$L = \frac{v^3}{\alpha R} = \frac{14^3}{0.3 \times 200} = 46 \text{ m}$$

Prob: A Road bend which deflects 80° is to be designed for a max speed of 100 km per hr, a max centrifugal ratio of ¼ and a max rate of change of acceleration of 30 cm/sec^3. the curve consisting of a circular arc combined with two cubic spirals. Calculate

(a) radius of circular arc,
(b) the requisite length of transition,
(c) the total length of composite curve
(d) The chainage of the beginning and the end of transition curve and of the junctions of the transition curves with the circular arc if the chainage of the P.I is 42862m.

Prob: Calculate the super elevation required for road of 7 m wide on a curve of 250 m radius for permissible speed of 80 kmph. Let the coefficient of friction be 0.15.

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

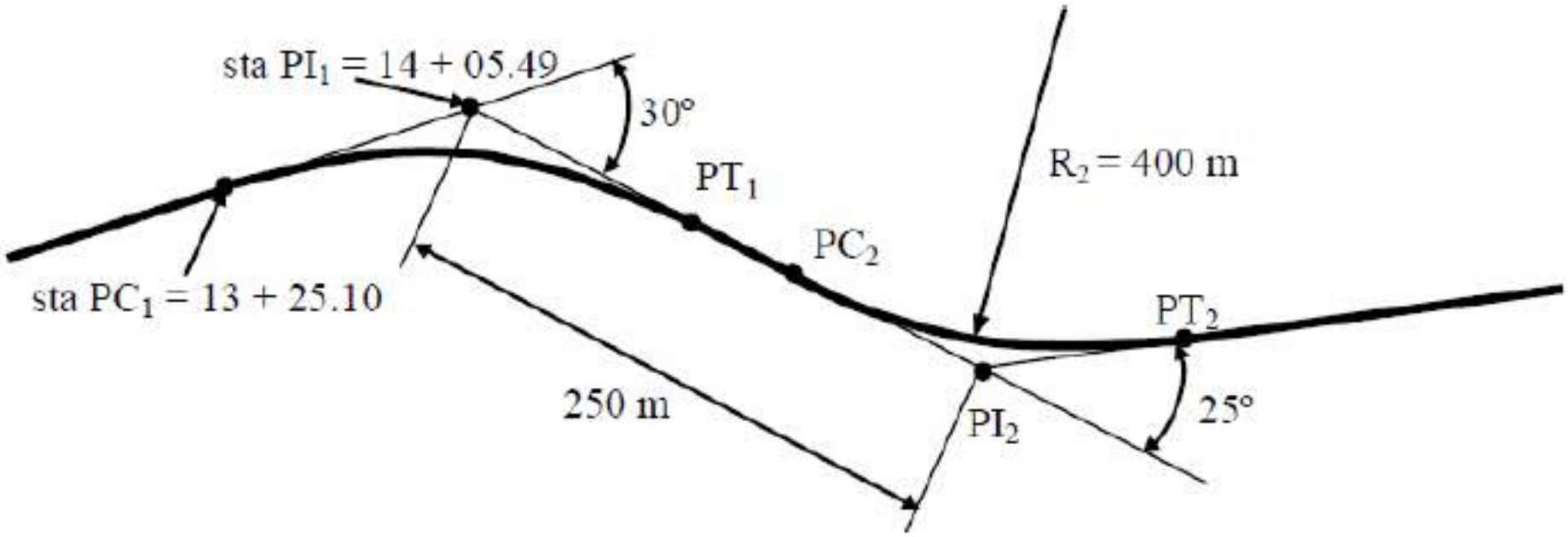
$$e + 0.15 = \frac{80^2}{127 \times 250} = 0.201$$

$$e + 0.15 = 0.201 - 0.15 = 0.051 \; per \; m \; of \; carraigeway$$

$$So, Superelevation = 0.051 \times 7 = 0.357 \; m$$
$$= 35.7 \; cm \; above \; the \; inner \; edge \; of \; the \; roadaigeway$$

Prob: a) For the horizontal alignment shown below, compute the stations of PT_1 and PC_2, and a point P that on curve 1 and is located 30.52 m before PT_1.

b) If the design speed is 80 km/h and the road is designed so that the superelevation for curve 1 is 0.058 (5.8 percent), determine the side friction demands on curve 1 for vehicles traveling at the design speed and at 10 km/h.



Maximum and Minimum superelevation

Maximum Superelevation

Maximum superelevation is provided to prevent the vehicle from being overturned. So, we can say, it is the maximum percentage of angle allowed for the road to prevent the vehicle from being overturned.
In plain and rolling terrain and in the snowbound area is 1 in 15 or 4° or 7 %.
On hill roads not bound by snow, a **maximum superelevation up to 10%** has been recommended by IRC.

Minimum Superelevation

The minimum super elevation is provided mainly for the drain of rainwater effectively.
The road surface should have a minimum **camber** to drain off rainwater. If the calculated superelevation is equal to or less than the camber of the road surface, then the minimum superelevation to be provided on the horizontal curve may be limited to the camber of the surface.
It is usually 2 to 4%.

Vertical Alignment

- The vertical alignment of a road consists of gradients (straight lines in a vertical plane) and vertical curves.
- A circular curve is used to connect horizontal straight stretches of road whereas vertical curves connect two gradients.
- When these two curves meet, they form either convex or concave. The former is called a summit curve, while the latter is called a valley curve.





Effect of gradient

- The effect of long steep gradient on the vehicular speed is considerable.
- This is **particularly important in roads where the proportion of heavy vehicles is significant**.
- Due to **restrictive sight distance at uphill gradients** the speed of traffic is often controlled by these heavy vehicles.
- As a result, not only the operating costs of the vehicles are increased, but also capacity of the roads will have to be reduced.
- Further, **due to high differential speed between heavy and light vehicles, and between uphill and downhill gradients, accidents abound in gradients**.

Vertical Alignment

- Change of grades from minus to plus should be placed in cuts and changes from a minus to plus grade should be planed in fills.
- **Max grade depends on design speed and topography**
- max grade ranges from 5 to 7 % depending on road way cl and surrounding topography.
- 5% for design speed of 70 mph
- **Min grade are governed by drainage condition**
- Whenever long sustained grades are used, the designer should not exceed the critical grade w/o provision of climbing lanes for slow mov veh. Critical grade vary from 1650 ft (for 3% grade) to 500 ft (for 8%).