INSTITUTE OF AERONAUTICAL ENGINEERING
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TRANSPORTATION ENGINEERING
(A-60132)
JNTUH-R15
By

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overview

- The course gives an overview about the Transportation engineering with respect to, planning, design, construction and maintenance of highways as per IRC standards, specifications and methods. To impart knowledge of Traffic engineering, traffic regulation, management and traffic safety with integrated approach in traffic planning as well.

SYLABUS

- **UNIT - I:**
- **HIGHWAY DEVELOPMENT AND PLANNING**-Highway development in india- Necessity for highway planning-Different road development plans; classification of roads- Road network patterns –Highway Alignment-Factors affecting alignment-Engineering surveys-Drawing and reports-Highway project.
- **UNIT – II:**
- **HIGHWAY GEOMETRIC DESIGN:** Importance of Geometric Design – factors affecting highway geometric design. Design controls and Criteria- Highway Cross Section Elements-Sight Distance Elements- Stopping sight Distance, Overtaking Sight Distance and intermediate Sight Distance- Design of Horizontal Alignment- Design of Super elevation and Extra widening- Design of Transition Curves-Design of Vertical alignment-Gradients-Vertical curves
- **UNIT – III:**
- **TRAFFIC ENGINEERING AND REGULATIONS**: Basic Parameters of Traffic – Volume, Speed and density-Traffic volume studies-Data collection and presentation-Speed studies – Data collection and presentation- Origin and Destinations studies,- Parking Studies–Onstreet and offstreet parking - Road
- Accidents - Causes and Preventive measures- Accident Data Recording–Condition Diagram and Collision Diagrams-Traffic Types and Specifications – Road markings-Need for Road Markings-Types of Road Markings- Design of Traffic Signals- Webster method.
- **UNIT – IV:**
- **INTERSECTION DESIGN :** Types of Intersections – Conflicts at Intersections-Requirements of At –Grade intersection- Types of at-Grade Intersections- Channelization -Traffic Islands - Types of Grade Separated Intersections- Rotary Intersection –concept of Rotary-Design factors of rotary-Advantages and limitations of rotary intersections.
- **UNIT – V:**
- **HIGHWAY MATERIAL, CONSTRUCTION ANDMAINTENANCE:** Highway material characterization; Sub grade soil, Stone aggregate, Bitumen materials, Construction of gravel roads-Construction of water bound macadam roads-Construction of bituminous pavements: Surface dressing, Bitumen bound macadam, Bituminous concrete-Construction of cement concrete pavements-Construction of joints in cement concrete pavements-Joint filter and seal-Pavement failures –Maintenance of highways-Highway Drainage.

UNIT - I:
HIGHWAY DEVELOPMENT AND PLANNING

Highway development in india-Necessity for highway planning-Different road development plans; classification of roads-Road network patterns –Highway Alignment-Factors affecting alignment-Engineering surveys-Drawing and reports-Highway project.

Role of Transportation

- Transport and economic growth
- Place utility of goods
- Time utility of goods
- Producer and consumer
- Preservation of quality of goods
- Mass production
- Exploitation of natural resources
- Transport and urbanization
- Transport and industrial development

Role of Transportation…

- Transport and agricultural development
- Costs of goods
- Administration
- Defence and strategic needs
- Tourism
- Transport facilities and social activities

Modes of Transport

- Railways
  - Surface
  - Underground
  - Elevated
  - Light rail transit (LRT)
- Road Transport
- Air Transport
- Water Transport
- Pipelines

Transport Modes Characteristics

- Speed
- Safety
- Adequacy
- Frequency
- Regularity
- Integration
- Responsibilities
- Cost
- Cheapness
- Fuel efficiency

Transport modes in India

- Railways :
  - 62500 km, Passengers- 300 bpk/year (20% of total traffic)
  - Freight traffic- 257 bt/year (40% of total traffic)

- Road Transport
  - 3 million km
  - National Highways: 66900 km
  - Total vehicles- 67 million and growth rate of 10%

Transport modes in India…

- Air India and Indian airlines, other private airlines
  - 7.1 million passengers (2004-2005)
  - Domestic air traffic increasing 10% per anum

- Indian coast-line: 5660 km, 176 ports – 10 major ports and 23 intermidiate

Review of Transport Systems and Technology

- Developments in personalized vehicle systems
- Developments in bus systems
- Developments in rapid rail transit
- Light rail transit
- Magnetic Leviation
- Para-transit
- Need for coordinated development
- Multimodal transport systems
- Use of IT in transportation

ITS and its Potential in India

- Application of modern information and communication technologies for the safer, faster, comfortable movement of persons and goods

- Advance Traveler Information Systems (ATIS)
- Advanced Public Transportation Systems (APTS)
- Automatic Vehicle Detection and Control Systems
- Commercial Vehicle Operations
- Automated Highway Systems
- Intelligent Vehicle and Highway Systems (IVHS)
- Electronic Tolling

Advantages and Disadvantages of Road Transport

- Wide geographical coverage provided by roads
- Low capital investments
- Quick and assured deliveries
- Flexibility
- Door-to-door service
- Simpler packaging
- Personalized service
- Personalized travel

Advantages and Disadvantages of Road Transport….

- Short hauls
- Safety
- Environmental pollution
- Parking problem
- Long-hauls
- Energy

Role of Roads in Indian Economy

- Connection to villages
- Communications in hilly terrain
- Strategic importance
- Carriers of fright and passengers as a feeder to other modes
- Helps agriculture, dairy, forest, fisheries, tourism, etc. development
- Employment
- Famine and flood relief
- Administrative convenience

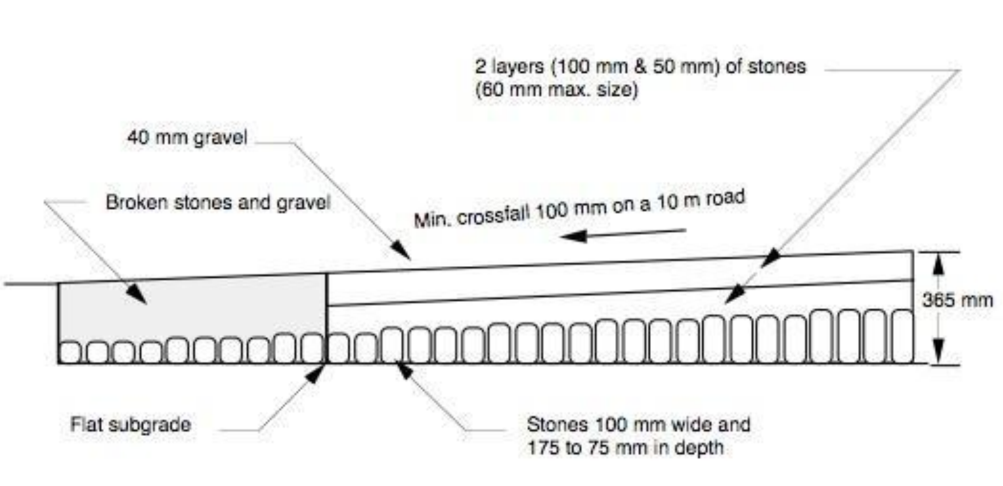
Research Areas in transportation Engineering

- Traffic engineering and management
- Transportation planning and management
- Road safety
- Transportation economics
- Urban mass transit planning, management and operation
- Pavement materials characterization
- Pavement management systems
- Pavement design and analysis

History of Growth of Highways

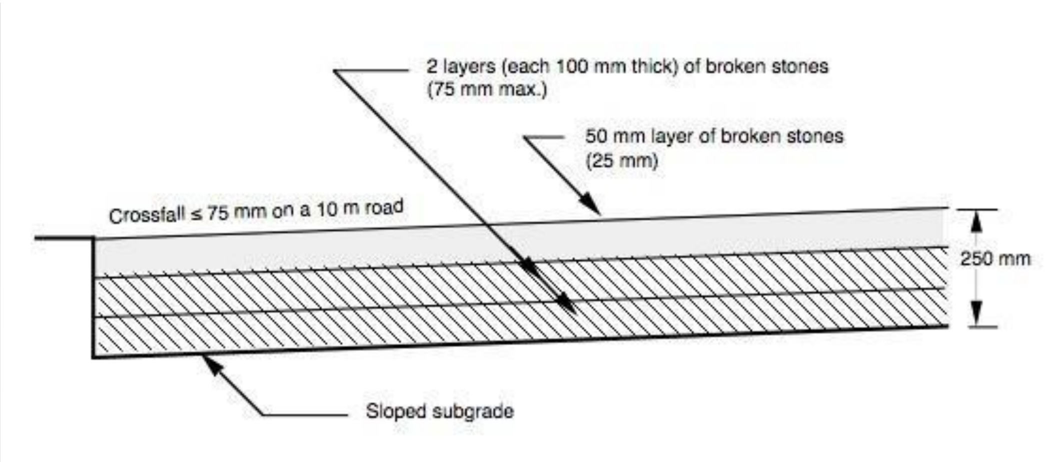
- Differences – Highways, Roads, Streets and Expressways
- Ancient man age and usage of animal drawn vehicles
- Invention of the wheel, steam engine, etc.
- The Roman Civilization
- The Persians and Chinese Civilizations
- Indus Valley Civilization
- The Mauryas, the Guptas and the mughals.

Cross Section of Early Roads



Telford Pavement

Macadam Pavement



Development of Roads in India during British Period

- Neglect of the road system in India
- Military and administrative purpose only
- Introduction of railways
- Feeder roads to the railways
- Jayakar Committee (1927)
  - Landmark in the planned development of roads
  - Central road fund as road development fund
- The Indian Roads Congress (1934)
  - Produced standards and codes of practices for the planning, design, operation and management of roads

Development of Roads in India

- Road Development Plans
  - Nagpur Plan (1943)
  - Twenty year road development plan (Bombay Plan) 1961-1981
  - Twenty year road development plan (Lucknow Plan) 1981-2001

- Road Development Plan, Vision 2021

Rural Roads, Vision 2025

- Indian Roads Congress drafted
- Building of core road network which gives accessibility to each village
- Habitations with a population above 100 should be connected by all whether roads
- It is estimated that the length o 2,90,000 km of new roads will be needed to achieve the full connectivity (outlay for this 26,000 c, besides 66,000 c already)
- Up gradation of 1,237,000 km length (1,64,000 c)
- Maintenance of Rural Road Network (7,500 c/ anum)

Roads in the World Today

- USA has the largest network of roads (6.3 M-km)
- India with its 3.3 M-km road network comes second
- Density of roads (km/sq km) is very high in Germany and Japan which are small in area
- India : 1 km/sq km, USA: 0.67 and China : 0.12 km/sq km
- Percentage of paved roads
  - UK : 100%
  - Germany : 99%
  - USA : 91%
  - India : 50%

International Comparison of Expressways

- USA – 88400 km
- Germany- 11000 km
- Japan – 8500 km
- China – 6000 km
- UK – 4000 km
- Malaysia – 1500 km
- India – 200 km

Car-Ownership Rates (cars/1000 persons)

Functional Classification of Roads

- Administration of the roads
- Appropriate design standards
- Developing appropriate and integrated network
- Broad Classification:
  - Urban roads
  - Rural roads

Classification of Urban Roads in India

- Expressways
- Arterial Streets
- Sub-arterial streets
- Collector streets
- Local Streets

Classification of non-urban roads in India

- Primary system
  - Expressways
  - National Highways
- Secondary System
  - State highways
  - Major district roads
- Tertiary System
  - Other District Roads
  - Village Roads

Administration of Roads

- Administration of National Highways
- Ministry of defense
- Ministry of railways
- The border road development board
- The ministry of rural development
- Ministry of Road Transport and Highways (MoRTH)
- National Highways Authority of India
- Central Road Fund (CRF)
- Administration of State Roads

Road Research

- Central Road Research Institute
- State Highway Research Laboratories
  - Highway Research Station, chennai
  - Maharashtra Engineering Research Institute, Nashik
  - Gujarat Engineering Research Institute, Vadodara
- Highway Staff Training Institute
  - National Institute for training of highway engineers, NOIDA
- IITs, NITs or institutions like BITS

National Rural Road Development Agency

- NRRDA
- Pradhan Mantri Gram Sadak Yojna (PMGSY)
- Connect every habitation with a population 1000 persons through good all weather roads (2003)
- Connect every habitation with a population 500 persons through good all weather roads (2007)
- Now it is habitations with population 100
- 60000 c and connectivity to about 1,00000 habitations

Types of Transportation Plans

- National Plan
- National Transport Plan
- Regional Transport Plan (State or Region)
- Local Transport Plan (District, city or town)
- National Transport Policy Committee

Highway Financing and Taxation in India

- Construction and maintenance of highways, roads and streets by the government
- Taxes, Levies and tolls
- Level of taxation on roads and road transport in India is very high as compared to its outlay

Year	Tax Revenue (C)	Expenditure on Roads (C)	Expenditure on roads as %
1950-51	47.37	34.47	72.7
1960-61	166.94	109.76	65.7
1970-71	683.12	257.60	37.7
1984-85	4400.00	1824.00	41.5
2001-02	5000.00	2100.00	42.0

Types of Taxes and Levies

- Central Tax Collection
  - Import duty on motor vehicles and spare parts
  - Import duty on petroleum products
  - Excise duty on motor vehicles, spares, tyres and tubes
  - Excise duty on petroleum products
  - Toll at selected bridges, tunnels and national highways

Types of Taxes and Levies…

- State Tax Collection
  - Sales tax on motor vehicles, spares and tyres and tubes
  - Sales tax on petroleum products
  - Motor vehicle taxes
  - Taxes on passenger and goods
  - Permit fees
  - Drivers' and conductors' license fees
  - Octroi, toll levied by state and wheel tax

Questions to ponder upon…

- What are the present shortcomings of present taxation system in India?
- Whether there is a need for implementing the constitutional reforms?
- Why there is a gap between revenues and actual outlay in road transport?

Planning Surveys

- Highway planning phase includes
  - Assessment of road length required for area
  - Preparation of master plan showing the phasing of plan
- Economic Studies
- Financial studies
- Traffic and rod use studies
- Engineering studies

Economic Studies

- Population and its distribution
- Trend and population growth
- Agricultural and industrial products
- Industrial and agricultural development and future trends
- Existing facilities with regard to communication, recreation and education
- Per capita income
- Vehicle ownership

Financial Studies

- Sources of income and estimated revenue from
- taxation on road transport
- Living standards
- Resources at local level, toll taxes, vehicle registration and fines
- Future trends in financial aspects
- Public-Private Partnership basis : BOOT, BOT, etc.
- Incentives for investors
- Other methods for raising funds

Traffic Studies

- Traffic volume in vehicles per day, annual average daily traffic, peak and design hourly traffic volume
- Origin and destination studies
- Traffic flow patterns
- Mass transportation facilities
- Accidents, cost analysis and causes
- Future trend and growth in traffic volume and goods traffic, trend in traffic pattern
- Growth of passenger trips and the trends in the choice of modes

Engineering Studies

- Topographic surveys
- Soil surveys
- Location and classification of existing roads
- Estimation of possible developments in all aspects due to proposed highway development
- Road life studies
- Special problems in drainage, construction and maintenance of roads

Preparation of Plans

- General Area Plan
- Distribution of population
- Locations of places with their respective productivity and quantity
- Existing road network with traffic flows and desire lines

Twenty Years Road Development Plans

Nagpur road congress 1943

- A twenty year development program for the period (1943-1963) was finalized.
- It was the first attempt to prepare a coordinated road development program in a planned manner.
- The roads were divided into four classes
- The committee planned to construct 2 lakh kms of road across the country within 20 years.
- They recommended the construction of star and grid pattern of roads throughout the country.
- One of the objective was that the road length should be increased so as to give a road density of 16 kms per 100 sq.km

Star and Grid Formulae

- The total length of the first category or mettalled roads for NH, SH and MDR in km is given by the formula as follows:

Where,

$$NH + SH + MDR(km) = [\frac{A}{8} + \frac{B}{32} + 1.6N + 8T] + D - R$$

Where,

A is agricultural area sqkm

B is non agricultural area sqkm

N number of towns and villages with population range 2001-5000

T number of towns and villages with population over 5000

D development allowance of 15 % of road length for next 20 years

R is existing length of railway track , km

Star and Grid Formulae…

- The total length of secondary category of roads (km)

- ODR + VR (km) = [0.32V+0.8Q+1.6P+3.2S] + D

Where,

V is number of villages with population 500 or less

Q number of villages with population range 501-1000

P number of villages with population range 1001 -2000

S number of villages with population range 2001 -5000

D development allowance of 15% for next 20 years

Example

The following data were collected for planning the road development program of a backward district.

1. Total Area = 9600 sq km
2. Agricultural and developed area = 3200
3. Existing railway track length = 105 km
4. Existing length of mettalled road = 322 km
5. Existing length of unmettalled road = 450 km
6. Number of towns and villages in different population ranges are :
7.

Population	>5000	2001-5000	1001-2000	501-1000	<500
Number of villages & towns	8	40	130	280	590

Bombay road congress 1961

- It was the second 20 year road plan (1961-1981)
- The total road length targeted to construct was about 10 lakhs.
- Rural roads were given specific attention. Scientific methods of construction was proposed for the rural roads.
- The necessary technical advice to the Panchayaths should be given by State PWD's.
- They suggested that the length of the road should be increased so as to give a road density of 32kms/100 sq.km
- The construction of 1600 km of expressways was also then
- included in the plan.

Formulae

$$NH\,(km) = \left[\frac{A}{64} + \frac{B}{80} + \frac{C}{96}\right] + [32K + 8M] + D$$

$$NH + SH\,(km) = \left[\frac{A}{20} + \frac{B}{24} + \frac{C}{32}\right] + [48k + 24M + 11.2N + 1.6P] + D$$

$$NH + SH + MDR(km) = \left[\frac{A}{8} + \frac{B}{16} + \frac{C}{24}\right] + [48k + 24M + 11.2N + 9.6P + 6.4Q + 2.4R] + D$$

$$NH + SH + MDR + ODR(km) = \left[\frac{3A}{16} + \frac{3B}{32} + \frac{C}{16}\right] + [48k + 24M + 11.2N + 9.6P + 12.8Q + 4R + 0.8S + 0.32T] + D$$

$$NH + SH + MDR + ODR + VR(km) = \left[\frac{A}{4} + \frac{B}{8} + \frac{C}{12}\right] + [48k + 24M + 11.2N + 9.6P + 12.8Q + 5.9R + 1.6S + 0.64T + 0.2V] + D$$

Formulae…

Where,

A is agricultural area sqkm

B is semi developed area sqkm

C is undeveloped area sqkm

K is number of towns with population over 1,00,000

M is number of towns with population range 1,00,000-50,000

N is number of towns with population range 50,000-20,000

P is number of towns with population range 20,000-10,000

Q is number of towns with population range 10,000-5,000

R is number of towns with population range 5,000-2,000

S is number of towns with population range 2,000-1,000

T is number of towns with population range 1,000-500

V number of towns with range below 500

D development allowance of 5 % of road length for next 20 years

•

Example

- Calculate the total lengths of NH, SH, MDR, ODR and VR needed in a district as per second 20-year plan . The data collected is as follows:
- Total area =18400 sq km
- Developed and agricultural area = 8000 sqkm
- Undeveloped area = 4800 Sq km
- Population distribution

Population range	Number of towns
<500	200
500-1000	350
1000-2000	750
2000-5000	360
5000-10000	150
10000-20000	80
20000-50000	25
50000-100000	10
>1,00000	5

Lucknow road congress 1984

- This was the third 20 year road plan (1981-2001). It is also called Lucknow road plan.
- It aimed at constructing a road length of 12 lakh kilometres by the year 1981 resulting in a road density of 82kms/100 sq.km
- The plan has set the target length of NH to be completed by the end of seventh, eighth and ninth five year plan periods.
- It aims at improving the transportation facilities in villages, towns etc. such that no part of country is farther than 50 km from NH.
- One of the goals contained in the plan was that expressways should be constructed on major traffic corridors to provide speedy travel.
- Energy conservation, environmental quality of roads and road safety measures were also given due importance in this plan.

Basis of the Formulae

- Primary Road System
  - Expressway – 2000 km : Based on some project formulation
  - National Highways: concept of 100 km Square grids
  - Length of the NH in country, km = 3287782/50 = 65,756 km

- Secondary System: length of SH
  - NH and SH should pass through every town and urban area: 3364 towns in the country (Based on census data: 1981)
  - Area of each square grid = 3287782/3364 = 977.3 Sq km (31.26 km each side)
  - Total SH +NH = 2*31.26* 3364 = 2,10,250 km
  - SH length = 2,10,250 km – 66000 km = 1,45,000 km.
  - By Total Area, SH , Length (km) = Area of the state/ 25 (Double of NH)
  - By total number of towns: {(62.5 * no of towns in the state) – (Area of state/ 50)}

Length of MDR, ODR and VR

- Major District Roads
  - Total length of MDR in the country = 3,00,000 km
  - By Total Area, MDR , Length (km) = Area of the state/ 12.5 (Double of SH)
  - By total number of towns in state : {(90*no of towns in the state)}
- Tertiary System
  - Total road length for the state
  - Density to be achieved per 100 sq km.

- The area of a certain district in India is 13,400 sq km and there were 12 towns as per 1981 census. Determine the lengths of different categories of roads to be provided in this district by the year 2001.

History of road development in India.

- History of road development in India.

- Classification of highways.

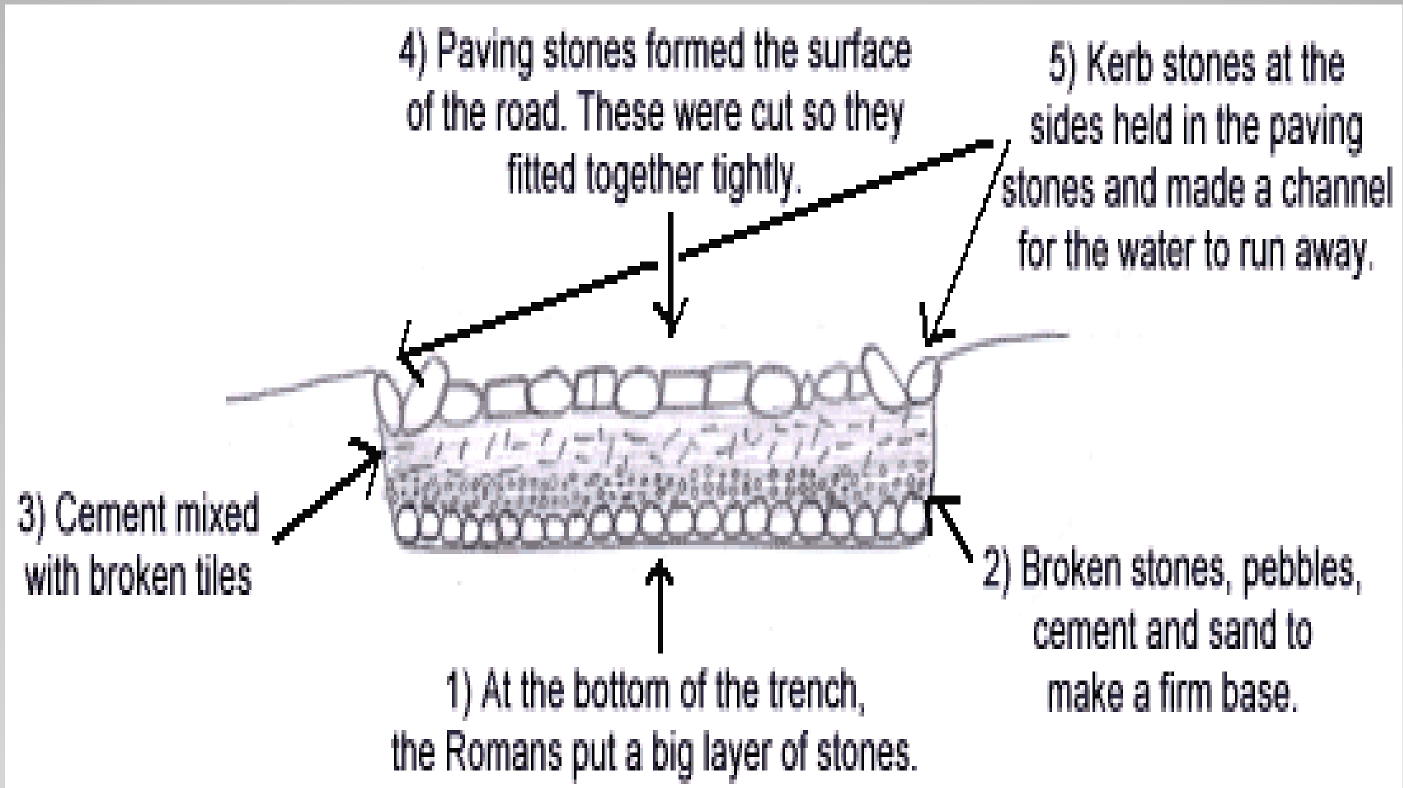
- Institutions for Highway planning, design and implementation at different levels

- Factors influencing highway alignment

•Engineering surveys for alignment, objectives, conventional and modern methods.

Roman Road Construction

Basic cross section



History of Road Development in India

- Ancient Period (3500 BC)
- Mughul Period (15th Century)
- British Period (17th & 18th Century)
- Free India (1950 onwards)

Types of Ancient Indian Roads

- **Indus Valley Civilization :**
  - ➢ Roads with brick drains on both sides.
- **Mauryan rule in the 4th century constructed**
  - ➢ Rajpath (high roads)
  - ➢ Banikpaths (merchant roads).
- **Ashoka Regime:**

➢Road networks with horticulture and rest houses at 4.8 – 6.4km along the roads.

- **Mughul Period**

➢Trunk roads between Northwest to Eastern part and also linking coastal and central part of India

- **British Period**
  - ➢ Trunk roads, bridges, PWD was formed, construction of Grand Trunk Road

Indian Roads

- India has a large road network of over 3.314 million kilometers of roadways (2.1 million miles), making it 3rd largest road network in the world.

- At 0.66 km of highway per square kilometer of land the density of India’s highway network is higher than that of the United States (0.65) and far higher than that of China's (0.16) or Brazil's (0.20).

Impact of Transportation

- Economic Development
- Social Development
- Spatial Development
- Cultural Development
- Political Development

Institution for Highway Planning, Design and Implementation at Different Levels

- Jayakar Committee (1927)
- Central Road Fund (1929)
- Indian Roads Congress (IRC), 1934
- Central Road Research Institute (CRRI), 1950
- National Highway Act, 1956
- National Highway Authority of India(NHAI),1995
- National highway act (1956)
- Second twenty year road plan (1961)
- Highway Research board (1973)
- National Transport Policy committee (1978)
- Third twenty year road plan (1981)

Jayakar Committee,1927

- Road development should be made a national interest since the provincial and local govt do not have financial and technical capacity for road development.

•Levy extra tax on petrol from road users to create the road development fund.

- To establish a semi-official ,technical institution to pool technical knowledge, sharing of ideas and to act as an advisory body.
- To create a national level institution to carry research , development works and consultation.

Central Road Fund , 1929

CRF Act , 2000

Distribution of 100% cess on petrol as follows:

- 57.5% for NH
- 30% for SH

} **MORTH**

- 12.5% for safety works on rail-Road crossing.

50% cess on diesel for Rural Road development

Indian Roads Congress, 1934

- To provide national forum for regular pooling of experience and ideas on matters related to construction and maintenance of highways.

- To recommend standard specifications.

- To provide a platform for expression of professional opinion on matters relating to roads and road transport.

List of IRC & IS Codes

1. IRC: SP: 13 – 2004 – Guidelines for Design for Small Bridges and Culverts
2. IRC: SP: 19 – 2001 – Manual for Survey, Investigation & Preparation of Road Project (1st Revision)
3. IRC: SP: 42 – 1994 – Guidelines for Drainage
4. IRC: 69 – 1977 – Space Standards for Roads in Urban Areas
5. IRC: 70 – 1977 – Guidelines on regulation and Control of Mixed Traffic in Urban Areas
6. IRC: SP: 50 – 1999 – Guidelines for Urban Drainage
7. IRC: 52 – 1981 – Recommendations about alignment Survey & Geometric Design of Hill Roads
8. IRC: SP: 48 – 1998 – Hill Road Manual
9. IRC: 102 – 1988 – Traffic Studies for Planning Bypasses around Towns
10. IS:7537- 1974 – Road Traffic Signals
11. IRC: 106 – 1990 – Guidelines for capacity of Urban Road in Plain Areas
12. IS:1498 -1970 – Classification & Identification of Soil for General Engineering Purpose (Reaffirmed – 1997)
13. IS: 1892 – 1979 – Code of Practice for Sub-surface Investigation for Foundation (Reaffirmed – 1997)
14. IS:2132 - 1986 – Code of Practice for Thin Wall Rube Sampling of Soil (Second Revision) (Reaffirmed – 1997)
15. IS: 2720 – Part 1 to Part 41 – Method of Test for Soil
16. IS: 6403 – 1981 – Code of Practice foe Determination of Breezing Capacity of Shallow Foundation
17. IS:8763 – 1978 – Guide for undisturbed Sampling of Sand and Sandy Soil (Reaffirmed – 1997)
18. IS:9640 – 1980 – Split Spoon Sampler (Amendment – 2) (Reaffirmed – 1997)
19. IS:10042 – 1981 – Code of Practice for Site Investigation for Foundation in Gravel Boundary Deposit (Reaffirmed – 1997)

CRRI

A constituent of Council of Scientific and Industrial Research (CSIR)

- **engaged in carrying out research and development projects.**
- **design, construction and maintenance of roads and runways, traffic and transportation planning of mega and medium cities, management of roads in different terrains,**
- **Improvement of marginal materials,**
- **Utilization of industrial waste in road construction,**
- **Landslide control,**
- **Ground improvements environmental pollution,**
- **Road traffic safety,**
- **Service life assessment and rehabilitation of highway & railway bridges.**

Ministry of Road Transport & Highways

- Planning, development and maintenance of National Highways in the country.
- Extends technical and financial support to State Governments for the development of state roads and the roads of inter-state connectivity and economic importance.
- Evolves standard specifications for roads and bridges in the country.
- Serves as a repository of technical knowledge on roads and bridges.

Classification of Highways

Depending on weather

All weather roads Fair weather roads

Depending the type of Carriage way

Paved roads

Unpaved roads

Depending upon the pavement surface

Surfaced roads

Un surfaced roads

Classification of Highways

Based on the Traffic Volume Heavy
Medium Light

Based on Load or Tonnage
Class 1 or Class 2 etc or Class A , B etc Tonnes per day

Based on location and function (Nagpur road plan) NH
SH MDR ODR VR

Based on modified system of Highways classification

- Primary
  - Expressways
  - National Highways

- Secondary
  - **SH**
  - **MDR**

- **Tertiary**
  - **ODR**
  - **VR**

Urban Road Classification

- ARTERIAL ROADS
- SUB ARTERIAL
- COLECTOR
- LOCAL STREET
- CUL-DE-SAC
- PATHWAY
- DRIVEWAY

Road Patterns

- Rectangular or Block patterns
- Radial or Star block pattern
- Radial or Star Circular pattern
- Radial or Star grid pattern
- Hexagonal Pattern
- Minimum travel Pattern

Classification of Roadways

• Expressways	200 Km
• National Highways	70,548 Km
• State Highways	1,31,899 Km
• Major District Roads	4,67,763 Km
• Rural and Other Roads	26,50,000 Km

Expressways

- Heavy traffic at high speed (120km/hr)
- Land Width (90m)
- Full access control
- Connects major points of traffic generation
- No slow moving traffic allowed
- No loading, unloading, parking.

National Highways

- India has a huge network of national highways.
- The national highways have a total length of 70,548 kms. Indian highways cover 2% of the total road network of India and carry 40% of the total traffic.
- The entire highway network of India is managed by the National Highway Authority of India which is responsible for development and maintenance of highways.

The longest highway in India is NH7 which stretches from Varansi in Uttar Pradesh to Kanyakumari in the southern most point of Indian mainland.

•The shortest highway is NH47A which stretches from Ernakulam to Kochi and covers total length of 4 Kms.

State Highways

- They are the arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within the state.

- Total length of all SH in the country is 1,37,119 Kms.

Major District Roads

- Important roads with in a district serving areas of production and markets , connecting those with each other or with the major highways.

- India has a total of 4,70,000 kms of MDR.

Other district roads

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

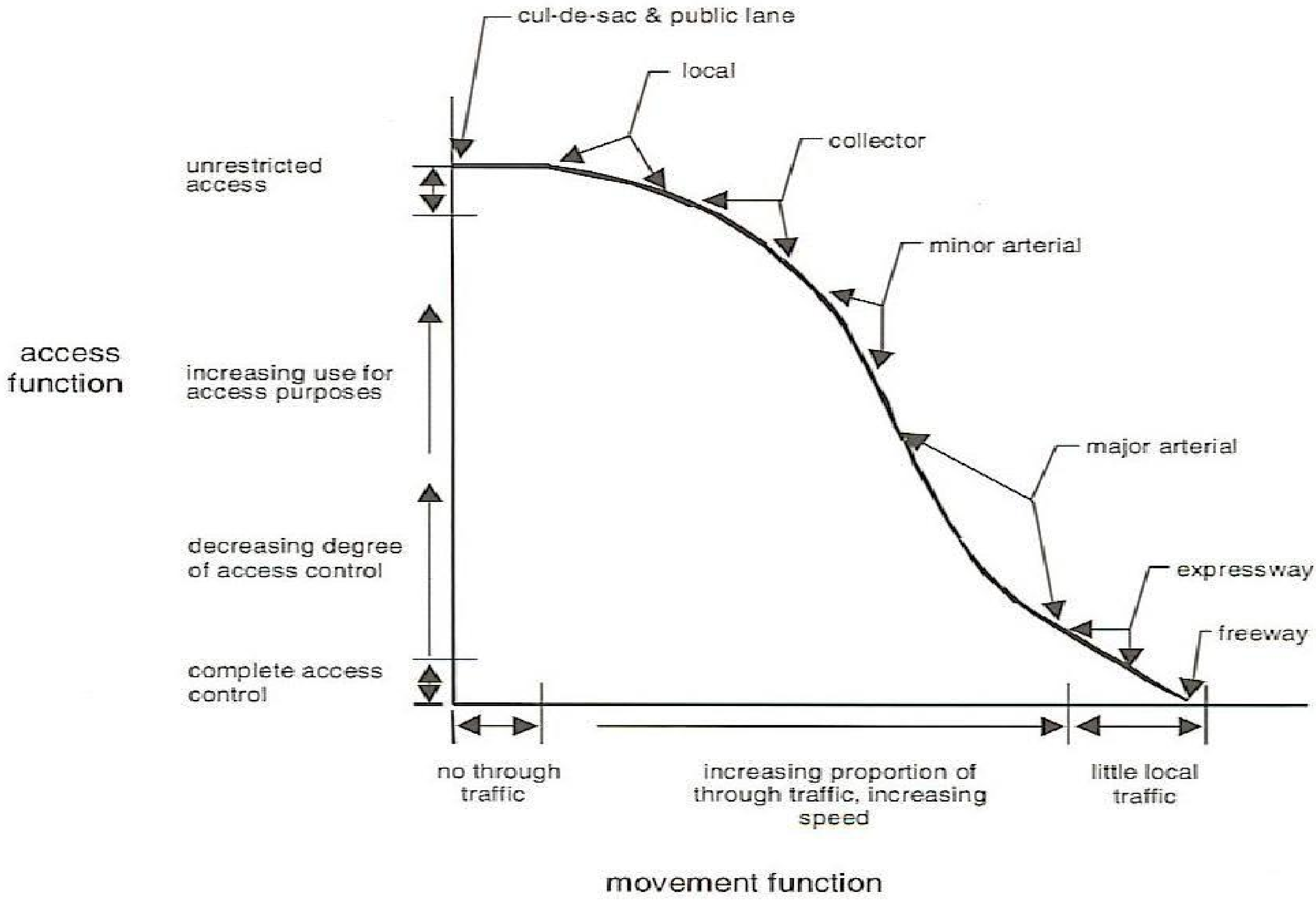
Village roads

- They are roads connecting villages or group of villages with each other or to the nearest road of a higher category like ODR or MDR.

- India has 26,50,000 kms of ODR+VR out of the total 33,15,231 kms of all type of roads.

Urban Road Classification

- ARTERIAL ROADS
- SUB ARTERIAL
- COLLECTOR
- LOCAL STREET
- CUL-DE-SAC
- PATHWAY
- DRIVEWAY



cul-de-sac & public lane
local
collector
minor arterial
major arterial
expressway
freeway
unrestricted access
access function
increasing use for access purposes
decreasing degree of access control
complete access control
no through traffic
increasing proportion of through traffic, increasing speed
little local traffic
movement function

ARTERIAL

- No frontage access, no standing vehicle, very little cross traffic.
- Design Speed : 80km/hr
- Land width : 50 – 60m
- Spacing 1.5km in CBD & 8km or more in sparsely developed areas.
- Divided roads with full or partial parking
- Pedestrian allowed to walk only at intersection

SUB ARTERIAL

- Bus stops but no standing vehicle.
- Less mobility than arterial.
- Spacing for CBD : 0.5km
- Sub-urban fringes : 3.5km
- Design speed : 60 km/hr
- Land width : 30 – 40 m

Collector Street

- Collects and distributes traffic from local streets
- Provides access to arterial roads
- Located in residential, business and industrial areas.
- Full access allowed.
- Parking permitted.
- Design speed : 50km/hr
- Land Width : 20-30m

Local Street

- Design Speed : 30km/hr.
- Land Width : 10 – 20m.
- Primary access to residence, business or other abutting property
- Less volume of traffic at slow speed
- Origin and termination of trips.
- Unrestricted parking, pedestrian movements. (with frontage access, parked vehicle, bus stops and no waiting restrictions)

CUL–DE- SAC

- Dead End Street with only one entry access for entry and exit.
- Recommended in Residential areas

Factors Influencing Highway Alignment

Requirements:

- Short
- Easy
- Safe
- Economical

Factors controlling alignment :

1)Obligatory points

A. Obligatory points through which alignment is to pass (bridge site, intermediate town , Mountain pass etc
B. Obligatory points through which alignment should not pass.

1)Traffic
3)Geometric design
4)Economics
5)Other considerations

<u>Additional care in hill roads</u>

Stability Drainage
Geometric standards of hill roads
Resisting length

Factors governing alignment

- Obligatory points
  - The location should avoid obstructions such as places of cemeteries, archeological, historical monument, public facilities like schools and hospitals, utility services.

- Geometric design features
  - Facilitate easy grade and curvature
  - Enable ruling gradient in most sections
  - Void sudden changes in sight distance, especially near crossings
  - Avoid sharp horizontal curves
  - Avoid road intersections near bend or at the top or bottom of a hill

Factors governing alignment

- Precautions at river and railway crossings
  - Bridges should be preferably be located at right angles to the river flow, not located on a horizontal curve
  - Crossing railway lines should avoid intersections at gradient, frequent crossing and recrossing

Factors governing alignment

- Topographical control points
  - The alignment, where possible should avoid passing through
    - Marshy and low lying land with poor drainage
    - Flood prone areas
    - Unstable hilly features
    - Avalanche prone areas
  - Flat terrain-below 3%
  - Rolling terrain -3 to 25%
  - Mountainous terrain – above 25%
  - A location on high ground should be preferred rather than valley to avoid cross drainage works

Factors governing alignment

- Materials and constructional features

– Deep cutting should be avoided

– Earth work is to be balanced; quantities for filling and excavation

  - Alignment should preferably be through better soil area to minimize pavement thickness
  - Location may be near sources of embankment and pavement materials

Traffic

- Trend, Direction and pattern of traffic are critical elements.
- OD survey should be conducted.
- Desire lines based on survey should be drawn to indicate the desired pattern of traffic flow.

ECONOMIC FACTORS

- Capital cost
- Maintenance Cost
- Operational cost
- Road User Cost
- Embankment and deep cuttings cost.

Other Considerations

- Engineering feasibility
- Environmental consideration
- Social consideration
- Political Acceptability
- Monotony.

Engineering Surveys for Highway locations

1)Provisional alignment Identification (Map study)

2) Reconnaissance survey

3) Preliminary survey

4) Final location to determine center line and detailed survey

Drawing and Report

1) Key map
2) Index map
3) Preliminary survey plans
4) Detailed plan and longitudinal section
5) Detailed cross section
6) Land acquisition plans
7) Drawings of cross drainage and other retaining structures
8) Drawings of road intersections
9) Land plans showing quarries etc

SURVEY DATA COLLECTION

- Natural and man made features.
- Proposed Geometric Design elements.
- Number of cross drainage structures.
- Soil characteristics
- Source of construction materials.
- Geological formation, type of rocks.
- Drainage

MAP STUDY

- Base Map preparation

  ➢Topographical map (SoI)

Scale -1: 2,50,000

1: 50,000

1: 25,000

- Shows man made and natural features and contour lines at 15 or 30m interval.
- Shows possible alignments with obligatory points and minimum number of cross drainage structures.

RECONNAISSANCE SURVEY

- Map updating – to confirm features indicated on map.

- Checking for:
  - Number of cross drainage structures.
  - High Flood Level (HFL)
  - Confirming Length and value of gradient to IRC standards.
  - Soil Characteristics.
  - Geological features.
  - Proximity to source of construction materials- quarries, water sources.

- Prepare a report on merits and demerits and profile map of scale 1:50,000.

PRELIMINARY SURVEY

- Base Plan

	Hz	Vr
➢ Built up area/hilly terrain	1:1000	1:100
➢ Plain and rolling terrain	1:2500	1:250

- Establish center line
- Incorporation of natural and man made features
- Longitudinal and cross sectional profile (Levelling).
  - ➢ Plain Terrain` : 100 – 200m
  - ➢ Rolling Terrain : 50m
  - ➢ Hilly Terrain : 30m
- Other studies
  - ➢ Drainage, Hydrological, soil, Traffic and Materials.
- Finalisation of the best alignment
  - ➢ Comparative analysis.
  - ➢ Choose best alignment among alternatives.
  - ➢ Design geometric elements.

DETAILED SURVEY FOR FINAL LOCATION

- Transferring the alignment on to ground.
- Detail Survey – levelling work for longitudinal and transverse direction.
- Intervals for cross sectional levelling
  - Plain 50 – 100m
  - Rolling 50 – 75m
  - Built up 50m 20m
  - Hilly
- Soil Profile

Alignment for hill roads

- Minimum hair pin bends.
- Bends should be located on stable and flat slopes.
- Cross section for hair pin bends should be at intervals of 20-25m.
- Avoid bends in valleys.
- Survey for a width of ;
  - 15 m on either side of centre line in straight alignment
  - 30m on sharp curves.

MODERN SURVEY METHODS

1) Provisional alignment Identification (Map study)

2) Reconnaissance survey
3) Hand held GPS giving 3D positions to an accuracy of 10-20m .
4) Preliminary Survey
   - Mapping of topography and relief
   - Use of aerial Photos
   - Airborne Laser Terain Mapping
5) Final location and detailed survey.

Modern Equipments for Surveying

- EDM – Electronic Distance Measurement
- Auto level.
- Digital level.
- Total station.
- GPS – global positioning system.

DATA FROM AERIAL SURVEY

- Mosaic for longitudinal and lateral overlaps.
- Control points

•Examination of photos for spot levels and contour lines

- Topo details
- Photo interpretation for geological features, soil and drainage for the study area

GEOMETRIC DESIGN

- Elements of design:
  - Sight distance
    - The length of road ahead visible to drivers
      - Stopping sight distance
      - Passing sight distance
  - Horizontal alignment
    - Super elevation rates (0.1 for rural areas, 0.06 for urban)
    - Minimum radius
  - Vertical alignment
  - Pavement design
  - Intersection and crossing design

Guidance for Route Selection

- Straight line alignment preferred.
- Avoid obstructions and frequent railway and river crossings.
- Avoid landslide, erosion prone and water logged and marshy area.
- Avoid alignment on clayey soil.
- Alignment should aim at maintaining uniform design speed, easy grades and curvature.

Comparison of Conventional and Modern Methods of Surveying

Elements of comparison	Conventional	Modern
Maps- Base material	Topo sheets	RS data, Aerial Photos, Satellite Imageries
Instruments	Chains, Tapes, Theodolite, Dumpy levels	EDM, Total Station, GPS, Auto and Digital Level, Photogrammetry.
Accuracy	Chain/Tape 1 in 3000 to 1 in 30,000 Tacheometer 1 in 1000 to 1 in 10,000	EDM/TS 1 in 10000 to 1 in 1,00,000 Photogrammetry. 1 in 10000 to 1 in 1,00,000
Plotting	CAD Systems	Software
Errors	Human errors	Closing Errors hence re measuring is required.

UNIT – II:
HIGHWAY GEOMETRIC DESIGN

- Importance of Geometric Design – factors affecting highway geometric design. Design controls and Criteria- Highway Cross Section Elements- Sight Distance Elements- Stopping sight Distance, Overtaking Sight Distance and intermediate Sight Distance- Design of Horizontal Alignment- Design of Super elevation and Extra widening- Design of Transition Curves-Design of Vertical alignment-Gradients- Vertical curves

Outline

1. Concepts
2. Vertical Alignment
    a. Fundamentals
    b. Crest Vertical Curves
    c. Sag Vertical Curves
    d. Examples
3. Horizontal Alignment
    a. Fundamentals
    b. Superelevation
4. Other Non-Testable Stuff

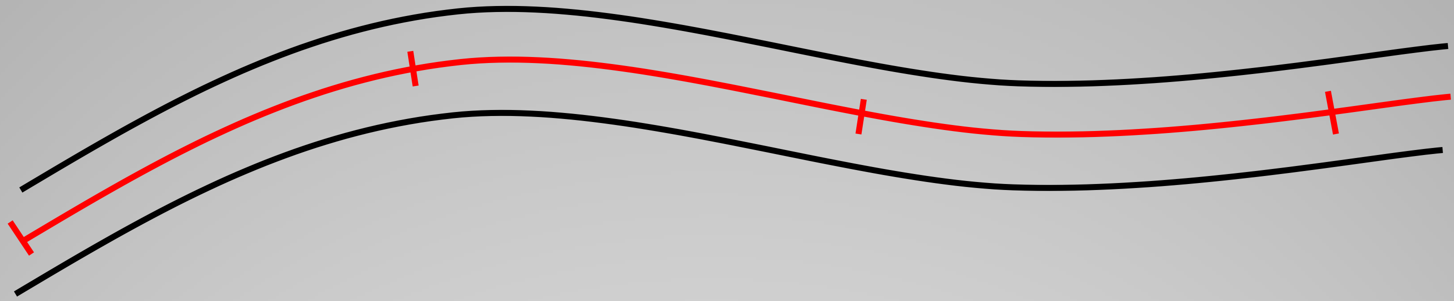
Concepts

- Alignment is a 3D problem broken down into two 2D problems
  - Horizontal Alignment (plan view)
  - Vertical Alignment (profile view)
- Stationing
  - Along horizontal alignment
  - 12+00 = 1,200 ft.

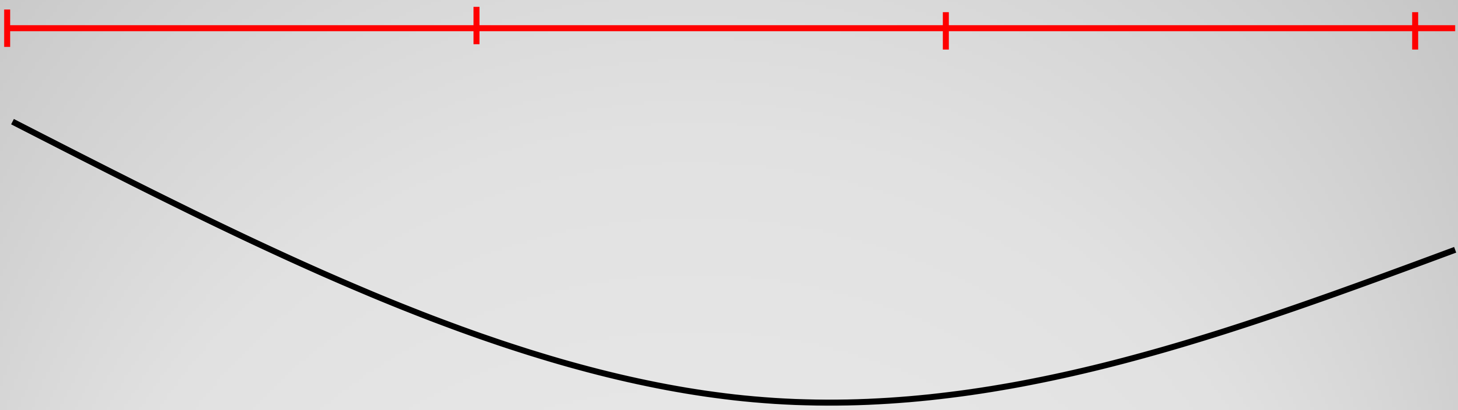
Piilani Highway on Maui

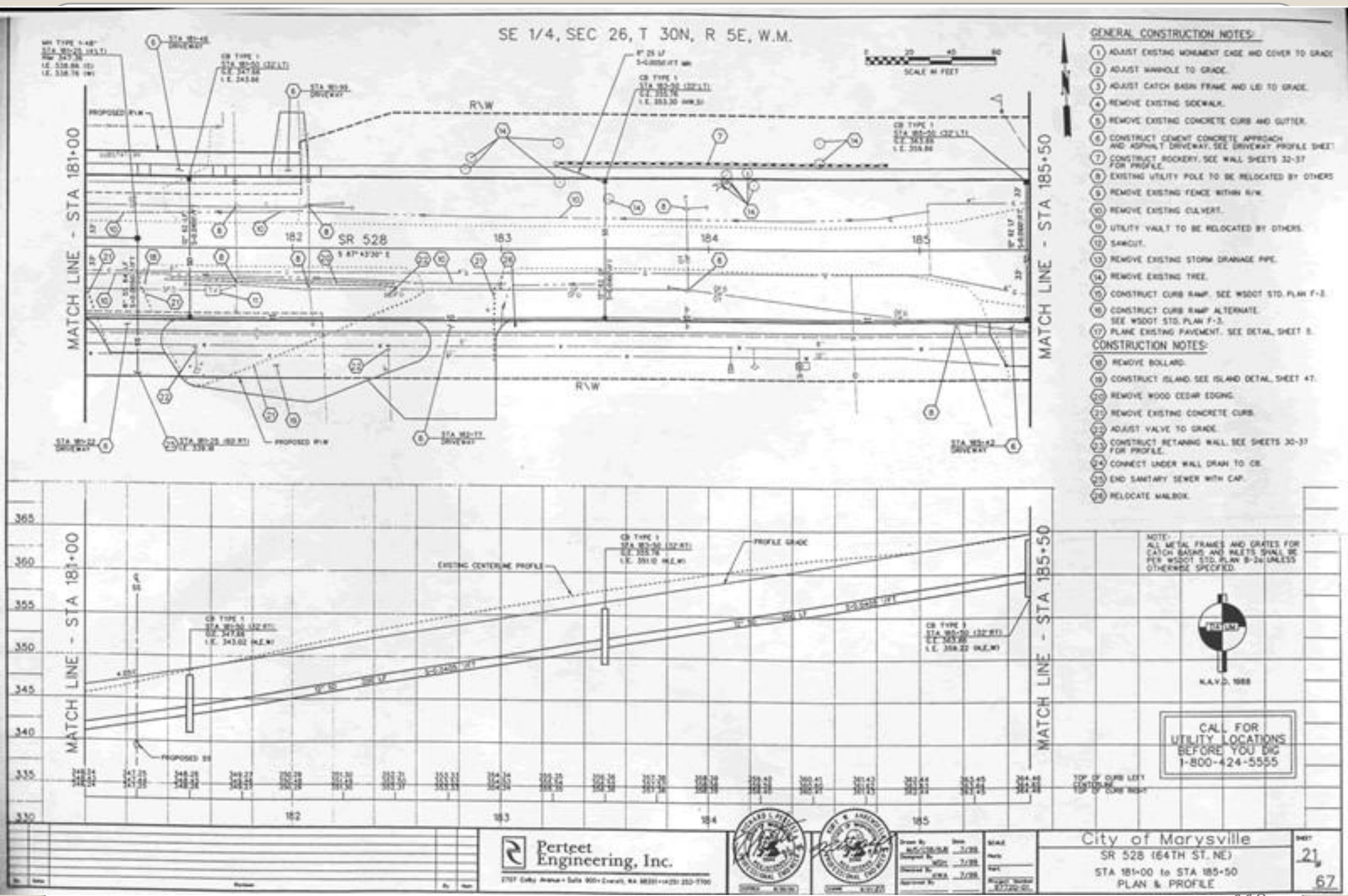
Stationing

Horizontal Alignment



Vertical Alignment



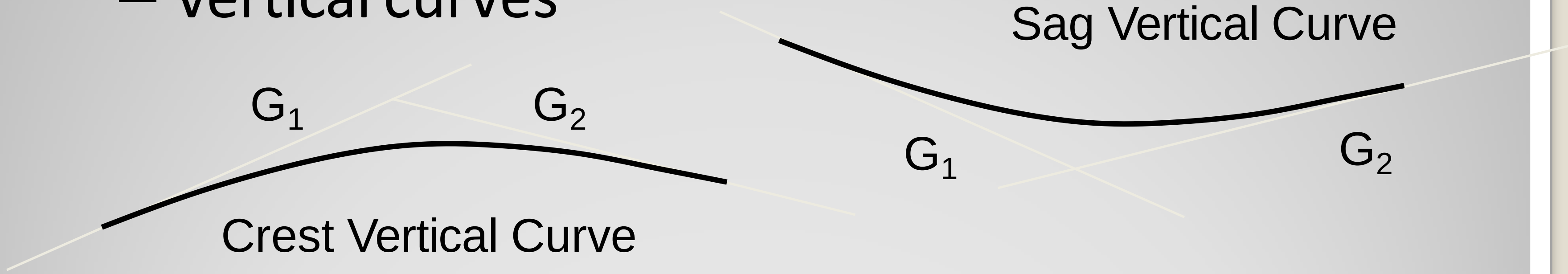


From Perteet Engineering

Vertical Alignment

Vertical Alignment

- Objective:
  - Determine elevation to ensure
    - Proper drainage
    - Acceptable level of safety
- Primary challenge
  - Transition between two grades
  - Vertical curves



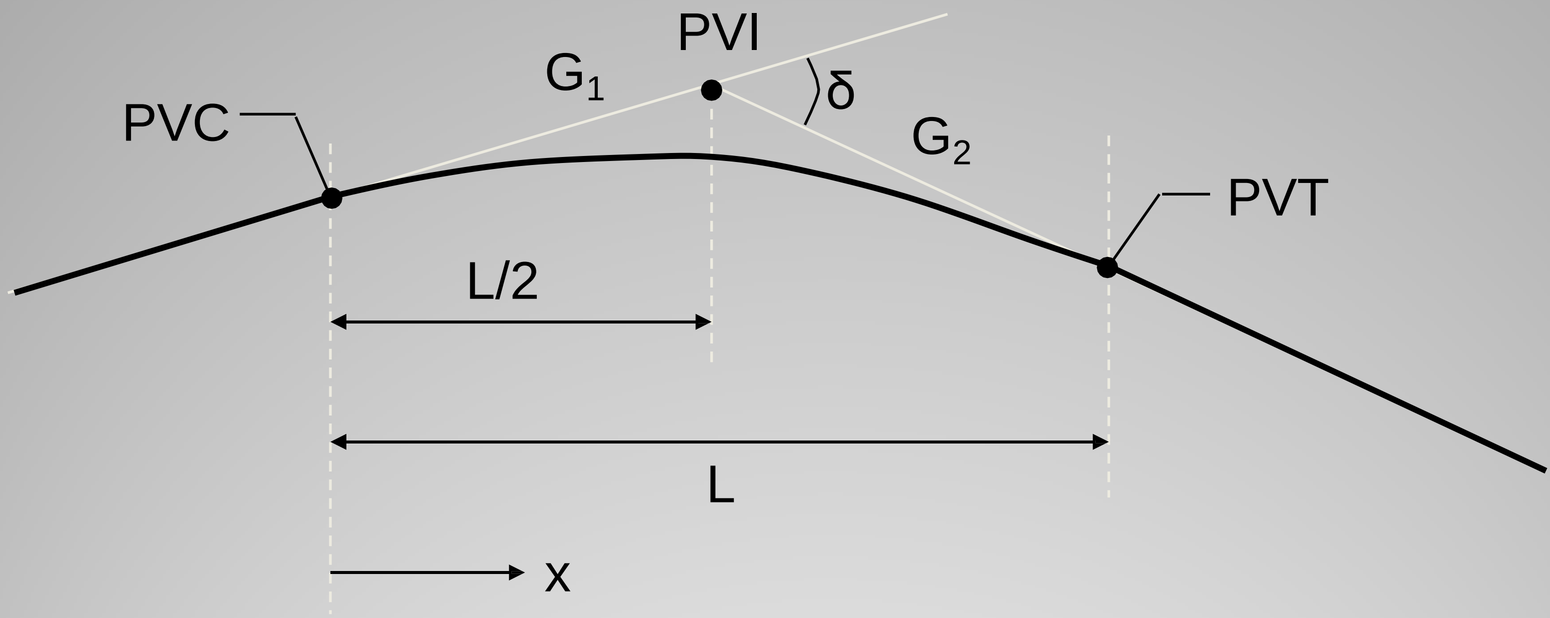
Vertical Curve Fundamentals

- Parabolic function
  - Constant rate of change of slope
  - Implies equal curve tangents

$$y = ax^2 + bx + c$$

- y is the roadway elevation x stations (or feet) from the beginning of the curve

Vertical Curve Fundamentals



$$y = ax^2 + bx + c$$

Choose Either:

- G_1, G_2 in decimal form, L in feet
- G_1, G_2 in percent, L in stations

Choose Either:

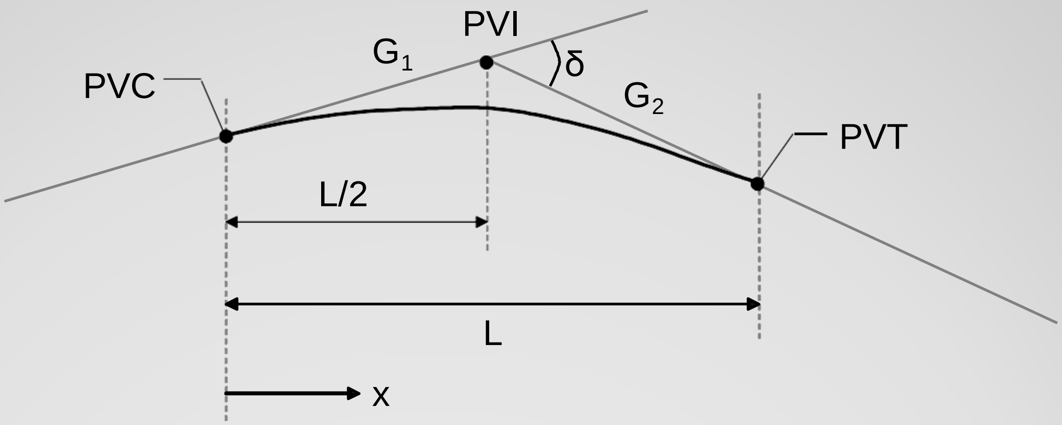
- G_1, G_2 in decimal form, L in feet
- **G_1, G_2 in percent, L in stations**

Relationships

$$\text{At the PVC}: \; x = 0 \quad \text{and} \quad Y = c$$

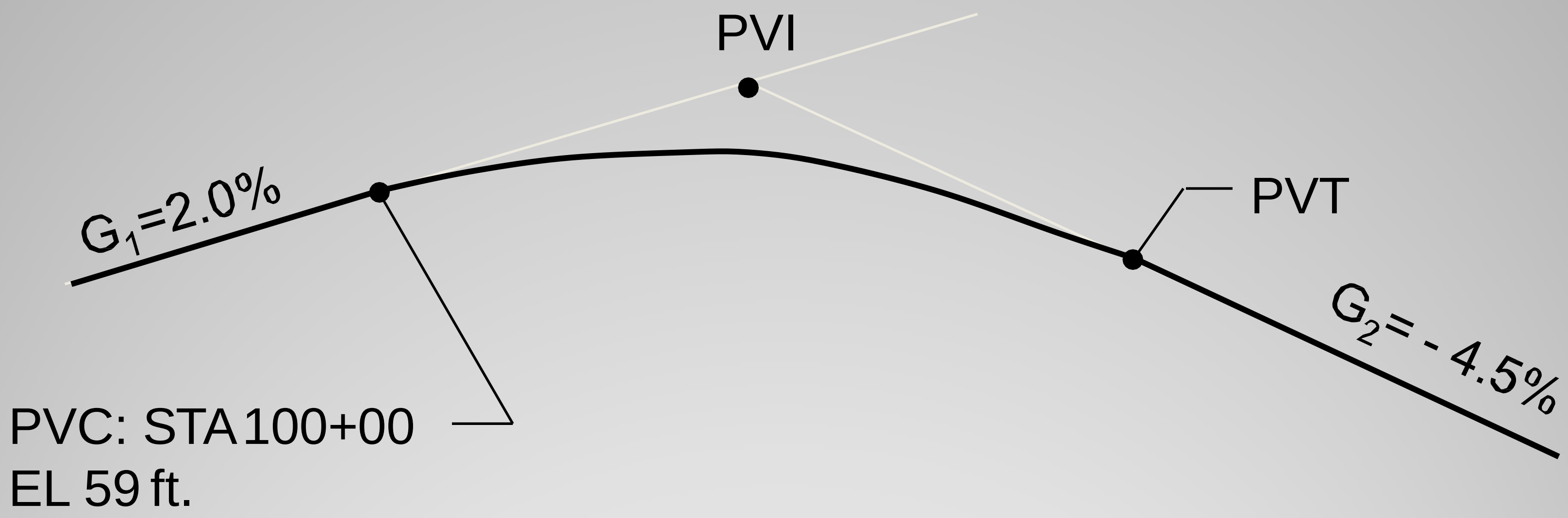
$$\text{At the PVC}: \; x = 0 \quad \text{and} \quad \frac{dY}{dx} = b = G_1$$

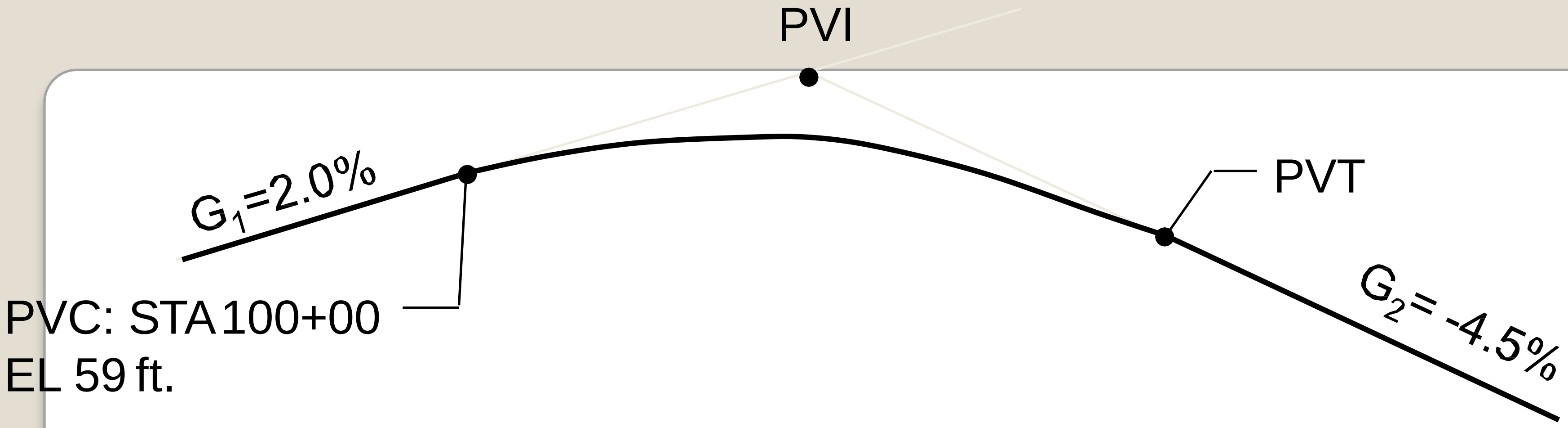
$$\text{Anywhere:} \quad \frac{d^2Y}{dx^2} = 2a = \frac{G_2 - G_1}{L} \Rightarrow a = \frac{G_2 - G_1}{2L}$$



Example

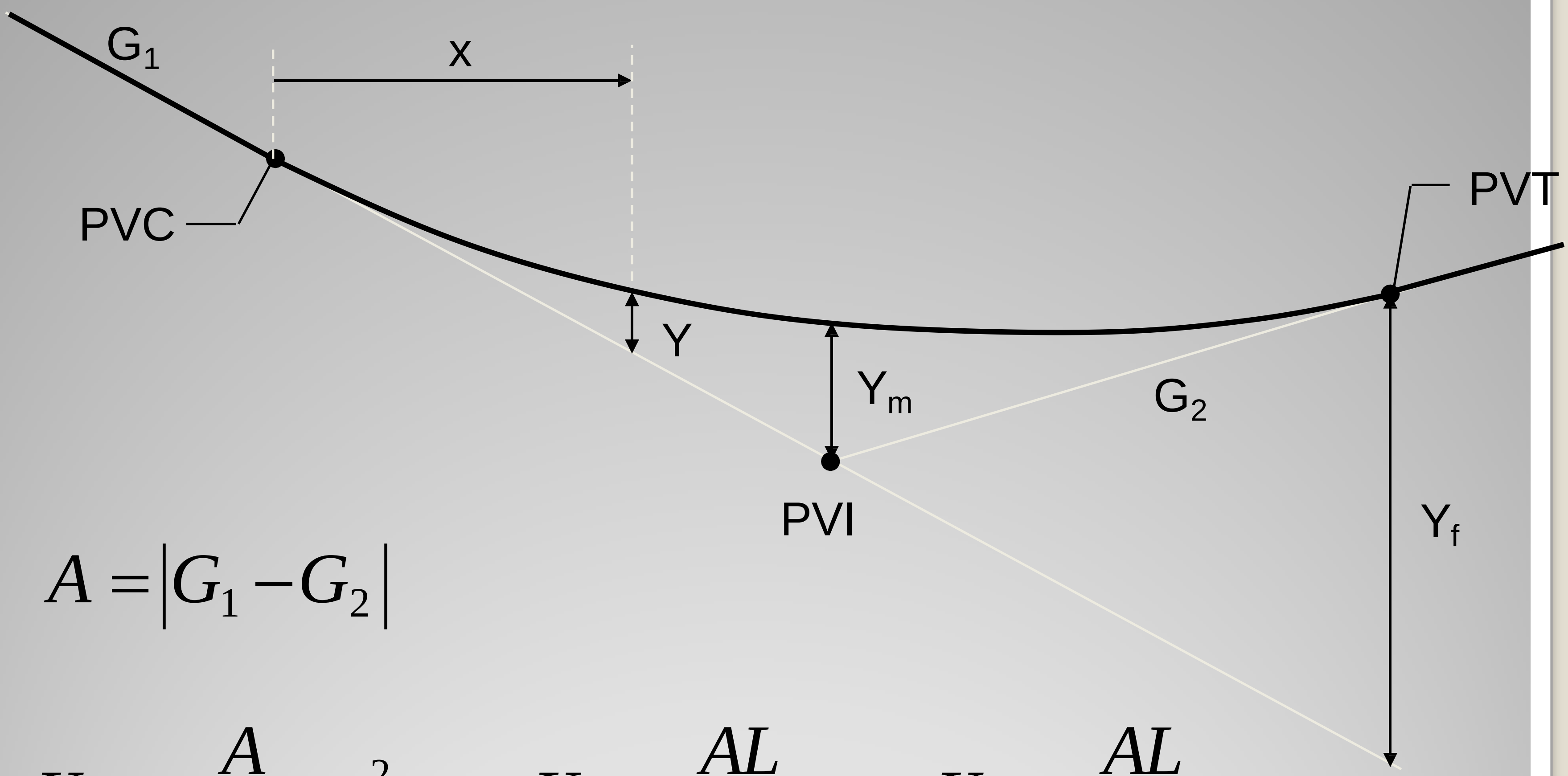
A 400 ft. equal tangent crest vertical curve has a PVC station of 100+00 at 59 ft. elevation. The initial grade is 2.0 percent and the final grade is -4.5 percent. Determine the elevation and stationing of PVI, PVT, and the high point of the curve.




PVI
G_1=2.0%
PVT
PVC: STA 100+00
EL 59 ft.
G_2= -4.5%

Other Properties

- G_1, G_2 in percent
- L in feet



$$A = \left| G_1 - G_2 \right|$$

$$Y = \frac{A}{200L} x^2 \qquad Y_m = \frac{AL}{800} \qquad Y_f = \frac{AL}{200}$$

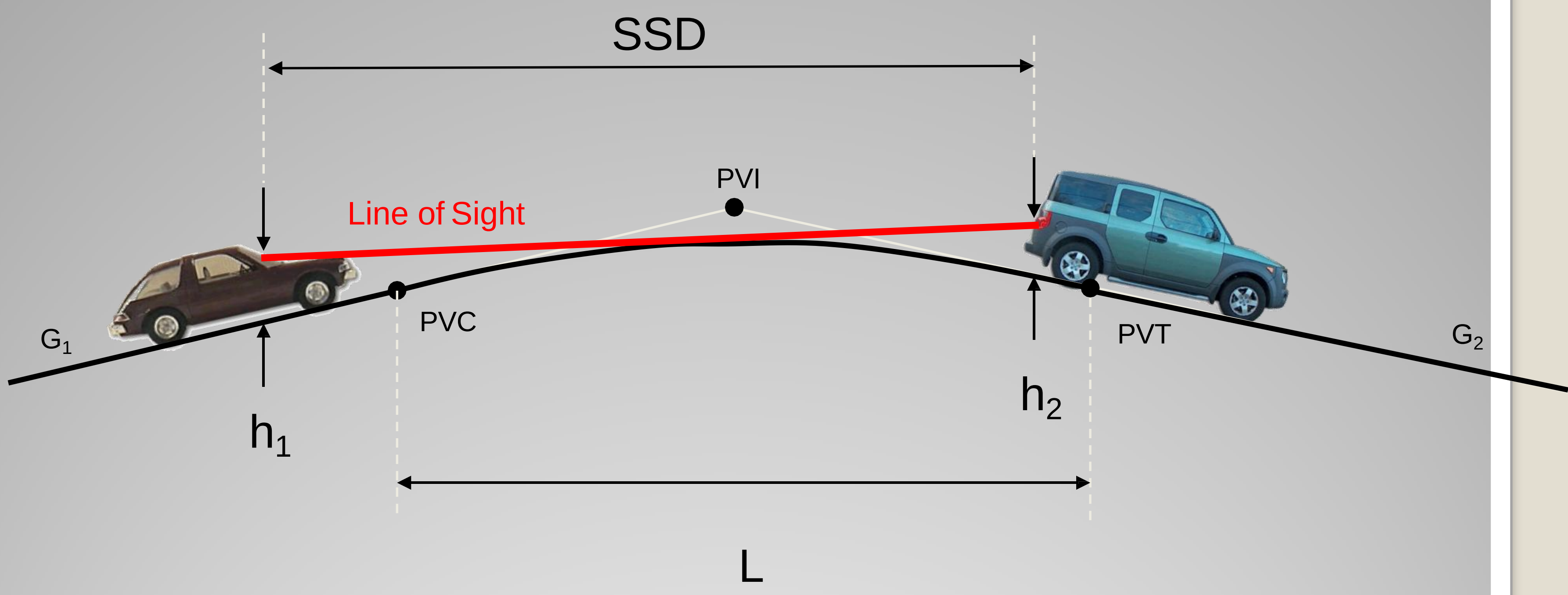
Other Properties

- K-Value (defines vertical curvature)
  - The number of horizontal feet needed for a 1% change in slope

$$K = \frac{L}{A}$$

$$high/low\ \ pt. \Rightarrow x = K\left|G_1\right|$$

Crest Vertical Curves



For SSD < L

$$L = \frac{A(SSD)^2}{100\left(\sqrt{2h_1}+\sqrt{2h_2}\right)^2}$$

For SSD > L

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

Crest Vertical Curves

- Assumptions for design
  - h_1 = driver's eye height = 3.5 ft.
  - h_2 = tail light height = 2.0 ft.

- Simplified Equations

<u>For SSD < L</u>

$$L = \frac{A(SSD)^2}{2158}$$

<u>For SSD > L</u>

$$L = 2(SSD) - \frac{2158}{A}$$

Crest Vertical Curves

- Assuming L > SSD…

$$K = \frac{SSD^2}{2158}$$

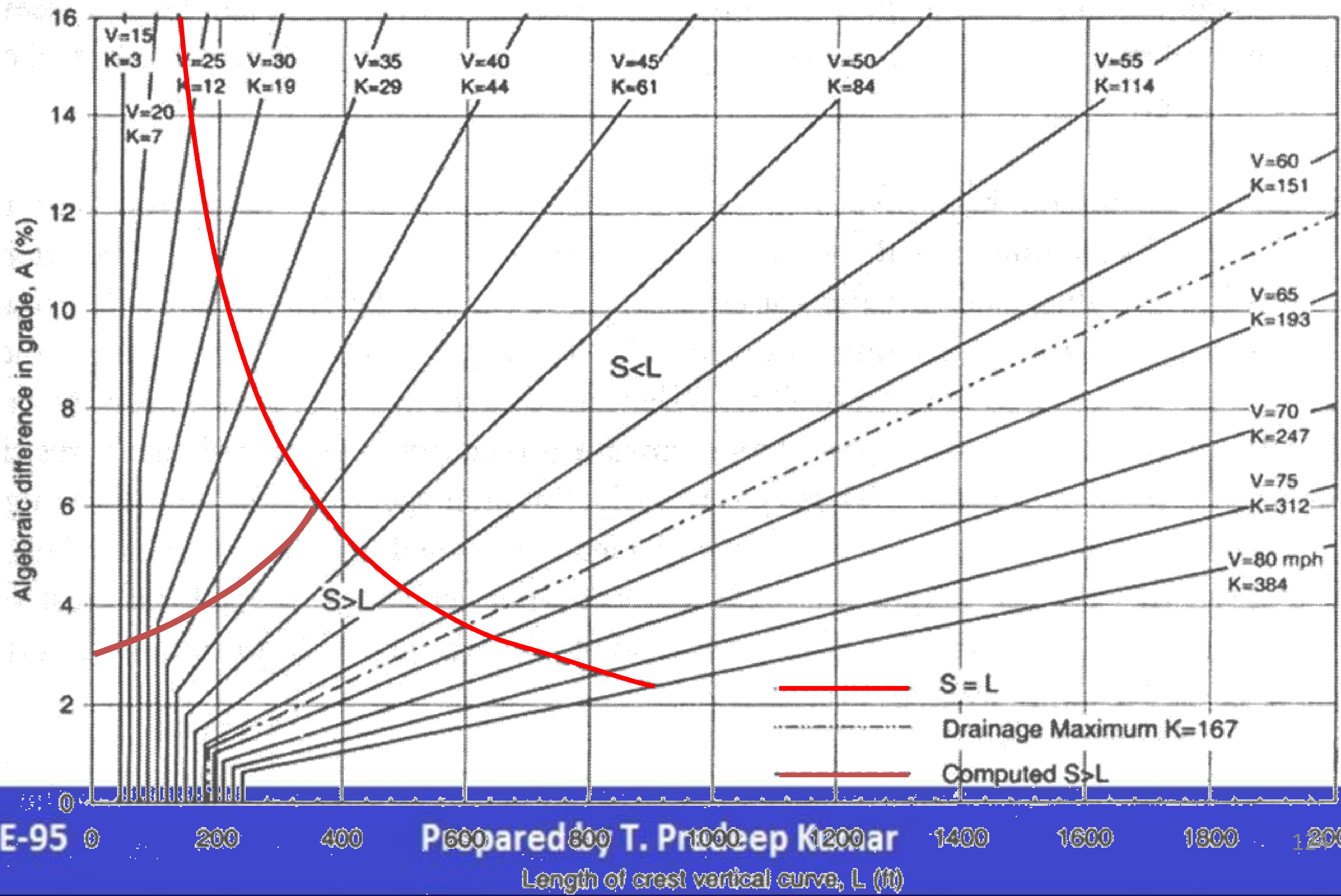
Design Controls for Crest Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a] Calculated	Design	Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a] Calculated	Design
20	20	0.6	1	15	80	3.0	3
30	35	1.9	2	20	115	6.1	7
40	50	3.8	4	25	155	11.1	12
50	65	6.4	7	30	200	18.5	19
60	85	11.0	11	35	250	29.0	29
70	105	16.8	17	40	305	43.1	44
80	130	25.7	26	45	360	60.1	61
90	160	38.9	39	50	425	83.7	84
100	185	52.0	52	55	495	113.5	114
110	220	73.6	74	60	570	150.6	151
120	250	95.0	95	65	645	192.8	193
130	285	123.4	124	70	730	246.9	247
				75	820	311.6	312
				80	910	383.7	384

[a] Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A). K = L/A

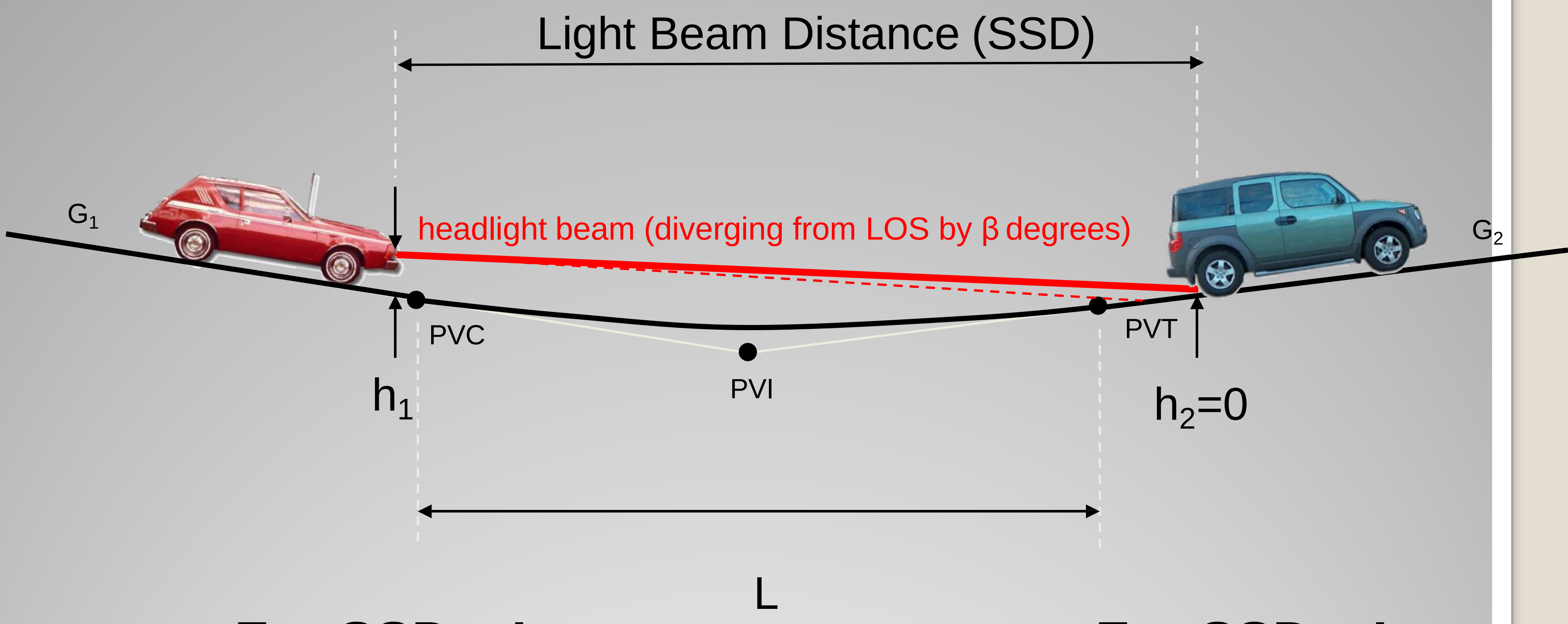
from AASHTO's *A Policy on Geometric Design of Highways and Streets 2001*

Design Controls for Crest Vertical Curves



from AASHTO's *A Policy on Geometric Design of Highways and Streets* 2001

Sag Vertical Curves



For SSD < L

$$L = \frac{A(SSD)^2}{200(h_1 + S\tan\beta)}$$

For SSD > L

$$L = 2(SSD) - \frac{200(h_1 + (SSD)\tan\beta)}{A}$$

Sag Vertical Curves

- Assumptions for design
  - h_1 = headlight height = 2.0 ft.
  - β = 1 degree

- Simplified Equations

For SSD < L

$$L = \frac{A(SSD)^2}{400 + 3.5(SSD)}$$

For SSD > L

$$L = 2(SSD) - \left(\frac{400 + 3.5(SSD)}{A}\right)$$

Sag Vertical Curves

- Assuming L > SSD…

$$K = \frac{SSD^2}{400 + 3.5SSD}$$

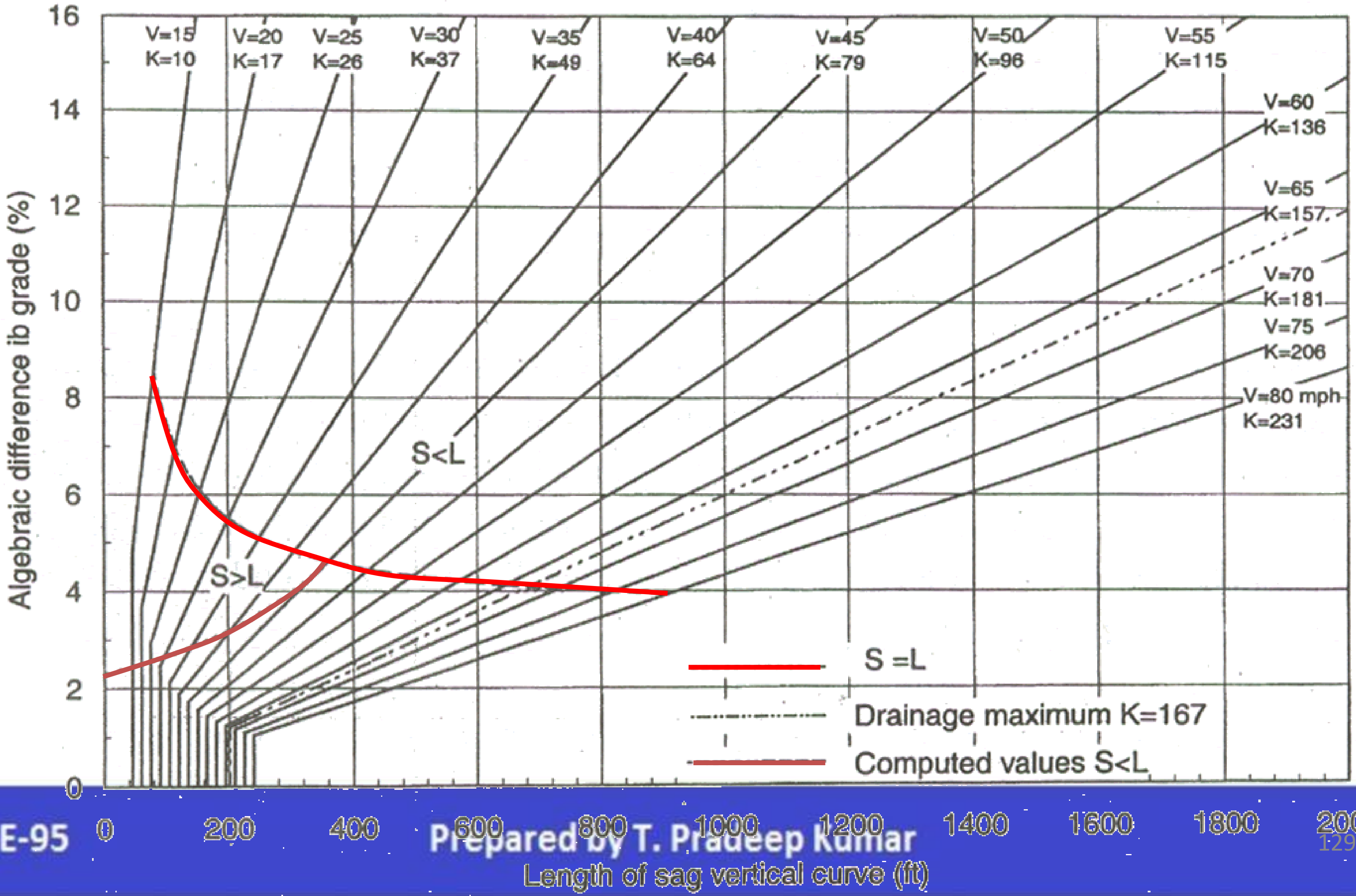
Design Controls for Sag Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a]		Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a]	
		Calculated	Design			Calculated	Design
20	20	2.1	3	15	80	9.4	10
30	35	5.1	6	20	115	16.5	17
40	50	8.5	9	25	155	25.5	26
50	65	12.2	13	30	200	36.4	37
60	85	17.3	18	35	250	49.0	49
70	105	22.6	23	40	305	63.4	64
80	130	29.4	30	45	360	78.1	79
90	160	37.6	38	50	425	95.7	96
100	185	44.6	45	55	495	114.9	115
110	220	54.4	55	60	570	135.7	136
120	250	62.8	63	65	645	156.5	157
130	285	72.7	73	70	730	180.3	181
				75	820	205.6	206
				80	910	231.0	231

[a] Rate of vertical curvature, K, is the length of curve (m) per percent algebraic difference intersecting grades (A). K = L/A

from AASHTO's *A Policy on Geometric Design of Highways and Streets 2001*

Design Controls for Sag Vertical Curves



from AASHTO's *A Policy on Geometric Design of Highways and Streets* 2001

Example 1

A car is traveling at 30 mph in the country at night on a wet road through a 150 ft. long sag vertical curve. The entering grade is -2.4 percent and the exiting grade is 4.0 percent. A tree has fallen across the road at approximately the PVT. Assuming the driver cannot see the tree until it is lit by her headlights, is it reasonable to expect the driver to be able to stop before hitting the tree?

Example 2

Similar to Example 1 but for a crest curve.

A car is traveling at 30 mph in the country at night on a wet road through a 150 ft. long crest vertical curve. The entering grade is 3.0 percent and the exiting grade is -3.4 percent. A tree has fallen across the road at approximately the PVT. Is it reasonable to expect the driver to be able to stop before hitting the tree?

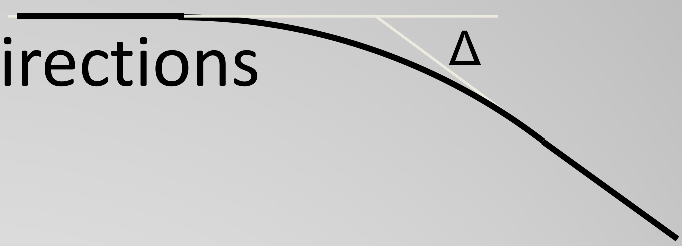
Example 3

A roadway is being designed using a 45 mph design speed. One section of the roadway must go up and over a small hill with an entering grade of 3.2 percent and an exiting grade of -2.0 percent. How long must the vertical curve be?

Horizontal Alignment

Horizontal Alignment

- Objective:
  - Geometry of directional transition to ensure:
    - Safety
    - Comfort
- Primary challenge
  - Transition between two directions
  - Horizontal curves
- Fundamentals
  - Circular curves
  - Superelevation

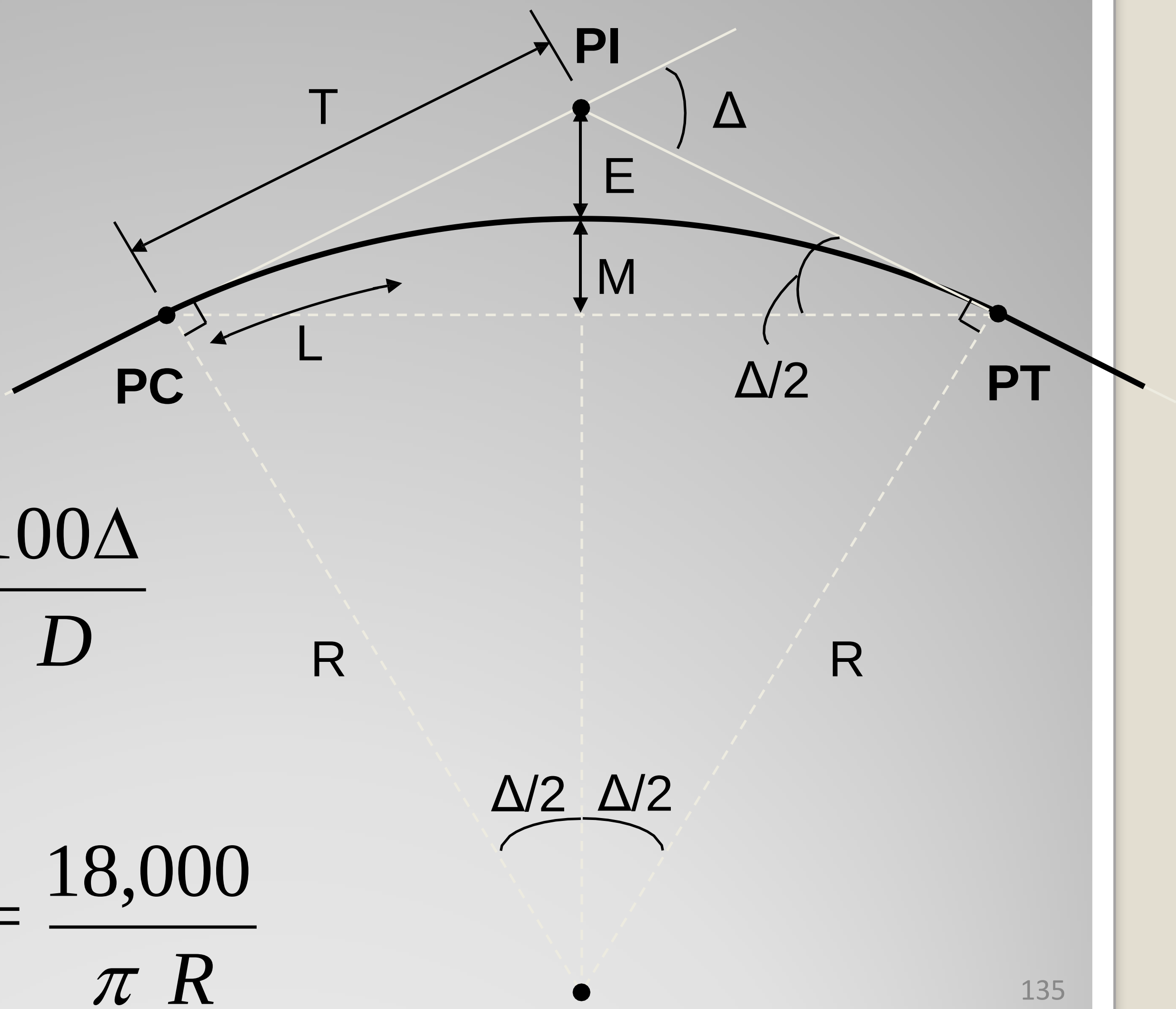


Horizontal Curve Fundamentals

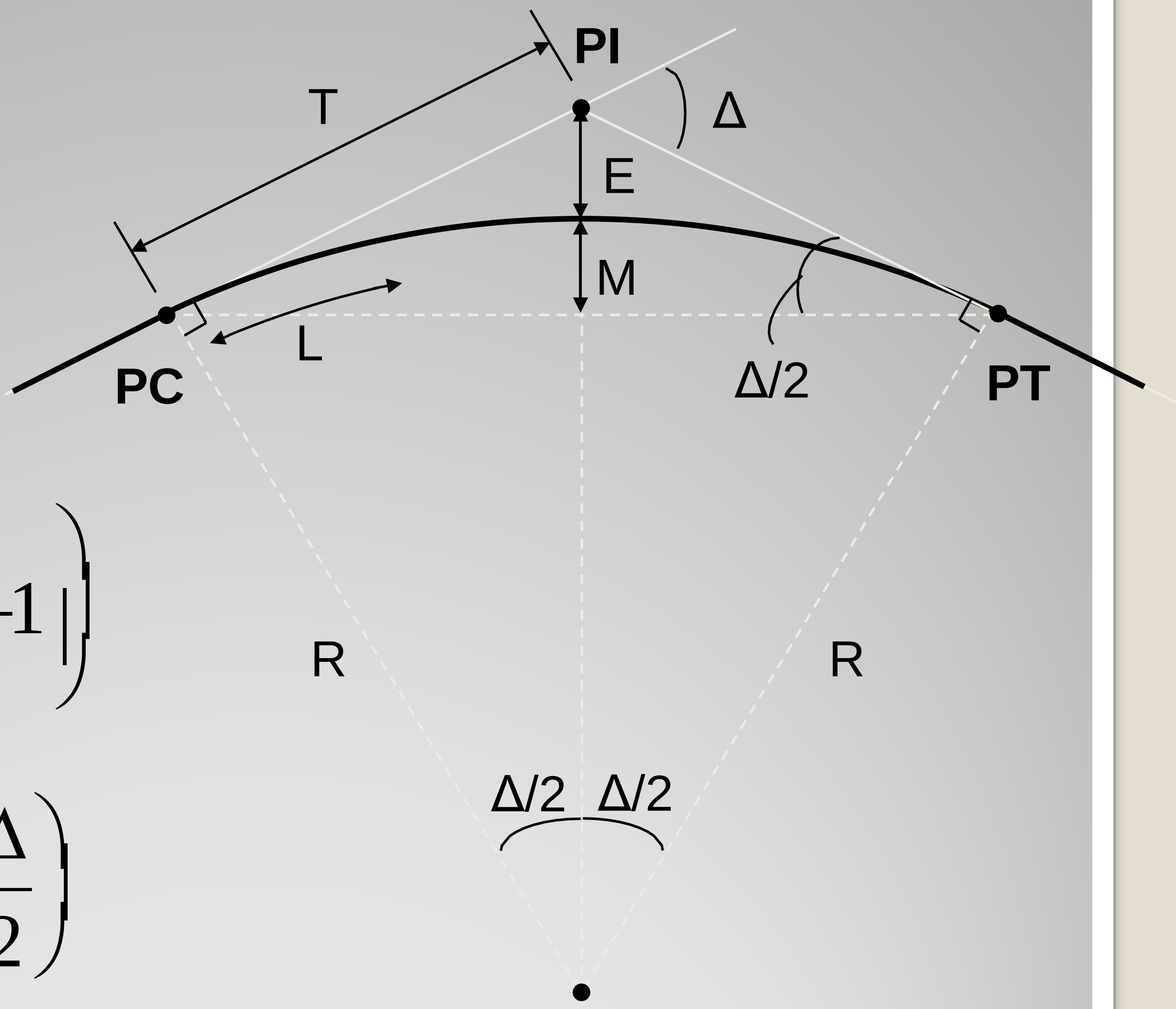
$$T = R \tan \frac{\Delta}{2}$$

$$L = \frac{\pi}{180} R\Delta = \frac{100\Delta}{D}$$

$$D = \frac{100\left(\frac{180}{\pi}\right)}{R} = \frac{18{,}000}{\pi \ R}$$



Horizontal Curve Fundamentals



$$E = R\left(\frac{1}{\cos \Delta/2} - 1\right)$$

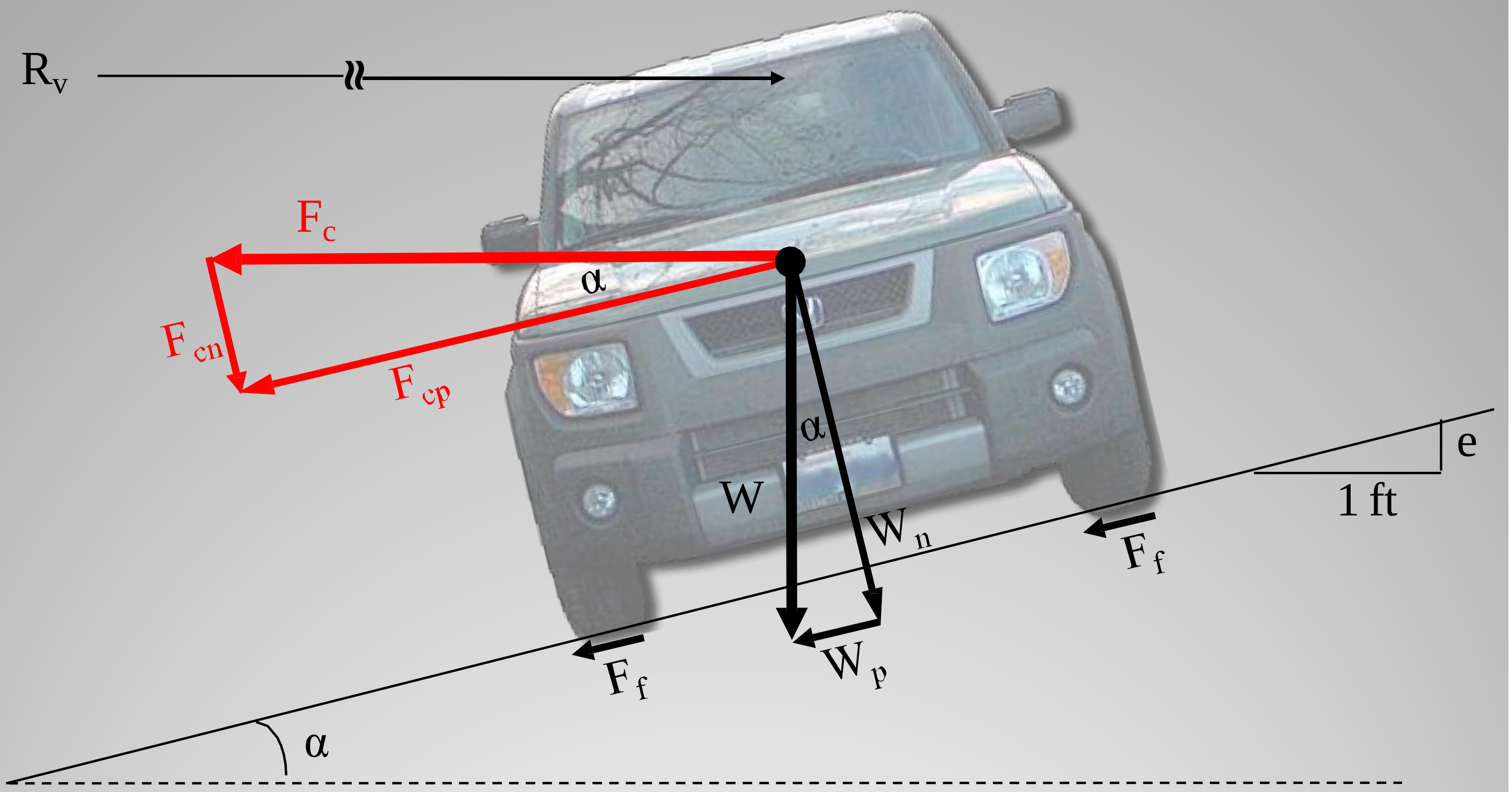
$$M = R\left(1 - \cos \frac{\Delta}{2}\right)$$

A horizontal curve is designed with a 1500 ft. radius. The tangent length is 400 ft. and the PT station is 20+00. What are the PI and PT stations?

Example 4

Superelevation

$$W_p + F_f = F_{cp}$$



$$W\sin\alpha + f_s\left(W\cos\alpha + \frac{WV^2}{gR_v}\sin\alpha\right) = \frac{WV^2}{gR_v}\cos\alpha$$

Superelevation

$$W \sin\alpha + f_s\left(W\cos\alpha + \frac{WV^2}{gR_v}\sin\alpha\right) = \frac{WV^2}{gR_v}\cos\alpha$$

$$\tan\alpha + f_s = \frac{V^2}{gR_v}\left(1 - f_s\tan\alpha\right)$$

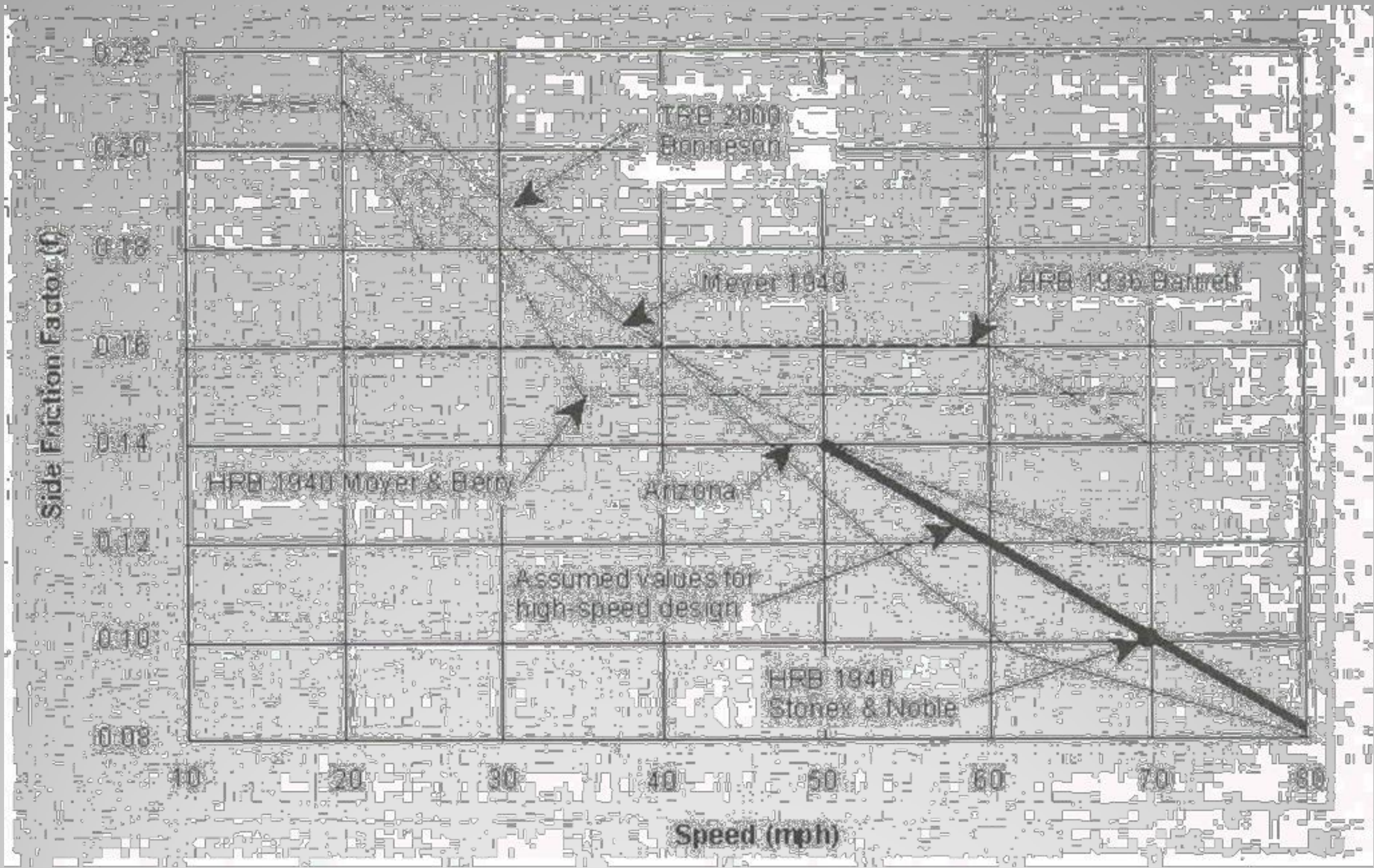
$$e + f_s = \frac{V^2}{gR_v}\left(1 - f_s e\right)$$

$$R_v = \frac{V^2}{g\left(f_s + e\right)}$$

Selection of e and f_s

- Practical limits on superelevation (e)
  - Climate
  - Constructability
  - Adjacent land use
- Side friction factor (f_s) variations
  - Vehicle speed
  - Pavement texture
  - Tire condition

Side Friction Factor



from AASHTO's *A Policy on Geometric Design of Highways and Streets 2004*

Minimum Radius Tables

US Customary					
Design Speed (mph)	Maximum *e* (%)	Maximum *f*	Total (*e*/100 + *f*)	Calculated Radius (ft)	Rounded Radius (ft)
10	4.0	0.38	0.42	15.9	16
15	4.0	0.32	0.36	41.7	42
20	4.0	0.27	0.31	86.0	86
25	4.0	0.23	0.27	154.3	154
30	4.0	0.20	0.24	250.0	250
35	4.0	0.18	0.22	371.2	371
40	4.0	0.16	0.20	533.3	533
45	4.0	0.15	0.19	710.5	711
50	4.0	0.14	0.18	925.9	926
55	4.0	0.13	0.17	1186.3	1190
60	4.0	0.12	0.16	1500.0	1500
10	6.0	0.38	0.44	15.2	15
15	6.0	0.32	0.38	39.5	39

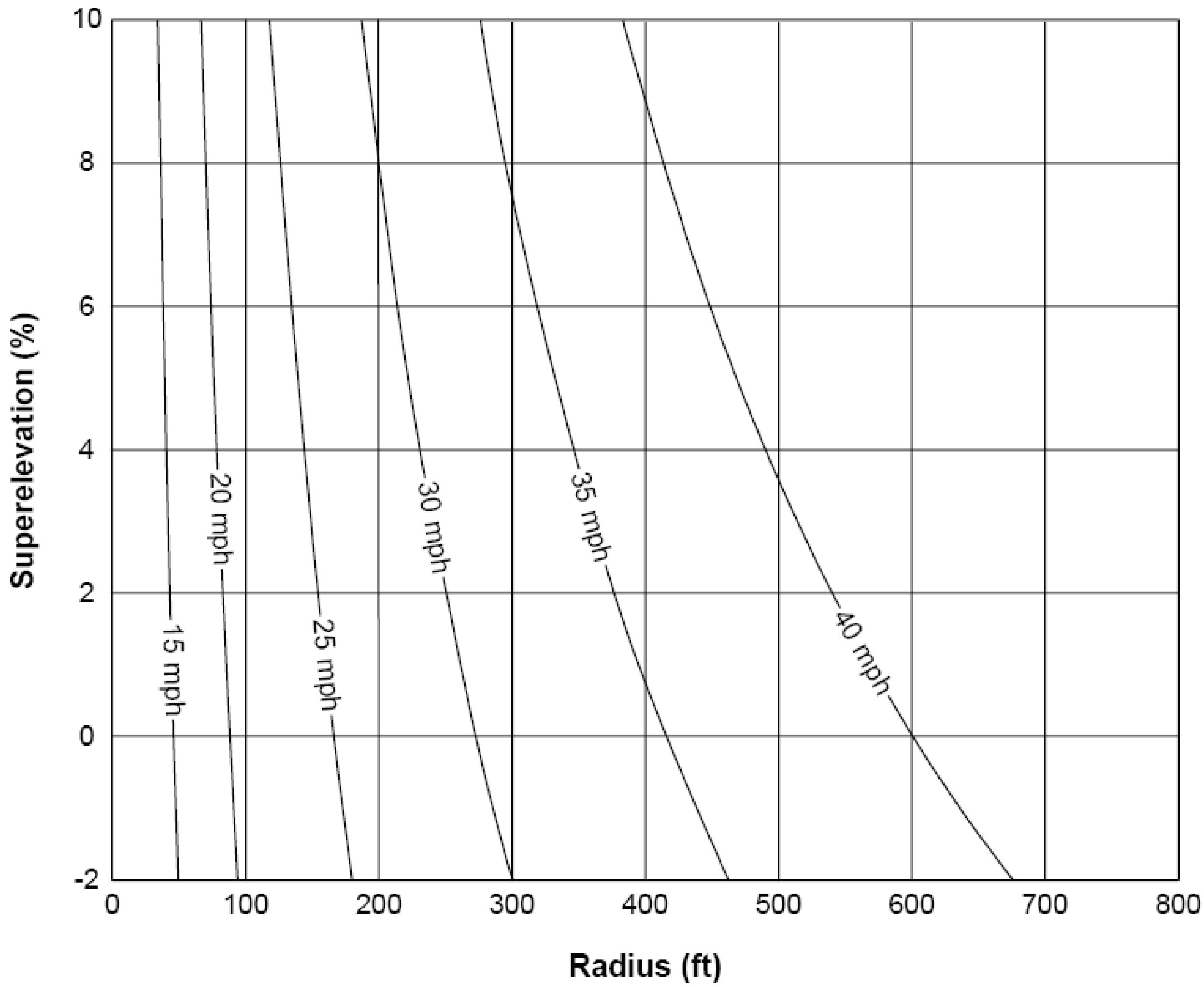
Factors

For Open Highways and Ramps

Design Speed (mph)	Side Friction Factor (f)
15	17.5
20	17
25	16.5
30	16
35	15.5
40	15
45	14.5
50	14
55	13
60	12
65	11
70	10
75	9
80	8

from the 2005 WSDOT *Design Manual*, M 22-01

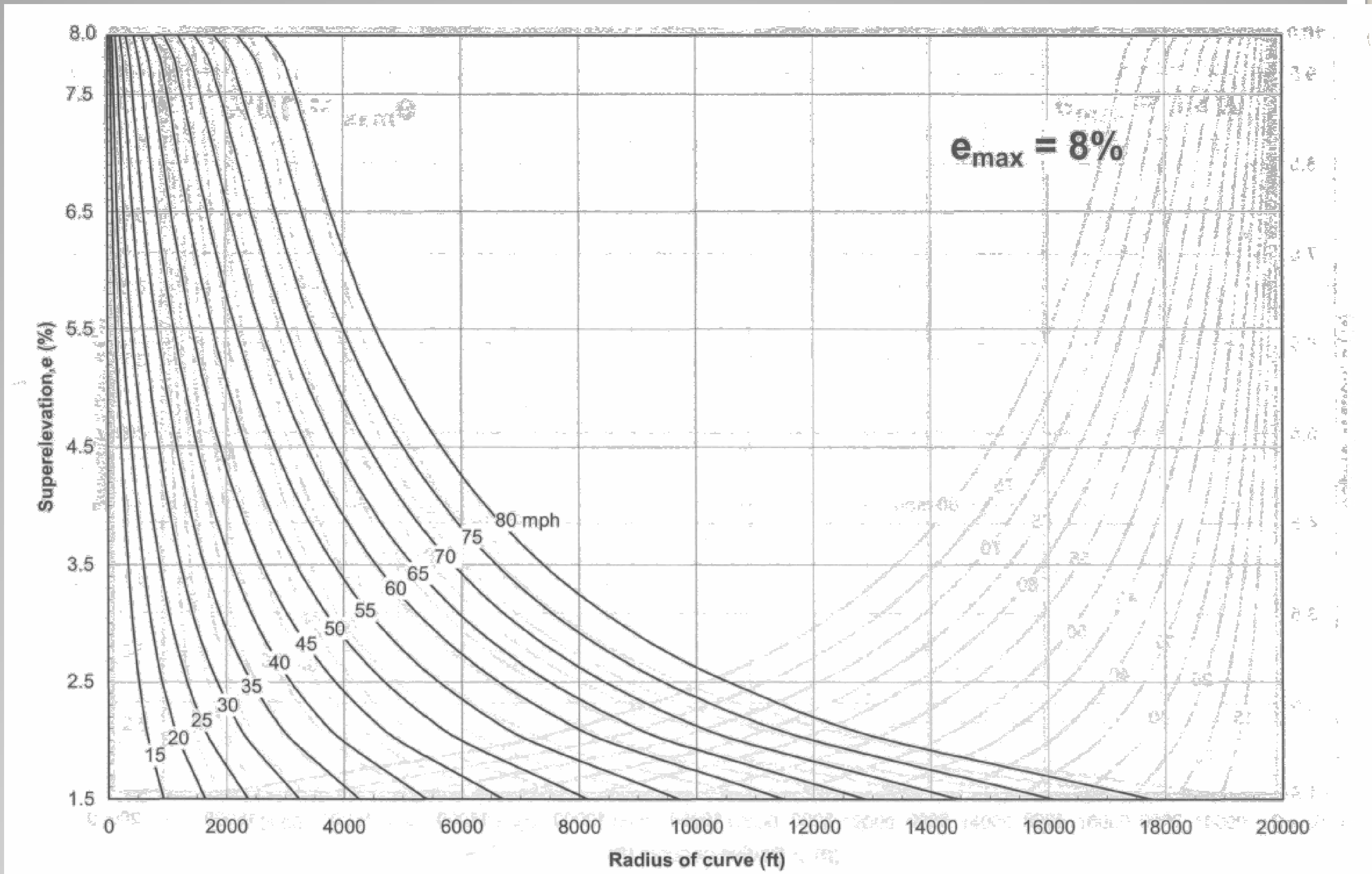
For Low-Speed Urban Managed Access Highways



ors

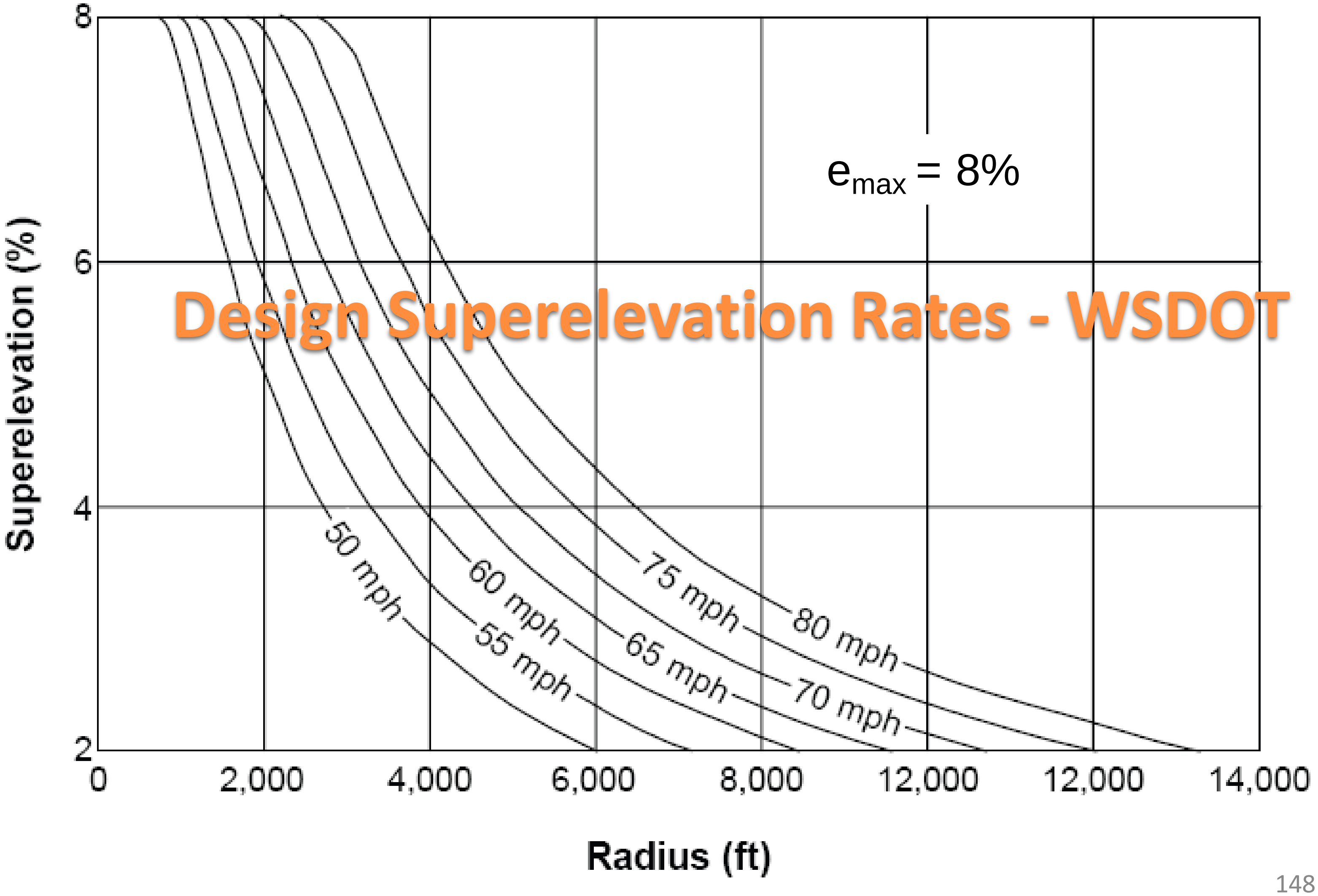
from the 2005 WSDOT *Design Manual*, M 22-01

Design Superelevation Rates - AASHTO



from AASHTO's *A Policy on Geometric Design of Highways and Streets*

Design Superelevation Rates - WSDOT



from the 2005 WSDOT *Design Manual*, M 22-01

Example 5

A section of SR 522 is being designed as a high-speed divided highway. The design speed is 70 mph. Using WSDOT standards, what is the minimum curve radius (as measured to the traveled vehicle path) for safe vehicle operation?

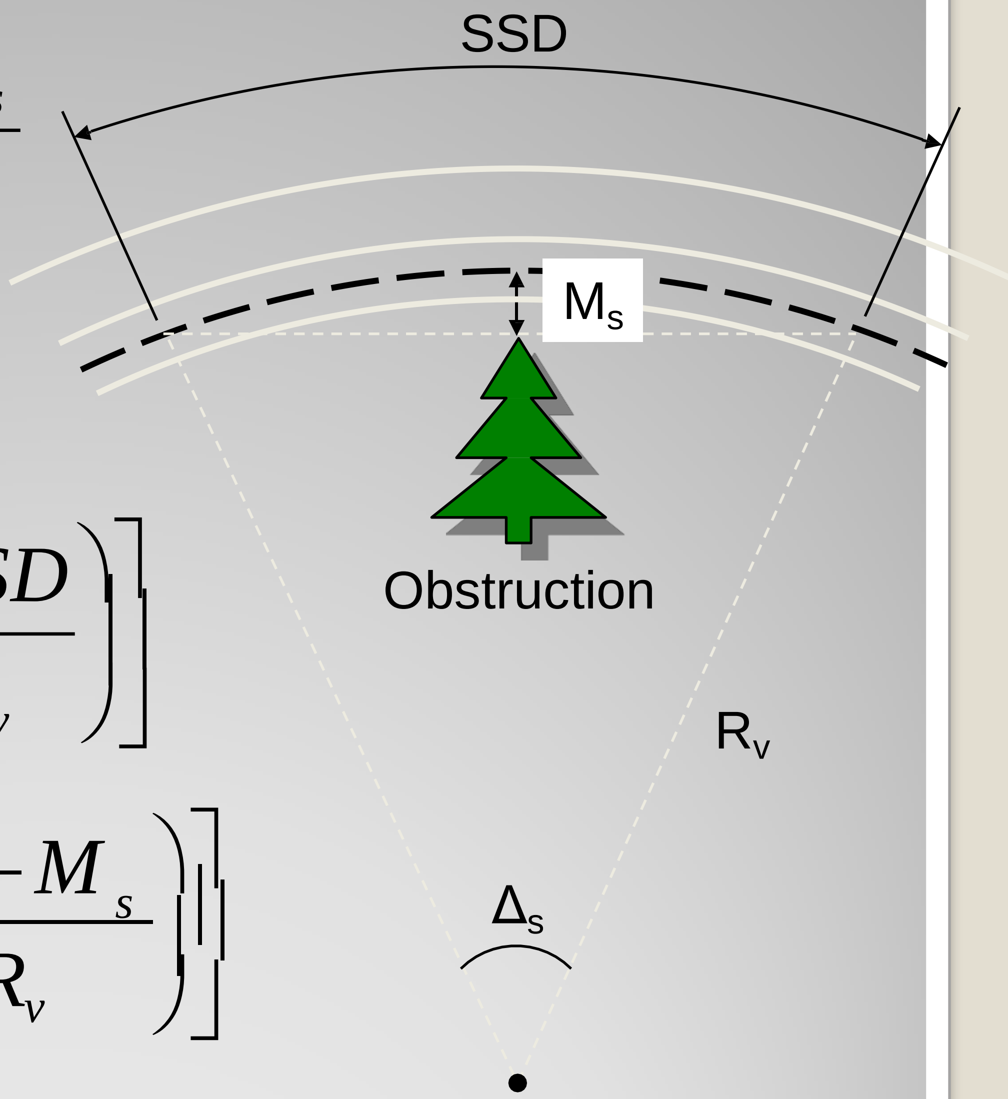
Stopping Sight Distance

$$SSD = \frac{\pi}{180} R_v \Delta_s = \frac{100\Delta_s}{D}$$

$$\Delta_s = \frac{180(SSD)}{\pi R_v}$$

$$M_s = R_v \left[1 - \cos\left(\frac{90 SSD}{\pi R_v} \right) \right]$$

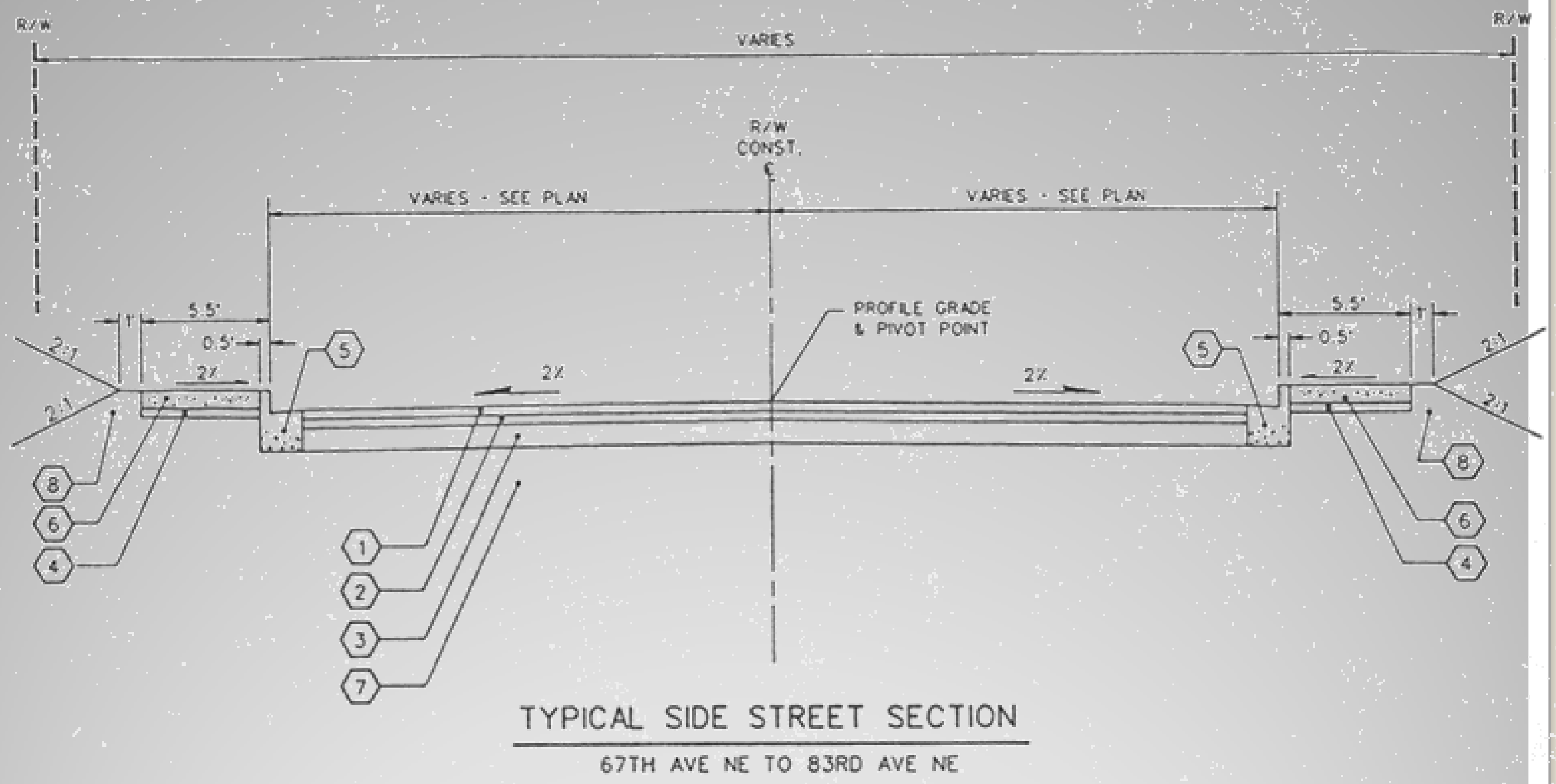
$$SSD = \frac{\pi R_v}{90} \left[\cos^{-1}\left(\frac{R_v - M_s}{R_v} \right) \right]$$



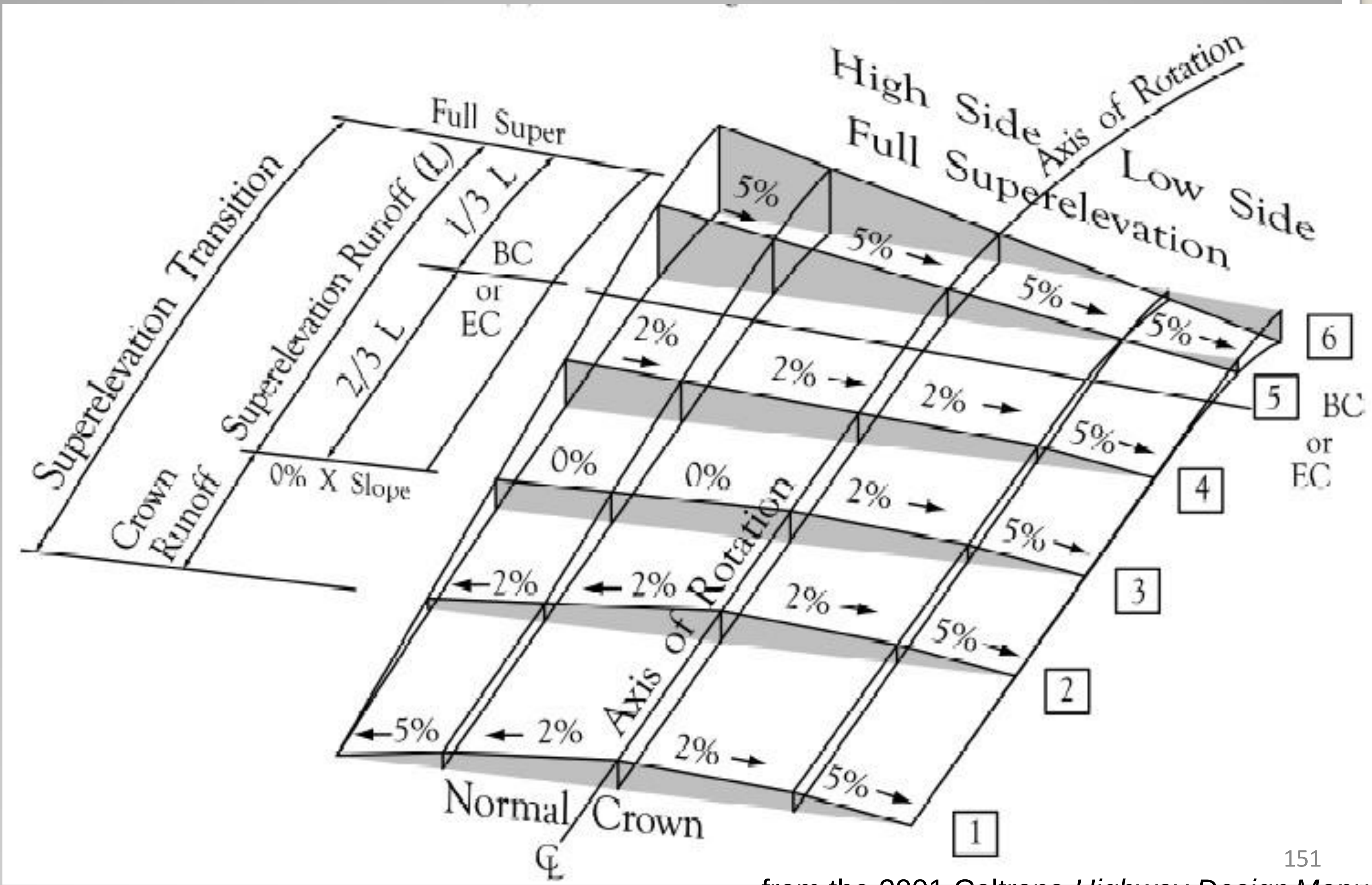
Supplemental Stuff

- Cross section
- Superelevation Transition
  - Runoff
  - Tangent runout
- Spiral curves
- Extra width for curves

Cross Section

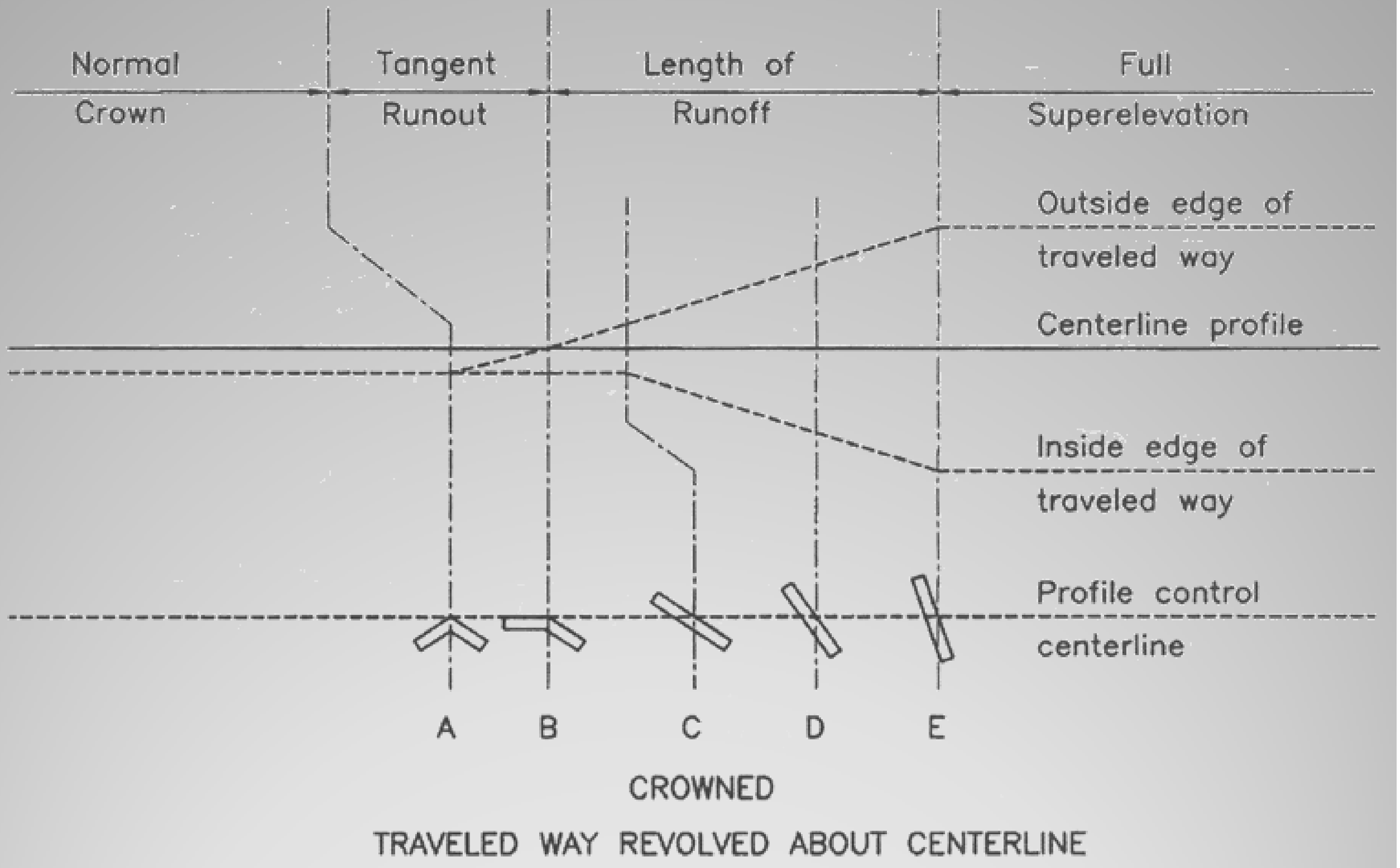


Superelevation Transition



from the 2001 Caltrans *Highway Design Manual*

Superelevation Transition



from AASHTO's *A Policy on Geometric Design of Highways and Streets 2001*

Superelevation Runoff/Runout

Metric							
Design speed (km/h)	Minimum runoff and runout length (m) — Runoff, Superelevation 2	4	6	8	10	12	Runout (any)
One lane rotated							
20	9	18	27	36	45	54	9
30	10	19	29	38	48	57	10
40	10	21	31	41	51	62	10
50	11	22	32	43	54	65	11
60	12	24	36	48	60	72	12
70	13	26	39	52	66	79	13
80	14	29	43	58	72	86	14
90	15	31	46	61	77	92	15
100	16	33	49	65	82	98	16
110	18	35	53	70	88	105	18
120	19	38	57	76	95	114	19
130	21	41	62	82	103	124	21
Two lanes rotated							
20	14	27	41	54	68	81	14
30	14	29	43	57	72	86	14
40	15	31	46	62	77	93	15
50	16	32	49	65	81	97	16
60	18	36	54	72	90	108	18
70	20	39	59	79	98	118	20
80	22	43	65	86	108	130	22
90	23	46	69	92	115	138	23
100	25	49	74	98	123	147	25
110	26	53	79	105	132	158	26
120	28	57	85	114	142	170	28
130	31	62	93	124	154	185	31

US Customary							
Design speed (mph)	Minimum runoff and runout length (ft) — Runoff, Superelevation 2	4	6	8	10	12	Runout (any)
One lane rotated							
15	31	61	92	123	154	184	31
20	32	65	97	130	162	194	32
25	34	69	103	137	172	206	34
30	36	73	109	146	182	219	36
35	39	77	116	155	193	232	39
40	41	83	124	165	206	248	41
45	44	89	133	178	222	266	44
50	48	96	144	192	240	288	48
55	51	102	153	204	256	307	51
60	53	107	160	213	266	320	53
65	56	112	168	224	280	336	56
70	60	120	180	240	300	360	60
75	63	126	189	252	316	379	63
80	69	137	206	275	343	412	69
Two lanes rotated							
15	46	92	138	184	230	276	46
20	49	97	146	194	243	292	49
25	51	103	154	206	257	309	51
30	55	109	164	219	274	328	55
35	58	116	174	232	290	348	58
40	62	124	186	248	310	372	62
45	67	133	200	266	333	400	67
50	72	144	216	288	360	432	72
55	77	153	230	307	383	460	77
60	80	160	240	320	400	480	80
65	84	168	252	336	419	503	84
70	90	180	270	360	450	540	90
75	95	189	284	379	473	568	95
80	103	206	309	412	515	618	103

Note: Based on 3.6 m [12 ft] lanes and on a 2.0% normal cross slope.

from AASHTO's *A Policy on Geometric Design of Highways and Streets 2001*

Superelevation Runoff - WSDOT

S (%)	L_B=Basic runoff in feet for Design Speed of:													
	15 mph	20 mph	25 mph	30 mph	35 mph	40 mph	45 mph	50 mph	55 mph	60 mph	65 mph	70 mph	75 mph	80 mph
2	30	30	35	35	40	40	45	50	50	55	55	60	65	70
3	45	50	50	55	60	60	65	70	75	80	85	90	95	105
4	60	65	70	75	75	85	90	95	100	105	110	120	125	135
5	75	80	85	90	95	105	110	120	130	135	140	150	160	170
6	90	95	105	110	115	125	135	145	155	160	170	180	190	205
7	110	115	120	130	135	145	155	170	180	185	195	210	220	240
8	125	130	135	145	155	165	180	190	205	215	225	240	250	275
9	140	145	155	165	175	185	200	215	230	240	250	270	285	310
10	155	160	170	180	195	205	220	240	255	265	280	300	315	345

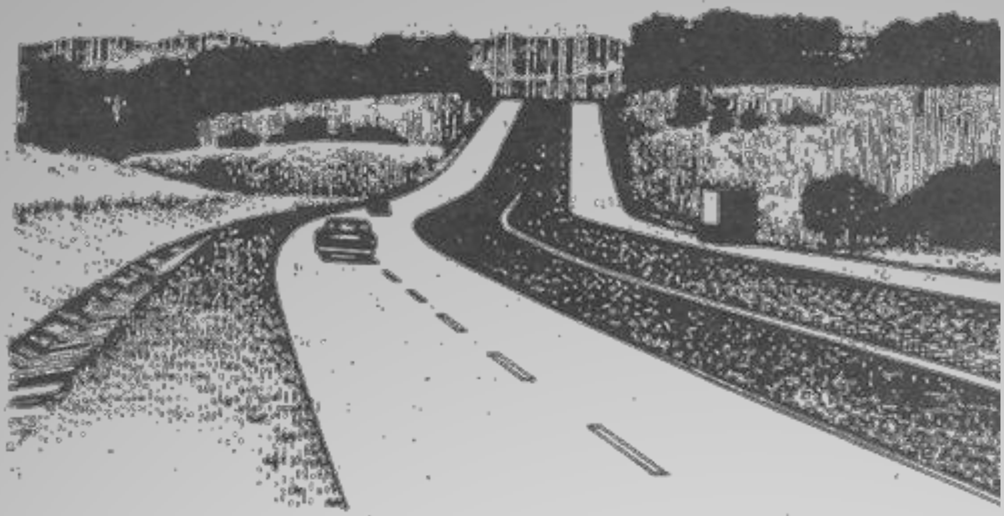
* Based on one 12 ft lane between the pivot point and the edge of traveled way. When the distance exceeds 12 ft use the following equation to obtain L_R:
$L_R = L_B(1+0.04167X)$

Where:

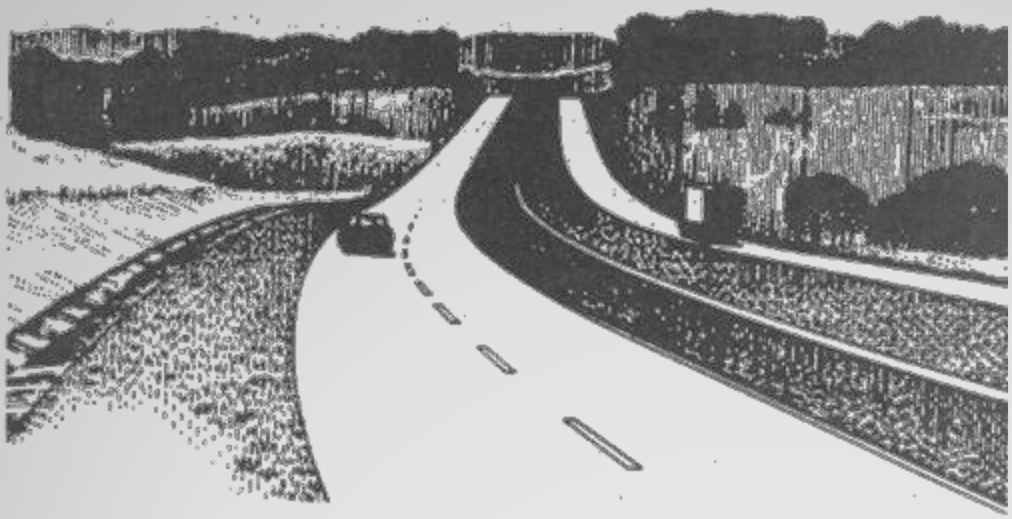
X = The distance in excess of 12 ft between the pivot point and the furthest edge of traveled way, in feet

from the 2005 WSDOT *Design Manual*, M 22-01

Spiral Curves



No Spiral



Spiral

from AASHTO's *A Policy on Geometric Design of Highways and Streets*

No Spiral

Spiral Curves

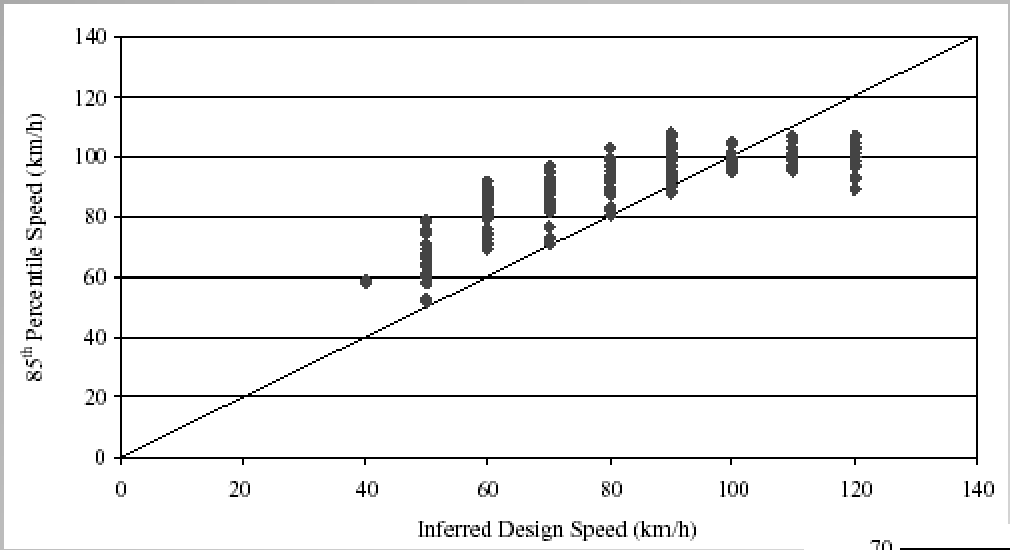
- WSDOT no longer uses spiral curves
- Involve complex geometry
- Require more surveying
- Are somewhat empirical
- If used, superelevation transition should occur entirely within spiral

Desirable Spiral Lengths

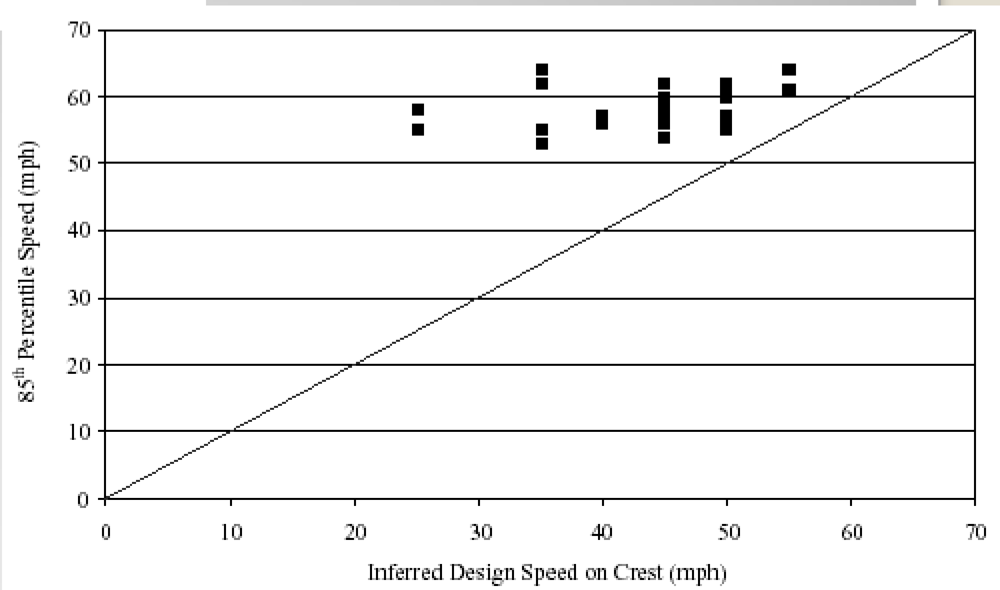
Metric		US Customary	
Design speed (km/h)	Spiral length (m)	Design speed (mph)	Spiral length (ft)
20	11	15	44
30	17	20	59
40	22	25	74
50	28	30	88
60	33	35	103
70	39	40	117
80	44	45	132
90	50	50	147
100	56	55	161
110	61	60	176
120	67	65	191
130	72	70	205
		75	220
		80	235

from AASHTO's *A Policy on Geometric Design of Highways and Streets 2001*

Operating vs. Design Speed



85th Percentile Speed vs. Inferred Design Speed for 138 Rural Two-Lane Highway Horizontal Curves



85th Percentile Speed vs. Inferred Design Speed for Rural Two-Lane Highway Limited Sight Distance Crest Vertical Curves

Primary References

- Mannering, F.L.; Kilareski, W.P. and Washburn, S.S. (2005). *Principles of Highway Engineering and Traffic Analysis*, Third Edition. Chapter 3

- American Association of State Highway and Transportation Officials (AASHTO). (2001). *A Policy on Geometric Design of Highways and Streets*, Fourth Edition. Washington, D.C.

UNIT – III:
TRAFFIC ENGINEERING AND REGULATIONS

Basic Parameters of Traffic –Volume, Speed and density-Traffic volume studies-Data collection and presentation-Speed studies – Data collection and presentation- Origin and Destinations studies,- Parking Studies –On street and off-street parking - Road Accidents - Causes and Preventive measures- Accident Data Recording – Condition Diagram and Collision Diagrams-Traffic Signs – Types and Specifications – Road markings-Need for Road Markings-Types of Road Markings- Design of Traffic Signals- Webster method.

Traffic Engineering Studies

- **Traffic studies may be grouped into three main categories:**
  - **(1) Inventories,**
  - **(2) Administrative studies, and**
  - **(3) Dynamic studies.**

Traffic Engineering Studies

(1) **Inventories:**

provide a list or graphic display of existing information, such as:

- street widths,
- parking spaces,
- transit routes,
- traffic regulations.

Traffic Engineering Studies

(2) Administrative studies

- use existing engineering records, available in government agencies and departments.
- include the results of surveys, which may involve:
  - field measurements and/or
  - aerial photography.

Traffic Engineering Studies

(3) Dynamic traffic studies

- involve the collection of data under operational conditions and
- include studies of:
  - speed,
  - traffic volume,
  - travel time and delay,
  - parking, and
  - crashes.
- They are described in detail in this chapter.

Traffic Engineering Studies

- **4.1 SPOT SPEED STUDIES**
  - Spot speed studies are conducted to estimate the distribution of speeds of vehicles in a stream of traffic at a particular location on a highway.
  - carried out by recording the speeds of a sample of vehicles at a specified location.

Traffic Engineering Studies

- **SPOT SPEED STUDIES**

Used to:

- Establish parameters for traffic operation and control, such as:
  - speed zones,
  - speed limits (85th-percentile speed)

Traffic Engineering Studies

- **4.1.1 Locations for Spot Speed Studies**
  - Represent different traffic conditions on a highway for *basic data collection.*
  - Mid-blocks of urban highways and straight, level sections of rural highways for *speed trend analyses.*
  - Any location may be used for solution of a *specific traffic engineering problem.*

Traffic Engineering Studies

- **4.1.1 Locations for Spot Speed Studies**

  Should be selected to achieve the following:
  - Unbiased data
  - Drivers be unaware
  - Equipment concealed from the driver,
  - Observers inconspicuous.

Traffic Engineering Studies

- **4.1.1 Locations for Spot Speed Studies**
  - statistical analysis,
  - statistically adequate number of vehicle speeds be recorded.

Traffic Engineering Studies

- **4.1.2 Time of Day and Duration of Spot Speed Studies**
  - depends on the purpose of the study.
  - recommended when traffic is free-flowing,
  - during off-peak hours.
  - typically:
    - the duration is at least 1 hour and
    - the sample size is at least 30 vehicles.

Traffic Engineering Studies

- **4.1.3 Sample Size for Spot Speed Studies**
  - The larger the sample size, will give an estimated mean within acceptable error limits.
    - Average Speed
    - Median Speed
    - Modal Speed
    - The ith-percentile Spot Speed
    - Pace
    - Standard Deviation of Speeds

Traffic Engineering Studies

- **4.1.4 Methods for Conducting Spot Speed Studies**
  - manual and automatic
  - manual method is seldom used
  - automatic devices
    1. road detectors
    2. radar-based
    3. the principles of electronics.

Traffic Engineering Studies

Traffic Engineering Studies

- Road Detectors
  - pneumatic road tubes & induction loops collect data on speeds & volume at the same time
  - **Advantage:**
    - Human errors are considerably reduced
  - **Disadvantages:**
    - expensive
    - may, affect driver behavior,

Traffic Engineering Studies

- Pneumatic road tubes
  - laid across the lane in which data are to be collected.
  - When moving vehicle passes over, an air impulse is transmitted to the counter.
  - two tubes are placed across the lane, 2 m apart.
  - An impulse is recorded when the front wheels of a moving vehicle pass over the first tube;

Traffic Engineering Studies

- Pneumatic road tubes
  - a second impulse is recorded when the front wheels pass over the second tube.
  - The time elapsed between the two impulses and the distance between the tubes are used to compute the speed of the vehicle.

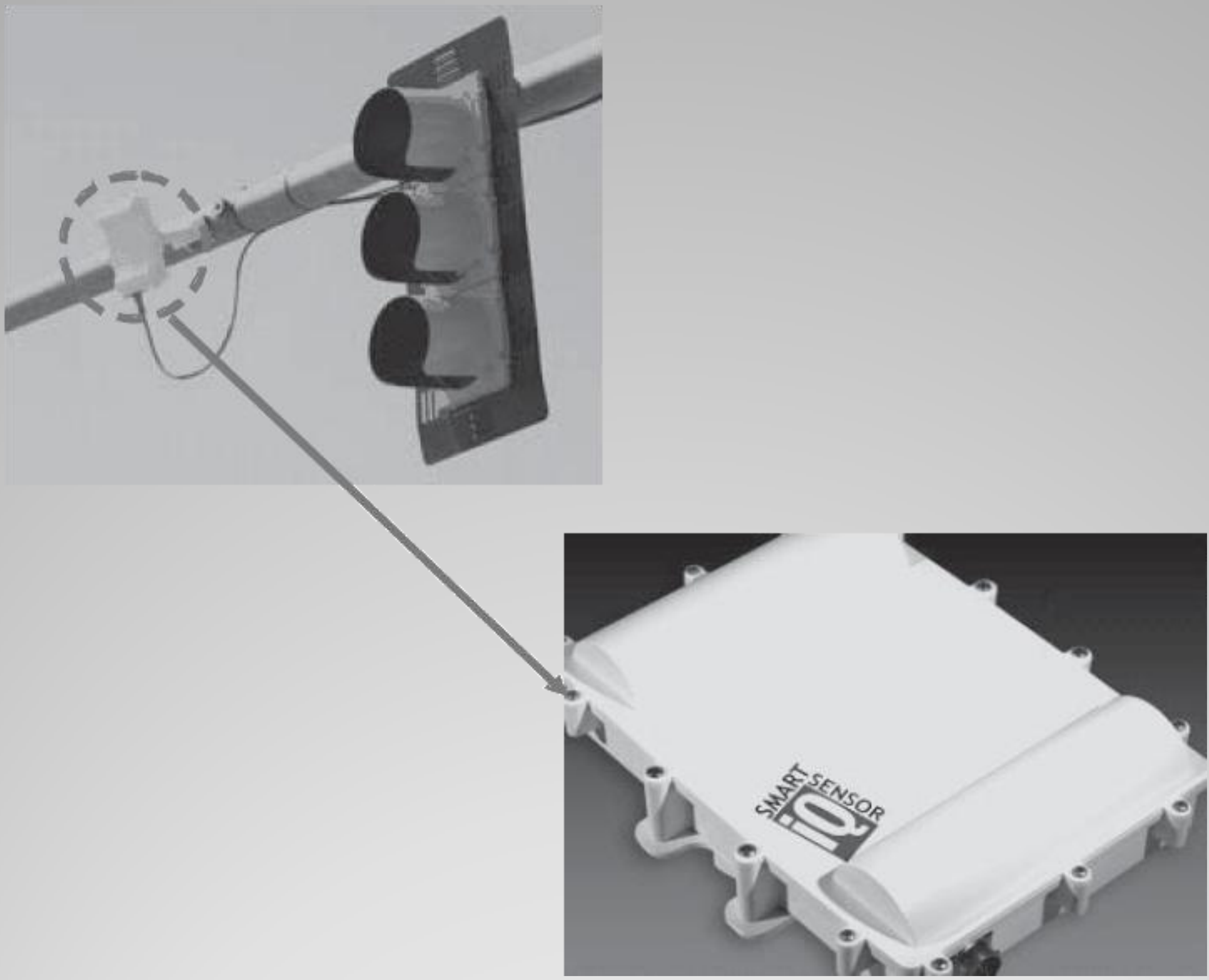
Traffic Engineering Studies

- inductive loop
  - a rectangular wire loop buried under the roadway surface.
  - It operates on the principle that a disturbance in the electrical field is created when a motor vehicle passes across it.

Traffic Engineering Studies

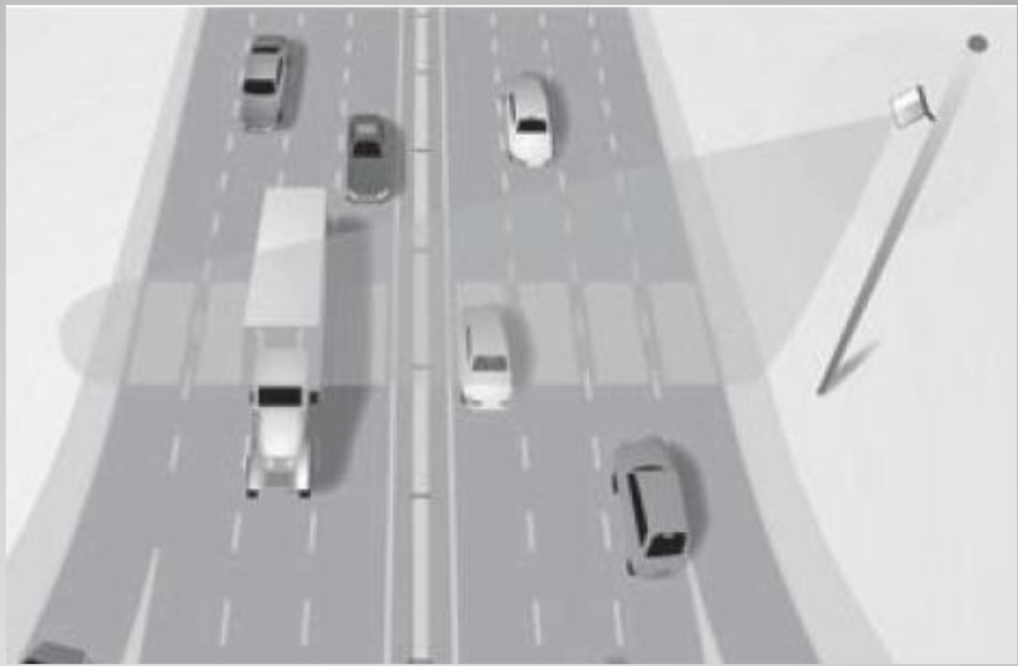
- Radar-Based Traffic Sensors
- Electronic-Principle Detectors
  - traffic characteristics, such as speed, volume, queues, and headways are computed.
  - Using video image processing

Traffic Engineering Studies



(a) RTMS Deployed in the Forward Looking Mode

Traffic Engineering Studies

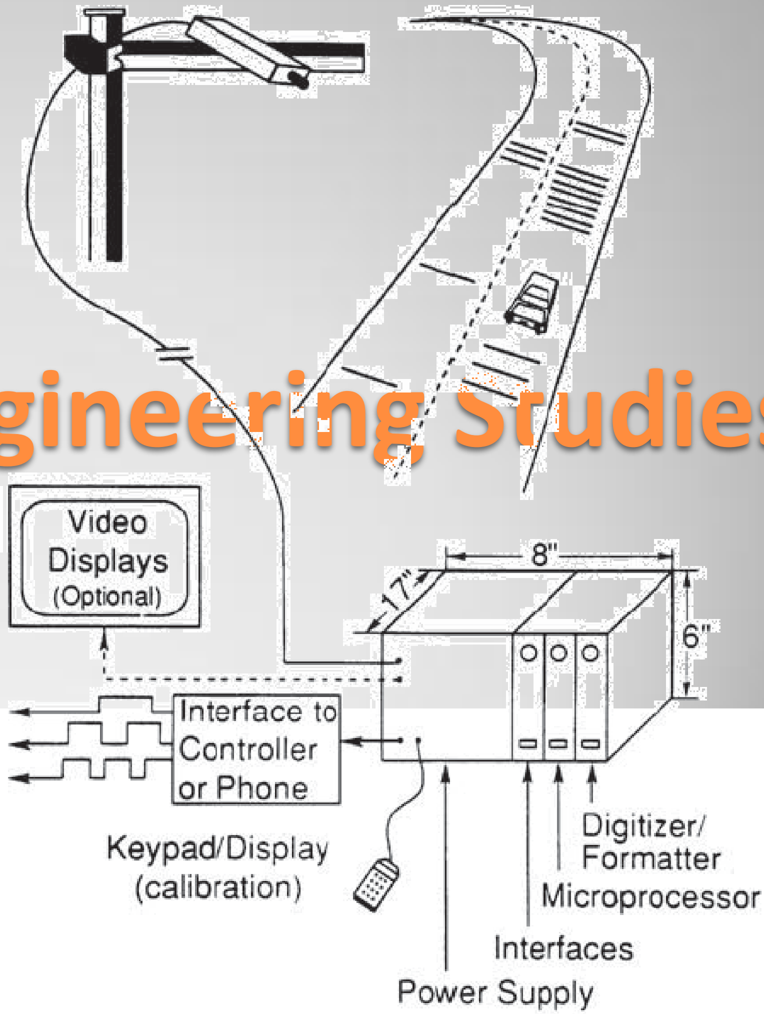


(b) RTMS Deployed in the Side-fire Mode

Traffic Engineering Studies

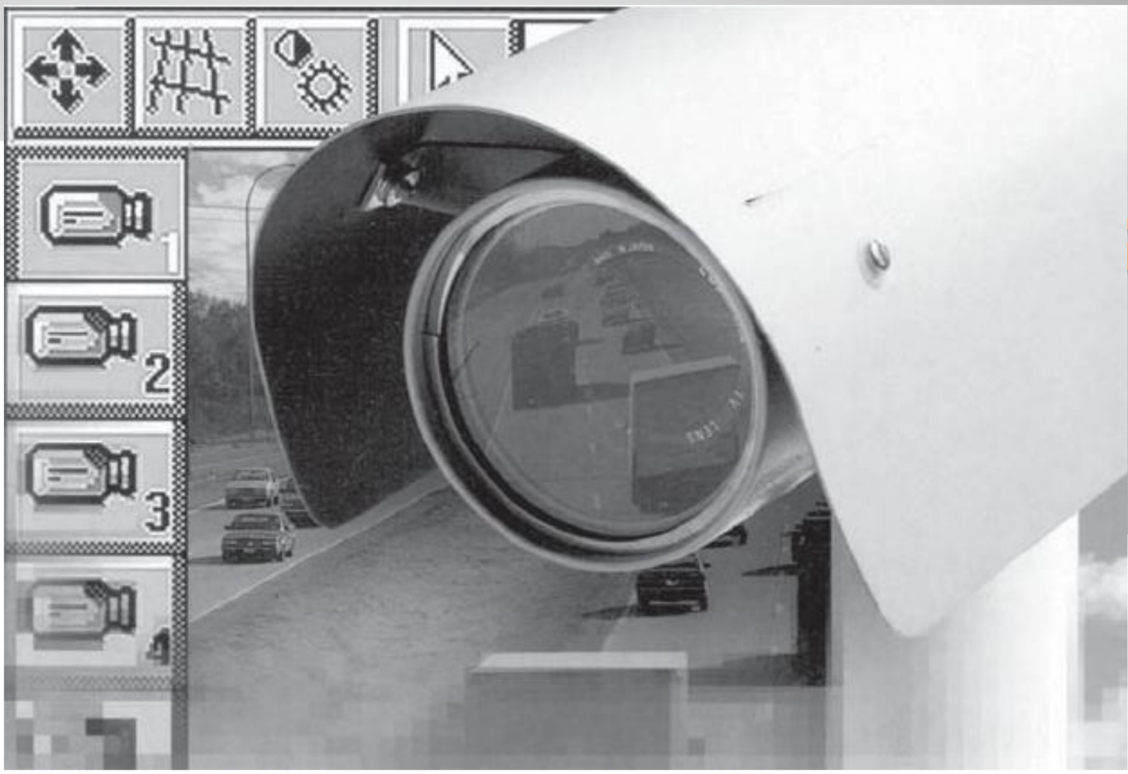
(a) Schematic Illustration of the Auto scope

Traffic Engineering Studies



Traffic Engineering Studies

(b) The Auto scope Deployed



Traffic Engineering Studies

- **4.1.5 Presentation and Analysis of Spot Speed Data**
  - Statistical methods
  - Analyzing data
  - frequency histogram
  - cumulative frequency distribution curve

Traffic Engineering Studies

- **Example 4.2** Determining Speed Characteristics from a Set of Speed Data.

  Table 4.2 shows the data collected on a rural highway in Virginia during a speed study. Develop the frequency histogram and the frequency distribution of the data and determine:

Traffic Engineering Studies

Traffic Engineering Studies

1. The arithmetic mean speed
2. The standard deviation
3. The median speed
4. The pace
5. The mode or modal speed
6. The 85^{th}-percentile speed

Traffic Engineering Studies

- **Solution:**
- The speeds range from 34.8 to 65.0 km/h, giving a speed range of 30.2.
- For eight classes, the range per class is 3.75 km/h;
- for 20 classes, the range per class is 1.51 km/h.
- It is convenient to choose a range of 2 km/h per class which will give 16 classes.
- A frequency distribution table can then be prepared, as shown in Table 4.3.

Traffic Engineering Studies

Car No.	Speed (mi/h)	Car No.	Speed (mi/h)	Car No.	Speed (mi/h)	Car No.	Speed (mi/h)
1	35.1	23	46.1	45	47.8	67	56.0
2	44.0	24	54.2	46	47.1	68	49.1
3	45.8	25	52.3	47	34.8	69	49.2
4	44.3	26	57.3	48	52.4	70	56.4
5	36.3	27	46.8	49	49.1	71	48.5
6	54.0	28	57.8	50	37.1	72	45.4
7	42.1	29	36.8	51	65.0	73	48.6
8	50.1	30	55.8	52	49.5	74	52.0
9	51.8	31	43.3	53	52.2	75	49.8
10	50.8	32	55.3	54	48.4	76	63.4
11	38.3	33	39.0	55	42.8	77	60.1
12	44.6	34	53.7	56	49.5	78	48.8
13	45.2	35	40.8	57	48.6	79	52.1
14	41.1	36	54.5	58	41.2	80	48.7
15	55.1	37	51.6	59	48.0	81	61.8
16	50.2	38	51.7	60	58.0	82	56.6
17	54.3	39	50.3	61	49.0	83	48.2
18	45.4	40	59.8	62	41.8	84	62.1
19	55.2	41	40.3	63	48.3	85	53.3
20	45.7	42	55.1	64	45.9	86	53.4
21	54.1	43	45.0	65	44.7		
22	54.0	44	48.3	66	49.5		

Table 4.2 Speed Data Obtained on a Rural Highway

Traffic Engineering Studies

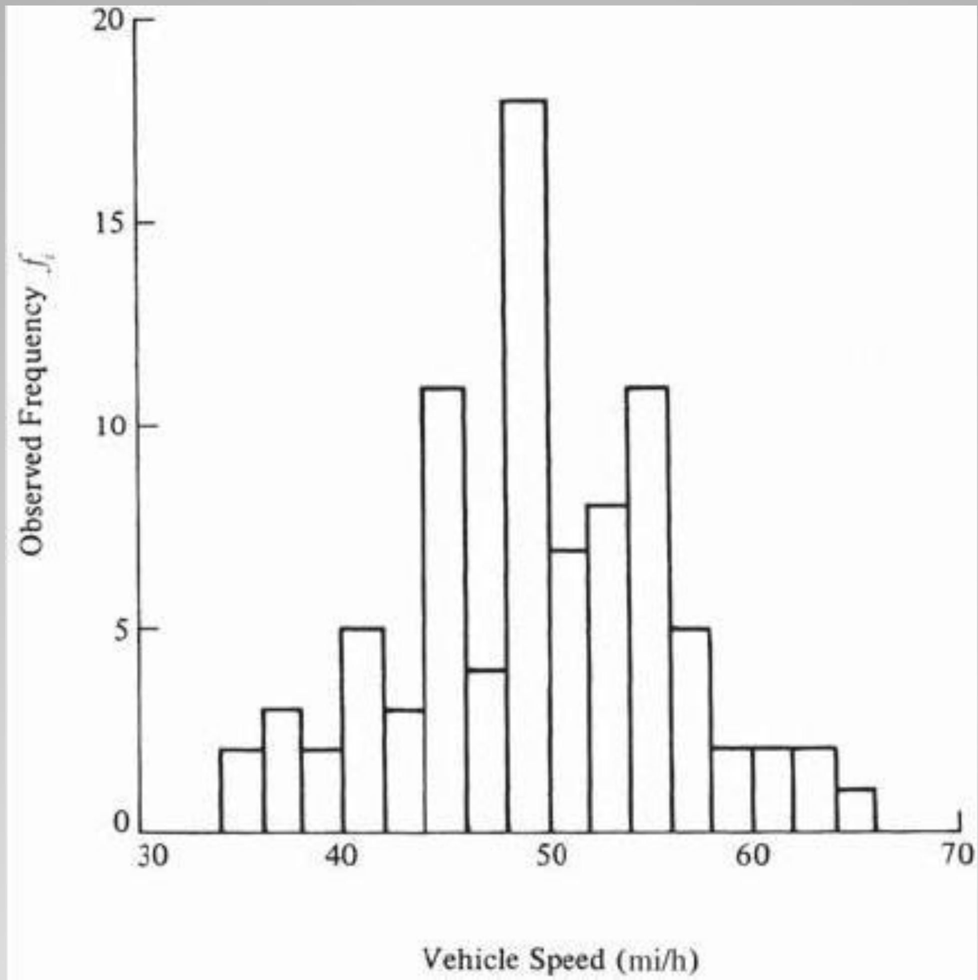


Figure 4.4 Histogram of Observed Vehicles' Speeds

Traffic Engineering Studies

1 Speed Class (mi/hr)	2 Class Midvalue, u_i	3 Class Frequency (Number of Observations in Class), f_i	4 $f_i u_i$	5 Percentage of Observations in Class	6 Cumulative Percentage of All Observations	7 $f(u_i - \bar{u})^2$
34–35.9	35.0	2	70	2.3	2.30	420.5
36–37.9	37.0	3	111	3.5	5.80	468.75
38–39.9	39.0	2	78	2.3	8.10	220.50
40–41.9	41.0	5	205	5.8	13.90	361.25
42–43.9	43.0	3	129	3.5	17.40	126.75
44–45.9	45.0	11	495	12.8	30.20	222.75
46–47.9	47.0	4	188	4.7	34.90	25.00
48–49.9	49.0	18	882	21.0	55.90	9.0
50–51.9	51.0	7	357	8.1	64.0	15.75
52–53.9	53.0	8	424	9.3	73.3	98.00
54–55.9	55.0	11	605	12.8	86.1	332.75
56–57.9	57.0	5	285	5.8	91.9	281.25
58–59.9	59.0	2	118	2.3	94.2	180.50
60–61.9	61.0	2	122	2.3	96.5	264.50
62–63.9	63.0	2	126	2.3	98.8	364.50
64–65.9	65.0	1	65	1.2	100.0	240.25
Totals		86	4260			3632.00

Table 4.3 Frequency Distribution Table for Set of Speed Data

Traffic Engineering Studies

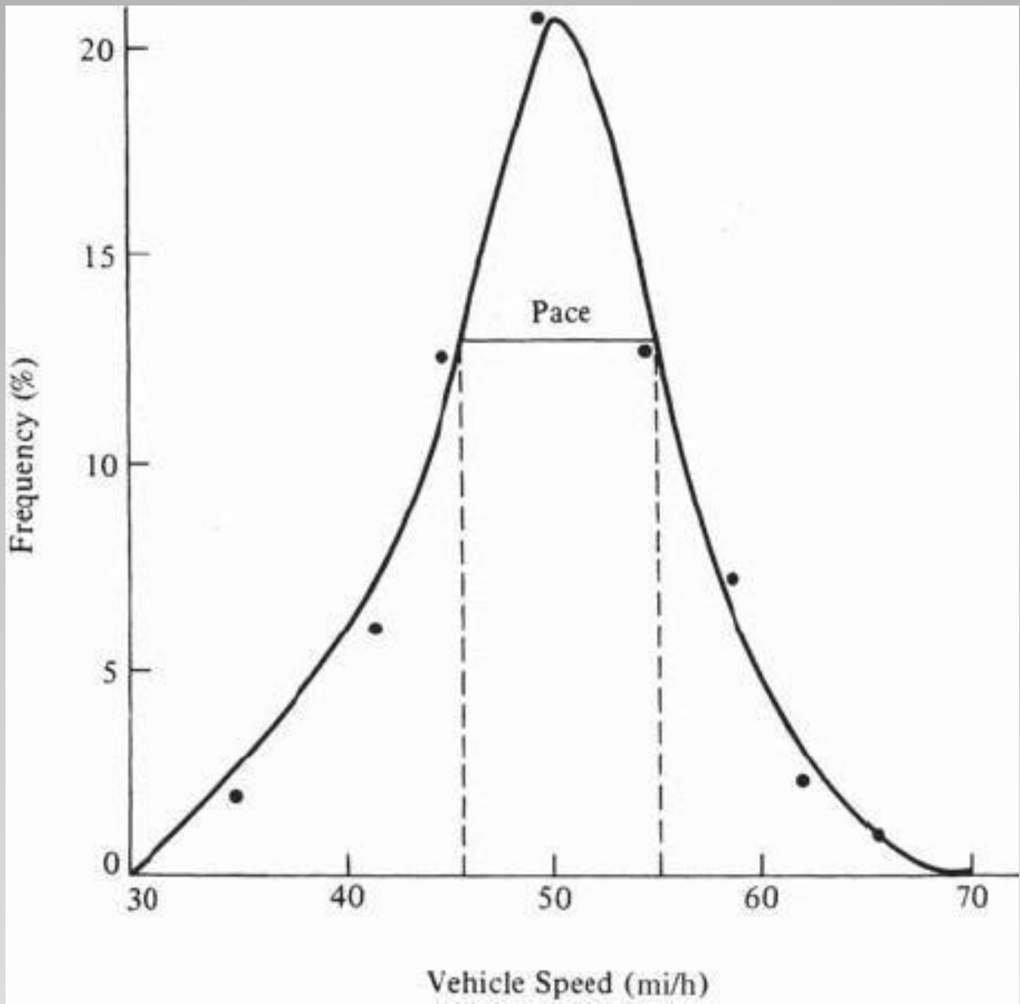


Figure 4.5 Frequency Distribution

Traffic Engineering Studies

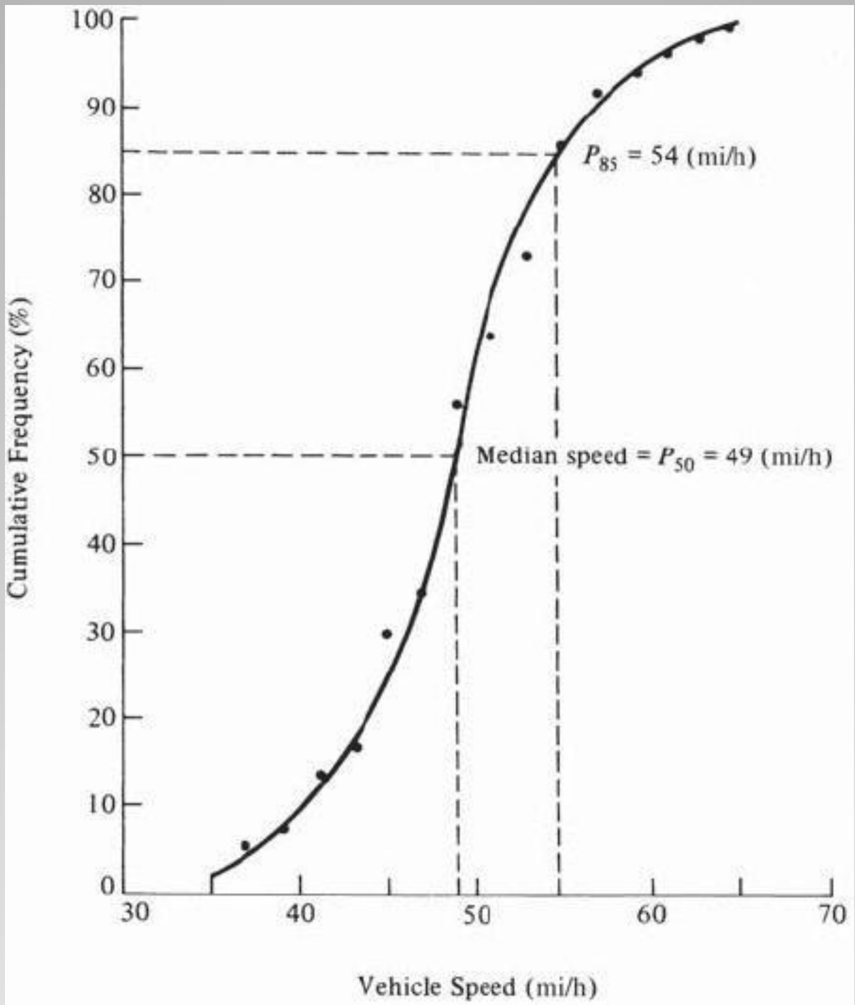


Figure 4.6 Cumulative Distribution

Traffic Engineering Studies

- The median speed 49 km/h,

  the 50th-percentile speed.
- 85th-percentile speed is 54 km/h

Traffic Engineering Studies

- **4.2 VOLUME STUDIES**

1. **Average Annual Daily Traffic** (AADT)

   the average of 24-hour counts collected every day of the year.

2. **Average Daily Traffic** (ADT)

   the average of 24-hour counts collected over a number of days greater than one but less than a year.

Traffic Engineering Studies

- **4.2 VOLUME STUDIES**

3. **Peak Hour Volume** (PHV)

   the maximum number of vehicles that pas a point on a highway during a period of 60 consecutive minutes.

4. **Vehicle Classification** (VC) with respect to the type of vehicles for cars, two-axle trucks, or three-axle trucks.
5. **Vehicle Miles of Travel** (VMT)

Traffic Engineering Studies

- **4.2.1 Methods of Conducting Volume Counts**
  - Manual Method
  - Automatic Method

Traffic Engineering Studies

Figure 4.7 Jamar Traffic Data Collector TDC-1 2 Hooked to a Computer

Traffic Engineering Studies

Figure 4.9 Apollo Traffic Counter/Classifier

Traffic Engineering Studies

Figure 4.10 Example of Counters that Require the Laying of Subsurface Detectors

Traffic Engineering Studies

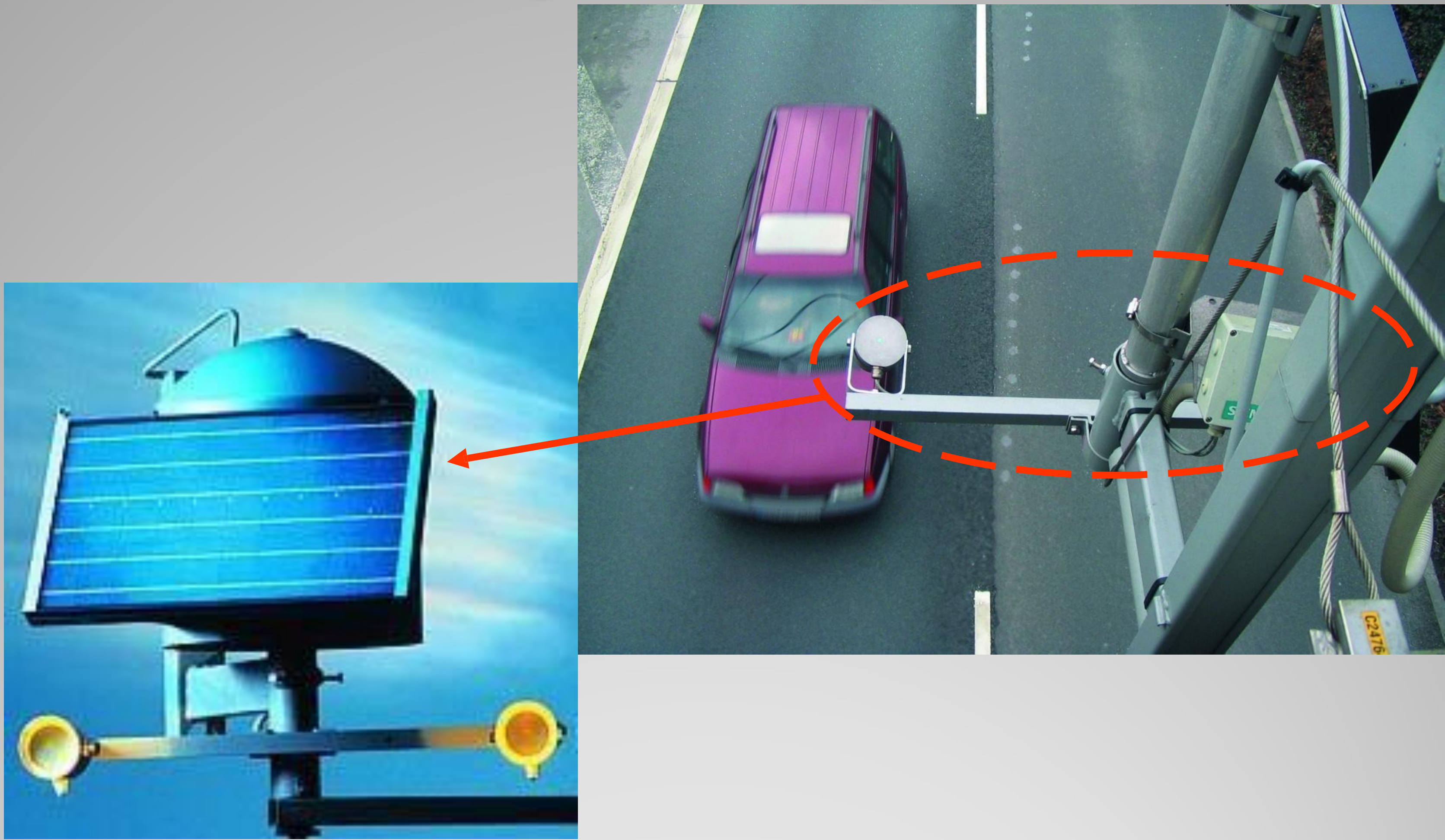


Figure 4.11 Traffic Eye Universal System

Traffic Engineering Studies

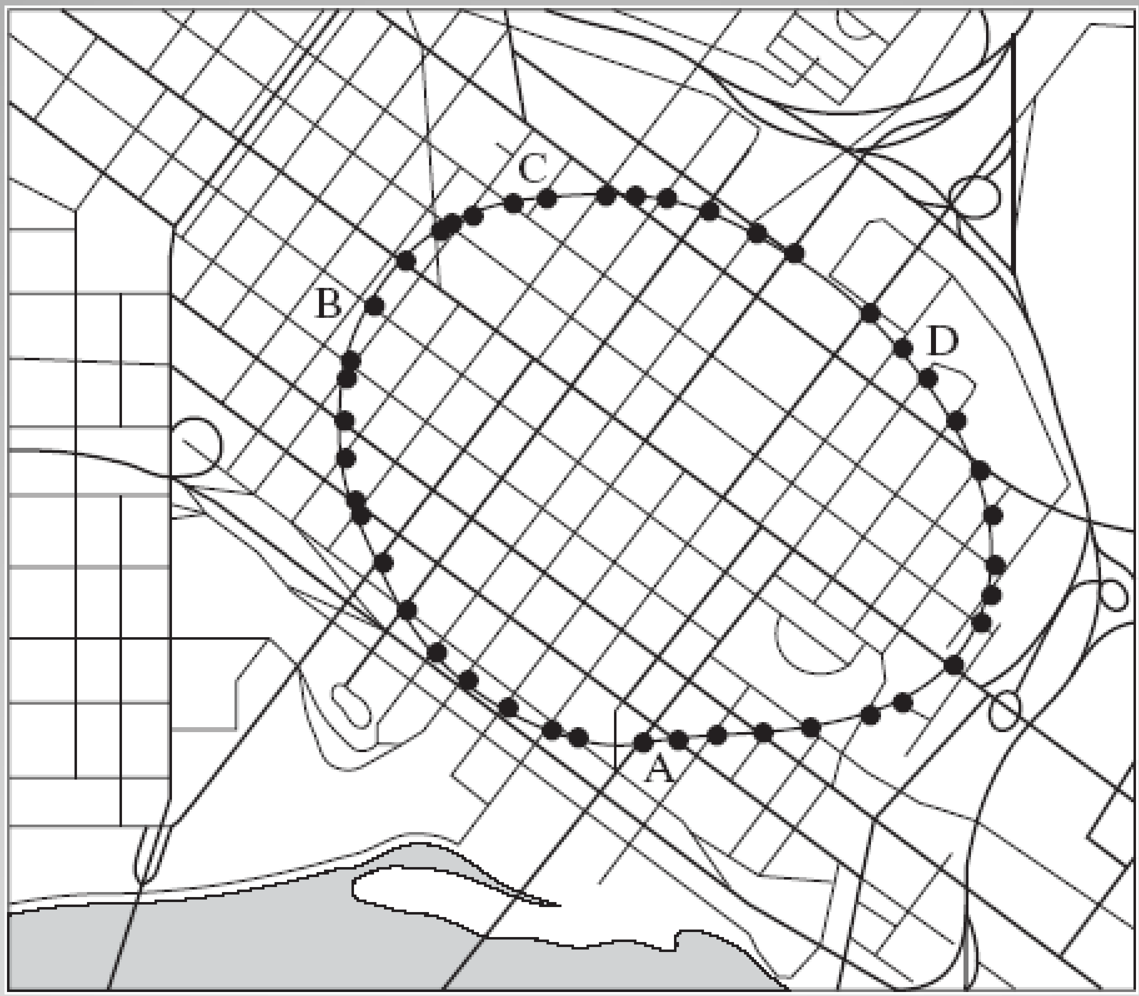


Figure 4.12 Example of Station Locations for a Cordon Count

Traffic Engineering Studies

- **4.2.2 Types of Volume Counts**
  - Depending on the anticipated use of the data to be collected.
- Intersection Counts
  - **vehicle classifications,**
  - **through movements,**
  - **turning movements.**

Traffic Engineering Studies

- **4.2.2 Types of Volume Counts**
  - Pedestrian Volume Counts
  - Periodic Volume Counts (AADT)

Traffic Engineering Studies

- **4.2.3 Traffic Volume Data Presentation**
  - **Traffic Flow Maps:** volume of traffic on each route is represented by the width of a band.

    Figure 4.13 shows a typical traffic flow map.

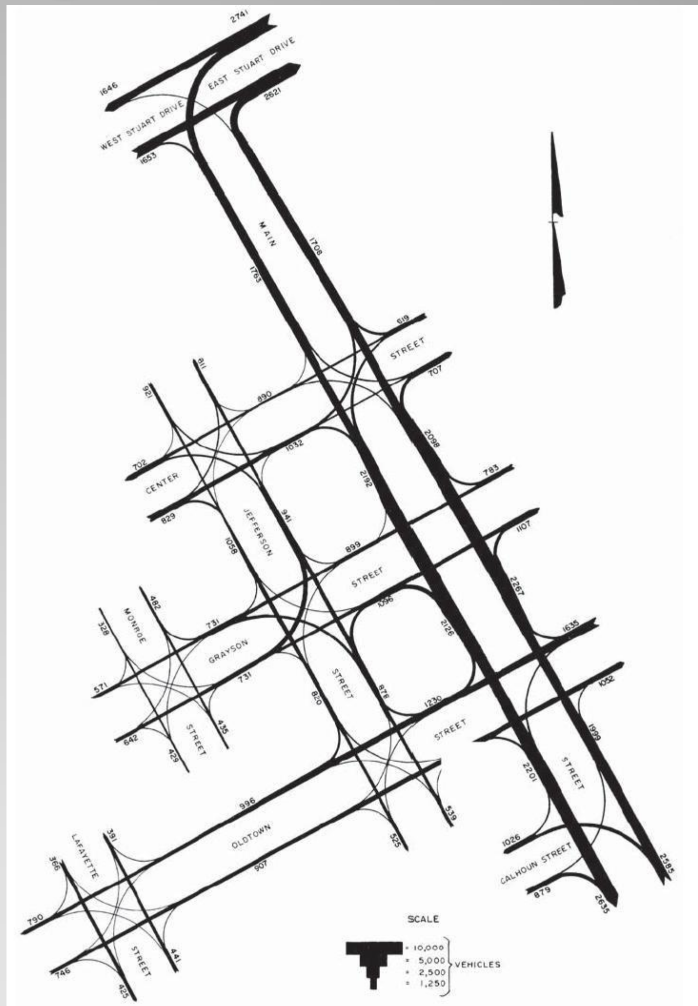


Figure 4.13 Example of a Traffic Flow Map

Traffic Engineering Studies

Intersection Summary Sheets:

Figure 4.14 shows a typical intersection summary sheet.

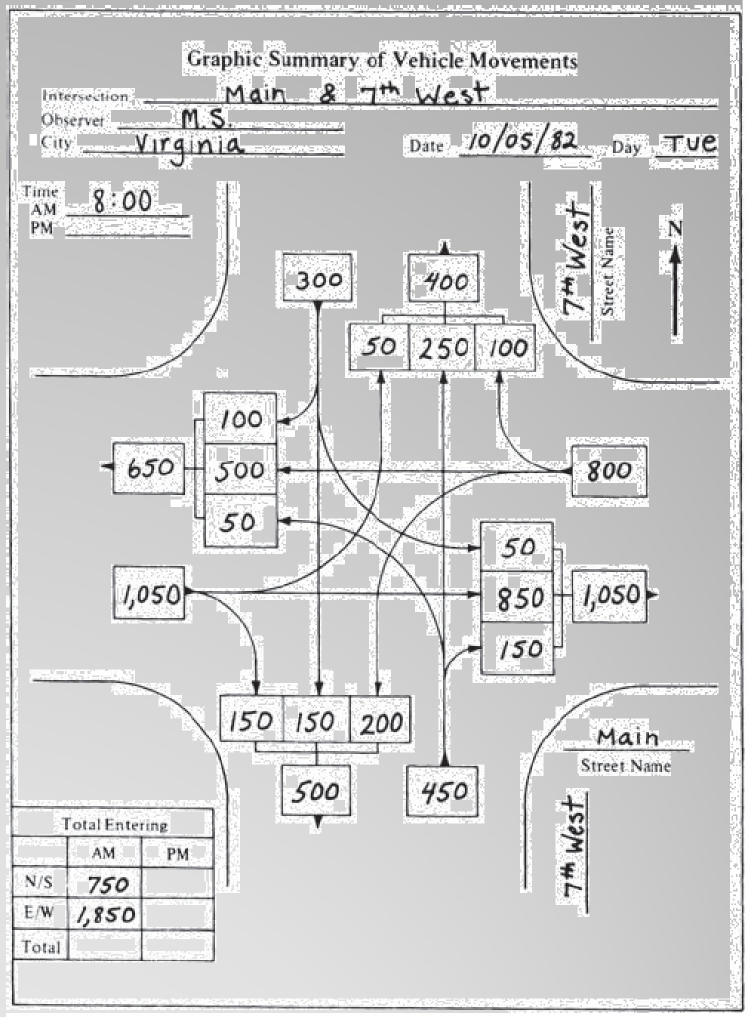


Figure 4.14 Intersection Summary Sheet

Traffic Engineering Studies

- **4.2.3 Traffic Volume Data Presentation**
  - Time-Based Distribution Charts:

    see Figure 4.15

Traffic Engineering Studies

Daily variations: see Figure 4.15b

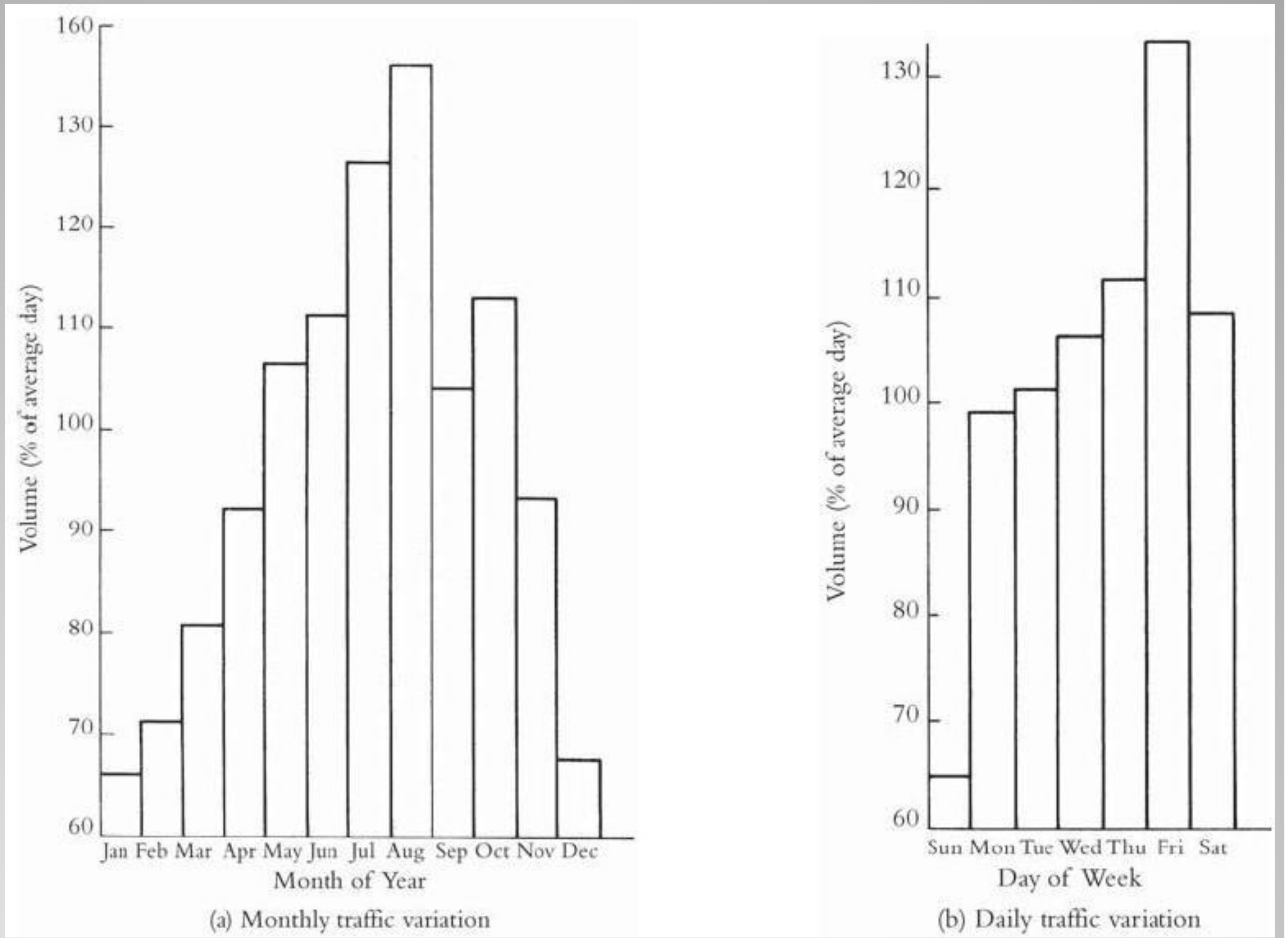


Figure 4.15 Traffic Volumes on an Urban Highway (A&B)

Traffic Engineering Studies

Hourly variations in traffic volume:

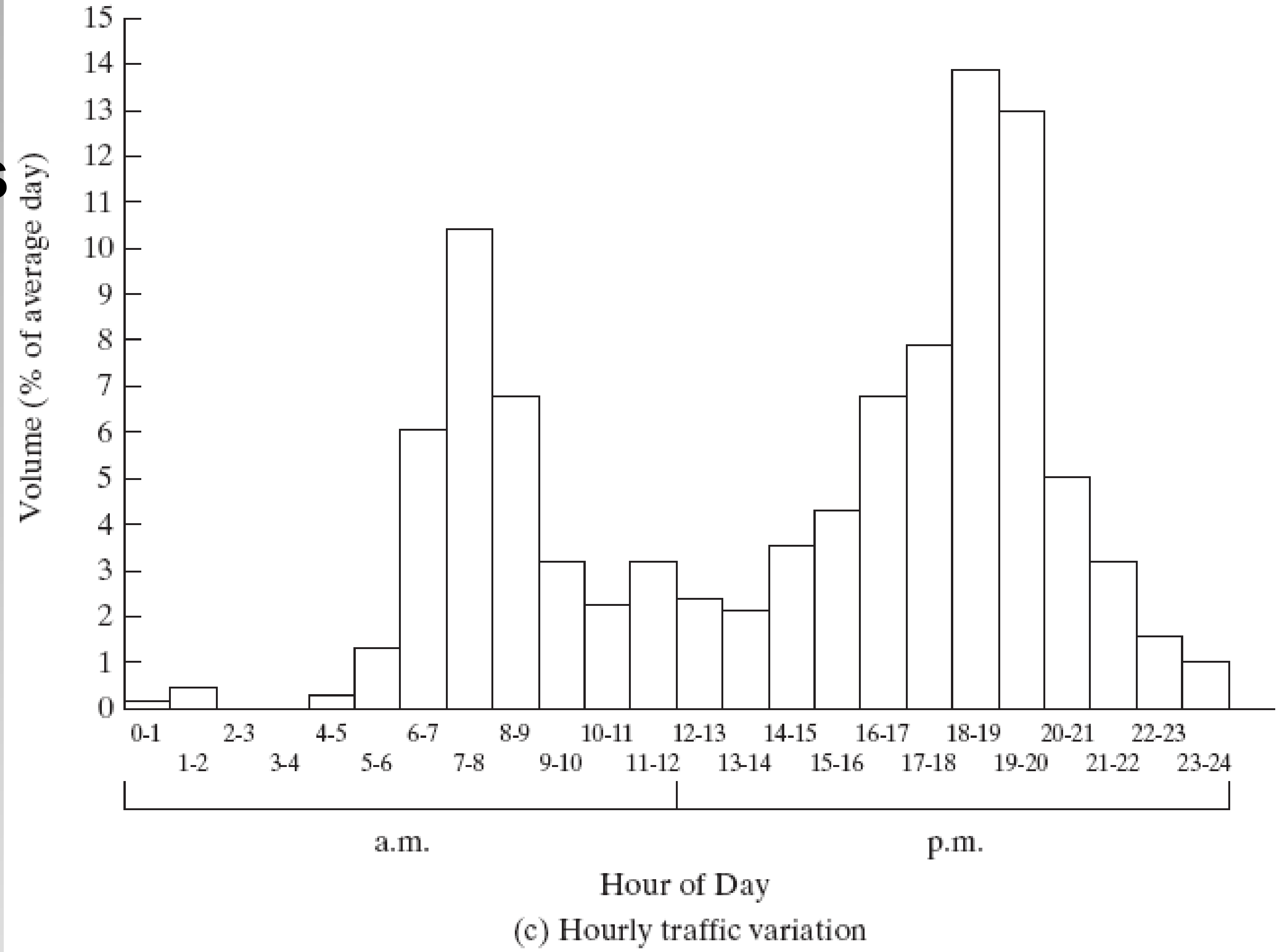


Figure 4.15 Traffic Volumes on an Urban Highway (C)

Traffic Engineering Studies

Traffic Engineering Studies

Summary Tables:

PHV, Vehicle Classification (VC), and ADT. See Table 4.4

Table 4.4 Summary of Traffic Volume Data for a Highway Section

PHV	430
ADT	5375
Vehicle Classification (VC)	
Passenger cars	70%
Two-axle trucks	20%
Three-axle trucks	8%
Other trucks	2%

Traffic Engineering Studies

- Adjustment of Periodic Counts
- Expansion Factors from Continuous Count Stations.
- Hourly expansion factors (HEFs) are determined by the formula

$$\text{HEF} = \frac{\text{total volume for 24-hr period}}{\text{volume for particular hour}}$$

Traffic Engineering Studies

Traffic Engineering Studies

- Daily expansion factors (DEFs) are computed as

$$\text{DEF} = \frac{\text{average total volume for week}}{\text{average volume for particular day}}$$

- Monthly expansion factors (MEFs) are computed as

$$\text{MEF} = \frac{\text{AADT}}{\text{ADT for particular month}}$$

Traffic Engineering Studies

Table 4.5 Hourly Expansion Factors for a Rural Primary Road

Hour	*Volume*	*HEF*	*Hour*	*Volume*	*HEF*
6:00–7:00 a.m.	294	42.00	6:00–7:00 p.m.	743	16.62
7:00–8:00 a.m.	426	29.00	7:00–8:00 p.m.	706	17.49
8:00–9:00 a.m.	560	22.05	8:00–9:00 p.m.	606	20.38
9:00–10:00 a.m.	657	18.80	9:00–10:00 p.m.	489	25.26
10:00–11:00 a.m.	722	17.10	10:00–11:00 p.m.	396	31.19
11:00–12:00 p.m.	667	18.52	11:00–12:00 a.m.	360	34.31
12:00–1:00 p.m.	660	18.71	12:00–1:00 a.m.	241	51.24
1:00–2:00 p.m.	739	16.71	1:00–2:00 a.m.	150	82.33
2:00–3:00 p.m.	832	14.84	2:00–3:00 a.m.	100	123.50
3:00–4:00 p.m.	836	14.77	3:00–4:00 a.m.	90	137.22
4:00–5:00 p.m.	961	12.85	4:00–5:00 a.m.	86	143.60
5:00–6:00 p.m.	892	13.85	5:00–6:00 a.m.	137	90.14

Total daily volume = 12,350.

Traffic Engineering Studies

Table 4.6 Daily Expansion Factors for a Rural Primary Road

Day of Week	*Volume*	*DEF*
Sunday	7895	9.515
Monday	10,714	7.012
Tuesday	9722	7.727
Wednesday	11,413	6.582
Thursday	10,714	7.012
Friday	13,125	5.724
Saturday	11,539	6.510

Total weekly volume = 75,122.

Traffic Engineering Studies

Table 4.7 Monthly Expansion Factors for a Rural Primary Road

Month	*ADT*	*MEF*
January	1350	1.756
February	1200	1.975
March	1450	1.635
April	1600	1.481
May	1700	1.394
June	2500	0.948
July	4100	0.578
August	4550	0.521
September	3750	0.632
October	2500	0.948
November	2000	1.185
December	1750	1.354

Total yearly volume = 28,450.
Mean average daily volume = 2370.

Traffic Engineering Studies

Example 4.5 Calculating AADT Using Expansion Factors

A traffic engineer urgently needs to determine the AADT on a rural primary road that has the volume distribution characteristics shown in Tables 4.5, 4.6, and 4.7. She collected the data shown below on a Tuesday during the month of May. Determine the AADT of the road.

7:00–8:00 a.m.	400
8:00–9:00 a.m.	535
9:00–10:00 a.m.	650
10:00–11:00 a.m.	710
11:00–12 noon	650

Traffic Engineering Studies

Solution:

- Estimate the 24-hr volume for Tuesday using the factors given in Table 4.5.

$$\frac{(400 \times 29.0 + 535 \times 22.05 + 650 \times 18.80 + 710 \times 17.10 + 650 \times 18.52)}{5} \approx 11{,}959$$

- Adjust the 24-hr volume for Tuesday to an average volume for the week using the factors given in Table 4.6.

$$\text{Total 7-day volume} = 11{,}959 \times 7.727$$

$$\text{Average 24-hr volume} = \frac{11{,}959 \times 7.727}{7} = 13{,}201$$

- Since the data were collected in May, use the factor shown for May in Table 4.7 to obtain the AADT.

$$\text{AADT} = 13{,}201 \times 1.394 = 18{,}402$$

Traffic Engineering Studies

- **4.3 TRAVEL TIME AND DELAY STUDIES**
  - Travel time: time required to travel from one point to another on a given route.
  - the locations, durations, and causes of delays.
  - good indication of the level of service
  - identifying problem locations,

Traffic Engineering Studies

- **4.3.1 Applications of Travel Time and Delay Data**
  - efficiency of a route
  - locations with relatively high delays
  - causes for delays
  - before-and-after studies
  - relative efficiency of a route
  - travel times on specific links
  - economic studies

Traffic Engineering Studies

- **4.3.2 Definition of Terms Related to Time and Delay Studies**

1. **Travel time:** time taken by a vehicle to traverse a given section of a highway.
2. **Running time:** time a vehicle is actually in motion

Traffic Engineering Studies

- 4.3.2 Definition of Terms Related to Time and Delay Studies

3. **Delay** time lost due to causes beyond the control of the driver.
4. **Operational delay:** delay caused by the impedance of other traffic.

   (for example, parking or unparking vehicles),

Traffic Engineering Studies

5. **Stopped-time delay**
6. **Fixed delay:** caused by control devices such as traffic signals, regardless of the traffic volume
7. **Travel-time delay:** difference between the actual travel time and the travel time obtained by assuming that a vehicle traverses at an average speed equal to that for an uncongested traffic flow

Traffic Engineering Studies

- **4.3.3 Methods for Conducting Travel Time and Delay Studies**
  - Methods Requiring a Test Vehicle: floating-car, average-speed, and moving-vehicle techniques.

Table 4.8 Speed and Delay Information

Street Name: 29 North *Date: July 7, 1994*
Weather: Clear *Non-peak* *Time: 2:00–3:00 p.m.*

Cross Streets	*Distance (ft)*	*Travel Time (sec)*	*Segment Speed (mi/h)*	*Stop Time (sec)*	*Reason for Stoppage*	*Speed Limit (mi/h)*	*Ideal Travel Time (sec)*	*Segment Delay (sec)*	*Net Speed (mi/h)*
Ivy Road	0	0.0	–	0.0		–	0.0	0.0	–
Massie Road	1584	42.6	25.4	20.1	Signal	40	27.0	15.6	17.2
Arlington Blvd.	1320	27.7	32.5	0.0		40	22.5	5.2	32.5
Wise Street	792	19.7	27.4	8.9	Signal	40	13.5	6.2	18.9
Barracks Road	1320	32.1	28.0	15.4	Signal	40	22.5	9.6	18.9
Angus Road	2244	49.8	30.7	9.2	Signal	40	38.3	11.5	25.9
Hydraulic Road	1584	24.4	44.3	0.0		45	24.0	0.4	44.3
Seminole Court	1584	42.6	25.4	19.5	Signal	45	24.0	18.6	17.4
Greenbrier Drive	1848	41.5	30.4	15.6	Signal	45	28.0	13.5	22.1
Premier Court	1320	37.4	24.1	11.8	Signal	45	20.0	17.4	18.3
Fashion Square I	1584	23.6	45.8	4.9	Signal	45	24.0	−0.4	37.9
Fashion Square II	1056	19.7	36.5	0.0		45	16.0	3.7	36.5
Rio Road	1056	20.2	35.6	14.1	Signal	45	16.0	4.2	21.0
Totals	17292	381.3	30.9	119.5			275.8	105.5	23.5

Note: Segment delay is the difference between observed travel time and calculated ideal travel time.
SOURCE: Study conducted in Charlottesville, VA, by Justin Black and John Ponder.

Traffic Engineering Studies

Moving-Vehicle Technique

(moving observer):

- the observer makes a round trip on a test section Figure 4.16,
- The observer starts at section X-X, drives the car eastward to section Y-Y,
- turns the vehicle around
- drives westward to section X-X again

Traffic Engineering Studies

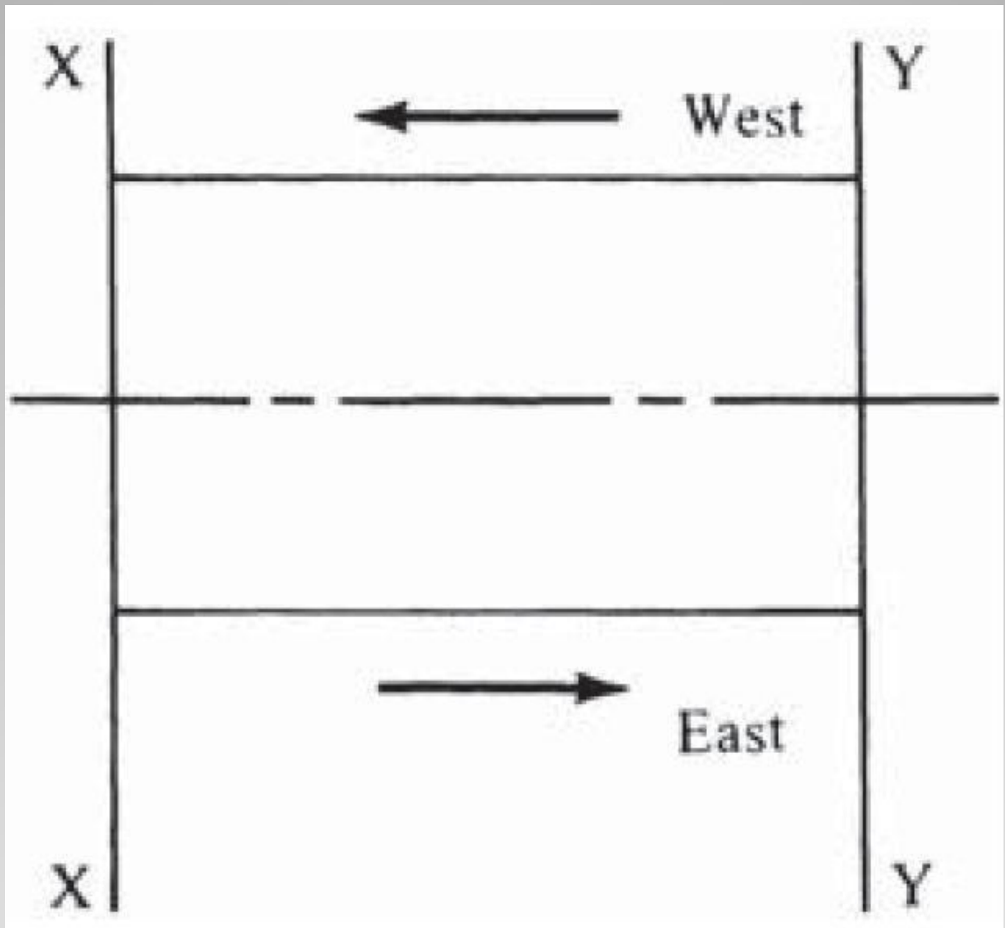
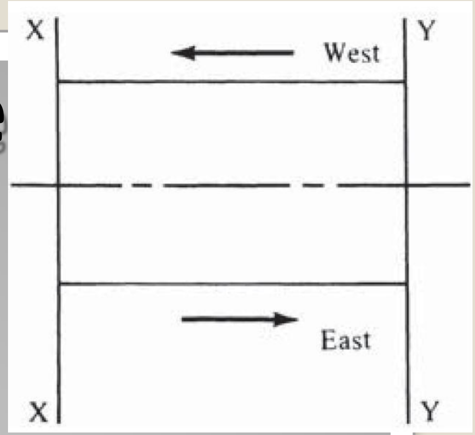


Figure 4.16 Test Site for Moving-Vehicle Method

Traffic Engineering Studie



Moving-Vehicle Technique.

- **following data are collected as**
  - The time it takes to travel east from X-X to Y-Y (*Te*), in minutes
  - The time it takes to travel west from Y-Y to X-X (*Tw*), in minutes
  - The number of vehicles traveling west in the opposite lane while the test car is traveling east (*Ne*)

Traffic Engineering Studies

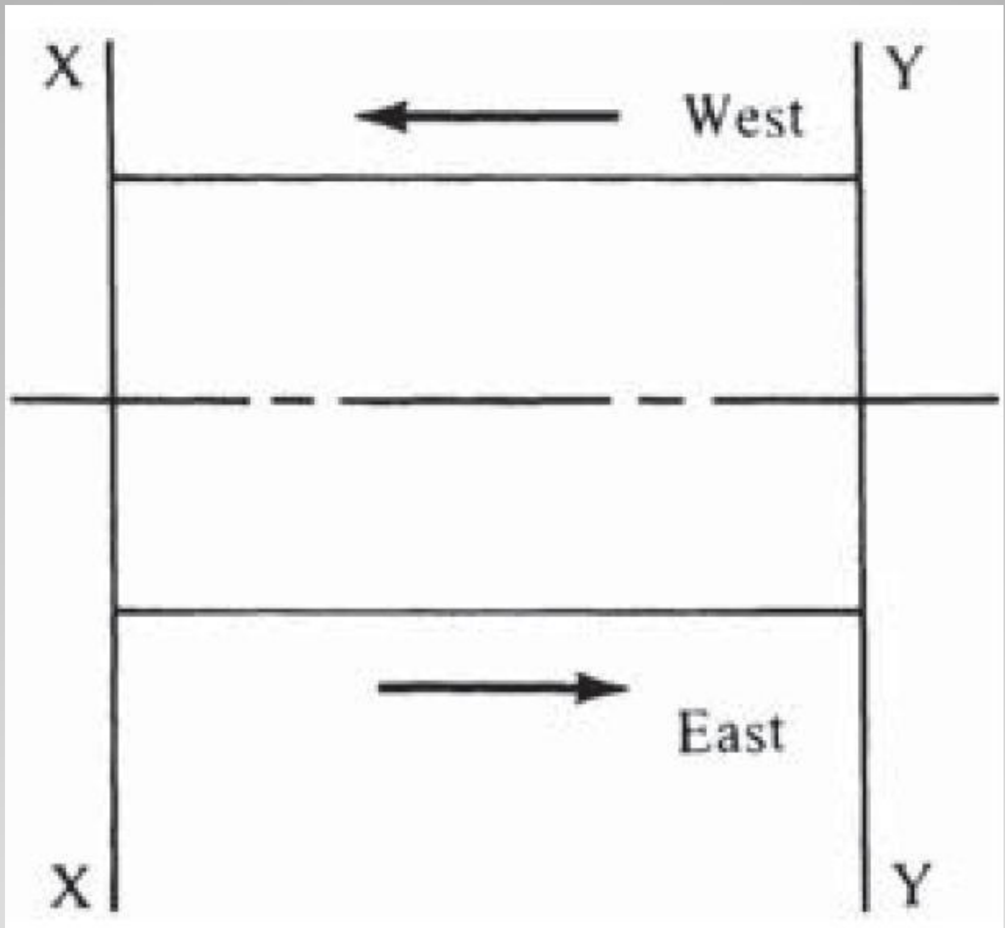
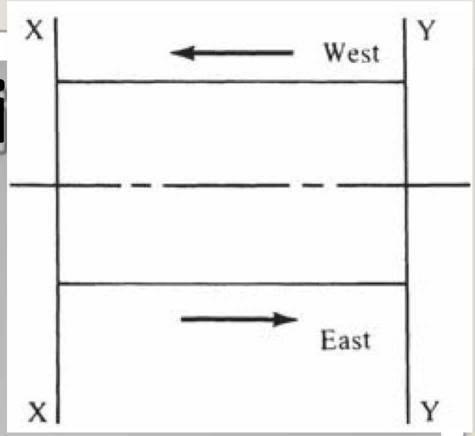


Figure 4.16 Test Site for Moving-Vehicle Method

Traffic Engineering Studi



Moving-Vehicle Technique.

- The number of vehicles that overtake the test car while it is traveling west from Y-Y to X-X, that is, traveling in the westbound direction (*Ow*)
- The number of vehicles that the test car passes while it is traveling west from Y-Y to X-X, that is, traveling in the westbound direction (*Pw*)

Traffic Engineering Studies

Moving-Vehicle Technique.

- The volume (V_w) in the westbound direction can then be obtained from the expression:

$$V_w = \frac{(N_e + O_w - P_w)60}{T_e + T_w}$$

Traffic Engineering Studies

Traffic Engineering Studies

- where (N_e O_w P_w) is the number of vehicles traveling westward that cross the line X-X during the time ($T_e T_w$).
- Similarly, the average travel time in the westbound direction is obtained from

$$\frac{\overline{T}_w}{60} = \frac{T_w}{60} - \frac{O_w - P_w}{V_w}$$

$$\overline{T}_w = T_w - \frac{60(O_w - P_w)}{V_w}$$

Traffic Engineering Studies

Example 4.6 Volume and Travel Time Using Moving-Vehicle Technique

The data in Table 4.9 were obtained in a travel time study on a section of highway using the moving-vehicle technique. Determine the travel time and volume in each direction at this section of the highway.

Mean time it takes to travel eastward (T_e) = 2.85 min

Mean time it takes to travel westbound (T_w) = 3.07 min

Average number of vehicles traveling westward when test vehicle is traveling eastward (N_e) = 79.50

Average number of vehicles traveling eastward when test vehicle is traveling westward (N_w) = 82.25

Average number of vehicles that overtake test vehicle while it is traveling westward (O_w) = 1.25

Traffic Engineering Studies

Table 4.9 Data from Travel Time Study Using the Moving-Vehicle Technique

Run Direction/ Number	*Travel Time (min)*	*No. of Vehicles Traveling in Opposite Direction*	*No. of Vehicles That Overtook Test Vehicle*	*No. of Vehicles Overtaken by Test Vehicle*
Eastward				
1	2.75	80	1	1
2	2.55	75	2	1
3	2.85	83	0	3
4	3.00	78	0	1
5	3.05	81	1	1
6	2.70	79	3	2
7	2.82	82	1	1
8	3.08	78	0	2
Average	2.85	79.50	1.00	1.50

Traffic Engineering Studies

Table 4.9 Data from Travel Time Study Using the Moving-Vehicle Technique

Westward				
1	2.95	78	2	0
2	3.15	83	1	1
3	3.20	89	1	1
4	2.83	86	1	0
5	3.30	80	2	1
6	3.00	79	1	2
7	3.22	82	2	1
8	2.91	81	0	1
Average	3.07	82.25	1.25	0.875

Average number of vehicles that overtake test vehicle while it is traveling eastward (O_e) = 1.00

Average number of vehicles the test vehicle passes while traveling westward (P_w) = 0.875

Average number of vehicles the test vehicle passes while traveling eastward (P_e) = 1.5

Traffic Engineering Studies

Solution:

- From Eq. 4.9, find the volume in the westbound direction.

$$V_w = \frac{(N_e + O_w - P_w)60}{T_e + T_w}$$

$$= \frac{(79.50 + 1.25 - 0.875)60}{2.85 + 3.07} = 809.5 \qquad \text{(or 810 veh/h)}$$

- Similarly, calculate the volume in the eastbound direction.

$$V_e = \frac{(82.25 + 1.00 - 1.50)60}{2.85 + 3.07} = 828.5 \qquad \text{(or 829 veh/h)}$$

Traffic Engineering Studies

Solution:

- Find the average travel time in the westbound direction.

$$\overline{T}_w = 3.07 - \frac{(1.25 - 0.875)}{810} 60 = 3.0 \text{ min}$$

- Find the average travel time in the eastbound direction.

$$\overline{T}_e = 2.85 - \frac{(1.00 - 1.50)}{829} 60 = 2.9 \text{ min}$$

Traffic Engineering Studies

- **Methods Not Requiring a Test Vehicle**
- ***License-Plate Observations:*** observers at the beginning and end of the test section.
- Each observer records the last three or four digits of the license plate of each car that passes, together with the time at which the car passes.

Traffic Engineering Studies

- in the office by matching the times of arrival at the beginning and end of the test section for each license plate recorded.
- difference between these times is the traveling time of each vehicle.
- average of these is the average traveling time on the test section.

Traffic Engineering Studies

- a sample size of 50 matched license plates.
- ***Interviews:*** obtaining information from people who drive on the study site regarding their travel times, experience of delays, requires the cooperation of the people.

Traffic Engineering Studies

- ***ITS Advanced Technologies:***
  - Advanced technologies
  - Cell phones
  - GPS satellite system
  - technology is used to determine average speeds and travel times along highways

Traffic Engineering Studies

4.4 PARKING STUDIES

- Any vehicle will at one time be parked short time or longer time, provision of parking facilities is essential
- need for parking spaces is usually very great in areas of business, residential, or commercial activities.
- park-and-ride

Traffic Engineering Studies

- Providing adequate parking space to meet the demand for parking in the Central Business District (CBD)
- This problem usually confronts a city traffic engineer.
- solution is not simple, Parking studies are used to determine the demand for and the supply of parking facilities.

Traffic Engineering Studies

4.4.1 Types of Parking Facilities

- On-Street Parking Facilities
  - also known as curb facilities. Parking bays are provided alongside the curb on one or both sides of the street.
  - unrestricted parking
  - unlimited and free
  - Restricted parking facilities

Traffic Engineering Studies

- On-Street Parking Facilities
  - limited to specific times for a maximum duration.
  - may or may not be free.
  - handicapped parking
  - bus stops
  - loading bays.

Traffic Engineering Studies

- Off-Street Parking Facilities
  - privately or publicly owned;
  - surface lots and garages.
  - Self-parking garages
  - attendant-parking garages

Traffic Engineering Studies

4.4.2 Definitions of Parking Terms

1. **A space-hour** is a unit of parking that defines the use of a single parking space for a period of 1 hour.
2. **Parking volume** is the total number of vehicles that park in a study area during a specific length of time, usually a day.

Traffic Engineering Studies

Traffic Engineering Studies

3. **Parking accumulation** is the number of parked vehicles in a study area at any specified time.
4. **parking load** the number of space-hours used during the specified period of time.
5. **Parking duration** length of time a vehicle is parked at a parking indication of how frequently a parking space becomes available.

Traffic Engineering Studies

6. **Parking turnover** rate of use of a parking space.

   Obtained by dividing the parking volume for a specified period by the number of parking spaces.

Traffic Engineering Studies

4.4.3 Methodology of Parking Studies

- Inventory of Existing Parking Facilities
  - detailed listing of the location and all other relevant characteristics of each legal parking facility, private and public.
  - The study area includes both on- and off-street facilities.

Traffic Engineering Studies

Traffic Engineering Studies

- Type and number of parking spaces at each parking facility
- Times of operation and limit on duration of parking, if any
- Type of ownership (private or public)
- Parking fees, method of collection
- Restrictions
- Other restrictions, loading and unloading zones, bus stops, taxi ranks
- Permanency

– The inventory should be updated at regular intervals of about four to five years.

Traffic Engineering Studies

4.4.3 Methodology of Parking Studies

- Collection of Parking Data
  - ***Accumulation:***
    - by checking the amount of parking during regular intervals on different days of the week.
    - Carried out on an hourly or 2-hour basis
    - used to determine hourly variations of parking and peak periods of parking demand.

Traffic Engineering Studies

- Collection of Parking Data
  - ***Turnover and Duration:***
    - collecting data on a sample of parking spaces in a given block.
    - recording the license plate of the vehicle parked on each parking space in the sample at the ends of fixed intervals during the study period.
    - The length of the fixed intervals depends on the maximum permissible duration.

Traffic Engineering Studies

– ***Turnover and Duration:***

- For example, if the maximum permissible duration of parking at a curb face is 1 hour, a suitable interval is every 20 minutes.
- If the permissible duration is 2 hours, checking every 30 minutes would be appropriate. Turnover is then obtained from the equation

$$T = \frac{\text{number of different vehicles parked}}{\text{number of parking spaces}}$$

Traffic Engineering Studies

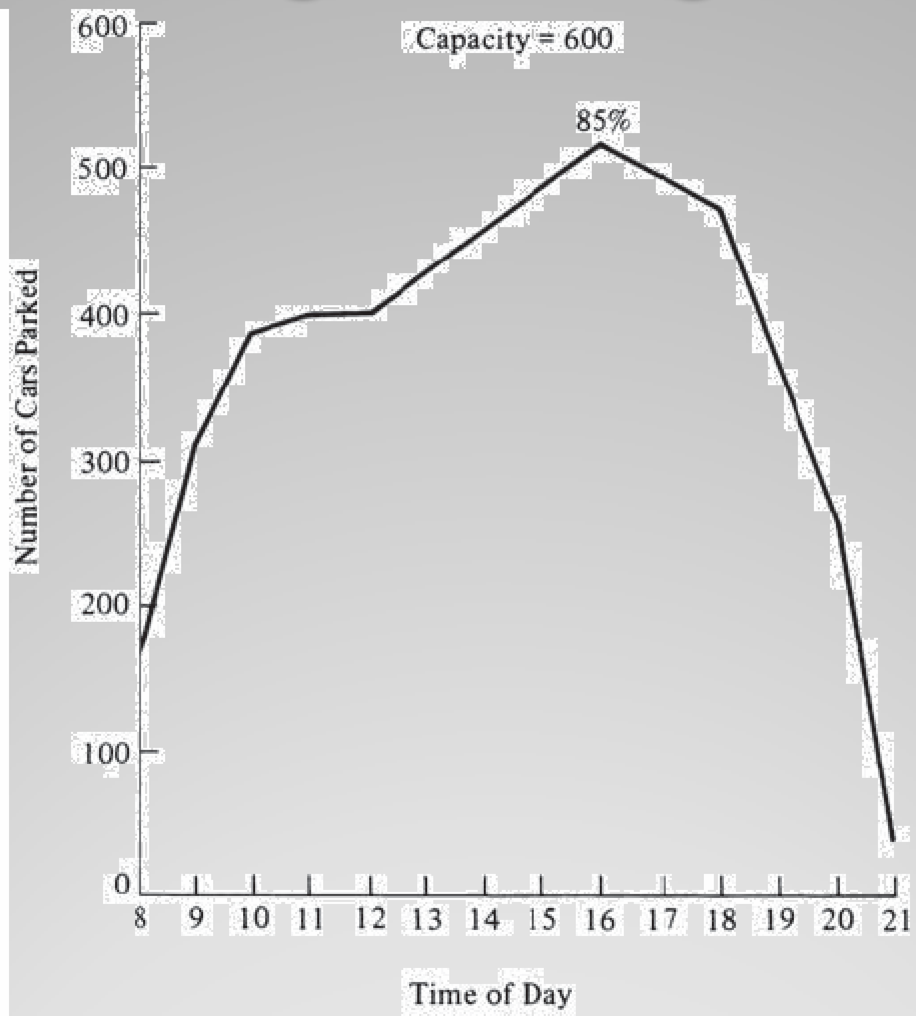


Figure 4.17 Parking Accumulation at a Parking Lot

Traffic Engineering Studies

- **Parking Demand**
  - by interviewing drivers at the various parking facilities
  - Interview all drivers using the parking facilities on a typical weekday between 8:00 a.m. and 10:00 p.m.
  - Information include (1) trip origin, (2) purpose of trip, (3) driver's destination after parking.
  - the location of the parking facility, times of arrival and departure, vehicle type.

Traffic Engineering Studies

- **Parking Demand**
  - Parking interviews also can be carried out using the postcard technique,
  - about 30 to 50 percent of the cards distributed are returned.

Traffic Engineering Studies

Example 4.7 Space Requirements for a Parking Garage

The owner of a parking garage located in a CBD has observed that 20% of those wishing to park are turned back every day during the open hours of 8 a.m. to 6 p.m. because of lack of parking spaces. An analysis of data collected at the garage indicates that 60% of those who park are commuters, with an average parking duration of 9 hr, and the remaining are shoppers, whose average parking duration is 2 hr. If 20% of those who cannot park are commuters and the rest are shoppers, and a total of 200 vehicles currently park daily in the garage, determine the number of additional spaces required to meet the excess demand. Assume parking efficiency is 0.90.

Traffic Engineering Studies

Solution:

- Calculate the space-hours of demand using Eq. 4.12.

$$D = \sum_{i=1}^{N} (n_i t_i)$$

Commuters now being served $= 0.6 \times 200 \times 9 = 1080$ space-hr
Shoppers now being served $= 0.4 \times 200 \times 2 = 160$ space-hr
Total number of vehicles turned away $= \dfrac{200}{0.8} - 200 = 50$
Commuters not being served $= 0.2 \times 50 \times 9 = 90$ space-hr
Shoppers not being served $= 0.8 \times 50 \times 2 = 80$ space-hr
Total space-hours of demand $= (1080 + 160 + 90 + 80) = 1410$
Total space-hours served $= 1080 + 160 = 1240$
Number of space-hours required $= 1410 - 1240 = 170$

Traffic Engineering Studies

- Determine the number of parking spaces required from Eq. 4.13.

$$S = f \sum_{i=1}^{N} t_i = 170 \text{ space-hr}$$

- Use the length of time each space can be legally parked on (8 a.m. through 6 p.m. = 10 hr) to determine the number of additional spaces.

$$0.9 \times 10 \times N = 170$$
$$N = 18.89$$

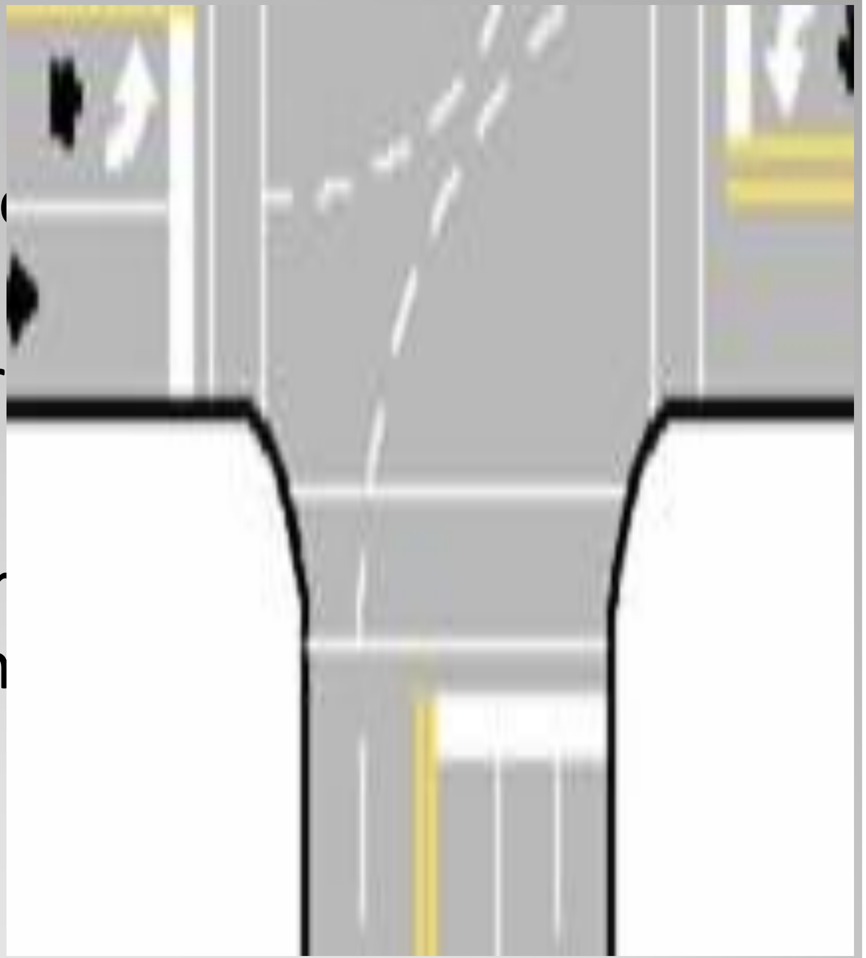
At least 19 additional spaces will be required, since a fraction of a space cannot be used.

UNIT – IV:
INTERSECTION DESIGN

Types of Intersections – Conflicts at Intersections-Requirements of At –Grade intersection- Types of at-Grade Intersections- Channelization -Traffic Islands - Types of Grade Separated Intersections- Rotary Intersection –concept of Rotary-Design factors of rotary-Advantages and limitations of rotary intersections

Intersections

- More **complicated** area fo
  drivers
- Main function is to provid
  for **change of direction**
- Source of congestion in u
  areas
- Concern for safety (fender
  benders in urban, fatals in
  rural)



Types of Intersections

- **Grade separated** with ramps (freeway interchange)
- Grade separated without ramps (over or underpass with **no access**)
- **At-grade**
  - Conventional
  - Roundabouts
  - New concepts (e.g., “continuous flow”)

Operational Requirements

- Provide adequate **sight distance** – for approach and departure maneuvers
- Minimize turning and through **conflicts**
- Provide **natural paths** for permitted movements
- Avoid geometry (**sharp curves/steep grades**) that complicates the driving task and adversely impacts acceleration or deceleration

Intersection Sight Distance – ISD

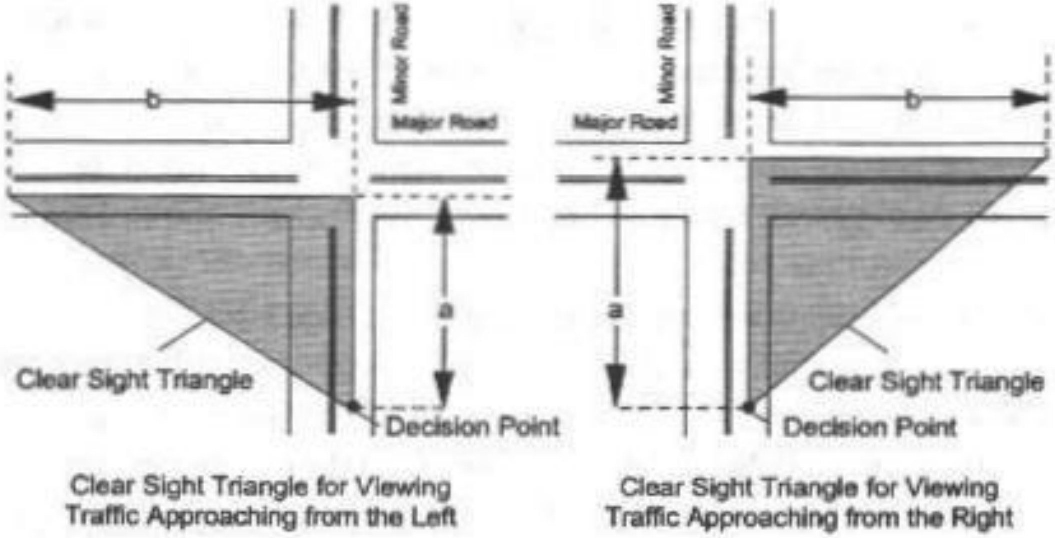
- Allow drivers to have an **unobstructed view** of intersection
- Definition: Required ISD is the **length** of cross road that must be visible such that the driver of a turning/crossing vehicle can **decide** to and **complete** the maneuver without conflict with vehicles approaching the intersection on the cross road.

Adequate ISD

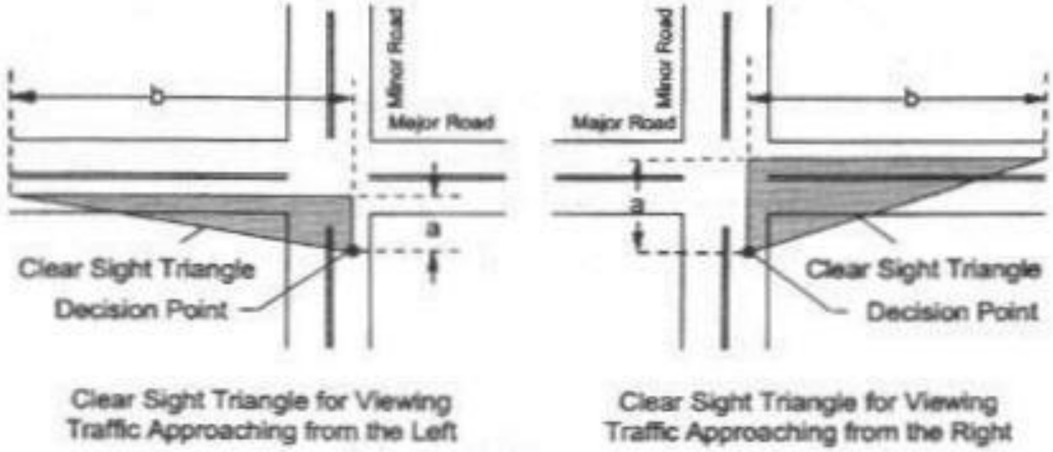
- **Sight Triangle** – area free of obstructions necessary to complete maneuver and avoid collision – **needed for approach and departure** (from stop sign for example)
- Allows driver to anticipate and avoid collisions
- Allows drivers of stopped vehicles enough view of the intersection to decide when to enter

Sight Triangle

- area free of obstructions necessary to complete maneuver and avoid collision – **needed for approach and departure** (from stop sign for example)
- Consider horizontal as well as vertical, object below driver eye height may not be an obstruction
- AASHTO assumes 3.5’ above roadway



A – Approach Sight Triangles



B – Departure Sight Triangles

Exhibit 9-50. Intersection Sight Triangles


Hidden Vehicle
CyRide

ISD Cases

- **No control**: vehicles adjust speed
- **Stop control**: where traffic on minor roadway must stop prior to entering major roadway
- **Yield control**: vehicles on minor roadway must yield to major roadway traffic
- **Signal control**: where vehicles on all approaches are required to stop by either a stop sign or traffic signal
- **All way stop**
- Stopped major roadway **left-turn** vehicles – must **yield** to oncoming traffic

Case A– No Control

- Minimum sight triangle sides = distance traveled in **3 seconds** (design or actual?) = 2 seconds for P/R and 1 second to actuate brake/accel.
- **Assumes vehicles slow ~ 50% of midblock running speed** (rural???)

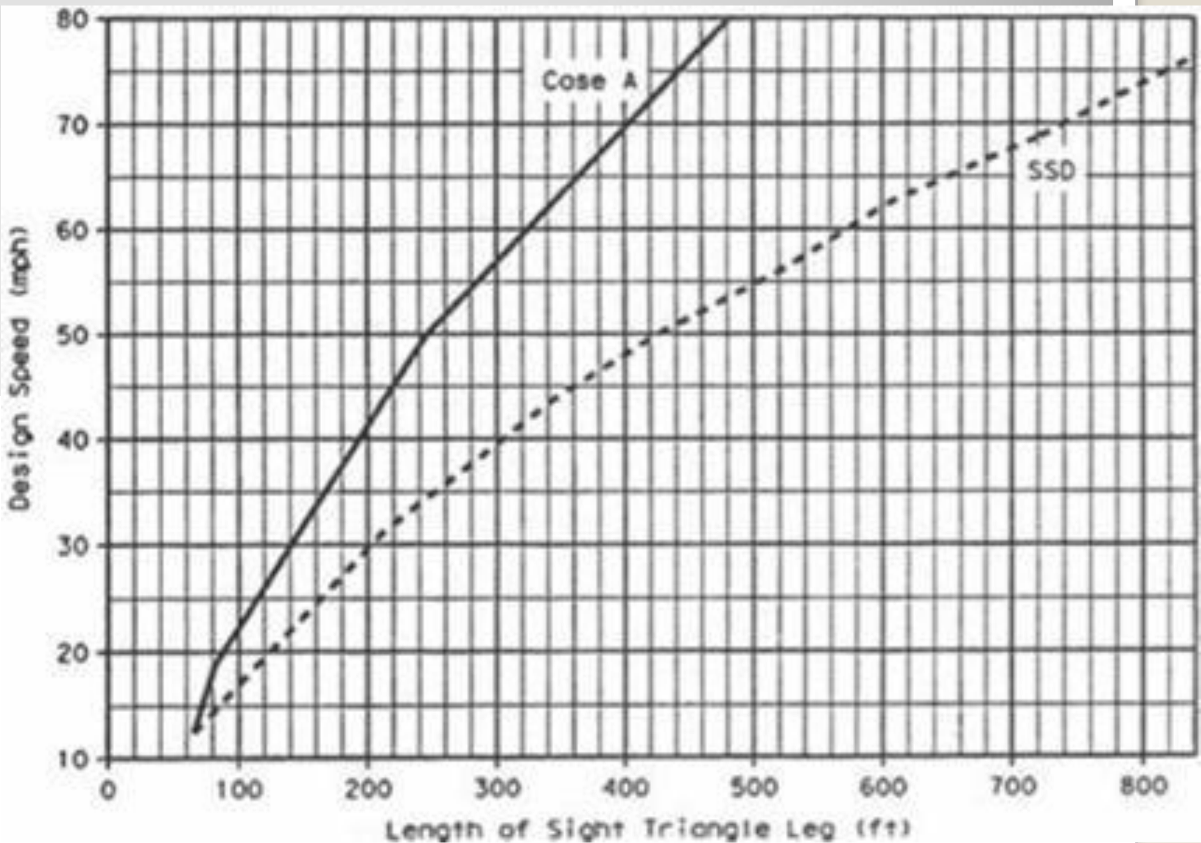
Case A– No Control

- **Prefer** appropriate SSD on both approaches (minimum really)
- Provided on **lightly traveled** roadways
- Provide **control if sight triangle not available**
- Assumes vehicle on the left yields to vehicle on the right if they arrive at same time

Metric		US Customary	
Design speed (km/h)	Length of leg (m)	Design speed (mph)	Length of leg (ft)
20	20	15	70
30	25	20	90
40	35	25	115
50	45	30	140
60	55	35	165
70	65	40	195
80	75	45	220
90	90	50	245
100	105	55	285
110	120	60	325
120	135	65	365
130	150	70	405
		75	445
		80	485

Note: For approach grades greater than 3%, multiply the sight distance values in this exhibit by the appropriate adjustment factor from Exhibit 9-53.

Can use table or graph



Modify for grade

US Customary														
Approach grade (%)	Design speed (mph)													
	15	20	25	30	35	40	45	50	55	60	65	70	75	80
−6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
−5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
−4	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
−3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Minimum Distances for Sight Triangle: No Control

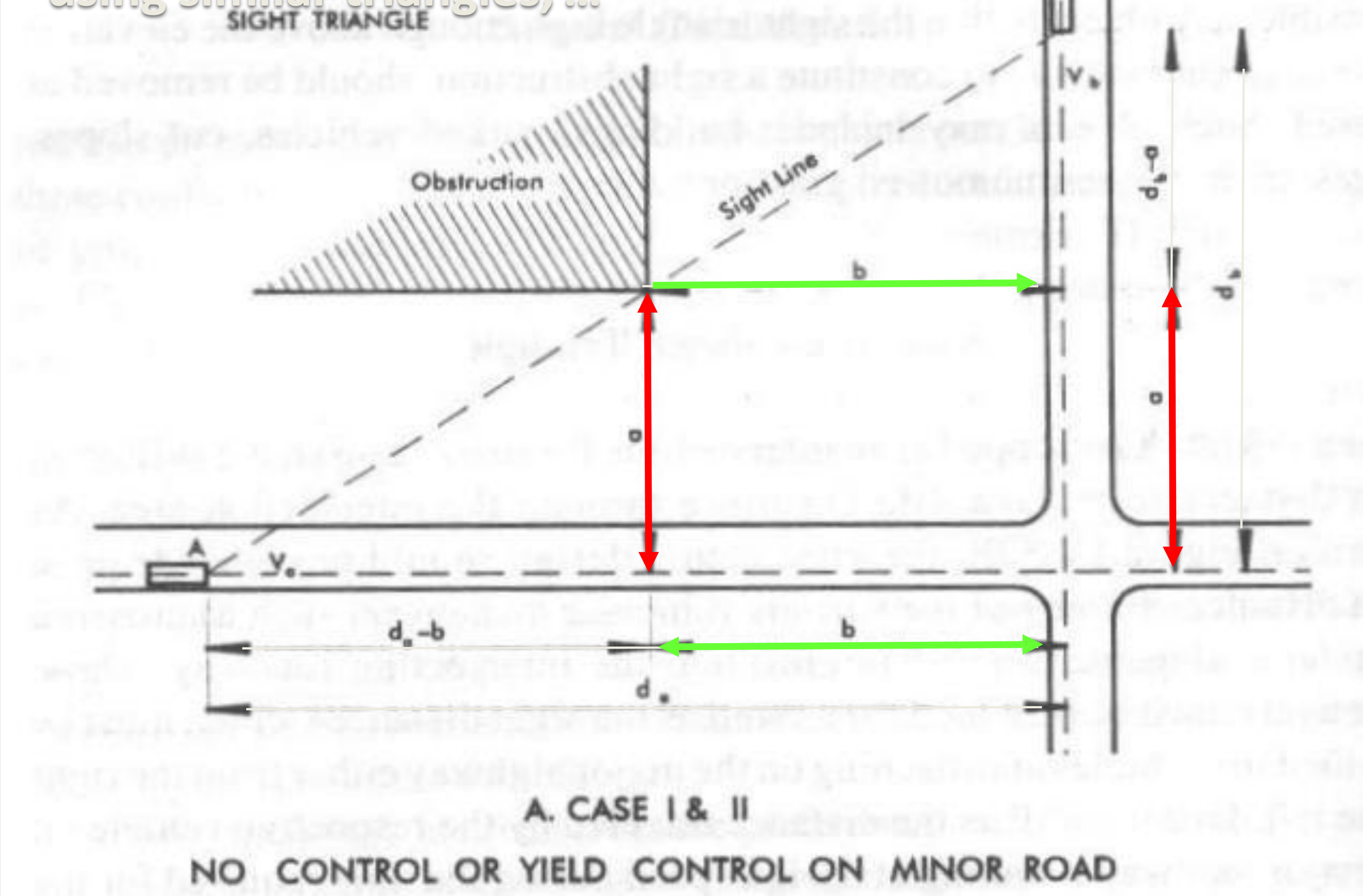
Speed (mph)	Distance (ft)
10	45
15	70
20	90
25	110
30	130
35	155
40	180
50	220
60	260
70	310

From Garber and Hoel

A little lower than Green Book Values

using similar triangles, ...

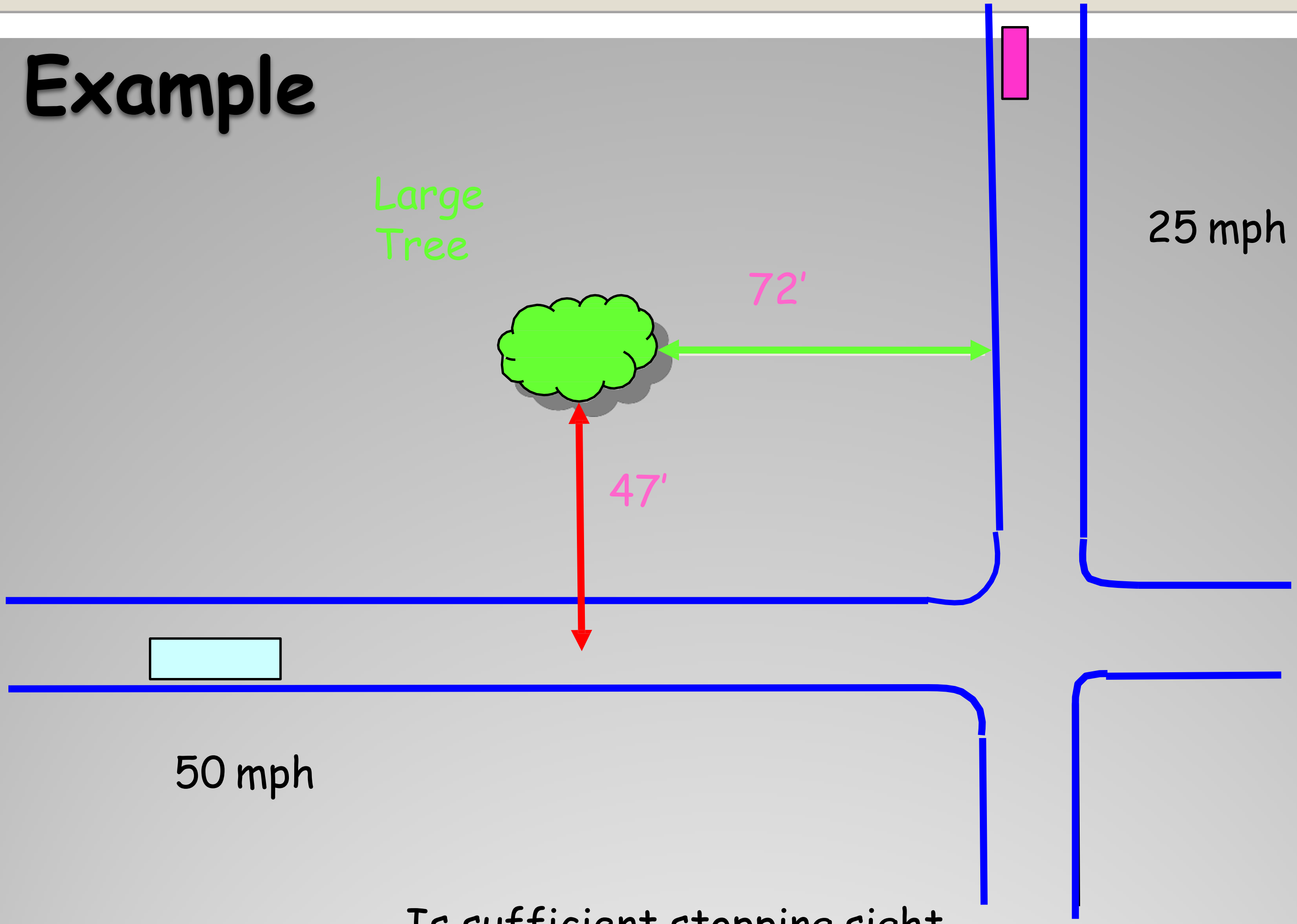
using similar triangles, ...



can set critical speed to available stopping distance,

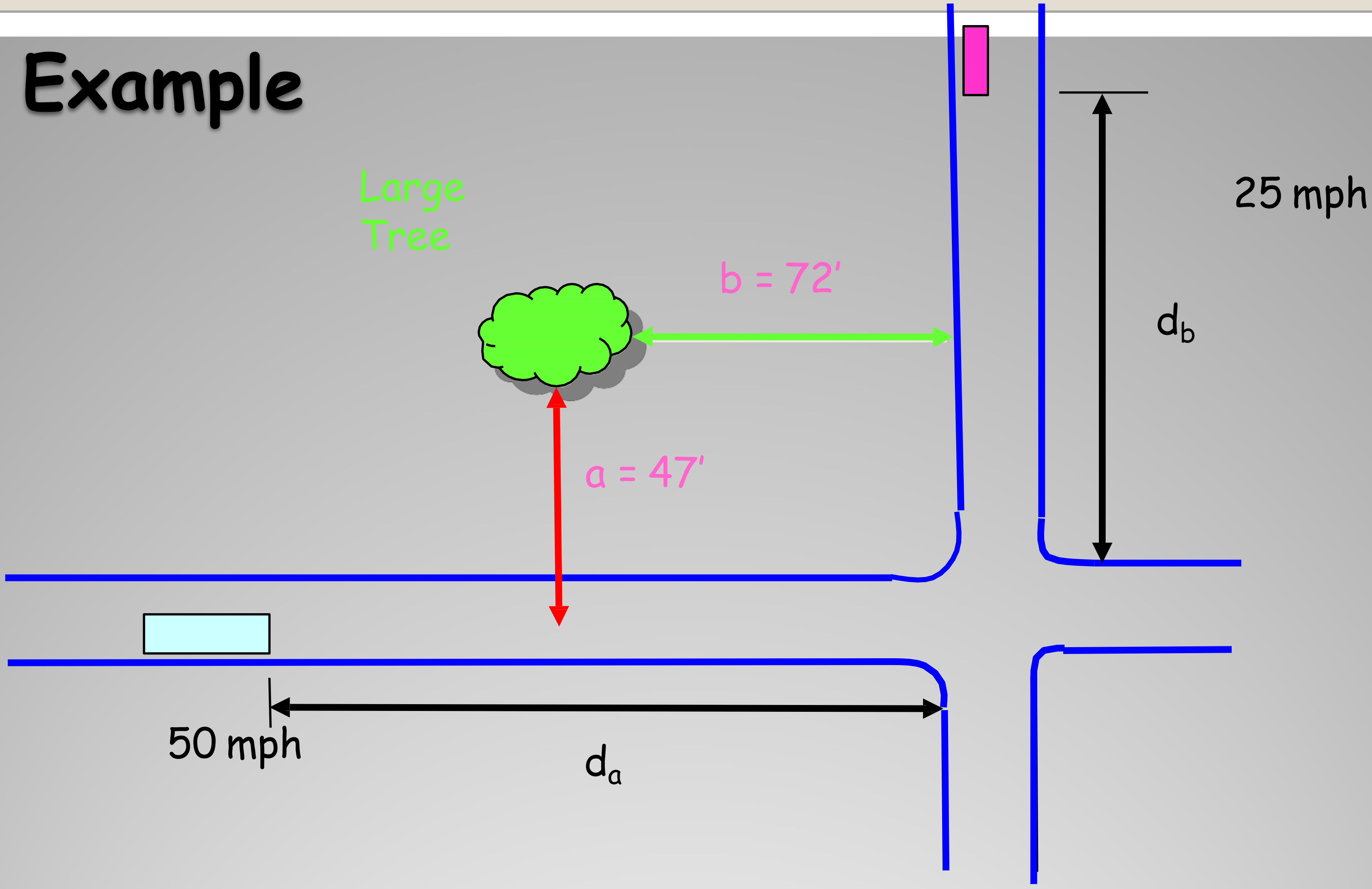
$$d_b = a \times \frac{d_a}{d_a - b}$$

Example



Is sufficient stopping sight distance provided?

Example



$$d_b = a \times \frac{d_a}{d_a - b}$$

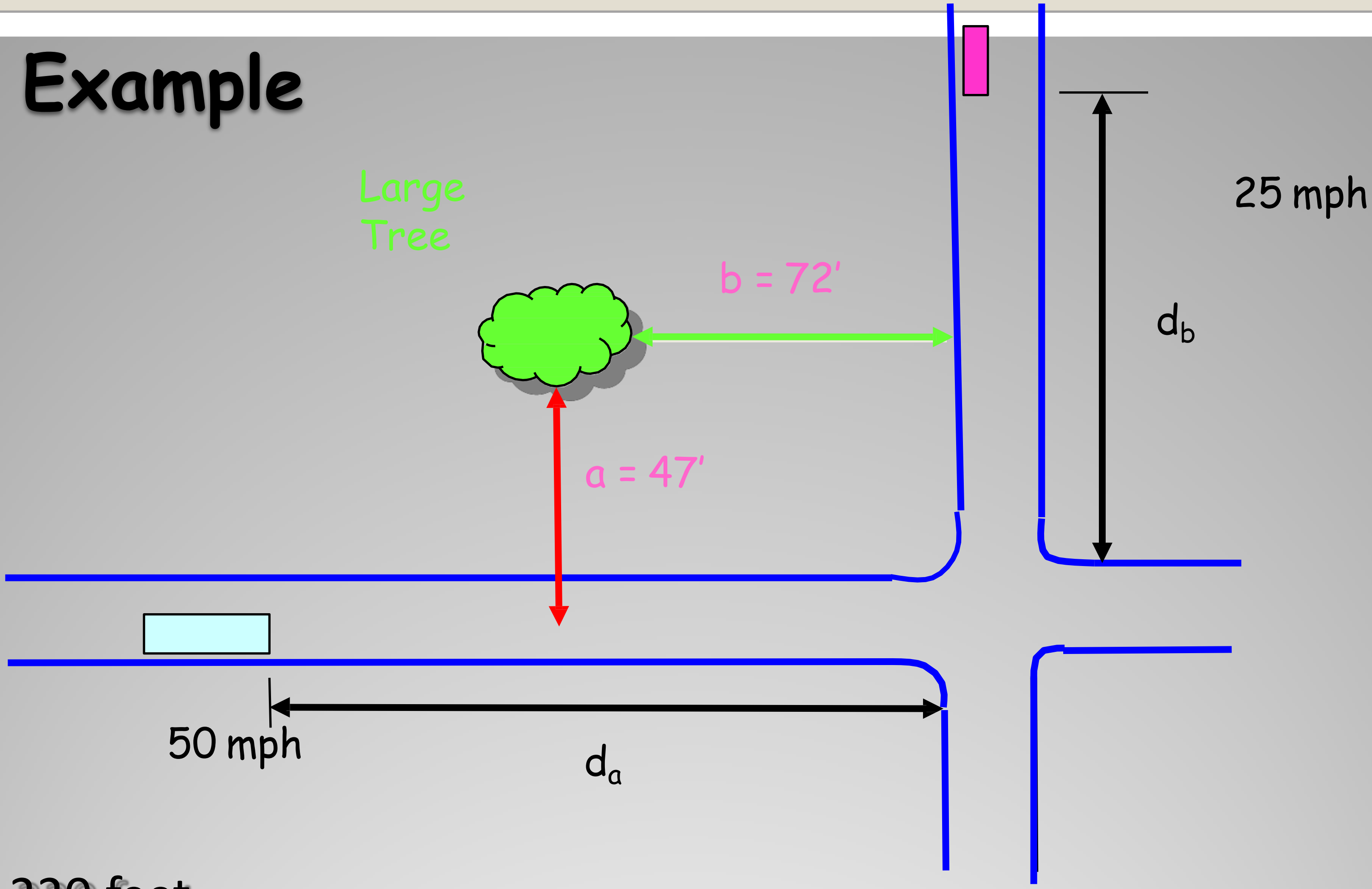
Minimum Distances for Sight Triangle: No Control

Speed (mph)	Distance (ft)
10	45
15	70
20	90
25	110
30	130
35	155
40	180
50	220
60	260
70	310

From Garber and Hoel

$d_a = 220$ feet

Example



d_a = 220 feet

$$d_b = \frac{47' (220')}{220' - 72'} = 69.9'$$

$$d_b = a \times \frac{d_a}{d_a - b}$$

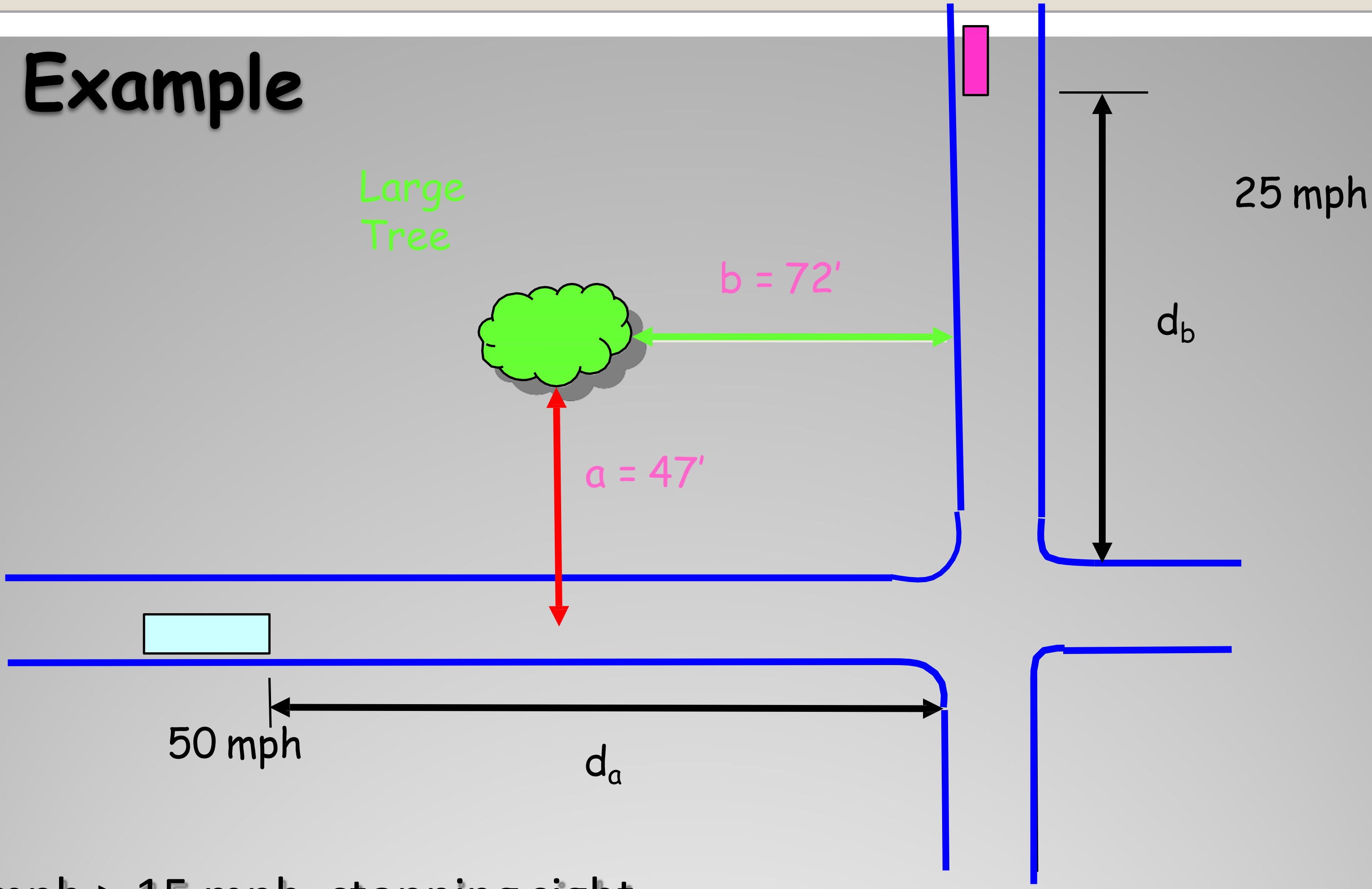
Minimum Distances for Sight Triangle: No Control

Speed (mph)	Distance (ft)
10	45
15	70
20	90
25	110
30	130
35	155
40	180
50	220
60	260
70	310

From Garber and Hoel

d_b = 69.9 feet corresponds to 15 mph

Example



25 mph > 15 mph, stopping sight distance is not sufficient for 25 mph

Case B – Stop Control

Three Sub Cases – Maneuvers

- **Turn left** on to major roadway (clear traffic left, enter traffic right)
- **Turn right** on to major roadway (enter traffic from left)
- **Crossing** (clear traffic left/right)

Case B – Stop Control

- Need ISD for departure and completion even if vehicle comes into view at point of departure = 1.47 $V_{major} * t_g$ where gap time, t_g**=7.5-11.5s**;
- add more time for grade or multilane;
- decrease by 1s. for right turns

Design vehicle	Time gap (s) at design speed of major road (t_g)
Passenger car	7.5
Single-unit truck	9.5
Combination truck	11.5

Note: Time gaps are for a stopped vehicle to turn right or left onto a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

For multilane highways:
For left turns onto two-way highways with more than two lanes, add 0.5 seconds for passenger cars or 0.7 seconds for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.

For minor road approach grades:
If the approach grade is an upgrade that exceeds 3 percent; add 0.2 seconds for each percent grade for left turns

Exhibit 9-54. Time Gap for Case B1—Left Turn from Stop

Metric				US Customary			
		Intersection sight distance for passenger cars				Intersection sight distance for passenger cars	
Design speed (km/h)	Stopping sight distance (m)	Calculated (m)	Design (m)	Design speed (mph)	Stopping sight distance (ft)	Calculated (ft)	Design (ft)
20	20	41.7	45	15	80	165.4	170
30	35	62.6	65	20	115	220.5	225
40	50	83.4	85	25	155	275.6	280
50	65	104.3	105	30	200	330.8	335
60	85	125.1	130	35	250	385.9	390
70	105	146.0	150	40	305	441.0	445
80	130	166.8	170	45	360	496.1	500
90	160	187.7	190	50	425	551.3	555
100	185	208.5	210	55	495	606.4	610
110	220	229.4	230	60	570	661.5	665
120	250	250.2	255	65	645	716.6	720
130	285	271.1	275	70	730	771.8	775
				75	820	826.9	830
				80	910	882.0	885

Note: Intersection sight distance shown is for a stopped passenger car to turn left onto a two-lane highway with no median and grades 3 percent or less. For other conditions, the time gap must be adjusted and required sight distance recalculated.

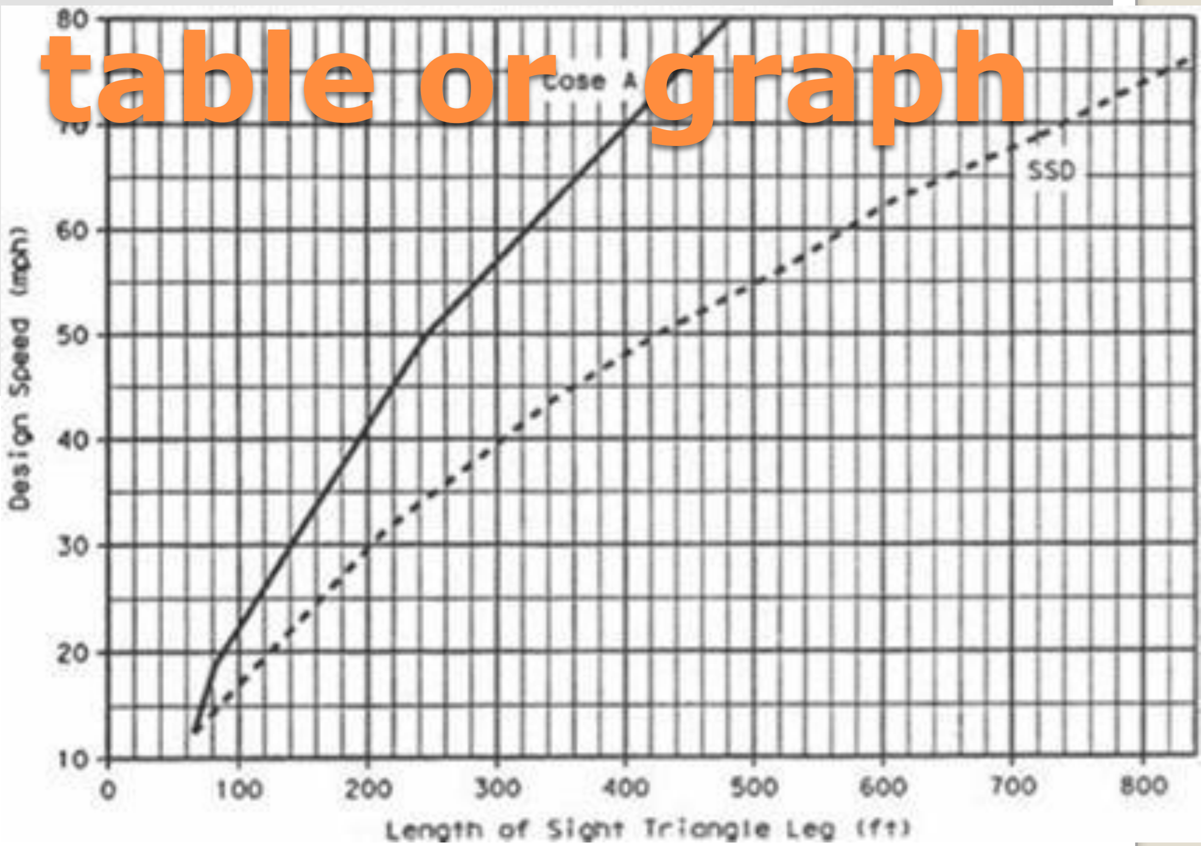
Exhibit 9-55. Design Intersection Sight Distance—Case B1—Left Turn From Stop

Left turn

Metric		US Customary	
Design speed (km/h)	Length of leg (m)	Design speed (mph)	Length of leg (ft)
20	20	15	70
30	25	20	90
40	35	25	115
50	45	30	140
60	55	35	165
70	65	40	195
80	75	45	220
90	90	50	245
100	105	55	285
110	120	60	325
120	135	65	365
130	150	70	405
		75	445
		80	485

Note: For approach grades greater than 3%, multiply the sight distance values in this exhibit by the appropriate adjustment factor from Exhibit 9-53.

Can use table or graph



Modify for grade

US Customary														
Approach grade (%)	Design speed (mph)													
	15	20	25	30	35	40	45	50	55	60	65	70	75	80
−6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
−5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
−4	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
−3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

right turn and crossing

Design vehicle	Time gap (s) at design speed of major road (t_g)
Passenger car	6.5
Single-unit truck	8.5
Combination truck	10.5

Note: Time gaps are for a stopped vehicle to turn right onto or cross a two-lane highway with no median and grades 3 percent or less. The table values require adjustment as follows:

For multilane highways:
For crossing a major road with more than two lanes, add 0.5 seconds for passenger cars and 0.7 seconds for trucks for each additional lane to be crossed and for narrow medians that cannot store the design vehicle.

For minor road approach grades:
If the approach grade is an upgrade that exceeds 3 percent, add 0.1 seconds for each percent grade.

Exhibit 9-57. Time Gap for Case B2—Right Turn from Stop and Case B3—Crossing Maneuver

US Customary			
Design speed (mph)	Stopping sight distance (ft)	Intersection sight distance for passenger cars	
		Calculated (ft)	Design (ft)
15	80	143.3	145
20	115	191.1	195
25	155	238.9	240
30	200	286.7	290
35	250	334.4	335
40	305	382.2	385
45	360	430.0	430
50	425	477.8	480
55	495	525.5	530
60	570	573.3	575
65	645	621.1	625
70	730	668.9	670
75	820	716.6	720
80	910	764.4	765

Exhibit 9-58. Design Intersection Sight Distance—Case B2—Right Turn from Stop and Case B3—Crossing Maneuver

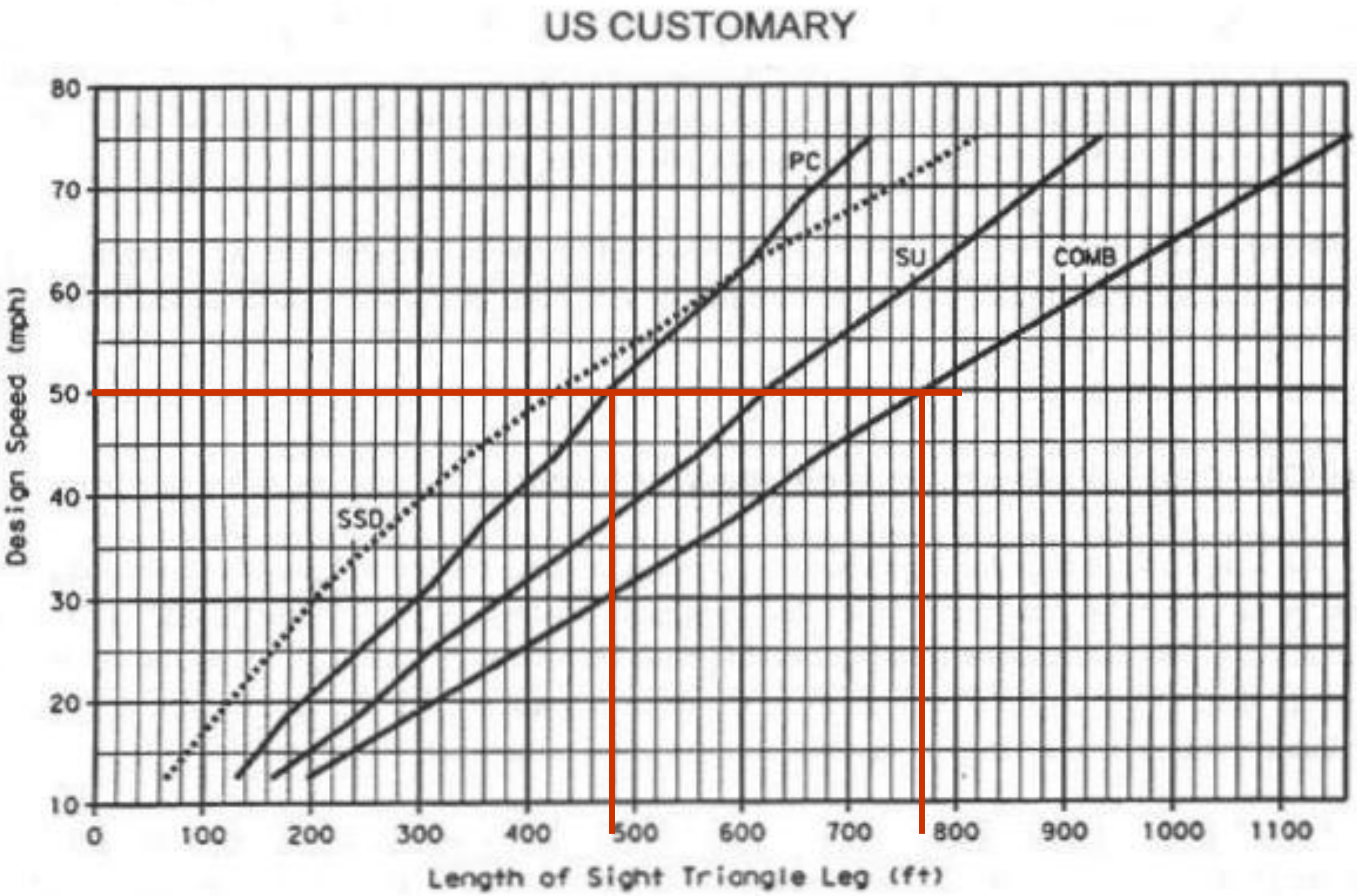


Exhibit 9-59. Intersection Sight Distance—Case B2—Right Turn from Stop and Case B3—Crossing Maneuver

Case C - Yield Control

- Minor Roadway Yields – must be able to see left/right – adjust speed – **possibly stop**
- **Sight distance exceeds that of stop control**
- Similar to no-control

Case C - Yield Control

- **Must** use minimum stopping sight distances for d_a and d_b
- SSD calculation should include effect of grade
- Required distance = **P/R + stopping distances**

Case C - Yield Control

- Typically Known – a, b
- Typically Assume V_a or V_b
- **Similar triangles** can be used to calculate safe approach speeds (given one approach speed) or allowable a and b.
- $d_a/d_b = (d_a - b)/a$
- $d_b = (d_a * a)/(d_a - b)$

Yield Control

- Case C 1: Crossing maneuver from minor road
- Assumes minor road vehicles that do not stop decelerate to 60% of minor road speed
- Vehicle should be able to:
  - Travel from decision point to intersection decelerating to 60% of design speed
  - Cross and clear the intersection at the same (i.e., 60%) speed

Metric	US Customary
$t_g = t_a + \frac{w + L_a}{0.167 V_{minor}}$ $b = 0.278 V_{major} t_g$	$t_g = t_a + \frac{w + L_a}{0.88 V_{minor}}$ (9-2) $b = 1.47 V_{major} t_g$
where: t_g = travel time to reach and clear the major road (s) b = length of leg of sight triangle along the major road (m) t_a = travel time to reach the major road from the decision point for a vehicle that does not stop (s) (use appropriate value for the minor-road design speed from Exhibit 9-60 adjusted for approach grade, where appropriate) w = width of intersection to be crossed (m) L_a = length of design vehicle (m) V_{minor} = design speed of minor road (km/h) V_{major} = design speed of major road (km/h)	where: t_g = travel time to reach and clear the major road (s) b = length of leg of sight triangle along the major road (ft) t_a = travel time to reach the major road from the decision point for a vehicle that does not stop (s) (use appropriate value for the minor-road design speed from Exhibit 9-60 adjusted for approach grade, where appropriate) w = width of intersection to be crossed (ft) L_a = length of design vehicle (ft) V_{minor} = design speed of minor road (mph) V_{major} = design speed of major road (mph)

t_g

Figure on page 671, AASHTO "Green Book" 2001

US CUSTOMARY

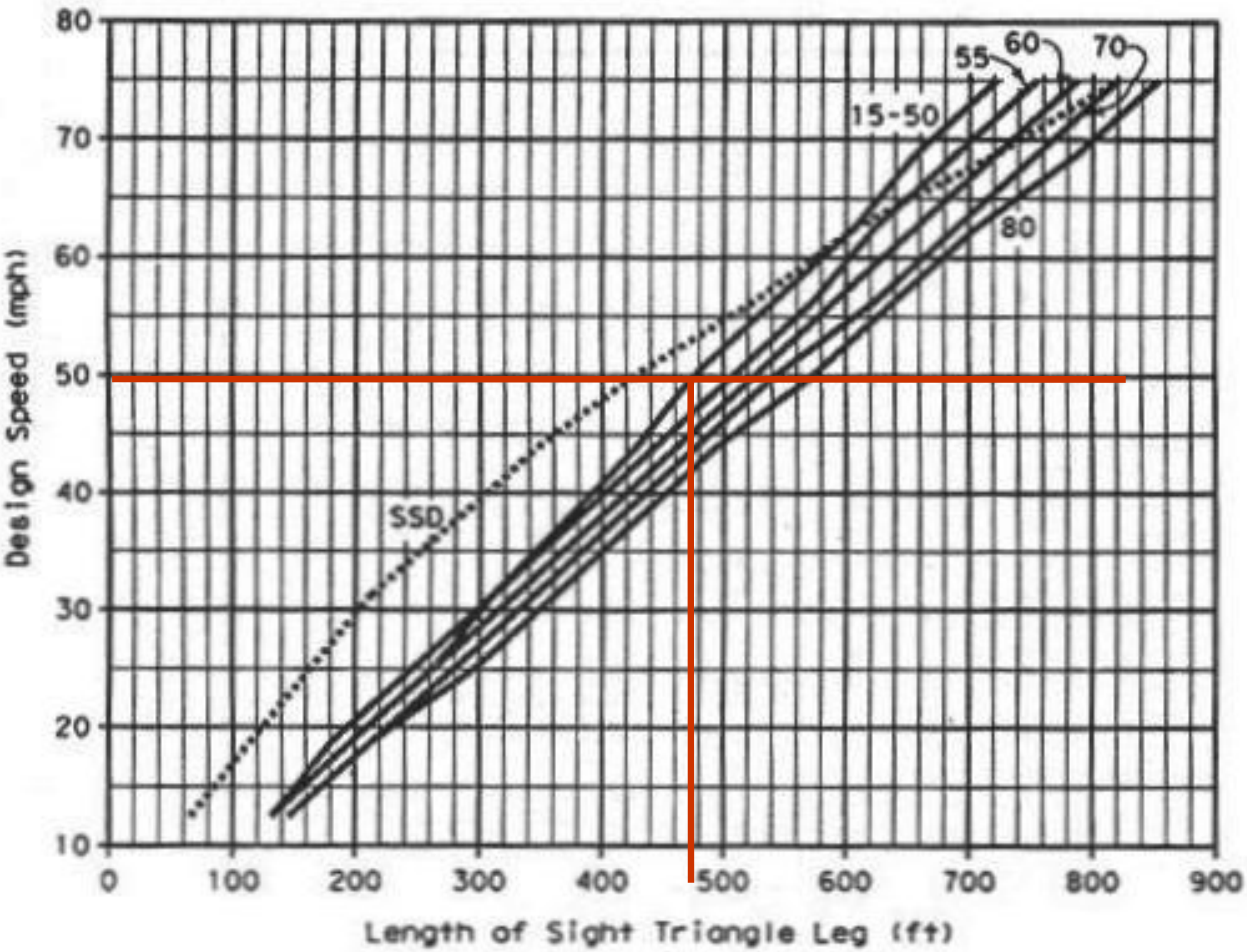


Exhibit 9-62. Length of Sight Triangle Leg Along Major Road for Passenger Cars—Case C1—Crossing Maneuver

Also …

- Case C2: Left and Right turns at **yield control**
- Case D: **Signal** control
- Case E: **All way stop**
- Case F: **Left turn from major**
- tg=5.5-7.5s + **multilane adjustment**
- **Effect of Skew**

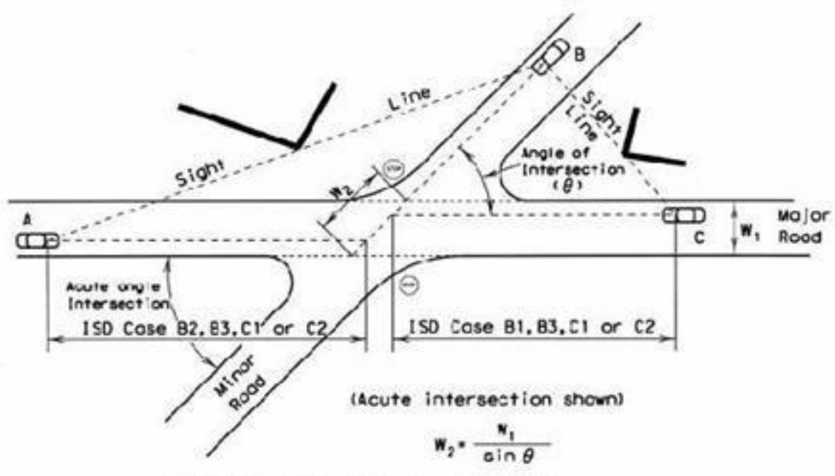
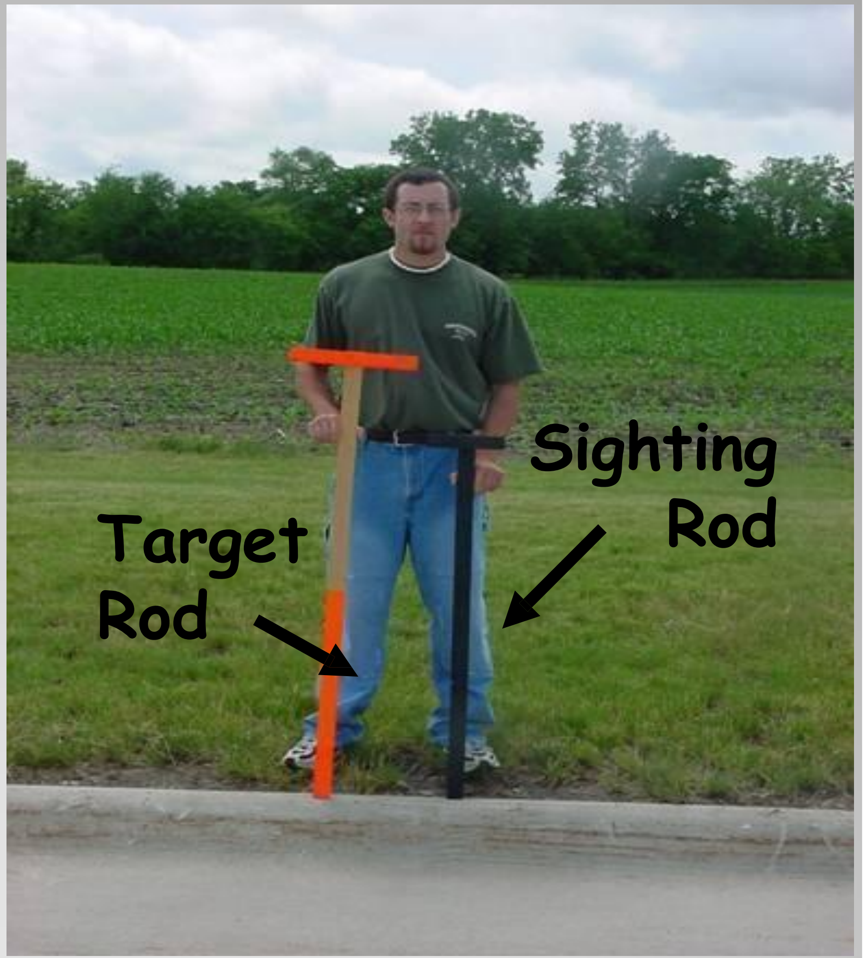


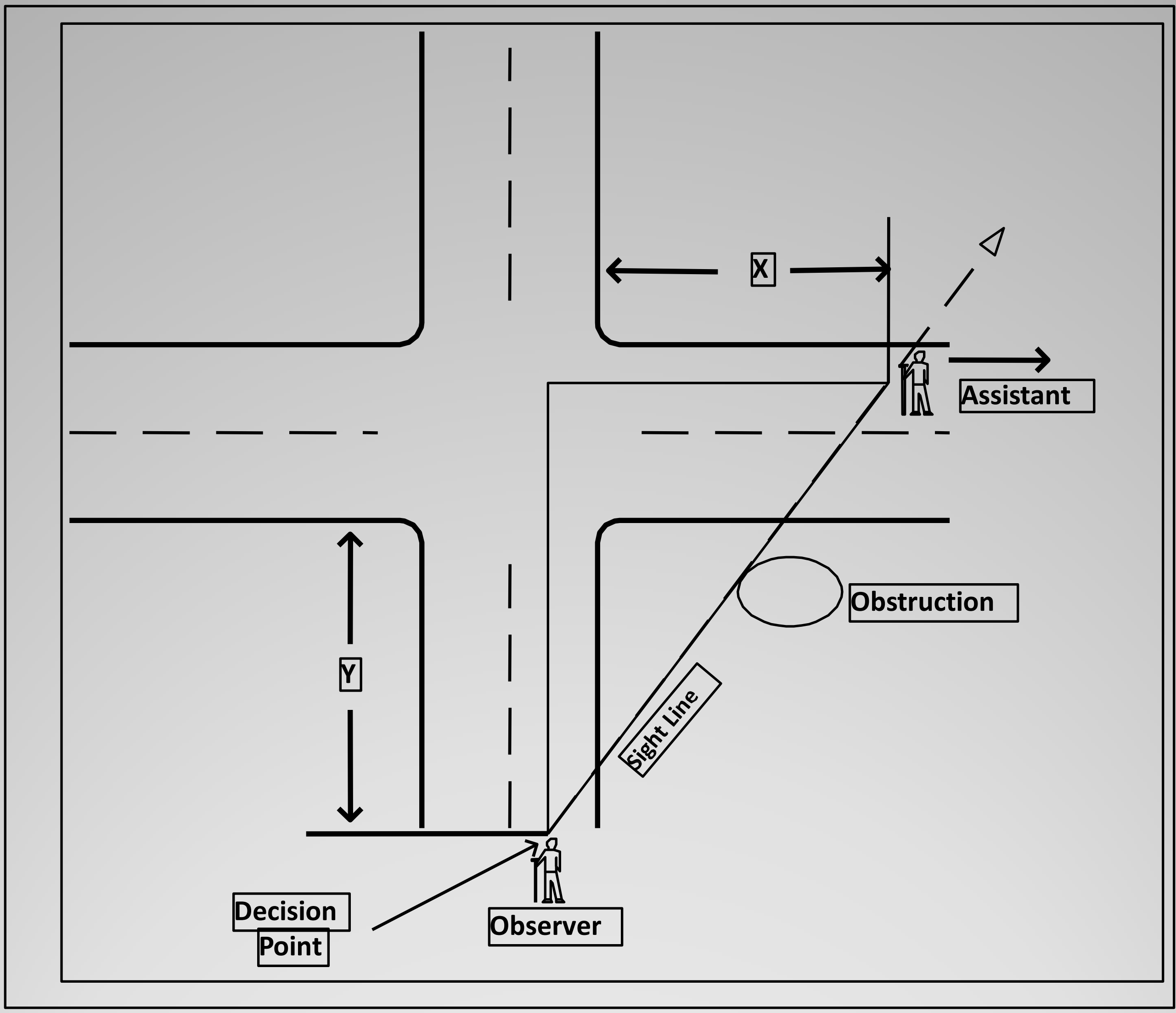
Exhibit 9-69. Sight Triangles at Skewed Intersections

Sighting Rod and Target Rod
(AASHTO)

- For vertical sight distance with vertical curves
- Sighting rod- 3.5 feet tall
- Target rod- 4.25 feet tall (Top portion and bottom 2 feet are painted orange)

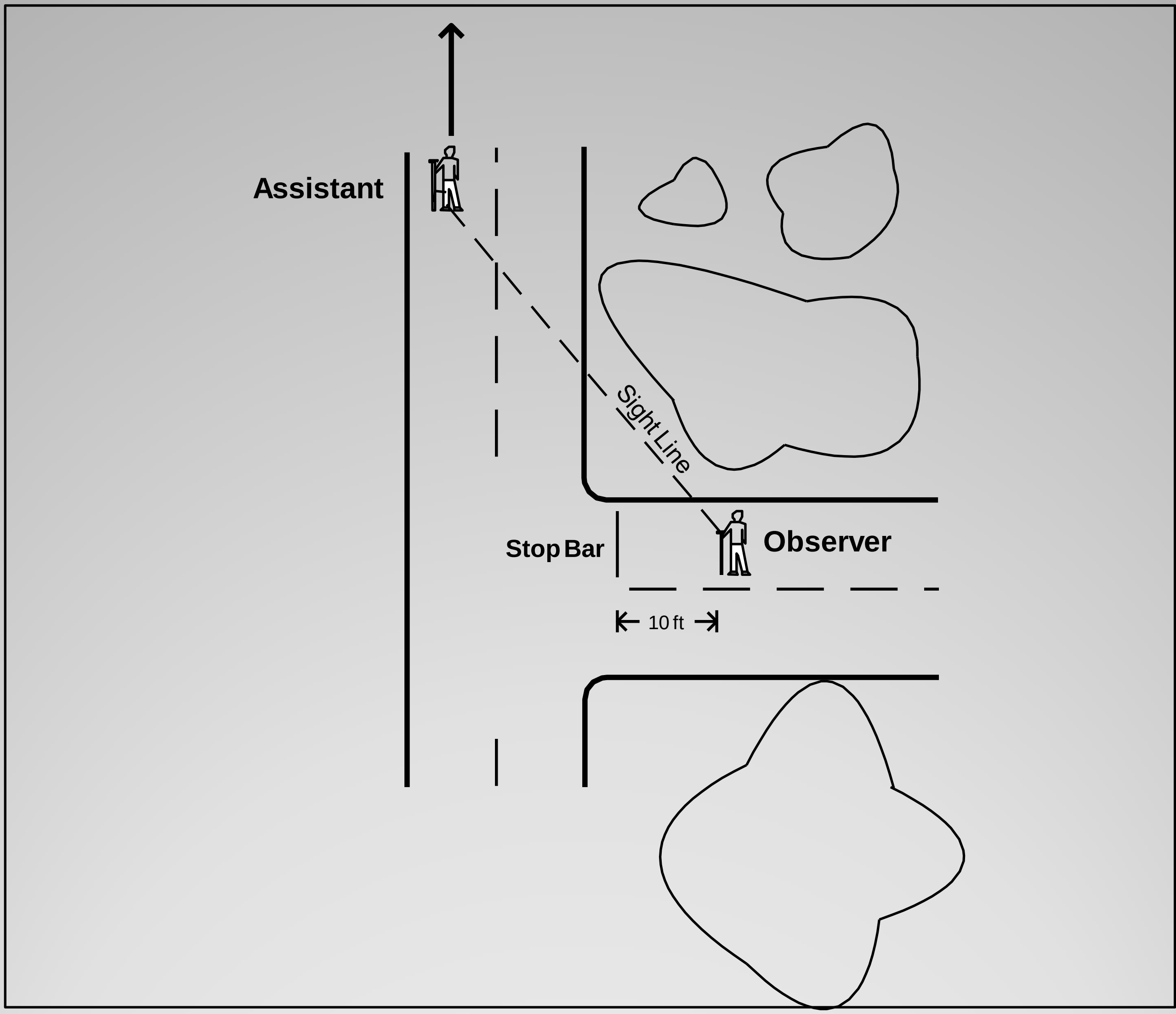


Measuring at an Uncontrolled Intersection




RESEARCH
PARK
Assistant
Movement of Assistant
Observer

Measuring at a Stop-controlled Intersection



STOP
4-WAY
Assistant with Target Rod (4.25 ft)
Observer with Sighting Rod (3.5 ft)

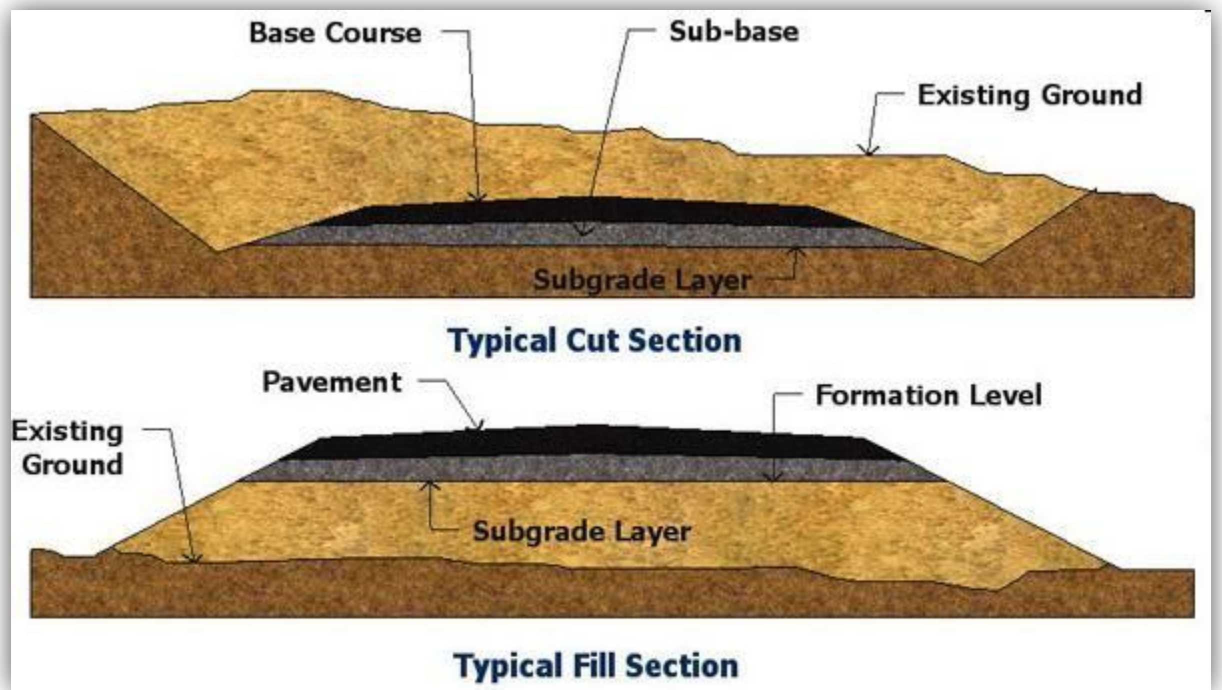
UNIT – 5
HIGHWAY MATERIAL, CONSTRUCTION
AND MAINTENANCE

Highway material characterization; Subgrade soil, Stone aggregate, Bitumen materials, Construction of gravel roads-Construction of water bound macadam roads-Construction of bituminous pavements: Surface dressing, Bitumen bound macadam, Bituminous concrete-Construction of cement concrete pavements-Construction of joints in cement concrete pavements-Joint filter and seal-Pavement failures –Maintenance of highways-Highway Drainage.

FUNCTION AND SIGNIFICANCE OF SUBGRADE PROPERTIES

- Basement soil of road bed.
- Important for structural and pavement life.
- Should not deflect excessively due to dynamic loading.
- May be in fill or embankment.
- Compacted or Natural Subgrade

CUT AND FILL (EMBANKMENT) SECTIONS



Subgrade Soil

- Granular or Coarse grained
- Fine Grained
- Organic

Unsuitable soil materials for subgrade

- Clay soil which contains the value of Liquid Limit more than 80% and/or Plasticity Index more than 55%,
- It is flammable materials (oily), and organically clay soil,
- Contain lots of rotten roots, grass and other vegetation,
- Soil which is soft and unstable because it is too wet or dry which makes it difficult to compact properly.

PROPERTIES ASSOCIATED WITH SUBGRADE SOIL

- Volume change with water.
- Load - Sustaining Power.
- Compression under static load.
- Workability during wet periods.
- Ease of drainage.
- Compactibility.

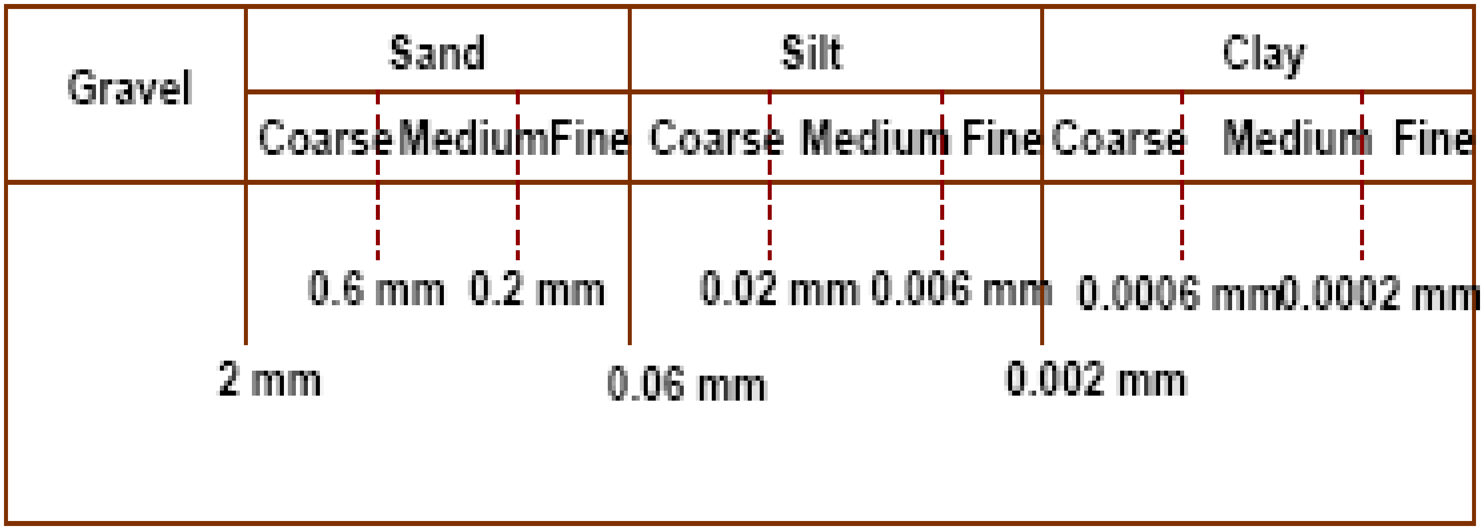
DESIRABLE PROPERTIES OF SOIL AS SUBGRADE MATERIAL

- Stability.
- Incompressibility.
- Minimum changes in volume and stability under adverse condition of weather and ground water.
- Permanency of strength.
- Good drainage.
- Ease of compaction.

Classification Identification of soil as subgrade material

- Index Properties
  - Size distribution (IS:2720 Part 4 – 1985)
  - Liquid limit
  - Plasticity Index
  - Shrinkage Limit
  - Field Moisture Equivalent – *adsorbed water*
  - Compacted Dry Density
  - Centrifuge Moisture Equivalent

Indian standard grain size classification



Gravel particle size < 2.36mm

Moorum

Silts

Clay

Grain Size Distribution

Significance of GSD:

- To know the relative proportions of different grain sizes.

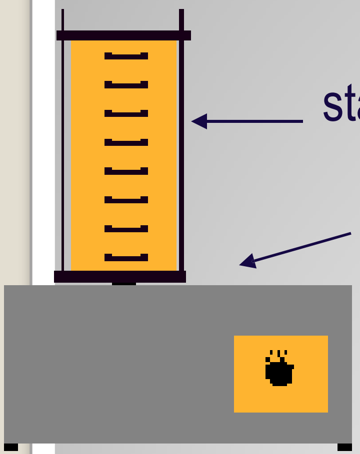
- An important factor influencing the geotechnical characteristics of a **coarse** grain soil.

- Not important in fine grain soils.

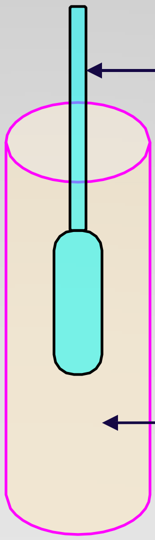
Grain Size Distribution

Determination of GSD:

- In coarse grain soils …… By sieve analysis
- In fine grain soils …… By hydrometer analysis



Sieve Analysis



Hydrometer Analysis

- HRB (AASHO) classification
- Public Roads (PR -1928)   A1-A7
- Group Index (GI)

A function of material passing through 200 mesh sieve(0.74mm)

$$GI = 0.2a + 0.005ac + 0.01bd$$

Min GI = 0;

Max GI = 20; when passing 200 mesh sieve, LL and PI are 75,60 and 30 resp.

Higher GI = poorer soil as subgrade material

A-6(4), A-6(16)

GROUND INDEX

Value of GI	Soil Condition
0	Excellent
1	Good
2 – 4	Fair
5 - 9	Poor
10 - 20	Very Poor

Indian Standard Soil Classification

Based on modification on Unified Soil Classification System.

Gravel : 80 – 4.75 mm

Sand : 4.75mm – 0.075mm (75 micron)

Silt : 75 – 2 micron

Clay : less than 2 micron

Particle size distribution -sieving and sedimentation analysis IS: 2720 (Part 4) – 1985

Liquid Limit and Plastic Limit IS:2720 (Part 5) –1985.

DRY DENSITY - M O R T H SPECIFICATION FOR ROAD BRIDGES WORKS(3RD REVISION 1995)

MORTH specification recommends:

- 97 % dry density - heavy compaction by modified proctor density. – IS:2720(Part 8) – NH,SH,MDR and heavily trafficked roads.
- Atleast 97% by Standard Proctor density – IS: 2720 (part 7)

SUBGRADE SOIL STRENGTH

Assessed in terms of CBR of subgrade soil for most critical moisture conditions.

- Soil type
- Moisture Content
- Dry Density
- Internal Structure of the soil
- Type and Mode of Stress Application.

Tests

FOR SUBGRADE SOIL/ EMBANKMENT

- Grain size analysis.
- Proctor compaction (Both light & heavy)
- California Bearing Ratio (CBR)
- Differential Free swell (DFS)
- Liquid Limit (L.L.) & Plastic Limit (P.L.)

FOR SUB BASE / ADMIXTURE

- Grain size Analysis.
- Proctor compaction (Both light & heavy)
- California Bearing Ratio (CBR)
- Differential Free swell (DFS)
- Liquid Limit (L.L.) & Plastic Limit (P.L.)

SUBGRADE PERFORMANCE

- **Load bearing capacity:**

  Affected by degree of compaction, moisture content, and soil type.

  California Bearing Ratio (CBR) test, falling weight deflect meter back calculations and other methods.

- **Moisture content:**

  Affects subgrade properties like load bearing capacity, shrinkage and swelling.

  Influenced by drainage, groundwater table elevation, infiltration, or pavement porosity

- **Shrinkage and/or swelling:**

  Soils with excessive fines content may be susceptible to frost heave in northern climates.

Moisture Content

- Water table
- Precipitation
- Soil Permeability
- Drainage conditions
- Extent to which pavement is water proof

Stability of Soil

- Stability of Soil depends on *stress -deformation characteristics of soil. (viscoelastic deformation)*

- *Repeated Application of Stress:*
  - *Frequency of Loading cycle*
  - *Magnitude of stress*
  - *Number of Repetitions .*

- *Static Stress :*
  - *Period of stress application*
  - *Intensity of Stress*

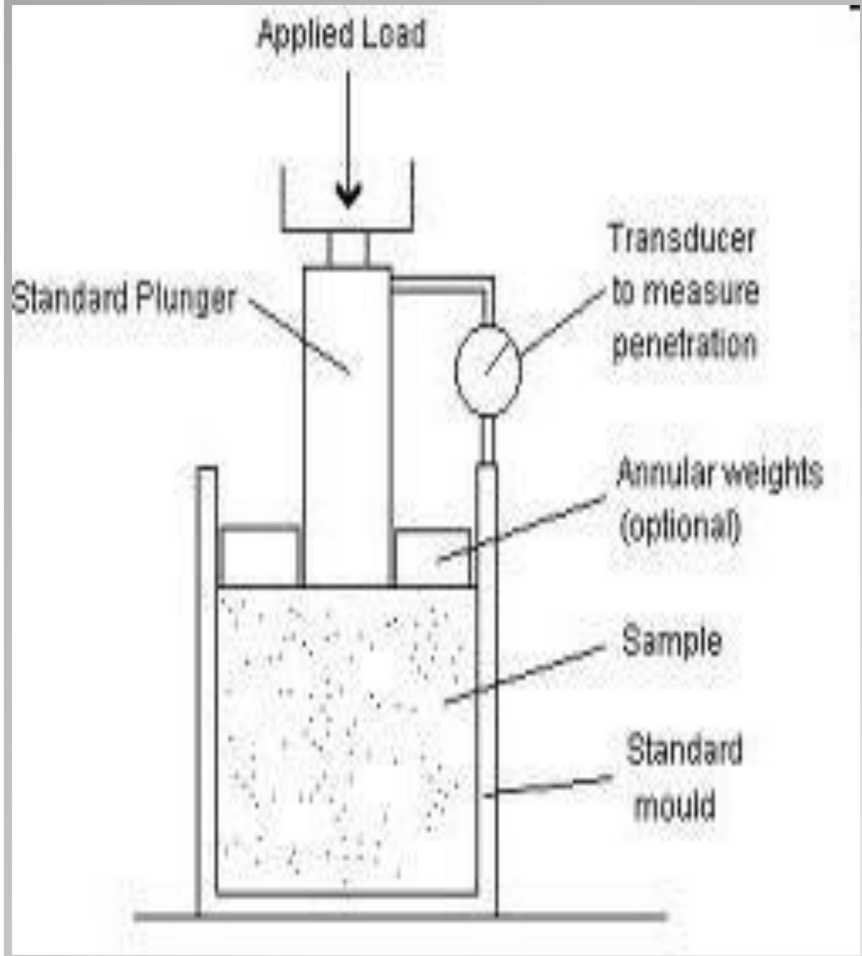
Evaluation of Strength of Subgrade Soil

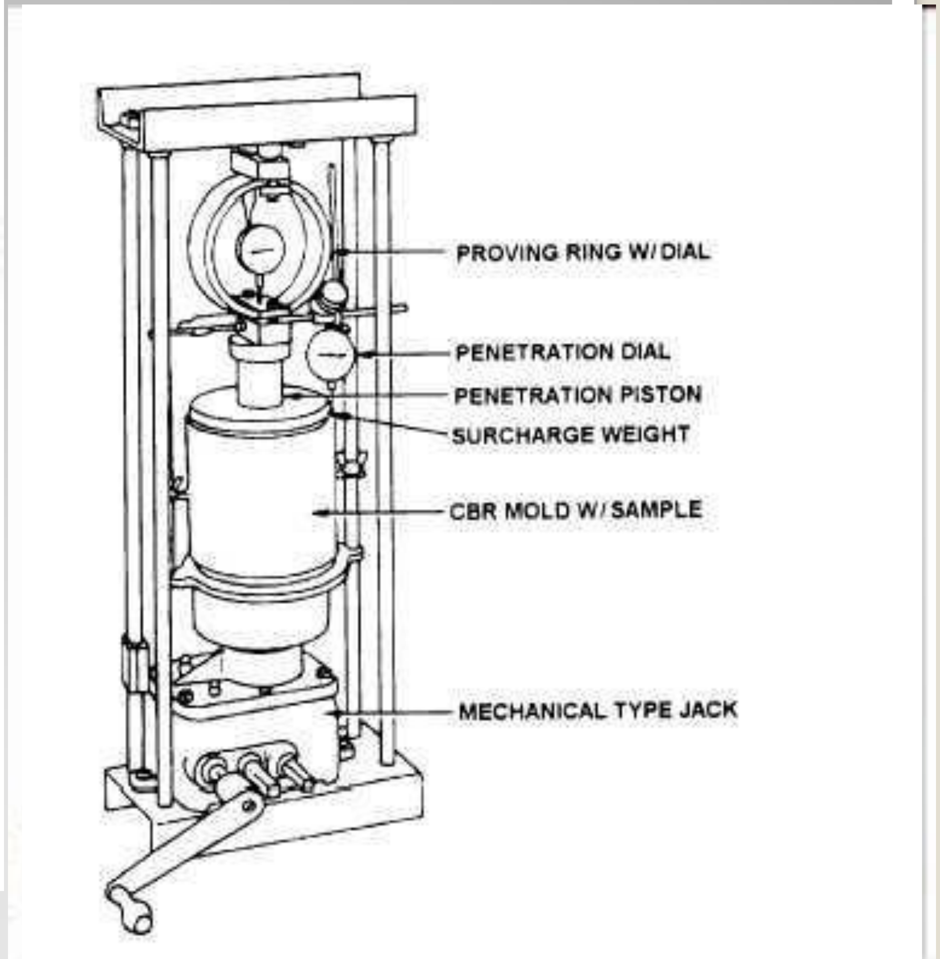
- Shear Test
- direct shear test, triaxial compression test, and unconfined compression test.
- Bearing Test
- Penetration Test

CALIFORNIA BEARING RATIO TEST

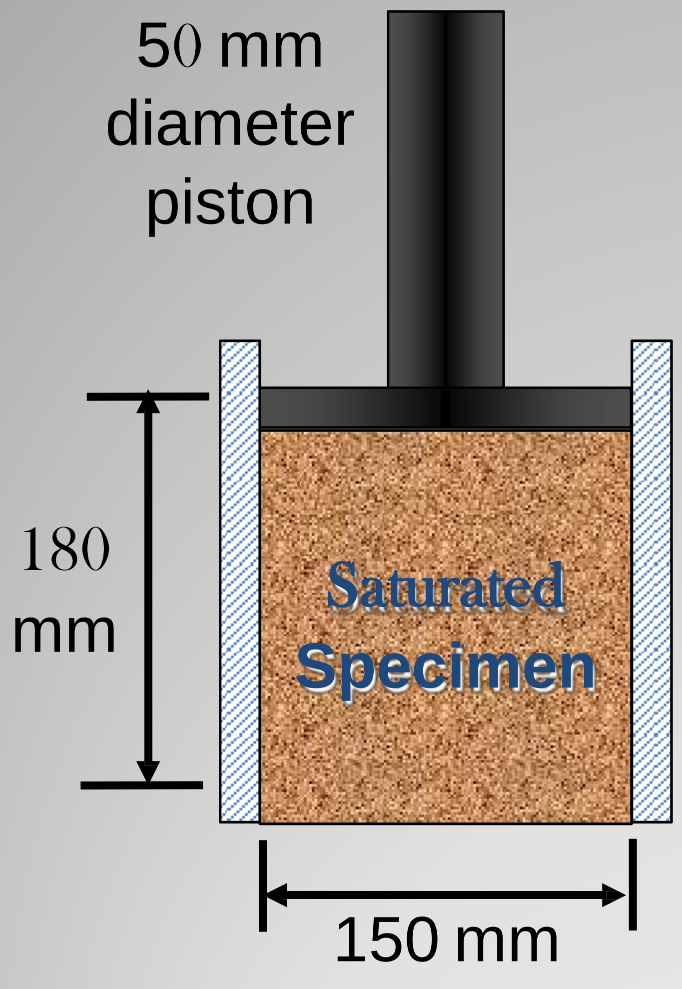
- a penetration test wherein a standard piston, having an area of 3 in (or 50 mm diameter), is used to penetrate the soil at a standard rate of 1.25 mm/minute.
- The pressure up to a penetration of 12.5 mm and it's ratio to the bearing value of a standard crushed rock is termed as the CBR.

CBR Testing Machine





California Bearing Ratio (CBR) Test



- Strength measure for unbound materials
- Piston advanced at 1.3 mm / min. rate
- Measure load at 2.5 mm penetration ($P_{2.5}$)
- CBR = $100*(P_{2.5}/P_{std})$

STANDARD LOADS ADOPTED FOR DIFFERENT PENETRATIONS FOR THE STANDARD MATERIAL WITH A C.B.R. VALUE OF 100%

Penetration of Plunger (mm)	Standard Load (kg)
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

AGGREGATE PHYSICAL PROPERTIES

- Aggregates can be classified by their mineral, chemical and physical properties.

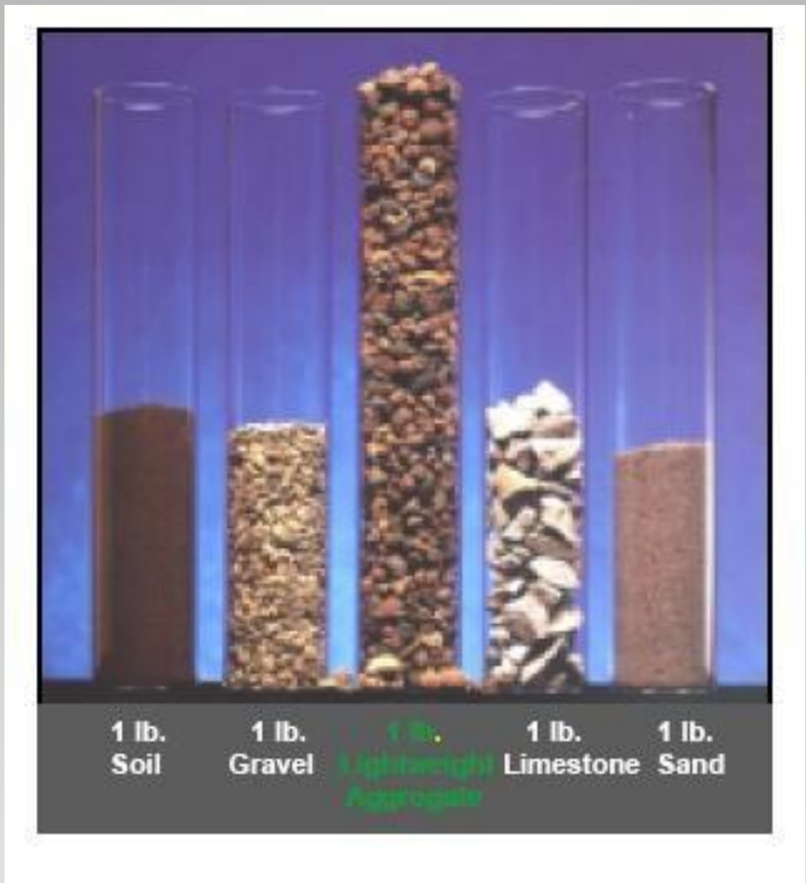
- An aggregate's physical properties are a direct result of its mineral and chemical properties.
- *Maximum size*: The smallest sieve through which 100 percent of the aggregate sample particles pass.

- *Nominal maximum size*: The largest sieve that retains some of the aggregate particles but generally not more than 10 percent by weight.

TEST ON AGGREGATES

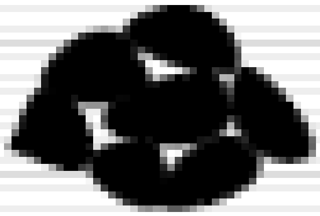
1. Aggregate Impact Test
2. Flakiness and Elongation Test
3. Angularity Index Test
4. Los Angeles Abrasion Test
5. Water Absorption Test
6. Specific Gravity Test
7. Soundness Test

Aggregate Gradation

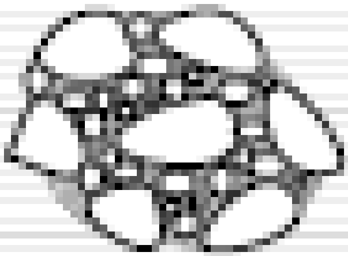


Types of Gradations

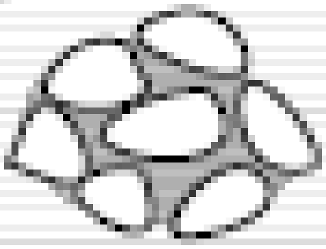
- Uniformly graded
    - Few points of contact
    - Poor interlock (shape dependent)
    - High permeability



- Well graded
    - Good interlock
    - Low permeability



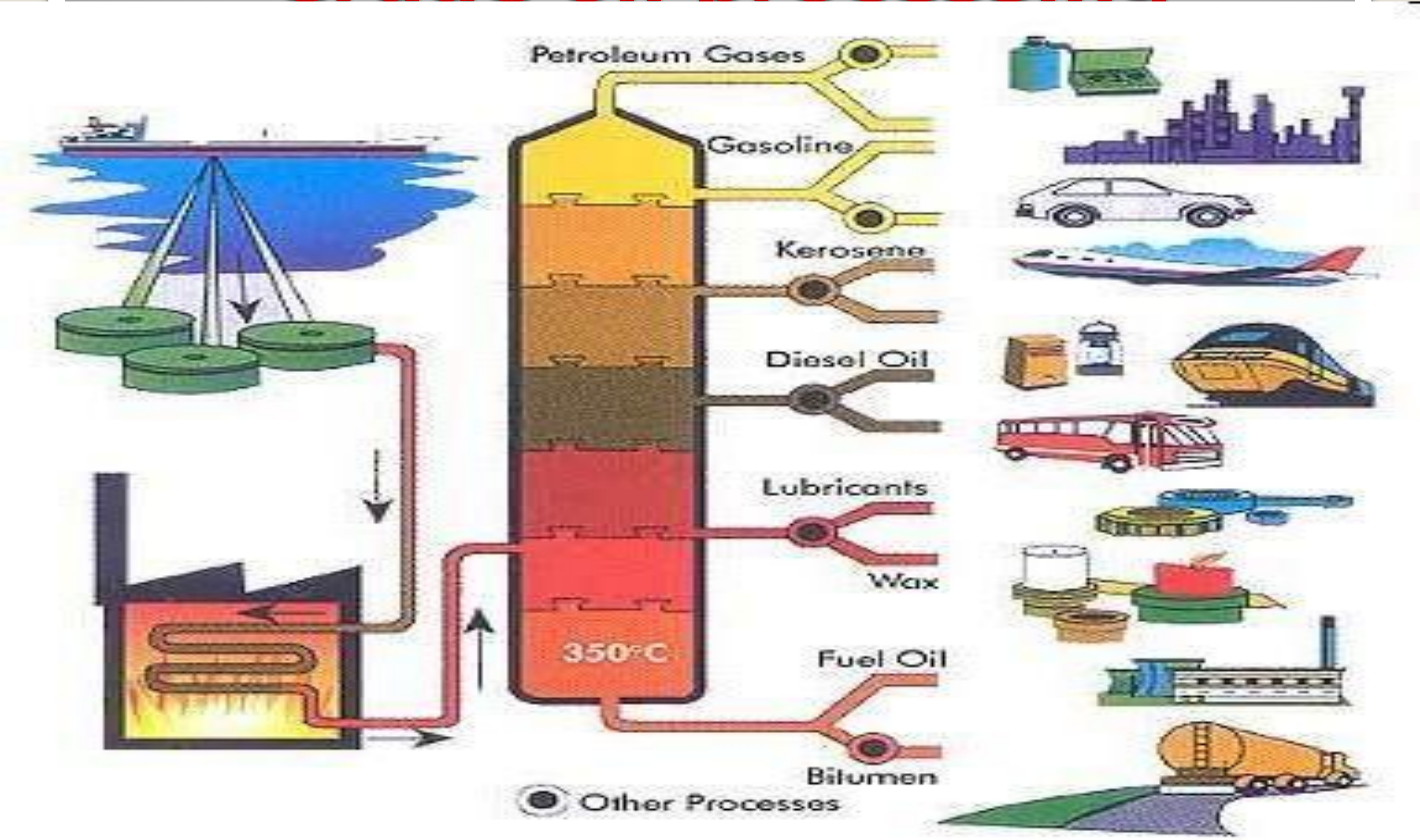
- Gap graded
    - Only limited sizes
    - Good interlock
    - Low permeability



Aggregate Characterization

- Aggregate Physical Properties
  - Maximum Aggregate Size
  - Gradation
  - Other Aggregate Properties
    - Toughness and Abrasion Resistance
    - Specific Gravity
    - Particle Shape and Surface Texture
    - Durability and Soundness
    - Cleanliness and Deleterious Materials

Crude oil processing



- **Bitumen:** distillation of petroleum crude.
- **Tar:** Destructive distillation of coal or wood.
- **Paving grade:** air fields, roads.
- **Industrial grades:** water proofing of structures, industrial floors, etc.

Construction Practice

Construction of embankments for subgrade

- **Materials** – soil, moorum, gravel

- **Unsuitable materials**
  - Materials from swamps, marshes
  - Clay with LL >70
  - PI > 45
  - Free swelling Index > 50
  - Size of Coarse materials

- **Embankments** <= 75mm
- **Subgrade** <= 50mm

Density of Materials of Embankment and Subgrade

Type of Work	Maximum Dry Density with heavy Compaction – IS: 2720 (Part 8)
Embankment up to 3 m height, not subjected to extensive flooding.	Not less than 15.2 kN/cu. m
Embankments exceeding 3m height or embankments of any height subject to long periods of inundation.	Not less than 16.0 kN/cu. m
Subgrade and earthen shoulders/ verges/backfill.	Not less than 17.5 kN/cu. m

COMPACTION OF EMBANKMENT AND SUBGRADE

Type of Work	Relative Compaction as percentage of max. laboratory dry density - IS:2720 (Part 8)
Subgrade and earthen shoulders	Not less than 97
Embankment	Not less than 95
Expansive Clays (of acceptable FSI) (a)Subgrade and 500 mm portion just below the subgrade. (b)Remaining portion of Embankment	Not allowed Not less than 90

Construction Operation

- Setting out the alignment.
- Dewatering
- Compacting ground to support embankment / subgrade
- Spreading of materials and moisture content

Sub base, base and shoulders

- Materials

  Natural sand, moorum, gravel, crushed stone or combination , lime treated if high % of clay is found.

- Construction Operation
  - Preparation of sub grade
  - Spreading Sub base material
  - Moisture content 1.0% - 2%

Construction of WBM

- Constructed of twelve inches of stone over all.
- An eight-inch foundation is provided of hard quarry stone, laid on edge, with the longest dimension placed at a right angle to the side line of the drive.
- After the stones are placed they should be cleared of the irregular edges using hammer
- The pieces of stone so broken off should be used to fill in chinks.

WBM

- Coarse Aggregates – hard and soft aggregates
- Screening
- Binding materials

Coarse aggregates in WBM

- Hard variety of crushed aggregates or broken stones.
- Properties:

Durable, hard, free from flaky and elongated particles.

Property	Requirements for pavement layer (max %)		
	Sub base	Base course	Surfacing course
Los Angeles Abrasion value	60	50	40
AI value	50	40	30
Flakiness Index	-	15	15

Soft aggregates in WBM

- Overburnt brick metal
- Naturally occurring soft agg – kankar, laterite
- Crushed slag from blast furnace

Size & Grading requirement of Coarse Aggregates for WBM			
Grading No	Size range (mm)	Sieve size (mm)	% by Wight passing sieve
1	90 - 40	100, 80, 63, 40, 20	100 65 – 85 25 – 60 0 – 15 0 – 5
2	63 - 40	80, 63, 50, 40, 20	100 90 – 100 35 – 70 0 – 15 0 – 5
3	50 - 20	63, 50, 40, 20, 10,	100 95 – 100 35 – 70 0 – 15 0 – 5

Screening

- For filling the voids in compacted layer
- IRC suggests use of non plastic material - kankar, moorum or gravel.
- Should satisfy:
  - LL , 20%
  - PI , 6%
  - Portion of fines passing 0.075mm size sieve , 10%

Binding Material

- To prevent raveling and rubbing between aggregates
- Grained material
- PI 4 to 9 % (surfacing Course)
- PI , 6% (with sub base and base course with bituminous surfacing course)
- No binding material for moorum and Gravel (low PI)

THANKS